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OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

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LINOSA AND ITS ROCKS

HENRY S. WASHINGTON

INTRODUCTION

In the present paper are described the geology and petrology of a small islet in the Mediterranean which, up to the present, has remained almost unknown to geologists. The observations and collections on which the paper is based were made in September, 1905, in the course of a trip to some of the less-known volcanoes of the western Mediterranean, undertaken for the Carnegie Institution of Washington, to the trustees of which I am indebted for permission to publish this paper here.

About half-way between Malta and the coast of Tunis three small islets—Linosa, Lampedusa, and Lampione—project above the sea, which are called collectively the Pelagic Islands (Isole Pelagie). While geographically grouped together, geologically they are very diverse, Linosa being entirely volcanic, while Lampedusa and Lampione are composed wholly of limestone.

Although this paper deals properly with Linosa alone, it may yet be of interest to record a few facts about Lampedusa.[1] This island, the largest of the group, is of narrow, oblong shape, the greatest length (east and west) being eleven kilometers, and the greatest breadth (north and south) about three kilometers, almost at the eastern end. It is essentially a tilted block of limestone, the highest

[1] Cf. W. Deecke, *Italien*, Berlin, 1899 (?), p. 479; and *Italy*, London and New York, 1904, p. 449.

point being at the west (133^m), and thence gradually sloping to the east end, where the general elevation above sea-level is but 20^m. The surface, which is in general fairly flat, is somewhat cut up by shallow erosion valleys, and there are no very prominent hills. The soil almost all over the island is stony and barren, a few gardens and vineyards being maintained with difficulty here and there, and the only trees are half a dozen date palms which are found in sheltered hollows. The rock composing Lampedusa is a white to creamy-yellow, soft limestone,[1] which is distinctly magnesian, as shown by the analysis of Speciale,[2] who has described the island briefly. According to him it is more recent than the Tertiary limestones of Malta, containing fossils of living mollusks. Lampedusa is of considerable commercial importance as the center of extensive sponge and sardine fisheries, and is the point of exchange for the sponge trade of the Mediterranean, the sponges from the Greek islands being largely brought here.[3]

Lampione, which lies about 8 nautical miles west of Lampedusa, is a mere rock, barely 400 meters across, 43 meters high at its western end, and sloping to sea-level at the east. It is said to be composed of limestone similar to that which forms Lampedusa.

GEOLOGY OF LINOSA

Bibliography.—The literature on the geology of Linosa is very scanty, commensurate with its small size and isolation, and its political and commercial insignificance. For the most part the papers which deal with it belong to the first half of the nineteenth century and are of little modern value. A list of them is given by Speciale. The standard general works on volcanoes either ignore or barely mention the island, Scrope,[4] for instance, giving it but three lines of description.

Mercalli,[5] who bases his account on the work of Calcara[6] (an author

[1] Lampedusa and Lampione are incorrectly colored as volcanic on Sheet 45 of the Carte géologique internationale de l'Europe. I saw no igneous rock on the island.

[2] S. Speciale, *Boll. Com. Geol. Ital.*, Vol. XV, 1884, p. 263.

[3] My thanks are due Signor S. di Maggio for courtesies and assistance during my few hours on Lampedusa.

[4] G. P. Scrope, *Volcanoes*, London, 2d ed., 1862, p. 345.

[5] G. Mercalli, *Vulcani d'Italia*, Milano, 1883, p. 161.

[6] P. Calcara, *Descrizione dell' isola Linosa*, Palermo, 1851, pp. 30.

whom I have been unable to consult), gives a page of description, with considerable detail as to altitudes, etc. He makes mention of but four volcanoes, but it is interesting to note that Calcara recognized the two periods of vulcanicity to be described later, though his "trachytic" rocks are shown by my observations and analyses to be basaltic tuffs, and were evidently referred to the trachytes because of their light color.

The most recent, and the only modern, paper dealing with the geology is that of Speciale,[1] which is but a preliminary one, the second part, which was to describe the petrography of the rocks, never having appeared. In this two-page paper Speciale briefly describes the general geology and several of the volcanoes, distinguishing between those of tuff and of lava, the limits of which are given on his map.

The last paper to be mentioned is that of D'Avezac,[2] who gives a general description, apparently based largely on the observations of Captain Smyth prior to 1823. The geology is summarily treated, but the history of the islet is discussed more fully, D'Avezac showing that Linosa is the *'Ανεμοῦσα* of Ptolemy.

Three maps of Linosa are available. The most satisfactory is that found on Sheet 211 of the charts of the Italian Instituto Idrografico, on a scale of 1 : 25,000, and which has been used as the base of that which accompanies this paper. A second is found on the Linosa and Lampedusa sheet (No. 193) of the British Admiralty, on a scale of 1 : 25,100, and this sheet is of special interest because it shows a view of the island from the southwest. The third is on Foglio 265 of the topographic maps of the Instituto Geografico Militare, the scale being 1 : 50,000. In all three the various volcanoes are shown and many altitudes noted, though, between the various maps, there are discrepancies as regards these and the names.

General description.—The island of Linosa[3] lies 20 miles northeast of Lampedusa and about 59 southeast of Pantelleria. In form it is nearly a square, the sides facing the cardinal points, with a length east and west of about 3 kilometers and a breadth north and south of

[1] *Op. cit.*, p. 165, with map.

[2] D'Avezac, *Iles de l'Afrique*, Paris, 1885, p. 119.

[3] According to the British chart the lighthouse is situated in Lat. 35° 52′ N. and Long. 12° 53′ E.

2.5 kilometers, the greatest length diagonally from northwest to southeast being 3.5 kilometers. Its total area is about 6.5 square kilometers. On the map of the island as given in Fig. 1, the contour lines are only approximate and give merely a rough idea of the topography.

FIG. 1.—Island of Linosa.

Linosa is dry in the extreme, not a single spring being found on the island, and the water supply being dependent on the rains, which are collected from the flat roofs and preserved in cisterns. At the time of my visit the island was favored with the first rain in five months, and the inhabitants were reduced to a daily ration of two liters of water apiece, a supply having had to be brought by a government vessel from Sicily. The greater part of the surface, where it is not bare lava and tuff, is covered with sterile sand and ashes, and in the few cultivatable areas, which are fenced in with opuntia cactus

(the fruit of which serves as food for man and the fleshy stems for beast), some sparse crops of grain are raised, or they are given over to straggling vineyards, from which a harsh, but not unpleasant, red wine is produced. Fishing is the only industry, and this barely suffices for local needs.

Communication with civilization is kept up by a small steamer, which touches at the island on its biweekly trip from Pantelleria to Girgenti, and again a day and a half later on the return voyage, touching at Lampedusa both ways. This interval was necessarily the limit of my visit, but the small size of the island enabled me to make a fairly complete study of its geology.

The earliest evidences of human occupation are seen in some ruins, which consist of long and narrow foundation walls, apparently of houses, built of blocks of tuff, and also several pot-shaped graves, lined with cement, which I saw near the summit of Monte Levante, and in which my guide said skeletons had been found. These, as well as vases and coins said to have been found on the island (none of which I saw), point to the habitation of the island in (probably) Roman times. But it was apparently abandoned during the Middle Ages and later, and remained uninhabited until 1845,[1] when some colonists were imported by the government. These earlier colonists inhabited several rude chambers hewn in the tuff on the west slope of Monte Bandiera, which are now unoccupied.[2] The modern village consists of a single street, with low, one-storied houses, and few houses are scattered about the island. At the time of my visit there were said to be about 240 persons residing on the island, including a customs officer, Signor N. Raneri, to whom I am deeply indebted for most courteous hospitality and assistance, a priest, and a government physician. A lighthouse occupies the northeast corner.

General geology.—The only rocks visible on the island are volcanic, and the whole mass has been built up out of the sea by a succession

[1] Cf. Mercalli, *op. cit.*, p. 161, note. According to D'Avezac, Captain Smyth (before 1823) found no inhabitants nor, indeed, any animal life, except some falcons. He set free on the island some goats and rabbits, and planted peas, beans, wheat, barley, tobacco, and castor beans in various places, all traces of which benefactions having now disappeared.

[2] According to Deecke (*loc. cit.*) they were abandoned in 1878.

of eruptions which formed a number of cones. The only clue to what lies beneath these is given by a small fragment of a light-colored, medium-grained, olivine-bearing, hornblende-diorite, which I found imbedded in a piece of scoria at Monte Rosso, and which is evidently a fragment of a plutonic rock from the basement brought up by the lava stream. In this respect Linosa resembles Pantelleria, where Foerstner[1] reports fragments of hornblende-granite likewise imbedded in the lava and tuffs, and which he refers to the basement complex of the island.

Small as is the island it yet shows nine distinct volcanic cones,[2] or centers of eruption, which may be referred to two distinct periods of activity, distinguished by the materials which compose them.

The first period is characterized by cones of basaltic tuff, lava being represented in these only as included blocks. Not only do these tuff cones show signs of greater age than the cinder cones in the greater extent to which they have suffered by erosion, but in many cases the tuffs are seen to be overlaid by the cinders and lavas of the cones of the second period.

In the center of the island is a rather prominent ridge of dark, greenish-gray tuff, running north and south, to which the name of Monte Bandiera is applied, and in the west slope of which the rude chambers mentioned above have been hewn. This ridge is the west wall of what is apparently the oldest cone of Linosa, to the east of it two distinct craters being visible. The most northerly of these, for which I could learn no name, but which may be called the North Bandiera Crater, is composed largely of yellow, with some dark-gray tuffs, which contain angular blocks of compact basalt. This crater, which measures some 300 meters across, is not very well preserved, but shows a well-defined rim on the west and south, the

[1] H. Foerstner, *Boll. Com. Geol. Ital.*, 1881, p. 550.

[2] Speciale considers that there are but five eruptive centers, namely: Monte Ponente proper (with which he includes Monte Pozzolana), the cone which I have named Monte Raneri, Monte Vulcano, Monte Rosso (of which he mentions only the barranca on the north, not speaking of the summit crater), and Monte Bandiera (which includes the two large craters immediately to the east, as well as Monte Biancarella to the north). He considers Monte Calcarella as forming a part of Monte Vulcano and does not mention the well-defined cone of Monte Levante, nor does he consider that the tuff and lava cones belong to two distinct periods.

western rim being about 150 meters above the sandy and lava-covered plain to the west and about 20 meters above the crater floor. To the east its tuffs are lost beneath the lavas and cinders of Monte Rosso. This northerly crater is older than its companion, as the tuffs of the latter cover part of its southern side, and it may be considered the oldest on the island, in view of its poor preservation and central position.

The southern crater, which is called Il Fosso, presents a flat, elliptical floor, of about the same size as that of the preceding, which is planted in vines and cactus. This crater is bounded on the north, west, and south by a well-defined rim of yellow and greenish-gray tuffs, which also contain blocks of compact basalt. This ridge reaches a height on the west, Monte Bandiera, of 102 meters, and on the south of 148 meters, this southern rim being known as Monte Calcarella. The south slopes of Calcarella are partly covered by the scoriae of Monte Vulcano, and to the east the low, ill-defined rim of Il Fosso is almost wholly buried beneath the lavas and ashes of this same volcano. A gap in the ridge on the southwest, between Monti Bandiera and Calcarella, gives access to the crater floor.

At the southeast corner of the island is a third tuff cone, that of Monte Levante.[1] Of this only the northern half remains, the southern portion having been washed away by the waves, forming a precipitous cliff and exposing a fine section, in an inaccessible outlying pinnacle of which was seen a dike of black basalt. What remains of the cone consists of thin-bedded yellow and dark, greenish-gray tuffs, which contain numerous, rather large, angular blocks of compact basalt. On the flat summit of the ridge, which is 92 meters above sea-level, weathering has developed in the tuff about these blocks a series of concentric thin shells, which resemble a nest of hemispherical basins in which the blocks lie. None of these shells were seen covering the blocks, that is, with the convexity uppermost. The origin of this peculiar structure is uncertain and, while it seems to be made evident by weathering, yet its cause must apparently be attributed to some other agency, possibly to the vibrations set up in

[1] This is the name as given on the Italian military map, and the one by which it may best be called here, though my guide called it Monte Calcarella. But this last name is given on all the maps to the southern rim of the crater just described.

the tuff by the impact of the falling block. The northern slopes of Monte Levante are covered by the scoriae of Monte Vulcano, which adjoins it on the northwest.

Monte Biancarella, which lies close to the north coast and immediately west of Monte Rosso, is a low, regular dome of yellow tuff, its summit about 50 meters above the base, and the whole about 150 meters across. There is no sign of a crater and the thin bedded tuffs dip quaquaversally on all sides, forming concentric, curving sheets, with step-like interruptions here and there due to erosion. The appearance is as if horizontal beds of tuff had been gently forced up by some invisible protrusion from below. Close to the south of this are some of the long foundation walls, constructed of blocks of tuff, which probably date from Roman times. They barely project above the surface. Excavation would be needed to expose them fully and would probably be repaid by some archaeological discoveries of interest, for which, unfortunately, time was lacking.

The last tuff cone to be described is marked Monte Ponente on all the maps, but seems to be called Monte Pozzolana by the inhabitants. As it is a composite cone, being composed both of tuff and lava, we may conveniently reserve the name Monte Pozzolana for the southern, tuffaceous portion, and let Monte Ponente denote specifically the northern, basaltic portion, though there is no orographic distinction between them. This cone is situated on the west coast of Linosa, the sea having cut away its west side and exposed a fine section. Immediately at its foot is the best landing-place of the island, a small cove, with rocky shores and a small artificial jetty, at which only small row boats can land, the steamer stopping about a mile from shore. If the wind is from the north or west, landing must be effected at the Scala Vecchia, a small bay on the south coast, likewise very rocky, and about one-third of a kilometer south of the village.

Monte Pozzolana consists of thin-bedded, very friable, yellow tuffs, which contain numerous very small fragments of somewhat scoriaceous basalt, but few large blocks, such as were noted at the other tuff cones. Toward the top the tuff mingles with, and is finally covered by, the scoriae of Monte Ponente. In the breach on the

west side is a vertical dike about 70 centimeters wide, of finely vesicular black basalt, which cuts through the yellow tuff beds, but not through the black scoriae above. The sides of this dike show distinct marks of flow, and it has not altered appreciably the yellow tuffs.

Of the cinder and lava cones, which mark the second period of vulcanicity, the highest is Monte Vulcano, immediately southeast of Monte Calcarella, and on the south coast of the island. The summit of this I measured with an aneroid as 199 meters above sea-level, while the Italian military map gives it as 195 meters, and the Italian hydrographic map as 160.[1] About 14 meters below the summit of this volcano is a well-preserved, circular crater, about 100 meters in diameter and 30 meters deep, the steep walls composed of scoria and blocks of lava. On the south slope of the volcano, toward Monte Levante, are many vesicular lava flows, interbedded with tuffs, and lava flows and cinder slopes are also seen on the east side. On the west side, some 80 meters below the summit, is an almost horizontal plateau, the upper surface of a series of six or eight lava flows, each a meter or so thick, frequently with a rough columnar structure, and separated from each other by thin layers of scoriaceous material. On the upper edge of this plateau is a natural pit, with an orifice about two by three meters across, and about fifteen meters deep, so far as one can see, from which issues constantly a strong stream of cold air, resembling a somewhat similar orifice at the Kaimeni, on Methana, in Greece, and the *bufadores* of Catalonia. On the south slope, below this plateau, are some bedded tuffs and a steep *sciarra* of lapilli which extends down to the water's edge and which closely resembles that of Stromboli. Elsewhere the sides of the cone are covered with scoriae and blocks of lava, with small lava flows here and there. As was noted above, the products of this volcano cover the lower slopes of Monte Calcarella on the northwest and of Monte Levante on the southeast, thus showing its later date.

The next highest cone of Linosa is Monte Rosso, in the northeast corner of the island. According to my aneroid this is 196 meters high, while the Italian maps give it as 186 meters, and the English one as 610 feet (186^{m}), so that it is only a trifle lower than Monte

[1] The British Admiralty chart gives the height as 525 feet (129^{m}), which is certainly much too low, and is possibly an error for 625 feet (191^{m}).

Vulcano. This is a typical, breached cinder cone, the outer slopes well preserved on the east, south, and west, but opened up on the north flank by a long, narrow, and deep *barranca*, which leads up nearly to the top, the upper part being edged by a narrow *arête* of rough lava on either side. Near the summit is a well-defined, almost circular crater, some 75 meters across, and whose floor is 20 meters below the highest point of the rim on the north, between it and the head of the barranca. Monte Rosso is composed almost wholly of rough scoriae and lapilli, to whose general red color the name of the cone is due, though some blocks of compact lava are seen here and there, and flows from near the base and from the mouth of the barranca have covered the island to the northeast, north, and northwest. Possibly some of the lavas to the south also belong to this cone, but the line of demarkation between these and the lavas of Monte Vulcano laid down on Speciale's map could not be made out by me, the surface being covered largely with sand and soil and partly given over to cultivation.

Immediately to the west of the mouth of the northerly barranca, and east of Monte Biancarella, is a small parasitic cone of reddish scoria, in which were found crystal fragments of feldspar and of a black hornblende, which is peculiar in containing 8.47 per cent. of TiO_2, and which will be described elsewhere. The occurrence of hornblende here is mentioned by Speciale. Similar crystals are said to be found at one other spot, on the east coast near I Faraglioni, south of the lighthouse, but I did not visit this locality.

The third cinder cone is that of Monte Ponente, on the west coast, which, as we have seen, is in close conjunction with the tuff cone of Monte Pozzolana, joining this on the north. At the summit, which my aneroid made out to be 98 meters above sea-level, (the Italian military map giving 107, and the Italian hydrographic map 92), is a small circular crater, with a diameter at the bottom of about 33 meters and a depth of 25 meters. The walls are precipitous and are composed of scoriae and lava blocks.

This volcano has poured out several large flows to the north and northeast, the place where the uppermost one of these has broken through the underlying yellow tuff of Monte Pozzolana being well seen in part of the section exposed by sea action on the northwest.

About half-way up a massive stream of black basalt, several meters thick, pierces the tuff, which it has reddened for some distance around. On the west coast, south of Ballata Piatta Point (the northwest corner of the island), six superposed flows are visible, which vary in thickness from one-half to one meter, and are separated from each other by scoriaceous bands. These flows of Monte Ponente, the surface of which is very rough and wholly devoid of cultivation, cover the surface to the northwest, north, and northeast of the cone, and extend into the sea, forming a very jagged shore line. On this lava surface, to the northeast of Monte Ponente and to the northwest of Monte Bandiera, are large knolls and hummocks of rough, large lava blocks, rudely piled on one another. These are apparently the remains of fallen-in lava caverns, or are possibly due to local explosions of steam.

From the relations of the two it is clear that the lavas and scoriae of Monte Ponente were ejected from the north flank of the already formed tuff cone of Monte Pozzolana, and that the two are geographically but a single mass, though petrographically quite distinct. So far as can be seen, however, there was only a little shifting of the vent northward when the second period was initiated.

To the east of Monte Ponente is an unnamed cone, for which I propose the name of Monte Raneri, after that of my host. This is 73 meters high, and shows a well-defined elliptical crater at the summit. The greater part of this cone is scoriaceous, but some lava flows are visible, and there are many blocks of a compact basalt, which differs from the others on the island in the greater abundance and size of the olivine phenocrysts. Monte Raneri is evidently older than Monte Ponente, as the scoriae of this latter cover the northwest flanks of the former.

From the characters and relations of the tuff and of the lava and cinder cones, it is quite clear that the former belong to an earlier and distinct period of activity. The tuff cones are all lower than those of the other kind, and their forms have suffered much more from erosion and their craters are not as well preserved, though this is probably due in part to the difference in the materials. Furthermore, as we have seen, when the two occur together the tuffs underlie the scoriae and lavas. Also, at Monte Pozzolana and Monte Levante

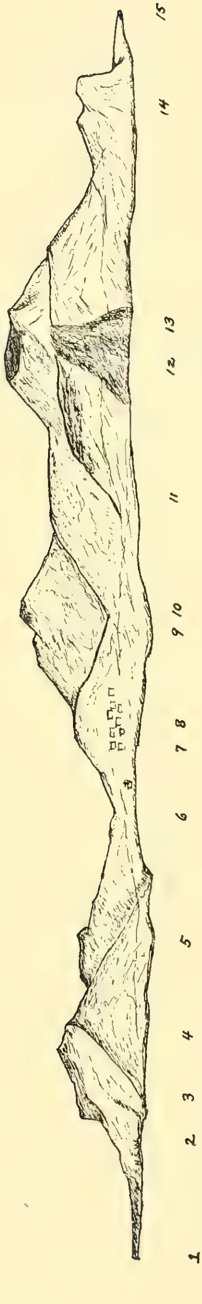

Fig. 2.—Linosa from the Southwest. 1, Ballata Piafta Point; 2, Scala Nuova; 3, Monte Ponente; 4, Monte Pozzolana; 5, Monte Raneri; 6, Scala Vecchia; 7, Linosa Village; 8, Monte Bandiera; 9, Il Fosso; 10, Monte Rosso; 11, Monte Calcarella; 12, La Sciarra; 13, Monte Vulcano; 14, Monte Levante; 15, Calcarella Point.

dikes and flows of basalt penetrate the tuffs. But it seems to be equally clear that, while the period of formation of the tuff cones antedated that of the lava ones, yet that in some cases, at least, the closing phases of the tuff cones coincided with the activity of the lava and cinder ones, as is shown by the intercalation of tuffs and lavas on the southeast slope of Monte Vulcano, and the intermingling of the tuffs of Monte Pozzolana and the scoriae of Monte Ponente in the upper portions of the mass. The usual presence of blocks of lava, scattered through the tuffs, points to the existence of lava flows beneath the surface at the time of the tuff eruptions, fragments of which were hurled up with the looser material. It might seem that the blocks in the tuff of Monte Levante have been ejected from the neighboring Monte Vulcano, as they are especially prominent in the upper beds. But this supposition is negatived by the fact that, while chemically similar to the later lavas of Vulcano, they belong to a different petrographic type, similar to that of the blocks in the other tuffs, and quite distinct from the usual types of the later lavas, as will be brought out later.

As to the geological age of these eruptions, the total absence of sedimentary and fossiliferous rocks precludes any definite evidence. But the well-preserved state of the cinder cones, the sharpness of outline of their craters and of the barranca at Monte Rosso, and the gen-

eral freshness of their lavas and scoriae, point unmistakably to their eruption in recent times. The lack of almost any reference to the island by ancient writers leaves us without any documentary data, but the presence of the graves in the tuffs of Monte Levante and of ruins near Monte Biancarella and in the north crater of Monte Bandiera proves that the extinction of these tuff cones, at least, antedates human occupation. No hot springs nor other evidences of present vulcanicity are found on the island, and its volcanoes must be regarded as extinct.

To recapitulate the apparent facts as to the order of eruption of the several cones, my observations show that the tuff cones belong to an earlier period than those of lava, though it is probable that the two periods overlapped to a slight extent. Of the former the north crater of Monte Bandiera is almost certainly the oldest on the island, followed, probably soon after, by the south crater, the so-called Il Fosso. Monti Levante, Pozzolana, and Biancarella are, almost unquestionably, later than these, and it seems probable that the date of the two former is prior to that of the last named, though the exact order is impossible to ascertain. It is more difficult to determine the sequence of the lava and cinder cones, as the relations of their several flows when adjoining, are, except in one instance, obscured by superficial sands, ashes, and cultivated soil. From their size it would seem reasonable to ascribe the eruptions of Monti Rosso and Vulcano to a rather early period, while Monte Raneri is probably of a later date, and is certainly earlier than Monte Ponente, the eruption of which may be regarded as closing the era of volcanic activity.

From the submarine topography indicated on the map (Fig. 1), it is probable that submarine eruptions, similar to those of the islands of 1831 and 1891 near Pantelleria, have taken place to the north and to the southeast of Linosa. It may be noted that rock is indicated on the chart as forming the sea-bottom at both these points, surrounded by sands.

In Fig. 2 is shown a view of the island from the southwest, based on a sketch made by me when leaving the island, as, unfortunately I had no camera with me during my visit. While somewhat diagrammatic, it yet shows the relative positions, shapes, and sizes of

the various cones, each of which may be easily identified, as well as the general appearance of the island.

PETROGRAPHY OF LINOSA

The lavas of Linosa are all feldspar-basalts according to the prevailing rock classifications, though a few contain very small amounts of nephelite, but scarcely sufficient to entitle them to the name of nephelite-basalt if account be taken of the quantitative relations. According to the quantitative system of classification recently proposed,[1] they are similarly monotonous, all of those analyzed and presumably all the others collected, so far as can be judged from the microscopic examination, falling in the subrangs camptonose (III. 5. 3. 4) and auvergnose (III. 5. 4. 4–5). Mineralogically they are very uniform and simple, the only constituent minerals being plagioclase, augite, olivine, and titaniferous magnetite, with occasionally some glass and traces of nephelite in a few instances. In the basalts themselves neither hornblende nor biotite could be detected, though crystals of hornblende occur loose in scoria at one or two points, as was noted above. The tuffs have apparently been derived from basaltic magmas, and will be briefly described after the basalts.

While the basalts vary from quite compact to highly vesicular and scoriaceous forms, such differences may be disregarded as being purely adventitious. They are all porphyritic, phenocrysts of olivine and of augite being present in every case, accompanied by abundant ones of feldspar in many of the flows, while in others feldspar phenocrysts are rare. But in the great majority of cases these megascopic differences largely disappear in the thin section, and even megascopically the extremes grade into one another to such an extent, and are connected by so many transition forms, that, as regards the majority of the rocks, a well-marked separation of the two is impossible, while the extremes may be referred to two distinct types, chiefly characterized by the abundant presence or almost complete absence of feldspar phenocrysts, as well as by certain slight chemical differences. A third type is more distinct, but even this would probably be found to intergrade with the others, were more specimens available.

[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks*, Chicago, 1903.

As has been explained elsewhere,[1] in connection with the Catalan basalts, since the modes and textures of these basalts are usual ones, represented by much better- and longer-known rocks, the types will not be designated systematically and definitively by the use of typal adjectives, but will be distinguished provisionally by prefixing to the magmatic name the name of a representative locality on the island.

CAMPTONOSE-AUVERGNOSE (FELDSPAR-BASALT), MONTE PONENTE TYPE

Megascopic characters.—In the hand specimen these rocks vary in color from a rather dark gray to black, and are sometimes compact but more often decidedly vesicular, highly scoriaceous forms being abundant. They are decidedly porphyritic, thin, tabular phenocrysts of white feldspar, from 2 to 4^{mm} long, being abundant, with fewer of olivine, 1 to 3^{mm} in diameter, usually pale yellow, but occasionally golden or rarely greenish, and still fewer of dark, greenish-black augite.

Microscopic characters.—In thin section the feldspar phenocrysts are seen to be wholly of labradorite, almost invariably twinned both according to the Carlsbad and the albite laws, the extinctions indicating a composition of about $Ab_1 An_1$. A zonal structure is rarely seen, the core being then more calcic, but the interior is not infrequently occupied by a sponge-like mass of inclusions, either of brownish glass or of augite and magnetite grains. The augite phenocrysts are rarely visible and present no features of special note. They are usually fragmentary or stoutly prismoidal, quite colorless, or less often pale gray, quite free from any zonal structure, and containing generally some inclusions of magnetite. The olivine phenocrysts, which are more abundant than those of augite, are colorless, usually highly euhedral, showing the common lozenge-shaped outlines, but occasionally with the edges corroded, especially on the faces of the domes and prisms. In most of the specimens the olivine phenocrysts are perfectly fresh, borders of iddingsite being extremely rare.

The ground-mass in which these lie is usually a typically intersertal one, thin tables of plagioclase, which has the same composition as that of the phenocrysts ($Ab_1 An_1$), being quite abundant and usually

[1] H. S. Washington, *American Journal of Science*, Vol. XXIV, 1907, p. 229.

divergently arranged. Between these feldspar laths is a granular aggregate of small, colorless augite anhedra, which are generally equant rather than prismoidal, and many opaque grains of magnetite, small grains of olivine and apatite prisms being rarely seen in the ground-mass. While some of the specimens seem to be holocrystalline, others are distinctly vitreous, and in these the femic constituents are not well crystallized, but are represented by dusty, dark specks, which render the ground-mass almost opaque. This is especially well seen in the rock which forms the dike at Monte Pozzolana. In this type nephelite seems to be rare or wholly wanting.

Mode.—The small size of the ground-mass constituents, especially of the augite and magnetite anhedra, and the great extent of overlapping, do not permit a satisfactory estimate of the mode by Rosiwal's method. But by making certain readjustments of the norm as calculated from the chemical analysis, the mode of the upper north flow of Monte Ponente was estimated to be approximately as follows:

Labradorite (Ab_1An_1)	57
Augite	26
Olivine	6
Magnetite (titaniferous)	10
Apatite	1
	100

The abundance of labradorite, and the relatively much greater amount of augite than of olivine, are the distinguishing features of this mode.

Chemical composition.—Two analyses of this type were made by me, one being of the uppermost, and the other of the lowest accessible, north flow of Monte Ponente. Parts of this latter flow showed a white mineral (gypsum) in the vesicles, but a specimen free from this was chosen for analysis. The gypsum itself will be described later. In this, as well as in the other analyses made of the basalts, especial attention was paid to the determination of titanium and nickel, the presence of which is so often disregarded, as these constituents have been found to be of considerable importance in considering the correlations of the Linosa rocks. Analysis No. II has been previously published,[1] but in a less complete form.

[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 75.

	I	II	I*a*	II*a*
SiO_2	48.06	48.84	0.801	0.814
Al_2O_3	15.90	14.62	0.156	0.143
Fe_2O_3	3.37	2.08	0.021	0.013
FeO	7.97	9.00	0.111	0.125
MgO	7.11	7.15	0.178	0.179
CaO	9.37	9.33	0.168	0.166
Na_2O	3.19	2.86	0.050	0.039
K_2O	0.85	0.89	0.009	0.010
H_2O+	0.40	0.49	.....	.....
H_2O-	0.06	0.07	.....	.....
CO_2	none	none	.....	.....
TiO_2	3.31	3.57	0.041	0.045
ZrO_2	....	none	.....	.....
P_2O_5	0.36	0.36	0.003	0.003
SO_3	....	0.05	.....	.....
Cl	0.14	0.42	0.002	0.006
Cr_2O_3	none	none	.....	.....
MnO	0.06	0.04	0.001	0.001
NiO	0.09	0.08	0.001	0.001
CuO	none	none	.....	.....
BaO	....	none	.....	....
SrO	....	0.04	.....	....
	100.24	99.89		
O=Cl	.03	.09		
	100.21	99.80		

I. Auvergnose-camptonose (feldspar-basalt). Upper north flow of Monte Ponente, Linosa.

II. Auvergnose (feldspar-basalt). Lower north flow of Monte Ponente, Linosa.

I*a*. Molecular ratios of I.

II*a*. Molecular ratios of II.

The two analyses are very closely alike, there being no noteworthy difference between the uppermost and the lowermost flow. The small amounts of chlorine shown in these were extracted by water, and belong (with equivalent amounts of sodium) to salt derived from the sea-water, the waves of which break over the lavas. In the columns of molecular ratios these amounts of Na_2O (0.002 in I and 0.006 in II) have been deducted. The small amount of SO_3 in II indicates the practically complete absence of gypsum in the specimen analyzed. Among details to which attention may be called are the great preponderance of ferrous over ferric oxide, and the high figures for titanium dioxide and nickel oxide, features which will be discussed at length on a later page. The absence of copper, zirconium, chromium, and barium, and the presence of but traces of strontium, may also be noted.

Classification.—The norms of the preceding analyses, on which their classification according to the quantitative system depends, are shown in the adjoining table.

Norm of I		Ratios of I
Or	5.00	$\frac{Sal}{Fem}=\frac{58.17}{41.34}=1.41.$ Class III, salfemane.
Ab	26.20	
An	26.97	$\frac{F}{Q, L}=\frac{58.17}{0}=\infty.$ Order 5, gallare.
Di	13.63	
Hy	10.30	$\frac{K_2O+Na_2O}{CaO'}=\frac{59}{97}=0.61.$ Rang 3, camptonase.
Ol	5.31	
Mt	4.87	
Il	6.23	$\frac{K_2O}{Na_2O}=\frac{9}{50}=0.18.$ Subrang 4, camptonose.
Ap	1.00	
Rest	0.75	Symbol, III. 5. 4–3. 4.
	100.26	

Norm of II		Ratios of II
Q	1.44	$\frac{Sal}{Fem}=\frac{53.57}{44.79}=1.20.$ Class III, salfemane.
Or	5.56	
Ab	20.44	$\frac{F}{Q}=\frac{52.13}{1.44}=36.20.$ Order 5, gallare.
An	26.13	
Di	13.90	
Hy	20.03	$\frac{K_2O+Na_2O}{CaO'}=\frac{49}{94}=0.52.$ Rang 4, auvergnase.
Mt	3.02	
Il	6.84	$\frac{K_2O}{Na_2O}=\frac{10}{39}=0.26.$ Subrang 4–5, auvergnose.
Ap	1.00	
Rest	1.19	Symbol, III. 5. 4. 4–5.
	99.55	

It is evident that both fall well within the salfemane class and the perfelic order gallare, though a very small amount of quartz is present in the norm of II. As regards the rang, which is based on the relations of the alkalies to salic lime, I falls in the alkalicalcic division, camptonase, but so close to the border of the docalcic order auvergnase that it must be considered transitional. II falls within the docalcic order auvergnase, but it may be noted that this position is due to the abstraction of the soda to satisfy the chlorine, present as sodium chloride derived from sea-water, and that, were this not determined, the rock would fall also in the alkalicalcic order camptonase, where it was placed when this analysis was published previously. This rock must therefore also be regarded as transitional. The subrang is, in every case, distinctly sodic, so that I is to be called auvergnose-

camptonose, and II camptonose-auvergnose. Collectively, therefore, these rocks may be considered to belong to the transitional division camptonose-auvergnose, as they apparently tend to be docalcic.

Relations of norm and mode.—In these rocks the relations of norm and mode are quite simple and the readjustments needed to compute the latter from the former are confined almost wholly to those necessary to form the modal augite. As this mineral has not yet been analyzed, it is needless to go into any great detail, but it may be pointed out that these readjustments would, on the analogy of many other similar cases which have been worked out, consist in the transfer of a little of the normative anorthite, magnetite, and ilmenite, combined with the whole of the normative diopside, to the more complex modal augite molecule. The normative orthoclase, but little of which is present, must be considered as entering the modal plagioclase, though a small part of it may be present in the base of the ground-mass. As the augite is not markedly titaniferous, and the olivine presumably not more so, and as no titanium minerals, as perofskite, titanite, or ilmenite, are present, the very considerable amount of normative ilmenite (except that which enters the augite) must be held in the opaque ore grains, which, therefore, are to be considered as titaniferous magnetite.

But all of these readjustments are of comparatively small magnitude, even those needed for the formation of augite, which are moreover the normal ones, or those necessary in the case of the vast majority of igneous rocks, in which the pyroxene is aluminous. The modes are, therefore, normative and, in view of the abundance of feldspar phenocrysts, the Monte Ponente type may be briefly described as salphyro-camptonose-auvergnose, which indicates very concisely a basalt of about the chemical composition shown by the analyses, showing the mode in general described above, and with prominent feldspar phenocrysts.

The presence of a slight amount of quartz in the norm of II may seem to be inconsistent with the presence of olivine in the mode. But this is by no means uncommon, and instances of basalts containing olivine in the mode, while the norm shows none and even some quartz, are met with quite frequently, as along the Pacific slope of the United

States,[1] and in the fiescolal ciminose (ciminite) near Viterbo, which has been discussed elsewhere.[2] In such cases the analysis leaves no doubt that there is an excess of silica which, owing to the modal presence of olivine, must be increased in the mode over that shown by the norm, and is to be looked for either in the residual base of the groundmass or, as in the quartz-basalts, is present as clearly recognizable quartz.

Occurrence.—Basalts of this type are especially well represented at Monte Ponente, composing the extensive northern flows of this cone as well as the dike which cuts the tuff of Monte Pozzolana. Other representatives of the type are met with in many of the flows of Monte Vulcano, some of those of Monte Rosso and Monte Raneri, and in the basalts about the Scala Vecchia, which are probably derived from Monte Vulcano.

Gypsum in vesicles.—In parts of one of the lower flows of Monte Ponente, as noted above, the vesicles of the lava contain a white, crystalline substance, which was supposed to be a zeolite, in the field. Examination in the laboratory, however, shows that it is gypsum, and as such an occurrence is unusual for this mineral it merits a brief description.

The mineral forms thin crusts, which are distinctly crystalline, though no definite crystal forms are to be seen. It is soft (H = about 2), and slight crushing develops poorly defined cleavage flakes. Under the microscope these show rather low refraction and double refraction, which were not determined quantitatively. Two other cleavages are prominent (one better developed than the other), crossing at about 114°, that of the two minor cleavages of gypsum. The acute bisectrix lies in the acute angle of the cleavage rhomb, making angles with the cleavage trace parallel to $10\bar{1}$ varying from 12° 30′ to 14°, the corresponding angle for gypsum being 13° 39′. An analysis (on 0.2122^{gm}) gave the following results, the calculated values for gypsum being given for comparison:

[1] See, for instance, *Professional Paper*, U. S. Geological Survey, No. 14, 1903, p. 289, hessose, Nos. 18, 23, 29, and p. 333, auvergnose, No. 32. Many other cases could be cited from this collection.

[2] H. S. Washington, *The Roman Comagmatic Region*, Carnegie Publication No. 57, 1906, p. 64

	Found	Calculated
CaO	32.04	32.56
SO_3	46.61	46.51
H_2O	20.70	20.93
SiO_2	0.48	.....
Fe_2O_3	trace	.....
	99.83	100.00

The occurrence of gypsum in vesicles of basalts is not mentioned in the standard works of Zirkel, Rosenbusch, Roth, Iddings, and Levy and Lacroix, but its presence has been recorded in the vesicular lavas and the fumarole products of Vesuvius[1] and Etna,[2] and it is also mentioned as present in the boiling water of the crater lake of Graham's Island;[3] though, on the other hand, no mention is made of its presence at some other volcanoes, as Santorini and those of the Hawaiian Islands. It may also be mentioned that I did not find it in the very similar lavas of the Catalan volcanoes, nor is it recorded by Fernandez-Navarro in his very complete description of these lavas.[4] It also seems to be absent from the basalts of Pantelleria, not being mentioned by Foerstner,[5] nor having been observed by me.

CAMPTONOSE (FELDSPAR-BASALT), IL FOSSO TYPE

Megascopic characters.—In general these lavas are rather lighter in color than those of the preceding type, being mostly light to rather dark gray, decidedly black lava being rare. They are also more apt to be compact, and highly vesicular forms are less often met with. While they are porphyritic, phenocrysts are less abundant, this being especially noticeable in those of feldspar, which are very few, somewhat tabular, but furnishing rounded outlines in the hand specimen, and are usually rather large, up to 10^{mm} long and 5^{mm} wide, though very small and inconspicuous ones are also present. The phenocrysts of

1 J. Roth, *Der Vesuv*, Berlin, 1857, p. 369; and J. L. Lobley, *Mount Vesuvius*, London, 1889, p. 287.

2 Sartorius von Waltershausen, *Der Aetna*, Leipzig, 1880, Vol. II, p. 525.

3 H. Abich, *Vulkanische Erscheinungen*, Braunschweig, 1841, p. 75.

4 Cf. "Formaciones volcanicas de la Provincia de Gerona," *Mem. Soc. Espan. Hist. Nat.*, Vol. IV, 1907, pp. 437–43.

5 E. Foerstner, *Boll. Com. Geol. Ital.*, 1881, p. 533.

olivine and of augite resemble those of the other type, both as to their characters and their amounts, and do not call for special mention.

Microscopic characters.—The general features shown in the thin section are much like those previously described, though there are some well-marked differences in the most representative specimens of this type. The very rarely seen feldspar phenocrysts are of a labradorite, highly twinned, of about the composition Ab_1An_1, as in the previous case, and similarly no constant difference of any importance can be detected in the characters of the phenocrysts of augite and olivine, though those of the latter are more abundant than in the Monte Ponente type.

The ground-mass, on the other hand, offers more points of difference. Small tabular, highly euhedral crystals of labradorite are abundant, but they are usually shorter and stouter than in the other rocks, and the arrangement, instead of being diverse, is typically subparallel, giving rise to well-marked flow textures, which are especially clearly developed in the blocks from the tuffs. Olivine is rarely seen in the ground-mass, and the anhedra of augite and magnetite are closely like those described above. The abundance of dark, dusty grains is seen only in one or two cases, and these transitional toward the preceding type, but the interstitial, colorless base is here less apt to be isotropic and often shows a faint birefringence, indicating the presence of the nephelite shown in the norm. Its amount, however, is never very great.

Mode.—Owing to the impossibility of a satisfactory application of the Rosiwal method, the mode of the specimen analyzed was estimated by readjustment from the norm, and is approximately as in I below, that of the other type being repeated in II for comparison.

	I	II
Labradorite (Ab_1An_1)	50	57
Nephelite	5	0
Augite	20	26
Olivine	14	6
Magnetite (titaniferous)	10	10
Apatite	1	1
	100	100

It will be seen that the relative amounts of salic and of alferric and femic minerals is about the same in the two, so that the ground-mass of the Fosso type must be more highly feldspathic than that of the Ponente type, much of the feldspar of which exists as phenocrysts, and this fact will account for the usually lighter color of the present rock. The amount of nephelite is small, and those of augite, magnetite, and apatite scarcely differ in both rocks, while olivine is distinctly higher in that from Il Fosso.

Chemical composition.—This was determined by the analysis of a specimen from a block in the tuffs of Il Fosso, the results of which are given below, along with the molecular ratios.

SiO_2	46.55	0.776
Al_2O_3	14.55	0.143
Fe_2O_3	3.17	0.020
FeO	7.88	0.110
MgO	8.61	0.215
CaO	8.75	0.156
Na_2O	3.71	0.060
K_2O	1.62	0.017
H_2O+	0.14	.....
H_2O-	0.03	.....
CO_2	none	.....
TiO_2	3.84	0.048
P_2O_5	0.55	0.004
MnO	0.10	0.001
NiO	0.12	0.001
	99.62	

Camptonose (feldspar-basalt). Block in tuff, Il Fosso, Linosa.

The general features of this analysis are closely like those of the two Monte Ponente rocks, even in the small details of titanium, manganese, and nickel. It may be noted, however, that this rock is very distinctly lower in silica and higher in alkalies, especially potash, while magnesia is a trifle higher and lime slightly lower, the other constituents remaining about the same.

Occurrence.—The most representative specimens of this type were met with as angular, compact blocks in the tuffs of Monte Levante, Il Fosso, and the north crater of Monte Bandiera, while other specimens, decidedly transitional toward the preceding type, occur as flows at Monte Vulcano and in the blocks of lava, apparently derived from Monte Ponente, which have been excavated at the Scala Nuova for use in building the jetty.

Classification.—The norm of this rock, calculated from the figures shown in the analysis, is as follows:

Norm		Ratios	
Or	9.45	$\frac{Sal}{Fem}=\frac{55.52}{43.86}=1.27.$	Class III, salfemane.
Ab	23.32		
An	18.35	$\frac{F}{L}=\frac{51.12}{4.40}=11.62.$	Order 5, gallare.
Ne	4.40		
Di	17.05	$\frac{K_2O+Na_2O}{CaO'}=\frac{77}{66}=1.17.$	Rang 3, camptonase.
Ol	13.53		
Mt	4.64		
Il	7.30	$\frac{K_2O}{Na_2O}=\frac{17}{60}=0.28.$	Subrang 4, camptonose.
Ap	1.34		
Rest	0.39	Symbol, III. 5. 3. 4.	
	99.77		

This rock, therefore, falls well within the salfemane class, the amount of nephelite being negligible, and it is also clearly in the perfelic order, the alkalicalcic rang, and the dosodic subrang, and is thus an almost central camptonose.

The relations of the norm and mode, which are almost identical with those discussed above, need not be repeated here. The mode may be considered as normative, and the type may be briefly described as an alferfemphyro-camptonose.

CAMPTONOSE (OLIVINE-BASALT), MONTE RANERI TYPE

Megascopic characters.—This type differs from the preceding in the abundance and size of the olivine phenocrysts, which are olive-green in color, from 2 to 10^{mm} in diameter, and constitute at least 20 per cent. of the rock. Feldspar phenocrysts are tabular, as in the salphyric subtype just described, but their number is very few, and they are small and inconspicuous, as are also the phenocrysts of augite. Most of the specimens of this type which were collected are compact, but scoriaceous and vesicular forms also occur. On weathering, the compact forms show a feature which was also noted in some of the Catalan basalts, namely a peculiar mottled appearance in patches of dark and light gray, or dark gray and slightly reddish gray, the rock tending also to disintegrate into small, angular pieces which correspond to these colored areas. This appearance, which has been called *Sonnenbrand* by German quarrymen, is not uncommon

in some basalts, especially in those which contain nephelite, and has been attributed by Leppla[1] to the presence of this mineral.

Microscopic characters.—In thin section the same minerals are seen to be present as in the preceding type but, corresponding to the megascopic characters, olivine phenocrysts are much more numerous. These are seldom euhedral, but usually present rounded outlines, which are frequently irregular, though embayments, such as are often ascribed to corrosion by the magma, are rare. The olivine phenocrysts carry some small inclusions of magnetite, and are occasionally slightly brown on the edges through incipient alteration. The few feldspar phenocrysts are of labradorite, about Ab_1An_1, thick tabular in shape, and frequently spongy in the interior through the presence of many inclusions of glass, augite, and magnetite. No augite phenocrysts were seen in the sections examined.

The ground-mass is somewhat coarser than in the preceding type, and the abundant, highly euhedral, labradorite tables are shorter and stouter, and an intersertal arrangement is not so pronounced. Small anhedra of colorless or yellowish augite and of magnetite are abundant, while small anhedra of colorless olivine are present in the ground-mass to a greater extent than in the preceding type, though they must be considered as but accessory ground-mass constituents. A glass base seems to be present occasionally, but its amount is very small.

Mode.—While no satisfactory estimate of the mode by Rosiwal's method was possible, the relative amounts of the various minerals present was readily estimated by some simple readjustments of the figures shown by the norm, which are given on a later page. The mode is approximately as follows:

Labradorite (Ab_1An_1)	47
Augite	11
Olivine	28
Magnetite (titaniferous)	10
Apatite	1
Glass and nephelite	3
	100

As compared with the modes of the preceding types it is clear that the most marked difference lies in the amounts of augite and

[1] A. Leppla, *Zeitschrift der praktischen Geologie*, Vol IX, 1901, p. 175.

olivine, the proportions of these being reversed. In the Monte Raneri type, also, the amount of labradorite is somewhat less than in the preceding rocks, while the ores and apatite remain about the same.

Chemical composition.—The results of an analysis made of the freshest specimen from Monte Raneri are here given. As compared

SiO_2	45.75	0.763
Al_2O_3	13.98	0.137
Fe_2O_3	3.23	0.020
FeO	8.02	0.111
MgO	14.69	0.367
CaO	7.11	0.127
Na_2O	3.10	0.050
K_2O	1.10	0.012
H_2O+	0.16	.....
H_2O-	0.04	.....
CO_2	none	.....
TiO_2	2.90	.036
P_2O_5	0.36	0.003
Cr_2O_3	trace	.....
MnO	0.06	0.001
NiO	0.14	0.002
	100.64	

Camptonose (olivine-basalt). Monte Raneri, Linosa.

with those of the preceding types the silica is decidedly lower than the lavas of Monte Ponente, but only slightly lower than the block from Il Fosso. Alumina, the oxides of iron, the alkalies, titanium, phosphorus, and manganese are almost the same; but lime is considerably lower, and magnesia, on the other hand, very much higher, these last features being in accord with the great abundance of olivine in this type and its comparative paucity in augite. Nickel also seems to be present in somewhat greater amount, and this is to be expected on account of the high content in magnesia, though the small figures are not very significant. Only a mere trace of chromium is present, and none of this was detected in the other rocks analyzed.

Occurrence.—Typical examples of this rock were found only at Monte Raneri, where they seem to be the prevailing type, but a very similar lava was met with as blocks at Monte Rosso, in which, however, the olivine phenocrysts, while prominent, are fewer and smaller than in the Monte Raneri rock.

Classification.—The norm and ratios of the specimen analyzed are as follows:

Norm		Ratios	
Or	6.67	$\frac{Sal}{Fem}=\frac{51.80}{48.54}=1.07.$	Class III, salfemane.
Ab	22.01		
An	20.85	$\frac{F}{L}=\frac{49.53}{2.27}=21.81.$	Order 5, gallare.
Ne	2.27		
Di	9.26		
Ol	28.17	$\frac{K_2O+Na_2O}{CaO'}=\frac{62}{75}=0.83.$	Rang 3, camptonase.
Mt	4.64		
Il	5.47	$\frac{K_2O}{Na_2O}=\frac{12}{50}=0.24.$	Subrang 4, camptonose.
Ap	1.00		
Rest	0.40	Symbol, III. 5. 3. 4.	
	100.74		

From the figures given it appears that this type falls well within all the magmatic divisions, and that it is a typical camptonose. The classificatory influence of the very high magnesia, in which respect it differs most widely from the other rocks analyzed, would be expressed in the minor divisions of the system, especially in the section of grad, which is based on the relations of olivine to pyroxene. But in the present introductory stage of the new system it is not deemed advisable to carry the classification as far as these minor divisions for ordinary purposes, since the main features of a rock may be quite clearly expressed by the use of the major magmatic divisions alone (from class to subrang inclusive), together with a typal qualifier or adjectival prefixes, to indicate the mode and texture.

So far as the relations of norm and mode are concerned, the readjustments needed to derive the mode from the norm are of slight importance, being confined chiefly to the augite, the amount of which is small, as we have seen above. The mode may therefore be considered as normative, and the rock may be described as an olivine-phyro-camptonose, which designates very concisely its mode, texture, and chemical composition. In the prevailing systems of classification it is an olivine-feldspar-basalt, but the use of a special name would be needed if it were desired to indicate the size and abundance of olivine phenocrysts, in which respects it differs from many others.

THE TUFFS

While volcanic tuffs, as a rule, offer few features of interest, yet as those of Linosa are so abundant and play such a conspicuous rôle in the formation of the cones of the earlier period, they may be described briefly.

These tuffs vary in color from dark, rather greenish, gray to a light brownish yellow. In some cases only one of these is present, as yellow tuffs at Monte Pozzolana and Monte Biancarella, or dark gray at the main ridge of Monte Bandiera; while elsewhere both varieties are met with, as at the two craters east of Monte Bandiera and at Monte Levante. As will be seen later, the differences between the two are probably to be ascribed only to differences in the progress of alteration.

The dark-gray tuffs are very fine grained and friable, readily rubbing down to an impalpable powder, at least in great part. Aside from the large blocks of lava which are embedded in them, they contain very small fragments of black basalt, seldom larger than a pea and running down to very small angular grains. A bedded structure is generally clearly manifest, and is frequently emphasized by thin layers more rich in the small fragments of basalt. Unfortunately, no sections were made of these, but the powder, when viewed under the microscope, shows fragments of colorless augite as the only recognizable mineral, the greater part of the mass being a dust of almost opaque, but apparently isotropic, minute grains, probably of glass.

The yellow tuffs[1] show, likewise, small pieces of black basalt, often vesicular, which stand out against the light-yellow background more prominently than do those in the gray tuff. The yellow portion is rather less friable than the preceding, and is somewhat porous, the constituent grains being agglomerated into very small, rounded aggregates, a millimeter or less in diameter, between which there are numerous crevices and pores. The powder of this, under the microscope, also reveals small fragments of augite, the light-yellow dust in which they lie being semi-transparent and apparently isotropic.

The chemical composition of these tuffs is shown in the two analyses given below, both analyses being made of average material which

[1] These are the trachytic rocks of Calcara.

includes the very small fragments of basalt which seem to be always present. They were made on air-dried material, the specimens having been kept in a drawer for over a year prior to the analysis. None of the minor constituents, except titanium dioxide, were determined, but both manganese and nickel were present, and apparently in amounts comparable to those shown by the preceding analyses.

	I	II	I*a*	II*a*
SiO_2	47.43	39.00	50.16	46.66
Al_2O_3	17.20	15.58	18.19	18.64
Fe_2O_3	4.2[illegible]	6.13	4.44	7.33
FeO	5.27	3.11	5.57	3.72
MgO	4.85	6.55	5.13	7.83
CaO	7.56	6.82	8.00	8.16
Na_2O	3.53	3.22	3.73	3.85
K_2O	1.51	0.59	1.60	0.71
H_2O+	2.42	6.03	....	....
H_2O-	3.12	8.18	....	....
CO_2	none	1.83	....	....
TiO_2	3.00	2.59	3.17	3.10
	100.09	99.63	99.99	100.00

I. Gray tuff. Monte Levante, Linosa.

II. Yellow tuff. Monte Pozzolana, Linosa.

I*a*. Analysis I calculated free from water.

II*a*. Analysis II calculated free from water and carbon dioxide.

These analyses present some features of interest. The silica of I is about the same as that of the lavas, while that of II is very much lower. Also the alumina of I is distinctly higher than in the lavas,[1] while that of II is about the same as in these. In view of the evidently very considerable weathering which these tuffs have undergone, the much lower ratio of ferrous to ferric oxide, as compared with the figures shown by the fresh lavas, is not surprising. Magnesia is very decidedly lower in I than in the majority of the lavas, while in II it is but slightly so, but the figures for lime as well as for the alkalies and titanium dioxide do not differ materially from those in the fresh rocks. The presence of considerable water only driven off at a high temperature, and of carbon dioxide in II, is readily understood, but the high

[1] This high alumina, taken in connection with the low magnesia, might be thought to be due to the common analytical error of partial precipitation of the magnesia with the alumina, owing to the presence of insufficient ammonium chloride. But this was specially guarded against, and the absence of magnesia from the precipitate by ammonium hydroxide was definitely proven.

figures for water which is driven off at 110°, and which cannot be due only to the moisture of the sample, indicates the presence of a zeolitic cement, the amount of which must be very large in the yellow tuffs, in which calcite also is present, and which serves to explain their more coherent character.

While the processes involved in weathering are highly complex and involve the abstraction of certain constituents, and to a less extent the addition of others, and in varying amounts for each,[1] so that the calculation of the figures shown by the analysis of weathered rocks to a water- and carbon-dioxide-free basis cannot usually express the original composition of the mass, yet the figures shown in the last two columns, which have been calculated on this basis, are not without interest. In spite of the higher alumina and ferric oxide, and lower ferrous oxide and magnesia, which they show, they indicate that the tuffs are derived from basalts which did not originally differ chemically very materially from the later lavas, especially those of the Monte Ponente type. The scarcely appreciable change in the figures for the alkalies, however, those for soda being even slightly higher in the tuffs than in the lavas, would indicate that the original magma of the tuffs was distinctly higher in these, especially in soda, and that nephelite would probably have been present in considerable amount had they formed compact lavas. The somewhat higher soda in the blocks of lava from the tuffs (page 23), over those of the later lava flows, leading to the presence of nephelite in the norm, and probably in the mode, of these rocks, also points the same way.

In general, however, regarding the tuffs as weathered representatives of original basaltic ones, the processes of alteration seem to have been normal, as explained by Roth[2] and Merrill,[3] the latter especially pointing out the usually more rapid loss in magnesia than in lime.

Although the figures shown in I*a* and II*a* above are open to the criticism that they do not adequately represent the original magmas, yet it is instructive to examine the norms which they yield, which are given here, the ratios being omitted.

[1] Cf. G. P. Merrill, *Rocks, Rock-weathering, and Soils*, New York and London, 1897, pp. 173–94.

[2] J. Roth, *Allgemeine und chemische Geologie*, Vol. III, 1893, p. 251.

[3] G. P. Merrill, *op. cit.*, pp. 218–24, 239.

	I*b*	II*b*
Or	9.45	3.89
Ab	31.44	31.16
An	28.08	31.69
Ne	....	0.71
Di	9.17	6.91
Hy	8.16	....
Ol	1.18	11.48
Mt	6.50	2.78
Il	6.08	5.93
Hm	....	5.44
	100.00	99.99

I*b*. Norm of I*a*, gray tuff of Monte Levante.
II*b*. Norm of II*a*, yellow tuff of Monte Pozzolana.

From these figures the gray tuffs, or rather the original rock on the assumption that the recalculated analysis correctly represents it, falls in the subrang andose (II. 5. 3. 4), while the original rock of the yellow tuff would fall in beerbachose (II. 5. 3. 5), but so close to the border of the docalcic order that it is nearly in hessose (II. 5. 4. 4–5), so that it should be called a hessose-beerbachose (II. 5. 4–3. 4–5). The most salient feature about these magmatic positions is the fact that, differing from the fresh lavas, these tuffs are in the dosalane class, not the salfemane. This position is brought about, in part by the high alumina, which increases the amount of normative anorthite, in part by the greater amount of ferric oxide relative to ferrous, and by the lower magnesia, both of which decrease the amounts of femic minerals. But apart from these differences of class, the rocks of the tuffs would seem to have been closely concordant, as far as the order, rang, and subrang are concerned, with the later lavas, and they were probably originally also in the salfemane class.

GENERAL PETROLOGICAL RELATIONS

Character and succession of the lavas.—The figures shown by the analyses, and the facts in regard to the relative ages of the various volcanic cones, presented in the preceding pages, furnish us with the data for a brief discussion of the general characters of the Linosa lavas, and their order of succession. For convenient reference all of the analyses of the lavas are repeated here, those of the tuffs being omitted, as their original characters are so obscured by weathering as to render these analyses of little use. There are also given in the

table some analyses of closely related rocks from Pantelleria, Sardinia, and Catalonia, which have already been published,[1] and which will be referred to in the subsequent discussion.

The lavas of Linosa would seem to be quite monotonous in chemical as well as mineral characters. Mineralogically they are of very simple composition, labradorite, augite, olivine, titaniferous magnetite, and apatite being the only minerals present in all cases, and usually in about this order of abundance, though in one rare type the amount of olivine surpasses that of the augite. Chemically, they are

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2....	48.06	48.84	46.55	45.75	46.22	44.83	52.40	52.67	47.66
Al_2O_3..	15.90	14.62	14.55	13.98	12.23	11.73	15.26	15.35	14.36
Fe_2O_3..	3.37	2.08	3.17	3.23	4.91	1.35	0.74	3.82	2.83
FeO....	7.97	9.00	7.88	8.02	7.71	11.79	8.33	5.42	8.44
MgO...	7.11	7.15	8.61	14.69	6.74	5.50	7.45	4.40	8.19
CaO....	9.37	9.33	8.75	7.11	9.86	9.63	7.33	5.91	9.36
Na_2O...	3.19	2.86	3.71	3.10	3.39	3.34	3.54	4.50	3.51
K_2O....	0.85	0.89	1.62	1.10	1.13	1.40	0.99	2.68	1.54
H_2O+ .	0.40	0.49	0.14	0.16	0.17	0.81	0.29	0.37	0.17
H_2O- .	0.06	0.07	0.03	0.04	0.05	0.10	0.06	0.14	0.20
CO_2....	none	none	none	none	none	none	none	none	none
TiO_2...	3.31	3.57	3.84	2.90	5.68	6.88	3.12	4.04	3.83
P_2O_5...	0.36	0.36	0.55	0.36	1.46	2.14	0.49	0.75	0.45
MnO...	0.06	0.04	0.10	0.06	....	....	0.08	....	....
NiO....	0.09	0.08	0.12	0.14	....	....	0.06	....	....
	100.24	99.89	99.62	100.64	99.55	99.50	100.14	100.05	100.54

I. Auvergnose-camptonose (III. 5. 4–3. 4) [feldspar-basalt]. Upper north flow, Monte Ponente, Linosa. Includes Cl 0.14, CuO none.

II. Auvergnose (III. 5. 4. 4, 5) [feldspar-basalt]. Lower north flow, Monte Ponente, Linosa. Includes SO_3 0.05, Cl 0.42, SrO 0.04, and ZrO_2, CuO, and BaO none.

III. Camptonose (III. 5. 3. 4.) [feldspar-basalt]. Block in tuff, Il Fosso, Linosa.

IV. Camptonose (III. 5. 3. 4) [olivine-basalt]. Monte Raneri, Linosa. Includes trace of Cr_2O_3.

V. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Monte San Elmo, Pantelleria.

VI. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Island of 1891, near Pantelleria.

VII. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Near Cuglieri, Sardinia.

VIII. Akerose (II. 5. 2. 4) [feldspar-basalt]. Monte San Mateo, near Ploaghe, Sardinia.

IX. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Castellfullit, near Olot, Catalonia, Spain.

[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 75.

characterized by rather low silica and alumina, high iron oxides, with ferrous oxide largely predominating over ferric, rather high magnesia and lime, the former being very high in the olivine-rich type, rather high soda (for such femic rocks), and low potash, very high titanium dioxide, small amounts of phosphoric pentoxide and manganese, and finally the constant presence of nickel oxide in rather high amounts for this constituent. Zirconium, chromium, copper, barium, and strontium seem to be either uniformly absent or present only in traces.

As regards the succession, or order of eruption, of the lavas, their uniform and monotonous character in general gives little scope for distinctions. From the figures furnished by the analyses of the tuffs and the blocks of the cones of the earlier period, however, as compared with those of the later lavas, it would seem that the earlier rocks were slightly higher in soda, and in general somewhat lower in silica and possibly in lime, than the later ones. The iron oxides, potash, titanium, and phosphorus apparently change but little, while there are indications of a slight drop in magnesia, though the high figure for this constituent in the Monte Raneri lava (which, however, is earlier than those of Monte Ponente) is anomalous. But the figures show, in general, variations of too slight an extent to justify any definite conclusion that a decided change has taken place, and indicate, on the contrary, that the chemical character of the magma has remained practically the same from the earliest eruption on Linosa to the latest. It is possible that this is connected with a short period of volcanic activity on the island, or it is possibly indicative of this. In the absence of any geological or stratigraphical means of measuring the time elapsed since the first eruptions, the interval between those of the tuff and of the lava cones, and the time that has passed since the last volcano became extinguished, we are not in a position to decide.

Relations of the Linosa lavas to others.—In a paper[1] published some years ago a possible genetic connection was suggested between the lavas of Linosa, Pantelleria, and Sardinia, the suggestion being based on the few analyses of the rocks of Pantelleria and Sardinia which had been published at that time, none of Linosa being known, as well as on some more general tectonic grounds. In a more recent

[1] H. S. Washington, *American Journal of Science*, Vol. VIII, 1899, p. 293.

paper,[1] based on numerous analyses which had been made of material collected during the trip on which Linosa was visited, especially of the basalts, the same idea was again expressed, the rocks of Catalonia being also considered as related to those of the other localities, and the probable existence of a distinct comagmatic region (petrographic province) in the western Mediterranean being pointed out. While this conclusion is based partly on the character of the basalts, there is considerable other evidence in its favor in the characters of the more salic rocks, and in other facts, but a full discussion must await the publication of the whole series of analyses, many of which remain to be made. In the present place it must suffice to point out the similarities between the basalts along this zone.

Turning to the table of analyses on page 32, it will be seen that the chemical characters of the basalts of Pantelleria, Sardinia, and Catalonia (only a few of which have been given here) are remarkably similar to those of Linosa and of each other. Except in Sardinia, where it is somewhat higher, silica is about the same in all, and the figures for the other constituents present close analogies with each other. This is especially well seen in those for the oxides of iron, ferrous oxide largely predominating over ferric, and those for titanium dioxide, the figures for this constituent, which reach a maximum at Pantelleria, being the highest known to me for any such large series of rocks. Also these basalts are highly dosodic, and in this respect in marked contrast to the salfemic rocks of the Italian peninsula, in which potash is abundant and is greatly in excess over soda, giving rise to the highly leucitic rocks for which the Bolsena-Vesuvius line of volcanoes is so famous.

While the general resemblance, and hence the probable genetic connection, between the basalts of Linosa, Pantelleria, Sardinia, and Catalonia are thus clear, it is noteworthy that the general monotony of the lavas of Linosa is in marked contrast with the conditions that obtain on the neighboring island of Pantelleria, as well as on Sardinia. On these two islands the earlier eruptions were of highly salic rocks, phonolites, trachytes, and rhyolites in the older classifications, being followed by, and the era of vulcanicity closing with, the eruption of

[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 69.

more femic rocks (basalts), which formed small cinder cones similar to those of Linosa. It might be argued from this that the last eruptions of Linosa belong to a very recent date, subsequent to those of the earlier salic lavas of Pantelleria, and possibly contemporaneous with those of the final basaltic cones of this island. And this view is strengthened by consideration of the very recent submarine eruptions of 1831 and 1891 in the neighborhood of Pantelleria, the lavas of which are highly femic, and resemble those of Linosa and the last eruptions of Pantelleria.

THE POST-JURASSIC IGNEOUS ROCKS OF SOUTH-WESTERN NEVADA[1]

SYDNEY H. BALL

INTRODUCTION

Three mighty periods of igneous activity mark the geological history of southwestern Nevada and eastern California. The latest of these, the Tertiary, has been ably treated by Spurr[2] while concerning the earliest, the pre-Cambrian, we know little. It is the purpose of this article to describe briefly the period of igneous activity beginning in post-Jurassic time and ceasing long prior to the Eocene.

During the field season of 1905 the writer made a reconnaissance of some 8,500 square miles in southwestern Nevada and eastern California for the United States Geological Survey.[3] This area lies between 36° 30′ and 38° North latitude and 117° 30′ and 116° West longitude (see Fig. 1).

GENERAL STATEMENT

The earliest of the post-Jurassic igneous rocks recognized in the area are the granular siliceous intrusive rocks; next came the intrusion of quartz-monzonite porphyry, poor in ferromagnesian minerals, while the youngest of the pre-Tertiary rocks are diorite and diorite-porphyry.

DISTRIBUTION

The post-Jurassic igneous rocks are widely distributed over the area under consideration although they cover larger expanses in its western portion, and are the predominant formation from longitude 117° 30′ westward to the Sierra Nevada. The Tertiary lavas and sedimentary rocks and the Pleistocene and Recent terrestrial deposits cover vast stretches so that a cursory examination of a geological map of Nevada gives but little idea of the importance of

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

[2] J. E. Spurr, *Journal of Geology*, Vol. VIII, pp. 621–46.

[3] See *Bull. U. S. Geological Survey No. 308.*

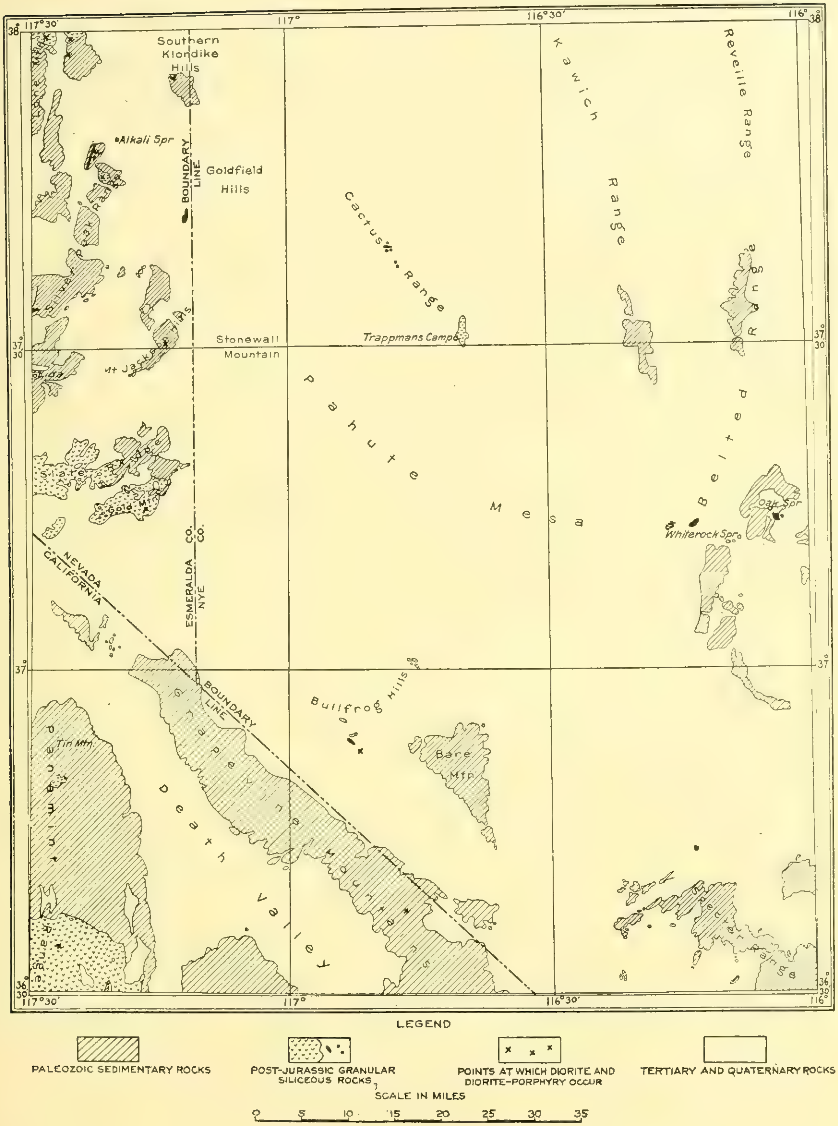
117°30'
117°
116°30'
116°
38°
37° 30'
37°
36° 30'
Southern Klondike Hills
Alkali Spr
Goldfield Hills
BOUNDARY LINE
Stonewall Mountain
Mt Jackson
Slate Ridge
Gold Mtn
ESMERALDA CO.
NYE CO.
NEVADA
CALIFORNIA
BOUNDARY LINE
Cactus Range
Trappmans Camp
Kawich Range
Reveille Range
Pahute Mesa
Belted Range
Oak Spr
Whiterock Spr
Bullfrog Hills
Bare Mtn
Tin Mtn
Death Valley
Grapevine Mountains
LEGEND
PALEOZOIC SEDIMENTARY ROCKS
POST-JURASSIC GRANULAR SILICEOUS ROCKS
POINTS AT WHICH DIORITE AND DIORITE-PORPHYRY OCCUR
TERTIARY AND QUATERNARY ROCKS
SCALE IN MILES
0 5 10 15 20 25 30 35

FIG. 1

the post-Jurassic igneous intrusives. But when we consider only the region at present covered by pre-Tertiary formations we find that the widely distributed masses of post-Jurassic igneous rocks form approximately one-sixth of this territory. Moreover, at many places where Tertiary lavas mask the older formations, fragments of pre-Tertiary igneous rocks are included in the lavas, thus showing the presence of these older rocks on the sides of the conduit through which the molten Tertiary rock welled.

THE GRANULAR SILICEOUS SERIES

GENERAL STATEMENT

This series is composed of four rocks which were intruded in the following order; monzonite and quartz-monzonite porphyry; granular rocks, including granite, quartz-monzonite, and soda syenite; aplites and pegmatites. These rocks in each separate batholith solidified successively from a single magma in the reverse order of their acidity.

MONZONITE AND QUARTZ-MONZONITE PORPHYRY

The granular igneous rocks of the Belted and Panamint ranges, of Pahute Mesa, and of Gold Mountain Ridge, contain fragments of fine-grained gray monzonitic rocks. That of Gold Mountain is a quartz-monzonite porphyry in which the ferromagnesian mineral is biotite. A specimen from the Belted Range is a basic hornblende-biotite-monzonite. These monzonites, while somewhat older than the granular siliceous rocks in which they occur, are massive and are believed to be a somewhat earlier crystallization of the magma from which the more siliceous rocks afterward solidified.

GRANITES, QUARTZ-MONZONITE AND SODA-SYENITE

Petrographic character.—These rocks range on the one hand from alaskite through muscovite-, muscovite-biotite-, and biotite-granite to a quartz-monzonite approaching granodiorite, and on the other hand from normal granite through soda-rich granite to soda-syenite. Most of these rocks grade into corresponding porphyries. The lithologic character of the rocks of most of the areas shown on the map (see Fig. 1) is usually rather constant, although in the Gold Mountain Ridge granite-porphyry grades into hornblende-bearing quartz-monzonite porphyry in a distance of only ten feet.

Many of these rocks are characterized by large porphyritic feld-

spars. The granite at Oak Spring in the Belted Range contains phenocrysts of feldspar, quartz, and biotite which reach maximum lengths of 4 inches, ½ inch, and 1 inch respectively. The feldspar phenocrysts are locally sufficiently abundant to form one-third of the rock mass. The microscopic character of the granular siliceous rocks are tabulated in Table I, and those of the corresponding porphyries in Table II.

From the east to the west edge of the area under consideration the rocks in the main become progressively less siliceous and the quartz-monzonite of the Panamint Range approaches in composition the granodiorite of the Sierra Nevada. In a broad way then the magmas in the various centers of igneous activity were less and less siliceous from meridian 116 west to the Sierra Nevada. There is also a slight increase in the soda content of the rocks from the eastern border of the area to the western.

The soda-syenite and soda-syenite porphyry which form a small mass intrusive in Pennsylvanian limestone 11½ miles southeast of Tin Mountain (Panamint Range) are worthy of more detailed description. The soda-syenite is characterized by abrupt and great changes in granularity and in the relative abundance of the constituent minerals. The most common type is a coarse to medium-grained gray rock composed of predominant gray with some pink feldspar, subordinate greenish-black amphibole or pyroxene, and biotite. Many of the feldspars have good crystal outlines and in the more porphyritic facies the abundant feldspar laths which have lengths of 1½ inches are aligned in flow orientation. The rock, next to the limestone, is very fine grained. Epidote has developed at the expense of the ferromagnesian minerals in all facies. Under the microscope this rock proves to be a soda-syenite or nordmarkite of uneven hypidiomorphic granular texture. Alkali feldspars are the predominant constituents and include the species orthoclase, microperthite, and anorthoclase. With these is a little oligoclase. The alkali feldspars form rude tabular crystals, many of which are twinned according to the Carlsbad law. Augite sometimes occurs in columns, or anhedra of augite, green hornblende, quartz, biotite, and yellowish-brown garnet may lie between these tabular forms. The augite shows characters approaching aegirite-augite. The

accessory minerals are titanite, magnetite, apatite, and fluorite. Fluorite flecks the alkali feldspar and was probably introduced by magmatic gases.

The soda-syenite is cut by dikes of a compact greenish-gray aplite. Pink feldspar is associated with the gray feldspar, and some veins are composed wholly of pink feldspar with pyroxene. Under the microscope the aplite has a very uneven-grained, allotriomorphic texture. The feldspars include microperthite, orthoclase, and some anorthoclase; a little quartz is also present. Although the rock is not rich in ferromagnesian minerals, there are many small grains and partial crystals of aegirite-augite, which show the usual zonal structure, with deeper green bands on the border. Irregular grains of a light-yellow garnet are rather abundant and titanite and apatite are accessories. Fluorite occurs in small blebs, surrounded by a mesh of sericite shreds, which were probably formed by the same gases that deposited the fluorite. Calcite is also present and its contacts with other minerals are so sharp that it was probably deposited in miarolitic openings. The contact between the aplite and the syenite is in some cases sharp, in others gradational. In one instance a dike of syenite porphyry is faulted along an aplitic dike, but there is little doubt that the two are genetically related. Narrow pegmatitic dikes, the feldspar and pyroxene of which reach a diameter of 1 inch, also occur.

The soda-syenite intrudes Pennsylvanian limestone and has suffered the same deformation as the quartz-monzonite which lies to the south of it (No. 11, Table I). Phases of the pegmatite of the monzonite closely resemble the soda-syenite in mineral composition and from this fact and the proximity of the two masses the soda-syenite is believed to be a later differentiation of the monzonitic magma. At places the pegmatite of the monzonite has a border composed of almost pure augite with a median band of feldspar. The boundary planes are rather distinct although individual crystals extend from the monzonite into the basic bands and from these into the acidic center. The more siliceous portion shows under the microscope the composition of a soda-syenite, and consists of orthoclase, anorthoclase, augite, hornblende, oligoclase, quartz, titanite, magnetite, apatite, and zircon. Titanite occurs both in well-crystallized wedges

Name and Place..	Alaskite Bullfrog
Texture..........	Allotriom
Granularity	Medium
Quartz...........	Essential
Orthoclase.......	Essential
Micropegmatite...	Present
Microperthitic intergrowth....	
Microcline.......	Present
Oligoclase........	
Muscovite........	Secondar
Biotite...........	Present
Hornblende......	
Augite...........	
Titanite.........	
Apatite..........	x[1]
Zircon...........	x
Magnetite........	x
Allanite..........	

[1] Symbol *x* indicates tha

Name and place..........
Proportions of phenocrysts ar ground-mass............
Texture of ground-mass....
Quartz of ground-mass.....
Orthoclase of ground-mass..
Plagioclase of ground-mass..
Other constituents of ground-
Quartz phenocrysts.........
Orthoclase phenocrysts.....
Plagioclase phenocrysts.....
Microperthite.............
Biotite phenocrysts.........
Hornblende phenocrysts....
Accessory minerals.........
Micropegmatite of quartz an orthoclase..............

TABLE I

Granular Siliceous Rocks

Name and Place	Alaskite	Muscovite-granite	Biotite-muscovite-granite	Biotite-granite	Biotite-granite	Biotite-granite	Biotite-granite	Biotite-granite	Biotite-granite	Biotite-hornblende-granite	Quartz-monzonite
	Bullfrog	Southern Klondike	Trapmann's Camp, Pahute Mesa	Slate Ridge	Gold Mountain, West End	White Rock Spring, Pahute Mesa	Silver Peak	Gold Mountain Ridge	Lone Mountain	Belted Range	Panamint Mountains
Texture	Allotriomorphic	Allotriomorphic	Allotriomorphic	Allotriomorphic	Hypidiomorphic	Hypidiomorphic with orthoclase poikilitic	Hypidiomorphic	Hypidiomorphic	Hypidiomorphic	Hypidiomorphic, porphyritic	Hypidiomorphic
Granularity	Medium	Fine	Fine to medium	Coarse	Fine	Coarse	Medium	Coarse	Medium to coarse	Coarse	Medium
Quartz	Essential	Predominant	Essential	Essential	Predominant	Essential	Essential	Essential	Not abundant	Essential	Present
Orthoclase	Essential	Essential	Predominant	Predominant	Essential	Predominant	Predominant	Essential	Predominant	Predominant	Essential
Micropegmatite	Present								Present		Present
Microperthitic intergrowth						Present	Present	Present			
Microcline	Present	Present						Present	Essential	Present	
Oligoclase		Present	Essential		Essential	Essential	Essential	Essential	Present	Essential	Predominant
Muscovite	Secondary	Essential	A little, both original and secondary		x						
Biotite	Present		Essential	Essential	Essential	Not abundant	Essential	Essential		Essential	Essential
Hornblende										Essential	Essential
Augite											Present
Titanite					x	x			x		x
Apatite	x[1]				x	x			x	x	x
Zircon	x		x	x	x	x	x		x	x	
Magnetite	x			x	x	x	x	x	x		x
Allanite									x		

[1] Symbol x indicates that the mineral is present as an accessory.

TABLE II

Porphyritic Rocks of Granular Siliceous Series

Name and place	Granite Porphyry	Granite Porphyry	Granite Porphyry	Granite Porphyry	Granite Porphyry	Granite Porphyry	Granite Porphyry	Quartz-monzonite Porphyry	Quartz-monzonite Porphyry
	Silver Peak	Panamint	Silver Peak	Grapevine Mountains	Kawich	Cactus Hills	Gold Mountain Ridge	Gold Mountain Ridge	Silver Peak Range
Proportions of phenocrysts and ground-mass	Phenocrysts = Ground-mass	Ground-mass > Phenocrysts	Ground-mass > Phenocrysts	Phenocrysts = Ground-mass	Phenocrysts = Ground-mass	Phenocrysts > Ground-mass	Phenocrysts > Ground-mass	Phenocrysts > Ground-mass	Phenocrysts > Ground-mass
Texture of ground-mass	Allotriomorphic with areas micropegmatitic	Allotriomorphic with areas micropegmatitic	Hypidiomorphic with micro-pegmatitic areas	Hypidiomorphic	Hypidiomorphic	Hypidiomorphic	Hypidiomorphic	Allotriomorphic	Hypidiomorphic with poikilitic areas, quartz enclosing others
Quartz of ground-mass	Essential	Essential	Predominant	Predominant	Essential	Essential	Essential	Predominant	Present
Orthoclase of ground-mass	Essential	Microcline and orthoclase predominant	Essential	Essential	Essential	Essential	Predominant	Essential	Essential
Plagioclase of ground-mass		Oligoclase	Present	Present	Present	Present	Present	Present	Predominant
Other constituents of ground-mass		Biotite				Biotite	Biotite essential	Biotite and Hornblende essential	
Quartz phenocrysts	Predominant	Predominant	Essential	Essential	Essential	Subordinate	Essential		
Orthoclase phenocrysts	Essential	Essential	Essential	Predominant	Predominant	Predominant	Microperthite and microcline predominant	Orthoclase and microcline predominant	Essential
Plagioclase phenocrysts	Present, Oligoclase-albite	Present	Present	Sparse	Present	Sparse		Essential	Predominant
Microperthite	Orthoclase phenocrysts microperthitic		Orthoclase phenocrysts microperthitic	Orthoclase phenocrysts microperthitic			Phenocrysts		
Biotite phenocrysts	Rare	Rare	Rare	Rare	Present	Essential	Essential		Essential
Hornblende phenocrysts									Present
Accessory minerals		Magnetite, Titanite, Apatite	Magnetite	Magnetite, Zircon, Apatite, Titanite	Magnetite, Zircon, Apatite	Magnetite, Zircon, Apatite	Magnetite, Apatite, Titanite	Magnetite, Titanite, Zircon, Magnetite	Magnetite, Apatite, Zircon, Allanite
Micropegmatite of quartz and orthoclase	Ground-mass, also coronae around phenocrysts; also phenocrysts	Ground-mass	Ground-mass				In ground-mass		

which were among the first to solidify from the magma and also in anhedra between the tabular feldspars, this titanite being among the last minerals to separate from the magma. In other phases of the pegmatite partial crystals of ferromagnesian minerals are inclosed in a coarse crystalline aggregate of feldspar. Microscopic examination shows that orthoclase and microperthite are so predominant over plagioclase in this rock that it has the composition of a syenite. A little quartz is present and the ferromagnesian minerals include augite, olivine, brown hornblende, and biotite. Augite in unusually large crystals and magnetite in grains also occur. In this rock there are associated the two minerals, quartz and olivine, which at one time were believed never to occur together.

Weathering.—Southwestern Nevada has an arid climate and consequently the granitoid rocks weather into a soil composed of fragments of the constituent minerals which are practically fresh. This mechanical disintegration, largely dependent upon stresses due to changes of temperature, is so rapid that broad basins of granitic soil extend up into the hills. Through these detrital embayments low domical outcrops of granite protrude and it is only in the highest peaks that exposures are conspicuous.

Age.—From the uniform amount of mashing which these rocks have suffered and from the similarity in the geological history of the various ranges, it is evident that all of these rocks are approximately of the same age. They intrude the Paleozoic rocks as batholiths, stocks, sheets, and dikes, where the contacts can be observed, and fragments of them are included in Tertiary lavas. The youngest Paleozoic rocks in the area are of Pennsylvanian age and these are intruded by granular igneous rocks in the Belted and Panamint ranges. The earliest lavas occur in the Stonewall Mountains and these rocks, which are of very late Cretaceous or early Eocene age,[1] contain fragments of granite. The granular rocks are, therefore, of post-Carboniferous and pre-Tertiary age. Spurr[2] found rocks of similar composition cutting Triassic strata in the Pilot and Excelsior

[1] Sydney H. Ball, *Bulletin 308 U. S. Geological Survey*, p. 33.

[2] J. E. Spurr, *Bulletin 208, U. S. Geological Survey*, pp. 103, 109.

(Nevada) ranges, and Louderback[1] states that granite intrudes Triassic rocks in the Humbolt (Nevada) range.

Later students of Nevada geology believe with King[2] that the mountain ranges of the western part of the state and the Sierra Nevada were formed simultaneously at the close of the Jurassic. The granite intrusion was probably a relatively late event in this period of deformation, an inference supported by the relatively unmashed condition of the granite. The erosion, prior to the outpouring of the earliest Tertiary lavas, of the thick covering of superincumbent rocks, which must have been present in order to produce the granular texture of the plutonic rocks also points to the post-Jurassic or very early Cretaceous age of the igneous rocks. Such an age determination is in harmony with that of the granodiorite of the Sierra Nevada. That mountain system and the ranges of western Nevada have had a closely parallel history.

While these granular siliceous rocks are thus believed to have been contemporaneous in a broad way, their consolidation unquestionably occurred at slightly different times. This is indicated not alone from the relation between the pegmatite of the quartz-monzonite and the soda-syenite of the Panamint Range, but also from the wide lithologic variety in the granular rocks of the Silver Peak Range (see column 7, Table I, and columns 1, 2, 6, and 7, Table II). There indeed the granular rocks may have solidified from wholly separate magmatic basins.

The conclusion as to the post-Jurassic age of these rocks is in accord with that of Spurr, for the granites of Silver Peak[3] and Goldfield,[4] Nevada, and that of Louderback[5] for similar rocks in the Humbolt Range, Nevada.

APLITE

The granitoid rocks of most of the areas are cut by narrow dikes of aplite, a fine-grained rock of white or pink color. In composition

[1] George D. Louderback, *Bulletin Geological Society of America*, Vol. XV, p. 318.

[2] Clarence King, *U. S. Geological Explor. 40th Parallel*, Vol. I, 1878, p. 759.

[3] J. E. Spurr, *Bi-monthly Bull. Amer. Inst. of Min. Engrs.*, 1905, No. 5, p. 955; also Professional Paper No. 55, *U. S. Geological Survey*, pp. 25, 26.

[4] J. E. Spurr, Bull. 260, *U. S. Geological Survey*, 1905, p. 133.

[5] G. D. Louderback, *Bull. Geol. Soc. of Amer.*, Vol. XV, 1904, p. 336.

the aplite and granitoid rocks differ in the relative proportions rather than in the kind of minerals present. The aplites are more siliceous than the older granitoid rocks, those of the granites usually having alaskitic affinities and those of the quartz-monzonite, granitic affinities. Upon weathering the aplites protrude from the surface of the granitoid rocks.

PEGMATITE

Pegmatite is usually associated with the granitoid rocks and is the only representative of the granular siliceous series at Bare Mountain, and is the predominant intrusive of the Bullfrog Hills. At most places it cuts the granitoid rocks with sharp contacts, and normally the intrusion of aplite intervened between that of granite and of pegmatite, although graduations from pegmatite to granite also occur. At one place in the Gold Mountain Ridge an aplite dike passes along its strike into a dike with narrow aplitic border and broad pegmatitic center.

The pegmatite usually occurs in well-defined dikes but throughout the more easterly of the two granite masses in the Pahute Mesa ellipsoidal masses of coarse quartz-feldspar-pegmatite are inclosed in the granite. The contact between the two rocks is at some places sharp, at others gradational. The ellipsoidal form and the absence of apparent channels from one mass to another in the plane of observation suggest that the pegmatite formed in place from the residual fluids of the granitic magma.

Chemically the pegmatites are more acid than their granitoid associates although in the Panamint Range the pegmatite of the quartz-monzonite has also undergone a considerable enrichment in soda. In texture the pegmatites are either coarse, irregular, granular aggregates or the intimate intergrowth commonly called graphic granite. The latter rock in the Gold Mountain Ridge is a transition phase between granite and coarsely granular pegmatite.

The pegmatites of southwestern Nevada contain but few rare minerals. Pyrite occurs as an original constituent of the pegmatite in the Belted Range and in the Bullfrog Hills. At the former locality it is reported to carry values in gold and silver and in 1905 was being prospected. The gradation from either a muscovite- or biotite-pegmatite to quartz veins is seen in most of the larger granite areas.

At the Bullfrog-George prospect in the Slate Ridge molybdenite, molybdite, and fluorite occur in a pegmatitic quartz vein. Molybdenite is present as metallic tablets and irregular scales of steel-gray color which lie between or are surrounded by the interlocking quartz crystals of the vein. It evidently solidified from the magmatic waters contemporaneously with the quartz. Its alteration product, a bright-yellow mineral in minute crystals and tufted aggregates, was determined by W. T. Schaller to be molybdite. Fluorite, which occurs in fractures in the quartz and also lines its vugs, is evidently somewhat younger than quartz and presumably was deposited by gases in the expiring stages of volcanism.

In the Bullfrog Hills there is some evidence of two separate intrusions of pegmatitic material. The older pegmatite is a feldspar-muscovite-quartz rock which is cut by a very siliceous pegmatite dike of almost pure quartz. It is probable then that from the residium of the granite magma a coarse-grained rock with the composition of a granite first separated and solidified and at a later period a more quartzose rock was deposited from the residual liquid in fractures in the older pegmatite.

QUARTZ-MONZONITE PORPHYRY

Dikes and sheets of quartz-monzonite porphyry, poor in ferromagnesian minerals, intrude Paleozoic rocks and granite of the Silver Peak Range and Slate Ridge. This rock near Lida is apparently cut by the diorite porphyry described below.

The monzonite porphyry is a dense white or greenish-white rock with abundant medium-sized phenocrysts, which however are subordinate in bulk to the ground-mass. They consist of whitish feldspars, some striated and others unstriated, silvery mica, and a few quartz crystals. The central portions of the dikes and sheets are more coarsely crystalline than the borders and in instances approach a granitoid texture.

Microscopic examination proves the medium-grained micrograniticground mass to consist of orthoclase, microperthite, and anorthoclase grains, plagioclase laths, and a few quartz anhedra. In some thin sections the alkali feldspars poikilitically inclose the other minerals and in others quartz and orthoclase are in graphic intergrowth.

The phenocrysts of orthoclase and microperthite predominate over those of plagioclase (oligoclase and oligoclase-andesine). Altered biotite phenocrysts are constantly present while quartz crystals, much corroded, appear in some thin sections. Zircon and magnetite are accessory minerals.

This quartz-monzonite porphyry which evidently contains considerable soda, is younger than the granite which it cuts in the area four miles west of Alkali Springs and pebbles of it are included in the Siebert lake beds (Miocene).

DIORITE PORPHYRY AND DIORITE

Dikes of diorite porphyry and a few intrusive masses of diorite occur in the Silver Peak, Panamint, Grapevine, and Cactus ranges, the Gold Mountain and Slate ridges and the Bullfrog, Mount Jackson, and Lone Mountain hills. These rocks are hence confined to the western half of the area under consideration. In composition they range from acid diorite approaching granodiorite to a quartz-augite diorite of ophitic texture. Brown hornblende characterizes the more basic types and fragments of serpentine found in the Lone Mountain foothills may be altered forms of still more basic phases.

The diorite-porphyry and diorite are younger than the Paleozoic rocks and the igneous rocks already described, but nowhere were they observed cutting Tertiary lavas. Pebbles occur in the Siebert lake beds (Miocene) and the rock is probably of pre-Tertiary age.

The quartz-monzonite porphyry and the diorite porphyry and diorite, which are the youngest of the pre-Tertiary igneous rocks, occur only in comparatively small masses. They are probably complementary differentiation products of a magma residual from the solidification of the granular siliceous rocks.

THE VARIATIONS OF GLACIERS. XII[1]

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The following is a brief summary of the report of the retiring president of the International Committee on Glaciers, which was presented to the International Congress of Geologists in Mexico in 1906.[2] The committee collects material regarding the variations of glaciers in all parts of the world; this material is collected in different ways in different countries. In Switzerland the Federal Foresters report on the changes in about 90 glaciers, and special work is being done in the study of the Rhone glacier under the auspices of the Helvetic Society of Natural Sciences. The German-Austrian Alpine Club encourages the observations of glaciers in the eastern Alps, the Italian Alpine Club and the Italian Geographical Society help in Italy, and there is a special committee in France which has lately received some help from the government in the observations of glacial variations. The Imperial Russian Geographical Society has done much in collecting and publishing the material regarding the little-known glaciers in the Russian Empire. The Norwegian Tourist Club in Norway, and the Swedish Tourist Club in Sweden have provided for the systematic study of glaciers in those countries, and lately the Swedish Geological Survey and the Reischtag have furnished pecuniary help. The glaciers of Greenland have been studied by exploratory expeditions sent out by the Danish government. Recent information regarding the glaciers of Iceland comes from the explorations of Dr. Thoroddsen; a topographic map now being made shows the positions of many glaciers. In Canada, also, the topographic maps are the most important contributions to glacial work being done by the government, but special studies of Canadian glaciers have been made independently by individuals. The same is true of the glaciers of New Zealand. In India the Geological Survey has undertaken to

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XIII.

[2] The complete report will appear in the *Comptes rendus* of the Congress.

keep the record of the movements of some glaciers, but observations there in the past have been very desultory. No systematic work has been done by the government in the United States, although the maps made by the Geological Survey and the Coast and Geodetic Survey in glacial regions are of value in fixing the present positions of the glaciers. Reports regarding the Antarctic and Arctic regions must necessarily be irregular and must be obtained from exploratory expeditions to those regions.

Eleven annual reports have been published by the commission, the first ten in the "Archives des sciences physiques et naturelles," in Geneva. The eleventh report was published in the new *Zeitschrift für Gletscherkunde*, edited by Professor Eduard Brückner, of Vienna, and future reports will appear there. A glance at these reports will show that glaciers in all parts of the world are now retreating. The tendency to advance, which showed itself in the western Alps about 1885 and which slowly passed on to the eastern Alps has now practically disappeared. It did not extend to other glaciated regions.

Since the organization of the committee many theoretical and observational studies of glaciers have been made. It has been shown that when a glacier advances there is first an increase of thickness and of velocity in the higher parts of the glacier and that a wave of greater thickness and greater velocity travels down the glacier and causes an advance of the end; this wave originates in an increased accumulation in the reservoir, and in general the longer the glacier the longer time will be needed for the wave to reach the end. It has also been shown that the greatest thickness in the reservoir will occur some time after the maximum snowfall; so that the advance of the end may be many years after the period of maximum snowfall. If the glacier itself advances sooner than this theory would lead us to expect it must be due to diminished melting at the end, rather than to increased accumulation in the reservoir. The application of the idea of hydrodynamic lines of flow to the motion of glaciers has greatly increased our understanding of glacial phenomena, and it is to the further development and application of this idea that we must look for the increase of our knowledge of glaciers in the near future. The long-continued controversy as to the origin of the blue bands has been at

least partially solved. It has been quite clearly shown that the orderly systems of blue bands in the body of the dissipator are the modified strata; but it has not yet been shown that the bands which exist close to the bed and at the very end of the glacier belong to the above systems.[1]

The following is a summary of the Eleventh Annual Report of the International Committee on Glaciers:[2]

REPORT ON GLACIERS FOR 1905

Swiss Alps.—Of the ninety glaciers under observations in Switzerland, forty-nine were measured in 1905. The changes in five are uncertain; three glaciers are stationary and the other forty-one are in retreat. No glacier measured in 1905 showed any certain advance.[3]

Eastern Alps.—Observations were made in the summer of 1905 on sixty-one glaciers; forty-nine were in retreat, five were stationary, and seven had advanced somewhat, so that the general tendency to retreat still dominates. Of the seven advancing glaciers, five are in the mountains of the Oetzthal, where are situated also three of the stationary glaciers. The other two advancing glaciers are in the Goldberg group of the Hohen Tauern. The Grosselendkees, which is stationary, lies in the Ankogel group, the most easterly part of the Alps bearing glaciers. The Gliederferner in the Zillerthal Alps, which was advancing last year, is now in retreat.

[1] The following changes have been made in the committee. Professor Francesco Porro, formerly representing Italy on the commission, was elected to represent Argentina; Professor Olinto Marinelli succeeded him as representative of Italy; Mr. Charles Rabot, represents France, as the successor to Professor W. Kilian, who has retired; and Dr. E. von Drygalski was elected to report on the Antarctic regions; Professor Brückner was made ordinary member of the commission to represent Austria, succeeding Dr. A. Penck, who has removed to Berlin. Other corresponding members have been added as follows: Professor Dr. Hans Angerer, Mr. Charles Jacob, Mr. A. B. Harper, Major Hon. E. G. Bruce, Mr. W. S. Vaux, Jr., Mr. G. K. Gilbert, General Carlo Porro. Professor Penck and Professor Kilian were elected corresponding members on their withdrawal from the list of ordinary members. The committee lost by death two of its important members, Professor Eduard Richter of Graz, and Professor Israel Russell of Michigan. The following officers were elected to serve until the next meeting of the International Congress of Geologists: Honorary President, Prince Roland Bonaparte, of Paris; Active President, Professor Dr. Eduard Brückner, of Vienna; Secretary, M. Ernest Muret, of Lausanne.

[2] *Zeitschrift für Gletscherkunde*, Vol. I, pp. 161–81.

[3] *Report* of Professor Forel and M. Muret.

In opposition to this general tendency to retreat we notice that certain glaciers of the Oetzthal, which have been retreating pretty rapidly, are now retreating more slowly and some of them are even in a stationary condition.[1]

Italian Alps.—The Italian glaciers do not seem to show any marked variations, but the general tendency is to retreat.[2]

French Alps.—The glaciers in the Grandes Rousses of Dauphiné are in general retreat. A map of these glaciers on a scale of $\frac{1}{10000}$ is now being made. Measures of snowfall in the Savoy have shown a smaller amount in the winter of 1904–5, than in that of 1903–4. Special observations on the Mont Blanc chain have shown that the greatest snowfall occurs at an altitude in the neighborhood of 2,550 meters. The glaciers of Mont Blanc and the Maurienne show a slight retreat though there are indications of increased activity which later may bring on an advance. In the Vanoise and the upper valley of the Arc the glaciers continue to retreat, and some large snow fields have disappeared; others have been broken up by projecting ridges of rock.

Pyrenees.—The glaciers in these mountains are stationary or retreating. There have been very great changes since the middle of the last century; for instance, between 1855 and 1904, the glacier de l'Est has retreated 1,140 meters and the glacier de la Brèche, 1,230 meters. In the last two years there seems to be an increase of snowfall on these glaciers. The disappearance of some small glaciers in the French Alps and in the Pyrenees has been injurious to agriculture on account of the decreased quantity of water available for irrigation. This has led the Minister of Agriculture to offer pecuniary support to glacial observations.[3]

Sweden and Norway.—One glacier was observed in Sweden in 1905, the Mika, and it has retreated three to four meters. In Norway the changes have been mixed, some glaciers have retreated and some have advanced. The three glaciers observed in the Jostedal have advanced from 5 to 19 meters.[4]

[1] *Report* of Dr. H. Angerer.

[2] *Report* of Dr. F. Porro.

[3] *Report* of M. Charles Rabot.

[4] *Reports* of Dr. F. W. Svenonius and M. P. A. Oyen.

Russia.—In the mountain chain of Peter the Great, Boukhara, two glaciers show an advance since 1899, one of them as much as 64 meters. One in the Tian-Chan shows a retreat since 1892.

Caucasus.—Many glaciers have been visited and named; the Bartui has steadily been retreating; the retreat amounted to 30 meters in 1900–1, 12 meters in 1902–3, 13.5 meters in 1903–4. The glaciers of the Caucasus seem to be in general retreat.[1]

British Columbia and Alberta.—The Illecillewaet glacier continues to retreat, but much more slowly; it lost but 2 feet 6 inches between 1905 and 1906, though there has been a general shrinking in the volume of the ice. The tongue of the Asulkan glacier is slowly melting away under the moraine.[2]

South America.—A short description of the glaciers of Poto, just north of Lake Titicaca, Peru, has been given by Otto F. Pfordte.[3] The San Francisco glacier has high terminal moraines, but the present end has not varied much since the Spanish occupation, as shown by the ruins of houses at the foot of the cliff, where the glacier now ends. Old observations and traditions of the natives indicate that the snow-line is gradually receding in this part of the Andes, which accounts for the gradual lowering of the lakes. Mr. Bandelier,[4] referring to this same general neighborhood, states that the glaciers of the Bolivian Andes have been in slow retrocession for a number of years.

Central Africa.—The Mubuhu glacier on the eastern slopes of Ruwenzori is apparently in retreat. An old moraine overgrown with vegetation may be recognized some 500 meters in advance of the existing tongue of the glacier, and from the appearance of the rocks nearby it would seem that a slow retreat is now in progress (1905). Morainic lakes have been observed on the western slope below the limits of the present glaciers by Dr. Stuhlmann.[5]

[1] *Report* of Colonel J. de Schokalsky.

[2] *Report* of Messrs. G. and W. S. Vaux.

[3] "The Glaciers of Poto, Peru," *Proceedings of Eighth International Geographical Congress*, Washington, 1904, pp. 497–500.

[4] *Bulletin of the American Geographical Society*, 1905, Vol. XXXVII, p. 454; also *Scottish Geographical Magazine*, 1905, Vol. XXI, p. 586.

[5] *Report* of Mr. D. W. Freshfield.

REPORTS ON THE GLACIERS OF THE UNITED STATES FOR 1906[1]

The snow fall in the Rocky Mountains in the summer of 1905 was very heavy and perhaps for that reason the Hallet Glacier shows a slight advance (*Mills*). But there has been a slight retreat at the north end of Arapahoe Glacier, which is not far from the Hallet (*Henderson*). The glaciers in the Montana Rockies are either stationary or slightly retreating (*Chaney*). A small glacier reported in Bighorn Mountains of Wyoming has apparently disappeared (*Salisbury*).

On the north side of Mt. Hood, Washington, Eliot Glacier is diminishing very markedly. The ice is growing much thinner at the end and a more rapid retreat will probably appear before long. Some of the snowfields are greatly altered and the ascent of the mountain has been rendered much more difficult than heretofore (*Mrs. Langille*). On the south side of Mt. Hood, the White Glacier has diminished in thickness but does not seem to have receded materially (*Montgomery*). Glacier Peak, in Washington, was climbed last summer by Mr. C. E. Rusk. He found that the glaciers showed signs of retreat but less than in other places in Washington; these glaciers carry comparatively little débris. Mount Baker was visited last summer by the Mazama Club, of Portland, Oregon; their magazine contained many excellent pictures of the glaciers and a sketch map of the mountain, showing a number of distinct glaciers, but no information is given as to the recent changes. When this mountain was visited in 1903 by Messrs. Rusk and Campbell there was a small, well-marked crater at the summit, about 50 feet in diameter, from which considerable volumes of black smoke were rolling away. In 1906 this vent was completely filled with snow and no evidence of its existence appeared except a slight depression in the surface of the snow (*Rusk*).

Last summer Messrs. F. E. and C. W. Wright visited Glacier Bay and repeated the survey which was made in that region in 1892. They found very remarkable changes in all the glaciers. The only definite information we have had of any of these glaciers since 1899,

[1] A synopsis of this report will appear in the *Twelfth Annual Report* of the International Committee. The report of the glaciers of the United States for 1905 was given in this *Journal*, Vol. XIV, pp. 406–10.

until the Messrs. Wright's visit, was due to a trip to Muir Glacier by Messrs. Andrews and Case, in May, 1903, and they reported a very considerable recession in that glacier.[1] The report of the Messrs. Wright will not be published before next winter but they have very kindly prepared an abstract of the glacial changes which they observed as follows;[2]

On comparing our map with your map of 1892, the following changes are most apparent: Beginning with Muir Glacier and its tributaries the ice front has receded a maximum distance of about 33,000 feet; Dirt Glacier is no longer tidal; White and Adams Glaciers are supplying very little ice to the general ice field; Morse Glacier terminus is about one mile from tide water; the crest of the stagnant ice mass between Girdled Glacier and Muir Inlet has melted down about 200 feet since the time of your measurements; Girdled Glacier and Berg Lake, however, have not changed materially in aspect. The length of the total ice front of Muir Glacier is now over 40,000 feet instead of 9,000 feet in 1892. The present ice front passes at its northern extremity at about the position of your 1,000 feet contour on the ice of 1892. This remarkable decrease in elevation is undoubtedly due not only to melting down but also to breaking down of the exposed ice masses. The ascent of the ice mass at this point is decidedly steep and the ice fairly cascades into the water. The present height of the ice fronts of all the tide water glaciers is about the same as noted by you in 1892 (150′–250′), and is a noteworthy fact in connection with these glaciers. Muir Inlet is at present choked by the ice pack which promises to remain congested so long as its source of supply is so active. A considerable portion of the present front of Muir Glacier is in very shallow water and in a few years should decrease in size very materially unless new avenues and inlets for tidal currents are exposed by the receding ice. Dying Glacier is still creeping back and wasting away.

Carroll Glacier has not changed much in aspect during the last 14 years; its terminal cliff has receded about 2,000 feet and at present, apparently, is continuing to do so. It is discharging icebergs very slowly and Queen Inlet is nearly free of ice.

Rendu Glacier has also changed but little and its front is about 2,000 feet back of its position in 1892. This Inlet also is not impeded by any amount of ice. The small glacier cascading from the west near its terminus appears to have changed still less.

In Reid Inlet the changes have been very great and things are still moving at a

[1] C. L. Andrews, "Muir Glacier," *National Geographical Magazine*, 1903, Vol. XIV, pp. 441–45, and this *Journal*, 1904, Vol. XII, p. 258. The positions of the glaciers in 1899 are described by G. K. Gilbert in the *Harriman Alaska Expedition*, Vol. III.

[2] A map of this region accompanies an article on "Glacier Bay and Its Glaciers," in the *Sixteenth Annual Report of the United States Geological Survey*, 1894–95.

rapid rate there. The inlet was congested with the ice pack last summer and on the south side near the large island the ice jam was completely frozen over and moved as one mass back and forth with the tides.

Grand Pacific Glacier has receded and left the large granite island surrounded by water. It has receded nearly 20,000 feet; but judging from the amount of ice it is now discharging and the shape of its valley it will not recede so rapidly in the next few years, other conditions remaining the same.

Johns Hopkins Glacier has receded about 11,000 feet and is still sending off icebergs at a rapid rate. The unnamed glacier directly east has become detached from it and is much like Reid Glacier in character and appearance.

Reid Glacier has receded perhaps 5,000 feet and still preserves its original aspect as indicated on your map.

The small dying glacier between Reid and Hugh Miller Glaciers has practically disappeared. At least no ice was visible in the rock and moraine débris.

Hugh Miller Glacier no longer reaches tide water in Reid Inlet and at low tide is nearly a mile back from it. The tide flats are long and with only a slight grade. In Hugh Miller Inlet this glacier was exposed to tide water only in the southwestern bay, where its front is intercepted in its central part by a large promontory of light colored granite. Eight thousand feet is approximately its amount of recession since 1892. Charpentier Glacier also receded about 9,000 feet and promises to continue its recession rapidly, especially along its southern front as its valley is opening out and allowing a greater exposure of ice front to the action of tide water.

The small stagnant glacier east of Charpentier is simply melting away and will probably disappear in ten or twenty years.

Favorite Glacier is still receding. Wood Glacier is no longer tidal and only a small part of Geikie Glacier ice front is exposed to salt water. Geikie Glacier has receded about 5,000 feet during the past 14 years.

On the whole, recession has been the rule for the glaciers of Glacier Bay. Those glaciers have receded most whose ice fronts have, on recession, increased appreciably in length. In the past 14 years the combined ice front of all the glaciers exposed to tide water has increased from 17,000 feet to over 40,000 feet and the amount of recession has in that time alone equalled that of the previous 20 years.

To the west of Glacier Bay, Brady Glacier in Taylor Bay has receded considerably. In Lituya Bay, the glacier at the northwestern end of the bay has advanced about one-half mile since 1894; the central and southeastern glaciers have apparently remained unchanged although the latter may have advanced slightly.

The two glaciers at the ends of the bay were reported in 1894 to be about three kilometers in advance of their positions of 1786. It is curious that the glaciers of Lituya Bay should be advancing, while those of Glacier Bay, about fifty kilometers to the east, are retreating so markedly.

It will be remembered that when Professor Tarr visited the region about Yakutat Bay in 1905 he found that the glaciers showed a general tendency to retreat, though the changes were not very great for tide-water glaciers. When he visited the region again in 1906, remarkable changes had taken place. The Marvine Glacier, to the west of Yakutat Bay, supplies the ice for the eastern part of the Malaspina Glacier; though all previous explorers had found it comparatively smooth and easily traversed, it had become greatly broken and crevassed. The glaciers next to the east, the Hayden and the Lucia, showed no such changes, whereas the Atrevida, next to the Lucia, exhibited changes similar to those of the Marvine. The Seward Glacier, farther west, which is the largest glacier supplying the Malaspina, seemed to be more crevassed than it was when crossed by the Duke of the Abruzzi in 1900, but was not broken and torn like the Atrevida and the Marvine. The part of the Malaspina Glacier which derives its ice from the Marvine, was full of crevasses for a distance of twelve to fifteen miles. The southern border of the Malaspina Glacier, which was formerly stagnant ice completely covered with moraine and heavy vegetation, has been so broken up that great blocks of ice are falling from the end, the moraine is sliding off, and the trees have been overturned. The Turner Glacier, which enters the western side of Disenchantment Bay showed no decided changes, whereas, the Haenke, a small glacier lying immediately north of the Turner, was advancing into the water; it had joined the end of the Turner Glacier and had thus lengthened the ice front by about a mile. The great Hubbard Glacier, which comes in from the north, showed no change, whereas the Orange Glacier immediately to the southeast, which in 1905 was smooth and easily traveled, was so broken in 1906 that even the lower part could not be traversed, and the region of stagnant ice covered by moraine had been transformed into clear ice, crevassed and pinnacled. That these remarkable changes had taken place between the summers of 1905 and 1906 is clearly shown by the observations and photographs of Professor Tarr; and that the advance, at least at the end of the Malaspina Glacier, was still in progress, was shown by the fact that the overturned trees had put forth their leaves in the early summer before being uprooted. The fact that certain glaciers, presenting, so far as

could be observed, no special characteristics, had experienced such changes, whereas adjoining ones had not, makes it evident that these changes were not due merely to general climatic conditions, but to some special cause. Professor Tarr suggests that this cause was the severe earthquakes which occurred in this region in September, 1899, and which brought about marked changes of level, in some places amounting to 40 feet.[1] Professor Tarr thinks that these earthquakes shook down enormous quantities of snow and ice from the surrounding mountains and thus added so large a supply to the reservoirs or to the upper parts of the dissipators of some of the glaciers as to cause a sudden and great increase in the velocity, resulting in a strong thrust, which produced abundant crevasses. Some glaciers, on account of the forms of the surrounding mountains, may not have received such great additions to their masses; and others, on account of greater length, may require several years before the change is shown in their lower portions. Professor Tarr's explanation seems entirely satisfactory and is supported by the observation of Mr. A. H. Brooks, who in September, 1899, was on the eastern side of the St. Elias chain and reports that he heard unusually large avalanches falling from the mountains. Examples are known of glaciers which have advanced when neighboring glaciers were retreating, due to the protection of their surfaces by avalanches of snow or by land slides; but the present case seems to be far more remarkable than any heretofore reported and it is greatly to be hoped that observations will be continued and the future changes recorded.[2] At present we only have sketch maps of these regions, but at some future time, when better maps are made we may be able to show more clearly the causes of the different behavior of the various glaciers.

[1] Ralph S. Tarr and Lawrence Martin, "Recent Changes of Level in the Yakutat Bay Region, Alaska," *Bulletin of the Geological Society of America*, 1906, Vol. XVII, pp. 29–64.

[2] Professor W. H. Sherzer has described some moraines in the Canadian Rockies, made up entirely of large blocks of rock. He thinks that this material may have been shaken down upon the glaciers by earthquakes. See "Glacial Studies in the Canadian Rockies and Selkirks," *Smithsonian Miscellaneous Collections*, 1905, Vol. XLVII, Part. 4, pp. 494–96.

FLAXMAN ISLAND, A GLACIAL REMNANT

ERNEST DE KOVEN LEFFINGWELL
Flaxman Island, Alaska.

Flaxman Island is located close to the north shore of Alaska, approximately in Lat. 70°, Long. 146°, and a hundred miles west of the international boundary. It is one of the innumerable small islands that fringe the coast between Point Barrow and Demarcation Point. Failing to reach their goal in Banks Land, this island was chosen as the winter quarters of the Anglo-American Polar Expedition, commanded by Capt. Ejnar Mikklesen, and the writer.

A couple of miles to the south lies the mainland, a low tundra plain extending some twenty miles back to the mountains. Both the mountains and the coastal plain are characteristic features of the northern part of Alaska. From Cape Lisburn on the west coast a chain of mountains runs eastward into Canada, separated from the ocean by a plain of greater or less width. At Point Barrow the plain is over a hundred miles wide, but it narrows to the eastward until at Demarcation Point the mountains come within a few miles of the coast.

Opposite Flaxman Island the nearer mountains have an elevation of between three and four thousand feet, but higher peaks can be seen beyond. The map[1] gives seven thousand feet along the Arctic-Yukon divide, but prospectors estimate it higher. From this chain several rivers make their way across the tundra to the Arctic Ocean. The Coville is probably the largest, but the Kugura is reported to be about 280 miles long.[2]

The coastal plain is covered with moss and grass, and with its ponds, lakes, and swamps forms a characteristic tundra. Near the ocean it usually ends in a low mud cliff which seldom reaches a height of thirty feet. Small bays and lagoons, behind sand spits and bar-

[1] Map of Alaska, *U. S. Geological Survey,* 1904.

[2] Schrader, F. C., Professional Paper, No. 20, p. 31, *U. S. Geological Survey.*

rier reefs, fringe the shore, while at a distance of a few miles occurs a nearly continuous chain of islands. With two exceptions known to the writer (Flaxman and Barter Islands, which are tundra) these are exposed portions of a wave-built barrier reef. Inside is a long shallow lagoon along which it is possible for light-draught vessels to make their way for miles, protected from the ice pack.

Flaxman Island is about three miles long and half a mile wide, running nearly parallel to the mainland. Its surface is a tundra plain about twenty feet above the sea. Ponds are scattered over the

FIG. 1.—A portion of the coast of Flaxman Island.

surface, and large crystalline boulders are frequently met with lying half buried in the soil. Immediately over the beach the plain ends in a steep mud cliff which is broken by frequent gullies. The beach itself is studded with boulders which are seen in all stages of being, weathered out of the cliff as it recedes under the action of the elements.

Where the cliff affords a good exposure, ice is nearly always seen immediately underlying the soil. Usually only a few feet are found, but on the northeast shore there are places showing at least twenty feet. Nowhere is the base of the ice exposed, so no estimate of its thickness can be made. The surface waters have often melted little

canyons into the ice by means of which its presence can be traced thirty to forty feet back from the face of the cliff. About thirty yards back, near the winter quarters, the writer found nearly pure fresh water ice, after digging through one foot of soil, and the same amount of frozen clay. It is the intention of the expedition to obtain their winter's supply of fresh water by sinking a shaft down into this ice, at the same time learning something further as to its thickness and constitution.

Its frequent exposure along the cliffs and its presence some distance inland, points to the presumption that the ground-ice formation underlies the whole island. As is the rule in arctic regions, the ground remains permanently frozen to an unknown depth. Only the upper foot or two thaw out during the short summer. At Point Barrow, Lieutenant Ray dug over thirty-five feet down without penetrating the frozen layer. At the bottom a temperature of 12° F. was held for months. This being the case, it is easily understood how a body of ice, once covered with a few feet of soil, would endure a very long time in the Arctic regions. Practically the only way such an island as this can be destroyed, is by wave-cutting at the sides and the consequent direct exposure of the ice to the sun. This is taking place very rapidly on the seaward side, as freshly fallen blocks of peat and ice show.

Good exposures show a mass of clean ice with an occasional discolored band running haphazard across it. There is no apparent stratification, and the ice is very clean as a whole. When the ice is examined closely it is seen to be full of minute air bubbles and to be coarsely granulated; which shows that it could not have been formed by the freezing of a body of standing water. It must be either glacier ice or snow that has become coarsely granulated by great age.

A single glance at the boulders scattered over the surface and weathered out along the beach is at once suggestive of glacial drift. Most of them have the characteristic outlines of glacial boulders, but many are angular from the shattering action of the intense frost. Their lithological heterogeneity is very striking. Among the crystallines it seems as if the whole gamut were run, but the sedimentaries seem to be confined to quartzites and limestones. The quartzites are the most conspicuous—pink, red, and purple; often banded, cross-

bedded, or conglomeratic. Next come dark crystallines of the gabbro type, then pink granites, then buff limestones. A few moments' search revealed abundant striae, not only on the limestones but on the crystallines as well. A quarter of an hour's walk along the beach showed scores of boulders so definitely striated that any one of them would settle the question of their glacial origin.

It next remains to inquire into the age of the ice. A careful search was made around the whole border of the island, but the base of the ice was nowhere visible. It cannot be denied, then, that some

FIG. 2.—Another part of the coast.

of the boulders might have come from beneath, but many, and probably most, of them came from the few feet of till that lies on top of the ice. Several were seen with ice immediately below them in the face of the cliff. Consequently there seems no escape from the conclusion that the ice is of equal or greater age than the glacial till that lies above it.

Two boulders, approximately ten and fifteen inches in diameter, were found imbedded in the ice itself. The former lay in the lower portion of a few feet of ice exposed in the cliff; the latter, thirty feet back from the face of the cliff, in the vertical wall of clear ice that

formed one side of a channel melted to a depth of five feet by the surface waters. We have seen that the ground ice probably underlies the whole island, that it is covered with glacial drift, and contains boulders imbedded within it; so the conclusion is forced upon us that our island is simply a portion of a glacier that has been kept from melting by a thin coating of drift upon its surface.

Naturally the mountains on the mainland to the south are to be looked to for the source of the glacier by which Flaxman Island was formed. As we have said, a chain of mountains about three thousand

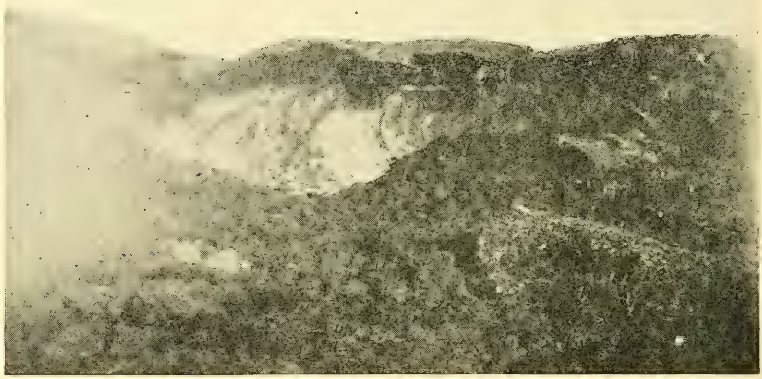

FIG. 3.—A characteristic exposure.

feet high runs parallel to the coast at a distance of some thirty miles inland. Through this the Kugura River breaks after heading among the higher peaks beyond. As seen from a distance, the nearer range does not seem to have suffered intense glaciation. It certainly was not covered by an ice cap; but small glaciers may have occupied the valleys on the north side. The presence of a piedmont glacier is not improbable. The deep cut of the Kugura, however, in its rounded outline has a heavily glaciated look, and it is here that we must look for the source of the ice that forms our island.

In his report on the Koyukuk, John, Anaktuvuk, and Coville

Rivers, Schrader[1] deals at some length with the glaciation of the region.

The glacial phenomena that have been described tend to show that, although the Endicotte Mountains do not on the whole seem to have been overridden by a moving ice cap, they were doubtless, especially in the northern part, largely occupied by an ice cap or perennial nevé constituting a breeding-ground for glaciers.

The mountains he traversed reached an elevation of between five and six thousand feet and he found no living glaciers, yet a heavy body of ice pushed northward along the valley of the Coville. Around the

FIG. 4.—A striated boulder on the island.

headwaters of the Kugura elevations of over seven thousand occur, and valley glaciers[2] of considerable size are reported to exist. Taking these things into consideration, it is to be expected that the basin of the Kugura would be occupied by a glacier of sufficient magnitude to push thirty miles beyond the mountains and reach the sea.

The presence of ground ice a few feet below the surface of the tundra is a characteristic feature of the Arctic coastal plain. Dall[3] is of the opinion that it is a widespread phenomenon, but Schrader[4]

[1] *Op. cit.*, p. 91. [2] Schrader, *op. cit.*, p. 30.

[3] W. H. Dall, "Correlation Papers," *Bull. U. S. Geological Survey*, No. 84, p. 92.

[4] *Op. cit.*, p. 92.

doubts its general occurrence. However widespread it may ultimately prove to be, it is certainly an interesting feature. Schrader's theory[1] is that the ground ice is the result of "frozen bays, lagoons, lakelets, or perhaps other coastal bodies of ponded water now raised into low anticlines and cut back by wave action." The localities visited by him were Capes Simpson and Halkett, between Point Barrow and the Coville River. Here the ice evidently was not glacial, for boulders are not known to exist on the beach west of Flaxman Island. An inquiry into the presence of air bubbles or granulation would soon settle the question as to whether the ground ice in that region could be accounted for by the freezing of bodies of standing water.

The writer believes that he has shown that the ground ice at Flaxman Island is of glacial origin. Its occurrence there is very similar to that of the same formation elsewhere, in that it closely underlies the tundra along the mud cliffs which are such a common feature on the northern shore of Alaska. If future investigation shows that the ice could have resulted from the freezing of bodies of standing water, the explanation given by Schrader seems the most probable one. But if it is granulated, the writer is of the opinion that its history will be found to be connected with that of the region during the glacial period. The following hypothesis is suggested:

At present the coastal plain is free from snow scarcely three months in the year. During the glacial period the snow did not entirely disappear during the short summer, but accumulated in favorable localities. As the climate grew warmer, silt was brought down by the mountain streams and distributed over the ice by the wind. Moss and grass quickly took root and increased the thickness by the formation of peat. Wherever this covering reached a sufficient depth the ice was prevented from melting and has remained until the present day. Where the thickness was insufficient, the ice melted leaving the depressions which are now occupied by the ponds and lakes which are such a characteristic feature of the tundra.[2]

The temperature of the plain adjacent to the Arctic Ocean is kept in the neighborhood of freezing by the presence of the ice-laden

[1] *Op. cit.*, p. 96.

[2] Schrader, *op. cit.*, p. 46.

waters. Inland the temperature is much higher. Schrader[1] reports the water of the Coville as being 52° F. near where it leaves the mountains. Consequently not only would the accumulation of snow be greater near the coast, but the subsequent melting less. The ground ice should therefore be confined to a narrow belt along the coast.

October 15, 1906

[1] *Op. cit.*, p. 129.

A NOTE ON THE GEOLOGY OF THE COSO RANGE, INYO COUNTY, CAL.

JOHN A. REID
Stockton, Cal.

The completion of the geological history of the Sierra Nevada and associated ranges appears to rest, for practical reasons, upon the determination, at different times and in different places, of the necessary facts. It is with this in mind that the writer presents the following data, ascertained on a recent short business trip. It is hoped that others may be fortunate enough to be able to dig more deeply into the rocks, both in the locality described and elsewhere in the adjacent regions.

The Coso Range lies between the Sierra Nevada on the west and the Darwin or Argus Range on the east, separated from each by a long narrow valley. At the north end the Coso Range forms the south boundary of Owens Valley, and extends thence southerly along its main axis for about forty-five miles. The greatest width at the north is twenty miles (see map, Fig. 1). A number of general statements have been made regarding this peculiar range, with but little in detail.

From whatever point of view seen, the Coso Range is strikingly different in appearance from the surrounding mountains. Fig. 2 shows the Range looking south from Keeler. The typical appearance is here well outlined. The flat, nearly horizontal, sky line, with, in general, gentle slopes to the bordering valleys, give an air of maturity not found in the precipitous fault scarps of the Basin Ranges. One comparatively small scarp is seen in the eastern part of the range, facing northeast, and its supplementary scarp occurs in the western portion. The form of the whole is that of a very flat elliptical dome, with its longer axis lying north and south. The periphery of this dome grades into the surrounding valley alluvium. The northern and western flanks are largely covered with basalt flows; the eastern

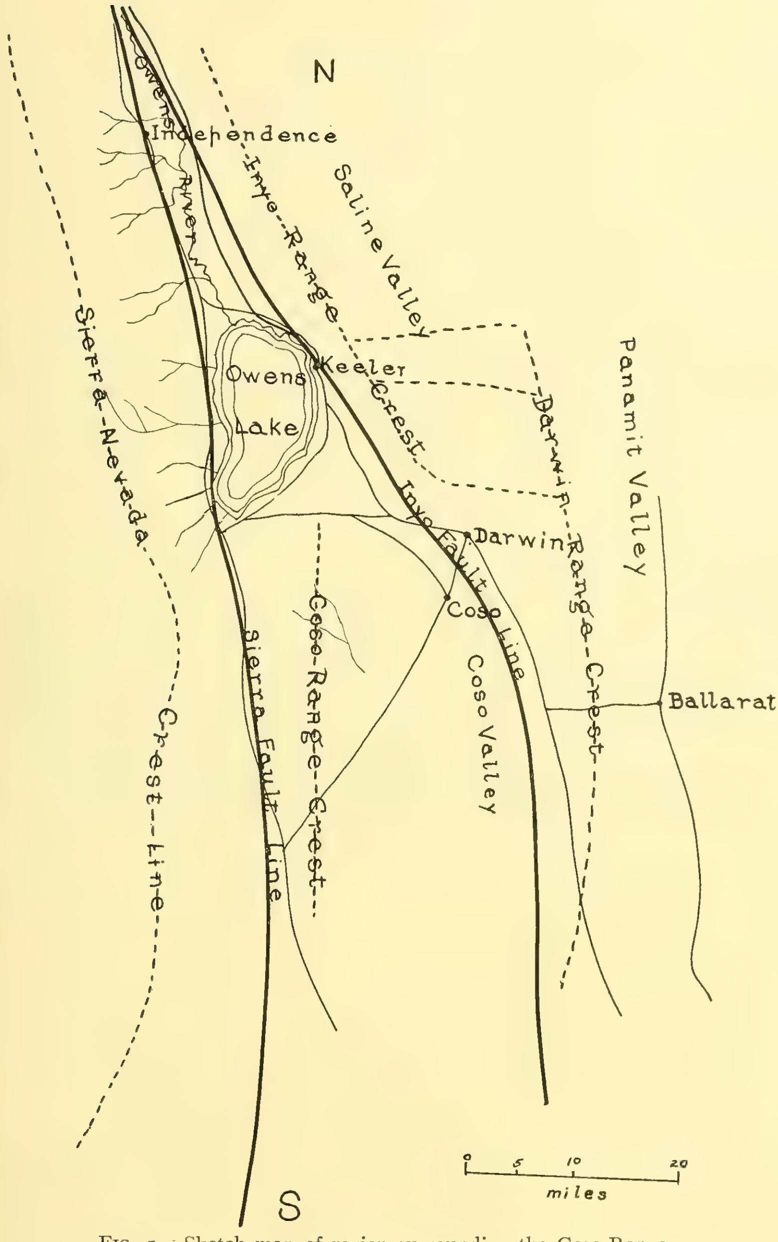

FIG. 1.—Sketch map of region surrounding the Coso Range.

side, facing Coso Valley, is free from these late volcanics. From Darwin, elevation 4,746 feet, on traveling westward, there comes first a long alluvial slope of about five miles, with small granite knobs and low hills rising slightly above the surface. Fig. 3 gives a view south of Darwin, showing a long eastern spur of the Coso Mountains which extends sufficiently far to show the effects of the faulting along the Coso Valley line. The contrast between the low granite hills and the fault topography of the Darwin Range is very evident.

FIG. 2.—View of Coso Range looking south from Keeler. Shows east-west profile of range and east fault scarp. The low basalt ridge connecting the Coso and Inyo ranges is seen at left.

From the upper edge of the alluvial apron, an elevation of 5,200 feet, the granite rises gradually westward for 2 miles to the foot of the fault scarp shown in Fig. 2, at an elevation of approximately 5,500 feet. Above this base the range rises about 1,900 feet. The fault scarp itself is less than 1,000 feet, though originally it may have been much more. From the east fault the east-west profile of the range is well shown in Fig. 2, with the gradual merging of the dome into the western valley. The north-south profile, see Fig. 4, is similar, with Coso Peak as the center and highest point. The present

height and character of Coso Peak are due in part to faulting; probably it is also near the original center of the granitic dome.

The granitic slopes descend on the east and disappear beneath the alluvial apron. But there are several important facts to be noted concerning this. In the slopes just west of Darwin the alluvium is deeply trenched by present wet weather streams. This trenching varies from a few feet in Coso Valley (see Fig. 3) to 75 feet or more in the low hills. The same dissection of alluvial aprons and fans is

FIG. 3.—View south over Darwin, showing low Coso hills at right, and fault topography of Darwin Range to left. Wet-weather stream wash in middle distance over Darwin.

found along the east base of the Sierra Nevada as far north at least as Carson City, Nev., and indicates a widespread climatic change. The conditions of large, heavily loaded torrential streams have been replaced by those of small, lightly loaded wet-weather ones.

In the Coso hills the stream gullies, locally termed washes, have exposed the nature of the material lying upon the granite. The surface layer is a coarse, angular, granitic sand, showing no traces of water action. That lying lower, on the crystalline base, varying in thickness from ten to thirty feet where seen, is stratified, and dips

very gently to the east. These beds are water-laid granitic sands of finer grain than the unsorted stuff above. They average six inches in thickness.

These water-laid strata might excite little more than passing notice were it not for the fact that they belong to an extensive formation. In traveling to Darwin from Keeler the road traverses the beds of the present lake to the north edge of the basalt flows shown in Fig. 4. The older Owens Lake cuts a small cliff in the volcanic about 150

FIG. 4.—View of Coso Range looking southwest from high end of Inyo Range. Basalt ridge in right center rests on lake beds at south edge, and is notched by older Owens Lake on north. Basalt shows much faulting. The white area south of basalt ridge is composed of lake beds with some recent alluvium. Coso Peak in left center, snow capped. Sierra Nevada—on extreme right.

feet higher than the present water level. Three well-formed beaches are preserved, with a number of smaller imperfect ones. Southward the basalt is found lying upon rather coarse sands stratified poorly at the top and well bedded below. These beds are granitic where examined, with traces of volcanic ash. Some finely stratified fine-grained beds occur in the lower part of the formation near the center of the valley, which seem to contain considerable ashy material; also some few small pebbles of schist and finer detritus of like nature

are found, but no such rocks were noted in place. The greatest thickness of the beds is about two hundred feet, with the base not exposed. In areal extent they persist from the basalt ridge on the north (see Fig. 4) to a low easterly spur of granite about eight miles north of Darwin. From this ridge southward the beds were not seen except in the exposures west of Darwin. The highest elevation is on the low granite spur, 60 feet above the bench mark of the U. S. Geological Survey marked elevation 5,101 feet. Here the section

FIG. 5.—Basalt-covered low south end of Inyo Range, looking southeast from Keeler. Shows the intense faulting of the late basalt flows resting on the old sedimentaries and Tertiary lake beds low down.

is small but complete. On the crystalline base, nearly horizontal, is roughly one hundred feet of well-stratified granitic sandstone, with one foot of reddened material at the top, overlaid by basalt. There is a slight northerly dip. Just south of the point of greatest elevation the stratified rock lies horizontal at a lower elevation.

In the basalt-covered portion of the low south end of the Inyo Range similar arenaceous beds are burned by volcanic flows (see Fig. 5). East of Keeler, above the deposits of the older Owens Lake, occurs a large amount of sand, which may, and probably does, repre-

sent a northerly continuation of the same beds. In general these beds dip slightly to the north; locally they are either gently folded, or broken and faulted near the basalt flows. The lowest elevation of their exposures is 3,760 feet, south of Keeler; the highest is 5,160 feet, nearer Darwin. This gives a vertical range of at least 1,400 feet and a height above the present lake of 1,560 feet. Lake beds are noted by Fairbanks,[1] occurring on the west flank of the Coso Range, which correspond in elevation with those on the east. These lake deposits probably extended northward and joined with those of Wancobi Lake of Walcott.[2] Spurr[3] has given a brief résumé of the existing knowledge of these, and concludes that no local faulting has been the cause of the elevation of the Wancobi beds. In the Coso strata many small faults have occurred, but it is very doubtful if their present position is due in the main to differential motion of the underlying rocks. If this be so, it is entirely probable that one large lake existed over this region, as Spurr[3] concludes, which was drained by tilting north and south from a point in the vicinity of Mono Lake. At this latter locality the beds are at elevation 7,100 feet; at Wancobi embayment 7,000 feet; and near Darwin at 5,200 feet. These figures would indicate a differential tilting, which combined with the fact of much faulting of the basalt overlying the lake beds southeast of Keeler (see Fig. 5), makes it very probable that local elevation in the Inyo Range has caused a part of the present elevation of the lacustrine formation.

A further point noted in the stream gullies west of Darwin is that the granite, though showing no faults of size, is intensely fractured as if squeezed between powerful jaws. The complexity of these small movements is well shown by the quartz veins, which are most intricately displaced in small blocks. The prevailing mode of this displacement consists of a series of northeast-southwest faults dipping northerly, along which the north walls have moved westward. The best-developed joints strike N. 40 W. with a dip of 85° northeast. The rocks are deeply weathered, with the surface covered by rounded boulders of disintegration.

[1] *American Geologist*, Vol. XVII, p. 69.

[2] *Journal of Geology*, Vol. V, pp. 340–48.

[3] *Bulletin 208*, U. S. Geological Survey, pp. 209, 210.

Of the rocks themselves no detailed petrographic investigation seems to have been made. The various writers have described them as granitic, with basalt flows north and west. The granite of the dome has the characteristics of the intrusive granodiorite of the Sierra Nevada, and ranges from a basic hornblende-biotite granite to a diorite. Traces of an older basic diorite are included in the normal facies. A few dark-colored basic dikes and a great number of pegmatite dikes also occur. Dikes of diorite-porphyrite are found, striking in general north and south. These are frequently andesitic in character. The basalt flows are agglomeratic at the base, grading upward to massive, often vescicular, at the top. Some of the earlier mud flows picked up considerable sandy material from the lake beds. The quartz veins are small and in two series, of different ages and characteristics in the localities visited. The older veins strike northwest and southeast and bear evidence of having been formed at great depths, the present veins being but the roots of the original ones. The gangue is quartz, with strong alteration of the granite walls. This alteration is shown by the development of large plates of biotite and the recrystallization of the constituents of the grano-diorite for a short distance from the vein. The ores are pyrite and chalcopyrite, carrying some gold. The later quartz veins strike northeast and southwest. The granite near the veins is metasomatically replaced by silica at times. The ores are pyrite, chalcopyrite, sphalerite, galena, sulphantimonides of silver and lead, and finely divided free gold rich in silver. These veins are connected genetically with the intrusions of the diorite-porphyrite, as seen in exposures studied in the Inyo Range to the north.

The Coso Range is peculiar in that its line of evolution did not wholly follow those of the surrounding ranges. The first uplift was simultaneous with the intrusion of the Sierra Nevada batholith, after which it was probably a range of great height and geographic importance. It must at that time have formed a southeast extension of the older Sierra Nevada, though probably as a distinct range underlaid by an intrusive granitic dome. The overlying sedimentaries were removed almost entirely by erosion before Tertiary faulting broke a long stable condition of the crust and formed lake basins along the east flank of the Sierra. The lines of this faulting were such

that the Coso Range became a very distinct unit, one main fault going to the west and forming the east wall of the Sierra, another passing to the east and forming the west wall of the Darwin Range (see Fig. 1). The large lake in which the Wancobi and Coso beds were deposited was formed at this time, and granitic detritus deposited from the Coso Mountains in the arm north of Darwin. The occurrence of the few fragments of schist indicates that the last remains of the older rocks in the body of the range were removed just previous to, and in part coincident with, the draining of the lake. The only locality where the older rocks yet remain is in an east-west ridge about eight miles north of Darwin and just east of the low granite spur noted above as marking a south limit of the lake beds. On this east-west ridge of older rocks is exposed a magnificent section about a mile thick, the strata dipping uniformly east at about 45°. No time could be given to an examination of these rocks. The older lake basin was eventually drained by further movements along the fault planes, and basalt eruptions covered the west and north flanks of the Coso Mountains, the south end of the Inyo Range, and a large area of the lake beds south of Keeler. As some of the basalt lies upon unstratified sands which are above the lake strata, the lake must have been partly drained previous to the initiation of the volcanic flows.

Still later faulting along the old lines produced further elevation of the Inyo Range and differential movements of the lake beds along this sierra. Through it all the Coso Range was faulted only by small displacements, caused by its position between the two great converging faults to east and west. Thus these comparatively insignificant mountains stand as a monument of the older geologic time when the western cordillera was composed of low mature ranges not characterized by the excessive and great faulting seen today.

A NATURAL BRIDGE DUE TO STREAM MEANDERING

V. H. BARNETT

Natural bridges were originally referred to the agency of caverns, as explained in Scott's *Geology*[1] and most of the less recent works. Scott gives the Natural Bridge of Virginia as an example of this method of formation, and it was not until 1893, when Walcott[2] described the bridge, that it was considered as having been formed in another way. Cleland[3] has reviewed several methods of origin in an article in the *American Journal of Science*, but so far as the writer knows none have ever been described as being due to stream meandering.

The bridge here described is located south of the White River below the mouth of Porcupine Creek, in South Dakota, and was visited by the writer in 1905, while working as field assistant to Professor E. S. Riggs, of the Field Columbian Museum. It is formed of White River beds. The opening of the archway is about 12 feet high by 8 feet wide, and the thickness of the arch is something like 10 feet in a vertical direction by 7 feet in a horizontal. The left side of the picture (Fig. 1) is the canyon wall, while on the right a pillar supports one end of the arch. The stream which formed this natural bridge once flowed on the outer side of the pillar, but making a sharp bend, it flowed just in front of the pillar to a point immediately under the near edge of the arch, where it turned and flowed along the foot of the wall toward the front of the picture. The position of this bridge is such that it was very difficult to photograph it so as to show its true relation to the stream. Between the foreground on the right, covered with weeds, and the pillar, one side of which only is shown, is the old channel of the stream. The gorge is about 30 feet deep,

[1] W. B. Scott, *An Introduction to Geology*, pp. 90, 91.

[2] *National Geographical Magazine*, Vol. V, 1893, p. 59.

[3] *American Journal of Science*, 4th ser., Vol. XX, 1905, pp. 119–24; 3 figs.

with almost vertical walls. The rock is a hard, rather blocky, light-blue clay, showing typical bad land topography and weathering rather rapidly, though not as fast as the softer maroon clays of the Oreodon

Fig. 1.—A natural bridge south of White River below mouth of Porcupine Creek, South Dakota.

beds. The bridge was formed in the following method: Flowing in the direction indicated by the arrows in Fig. 2, and taking the course of the dotted lines, the stream kept cutting in on the narrow ridge at

A from both sides, until it had eaten its way through, thus straightening its channel but leaving a pillar (*B*) supporting an arch over the stream.

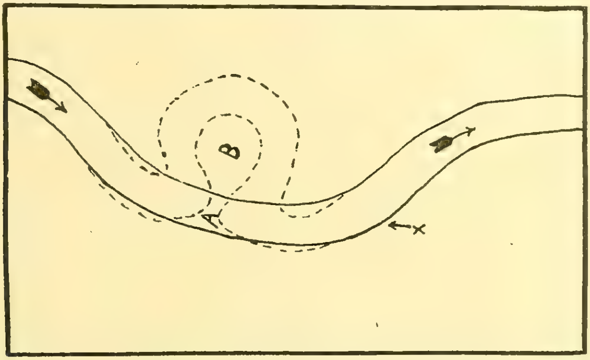

FIG. 2.—A drawing to illustrate the way in which the natural bridge was formed. The view (Fig. 1) was taken from a position indicated by the cross and looking in the direction of the arrow.

STRIATIONS IN GRAVEL BARS OF THE YUKON AND PORCUPINE RIVERS, ALASKA[1]

V. H. BARNETT

The presence of furrows in gravel bars of spreading and meandering streams in Alaska seems not to have been mentioned in the literature on Alaskan geology.

These channels may be seen on the extensive bars of the Yukon and of the Porcupine rivers throughout the Yukon Flats. The bars are remarkably well developed along the Porcupine for about a hundred miles above its union with the Yukon and in low water they are exposed as broad, gravelly, and sandy beaches from one to five miles in extent. These extensive bars give excellent opportunity to observe the striations. An uprooted tree is often seen lodged on a bar with a channel marking its trail (Fig. 1).

Three hypotheses may be offered in explanation of these furrows: first, that they are caused by tree trunks held firmly to the river bottom, either by accumulated débris or ice, and moved forward by the force of the stream; second, that they are caused by blocks of ice beneath a load or ice jam and moved forward in the breakup; or, third, that they are due to trees passing over bars only partly supported by water, the current banking up behind the stump, though having sufficient force to push slowly along, yet not able to remove the marks of the tree.

The third method would seem a simple explanation for the origin of the furrow shown in Fig. 1. Here an uprooted pine tree may be seen at the down-stream side with a straight furrow passing up stream.

It does not seem to the writer that any accumulation of débris that might collect in the roots of a tree would be competent to hold it to the bottom with sufficient force to make the furrows shown in

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

Fig. 2. The force of the water would tend to relieve the roots of any material competent to sink the tree, such as rocks or frozen earth. The only other material at hand to which one might ascribe such a force, is ice.

There is evidence that during the ice breakup of spring, great pressure is exerted on the banks and shallow portions of the stream.[1]

At a number of places last summer the writer observed talus where

FIG. 1

rock fragments were pressed into a pavement. These were seen both along the Yukon and along the Porcupine rivers. Russell[2] in his paper on the surface geology of Alaska speaks of the river ice as producing pavements of pebbles along the banks and of the pebbles being faced and striated on their upper side. These pavements occur between the high-water and low-water lines, and as the water was low

[1] For an account of the "breakup" see F. C. Schrader, "Professional Paper," *U. S. Geological Survey No. 20*, 1904, pp. 15, 16. Also see Stoney, *Naval Exploration in Alaska*, U. S. Naval Institution, Annapolis, Md., 1900, p. 52.

[2] *Bulletin of the Geological Society of America*, Vol. I, 1890, pp. 119, 120.

at the time of the writer's visit, an excellent opportunity was presented to observe them. The pavements are composed of variously sized rock fragments, from a few inches in diameter up to two or three feet, sometimes water-worn, but more often angular, with their upper side smooth and striated parallel to the stream.

There seems no doubt, therefore, that moving ice if equipped with proper means could produce the furrows observed in the gravels.

Fig. 2

Cut banks occur on one side or the other of the rivers throughout the flats, from which spruce trees are certainly tumbling during summer. An uprooted tree held to the river bank by some of its roots would serve as a lodgment for drifting trees and the whole mass would be frozen in the ice as it formed. In the spring, with the heavy pressure of an ice jam, the mass would be dragged along intact, producing such forms as shown in Fig. 2, but ice blocks caught in the jam probably occupy an equally important place in the origin of these lines.

CAUSES OF PERMO-CARBONIFEROUS GLACIATION

The article by David White on "Permo-Carboniferous Climatic Changes in South America" in a recent number of this *Journal* contains a discussion of the causes of that remarkable period of glaciation. One section of the article is headed, "Exaggerated Temperature Effects of Elevation"—a heading that seems to me more appropriate than the author presumably intended it to be; for the temperature effects of elevation, as a cause of the Permian glaciation of South Africa at least, appear to be greatly overrated in the argument there set forth.

It is not to be questioned that elevation of that part of South Africa from which the Permian ice sheet spread across the neighboring lower lands would have been an efficient cause of lower temperature; but at present the chief evidence of elevation is the need of it in the climatic argument; and we are not yet in the position of having so effectually excluded all other causes of glaciation as to warrant the acceptance of the elevation of the area of glacial dispersion on the ground that no other possible cause remains. It is true that the idea of great elevation of the area of dispersion was current among geologists in South Africa when I was there in 1905; but on inquiring more particularly for the evidence in favor of this idea, there appeared to be nothing more than its assumed necessity.

Two reasons are assigned by White as indicative of land elevation: "The enormous accumulations of coarse conglomeratic material in the eastern regions testify to the steep gradient of the drainage systems," and "The presence in nearly all regions of the great unconformity is itself evidence of the vigor of the post-Carboniferous uplift" (p. 631). As I see the case, neither of these reasons can be applied with force to South Africa.

As to the first of these reasons: the Dwyka tillite or glacial conglomerate of South Africa is itself the chief conglomeratic deposit of great series of continental formations in which it is the basal member; the other members are largely sandstones and shales; the Ecca formation, which follows the Dwyka more or less conformably, contains coal seams, which testify to gentle gradients, not to steep gradients in the stream systems. The great total thickness of these continental formations indicates a long-continued progressive depression of their basin, and this is quite as consistent with a long-continued uplift of never-lofty neighboring lands as with a great

elevation of the neighboring lands during the formation of the Dwyka tillite.

As to the second reason: The great unconformity between the Dwyka tillite and the older formations cannot be interpreted in South Africa as meaning a vigorous post-Carboniferous uplift. The underlying deformed formations are all much older than the Dwyka, and were enormously eroded after their deformation before the Dwyka tillite was deposited upon them; hence the time of the pre-Dwyka deformation and uplift which initiated the great erosion resulting in the unconformity must have been pre-Carboniferous, not post-Carboniferous. Indeed, as far as the surface of unconformity has been traced, it everywhere shows forms of small relief; either low, well-subdued mountains, or peneplains; hence a long time must have elapsed between uplift and glaciation. Furthermore, the Waterberg sandstone of the Transvaal, supposed to correspond to the Table-mountain sandstone farther south, and surely older than the Dwyka, because it is unconformably covered by patches of Dwyka tillite, itself rests unconformably upon the eroded surface of the strongly deformed older formations, and here also the surface of unconformity is of small relief; and the Waterberg sandstone is nearly horizontal or gently inclined, thus testifying to the relative absence of vigorous uplifts in the Transvaal for a long period before Dwyka time.

Inasmuch as the Dwyka is associated with continental formations, it may have been deposited in an inclosed continental basin; and if so, it is evident that no safe inference as to the altitude of the pre-Dwyka land surface above sea level can be drawn from the small relief to which the surface had been worn down by pre-Dwyka erosion; for erosion in an interior basin may produce a peneplain at an altitude unrelated to the general baselevel of the oceans. Nevertheless, it is improbable that the interior basin of South Africa stood at a great altitude in Dwyka time; for the southern part of the Dwyka tillite follows conformably after a series of presumably continental shales and sandstones, which in turn rest conformably upon marine Devonian (Bokkeveld) strata: and it is hardly probable that the region which was low in Devonian time could have been raised to a great altitude as an interior basin in Dwyka time without interrupting the conformable sequence of stratified deposits that connect the marine and the glacial formations. True, it is possible to imagine such a case, but the imagined case includes conditions so improbable that they do not form a satisfactory ground on which to build the explanation of the Dwyka glacial climate; far less do they suffice to lead to a demonstrated explanation.

In view of all this, is it not premature to assert that "the elevation of the southern land masses" in Dwyka time is "fully demonstrated"? There certainly were times when parts of the South African land masses were deformed and elevated; but one of these times of elevation was so long before the Dwyka period that the elevated areas had been worn down to small relief when glaciation occurred; and the next occasion of strong deformation and elevation was after all the continental formations, of which the Dwyka is the basal member, had been deposited; and moreover, this elevation occurred well to the south of the area of glacial dispersion. But in Dwyka time, all direct evidence suggests that South Africa was a low-lying continental area. It is of course permissible to postulate an elevated continental area in a region concerning which we have no direct information as to Dwyka topography, north of the northernmost Dwyka tillite patches in the Transvaal; and this postulated highland may be regarded provisionally as the source of the Dwyka ice sheet; but postulating an elevation and demonstrating it are very different processes.

White says also that "the occurrence of glacial phenomena within the tropics was presumably due in part to an extension of the southern cold with the favoring assistance of ocean currents and perpetual atmospheric 'lows,' resulting in part from continental relations and topography" (p. 631). Here again, it is perfectly legitimate to postulate favoring ocean currents and perpetual atmospheric "lows," if one wishes to do so, and then to deduce the consequences of the postulates; but the value of the deductions will necessarily depend upon the validity of the postulates themselves; hence they must be examined. Ancient currents in the ocean and areas of low pressure in the atmosphere should not, in the present state of scientific inquiry, be arbitrarily assigned to this or that part of the world. The existing currents of the ocean and areas of low pressure in the atmosphere are so systematically arranged that one may fairly object to any assumed ancient distribution of these phenomena that is inconsistent with the controls by which they are determined today. For example, a continental area of low pressure in latitude 25° can occur only in the warm season, when the high temperature on the land may suffice to reverse the tendency to high pressure perpetually induced in that latitude by the processes of planetary (atmospheric) circulation; and the relatively high temperature by which a low-pressure area is formed in such a region is evidently unfavorable to the occurrence of snowy precipitation. In the cold season of the same region, when the temperature is more favorable to snowfall than at other times, the atmospheric pressure will be high, but precipitation in the area of high pressure will be small. Hence little aid

can be given to Dwyka glaciation by areas of low pressure. It may be the same with ocean currents. Until a reasonable cause can be given for the occurrence of favoring ocean currents, their part in aiding the formation of the Dwyka ice sheet is only a gratuitous postulate. However satisfactory an explanation of a problem is, reached from such a postulate, it is not safe to regard the explanation as fully demonstrated until the postulate is independently established. The desirable thing in such a problem as this is the publication of diagrams, on which the distribution of lands should be indicated as described by White—"an Antarctic continent, of which Australia, South Africa, and a part of South America were possibly but lobes" (p. 630)—with a reasonable and warrantable distribution of ocean currents and areas of low atmospheric pressure in proper relation to the postulated lands and oceans. It would then be possible for a reader to judge how much favoring assistance might be expected from these contributive causes.

The Permian glacial climate is one of the most remarkable problems disclosed by geology. The addition of a South American glaciated area to the others in Australia, India, and South Africa goes far, as White points out, toward excluding any recourse to tempting explanations based on the displacement of the earth's axis. The present limitation of precipitation in at least the South African glaciated area chiefly to the warmer season, while the colder season is prevailingly clear and dry, is a difficulty that must not be overlooked. The full explanation of the problem does not involve only a moderate reduction of temperature; it involves either so strong a reduction of temperature that snowy precipitation may prevail in the warmer season, or a more moderate reduction of temperature with a change of the season of precipitation from the warmer to the cooler part of the year. Under the present understanding of atmospheric circulation, the first of these alternatives is less puzzling than the second.

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Harvard University
November 24, 1907

Reviews

The Okanagan Composite Batholith of the Cascade Mountain System. By Reginald A. Daly. (Bulletin of the Geological Society of America, Vol. XVII, pp. 329–76, 1906.)

This batholith is on the international boundary between British Columbia and the state of Washington. Its east-west dimension is about sixty miles; the north and south limits are not known. The batholith is composite, the individual intrusions having been made from late Paleozoic to late Tertiary time. There is considerable variation petrographically in these intrusions, the later ones being as a whole progressively more acid, but the series was broken near the close of the Laramie by the intrusion of some alkaline syenites and malignite. The small Paleozoic bodies are a complex, variable, highly metamorphosed series of gabbros, peridotites and dunite. The Jurassic batholiths are of granodiorite, and the Tertiary batholiths are of biotite-hornblende-granite and biotite-granite. There are a few dikes of olivine basalt, thought to be of Pleistocene age.

It is evident from Daly's descriptions that these rocks are in general accord with the rest of the Pacific Coast petrographic province in their moderately high ratio of soda to potash.

In Lower Cretaceous time the Jurassic granodiorites had been exposed by erosion, and over 30,000 feet of arkose sandstones, grits, and conglomerates were deposited on them. This was followed by deformation, which resulted in the production of faults and folds in the Cretaceous strata, with dips averaging over 45°. Probably at the same time the granodiorites were sheared and crushed into banded gneisses and gneissic granites.

The method of batholitic intrusion by replacement is discussed, and an ideal skeleton history of a batholite is given.

C. W. W.

Crescentic Gouges on Glaciated Surfaces. By G. K. Gilbert. (Bulletin of the Geological Society of America, Vol. XVII, pp. 303–16; Pls. 37–39. 1906.)

The chatter-mark and crescentic crack are described. The former is thought to be due to the slow, rhythmic striking of bowlders embedded in the basal ice. Fracture results, if the surface of the rock is under tension.

Crescentic cracks which are vertical and, like chatter-marks, are concave forward, may be explained as the result of the difference in stress parallel to the rock-face, arising from differential friction.

Crescentic gouges are convex forward (downstream). Those here described measure from a few inches to over six feet across. The gouges generally occur in sets, the members of a set being usually of nearly equal size. They occur on both bottoms and walls of glacial troughs. Crescentic gouges consist of two elements: a gently sloping, incomplete, conoid fracture, on the upstream side; and a subsequent, vertical, crescentic fracture, that forms the downstream side of the gouge. The "conoid" fracture is due to shear from an inclined pressure arising from the downward and forward pressures of the ice, as modified by differential friction. This inclined pressure is thought to have been applied by bowlders acting through a thin cushion of débris or of débris-loaded ice, at places where the ice rose over obstructions. The thin wedge formed by this fracture was broken across vertically, and the crescentic wall produced. This second break is due to stress from the upturning of the edge of the wedge when the formation of the first crack relieved it of compression, and the resistance of the ice pressure against this upturning.

The author regards the gouges as the result of "a mechanical rhythm of some sort," and suggests that the constant pressure of the ice may induce a group of mechanical rhythms to accumulate stress and strain within the rock, until the breaking-point is reached and a conoid fracture produced.

C. W. W.

Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington. By Ralph Arnold. (Bulletin of the Geological Society of America, Vol. XVII, pp. 451–68; Pls. 55–58.)

This paper gives the preliminary results of the first measurement and study of any comprehensive Tertiary section in the Pacific Northwest.

The topography of the Peninsula is not very well known. Its dominant feature is the Olympic Mountains, a rugged alpine group rising to a maximum elevation of 8,200 feet, and having a local relief of about 7,000 feet. There are no railroads, wagon roads, or trails in the higher mountains, and considerable areas are almost impassable even to a man afoot.

Surrounding the higher mountains, especially on the northwest, west, and south sides is a maturely dissected plain, sloping seaward from elevations of 4,500 to 5,000 feet. The streams crossing this plain, in fact all the streams of the Peninsula, flow nearly straight outward from the central

area of high mountains. This radial drainage is thought to be consequent to some domed surface, probably a peneplain.

The formations involved in the geology of the coastal region of the Olympic Peninsula include serpentine, old diabase or greenstone, metamorphosed sandstone, and quartzite, probably of Jurassic age; 6,000+ feet of gray sandstone with minor quantities of carbonaceous shales, supposed to represent the lower part of the *Puget Group* and of Cretaceous age; 1,200+ feet of basalt tuffs of Eocene age; 15,000 feet of Oligocene-Miocene conglomerate, sandstone and shale; 2,260 feet of Pliocene conglomerate, sandstone, and shale; and at least 300 feet of Pleistocene till, clay, and gravel.

Fossils are abundant in the Tertiary formations. One fauna is described from the Eocene, five from the Oligocene-Miocene, and one from the Pliocene. The peculiar upper Miocene fauna of the Looke beds, which is well developed on Vancouver Island, only 15 miles northward, is conspicuous by its absence.

C. W. W.

Contribution to the Geology and Paleontology of Vermont. By HENRY M. SEELY. From the *Fifth Report Vermont State Geologist,* pp. 1–34, Plates XXXIV–XLV. Montpelier, Vt., 1906.

The greater part of this paper is taken up with description of new species of the so-called genus, Cryptozoön. None of the characters assigned to these three new species, *C. steeli*, *C. saxiroseum*, and *C. wingi* differ from structures that may be occasionally observed in undoubted concretions. The reviewer can find no reason for regarding such structures as organic, except to the extent that bacteria or similar organisms may have contributed to the precipitation of the calcite or silica composing them. In fact the only structure in Hall's description of the type species[1] that may be organic is certain doubtful canals, of which he writes: "The substance between the concentric lines, in well-preserved specimens, is traversed by numerous minute irregular canaliculi which branch and anastomose without regularity." The exact nature of these is not clear, but probably they are similar to the "pilae" figured by Seely (Plate XXXVII, Fig. 3) which cannot be distinguished from irregular inorganic segregations common in many concretions, cherts, and limestones.

A startling feature of the paper is the description (p. 12, Plate XXXVII, Figs. 5, 6) of a specialized ovarium with ova in "Cryptozoön saxiroseum." That such a structure, so well developed, should exist in so primitive an

[1] James Hall, *Thirty-Sixth Annual Report N. Y. Mus. of Natural History*, transmitted to the legislature, January 12, 1883. (*Cryptozoön proliferum.*)

organism as "Cryptozoön" would be, is not probable. Perhaps the structure is the shell of some specialized organism included in the concretion. Until someone can find organic structures in "Cryptozoön" the description of new species is an unnecessary burden to science.

C. W. W.

On the Radioactive Matter in the Earth and the Atmosphere. By A. S. Eve. Separate from the *Philosophical Magazine,* September, 1906, pp. 189–200.

For geologists, the most important feature of this paper is the determination of the radioactive matter in the earth's crust. "About 1.8×10^{-11} grams of radium bromide is the estimated equivalent of the active matter per c.c. present in the earth's crust sufficient to account for the penetrating radiation." This is four times the average amount found by Strutt by direct observation on rock specimens.

C. W. W.

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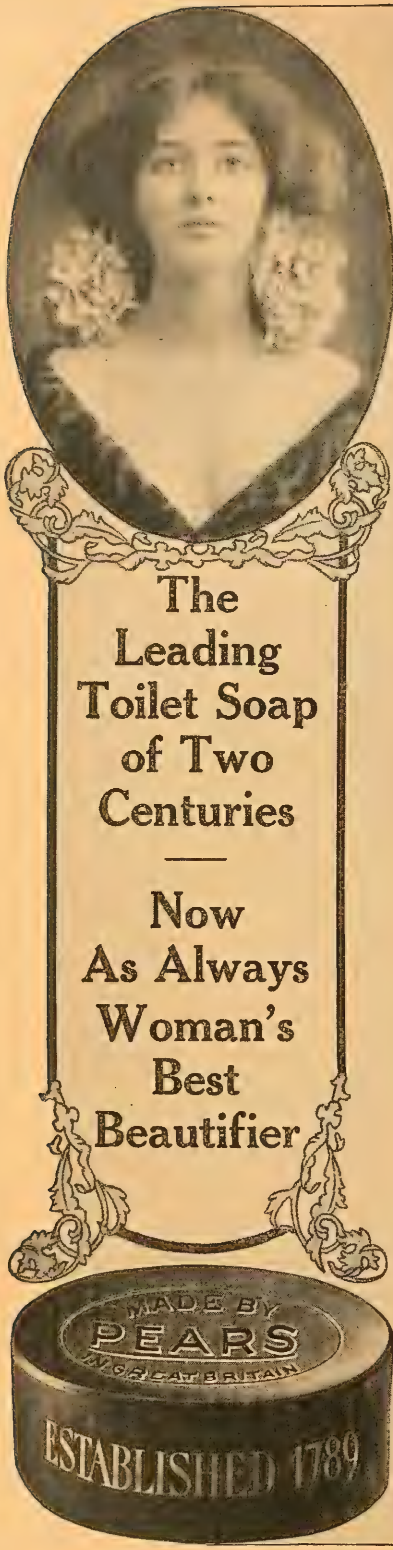
PEARS' SOAP

was beautifying complexions when George the Third was King, and before the great historic event of modern times, the French Revolution



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THE

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THE TRIASSIC PORTION OF THE SHINARUMP GROUP, POWELL

WHITMAN CROSS[1]

Introduction.—Among the great sedimentary formations or groups of the Plateau Province, described by Powell, Dutton, Gilbert, and others, that one named by Powell the Shinarump is today the least known and occasions the greatest difficulty in correlation. As I have recently attempted to correlate the formations of the Plateau Province with those of the adjoining mountain district of southwestern Colorado, the difficulties in regard to the Shinarump have come prominently to my attention, and it is hoped that a brief review of the subject may be of material assistance to geologists who attack the problem in future.

The Shinarump is the lowest of three formations or groups assigned by Powell to the Trias, the others being the intermediate Vermilion Cliff sandstone and the White Cliff sandstone at the top. The Triassic was thus supposed by him to embrace everything present in the great section north of the Grand Canyon between the upper Aubrey (Pennsylvanian) and the marine Jurassic.

Dutton and other writers have referred the White Cliff sandstone to the Jurassic, and this reference is no doubt correct, since the continuity has been established between this very well-marked formation and the La Plata sandstone of Colorado, which is in angular unconformity with the Triassic and the entire Paleozoic section (4).[2] The

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

[2] Numbers in parentheses refer to the bibliographic list to be found at the end of this paper.

Triassic age of the Vermilion Cliff sandstone has not been directly questioned, neither has it been fully proven, and it will appear in the course of this discussion that there is some slight basis for the suggestion that it is lower Jurassic.

As for the Shinarump group, Walcott long ago found Permian fossils (24) in the lower beds referred to it by Powell and possibly Jurassic fossils (4) in the upper part, while a Triassic vertebrate fauna occurs near the middle of what Ward refers to the Shinarump (26). The question as to the real character, scope, and correlation of this group is then plainly one requiring further study and consideration.

The standpoint from which this review is written is that of several years' experience in the stratigraphic section of southwestern Colorado, with some information as to the gradual changes exhibited by the formations as they pass from the mountain slopes into the adjoining vast area of plain and canyon—the Plateau Province. It may be well to present in the outset the facts of major importance bearing on the topic under discussion and indicate frankly the tentative conclusions I have reached as to their application.

It has been established that the Dolores formation of the San Juan region of Colorado is of Triassic, and probably of upper Triassic age. An angular unconformity has been found below the Dolores by which the whole upper Paleozoic red-bed series and a part of the Pennsylvanian strata are locally cut out. No middle or lower Triassic beds have been found and none demonstrably Permian. The stratigraphic break below the Dolores is thus shown to be of much importance.

The Dolores formation has been traced from the mountains into the heart of the Plateau district along two lines of approach. The most important fact established is that the fossiliferous basal member of the formation extends west and northwest from the San Juan Mountains as far at least as Grand River, in Utah, where the angular unconformity below it is very marked, and 1,500 to 2,000 feet of probable Paleozoic beds are gone at some places. An overlap of the basal Dolores conglomerate from Permian (?) beds directly to the pre-Cambrian complex occurs on the western side of the Uncompahgre Plateau, in Colorado, where it was observed by Peale in 1875. The

fossiliferous lower strata of the Dolores have also been traced down the San Juan Valley nearly to the Glen Canyon of the Colorado, below the Henry Mountains.

While nothing similar to the Dolores fossiliferous conglomerate has been described from the original area of the Shinarump Group in Utah or Arizona, the discovery by Ward (26) on the Little Colorado River of the vertebrate fauna characteristic of the Dolores shows plainly that a correlation of great importance is to be anticipated when the requisite studies have been made.

In the literature of geological investigation in the Plateau Province, which is almost wholly of reconnaissance character, a certain bed or zone of strata in many widely separated localities has been called "the Shinarump conglomerate" and its identity in those places asserted. This has been done without much descriptive detail and chiefly on the basis of lithologic character. Now in the Dolores formation the lower zone, embracing all beds found to be fossiliferous, has also a most perfectly diagnostic lithologic phase. This is found almost invariably at the base of, and irregularly developed through, 200 or 300 feet of beds. Those who have worked in the San Juan region have come to apply the convenient field term "saurian conglomerate" to this diagnostic phase because one seldom searches in vain in it for teeth or bone fragments belonging to dinosaurs or to belodont crocodiles.

The peculiar lithologic feature of the "saurian conglomerate" is that it consists mainly of small round gray limestone pebbles, in many places almost pisolitic in appearance, though never showing the structure of true pisolite spheres, and rarely reaching one inch in diameter. The conglomerate is most irregularly distributed, with cross-bedding structure, through sandstone ledges from a few inches to perhaps thirty feet in thickness. The color of conglomerate-bearing ledges is often greenish gray and shales or sandstones of the same tones are common between them. More complete descriptions of the conglomerate zone are given in the Telluride and Rico folios (1 and 3).

The upper part of the Dolores formation is of very variable thickness in the San Juan region, owing in all probability to erosion in the ensuing epoch. It thickens westward and has been confidently correlated with the Vermilion Cliff sandstone of the Plateau Province (4).

The foregoing brief statement will, it is hoped, be sufficient to show the desirability of tracing the horizon represented by the basal beds of the Dolores formation through the Plateau country, not only to establish the base of the Trias but to discover the most favorable localities for the study of the older, and probably Paleozoic red beds, the full section of which is perhaps not yet known. According to present knowledge the horizon in question is not far below the Vermilion Cliff sandstone in the central and northern parts of the Plateau. In southern Utah and Arizona there is evidence of a decided increase in the thickness of the Triassic beds below the Vermilion Cliff sandstone, sufficient to warrant the suspicion that the true Shinarump conglomerate of the Shinarump Cliffs, while a thousand feet below that sandstone, may still be at the same horizon as the "saurian conglomerate" of the Dolores formation.

We will turn now to a scrutiny of the literature bearing upon the subject.

The Shinarump conglomerate described.—The term "Shinarump conglomerate" appears to have been used for the first time by Powell, in 1873, while describing the geologic structure and naming the topographic features of the district lying north of the Grand Canyon of the Colorado (**21**, p. 457, 458). Powell says that from the Grand Canyon northward one travels over Carboniferous beds to the first line of cliffs, one hundred to four hundred feet high.

> This escarpment is capped by a firmly cemented conglomerate containing many fragments of silicified wood, and over its surface are scattered many like fragments, and sometimes huge tree trunks, which are the remnants of rocks at one time overlying the conglomerate, but now carried away by erosion. Underlying this cap are variegated sandstones and marls. The whole group is probably of lower Triassic age.

In 1875, Gilbert, Marvine, and Howell, of the Wheeler Survey, published the results of their work in the country adjacent to the Colorado River, and refer to the Shinarump conglomerate as something defined by Powell. Their observations covered a wide territory, including that of the Shinarump Cliff, and there seems to be no doubt but that their references are to a single well-defined conglomerate stratum or bed.

Gilbert assigned to the Trias 2,500 to 3,500 feet of beds between the

marine-fossil horizon of the Jurassic and that of the "Permo-Carboniferous" (11). The upper, sandy portion of his Triassic section clearly includes the White and Vermilion Cliff sandstones, although they are not so named. The lower portion is described in general terms as "variegated, saliferous, and gypsiferous clays."

In the midst of the clays is a bed of conglomerate. The lower shales were somewhat eroded by the current which spread it, as is shown by the inequality of the surface on which it rests. Its thickness is variable, and it is not universally present; but its persistence over large areas is nevertheless such as to excite wonder. In the conglomerate and in the superjacent clays are silicified tree trunks in great numbers. The fossil horizon discovered by Mr. Howell near Toquerville, and another that was noted south of Kanab, are lower than the Shinarump conglomerate (11, pp. 175, 176).

The Shinarump conglomerate appears to be definitely placed in several detailed sections published by Gilbert, between "variegated gypsiferous clays with silicified wood," above it, and "chocolate gypsiferous clays," below (11, pp. 158–60). On Paria Creek and at Jacob's Pool, Arizona, unconformities by erosion were noted below the conglomerate, but of no great extent, and Gilbert laid no special stress on the importance of the break indicated. Jacob's Pool is between Kanab Greek and the Paria, at the south base of the Paria Plateau.

Marvine speaks incidentally of "a conglomerate of siliceous pebbles, the Shin-ar-ump Triassic conglomerate of Powell" (19, p. 215). He apparently saw this bed only near St. George in Utah, near its western limit of outcrop, and on the Little Colorado, in Arizona.

Howell seems to have practically followed the Shinarump conglomerate for several hundred miles. He says:

The conglomerate bed to which Mr. Powell has given the name Shinarump is a very singular formation. . . . . Having a maximum thickness at St. George of one hundred feet, it seldom exceeds forty or fifty to the east, but is coextensive, so far as I know, with the Trias of the Colorado Plateau. Occasionally it is little more than a coarse sandstone, and sometimes thins out to eight or ten feet, but never have I passed that horizon without seeing it. One of its constant features, almost as constant as its existence, is the great amount of silicified wood which it contains (13, p. 283).

Just below the ledge of the conglomerate, near Toquerville, in

southwestern Utah, a few fragments of lamellibranch shells were found by Howell. These were too imperfect for determination.

The Shinarump Group.—The comprehensive term "Shinarump Group" was proposed by Powell in 1876, in his *Geology of the Uinta Mountains*, for all the strata known to him between the upper Aubrey limestones and the Vermilion Cliff sandstone. Its Triassic age is assumed. The group is not described in much detail, the following section made by Powell "along the course of the Kanab in the winter of 1871" being the most complete statement given.

SECTION OF THE SHINARUMP GROUP, POWELL

	Top	FEET
11.	Bad-land sandstones, rapidly disintegrating; argillaceous; weathering in variegated hills	800
12.	Conglomerate	80
13.	Red bad-land sandstone; very friable, with much gypsum	195
14.	Greenish-gray bad-land sandstone, with much gypsum, and rapidly disintegrating	100
15.	Compact gray sandstone	8
16.	Red sandstones and arenaceous shales; gypsum in seams and joints	300
17.	Red and brown sandstone; rather thinly bedded, with many ripple marks	250
18.	Conglomerate with angular and rounded fragments of limestone in a matrix of calciferous sand	50
		1,783

The conglomerate eight hundred feet below the top of the group is evidently the one elsewhere designated Shinarump conglomerate. Powell gives no hint that an unconformity had been noted by Gilbert beneath that horizon, but he repeatedly refers to the one at the base. The upper and lower parts of the group are described in very similar terms, and fossil wood is said to characterize the whole group. It is pointed out that, "The Shinarump conglomerate is usually very hard, and weathers in such a manner as to form hogbacks or cliffs, and the softer gypsiferous beds above, when carried away by rains, leave behind fragments of this silicified wood," etc.

It is evident that Powell did not suppose that his Shinarump Group contained Permian or other pre-Triassic beds. Neither he nor any other early observer commented upon the fact that if the Shinarump conglomerate contained worn pebbles of fossil wood

there was probably a considerable difference in age between the silicified wood of the upper and lower parts of the group.

Without detailed description and with no suggestion of variation in character, Powell affirms the wide extension of the Shinarump group in the following sentence:

> The variegated beds above and below the [Shinarump] conglomerate are seen in many places on either flank of the Uinta Mountains, and from time to time this horizon is brought up by faults or flexures in all the stretch of country which intervenes between the Shinarump Cliffs and the Uinta Mountains. [23, p. 54]. . . . . [With regard to the Shinarump conglomerate, Powell does acknowledge that it is not easily recognizable, toward the north about twenty feet in thickness, but increasing southward until it attains two hundred feet (23, p. 41).]

The Shinarump as treated by Dutton in 1880.—A treatment of the Shinarump group very similar to that of Powell was given by Dutton in 1880 in his *Geology of the High Plateaus of Utah* (**6**). The range given to the group is the same, and on account of the constancy of character few descriptive details are given. Dutton thus introduces the discussion of the Shinarump:

> Resting everywhere upon the Carboniferous of the Plateau country is a series of sandy shales, which in some respects are the most extraordinary group of strata in the West, and perhaps the most extraordinary in the world. . . . . There are especially three characteristics, either one of which would render them in the highest degree conspicuous, curious, and entertaining. First may be mentioned the constancy with which the component members of the series preserve their characters throughout the entire province. Wherever their proper horizon is exposed they are always disclosed, and the same well-known features are presented in southwestern Utah, in central Utah, around the junction of the Grand and the Green, in the San Rafael Swell, and at the base of the Uinta Mountains. As we pass from one of these localities to another, not a line seems to have disappeared, not a color to have deepened or paled. . . . . The constancy is, so far as known to me, without a parallel in any formation in any other region (**6**, p. 144).

Only slight changes in thickness and in constitution are admitted. The varied coloration of different beds and the architectural forms resulting from erosion are the other two marked characteristics.

The constancy in lithologic character, the wonderful coloring, and the peculiar architecture of erosional forms here emphasized, all avowedly pertain to the lower part of the group, recognized by Dutton two years later as belonging to the Permian.

The Shinarump conglomerate is said to be within "the transitional shales" of 550 to 750 feet thickness below the Vermilion Cliff sandstone—shales not described except as "monotonous." The conglomerate is said to "consist of fragments of silicified wood imbedded in a matrix of sand and gravel." Its thickness rarely exceeds fifty feet. "It occasionally thins out and disappears, but usually recurs if the outcrops be traced onwards, resembling the mode of occurrence common to the coal seams of the Carboniferous coal measures." It is indeed suggested that the conditions under which the conglomerate was accumulated "may have been similar to those attending the formation of coal." "The subsequent silicification of the wood" is regarded as remarkable and no possibility that any part of the wood may have been derived from earlier formations seems to have been entertained (**6**, p. 147).

Walcott's section in the Kanab Valley.—In 1879, as his first work in connection with the U. S. Geological Survey, C. D. Walcott made a careful section of the formations displayed so well in the Kanab Valley, from the lower Tertiary to the pre-Cambrian of the Grand Canyon. As a result of this study, Walcott announced in 1880 the discovery of Permian fossils in the beds between the Aubrey limestone and the Shinarump conglomerate, i. e., the lower part of Powell's Shinarump Group (**24**). He found a plane of unconformity by erosion above the Aubrey, as stated by Powell, and another below the Shinarump conglomerate, as noted by Gilbert at other localities, and a third in the intermediate beds. Permian fossils were found either side of the last break.

The unconformity below the Shinarump conglomerate was further described some years later (**25**) on the basis of new observations, but the full section of the Shinarump and superjacent formations was first published in connection with a discussion of the western Colorado red beds and their correlation, by myself (**4**, p. 484). For comparison with Powell's section, also in the Kanab Valley, and that of Ward, to be given later, it seems desirable to give the section made by Walcott from the Aubrey to the Marine Jura. This I am able to do through Mr. Walcott's generosity and kindness in giving me unrestricted use of his notes

SECTION IN KANAB VALLEY, UTAH, MADE BY C. D. WALCOTT, 1879

Jurassic

		FEET
1.	White Cliff sandstone, massive, cross-bedded, light gray, broken into five principal belts by horizontal lines of bedding	585

Triassic

		FEET
2.	Vermilion sandstone; cross-bedded, friable, readily disintegrating, forming the foothills and slope to the more compact sandstones at the northern end of Vermilion Cliff Canyon	650
3.	Gray and reddish-brown, cross-bedded sandstone. Horizontal beds of varying thickness divide the mass into bands of from twenty-five to one hundred feet in thickness	300
4.	Evenly bedded red sandstones; upper portion an indurated, dark-reddish-brown stratum; indurated layers alternate with more friable layers and shales beneath	120
5.	Massive gray sandstone, cross-bedded; upper portion is a light-gray massive friable bed. The entire mass is subdivided into six principal beds by subhorizontal lines of bedding of a dark, more indurated sandstone. The beds are from twenty to eighty feet in thickness, and may be seen on many steep escarpments along the cañon	310
6.	Solid, partially cross-bedded sandstone, changing from gray to various shades of red	20
7.	Evenly bedded, light-red sandstone with a thin layer of intercalated gray sandstone	20
8.	Dark-red sandstone; massive layers alternating with shale, which disintegrates and forms a sloping talus to the gray sandstone beneath	180
9.	Light-gray sandstone	5
10.	Bedded sandstone of various shades of red and gray. The layers of sandstone and their shaly partings are irregular in thickness. Scolithus borings occur in great numbers in a friable yellow sandstone. Fragments of vegetable matter and carbonized wood also were seen	230
11.	Thin layers of sandstone, alternating with bands of fine argillaceous shale holding fish teeth and shells	25
12.	Massive light-brown sandstone, broken up into thick layers	50
13.	Alternating layers of sandstone and fine argillaceous shales with fish teeth, etc.	25

A detailed section of 13 is as follows:

a.	Light sandy layers with shaly partings	7
b.	Fine, smooth, arenaceous and argillaceous shales, drab brown to red with fillets of green. A few fish scales were found	6
c.	Fine-grained, light-colored sandstone, 2 to 4 feet in thickness	4
d.	Same as (*b*), only more fossiliferous	8

14. Reddish-brown friable sandstone, broken into layers one to six feet thick, with shaly partings	120
15. Alternating bands of marls and shales, with layers of friable light and reddish-brown sandstone	70
16. Reddish-brown sandstone broken up into layers two to seven feet in thickness with a stratum of gray sandstone at the base	20
17. Arenaceous and earthy gypsiferous shales; marlites, purple, brown, bluish-green, and green, forming low, rounded foothills and slopes from the Vermilion cliffs to the Shinarump conglomerate	650
18. Gray conglomerate and sandstone. Conglomerate formed of small, agatized pebbles and holding silicified wood	50
Total of Triassic	2,845

UNCONFORMITY

Permian

	FEET
19. Dark, reddish-brown, shaly sandstones, passing into a massive evenly bedded sandstone twenty feet from the summit of the bed. Ripple marks and mud cracks occur in the upper part. Erosion has removed portions of the upper shaly stratum in places, leaving an irregular surface for the conglomerate above to rest on	135
20. Red, arenaceous shales with seams of gypsum ramifying through them in every direction	105
21. Gray, gypsiferous marls with intercalated arenaceous shales	125
22. Red gypsiferous marls, with a large proportion of arenaceous shales	300
23. Impure limestone, with small fossils—Rhynchonella, Mytilus, Bakewellia, Pleurophorus, etc.	4
24. Red gypsiferous marl	15
25. Impure shaly limestone with arenaceous and gypsiferous shales beneath. The sandy shales thicken into layers of from two to six inches in thickness. A stratum of red marl separates this from a somewhat similar band of limestone and shales beneath. On an outlying butte, two miles from the Shinarump Cliff, the entire bed is a shaly limestone. This stratum varies in thickness, as it was deposited on the uneven surface of the beds beneath. Numerous fossils occur both in the limestone and arenaceous layers—Discina, Rhynchonella, Bakewellia, Pleurophorus, Schizodus, Myalina, Rissoa, Goniatites, Nautilus, etc., found	25
26. Red gypsiferous marl with arenaceous shales throughout	108
27. Yellowish sandstone with red gypsiferous shale beneath, resting in eroded hollows of the Aubrey limestone	37
Total of Permian	854
Total of Section	4,284

UNCONFORMITY

It is impossible to closely correlate Walcott's section with that given by Powell for the Kanab Valley (**23**, p. 53), except that the conglomerate, No. 18, is clearly the Shinarump conglomerate of Powell. It seems probable that No. 4 is the lowest member of the Vermilion Cliff group of Powell. Assuming that to be the case, it will be seen that fossil remains were found by Walcott at several horizons, in the members Nos. 10, 11, and 13, all in the upper part of the section. No fossils except silicified wood were noted in the lower 910 feet of strata assigned to the Triassic.

The fish remains obtained by Walcott in No. 13 of the above section were, at my suggestion, submitted to Dr. C. R. Eastman for examination, and he has published the following preliminary statement concerning them in connection with a discussion of the Triassic fishes of New Jersey.

> Of the few genera which are tolerably well indicated, such as *Pholidophorus* and several *Lepidotus*-like forms, it cannot be said that they evince anything in common with the Triassic fauna of the eastern states. Some resemblance is to be noted between the Kanab fish fauna and that of Perledo, near Lake Como, but the general aspect of the material collected by Walcott is much more suggestive of Jurassic than of Triassic relations. This might very well happen notwithstanding the horizon be definitely proved by stratigraphic and other evidence to be of Triassic age, as other instances of pioneer faunas and overlapping types are not uncommon. It does not appear, however, that the data thus far obtained warrants more than a plausible supposition that the Kanab beds are of Triassic age, their reddish color and relative position being consistent with what we should expect of rocks of that horizon. Accepting the evidence furnished by the fossil fishes at its full value, we shall have to regard the red beds of Kanab Canyon as belonging presumably to the Lias (**9**, p. 66 and **4**, p. 486).

The invertebrates obtained by Mr. Walcott in association with the vertebrates have been examined by Dr. H. W. Shimer, who has kindly given me (through Dr. Eastman) a report upon them. The material studied contains one indeterminable Ammonitoid fragment and two representatives of the Entomostracans. Of the latter, Dr. Shimer gives the following description:

ORDER OSTRACODA

Candona? Rogersii Jones

This species is exceedingly abundant on some bedding planes, the tests varying in length from .25^{mm} to 1^{mm}. They show variation in form, some being

regularly oval, others obliquely pointed at one end. Notwithstanding their great abundance no separation of the two valves was discernable. Remains of this species occur profusely with *Estheria ovata* in the rocks of the Newark formation of Virginia and North Carolina.

ORDER PHYLLOPODA

Estheria ovata Lea

The specimens of Estheria are of different sizes, but all agree with the characters of this species where they are distinctly recognizable. The valves are rather strongly convex, slope forward from the umbo, and are prolonged on the ventral side posteriorly. Average specimens measure 4^{mm} in length and 3^{mm} in height ($\frac{3}{16} \times \frac{1}{8}$ inch). Some specimens show considerable resemblance to *Estheria minuta* var. *brodieana* Jones, but lack the greater development of the valves anteriorly, and their lesser development posteriorly.

This species is abundant in the Newark formation of the Atlantic border.

The fossil fishes of the Kanab section undoubtedly occur some hundreds of feet above the Shinarump conglomerate, but in view of the present meager knowledge of that fauna, and considering the character of the invertebrates, as identified by Dr. Shimer, as well as the stratigraphic relations of the section, it would manifestly be premature to accept at this time the qualified suggestion of Doctor Eastman and refer the fish-bearing strata and the higher beds of the Kanab section, including the Vermilion Cliff sandstone, to the lower Jurassic.

While Walcott found no fossils except silicified wood in the Shinarump conglomerate, there is evidence that a Triassic reptilian fauna occurs locally at least in that bed or near it. This has been established by the investigations of Ward, soon to be considered.

Dutton's treatment of the Shinarump in 1882.—In his monograph on the Grand Canyon district (7) Dutton accepts the reference of the strata between the Shinarump conglomerate and the Aubrey to the Permian, in accordance with Walcott's Kanab section. From his general treatment of the subject it now becomes clear that the description of the Shinarump Group given in the *Geology of the High Plateaus*, and especially the references to its wonderful coloring and constancy of character apply most particularly to the Permian portion, for that is the part best exposed in the "Permian Terrace," as Dutton still calls the one floored by the Shinarump conglomerate. The inconvenience caused by the distribution of this conglomerate,

interfering as it does with the harmony of broad architectural features and stratigraphic geology shown elsewhere in the section, leads Dutton to humorously complain that, "Somehow we cannot help thinking that the conglomerate has no business there, and that it ought to have been cut off at the base of the Vermilion Cliffs, or else it ought to be relegated to the Permian (**7**, p. 45)."

Dutton found, and specially notes, the erosional unconformity below the Shinarump conglomerate at Pipe Spring, a few miles west of the Kanab Valley (**7**, p. 80), and in discussing various unconformities by erosion noticeable in the Plateau district says: "Perhaps the most widely spread occurrence of this kind is the contact of the summit of the Permian with the Shinarump conglomerate which forms the base of the Trias. Wherever this horizon is exposed, this unconformity is generally manifest" (**7**, p. 211).

As to the character of the Shinarump conglomerate Dutton adds little, in the publication under review, to the earlier statements. His general characterization of it is as "a light-brown, coarse sandstone, here and there passing into a conglomerate" (**7**, p. 17). There never seems to be any question as to the ability to recognize the conglomerate horizon, with Dutton or other early observers. Commenting on the uniformity of strata of the whole Plateau section, Dutton remarks that: "The curious Shinarump conglomerate is the same in Pine Valley Mountains (near St. George), in the terrace at Kanab, at the base of the Echo Cliffs, and in the land of the Standing Rocks" (**7**, p. 208). The last-named locality is about the junction of the Grand and Green rivers.

On the geological map accompanying this monograph Dutton distinguishes the Permian from the Trias, and represents both extending south along the eastern side of the Little Colorado Valley.

The Shinarump of Little Colorado Valley.—All students of the northern and eastern borders of the Colorado Plateau agree in the general view expressed by Dutton on his map that the various formations or groups between the Aubrey and the base of the Cretaceous cross the Colorado Canyon near the mouth of the Paria River, and that their outcrops extend thence southeasterly on the northeast side of the Little Colorado Valley. From the statements of Marvine

(**19**, p. 215) it would appear that the exact horizon of the Shinarump conglomerate of Powell could be recognized on the Little Colorado near the main crossing of the early route of travel. Dutton reports it at the base of the Echo Cliffs. The only detailed investigation of the Shinarump beds of this valley thus far made has, however, produced results so different from those generally accepted, and especially at variance with Walcott's section as to require some discussion.

In connection with an examination of the "petrified forests" of northeastern Arizona in 1899 and 1901, Lester F. Ward made a study of the formations either side of the Little Colorado from the Aubrey (Carboniferous) to the Cretaceous. In a paper on the "Geology of the Little Colorado Valley" (**26**) Ward assigns all beds of this section to the Triassic, the Jurassic being entirely absent, in his opinion. This supposed Triassic system embraces 3,500 feet of strata divided by Ward into three parts, according to the following generalized columnar section.

SECTION IN LITTLE COLORADO VALLEY. WARD

				Feet
	Painted Desert beds	15.	White sandstones	100
		14.	Brown sandstones	200
		13.	Variegated sandstones, regularly stratified, and brilliantly colored; the well-known Painted Cliffs	800
		12.	Red-orange sandstones	100
				1,200
Shinarump Group	Leroux beds	11.	Calcareous marls, sometimes worn into buttes	200
		10.	Mortar beds, flint stones	80
		9.	Limestone ledge, definitely stratified	20
		8.	Sandstone ledge	100
		7.	Variegated marls, argillaceous and calcareous with bones of belodonts, labyrinthodonts, and dinosaurs	400
	Shinarump conglomerate	6.	Conglomerate and coarse cross-bedded sandstones with clay lenses interstratified with gray argillaceous shales and variegated marls	800
				1,600

Moencopie beds	5. Dark chocolate-brown, argillaceous shales; saliferous	200
	4. Argillaceous sandstones, soft, dark brown	100
	3. Argillaceous shales, dark brown	200
	2. Calcareous shales, white	100
	1. Argillaceous shales, saliferous	100
		700
	Total	3,500

Limestone or Sandstone of Aubrey (Pennsylvanian)

In a later publication Ward revises the nomenclature of this section, speaking of the Moencopie, Shinarump, and Painted Desert *formations*, and under the Shinarump distinguishing the Leroux and Lithodendron members, the latter corresponding to the Shinarump conglomerate of his section (**27**, pp. 13–46). The term "Lithodendron member" refers to the fossil tree trunks, but is not distinctive, since these remains are also prominent in the Leroux member.

The discovery of a vertebrate fauna associated with fossil wood in a definite part of this section is certainly a most important contribution, but the systematic treatment by Ward is rather confusing as he does not attempt to harmonize his results with those of Powell, Dutton, Walcott, and others, which are, for the most part, not even referred to.

The Painted Desert formation, upon which, according to Ward, "the Cretaceous lignites and limestones lie unconformably" (**26**, p. 412) is clearly the equivalent of the Vermilion Cliff and White Cliff sandstones, although he makes no reference to earlier opinions or statements concerning the extension of these formations into the area where his section was made.

The Moencopie formation, on the other hand, corresponds in position and general character to the Permian beds found by Walcott in the Kanab section. Ward, however, found no fossiliferous limestones and makes no allusion to the work of Walcott; but if the Moencopie beds are Triassic they clearly belong in the Shinarump Group of Powell. In any case, Ward's use of Shinarump in a third sense, as a formation name for 1,600 feet of strata, seems unwarranted.

The correlation of eight hundred feet of sediments of variable character, grading into marls in some places, with the Shinarump conglomerate, is a procedure requiring clear justification by facts of

observation not to be found in Ward's papers. It is plain that Powell applied the name to a particular conglomerate seldom found to exceed more than one hundred feet in thickness and that all other writers I have cited, with the exception of Ward, have used the term for what they believed to be the same conglomerate. It appears to be impossible to locate the actual horizon of the Shinarump conglomerate in the Shinarump formation of Ward, yet, as the ensuing discussion will show, it is particularly important to ascertain the relation of the beds containing the reptilian fauna discovered by Ward to the Shinarump conglomerate of earlier investigators.

For reasons to be developed, it appears to me not improbable that the horizon of the Shinarump conglomerate proper is near the beds in which the vertebrate fossils were found, possibly at the base of the Leroux member of Ward. The statements of Powell and Dutton indicate that the conglomerate may become inconspicuous through thinning and that it may locally disappear as a conglomerate. Its horizon may be difficult of detection where the conglomerate phase is absent.

If it be assumed for the moment that the eight hundred feet of beds designated by Ward the Lithodendron member are below the horizon of the Shinarump conglomerate proper, there is reason to believe that those eight hundred feet of strata belong in truth with the Moencopie beds, the transition reported by Ward in Red Butte having the significance suggested for it by him. On this same assumption the Leroux beds of Ward fall into place as the lower Triassic of the Little Colorado Valley.

No fossils surely belonging to the Moencopie formation were found by Ward. Fossil wood is common in both members of the Shinarump. The celebrated "petrified forest" in which large prostrate silicified trunks are abundant represents more than one stratigraphic horizon. The so-called "upper" and "lower" forests are said to be in the Lithodendron beds, while the "middle" forest is in the Leroux member. As but one species of the silicified wood has been identified this abundant material is of little diagnostic value at present. The single species studied is *Araucarioxylon arizonicum Knowlton* (**15**), based on two fossil trunks collected by Lieutenant Hegewald, in 1879, of which the horizon of occurrence is unknown.

It seems to be assumed by Ward, as by others, that the occurrence of fossil wood throughout his Shinarump formation is an indication of its unity. But until these woods have been studied the correctness of that view is open to question. The presence of rounded pebbles of silicified wood in the Shinarump conglomerate has been asserted by several observers, and, if true, this fact alone must cause critical comparison of the fossil trunks occurring above and below this horizon.

The only tree trunks found by Ward in vertical position, as though in the place of growth, were in the Leroux beds very near the locality at which the best vertebrate remains were found, east of Tanner's crossing of the Little Colorado.

Vertebrate remains were found by Ward and Brown only in the Leroux beds and mostly in their lower portion. The principal localities from which they were collected by Brown for the National Museum are a few miles east or north of Tanner's Crossing, but they were noted at other places, including the "petrified forest." The material has been examined and partially described by Lucas (**17** and **18**), the forms identified by him being the following:

Two belodont crocodiles, *Episcoposaurus* sp.? Cope, and *Heterodontosuchus ganei*, Lucas, the type of which came from the San Juan Valley, Utah; *Metoposaurus fraasi*, Lucas, n. sp., *Placerias hesternus*, Lucas, n. sp., and *Palaeoctonus* sp.? Cope.

This fauna is in Lucas' opinion a distinctly upper Triassic one. He remarks that:

> Aside from the interest attached to the finding of this new species (of *Metoposaurus*) is the more important fact pointed out by Dr. Fraas (personally) that the genus *Metoposaurus* is characteristic of the Keuper of Europe, and that we have in these Triassic beds of Arizona, Utah, and Wyoming the same combination of belodont and labyrinthodont as in the Keuper (**18**, p. 195).

He might have added that the fauna is clearly present in the Dolores formation of Colorado.

Ward states that Brown found "a small number of shells and a few other invertebrates" with the vertebrate remains, but since their diagnostic value was questioned by Ward, they do not seem to have been submitted to a specialist for examination. Mr. T. W. Stanton informs me that the only invertebrates now in Brown's collection in the National Museum are Paleozoic brachiopods, corals, etc., in

pebbles. It is not certain that Ward referred to this material, the significance of which is not known.

Comparing the results obtained by Walcott and Ward in portions of the Colorado Plateau not many miles apart and where all earlier geologists have given the impression that the formations change but little from place to place, we find in fact remarkable differences. Walcott established an unconformity below the original Shinarump conglomerate; he discovered no vertebrate fossils in or near that stratum; but 910 feet above it, below the Vermilion Cliff sandstone, he found fish remains of unique character suggesting to the specialist Jurassic rather than Triassic affinities. Ward, on the other hand, finds at 400 to 800 feet below the Vermilion Cliff the Triassic reptilian fauna characterizing the basal portion of the Dolores formation through western Colorado and on Grand River; he noted no unconformity near this vertebrate horizon and does not recognize the Shinarump conglomerate of Powell, Walcott, and others. These discrepancies demonstrate that there is room for much further study of the Shinarump and associated formations in northern Arizona.

The lower Trias of the Zuñi Plateau.—The continuity of Mesozoic and upper Paleozoic formations from the vicinity of the Grand Canyon into northwestern New Mexico is a subject on which all geologists who have examined the region are agreed. In his report on the Zuñi Plateau, Dutton (**8**, p. 134) identifies 450 feet of strata as Permian, through the presence of fossils mentioned as *Bakewellia* and *Myalina* (without specific identification) and from the stratigraphic position of the beds between the Aubrey and a sandstone identified by Dutton as the Shinarump conglomerate. The identification is not convincing, for the only descriptive terms employed are of general application and indicate a character which one cannot suppose to be persistent. The Shinarump conglomerate is referred to by Dutton, in speaking of its general character, as "a well-marked, coarse sandstone," and as "a very coarse conglomeratic sandstone." The only statement of its character in the Zuñi Plateau is in the first three words of the following sentence: "The coarse sandstone, equivalent, I believe, to Powell's Shinarump conglomerate, will be for the present the provisional base of the [Triassic] series" (**8**, p. 135). In view of Ward's statement that conglomeratic beds appear variably through some

eight hundred feet of strata, on the Little Colorado, one may question the correctness of Dutton's identification of this datum horizon. This doubt is strengthened by the statement that for 650 feet above the "conglomerate" the "strongly-colored sandy shales abounding in selenite and silicified wood . . . . resemble so exactly the Permian below that it is quite impossible to distinguish them lithologically" (**8**, p. 135). Between these shales of Permian aspect and the Wingate sandstone which Dutton correlates with the Vermilion Cliff occur eight hundred to nine hundred feet of strata which are rarely so well exposed that their character can be ascertained. They are referred to as "lighter colored, pale, dull-red shales." It seems inherently probable that the base of the Triassic series is in this ill exposed part of the section, not far below the Vermilion Cliff or Wingate sandstone.

The original sweeping assertions of Powell and Dutton that the Shinarump Group, including all beds between the Aubrey and the Vermilion Cliff, extends, in almost unmodified development, north through the Plateau country to the Uinta Mountains were based on insufficient knowledge. There is much evidence to show that the strata of the section in question do not preserve that wonderful constancy of character, nor the uniform thickness to be inferred from Dutton's words, which have been quoted. This holds true for both Triassic and Paleozoic parts of the section.

Let us first review the knowledge concerning these deposits in the upper reaches of the cañon of the Colorado, and of its branches, the Grand and Green Rivers.

Vicinity of the Henry Mountains.—Going up the Colorado less than seventy-five miles above the mouth of Paria River, where Powell, Dutton, Gilbert, and others have examined the section, we come to the area included in Gilbert's study of the Henry Mountains. For that area he has given the following general section of the Shinarump Group (**12**, p. 6).

Top	FEET
a. Variegated clay shale; purple and white above and chocolate below, with silicified wood	300
b. Gray conglomerate, with silicified wood; the Shinarump conglomerate	30
c. Chocolate-colored shale, in part sandy	400
	730

Beneath this section comes the Aubrey sandstone; above it is the Vermilion Cliff sandstone.

This section is materially different from those given by Powell, Walcott, and Ward, but no explanation is offered by Gilbert. He states that evidence of unconformity below the Shinarump conglomerate was not found in the Henry Mountains, but if only four hundred feet of strata there intervenes between the conglomerate and the fossiliferous Aubrey, there is reason to believe that the stratigraphic break at that horizon is considerable.

The constitution of the beds assigned to the Shinarump is certainly different from that of the typical section of the Kanab. There is nothing said of sandstones on the one hand or gypsiferous beds on the other.

The Lower San Juan Valley.—In connection with this Henry Mountains section, it is well to consider the observations made by H. S. Gane on the northern side of San Juan River, near the Colorado, which I made public in an earlier discussion of the red beds of the Plateau Province (**4**, p. 476). Gane traced several Mesozoic formations down the San Juan Valley from the head of McElmo Creek in Colorado, a point very near the La Plata quadrangle, where he had assisted in the study and mapping of those formations, under my direction (**2**). Among the formations, the continuity of which to the Colorado Canyon seemed clear to Gane, is the Dolores Triassic formation, at the base of which and recurring irregularly in the lower sandstone is a fine-graided conglomerate consisting largely of limestone pebbles and carrying teeth and fragments of bones of several vertebrates. Tracing this fossiliferous zone down the valley, Gane found in it at Clay Hill divide, about twenty miles east of the northern end of Glen Canyon, a portion of a crocodile jaw, unusually well preserved. This specimen was described by Lucas (**16**) as the type of *Heterodentosuchus ganei.* This form is the most abundant one in the collection made by Ward and Brown in the Leroux beds and it is also very common in the Dolores formation in the San Juan region of Colorado, as appears from the work in my charge. Unios were noted by Gane associated with the vertebrate.

There is no means of proving that the conglomerate called the Shinarump by Gilbert in his section is the same as that carrying

crocodilian remains at Clay Hill, but, from the ensuing discussion, it will seem not at all unlikely that such is the case.

Newberry's Grand River section.—Where the Colorado begins, at the junction of Grand and Green Rivers, about forty-five miles northeast of the Henry Mountains, is one of the points cited by Dutton at which the Shinarump Group is typically developed (see p. 103) and where he says the Shinarump conglomerate is found in its characteristic form. Aside from the very general statements of Powell (**22**), I can find nothing in the literature of the Plateau Province recording observations made at this locality. Dutton refers to Newberry's description of the formations on Grand River some miles above the junction with the Green. The vivid pen pictures of the scenery and of the broader stratigraphic features given by this earlier explorer of the region do indeed agree very well with those of Powell, but it is difficult to recognize the Shinarump of Arizona in the section Newberry gives of the possible Triassic beds. He found fossiliferous Carboniferous strata (which Dutton and Powell considered as Aubrey) in the Grand River Canyon where he descended to the stream,[1] and measured the superjacent section of red beds in "Cañon Colorado," the side gorge traversed in making the descent. This section follows (**20**, p. 99):

SECTION IN CAÑON COLORADO, UTAH (NEWBERRY)

		FEET
9.	Red and brown massive sandstone, fine-grained, not hard. No fossils	270
10.	Soft red sandstone, in thin layers, separated by beds of red or dark brown shales	350
11.	Greenish-gray micaceous conglomerate and gray sandstone, separated by red and purple shales	92
12.	Soft liver-colored sandstones, becoming suddenly and locally nearly white, with partings of shale	350
13.	Brick-red massive calcareous sandstones, with some like the last	164

As I have explained in the paper on a reconnaissance to Grand River, at Moab (**5**, p. 644), the strata under No. 9 of Newberry's section clearly belong to the lower part of the La Plata or White Cliff

[1] Newberry believed that the side cañon descended by him to Grand River was but a few miles above the union with Green River. But it seems from most recent maps that the "Cañon Colorado," in which Newberry's route lay, enters Grand River cañon about twenty-four miles above Green River, and only about nine miles below the present site of Moab.

Jurassic sandstone, and No. 10 to the Vermilion Cliff sandstone. Possibly No. 11 contains the Shinarump conglomerate. If so, it would appear that the Triassic portion of the Shinarump is represented by but ninty-two feet of beds at this point. On that basis Newberry's section is in close agreement with that a few miles farther up Grand River, next to be considered. But Nos. 12 and 13 are quite unlike the strata underlying the Shinarump conglomerate in Arizona. Fossil wood was not mentioned by Newberry in any of the strata assigned to the Trias. These considerations show that that part of the section on lower Grand River corresponding to the Shinarump in stratigraphic position does not in fact resemble the typical section of that group closely in any particular.

Grand River Valley near Moab.—That the generalization just expressed is correct has been amply demonstrated by an examination by myself and associates of the formations exposed in the Grand River Valley near Moab and for about twenty five miles above that point. I have recently published (5) the results of that reconnaissance, made in 1905, and need here repeat only the salient facts affecting the question of the Shinarump.

The Vermilion Cliff and White Cliff sandstones, of the general character noted by Powell, are unmistakable datum formations from which to start in stratigraphic studies in Grand River Valley. Below the former, however, we found many things at variance with the idea of simplicity and regularity in this part of the section. Opposite Moab on the northwest side of Grand River the section exposed below the Vermilion Cliff sandstone is as follows:

SECTION NEAR MOAB, UTAH

		FEET
	Top, Vermilion Cliff Sandstone	
12.	Sandstone, massive or shaly, dark red at base and bright red at top	20
11.	Shaly, conglomeratic sandstone with numerous reddish limestone pebbles the size of a pea or smaller; a few small bone fragments	6
10.	Sandy shales, red and green	5
9.	Débris slope apparently representing red shale	20
8.	Limestone conglomerate, with a few inches of limestone at top; fossil wood and bone fragments; pebbles less than two inches diameter	10
7.	Sandstone, gray, massive	20
		81

	Carried forward	81
6.	Limestone conglomerate, grading into sandstone	1½
5.	Sandstone, gray, massive, becoming shaly near top	23
4.	Calcareous sandstone with fine-grained conglomerate near base and top; pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of a pea to several inches diameter	9
3.	Red sandy shale alternating with sandstone	8
2.	Conglomerate containing pebbles of limestone and sandstone	1
1.	Sandstone and shale alternating, red and green, the shales sandy and friable	35
		158½

Beneath No. 1 of this section is a blue limestone carrying coral (Zaphrentis), and, in all, 380 feet of Pennsylvanian beds are exposed, consisting of alternating sandstones and limestones, with abundant fossils. No unconformity was noticeable between the coralline limestone and the overlying sandstone and it is not certain whether Nos. 1, 2, and 3 of the above section should be included with the Carboniferous or not.

The point to be emphasized is that for somewhat more than one hundred feet below the Vermilion Cliff in this section the beds present the characteristics of the lower part of the Dolores formation of Colorado rather than of anything hitherto described from the Shinarump. There is at most only about forty-five feet of beds referable to any formation between the Pennsylvanian and Dolores.

In Grand River Canyon, twelve miles above Moab, the bone-bearing limestone-conglomerate series is found in marked angular unconformity with the underlying beds and it is probable that two thousand feet of strata consisting of two groups of sandstones, conglomerates, and shales, separated by a gypsiferous-shale series, are present between the Pennsylvanian and Dolores strata. No fossils were found in these intermediate beds, but they seem to correspond to the strata of possible Permian age known in Colorado between the Dolores and Hermosa (Pennsylvanian) formations, and collectively termed the Cutler formation in the San Juan folios (3).

We found no specifically determinable bones in the beds below the Vermilion Cliff on Grand River. The best obtained was a crushed vertebra belonging, according to Mr. Gidley, to a Triassic form of carnivorous Dinosaur, or possibly to a belodont crocodile. The

fragmentary condition of the remains and the rarity of determinable specimens is, however, entirely analoguous with the occurrence of similar material in the Dolores beds in Colorado.

Poorly preserved Unios are common in the Dolores formation and we observed very similar undeterminable shells in the conglomerate with bone fragments, at Moab. Three species of Triassic Unios in a much better state of preservation were found some years ago on Grand River very near the Vermilion Cliff sandstone by L. M. Prindle (**5**, p. 653), and there is no basis for doubting that they came from the bone-bearing series of beds.

With this knowledge of the Moab and Grand River sections, it seems almost certain that the ninety-two feet of strata embraced under No. 11 of Newberry's section represent the series of bone-bearing conglomerates, etc., which we refer to the Dolores formation. The absence of the gypsiferous shales and of the overlying conglomerates, sandstones, and shales, indicates a stratigraphic break in Newberry's section and the probable horizon of the break is beneath No. 11.

Uinta Mountains.—The statements of Powell and Dutton that the Shinarump Group is typically developed on the flanks of the Unita Mountains are without confirmation in the descriptions of the strata referred to the Triassic by these authors or the geologists of the Fortieth Parallel Survey. Powell refers 1,095 feet of beds west of Flaming Gorge to the Shinarump and describes them briefly as follows: "Shales and sandstones containing much gypsum; weathering in many colors, but brown and chocolate tints prevailing; in many places constituting bad-land beds" (**23**, p. 152). There is no suggestion of the Shinarump conglomerate in this section.

It is clear that Powell included in the Shinarump of the Uintas the beds called Permo-Carboniferous by the Fortieth Parallel geologists, and Permian by Dutton in his Grand Canyon monograph, and the description above cited seems to apply to those strata. There is no known evidence that the fossiliferous horizon found at Moab is present on the Uinta slopes, but the discovery reported by Williston (**28**) of a Triassic vertebrate fauna in Wyoming closely related to, if not identical with, that from the Little Colorado Valley and the Dolores formation makes it not improbable that closer study will

disclose the fossiliferous horizon in the Uinta Mountains. From the relations found on Grand River, it seems probable that the equivalent of the "saurian conglomerate" occurs near the Vermilion Cliff sandstone if present at all in the Uinta section.

The only statement I have found in regard to the Trias of the Uintas suggesting the presence of the fossiliferous horizon of the Dolores formation, or, as it might be otherwise interpreted, of the Shinarump conglomerate, is a passage from King's description of the section on the northern slopes of the mountains near Vermilion Creek. He remarks that the basal portion of the Trias consists "of red conglomerate-bearing sandstones which carry a seam of drab limestone. Above these is a body of red sandstone of several hundred feet" (**14**, p. 259). This heavy sandstone seems to correspond to the Vermilion Cliff sandstone, for above it comes a lighter-colored cross-bedded sandstone answering to the White Cliff or La Plata sandstone. Emmons describes the same section in similar terms (**10**, p. 275). Presumably the "conglomerate-bearing sandstone" is quite near the Vermilion Cliff and this at once suggests comparison with the Grand River section.

The foregoing discussion has not taken into account the lower Triassic beds of southeastern Idaho, often termed the "Meekoceras beds" from characteristic marine fossils they contain. These beds are not known in any of the areas referred to in this paper. If ever present in Colorado or the Plateau Province the marine lower Triassic beds must have been removed by the pre-Dolores erosion. The interesting problem as to the relations of the Meekoceras beds to the so-called Permian or Permo-Carboniferous formations of Utah is clearly beyond the scope of this paper.

It is hoped that the foregoing discussion will have made clear to the reader that there are strong reasons for correlating the Triassic portion of Powell's Shinarump Group with the lower part of the Dolores formation of Colorado. The fossiliferous "saurian conglomerate" of the Dolores has been traced into the heart of the Plateau country and a notable unconformity found below it there as well as in the San Juan Mountains of Colorado. The reptilian fauna of the "saurian conglomerate" has been found on the Little Colorado,

at a horizon corresponding closely to that at which the Shinarump conglomerate must come, and at a point only about sixty miles southeast of typical exposures of that conglomerate in the cliffs of the Paria Plateau. On stratigraphic grounds it appears probable that the Shinarump conglomerate and the "saurian conglomerate" occur at the same horizon.

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A PYRRHOTITIC PERIDOTITE FROM KNOX COUNTY, MAINE[1]—A SULPHIDE ORE OF IGNEOUS ORIGIN

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The rock here described, though of slight areal extent, is of rather unusual interest as a representative of a little-known type of sulphide ores consolidated from a molten magma, and also as the first-described representative of subclass 2 of the perfemane class (class V) of the quantitative system of classification, all of the extremely basic rocks thus far described falling in subclass 1, perfemane, of this class. The rock also shows beautiful examples of reaction rims of hornblende between plagioclase feldspar and olivine, an alteration to which little reference has been made in petrographic literature.

Location and geologic occurrence.—The rock here described occurs on the farm of Mr. Charles A. Millers, about three-fourths of a mile southwest of the village of East Union in the town of Union, Knox County, Maine. It constitutes a single outcrop about forty to fifty feet across. The rock disintegrates rapidly, and the partly disintegrated material has been excavated to some extent for use in improving the roads. All of the present surfaces are rusty, and a number of well-rounded bowlders of disintegration which have withstood weathering longer than other portions lie partially imbedded in the gravelly disintegrated material. The rock is extremely tough and resistant under the hammer.

In the woods, about one-half mile southeast of the outcrop described above, a small prospect pit has been dug in loose ferruginous material, which probably passes below into rock similar to that on the Millers farm.

The above-mentioned localities lie within the area of the Rockland quadrangle, near its western border. The rocks of the region are regionally metamorphosed sediments probably of Cambro-Ordovician age, which have been intruded and further metamorphosed by granitic rocks. The peridotite here described is in all probability intrusive

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

into these sediments. Gabbroid and dioritic rocks whose relations show them to be differentiation products from the granitic magmas are of common occurrence in this region, and the pyrrhotitic peridotite under discussion probably represents an extreme phase of this differentiation process, although it may on the other hand be wholly unconnected in origin with the granitic intrusions.

MEGASCOPIC APPEARANCE

The megascopic appearance of this rock is so unusual as to attract immediate attention in the field. It is medium-grained (millimeter-

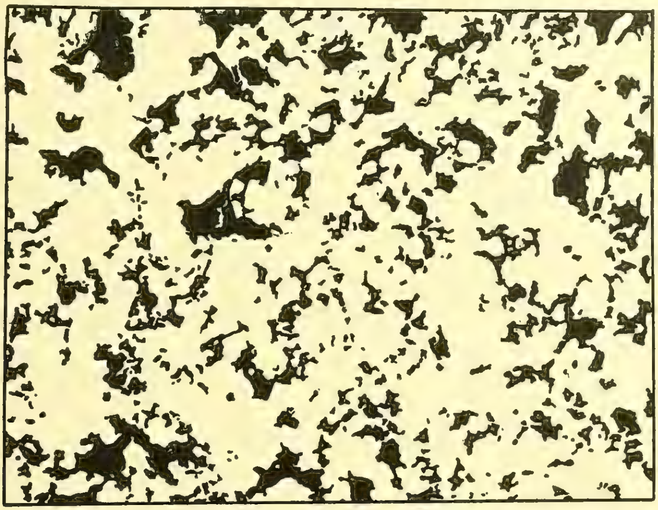

FIG. 1.—Tracing from polished surface of peridotite. The black areas represent pyrrhotite with small associated amounts of chalcopyrite and pyrite. The white areas are occupied mainly by olivine with some hornblende and plagioclase feldspar. (Natural size.)

grained), holocrystalline, and equigranular, and is composed of a yellowish-gray, metallic-looking mineral, which proves to be pyrrhotite scattered in very irregular masses through a ground-mass which for the most part appears structureless and is dark green to nearly black in color. The form and natural size of the pyrrhotite areas are shown in Fig. 1, which was traced from a polished surface.

In irregular association with the pyrrhotite are small amounts of chalcopyrite distinguishable by its yellower tint. Most of the nearly black matrix between the sulphide masses exhibits no trace

of cleavage and is shown under the microscope to be olivine, its dark color being due to the abundance of minute magnetite inclusions which it contains. Scattered dark-green or bronze-colored grains in the ground-mass which show distinct cleavage faces are seen under the microscope to be hornblende. Small, scattered areas, gray in color with a dull luster, are plagioclase feldspar. In general the rock is remarkably fresh. Serpentine and chlorite, which have resulted from olivine and hornblende decomposition, are confined largely to certain layers which are thread-like in form as seen in cross-section on a polished surface. These areas of decomposition are largest between closely grouped pyrrhotite masses, and the narrower strands run from one pyrrhotite mass to another and are parallel in their general trend throughout the hand specimen.

The characters and relationships of the various original and secondary minerals which compose the rock are described in detail below.

ORIGINAL MINERALS

Olivine.—This is the most abundant original constituent of the rock, and estimates on six slides show that it makes up about 60 per cent. by volume of the whole rock. Since the specific gravity of the rock is about 3.42 while the average for olivine is in the neighborhood of 3.35, the percentage of olivine by weight would be only slightly less than this figure. The norm shows only 30.99 per cent. by weight of olivine but in addition shows 22.06 per cent. by weight of hypersthene, a mineral not observed in the rock itself. A part of the iron belonging to the hypersthene in the norm appears in the mode in the more siliceous mineral hornblende, while the remainder appears in olivine, a mineral less siliceous than hypersthene.

The olivine occurs in rounded grains ranging from 1 or 2^{mm} to 8^{mm} in length, the majority being between 3 and 4 ^{mm}. Most of the grains are entirely fresh except for a narrow alteration zone of fibrous serpentine about their borders. Certain narrow bands traversing the rock in a manner already described are characterized, however, by much more extensive alteration, and in these areas the olivine grains may be partly or wholly serpentinized, the alteration having, as is usual, been most extensive along the irregular cracks

and about the peripheries of the grains. The characteristic appearance of the less altered olivine grains is shown in Fig. 2, in which most of the narrow serpentine borders appear white. The large black area is pyrrhotite.

Pyrrhotite.—Next to olivine, pyrrhotite is the most important mineral of the rock. The analysis shows that it contains small

FIG. 2.—Pyrrhotite (black) in characteristic allotriomorphic association with olivine. The dark bands traversing the olivine are lines of magnetite inclusions. The white borders around some of the olivine grains are serpentine. (Magnification about thirty diameters, polarized light.)

amounts of nickel and cobalt, and constitutes 22.50 per cent. by weight of the whole rock. A small amount of pyrite is also included in this determination and under the microscope this mineral is seen to form a small part of some of the areas between the olivine grains, which are occupied mainly by pyrrhotite. The volume relations between the pyrrhotite (with small amounts of other sulphides) and the other rock constituents may be judged from Fig. 1.

As shown in Fig 2, the pyrrhotite is normally completely allotriomorphic with respect to olivine grains, its relations in this respect being similar in every way to those exhibited by the feldspar. The pyrrhotite is also in contact with fresh massive hornblende and with almost unaltered plagioclase feldspar. The allotriomorphic relation of nearly all the pyrrhotite to unaltered grains of the original mineral olivine is considered to be conclusive evidence that practically all the pyrrhotite is an original crystallization from the magma and is essentially contemporaneous with the other principal constituents of the rock. In a few narrow zones traversing the rock, pyrrhotite occurs in angular areas more or less connected with each other and associated with chlorite and hornblende. These very limited portions may be a secondary crystallization.

Feldspar.—In the hand specimens this mineral forms dull-gray areas with irregular outlines, never over one-fourth of an inch and seldom over one-eighth of an inch across. Under the microscope it is found to occupy irregular areas between the rounded olivine grains, with respect to which the feldspar is entirely allotriomorphic. It shows albite and occasionally carlsbad twinning, the angles of the former running up to thirty degrees. The index of refraction as determined on powdered material by the immersion method approximates 1.55. The angle in the section perpendicular to the negative bisectrix between M and the plane of the optic axes is twenty-nine degrees. These results show that the feldspar is andesine-labradorite with approximately the composition Ab_1An_1. These are also the exact proportions in which albite and anorthite are present in the norm as calculated from the analysis.

With the exception of the reaction rims of amphibole described in the section on secondary minerals, the feldspar is in general very fresh though some of it is clouded with aggregates of small, highly refracting plates and flakes. Most of these have indices of refraction which are only slightly greater than that of the feldspar, and are probably muscovite. Others of higher index are probably an amphibole similar to that developed between the feldspar and the olivine.

Hornblende.—The mineral next in importance is hornblende, which, in some parts of the rock, is almost wholly absent, but in other parts is present in large crystals, which are allotriomorphic with

respect to the olivine grains. Nearly all of the larger hornblende crystals contain small, rounded olivine inclusions, usually fresh, though sometimes serpentinized. The mineral is identified as hornblende by the rhombic cleavage exhibited in some sections, by its index of refraction, which is intermediate between those of olivine and serpentine, and by its double refraction, which, by comparison of its interference colors with those exhibited by olivine, is found to be about 0.022 to 0.024. Its extinction angles in sections in which the cleavage parallel to c is well defined range up to twenty-seven degrees. The pleochroism is usually weak though strong in certain sections. The colors vary from pale pink to pale green and, in some sections, deep brown. There is frequently more or less mottling, due to slight variations in color and birefringence from point to point. The contacts between hornblende and olivine and between hornblende and pyrrhotite are in most cases perfectly sharp, neither mineral having undergone alteration. Between hornblende and feldspar, the contact though normally sharp, occasionally shows evidence of some recrystallization of the hornblende next the feldspar. The abundant small olivine inclusions present in the larger hornblendes seem to indicate that the latter mineral followed very close upon the olivine in crystallization and was probably in part contemporaneous with it. The pyrrhotite and feldspar probably crystallized at about the same time, and followed close upon the hornblende crystallization.

Magnetite.—Magnetite is present only in minute irregular grains scattered through the olivine crystals in bands of varying width, many of which represent fracture planes. The magnetite as seen in the thin sections seems to form from 5 to 40 per cent. by volume of the olivine grains. The average is estimated at at least 10 per cent. by volume or about 17 per cent. by weight. Since the olivine was estimated to constitute about 60 per cent. by weight of the whole rock the magnetite included in it will form 17 per cent. of 60 per cent. or about 10 per cent. by weight of the whole rock. In the analysis all the iron was determined as FeO but in the calculation of the norm a part was apportioned to 10 per cent. of magnetite, the remaining iron forming 5.64 per cent. of FeO. Many of the magnetite bands extend from one olivine grain into another which is in contact with

it, but they are nowhere observed to continue into adjacent areas of feldspar, hornblende, or pyrrhotite.

Chalcopyrite.—The analysis shows this mineral to constitute 1.03 per cent. by weight of the rock. In the hand specimens and slides it is seen to be associated irregularly and in small amounts, as was pyrite, with the areas of pyrrhotite.

Pyrite.—Small amounts of pyrite are associated irregularly with the pyrrhotite.

Biotite.—This mineral occurs as a few scattered plates seldom over 0.7^{mm} in greatest dimension, which in some sections are entirely surrounded by olivine. In other cases the biotite occurs in long narrow areas between olivine and pyrrhotite. In one case, which is shown in Fig. 2, a narrow biotite blade lies at right angles to the contact between perfectly fresh olivine and pyrrhotite, penetrating some distance into each of the crystals. In this occurrence at least it is undoubtedly primary, though some of the plates may be of secondary origin.

Spinel.—A few grains of a dark green isotropic mineral occur in certain portions of the rock in irregular association with pyrrotite and hornblende or as inclusions in the latter mineral. Its grains are without regularity in form and range in size up to 0.4^{mm} though mostly under 0.2^{mm}. The mineral is probably pleonaste or chlorospinel.

SECONDARY MINERALS

Serpentine.—This mineral is developed in short, closely aggregated fibers as an alteration product of olivine. Most of it is colorless in the thin section; but rarely light to deep yellow colors occur. Between crossed nicols it is, in some cases, nearly isotropic, while in other cases showing blue-gray interference colors. The serpentinization begins in the normal manner at the borders of the olivine grains and proceeds inwards along irregular cracks. The degree of serpentinization varies greatly in different portions of the rock, some olivine grains showing only a narrow border of serpentine not exceeding 0.015^{mm} in width along their contact with pyrrhotite and chalcopyrite, while in other cases the olivine grains have been almost entirely serpentinized.

Amphibole.—In addition to original hornblende, whose occurrence has already been described, amphibole occurs as reaction rims between

plagioclase feldspar and olivine or pyrrhotite. Most of these zones vary in width from 0.02^{mm} to 1^{mm}, and show a more or less radiate structure, amphibole fibers or brushes being directed about at right angles to the borders of the feldspar crystals. The mineral forming the rims is identified as amphibole by the fact that it is in some places in crystallographic continuity with the massive hornblende already

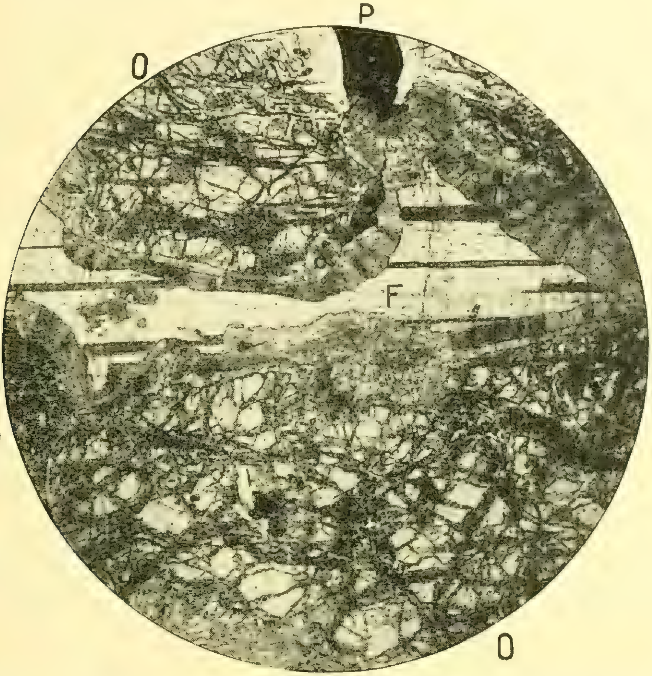

FIG. 3.—Reaction rims of amphibole bordering feldspar. F = Feldspar (andesite-labradorite), P = Pyrrhotite, O = Olivine. Note the double character of the rims between feldspar and olivine, their single character between feldspar and pyrrhotite, and their entire absence between olivine and pyrrhotite. (Magnification about thirty diameters, polarized light.)

described, by its double refraction (about 0.024), and its index of refraction, which is intermediate between those of olivine and serpentine.

Some of these fringe-like borders show two layers of fibers, usually in close contact with each other, but in some cases separated by a narrow band of a non-fibrous hornblende, which usually shows a faint tint of brown. In the double borders developed between

plagioclase and olivine, the bands of minute magnetite inclusions so characteristic of the latter frequently continue through the amphibole band nearest the olivine, but are not present in the band nearest the feldspar, a relation which indicates that both these minerals have been involved in the replacement. The layer nearest the olivine is usually nearly colorless while that nearest the feldspar usually shows a pale-greenish tint. Usually, though not invariably, the rim next the olivine is narrower than that bordering the feldspar. Between feldspar and pyrrhotite only a single reaction rim is developed; it frequently is pale brown in color especially near the pyrrhotite.

The general appearance of the reaction rims is shown in Fig. 3. In the more altered portions of the rock, the reaction zones become somewhat broader and in some cases lose their fibrous character probably as a result of recrystallization. Secondary hornblende of this type in some places grades with perfect continuity into original hornblende. Larger crystals of hornblende associated with chlorite and angular areas of pyrrhotite in certain narrow zones traversing the rock are probably of secondary origin. The hornblende of the reaction rims occasionally grades into hornblende of this type.

In seeking to determine what original minerals were the source, partial or complete, of the hornblende of the reaction rims, it is evident that the best results are likely to be obtained from a study of the freshest portions of the rock, where the alterations are in their initial stages. In these parts of the rock hornblende is uniformly absent between the olivine and the pyrrhotite, serpentine being the secondary mineral developed along these contacts. Between the feldspar and olivine and between feldspar and pyrrhotite, however, a reaction rim of hornblende is always present. The darker color exhibited by the hornblende formed along the feldspar-pyrrhotite contact presumably indicates that the mineral here is richer in iron and proportionately poorer in magnesia than that developed next to the olivine. These relations clearly indicate that the hornblende is developed as a result of chemical interchange between plagioclase and the femic minerals, olivine or pyrrhotite.

It is hardly possible, however, to regard this change as taking place without accession of material from outside or loss to other parts of the rock. This follows from a consideration of the chemical

composition of the original minerals involved. The feldspar of the rock, andesine-labradorite, has the composition $Na_2O \cdot 2CaO \cdot 3Al_2O_3 \cdot 10SiO_2$ and the olivine $2(MgFe)O \cdot SiO_2$. In the former the molecular proportion of soda to lime is as 1:2. In any reaction in which andesine-labradorite and olivine were involved without outside gain or loss, the resulting product should show a similar proportion between Na_2O and CaO. As shown by the microscopic studies, the resulting mineral is hornblende, but an examination of the available hornblende analyses shows that in nearly every case the soda is greatly subordinate to the lime, the molecular proportions ranging from soda 1 and lime 12 to soda 1 and lime 3, but in no case approaching the proportion of 1:2. The reaction probably involved, therefore, either a loss of soda, or a notable addition of lime, or both. In the more altered portions of the rock the hornblende, as already stated, occurs in larger, massive crystals which occur not alone between feldspar and the femic minerals but in contact with other constituents. In some places areas originally occupied by plagioclase now show only a few feldspar remnants entirely surrounded by hornblende.

Alterations of the type just described are probably of somewhat common occurrence among peridotites though readily traceable only in rocks which show the initial stages of alteration. Few instances are described in the literature. Van Hise[1] makes the following statement in regard to a reaction between olivine and anorthite:

> In some instances the alteration into actinolite is described as taking place in connection with feldspar as a reaction rim. In this case the calcium may be supposed to be derived from anorthite, as calcium silicate. The aluminum may be supposed to pass into common spinel and hercynite (isometric; sp. gr. 3.93), which are well known to be alteration products of olivine. The reaction may be

$$\underbrace{4Mg_3FeSi_2O_8}_{\text{Olivine}} + \underbrace{4Ca\,Al_2Si_2O_8}_{\text{Anorthite}} = \underbrace{Mg_9Fe_3Ca_4Si_{16}O_{48}}_{\text{Actinolite}} + \underbrace{3MgAl_2O_4}_{\text{Common spinel}} + \underbrace{FeAl_2O_4}_{\text{Hercynite}}.$$

Törnebohm in a description of some of the diabases and gabbros of Sweden describes an alteration to hornblende almost identical with that observed in the Maine rock.

> The alteration of the olivine, as usually exhibited in the rocks under discussion, proceeds exclusively from the borders of the grains. There forms next to it a

[1] C. R. Van Hise, *Treatise on Metamorphism*, Mon. XLVII, U. S. Geological Survey, pp. 310, 311.

colorless zone showing a radial structure, and, especially where the olivine is in contact with plagioclase, there is present always a second more or less regular zone with similar structure. The latter is made up of an aggregate of green, rather highly dichroic grains, all of which are hornblende. It seems as if these zones were developed in consequence of a reaction between the plagioclase and the olivine, the inner zone being formed at the cost of the latter, and the outer zone at the cost of the former. The reaction zone is of particularly constant occurrence between olivine and plagioclase, but between olivine and augite it is absent and if augite penetrates in wedge-like form between olivine and plagioclase then the two zones separate, the green remaining between the augite and the plagioclase and the lighter zone between the olivine and the plagioclase, though both soon wedge out. Neither by heating nor by acids were the zones notably affected. In the much weathered portions of the rock the olivine inside the bright zone is more or less completely altered to a dirty-green mass of serpentine."[1]

THE FOLLOWING ANALYSIS OF THE ROCK IS BY DR. W. F. HILLEBRAND[2]

SiO_2	28.04	TiO_2	.20
Al_2O_3	3.51	P_2O_5	.04
Fe_2O_3 / FeO	14.95[3]	MnO	.24
		SrO	trace?
MgO	21.97	CO_2	1.01
CaO	1.78	Fe_7S_8	21.53[4]
Na_2O	.28	NiS	.94[5]
K_2O	.08	CoS	.03[5]
H_2O+	2.54	$CuFeS_2$	1.03
H_2O-	1.48	Total	99.65

Chlorite and calcite.—These minerals occur only in the more weathered portions of the rock in association with massive secondary hornblende and recrystallized (?) pyrrhotite. The chlorite belongs to the chlinocore variety and is mostly light green in color though a

[1] A. E. Törnebohm, "Ueber die wichtigeren Diabas und Gabbro-Gesteine Schwedens," *Neues Jahrbuch für Mineralogie*, 1877, pp. 382, 383. Translation by E. S. B.

[2] Laboratory of U. S. Geological Survey.

One hundred grams of pyrrhotite were tested for platinum, but none was found.

[3] The iron was calculated as FeO. Some is present as Fe_3O_4, which would raise the summation. The figure for the oxides of iron is only approximate because of the impossibility of calculating the amount of pyrite or the exact composition of the other sulphides.

[4] Includes some pyrite.

[5] Occurs combined with or closely associated with pyrrhotite.

The olivine grains contain so much magnetite in the form of inclusions that they adhere strongly to a magnet. From microscopic examination it was estimated that the magnetite formed about 17 per cent. by weight of the olivine or approximately 10 per cent. by weight of the whole rock. The iron belonging to the 14.95 per cent. of FeO in the analysis (11.63 per cent. of Fe) was redistributed on the basis of 10 per cent. of Fe_3O_4, the total of the rock constituents thus being raised to 100.34 per cent.

few of the larger and more massive grains are a deep grass green. The interference colors between crossed nicols vary from greenish yellow and dark gray in the light-green portions to very dark gray in the deep green. The mineral is, in part at least, the product of hornblende decomposition. Calcite occurs in small, irregular crystals and in aggregates of minute grains associated with chlorite, and also as a few larger grains associated mainly with secondary hornblende.

CALCULATION OF THE NORM FROM THE ANALYSIS

	Percentage Weights	Mol. Proportions	Cal.	Or.	Ab.	An.	Cor.	Rut.	Hy.	Ol.
SiO_2	28.04	467		6	24	16			212	209
Al_2O_3	3.51	34		1	4	8	21			
Fe_3O_4	10.00									
FeO	5.64 }	81							27	54
MnO	.24 }									
MgO	21.97	549							185	364
CaO	1.78	31	23			8				
Na_2O	.28	4			4					
K_2O	.08	1		1						
H_2O	4.02									
TiO_2	.20	3						3		
P_2O_5	.04									
CO_2	1.01	23	23							
Fe_7S_8	21.53									
NiS	.94									
CoS	.03									
$CuFeS_2$	1.03									
Total	100.34		23	1	4	8	21	3	212	209

Orthoclase	.56	Salic 7.02
Albite	2.10	
Anorthite	2.22	
Corundum	2.14	
Rutile	.20	Femic 86.78
Hypersthene { $FeO \cdot SiO_2 = 3.56$, $MgO \cdot SiO_2 = 18.50$ }	22.60	
Olivine { $2\,FeO \cdot SiO_2 = 5.51$, $2\,MgO \cdot SiO_2 = 25.48$ }	30.99	
Nickel- and cobalt-bearing Pyrrhotite	22.50	
Magnetite	10.00	
Chalcopyrite	1.03	
Water	4.02	
Calcite	2.30	
P_2O_5	.04	
	100.16	

Class	$\frac{\text{Sal.}}{\text{Fem.}}=\frac{7.02}{86.78}=<\frac{1}{7}$	=V, perfemane.
Subclass.	$\frac{\text{POM}}{\text{A}}=\frac{63.25}{23.53}=<\frac{7}{1}>\frac{5}{8}$	=2, dofemone.
Order.	$\frac{\text{PO}}{\text{M}}=\frac{53.05}{10.00}=<\frac{7}{1}>\frac{5}{3}$	=2, dopolic, Mainare.
Section.	$\frac{\text{P}}{\text{O}}=\frac{22.06}{30.99}=<\frac{5}{3}>\frac{3}{5}$	=3, pyrolic, Mainiare.
Rang.	$\frac{(\text{MgFe})\text{O}+\text{CaO}}{\text{K}_2\text{O}+\text{Na}_2\text{O}}=\frac{29.63}{.36}=>\frac{7}{1}$	=1, permirlic.
Section.	$\frac{(\text{MgFe})\text{O}}{\text{CaO}}=\frac{27.85}{1.78}=>\frac{7}{1}$	=1, permiric.
Subrang	$\frac{\text{MgO}}{\text{FeO}}=\frac{21.97}{5.88}=<\frac{7}{1}>\frac{5}{3}$	=2, domagnesic, Lermondose

Since the rock shows a slight amount of alteration the norm computed above can be regarded only as approximating that of the fresh rock. The rock, however, falls well within the limits of each of the divisions in the above classification, and it is not probable that the weathering has produced changes sufficient to change its position in the quantitative classification.

The name Lermondose which is here proposed for the rock is derived from Lermond Pond, situated about one mile northeast of its type exposure. The ordinal name Mainare is a reference to the state of Maine, in which the rock occurs.

Bearing on the origin of certain sulphide ores.—Chalcopyrite is present in such small amounts and the percentages of nickel and cobalt associated with the pyrrhotite are so small that the rock has no present economic value as an ore. The sulphides are also associated in such an intimate way with the other rock minerals as to make their complete separation difficult. The rock, nevertheless, exhibits an unusual concentration of metallic sulphides common in many ore deposits, and from a theoretical standpoint at least may be regarded as an example of ore formed by original crystallization from the molten magma. It seems but a short step from a rock of this type to one in which chalcopyrite is present in sufficient amounts or in which the percentage of nickel or cobalt in the pyrrhotite is large enough to give the ore commercial value. The existence of commercial deposits of sulphide ores of such purely igneous origin has, so far as known to the writer, never been satisfactorily demon-

strated, but the possibility of their existence can hardly be questioned in view of the known occurrence of igneous rocks as rich in sulphides as the one here described. That this rock is itself a differentiation from a less basic magma is shown by the occurrence about one-quarter mile northeast of the Millers farm of a much less basic rock belonging apparently to the same intrusion but containing relatively small amounts of pyrrhotite. The original characters of this rock are obscured by intense weathering, which has reduced the rock to an irregular aggregate of pale-green chlorite, pale-green or brown amphibole, much of it fibrous, and calcite.

Sulphide-bearing rocks of the type here described are, however, even more suggestive in their bearing on workable ore deposits when we take into account the possibilities of local sulphide enrichment by aqueous or pneumatolytic action. There is no evidence of such enrichment at the locality near East Union, nor do the rocks of the surrounding region contain ore veins of any kind. It is evident, however, that such processes acting upon a rock of this type would be fully capable of producing ore deposists of a commercial character.

Adams,[1] Coleman,[2] and Barlow[3] of the Canadian Geological Survey have all attributed the primary concentration in the copper, nickel, and cobalt ores of the Sudbury district of Ontario to magmatic differentiation in a magma which normally crystallized as a norite or gabbro, while admitting the importance in this region of secondary concentration by aqueous agencies. Vogt has expressed similar views of the genesis of the sulphide ores of the Scandinavian nickel deposits. On the other hand Posepny[4] has affirmed that the original crystallization of pyrrhotite in any notable quantities is a chemical impossibility, and the views of Adams, Coleman, and Barlow have been challenged by a number of writers partly on theoretical and partly on observational grounds.

While affirming nothing in regard to the origin of the ore deposits

[1] F. D. Adams, *Canadian Mining Bureau*, January, 1894, p. 8.

[2] A. P. Coleman, *Bureau of Mines Report*, Ontario, 1905, Part III, and this Journal, Vol. XV, pp. 759–82, 1907.

[3] A. E. Barlow, *Summary Report of the Director of the Geological Survey of Canada*, 1901.

[4] "The Genesis of Ore Deposits," *Transactions of American Institute of Mining Engineers*, 1893.

of either of these regions, the writer believes that such occurrences, as that near East Union demonstrate beyond question that pyrrhotite, in very considerable percentages, may occur as an original crystallization from igneous magmas, and the possibility of at least a primary concentration of this sort must be recognized in the study of the origin of sulphide ores, particularly those of nickel and cobalt.

THE COTYLOSAURIA

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The studies of Broili, and especially of Case, have furnished much welcome information concerning the Permian reptiles of America within recent years. But our knowledge of many of them is yet meager, and much obscurity yet prevails as to their rank and affinities, and especially as to their relationships with the known European and African types. The ordinal name Cotylosauria has, within the past few years, come into rather general use for many of the early stegocrotaphous reptiles to the exclusion of other terms which had previously been applied to them. A brief historical review of the origin and use of the term will be of interest.

Cope early introduced and made use of the term Theromorpha, afterward changed to Theromera, to include many of the older reptiles now recognized as quite diverse, and which he later so recognized, abandoning it. In 1880[1] he proposed the subordinal term Cotylosauria for a division of this group, founded exclusively on the Diadectidae of Texas, and based upon a real or apparent dicondylar structure of the skull. Later,[2] he expressed doubt of its validity as follows:

> I am still inclined to question whether the extraordinary characters of the cranio-vertebral articulation I have described justify the separation of the Diadectidae as a third suborder of the Theromorpha, which I have called the Cotylosauria, or whether they are not due to the loss of a loosely articulated basioccipital bone.

The two other suborders of his Theromorpha to which he refers were the Pelycosauria and Anomodontia—this latter of course in its wide sense. In 1889[3] he included in his order Theromera the following six suborders: Placodontia, Proganosauria, Parasuchia, Anomodontia, Pelycosauria and Cotylosauria. His Pelycosauria included

[1] *American Naturalist,* p. 334.

[2] *Proceedings of the American Philosophical Society,* 1882, p. 448.

[3] *American Naturalist,* p. 886.

the families Clepsydropidae, Pariotichidae and Bolosauridae; his Cotylosauria, the Diadectidae and Pareiasauridae; the Proganosauria, the Mesosauridae, Procolophonidae, Paleohateriidae, Proterosauridae, and Rhynchosauridae (equivalent, it is seen, plus the Rhynchocephalia and Choristodera, to Osborn's Diaptosauria). In 1891,[1] Cope defined the Cotylosauria, now for the first time considered an order, as including four families, the Diadectidae, Pareiasauridae, Pariotichidae, and Elginiidae. In the later publication he erected the order Chelydosauria for the Otocoelidae proposed a few years before for certain new reptiles from Texas, defining it as having the scapular arch internal to the ribs, a dermal carapace, and the temporal roof excavated posteriorly for the auricular meatus. Until this time *Pariotichus* had been included among the Pelycosauria. In 1896,[2] however, he referred one species described as *Pariotichus*, *P. hamatus*, to a distinct genus, *Labidosaurus*, which he provisionally placed among the Pareiasauridae.

In a few words, it is seen that Cope based the suborder Cotylosauria upon the Diadectidae, and not until his later papers did he unite any other American forms with it in the same group. In 1905,[3] Case brought evidence to show that the essential characters assigned to the Chelydosauria were also common to *Diadectes* and its allies, and he has withdrawn the family from the Cotylosauria to include it, with the Otocoelidae, in the Chelydosauria, leaving *Pariotichus* and certain other less well-known forms as the sole American representatives of the Cotylosauria. But this contravenes the basal rules of nomenclature. The group originally was based exclusively upon the Diadectidae, and, while we may add as many other families as we choose, we may not substract the one upon which it was alone based. The name Cotylosauria, of which Chelydosauria is purely a synonym, must accompany the Diadectidae wherever the family is placed.

With the elimination of Chelydosauria we have three ordinal terms which have been proposed for the primitive stegocrotaphous reptiles: Cotylosauria Cope (suborder, 1880, order 1891); Pareia-

[1] *Amer. Naturalist*, p. 644; *Syllabus of Lectures on the Vertebrates*, p. 68.

[2] *Proceedings of the American Philosophical Society*, p. 136.

[3] *Journal of Geology*, No. 2, 1905, p. 126.

sauria Seeley (1892);[1] and Procolophonia Seeley (1889).[2] The question of immediate interest is, in which of these two latter groups, if either, can *Pariotichus* and the other forms eliminated by Case from the Cotylosauria be placed. Its interest has led me to re-examine in the light of the recently accumulated facts concerning the older reptiles, the excellent specimen in the Chicago University collections described by Case some years ago[3] as *Pariotichus incisivus* Cope. For the general description of the specimen the reader is referred to the cited paper. By further preparation of the specimen I am able to make some additions of interest.

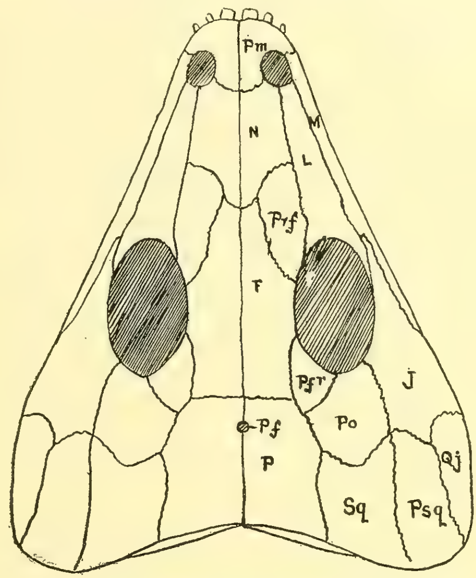

FIG. 1.—Skull of *Labidosaurus incisivus*, upper surface; one-half natural size. *Pm*, premaxilla; *N*, nasal; *M*, maxilla; *L*, lachrymal; *F*, frontal; *Pfr*, prefrontal; *Pfr*, postfrontal; *Po*, postorbital; *J*, jugal; *Pf*, parietal foramen; *P*, parietal; *Sq*, squamosal; *Psq*, prosquamosal; *Qj*, quadratojugal.

My determination of the upper elements of the skull (Fig. 1) made independently, agrees well with Case's. On the under surface, however (Fig. 2), I am quite unable to differentiate the pterygoids, palatines, and vomers anteriorly, they are so closely fused together. I do not feel at all sure about the distinction of the paroccipital as a separate element. The epiotics may be present, but I am not sure.

Eighteen presacral vertebrae were collected by Professor Case with the specimen, and he was inclined to the belief that this was the full number. Four of these, without rib attachments, are connected

[1] *Philosophical Transactions*, 1892, p. 106.

[2] *Ibid.*, 1889, p. 270.

[3] *Zoölogical Bulletin*, Vol. II, 1899, p. 231

yet with the sacrum and pelvis. Six are united in a series lying over the pectoral girdle, with ribs or portions of ribs attached. In addition, there are two united pairs, and two single vertebrae. Between the two series there are quite evidently several missing, since the diapophyses end abruptly with the pectoral series. From the size and shape it seems apparent that the two pairs belong here, making at least fourteen dorsals. Both of the single vertebrae have small rib diapophyses; they are also smaller in size. I have placed them in the neck in the restoration (Fig. 6). However, *Labidosaurus hamatus* has, according to Broili,[1] at least twenty-two presacral vertebrae; and *Telerpeton*, according to Boulenger,[2] twenty. It is probable, hence, that two or more vertebrae have been lost in the present specimen from in front of the sacrum. The neck could not have been longer than is represented in the restoration, perhaps not so long, since so broad and ungainly a head would have been sadly unmanageable on a slender neck. At least four presacral vertebrae bore no ribs, but I believe

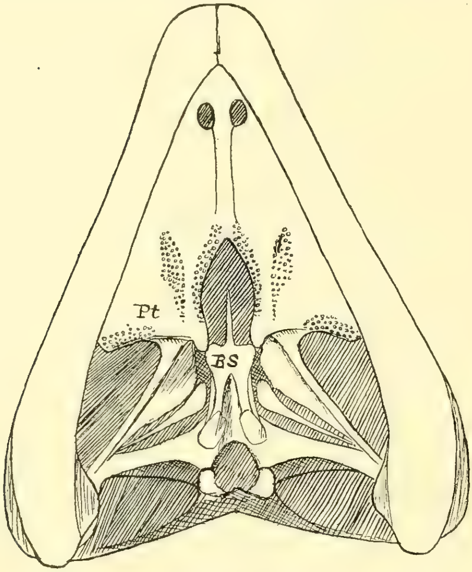

FIG. 2.—*Labidosaurus incisivus*, under surface of skull; one-half natural size. *Pt*, pterygoid; *Bs*, basisphenoid.

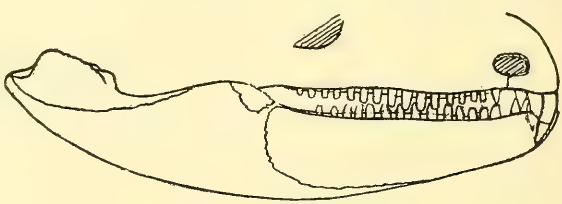

FIG. 3.—Mandible and maxillary teeth of *Labidosaurus incisivus*, one-half natural size.

[1] *Paleontographica*, 1904.

[2] *Proceedings of the Zoölogical Society*, London, 1904, p. 474.

that all the others, save perhaps the atlas, had such bones. Three caudal vertebrae are preserved together, in addition to two connected with the sacrum. They evidently bore ribs and indicate a short tail.

The pectoral girdle I am able to restore completely with assurance. The sutures between the scapula and the coracoid elements I find to be as represented in the drawing, with the exception of that between the scapula and the procoracoid anteriorly, of which I am in doubt, because of the absence of that part of the arch on the left side with

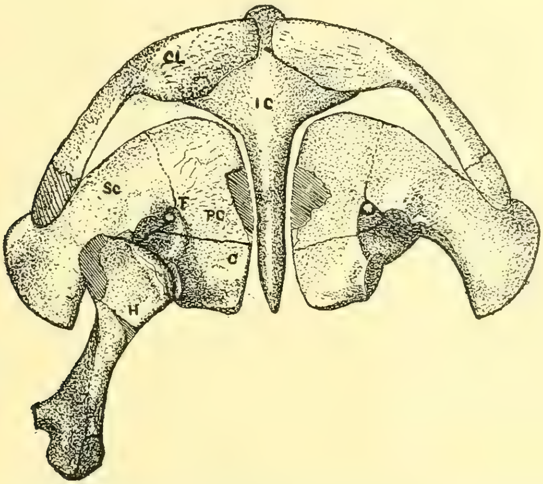

FIG. 4.—Pectoral girdle of *Labidosaurus incisivus;* one-half natural size. *I*, interclavicle; *Cl*, clavicle; *Sc*, scapula; *C*, coracoid; *Pc*, procoracoid; *F*, coracoid foramen.

its corroboratory evidence. There is a small but distinct, coracoid foramen between the procoracoid and the scapula. There is, as Case has said, no evidence of a cleithrum, nor is there any place where one could have been attached. The scapular surface of the distal extremity of the clavicle, of which the tip only is wanting, is striated, and the scapula presents a similar surface for its attachment in the position shown in the drawing. The diagrammatic position in which it is necessary to figure the arch distorts somewhat the relations of scapulae and clavicles. The distal extremity of the scapula was evidently turned dorsad at nearly a right angle with the plane of the

coracoid surface. The proximal end of the right humerus lies perfectly in position in the glenoid fossa. The distal extremity of the bone, twisted in a plane nearly at right angles with that of the proximal, presents not the slightest indication of an entepicondylar foramen, and the bone is not at all mutilated. The absence of this foramen is, however, extraordinary, since very nearly all the known reptilian vertebrates of the Permian have it, though not all, according to Cope. The thinned margin of the proximal expansion has been lost in the specimen. There is the possibility, a remote one I believe in view of the fact that the relations of the various bones of the skeleton had suffered little disturbance, that the humerus had been completely and perfectly reversed in the glenoid socket, and some indication of this reversion is furnished in that the so-called distal end agrees fairly well with the proximal end of some forms.

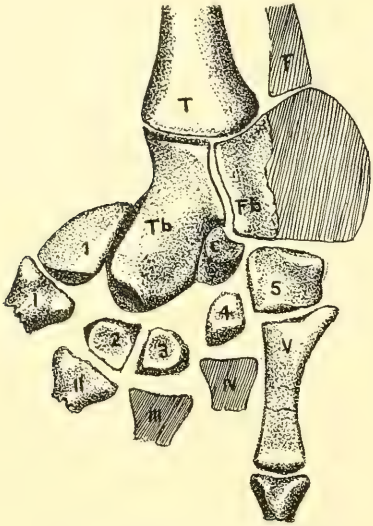

FIG. 5.—Hind foot of *Labidosaurus incisivus;* natural size. *T*, tibia; *F*, fibula; *Tb*, tibiale; *Fb*, fibulare; *C*, centrale; 1–5, distal tarsals; I–V, metatarsals.

In the structure of the feet I have no emendations to make of Professor Case's interpretations, save of the centrale of the pes. This bone I find, on removal of the bone lying over it, to be pretty well fused with the tibiale, the union shown, however, clearly in a sutural line. Broom has expressed a doubt of the structure of the feet in this specimen. There can be none. The number and arrangement of the bones of the carpus are assuredly as Case has figured them. As to the number of the phalanges in the digits I believe that they will be found to be as in *Procolophon* and *Telerpeton*, 2, 3, 4, 5, 3, or 4. The pelvic girdle in this specimen is typically that of the old reptiles, elongated, flat, plate-like pubes and ischia, closely united by suture and wholly without a thyroid foramen. It is the pelvis of *Procolophon*, *Telerpeton*, *Paleohatteria*, etc.

Briefly the important characters of this specimen may be summed up as follows:

Skull stegocrotaphous, with distinct elements; epiotic probably present; the lachrymal (postnasal of Jaekel) entering into the posterior border of the external nareal opening. Surface of skull sculptured; a pineal foramen between the parietals; orbital and nasal openings not large, the latter situated near extremity of face. Premaxillae with three teeth, the first one much elongated, the second less so. Maxillae with about sixteen teeth, inserted in a single row, with a pleurodont elevation internally, and not very different in size. Mandibular teeth in a single row, biting within the upper teeth, about seventeen in number, the front ones somewhat elongated; teeth thecodont, not transverse. Palate with small teeth in two or more rows each, inserted on pterygoids and probably palatines and vomers, dependent upon the location of the sutures. Internal nares small, situated far forward. A cordiform interpterygoidal space. Pterygoids articulating with basipterygoid processes, their dilated posterior processes united with quadrates.

Vertebrae deeply biconcave, with persistent intercentra. Coracoids and large procoracoids united by suture with scapula; a supracoracoid foramen between scapula and procoracoid. Interclavicle with an elongate posterior process and dilated anterior extremity; clavicles closely attached to interclavicle and scapula; no cleithra. Ribs functionally double-headed, attached to intercentra and diapophyses. Two sacral vertebrae. Pubes and ischia expanded, plate-like, without thyroid foramen. Caudal vertebrae with ribs. Carpus with three bones in the proximal row and four in the distal, and with two centrales; tarsus with two in proximal row, five in the distal and a partially fused centrale, possibly two. Phalangeal formula probably 2-3-4-5-3, 4.

As to the identity of our specimen I can be but a little more certain than was Case. That it does not belong in the genus *Pariotichus* is certain, since there is but a single row of teeth on maxillae and dentaries. That it is not specifically identical with *Labidosaurus hamatus* I believe is equally certain, that is if Broili has rightly identified that species, and I think that he has. It presents some differences from the species *incisivus*, as described by Cope, but it may provision-

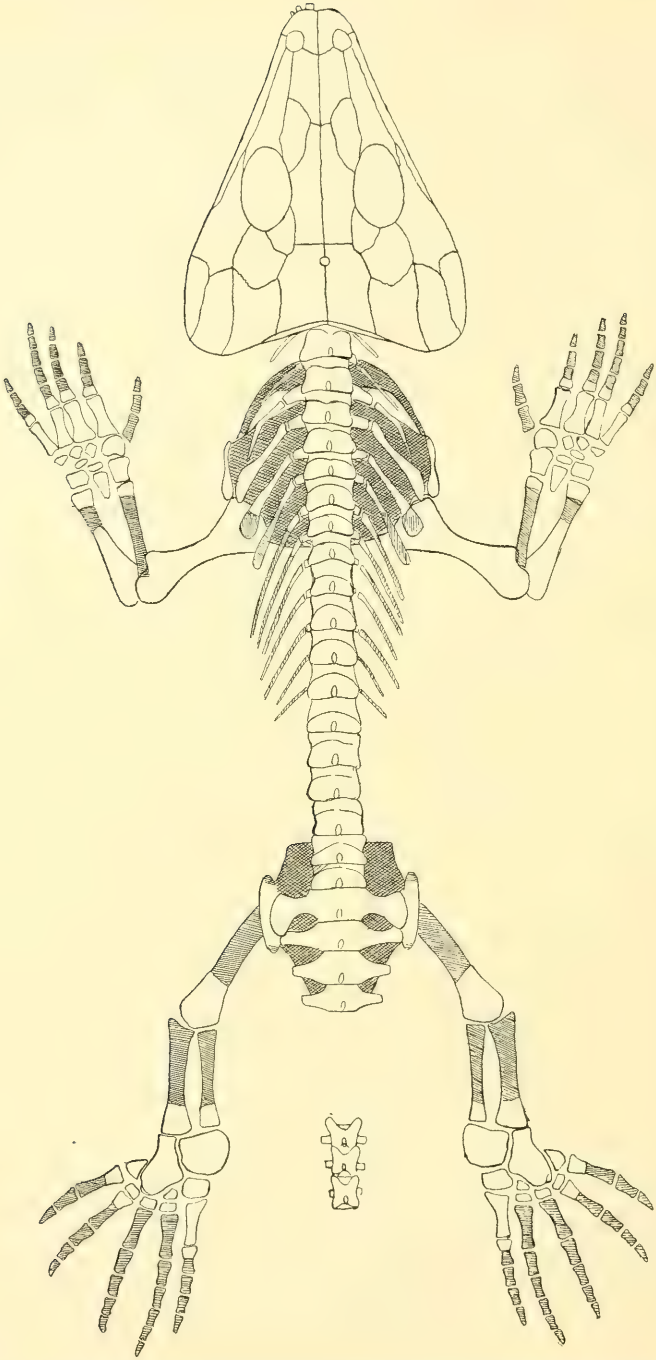

FIG. 6.—Restoration of *Labidosaurus incisivus;* a little less than one-third natural size.

ally be placed there, and in the genus *Labidosaurus* until such time as Cope's types have been examined and compared. The specific or even generic identity, however, matters little at present. The more important matter is, what relation does the form have to *Procolophon* and *Telerpeton* especially.

Boulenger has shown, forcefully I think, the relationship between *Procolophon* and *Telerpeton*,[1] about the only differences which he found being the absence of ventral ribs in *Telerpeton*. Seeley[2] and Broom[3] have, more recently, added to this the newly discovered characters of the acrodont and transverse teeth,[4] and it is on the strength of these differences, in face of the resemblances, that Broom would associate *Procolophon* with the Rhynchocephalia, *et al.*, in the superorder Diaptosauria and in the phylum Diapsida, arguing that, in any phylogenic classification the separation of the phyla should be carried back to the very beginning, even though the earliest forms may differ vastly more from the later ones than they do from those immediately preceding them. It is true that, so far, no reptile with a roofed over skull, save *Procolophon* (and of course the Chelonia) has been found to possess abdominal ribs, so commonly present among the saurocrotaphous reptiles. Indeed, of the single-arched reptiles only the Sauropterygia and Ichthyosauria have such ribs, and, carrying the argument to its extreme, Broom would unite both of these with the subclass Diapsida of Osborn, quite vitiating the original meaning of the term and requiring a new name for the modified phylum. But it is a more difficult thing to treat the Chelonia in the same way. No one has yet had the temerity to transfer the Chelonia to the Diapsida and we are forced to the inevitable conclusion that both of these reputed subclasses, the Diapsida and Synapsida, had abdominal ribs. And indeed such a conclusion is beyond dispute; certainly the oldest reptiles must have had ventral ribs and they must have been essentially Cotylosaurian in structure, for these reptiles, espe-

[1] *Proceedings of the Zoölogical Society*, London, 1904, p. 476.

[2] *Ibid.*, London, 1905.

[3] *Ibid.*, 1905.

[4] It is of interest to observe that the genera *Phanerosaurus* and *Stephano spondylus* according to Stappenbeck, have acrodont teeth placed transversely, and surely they are not also related to the Rhynchocephalia (*Zeitschrift d. deutsch. Geolog. Gesellschaft*, 1905, p. 379).

cially such forms as *Seymouria* Broili[1] are about as close to the temnospondylous amphibians, save in the palatal structure, as it would be possible to have them and still call them reptiles; unless, indeed, we accept Boulenger's rather improbable views and derive the double-arched forms from the Microsauria and the stegocrotaphous and single arched from the Temnospondyli. And here too, the Chelonia upset our best-laid schemes. Not all dinosaurs possess such ribs, and I do not think that their loss, without other important differences is of great moment. And by no means is it yet sure that the Cotylosauria, and the acleithral forms were without them. Indeed I believe that we shall find some of them with such ribs eventually.

Our "*Labidosaurus incisivus*" differs from *Telerpeton* chiefly in the sculptured skull, a character which that genus shares with *Procolophon* and *Sclerosaurus*,[2] and from *Procolophon* in that and the character of the teeth, and in practically nothing else. If *Procolophon* be admitted to a distinct order, superorder, and subclass from *Telerpeton*, what shall we do with *Telerpeton*, *Pariotichus*, *Labidosaurus*, *Elginia*, *Sclerosaurus*, etc.? They all lack the cleithrum; they are, for the most part at least, small, crawling reptiles and can hardly be united with *Pareiasaurus* nor with *Diadectes* and *Otocoelus*. Shall we erect a new order for them?

The resemblances between the pectoral and pelvic girdles of *Dimetrodon* and our present specimen are evident at a glance. But, the Pelycosauria, notwithstanding the two temporal vacuities of the skull, and its supposed membership in the Diaptosauria, have well developed cleithra, and that character must be added to the Diaptosauria as well as to the Cotylosauria and Pareiasauria!

I may add, by way of postscript, that, in a recent review of the literature of the reptilia, I find all of the older groups usually called orders have been raised in recent years by well-known writers to superordinal or subclass rank, save the Ichthyosauria and Chelonia, the two groups of all others most entitled to high rank! And most of the suborders have been elevated to orders—thirty or more. And what has been gained?

[1] *Paleontographica*, 1904.

[2] Von Huene, *Geologische pal. Abhandlungen*, X, 1902, p. 29.

THE LOWER HURONIAN ICE AGE

A. P. COLEMAN

INTRODUCTION

When geologists slowly became convinced of the reality of the Pleistocene glacial period it was held to be a unique catastrophe belonging to the later history of a cooling world, something without precedent in earlier geological epochs. Then, reluctantly and with astonishment, a Permo-Carboniferous glacial period, even more tremendous than that of the Pleistocene, was admitted as proved. Later still, an extensive ice age in early Cambrian or late pre-Cambrian times has been demonstrated, carrying back continental glaciers to the beginning of known life in the world.

For a number of years it has been my belief that a still earlier glacial period was the cause of the widespread basal conglomerate of the Lower Huronian; and last year, when a few scratched stones were obtained from this conglomerate at the silver-mining region of Cobalt, it seemed worth while to show that a Lower Huronian ice age was highly probable.[1]

During the past summer fresh material has been collected in the Cobalt region, including some well-preserved "soled" bowlders with ice-smoothed surfaces and well-marked striae, removing all doubt of the glacial origin of the conglomerate; and it is proposed to present here the evidence for this most ancient of known ice ages.

THE STONES OF THE BOWLDER CLAY

It requires patience to separate the pebbles and bowlders from the hard matrix of the conglomerate, or tillite, to use Penck's term, and no very large number have been extracted, but most of them have the characteristic subangular forms of glaciated stones. As illustrations, two photographs are reproduced, the largest stone represented being about eight inches across, and having good striae on both sides and in more than one direction, one set crossing another. If the speci-

[1] *American Journal of Science*, Vol. XXIII, March, 1907.

mens collected were mixed with Pleistocene bowlder clay they could hardly be distinguished from the other stones in the clay unless perhaps by lacking the polish found on some from the Pleistocene. When it is remembered that the Lower Huronian tillite has undergone mountain-building stresses and a certain amount of metamorphism, it is astonishing to find the striations so perfectly perserved,

FIG. 1.—Lower Huronian "soled" bowlder with striations in several directions.

especially in the absence of limestone and slate pebbles, which afford the best marked glaciated stones of the Pleistocene. In the Lower Huronian tillite, felsites and fine-grained greenstones show the striae best. The illustrations given are of greenstones.

The types of rock observed are granite, gneiss, massive greenstone, green schist, felsite, and banded chert or jasper of the iron formation; all found in place in the underlying Keewatin and Laurentian, the only older formations existing in the localities. The granites are of at least three kinds, and include most of the larger bowlders, one

which was measured reaching diameters of 5×3×3 feet; but the largest bowlder seen, near Temagami station, was of greenstone showing pillow structure, having diameters of 8×5 ft. as exposed on an ice-smoothed surface. Many of these bowlders are several tons in weight and some of the granites are miles away from the nearest known source. The smaller pebbles of felsite often show exactly the same subangular shapes with irregular well-polished surfaces as are found on pebbles of fine-grained rock in later bowlder clays.

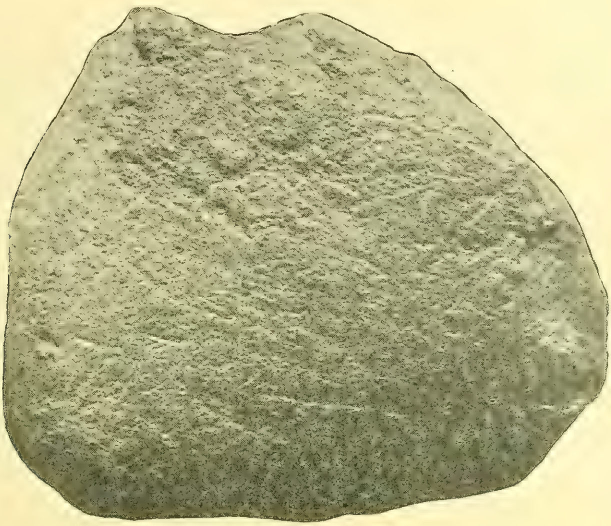

FIG. 2.—Lower Huronian "soled" bowlder.

In many parts of the tillite the stones are sparsely distributed, sometimes several feet or even yards apart, and the red granites stand out sharply from the green-gray ground-mass. Such parts of the conglomerate present exactly the characters of till or ground moraine.

THE MATRIX OF THE BOWLDER CLAY

The matrix of the tillite is generally graywacke, fine grained, but containing small angular particles of quartz and feldspar. It shows no stratification as a rule, though the rock as a whole may have a rude banding, pebbles and bowlders being more numerous in some layers than in others. In the original Huronian region, as described by Murray and Logan, the matrix was called slate, the rock being

referred to as "slate conglomerate," but some varieties of it were described as like quartzite or diorite or greenstone. In fact, the rock not seldom looks so massive in the field that it might easily be taken for a fine-grained basic eruptive, if it were not for the red granite bowlders scattered here and there through it; and some geologists have thought it a tuff or volcanic breccia, just as the Dwyka in South Africa was at first explained.

In reality, of course, till consists of the more or less finely ground materials of the rocks over which the ice sheet passed. If it traversed

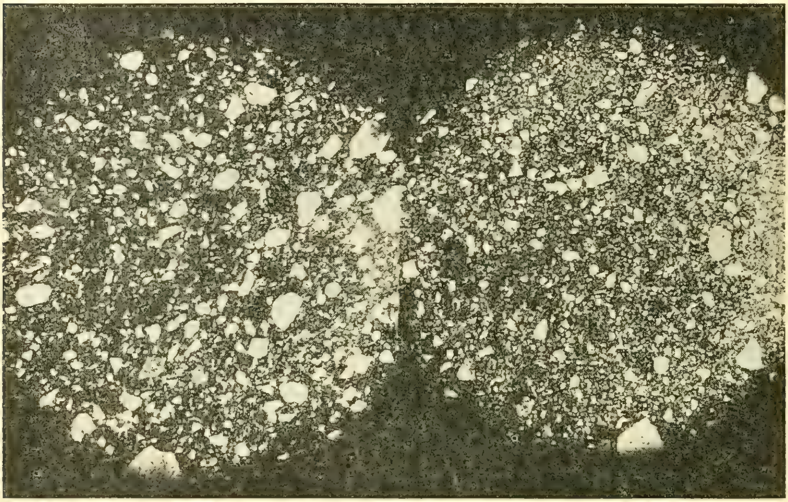

FIG. 3.—Thin sections of matrix of bowlder clays. Dwyka to the left, Lower Huronian to the right.

granite, the clayey substratum would be mixed with grains of feldspar and quartz; if it passed over fine-grained greenstones, the particles might suggest an ash rock; if the two materials were mixed, as must have been the case when the Lower Huronian glaciers moved over a surface of Keewatin penetrated by Laurentian granite and gneiss, the resulting bowlder clay would have the composition which we actually find.

The sections from near Cobalt show a small amount of very fine-grained turbid material, in which a few scales of chlorite can be recognized, crowded with angular bits of quartz, orthoclase and plagio-

clase of all shapes and sizes, and with some larger rock fragments such as diabase porphyrite or felsite or porphyritic felsite. A section from near Thessalon, north of Lake Huron, has essentially the same composition, but the minerals have been a little more rearranged.

For comparison, thin sections of the Dwyka matrix were studied, and were found to be surprisingly like those mentioned above; the only noticeable difference being the absence of chlorite scales, and a somewhat darker and less translucent ground-mass. These slight differences are no doubt due to the fact that the Dwyka conglomerate, being much younger, has undergone less rearrangement. In the illustrations the great resemblance of the two bowlder clays is shown, though by chance a rather fine-grained part of the Cobalt thin section was photographed.

COMPARISON WITH LATER GLACIAL DEPOSITS

While much of the Lower Huronian conglomerate has the character of till, there are also phases made up almost wholly of coarse materials, bowlders, pebbles, and smaller bits of rock, with very little of the finer matrix representing clay; and these may be compared with terminal-moraine stuff.

On the other hand, the tillite sometimes passes into stratified slate with only here and there a bowlder or with no bowlders at all. In one case a bowlder nearly a foot thick was seen with the stratification bending round it as though it had been dropped into mud from floating ice.

Beside the distinctly till-like and morainic varieties of the graywacke conglomerate there are sometimes bands of crowded pebbles somewhat assorted as to size, well rounded, and no doubt water formed, corresponding to the kame materials of Pleistocene deposits. Where stratified conglomerate beds or thinly bedded slates lie between sheets of unstratified tillite, we may safely compare them with the interglacial beds of stratified sand and gravel between layers of till found at Scarboro Heights, for instance.

The known thickness of the conglomerate including the other phases mentioned is about 500 feet as measured by Professor Miller at Cobalt, which may be compared with the 400 feet of drift deposits at Scarboro near Toronto.

From the outline just given it will be seen that every feature of the Lower Huronian rocks has its close parallel in the complex of bowlder clays and sediments of the Pleistocene, though the latter are, of course, loose and unconsolidated. A comparison with the Dwyka conglomerate of Permo-Carboniferous times is more convincing still, since the Dwyka is now solid rock. Hand specimens of the two tillites might easily be interchanged by one not familiar with them. Specimens from Matjesfontein in Cape Colony or N'gotsche Mountain in

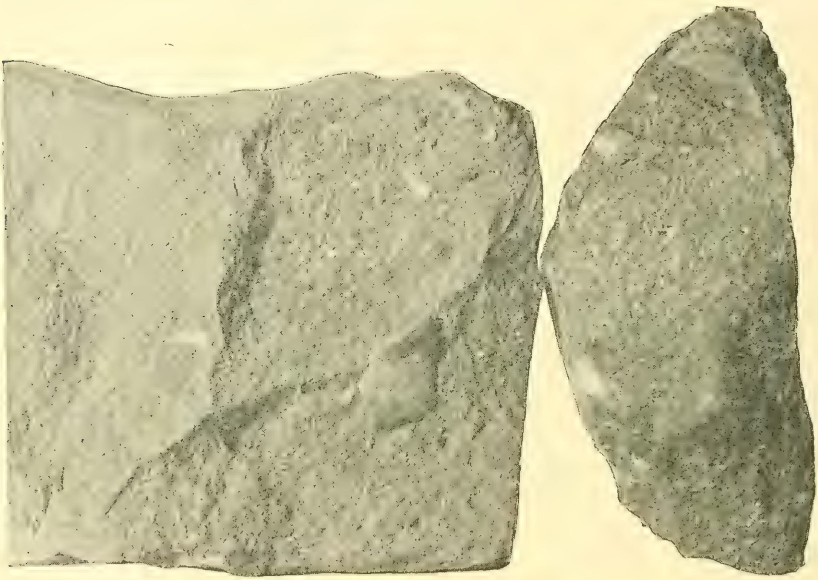

FIG. 4.—Polished pebbles in ancient till. Dwyka to left, Lower Huronian to right.

Natal placed beside specimens from Cobalt or north of Lake Huron present the same fine-grained gray matrix with angular bits of quartz and feldspar, or fragments of granite, or small polished pebbles of felsite. As shown before, even thin sections under the microscope present no material differences.

In fact, the only important point of distinction between the two tillites is the comparative ease with which the Dwyka matrix weathers, setting free the inclosed stones; while in the Cobalt rock matrix and pebbles weather at nearly the same rate. In both tillites when fresh it is hard to break out the stones by the hammer, since the fractures

are apt to run impartially through pebble and matrix. One cannot but be struck by the close resemblance the two rocks have to one another in every particular. Every argument which goes to prove the glacial origin of the Dwyka conglomerate applies equally well to the Lower Huronian conglomerate of northern Ontario, with one exception.

No underlying striated surfaces or *roches moutonnées* have been found beneath the Lower Huronian tillite; while beautifully glaciated surfaces are displayed beneath the northern Dwyka. It should be remembered, however, that no such surfaces have been found under the southern Dwyka, where the conglomerate passes downward into

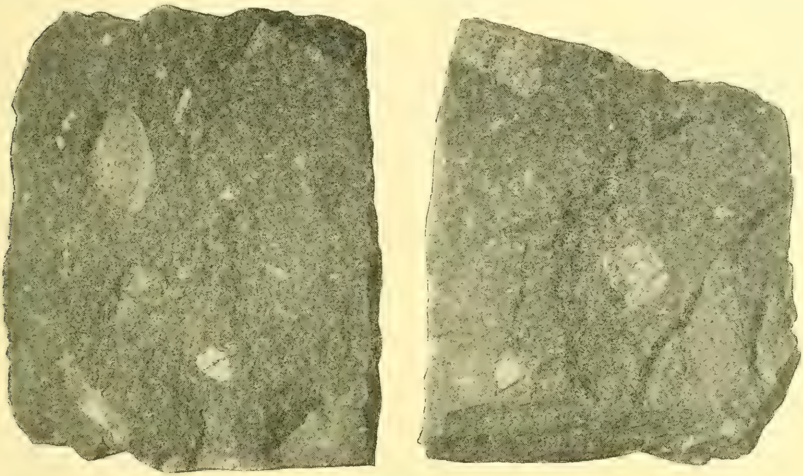

FIG. 5.—Dwyka tillite to left, Lower Huronian to right.

shale, e. g., near Matjesfontein. It may be recalled also that at many points in North America no ice-smoothed surfaces are found under Pleistocene bowlder clay. This is the case at Toronto, where the underlying Hudson shale is never polished or striated but seems almost to blend upward into the lowest sheet of bowlder clay. The absence so far as known of *roches moutonnées* under the Lower Huronian conglomerate is then no valid argument against its glacial origin.

EXTENT OF THE LOWER HURONIAN GLACIATION

The striated stones referred to earlier in this paper were obtained at two points three or four miles apart, in a cutting on the Temis-

caming railroad near mile 100, and on the Trethewey silver-mining location; both localities being included in the same area of conglomerate as mapped by Professor Miller. Search was made for glaciated stones near Temagami, twenty-eight miles southwest, where the conglomerate is prominent in railway cuttings, but the rock proved to be somewhat squeezed and decidedly more metamorphosed than at Cobalt, so that the stones broken out of the matrix showed no well-preserved surfaces. In every other respect the conglomerate is exactly like that of the silver region.

Conglomerates of the same age are known from almost every area mapped as Huronian in Ontario, from Lake Temiscaming on the east to Lake-of-the-Woods on the west, a distance of more than 700 miles; and from Lake Huron on the south to the north end of Lake Nipigon, 250 miles. In my own field-work such conglomerates have been studied at more than twenty localities scattered over the great region.

In most cases the conglomerate has proved to be far more metamorphosed than at Cobalt, often transformed into schist conglomerate with the pebbles and bowlders flattened into lenses. In such cases the resemblance to bowlder clay is lost, though the varied size and lithographical characters of the stones, and often also their wide spacing in the matrix, are suggestive of a glacial origin.

In several places, however, the Lower Huronian conglomerate is almost as unchanged as at Cobalt, for instance, near Lake Wahnapitae, east of Sudbury, and at various places in the typical Huronian region north of Lake Huron. Years ago these impressed me as resembling bowlder clay, but at that time no striated stones were found.

These areas of characteristic tillite occur at points 200 miles apart, about in lat. 46°. Of the other conglomerate areas one can only say that in all probability they are glacial also. In some places where the pebbles form closely crowded bands and are fairly uniform in size they are probably water formed, and may be explained as kames or marginal gravel beds like the Saskatchewan gravels of Alberta, glacial materials rearranged by rivers or by wave action.

Very similar bowlder conglomerates are described from Huronian regions not visited by the present writer. Dr. Bell maps schist conglomerates in northern Quebec, the most easterly at Mattagami Lake, in long. 77° 30′, and Mr. Low describes bowlder conglomerates from

southern Labrador. Mr. J. B. Tyrrell has found them on Pipestone and Cross lakes northeast of Lake Winnipeg, in long. 97° 30′, and Mr. Stewart Dobbs has described them from Manitou River near Hudson Bay, in lat. 57° and long. 92°. Huronian conglomerates exist, then, at points 1,000 miles apart from east to west and 750 miles apart from south to north; and there is little doubt that areas still remain to be discovered in the far north. To the south of the Great Lakes very similar Lower Huronian conglomerates are known in Minnesota and Michigan, and it is altogether probable that other areas to the south are buried beneath the Paleozoic sediments. Supposedly Huronian conglomerates have been described also from the Avalon Peninsula of Newfoundland.

So far as North America is concerned the probable extent of glaciated territory is comparable to that of the Permo-Carboniferous and the Pleistocene. In the Old World also there are very ancient bowlder conglomerates which may be of the same age and origin. Sir Archibald Geikie says of such bowlder beds in Scotland that, "where the component blocks are large and angular, as at Gairlock, they remind the observer of the stones in a moraine or in bowlder clay."[1] Similar pre-Cambrian conglomerates are found in Scandinavia and in Finland; and probably also in India and China; but whether they are equivalent in age to the Lower Huronian of Canada is uncertain.

GENERAL CONCLUSIONS

It has been shown that convincing evidence of glacial action in Lower Huronian times has been found in the Cobalt region of northern Ontario, the glaciated stones obtained there furnishing the final proof; that exactly similar conglomerates occur at points 50 and 200 miles farther west, though no striated stones have yet been found in them; and that bowlder conglomerates, once probably of the same kind, but now squeezed and rendered schistose, occur in every important tract of Huronian in North America, suggesting strongly that the whole region was glaciated at that time.

Moved by conservatism and having in mind the long-accepted theory of a molten earth slowly cooling to its present temperatures, some geologists may object to the conclusions given above and may think that too much stress has been put on the few scratched bowlders

[1] *Text Book of Geology*, p. 705.

thus far obtained. In reply it may be stated that the striated stones are merely the climax of the evidence in favor of a Lower Huronian ice age. The character and extent of the conglomerates themselves are unaccountable on any other theory. If these conglomerates were known only from a few small patches, one might perhaps invoke crushing and faulting, or talus formation, or exceptionally heavy river currents to account for them; but when one finds that they often cover many square miles, with thicknesses of hundreds or even more than a thousand feet, and occur in every Huronian district with the same characteristics, any such cause becomes incredible. It must be remembered that, large as the conglomerate areas are, they represent only remnants of a much more widely spread formation; for the greater part they are merely bands caught in synclines during the elevation of the Archaean mountain ranges. In the beginning the conglomerate must have been far more extensive and was perhaps continuous over the hundreds of thousands of square miles where it is now found in scattered patches. The only comparable bowlder-bearing formations known are the bowlder clays of Permo-Carboniferous and Pleistocene times. Under these circumstances the burden of proof lies with those who oppose the glacial origin of the Lower Huronian conglomerate, and not with those who support it.

Since there is only one older sedimentary formation, the Keewatin, below the Lower Huronian, the glacial period just described comes very close to the beginning of known geological history. The surface of North America was much colder then than at present, and there is every reason to think that the earth's climates were then, as now, controlled from without, and not influenced by stores of internal heat much greater than in recent times. The earth has not cooled down from the earliest ages known to geology, but may have kept a uniform temperature, or may have been warming up as the ages advanced.

If a Lower Huronian ice age is admitted, geologists should cease to speak of the earth as once a molten globe, and to begin historical geology with its cooling so as to form a solid crust, on which, much later, water could condense, and sedimentary deposits be formed. There is no geological evidence of any such early history, and we should not cling to an outworn nebular hypothesis which the astronomers themselves are throwing overboard.

STUDIES FOR STUDENTS

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS[1]

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GENERAL INTRODUCTION

The environment of the lands may be classified into three fundamental and independent factors—the relations to the surrounding seas, the topography which forms their surfaces, and the climates

[1] Presented in abstract before the Geological Society of America, December 26, 1906. The term terrestrial deposits has special reference here to fluvial and pluvial deposits rather than glacial, lacustrine, and eolion deposits.

[2] Parts II and III will be published in later numbers.

which envelope them; each of major importance in controlling the character of the lands and the evolution of their inhabitants.

The relations of the lands and seas of previous ages is the one of these environmental conditions which has been longest under investigation, since the seas have left a positive record of their invasions in the form of marine sedimentary strata and the remains of the inhabiting organisms.

The topographic changes of the lands of earlier ages give problems of equal importance, both in connection with the history of crustal movements, as sources of the sedimentary rocks, and in the evolution of terrestrial life; now raising mountain barriers and again opening fields for migration and expansive evolution. But until recent years the problem of restoring earlier land-forms had not attained to a systematic and scientific state. That knowledge of the topographic history of the land should be slower in development than the relations of land and sea is seen to be natural when it is considered that each erosion surface is made only through the destruction of the preceding land-form, with the result that the earlier leaves in the volume of land history, contrary to that of the sea, are destroyed in the making of the last, and it is only through processes of deduction that the earlier stages may in a general way be restored.

The third great problem of terrestrial environment, the succession of ancient climates, lags still farther behind in development, but is no less important in a complete understanding of the history of the earth and its inhabitants. This lack of development is doubtless due to the intangible nature of climate and the absence of direct record of its geologic changes. When it is considered, however, how fundamental are the relations of continental deposits to the climates in which they are formed, it is seen that the record of geologic climates, while indirect and largely awaiting interpretation, is nevertheless in existence.

The significance of salt and gypsum deposits on the one hand or of glacial deposits on the other is of course universally recognized, but these are the marks of climatic extremes. The causes of climatic variations, as distinct from the record, have likewise in recent years received a great amount of attention, with the result that a considerable body of knowledge has taken the place of previous speculation. But

what are the geologic records of that great variety of climates which, excluding the desert belts of the world, reach at present from the equator to the polar zones? They may be studied most favorably in ancient terrestrial deposits, since these are free from the contributory record of the sea, and, as it is the problem of the average climates which it is sought to investigate, it is especially in ancient fluvial and pluvial deposits rather than in deposits of desert or glacial origin that the record is to be found. In such river deposits each stratum represents an old land surface, the seat of abundant animal and vegetable life, sealed and protected instead of destroyed, by the making of the succeeding land record. In such deposits the evidence most usually studied is that from the teeth and feet of animal fossils, or the nature of vegetable remains. But many continental deposits are without fossils and many groups of organisms show a wide climatic range, so that it is very desirable that other features constantly present, such as the chemical, textural, and structural characteristics of the strata, should be available for the climatic interpretation. The significances of such features have of course not entirely escaped attention, the presence of red in shales or sandstones is sometimes cited as evidence of derivation from a deeply decayed and highly oxidized regolith; or the existence of a conglomerate whose pebbles are of vein quartz as evidence of the thorough decomposition of an ancient soil. But such statements have been made without a preliminary investigation into all the possible modes of origin, and it will be found that in the following pages other interpretations are pointed out. The problem, then, in the present paper is to separate the influence of the climatic and topographic factors in the making of fluviatile continental sediments. In seeking for data to draw the lines more closely it is found that the relations of climate to the nature of the land waste and river sediments have attracted the attention of relatively few explorers and scientists. Such exceptions must, however, be noted, as Blanford and Oldham, Walther, Hilgard, Merrill, Russell, Davis, and Huntington. These men, with a few others, have largely supplied the data which make the following articles possible.

The mode of treatment adopted is to divide the influence of climate upon fluvial and pluvial deposits into three parts: first, the influence on the kind and quantity of the material eroded, allowing for the

effects of various land reliefs and lithologic characters; second, the influence upon the sediments in the region of deposition, allowing for the various geographic conditions under which the deposit may take place; third, the relations of climate to transportation by running water. Each of these relations forms a largely independent problem and by the concurrence of evidence from them other factors may be eliminated and a fair degree of certainty attained in regard to the climatic conditions existing during the formation of ancient stream deposits.

The first part, dealing with the relations of climate to erosion, is necessarily largely physiographic and, in the case of sediments which are carried long distances, is of less final influence than the conditions under which the sediments are deposited and those of the preceding transportation. The purpose of the whole paper is, however, not physiographic but stratigraphic. For this reason it is the relation of physiography to erosion and the consequent supply of sediments which is dwelt upon, rather than the discussion of the land-forms as an end of investigation. Owing to this somewhat unusual use of physiography as well as the desire to make the discussion more complete for students in other branches of geology, it is necessary to go over some ground which is familiar to physiographers. Even from a physiographical standpoint, however, it is thought that a brief general discussion of all the climatic factors influencing erosion is not without its value, since it is found to suggest some new points of view upon several old problems.

For the elaboration of the second and third parts, those upon the relations of climate to terrestrial deposition and the preceding transportation, sufficient reason is found in the existence of diverse views held by many working geologists upon the significance of various stratigraphic characters; and, furthermore, in the general conclusion that climate is a factor comparable to disturbances of the crust or movements of the shore line in determining the nature and the variations in the stratified rocks of continental or off-shore origin, thus playing a part of large, though but little-appreciated, importance in the making of the stratigraphic record.

The investigation was instituted to see to what extent profound climatic variations, complicated doubtless with some tectonic movements, could account for the great contrasts in the Lower and

Upper Carboniferous formations of eastern Pennsylvania; formations which had been found by the writer from field investigations to be continental in origin and therefore their contrasted features not to be attributed to changes in the relations of land and sea. As an illustration of the importance of the climatic factor in sedimentation, it may be stated that an application of the conclusions of this paper goes to show on several lines of evidence, which it is hoped to publish in the near future, that the changes from the red beds of the Catskill formation, several thousand feet in thickness, to the gray Pocono sandstones with a maximum thickness of 1,200 to 1,300 feet, then to the sharply contrasted red shales and sandstones of the Mauch Chunck, 3,000 feet in maximum thickness, and back to the massive white conglomerates of the Pottsville conglomerate, 1,200 feet in maximum thickness, followed by the coal measures, are all the result of increasingly wide swings of the climatic pendulum which carried the world from Upper Devonian warmth and semi-aridity to Upper Carboniferous coolness, humidity, and glaciation.

PART I. RELATIONS OF SEDIMENTS TO REGIONS OF EROSION

Introduction

The larger rivers of the world, of which the Missouri and the Nile may be cited as striking examples, frequently rise in a climatic zone entirely distinct from that of the mouth. Such rivers usually flow for some hundreds of miles across low-lying country after escaping from the mountains, and carry nothing coarser than fine sand in their lower reaches, the dominant deposits over the surfaces of the large deltas being a great volume of clay and loam. That the climatic conditions under which the sediment is supplied at the source, has an appreciable influence even in these extreme cases is shown by Walther, who points out that the alluvium of the large tropical rivers is usually red in color while that of the Ganges and Mississippi, brought to the limits of the tropics from temperate regions, is gray instead of red.[1]

In shorter river systems, however, not only is the climate of the headwaters more closely related to that of the alluvial plains, but both the climatic and geographic conditions existing over the former region

[1] *Einleitung in die Geologie*, 1894, p. 815.

will notably modify the character of the sediments laid down upon the latter. It is necessary, therefore, to consider geographic factors as well as climatic, and to begin at the river's source. The geographic and topographic relations in the regions of erosion existing during a distant epoch cannot, however, be directly ascertained by observation of the existing rocks, as may the conditions in the region of deposition. These relations may, furthermore, in their effect upon the alluvium, simulate and mask the climatic effects to some extent. As a result it is impracticable to make fine distinctions in climatic cause over the regions of erosion, and in general only those types of climate which markedly affect the quantity and kind of land waste need be considered. These may be classified as of four types, as follows: warm and rainy, warm and arid, cold and rainy, cold and arid; truly glacial climates being excluded from the scope of the paper.

Character of Rocks Supplying Sediment

SIMILAR EFFECTS FROM LITHOLOGIC AND CLIMATIC CAUSES

In alluvial deposits the nature of the rocks supplying sediment is a matter of importance. A basic igneous rock, for instance, even in a subarid climate, such as exists over the Deccan of India and the northwestern United States, may give rise to a large amount of ferruginous clay containing mineral fragments other than quartz, and of various sizes. After sufficient transportation and sorting such clays would be the dominating deposits, and except for a greater content of lime, must closely simulate clays from well-decayed normally acidic rocks of a more pluvial climate. Again, a region of calcareous rocks will furnish a large amount of lime in solution, and this, by cementing the alluvium of the delta, as for example, in that of the Rhine, may cause the river deposits of a humid climate to resemble in this respect the alluvium of subarid regions. Further, the material derived from rocks of a sedimentary nature owes part of its character to a previous cycle of erosion and deposition under different climatic and geographic conditions.

ELIMINATION OF LITHOLOGIC FACTORS

This possibility of confusion between climatic and lithologic influences over the region of the headwaters may be obviated to a large extent, first, through the determination of the source of sediments and, if

this region is still above the sea, observation as to the kind of rocks now outcropping and probably present at that time; second, by a detailed study of the nature of the sedimentary particles (Sorby, Bonney, and others have shown to what an extent microscopic study of sedimentary materials may indicate the lithologic nature of the source);[1] third, by comparing the particles in deposits of dissimilar nature but of similar coarseness or fineness accumulated in successive epochs in the same region, and presumably from the same general source. For example, the material forming the coal-measure shales and sandstones of eastern Pennsylvania is of about the same grain and doubtless from the same ultimate source as the Upper Devonian and Subcarboniferous shales and sandstones of the same region. Scattered microscopic particles of feldspar in one of these formations and an absence of them in another may be taken as due to a difference in topographic or climatic conditions of origin in the region of the headwaters, and not due to derivation from unlike lithologic sources.

The preceding statements regarding the influence of the sedimentary source must not be allowed, however, to give an exaggerated importance to the lithologic character of the original rock; important near the regions of erosion, it diminishes with the distance of transportation. In regard to this matter E. W. Hilgard states:

> Alluvial soils are to a certain extent dependent upon the character of the rocks and surface deposits occurring within the drainage area of the depositing stream. As a rule their composition is much more generalized; and their character as to the relative proportions of sand and clay is essentially dependent upon the velocity of the water current.[2]

This diminution in influence of origin with distance of transportation is due partly to the contributions from tributary streams coming from somewhat different geologic provinces, partly to continued decomposition of the sediments during transportation, tending to leave similar insoluble residues, but largely to the sorting action of the water in separating unlike constituents. The sediments from dissimilar geologic provinces, therefore, are apt to consist of similarly classified products, such as ferruginous clays and siliceous sands,

[1] T. G. Bonney, Presidential Address, Section C—Geology, *Proceedings of the British Association for the Advancement of Science*, 1886, pp. 601–21.

[2] *Soils in the Humid and Arid Regions*, 1906, p. 13.

though the total amounts of these may hold to each other entirely different proportions. It is to be concluded that the nature of the parent rock is best reflected by the nature of the sediment where this is but slightly transported, but may show in minor degree for long distances.

Relations of Rainfall and Topography to Erosion

interrelations of topographic and climatic causes

The relation between the topographic character of the land and the resulting sediment has been discussed by Bailey Willis, who points out that in the youthful topographic stages rock-breaking as a method of erosion dominates over rock decay; in topographic old age the reverse is true. The former supplies a maximum of unleached mechanical sediments; the second, a maximum of rock matter in solution.[1]

Under arid climates, however, and to a lesser extent in cold climates, the material derived from the rocks is characterized by the same dominance of disintegration over decomposition, even in regions of topographic maturity or old age; sun and wind serving to erode and transport rock material without producing rock decay. When swept to a distance by rivers and laid down upon flood-plains, there may be strong chemical resemblances between the sediments originating under such dissimilar conditions and consequently a resulting confusion between distinct topographic and climatic causes.

Furthermore, topography and climate not only have independent and sometimes similar effects upon the sediments, but have mutual effects upon each other. On the one hand, topography in its major features modifies climate, on the other, climate materially affects the minor features of topography.

Different kinds of climate and topography may, therefore, lead to various results, and a change in either the climatic or topographic factor in the regions of erosion may be expressed by a change in sedimentation over a distant flood-plain. In analyzing and separating these interrelations and simulated effects three kinds of topography may be considered: first, young and mountainous topography, characterized by deep and precipitous valley walls, high elevations,

[1] Studies for Students, "Conditions of Sedimentary Deposition," *Journal of Geology*, Vol. I, 1893, pp. 476–80.

and a maximum of naked rock surface; second, mature mountainous topography, marked by broadly V-shaped valleys, long slopes covered with soil and talus, and lower rounded summits; third, old topography, with widely opened, flattened valleys holding meandering rivers and with the interstream spaces no longer mountainous, but reduced to rolling hills. The four kinds of climate to be considered have already been mentioned as combinations of pluvial and arid, warm and cold.

YOUNG TOPOGRAPHY AND VARIOUS CLIMATES

Young and mountainous topography, as is well known, produces an intensification of climatic effects and a heightening of the climatic contrasts of nearby regions, inducing an extreme precipitation, often largely as snow, upon the windward slopes and to a lesser extent upon the leeward slopes, and resulting in semiarid or truly arid tracts farther to leeward. Rapid erosion will prevail in both regions, but the results are of essentially different characters. Where the precipitation is regular and not violent, that is, not as snowfall or irregular cloud-bursts, the rivers and valley walls tend to become graded, vegetation holds the soil to the slopes, and interstream erosion over the soil-covered regions is diminished, and the material carried away by the rivers is finer[1] and more thoroughly leached of its soluble elements.[2] Over the steeper slopes and along the streams, however, erosion may go forward with immense rapidity. The waste which is held within the region is, therefore, largely held as soil, on the moderate slopes, and not as detritus, and upon any climatic change which shall diminish the effectiveness of the vegetative covering is liable to be swept away with geological suddenness as a flood of clay, sand, and gravel.

On the side of the mountains possessing a subarid or arid climate, the waste is swept away as soon as disintegration frees it from the rock, and is largely stored in interior basins or on piedmont slopes. This material adjacent to the mountains is but little decomposed, has less true clay, and on the whole is coarser than the similarly situated waste of milder or more pluvial climates. As examples

[1] E. Huntington, *Explorations in Turkestan, with an Account of the Basin of Eastern Persia and Sisten*, Carnegie Institution Publications, No. 26, 1905, p. 269.

[2] E. W. Hilgard, *Soils of the Humid and Arid Regions*, p. 413, 1906.

may be cited the coalescent gravel fans of Persia forming the "skirts of the mountains," and the detrital slopes of the mountains in New Mexico and Arizona.

As a description of the character of erosion in the heart of the desert mountain region of Arizona may be cited a paragraph by Ransome, who, writing of the Globe copper district, says:

> With the exception of the timbered slopes of the Pinal Mountains, and a few alluvial areas along the main arroyos, the surface of the region is almost destitute of soil. The scanty shrubbery, and the sparse grass and herbage which spring up with wonderful rapidity after the rains, are insufficient to prevent such soil as may form from being quickly washed away. The humus acids, which in moister climates and beneath the covering of soil aid in rock decay, have in this region little opportunity to form or to attack the rocks. The latter crumble or flake under the influence of sharp atmospheric changes, and these fragments are rapidly carried into the valleys. The granitic masses crumble into particles of quartz, flakes of mica, and angular fragments or crystals of comparatively fresh feldspar. The rains acting on this disintegrated material soon wash it down to the larger streams, which carry off the quartz and mica. The larger fragments of feldspar often build up alluvial fans at the mouths of the small ravines heading in a granitic area, and such fans are remarkable for the purity and freshness of the feldspathic material which composes them, the numerous cleavage faces flashing brightly in the sun. Excellent examples of these fans were observed along Pinto Creek, north of Horrell's west ranch. They are evidently transient phenomena, accumulating until an exceptionally wet season causes Pinto Creek to rise and sweep them away.[1]

The rainfall varies in adjacent parts of this region and in successive years, the amounts ranging from 11 to 20 inches per year, a considerable proportion falling as rain during the sudden and violent downpours which are common in July and August.[2]

Upon a climatic change causing more voluminous streams to flow across the piedmont slopes or drain the interior basins, the stream profile for equilibrium is altered, a large amount of coarse, unleached, and incoherent waste may be quickly swept downstream, even to the delta, and be deposited either upon its upper surface as partly subaerial products, or swept to the front, building the delta farther seaward.

[1] *Geology of the Globe Copper District, Arizona*, Professional Paper No. 12, U. S. Geological Survey, 1903, p. 21.

[2] *Op. cit.*, p. 20.

MATURE TOPOGRAPHY AND VARIOUS CLIMATES

Upon a mountain region becoming mature, its lower summits and rounded slopes exercise less effect upon the climate, which now becomes less accentuated and contrasted in nearby regions, and the rainfall may extend for some distance beyond the crest line. Broad extents of continental lands are here more important as modifiers of the climates natural to the several zones. There is still a marked relation in detail, however, between the climate and the surface. The problem has been studied in Persia with particular reference to climate by Huntington, who states:

A prominent characteristic of the mature mountains of Persia is their nakedness, roughness, and sterility. In a young country it is to be expected that there shall be large areas of naked rock, but in a mature country, if the rainfall is abundant, most of the surface, except the immediate valley sides, is graded, and thus covered more or less deeply with soil. Eastern Persia, however, is so arid that the ordinary state of affairs is reversed. All the mountains, whether young or mature, are characterized by nakedness. Graded slopes are not a feature of maturity in an arid climate.[1]

The valleys and basins are deeply filled with waste and the area of exposed rock is not, however, so great as during the period of youth.

The differences in the chemical and physical composition and the place of storage of the rock waste of arid and well-watered mountains become emphasized with maturity. This heightened contrast is due to the larger and deeper mantle of rock waste exposed to the particular climatic influences and moving more leisurely from its original source to the reach of the streams. The contrast in kind of products due to the climatic difference is well brought out by Hilgard,[2] who points out that—

since kaolinization is also a process of hydration, the presence of water must greatly influence its intensity, and especially the subsequent formation of colloidal clay; so that rocks forming clay soils in the region of summer rains may in the arid regions form merely pulverulent soil materials. Many striking examples of these differences may be observed, e. g., in comparing the outcome of the weathering of granitic rocks in the southern Alleghenies with that of the same rocks in the Rocky Mountains and westward, especially in California and Arizona.

[1] *Explorations in Turkestan,* Carnegie Institution Publications, No. 26, 1905, pp. 247, 248.

[2] *Soils,* 1906, p. 47.

The sharpness of the ridges of the Sierra Madre, and the roughness of the hard granitic surfaces, contrast sharply with the rounded ranges formed by the "rotten" granites of the Atlantic slope, where sound, unaltered rock can sometimes not be found at a less depth than forty feet; while at the foot of the Sierra Madre ridges, thick beds of sharp, fresh granitic sand, too open and pervious to serve as soils, cover the upper slopes and the "washes" of the streams, causing the latter to sink out of sight. A general discussion of the kinds of soils formed from the various rocks must, therefore, take these differences into due consideration.

The lack of decomposition and the dominance of disintegration in desert regions, giving rise to fresh and unweathered sands, have also been emphasized by Walther, who shows that insolation breaks up crystalline rocks into a rubbish of crystals scarcely altered chemically.[1] Merrill and others have abundantly confirmed this as a principle dominating the production of rock waste in arid climates.

OLD TOPOGRAPHY AND VARIOUS CLIMATES

Regions topographically old are of lessened importance from the view-point of the mechanical sediments of running water, but little waste being contributed to the deltas and the seas and the conditions for limestone formation approaching close to the shores. In the old age of the humid region the blanket of decomposed rock becomes universal and increased in thickness, giving rise upon erosion to fine-grained and well-decomposed silts. In the arid regions, on the contrary, the waste in the rock basins diminishes in thickness through wind and water erosion and the desert becomes finally covered with a thin gravelly or sandy mantle still characterized by lack of decomposition. In the old age of arid regions, as shown by Passarge, wind erosion becomes increasingly more important than water erosion, since the water loses its force upon the flat desert surface, while the action of the wind does not diminish in intensity. The products of erosion in old age, therefore, are chiefly wind-borne loess and dune sand, possessing distinctive qualities and a different distribution from sediments of fluvial and pluvial origin.

Relations of Temperature and Topography to Erosion

EFFECTS OF TEMPERATURE VARIATIONS ON VEGETATION AND SOIL RETENTION

Besides the relations dependent upon rainfall, those dependent upon temperature may also be considered. In general, increased cold

[1] *Einleitung in die Geologie*, 1893–94, pp. 546–47.

with stable precipitation but without glaciation has been considered geologically equivalent to stable temperature and increased rainfall, since the evaporation is decreased and the run-off consequently increased, but an analysis of the problem would appear to show that in its ultimate stratigraphic effects it is much more complex than this, a complexity which has been recognized possibly for the first time by Chamberlin and Salisbury,[1] who state:

> The cold climate probably affected erosion, and therefore deposition in another way, for the reduction of temperature was probably attended by a reduction of vegetation, and any diminution of vegetation must have reflected itself in increased erosion. The reduction of vegetation was probably greatest just where erosion was most readily stimulated, namely, in the higher altitudes. The importance of this consideration has perhaps not been duly considered.

On the other hand, a marked rise in mean annual temperature without change in precipitation will, in a region already under optimum climatic conditions for vegetation, be equivalent to a movement toward aridity. This is seen on comparing tropical deserts with those of the temperate zone, where in the former a precipitation twice as great may not prevent the existence of a similar aridity. The results in the decrease of the vegetative hold upon the soil and a consequent increased erosion, provided there is sufficient run-off to remove the rock waste, will be similar to the results of a change toward unfavorable cold.

It may be stated in conclusion, therefore, that any marked variation of temperature away from that which in combination with the rainfall gives the optimum conditions for vegetable growth will result in a loosening of the soil and a corresponding increase in the rate of erosion. The diminished area of rock covered by the soil and the thinner covering where it does exist will, in combination with the lessened amount of organic matter, result in an increase of disintegration and a relative diminution of rock decay.

EFFECTS OF INCREASED COLD

On frost action and erosion.—Not only is the balance of the vegetative covering to erosive power disturbed, but during periods of increased cold the frost action over exposed rock surfaces becomes more energetic. Its intensity at high mountain elevations or in high

[1] *Geology*, Vol. III, 1906, p. 453.

latitudes has been pointed out by Walther,[1] by Russell,[2] by Merrill,[3] and others, and reliance upon this action has been employed by Oldham to reach the conclusion as to the existence of a period of cold, but one not attended by glaciation during the deposition of the Panchet group, early Mesozoic of India.[4]

It has been thought by some that perhaps a rigorous winter climate does not promote corresponding disintegration, since during a considerable portion of the year there may be no thaw. Observation seems to indicate, however, that with increase of altitude or latitude the results of frost action become progressively more pronounced. The explanation is apparently to be found in the fact that although surface melting and refreezing may be absent, frost action is at such times penetrating constantly deeper. The period of daily freezing and thawing will in this case occur at the two ends of the winter season instead of the middle and on account of the greater daily insolation and nocturnal radiation the effects may be as pronounced as during a somewhat longer period near the winter solstice.

If the cold becomes so great, however, as to result in a perpetually frozen substratum, the disintegrative action will presumably become less instead of greater, but such a condition does not exist at present except under polar climates. It is not one which would, so far as known, become widespread even at times of glaciation, and is the consequence of a climatic extreme which need hardly be considered.

The effects of increased cold in regions of no glaciation must consequently be either one of two kinds, depending upon whether frost action or snowfall is increased: frost tending to make more rock waste; snow tending to prevent frost action and by its melting to carry waste away.

In climates possessing but little snowfall, increased variations of temperature and increased frost action will be the most marked results of a change to a colder climate. In regions of exposed rock

[1] *Einleitung in die Geologie*, 1893–94, p. 559.

[2] *Notes on the Surface Geology of Alaska*, Bulletin of the Geological Society of America, Vol. I, 1890, pp. 133–37.

[3] *Disintegration and Decomposition of Diabase at Medford, Mass.*, Bulletin of the Geological Society of America, Vol. VII, 1896, pp. 349–62.

[4] *A Manual of the Geology of India: Stratigraphical and Structural Geology*, 2d ed., 1893, p. 201.

surfaces, and therefore typically in rugged mountainous regions, this must result in a more rapid disintegration of the naked rock masses and an increased supply of talus to the streams. Under the small precipitation postulated, however, the streams will be only slightly increased in volume by the decreased evaporation, and presumably not able to carry away the excess of load. The weakening of the vegetative covering over the soil-covered slopes would work to the same end, but in a desert region this factor would be absent. The tendency of the increased disintegration would be to build up piedmont slopes, whose rate of growth would diminish or even cease upon a return to less rigorous winters. The effects of increased cold in many cases may, therefore, disturb the balance of erosion to transportation, in the same way as a change toward more marked aridity without increased cold.

The Gila conglomerate of Arizona.[1]—As an example of a Pleistocene formation which it was thought might be due to some such cause, the writer has examined the literature on the Gila conglomerate of Arizona, a formation now dissected in many places to the depth of a thousand feet and attaining its maximum development in the upper portions of the valleys of New Mexico, Arizona, and southern California. The specific nature of the climatic or tectonic changes which could have resulted in its production does not seem to have been fully discussed, the only definite opinion expressed being that of Lee that in so far as climate was a factor in the accumulation of this upland débris in southern California and Arizona, it was in the nature of a desiccation.[2] Others consider that their Pleistocene age and the finding in New Mexico of contemporaneous elephant, horse, and tapir bones are an indication of the accumulation of similar New Mexican deposits during an epoch of moist climate in the early Pleistocene.[3]

An examination of the literature showed that the relations of the two divisions of the Gila conglomerate, the volumes and relative

[1] The writer hopes to publish a fuller discussion of this subject than can be given here.

[2] "Underground Waters of Salt River Valley, Arizona," *Water Supply and Irrigation Paper No. 136*, U. S. Geological Survey, 1905, p. 115.

[3] George B. Richardson, *Science*, New Series, Vol. XXV, 1907, p. 32.

ages of each, corresponded with the two epochs of glaciation which were pronounced in Utah and Nevada and the two periods of expansion of Lakes Bonneville and Lahontan. This taken in consideration with the place of deposit of the gravels, in the upper portions of the river valleys, leads to the view that the Gila conglomerate originated from an increase in the ratio of erosion to transportation, due to the severe cold and consequent frost action of the glacial times, without a correspondingly large increase, in this arid region, of precipitation. The ultimate cause of the accumulation under this view was greater cold and not a desiccation, since the precipitation was doubtless somewhat increased as shown by the mammalian bones. Any conclusion in regard to the exact cause and correlation is, however, of minor importance in comparison with the broader one that the deposit is due to climatic causes rather than those of a local or regional tectonic nature. If this conclusion be well founded it is seen that in this desert region with mountainous topography climatic changes have been a sufficient cause to result in the laying-down over wide areas adjacent to the higher mountains of a conglomerate formation largely over a thousand feet in thickness, justifying the statement that climatic changes may result in sedimentary formations as important as those due to tectonic or oceanic causes.

Effects of increased cold on snowfall and erosion.—In regions where the increased cold results in the precipitation of snow which previously had fallen as rain, frost action and also chemical action may not be increased, and the chief results of the spring floods resulting from the melting snow may be an increase of transportative power. The protecting power of snow against both disintegrating and decomposing agencies has been cited by Salisbury as probably contributing to the fresh and unweathered appearance of the Wisconsin drift of the Bighorn Mountains when compared with that of the continental interior.[1]

In mountainous regions such as the Sierras, where the snowfall is markedly greater at the higher elevations, the floods produced by the spring melting are not proportionately augmented upon reaching the lowlands, and deposition of the excess load is to be expected

[1] *Geology of the Bighorn Mountains,* Professional Paper 51, U. S. Geological Survey, 1906, p. 87.

upon the piedmont slopes. The same is found to be true on the eastern slopes of the southern Andes on portions of which aggradation is now in active progress. An increased snowfall without actual glaciation, especially if it takes the place of what had previously fallen as rain, may therefore result in the waste being carried farther before deposition, accompanied by a dissection of the upper portion of the piedmont slope, the results being opposite to those of increased frost action. In regions of less elevation, however, the rainfall and snowfall are nearly the same upon upland and lowland, the volumes of the streams are increased as they flow toward the sea, the sediment once picked up is carried through by the river, and as a result of increased snowfall an increased erosion may take place without the tendency to aggradation in the middle portions of the streams. Such an effect is in many ways equivalent to a change toward a more voluminous or at least more concentrated regional rainfall. In the preceding statements snow and frost action have been considered separately. In nature, however, there may be various combinations of these agencies. Increased cold may lessen the hold of the vegetation on the soil, the latter, saturated in the spring with snow water, may be more rapidly removed, and an opportunity be given for increased frost action. Consequently, while a greater amount of sediment may be carried through to the lower portions of the river system, aggradation may yet take place to some extent in the upper portions. Some such change of relations seems to have occurred during glacial times over certain regions outside of the limits of glaciation, since terraces and fans of glacial age characterize the upper portions of many river systems. These conditions find their maximum development at the present time in the subglacial polar or mountain climates. The subject has been discussed by J. G. Andersson,[1] who shows that the regolith, becoming saturated with snow water, creeps slowly but bodily down even the gentler slopes. The production of new waste is chiefly dependent upon frost action; so that the two results of a lowering of temperature co-operate and it is not practicable clearly to separate them. The Gila conglomerate, however, on account of the short distance which the bulk of the material was transported,

[1] "Solifluction, a Component of Subaerial Denudation," *Journal of Geology*, Vol. XIV, 1906, pp. 91–112.

and the lack of evidence of highly increased precipitation at the time would seem to be due more largely to frost action.

In conclusion it would appear that where the chief effect of increased cold is an increase of snowfall the change results in an increase in the ratio of transportation to erosion, extending to the limits of such increased snowfall, and not as in the case of increased frost action to an increase of erosion over transportation. The absolute value of both erosion and transportation may increase in both cases.

EFFECTS OF INCREASED HEAT ON ROCK DISINTEGRATION AND DECAY

It is seen that rock disintegration or physical weathering is at a maximum in regions of exposed rock surfaces, while rock decay is pronounced, on the contrary, where the solid rock is protected from physical changes by the interposition of a layer of soil. The former conditions of bare surfaces are found in mountainous regions, where the steep slopes prevent the retention of soil; or in the deserts, where the absence of ground-water prevents either the formation of an effective vegetable covering or the carrying-forward of the chemical processes of rock decay. The contrary conditions of soil-mantled surface exist where the slopes are moderate or the presence of ground-water gives rise to a vegetable covering sufficient to hold the soil and diminish erosion of its upper surface to a rate equal to that at which decay contributes to the lower strata of the soil. In a climate where rock decay operates strongly there thus arises a very deep soil, partially protecting the deeply buried solid rock from further decomposition and slowing down the rate of decay till it equals the rate of surface ablation, hindered in turn by the luxuriant vegetation also existing in such a region. Both the topographic and climatic factors are thus seen to be fundamental in the result. Under the present topic it is desired to note what effects a climatic variation toward an increase of temperature will have upon these processes of physical and chemical rock destruction which necessarily precede subaerial denudation and are the supplying agents for the diverse materials of sedimentary formations.

Effects on rock disintegration.—To produce rock disintegration a high temperature is not necessary but diurnal or hourly variations

of temperature must occur, and the effects will be proportional to the magnitude and rapidity of these changes. As causes tending to magnify these rapid temperature variations may be cited: first, a short transmission of the sun's rays through the atmosphere, implying a thin atmosphere as found on mountains and high plateaus or a high altitude of the sun; second, surfaces at right angles or nearly so to the sun's rays; third, a lack of clouds or of water vapor and to a lesser extent a lack of carbon dioxide in the atmosphere, the former characteristic of continental interiors, the latter of certain geological epochs; fourth, a high value of the solar radiation will increase the disintegrative effects by producing more rapid heating and, as a result of the higher surface temperatures attained, a more rapid cooling when the rock surface passes into shade. Sudden dashes of rain, such as are characteristic of arid and semiarid regions, also operate as a powerful cause of rock disintegration.

To take up these in order: Angot has shown that, although at the summer solstice the quantity of heat received per day at the poles is greater than at the equator, if 0.2 of the solar radiation is absorbed by passing vertically through the atmosphere, then at the poles less reaches the surface of the ground than at the equator.[1] The constancy of the polar daylight at the solstice tends also to prevent rapid temperature changes.

The daily *maximum* insolation of the surface is found to be not far from a constant quantity up to lat. 60, with a maximum at from 30 to 40 degrees. In the higher latitudes, however, this maximum insolation occurring at the summer solstice lasts for but a short time, sinking in the winter to an insignificant quantity. It may be stated then on theoretical grounds that, other conditions being favorable, thermal disintegration may operate strongly to the limits of the polar zones, but that the aggregate effect varies approximately with the latitude, reaching a maximum at the equator and disappearing as an important factor on the polar circles.

Mountain elevations exert an influence upon insolation as important as latitude, a marked difference being noted between the air and

[1] Alfred Angot, "Recherches théorétiques sur la distribution de la chaleur à la surface du Globe," *Ann. bur. central met. de France*, Tome I, 1883, Paris, 1885, B 121–B 169.

ground temperatures, the intensity of solar radiation being 26 per cent. greater on the summit of Mount Blanc than at Paris.[1] Steep rock faces favoring perpendicular action by the sun become of increasing influence in the higher portions of the temperate zones and may even in the arctic, as in Greenland, give a local importance to insolation as a cause of rock destruction, von Drygalski having observed a temperature difference of 20° C. between the air and rock surface.[2]

In regard to the influence of atmospheric composition, it is known that water vapor is the most efficient absorbing medium of the solar heat and also prevents the rapid re-radiation of that part absorbed by the earth's surface, preventing by both means high temperature differences. Clouds also act both by preventing solar radiation from reaching the ground and checking the escape of that already absorbed. These direct effects, taken also in connection with the indirect effects of the presence of water through vegetation, limit insolation as a mode of rock destruction to mountain and desert regions.

Finally, in considering the geological relations of climates to erosion, possible variations of the solar constant of radiation must be considered, an increased intensity of radiation, as previously pointed out, increasing insolative rock disintegration, but only within the limits given by the other conditions. The chief effects of such solar variation would therefore be indirect, by changing the vapor content and cloudiness of the atmosphere, both in geographic location and amount. There are strong reasons for believing, though perhaps hardly yet demonstrated, that an increase in solar radiation would result not only in a slight increase in the mean annual temperature of the earth but also in areal increase of those portions of continental interiors subject to arid and subarid climates. At the same time it is probable that an expansion of the trade-wind belts into somewhat higher latitudes would occur. Certain other regions would also be marked by heavier rainfalls. On the whole, the result would be an accentuation of climates and a marked increase in insolation as a cause of rock disintegration.

In conclusion, it is seen that the control of insolative rock disintegration is largely geographic, being favored in past times by increase

[1] Julius Hann, *Handbook of Climatology*, transl. by R. de C. Ward, p. 233.

[2] *Verdhältniss Geschichte für Erdkunde*, Berlin, 1891, p. 457.

of area and unification of the continental surfaces, giving rise to largely increased areas of continental climates. The indirect action of the sun, however, as just pointed out, is probably an equally potent factor.

According to Murray, one-fifth of the land surface is now desert, having no drainage to the sea.[1] Over this region insolation and eolian abrasion are the chief modes of rock destruction. It may well have happened that in past times of wide epicontinental seas with moist atmospheres and world-wide equable climates, or in times of cold and glaciation, insolation may have sunk to half its present importance as a mode of rock destruction. On the other hand, times of broadened land areas, especially if occurring simultaneously with high solar radiation, may have increased the desert areas beyond their present extent, or at least shifted their limits into higher latitudes, giving rise to peculiar characteristics, such as distinguish particularly the Triassic formations.

The first factor in the acquisition of any such distinctive characters of sediments must depend upon the mode by which the parent rock masses are destroyed. In this respect frost action and insolation act alike, producing rock disintegration without rock decay, both most efficient in regions without heavy precipitation and accentuated by climatic movements away from a temperate condition, but in opposite directions. The subsequent effects of these opposite climates upon the sediments are, however, widely different, as will be made evident on other pages.

A conclusion of some stratigraphic importance is that, if the Gila conglomerate has been correctly interpreted, it is seen that in desert mountains strongly increased frost action with slightly decreased insolation of glacial times is more effective in supplying waste than the present slightly increased insolation with much weakened frost action.

Effects of increased heat on rock decay.—Rock decay implies the presence of water, since it is only in its presence that not only hydration but carbonation and oxidation of mineral substances can take place. The problem, then, is in regard to the influence of temperature in promoting rock decay in regions of moist climate. In regard to this von Richthofen is one of the first to observe that—

[1] "Origin and Character of the Sahara," *Science*, Vol. XVI (1890), p. 106.

weathering in fact becomes in large measure a climatic phenomenon. In moist and hot regions it is accomplished easily and rapidly; in hot and dry regions it seems to play an unimportant part, and where high degrees of cold prevail even an abundance of water is unable to produce it in any but an insignificant amount. Beneath the ever-moist moss cushions of Finland and the northern Ural, granite shows undecomposed surfaces.[1]

Russell, from observations in the southern hemisphere, reaches the same conclusions, his statements being as follows:

I may remark from observation that in the Kerguelen and Crozet Islands, in the South Indian Ocean, where a cold, humid climate prevails, and where not only forests but arborescent growths of every description are wanting, there is but little soil, and nothing approaching terra rossa is to be seen. These islands are formed, probably throughout, of dark basaltic rocks, rich in iron, which under more favorable conditions would yield a deep layer of ferruginous soil. Contrast with the Kerguelen Islands others of similar origin in the tropics, as the Samoan Islands, for example. On Kerguelen the highest vegetation is a bitter cabbage which grows mostly in sheltered places along the coast, where it is surrounded with matted ferns and tussocks of moss. The landscape, even on the exceptional days of sunshine, is dark, silent, and gloomy. Among navigators this island is called, not unjustly, the "Land of Desolation." In the Samoan Islands the rank luxuriance of tropical vegetation imparts to the land when seen from the ocean the deep tint of malachite. Wherever the bare earth appears it gleams forth through the overshadowing boughs with a brilliancy that is enhanced by contrast and gives a dash of Pompeian red to the picture of tropical beauty. The soil is deep and rich, and, as in Bermuda, must have been derived entirely from the decay of the rocks forming the islands, which in this case, however, are basaltic, and agree in many ways with the rocks forming the Kerguelen Islands.

The contrast between the present condition of the Kerguelen Islands and that of the Samoan Islands has resulted from differences in climatic conditions. This conclusion would have to be modified, perhaps, should it be found that the former had recently been glaciated. There are abundant observations to show, however, that, in general, islands below latitude 50° south, where winter is almost continuous, are desolate, uninhabitable wilds, and that forty degrees nearer the equator, where perpetual summer reigns, lands formed of nearly identical rock have suffered deep decay and are covered with a rich ferruginous soil, which supports a varied and luxuriant tropical flora.[2]

That rock decay may take place to some extent in cold climates and is frequently absent because of glaciation is indicated by the observa-

[1] *Führer für Forschungsreisende*, Berlin, 1886, p. 100.

[2] *Subaerial Decay of Rocks and Origin of the Red Color of Certain Formations*, Bulletin 52, U. S. Geological Survey, pp. 30, 31, 1889.

tions of Chamberlin in Greenland and of others in Alaska cited by Merrill.[1] Observation and theory combine, however, in pointing to the greater dominance of the forces of rock decay in warmer pluvial climates and especially in the rainy portion of the torrid zone, the natural activity of the warmer waters being further increased by the organic acids supplied by the large amount of decaying vegetable matter, giving rise to a mantle of rock waste of maximum thickness, thoroughly hydrated and leached by the heavy periodic rains, and thoroughly oxidized by the intervening seasons of dryness. The result is the formation of the red or pink laterite soils of the tropics, and the characteristic red alluvium of the rivers,[2] alluvium poor in soluble constituents.[3]

The effect of moderate cold, such as characterizes the winters of the middle temperate zone, appears to have slight effect upon the erosion of regions in topographic maturity, save that the melting of the winter's snow gives a temporarily higher flood and greater erosive power than would otherwise occur. The summer's heat being less prolonged and intense, gives rise also to less intense oxidation of the soil and less dehydration of the iron oxide, yellows and browns prevailing as soil colors and yellows or grays characterizing the river silts in place of the browns or reds of tropical rivers.

In conclusion, therefore, it may be stated that an increase of temperature away from a temperate mean in regions of heavy rainfall will result in increased rock decay and decreased frost action, and in the opposite characteristics in the case of a temperature decrease. Either variation away from a climatic mean would therefore result in an increase of rock destruction, but of opposite kinds. It is not known, however, but that in the case of an increase of temperature with an abundant rainfall the hold of the vegetation upon the soil may be increased to such an extent as to neutralize the tendency toward more rapid production of rock waste by decay. A close comparative study of valley forms of similar age in the middle and southern Appalachian states in similar rocks would tend to throw light on this problem and show if *erosion* as distinguished from *rock decay*

[1] *Rocks, Rock-weathering, and Soils,* 1897, pp. 278, 279.

[2] Walther, *Einleitung in die Geologie,* p. 815.

[3] Hilgard, *Soils,* 1906, chap. xxi.

is faster in the warmer or cooler climate. In any case, it is evident from the preceding discussion that a series of climatic oscillations involving merely temperature changes would find record in the varying kind and rate of erosion and consequent sedimentation in regions either where this climatic change was between cold and temperate or between temperate and torrid limits.

Separation of the Topographic and Climatic Factors

As previously stated, under the relations of rainfall and topography to erosion, young, mountainous topography not only gives rise to rapid erosion, but accentuates climatic contrasts, so that a marked distinction may still have opportunity to become developed between the products of erosion of humid and arid mountain regions. The extent to which this is true may be seen by comparing the alluvium of the Rio Grande with that of the Missouri-Mississippi system, where in silts of the same degree of fineness that from the arid region shows a much higher ratio of soluble constituents.[1] The researches of the geologists of India indicate the same contrast between the alluvium of the Indo-Gangetic plain and that of the Brahmapootra in southern Assam.[2] In these examples the material is derived from regions of high relief and rapid erosion. Gravels or cobbles may be deposited under such circumstances nearer the sources, but the production of the conglomerate has involved initial rock-breaking and the production of a considerable quantity of fine material which may occur as a matrix or as separate deposits of clay or silt. These finer materials, as stated, have distinctive characters in each strongly marked climatic province.

It is concluded, therefore, that an examination of the character of the matrix or associated fine beds is of importance in determining the climatic conditions attending the origin of a terrestrial conglomerate or sandstone. This conclusion may be illustrated by contrasting the red sandstones and shales, occasionally conglomeratic, of the Connecticut Valley, with the predominantly gray conglomerates and black shales of the Carboniferous basin of Rhode Island; the two regions being separated by less than fifty miles, and both containing sediments of rather local origin. There are strong evidences in

[1] Hilgard, *Soils*, 1906, pp. 368, 378. [2] Hilgard, *op. cit.*, p. 413.

each case indicating subaerial origin, much of which however is not published. The dominant red color of the whole of the Triassic formation, considered in connection with its feldspathic sandstones indicative of the kind of erosion, mud-cracked shales, disseminated gypsum, and calcite, indicative of conditions of sedimentation, point on the one hand to a subarid climate, while the carbonaceous and leached shales of the Rhode Island coal measures indicate a climate markedly pluvial and cool. It is to be noted that in the Rhode Island basin arkose conglomerates of local origin grade into carbonaceous shales.[1] The conglomerates are extremely abundant and except in the Wamsutta red beds possess a light-gray matrix, while the shales are usually darker in color. Thus the conclusion previously stated is emphasized, that in humid climates, even in regions of rapid denudation and deposit, the finer materials eroded will show greater decomposition and leaching than material of similar fineness, even when derived more slowly from the erosion of surfaces of moderate relief in arid climates. The character of the fine fluviatile or wash detritus *in the region of its origin* may, therefore, be taken as an index of climate. The size or abundance of the coarser material on the other hand forms a measure of the rapidity of erosion, and roughly of the degree of topographic relief. Where the matrix or the form of the cobbles indicates, in association with other evidence, the presence of arid or cold climates, however, disintegration dominates over decomposition, and conglomerates in the region of erosion must be correspondingly coarser and more abundant to indicate the same relief as that of a more rainy region. In rivers sufficiently large so that the erosion and deposition occur in different climatic zones only the finer débris will reach the delta. The chief effect of rugged topography in that case is found in the quantity of sediment and, as will be further discussed in Part III under the topic of the "Effects of Fluviatile Transportation," the evidence as to the climate of the *soucre* becomes more obscure the farther the alluvium is carried.

Separation of Tectonic and Climatic Oscillations

A full discussion of this topic involves the effects of tectonic and climatic movements upon both transportation and deposition as well

[1] A. S. Packard, "View of the Carboniferous Fauna of the Narragansett Basin," *Proceedings of the American Academy*, Vol. XXXV, 1900, p. 405.

as erosion, subjects which are treated in the following chapters. A partial statement, in so far as erosion is involved, may, however, be made at this place.

It has been seen that climatic variations are potent causes of changes both in the absolute rate of erosion and in the ratio of erosion to the forces removing the waste. While erosion is dependent for its existence upon initial tectonic movements, it has been seen that its varying rate is as dependent upon climatic variations as upon those secondary crustal movements by which occur further uplift or depression or distortion.

Criteria for the distinction of these tectonic and climatic factors are discussed by Davis, in so far as erosion at the headwaters and aggradation of the middle slopes are concerned, and the conclusion is reached that in general the terracing in Central Turkestan seems to be due to climatic variation.[1] The recognition of the importance of climate in building river terraces is in fact a feature in this volume in both the papers of Davis and Huntington. It is only necessary in consequence to summarize briefly certain points which distinguish the upstream terraces built as a result of climatic from those formed by tectonic oscillations. First, the development of terraces on the upper portions of the streams, terraces which die out lower down in the valleys, implies a change in the stream gradients not due to a raising or lowering of the mouth. Regional uplift or depression is excluded in this way. Such a change in gradient in the upper portion of a stream may be due to a local uplift, to a regional warping or a change in the ratio of erosion to transportation brought about by a climatic change. Second, the universality of an epoch of aggradation or degradation in all of the streams of a region is a strong indication of a climatic change, since, as Davis has noted, the crustal bendings necessary to rejuvenate all streams flowing in various directions and finally frequently to bring them back to the initial profile would be extremely complicated and involve an adjustment of subsurface movement to detailed surface form such as is not known to occur and is in fact unthinkable. Although a general similarity in the action of various streams would be expected to occur as a result of climatic

[1] *Explorations in Turkestan*, Publications of the Carnegie Institution, No. 26, 1905, p. 203.

change, this could not be carried down to all details; since it is seen, for instance, that in Arizona, Queen Creek at the present time begins to deposit sediment immediately upon leaving the mountains, while the much larger Gila flowing parallel and but eleven miles to the south flows through the plain as far as Florence in a well-marked valley. In this respect it is to be expected that various streams will behave somewhat after the manner of glaciers, where each responds in its own time and to varying degrees to periods of increased or decreased precipitation of snow. Third, while extremely contrasted climates may leave many distinctive marks in the character of the matrix of even locally transported materials, as shown in the contrast of the Carboniferous of Rhode Island to the Triassic of Connecticut, minor climatic fluctuations cannot be expected to be so recorded. As evidence of such variations, therefore, disturbance of the stream gradient and changes in the coarseness of the detritus must be looked for.

CONCLUSIONS ON RELATIONS OF CLIMATE AND EROSION

The relative rates of erosion in desert, tropical, and polar climates is a subject upon which there is much diversity of opinion, as Merrill has shown.[1] The difficulties are largely due to the differences in kind of erosion between hot and cold, and arid and rainy climates. The usual geographic remoteness of these extreme types from each other further increases the difficulty. Doubtful conclusions have also sometimes been founded upon the quantities of rock waste present, it being assumed that where rock is deeply decayed, as in the rainy belts of the tropics, it now weathers and erodes rapidly, whereas, on the contrary, the deep regolith may check further decay and the matted vegetation retard the erosion of the surface. Or a traveler may be impressed with the naked mountains and waste-filled valleys of a desert region and conclude that here rock destruction progresses more rapidly than elsewhere on the earth.

A more satisfactory method than that of founding conclusions on quantitative estimates from a few unlike localities is to compare the decay and erosion of unlike climates not with each other but with a third term. For example, the subaerial erosion of arid and rainy regions may be compared with the marine erosion of their coasts, a

[1] *Rocks, Rock-weathering, and Soils*, 1897, pp. 278–85.

common third term, while the influence of warm and cold climates upon erosion may be studied by comparing the erosional rate of glacial times with that of the same regions at present, here the common third term being the topography. This has already been done under the topic of the effects of increased cold.

Turning to the ratio of erosion in arid and rainy climates, as compared with marine denudation, it must be noted that a conclusion should be founded on the average of many instances rather than on a few, since in each the age of the cycle, the attitude and strength of the rock masses, and the strength of the marine erosion will vary. The present discussion must therefore be considered as merely tentative. Very different views have been developed in Great Britain and the United States as to the marine or subaerial production of uplifted and dissected peneplains of Cretaceous and Tertiary age which border the continents, but the growth of knowledge in regard to the capacity of subaerial denudation first in America and more recently in England has given rise to the belief that these are mostly due to subaerial erosion, views confirmed by the application of such criteria as can be applied.[1] In general in rainy climates the rivers are observed to sink rapidly toward base level upon an uplift of the land, to open out interior plains in soft formations, and to dissect deeply the hard ones, while the sea, compelled to work on the outlying formations whether they be hard or soft, cuts inland over a comparatively small area and with increasing difficulty. The problem in such climates is to find good and unquestioned examples of elevated plains of marine denudation comparable to the elevated plains of subaerial origin.

Along the arid coasts of the world very different conditions are, however, found to prevail. To cite examples:

While the Patagonian plains have an altitude of some three thousand feet at the base of the Andes, they slope very gently to the eastward, and at a distance of some fifty miles from the Atlantic coast, their elevation is more rapidly decreased by a series of escarpments or terrace-like slopes, which face to the eastward and terminate a succession of level plains, decreasing in altitude as one passes from the interior to the coast and finally ending in the lowermost, which, with an average altitude of some three hundred and fifty feet, extends almost uninterruptedly along

[1] W. M. Davis, "Plains of Marine and Subaerial Denudation," *Bulletin of the Geological Society of America*, Vol. VII, 1895, pp. 377–98.

the entire eastern shore, terminating abruptly in the lofty and precipitous cliffs, which for a thousand miles constitute the predominant feature of this coast.

In addition to the characters described above, there may be mentioned as among the more important features of these plains a series of deep transverse valleys that extend from the Andes to the Atlantic. These are all true valleys of erosion, and for the most part they are still occupied by considerable streams.[1]

The prominence of these cliffs indicates the extent to which the waves have planed inland, beginning a new and lower cut upon each uplift of the land. The inadequacy of subaerial denudation in this semiarid climate, with less than ten inches annual rainfall, is indicated by the presence, except in the few river valleys, of the shingle formation left by the retreat of the sea and the fact that the large river valleys are such as derive their waters from the Andes. In more rainy regions the almost level and porous deposits left upon a retreat of the sea also resist rain erosion in the interstream areas for considerable periods of time, but in such regions there is much local drainage and the development of a network of valleys which upon a pronounced uplift permit a rapid erosion.

Along the southwestern coast of Australia for a distance of seven hundred miles the land is terminated by a line of cliffs more than five hundred feet in height unbroken by any stream course and facing a shallow sea which in the Great Australian Bight extends to one hundred and fifty miles from land before attaining a depth of one hundred fathoms. The rainfall is here not over ten inches per year. Such lofty and unbroken walls indicating the dominance of marine over subaerial erosion, it would seem impossible to match in more generously watered regions of theworld; such cliffs as those of Norway and Scotland being cut through on the contrary by valleys of erosion besides forming the front of mountain regions and therefore not necessarily implying a wide horizontal cut for their formation.

The preceding discussion has turned upon the slowness of subaerial erosion in arid climates when acting upon more or less horizontal and débris-mantled formations. An indication of the relative slowness of deflation may also be obtained from southern California and its adjacent islands by noting the remarkable freshness of the naked granite rocks and the sharpness of the post-Pliocene elevated sea-

[1] J. B. Hatcher, *Princeton Patagonia Expeditions*, Vol. I, pp. 214, 215, 1903.

cut cliffs reaching an elevation on San Clemente of 1,320 feet. These according to Lawson are the most remarkable and most magnificent examples of this type of topography which it has ever been his good fortune to behold. He further remarks that such features one might expect to find on a planet, which after their formation, had become stripped of its atmosphere.[1] Similar terraces are found on the coast of northern California, and Lawson regards the whole as due to epeirogenic movement which he considers as sufficiently simultaneous to inaugurate a new geomorphic cycle which is in a nearly uniform state of advancement all along the coast.[2] Under the rainy climate of the coast of northern California, but especially of Oregon, these raised beaches are still conspicuous; but it is noteworthy that they have not called forth such descriptions as those of the arid portions of the coast line, while Diller speaks of the raised beaches of the Oregon coast as being less distinct above eight hundred feet.[3]

It would seem from the above that on the Pacific Coast is an ideal region for comparing the rates and kinds of erosion upon the same initial earth forms, offering an attractive problem for physiographic study.

In conclusion, from the preceding résumé it would appear that an arid climate is an important contributory factor in the development of plains of marine denudation, a factor which so far as the writer is aware has not previously entered into the discussion of the problem of the relative development of plains of subaerial and marine erosion.

Finally, from the discussions under this and preceding topics, the following estimates may be made of the relative rates of erosion under different climates upon average rock materials in a state of topographic maturity. From such a brief study such a statement is clearly nothing but an estimate. Proceeding from what is thought to be the less rapid to the more rapid they would be—

[1] *The Post-Pliocene Diastrophism of the Coast of Southern California*, Bulletin of the Department of Geology, University of California, Vol. I, No. 4, 1893, p. 129.

[2] *The Geomorphogeny of Northern California.* Bulletin of the Department of Geology, University of California, Vol. I, No. 8, 1894, p. 270.

[3] *Coos Bay Folio*, U. S. Geological Survey, p. 1, 1901.

FOR ARID CLIMATES

1. Warm-temperate arid: moderate sun and wind action.
2. Tropical arid: strong sun and wind action.
3. Cold-temperate arid: strong frost and wind action.

FOR RAINY CLIMATES

1. Temperate rainy: moderate mechanical and chemical disintegration.
2. Tropical rainy: moderate mechanical, intense chemical disintegration.
3. Subpolar rainy: intense mechanical, moderate chemical disintegration.

The evidence in regard to the relative position of the varieties of rainy climate does not seem to be as secure as that in regard to the arid climates.

In comparing the rainy climates to the arid it is thought that, on the whole, the rainy climates are the greater destroying agents, but so many factors enter in the final result that it is thought that *a change toward semiaridity will hasten instead of retard erosion* through a weakening of the vegetal covering and a concentration of rainfall. The local accumulations of waste resulting from a movement toward aridity, while apparently indicative of great erosion, should really from their mere presence not be allowed to influence the judgment.

Recent geological times have been marked by climatic oscillations of great magnitude resulting in synchronous erosional and sedimentary oscillations. In past geological times other climatic oscillations must be presumed to have taken place frequently, though normally of much less intensity than during the past ice age. The sedimentary effect of climatic variations as well as stable climates is therefore of geological importance. From the previous discussion it would appear that any variation *from* a temperate climate, either arid or pluvial, would involve a temporary, abnormally rapid increase of rock waste until the regolith had become adjusted to the new conditions. Any variation *toward* these temperate means, such as the normal changes in the temperate zones since glacial times, will result, on the other hand, in a rapid slackening of rock destruction. Through geological time, therefore, the slowly but perpetually fluxing climates would

find a delicate response in the rates of erosion and the kinds of material supplied to the streams. With each climatic oscillation the delicate balance of erosion to stream transportation is thrown out of equilibrium and a wave of disturbance *originating at the headwaters* is sent to, and even beyond, the river's mouth. Even when the nature of the climatic changes at the distant source cannot be determined, they should still be recognized as possible factors in those lithologic distinctions which characterize the successive stages of a sedimentary formation.

The influence of climatic changes upon sedimentation has been tacitly recognized by certain leading writers, either as a hypothesis to account for a regular alternation of marine strata, as has been done by Gilbert;[1] or, through the use of gravel terraces as a means of correlation between glaciated and unglaciated regions. In the latter case they have been distinctly recognized and classified by Davis and Huntington as terraces of climatic origin, and criteria for their distinction have been devised. The relations of climate to erosion appear to be so sensitive, however, and so important, as a causal factor in the variations of stratified rocks, that it would seem desirable to distinguish it clearly as a separate cause, and call special attention to it, as is here done, as of co-ordinate importance with minor movements of the earth's crust. The lack of conscious recognition of this factor has without doubt caused many minor sedimentary changes, and even some greater ones, to be taken as evidence of earth movement, when climatic changes have at least entered as important contributory factors.

Before these waves of climatic effect find record in the strata, however, they are modified by the accompanying variations in the power of transportation and the changes which the sediments undergo before burial on the surface of the flood-plain or bottom of the shallow sea, modifications which will be discussed in the two succeeding parts.

[1] "Sedimentary Measurement of Cretaceous Time," *Journal of Geology*, Vol. III, 1895, pp. 121–27.

[*To be continued*]

Reviews

The Earth a Failing Structure. Presidential Address before the Philosophical Society of Washington. By John F. Hayford. *Bulletin of the Philosophical Society of Washington, D. C.*, Vol. XV, pp. 57–74, December, 1907.

The title of the address clearly expresses its central thought. The endeavor is to show that the earth is not a competent elastic structure. The main basis of argument is that, in the past, the earth has yielded frequently, if not continuously, to the stress-differences brought to bear upon it, and that it is still yielding. This yielding is repeatedly spoken of as non-elastic, but specific evidence is not given that the yielding is strictly of the non-elastic type. Every geologist will accept the fact of yielding without hesitation, but some of us might be disposed to question the precise method by which the yielding takes place, for it is just at this point that discrimination now halts for adequate evidence, and it is just here that some of the greatest advances in deformation appear now to be on the verge of realization. If the conclusion that the earth is a failing structure can be safely based on the gross observation that it, or parts of it, have yielded to stresses in the past, there can be little ground for difference of view, and little occasion to regard the view as new except in its form of expression, and we may all acquiesce in the striking text of the address.

At the same time it may be said with equal deference to observed fact that the earth is a *creative* structure and that it long has been and still is *generating* structural strength, elasticity, and rigidity. On the whole, its creative activities seem to have been quite as pronounced as its failing tendencies; its acquisitions of competency to have been quite as great as its exhibitions of incompetency.

Perhaps nothing better represents a failing structure, in the sense of the address, than a glacier which, under normal conditions, is ever yielding to the stress of gravity. And yet if one wanted to select a cubic foot of ice which had the maximum of strength and rigidity and the highest elastic limit, he would seek it at the lower end rather than the upper end of the glacier. The structural competency of the ice normally increases in about the proportion in which it has previously failed as a competent elastic structure, if one so interprets its yielding.

If a sandstone be sufficiently stressed, it will perhaps seem to fail as a structure, but the quartzite into which it might pass would doubtless

show under test greater strength, greater rigidity, and a higher elastic limit, than the original sandstone. A plastic shale, if duly forced to "fail" often enough and sufficiently, might, like certain of our shopmen, come out of the process a highly elastic schist. If ten million blocks of earth-material, so distributed throughout the earth as best to represent its structural competency, could be tested today and the results compared with a similar test made in Cambrian times, the elastic competency would quite certainly be found to be as great now as then. There is some presumption that it would be rather greater.

The engineer in dealing with an artificial structure properly enough proceeds on the assumption that there is present a certain modicum of structural competency, and that when this is once broken down that ends the matter. The earth cannot be dealt with advisedly in this way. The constant regeneration of strength, of rigidity, and of elasticity, under appropriate conditions, is as vital a factor in the earth problems as is the breaking-down of such acquisitions of these properties as had been inherited from the previous constructive processes.

There are many things in the address which are suggestive and helpful, and in so far as they lead on to more critical studies they are heartily to be welcomed. The reviewer would suggest, however, as a running mate to this address, one on the earth as a generative structure. T. C. C.

Schmidt's Geological Sections of the Alps.

American geologists who are interested in modern interpretations of Alpine structure will find a valuable series of colored sections in several pamphlets by Professor C. Schmidt of Basel, as follows: (1) *Bild und Bau der Schweizeralpen*, which appeared as a supplement to Vol. XLII of the Swiss Alpine Club, 1907 (Basel: Finckh. Fr. 5), contains, besides a beautifully illustrated text, a small geological map and a remarkable group of sections illustrating the extreme extension now given to the idea of overthrust folds. (2) *Führer zu den Exkursionen der deutschen geologischen Gesellschaft im südlichen Schwarzwald, im Jura und in den Alpen, August, 1907*, by Schmidt, Buxtorf, and Preiswerk (Stuttgart: Schweizerbart. M. 5), containing a number of more detailed sections, as well as the group of general sections. (3) *Ueber die Geologie des Simplongebietes und die Tektonik der Schweizeralpen* (*Eclog. geol. Helv.*, IX), with a number of detailed sections and a general geological map of the Alps between St. Gotthard and Mont Blanc. (4) *Tektonische Demonstrationsbilder* (to be had of the author. Fr. 1), with some of the same Alpine sections and several additional sections for the Vosges and the Schwarzwald.

W. M. D.

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APRIL–MAY, 1908

GEOLOGY OF THE HAYSTACK STOCK, COWLES, PARK COUNTY, MONTANA

WILLIAM H. EMMONS

INTRODUCTION

The Haystack stock is a mass of coarse-grained gabbro, diorite, and allied rocks, situated at the head of Boulder River, near Cowles Post-Office, Park County, Montana, in the southeastern quarter of the Livingston quadrangle, about 65 miles by stage from Livingston. The geology of this portion of the Livingston quadrangle was mapped in 1890 by Professor J. P. Iddings, but the Haystack stock, and its relations to the surrounding rocks, were regarded by him as of sufficient interest to warrant further study, and, accordingly, in 1903, additional field-work was done by the writer, assisted by Robert Butler, A. C. Ellsworth, and James Walker. No claim for originality is made for the geological map, Fig. 1, since it is essentially that published in the Livingston folio. Mr. Iddings further directed the office work, and placed in the hands of the writer his field notes and a large amount of material collected during the mapping of the Livingston quadrangle. Analyses of six type specimens, and of two mineral separations were made in the laboratory of the U. S. Geological Survey by Mr. George H. Steiger.

PHYSIOGRAPHY

Topography.—The area included within the limits of the map, (Fig. 1), is a part of the high dissected plateau which is somewhat indefinitely called the Snowy Mountains. The general elevation of

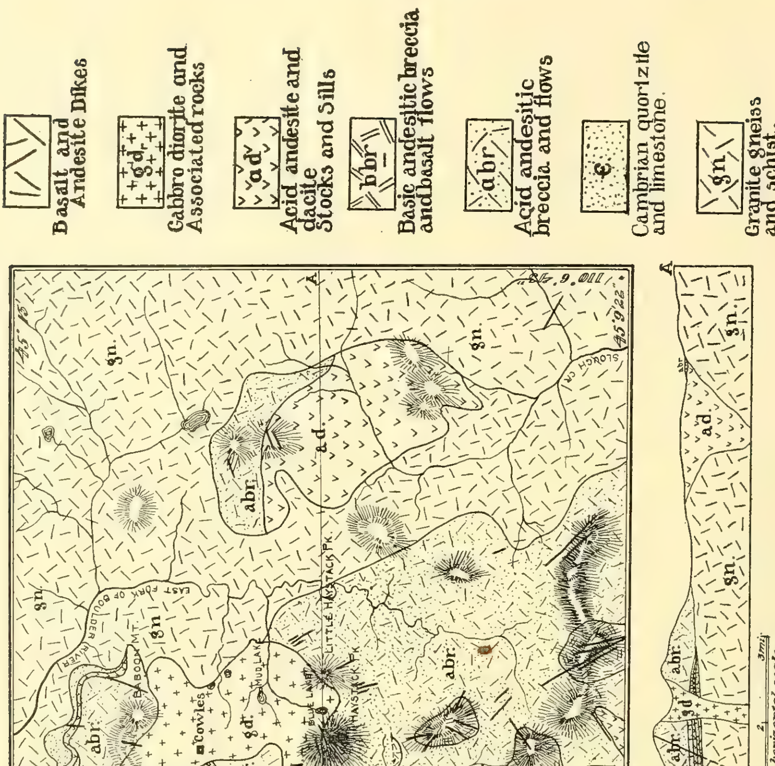

FIG. 1.—Map of Haystack stock and vicinity, Cowles, Park Co., Mont.

this plateau is from 9,000 to 10,000 feet above sea level and numerous peaks are higher. Of these the most conspicuous are Haystack Peak, Little Haystack Peak, and Baboon Mountain. Many canyons traverse the plateau and are sunk from 2,000 to 3,000 feet below the level of the upland. They are narrow, U-shaped, and their walls are very steep, even to the sources of the streams. The trees are mainly spruce, white bark pine, and lodge-pole pine. They are comparatively small and are valuable only for local use in connection with the nearly dormant mining industry. Aspens and willows grow in the marshes along the streams, and above 9,500 feet the vegetation consists chiefly of small junipers and stunted cedars.

Drainage.—The Boulder River is the most important stream of the area; rising south of Haystack Mountain it flows northward through the Snowy Range and enters the Livingston River at Bigtimber. Several tributaries join the Boulder River from the west, among which are Elk Creek, Copper Creek, and Sheep Creek. From the east its affluents are East Fork and Basin Creek. The southeastern portion of the area mapped is drained by Slough Creek which, flowing southward, joins the Yellowstone River in the Yellowstone National Park. Haystack Basin lies between Haystack Peak and Baboon Mountain. A low ridge, trending north and south, forms a watershed west of which the drainage is through Basin Creek into the Boulder River.

Effect of character of rocks upon topography.—The stock of Haystack Basin, especially the coarse-grained central portion, weathers very readily, falling into coarse arkose and consequently forms a relatively low area. The eruptive rock around the stock is very resistant, since it has been indurated at the contact and it forms the mountain crests to the north and to the south of the basin. Elsewhere, the breccia and minor intrusives appear to have been eroded at about equal rates. Dikes seldom stand out conspicuously above the surface, and other intrusives, aside from the Haystack stock, do not find marked expression in the topography. Sedimentary rocks have only a small areal distribution. They are nearly flat and do not form notable physiographic features. They outcrop only on the sides of the canyons and are represented by a quartzite member which usually forms a bench, above which is a ledge of limestone.

The differences in the constitution of the crystalline schists are too slight to find expression in topographic form.

Glaciation.—The effects of glacial erosion are conspicuous in the Snowy Mountains. The streams head in typical glacial amphitheaters, sharp and clear cut. On the floors of these amphitheaters in rock basins are occasional lakes. In this part of the valleys drift is thin or absent and at many places the rocks are polished or striated. Lower down in the mountains, usually three or four miles below the sources of the streams, the floors of the canyons are covered with drift which at many places occurs as knobs or hillocks from ten to forty feet high. Lakes and kettles within the morainal belt are comparatively rare.

Culture.—In some years a five-stamp mill is operated at Cowles Post-Office during a part of the summer and a number of prospectors do assessment work. As soon as the snow becomes too deep for easy travel, the country is almost deserted until the following spring. A wagon road connects Livingston with Cowles. From there trails lead southeast to Cook City and to the mines around Horseshoe Mountain. In the early 90's this area was the scene of considerable mining excitement, and a camp of a hundred or more houses, known as Independence, was built at the junction of Basin Creek and Boulder River. A mill was installed at this point and ore was hauled by wagon from the Independence mine in Haystack Basin. The camp was soon deserted, but the name is sometimes used for the camp at Cowles Post-Office, about a mile east of the old camp.

OUTLINE OF GENERAL GEOLOGY

Pre-Cambrian gneisses and schists.—The oldest rocks within this area form a crystalline complex consisting in the main of crenulated and intensely folded granite-gneiss and mica-schist. The gneiss is at most places coarse-grained, though medium or fine-grained facies are common. The gneiss is composed of feldspar, quartz, biotite, and muscovite, with hornblende and magnetite as accessory minerals. Like minerals are arranged in laminae giving the gneiss its banded appearance.

Traversing the gneiss in all directions are streaks of dark mica-schists varying in width from less than an inch to more than fifty

feet. The direction of schistosity agrees closely with the banding of the gneiss, and both were apparently produced at the same time. The dark schists consist essentially of biotite, feldspar, and hornblende. The contacts between the gneiss and the included schists are not sharp and distinct, though a short distance away they appear to be so, owing to the contrast in color between the light and dark rock. The two merge into each other within a narrow zone, and the bands of schist thin out and end within the gneiss. The forms assumed by the bands of schist are extremely irregular; some of them are curved lines; sigmoidal forms are not uncommon; rectilinear bands do not occur for any considerable distance. Some of the curved bands are fractured and broken by faults which have been completely healed.

Pegmatite.—The crystalline complex is cut by dikes of pegmatite which is composed of feldspar, quartz, and mica. Such dikes are especially well developed on Lake Plateau about two miles north of the northeast corner of the area mapped (Fig. 1) where red feldspars occur in large crystals which inclose smaller bodies of quartz, most of them about two inches in longest dimension, and thick six-sided plates of mica about half as large. The pegmatite is not mashed and, therefore, is later than the metamorphism of the gneiss and schist, but since it does not cut the Cambrian sediments it is probably of pre-Cambrian age.

CAMBRIAN

Overlying the pre-Cambrian rocks unconformably are beds of Cambrian quartzite, limestone, and shale. The basal member is a buff, pink, or gray quartzite from 200′ to 300′ thick, and its basal layers at some places contain small pebbles of the crystalline schists. The quartzite is thoroughly indurated, and under the microscope shows characteristic secondary enlargements of the grains of quartz.

Above the quartzite and conformable with it in dip is blue or gray limestone from 50′ to 300′ thick, near the base of which are a few feet of shale. It is sometimes massive, more often thinly bedded, and contains cherty layers. Some of the layers of the limestone are limestone conglomerate, composed of flat limestone pebbles from

one-half inch to five inches in diameter, cemented by a limestone matrix. The limestone has been extensively recrystallized since it was deposited and is largely composed of closely interlocking anhedrons of calcite, 1 ^{mm} or less in longest diameter. In some localities it is rich in fossils. On the trail about two miles northwest of the point where Boulder River is intersected by the northern boundary of the area mapped on Fig. 1, exposures show that certain beds of the limestone are composed almost entirely of fragments of trilobites. The quartzite is the Flathead quartzite of Mr. Weed[1] and the limestone is very probably to be correlated with the Meagher limestone in his section at Helena.[2]

Immediately south of Copper Creek, at a point about three-quarters of a mile above its junction with the Boulder River, the limestone, here thinly bedded and shaly, rests upon gneiss, showing that it was deposited by overlap upon the sinking Cambrian sea bottom.

The Cambrian beds dip gently west-southwest away from the pre-Cambrian rocks and are intruded by sills of andesite-dacite, and cut by the Haystack stock. At the contact with the stock the limestone is metamorphosed and locally contains secondary quartz, epidote, garnet, and an undetermined amphibole. The attitude of the Cambrian beds at the contact with the Haystack stock is approximately the same as away from it.

EXTRUSIVE ROCKS

Occurrence and distribution.—Overlying the crystalline schists and the sedimentary rocks and conforming to the irregularities of their eroded surface is a great thickness of extrusive rocks, consisting of breccias, tuffs, agglomerates, and lava flows. These rocks are formed of material thrown out of volcanic vents and are more or less continuous for many miles to the south and west, covering a vast area in and around the Yellowstone National Park.

The extrusive rocks do not represent a continuous series, for unconformities of erosion occur at many places. The presence of silicified trunks and stumps of trees, some of them upright as they grew, shows that between the volcanic eruptions there were periods of

[1] *Livingston Folio,* Geological Atlas of the U. S., U. S. Geological Survey.

[2] *Helena Folio,* Geological Atlas of the U. S., U. S. Geological Survey.

quiescence of considerable duration. At some of these unconformities there is an abrupt change in the appearance of the breccia. There are more or less constant differences between the lower and the upper portions of the breccia, and the series has been divided by Mr. Iddings[1] into the acid andesitic and the basic andesitic breccia.

The acid andesitic breccia.—The acid andesitic breccia consists chiefly of light-colored andesite, dacite, and latite fragments which vary in size from fine dust to masses several feet in longest dimensions. The coarse material is most abundant in the lower portion of the formation, while the upper portion contains beds which are composed almost entirely of volcanic dust. The chaotic basal portion contains large fragments of gneiss and quartzite, which were broken from the pre-Cambrian and Cambrian formations, and probably represent material thrown out at the time of the earliest eruptions. Such fragments are very abundant in the west wall of the Boulder Canyon due west of Haystack Peak.

The upper portion of the acid breccia is largely composed of fine material; some of it is well stratified but probably of subaerial origin. The bedded tuffs dip at low angles but the dip is not quaquaversal with respect to the Haystack stock. It is probable that the material from these beds came from several sources, and since much of it is very fine, the sources may have been a considerable distance away. The thickness of the lower acid breccia is variable and reaches a maximum of 1,500 feet. It is well exposed above the Cambrian on the divides between the tributaries of the Boulder River at the head-waters of this stream, also south of Haystack Peak at the head of East Fork, and at the head of the drainage of Buffalo Creek. There is an isolated remnant of the breccia capping the gneiss about two miles northeast of Little Haystack Peak. The acid breccia probably once covered a much more extensive area than it does now, and has since been eroded. Mr. Arnold Hague[2] has shown that in the Yellowstone National Park this early acid breccia belongs to the Eocene period and corresponds with the Fort Union horizon. The early acid breccia is cut by andesite-dacite stocks and

[1] Iddings, *Livingston Folio*, p. 6.

[2] "The Age of the Igneous Rocks of the Yellowstone National Park," *American Journal of Science*, Fourth Ser., 1896, p. 450.

by the Haystack stock. At its contacts with the Haystack stock the breccia is greatly indurated and weathers at some places like a massive rock. On account of its greater hardness this contact at most places forms a ridge. Since the border facies of the Haystack stock is fine-grained, it is impossible at many places to locate precisely the contact, though the doubtful zone is usually not more than a few yards wide.

Basic andesitic breccia.—The basic andesitic breccia is darker than the acid breccia. Chocolate, dark grays, and somber shades of red and yellow predominate. It is composed of pyroxene-andesite and hornblende-pyroxene-andesite, with a subordinate amount of dacite and latite. Fragments of gneiss or of quartzite are much less abundant than in the lower breccia. The fragments are generally smaller than those in the basal portion of the acid breccia and beds of fine-grained tuff are less conspicuous than in the acid breccia. Basaltic lava flows which are very common, especially near the top of the formation, are best developed in the southwest portion of the area. The thickness of the upper breccia is very great. The canyon of Hell Roaring Creek, several miles southwest of the area mapped, is nearly 3,000 feet deep and is cut entirely in this formation. It is probable that this breccia also was formerly more extensive and it may have completely covered the acid breccia. The basic breccia is of Neocene age.[1]

ANDESITE-DACITE INTRUSIVES

Andesite-dacite sills.—Andesite-dacite sills occur as sheets injected between the Cambrian strata. In this area they are present wherever a section of Cambrian rocks is exposed. At most places there is a sheet between the quartzite and the limestone at the horizon of the shales which occur at the base of the limestone and several sheets are intercalated within the limestone. The cartographic representation is necessarily generalized, showing from one to three of these sheets, but where the Cambrian beds are thickest there are sometimes more. The maximum thickness of the sills is about two hundred feet.

The andesite-dacite is dark gray, reddish gray, or brown, and contains phenocrysts of feldspar, hornblende, quartz, and biotite.

[1] J. P. Iddings, Folio 30, "Yellowstone National Park," Geological Atlas of U. S., U. S. Geological Survey.

Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, green hornblende, quartz, orthoclase, magnetite, and biotite. Calcite and serpentine are present as secondary minerals. Orthoclase and quartz are sometimes present in considerable amount when the composition of the rock approaches that of quartz-monzonite-porphyry. Since the sills are cut by the Haystack stock they are older than it, and since they do not cut the breccias they are possibly older than them, and presumably the oldest Tertiary volcanics in the district.

Andesite-dacite stocks.—Andesite-dacite stocks cut the pre-Cambrian rocks and the basic breccia. The largest one is about two miles east of Little Haystack Peak, and covers an area of nearly two square miles. Several smaller bodies occur along the southern border of the area mapped.

The andesite-dacite is gray or pinkish gray, and contains phenocrysts of feldspar, hornblende, quartz, and mica. Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, quartz, green hornblende, pyroxene, orthoclase, and magnetite. The andesite-dacite stocks are younger than the early breccia and probably older than the later breccia. They are closely allied to the sills in composition, but if the sills are older than the early breccia, which the stocks cut, a considerable period intervened between the two intrusions. The composition of the andesite-dacite is near that of the early breccia, and the sills, stocks, and breccia probably came from the same or closely related magmas.

The Haystack stock.—The Haystack stock is an intrusive body of irregular shape cutting through pre-Cambrian schists, Cambrian sedimentary rocks, and the early acid breccia. It is composed entirely of granitic rocks varying in composition from quartz-monzonite to olivine-gabbro. These grade into one another, and it is assumed that they represent the products of differentiation from a common magma.

Basalt and andesite dikes.—Basalt or andesite dikes cut all the other rocks. They are most abundant in the country south, west, and east of the Haystack stock, and have a rudely radial arrangement around it. In width they vary from four inches to forty feet and some are exposed for considerable distances, though most of them

are partially concealed by detrital material. In appearance the dike rocks are dark and either aphanitic or contain inconspicuous phenocrysts of augite, feldspar, and olivine. Under the microscope they show a considerable range of composition. The basalt dikes have a microcrystalline groundmass containing a large number of lath-shaped labradorite crystals which flow around larger phenocrysts of augite and olivine. Hornblende phenocrysts are present in some thin sections. In the less basic dikes, the andesites, the groundmass, sometimes glassy, contains a smaller amount of plagioclase and augite. Hornblende is more abundant than in the basalt dikes. Some thin sections show numerous large andesine phenocrysts. Some of the dikes can be traced into the Haystack stock, though none of them crosses it. Probably many of them are connected with it in depth.

PETROGRAPHY OF HAYSTACK STOCK

Relation to other rocks.—The Haystack stock occupies the greater part of Haystack Basin, extending eastward nearly to the East Fork of the Boulder River. A long arm trends westward from Haystack Peak for nearly a mile and crosses the West Fork of the Boulder River; another arm extends northwest to the western spur of Baboon Mountain. Its outcrop altogether occupies an area of about two and one-half square miles. The stock cuts through the crystalline schists, the Cambrian sedimentary rocks with intruding sills, and the early acid breccia. There is no evidence that the Cambrian beds were turned up by the intrusion, for wherever they outcrop near the stock, their attitude is approximately uniform and they dip southwestward at low angles near the stock in the same manner as at some distance away from it.

The western arm of the stock is closely related to a fault which extends westward from the north spur of Haystack Peak and crosses the Boulder River at an elevation of about 7,900 feet. North of the fault the Cambrian sediments occur some 600 feet above the stream bed on both sides of the Boulder River. South of the fault the Cambrian is wanting and the breccia is the lowest formation exposed. The minimum throw of the fault at this point is 600 feet. So far as known, the Haystack magma did not penetrate the shaly beds between

the Cambrian quartzite and the limestone. The sills in the Cambrian are characteristic of this formation over wide areas and are not to be regarded as apophyses of the Haystack stock; further, they are more siliceous in composition than the average of the stock, and they are thicker away from the stock than near it.

There is no conclusive evidence that the Haystack stock ever reached the surface. It is of later age than the acid breccia, and appears to have extended to near the top of this formation, but it may have been deeply buried under the basic breccia, which has a thickness of 2,000 feet or more in Hell Roaring Creek near by. Since, however, its composition is near that of the basic breccia, it is possible that it formed a channel through which a portion of this breccia reached the surface.

Appearance.—The peripheral facies of the Haystack stock is dark, fine-grained, and contains a few inconspicuous anhedra of feldspar and biotite. A short distance toward the center from the periphery, it becomes of lighter color and coarse grain, and is composed of feldspar, quartz, hornblende, and mica. Still farther from the border, it becomes much more coarsely crystalline, of darker color, and is composed of biotite, pyroxene, and magnetite. In the more basic facies of the central portion of the stock the ferro-magnesian minerals approximately equal the light-colored constituents. The various facies grade one into the other except in rare cases where locally there is a rather sharp contact between them. A notable example occurs near the wagon road a few rods south of the divide between West Basin Creek and East Basin Creek, where dark gabbro of medium grain appears to cut the coarser, lighter gabbro, but a few feet away from this contact these two rocks, traced continuously between, grade into each other as elsewhere. The various rocks of the stock are always massive, and do not show evidence of mashing. Near the border a few fragments of surrounding rocks are present, but these are rare or wanting in the interior of the stock. There has been fracturing since the solidification of the stock and it is traversed by joints in several directions. Along some of these fractures the surrounding rock is extensively altered, but this alteration is local and the rocks of the stock are for the most part fresh.

At a number of localities veins of coarse-grained granite cut the

stock. These vary in width from less than one inch to six or eight inches, and contrast strongly in color and composition with the surrounding rock. Basalt and andesite dikes which are exposed at numerous places a short distance from its border do not cross the stock, nor do they occur near its center.

Minerals of the stock.—The constituent minerals of the stock, though all are not present in a single specimen, in approximate order of abundance are: plagioclase, orthoclase, augite, hypersthene, biotite, quartz, hornblende, magnetite, olivine, apatite, pyrite, and zircon. Plagioclase shows the usual albite and carlsbad twinning, and frequently zonal structure. Some of the plagioclase contains a large number of minute dark inclusions, which give it a grayish color. Small prisms of apatite, together with a few anhedrons of ferromagnesian minerals are similarly included. In composition the plagioclase varies from oligoclase to labradorite. In the diorite and quartz-diorite plagioclase is as a rule oligoclase or andesine, and in the most basic types it is labradorite. The total amount of plagioclase in the different rocks of the stock is remarkably uniform, and in most instances it constitutes from 40 per cent. to 50 per cent. of the rock. Plagioclase was among the first minerals formed.

Orthoclase, always present, and in some specimens in considerable amount, forms irregular anhedrons which fill the interstices between all the other minerals, except quartz. Some of it incloses ferromagnesian minerals, and apatite; and again it incloses plagioclase poikilitically or is microperthitic with albite. It was one of the latest minerals formed, and constitutes from 2 to 18 per cent. of the rock. Quartz occurs as irregular bodies in nearly all of the rocks of the stock, though it is wanting in some of the olivine gabbros. It reaches a maximum in the granodiorites, where it constitutes nearly 20 per cent. of the rock. In many specimens quartz and orthoclase form a micrographic intergrowth in which orthoclase exceeds quartz. The micrographic intergrowth crystallized after all other minerals had formed.

Pyroxene, though not present in every facies of the stock is, altogether, the most abundant ferromagnesian mineral. Its anhedra are for the most part irregular, but some of them approach idiomorphism. Augite and hypersthene are both present. Augite is pale violet.

buff, and is very faintly pleochroic. It is twinned parallel to the first pinacoid. Hypersthene is rather irregular in outline, is never twinned, and is less well cleaved than augite. The pleochroism varies from pale green parallel to $\mathfrak{c}$ to reddish yellow parallel to $\mathfrak{a}$ and $\mathfrak{b}$. The two pyroxenes are intricately intergrown and were synchronous in their crystallization which was, in some cases, contemporaneous with and in others immediately followed that of plagioclase. Some of the pyroxene is altered to bastite. An analysis of a mixture of the two pyroxenes from the olivine-gabbro (variety E) is given on p. 215.

Biotite is present in all varieties of the rock and occurs as irregular flakes of various sizes up to 2^{mm} in diameter. Biotite incloses small grains of magnetite and more rarely minute bodies of plagioclase; in many specimens it constitutes about 5 per cent. of the rock. An analysis of biotite separated from variety D is given on p. 213.

Hornblende occurs as small irregular anhedrons longer than they are wide; nearly all are fibrous, only a few sections showing the usual hornblende cleavage. It is pale-yellowish green and slightly pleochroic. A part of the hornblende is probably secondary and it may be uralite, though there is nothing in its crystal form to suggest derivation from a previous pyroxene, and it is possible that it is secondary to another hornblende. Minute inclusions of magnetite are present in the hornblende and small shreds of biotite are similarly included, Many of the rocks of Haystack Basin contain no hornblende at all, but it is the chief ferromagnesian mineral of the quartz-diorite.

Magnetite is present in all specimens constituting from 2 per cent. to 5 per cent. of the rock. It is a little more abundant in the more basic gabbros and occurs both as irregular anhedrons and idiomorphic crystals. In feldspar it is present as minute dust-like particles and also in larger bodies, but the greater portion of it is included in or associated with the ferromagnesian minerals. The chemical analysis of the rock shows that it contains considerable titanium. It crystallized partly after the plagioclase and contemporaneously with the ferromagnesian minerals.

Olivine, for the most part allotriomorphic, is present in a few of the more basic varieties of the gabbros. It is fractured and along the cracks is altered to serpentine. Some of it is completely replaced

by the serpentine, and the serpentine includes minute bodies of magnetite. In all the rocks containing olivine a portion of it occurs in small, rounded, oval, or irregular inclusions in the pyroxene, and in specimens where only a small amount of olivine is present all is so included. The quantity of olivine varies from nothing to 5 per cent.

Apatite occurs as slender prisms about $.1^{mm}$ in length, wholly or partially included in the other minerals. In some specimens the prisms are arranged roughly parallel to one another, somewhat analogous to flow structure sometimes exhibited by lath-shaped feldspar in basalts, though the alignment is less perfect. These parallel prisms are included in plagioclase, orthoclase, and in the ferromagnesian minerals, showing that the crystallization of the apatite had begun but that the other minerals had not formed when the magma came to rest. The amount of apatite is nearly uniform and it usually constitutes about 1 per cent. of the rock. Pyrite occurs sparingly except in altered varieties where it is in part secondary. A very small amount of zircon is present in some specimens as characteristic prisms.

Description of Types of Haystack Stock

VARIETY A. ADAMELLOSE: GRANODIORITE

The most acid part of the stock covers a considerable area on the southern portion of the west spur of Baboon Mountain. It occurs near but not immediately at the edge of the stock. The rock is light gray, medium-grained, and has a smaller percentage of ferromagnesian minerals than any other of the stock rocks, hornblende, magnetite, and biotite constituting less than one-sixth of the mass. It is comparatively homogeneous in composition, although southward it grades into a more basic and more coarsely crystalline diorite.

The pinkish-white feldspar anhedra are from 3 to 5^{mm} long and the quartz is of smaller size. Hornblende is the most abundant ferromagnesian mineral, though magnetite and biotite are present.

Under the microscope the texture of the rock is seen to be hypidiomorphic granular. The minerals present in order of abundance are plagioclase, orthoclase, quartz, hornblende, biotite, magnetite, and apatite. Plagioclase occurs in nearly idiomorphic forms, tabular, parallel to the brachypinacoid. Many carlsbad twins and zonally

built crystals are present. Its composition is that of oligoclase-andesine, Ab_3An_1.

Orthoclase and quartz are relatively abundant, together nearly equalling plagioclase. Orthoclase, frequently microperthite, occurs as anhedra with a maximum length of 1^{mm}, and is also graphically intergrown with quartz. It also occurs as zones surrounding crystals of plagioclase. Quartz occurs as anhedra from 0.1^{mm} to 0.5^{mm} long.

Hornblende forms irregular anhedra, usually about 0.4^{mm} long, which inclose a large number of minute bodies of magnetite and biotite. A part of the hornblende, from its fibrous form, is believed to be secondary, possibly to pyroxene, though there is nothing in its outline which suggests the form of pyroxene and it may have been derived from an original hornblende. Biotite occurs as anhedra smaller than those of hornblende. Magnetite is included in the ferromagnesian minerals, and to a less extent in plagioclase. Long prisms of apatite are present. The order of crystallization was as follows: (1) Magnetite and apatite; (2) hornblende and biotite; (3) plagioclase; (4) orthoclase and quartz. The feldspars are slightly altered to kaolin and biotite to a lighter colored mica and to chlorite. An analysis of type A from the west spur of Baboon Mountain (See Fig. 3 p. 222) is given below:

ANALYSIS OF VARIETY A. GEO. STEIGER, ANALYST

Si_2O	65.06	H_2O-	.31
Al_2O_3	14.71	H_2O+	1.10
Fe_2O_3	2.82	TiO_2	.61
FeO	1.31	P_2O_5	.18
MgO	2.48	MnO	.18
CaO	3.43	BaO	.10
Na_2O	3.86	SrO	.05
K_2O	3.48	Total	99.68

NORM AND MODE OF VARIETY A

The norm of A calculated from the analysis is given in column I of the table below. The mode is given in column II. According to the quantitative classification this rock is adamellose. Its chemical composition closely resembles that of a quartz-mica-diorite, occurring in a stock at Crandall Basin, Hurricane Ridge, Yellowstone National

Park, described by Mr. Iddings.[1] It also resembles that of a hornblende-mica-porphyry from Cliff Creek, West Elk Mountains, Colorado, described by Dr. Whitman Cross,[2] and a mica-diorite from Lippenhof, N. Tryberg, Schwartzwald, Baden, described by Dr. G. H. Williams.[3]

I. Norm	
Quartz	19.50
Orthoclase	20.57
Albite	32.49
Anorthite	12.51
Hypersthene	4.80
Diopside	3.02
Magnetite	3.02
Ilmenite	1.22
Hematite	0.80
Apatite	0.34
	98.27
Water	1.41
Total	99.68

II. Mode	
Quartz	22.9
Orthoclase	17.8
Albite	30.7
Anorthite	10.3
Hornblende	9.7
Biotite	4.2
Magnetite and Ilmenite	4.1
Apatite	0.3
Total	100.0

VARIETY B. HARTZOSE: GRANODIORITE-PORPHYRY

At the eastern edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone Park a small tongue extends from the stock into gneiss. The specimen, taken 28 yards south of the northern edge of this tongue, is dark gray, fine-grained, and contains numerous phenocrysts of yellow feldspar, together with a smaller number of phenocrysts which appear from their form to be hornblende, but which in some cases have the luster and cleavage of mica.

Under the microscope the groundmass of the rock is seen to be composed of small interlocking anhedra of poikilitic quartz and alkali feldspar, a large number of minute pyroxene prisms, and a few anhedra of magnetite, plagioclase (oligoclase-andesine), and biotite. The porphyritic bodies, which in hand specimens appear to be crystals of single minerals, are found to consist of several minerals. These aggregations are of two kinds: those composed mainly of feldspar, and those composed mainly of ferromagnesian minerals.

[1] *Mon. XXXII*, U. S. Geological Survey, p. 261, 1889.

[2] *Fourteenth Annual Report*, U. S. Geological Survey, Part II, p. 227, 1894.

[3] *Neues Jahr.*, Band II, p. 624, 1883.

The outlines of the sections of feldspar aggregates are for the most part irregular but some are those of feldspar crystals. They vary from 0.3^{mm} to 1.5^{mm} in length. The matrix of the feldspar aggregates is mainly orthoclase and included within it are minute bodies of plagioclase, some approaching idiomorphism and showing both carlsbad and albite twinning. They are from 0.1 to 0.2^{mm} long, and are oligoclase-andesine. They penetrate one another most complexly. The plagioclase crystals of the aggregates do not lie entirely within the outlines of the orthoclase, but along its edges they penetrate the groundmass of the rock. The amount of plagioclase in the aggregates varies from 10 per cent. to 90 per cent. of the whole, and the quantity of orthoclase is reciprocal with that of the plagioclase. The other aggregates, composed mainly of ferromagnesian minerals, in some cases have outlines which strongly suggest the crystal form of hornblende. These aggregates are composed of mica, pyroxene, magnetite, feldspar, quartz, and apatite, but the proportion of these constituents varies greatly in different cases. In most sections of these aggregates, cut parallel to the *c* axis of hornblende, the minerals are arranged in rows, while in oblique sections and in those cut across the prism, the arrangement, sometimes roughly concentric, is usually quite irregular. The description of a typical section parallel to the *c* axis follows. It is 0.9^{mm} long and 0.4^{mm} wide, and is composed of mica, magnetite, feldspar, pyroxene, and quartz; mica and magnetite being most abundant. There are four belts parallel to *c* each about 0.1^{mm} wide; two of these are composed chiefly of mica, while the alternate two are chiefly magnetite. All the minerals within the aggregate are of small size, though the mica flakes are larger than the anhedra of other minerals. They are in various optical orientations; a little quartz and feldspar are present in all of the belts. Rimming these belts of mica and magnetite is a colorless border consisting of very minute anhedra of feldspar. It is 0.012^{mm} wide, and has the outline of a previous crystal. Beyond this is a fringe of minute pyroxene crystals which approach idiomorphism, and interspersed with these there is a small quantity of allotriomorphic feldspar. The inner outline of this fringe is very definite and sharp but the outer border is very irregular. Many of the crystals of pyroxene join the border of feldspar at right angles.

If the pyroxene border is a portion of the aggregate, then its outline is very irregular, but if the inner border of the pyroxene is considered as limiting the aggregate it has a definite crystal form. In other ferromagnesian aggregates rows of magnetite and mica are *en echelon*, and others are composed entirely of magnetite and feldspar, and still others of biotite and feldspar. All of them are surrounded by the fringe of minute pyroxenes.

The magmatic alteration shown by variety B is not unusual in igneous rocks of intermediate composition and is commonly regarded as showing a change in conditions after the phenocrysts formed and before the rock solidified. It is quite possible that some feldspar and hornblende had formed before the lava rose, and that when pressure was relieved they were partially or wholly dissolved, and under the new conditions recrystallized, their elements going into a number of other minerals. The mineral composition of the aggregates is not constant and could not have resulted merely from recrystallization of the original minerals without substitution.

An analysis of B taken from a point near the edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone National Park, is given below.

ANALYSIS OF VARIETY B. GEO. STEIGER, ANALYST

SiO_2	64.09	H_2O-	0.22
Al_2O_3	16.20	H_2O+	0.44
Fe_2O_3	2.61	TiO_2	0.49
FeO	2.40	P_2O_5	0.24
MgO	2.06	MnO	0.09
CaO	4.51	BaO	0.15
Na_2O	3.88	SrO	0.03
K_2O	2.51	Total	99.92

I. Norm		II. Mode	
Quartz	19.20	Quartz	21.8
Orthoclase	15.01	Orthoclase	11.7
Albite	33.01	Albite	30.1
Anorthite	19.18	Anorthite	15.1
Hypersthene	5.82	Pyroxene	11.2
Diopside	2.08	Biotite	4.8
Magnetite	3.71	Magnetite and Ilmenite	4.9
Ilmenite	0.91	Apatite	0.4
Apatite	0.34	Total	100.0
Water	0.66		
Total	99.92		

The norm of B calculated from the analysis is given in column I of the above table. This variety is a little lower in silica, potash, and magnesia than variety A, and richer in alumina, ferrous iron, and lime, while it contains approximately an equal amount of soda and ferric iron. Its mode is given in column II of the above table. According to the quantitative classification it is hartzose and in composition closely resembles a granodiorite from Grass Valley, Nev., described by Mr. W. Lindgren.[1] It is also somewhat similar to a granite from Butte, Montana, described by Mr. W. H. Weed.[2]

VARIETY C. TONALOSE: QUARTZ-BEARING DIORITE

Southwest of the summit of Baboon Mountain and near the outer edge of the stock the rock is fine-grained, dark, and nearly aphanitic, though a few small dark minerals are visible. This rock is cut by small dikes of light-colored medium-grained granite, which are described on p. 223.

Under the microscope the rock is seen to be holocrystalline, and allotriomorphic granular. The minerals, in order of relative abundance are andesine, pyroxene, orthoclase, quartz, biotite, magnetite, and apatite. Andesine, orthoclase, and quartz occur as interlocking anhedra, varying from 0.02 to 0.04^{mm} in diameter and constituting approximately 70 per cent. of the rock. The ferromagnesian minerals are rather evenly spaced with respect to the quartz and feldspar. Pyroxene occurs in bodies from 0.02 to 0.32^{mm} in diameter, those of the smaller size being much the more numerous. The smaller bodies approach idiomorphism, while the larger ones are irregular in form. Both augite and hypersthene are present. Biotite is less abundant and occurs as foliae from 0.1 to 0.3^{mm} long. Magnetite occurs in irregular bodies the size and number of which are something less than those of biotite. Apatite is present as long prisms. The usual order of crystallization was as follows: (1) Magnetite and apatite; (2) Pyroxene, plagioclase, and biotite; (3) Orthoclase and quartz.

An analysis of C, from a specimen taken near the outer edge

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 724, 1896.

[2] *Journal of Geology*, Vol. VII, p. 739, 1899.

of the stock, south of the summit of Baboon Mountain (see Fig. 3) is given below.

ANALYSIS OF VARIETY C. GEO. STEIGER, ANALYST

SiO_2	57.98	H_2O+	.49
Al_2O_3	17.01	TiO_2	.90
Fe_2O_3	3.34	P_2O_5	.43
FeO	3.34	NiO	trace
MgO	2.74	MnO	.12
CaO	7.35	BaO	.06
Na_2O	3.92	SrO	.02
K_2O	2.02	Total	99.86
H_2O-	.14		

The norm of C calculated from the analysis is given in column I of the table below, the mode in column II.

I. Norm		II. Mode	
Quartz	10.38	Quartz	12.1
Orthoclase	11.68	Orthoclase	9.7
Albite	33.01	Albite	31.2
Anorthite	23.07	Anorthite	20.8
Hypersthene	4.71	Pyroxene	13.5
Diopside	8.64	Biotite	6.7
Magnetite	4.87	Magnetite and Ilmenite	4.9
Ilmenite	1.67	Apatite	1.1
Apatite	1.01	Total	100.0
Water	0.63		
Total	99.72		

According to the quantitative classification this rock is a tonalose and its chemical composition very closely resembles that of a hornblende-augite-andesite from the Wind River Plateau, Yellowstone National Park, described by Hague and Jaggar,[1] and a diorite from Captains Bay, Unalaska Island, Alaska, described by G. F. Becker.[2] It is similar in composition to a large number of rocks from nearly every continent, being one of the commonest types known. It is very close to Clark's average rock for the United States, but exceeds it slightly in alumina, lime, and titania, and contains a little less magnesia and potash.[3]

[1] *Bulletin No. 168,* U. S. Geological Survey, p. 96.

[2] *Bulletin No. 148,* U. S. Geological Survey, p. 232.

[3] *Bulletin No. 78,* U. S. Geological Survey, p. 37.

VARIETY D. MONZANOSE: QUARTZ-BEARING ORTHOCLASE-GABBRO

Toward the interior of the stock the proportion of ferromagnesian minerals increases and the rock becomes more coarsely crystalline. The specimen described is a grayish-brown gabbro occurring about halfway betweeen Mud and Blue Lakes, and is composed chiefly of feldspar, pyroxene, and biotite.

Under the microscope the following minerals are seen to be present and are mentioned in the order of abundance: plagioclase, orthoclase, augite, hypersthene, magnetite, biotite, quartz, serpentine, and apatite.

Plagioclase occurs in nearly idiomorphic crystals. Carlsbad twins about 1^{mm} long are common, and some crystals show zonal structure. Both andesine and labradorite are present. Minute dust-like opaque bodies and larger ones of brown glass, with a little apatite, pyroxene, and magnetite, are included in the plagioclase. Orthoclase and quartz, micrographically intergrown, fill the interstices between other minerals. Augite is more abundant than hypersthene.

Biotite occurs as plates up to 3^{mm} in length, partly altered to hydro-biotite. An analysis of biotite separated from D is given below. Magnetite, highly titaniferous, is included in the other

ANALYSIS OF BIOTITE FROM VARIETY D. GEO. STEIGER, ANALYST

SiO_2	33.07	Na_2O	0.28
Al_2O_3	13.00	K_2O	6.11
Fe_2O_3	17.22*	H_2O-	5.41
FeO	not det.†	H_2O+	11.61
MgO	11.33		
CaO	2.45	Total	100.48

*Contains ferrous iron P_2O_5 and TiO_2. †Determined as Fe_2O_3.

minerals, and is especially abundant in the ferromagnesian constituents. A little serpentinized olivine is present. Long prisms of apatite show a tendency to parallelism. The order of crystallization was as follows: (1) Apatite and magnetite; (2) Plagioclase and the ferromagnesian silicates; (3) orthoclase and quartz. Feldspar is slightly kaolinized, hypersthene is partly altered to bastite, biotite to hydro-biotite, olivine to serpentine. An analysis of D from a specimen taken midway between Mud and Blue Lakes (see Fig. 3) is as follows:

ANALYSIS OF VARIETY D. GEO. STEIGER, ANALYST

SiO_2	54.84	H_2O-	.34
Al_2O_3	16.41	H_2O+	.93
Fe_2O_3	3.63	TiO_2	.99
FeO	4.54	P_2O_5	.35
MgO	4.71	BaO	.12
CaO	6.64	SrO	.05
Na_2O	3.27	Total	99.65
K_2O	2.83		

The norm of D is shown in column I of the following table; the mode in column II.

I. Norm		II. Mode	
Quartz	4.68	Quartz	6.8
Orthoclase	16.68	Orthoclase	15.4
Albite	28.30	Albite	27.5
Anorthite	21.41	Anorthite	19.7
Hypersthene	11.87	Pyroxene	19.5
Diopside	7.32	Olivine and Serpentine	0.5
Magnetite	5.34	Biotite	4.6
Ilmenite	1.98	Magnetite and Ilmenite	5.2
Apatite	1.01	Apatite	0.8
Water	1.27	Total	100.0
Total	99.84		

According to the quantitative system, variety D is a monzonose. It is less siliceous than those previously described and is chemically similar to an augite-andesite-porphyry from the Indian Creek laccolith, Yellowstone National Park, described by Mr. Iddings,[1] and to a diorite from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[2]

VARIETY E. SHOSHONOSE: ORTHOCLASE-GABBRO

This variety occurs about a half-mile northeast of the summit of Haystack Peak and a quarter-mile west of Mud Lake, or about halfway between the western shore of this lake and the north spur of Haystack Peak. It is a dark, coarse-grained gabbro in which feldspar, pyroxene, and biotite are visible in hand specimen, the ferromagnesian minerals constituting about one-third of its volume.

Under the microscope the texture is seen to be hypidiomorphic granular; plagioclase and pyroxene approach idiomorphism; ortho-

1 *Mon. XXXII*, U. S. Geological Survey, p. 83.

2 *Bulletin No. 148*, U. S. Geological Survey, p. 69.

clase and quartz are poikilitic with respect to the other constituents. The minerals present in order of abundance are: andesine, augite, orthoclase, hypersthene, magnetite, biotite, quartz, apatite, and olivine.

Andesine occurs in prisms from 1 to 2^{mm} long and about 0.3^{mm} wide, and commonly as carlsbad twins. Orthoclase occurs as a matrix for plagioclase and the ferromagnesian minerals, filling the angular interstices between them. Quartz is present only as a micrographic intergrowth with orthoclase. Augite, pale violet-buff, occurs as anhedra from 0.5 to 1.5^{mm} long. Hypersthene is of the same size and is pleochroic, green parallel to $\mathfrak{c}$, and reddish yellow parallel to $\mathfrak{a}$ and $\mathfrak{b}$. Both pyroxenes contain minute bodies of magnetite, biotite, and apatite, and a little serpentinized olivine, which taken together equal about 2 per cent. of the mineral. An analysis of a mixture of the two pyroxenes is given below. In the preparation of the sample the crushed and sized minerals were separated by Thoulet's heavy solution. The portion of the rock which came down at a specific gravity of 3.1, the maximum specific gravity of the solution, included, besides the pyroxenes, magnetite and bodies composed of magnetite and feldspar or pyroxene and feldspar. Those particles in which there was a considerable proportion of magnetite were removed with the magnet, and the remainder was treated with acid to remove small adhering particles of magnetite from the pyroxene. The resulting nearly pure pyroxene was recrushed, resized, and passed through the solution again, after which the treatment with the acid was repeated.

ANALYSIS OF PYROXENES FROM VARIETY E. GEO. STEIGER, ANALYST

		Molecular Proportion	Diopside	Soda Pyroxene	Alumina Pyroxene	Hypersthene	Quartz
SiO_2	50.95	+TiO_2 867	408	20	32	351	54
Al_2O_3	2.72	26	...	5	21	...	..
Fe_2O_3	1.70	11	...	..	11	...	..
FeO	13.87	197	69	..	11	117	..
MgO	15.58	390	135	..	21	234	..
CaO	11.39	+MnO 204	204	..	..	...	..
Na_2O	0.31	5	...	5	..	...	..
TiO	1.42	...	...	..	..	...	..
MnO	0.26	...	...	..	..	...	..
Total	98.19						

To ascertain the relative amounts of hypersthene and augite the following ideal compositions for the two pyroxenes were assumed:

Hypersthene $(Mg, Fe)O \cdot SiO_2$
Augite (a) $CaO \cdot (Mg, Fe)O \cdot 2SiO_2$
(b) $Na_2O \cdot Al_2O_3 \cdot 4SiO_2$
(c) $(Mg, Fe)O \cdot (Al Fe)_2O_3 \cdot SiO_2$

In the adjustment the TiO_2 was regarded as isomorphous with SiO_2 and the MnO isomorphous with FeO. A quantity of silica amounting to 3.24 per cent. cannot be accounted for by any probable adjustment, and it may have resulted from decomposition of adhering feldspar after treatment with acid, the insoluble silica remaining behind. In the hypersthene, iron : magnesia as 1 : 2. In the augite, diopside (*a*): soda pyroxene (*b*): aluminous pyroxene (*c*) as 204 : 5 : 32. With this adjustment of molecules the proportion of the two pyroxenes as they occur in the specimen gives:

Hypersthene	38.84
Augite	56.12
Quartz	3.24
Total	98.20

Hypersthene is 40.91 per cent. of the pyroxene, and augite 59.09 per cent. of the pyroxene.

Biotite is present as irregular plates, and magnetite occurs as bodies up to 0.8^{mm} in diameter. Apatite occurs as prisms in all the other minerals. The order of crystallization was the same as in D. The chemical analysis of E, taken one quarter-mile west of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY E. GEO. STEIGER, ANALYST

SiO_2	54.09	H_2O-	0.20
Al_2O_3	16.00	H_2O+	0.77
Fe_2O_3	2.92	TiO_2	0.99
FeO	5.54	P_2O_5	0.35
MgO	5.19	MnO	0.15
CaO	7.37	BaO	0.10
Na_2O	3.38	SrO	0.06
K_2O	2.67	Total	99.78

The norm of E, calculated from the analysis, is given in column I of the following table, the mode in column II.

I. Norm		II. Mode	
Quartz	1.56	Quartz	3.7
Orthoclase	16.12	Orthoclase	13.2
Albite	28.82	Albite	26.5
Anorthite	20.29	Anorthite	18.9
Hypersthene	13.88	Pyroxene	28.8
Diopside	11.22	Olivine and Serpentine	0.3
Magnetite	4.18	Biotite	3.1
Ilmenite	1.98	Magnetite and Ilmenite	4.8
Apatite	1.01	Apatite	0.7
Water	0.97	Total	100.0
Total	100.03		

Variety E is among the most basic of the Haystack rocks, and, according to the quantitative system of classification, is a shoshonose. It is closely similar to a diorite from Rock Creek, Crazy Mountains, Mont., described by Mr. J. E. Wolff,[1] and to a large number of shoshonites from the Yellowstone National Park, described by Mr. Iddings.[2] It is a little lower in potash than these rocks and richer in the ferromagnesian constituents.

VARIETY F. HESSOSE: OLIVINE-GABBRO

This variety is a dark gray, coarsely crystalline olivine-gabbro which occurs near the center of the stock. The specimen was taken near the base of the cliff southwest of Mud Lake. It is the most basic variety of the stock and is composed of feldspar, pyroxene, biotite, and olivine, the ferromagnesian minerals constituting about two-fifths of the whole.

Under the microscope the texture of the rock is hypidiomorphic granular, and the following minerals, named in relative order of abundance, are present: labradorite, augite, hypersthene, olivine, orthoclase, magnetite, biotite, and apatite. Labradorite occurs as crystals about 1^{mm} long, approaching idiomorphism, and is twinned according to albite and carlsbad laws. Orthoclase, containing a little graphic quartz, is present as irregular bodies, filling interstices between other minerals. The pyroxenes occur as anhedra from $\frac{1}{2}$

[1] *Bulletin No. 148,* U. S. Geological Survey, p. 144.

[2] *Journal of Geology,* Vol. III, and *Bulletin No. 168,* U. S. Geological Survey.

to 2^{mm} long and include a considerable amount of magnetite and minute particles of olivine and biotite. Olivine occurs as rounded or irregular bodies, in part included in pyroxene. It is partly altered to serpentine which either replaces the olivine completely, or occurs along its cracks. The fibers of the serpentine are parallel and not perpendicular to the boundaries and cracks of olivine. Biotite surrounds magnetite and is partially altered to chlorite. Small irregular grains of magnetite are present, wholly or partially included in the ferromagnesian minerals. The feldspar is almost free from magnetite. Apatite prisms are included in all the other minerals. A small amount of calcite is present.

The order of crystallization is as follows: (1) Olivine, apatite, and some magnetite; (2) some labradorite, pyroxene, more magnetite, and biotite; (3) more labradorite; (4) orthoclase and quartz. An analysis of F, from a specimen taken near the base of the cliff southwest of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY F. GEO. STEIGER, ANALYST

SiO_2	47.87	H_2O+	1.25
Al_2O_3	16.34	TiO_2	1.02
Fe_2O_3	3.59	CO_2	.44
FeO	7.17	P_2O_5	.41
MgO	7.80	NiO	.02
CaO	10.33	MnO	.14
Na_2O	2.43	BaO	.03
K_2O	.92	Total	100.04
H_2O-	.28		

The norm of F calculated from the analysis is given in column I of the following table; the mode in column II.

I. Norm		II. Mode	
Quartz	0	Quartz	0
Orthoclase	5.56	Orthoclase	4.9
Albite	20.44	Albite	19.2
Anorthite	30.86	Anorthite	26.7
Hypersthene	12.00	Pyroxene	30.9
Diopside	14.34	Olivine and Serpentine	6.8
Olivine	6.72	Biotite	4.5
Magnetite	5.34	Magnetite and Ilmenite	5.8
Ilmenite	1.98	Apatite	1.2
Apatite	1.01	Total	100.0
Water	1.53		
Total	99.78		

Variety F is the most basic of the Haystack rocks, and, according to the quantitative classification, is hessose. In composition it resembles an olivine-basalt from Franklin Hill, Plumas County, California, described by Mr. H. W. Turner,[1] an augite-diorite from Stony Mountain, Ouray County, Colorado, described by Dr. Whitman Cross,[2] and a basalt from Prospect Peak, Yellowstone National Park, described by Mr. Iddings.[3]

Chemical variation of varieties.—The analyses of the six varieties are given in the table below. The combining molecules of the rocks which

ANALYSIS OF TYPES OF HAYSTACK STOCK. GEO. STEIGER, ANALYST

	A	B	C	D	E	F
SiO_2	65.06	64.09	57.98	54.84	54.09	47.87
Al_2O_3	14.71	16.20	17.01	16.41	16.00	16.34
Fe_2O_3	2.82	2.61	3.34	3.63	2.92	3.59
FeO	1.31	2.40	3.34	4.54	5.54	7.17
MgO	2.48	2.06	2.74	4.71	5.19	7.80
CaO	3.43	4.51	7.35	6.64	7.37	10.33
Na_2O	3.86	3.88	3.92	3.27	3.38	2.43
K_2O	3.48	2.51	2.02	2.83	2.67	0.92
H_2O-	0.31	0.22	0.14	0.34	0.20	0.28
H_2O+	1.10	0.44	0.49	0.93	0.77	1.25
TiO_2	0.61	0.49	0.90	0.99	0.99	1.02
CO_2	.....	.....	.....	.....	.....	0.44
P_2O_5	0.18	0.24	0.43	0.35	0.35	0.41
NiO	.....	.....	trace	.....	.....	0.02
MnO	0.18	0.09	0.12	.....	0.15	0.14
BaO	0.10	0.15	0.06	0.12	0.10	0.03
SrO	0.05	0.03	0.02	0.05	0.06	.....
Total	99.68	99.92	99.86	99.65	99.78	100.04

have been analyzed, arranged according to the increase of silica, are shown in Fig. 2. Silica is platted as the abscissa and 798 combining molecules are taken as an initial point. The alkalies, alkali earths, alumina, and iron are taken as ordinates. The diagram shows graphically the irregularity in the variation of the oxides. Alumina shows little variation, about the same quantity being present in all analyses. Its total range of variation is but 23 molecules. The granodiorite A is least aluminous. None of the oxides vary directly or inversely with alumina, which is higher than any of the

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 734.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 180.

[3] *Mon. XXXII*, U. S. Geological Survey, p. 438.

other oxides except silica and lime and magnesia, at the basic end of the diagram. Ferrous and ferric iron are in a measure inversely proportional to each other, an increase in one usually being accompanied by a decrease in the other. The total amount of iron decreases irregularly to the more siliceous end of the series. Magnesia also decreases rapidly as the silica increases and this decrease more nearly agrees with that of the ferrous than of the ferric iron. Lime,

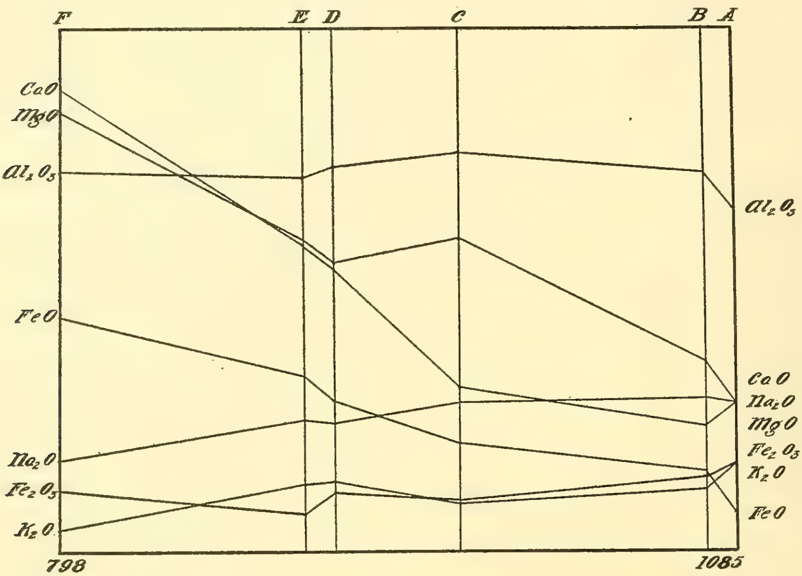

FIG. 2.—Chemical variation of types of the Haystack stock.

like magnesia, decreases steadily from the less siliceous toward the more siliceous end of the series, but increases slightly in the granodiorite at the extreme end. The soda, low in F, increases gradually and steadily to B, and falls slightly in A. Potash increases very irregularly to the more siliceous end of the diagram. The alkalies vary neither directly nor reciprocally with each other, though both increase with silica.

Mr. H. S. Washington,[1] in discussing the differentiated complex at Magnet Cove, Ark., ranges six analyses in order of ascending silica. In his diagram with but one exception the oxides increase

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 404.

or decrease with the silica. The variations of the oxides in the Haystack series, with respect to silica and to each other, are much less regular than is the series at Magnet Cove. This is well illustrated by the crossing descending lines in the diagram.

Probable average composition of stock.—The average composition of the six analyzed varieties of the Haystack stock is as follows:

AVERAGE CHEMICAL COMPOSITION OF THE SIX ANALYZED VARIETIES

SiO_2	57.32	H_2O+	0.83
Al_2O_3	16.11	TiO_2	0.83
Fe_2O_3	3.15	CO_2	0.07
FeO	4.05	P_2O_5	0.33
MgO	4.16	MnO	0.11
CaO	6.61	BaO	0.09
Na_2O	3.46	SrO	0.03
K_2O	2.40		
H_2O-	0.25	Total	99.80

NORM OF THE AVERAGE OF THE SIX ANALYZED VARIETIES

Quartz	8.58	Magnetite	4.41
Orthoclase	14.46	Ilmenite	1.52
Albite	29.34	Water	1.08
Anorthite	21.13	Fluorine	0.67
Diopside	8.51		
Hypersthene	10.37	Total	100.07

This is probably very close to the average composition of the stock, and is perhaps as good an estimate as could be made with the data at hand. Its composition closely resembles that of a large number of orthoclase-gabbro-diorites, andesites, and related rocks from Crandall Basin and Sepulcher Mountains, described by Mr. Iddings,[1] a number of monzonites and andesites from Colorado, described by Dr. Whitman Cross,[2] and diorites from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[3] Of the Haystack rocks the average is nearest C, which is a contact facies of the stock.

Asymmetry of the stock.—The map (Fig. 1) shows that the Haystack stock is asymmetrical. The stock is also asymmetrical with respect to its composition. Fig. 3 is a sketch map which shows the

[1] *Mon. XXXII*, U. S. Geological Survey, Part II.

[2] *Bulletins 1* and *168*, U. S. Geological Survey.

[3] *Bulletin 148*, U. S. Geological Survey, p. 69.

location of the rocks analyzed. The most basic (F) is not at the center of the stock, but southeast of it, and the most acid variety (A) is farther from F than the edge of the stock in several other directions. Moreover, the diorite south of F or between F and the border toward the south is less acid than A, though it is much more acid than F. It will hold true, however, that if lines are drawn to the border radiating from F, the composition of the stock along these lines becomes gradually more acid, though at different rates, and

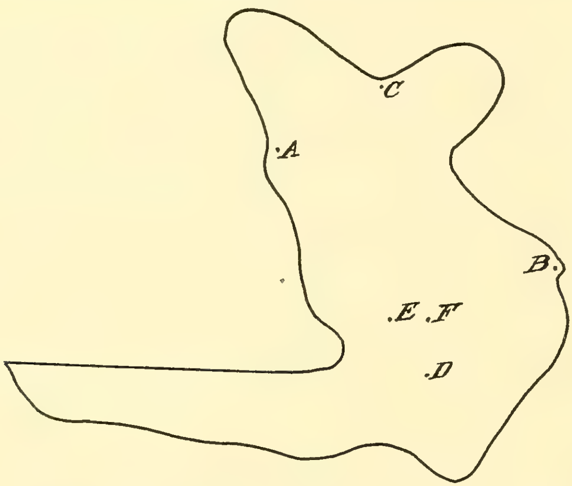

FIG. 3.—Outline of Haystack stock. The letters show the position of analyzed types.

some portions of the periphery are more acid than others. The modes of the six varieties are tabulated below, A, B, and C are the

MODES OF VARIETIES OF HAYSTACK STOCK

	A	B	C	D	E	F
Quartz	22.9	21.8	12.1	6.8	3.7	....
Orthoclase	17.8	11.7	9.7	15.4	13.2	4.9
Albite	30.7	30.1	31.2	27.5	26.5	19.2
Anorthite	10.3	15.1	20.8	19.7	18.9	26.7
Hornblende	9.7	....	....	....	....	....
Pyroxene	....	11.2	13.5	19.5	28.8	30.9
Biotite	4.2	4.8	6.7	4.6	3.1	4.5
Olivine and Serpentine	....	....	....	0.5	0.3	6.8
Magnetite and Ilmenite	4.1	4.9	4.9	5.2	4.8	5.8
Apatite	0.3	0.4	1.1	0.8	0.7	1.2

peripheral acid varieties, while D, E, and F are the basic central varieties. This table shows that quartz is present in the outer border of the stock in largest amount, and decreases toward the center of the stock. Orthoclase is present in every case, but is most abundant in the facies not far from the periphery. Plagioclase is present in approximately the same amount in all varieties, but is more calcic in the central ones. Pyroxene is least abundant near the periphery, and most abundant in the most basic facies near the center of the stock. Hornblende, in part probably secondary to pyroxene, is relatively abundant only in the most acid portion near the periphery. Olivine is abundant only in the most basic varieties near the center. Biotite and magnetite are fairly uniform in quantity.

The order of crystallization of the minerals of the stock, briefly summarized, is as follows:

1. Apatite, crystallized first, since it occurs in all the other minerals.

2. The ferromagnesian minerals, pyroxene, hornblende, biotite, magnetite, and olivine, crystallized early but mainly after apatite had formed.

3. Plagioclase, crystallized after apatite, after and along with the ferromagnesian minerals.

4. Orthoclase and quartz, crystallized together after plagioclase and the ferromagnesian minerals had formed.

GRANITE (OMEOSE) VEINS CUTTING THE HAYSTACK STOCK

Granite veins one-half inch to six inches wide cut various rocks of the Haystack stock. These occur at the base of the cliff of the southeast of Blue Lake, on the southwestern slope of Baboon Mountain near the summit, on the wagon road from Cowles to the Yellowstone National Park about two hundred and fifty yards east of the divide in Haystack Basin, and at many other localities. The granite is everywhere from medium to coarse-grained, and is lighter colored than the rock it cuts. The granite is composed of feldspar and quartz with a little biotite and hornblende. The veins do not appear to be persistent in length, since they cannot be traced continuously for any great distance. A specimen from a 2-inch vein cutting a very dark fine-grained quartz-bearing diorite (C) on the southwest slope of Baboon Mountain is a pinkish gray, medium-grained rock.

Under the microscope the following minerals are present in the order of their abundance: alkali feldspar, quartz, andesine, magnetite, hornblende, and biotite. The alkali feldspar is orthoclase, microperthitically intergrown with albite, and occurs as anhedra which reach a maximum diameter of 2.4^{mm}. Quartz occurs as irregular anhedra of equal size interlocking with orthoclase and sometimes as a graphic intergrowth. A small amount of andesine (Ab_3 An_2) is present, as slender laths about 0.5^{mm} long. These laths are concentrated along the margin of the vein and in many cases their long axes are normal to the contact. Anhedra of magnetite as large as 0.5^{mm} in diameter, fibrous green hornblende, and biotite are included in orthoclase and quartz. Biotite is slightly altered to chlorite.

The contact of intruding and intruded rock is sharp in the hand specimen, but under the microscope these two rocks appear to grade into each other within a zone about 0.2^{mm} wide. In this zone some of the quartz of the intruding rock appears to have attached itself with similar optical orientation to quartz in the intruded rock. In the crystallization of the veins magnetite, hornblende, biotite, and plagioclase were formed before alkali feldspar and quartz, and the latter two crystallized synchronously. Perhaps all of the minerals, except alkali feldspar and quartz had formed before the intrusion, but if so the magma must have been very fluid, since these minerals do not show flow structure and since the long axes of the plagioclase laths, more frequently than otherwise, make a large angle with the walls.

The composition of the granite veins is not far from that of the micrographic intergrowth of quartz and orthoclase which solidified last in nearly all of the Haystack rocks. The veins were probably formed during the latter stages of the solidification of the rocks they cut, and may represent the liquid portion of the magma after most of the plagioclase and nearly all of the ferromagnesian minerals had crystallized out. Even the smallest veins are very coarse grained and must have cooled slowly. This suggests that they were intruded while the rock which they cut was still hot, or that their water content was sufficiently high to permit the growth of large crystals. The cracks they fill are probably shrinkage cracks formed directly after solidification of the rock.

The mode of the granite is as follows:

Quartz	25.51	Biotite	2.78
Alkali feldspar	60.70	Magnetite	3.50
Andesine (Ab_3An_2)	4.09		
Hornblende	3.42	Total	100.00

From this mode the following chemical constitution is estimated:

SiO_2	70.38	CaO	.75
Al_2O_3	13.17	Na_2O	2.10
Fe_2O_3	2.74	K_2O	7.99
FeO	1.87		
MgO	.73	Total	99.73

From a study of thin sections it is estimated that the alkali feldspar is 15.17 albite and 45.52 orthoclase and that the plagioclase is andesine, Ab_3An_2. It is assumed that the hornblende is chemically like that from a quartz-monzonite, at Mt. Hoffman, Colo., and that the biotite is chemically like that from a granodiorite at El Capitan, Yosemite Valley, Cal.

The norm of the granite vein calculated from the estimated composition is,

Quartz	24.50	Hypersthene	2.65
Orthoclase	47.26	Diopside	.68
Albite	17.82	Magnetite	3.94
Anorthite	2.78	Total	99.67

According to the quantitative classification the rock is omeose. In composition it closely resembles a granite from Currant Creek Canyon, Pike's Peak, Colo., described by Mr. E. B. Mathews,[1] a graphic granite from Omeo, Victoria, described by Mr. A. W. Howitt,[2] and a rhyolite from Round Mountain, Rosita Hills, Colo., described by Dr. Whitman Cross.[3] It is not far from the composition of micropegmatite estimated by Mr. J. J. H. Teall from a vein-cutting diabase near Kington.[4]

GENESIS OF THE ROCKS OF THE STOCK

The gradational character of the various rocks of the Haystack stock shows that it is geologically a unit and should be classed with

[1] *Bulletin No. 148*, U. S. Geological Survey.

[2] *Transactions of the Royal Society of Victoria*, Vol. XXIV, p. 120.

[3] *Proceedings of the Colorado Scientific Society*, Vol. II, p. 33.

[4] *British Petrography*, p. 401.

such bodies as are assumed to have resulted from the differentiation of a single magma. The various rocks must be regarded as essentially of the same age, since they are not separated by sharp contacts, as is the case where an igneous rock is intruded by a later one.

Gradational series of rocks have been recognized and described by a large number of observers. Those who have attempted to explain the phenomenon are in the main agreed that the differences in composition have been brought about through differences of temperature and pressure, or by the direct operation of gravity during crystallization. For some differentiated bodies it is assumed that these processes operated after the homogeneous magma had risen to the place at which the rocks now occur, while for other bodies the magma appears to have been of heterogeneous composition before it rose to its final resting place. These processes have been reviewed comprehensively by Professor L. V. Pirsson, in a recent publication by the U. S. Geological Survey,[1] and to do so here would largely be repetition. Some of them will be briefly stated however and examined not with regard to their general application but with especial reference to the Haystack stock.

Falling of crystals.—The simplest theory to account for differences in an igneous body which supposedly was once homogeneous is to assume that, of the minerals crystallizing first, the heavier ones sink, and the lighter ones rise much as the constituent minerals of rocks are separated in heavy solutions in the laboratory. Schweig[2] has made the suggestion that heavy crystals formed in the early stages of rock solidification, fall, and are remelted, thus changing the composition of the magma at different depths. For the operation of the process the viscosity of the magma must not be too great to allow minerals to settle by their own weight. Magnetite, the heaviest mineral in the Haystack stock, was also one of the first to solidify, and it is present in all varieties in nearly the same quantity; consequently at the time crystallization began the magma must have been too viscous for magnetite to fall.

The ferro magnesian minerals, which are much heavier than the feldspars, are most abundant in the central portion of the stock

[1] *Bulletin No. 237*, p. 183.

[2] *Neues Jahrbuch für min. Beil.*, Bd. 17, p. 516.

(D, E, F, Fig. 3), while the feldspars and quartz predominate in the rocks around the border (A, B, C). Variety B, containing 78 per cent. of quartz and feldspars, occurs at approximately the same elevation as F, which contains only 50 per cent. of quartz and feldspar. If differentiation occurred after the magma had reached the place at which the rocks are now exposed it was such that the elements forming the ferromagnesian minerals moved toward the center of the stock rather than downward in the stock. Accordingly the falling of the heavy crystals does not appear to have been an important process after the magma rose to the place at which the rocks are exposed.

Fractional crystallization.—Certain intrusive masses appear to have differentiated into rocks of various compositions by simple crystallization during cooling. Since the outer portion of an intrusive body is nearer the colder rocks into which it is thrust, this portion of the intrusive is supposed to solidify first, and the minerals which form first in the rocks would form first of all in the outer zone, and having once commenced to crystallize they would continue to grow while the more soluble constituents would be crowded to the center of the stock. This process, according to Mr. H. S. Washington, accounts for the gradational series of rocks which form the igneous complex at Magnet Cave, Arkansas.[1]

As is shown by the order of crystallization of the minerals (p. 223) quartz and orthoclase formed after the ferromagnesian minerals and plagioclase. If differentiation had been brought about by the process of fractional crystallization, the types in which quartz and orthoclase are present in greater abundance should be the types which were last to form, but the reverse is true if the outer portion of the stock solidified first, for the border varieties A, B, C contain a much larger proportion of quartz and orthoclase and a much smaller proportion of the ferromagnesian minerals than the varieties D, E, F, which occur near the center.

Fractional crystallization with convection currents.—According to Becker,[2] gradational series of rocks which constitute certain dikes and laccoliths can have been formed only through fractional crystal-

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 390.

[2] *American Journal of Science*, 4th Ser., Vol. III, p. 21.

lization with convection currents which during crystallization serve to keep the still liquid central portion of the mass of uniform composition. The least soluble minerals will go out of solution first and these will form around the outer portion of the stock, while the liquid magma inside continues to supply like material which it deposits on the walls as it moves by them. Applied to the Haystack stock this hypothesis is open to the same objections as the one previously discussed for the minerals which are most abundant in the rocks forming the periphyry are those which formed last in all the rock types of the stock.

Differentiation prior to intrusion.—Intrusive masses made up of a gradational series of rocks not showing a zonal arrangement across the outcrop are of common occurrence and in most cases they seem to have resulted from differences in the composition of the magma before it came to rest. Mt. Johnson, of the Montenegran Hills, which has been described by Dr. F. D. Adams[1] belongs genetically to the same class, although it is composed of a hollow cylinder of laurvikose inclosing a smaller hollow cylinder of andose, which in turn incloses a cylinder of essexose, the three types grading each into the other. Dr. Adams concludes that before the lava reached its present position, a reservoir somewhere below the mountain had differentiated into a liquid mass of which the heavier portion had the composition of essexose, the upper portion laurvikose, and the central portion andose. The upper portion rising first would form the outer cylinder which in turn would be filled or intruded by andose. Subsequently that would be intruded by essexose. Accordingly the arrangement of the rocks from the bottom up in the earlier body would be the same as that from the center out in the later one. Although the zones are not so well defined in the Haystack stock the rocks of the lowest specific gravity occur near the outer portion of the stock, while the heavier varieties, D, E, and F are near the central portion.

Since no process of magmatic differentiation appears to have operated after the intrusion to form the gradational series of the Haystack stock, it is probable that the differentiation occurred before the magma was intruded and that the basic central portion represents a magma which was erupted after the more acid portion,

[1] *Journal of Geology*, Vol. XI, p. 22.

but that the eruptions followed each other so closely that the magma of one type had not solidified before a magma of different composition rose through it. The resulting rock mass was therefore, a gradational series of rocks rather than a complex of distinctly different intersecting rocks.

SOME IGNEOUS ROCKS FROM THE ORTIZ MOUNTAINS, NEW MEXICO

I. H. OGILVIE
With Chemical Analyses by M. W. Adams

The Ortiz Mountains are a deeply sculptured laccolith, lying on the San Pedro quadrangle, some twenty-five miles east of Albuquerque. They are roughly circular in outline with a diameter of about five miles, and have a relief of about 3,000 ft., the highest peak rising to an altitude of 8,998 ft. They afford interesting data on erosion in an arid climate; on Mesozoic stratigraphy and paleontology; on the events of the Pleistocene period in the region south of the ice sheets; and on petrology. The present paper is preliminary, and deals with a few of the more conspicuous rock types.

The quantitative system is used in classification, the names being based on analyses. The following table indicates the rock types represented.

TABLE I

Class	Order	Rang	Subrang	Old Name
I. Persalane.....	4. Canadare-Britannare	2. Toscanase	4. Lassenose	Dacite
		3. Coloradase	4. Yellowstonose	Dacite
II. Dosalane......	5. Germanare	2. Monzonase	3. Monzonose	Diorite
			4. Akerose	Diorite
		3. Andase	4. Andose	Diorite
	6. Norgare	2. Essexase	4. Essexose	Essexite
III. Salfemane.....	5. Gallare	4. Auvergnase	3. Auvergnose	Andesite

The distribution of these types is found to be noteworthy: The main mass of the laccolith is of the more femic types, essexose and Auvergnose (andesites); the sheets which border the mass are of the most salic types, the persalanes (dacites); while the spurs and flanks of the mountains, lying between the above are of the intermediate types. It should however be noted that all of the rocks are intermediate when compared with igneous rocks in general.

This laccolith is the largest of four, lying in a north and south line. The northernmost, the Cerrillos Hills, has been described by D. W. Johnson.[1] The Ortiz is the next group, while the San Pedro and the South Mountains make up the southernmost groups. It is apparent that these groups are closely related and they probably constitute a single comagmatic region.

The scope of the present paper is primarily chemical. A brief statement of field relations, texture, and mineralogy will be given for each type analyzed, but a detailed discussion of optical characters will not be undertaken in this preliminary paper. It is probable that all the types here discussed are of post-Cretaceous age.

Laurvikose—Lassenose I. 4-5.2.4 (Dacite)

Rocks of this type are gray, porphyritic, and form sheets on all sides of the main mass. The phenocrysts are of pink or white feldspar, the ground mass is phanerocrystalline but fine-grained.

Microscopically the phenocrysts are found to be soda orthoclase with more or less concentric structure. A few phenocrysts of green

TABLE II

Chemical Composition of Lassenose

	I	Mol. Prop.	II	Mol. Prop.	Norms		
						I	II
SiO_2	63.11	1.052	62.36	1.039	Qu	12.72	11.76
Al_2O_3	16.75	0.164	17.78	0.175	Or	20.57	20.02
Fe_2O_3	2.68	0.017	2.74	0.017	Ab	39.82	39.82
FeO	1.39	0.019	1.66	0.024	An	14.18	17.51
MgO	1.22	0.040	1.37	0.034	Diop	4.32	2.38
CaO	3.88	0.070	4.49	0.080	Hyp	2.00	2.30
Na_2O	4.76	0.076	4.75	0.076	Mag	2.32	3.94
K_2O	3.48	0.037	3.37	0.036	Hem	1.12	
H_2O+	1.09	.....	0.26	.....	Ilm	1.52	1.37
H_2O-	0.32	.....	0.11	.....	Ap	0.34	0.67
CO_2	none	.....	none	.....			
TiO_2	0.80	0.010	0.73	0.009			
ZrO_2	none	.....	none	.....			
P_2O_5	0.25	0.001	0.29	0.002			
S	0.03	.....	0.03	.....			
MnO	0.11	0.001	0.12	0.002			
BaO	0.16	0.001	0.03	.....			
Total	100.03		100.09				

[1] *School of Mines Quarterly*, 1903-4.

hornblende and of quartz may also be seen. The ground mass consists of fine grains of plagioclase with augite and magnetite.

Analyses 1 and 2 were from specimens taken from two sheets, respectively on the west and the southwest of the group. It is noteworthy that all of the FeO is in magnetite and ilmenite and that the normative diopside and hypersthene are of a pure magnesian variety. The second analysis is close to a division line in both order and rang, so this type is properly a Laurvikose-Yellowstonose-Lassenose. Norm and mode agree fairly well.

Yellowstonose. I. 4. 3. 4 (Dacite)

This type is in all megascopic and microscopic respects similar to the Lassenose. It is a porphyritic dacite, and occurs in sheets. The sole important difference is that potash, and hence the sum of the alkalies, is lower in Yellowstonose, thus placing the rock in rang 3, in spite of the fact that lime and soda are present in approximately equal amounts in both types. The second analysis (IV) approaches rang 2 and might be termed a Lassenose-Yellowstonose.

The sheets from which specimens for analysis were taken are respectively on the northeast and southeast sides of the mountains.

TABLE III

Chemical Composition of Yellowstonose

	III	Mol. Prop.	IV	Mol. Prop.	Norms		
						III	IV
SiO_2.....	62.48	1.041	62.61	1.032	Qu.....	15.06	16.98
Al_2O_3....	18.07	0.177	17.54	0.172	Or.....	12.79	12.79
Fe_2O_3....	2.61	0.016	2.72	0.017	Ab.....	39.82	41.39
FeO......	1.97	0.028	1.52	0.021	An.....	21.68	19.46
MgO.....	1.34	0.034	1.39	0.035	Diop...	0.22	.....
CaO.....	4.67	0.084	4.18	0.075	Hyp....	4.12	3.50
Na_2O....	4.69	0.076	4.88	0.079	Mag...	3.71	3.48
K_2O.....	2.16	0.023	2.21	0.023	Ilm....	1.22	1.22
H_2O+...	0.52	.....	1.52	.....	Ap.....	0.67	0.67
H_2O-...	0.12	.....	0.22	.....	Hem...	.....	.48
CO_2......	none	.....	none	.....			
TiO_2.....	0.60	0.008	0.60	0.008			
ZrO_2.....	none	.....	none	.....			
P_2O_5.....	0.28	0.002	0.27	0.002			
S........	0.03	.....	0.06	.....			
MnO.....	0.17	0.002	0.14	0.002			
BaO.....	0.09	0.001	0.18	0.001			
Total...	99.79		100.04				

Shoshonose-Monzonose-Akerose-Andose. II. 5. 2–3. 3–4. (Diorite)

This rock is gray, fine-grained, and holocrystalline. It is not porphyritic. The specimen from which the analysis was made is from a spur of about 7,500 feet in altitude on the southeastern side of the group.

Chemically the type is remarkable in being exactly on the division line between rangs 2 and 3, and nearly so between subrangs 3 and 4. Hence the complex name.

Microscopically it contains orthoclase, two plagioclases, augite, a green pleochroic hornblende, titanite, magnetite, apatite, and a small amount of nepheline.

TABLE IV

Chemical Composition of Shoshonose-Monzonose-Akerose-Andose

	V	Mol. Prop.		Norm
SiO_2	55.04	0.917	Or	25.58
Al_2O_3	20.45	0.200	Ab	36.15
Fe_2O_3	2.09	0.013	An	20.85
FeO	2.71	0.038	Ne	2.84
MgO	1.63	0.041	Di	4.48
CaO	5.82	0.104	Ol	2.84
Na_2O	4.92	0.079	Mg	3.02
K_2O	4.29	0.046	Ilm	2.28
H_2O+	0.69	.....	Ap	1.01
H_2O-	0.10	.....		
CO_2	none	.....		
TiO_2	1.17	0.015		
ZrO_2	none	.....		
P_2O_5	0.37	0.003		
S	0.04	.....		
MnO	0.26	0.004		
BaO	0.19	0.001		
Total	99.77			

Akerose. II. 5. 2. 4 (Diorite)

The type is essentially similar to the last, except that its color is pinker in tone, due to the presence of considerable red orthoclase. No nepheline is present, but there is a small amount of quartz. It forms the mountain 8,200 feet high on the southeastern side of the group.

TABLE V
Chemical Composition of Akerose and Andose

	VI	Mol. Prop.	VII	Mol. Prop.	VIII	Mol. Prop.
SiO_2	57.70	0.961	55.46	0.924	54.86	0.914
Al_2O_3	19.63	0.192	18.15	0.178	19.33	0.189
Fe_2O_3	3.30	0.021	3.93	0.024	3.35	0.021
FeO	1.60	0.022	3.42	0.047	2.59	0.036
MgO	1.21	0.030	3.19	0.080	3.05	0.076
CaO	5.14	0.091	7.37	0.132	7.69	0.138
Na_2O	5.42	0.087	3.44	0.055	4.38	0.071
K_2O	3.74	0.039	2.14	0.022	2.33	0.024
H_2O+	0.24	.....	0.38	.....	0.80	.....
H_2O-	0.13	.....	0.24	.....	0.16	.....
CO_2	none	.....	none	.....	none	.....
TiO_2	1.10	0.014	1.20	0.015	1.32	0.016
ZrO_2	none	.....	none	.....	none	.....
P_2O_5	0.29	0.002	0.38	0.003	0.41	0.003
S	0.06	0.002	0.04	.....	0.06	.....
MnO	0.17	0.001	0.21	0.003	0.22	0.003
BaO	0.09	0.001	0.07	.....	0.17	0.001
Total	99.77		99.62		100.72	

Norms	VI	VII	VIII
	Akerose	Andose	Andose
Qu	1.38	8.82	2.58
Or	21.68	12.23	13.34
Ab	45.59	28.82	37.20
An	18.35	28.08	26.13
Diop	4.32	4.85	7.81
Hyp	1.00	7.16	4.23
Hem	1.92	....	....
Mag	2.09	5.57	4.87
Ilm	2.13	2.28	2.43
Ap	.67	1.01	1.01

Andose. II. 5. 3. 4 (Diorite)

This rock is in most respects identical with the preceding types but differs in having a tendency toward a porphyritic texture. It forms the massif of Lone Mountain, a partially isolated peak to the southeast of the Ortiz group. Its consanguinity with the main stock is evident from the analyses. Two of these were made, from the top and side respectively, and these are given in the preceding table. They are placed next the Akerose for comparison, this latter type being most closely related chemically and also the nearest in space. The most noteworthy differences are the higher lime and lower potash of the Andose.

Essexose. II. 6. 2. 4 (Diorite and Essexite)

This rock type is an exceedingly common one, and is somewhat variable. It forms the outlying hills on the southeast, and usually forms the top of those with an altitude of about 8,300 feet. It is from one of these that X is taken. IX is from the top of the highest mountain. The recalculated analysis requires nepheline. This is sometimes present in the slides; more often a porphyritic structure

TABLE VI

Chemical Composition of Essexose

	IX	Mol. Prop.	X	Mol. Prop.	Norms		
						IX	X
SiO_2	51.42	0.857	51.19	0.850	Or	23.91	28.36
Al_2O_3	19.40	0.190	21.16	0.208	Ab	22.01	18.34
Fe_2O_3	3.72	0.023	2.85	0.018	Ne	12.21	15.34
FeO	3.33	0.046	2.31	0.032	An	17.24	19.18
MgO	2.56	0.064	2.34	0.059	Diop	14.48	8.86
CaO	7.80	0.139	6.79	0.121	Ol	0.90	1.26
Na_2O	5.28	0.085	5.43	0.088	Mag	5.34	4.18
K_2O	3.96	0.043	4.78	0.051	Ilm	2.74	3.04
H_2O+	0.49	.....	0.54	.....	Ap	1.34	1.34
H_2O-	0.04	.....	0.08	.....			
CO_2	none	.....	none	.....			
TiO_2	1.39	0.018	1.54	0.020			
ZrO_2	none	.....	none	.....			
P_2O_5	0.53	0.004	0.62	0.004			
S	0.03	.....	0.04	.....			
MnO	0.23	0.003	0.25	0.004			
BaO	0.21	0.001	0.11	0.001			
Total	100.39		100.03				

is developed with large phenocrysts of olivine and no nepheline. The olivine phenocrysts contain inclusions of magnetite, apatite, biotite, plagioclase; a few phenocrysts of twinned augite are occasionally present. In this variety the groundmass contains intergrowths of feldspars, and broad laths of both orthoclase and plagioclase. The nepheline-bearing variety has a granitic texture, and lacks olivine.

Auvergnose III. 5. 4. 3 (Andesite)

This rock is holocrystalline, dark-bluish gray, and contains many basic segregations. It occupies the central part of the group and lower levels of the surrounding hills whose tops are less basic.

TABLE VII

Chemical Composition of Auvergnose

	XI	Mol. Prop.	Norm	
				XI
SiO_2	49.09	0.818	Or	2.22
Al_2O_3	15.11	0.148	Ab	27.25
Fe_2O_3	0.48	0.003	An	25.58
FeO	7.85	0.110	Diop	22.07
MgO	7.66	0.191	Hyp	4.65
CaO	11.03	0.196	Ol	9.08
Na_2O	3.24	0.052	Mag	0.70
K_2O	0.37	0.004	Ilm	6.54
H_2O+	0.39	.....	Ap	0.67
H_2O-	0.02	.....		
CO_2	none	.....		
TiO_2	3.40	0.043		
ZrO_2	none	.....		
P_2O_5	0.34	0.002		
S	0.06	.....		
MnO	0.25	0.004		
BaO	none	.....		
Cr_2O_3	0.04	.....		
Total	99.33			

In the following table the analyses are compared. The range of silica is moderate, from 63 to 49 per cent. Alumina is generally high and its range is not great. Iron and magnesia are uniformly low and of slight range, with the exception of II, Auvergnose. Lime is high and of great range; soda is moderate and of little range; potash is moderate and of considerable range. Titanium is almost invariably high; zirconia is entirely absent; baryta is high.

TABLE VIII

		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	TiO_2	P_2O_5	S	MnO	BaO	Total
1	I.4.24	63.11	16.75	2.68	1.39	1.22	3.88	4.76	3.48	1.09	0.32	0.80	0.25	0.03	0.11	0.16	100.03
2	I.4.2.4	62.36	17.78	2.74	1.66	1.37	4.49	4.75	3.37	0.26	0.11	0.73	0.29	0.03	0.12	0.03	100.09
3	I.4.3.4	62.48	18.07	2.61	1.97	1.34	4.67	4.69	2.16	0.52	0.12	0.60	0.28	0.03	0.17	0.09	99.79
4	I.4.3.4	62.61	17.54	2.72	1.52	1.39	4.18	4.88	2.21	1.52	0.22	0.60	0.27	0.06	0.14	0.18	100.04
5	II.5 (2–3)(3–4)	55.04	20.45	2.09	2.71	1.63	5.82	4.92	4.29	0.69	0.10	1.17	0.37	0.04	0.26	0.19	99.77
6	II.5.2.4	57.70	19.63	3.30	1.60	1.21	5.14	5.42	3.74	0.24	0.13	1.10	0.29	0.06	0.17	0.09	99.77
7	II.5.3.4	55.46	18.15	3.93	3.42	3.19	7.37	3.44	2.14	0.38	0.24	1.20	0.38	0.04	0.21	0.07	99.62
8	II.5.3.4	54.86	19.33	3.35	2.59	3.05	7.69	4.38	2.33	0.80	0.16	1.32	0.41	0.06	0.22	0.17	100.72
9	II.6.2.4	51.42	19.40	3.72	3.33	2.56	7.80	5.28	3.96	0.49	0.04	1.39	0.53	0.03	0.23	0.21	100.39
10	II.6.2.4	51.19	21.16	2.85	2.31	2.34	6.79	5.43	4.78	0.54	0.08	1.54	0.62	0.04	0.25	0.11	100.03
11	III.5.4.3	49.09	15.11	0.48	7.85	7.66	11.03	3.24	0.37	0.39	0.02	3.40	0.34	0.06	0.25	none[1]	99.33

NOTE.—CO_2 and ZrO_2 being lacking in all of the analyses are not tabulated.

[1] Cr_2O_3 .04.

The Lassenoses and Yellowstonoses contain small amounts of gold, copper, antimony, lead, and bismuth.

A consideration of the serial chemical characters of the region brings out the fact that soda is practically constant and alumina nearly so. As silica decreases iron and magnesia increase but very slightly, and somewhat irregularly; on the other hand the increase in lime is regular and normal. Potash varies from 0.39 to 4.78, and its variations bear no definite relation to the decrease in silica, nor does the sum of the alkalies uniformly change. The sum of the alkalies invariably either equals or exceeds salic lime, which finds expression in the rang.

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DISCOID CRINOIDAL ROOTS AND CAMAROCRINUS

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Since the writings of Wachsmuth and Springer,[1] and of Bather[2] have given an increased scientific interest to fossil Crinoidal roots or stem bases, fossils of this sort which occur in the Galena (Trenton) stage of the Ordovician in Minnesota, have been collected by me with some especial care. In particular, certain disc-shaped roots have been collected and studied. These are believed to represent the primitive form and structure of Crinoidal roots, and are of special interest for that reason, as also because they are rare and little known. Few fossils of this kind have been described heretofore. Since my collection represents a relatively large number, about 100 specimens, and since they afford some new information regarding the structure and relationship of such Crinoidal roots, description and discussion of them is here offered.

The specimens in hand are discoid or conical with flat base, or bent from that form when the surface to which the base had attached is not plane. They are found adhering to shells, Monticuliporoid stalks, Crinoid stems and especially to pebbles. They consist of polygonal calcite plates in the manner of Echinoderms in general. The center or apex of the cone bears a scar with central perforation. This scar is like those which are characteristic of Crinoidal roots and shows where a Crinoidal stem has been detached. In a few cases an attached stem fragment remains.

Among the specimens several species are represented, ranging in structure from those similar to the well-known *Lichenocrinus* on the one hand, and on the other to forms with lobate basal margin which link rather to the well-known and common form of roots with long, round cirri. Others tend to become globular and a relation to the problematical *Camarocrinus* is therefore to be considered.

[1] *The North American Crinoidea Camarata*, p. 49–51, 1897.

[2] *Geological Magazine*, Vol. V, p. 328, 1898.

PREVIOUSLY DESCRIBED FORMS

A few primitive Crinoidal bases have been heretofore described. James Hall noticed specimens from Trenton Falls in the Trenton limestone.[1] A drawing after Hall's figure *2a*, is reproduced here in Fig. 1. p. 243. His description of this and others merely states that they are "bases of attachment" "of the columns of some (uncertain) species of Crinoidea." Again James Hall described[2] specimens as occurring in the Niagara limestone, which may perhaps be well considered in this connection. One, represented by his Fig. 11, is described as "a fragment of a root with few radicles, ... showing a hexagonal canal," and the other, Fig. 10, is described as "a fragment of a root with numerous radicles." Those Figs. 11 and 10 are here represented by Figs. 2 and 3 respectively, by which their general character can be seen. Bather[3] calls attention to others which James Hall had described, in *Pal. N. Y.*, Vol. III, 1859, as *Aspidocrinus*, and of which Hall distinguishes three species, all from the Lower Helderberg, describing them on pp. 122–23, and giving figures of them, Plate V, Figs. 13–20. Hall appears much in doubt about their structure and relations. Neither his descriptions nor his figures are in any respect satisfactory. The fossils may, I think, rather be columnals, than bases.

From the Trenton limestone at Ottawa, Canada, Billings reports[4] certain specimens which should be noted. One specimen, represented in Fig. 1*g*, Plate V, *loc. cit.*, he says is "the base of the column" of *cleiocrinus regius* Bill. This specimen is not further described nor details of the root's structure shown. One may, however, infer that it is similar to that of the fragmental columns upon which he bases the species, *C. grandis* Bill.,[5] and of which he says, "The radix or base of attachment of the column consists of a number of large roots which appear to be composed of small polygonal plates." The figure of this one shows no more than the meager description gives,

[1] *Pal. N. Y.*, Vol. I, p. 86, Pl. XXIX, Fig. 2 *a, b*, 1847.

[2] *Pal. N. Y.*, Vol. II, p. 231, Pl. XLV, Figs. 10, 11.

[3] *Loc. cit.*

[4] *Canadian Organic Remains*, Decade 4, 1859.

[5] *Loc. cit.*, p. 54, Pl. V, Fig. *2a*.

except that the column and root appear sharply defined at their junction.

In a little later publication,[1] James Hall presents conclusive evidence of a fragment of Crinoidal stem attached to a discoid base. The stem and therefore the base is identified as belonging to a particular species of Crinoidea, i. e., *Calceocrinus* (*Cheirocrinus*) *clarus* (Hall). These fossils come from the Silurian Niagara group. The base is similar to Fig. 1 and Figs. 6 and 7. Another base to which a fragment of stem remains attached is described from the Ordovician in the upper part of the Cincinnati group, at Cincinnati, Ohio, by F. B. Meek.[2] He says that it probably belongs to *Anomalocrinus incurvus* M. & W. It "consists of a solid expansion near an inch in diameter, with irregular margins." "It has a short piece of the column attached, which rises abruptly from the expansion, and is composed of very thin anchylosed segments, showing the appearance of being each made up of numerous little pieces, ... " i. e., like stems of *A. incurvus* M. & W. Fig. 4 and 5 here are drawn after his figures 6 *d*, *c*.

Wachsmuth and Springer,[3] say that "in the Hudson River group of Cincinnati, we occasionally find Crinoidal disks attached to pieces of coral, which closely resemble the dorso-central of *Antedon*. These disks have a pit or depression at the middle of the upper face, sometimes inclosing a small stem joint. They are irregularly round, and some of them have small processes passing outward from the sides which seem to represent primitive cirri (Plate I, Figs. 9, 10)." Drawings after their Figs. 9, 10, are given here in Figs. 6, 7. Opposite Plate I, in the description to Figs. 9, 10, they say "dorso-central plates, supposed to belong to a species of *Heterocrinus*." Wachsmuth and Springer consider the roots as having separated from the stem during the life of the Crinoid.

In a former paper on "A New Cystocrinoidean Species from the Ordovician,"[4] I have described a few specimens of discoid roots which were found associated with *Strophocrinus dicyclicus* Sar.,

[1] *Fifteenth Rep. N. Y. State. Cab. Nat. Hist.*, Pl. I, Figs. 17, 18, 1862.

[2] *Geol. Sur. Ohio*, Vol. I, "Paleontology," p. 18, Pl. II, Fig. 6, *d*, *e*, 1873.

[3] *Op. cit.*, p. 49.

[4] *American Geologist*, Vol. XXIV, pp. 263–76, 1899.

and which probably belong to that species. Three figures published[1] are reproduced here as Figs. 8, 9, 10.

Associated with discoid Crinoidal roots, in the Ordovician are the similar fossils known as *Lichenocrinus*. Several species of these have been described with such thoroughness, especially by Meek,[2] and with such citations as to make a review of the genus here seem unnecessary. The crateriform bases of these fossils are known to bear a slender stalk of polygonal plates in some cases. Yet this stalk is not known to have been identified, with certainty, as a Crinoidal structure. *Lichenocrinus* can be treated only as a problematic structure, notwithstanding concise knowledge of the fossils as they occur, and it may therefore be quite neglected here. In a large number of specimens of it which I have collected, nothing new has appeared. In regard to the discoid Crinoidal roots on the contrary, their structure has not been thoroughly described and they invite further study n this respect, as well as identification with recognized species of Crinoidea.

NEW DESCRIPTIONS

In order to facilitate scientific description a generic name is used here to include several taxonomic species of Crinoidal roots. This generic name, as in case of *Lichenocrinus* and of *Camarocrinus*, is not expected to coincide with any one generic term based upon described crowns and will be superseded by such generic terms as often as root structures are identified specifically with previously described crowns.

PODOLITHUS n. gen.

Primitive discoid or conical Crinoidal root-structures with more or less lobate margins and with a fixing-plate. Region about the stem-scar not depressed. Type *Podolithus schizocrinus*, n. sp., Fig. 11.

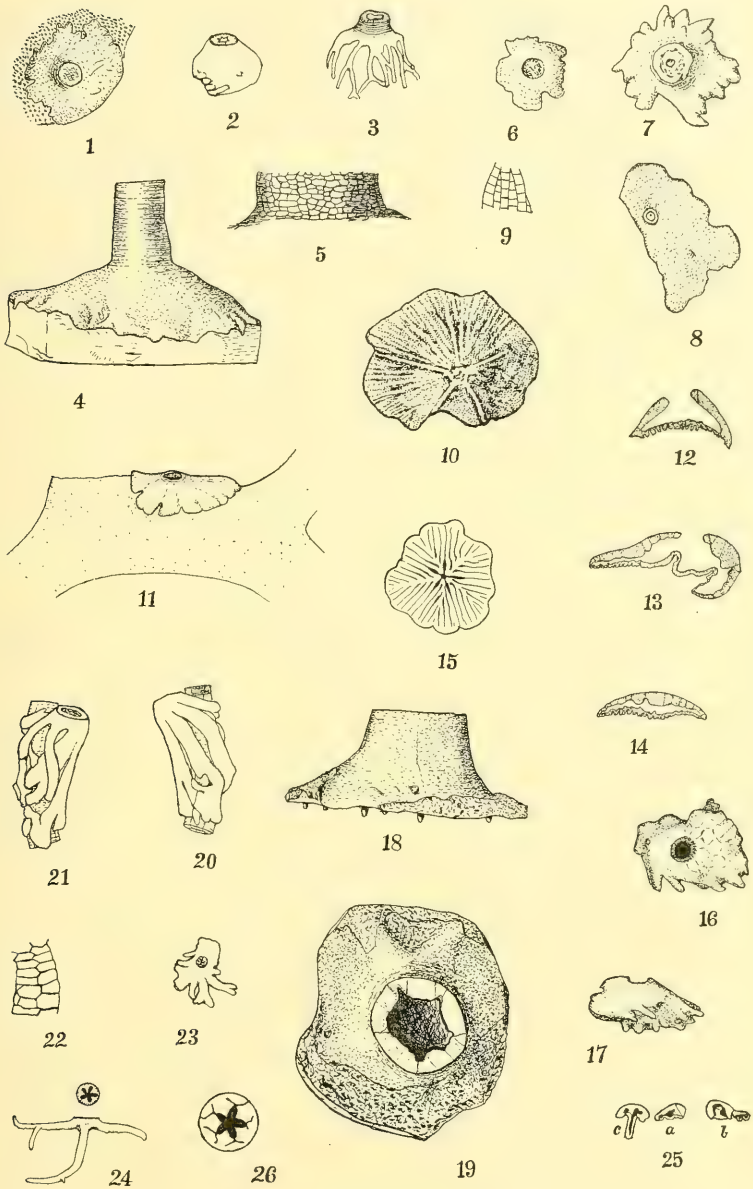
Podolithus strophocrinus nom. nov.

(Figs. 8, 9, 10)

To this type belong stem-bases which are low, conical, 1 to 5^{cm} in diameter, with nearly entire margin and generally circular outline, although by accident sometimes quite irregular. Fig. 8 shows the most unsymmetrical specimen found, while Fig. 10 represents one

[1] *Op. cit.*, Pl. XII, Figs. 14, 15, 16. [2] *Op. cit.*, pp. 44–52.

Figs. 1–26



which although circular, appears not to be so because the margin is bent under. In the fossils, the stem is wanting, but from the scar it is seen to have been slender. The upper surface is smooth when well preserved. Suture lines show indistinctly that there are quadrangular plates, generally in rows, Fig. 9, arranged radially. Five rows of plates radiate from the center and between these other rows gradually intercalate. The interior is separated into canal-like spaces by partitions which appear to be inward thickenings of the plates, traversing the same along the rows radially. This structure has been seen by means of macerated and weathered specimens only, as is shown in Fig. 10, and the extension downward of the partitions is not exactly determined; but these probably touch the ground layer or fixing plate.

This type of Crinoidal root is remarkable for its large radius, small height, and relatively small stem-scar. A number of specimens were found at a particular part of a quarry where plates of *Strophocrinus* were abundant, and they are all believed to be structures of one species, i. e., *Podolithus strophocrinus* = *Strophocrinus dicyclicus*. These bases and the plates of *Strophocrinus* are otherwise rare. Their occurrence is in association with intra-formational conglomerate at the top of zone No. 4 (Stictopora bed) and in zone No. 5 (Fucoid bed) of the Galena-Trenton stage, at St. Paul, Minn. In view of their large size and close association with crown plates, it appears to be most probable that the bases were permanent anchors.

Podolithus schizocrinus n. sp.

(Figs. 11–17)

This species includes stem-bases which are from 3^{mm} to 2^{cm} in diameter, about one-fourth as high as wide, and in general outline conical but with thick and irregularly lobed margin (Fig. 11). The apex of one small specimen shows a flat circular stem-scar, with a star-shaped lumen, while others seem to have been either excessively macerated or reabsorbed in this part. Generally there is a circle of small pores or canal ends seen just within the rim of the central opening. No other openings through the wall appear anywhere. The top surface is dense and smooth with indistinct sutures. Transverse thin-section reveals, under the petrographic microscope, that

the top consists of calcite plates, increasingly numerous in larger specimens (Figs. 12 and 13). The plates are hexagonal to quadrangular, and arranged radially in short intercalating rows. The inner part of the plates appears in thin-section less dense than the outer, and is rough surfaced. Radiating ridges are also evident (Fig. 14), on the inside. Maceration may have reduced them, but they are not now seen to touch the fixing plate.

The fixing plate is thin and closely knit to the surface of support. It is a single large plate, united by suture only around the periphery of the root. On the upper surface of the fixing plate there are raised lines or ridges. These are well seen in one specimen from which the top plates are partly broken off, and in several others which have been weathered. None are complete, and a diagram (Fig. 15), is given, for the sake of completeness and clearness also, instead of a drawing of a single specimen. There is a central sharp elevation, from which radiate five angular ridges, and these are widest and highest at a short distance from the center. Other ridges intercalate, chiefly in diverging pairs, and all diminish in intensity toward the periphery.

The internal structure might be quite geometrically symmetrical if the external form were so, but in every specimen the place of growth has modified the form of the root more or less. The fixing-plate follows closely the surface of support, whose irregularities are reflected within. Again, some specimens have the stem-scar near or at one side, and directed obliquely to that side as if the surface of support had been vertical or inclined, the stem too having been vertical. In those cases the longer side is in every way the more developed. Figure 13 shows a root which had grown over the edge of the supporting object.

Figs. 16 and 17 represent a specimen which has grown on a slender branch of *Pachydictya acuta* Hall and surrounded it, the fixing-plate thence having bedded to an irregular, probably muddy, surface. The marginal lobes are extended as round short roots. Two of these, which are cleaved off, show central circular canals. One other specimen which was found near this one has grown in a similar way but has flat areas around the top.

This type of discoid base I find in greater numbers and through

greater range and wider distribution than any other. At Minneapolis and St. Paul it has been found in the Galena-Trenton in zone No. 4. (Stictopora bed) (Figs. 11, 12, and 15), in zone No. 5. (Fucoid bed) (Figs. 13, 14), and in zone No. 6. (Orthisina bed), and at Kenyon, Minn., also in zone No. 6 (Figs. 16, 17). Those from the Trenton of New York, as described by Hall (see Fig. 1), may belong to the same. In their occurrence they are associated with stems and crowns of *Schizocrinus*, to which they may belong. No other Crinoidal stems and plates are as abundant and no others are known in each bed. From the reabsorbed appearance of the stem-scar, as compared with other parts of the root in all sizes of specimens, I am led to adopt further the interpretation that the stems were loosed from the root at any convenient time during the animal's life.

Podolithus Anomalocrinus n. sp.

(Figs. 18, 19)

This species is known by a single specimen from zone No. 6 (Orthisina bed) of the Galena-Trenton, below Mantorville, Dodge Co., Minn. The specimen is a root with a fragment of a large stem with large lumen. From the stem to the margin its top surface is concave. The specimen is now free, although the fixing-plate on its under side bears a distinct impression from a former attachment upon a nearly flat surface. This impression shows quadrangular figures in transverse rows, and appears to be that of the inside of a *Receptaculites*. Short blunt processes occur at the angles where canals would run through that wall of *Receptaculites*. This impression indicates, I think, that the root grew on an intra-formational conglomerate pebble, which consisted of a fossil *Receptaculites*. Such fossils with more or less of adhering matrix are not uncommon as pebbles in that zone.

The margin of the root forms a sharp, slightly serrate edge in one place (left side of Fig. 19); in another it is abruptly turned upward, right side, and for the rest it appears to be overturned upon the top surface. The overturned part has a spongy-looking surface. Evidently the root was accidentally restricted in its growth. If it had not been, then the specimen would have resembled more closely the one described by Meek (see Fig. 4). The margin would have probably been five-lobed, corresponding to five prominences which radiate

from the rounded angles of the stem. As the specimen is, there appear distinct depressions of the top surface between the radial prominences where not covered by the overturned margin.

The stem's surface is marked by slightly raised transverse ridges, and a little weathering has brought intermediate rows of small pores to view. The exposed end of the stem shows numerous fine radiating anastomosing furrows, and a few larger ones. These were evidently canals between segments of the unbroken stem and the pores on the outer surface are obviously the ends of the same. The pores are united superficially by suture-like lines which give the stem the appearance of consisting of small plates. Meek describes a very similar structure in his specimen (see Fig. 5.). At each angle of the stem is a coarse suture. By observing these described marks, it is seen that the stem on my specimen extends down 5^{mm} from the top, and consists of about eight circles of thin undulating plates, which alternate in five vertical rows.

The surface below the stem shows faint close sutures, indicating that the top of the root proper is made up of numerous polygonal distributed plates.

Podolithus eucheirocrinus n. sp.

(Figs. 20–23)

This species includes bases, the conical form of which is concealed more or less by long root-like lobes of the margin. The largest specimen is grown around a Crinoid stem so that the lobes or radicles extend across one another (Figs. 20, 21). One small specimen has grown obliquely on a curved surface and has the lobes at the sides and lower margin only well extended (Fig. 23). The top or outer surface is dense, and consists of polygonal plates, though the sutures are in part indistinct. About the stem-scar the plates appear subhexagonal, alternating in radial rows, while on the lobes or radicles and their branches, the plates are transversely elongated and alternate in two rows (Fig. 22). The radicles are flattened on top but convexed on the sides.

The stem-scar is obscured on each specimen, and no stem fragment being attached, identification of these roots with any columns is uncertain. They are associated with Crinoid columns like the one upon which a root has grown (Fig. 20), which has five rows of colum-

nals, nearly corresponding in circles. They are found in the upper part of zone No. 4 (Stictopora bed), where specimens figured were found, and in the base of zone No. 5 (Fucoid bed) of the Galena-Trenton stage at St. Paul, Minn. The only probable related calyx is that of *Eucheirocrinus punctatus* (Ulr.) which has the same range, and although pieces of stem one-half inch long attached to them have oval rings yet, in view of the great differences known to mark Crinoidal columns, the lower part of the same might be the one under consideration.

Podolithus dendrocrinus n. sp.

(Figs. 24, 25, 26)

This species comprises roots in which the discoid or conical form is concealed, but in which the structure remains. They occur attached to hard surfaces with one to five simple or branched radicles of various lengths. Fig. 24 is of the largest specimen. One of its radicles curves downward. The radicles or lobes are smooth and quite round, excepting the under side by which they are attached. Seen from the upper side they consist of narrow transverse rings, but a thin-section shows that these are interrupted by the fixing-plate which unites with them by suture. Fig. 25 shows the thin-section ×4. The section is cut across three lobes, *a*, *b*, *c*, each of which attaches to the same Monticuliporoid stock. Fig. *a* cuts obliquely, striking two plates above, while *b* cuts a bifurcation. The fixing-plate in *c* penetrates a cell of the Monticuliporoid at that point. Compare Fig. 18. The lumen is represented in black.

The stem-scar is preserved in several cases and clearly shows a stellate lumen and radiate ligamental scars. Certain cylindrical Crinoid columns are found in the same strata and are easily matched with these though generally larger in size. Fig. 26 represents the end of such a column ×2 without the radiating striae, about 75 in number, which are omitted. It shows the lumen and ten distinct canals which run in the joint and in part thence through the segment. On the outer surface, the canals appear as distributed pores. The same canals are seen at the stem-scar of the roots, but I cannot find them lower on the disk or its lobes.

These roots and columns occur rarely in zones Nos. 4, 5, and 6, of the Galena-Trenton stage. Figs. 24, 25, 26, are of specimens

from zone No. 5, at St. Paul, Minn. An associated species of *Dendrocrinus* was the probable possessor of them.

DISCUSSION

In collecting specimens, I have not only obtained well-preserved materials for the study of structures, but have tried also to find means for identification of them. A root with entire column and crown has not been found, and should scarcely be expected to occur where all Echinodermal remains were badly scattered. But, roots and associated stems can be matched with crowns more or less successfully and careful effort to do this has been made.

From the evidence which is afforded by the described specimens, it may safely be concluded that these discoid stem-bases belong to Crinoidea, and admitting circumstantial evidence, the conclusion is imminent that they also belong to a diversity of Crinoidea. *Calceocrinus*, *Eucheirocrinus*, *Heterocrinus*, and *Anomalocrinus* belong to Bather's Order, Monocyclica Inadunata; *Schizocrinus* to Order, Monocyclica Camerata; *Dendrocrinus* and *Strophocrinus* to Order, Dicyclica Inadunata. To the circumstantial evidence may be added the fact that certain Cystidea have similar structures, the fixing-plate in *Lepidodiscus*, which I have collected here, being very like those of the Crinoidal discoid bases. This tends to prove that this structure is primitive and might persist in diverse lines of Crinoidal evolution.

As to structure, there is conclusive evidence that the fixing-plate in *Podolithus* is a single piece, while the top of the root is perhaps always of many plates. If I understand rightly, Wachsmuth and Springer[1] considered the entire root or discoid base as a single plate and compared it to the "dorso-central" plate of *Antedon*. Whether the fixing-plate or the entire root should be now called dorso-central, or perhaps neither comparison be made, I am not able to decide. Again the interior presents always, as far as known, raised radiating structures upon the fixing-plate and under the top plates, resembling *Lichenocrinus* in the latter. Also as in *Lichenocrinus*, no pores or canals to the exterior are seen aside from the stem-lumen and scar, even though attached columnals present external pores. Accidental

[1] *Op. cit.*

penetration of foreign substances into the root are probably always walled off from the internal cavity.

The described new species of *Podolithus* with species of *Lichenocrinus* include all the Crinoidal roots which are known to me to occur in the Galena-Trenton stage. Together they form a series which may illustrate the early evolution of Crinoidal roots from a primitive conical expansion of distributed polygonal plates, over a large circular fixing-plate, to a lobate form with plates in single rows over a deeply cut fixing-plate. Further reduction of the fixing-plate could produce the commonly known cirri with circular, perforated segments.

COMPARISON WITH *Camarocrinus*

At first sight, the discoid roots appear to differ greatly from *Camarocrinus*, but upon close comparison they are much more alike, the latter being a modified form of the former. Before trying to show this, the problem concerning *Camarocrinus* alone requires attention. That problem appears in the recently published work *On Siluric and Devonic Cystidea and Camarocrinus*, by Charles Schuchert.[1] In this work *Camarocrinus* is discussed in regard to history of the genus, mode of occurrence of fossil specimens, their structures and possible relationships. The discussion appears to be quite exhaustive and the description of the fossils, very thorough. The work is based upon a wealth of best materials of all three known species,[2] two of which Schuchert redescribes and one of which he presents as new. I may say further that nothing new or not described by Schuchert was found by me in materials which were obtained through the kindness of Mr. Schuchert and of Mr. Bassler of the U. S. National Museum. Following his thorough discussion Schuchert says in the summary:[3] "The writer realizes that the last word has not been said in regard to *Camarocrinus*, and the present work is offered with the hope that some paleontologists will attack the problem from another point of view."

Schuchert's statement just quoted follows paragraphs in which the belief is expressed, following the opinion of James Hall and other

[1] "Smithsonian Miscellaneous Collections," Vol. XLVII, Part 2, 1904.

[2] A fourth species, *C. asiaticus* Reed, has been later described. See *Paleontologia Indica,* New Series Vol. II, Memoir No. 3, 1906, p. 88.

[3] *Op. cit.*, p. 269.

authors, that the *Camarocrinus* structures were roots of Crinoids, serving as floats, from which the stems had parted before their sinking to place of rest. Bather[1] had stated a little more in particular, and Schuchert quotes him as saying of these fossils, that, "another curious modification, perhaps connected with a free-floating existence, was presented by the root of *Scyphocrinus* [=*Lobolithus*=*Camarocrinus*]." Schuchert's discussion, as I read it, throws a shadow over the grounds upon which Bather may have based his belief concerning *Scyphocrinus*, and tends to leave the fossil *Camarocrinus* as problematic as when James Hall first described it.[2]

Authorities agree, in short, upon these peculiar balloon-shaped fossils being the modified root-structures of some Crinoid or other. It may also be taken as evident that they floated. The unsolved problem concerns their origin, the interpretation of their structural parts, and their relation to any particular species of Crinoids.

Camarocrinus appears not to have been considered from the side of the known Crinoidal discoid roots. The nearest approach to such a point of view is the suggestion which will be here quoted about *Lichenocrinus* and in which Schuchert makes really no progress toward the solution of the problem. "*Lichenocrinus* represents the nearest approach of a modified Crinoid root to *Camarocrinus*. It, too, is camerate, the radiating striae seen on weathered examples being vertical plates extending upward from the attached base to the inner side of the surface plates."[3] Again, p. 269, "this form when compared with *Camarocrinus* is wholly different, as the base of *Lichenocrinus* is attached to foreign bodies. . . . ." Bather, too, cites *Lichenocrinus* as a Crinoid root[4] yet it is quite as problematic as *Camarocrinus*. Moreover, the comparison of the camarae of *Camarocrinus* with the camerate structure of *Lichenocrinus*, as just quoted, is not the right view, as I shall endeavor to show.

To explain the origin and homologies of *Camarocrinus*, I wish rather to compare it with such discoid roots as are here described, e. g.,

[1] *Treatise on Zoölogy*, Vol. III, "Echinoderma," p. 135 (1900).

[2] More recently, Butler has found further evidence in support of his view, in the association of *Scyphocrinus* and *Lobolithus* remains in Silurian rocks of Cornwall. See Transactions of the Royal Geological Society of Cornwall, Vol. XIII, Part III, pp. 191–97, 1907.

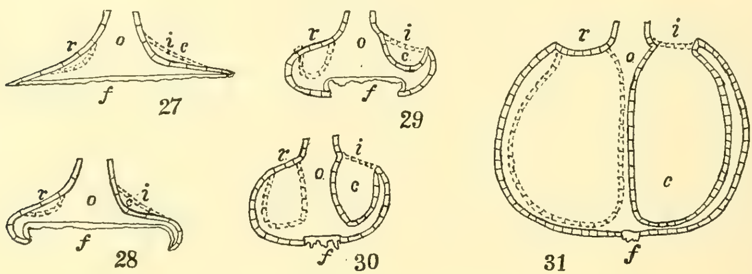
[3] *Op. cit.*, p. 268.

[4] *Op. cit.* p. 133.

Figs. 11, 13, 17, and 18. These bases are evidently very plastic to environmental conditions and certain characters in them if increased under exceptional conditions might well have changed to such as *Camarocrinus* possesses. Those characters are the occasionally turned-under margin (Fig. 13), and the five or more depressed spaces of the top surface (Fig. 19). These depressions may be termed inter-radicle pockets, since they lie between the main canals and lobes which radiate from the corners of the stem and lumen, or between branches of the same, all of which may be termed radicles.

A series of diagrams are given here to help show the probable origin of *Camarocrinus* (Fig. 31) from a discoid root (Fig. 27).

FIGS. 27–31



Taking the pentameral symmetry as typical, then a vertical section passing through a radicle, *r*, on one side, would cut the inter-radicle *i* on the other side. The respective inter-radicle and radicle contours, not cut by the plane of the section, are drawn in broken lines. Since *Camarocrinus* is supposed to have floated in inverted position, it should be represented so, except that comparison is easier when all figures correspond. Fig. 27 represents a known discoid base with normal, wide fixing-plate, *f*, and shallow, inter-radial pockets, *c*. Fig. 28 represents it with the margin turned under because of limited ground. Fig. 29 is an hypothetical representation of the same attached to a floating object by still more limited area, so that a smaller fixing-plate, *f*, and deeper pockets, *c*, result. Fig. 30 represents an adaptation where the supporting object and fixing-plate are less in surface and the pockets—gas filled—are enlarged. Fig. 31 represents *Camarocrinus* with fixing-plate, *f*, very small, not larger than other plates, while the pockets, *c*, are correspondingly enlarged and approximated.

The pockets or camarae of *Camarocrinus* are not internal divisions but invaginations of the outer wall, hence communicating not with the interior but the exterior. The internal partitions of *Podolithus* and of *Lichenocrinus*, too, correspond not with its "camarae" but with the canals of the interior, Fig. 27, and with partitions of the medio-basal chamber *o*, Fig. 31, and of other interspaces of the closely folded "double" wall. *Camarocrinus* is not to be considered as "double walled" but single walled. The wall, folded upon itself is united "by many short, stout, blunt processes,"[1] and these processes may be considered as homologous with the internal partitions of *Podolithus* and of *Lichenocrinus*. The inner surface of the wall of *Camarocrinus* is in fact marked by knoblike extensions, especially of the larger of the plates, and by pore-like enlargements of the sutures. Maceration and weathering must tend to open these latter, one after another, to the exterior. I am in doubt, therefore, whether the pores through the walls which Schuchert so clearly represents,[2] were originally open to the exterior or not. Presuming that they were, their nature may be the same as the pores on the column, though not seen on the base of *Podolithus anomalocrinus*. I have not discovered in the specimens of *Camarocrinus* the particular plate which is the original fixing-plate, but it might be seen on favorably young specimens.

Excepting possibly the supposed pores, the structures of *Camarocrinus* are those of *Podolithus*. Further, the observation may be made, that since *Schizocrinus* Hall and *Scyphocrinus* Zenker belong to the same family, *Glyptocrinidae* according to Bather, the probability that *Podolithus schizocrinus* belongs to the one, gives greater weight to the contention that *Camarocrinus* in part, at least, belongs to the other.

EXPLANATION OF FIGURES

Fig. 1.—Base of a Crinoidal column, on a coral, from the Trenton limestone; after Hall.

Figs. 2, 3.—Crinoïdal roots from the Niagara limestone; after Hall.

Figs. 4, 5.—Root with fragment of column, from shales of the Cincinnati stage, and part of column of same, magnified; after Meek.

Figs. 6, 7.—Roots or "dorso-central plates," from shales of the Cincinnati stage; after Wachsmuth and Springer.

[1] Schuchert *op. cit.*, p. 263.   [2] *Op. cit.*, Pl. XL, Figs. 8 10.

Figs. 8, 9, 10.—*Podolithus dicyclicus* nom. nov., from the Galena stage. Fig. 8, a well-preserved but unsymmetrical root; Fig. 9. part of surface of the same ×2; Fig. 10, a weathered specimen.

Figs. 11–17.—*Podolithus schizocrinus* n. sp., from the Galena stage. Fig. 11, a small root on a coral ×2; Fig. 12, vertical section of a similar one ×2; Fig. 13, vertical median section ×2, of a specimen which has overlapped the supporting coral; Fig. 14, section of same ×2, not median; Fig. 15, diagram of upper surface of fixing-plate with ridges; Figs. 16, 17, top and side views of a large specimen which has surrounded its attachment.

Figs. 18, 19.—*Podolithus anomalocrinus* n. sp. Side and top view of root and part of column; from the Galena stage.

Figs. 20–23.—*Podolithus eucheirocrinus* n. sp., from the Galena stage. Figs. 20, 21, views of a large lobate root surrounding a Crinoidal column; Fig. 22, part of surface of same ×2; Fig. 23 a small specimen.

Figs. 24, 25.—*Podolithus dendrocrinus* n. sp., from the Galena stage. Fig. 24, side view of root with long rounded lobes, and of stem-scar of same; Fig. 25, section ×4, across three lobes, *a*, *b*, *c*, of another specimen.

Fig. 26.—End of a round column ×2, showing lumen and canals; corresponding to Fig. 24.

Figs. 27–31.—Diagrammatic sections, Fig. 27, of *Podolithus*; Fig. 28 of same with margins turned under; Figs. 29, 30, hypothetical modifications; Fig. 31, of *Camarocrinus; f*, fixing plate; *o*, "medio-basal" cavity; *r*, radicle; *i*, interradicle contours; *c*, pockets or camerae.

STUDIES FOR STUDENTS

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS—*Continued*

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PART II. RELATION OF SEDIMENTS TO REGIONS OF DEPOSITION

INTRODUCTION

Upon a comparison of the character of the deposits laid down upon the topographically somewhat similar surfaces of large deltas but

under the most unlike conditions of temperature and rainfall, such, for instance, as the deposits upon the deltas of the Indus, the Amazon, and the Yukon, it is perceived that the climatic conditions existing over the surface of deposition form a factor of primary importance in governing the nature of fluvial and pluvial deposits. A proper interpretation of ancient continental sediments cannot be made, therefore, if the climatic factor be neglected, and on the other hand the deposits of ancient delta surfaces should contain a more or less accurate record of the climatic conditions of origin. But a closer inspection of modern deltas shows that different parts of the same delta surface exhibit markedly different conditions of deposition owing to the somewhat varying local geographic features, such as lakes, swamps, and natural levees, which may exist. In desert regions, as exemplified by the delta of the Helmund, the great internal river of Persia, portions not now used by the river are barren sandy deserts subjected to deep wind scour, occasionally in this instance exposing ancient ruins, and the corresponding heaping-up of aeolian deposits, while at the same time such shifting, shallow, and variable lakes as that of Seistan, the reservoir into which the Helmund drains, are giving rise to interstratified, truly lacustrine deposits.[1]

Therefore in the climatic interpretation of ancient continental deposits proper allowance must first be made for the geographic variations which occur within the region of deposition. The field studies must be sufficiently broad to lead to some recognition of the ancient geography before the ancient climate may be determined. To that end the modifications in deposit due to the influence of the local geographic conditions will first be discussed.

Influence of Nature of Surface of Deposition

PIEDMONT SLOPES—AERIAL DELTAS

These are more usually formed in arid or sub-arid climates, since in such the river waters progressively escape, after leaving the mountains, into the thirsty soil and air. The overloaded stream consequently throws down its burden of waste upon a slope which may vary from 100 feet per mile in the case of the coarser and steeper fans

[1] Col. Sir Henry McMahon, "Recent Survey and Exploration in Seistan," *The Geographical Journal of London*, Vol. XXVIII, 1906, pp. 209–228.

to those which may be as low in grade as five or ten feet per mile. The latter are built by the more slowly diminishing volume of the larger streams, and their sands or silts, when properly irrigated, form soils of the greatest richness. As an instance of the physical conditions which may exist upon such subaerial delta fans there may be quoted the following description by Davis of the plains of the rivers which flow north from the mountains of northern Afghanistan into the Kara Kum desert:

> The surface was absolutely plain to the eye, except for the dunes, and the dunes departed from the plain only as wind waves at sea depart from a calm surface. Although apparently level the plain has slope enough to give the Tejen, the Murg-ab, and the Amu rapid currents, in which these rivers carry forward a great volume of mountain waste. We were fortunate enough to see the Tejen and the Murg-ab in flood. The former had overflowed its channel and spread in a thin sheet for miles over the plain. The latter would have spread but for the restraint of dykes at Merv. Some of its waters had escaped farther upstream and came to the railroad, wandering across the plain among the dunes, a curious combination of too much and too little water supply.[1]

Following the inundation under natural conditions a temporary vegetation springs up, finally withering and giving place to the desert until the period of the next season of flood. Such districts of sedimentation give a maximum contrast of seasons of desert aridity alternating with periodic inundations; a contrast which is to be regarded as due not only to the arid climate but equally to the slope of the surface supplemented by the porous nature of the deposits, allowing of rapid drainage followed by a drying of the soil. In climates of a semi-arid character, as over the High Plains of the United States, the flood plains show a similarly well-drained character, the swampy areas being found more commonly among the dunes of the upland than over the river plain and due to aeolian more than to fluviatile action.[2] In wet climates the opportunity for deposition of waste upon such slopes is more rare and can occur in marked development only where streams in a highly loaded condition escape from lofty mountains. Such fans may be noted among the Alps with surfaces free from swampy areas, except, as in the case of the valley of the Upper Rhone, where

[1] W. M. Davis, *Explorations in Turkestan*, 1905, p 54, "Carnegie Institution Publications," No. 26.[1]

[2] See the Brown's Creek and Camp Clarke, Nebraska, quadrangles, "Topographic Sheets," *U. S. Geological Survey*.

opposing fans dam up the line of confluent drainage. The final conclusion, therefore, is that over such piedmont slopes there is a great freedom from areas of swamp and the greatest opportunity for drying and aeration of the soil between the times of flood. Such deposits should normally show complete oxidation of the iron and a complete absence of carbon. In hot climates evaporation from the soil is very rapid and oxidation of the humus is also rapid, resulting in the red clays characteristic of the moist tropical climates. Even the short intervals between rains which occur in the most pluvial of tropical regions are sufficient, therefore, to bring about the oxidation of the iron and elimination of the carbon from all but permanently swampy areas, giving rise to the red muds of the Amazon and Congo rivers.

In cool climates, on the contrary, evaporation and oxidation are both diminished in intensity with the result that carbon may accumulate upon slopes to an extent impossible in warmer climates, giving rise upon consolidation to carbonaceous sandstones or even conglomerates. The existence of the latter chemical conditions, leading to the accumulation of carbon even upon sloping surfaces, is found only in climates which approach a continuously rainy character and possess in addition cool summers. As an example, such climatic conditions are found at present upon the western slopes of Ireland, though the accumulating piedmont slopes are there wanting. Peat swamps, however, are observed to exist upon hilltops, slopes, and valley bottoms, covering one-seventh of the entire island. Many bogs possess a grade sufficient so that in times of excessive rain they may swell and burst and disastrously flood the lower valleys. Less familiar but still better examples are offered by the cool and humid maritime mountain slopes of Alaska. Of these Russell states:

> About the shores of Unalaska and for fully 2,000 feet up its rugged mountain slopes the vegetation is essentially the same as at St. Michaels upon the Yukon delta. In climbing the steep slopes about Iliuliuk I often had great assistance from the dense mat of vegetation two or three feet thick, which, clinging to the rocks, converts their angular crags and shattered crests into smooth domes of soft, yielding moss. On the steep slopes, as in the swamps, the vegetation is always water soaked, owing to the extreme humidity of the climate in which it thrives. Lakelets are common on slopes and hillsides that would be well drained were it not for the spongy nature of their mossy banks.[1]

[1] "Notes on the Surface Geology of Alaska," *Bulletin of the Geological Society of America*, Vol. I, 1890, pp. 125, 126.

Turning to the past for illustrations of these conclusions, we may point out that the coarse, coal-measure conglomerates of the Narragansett Basin and the less coarse, but still conspicuous, Triassic conglomerates of the Connecticut Valley, both give evidence of rather local derivation and of continental deposition, evidence which cannot, however, as previously stated, be here discussed in detail. The local origin and coarse texture indicate deposition upon slopes of at least from five to ten feet per mile and possibly much greater, sufficient, under the usual climatic conditions, for good drainage. The Triassic conglomerates of the Connecticut Valley show a large amount of fragmentary fresh feldspar, iron completely oxidized, and no trace of carbon, either in the matrix or associated red shales, the fish fossils being found in the rare black shale bands. The conglomerates of the Narragansett Basin, on the other hand, with the exception of the Wamsutta beds, show a bleached matrix containing more or less carbon and are associated with a great volume of highly carbonaceous shales.

From these facts alone, therefore, it would be judged that the Carboniferous conglomerates, granting their subaerial origin, were accumulated during a period of cool and more or less continuously rainy climate.

The Triassic conglomerates, on the other hand, are associated with many features of climatic significance which also cannot be taken up here in detail, but which independently indicate a semiarid climate with hot summers and possibly cold winters. The characteristics, therefore, of these conglomerates, originating from the same geologic province, but in climatically dissimilar geologic times, are such as to emphasize the importance of the present conclusions regarding climatic influences upon the deposits of piedmont slopes. Further discussion of this subject must be left for the section on climatic influences.

LOWER FLOOD PLAINS—AQUEOUS DELTAS

The slope of graded streams progressively diminishes from source to mouth, the larger and longer the stream the flatter the grade tending to become. The deltas of the larger rivers commonly possess a slope of less than a foot per mile, and on the seaward margin pass into practically level salt-water marshes, underlaid by heavy deposits of

flocculated clay, giving rise to conditions unfavorable for either underground or surface drainage. In the case of piedmont slopes it was seen that in desert climates the greatest seasonal contrasts exist between too much and too little water, but that all parts fare much alike and become dried out through the greater portion of the year. Over the lower flood plains, on the contrary, such striking contrasts of swamp and desert are permanent features through series of years. Using the delta of the Colorado River as an example of one developed under highly arid conditions, Macdougal describes in a recent work how:

> At places where the river is cutting into gravelly and sandy bluffs, within the compass of one hundred feet may be found the most vivid contrasts of rank swamp vegetation and water-loving plants having broad leaves and delicate tissues with the toughened spinose, and hairy xerophytic forms of the desert.
>
> The quantity of food furnished by the swampy jungles is sufficient to support a vast amount of native animal life, and furnishes inviting feeding-grounds for migrating birds. The countless millions of young willow and poplar shoots supply food for the beaver, which bids well to hold out long in the impassable bayous and swamps against its trapper foe.
>
> Nearer the gulf are found great sloughs, in which are extensive fields of the "wild rice," while the land subject to the action of the overflow of the tides supports a carpet of salt-grass.[1]

Similar areas of more or less permanent swamp, increasing toward the seaward margin, may be noted as characteristic of other large deltas, such as those of the Nile and the Indus, developed as with the Colorado in truly desert regions. In ancient river deposits, therefore, an appreciable proportion of paludal deposits must be expected to occur over the terminal portions of the delta under all climatic conditions, and such must be allowed for in making inferences in regard to the ancient climate. As means for separating these geographic and climatic factors, however, may be noted the close association over the desert delta of paludal and desert conditions and the much smaller proportion of swamp which is permanent than in the case of more pluvial climates. In the long seasons of dessication all but the lowest bottoms become dried out and mud-cracked.[2]

[1] "The Delta of the Rio Colorado," *Bulletin of the American Geographical Society*, January, 1906, pp. 4, 10, 11.

[2] D. T. Macdougal, *op. cit.;* see Fig. 1.

A number of conditions besides the climate will be found, however, to affect the ratio over the marginal portion of the delta, of swamp to the well drained areas. These may be enumerated as follows:

First, a slowly rising water level tends to flood the lower portion of a delta and bring large tracts into the condition of permanent swamps. As such movements of water level are variable and intermittent the extent and ratio of the seaward paludal deposits seen in cross-section in ancient deltas will vary through the section. Such, however, will be practically absent from the region of the apex of the delta, but will be marginal to, and most commonly underlie, marine strata marking invasions of the sea.

Second, the contest of two or more rivers in building up a common flood plain or delta results in the damming back of the weaker members of the system. The paludal regions tend to migrate away from the greater sources of sediment.

Third, the possession of a wide flood plain, as in the case of the lower Mississippi Valley, is liable to result in a considerable area of back swamp, there being less infilling from the sides, and the river with its natural levees occupying a lesser portion of the whole.

As factors tending on the contrary toward good drainage of the lower river plains may be mentioned: first, a stationary or even slowly subsiding water level; second, the possession of a flood plain by a single river such as the Nile as contrasted with the Euphrates-Tigris system of Mesopotamia; third, aggradation within a confined valley, exemplified by the Great Valley of California, where side wash is present to such an extent that the ground slopes gently but continuously from the hillsides to the trough of the valley.

ELIMINATION OF LOCAL GEOGRAPHIC FACTORS

The preceding discussion has dealt with the upper or lower flood plains of the river system as a whole and it has been seen that the character of the sediments deposited must be largely influenced by the physical conditions existing in the region of deposition, whether near the mountains as piedmont slopes, or at a distance as deltas built into shallow seas. Within the confines of the terminal deltas, however, there exists greater local diversity of conditions.

In the study of ancient deposits now exposed to view in scattered

and fragmentary sections such a comprehensive knowledge of the limits and surface nature of the original formation becomes, however, a difficult problem. Certain rules should, therefore, be formulated, by following which the local geographic conditions may be most largely eliminated from the problem of the climatic interpretation. Such rules may be stated as follows: First, the general direction of the former land on the one hand and of the sea on the other is ordinarily readily determinable. The deposit is coarsest, the slope of the river-plain steepest, the surface and underground drainage best, over those portions of the deposit nearest the source of sediment. The highest proportion of continental as opposed to marine strata will ordinarily be found in the same region. This, therefore, will be the most favorable place for the study of all but the chemical or organic deposits. Second, toward the landward or upstream side the thicknesses of the formation will commonly vary along successive outcrops. Such variable thicknesses may be due either to excessive subsidence causing drainage of the sediments *toward* and into the basin, filling it in; or excessive sedimentation building up piedmont slopes, the excess passing *outward* in other directions, or to a combination of both conditions. Observation of ancient geosynclines, such as that which faced Paleozoic Appalachia, shows that in many cases excessive sedimentation in the vicinity of some large river appears to be the more common and fundamental cause, the zone of maximum deposition being characterized at the same time by the coarsest material and a decreased proportion of chemical and organic deposits. In continental formations, therefore, the region of maximum thickness, as well as greatest coarseness, is usually the most favorable for the study of the mechanical conditions of deposition. Third, the regions of scanty sedimentation and the paludal zone facing the ancient water body are the most favorable for the development of chemical and organic deposits. Under arid climates will here be found beds of salt and gypsum intercalated with both continental and marine argillaceous strata, possibly associated with a small amount of variegated shales; but, judging from geological experience, never deposits of carbon. Under typically rainy climates, on the other hand, whatever occasional deposits of salt and gypsum may form are speedily washed away during a following season of rain, and the permanently

flooded condition of the swamp areas leads to the preservation of carbonaceous strata.

With the accentuation of climates toward aridity or toward a cool and continuously pluvial condition, these chemical and organic deposits, developed most typically on the distal margin of the delta, spread inland and become of greater geological importance, as illustrated by the brine pools of the desert delta of the Volga, on the one hand, or the impenetrable flooded jungles of the Amazonian silvas, on the other.

Climatic Influences in Regions of Deposition

The geographic and climatic influences in the regions of erosion produce two effects in the region of deposition. One, a chemical and mineralogical influence which becomes generalized and vague with prolonged transportation; the other through variations in erosion causing variations in the coarseness and quantity of waste, also becoming masked by the effects of long transportation. On piedmont slopes, therefore, being nearer the headwaters, the climatic conditions of erosion, of transportation, and of deposition all find obvious expression; but over the more distant parts of a river system the more conspicuous factors governing the nature of the sedimentation are the *variable nature of the transportation*, regulating the coarseness and quantity of the waste, and the *variable climatic conditions existing in the region of deposition*, largely governing the chemical and mineral nature of the deposit. The microscope and the chemical analysis will still, however, be able to trace underlying influences due to the nature of erosion, as indicated by existing deposits of loess in Mississippi and red laterite muds spread in places upon the bottoms of tropical seas.

In taking up in detail the present topic of the influence of climate in regions of deposition, the effects upon the deposits of four kinds of climates may be considered, namely, constantly rainy, intermittently rainy, subarid, and arid. The effects of increased cold, by preventing evaporation, produce results similar to an increased and more continuous rainfall. Cool summers rather than cold winters are more effective in this way and lead in northwestern Europe to the production of extensive peat deposits in regions which receive but twenty-five to

forty inches of rain per year, distributed, however, rather uniformly through the seasons. Where the cold is prolonged and intense, however, as found over the tundras within the Arctic Circle, a fifth class, that of the frigid climates, may be considered.

EFFECTS OF CONSTANTLY RAINY CLIMATES

Constantly rainy climates are defined by W. Köppen as those where no month has less than fifteen rainy days.[1] Such climates are dominant south of south lat. 45°, touching southwestern Patagonia, Tierra del Fuego, and southern New Zealand. Another large area exists in the North Atlantic, touching Iceland and approaching the shores of Ireland, Scotland, and Norway. Certain tropical areas also have nearly constantly rainy climates, at least six days in every month being rainy, the northern half of the basin of the Amazon being the most notable from the present point of view. In such regions the forest vegetation attains its maximum development, the cooler parts of the temperate zones hardly lagging behind the most favored tropics in luxuriance, provided that the winter winds are moist, the soil and antecedent vegetation have been spared by glaciation, and the more recent forests by man. On the southwestern side of Patagonia, for instance, in south lat. 55°, Hatcher speaks of a vegetation so profuse as to suggest that he had been transported into the midst of some tropical jungle.[2] Dusén states also that in the interior of Tierra del Fuego, near the harbor of Puerto Angosta, the typical virgin forest reminded him of the West African virgin forests which he had seen.[3]

In this connection the observations of Darwin upon the forests of Tierra del Fuego are significant. He mentions the thick bed of swampy peat covering the steep slopes above the timber line while of the almost impenetrable forest below he states:

> In the valleys it was scarcely possible to crawl along, they were so completely barricaded by great mouldering trunks, which had fallen down in every direction. When passing over these natural bridges, one's course was often arrested by sinking knee-deep into the rotten wood; at other times when attempting to lean against a firm tree, one was startled by finding a mass of decayed matter ready

[1] *Bartholomew's Physical Atlas*, Vol. III, 1899, Plate XIX.

[2] *Princeton Patagonia Expeditions*, Vol. I, 1903, p. 150.

[3] P. Dusén, "Ueber die Vegetation der feuerländischen Inselgruppe," *Englers Jahrbücher*, Band XXIV, 1898.

to fall at the slightest touch.[1] . . . . The entangled mass of the thriving and the fallen reminded me of the forests within the tropics—yet there was a difference: for in these still solitudes, death, instead of life, seemed the predominant spirit.[2]

These statements bring into prominence the slowness of organic decay in cool climates and its rapidity in warm, permitting the accumulation of dead vegetable matter in the one region, quickly removing it from view in the other. Schimper also calls attention to the relative poverty of humus in tropical soils and emphasizes the statement that peat is never produced in the tropics except on mountains over 1,200 meters in height.[3]

Influence of arctic climates.—Within the colder portions of the temperate zones a lesser rainfall and severer winters result in a somewhat diminished luxuriance of vegetation, but, as previously noted, on account of the less intense evaporation and oxidation notable deposits of carbon may still result. In the interior of Alaska the precipitation varies from about ten inches per year on the eastern boundary to about twenty-five inches per year where the interior province passes on the west into the relatively humid Behring Sea province. The heaviest precipitation is in summer, but is always moderate in amount.[4] Under these conditions of rainfall, which in a hotter climate would lead to aridity or semiaridity, there is here found on the lowlands, where these are within the timber line, a luxuriant forest of spruce and willow with an undergrowth of cryptogamic character.

Within the Arctic Circle beyond the limit of arboreal vegetation exist the vast treeless moss-covered plains known as the tundra, perpetually frozen below the depth of a foot or two. In the far north the tundra may be developed under a rainfall of not over ten inches per year, but in such regions the vegetation is meager and barely covers the soil. Farther south, however, and in more rainy districts a thick carpet of peaty vegetable matter may accumulate. A tundra of this character is found on the delta of the Yukon under a rainfall of from

[1] "Ascent of Mount Tarn," *The Voyage of the Beagle*, June, 1834.

[2] *Ibid.*, "Scenery of the Mountains and Retrospect."

[3] *Plant Geography*, 1898 (Eng. trans.), pp. 381, 382.

[4] Cleveland Abbe, Jr., "Climate of Alaska," pp. 147, 154–157, Professional Paper No. 45, *U. S. Geological Survey*, 1906.

eighteen inches at St. Michaels to thirty-three inches at Fort Alexander, the precipitation occurring largely as rain and from May to October.[1]

Russell, speaking of the tundra as developed upon the delta of the Yukon and the south, says:

General characters.—The tundra in typical localities is a swampy, moderately level country, covered with mosses, lichens, and a great number of small but exceedingly beautiful flowering plants, together with a few ferns. The soil beneath the luxuriant carpet of dense vegetation is a dark humus, and at a depth exceeding about a foot is always frozen. On its surface there are many lakelets and ponds surrounded by banks of moss even more luxuriant than on the general surface. It is not always a level plain, however, but is frequently undulating and may surround and completely cover hills of considerable elevation. The dense tundra vegetation also extends up the mountain side and occupies the entire region where the conditions are favorable for its formation. At the localities where I examined it the whole surface, excepting the faces of steep cliffs and the summits of high mountains, was covered with the same dense brown and green carpet. The characteristics are the abundance of mosses and lichens and the absence of trees. Cryptogamic plants make more than nine-tenths of its mass. On their power to grow above as they die and decay below depends the existence of the tundra.

The depth of the humus layer beneath the moss was found to be about two feet at St. Michaels. A mile east of the village it was about twelve feet. In the delta of the Yukon a depth of over fifteen feet was seen at one locality. As satisfactory sections are rare, these measurements do not indicate its average thickness. A depth of 150 to 300 feet has been assigned by several observers to the tundra where it is exposed in a sea cliff on Eschscholtz Bay, at the head of Kotzebue Sound.[2]

Chemical nature of deposits of constantly rainy climates.—The distinctive chemical effects are to be noted in the absence or small amount of the soluble elements, embracing iron, magnesia, lime, potash, and soda, and in contrast, the presence of carbon. Owing to the diminished evaporation and the constant saturation of the soil of the entire flood plain, aeration and oxidation of the soil is prevented while the decaying organic matter results in deoxidizing effects. Where the leaching and deoxidizing actions have fullest opportunities for work, as in the clay soils beneath swamps, all soluble plant food may be leached out. Where the chemical effects are less pronounced

[1] Cleveland Abbe, Jr., *op. cit.*, pp. 146, 152.

[2] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bulletin of the Geological Society of America*, Vol. I, pp. 125–27.

the iron may be deoxidized and concentrated, but not eliminated. The colors of the deposits are consequently white or black or gray. These opposed relations of carbon and iron and the leaching of soluble components from the fire-clays underlying swamp deposits as derived from the study of modern instances are seen to correspond to the nature of the coal-measures and the conditions of moisture necessary for their formation have long been emphasized, but the added condition of coolness as favoring more extensive accumulations of carbonaceous character has not until within the past few years been generally recognized. The great influence of coolness was perhaps first pointed out by Russell, who in connection with the carbonaceous deposits of Alaska expresses the following opinion:

A possible origin of coal seams.—So vast is the amount of vegetable matter now imprisoned in the tundra of the North, that I venture to suggest that possibly some coal seams may have had a similar origin.

This suggestion does not seem so very unreasonable when one remembers that except in the circumpolar tundra, deposits of vegetable matter are nowhere accumulating at the present day to anything like the extent or thickness required for the formation of coal fields like the one, for example, of which Pennsylvania still retains a remnant. Botanists will say at once, in opposition to this suggestion, that the flora of most of our coal fields, and especially those of Paleozoic age, indicate tropical or sub-tropical conditions. The flora of the tundra, however, like the plants of the Carboniferous, is essentially and characteristically cryptogamic. Two species of Equisetum, which may be considered as representing the Calamites of former times, flourish with rank luxuriance over great areas along the Yukon.[1]

It is further desired at this place to call attention to the other chemical characters of the deposits, by which even without the presence of carbon the rainy nature of the climate may be inferred. Various investigators have shown that in those portions of tropical soils leached by heavy rainfall which are soluble in hydrochloric acid soda is quite absent, potash is low, the residual soils usually not possessing over 0.1 per cent.[2] of potash and the river alluvium not over 0.2 to 0.3 per cent.,[3] the leached alluvium of Assam, a region of extremely heavy rainfall, containing but about one-half the potash of the drier soils of the Indo-Gangetic plain. The same characteristics

[1] *Op. cit.*, pp. 127, 128.

[2] E. W. Hilgard, *Soils*, 1906, p. 355.

[3] *Op. cit.*, pp. 412, 413.

would be evident upon a complete analysis of the alluvium, but unfortunately for geological purposes such complete analyses of soils are seldom made. Lime exists in higher percentage in river alluvium than in upland soils, but Mann has shown that it is extremely deficient in the soils subjected to heavy rainfall, the general average in the Assam alluvium soluble in hydrochloric acid being about 0.08 per cent., as against nearly 1.0 per cent. in the average Indo-Gangetic soil.[1] It is noticeable that in the true tropical soils the content of magnesia is considerably above that of lime; a fact readily intelligible from the more ready solubility of lime in carbonated water.[2] That it is leached out also, however, is indicated by its content of 0.5 per cent. in the soluble portion of the Assam tea soils as contrasted with its presence to the extent of 1.3 per cent. in the soluble portion of the Indo-Gangetic alluvium.[3] The iron of the Assam soils is also low, but it is not deficient in tropical soils in general, giving on the contrary a characteristic red to such lands as Madagascar and Ceylon.

The continuously rainy climates may be divided into those situated in the equatorial belt, usually possessing at least short dry seasons, and those situated in the cooler parts of the temperate zones. The preceding discussion on the chemical distinctions has been largely based upon soils of the torrid zone or warm temperate, as in the case of the Assam alluvium. In the cold temperate regions recent glaciation has in many cases prevented the establishment of normal chemical relations between the rocks and the atmosphere, but such observations as have been made indicate, as was shown in Part I, that decomposition is greatly reduced. From the foregoing it may be concluded that the broad association of carbon with sediments which are thoroughly decomposed and leached throughout is the mark of continuously rainy climates which are tropic or at least warm temperate; with sediments imperfectly decomposed and incompletely leached the mark of more or less continuously rainy climates which are in addition cool or cold. The best microscopic test after the lithification of the alluvium may be the absence or presence of potash minerals. The carbonaceous shales of the anthracite coal-measures of Pennsylvania, except the fire clays immediately below the coal beds, possess a marked abundance of muscovite, indicating the presence of consider-

[1] Hilgard, *op. cit.*, p. 413. [2] *Op. cit.*, p. 405. [3] *Op. cit.*, p. 413.

able potash and magnesia. From this would be inferred an origin under cool climatic conditions, in line with the inference previously drawn from the Carboniferous conglomerates of Rhode Island—calling attention to the importance of microscopical or chemical examination and comparison of argillaceous sediments of similar continental but presumably of unlike climatic origin. In contrast with the muscovite shales of the coal-measures may be noted the absence of muscovite in the carbonaceous shales of the Hudson River and Hamilton periods which underlie the Carboniferous and have consequently been subjected to equal or even greater metamorphism. While these latter shales are of marine origin it is not clear that that fact alone could lead to this peculiar distinction.

That a cool climate, while undoubtedly favorable, is not necessary for the production of coal-measures is, however, shown at the present time by the swamps of the Amazon and, in the past, by the warm-temperate flora of the Eocene coals of the Pacific slope. The absence of frost rather than a hot climate is, however, all that is necessarily implied by the Eocene vegetation.

EFFECTS OF INTERMITTENTLY RAINY CLIMATES

Intermediate character of deposits.—Climates of this class are such as characterize those portions of the world where crops may be grown without the aid of irrigation, but where one or more months may be relatively free from rain. Under these familiar conditions the soil of the flood plains normally contains considerable humus, but much of it is yellow or red, instead of brown or black, from the subordination in quantity of the humus to the ferric hydrate. The greater part of the soil of flood plains is sufficiently dry during a growing season for such crops as corn and cotton. The clays are slightly calcareous and occasionally sufficiently so to give rise to the so-called "buckshot" soils such as are found over portions of the Mississippi flood plain.[1] The subsoils of such plains are observed to carry more compact clay and less humus than the soil, the carbon thus gradually disappearing with depth in aerated soils.

Only in the lower bottoms or abandoned ox bows is the land so saturated with moisture that swamp vegetation dominates, organic

[1] E. W. Hilgard, *Soils in the Humid and Arid Regions*, 1906, p. 116.

matter indefinitely accumulates, and the iron is eliminated or at least reduced partly to the ferrous conditions, giving rise to the blue and green clays found in the subsoils of certain undrained lands. From the discussion on the climatic significance of color, as given in a later portion, it is believed that the usual yellow or brown of such flood-plain deposits frequently deepens upon the consolidation into shades of red or deeper brown. When such flood-plain deposits are buried and lithified the upstream portions will consequently be found somewhat more arenaceous, varying from red to brown sandstones and usually inclosing red, green, and some black shales; the last in very subordinate quantity. Over the terminal land portions of the deposit on the contrary the sandstones should be finer grained and the quantity of shales should increase. With this increase in shales, grey, green, and black varieties should be relatively more abundant and thin lenticular discontinuous coal beds may be expected to occur. Thick, uniform, and widespreading coal deposits are, however, theoretically impossible, since the swamp areas are restricted to the lowest-lying portions of the plain.

Organic characteristics.—A forest growth normally covers the entire surface of such flood plains, varying from mesophytic to hydrophytic types, salt marshes marginal to the sea and internal shallow lakes alone being occupied by reedy growths. The alternate wetting and drying occurring in such soils leads to the rapid humification of animal and vegetable substances, and ultimately to their complete destroyal. Consequently, but few fossil evidences will remain beyond the casts of leaves and trunks occurring in the lighter-colored shales and sandstones, and the preservation of some carbonized tissues in the occasional black and coaly shales.

Conclusion on unappreciated extent of such deposits.—In conclusion it may be said that the deposits of intermittently rainy climates are of a chemical and organic character intermediate between those of continually rainy climates on the one hand and those of a subarid or arid character on the other, lacking the sharply distinguishing characteristics of each. In consequence of the absence of such distinctive marks such deposits, while abundant, may be the most difficult of continental formations to distinguish and convincingly separate from those of shallow-water, off-shore marine origin.

The section of the Ganges delta given by the Calcutta borehole shows no trace of marine deposits, but on the other hand the proofs of land surfaces in the form of ancient swamp deposits, even in this marginal portion of the delta, were encountered only at two levels in the 481 feet of the boring.[1] Scattered vegetable matter and the bones of terrestrial mammals and fluviatile reptiles which were found, while suggestive of continental deposition, may possibly occur in off-shore marine deposits and alone do not conclusively demonstrate the continental origin. Farther inland, at Umballa, on the watershed of the Indo-Gangetic plain, a bore-hole 701 feet deep passed through alternations of sand and clay, the colors usually red or brown but with some clays blue and black. In places the bore-hole encountered a few pebbles and bowlders, but no mention is made of organic remains, which according to Medlicott and Blanford occur but rarely in the alluvial formations of the Gangetic plain.[2] Numerous layers of Kankar (concretionary strata of calcium carbonate) suggest the previous existence at this place of the semiaridity which now prevails in that region. The Mississippi delta shows much of the same characteristics as that of the Ganges at Calcutta. Consequently, where sands and clays or their consolidated representatives constitute a formation with no trace of marine fossils but possessing even fragmentary remains of land life, it is to be concluded with high probability, if no other evidence overweighs the decision, that the entire formation is continental and, further, if no positive marks of other climatic conditions are evident, that it was probably formed on a river flood plain under the intermittently rainy climates, which, though at times diminished and again magnified in importance, have yet existed uninterruptedly through all geologic time and formed those shifting zones within which the chemical activities of the atmosphere and the biologic forces of terrestrial evolution have found their fields for fullest action.

EFFECTS OF SEMIARID CLIMATES

Chemical and structural characteristics.—Semiarid climates are those where irrigation is usually necessary for the maturing of crops

[1] Medlicott and Blanford, *A Manual of the Geology of India*, Part I, 1879, pp. 397–400.

[2] *Op. cit.*, pp. 401, 402.

or where protracted periods of drought are to be expected during certain seasons of the year. In temperate latitudes this corresponds roughly to between ten and twenty inches of annual rainfall. Under such conditions, as illustrated over the High Plains of the United States and much of the Cordilleran province, the humus is oxidized out of the soil more rapidly than in more rainy climates, being deficient in amount but rich in nitrogen; the iron is not leached or concentrated, except in the presence of occasional shallow lakes or swamps; the soil is uniformly high in potash, lime, and magnesia. The potash is, moreover, largely in the form of comminuted orthoclase, giving less plasticity to the finer elements of the soil.[1] Very little distinction is to be noted between the soil and subsoil of alluvial plains.

The swampy portions of the flood plain largely become dry during the long dry season, excluding fishes and offering favorable breeding-places for mosquitoes during the times that the swamps exist. The delta regions of subarid climates are consequently particularly malarious. As examples of such deltas may be cited those along the north shores of the Mediterranean. The Gedis, flowing into the Gulf of Smyrna, possesses extensive delta swamps dry during the summer,[2] while the small proportion of swamp in the case of the Nile delta in a truly arid climate is to be compared with the extensive swamps of the Mississippi. Other factors besides climate, however, may assist in governing the ratio of swamps in the latter cases. The thorough seasonal oxidation which is thus allowed of nearly all deposits except those made in permanent water bodies should result, upon their incorporation into the geological record, in a marked dominance of deep-red and brown shales and sandstones, a moderate amount of variegated shales, confined almost entirely to the marginal portion of the deposit, and few or none holding carbon. Lime will exist disseminated in noticeable amount through both shales and sandstones and may occasionally give rise to markedly nodular or solid calcareous strata.[3] The microscope should show some muscovite and in addition a noticeable amount of feldspar in the finer portions

[1] E. W. Hilgard, *Soils*, 1906, chaps. xx, xxi.

[2] G. R. Credner, "Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen, *Petermann's Mitth. Ergänzungsheft*, No. 56, Vol. XII, 1878, Plate I.

[3] Medlicott and Blanford, *Geology of India*, 1879, Part I, chaps. xvi, xvii.

of the rock. The contrast between the river deposits of humid and subarid regions is well brought out by the comparison of the alluvium of the Indo-Gangetic plain with that of the Brahmapootra in Assam, the material in both cases coming from the same mountain system.[1]

The most marked chemical distinction of subarid flood-plain deposits from those of truly arid regions is found in the small quantity of evaporation deposits of calcium carbonate, gypsum, and salt, but especially of the two latter. Lime may be quite abundant, as shown by the Kankar of the Indo-Gangetic plain, its importance depending largely upon the quantity in solution in the river water. Gypsum and salt, however, formed by the evaporation of salt lagoons bordering the sea, are largely washed out by the rains and floods of the rainy season. As gypsum and salt impregnations of clay strata they may be preserved and sometimes as purer deposits of salt, as illustrated by the deposits now occasionally formed on the Rhone delta, as noted long since by Lyell,[2] in a climate which approaches subaridity. Such deposits cannot be formed, however, in anything like the areal extent or thickness with which they may occur in truly arid regions. Gypsum in delta deposits is less an indication of aridity than salt, since the former is precipitated upon the evaporation of 37 per cent. of normal sea water while the precipitation of salt only begins when 93 per cent. has been evaporated. It is to be noted, however, that the majority of recent sediments containing gypsum are found in arid climates, and where occurring as impregnations in ancient deposits which were not laid down in contact with sea water would seem surely to indicate a high degree of subaridity bordering upon truly arid conditions.

The alluvial soils of semiarid flood plains are particularly liable to become deeply mud-cracked during the seasons of drought, but this cracking may or may not be preserved in the sedimentary record.[3] Over the regions of alternating sands and clays where the clay is not calcareous the conditions are most favorable for the formation and preserval of mud cracks. The importance of mud-cracking in further drying out the soil and tearing the roots of plants has recently been

[1] E. W. Hilgard, *Soils*, 1906, pp. 410–14.

[2] Charles Lyell, *Principles of Geology*, 9th ed., 1853, p. 259.

[3] J. Barrell, *Journal of Geology*, Vol. XIV, pp. 528–33.

pointed out by Hilgard.[1] The climatic point where mud-cracking becomes broadly effective upon the clays of a flood plain is therefore rather a critical one tending to separate the floral characteristics of well-watered from subarid climates.

Floral characteristics of semiarid flood plains.—One of the most secure means at present commonly used to determine the climate of a past age consists in the study of a fossil fauna and flora, the identification of genera and species, and the inference that the optimum climatic environment for such organisms has remained the same from the past to the present time. As examples may be cited the conclusions in regard to the warm polar climate of the Miocene based on the presence of magnolias in Greenland and the same in Mississippian times as determined by fossil corals in the rocks of Spitzbergen. Such strictly paleontological sides of the problem are beyond the province of the present article, but there may be profitably considered the relations between climate and the kind of fossils to be expected and certain general adaptive characteristics of plants or animals to arid or moist, cold or warm conditions, especially when these are of a nature which may be preserved. The present statements will be chiefly confined, however, to the effects of semiarid climates upon vegetation.

The vegetation of the flood plains of semiarid climates is more largely arboreal than that of the inter-stream slopes.[2] Many large tracts of the flood plain away from the river banks are, however, either sparsely covered with trees or given over to grass land. Even the latter may find difficulty in existing where an unfavorable nature of alluvial deposit is added to the unfavorable conditions of a hot or dry growing season.[3] The occupancy of the soil by grass or forest depends upon the underground water. For forests there must be an adequate amount of moisture in the subsoil during the growing season, though this water may have come from winter floods or rains. For grassy plains the water in the subsoil is immaterial, the essential con-

[1] *Soils*, 1906, p. 112.

[2] A. F. W. Schimper, *Plant Geography* (Eng. trans.), 1898, Map 3.

[3] Views of piedmont and terminal flood plains of the semiarid belts of the United States may be found in various reports. For a study, with photographs, of the vegetation of the Rhone delta of the Mediterranean in a climate which approaches semiaridity see *Flahault et Combres*, Sur la flore de la Camargue et des alluvions du Rhone, *Bulletin de la société botanique de France*, T. 41, 1894, pp. 37–58.

dition being a moist soil during the season of growth.[1] Although the level of the ground water in flood plains of even subarid climates may lie not many feet below the surface, the alternate stratification of fine sand and clay which is frequently present is very unfavorable for a forest vegetation. The clay is capable of carrying the water upward to a greater height, even as high as ten feet, but transmits it very slowly. The sand, on the other hand, cannot lift the capillary water more than one or two feet, but does this very quickly.[2] If the upper portion of a sand stratum is dry, the plants cannot feel the moisture below and will fail to send roots after it. In the presence of such strata a vegetative covering of bunch grass is to be expected, leaving no appreciable organic record. A deep loamy soil favorable for storing water and for its capillary rise is the most favorable condition for the growth of trees and shrubs over semiarid flood plains. The roots in such cases strike downward rather than horizontally and may penetrate to great depths, twenty feet being not uncommon.[3] The angle of penetration of fossil roots is therefore a matter of importance from a climatic point of view. The strong oxidation acting at the surface normally destroys all vegetable tissues before they become buried in the course of time below the deep zone of oxidation, but there is a chance of finding casts of downward-branching rootlets in massive arenaceous shales and more rarely of vegetable remains buried by superficial accumulations. It is seen, therefore, that in the river deposits of semiarid climates casts of logs are most likely to be preserved in the sands deposited in the neighborhood of stream channels. At a distance from the channels, wetting and oxidation would tend to destroy the logs and larger fragments if such existed, before sufficient time had elapsed for burial. Root impressions of trees in such regions would be of more common occurrence than trunks and confined possibly to what were originally deep loamy sands. The herbaceous types of vegetation, however, are the more common over the well-drained portions of truly semiarid flood plains, and the plant impressions recorded in the strata would consequently be of small size compared to those of the large and luxuriant vegetable forms of more rainy climates.

[1] *Op. cit.*, pp. 164–75.

[2] E. W. Hilgard, *Soils*, 1906, pp. 202–13.

[3] *Loc. cit.*, pp. 167–83.

The above discussion is based on the present floral societies, composed almost wholly of flowering plants. The conclusions, however, in regard to the climatic relations of herbaceous and arboreal vegetation may with probability be extended backward in time to ages as early as the Devonian, when all plants were either cryptogamic or gymnospermous, since in the later Paleozoic, long before the advent of the Mesozoic phanerogams, plant societies existed then as now which included forms from arboreal to herbaceous and ranged in adaptation from hygrophilous to xerophylous. The present usual restriction of cryptogamic vegetation to small forms occupying habitats moist, shady, or cold, habitats not strongly sought by the higher vegetation, did not then necessarily hold; conditions to some extent perpetuated in Australia, where tree ferns still abound in the coastal districts of New South Wales and Victoria, and vascular cryptogams with xerophytic adaptations are known to occur in other portions of the island continent.

In illustration of these conclusions a comparison may be made of the fossil vegetation of the Mauch Chunk (Mississippian) shale of eastern Pennsylvania, believed by the writer from other considerations to be a continental deposit of a semiarid climate,[1] with the flora of the overlying coal-measures, believed to be continental deposits of a climate cool and rainy. In the Mauch Chunk strata, as observed by the writer, impressions of small plant fragments are not uncommon, consisting of first, the fragments of slender grasslike reeds probably belonging to the equisetae; second, impressions of flattened, straplike coarser stems and leaves up to an inch in width and exhibiting suggestions of parallel venation; third, impressions of stems with close-set spiny leafage, the spines not being over half an inch in length; fourth, casts of roots showing branching rootlets, the latter clothed with fine tendrils. The roots occur in massive argillaceous sandstones and in favorable cases are exposed by the rock fractures for depths of a foot with indications of being considerably more extensive. A striking feature of those root casts found in place is that they branch downward and not horizontally. Other observers have detected a leathery character in certain of these plant impressions. No casts of logs have

[1] J. Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bulletin of the Geological Society of America*, Vol. XVIII (1907), pp: 449–76.

been seen by the writer or described by others and no carbon from the plant tissues is ever preserved. These characteristics are opposed throughout to those of the overlying carbonaceous beds of the true Carboniferous. In these the carbon is preserved, impressions of logs are abundant, the vegetation is coarse and luxuriant, and grasslike forms give place to a water-loving forest growth. The roots preserved in the underclay show no such tendency to penetrate constantly downward and in the case of the stigmaria are developed into stolen-like forms such as are possessed by many existing marsh plants.

The conclusions as to climate, based on the character of the vegetation in the case of these late Paleozoic formations and determined from adaptive relations observed to exist at present in quite different divisions of the vegetable kingdom, are thus seen to be in harmony with conclusions based on a number of other and independent lines of evidence. The latter, however, cannot be given at this place.

The animal life also shows adaptations to the climate, but these are far from being as strongly marked or so dominated by climate as in the case of plants, so that neither can a discussion of such general characteristics be considered under the present subject.

EFFECTS OF ARID CLIMATES UPON FLUVIAL AND PLUVIAL DEPOSITS

Chemical characteristics, evaporation deposits.—Arid climates, those of true deserts, typically possess no drainage to the sea and no agriculture is possible without either natural or artificial irrigation. Fluvial and pluvial deposits may, however, be abundantly developed, owing to the torrential nature of the occasional rains acting upon a loose and unprotected mantle rock. In this hasty transfer of disintegrated rather than decayed rock débris but little leaching is likely to occur, soluble and insoluble materials remaining together, the two tending to become somewhat separated by later and local action. The rainfall of such regions is, in the temperate zone, less than ten inches per year.

As noteworthy examples of deltas in arid climates may be cited those of the Volga, the Indus, the Nile, and the Colorado. The lime in such may form still more striking inorganic deposits than the "Kankar" of the subarid flood plains of India, forming such incrustations

as the massive travertine and caliche deposits of Arizona and Mexico.[1] In other cases, however, the content of lime may be no higher than in the deposits of subarid flood plains, the percentage of dissolved lime in the river water to undissolved detritus apparently having a strong influence in this respect. For example, the deltas of both the Rhine and the Rhone, especially the latter, show a considerable proportion of calcium carbonate due to the highly calcareous nature of the formations subjected to erosion, supplemented in the case of the Rhone by the approach toward a semiarid climate over its delta in the Mediterranean Sea. This delta consists in large part of sand cemented by lime.[2] In the deposits of the Nile delta, on the other hand, calcium carbonate is probably no more or possibly even less abundant than in the case of the Rhone. Analyses by Regnault of fresh Nile mud gave 22 per cent. of carbonates, of old Nile mud gave 11 per cent. Other analyses by Knop from other localities gave, however, only 4.1 to 4.7 per cent. of carbonates in the dried inorganic residues of Nile mud.[3] These may be compared with 0.1 per cent. of $CaCO_3$ as the average content in three alluvial soils of the Ohio Valley and 1.38 per cent. of $CaCO_3$ in two alluvial soils of the Mississippi Valley.[4] In the delta muds of arid climates the proportion of true clay may be low, and alkalis exist, largely either in the form of comminuted feldspar or as soluble alkaline salts in the surface soil. Brine pools and gypsum deposits will be not uncommon in the lower areas, especially near the margins of the deltas. Dense reedy jungles and fever-breeding salt swamps frequently dry at some season of the year may be common, but the presence of evaporation deposits with the decolorized shales is a characteristic which separates them from those of semiarid climates.

Those parts of the potash and soda which are dissolved from the silicate minerals and form alkali crusts or flat lands in arid regions are kept near the surface, being carried upward by capillary action in the dry season and washed downward a short distance by the occa-

[1] W. P. Blake, "The Caliche of Southern Arizona," Abstract, *Engineering and Mining Journal*, Vol. LXXII, 1901, pp. 601, 602.

[2] G. R. Credner, "Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen," *Petermann's Mitth. Ergänzungsheft*, No. 56, Vol. XII, 1878, p. 16.

[3] G. R. Credner, *op. cit.*, p. 15.

[4] G. P. Merrill, *Rocks, Rock-Weathering, and Soils*, 1906, p. 351.

sional rains or floods. The diagrams given by Hilgard show that in clay lands the bulk of the alkali is within two feet of the surface and in sandy lands within seven feet.[1] Medlicott and Blanford state that in the worst alkali tracts of India sweet water is obtainable at depths below sixty to eighty feet.[2] Except in the most arid regions the soluble alkali salts are thus seen to be prevented from accumulating through the strata.

Combinations of Fluvial and Aeolian Structures.—The surfaces of arid flood-plains and to a lesser extent those of semiarid climates are dry and barren for a considerable portion of each year, and the detritus becomes reworked by wind action, with the result that in flood plain deposits of desert climates fluvial, pluvial, and aeolian formations are all of wide occurrence and brought into immediate juxtaposition, producing combinations of structures which may be more or less readily recognized in the buried strata. The clayey layers deposited by flood waters crack upon drying into polygonal discs which curl upward on their edges, giving concave mud-cracked surfaces. The fine silt and sand, not possessing coherency when dry, and not being held by vegetation, give rise to intolerable dust storms. The finer silt may cover the adjacent regions with loess and the coarser portions, derived from the stream channels, may be the source of widespread dune sands, such as mantle the deltas of the Indus and the Helmund, burying many ancient cities and subjecting the still exposed ruins to aeolian scour.

The more distinctive structures resulting from the combinations of water and wind action may be classified and described as follows:

First, *mud-cracks filled with aeolian sands.*—Silt and sand will be blown over and fill up the cracks developed by the drying of argillaceous water-laid deposits. Consequently, the sand is filled in under the raised rims of the polygonal discs and becomes continuous with the mantle of sand above. In this way, the concavity upward of the individual plates is preserved and the mud-cracks are not obliterated, even in a silty clay which would slack and crumble immediately upon being rewet by the advancing waters of the following inundation. Experiments by the writer go to show that the upturned edges of the

[1] *Soils,* 1906, chap. xxii.

[2] *Geology of India,* Part I, 1879, p. 413.

clay plates would not usually hold their form while the broad sweep of sand-laden waters should deposit clean sand both under the edges and over the plates. The concavity of the plates thus testifies to aeolian burial and such may be distinguished from mud-cracked flats buried by fluvial action. Since writing a previous article on "Mud Cracks as a Criterion of Continental Sedimentation,"[1] evidence has come to hand from widely separated regions indicating the great geological significance of aeolian-filled mud-cracks in the flood plain deposits of arid climates. A. W. Rogers writing from South Africa makes the following statement:

KHEIS, GRIQUALAND WEST, May 19, 1907.

Today . . . . I happen to be camped on the narrow flood plain of the Orange River which is a fine place for the observation of mud-cracks. The mud flats are exposed for months and even years before being covered again by water. The mud is a gray-brown silt and the cracks become filled with the deep red Kalahari sand from the north. In places the sand advances as fairly high dunes and buries the mud deeply. Generally, however, small thicknesses of the sand are laid down on the mud.[2]

Isaiah Bowman, writing from South America, makes the following statement:

IQUIQUE, CHILI, May 4, 1907.

Along the inner edge of the Desert of Tarapacá, roughly between the towns of Tarapacá and Quillagua, Chili, the piedmont gravels, sands, silts, and muds extend for over a hundred miles, flanking the western Andes and forming a transition belt between these mountains and the interior basins of the coast desert. The silts and muds constitute the outer fringe of the piedmont and are interrupted here and there where sands are blown upon them from the higher portions of the piedmont or from the desert mountains and plains on the seaward side. Practically no rain falls upon the greater part of the desert and the only water it receives is that borne to it by the piedmont streams in the early summer from the rains and melted snows of the high plateau and mountains to the eastward. These temporary streams spread upon the outer edge of the piedmont a wide sheet of mud and silt which then dries and becomes cracked, the curled and warped plates retaining their character until the next wet season, or until covered with wind-blown sand. The wind-driven sand fills the cracks in the muds and is even drifted under the edges of the up-curled plates, filling the spaces completely. Over this combined fluvial and aeolian deposit is spread the next layer

[1] Joseph Barrell, *Journal of Geology,* Vol. XIV (1906), pp. 524–68.

[2] Personal communication to the author.

of mud, which frequently is less extensive than the earlier deposits, thus giving abundant opportunity for the observation of the exact manner of burial of the older sand-covered stratum. The process described above is thought to be of particular interest on account of the generality of its occurrence in this desert.[1]

Ellsworth Huntington contributes the following statement concerning relations observed by him in central Asia:

The floor of the great desert basin of Lop in western China furnishes examples of various associations of mud-cracks with aeolian deposits.

At Yartungaz, 450 miles southwest of Lop-Nor, the floor of the basin consists of a fine-grained saline silt which appears to have been deposited in broad, shallow playas. The surface of the ground is smooth, and there is no sign of buckling, but polygons from three to twelve feet in diameter are plainly visible. The division lines stand out as dark markings dividing the light gray plain into innumerable fairly symmetrical polygons. The prominence of the markings is due to the fact that they are composed of sand which seems to have been blown by the wind into the original cracks in the plain.

A hundred miles farther to the southeast, near Chira, the barrenness of the wind-swept plain of piedmont gravel at the base of the Kwen Lun mountains is slightly relieved by lines of grassy weeds arranged in polygonal patterns like those of Yartungaz. Digging among them, one finds that the plants grow in fine brown sand which fills old cracks in a hard deposit of fine and very saline gravel. The sand is of the same texture as that of the small dunes of the neighborhood.

The most striking case, however, is that of the old bed of the expanded glacial lake of Lop-Nor. For scores of miles a layer of impure rock salt, from one to three inches thick, has split into polygons ranging from five to twelve feet in diameter. The edges have buckled up in exactly the same manner as the edges of ordinary mud-cracks, and frequently stick up two or three feet. The underlying hollows are often partially filled with sand which has been blown in from the distant shores of the lake-bed.[1]

Thus it is seen that this peculiar method of preserval of mud-cracks is widely prevalent at the present time upon the flood-plains of arid regions in various parts of the world. The writer has observed that the same structure has been also widely developed in certain ancient formations.

In the Mauch Chunk shale of Pennsylvania the mud-cracked shale partings between sandstone strata are frequently in the form of tesselated polygonal plates concave upward, the covering layer of

[1] Personal communication to the author.

sand filling the cracks and passing beneath the upraised rims of the plates.[1]

In the Triassic of the Connecticut valley the same structure may be frequently observed, the concave shale plates being in this formation frequently buried in undecomposed feldspathic sand.

Second, *interbedding of fluvial and aeolian sands.*—Gravel and sands which are originally transported by fluvial or pluvial actions upon flood plains in arid climates are later subjected to the action of the wind. Truly fluvial sands and gravels consequently become repeatedly interbedded with aeolian sands, and Huntington states that this is a striking and frequent relation, as seen in the freshly exposed terrace faces on the margins of the desert basins of Asia.

The fluvial and pluvial deposits are characterized by a more heterogeneous and coarser nature and by the absence of the characteristics which mark aeolian sands. It is necessary therefore to summarize some of the distinguishing features of the latter deposits. Dune sands are deposited on the sloping surfaces of the leeward faces of dunes and may reach heights of several hundred feet. At the bottom the inclined layers decrease in dip and pass horizontally to the intervening desert surface. In a region of accumulating sands each passing dune leaves its basal portions to be covered by the march of the following succession of dunes, so that the lower portion of this cross-bedded structure becomes deeply buried and permanently preserved.

As has been recently pointed out by a number of geologists, the characteristic features of such dune sands, separating them from fluvial or littoral deposits, consist consequently in the homogeneous nature, the development of "millet seed" texture, and the presence in striking degree of cross-bedding which may reach great thicknesses. The cross-bedded strata are abruptly truncated above but flatten out and become tangent to the general stratification at the bottom. It is probable that a number of arenaceous formations which have been customarily considered marine are, on the contrary, of such mixed fluvial and aeolian origin. For example, Davis, Huntington, and

[1] For illustrations see Joseph Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bulletin of the Geological Society of America*, Vol. XVIII (1907), Pls. XLIX, L, and Fig. 1, p. 457.

Goldthwait have raised the question if such has not been the mode of origin of the Triassic and Jurassic sedimentary formations of the Colorado plateaus.[1]

Third, *scattered and facetted pebbles.*—In truly aeolian sands the size of the material is rather sharply limited, but in stream channels pebbles or larger fragments may be carried indefinite distances from the fields of erosion. Cloud-bursts and sheet-flood deposition may also sweep large fragments along with the fine, but such action is necessarily more closely limited to the vicinity of the sources of sedimentary supply. In such ways pebbles of various sizes may be clustered or scattered through a finer textured deposit without necessarily implying transportation by either the roots of floating trees, or floating, or glacial ice. Pebbles carried by each of these agencies will be apt to exhibit distinctive characteristics and associations. Those carried by fluvial or pluvial action upon arid flood-plains are the ones to be here considered. The association with various indications of climatic conditions such as those already considered may often suggest the mode of origin. It seems probable, however, that in many instances such pebbles should carry their own evidence through being subjected to wind scour upon the drifting away of the enveloping sand. They would become facetted in consequence, giving rise in the consolidated conglomeratic sandstone to the occasional presence of "dreikanter." Such peculiarly facetted but unstriated pebbles have been collected from a number of formations, dating back even to the pre-Cambrian, but have sometimes been claimed to be of glacial origin. An instance where the hypothesis of aeolian origin appears to offer by far the best explanations has recently been described with illustrations by Lisboa in the case of pebbles which are probably of upper Mesozoic age from the central plateau of Brazil.[2]

Organic characteristics.—Over the more truly desert portions of arid flood plains the life is unimportant at the present time, and in past times has been equally unimportant, if not more so, since the

[1] E. Huntington and J. W. Goldthwait, "The Hurricane Fault in the Toqueville District, Utah," *Bulletin of the Museum of Comparative Zoölogy at Harvard College,* Geological Series, Vol. VI, No. 5, 1904, pp. 210–17.

[2] "The Occurrence of Facetted Pebbles on the Central Plateau of Brazil," *American Journal of Science*, Vol. XXIII, 1907, pp. 9–19.

progress of evolution has been to progressively specialize life forms for such extremely unfavorable habitats. The present relations are briefly as follows:

A sparse vegetation occurs over the drier or more-alkaline portions of the plains. Other portions may be covered with dense scrub as seen in the Australian bush. Along the streams tree growth commonly occurs, and hence casts of roots and leaves might be left. In the swamps reed growths are abundant and may become fossilized and associated with white or greenish clay strata.[1] Animal bones embedded in the desert plains stand excellent chances of preserval and observation of the accumulating prairie loess has led Matthew to believe in an aeolian origin for the fine-grained calcareous clays of the White River Tertiary formation covering a considerable area of the Great Plains of the United States,[2] though these tracts are presumed not to have been really arid but rather subarid in climate. The fossil fauna of this deposit as Matthew has shown is such as can be explained by the aeolian hypothesis, but not by one of lacustrine origin.

Ease of recognition in the geological column.—From these characteristic features of the river plains of arid regions it is to be concluded that their fossil representatives should be rather readily recognized. In the marginal region of the delta and for some distance inland beds of salt, gypsum, and marl are interstratified with red shales, in which, however, occasional decolorization may occur. Farther inland the strata will show fewer pure evaporation deposits, but these minerals will still be diffused through the strata. Carbonaceous matter will be practically absent, but well-preserved animal remains may be abundant. Dune sands, characterized by cross-bedding and a high degree of rounding, giving "millet seed" sand beds such as those which Phillips has described from the English Triassic,[3] will be associated with true river deposits, sometimes mud-cracked, and the whole will be characterized by a relative absence of rock decay in the process of sedimentation.

[1] Huntington, "The Basin of Eastern Persia and Sistan," *Carnegie Institution*, 1905, pp. 279–87.

[2] W. D. Matthew, "Is the White River Tertiary an Aeolian Formation?" *The American Naturalist*, Vol. XXXIII, 1899, pp. 403–8.

[3] J. A. Phillips, "On the Constitution and History of Grits and Sandstones," *Quarterly Journal of the Geological Society*, Vol. XXXVII, 1881, p. 26.

THE CLIMATIC SIGNIFICANCE OF COLOR

One of the most obvious features of the sedimentary rocks is their color, due partly to climatic, partly to various other, conditions of origin. Among the latter Walther calls attention to the fact that—

> The colors of continental deposits are different according as they are formed above or below a water surface. The deposits in the courses of streams or in interior seas have usually either greenish or bluish colors which also characterize the marine deposits of the continental shelves. The typical continental deposits, formed upon the dry land, are characterized by bright clean colors. The carmine or vermilion tropical laterite, the red-colored sand dunes of the Coromandel lowland and the inner Arabian desert, the yellow or brown loam and loess deposits of the steppes, the white or yellow dunes of the coast lands or the Sahara are convincing examples.[1]

The influence of climate as distinct from other conditions of origin is rendered evident on contrasting the brilliant reds of the moist tropical or subtropical regions with the yellow or dark soils of colder temperate climates or the prevailing ashen gray of deserts. The significance of color in the older rocks cannot, however, be directly inferred from the study of modern deposits since the changes which transform a soft sediment into a solid rock may also conceivably alter the color.

For the purposes of the present discussion, the colors of shales and sandstones may be grouped under three heads: first, red; second, light and variegated; third, gray to black. Each of these color groups is of importance and includes appreciable portions of the sedimentary rocks. On account of the diversity of views, however, respecting the significance of red and its climatic bearings, it will be necessary greatly to enlarge the discussion upon that topic.

The origin of red formations.—Red shading into brown is one of the most frequent colors of ancient continental shales and sandstones and may also occur among those of marine origin. That there is no unanimity in regard to its significance among geologists may, however, be gathered from an examination of the literature. Russell has given a full review of these views.[2] Certain authors have supposed

[1] *Einleitung in die Geologie*, translated from *Lithogenesis der Gegenwart*, 1893–94, p. 725.

[2] "Subaerial Decay of Rocks and Origin of the Red Color of Certain Formations," *Bulletin 52*, U. S. Geological Survey, 1899, pp. 47–56.

that the red is due to igneous agencies, oxidizing iron pyrites, or to volcanic dust or the heat of igneous intrusions. All such hypotheses fail, owing to the widespread occurrence of red rocks, their uniform color, and the absence of metamorphism. Another group of hypotheses ascribes the oxidation to weathering at the time of origin of the sediments and this is undoubtedly correct, the iron peroxide being a component part of the accumulating sediments. Nearly all writers, however, assume that the oxide which is now more or less completely dehydrated and consequently red was in this dehydrated state at the time the sediments were deposited. This assumption runs through the work of Russell and is the basis of many such statements as that of Darton that "red shales and sandstones, such as make up the red-beds, usually result directly from the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil. . . . . There is such uniformity of the deep-red tint that this is undoubtedly the original color."[1] Russell considers that the incrustation of the sandstone grains of the Newark formation by ferric oxide, resembling that surrounding the grains of quartz in the residual soil of the southern states, indicates that the grains were transported without sufficient wear to remove the original incrustation. From the distribution of present red earths, he further concludes that their formation requires the presence of heat and moisture. All such special modes of origin, however, are difficult of acceptance in view of the great predominance of red, or red-brown in ancient ferruginous formations and the comparative absence of yellow tones such as dominate modern alluvium.

In view of such a conflict of opinions and the special nature of the hypotheses used to explain the general nature of the phenomenon, the need of discussion is seen. Certain essential facts which have bearings on the conclusions may be stated as follows: As indicating the influence of a moist climate, Russell notes the brilliant reds and yellows of the soils of the South Atlantic states as compared with the ashen tints of the Mojave desert,[2] and he elsewhere speaks of the creamy-white color of the playa-lake deposits of Nevada and Arizona,

[1] "Geology of the Bighorn Mountains," *Professional Paper No. 51*, U. S. Geological Survey, 1906, pp. 105–7.

[2] I. C. Russell, *op. cit.*, p. 27.

beds exposed during the summer months to temperatures of from 110° to 120° Fahr. in the shade.[1] As indicating the influence of heat may be mentioned the uniform restriction of red soils, neglecting those derived directly from red formations, to the warm temperate and especially the torrid zone. That the contrast is not due to the younger age or glacial origin of the soils of the cold temperate zones is found upon examination of driftless areas in such regions. As indicating the influence of prolonged exposure to the air, Crosby notes that it is the older soils and especially the surface portions in the warm regions which show red to a striking degree.[2]

Where reds in surficial formations are noted in arid regions they are frequently the accompaniments of aeolian action. Dune sands may be white, yellow, or red. Red deserts have been noted in both Africa and Asia and Phillips has shown that the red sands of the Arabian desert owe their color to a coating of ferric oxide deposited after the grains of sand had become round. The source of the iron oxide, which comprised about 1–500 of the total weight, he was unable to determine.[3] All these facts emphasize the influence of lapse of time and the presence of moderate heat, such as that of the torrid regions, as causes sufficient partially to effect the dehydration of ferric oxide, even without the agency of pressure; thereby transforming the yellow and light-brown colors into the brilliant reds which characterize the tropical regions of rainy climate.

In view of these facts, one of the chief true causes of the red color of the older ferruginous formations seems to have been reached by Crosby, whose statements are as follows:

> The dehydration of the ferric oxide is not wholly dependent upon heat or pressure or any obvious extraneous agency, but it is in a large degree, apparently, a spontaneous process. Of this we have abundant evidence in nature and in the laboratory. When the iron, which exists in the various silicate minerals chiefly in the ferrous state, is liberated and peroxidized during the decay of these species, it combines naturally with a very large and indefinite proportion of water, forming the yellow hydrate, which is seen as a flocculent or a gelatinous colloid in the waters of springs, bogs, and marshes, and when the hydrate is obtained as

[1] *Op. cit.*, p. 42.

[2] On the contrast in color of the soils of high and low latitudes, *American Geologist*, Vol. VIII, 1891, p. 77.

[3] "The Red Sands of the Arabian Desert," *Quarterly Journal of the Geological Society*, Vol. XXXVIII, 1882, pp. 110–13.

a precipitate in the laboratory. But this colloid mass, even if immersed in water and entirely undisturbed, gradually and spontaneously gives off a large part of the water which the ferric oxide has so greedily absorbed when in the nascent state; and it appears thus, as it slowly solidifies and hardens, to pass in succession through the forms of the various native yellow hydrates—limnite, *xanthosiderite*, and limonite, to göthite. That this progressive change continues is evident from the fact that these yellow hydrates are gradually replaced in the older formations by the red hydrate (turgite) and by ferric anhydride (hematite). When occurring as original or contemporaneous, and not as secondary, deposits, the yellow ores of iron are found, as a rule, only in the later rocks; while the red ores are generally restricted to the earlier rocks. This genetic relation of the yellow and red ores is one of the most familiar and generally accepted facts in geology. However recent the origin of the red ore (turgite or hematite) may appear to be in any case, we naturally infer that it was first yellow, and that it has passed slowly or rapidly, as the case may be, but gradually, through the series of yellow hydrates. . . . .

If it be conceded that the dehydration is virtually, if not absolutely, spontaneous, and there is no apparent alternative, it follows that the color of a deposit, so far as it is due to ferric oxide, is, other things being equal, a function of its geological age. In other words, the color naturally tends with the lapse of time to change from yellow to red; and, although this tendency exists independently of the temperature, it is undoubtedly greatly favored by a warm climate. Applying this principle to the sedimentary soil of the South, we find that the superficial portion is red, not alone because it is exposed to a higher temperature than the subjacent yellow clay, but also because it is the oldest part. On the other hand, the limited occurrences of post-glacial sedimentary detritus in the North are, in the absence of the favoring climatic influence, still too young to exhibit the change of color even superficially.[1]

Judging from the later expressions of opinion, this article does not seem to have received the attention which it deserves.

Spontaneous dehydration assisted by heat and favored by time does not appear, however, to be the sole cause of the great contrast in color between the consolidated and the surficial ferruginous sediments, a still more potent cause existing in the dehydration effected by the great increase in pressure and moderate rise in temperature which takes place upon the burial of the material to some thousands of feet beneath later accumulations. The efficiency of pressure in this connection is exhibited in the formation of shales, where about one-half of the combined water is eliminated at temperatures which must be frequently far below the boiling-point, since with the normal gradient

[1] *Op. cit.*, pp. 80, 81.

a temperature of 110° C. is attained only at a depth of about 11,000 feet (3,300 meters). The ferric oxide, holding its water with much less tenacity than the silicate of alumina, seems to respond most readily to the influence of pressure, giving rise to minerals of notably less volume and greater density, apart from the water which is eliminated in the process.

Still a third factor in the development of a red color in ferruginous rocks is found in the physical state of the oxide, as may be seen upon contrasting the brilliant color of earthy hematite with the deep colors of the same mineral in its crystalline form. The red color depends therefore not only upon the presence of anhydrous or partially anhydrous ferric oxide, but also upon a fine state of division and diffusion. Dawson speaks of the very fine state of division of the red coloring matter in the lower Carboniferous of Nova Scotia—

having indeed the aspect of a chemical precipitate rather than of a substance triturated mechanically. In addition to the oxide of iron distributed through the beds, there is, in the fissures traversing them, a considerable quantity of the same substance in the state of brown hematite and red ochre, as if the coloring matter had been superabundant or had been in part removed and accumulated in these veins.[1]

Hilgard states further that the general red aspect of tropical soils is by no means always accompanied by markedly high percentages of ferric oxide, but the latter is very finely diffused so as to be very effective in coloration. The soils of the arid regions on the other hand are not deficient in ferric oxide.[2] The present writer has also noted that pebbles of feldspar showing glistening cleavage embedded in the red Triassic arkoses of the eastern United States are stained red throughout with ferric oxide while those of quartzite are stained to variable depths and those of vein quartz only along the fractures. The completeness of the staining, its development about the stream-worn surfaces of pebbles, and its presence in all materials, depending only upon their porosity, are indications that this was done after incorporation in the sediments and through a considerable period of time. The above facts seem to show that ferric oxide in rocks is rather readily

[1] J. W. Dawson, "On the Coloring Matter of Red Sandstones and of Greyish and White Beds Associated with Them," *Quarterly Journal of the Geological Society*, Vol. V, 1848, pp. 25, 26.

[2] Hilgard, *Soils*, 1906, pp. 392, 400.

diffusable, permeating the entire rock mass and thereby becoming more effective as a coloring substance. In view of this ready diffusability and ease of dehydration, such a special hypothesis as that of Russell—that the crusts of ferric oxide had been retained by sand grains during their transportation from a residual soil—seems unnecessary and as a general explanation does not apply.

To sum up, it is seen that the cause of the red color in ferruginous rocks as contrasted with the predominant yellows of modern alluvium is to be found in three co-operating causes: First, spontaneous dehydration operates to some extent at the surface in the warmer regions. Second, dehydration under great pressure and moderate temperatures is nearly universal in sediments which become buried and consolidated. Third, diffusion operates under conditions of warmth and moisture, whether these be found at the surface, as in warm and humid regions, or beneath the surface, as may occur in any portion of the earth. By these three means light-colored, yellow or brown muds and sands may become red shales and sandstones. Only in the presence of considerable heat, as on the walls of dikes, or in the presence of some highly dissolving fluid does the tendency toward crystallization or new combination reverse the coloring effects of capillary diffusion.

Red in shales or sandstones is therefore normally assumed, like the hardness, upon the consolidation into a shale or sandstone of any sediment possessing an appreciable amount of ferric hydrate and is no more necessarily original than is the red of a burned brick.

The reliability of these conclusions may be tested by observing the stratigraphic relations of ancient deposits. As a typical example may be cited the Permian red-beds developed east of the Rocky Mountains, which contain conspicuous strata of gypsum and are impregnated with salt, giving thus undoubted evidence of deposition under an arid climate. The same association of salt and gypsum with red shales and sandstones might be cited from Nova Scotia and a dozen other localities.

This is in striking contrast to the usual present development of salt and gypsum in association with gray or yellow sediments. For example, the marginal bottom of the Dead Sea when exposed by unusual dessication shows a surface of bluish-gray clay or marl full of crystals of common salt and gypsum, and light-grays are char-

acteristic also of the salty flats in the Great Basin of the United States. Furthermore, the Red Sea, surrounded by intensely arid lands, shows dominant light yellow as the color of the bottom muds, varying in certain soundings to tones of grayish or brownish yellow.[1] Contrary to what might be expected from the name, the Red Sea contains no red sediment and the origin of the name is in doubt.[2]

From these statements it is seen that, while red in present soils is particularly characteristic of the residual soils of warm moist climates, in ancient deposits it is a usual accompaniment of arid conditions.

Furthermore, that hot climates were not necessary for the origin of certain ancient red shales and sandstones is suggested, but far from proved, by the occurrence of such rocks within the Arctic Circle, Nathorst having found the Old Red Sandstone in Spitzbergen, lat. 79–80° N.[3] On Bear Island, also, somewhat farther to the south, in lat. 74° 30′ N., and again in northern Norway, red strata of this age occur.[4] Turning to the antipodes, it is to be noted that Wilkes in 1840 landed on an ice island off the Antarctic continent in lat. 65° 60′, long. 106 °19′ E. He found imbedded in it, in places, bowlders, stones, gravel sand, and mud or clay. The larger specimens were of red sandstone and basalt.[5] The "Challenger" expedition in 1874 in the vicinity of the Antarctic ice in lat. 65° 42′, long. 79° 49′ E., dredged up specimens of igneous and metamorphic rocks and red sandstone.[6]

That a special origin, such as by "the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil," is not necessary is indicated by the very great thickness and uniform color of certain red formations; by the

[1] Joseph Luksch, "Vorläufiger Bericht über die physikalisch-oceanographischen Untersuchungen im Rothen Meere," *Wiener Akademie Sitzungsberichte, Mathematisch-Naturwissenschaftlichen Classe*, Abtheilung I, Band CVII (1898), pp. 636, 637.

[2] Major J. S. King, "The Red Sea: Why so Called," *Journal of the Royal Asiatic Society* (1898), pp. 617, 618.

[3] E. Suess, *Das Antlitz der Erde*, Eng. trans., Vol. II, pp. 68, 69.

[4] A. Geikie, *Text Book of Geology*, 4th ed., 1903, pp. 1012.

[5] *Narrative of the United States Exploring Expedition During the Years 1838–1842*, Vol. II, p. 325.

[6] John Murray, "Deep Sea Deposits," "*Challenger*" *Reports* (1891), pp. 80, 81.

inclusion of conglomerates whose component pebbles frequently consist of fresh blocks of granite, pegmatite, and other rocks subject to decay, testifying to a partial dominance of disintegration over decomposition; by such an example as the Mauch Chunk red shales and sandstones, 3,000 feet in maximum thickness, following immediately upon the gray Pocono sandstone and its gradual transition above into Pottsville conglomerate, red shales alternating with conglomerate horizons.

That conditions of deposition permitting oxidation had much to do with the development of red in the consolidated sediment is indicated by the usual poverty in fossils, especially in those of marine origin; by the repeated intercalation in the Basin of Sistan of pink to brown silts, regarded by Huntington as having been deposited subaerially, with green clays, considered with good evidence as typically lacustrine.[1] As a further illustration, the Wamsutta red-beds of the Carboniferous of the Narragansett basin are regarded by Woodworth as represented south of Providence by the lower strata of the Kingstown coal-bearing series. In the vicinity of Pawtucket the coal-measures underlie the Wamsutta, though somewhat farther north the latter are only separated from the granite by the basal arkose beds of the Pondville group.[2] Woodworth states that the coloring of the Wamsutta red-beds appears to have taken place before transportation. This view, however, leads to difficulties which he states on the same page. All difficulties, seem, however, to be avoided if it be considered that the red is the result of dehydration during consolidation and that these beds retained their iron because they were deposited in an upper and better-drained portion of the basin under a climate which permitted for a time their seasonal drying.

Turning to the climatic significance of red, it would therefore appear both from theoretical considerations and geological observations that the chief condition for the formation of red shales and sandstones is merely the alternation of seasons of warmth and dryness with seasons of flood, by means of which hydration, but especially

[1] *The Basin of Eastern Persia and Sistan*, "Carnegie Institution Publications," No. 26, 1905, p. 287.

[2] "Geology of the Narragansett Basin," *Monograph XXXIII*, U. S. Geological Survey, 1899, pp. 134, 141.

oxidation of the ferruginous material in the flood-plain deposits is accomplished. This supplements the decomposition at the source and that which takes place in the long transportation and great wear to which the larger rivers subject the detritus rolled along their beds. The annual wetting, drying, and oxidation not only decompose the original iron minerals but completely remove all traces of carbon. If this conclusion be correct, red shales or sandstones, as distinct from red mud and sand, may originate under intermittently rainy, subarid, or arid climates without any close relation to temperature and typically as fluvial and pluvial deposits upon the land, though to a limited extent as fluviatile sediments coming to rest upon the bottom of the shallow sea. The origin of such sediment is most favored by climates which are hot and alternately wet and dry as opposed to climates which are either constantly cool or constantly wet or constantly dry.

The origin of light and variegated colors.—White or light gray in rocks indicates an absence of iron, an absence which may be due to entirely mechanical causes, as in white clean sandstones of either fluvial, pluvial, marine, or aeolian origin; or to chemical causes, as in gray or black clays.

Aeolian deposits whether coarse or fine, as dune sand or loess, are typically light in color, varying from nearly white to pale yellow or pink. The lightness in color appears to be due in dune sand to the mechanical segregation of the grains, but in loess partly to the lack of decomposition, partly to the lack of diffusion of the coloring substance. The preceding discussion upon the significance of red would suggest that loess deposits older than the Pleistocene should be dominantly colored from white to light pink rather than the more customary pale buff of the recent deposits. Upon weathering, however, such a buff color would tend to be to some extent restored on account of the porous nature and the new decomposition which is possible in the case of loess.

Where lightness in color is due to chemical causes it is to be noted that the first result of the action of fermenting organic matter upon ferruginous clays is a change of color from rusty to bluish or greenish by the reduction of ferric to ferroso-ferric hydrate. Afterward, if the action be continued, the solution of ferrous carbonate may be formed, and the greenish or bluish color may disappear. The impor-

tance of this reaction lies in the fact that the blue or green tint, wherever it occurs, indicates a lack of aeration, usually by the stagnation of water, in consequence of imperfect drainage.[1]

It is seen in conclusion that where the light color is due to mechanical causes the mode of origin of the formation and the climatic conditions must be determined on other grounds than color. Further, where limited development of white, gray, green, or blue occurs, owing to chemical action upon the iron, the conditions represent a variable balance between the action of iron and carbon determined by local topographic rather than climatic conditions. Where such colors are rather abundant, however, over broad areas of non-marine formations a mean, rather than an extreme, climate is indicated.

The origin of gray to black formations.—The conclusions on this topic are rather obvious from the preceding discussion on the "effects of constantly rainy climates." They need, therefore, only be summarized at this point for completeness.

Where a whole formation, representing an ancient floodplain or delta, shows in its unweathered portions an absence throughout of the colors due to iron oxide, and a variable presence of carbon, giving grays to black, the inference is that the formation accumulated under a continuously rainy climate or one which in the drier season was sufficiently cool or cold to prevent noteworthy evaporation; such climates as exist in Ireland, Iceland, or western Alaska; to a minor extent on windward slopes in the trade-wind zones and also to a minor extent in a few tropical belts which never quite escape from the shifting zones of tropical rains.

CONCLUSIONS ON CLIMATIC INFLUENCES IN REGIONS OF DEPOSITION

It was seen in the discussion on the relations of climate to regions of erosion that climate was one of the controlling factors in determining the quantity, but more especially the physical and chemical nature, of the sediment supplied to the rivers. But some large river systems have their sources in climatic zones distinct from that of their lower courses. Furthermore, the comminution and decay involved in transportation and the varied contributions of tributaries obscure

[1] Hilgard, *Soils*, 1906, p. 45.

to an extent, depending upon the size of these factors, the climatic indications given by erosion. In proportion as such occur, however, the climatic influences in the region of deposition grow more pronounced, until finally over the larger deltas, where the fine-grained waste is deposited on nearly horizontal surfaces, the climatic effects become a dominant influence in the nature of sedimentation.

From the extremes of cool and rainy climates on the one hand to hot and arid on the other a gradation in character of deposits may be observed corresponding to that gradation which exists in climatic cause. For the sake of discussion, however, artificial division lines must be drawn separating the climates into several categories, as has been done. In consequence, except in clearly marked instances there may be some doubt as to the exact climatic division to which a certain deposit belongs. To reach the greatest certainty every line of evidence must be followed to its end and given appropriate weight in governing the conclusion. Only by the convergence of many probabilities may reasonable certainty be attained.

The most obvious chemical features of subaerial river deposits which depend upon the climatic gamut consist in the antithetical relations of carbon and ferric oxide. Supplemental to these two chief indicators stand the other more or less soluble substances, magnesium and calcium carbonates, hydrous calcium sulphate, sodium and potassium chlorides; wholly absent from river deposits of the one climatic extreme, appearing in successive order in deposits made under climates representing gradations toward and to the other. Supplemental to these primary chemical distinctions are the textural, structural, and organic evidences.

Varying powers of erosion and transportation giving rise to varying quality and quantity of sediment are seen to be the most delicate stratigraphic indicators of *climatic fluctuations*. On the other hand the chemical and organic conditions accompanying the deposition of the sediment upon the delta plain are the more secure indicators of the *stable and average climatic conditions* under which the formation as a whole was made.

(*To be concluded*)

EDITORIAL

American geologists are well aware that there has been in progress for some time a movement looking toward the establishment of a mining bureau by the United States government and the transfer to this bureau of some of the functions now served by the United States Geological Survey. It is also well known that there has been no little difference of opinion, not only among geologists but among mining engineers and mine owners as to the advisability of a separate organization and as to the relationship it should sustain, if established, to the Geological Survey. It is gratifying to observe that influential opinion is crystallizing in a very natural way and along true basic lines, and that a satisfactory outcome may be anticipated. Director Smith, of the Geological Survey, entertains the view that the proper line of cleavage lies between that class of work which is fundamentally geological and which should remain with the Survey, and that class which centers about engineering and allied technologic sciences and which should be committed to a technologic organization; and he is actively urging this view. He feels however, that the term "mining" is too broad to be properly monopolized by the new bureau, but that the term "mining technology" is fitting for a bureau devoted to the non-geological phases of mining investigation, and this term is used in most of the bills before Congress. If this division of labor and this distinction in nomenclature can be established and maintained, the Geological Survey will be glad to share the field of mining investigations with another organization, and on this basis the Survey is exerting its influence in favor of the establishment of such an independent bureau. In view of the doubt as to the establishment of this bureau during the present session of Congress, Dr. Smith has given assurance, in a letter to the Secretary of the Interior, that so long as the technological investigations relative to mining continue to be intrusted to the Survey, it will be his endeavor to develop the proposed lines of cleavage rather than to conceal them, to the end that an ultimate separation may be promoted. This attitude of the Survey is greatly to be commended, not only because of its inherent wisdom, but because it gives

assurance of a gradual, if not immediate, evolution along true basic lines, with every prospect that, when the complete separation shall take place, the relationships between the geological and technological bureaus will be most intimate and cordial, and that these bureaus will each contribute effectively to the success of the other.

T. C. C.

Reviews

CRYPTOZOÖN. REPLY TO THE REVIEW OF C. W. W.

Before the genus Cryptozoön is relegated to the indiscriminate heap of concretions, as proposed by the reviewer C. W. W. in the *Journal of Geology* (Jan.–Feb., 1908, p. 85), facts like the following ought to be considered:

This form—Cryptozoön or Concretion?—is found like concretions in wide apart localities, but unlike concretions it occurs only in connection with a certain geological formation, the Beekmantown, and in this formation it is restricted to a narrow horizon, only two of the five divisions, so far as observed, containing it.

The peculiar character of its concentric bands in the spherical or spheroidal masses so marked it that for a long time it passed as a Stromatopora, and it was not until after Dr. Roeminger's careful discrimination of the genus, that it was distinguished from Stromatopora.

The minute structure is so like that of the undoubted fossil Stromatocerima, that in some cases when sections of each are placed side by side it is difficult to distinguish them.

Passing by other indications of the organic origin of the form, it should be added that the conclusions of Mather, Hall, and Dawson should have some consideration. Dawson's views were based on the study of many sections of what he came to regard as good species of Hall's genus Cryptozoön. Such facts and considerations forbid the dropping of the genus Cryptozoön.

In the matter of ova an interrogation point should have followed the figure, as it was designed as a suggestion, rather than a demonstration. Thus one making slices of Stromatocerium finds in the microscopic field distinct lacunae. In some of these exist minute spherical masses, apparently more compact than pilae. Now it may never be possible to prove that these little spheres actually are; that they may be ova, however, is not an improbable suggestion.

H. M. S.

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FEATURES INDICATIVE OF PHYSIOGRAPHIC CONDITIONS PREVAILING AT THE TIME OF THE TRAP EXTRUSIONS IN NEW JERSEY

C. N. FENNER

The Watchung Mountains form prominent features in the topography of Northern New Jersey. On account of the great hardness and erosion-resisting qualities of the rocks composing them, they rise well above the surrounding shales and sandstones and add much to the beauty and picturesqueness of this portion of the state.

Their geological features and their relation to the adjacent strata have been the subject of study since the early years of the last century. Views regarding them have changed greatly. New facts have been brought to light and the interpretation of the observed conditions has changed with the advance of geological science. Gradually, however, a close agreement has been reached in the conclusions of various observers with regard to the major features of their structure and relations, and in brief form it may be said to be held that these three ridges are the remnants of three successive flows of lava which were poured out as great sheets over the surface of beds of sandstone, or similar material, which was in course of deposition at the time. After each flow the process of deposition of the sandstones was resumed until interrupted by the next flow. Later the whole series of sandstones and intercalated traps was slightly tilted so as to form a monocline with gentle western dips, and the edges were eroded and carried away. The trap sheets, on account of their resistant qualities, were

less degraded, so that now their projecting edges form the ridges of the Watchung Mountains.

In this article it is my purpose to describe certain facts of observation which have been met with in studying this region, especially that portion of it lying in the territory of the First Watchung trap from Paterson southward, and which may throw some additional light upon the relations of the traps and underlying sandstones and upon the general physiographic conditions which existed at the time of their formation. Quarrying operations of recent years have brought certain features to light which are of importance in their bearing upon this subject.

In order to lay a proper foundation for the facts which are about to be described and to show their significance, it is necessary to enter into some description of the underlying clastic formations.

THE CLASTICS

The lowest trap sheet (the First Watchung Trap) rests everywhere upon a series of siliceous stratified rocks. On account of the paucity of fossils contained in these associated strata and the somewhat uncertain position in the paleontological succession of the fossils which have been found, the exact horizon of these rocks is somewhat uncertain. They are generally regarded as being of Triassic Age, but it is preferable to use the indefinite term, "the Newark Formation," in referring to them, as is done by the United States Geological Survey, until more exact correlation can be established. In this article it is my intention to consider in detail only those members of the Newark Formation which are found in immediate association with the base of the First Watchung Trap, and to study these chiefly for the purpose of determining the conditions existing at the period when the trap sheet was poured forth. The rocks of the Newark Formation as a whole are of interest in this connection in forming general conclusions with regard to these conditions; but there is the possibility of undiscovered faults running through the series, which might throw altogether out of concordance the strata on the two sides of the break, and vitiate the value of the conclusions drawn. Therefore in endeavoring to arrive at a proper conception of the conditions immediately preceding the trap-flow, it is better to confine our studies to the terri-

tory closely adjacent to the trap itself, using in addition only such conclusions as apply to the Newark Formation as a whole.

At one time, before a detailed study of the region had been made and before the present advance of geology, a submarine origin was assigned to the Newark beds. Later the impossibility of their deposition under such conditions was perceived and it was suggested that they were laid down in an estuary or on the bed of a great river. This theory is still quite commonly held, but many later observers have come to the conclusion that they are almost wholly of continental origin. By this it is meant that they were laid down on land surfaces standing at some elevation above sea-level, on which bodies of standing water, such as lakes or pools, formed but a minor factor so far as sorting of material and deposition of sediments were involved. The conditions must be conceived to have been similar to those now present in the semi-arid inland basins of the West. The chief agencies of transportation and deposition were the general creep of waste material down slopes from disintegrating areas of older rocks in the high lands, the rush of torrential streams, the flow of rivers of more or less permanence, and the sweep of winds. In the lowest portions of the troughs of deposition there would naturally be shallow lakes, unless conditions of extreme aridity prevailed, and I will endeavor to show later that such lakes were probably present in the area under discussion at the time of the overflow of the trap.

In connection with the theory of a continental origin for these deposits we may quote W. M. Davis on the similar area in Connecticut:

> There is little or no direct evidence for marine deposition of the Connecticut Trias. There are no marine fossils yet found. The fish whose imprints occur plentifully in certain occasional strata of black shale are allied to fresh- or brackish-water forms. The prints of land plants and the tracks of land animals argue against the presence of the sea. The tidal currents that have been assumed to be necessary to carry the materials found in some of the coarser layers may be replaced by other agencies that can as well accomplish this result over the moderate distances here involved. If marine at all, the waters must have been littoral and shallow, and the bottom must have been frequently bared to the sun.[1]

These remarks are equally applicable to the New Jersey area.

Let us now examine the clastic deposits immediately underlying

[1] *Tenth Annual Report* U. S. Geological Survey, Part II, p. 32.

the Watchung traps and ascertain to what extent their structure bears out the theory of continental origin. We find that they form a monotonous series of shales, sandstones and conglomerates, composed mostly of quartz fragments. Sufficient oxide of iron is usually present to give a reddish, brownish, or purplish color to the whole. Feldspathic material is often visible, and the derivation of all these is plainly referable to the crystalline areas on the East or West. In addition to these we find in many of the coarser layers plentiful pebbles of limestone, up to six inches or more in diameter, whose source is obscure.

In observing carefully the succession of strata in this series one is at once impressed with the lack of continuance of the beds in any direction and the variation in the succession at different sections along the same horizon. Within a distance of a few hundred feet the character of the section may change markedly. This may be brought about in three ways.

1. A bed may gradually thin out and disappear. This is especially true of the sandstones.

2. The size of the fragmental material may alter in a pronounced manner, while the thickness of the stratum remains approximately the same. The proportion of pebbles in a bed of sandstone or even of shale may increase or diminish rapidly. This is generally brought about, however, by the intercalation of pebble beds in the sandstone layers, rather than by a general increase in the coarseness of all the material.

3. A given stratum may be cut sharply away, and different material abut against it.

All these variations are shown in the gorge of the Passaic River, a short distance below the falls at Paterson. Fig. 1 is from a sketch made just south of Ryle Avenue. Two very irregular bands of shale (*a* and *b*) cut sharply downward across the sandstone and pebble beds, and are overlain by strata differing from those in the same horizontal planes on the right. It appears evident that a water-course has cut its way through previously deposited strata, and the valley thus formed has later been filled by water-borne sediments or wind-blown sands until a level was again reached and a more orderly course of deposition was continued across it. The pot-hole at (*c*) filled with gravel, stones,

and shaley material, is instructive in this connection. Following these bluffs southward about 350 feet we come to the southern side of the same river-valley, as shown in Fig. 2. We find there, as we

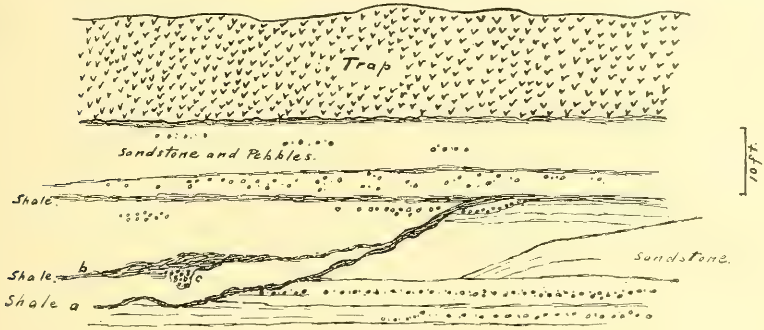


Fig. 1.

should expect, that while the line of the bank is shown by the same downward sweep of the strata, the succession of deposition is quite different from that shown in Fig. 1, indicating a desert stream which

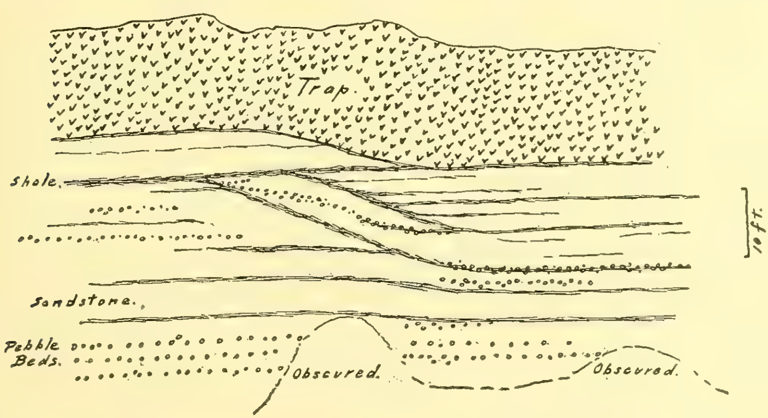


Fig. 2.

at times may have spread over the whole width of its course, and again dwindled to a rivulet or become dry. It is noticeable that the trap-sheet above also bends downward at this point, showing that a shallow depression still existed here when the lava stream covered the whole.

Another example of variations in strata is shown in Fig. 3, a section at Pope's old quarry, near Garret Rock. This is a sketch of the west face, north end of quarry. Marked variations of the strata show themselves along the quarry face, and the section shows no resemblance to any part of Fig. 1 or Fig. 2, though less than a mile distant and at the same horizon (just beneath the trap sheet).

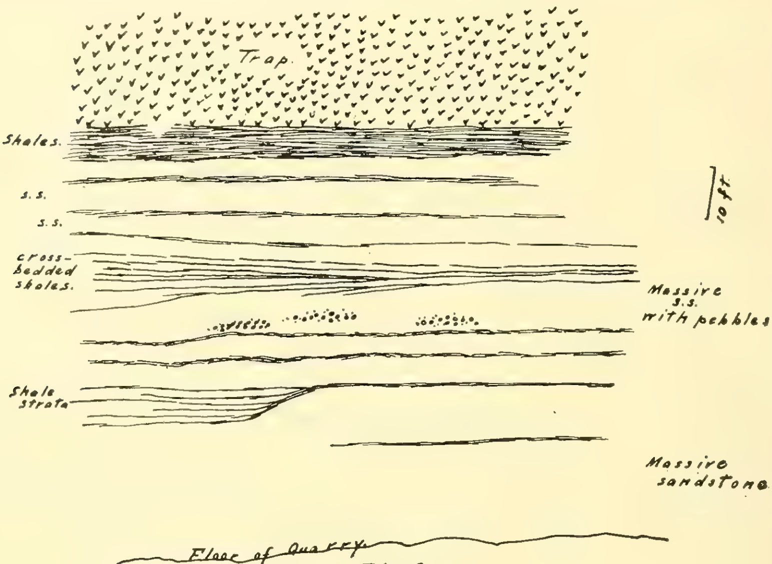


Fig. 3.

At Thomas' quarry at Albion Place there is an instance of the complete thinning-out and disappearance of a sandstone bed, probably five feet thick at its maximum. This is at the northern end. High up on the western wall a massive bed of sandstone has several feet of its upper part cut sharply away at one place, and shales abut against it.

These examples show the great tendency of the strata to vary in a large way, and are inconsistent with any form of marine deposition, or of any theory of deposition which does not take cognizance of sharp changes within small areas. When we take up the consideration of smaller details of structure we are met again with proofs of this same tendency to variation, as is shown by a study of the smaller features of the shale, sandstone, and conglomerate beds.

THE SHALES

These are well described by the term "ferruginous silicilutytes" of Professor Grabau's classification; that is, they are finely-comminuted siliceous material, strongly impregnated with oxide of iron. Their laminations may be paper-like in thinness but are generally coarser. On exposure to the weather they break up into a multitude of crumbly fragments. Mica scales are very plentiful. The surfaces of the laminae frequently show a multitude of irregular markings—grooves, pits, curved lines, lumps, smooth patches of irregular shape, etc., not all of which can be deciphered with any certainty. Many, however, can be identified. Mud-cracks, rain-pits, and worm-grooves are frequent. Rill-marks are sometimes found. At times films of impalpable sediment are found in the depressions in the lumpy surfaces of certain sandstone layers, which, in their delicate markings, suggest irresistibly the frothy scum left in hollows after a rain. Again thin curled layers of shale appear plentifully in the midst of sandstone. The effect is precisely that which would be produced by a layer of mud, drying and curling at the edges, being buried by a deposit of wind-blown sand. The layers of mud are too fragile to permit the supposition that the sand was carried by currents of water. Other examples show plentiful flakes of shale mixed with sand, the occurrence being apparently due to a mixture of material produced by the wind. I have seen wave-marks in the shales and have found them also in the finer sandstones. In the latter too I have found one very distinct print of an apparently three-toed reptile. The impression is a trifle over an inch in width and on one side is an irregular, curved groove, probably made by the animal's tail. In the fine shales there are many impressions which suggest the marks which would be made by living creatures moving about in soft mud. They are too uncertain, however, to offer more than a suggestion. In other localities, as in the Connecticut valley and other parts of New Jersey, many reptile trails have been found, but those spoken of here were found in the territory under discussion in material taken from a short distance below the trap sheet, and serve as an index of conditions just preceding the flow.

These shales are to be regarded as muds deposited in lakes, rivers, or pools. The markings described owe their preservation to the

retreat of the waters and the baking of the mud under a hot sun. That arid conditions prevailed is indicated also by the frequent presence of sharply defined pieces of shale in the pebble beds. During long exposure the iron-impregnated mud must have hardened to such a degree as not to be ground up and destroyed by a succeeding rush of torrential waters.

THE SANDSTONES

These are ferruginous silicarenytes—siliceous sands, colored by oxide of iron. In places they form extremely massive beds in the series, up to 25 or 30 feet in thickness, with hardly a line of parting. Beds of this kind are made up of rather coarse quartz fragments, rounded or subangular, mixed with a little decomposed feldspar, and frequently show no hint of stratification on either fresh or weathered surfaces. The finer sandstones carry much mica and are generally better stratified. A little cross-bedding has been observed, the direction of the lines differing by a slight angle.

Fig. 4

The sandstone strata may contain anywhere in their mass individual pebbles or small beds of pebbles of irregular shape and extent.

Fig. 4 shows a characteristic pebble bed on the west side of Thomas' quarry. Pebbles are up to one-half inch or more in diameter. Below is even-grained sandstone separated by a sharp line from the pebbles. Above, the gravel grades into sandstone. Fig. 5 represents the structure of a gravel bed a few hundred feet north of the D. L. & W. R. R. station at Paterson. On the left side the dividing line between gravel beds and sandstone cuts sharply downward across the sandstone layer. On the right there is a grading of pebbles into sand. A rough stratification is apparent in the pebbles. Fig. 6, from Pope's quarry, illustrates a somewhat different feature. The intercalated bed is here mostly shale, in the midst of a massive sandstone.

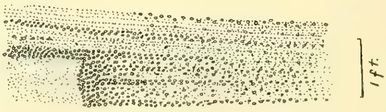


Fig. 5

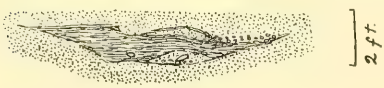


Fig. 6.

These are by no means isolated occurrences, but are repeated in a similar fashion in innumerable exposures. The obvious explanation is that they represent the channels of small streams which cut across the face of the country. The sandstones in which they occur I would refer to an aeolian origin, and believe them to have formed the surface of the ground at the time the streams cut their channels. By this I would not be understood to imply that water played no part in the transportation of the sand grains from their original homes in the crystallines. They may have been picked up and laid down repeatedly, now by wind and again by water, before reaching their final resting place, and it would be impossible to draw a sharp line and say that here the work of water ceased and here the work of the wind began. Their final attitude, however, is to be attributed chiefly to the action of the wind. The fact of the subaerial accumulation of the great masses of sandstone should be emphasized, for their freedom from moisture at the time of the trap flow has an important bearing upon certain structural features of the trap.

At Little Falls, a few miles west of Paterson, a bed of sandstone lying about fifteen feet below the second Watchung sheet, carries abundant plant impressions. The remains of woody stems are found which have been converted into coal, and twigs and leaves have also left their impressions in the stone. From the completeness of the forms preserved the trees were evidently not carried to this point from a distance and I am inclined to believe that this is actually the site upon which they grew. Although not in the area under discussion, this occurrence is interesting as indicating the continuation of continental conditions up to the time that the second flow of trap spread over the region.

THE CONGLOMERATES

Everywhere throughout the sandstone strata pebble beds similar to those described are of frequent occurrence. Even the shales may contain locally a large amount of gravel. In addition to these, heavy beds of coarse conglomerate are sometimes seen, though they are not as frequent as the sandstones and shales. They were exposed a number of years ago a little to the southeast of the Great Notch in a trench dug for a water-supply system, and at the present time are especially well seen in the sandstone quarry in the gorge of the Passaic,

on the eastern side of the river. The conglomerates here carry quantities of shale mixed with the gravel. The old streams, of which these are the beds, evidently deposited at times quantities of mud. As the waters ceased flowing the mud was dried and baked till it became well hardened. When the next rush of waters came some of the strata of hardened mud withstood the force of the stream, but others were broken up and the pieces mixed with the pebbles and swept along with the current. From the recurrence of the phenomena this must have happened time and again.

The pebbles of the beds are mostly quartz, sometimes only slightly rounded. Limestone is also of frequent occurrence.[1] Often weathered surfaces of the conglomerate show rounded cavities from which limestone pebbles have been dissolved, and the general porosity of the beds may be partly due to the solution of smaller lime grains. The presence of these limestone pebbles indicates a not distant source, but nothing from which they could have been derived is to be found for many miles. The original strata were either totally broken up and carried away or, more probably, were buried beneath later deposits.

It is to be noted that the pebbles are all of moderate size, rarely more than six inches in diameter. No bowlder masses, like those which are common in river channels, ancient and modern, in regions of rugged relief, are to be found here. The trough of depression, in which deposition was proceeding, had been filled so that the surface of the buried valley was now almost a level plain, on which the rush of waters, even from torrential streams, soon lost its force.

From the evidence of the rocks themselves at the base of the First Watchung Trap we are able to picture, with a fair amount of certainty, the character of the region and the conditions of the deposition of strata preceding the period of the lava flow. We see on the east and the west chains of hills of moderate relief, composed of the old crystalline rocks, whose surfaces gradually disintegrated under the effects of the weather, and the detritus from which was carried down the slopes and spread over the intervening valley. The climate was arid,

[1] In a couple of pebbles of decomposed limestone which I found in these conglomerates there were abundant fossils. Crinoid segments were very numerous, and bryozoans were abundant. There was also a fragment which may have been the pygidium of a trilobite.

and during the long periods of drought the streams dwindled away or sank into the sands. At times, however, torrential storms or cloud-bursts occurred and the sudden rush of waters carried heavy loads of waste material before them. In the dry periods strong winds played an important part. They gathered up every exposed grain of moderate size from the higher ground, and swept it into the valley and spread it out in accumulations which reached great thickness.

The floor of the valley was almost flat, or at most had a gentle slope away from the mountains toward the axis. In the lower-lying portions lay one or more shallow lakes, which in periods of comparatively large rainfall spread over wide expanses, and in dry periods contracted within narrow limits.

THE LAVA FLOW

Over such a region as we have pictured a great lava flow was suddenly poured forth. The points at which extrusion took place are uncertain. There seem to have been no preliminary phenomena such as often precede lava flows. No deposits of tuff or other ejectamenta, indicative of explosive violence, are found in this region. The lava seems to have quietly welled forth and, as we shall see later, spread out in a thick sheet in a flow which was practically continuous.

From whatever point the flow may have entered the region its natural course would be along the trough of the valley. The shallow inequalities which existed in the surface offered no serious obstacle to it; the fluid lava filled them and passed on. Such small bodies of water as were encountered were perhaps quickly turned to vapor and driven off. Nevertheless the lakes have left their record upon the molten rock, and though in places the writing has become dim with the lapse of ages, it has proved so nearly indestructible that it can still be deciphered, and the site of the lake beds, and hence the line of central depression of the valley, can be determined with a fair degree of confidence. If we are not able to do this throughout the area, it is because the field has not yet been thoroughly studied with this object in view, or because the structure of the trap is not sufficiently revealed in the surface exposures.

The process of reasoning is as follows: Where the lava covered arid soil it was practically unaffected by water. The air and the

trace of water contained in the interstices of the ground would be expanded by the heat, and having no other escape would force themselves into the molten lava and render it vesicular for a short distance above the contact, but the great mass of lava would be left dense and unaltered. At the surface of the sheet the escape of occluded gases might also produce a slightly porous structure. But where the lava poured over lake beds the case was different. The standing water was probably not of sufficient volume to produce much effect, but the underlying strata were thoroughly saturated. The heat of the lava penetrated downward slowly but irresistibly, and the water was vaporized. If there had been no means of escape, the pressure would have gone on accumulating until it became enormous, but before this the vapor began to push itself up through the over-lying lava, and thus found vent. It continued thus to force its way long after the lava congealed, and finally the temperature dropped to such a degree that currents of heated water replaced the steam. The effects produced constitute the record left and will be described in detail.

Let us first, however, examine the structure of the trap in its less affected portions. The gorge of the Passaic in the vicinity of Figs. 1 and 2 offers good opportunities for this. It is seen that the contact is practically conformable with the stratification of the underlying sandstone series, but there are slight irregularities, and at the point where Fig. 2 was sketched the trap drops about six feet. For a short distance above the contact, that is, from a few inches up to four or five feet, the trap is vesicular. Above this it is firm and dense to the top of the cliff. At Garret Rock there is another good exposure of the contact where the D. L. & W. R. R. rounds the point of the mountain. The contact is perfectly sharp, but slightly irregular. There is no mixture of the trap and sandstone. The vesicularity of the trap extends about three feet up and the sandstone also shows small passages through which gases were forced. Fig. 7 shows a typical example of the contact here. In some places the trap is so welded to the sandstone that the same hand specimen will show both.

Fig. 7.

At the trap quarry southwest of Albion Place there are certain features of interest. At the contact there is a mixture of vesicular,

decomposed trap, and lumps of hardened mud. The whole is much affected by weathering, but it is easy to distinguish between the igneous and sedimentary material. This mixture forms an irregular band about six inches in width. Below is red shale, not perceptibly altered, extending downward for several feet. Above the mixed band, the trap is vesicular for a few inches, and passes upward into fine-grained, dense rock. The impression produced is that the first thin stream of advancing lava flowed over a bed of rather damp mud and became mixed with it, and that this in turn was soon covered by later streams.

In this quarry for one hundred feet or so along the quarry face, about six feet above the contact, there is a band of trap, two or three feet in width, having the structure shown in Fig. 8. The lines of the sketch represent cracks from one-half inch wide down to a mere seam, which extend approximately horizontally along the cliff face and back into the rock, and permit it to be separated easily into slabs. The cracks are filled with a loose, granular material, generally of a dark color, but showing calcite grains in places. This same slab-like or platy structure can be observed as of frequent occurrence in the more massive portions of the trap sheet in various localities, though seldom so well developed as here. It is a fair inference that these plates represent rivulets of lava, and that the chilled surfaces have been more easily weathered. The advance of the lava flow should not be pictured as similar to that of a sheet of water. On account of viscosity and partial congelation, the spreading out of a sheet of even the most fluid lava is quite a different process. We should picture the advance of this Watchung sheet as similar to the form of the Hawaiian lava flows described by Major Dutton:

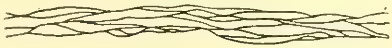


Fig. 8.

> When these lavas are discharged they come up out of the ground in enormous volumes, are intensely heated, and are very liquid. . . . . As they become cooler they become more viscous. The cooling takes place upon the surface of the mass while the interior still remains hot and preserves a viscous liquidity. The superficial crust of cooled lava undergoes rupture at numberless points, and little rivulets of lava are shot out under pressure. Preserving their liquidity for a short time, they spread out very thin and are quickly cooled, forming pahoehoe. Scarcely is one of these little offshoots of lava cooled when it is overflowed by another and similar one, and this process is repeated over and over again. In a

word pahoehoe is formed by small offshoots of very hot and highly liquid lava from the main stream, driven out laterally or in advance of it in a succession of small belches. These spread out very thin, cool quickly, and attain a stable form before they are covered by succeeding belches of the same sort.[1]

Above the reticulated strip described comes fifteen feet of nearly massive trap with few joints or planes of separation, and above this, along an irregular line, there is a blocky variety of considerable thickness. Except for the narrow band of vesicular trap on the contact the texture of the whole mass is firm and dense and the rock is of flint-like hardness.

We may continue southward for several miles along the cliffs marking the eastern face of the mountain, and find almost identical conditions everywhere. The base of the trap sheet shows slight irregularities but is practically conformable with the bedding of the sandstones and shales. For a short distance above it is apt to be somewhat porous, but the great upper mass is perfectly dense.

Evidence of the existence of a lake bed, covered by the lava flow.—Let us now follow the D. L. & W. R. R. westward from Garret Rock to the West Paterson trap quarry. Garret Rock is a bold cliff marking the eastward scarp of the mountain, and from here the railroad makes a section almost at right angles to the line of the ridge. About three thousand feet from the rock it passes the quarry mentioned, which is in the very midst of the trap area. The quarry has been famous to mineralogists for years for the specimens of zeolites and associated minerals which have been obtained from it. It is only within about a year, however, that operations have proceeded so far that the geological conditions have become plain and the whole story revealed so that it can be easily read. The section is so perfect, and the rock and its minerals are so fresh and unaltered that a careful study of the exposure should be made. We shall find here the explanation of features occurring elsewhere, which by themselves might convey little meaning.

The first observation which will probably be made is that here in the midst of the trap area the bottom of the quarry shows a floor of hardened red mud rising from the west toward the east. On this the trap rests. Along the contact for a width of ten feet or more the

[1] *Fourth Annual Report,* U. S. Geological Survey, pp. 95, 96.

trap and mud show evidences of having experienced the most violent agitation. The two are mixed and kneaded in a manner so involved that it can hardly be imagined. The mud has boiled through and through the seething body of lava until particles of mud of every size from minute specks to large masses have become incorporated in the pasty flow. Both lava and mud are full of blow holes, steam vents, and other forms of irregular pipes and cavities which attest the violent escape of gases.

Above this confused mixture the lava is generally found to show a transition to a purer condition. It is still thoroughly vesicular for

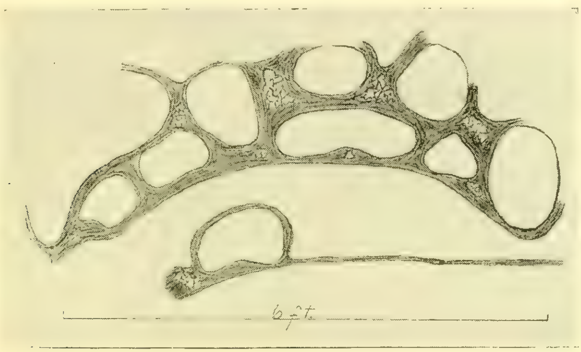


FIG. 9

several feet, but less mud is found in it as we go upward. Still higher no mud whatever is found, and the overlying mass of lava, probably nearly seventy-five feet in thickness to the surface, is purely igneous rock. The structure of this, however, is very different from the close-textured rock which we found along the eastern border of the trap sheet; and, in its way, the evidence of the action of escaping gases and heated waters is as perfect as in the underlying portions. Amygdules are still frequent, but the more characteristic appearance is the bowlder-like structure shown in Fig. 9. The bowlders are of dense trap, with crusts of dark glass. Vugs of mineral lie between, and it is in these vugs that the crystallized zeolites are found.

This structure is common throughout the whole quarry. Even the masses of trap which do not show the glassy crusts or the vugs are so seamed with fissures as to be easily broken apart. Toward

the surface of the ground this structure is not so evident. This is mostly due, no doubt, to the leaching-out of the secondary minerals, but the impression is left that in its original occurrence it may not have been so well developed in the upper layers.

The course of events which gave rise to these features is to be explained as follows: Before the lava flow occurred this site was occupied by a shallow body of water with a muddy bottom. When the first thin flow of intensely heated igneous rock plunged into it, the violent agitation resulted in a thorough mixture of the two. At short intervals further flows added to the depth of the mass. The successive spurts and tongues of fused material burst forth everywhere. Chilled almost at once by the steam pouring around them, they built up a structure of bowlder-like forms. The original body of water was quickly driven off, but that contained in the saturated strata beneath was changed to steam and rushed up through the mass. Some of it found its way into and through the fused material, but the greater part worked its way around and among the bowlders, with the result of quickly cooling the crusts, producing a glassy texture and a multitude of cracks. The evidence of these effects throughout the seventy or eighty feet to the surface indicates that at least this depth of lava had reached its position while the action was still continuing, though it does not follow that there may not have been intervals during which the flow of lava ceased.

Further than the physical effects of chilling the lava and producing the crusts and cracks, the steam seems to have had little result. In places the inner surfaces of the blow-holes have no lining of minerals but appear entirely unaltered. In another locality, which will be described later, many of the steam vents were blown full of sand or dust and this frequently lies up against the chilled glass, without any indication of alteration in the latter. Later, after a considerable interval of time, the mass of lava cooled to such a degree that the underlying reservoirs began to supply a mixture of water with the steam, and finally merely heated waters passed up through the vents, and with these the crystallizing action and formation of minerals began. The lava had been so thoroughly seamed and cracked that it could not have offered much obstruction to the flow of these waters, and it does not seem that they could have been at any time under a

pressure which would greatly raise their boiling point. Rather must we suppose that the principal mineralizing effects were due to waters having a temperature but little above 100° C.

Further evidence of a relatively unobstructed and rapid circulation of water is supplied in the fact that frequently the transparent crystals lining the vugs show inclusions of dark sediment, or again the crust of perfectly formed crystals is covered with a deposit of the same sedimentary material.

The minerals produced are largely due to the action of these hot waters upon the glassy crusts of rapidly chilled trap. The muds themselves show practically no alteration except hardening, and the elements of the minerals are those of the igneous rock, with water added. In fact the zeolites seem to be the direct result of the addition of water of crystallization to the albite and anorthite mixtures of the feldspars and result from a crystallization of previously existing silicate material by a slight modification of its composition. The presence of datolite and apophyllite—compounds carrying boron and fluorine—indicates that the elimination of magmatic vapors from the igneous material was still in progress during the process of formation of the secondary minerals. Such emanations may have been powerful agents in conveying to the channels of circulation material derived from the magma, and in the rearrangement of the various elements present.

All stages of transition in the alteration of the trap and the formation of minerals from it are common. Frequently we find a breccia with angular fragments of trap as nuclei and crystalline minerals for a filling. The most perfect crystals, however, form linings to the cavities between the bowlders. I believe there is evidence of a definite sequence in the formation of the minerals but there are difficulties in determining it in many cases. Apparently, however, it is as follows: First, a dark green, chloritic mineral, followed by prehnite, datolite, and pectolite; then the zeolites, analcite, laumontite, chabazite, natrolite, heulandite and stilbite; ending with apophyllite and thaumasite. Quartz and calcite are very common but seem to have been deposited at several stages and cannot be assigned a definite position in the series. The only metallic minerals observed are chalcopyrite and hematite. Small grains of these, sometimes well crys-

tallized, are common, but like quartz and calcite, they cannot be given a definite place in the order of deposition.

The structure which I have described changes toward the surface. It may not have been so well developed in the upper layers, and weathering has obscured the effects. So far have the changes proceeded at this point that the outcrops of rock just above the quarry have to be examined very carefully before any difference in structure can be noted between these rocks and the ordinary firm-textured trap. A wide area of surface surrounding this point plainly shows a survival of the structural differences described, but immediately back of the quarry they are almost gone, though so well developed in the rock beneath. This point should be noted, for in following on the surface

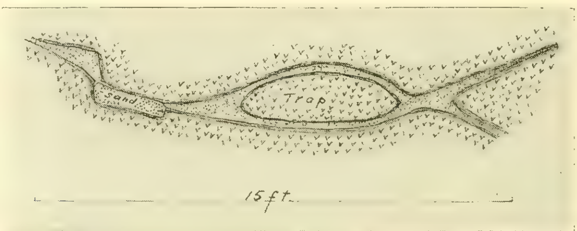


FIG. 10

the area which was underlain by the lake we find occasionally areas of dense-textured rock, lacking practically all evidence of being different from that which overflowed the arid country, and we should perceive that the presence of surface rock of this nature does not necessarily imply the lack of the characteristic structure beneath. In the areas which I have explored, however, the altered rock has been so frequently found where it has been expected, and where it should have been developed if the lake had the form assumed from the position of the few well-developed exposures which I first noted and on which I based the theory of its existence, that its general form and position can be predicated with fair confidence.

The features which best survive the effects of weathering are the extremely vesicular or sponge-like facies of the lower layers near the contact, and the smooth, rounded, bowldery forms with brecciated crusts of the upper parts. Of the secondary minerals few survive prolonged weathering, except quartz and prehnite and occasionally

calcite, but the irregular cavities from which they have been dissolved have frequently been noted.

The surface areas on which I found these structures in the immediate vicinity are indicated on the map.

Let us now go southward about three miles to an old trap quarry near the Great Notch, formerly worked by Francisco Brothers.

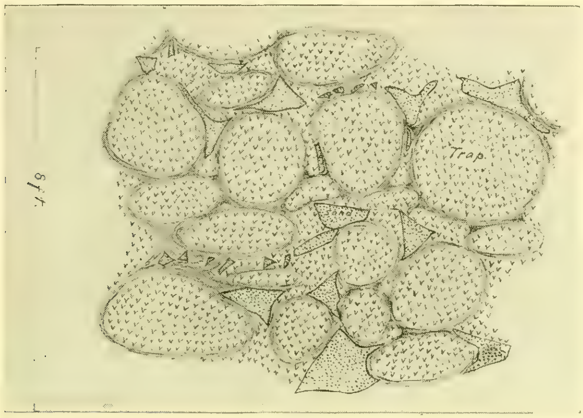
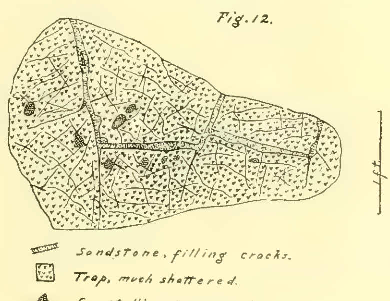


FIG. 11

Unfortunately no work has been going on here for several years so that the features to which I wish to call especial attention can now be seen at a few points only, though formerly visible over a good part of the quarry. Fig. 10 is from a sketch of the south side of the quarry made in 1902, and Fig. 11 is of the east side made at the same time. The bowlder-forms noted in the West Paterson quarry were well developed and the crystal vugs were also present; but a new feature to be noted is what at first sight appears to be a breccia of sharply defined, angular blocks of sandstone, ranging up to a foot in diameter, lying in the midst of the trap. Their presence in a surface flow of lava might be extremely puzzling until some such occurrence as that shown in Fig. 12 is noted. From a



study of this and of the other occurrences it is seen that the blocks of sandstone are in reality made up of finely divided material caught up from the bottom of the lake and carried to their present position in the form of dust by the blast of steam. Later they were consolidated by the deposition of secondary

FIG. 13

minerals, but the amount of the latter is so small as not to be perceived at a casual glance. So fine was the dust that it penetrated the most minute crevices and at times its presence can be detected only with a lens. Fig. 13 shows a small block of trap with sand inclusions, drawn in careful detail, and Fig. 14 is another portion of the same block as Fig. 13, showing dust-lined amygdules, later

filled with zeolites. It should be noted that the surface trap at this quarry is of the dense variety for a thickness of several feet and gives no hint of the structure underneath. A short distance west of this point, just below the main line of the N. Y. and Greenwood Lake R. R. is the entrance to a water-supply tunnel, which was driven under the mountain a number of years ago. It entered trap on the western side and came out in the sandstone country on the east, and

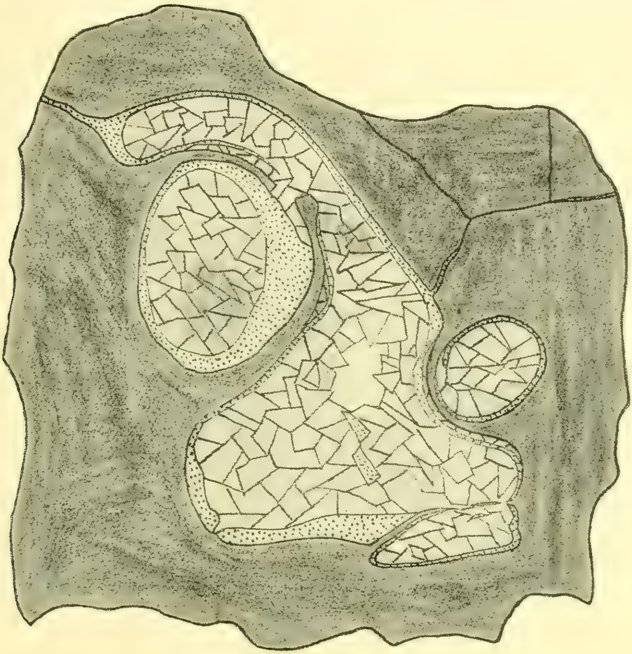


FIG. 14

in its course passed almost directly beneath the Francisco quarry just described, but at a much lower level. At the time that work was in progress much of the material brought out and thrown on the dump was of the characteristic structure which we recognize as being associated with the portion of the lava flow which plunged into the old lake. Glassy crusts, crystal-lined vugs, and sandstone inclusions were all common.

The two localities described, the one at West Paterson and the other at Great Notch, give us the general line of the lake valley and

show us the changes in the trap by which we can recognize its position. I will now take up some of the typical exposures and describe any details which may seem of importance. The most northerly point at which I have found evidence of the existence of the lake is at the corner of Union Ave. and Marion St. in Paterson. There is a small outcrop of trap here, showing bowlder forms and glassy crusts, stained with copper. About half a block south is the site of Hoxsey's quarry, which many years ago was a famous hunting-ground for mineral collectors, and specimens from which are found in cabinets throughout the country. The hill of trap which formed the quarry was leveled off years ago and work was abandoned. A large part of the quarry ground is now built up with houses and nearly all trace of it is gone. When I was familiar with it the form of its structure bore little significance to me, but I remember the general details and believe the structure was almost a duplicate of that now showing in the upper portions of the West Paterson quarry. In one place the floor of the quarry showed calcite-impregnated, amygdular trap, but work was not carried below this. I do not recall the presence of sandstone inclusions, but upon a recent visit to the locality (September, 1907) I was lucky enough to find a little work going on in Kearney St., apparently for a sewer connection, which showed perfectly the crusted bowlder-forms and the vugs and also sandstone inclusions.

Southerly from here is an exposure just east of the reservoir on the hill near the Soldiers' Monument. The outcrop is small but the characteristic features are well developed. This exposure is only a few hundred feet west of the cliffs where Figs. 1 and 2 were sketched and we are now able to appreciate the full significance of the valley shown in these sketches. We see that a river at one time entered the lake at this point, but its valley had been nearly filled and its course almost obliterated until only a shallow depression remained at the time of the trap flow. Its bed was dry, as is shown by the slight degree of vesicularity of the trap at the contact and the close texture above, whereas, over the lake bed the water-soaked muds wrought changes in the trap to a much higher level.

Going a little farther south we come to a small abandoned quarry just across the road from the Water Works Pumping Station. We may note the bowlder-forms here with which we have become familiar

and there is another feature of especial interest. The slaggy, wrinkled crust of one of the flows is finely exposed in two or three places. It projects as an inclined shelf, one or two feet wide and fifteen or eighteen feet long, from under later trap, but at only two or three places on this shelf is the structure perfectly developed. The wrinkled surface is shown in Fig. 15. It appears to be a crust one-half to two inches thick, over another flow which also shows a wrinkled surface in one place. Although somewhat weathered the original rock was plainly of a close, glassy texture. No vesicles are visible. The wrinkles are plentiful, forming curved grooves one-fourth to one-half inch deep. The direction of all of them points to a flow northward at this point, and though we must not lay too much stress upon this, a northward flow is perfectly consistent with the shape of the valley. This crust does not of course represent a part of the final surface of the lava flow. It is merely the crust of one of the small sheets, spurted forth under pressure, and soon covered by other portions of the flow. The innumerable bowlder-crusts to be found throughout the area which we are studying are practically the same thing, but in few cases was the wrinkled surface preserved so perfectly as in this example.

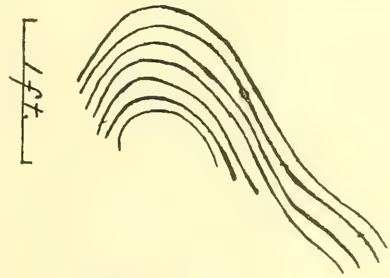


Fig. 15.

At the Falls the rocks on both sides of the river at the brink of the chasm show many irregular vug holes and in places crystals can be seen. We are here, however, far above the base of the sheet and the exposure is not a typical one. Farther south there is an occurrence on the Little Falls turnpike, showing the characteristic structure. The most noteworthy feature is the recurrence here of the wrinkled crust of one of the bowlder masses, showing as a slight projection.

Next comes the West Paterson quarry already described in detail. I have found in this vicinity evidences of the lake valley over a large surface area but have not yet had the opportunity to explore the vicinity in sufficient detail to fix definitely the limits of the area covered by the lake.

Going southward from this point along the mountain road there are positive evidences at many places, as indicated on the map. I have no doubt that with some search other characteristic exposures can be found in this vicinity.

Southwest of the mountain reservoir there is another large area shown. Along the road and in adjacent fields the trap is very vesicular. Plowed fields are filled with the honeycombed fragments and some is plainly in place. A little to the westward the stone walls are built of the crusted bowlders and rock of this structure is also found in place.

South of Great Notch the occurrences in the pipe-line tunnel and in the old quarry of Francisco Brothers have been described. Francisco's new quarry also shows it well at the southern end.

About a half-mile south of Great Notch station is the reservoir of the Newark water department. The work here was done in 1902 and at that time the progress of the work showed the character of the trap underlying the valley. From the gate-house a deep trench was excavated North and South as a foundation for the dam. In this the trap was very porous and vesicular for many hundred feet. From the surface to a depth of twenty feet or so the trench showed bowlder-drift. For probably forty feet below this the trench was in rock, very vesicular, with abundant minerals. Stilbite, chabazite, heulandite, prehnite, calcite, and quartz were recognized. From the gate-house other trenches running east and west showed vesicular trap for several hundred feet. A little to the north the quarry which was opened up for the purpose of obtaining rock for the concrete of the dam shows the bowlder-structure and alongside the road running eastward in front of the dam the rock is honeycombed. These last two exposures are still in evidence, but that in the trenches is now covered with tons of earth and masonry, and the only indications of the rock taken out are the bowlders piled in the road embankment.

I have not traced the prolongation of the valley south of this point. At Upper Montclair the trap quarry of Osborne and Marsellis shows a set of phenomena which probably has some connection with it, but the exact relations are not certain. The contact of trap and sandstone is seen to be very ragged. Angular blocks of sandstone project upward a distance of eighteen inches or two feet into the trap

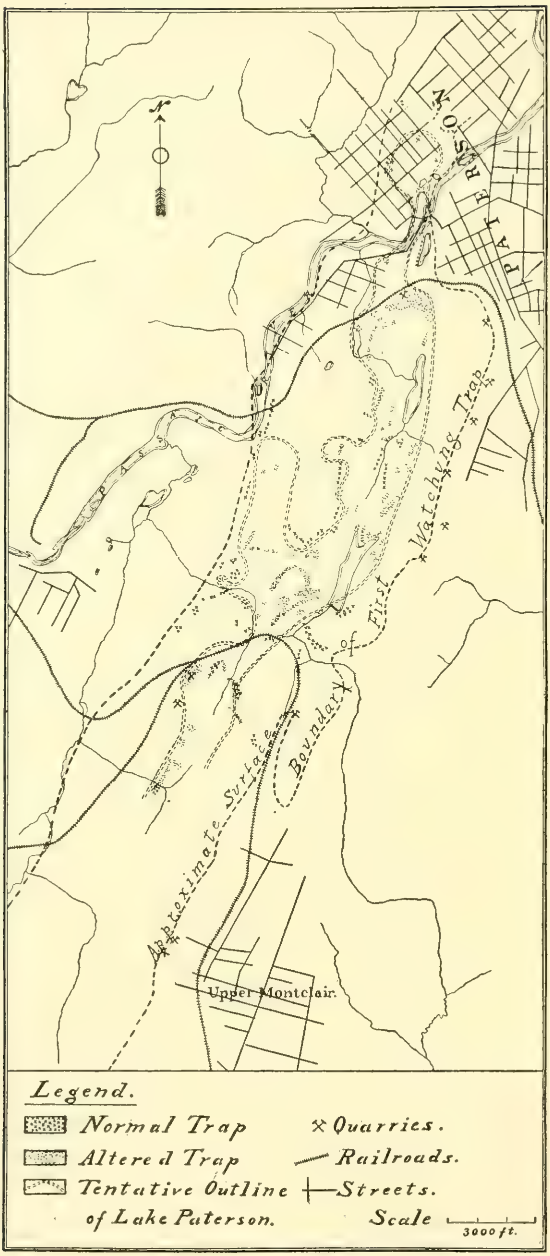
in many places. Above the contact much of the trap is vesicular, but in places dense trap comes down to the contact. The vesicular trap gives on weathering a brownish, pulverulent, tuff-like material, but I do not think that true tuff is present. Where not weathered it contains many seams and vugs of crystals. The dense trap is sometimes separated quite abruptly from the vesicular form and in other places there is a transition from one to the other.

There was evidently considerable agitation here at the time of the trap flow, but it does not appear to have been so violent as in the cases previously described. The position of this quarry is on the eastern edge of the trap sheet, somewhat removed from the line of direction of the lake valley, so far as determined. I should consider that this marked a spot of marshy ground in the general area of the lake basins, rather than a large body of water. Professor Kemp (in a personal communication) reports the discovery of reptile trails in the shales underlying the trap at this quarry.

A reference to the accompanying map will show many other localities in which typical exposures have been found. In most of these cases the crusted bowlders are the most prominent features to be observed in the structure of the rock. In a few cases I have indicated on the map outcrops of normal, dense trap. These are only shown where they have some significance in defining the limits of the lake area.

FAULTS

An explanation of the appearance of the shales beneath the trap sheet at the West Paterson quarry in the midst of the trap area is required. Along the eastern scarp of the ridge the sandstone series is found to have everywhere a gentle westerly dip, averaging six or seven degrees, as it disappears beneath the trap. Assuming that this dip continued from Garret Rock westward to the quarry, the base of the trap sheet should lie several hundred feet beneath the surface at this point. To explain the reappearance of the sandstone then we must suppose either that there has been a sudden reversal in the direction of the dip or that it has been brought up by faulting. There is no evidence of a reversal of dip and its existence would be contrary to the general monoclinal


N
PATERSON
PASSAIC
Approximate Surface Boundary of First Watchung Trap
Upper Montclair.
Legend.
Normal Trap
Altered Trap
Tentative Outline of Lake Paterson.
Quarries.
Railroads.
Streets.
Scale
3000 ft.

structure of the region. There are, however, excellent reasons for supposing that a series of northerly and southerly faults runs through the country.

A little west of Garret Rock there is a very evident displacement, described and figured by Davis in his paper on the "Triassic Traps and Sandstones," and referred to by Darton,[1] who figures a displacement of about seventy feet, with downthrow on the eastern side, and with this allowance calculates a thickness of seven hundred feet for the trap sheet along this section. On this supposition the underlying shales should lie not less than two hundred feet beneath the surface at the West Paterson quarry. As they are brought up again at this point a displacement of something like two hundred feet by faulting is shown to have occurred, in addition to the seventy-foot throw referred to by Darton. In the quarry itself there are many nearly vertical planes of cleavage, running from top to bottom of the quarry and having a direction nearly north and south. Over much of the country covered by the map there is a prominently developed set of cleavage planes having a general northerly and southerly direction (N. 0 E. to N. 30 E). Frequently where a little quarrying has been done they appear as innumerable sharply defined breaks in the quarry walls. Near the road which runs through the gap of the Great Notch a series of pinnacles on the northern side indicates a faulted structure. This same series of faults continued southward follows the line of valley along which the N. Y. & G. L. R. R. has been built from the station at Montclair Heights northward, and apparently has resulted in the two parallel crests of the ridge here. The faults are well shown in the large quarry near the railroad line in this inner valley and the movements have resulted in the formation of slickensides and gouge matter. There is reason to believe from the evidence at hand that a multitude of displacements of slight throw, and a few well-developed faults of greater throw, all having a northerly and southerly course, have affected the country. The appearance of the underlying lake bottom at West Paterson subtracts two hundred feet from Darton's estimate, and possible displacements to the west of this are likely to reduce the figures still more.

[1] *Bulletin 67*, U. S. Geological Survey, "The Relations of the Traps of the Newark System in the New Jersey Region," p. 23.

RÉSUMÉ

We have seen that the series of clastic rocks of the Newark Formation underlying the First Watchung Trap was deposited as surface accumulations in a semi-desert area, mostly under subaerial conditions, in which the wind played an important part. Most of the material from which it was derived is plainly traceable to the old crystallines on the borders of the basin. Either the original floor of the basin on which accumulation began was almost a plain, or accumulation had proceeded to such a degree that minor features of relief had been buried by it, resulting in a surface with only gentle slopes at the period immediately preceding the extrusion of the trap sheet. The usual topographical features of such a surface, in the nature of shallow valleys and stream channels, were present, and we must suppose that the naturally heavier accumulation of detrital material along the bases of the bordering ridges resulted in lines of consequent drainage from the ridges toward a central area of lower-lying ground, which, in the logic of circumstances, would be occupied by a shallow lake or series of lakes. Inasmuch as the drainage on the eastern side of the lakes came from the country lying on the east, we are able to affirm that at least the heavier sediments in the sandstone series on this side of the lakes had their origin in the eastern hills and to point to this section as the original home of the limestone pebbles in the conglomerate beds.

Over such a region a flow of lava poured forth, which accumulated in the low-lying areas occupied by the lakes, and spread out over the sloping ground along the border lines.

When we came to examine the lava itself we saw that it carried in its own mass plain evidences of the structural changes which were produced by the presence of the lakes and of the water-bearing strata beneath. Whereas beyond the borders of the lakes the lava was of a close, firm texture and showed a condition of quiet and tranquillity during the process of cooling and hardening, over the area of lake bottom there was evidence of violent agitation having affected it during the initial flows, and rapid cooling and the production of much glassy material during succeeding flows, followed still later by the crystallizing effects wrought by heated waters and the production of secondary minerals.

By an examination of the territory and a study of the structure of the trap sheet we are able to define approximately the shape of the area covered by the lake or lakes.

I have outlined on the map a tentative boundary. The lake itself seems a sufficiently distinctive feature of the ancient topography to receive a specific name, and I have called it Lake Paterson, from the locality where some of the most typical exposures are to be found.[1]

[1] In the *Transactions of the Geological Society of America* for 1897 (Vol. VIII, pp. 59 ff.) Professor B. K. Emerson gives a detailed description of the occurrence of sandstone inclusions in the Connecticut valley traps, which have many points of similarity to those of the New Jersey area. The theory by which he accounts for their presence, however, is, in some features, radically different from that offered here, chiefly in that it is based upon a fundamental conception that the lava was a submarine flow, covering the muddy bottom of a bay. While this may account for the features which he describes in the New England area, I think that the explanation proposed in the preceding pages will better account for the features of the trap sheet and for the relations of trap and sandstones in the New Jersey area.

THE SUCCESSION OF FAUNAS IN THE PORTAGE AND CHEMUNG FORMATIONS OF MARYLAND[1]

CHARLES K. SWARTZ
Johns Hopkins University

In April, 1904, the author visited Great Cacapon, Western Maryland, in company with Messrs. Charles Butts, G. W. Stose, and George C. Martin. At that time certain fossils were observed which, it was believed, might indicate the presence of the Ithaca fauna in Maryland. Subsequent and fuller investigations have been made which have confirmed this view.[2] As the extension of the Ithaca fauna into this area had not been previously noted, it is believed that a brief presentation of the results obtained may be of interest. A résumé of the history of the earlier investigations of the Upper Devonian formations of Maryland will be helpful in understanding the facts to be presented.

HISTORICAL REVIEW

In 1892 Mr. H. N. Darton proposed the name Jennings formation for the Upper Devonian rocks which lie below the Hampshire, and above the Romney in the Staunton, Virginia, quadrangle.[3] The name was subsequently adopted by the Maryland Geological Survey for similar strata in Maryland.

A detailed study of the Upper Devonian formations of western Maryland was made by Professor Charles S. Prosser, assisted by R. B. Rowe, C. C. O'Harra, and others in the years 1898, 1899, and 1900. The fossils collected were described by Dr. J. M. Clarke. A brief statement of the results obtained was published by Professor Prosser in the *Journal of Geology* in 1901.[4]

It was shown that the Jennings formation in Maryland embraces three members which are, in general, equivalent to the Genesee, Portage, and Chemung of New York.

[1] Published by permission of the Maryland Geological Survey.

[2] A brief statement of this fact was published in *Maryland Geol. Survey*, Vol. V, 1905, and in the Johns Hopkins University Circular, New Series, No. 7, p. 50, 1907.

[3] *American Geology*, Vol. X, 1892, p. 17.

[4] *Journal of Geology*, Vol. IX, pp. 419, 420, 1901.

The fossils described from the Portage were those characteristic of the Naples fauna of New York.[1] A thickness of approximately 2,000 feet was assigned to it in the central part of the area studied.[2]

All strata from which brachiopods were described were assigned to the Chemung. This fauna was known to contain two elements, one characteristic of the Ithaca fauna and another of recognized Chemung facies, while the two elements were supposed to be commingled in the Chemung of Maryland.

The Jennings, though comprising diverse elements, was mapped as a unit because it was deemed impracticable to attempt a cartographic separation of its members at that time.

It appears from the work here discussed that a considerable number of the species previously referred to the Chemung of Maryland occur in reality in the Ithaca facies of the Portage formation. The number of species thus far observed in it is not large, but they are represented by a profusion of individuals.

The various sections will be discribed, those in Washington County being first considered, then those in Allegany County, adjoining it on the west; their faunules will be analyzed, and the correlation of the faunules with those of New York will be finally discussed.

The present article is a preliminary discussion of the results obtained. The author wishes to acknowledge his indebtedness to Mr. D. W. Ohern, Fellow in Johns Hopkins University, for much assistance, particularly in mapping the divisions in Allegany County, and in the measurement and detailed study of a number of the sections.

SECTIONS IN WASHINGTON COUNTY

The Genesee is absent in Washington County.

Great Cacapon.—This section is situated north of the Potomac River opposite Great Cacapon, West Virginia, 8½ miles southwest of Hancock, Md. The strata are well exposed in the cut of the Western Maryland Railroad, standing nearly vertical. They comprise the Portage and part of the Chemung. The base of the Jennings is well marked, on the east, by a massive sandstone which forms the top of the Romney, and which contains Hamilton fossils.

[1] *Journal of Geology*, Vol. IX, p. 420.

[2] *Maryland Geological Survey*, Vol. VI, Part I, p. 136, 1906.

The lower 500 feet of the Jennings contains only species of the Naples fauna. These are especially abundant at its base where occur

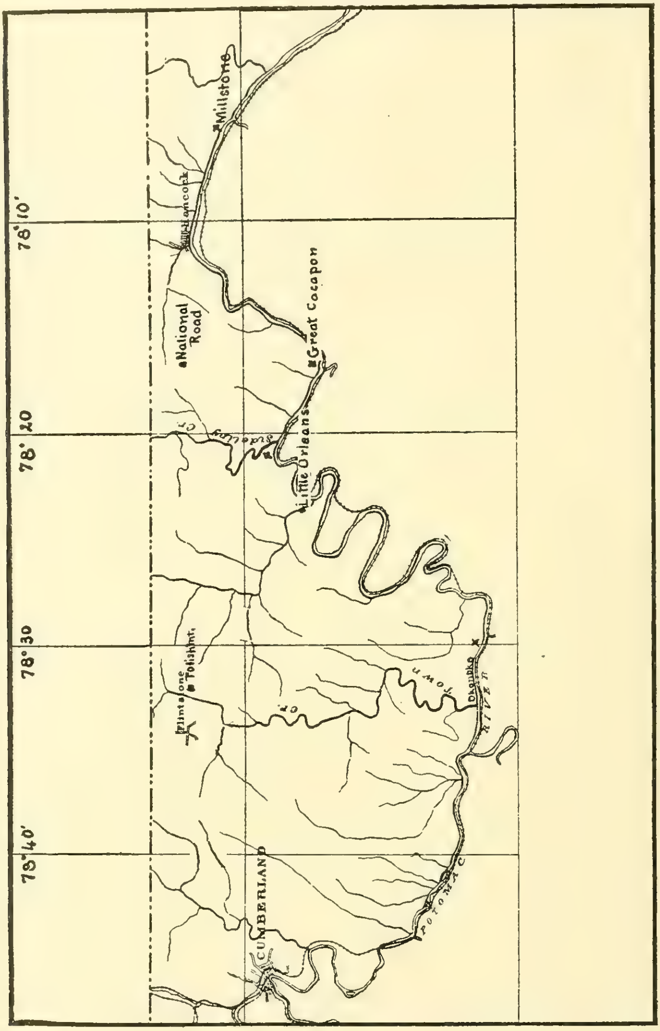


Fig. 1.—Map showing sections in Western Maryland.

various *Goniatites* together with species of the genera *Buchiola*, *Pterochaenia*, etc. A brachiopod fauna appears above this. At 520 feet above the base of the Jennings *Atrypa reticularis* (L.) occurs, apparently marking the advent of the new fauna. At 735 feet altitude

Schizophoria striatula (Schloth) was found, a species abundant in the Ithaca of New York, and at 785 feet *Spirifer pennatus* var. *posterus* Hall and Clarke, was observed.

At an altitude of 1,000 feet a profusion of individuals was found belonging to the following species:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, abundant
Leiorhynchus globuliforme (Vanuxem), common
Pugnax pugnus (Martin), common
Cyrtina hamiltonensis Hall, common
Ectenodesma birostratum Hall, rare

Spirifer pennatus var. *posterus* has very long wings, while casts of the ventral valves are without median septum. Individuals of this species are very abundant and well characterized. The forms referred to *Productella speciosa* possess small umbos, and have rather thickly set spines, with small bases.

At 1,400 feet a conglomerate occurs which contains *Camarotoechia congregata.* This seems to be identical with a simularly situated conglomerate farther north, which contains *Camarotoechia congregata* and which will be shown to be referable to the horizon-bearing *Spirifer mesacostalis* at other localities. At 1,750 feet above the base of the Jennings *Spirifer mesastrialis* appears.

The faunules occurring between 520 and 1,000 feet altitude consist of species all of which occur in the Ithaca fauna of New York or Pennsylvania. *Spirifer pennatus* var. *posterus*, *Productella speciosa*, *Pugnax pugnus* and *Schizophoria striatula* are characteristic species of the Ithaca fauna of New York, while J. M. Clarke cites *Leiorhynchus globuliforme* as occurring frequently in the same fauna. *Cyrtina hamiltonensis* and *Ectenodesma birostratum* are cited by Kindle and Williams from the Ithaca fauna at Catawissa, Pa. The entire association therefore consists of species occurring elsewhere in the Ithaca fauna and contains no diagnostic Chemung forms. Its position is above the Naples fauna and below the *Spirifer disjunctus* fauna of this section. Thus both in composition and position it appears to be referable to the Ithaca fauna.

In order to ascertain whether Chemung forms may not be mingled with these species at other places, a careful examination was made of similar horizons in a number of localities.

National Road west of Tonoloway Ridge.—The section is exposed along the National Road east of the schoolhouse. The strata dip at high angles and are more or less complicated by minor folds. It is upon the strike northeast of the Great Cacapon section.

The top of the Romney is marked by a massive sandstone which is exposed 250 feet east of the schoolhouse. *Goniatites, Buchiola,* etc., occur at the base of the Jennings as in the preceding section, representing the Naples fauna. At 830 feet above the base of the Jennings occur *Spirifer pennatus* var. *posterus* Hall and Clarke, *Schizophoria striatula* (Schloth) and *Productella speciosa* Hall. At 950 feet the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, abundant
Pugnax pugnus (Martin), common
Leiorhynchus globuliforme (Vanuxem), common
Cyrtina hamiltonensis Hall, common

At 1,020 feet *Spirifer pennatus* var. *posterus* aand *Productella speciosa* were observed. A yellow iron-stained conglomerate abounding in *Camarotoechia congregata* (Conrad) occurs at about 1,350 to 1,400 feet above the base of the Jennings. Red bands are seen beneath it. This conglomerate seems to be identical with a similarly situated conglomerate east of Hancock, which there contains *Spirifer mesacostalis. Spirifer disjunctus* and its associated forms are found at still higher horizons.

The faunules are thus seen to be similar to those of the Great Cacapon section, which they closely resemble both in composition and altitude. All the species found between 820 and 1,020 feet altitude are found in the Ithaca fauna in New York.

National Road east of Hancock, Md.—The section described is exposed on the National Road beginning just east of the village and extending eastward to Tonoloway Creek. The top of the Romney is marked by a heavy sandstone exposed along the road east of the stream, east of the Catholic church. The Naples fauna was found in the lower part of the Jennings, while above it the following faunules were collected.

750 feet above the base, *Schizophoria striatula* (Schloth)

1000–1100 feet above the base, *Spirifer pennatus* var. *posterus* Hall and Clarke, abundant.

Productella speciosa Hall, abundant
Leiorhynchus globuliforme (Vanuxem), common
Cyrtina hamiltonensis Hall, common
Lingula spatulata Vanuxem?
Spirifer mesastrialis Hall, rare

The above faunule suggests that found at 1,000 feet altitude at Great Cacapon. About 1,500 feet above the base of the Jennings occurs an iron-stained conglomeratic sandstone 1 foot thick, loaded with *Camarotoechia congregata* (Conrad), and bearing also *Camarotoechia eximia* Hall? and *Spirifer mesacostalis* Hall. The latter shows a strongly developed median septum in the ventral valve. Red bands appear just below this stratum, which seems to be identical with the similarly situated conglomerate already mentioned in the preceding section. *Tropidoleptus carinatus* Conrad was obtained in apparently the same horizon south of the Potomac River. About 2,100 feet above the base of the Jennings (at the turn of the road west of Tonoloway Creek) occur:

Spirifer mesastrialis Hall
Chontes scitulus Hall
Ambocoelia umbonata (Conrad)
Orthoceras sp.

Fifty feet above the latter *Spirifer disjunctus* was found.[1]

Harrisonville Road.—This section is exposed on the Harrisonville Road two miles north of Hancock and one mile east of Dogtown, Pa. The lower part of the Jennings contains the Naples fauna. Seven hundred and twenty-five feet above the base of the Jennings the following species were obtained:

Atrypa reticularis (L).
Pugnax pugnus (Martin).
Schizophoria striatula (Schloth).
Camarotoechia sp.
Aulopora (?) sp.

It will be observed that the lower brachiopod fauna appears at about the same altitude in the Great Cacapon section.

Millstone.—This section is exposed on the Western Maryland Railroad one-half mile east of Millstone, and five miles east of Han-

[1] This section is complicated by minor folds. The measurements are taken from the section at Berkley Spring which is on the strike of the section discussed and is free from folds.

cock. West of a ravine, one-half mile east of Millstone, occurs a massive conglomeratic sandstone 25 feet thick, bearing the following species:

Spirifer mesastrialis Hall, common
Orthothetes chemungensis (Conrad)
Schizodus gregarius Hall (?), common

The two latter species are poorly preserved.

Two hundred and fifty feet above the preceding occurs a very thick and massive conglomerate, while 370 feet higher *Spirifer disjunctus* was observed. A short distance above the latter *Spirifer mesastrialis* is abundant.

One hundred and eighty feet below the first-named sandstone *Camarotoechia congregata* and *Spirifer mesacostalis* occur as at Hancock in an iron-stained stratum.

Four hundred and sixty feet beneath the *Camarotoechia congregata* zone the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, common
Leiorhynchus globuliforme (Vanuxem)
Cyrtina hamiltonensis Hall

This faunule resembles the *Spirifer pennatus* var. *posterus* faunule of the preceding sections, both in position and composition.

SECTIONS IN ALLEGANY COUNTY

The sections will be examined in their order from east to west. The Genesee is present at the base of the Jennings in this county.

Sideling Creek.—The section is exposed on the west bank of Sideling Creek two miles above its confluence with the Potomac. The stratum there exposed is the lowest observed horizon containing *Spirifer mesacostalis*, *Camarotoechia congregata*, etc. This horizon is more or less conglomeratic in character at most localities, and is believed to represent the western extension of the conglomeratic sandstone bearing *Camarotoechia congregata* and *Spirifer mesacostalis* in the section in Washington County. It is highly fossiliferous, the following species being observed in it:

Atrypa reticularis (L.)
Camarotoechia congregata (Conrad)
Cyrtina hamiltonensis Hall

Productella lachrymosa Conrad
Spirifer mesacostalis Hall
S. marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Goniophora sp.
Cypricardella bellistriata (Conrad)
C. gregaria (Hall)
Nuculites oblongatus Conrad
Leptodesma sp.
Bellerophon maera Conrad
Bellerophon sp.
Bellerophon n. sp.
Cyclonema concinnum Hall
C. hamiltoniae
Coleolus tenuicinctus Hall
Euomphalus laxus Hall
Murchisonia sp.
Pleurotomaria itys Hall
Pleurotomaria n. sp. resembles *P. rotalia* Hall
Phacops rana Green
Bryozoa

Little Orleans.—This section is exposed in the cut of the Western Maryland Railroad. A conglomeratic sandstone occurs just west of the tunnel, bearing the following species:

Spirifer mesacostalis Hall, abundant
Camarotoechia congregata (Conrad), abundant
Nuculites oblongatus Conrad
Goniophora sp.
Bellerophon maera Conrad, abundant
Bellerophon n. sp., approaches *B. acutilira* Hall
Murchisonia n. sp., abundant

The following species were found somewhat below the above horizon, by the wagon road above the railroad:

Cyrtina hamiltonensis Hall
Pugnax pugnus (Martin)
Spirifer pennatus var. *posterus* Hall and Clarke
Leiorhynchus globuliforme Vanuxem
Tropidoleptus carinatus (Conrad)
Productella speciosa Hall
Schizophoria striatula (Schloth)
Stropheodonta demissa Conrad
Ectenodesma birostratum Hall

Nuculites oblongatus Conrad
Palaeoneilo brevis Conrad (?)
Bellerophon maera Conrad
Bellerophon n. sp., approaches *B. acutilira* Hall

It will be observed that this faunule, both in position and composition, is quite similar to the *Spirifer pennatus* var. *posterus* faunule which lies below the conglomerate in the Great Cacapon section.

Fifteen-Mile Creek.—This section is seen on Fifteen-Mile Creek one mile above Little Orleans. A conglomerate is there exposed bearing abundant *Camarotoechia congregata* and *Spirifer mesacostalis.* Three hundred feet below the latter the following species were obtained:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall
Schizophoria striatula (Schloth), common
Cyrtina hamiltonensis Hall, common

The relations are here as in the preceeding sections.

Polish Mountain near Gilpin.—This section is exposed along the National Road on the western flank of Polish Mountain. Black shales bearing characteristic Genesee fossils occur at the base of the Jennings southwest of the bridge. The Naples fauna is found in the lower part of the Jennings east of the bridge. Twelve hundred feet above the base of the Jennings at the second turn of the road east of the bridge, the following species were observed:

Spirifer mesacostalis Hall
Spirifer marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Camarotoechia sp.

Fourteen hundred feet above the base of this section *Spirifer mesacostalis* Hall was observed and at 2,000 feet *Spirifer disjunctus* was found.

Section east of Okonoko.—Twelve miles south of the preceding section the Jennings is admirably exposed in the vicinity of Okonoko, in the cuts of the Western Maryland Railroad, north of the Potomac River. About 6,000 feet east of the canal lock, the Hampshire-Jennings contact is observed. At 1,350 feet below the top of the Jennings occurs a massive conglomerate, 20 feet thick. At 3,200 feet below the contact, *Spirifer mesacostalis* was found associated with

Camarotoechia sp. On the eastern limb of an anticline whose axis is 250 lower, the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke
Leiorhynchus globuliforme (Vanuxem)
Cyrtina hamiltonensis Hall
Schizophoria striatula (Schloth).

This suggests the *Spirifer pennatus* var. *posterus* faunule of the preceding sections.

Cumberland.—An excellent section is exposed on the Williams Road about 3½ miles east of Cumberland. The Genesee occurs at the base of the Jennings, above which the Naples fauna was found. The lowest horizon of brachiopods observed contained the following species:

Spirifer marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Chonetes scitulus Hall
Productella speciosa Hall
Camarotoechia sappho Hall (?)
Leptodesma sp.
Orthoceras sp.

Spirifer mesacostalis was found, apparently at the same horizon, a short distance southwest of this locality. The *Spirifer pennatus* var. *posterus* fauna has not been observed in this section.

Allegany Grove.—The section is exposed in the cuts of the C. P. and G. C. C. R. R., extending from the Winchester road westwards. The lower Jennings is abnormally thin in this section, as is also the Romney. This is probably due to compression in folding. The Naples fauna was found near the base of the section. The following species were observed at the altitudes named, above the base of the Jennings:

675	feet	altitude,	*Camarotoechia congregata* (Conrad)
850	"	"	*Productella speciosa* Hall (?)
850	"	"	*Leiorhynchus mesacostale* Hall (?)
850	"	"	*Cyrtina hamiltonensis* Hall
850	"	"	*Pterinea chemungensis* Conrad
1,100	"	"	*Spirifer mesacostalis* Hall, abundant
1,400	"	"	*Spirifer mesacostalis* Hall, abundant
1,600	"	"	*Orthothetes chemungensis* (Conrad)
1,800	"	"	*Stropheodonta (Douvillina) cayuta* Hall
1,800	"	"	*Orthothetes chemungensis* (Conrad)

The species occurring at 850 feet altitude are rare and poorly preserved. In position and composition they seem to be referable to the *Spirifer pennatus* var. *posterus* fauna which would appear to be very slightly developed here. *Spirifer disjunctus* occurs at 1,300 feet above the base of the Jennings at Ellerslie, six miles northeast on the strike of the preceding section.

ANALYSIS OF FAUNAS

An examination of the preceding lists shows that certain faunas may be discriminated in the Upper Devonian of Maryland, which are

TABLE I

SPECIES OBSERVED IN THE *Spirifer pennatus* VAR. *posterus* FAUNA

	Occurrence in		
	Hamilton	Portage	
		New York	P'nsylvania
Atrypa reticularis (L.), r	*	*	*
Camarotoechia congregata (Conrad), r	*	*	
Cyrtina hamiltonensis Hall, c	*	*	*
Leiorhynchus globuliforme (Vanuxem), c		*	?
Leiorhynchus mesacostale Hall, rr		*	*
Lingula spatulata Vanuxem, r		*	
Productella speciosa Hall, a		*	*
Pugnax pugnus (Martin), c		*	*
Schizophoria striatula (Schloth), c	*	*	*
Spirifer mesastrialis Hall, rr		*	*
Spirifer pennatus var. posterus Hall & Clarke, a		*	*
Stropheodonta demissa Conrad, r	*	*	*
Tropedoleptus carinatus Conrad, r	*	*	*
Nuculus oblongatus Conrad, r	*	*	
Palaeoneilo brevis Hall (?), r		*	*
Ectenodesma birostratum Hall, c			*
Pterinea chemungensis Conrad, rr			*
Bellerophon sp., r			
Bellerophon n. sp., r			
Bellerophon maera Conrad		*	*
Bellerophon n. sp. approaches B. acutilira Hall			

well characterized both by their composition and position. They may be designated as follows:

Spirifer disjunctus fauna
Spirifer mesacostalis fauna
Spirifer pennatus var. *posterus* fauna
Naples fauna
Genesee fauna

These faunas are to be traced throughout most of the area discussed. Their relations are indicated upon the accompanying chart. Their constancy of composition, shown by their predominating species, and their occurrence at the same relative position in the various sections, seem to indicate that they are recognizable units, and that they preserve their integrity throughout the area discussed. If we assume that the species occurring in the same relative position in the various sections belong to one fauna, the lists in Tables I and II may be taken as

TABLE II

SPECIES OBSERVED IN THE *Spirifer mesacostalis* FAUNA

	Occurrence in		
	Hamilton	Portage	
		New York	P'nsylvania
Atrypa reticularis (L.), r	*	*	*
Camarotoechia congregata (Conrad), aa	*	*	
Camarotoechia eximia Hall, r	*	*	*
Camarotoechia sappho Hall (?), r	*		*
Cyrtina hamiltonensis Hall, c	*	*	*
Chonetus scitulus Hall	*	*	*
Productella lachrymosa (Conrad), a		*	
Lingula sp			
Spirifer mesacostalis Hall, aa		*	
Spirifer marcyi Hall var	*	*	
Tropidoleptus carinatus (Conrad), aa	*	*	*
Goniophora glaucus Hall	*		
Goniophora sp			
Goniophora n. sp			
Cypricardella bellistriata (Conrad)	*		*
Cypricardella gregaria (Hall)	*		*
Nuculites oblongatus Conrad	*	*	
Leptodesma sp			
Bellerophon maera Conrad		*	*
Bellerophon sp			
Bellerophon n. sp			
Bellerophon n. sp. approaches B. acutilira Hall	*		
Cyclonema concinnum Hall	*		
Cyclonema hamiltoniae Hall	*		
Coleolus tenuicinctus Hall	*		
Euomphalus laxus Hall	*	*	
Murchisonia sp	*	*	
Murchisonia n. sp			
Pleorotomaria itys Hall	*	*	
Pleurotomaria n. sp. resembles P. rotalia Hall	*		
Platyceras sp			
Platyceras n. sp			
Orthoceras sp			
Trochoceras n. sp			
Phacops rana Green	*	*	
Bryozoa, 2 species			

indicating all the species thus far observed in each fauna. (Only those occurring in the three lower brachiopod faunas will be cited here.)[1]

CORRELATION OF THE FAUNAS

We may now examine the problem of the correlation of the Upper Devonian faunas of Maryland with those of New York and Pennsylvania by the use of the data given above.

Genesee Fauna.—The Genesee of Maryland, as has been shown by earlier students of the problem, bears a fauna very similar to that of the Genesee of New York which it also resembles in thinning out and disappearing toward the east.

Naples fauna.—Above the Genesee, in the western sections, or immediately overlying the Hamilton, in the eastern sections, are smooth fissile shales and interbedded sandstones carrying *Goniatites*, *Buchiola*, *Pterochaenia*, etc., as in the Naples fauna of New York. These strata are about 700 feet thick in the Allegany Grove Section. They increase considerably in thickness in the vicinity of Cumberland, and thin to about 500 feet in the eastern sections. The correlation of this division has been previously discussed by Professor Prosser[2] who assigned to it a thickness of about 2,000 feet in the central part of the area.[3]

Spirifer pennatus var. *posterus fauna.*—This fauna occurs immediately above the Naples fauna. It is of wide extent and is especially developed in the eastern sections. It is characterized by the abundance of *Spirifer pennatus* var. *posterus*, *Productella speciosa*, *Pugnax pugnus*, *Cyrtina hamiltonensis*, *Schizophoria striatula*, and *Leiorhynchus globuliforme* at most of its localities. The complete list of species observed in it is given on a preceding page. Of these, five, *Spirifer pennatus* var. *posterus*, *Productella speciosa*, *Tropidoleptus carinatus*, *Cyrtina hamiltonensis*, *Spirifer mesastrialis*, and *Leiorhynchus mesacostale* are placed by Williams[4] among the dominant species of the Ithaca fauna, which he has named the *Productella speciosa* fauna, while *Pugnax pugnus* and *Schizophoria striatula* are also prominent members of that fauna. *Leiorhynchus globuliforme* is also quoted by

[1] The new species here cited will be described later in the *Report on the Devonian of Maryland*, to be issued by the Maryland Geological Survey.

[2] *Journal of Geology*, Vol. IX, pp. 419, 420, 1901.

[3] *Maryland Geology Survey*, Vol. VI, Part I, p. 136, 1906.

[4] *Bulletin of the U. S. Geological Survey*, No. 210, p. 74, 1903.

Clarke[1] as frequently present in it in New York. It contains one species, *Pterinea chemungensis*, which is stated by Williams to be characteristic of the Chemung of New York.[2] This species is, however, cited from the Ithaca of New York by Clarke[3] and is quoted by Williams and Kindle[4] in what they regard as the Ithaca fauna in the Catawissa, Pa., fauna. The occurrence of this species therefore does not seem sufficient to determine the Chemung age of the fauna. All the species contained in the list, save one, are found in the Ithaca fauna of New York,[5] and that exception, *Ectenodesma birostratum*, is found in the Ithaca fauna in the section at Catawissa, Pa.[6] These facts would seem to indicate the Ithaca age of this fauna.

It is interesting to note that *Ectenodesma birostratum* and *Pterinea chemungensis* are restricted to the upper zone of the Ithaca fauna of the Catawissa section, and are also restricted to the upper zone of the fauna in Maryland. Indeed, there are numerous resemblances between the upper horizons of the two sections.

There is also a resemblance between this fauna and the Leiorhynchus globuliforme fauna found above the Oneonta sandstone of New York, as shown by the following list of species of brachiopods occurring at Cowles Hill, Greene, New York.[7]

Atrypa reticularis
Schizophoria impressa (=*S. Striatula*)
Leiorhynchus globuliforme
Spirifer mucronatus (=*pennatus*) var.
Productella speciosa
Stropheodonta demissa
Spirifer laevis
Cyrtina recta
Leptostrophia mucronata

The resemblance is very close. It will be noted that *Spirifer laevis* is quoted by Kindle and Williams from the upper zone of the Ithaca

[1] *Ithaca Fauna of Central New York*, Bulletin 82, N. Y. State Mus., p. 64, 1905.

[2] *Journal of Geology*, Vol. XV, p. 98, 1907.

[3] *Bulletin 82*, N. Y. State Museum, p. 62, 1905.

[4] *Bulletin of the U. S. Geological Survey*, No. 244, p. 77, 1905.

[5] *Bulletin 82*, N. Y. State Mus., pp. 61–65, 1905.

[6] Kindle and Williams, *Bulletin of the U. S. Geological Survey*, No. 244, p. 77, 1905.

[7] *49th Ann. Rept.* for 1895, N. Y. State Museum, Vol. II, pp. 36–38, 1898.

fauna at Catawissa, Pa. Clarke[1] and Prosser[2] refer the Cowles Hill fauna to the Chemung, Williams to the Ithaca.

Spirifer mesacostalis fauna.—This fauna occurs above the preceding and is present throughout the entire area. Its dominant forms are *Tropidoleptus carinatus, Spirifer mesacostalis, Spirifer marcyi* and many gastropods. The list of species observed is given on a preceding page. Many of these have marked Hamilton affinities. This is especially true of the dominant brachiopods which include:

Tropidoleptus carinatus (Conrad)
Camarotoechia congregata (Conrad)
Spirifer mesacostalis Hall (cf. *S. consobrinus* of the Hamilton)
Spirifer marcyi Hall var.
Cyrtina hamiltonensis Hall

Goniophora glaucus Hall, *Coleotus tenuicinctus* Hall, and *Phacops rana* are also suggestive of Hamilton affinities. One species, *Productella lachrymosa* is quoted by Williams[3] as diagnostic of the Chemung in the Watkins, New York, quadrangle. Clarke, however, quotes it as of frequent occurrence in the Ithaca further east.[4] All of the forms specifically determined, save *Cyclonema concinnum*, are found in the Ithaca fauna.[5] These facts seem sufficient to refer this fauna to the Portage formation. In certain respects it resembles the Enfield fauna of Williams which, according to him, lies in the Nunda above the Ithaca and below the Chemung in the Watkins quadrangle. The following species of the above list are quoted by him as characteristic of that horizon: *Tropidoleptus carinatus, Spirifer marcyi, Delthyrus mesacostalis,* and numerous gastropods.[6] It will be noted that this fauna occupies a similar position in Maryland.

Spirifer disjunctus fauna.—The lowest observed occurrence of *Spirifer disjunctus* is in general 400–700 feet above the base of the *Spirifer mesacostalis* fauna. With it are associated *Douvillina cayuta* and *Camarotoechia contracta*, which have not been observed in the preceding faunas. *Spirifer mesastrialis* is also abundant in the fauna while it has been observed but rarely at lower horizons in Maryland.

[1] *49th Ann. Rept.*, for 1895, N. Y. State Museum, Vol. II, p. 39, 1898.

[2] *Ibid.*, p. 165.

[3] *Journal of Geology*, Vol. XV, p. 98, 1907.

[4] *Bulletin 82*, N. Y. State Museum, p. 64, 1905.

[5] *Ibid.*, pp. 61–65.

[6] *Journal of Geology*, Vol. XV, p. 109, 1907.

PORTAGE-CHEMUNG BOUNDARY

It is very difficult to determine this horizon when the brachiopod facies of the Portage immediately underlies the Chemung. Of the New York section Clarke remarks "It is extraordinarily difficult to fix on a division plane between the Ithaca and the overlying Chemung faunas."[1] If this be true in New York, it must be still more true when an attempt is made to correlate that section with those of other states, and the results attained must be open to revision as fuller investigations give increased data. Nevertheless, it seems reasonably probable from the preceding studies, that the horizon in question is to be placed between the strata bearing the *Spirifer disjunctus* and *Spirifer mesacostalis* faunas, giving the following succession:

Chemung, Spirifer disjunctus fauna

Portage { Spirifer mesacostalis fauna
Spirifer pennatus var. posterus fauna
Naples fauna

Genesee, Black shales with Buchiola fauna

Lithologically the horizon is not well defined, the conditions varying at different localities. In general the Portage is characterized by smooth fissile shales and interbedded sandstones and the Chemung by a larger percentage of sandstones, while its shales are softer and break with a hackly fracture. The transition from Portage to Chemung is however not sharply defined by any lithological features.

GENERAL RELATIONS

Certain general facts seem to harmonize with those of New York.

1. The general succession of forms seems to be that of New York. At the base occurs the Genesee thinning eastward, followed by the Naples fauna of the Portage. Above the latter is found *Spirifer pennatus* var. *posterus*, succeeded by *Spirifer mesacostalis*, and finally by *Spirifer disjunctus*.

2. There is a greater development of the Naples fauna in the west and of the Ithaca fauna in the east.

3. The shore line was probably eastward as indicated by the fact that there is a marked development of conglomerates eastward, as at Millstone. These diminish toward the west where the lower Jennings is largely composed of argillaceous shales, as at Allegany Grove.

[1] *Memoir 6*, N. Y. State Museum, p. 213, 1904.

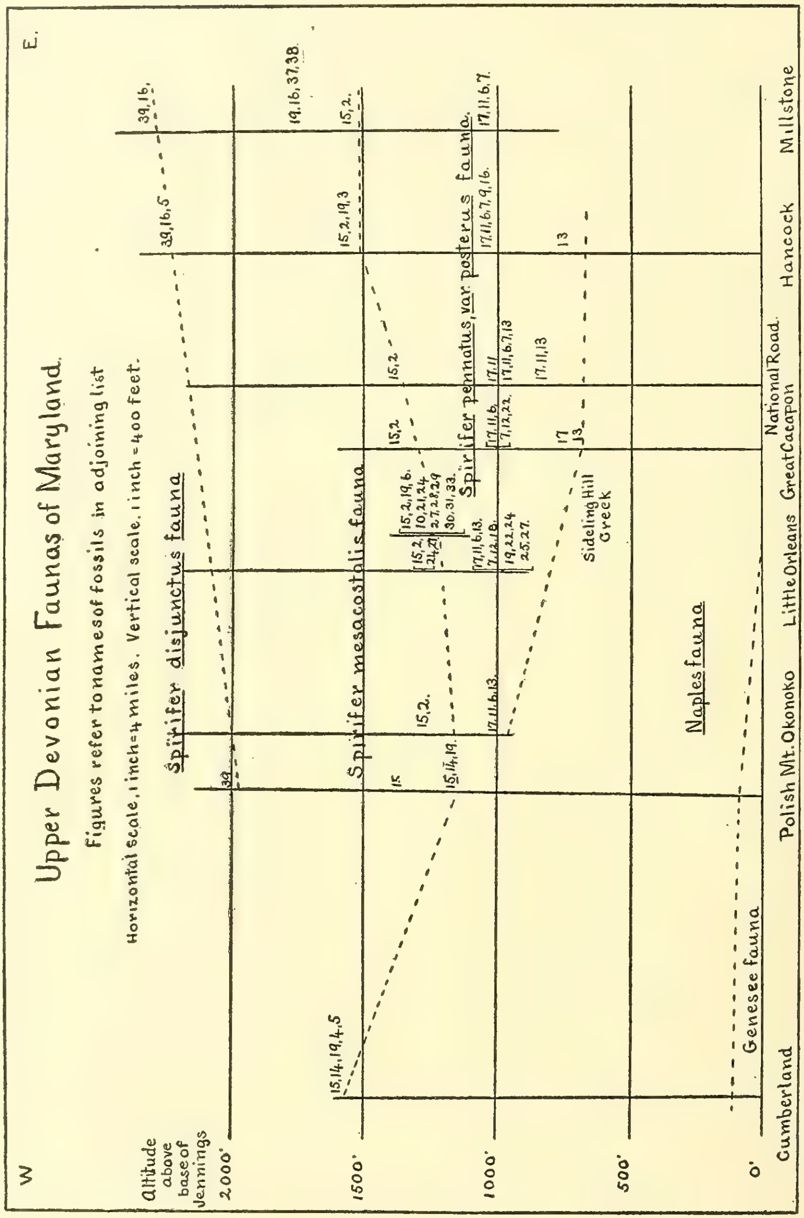

Upper Devonian Faunas of Maryland.
Figures refer to names of fossils in adjoining list
Horizontal scale, 1 inch = 4 miles. Vertical scale, 1 inch = 400 feet.
W
E.
Altitude above base of Jennings
2000'
1500'
1000'
500'
0'
Spirifer disjunctus fauna
Spirifer mesacostalis fauna
Spirifer pennatus, var. posterus fauna.
Naples fauna
Genesee fauna
Sideling Hill Creek
Cumberland
Polish Mt. Okonoko
Little Orleans
Great Cacapon
National Road.
Hancock
Millstone

Fig. 2

TABLE III

UPPER DEVONIAN FAUNAS OF MARYLAND

The numbers on accompanying chart indicate the fossils of subjoined list. Only forms specifically identified from the brachiopod fauna of the middle and lower Jennings are recorded.

	Hamilton	Portage		Portage or Hamilton
		New York	Pennsylvania	
1. Atrypa reticularis (L.)	*	*	*	*
2. Camarotoechia congregata (Conrad)	*	*		*
3. Camarotoechia eximia Hall	*	*	*	*
4. Camarotoechia sappho Hall (?)	*	*		*
5. Chonetes scitulus Hall	*	*	*	*
6. Cyrtina hamiltonensis Hall	*	*	*	*
7. Leiorhynchus globuliforme (Vanuxem)		*	?	*
8. Leiorhynchus mesacostale Hall		*	*	*
9. Lingula spatulata Vanuxem		*		*
10. Productella lachrymosa (Conrad)		*		*
11. Productella speciosa Hall		*	*	*
12. Pugnax pugnus (Martin)		*	*	*
13. Schizophoria striatata (Schloth)	*	*	*	*
14. Spirifer marcyi Hall var.		*		*
15. Spirifer mesacostalis Hall		*		*
16. Spirifer mesastrialis Hall		*	*	*
17. Spirifer pennatus var. posterus Hall & Clarke		*	*	*
18. Stropheodonta demissa Conrad	*	*	*	*
19. Tropidoleptus carinatus (Conrad)	*	*	*	*
20. Cypricardella bellistriata (Conrad)	*		*	*
21. Cypricardella gregaria (Hall)	*	*		*
22. Ectenodesma birostratum Hall			*	*
23. Goniophora glaucus Hall	*			*
24. Nuculites oblongatus Conrad	*	*		*
25. Palaeoneilo brevis Hall ?		*	*	*
26. Pterinea chemungensis Conrad	*	*		*
27. Bellerophon maera Conrad		*	*	*
28. Cyclonema concinnum Hall ?				
29. Cyclonema hamiltoniae Hall	*			*
30. Euomphalus laxus Hall	*	*		*
31. Pleurotomaria itys Hall	*	*		*
32. Coleolus tenuicinctus Hall	*	*		*
33. Phacops rana Green	*	*		*
34. Ambocoelia umbonata (Conrad)				
35. Dalmanella tioga Hall				
36. Douvillina cayuta Hall & Clarke				
37. Orthothetes chemungensis (Conrad)				
38. Schizodus gregarius Hall				
39. Spirifer disjunctus Sowerby				

4. An interesting additional feature is that there is an earlier development of red beds in the eastern sections. Red strata appear below the top of the Portage in the east, but become marked only toward the

close of the Chemung in the western sections, a fact noted by earlier investigators of the Jennings.

5. The Chemung closes with the incoming of the nearly unfossiliferous red strata of the Hampshire, which are similar to those of the Catskill of New York.

The facts given indicate that the Ithaca fauna extends southward into Maryland, and that there was a general agreement in many of the conditions in New York and Maryland in Portage and Chemung time.

ANCIENT WATER-PLANES AND CRUSTAL DEFORMATION

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In a recent bulletin of the Wisconsin Geological Survey,[1] Goldthwait has presented the results of an interesting study of the strands of the ancient Great Lakes as they occur in eastern Wisconsin. The field-work is much more detailed and accurate than the average, and the success in reconstructing the complex series of shore-lines of Lake Algonquin, in the region studied, is largely the result of using a wye level, instead of a hand level, or aneroid barometer, in determining the heights of the ancient beaches and terraces above the present lake level as a datum plane.

By far the greater part of the report is devoted to the descriptions of the old shore-lines and a review of previous work. And the conclusions on p. 42 bear only on the history of the ancient Great Lakes. In chap. iv, however, the author takes up the question of the deformation of the Great Lakes region and presents a new hypothesis as to the character of the crustal movements which have deformed the ancient shore-lines.

The hypothesis in brief is: that tilting of the earth's crust took place on the north side of axes which moved northward at intervals, resulting in the originally horizontal Algonquin beach-lines being given a broken profile with progressively steeper slopes northward. The movement was such as to tilt the surface of any block without warping. The idea expressed, it will be seen, is more definite than that of the older hypothesis of "differential warping" and may be spoken of as "differential tilting."

In this article it is desired to analyze the data upon which these hypotheses rest in order to form some idea as to their probable error, and also to compare the two hypotheses in order to see which is the

[1] J. W. Goldthwait, "The Abandoned Shore-Lines of Eastern Wisconsin," *Wisconsin Geological and National History Survey,* Bull. No. XVII, Sci. Ser., No. 5, 1907.

more probable. The result will show that both hypotheses are equally probable, but as that of differential warping involves simpler assumptions, it is considered preferable in our present state of knowledge concerning the subject.

As ideas in regard to the character of crustal movements in the Great Lakes region are based upon the water-planes reconstructed from observations upon the beaches, terraces, and other shore-line features of the ancient Great Lakes, it seems advisable first to consider the several errors that may enter into the determination of the position of such water-planes. These errors have been recognized for many years, and statements respecting most of them may be found in various reports dealing with both the ancient and modern Great Lakes. They have not, however, been collected in any one article, so far as the reviewer knows. It seems appropriate, therefore, to bring them together and point out the limitations they impose upon the correlation of old shore-lines and the deductions that may be drawn from reconstructed water-planes in regard to the character of the deformation of the Great Lakes region, especially as work in this field is now being placed upon a more accurate and refined basis.

The errors that enter into the determination of the height of the ancient beaches, etc., above the present lake levels—the datum planes—need only brief consideration, since with proper care they may be practically eliminated. The principal ones are, perhaps, those connected with the measurements of heights, seasonal fluctuations of the lake level, and changes in level by winds and waves. The first one can only be reduced to a negligible quantity by the use of a wye level, the instrument adopted by Spencer, Lawson, Upham, and Goldthwait in their work. The second may be eliminated by applying to the altitude determinations a correction obtained from a continuous record of the fluctuation of the lake level, a correction that was applied by Goldthwait. The last two errors appear rather troublesome, though they may be largely eliminated by restricting work to calm days. To do this, however, might often prove inconvenient, and it may be assumed that an error of from 1 to 2 feet[1] may arise from these causes.

The more important errors are connected with the location of water-planes with respect to ancient beaches and terraces, with the

[1] Goldthwait, *op. cit.*, p. 100.

former larger fluctuations in water-levels, and with other points that will be taken up in categorical order.

1. The exact position of an old water-plane is very difficult to determine because of its variable relation to different beaches, terraces, and other shore forms. The common practice has been to take the top of a beach ridge as fixing the position of the old water-plane, "although it is of course recognized that the beach ridge probably stood anywhere from 3 to 6 feet above the actual water-plane."[1] If in the case of a true beach ridge the actual water-plane will average 3 feet below the top of the ridge, elevations should be corrected by this amount in order to bring them as near the true water-plane as possible. If observations were entirely upon beaches this correction would be a constant and might be omitted in considering the relative displacements suffered by the shore-lines. But as they are also made upon terraces, spits, and bars, which require different assumptions in regard to the height of the water-plane, the above correction should be applied, otherwise the observations are not comparable within the assumed limit of 3 feet. In the case of a cut terrace the foot of the bluff is taken as fixing the position of the water-plane, although the true water-plane may have been as much as 2 feet either above or below that point. Where a terrace is cut in unconsolidated material the actual water-plane would in most instances be above the foot of the bluff and a correction might be applied to allow for this. Where terraces are cut in rock its location would depend upon the character and dip of the strata. In this instance a close study of present conditions might furnish a correction that could be applied in certain cases at least.

2. The variability in the position of a beach ridge with respect to the water-plane may particularly be noted. While a "normal" beach may be 3 feet above the surface of the water, storm beaches as much as 6 feet above the lake level may be considered as common, and a few have been reported at still higher elevations. Unless such beaches are situated so that their true nature can be recognized by comparison with neighboring shore-line features, they may introduce serious errors. One will be noted in the next paragraph. Storm beaches are formed, of course, only on the exposed parts of the shore-

[1] Goldthwait, *op. cit.*, p. 100.

line and evidently vary in height on the shores of different lakes. The configuration of the shore and its relation to the direction of storms exercise a great influence on the height of such beaches, and many interesting observations have been made on this point.[1] Lawson states[2] that on the north shore of Lake Superior he measured crests of living beaches facing the open lake at all elevations between 9 and 14 feet above calm water, while in less exposed parts of the shore they did not usually exceed 6 feet in height. Goldthwait,[3] for the western shore of Lake Michigan, sets the upper limit at 6 feet, and in one instance possibly at 8 or 9 feet. A correction should be applied to Lawson's figures, at least, to allow for the drop in the lake level from the high-water stage of 1886 to the 1891 stage on which his observations were based. This correction may be taken at 2 feet, so that the figures read 7, 12, and 4 feet, respectively. The error introduced by the variable position of a beach may be placed at 4 feet, allowance being made for the 3-foot correction above noted.

3. Cyclic fluctuations in water-level of the ancient lakes, due to short climatic variations, no doubt occurred as they do in the present lakes. The Milwaukee (Wis.) record shows an average change of 1.5 feet in the level of Lake Michigan from summer to winter. Lane says: "The water-level of the lakes at those (former) times undoubtedly varied from year to year and from month to month as it does now, probably in even more marked degree, as the cold of winter would have even more effect in checking the flow of water from the ice sheet;"[4] while Upham states: "Fluctuations of the lake level (in Lake Agassiz), which doubtless rose in summer a few feet higher than in winter because of variations in the volume of water supplied, have given a variability within the limits generally 5 feet and perhaps sometimes 8 or 10 feet apart to the heights of the lake and of its shore deposits

[1] Chas. Whittlesey, "Fluctuations in the Level of the North American Lakes." *Smithsonian Contributions to Knowledge.* Vol. XII; A. J. Henry, "Wind Velocity and Fluctuations of Water Level on Lake Erie," *U. S. Weather Bureau,* Bull. J., 1902.

[2] A. C. Lawson, "Coastal Topography of the North Side of Lake Superior," *Geological and National History Survey of Minnesota,* Twentieth Annual Report, p. 231.

[3] Personal communication.

[4] A. C. Lane, "Geological Report on Huron County, Michigan," *Geological Survey of Michigan,* Vol. VII, Pt. II, p. 65.

in different stages."[1] Much more important, however, are the changes in level that occur over a period of years rather than months. The record of the fluctuations of lakes Michigan and Huron from the year 1800 to 1899[2] is most instructive upon this point. The maximum change of level shown is 6 feet, while the average fluctuation between successive high and low stages, for all changes over 1 foot, is about 2.5 feet. What then is the true water-level? The question has a very direct bearing on the problem of fixing the position of the water-planes of the glacial Great Lakes from observations upon their shore-lines, since one beach formed in one decade might well be several feet higher or lower than a second constructed at another point in a following decade. Lane has noted the effect of such fluctuations in speaking of a 14-foot beach ridge in Huron County, Michigan. He says: "The water-line probably lay a little lower, at 10 or 11 feet above the 582-foot datum (the present lake level), at a time perhaps within range of tradition. . . . . The high water-line of 1886 is well marked in a crest from 4 to 7 feet above the present lake level."[3] The idea naturally suggests itself that a reconstructed water-plane, when drawn on a large enough scale, instead of being represented as a single line, should be shown as a zone of such a width as would take account of these changes of level.

As an extreme case, it may be supposed that at a time of maximum high water a storm beach was built up 6 feet above the water-level, while at a time of low water a terrace was cut 2 feet below the lake level. There would be a difference of 14 feet (8 in beach and terrace +6 in water-level) between the two, yet they would belong to the same period and might have been formed within 25 years of each other. Such an explanation may account for the discrepancy (of 10 or 12 feet) between a cut terrace and bowlder beach on the north shore of Lake Superior which Taylor believed belonged to the same shore-line. He says: "Measurements of the same shore-line often vary 7 or 8 feet, sometimes more, from this cause"[4] (one measure-

[1] W. Upham, "The Glacial Lake Agassiz," *U. S. Geological Survey, Monograph 25*, p. 277, 1896.

[2] Lane, *op. cit.*, Plate V.

[3] *Op. cit.*, p. 76.

[4] F. B. Taylor, "The Nipissing Beach on the North Superior Shore," *American Geologist*, Vol. XV (1895), p. 307.

ment on a beach, the other on a terrace). Such discrepancies as just noted may give rise to large errors (50 per cent. or more) in the calculated gradient of a shore-line when the distance between the two points of observation is short. These larger fluctuations in water-level would prove especially troublesome where strong cutting or filling was occurring. When the water-plane is gradually dropping a blurring of shore forms frequently results, although this is not always the case as Goldthwait's profile at Jacksonport shows.[1] On the other hand, if the water-level remained constant for several years a well-marked terrace might easily be cut or a strong beach built, while with a drop to a new level, at which the water might again stand for some time, a second terrace or beach might be formed. As the record shows, differences of 2 or 3 feet would be common between such terraces and beaches. It seems difficult to escape the conclusion that a source of error in the reconstruction of water-planes exists here that cannot be eliminated. It may range from 0 to 6 and possibly a larger number of feet.

4. The quotation from Taylor, above given, raises the question whether the level of a water-plane can be judged more closely from cut terraces or beaches. From the fact that beaches show such wide variations in position with respect to the water-plane, it would seem probable that terraces furnished the best guide. Upham has stated: "Cliffs eroded by the lake waves give more definitely the plane of the water surface"[2] than beaches. This applies, however, only where the forms are well preserved. When they are not well preserved, it seems likely that a beach would be a better guide than a terrace, since the original surface of a terrace is more liable to become obscured than that of a beach. This brings up the point that both beaches and terraces in time become more or less eroded and covered with vegetation, thus making it difficult to tell just what point should be chosen in measuring their elevations, and leading to uncertainty in correlation. Lawson has said, in speaking of a certain locality on the north shore of Lake Superior, that "a series of terraces can be seen scoring the hills to the north at a distance of probably a little more than a mile and a half at the farthest. An effort was made to locate these terraces by running a line of levels from the railway, but this

[1] *Op. cit.*, p. 76. [2] *Op. cit.*, p. 277.

met only with partial success. The terraces which appeared so sharp and unequivocal from the railway station lost their character when approached closely, and could be recognized as terraces only with considerable doubt."[1] What error may be introduced through the alteration of original forms is difficult, perhaps, to say. In the case of beaches it would be small as compared with that resulting from the variable height of a beach above the water-level. For terraces the error would generally be somewhat greater, since the base of a bluff is frequently obscured by talus, wash, etc. An error of 1 foot may be assumed as due to this cause.

It will be recognized, of course, that observations in the field, that is, our so-called geologic facts, vary greatly in value, and in any refined work should be weighted accordingly. Observations on the ancient shore-lines, however, serve two purposes. The first is to unravel the history of the glacial Great Lakes and as continuous tracing of shore-lines is a very important part of this work, observations should be as numerous as possible. The second is to determine the character of crustal movements in the Great Lakes region. This is a different problem and the value of results depends upon the probable error of observation. In refined work this error should be reduced to a minimum, for which reason it would seem advisable to use, if possible, only those observations that have small errors.

5. Progressive climatic changes over long periods of time may also have produced important variations in the water-levels of the lakes. That such climatic changes occurred may reasonably be inferred from the pronounced movements of the continental ice sheet during that period. This factor may well have been of considerable importance, but is at present undeterminable. It is simply presented as one of the unknown factors in the problem of the history of the ancient Great Lakes which might alter conclusions were its value known.

6. Secular changes in the water-level due to (1) show crustal movements, and (2) changes produced by erosion in the elevation of outlets are to be noted. Errors arising from these sources may eventually be eliminated—when the history of the ancient lakes has been worked out in fuller detail. Attention, however, may be called to one condi-

[1] *Op. cit.*, p. 263.

tion which must be taken into account, namely, the gradual lowering of the water-level from one stage to another. The condition is similar to that described under (3), but is of greater magnitude. It necessitates representing the water-planes as zones of such a width as will include these variations in water-level.

7. Variations in the elevations of the old shore-lines would result from deformation of the water-level induced by local attraction of the ice sheet. The error introduced is small, though it would have to be taken into account in any consideration of the old shore-lines as a whole. For small areas, presumably remote from the ice sheet, it may be neglected.

It will be seen from the foregoing that there are several noticeable errors connected with the location of a water-plane with respect to ancient shore-lines. A calculation, which takes account of only the more important errors, gives the probable error of observation as ± 1.5 feet, the limit of error 10 feet.

While these errors affect to some extent the correlation of a series of ancient beaches, terraces, and related shore forms, it is desired to point out here the influence they have upon conclusions, based on the present attitude of the reconstructed water-planes, as to the character of the crustal movements in the Great Lakes region. This may be illustrated by fitting curves of different kinds to Goldthwait's very complete set of observations as they are plotted on Plate XXXVII of his report.

We may consider first that portion of the profile extending from Rock Island to Jacksonport, a distance of 35 miles, since this is the stretch in which the several ancient water-planes have been individually distinguished. For the sake of simplicity a straight line may be drawn through each of the series of observations representing the four water-planes *A*, *A′*, *B*, and *C*. The deviations of all points of observation in each series from its respective straight line may then be measured, and likewise from the broken lines as drawn by Goldthwait. The results are as follows:

Average deviation of all sure points from straight lines = 1.4 feet.
" " " " " " " broken " = 1.1 "
Maximum deviation of any sure point from straight " = 4.0 "
" " " " " " " broken " = 4.0 "

Both the average and the maximum deviation in each case are within the probable error of observation and the limit of error respectively, so that the difference of 0.30 foot in favor of the broken lines possesses no significance. It may be shown likewise that a curved line would fit the observed points with no greater error than noted above.

The certain conclusion is reached, then, that either a straight, a curved, or a broken line may be drawn through the points of observation with equal accuracy, and that, consequently, in this distance of 35 miles the present attitude of the old shore-lines may be the result either of a uniform tilting, a differential warping, or a differential tilting of the earth's crust.

It may be said, however, that a distance of 35 miles is too short for a test of this character. We may consider, then, the entire length of the profile from Rock Island to Two Rivers, a distance of about 100 miles. In so doing the conclusion that the Algonquin beaches encircle the southern half of Lake Michigan as the "Toleston" beach, instead of descending beneath the level of the lake somewhere north of Two Rivers, will be assumed as correct.

The first thing to be noted is that a straight line cannot be drawn through the points of observation without far exceeding the probable error of observation. The hypothesis of uniform tilting, therefore, drops out. It appears possible, however, to fit a curve. For the sake of simplicity a circular curve, with a radius of approximately 11.75 feet, may be drawn through the points of observation as plotted on Goldthwait's profile, and the deviations of the points measured. The results are as follows: Average deviation of all sure points = 1.2 feet; maximum deviation of any sure point = 3 feet. The deviations of all the observed points from the broken profile of Goldthwait were not measured for the entire length of the profile, since it was evident that they would be essentially the same as measured for the profile from Rock Island to Jacksonport, namely, 1.1 and 4.0 feet respectively.

The conclusion may be stated, then, that the Algonquin shoreline for the whole length of the profile, about 100 miles, furnishes no evidence in favor of the hypothesis of differential tilting over the older one of differential warping; both are equally probable so far as the observations go. The hypothesis of differential warping, however,

involves a simpler assumption respecting the distribution of stresses within the earth's crust, and for this reason should be considered preferable to the hypothesis of differential tilting.

If earth movements in the Great Lakes region had been great instead of small, and the errors in the water-plane determinations small instead of great, the character of the crustal deformations might well be ascertained; but on the contrary we find the probable error of observation so large—it is expressed in feet, rather than tens of feet or in inches—that it leads to the impression that but little refinement of the old idea of differential warping is possible on the basis of the ancient shore-lines alone.

NOTICE OF A NEW COELACANTH FISH FROM THE IOWA KINDERHOOK

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The family of Coelacanth ("hollow spined") ganoids, first proposed by Agassiz in 1844, and subsequently emended by Huxley in two important memoirs of the *Geological Survey of the United Kingdom* (Decades X and XII), is at present understood as comprising not more than six satisfactorily known genera, among which Coelacanthus itself, Macropoma, and Undina are of paramount importance. The first-named of these, which is typical of the family and likewise of the group Actinistia, enjoys the truly remarkable geological range from the Upper Devonian to the close of the Paleozoic, or, if the evidence of certain doubtful indications be accepted, possibly even higher; the remaining genera continue throughout the Mesozoic, and exhibit such constancy of structural characters as to render the family one of the most compact and well defined in the animal kingdom.

Attention has frequently been called to the extraordinary conservatism and persistency maintained by the group throughout an unusually long life-period. Its singular history impressed both of the distinguished naturalists to whom we owe our principal knowledge of the family, Huxley's views upon the matter being thus stated by him:

> Bearing in mind the range of the Coelacanths from the Carboniferous [since ascertained to extend from the Devonian] to the Chalk formations inclusive, the uniformity of organization of the group appears something wonderful. I have no evidence as to the structure of the base and side-walls of the skull in Coelacanthus, but the data collected together in the present Decade shows that, in every other particular save the ornamentation of the fin-rays and scales, the organization of the Coelacanths has remained stationary from their first recorded appearance to their exit. They are remarkable examples of what I have called elsewhere "persistent types," and like the Labyrinthodonts, assist in bridging over the gap between the Paleozoic and the Mesozoic faunae.[1]

[1] *Mem. Geol. Surv. United Kingdom*, Decade XII (1866); reprinted in the supplementary volume of the *Scientific Memoirs of T. H. Huxley* (1903), p. 65.

The earliest known representative of the family is a small form occurring in the lower part of the Upper Devonian near Gerolstein, in the Eifel District, first described by A. von Koenen[1] in 1895, and referred by him with some hesitation to Holoptychius, but afterward recognized by Smith Woodward[2] as an undoubted Coelacanth, and transferred by him to the typical genus. Prior to this discovery the opinion had been generally entertained that, owing to the sudden appearance of Coelacanth fishes in a complete state of development in the Calciferous sandstones of Scotland, it was necessary to postulate the existence of their ancestors during the Devonian, notwithstanding their apparent failure to be preserved in both Europe and North America. In fact, the oldest remains of Coelacanth fishes hitherto found in this country are in strata of Coal Measure Age, and the few species that are known are poorly or at best indifferently preserved. Under these circumstances it is interesting to record the discovery, made by Dr. Stuart Weller a few years ago, of an unusually perfect example of Coelacanthus from the very base of the Mississippian series near Burlington, Iowa. The exact horizon whence the specimen was obtained is the blue shale bed forming the basal member of the Kinderhook limestone, and designated as No. 1 in the local section whose fauna is analyzed by Dr. Weller in Vol. X of the *Iowa Geological Survey Reports* (p. 69 ff.). In recognition of the important results achieved by the author of *Kinderhook Faunal Studies*, and also as a testimonial of personal regard, we have pleasure in presenting the following description under a specific title dedicated in his honor. It should be stated that the holotype is preserved in the Walker Museum of the University of Chicago, and for the privilege of studying it in behalf of the Iowa Geological Survey the writer desires to express here his indebtedness to Dr. Weller.

Cœlacanthus welleri, SP. NOV.

Holotype, a somewhat imperfect fish, the total length of which to the base of the caudal fin is about 19^{cm}, or a little more than three times the length of the head with opercular apparatus. Trunk

[1] A. Von Koenen, "Ueber einige Fischreste des norddeutschen und böhmischen Devons," *Abhandl. k. Ges. Wiss. Göttingen, phys. Cl.* (1895), Vol. XL, p. 28.

[2] A. S. Woodward, "Note on a Devonian Coelacanth Fish." *Geol. Mag.* (1898), Dec. 4, Vol. V, p. 529.

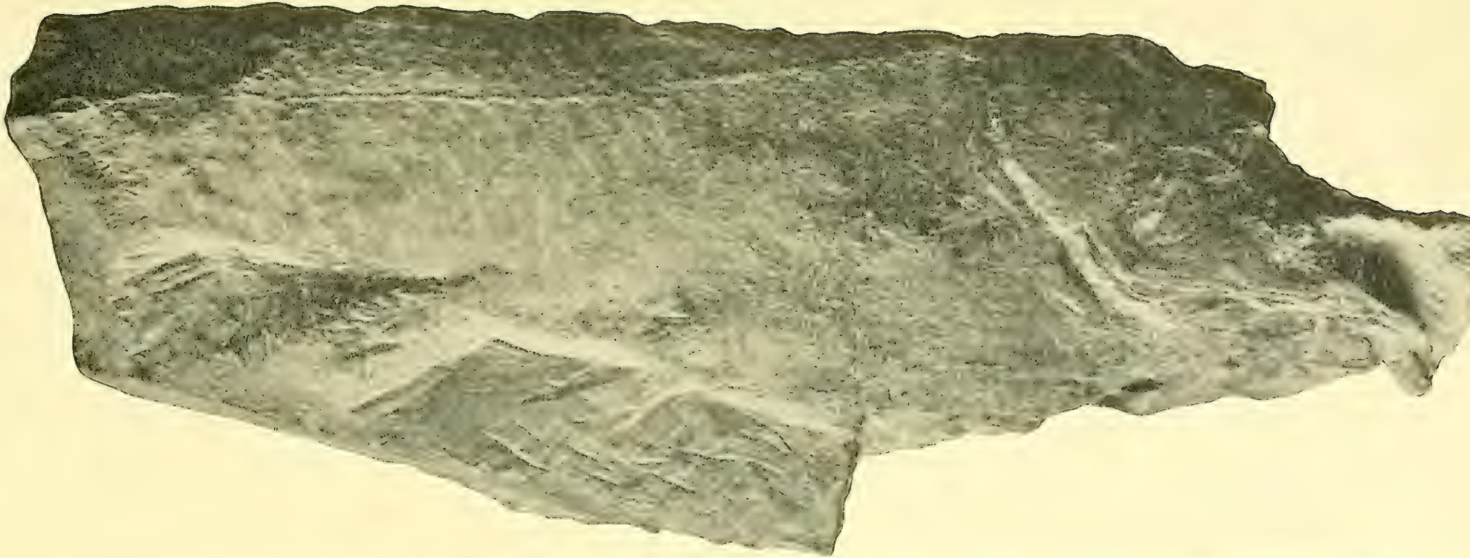

FIG. 1.—*Coelacanthus welleri*, sp. nov. From the basal member of the Kinderhook limestone; Burlington, Iowa. Lateral aspect of holotype showing nearly complete trunk, but deficient as to portions of the head and most of the fin structures, × 1/1.

robust, its maximum depth twice as great as that of the caudal pedicle. Anal and paired fins situated as in the typical species (*C. granulatus* Ag.), the greater part of the caudal and both dorsals not preserved. Operculum and cheek-plates ornamented with numerous fine antero-posteriorly directed spiniform ridges, their position being indicated in the worn condition by faint tubercles. Scales ornamented with numerous fine raised lines of ganoine, more or less continuous and rectilinear in arrangement, but when worn assuming the appearance of elongated tubercles. Lateral line scales with prominent raised tubules directed parallel with the body axis.

The characters serving chiefly to distinguish the present form from other species may be enumerated as follows: (1) The delicate spiniform ornamentation of the operculum and cheek-plates, together with the form and disposition of the latter; (2) the peculiar form of the mandibular ramus; (3) details of superficial scale ornament; and (4) prominence of the lateral line canal. Owing to the defective preservation of most of the fin structures, it is impossible to say in what respects, if any, these differ from the prevailing type. The cranial structure, however, offers a number of interesting points of comparison with other forms, as will be immediately pointed out. Be it noted in passing that the totality of characters by no means indicates a primitive forerunner of the family, but on the contrary bespeaks a typical Coelacanth as completely developed as any subsequent form with which we are acquainted. In this respect the Kinderhook species resembles the only well known British Coelacanth of an age anterior to the Coal Measures, namely *C. huxleyi*, from the Calciferous sandstones of southern Scotland.

With reference to the skull it is to be noted that the cranial roofing-bones are missing in the type specimen, and that a portion of the head in advance of the orbits has been fractured in such manner as to strip off the maxillary and other facial elements, at the same time exposing the anterior spatulate portion of the parasphenoid, together with the steeply inclined triangular palatine plates that abut against it on either side. The inferior border of the palatines, parasphenoid and vomer appears to have suffered somewhat from chemical corrosion, in consequence of which no indications of teeth are anywhere visible. Possibly for the same reason no teeth are to be observed along the

margin of the lower jaw, nor lying free in the matrix, in case any had been broken away.

The mandibular ramus of the right side is well displayed, and the dentary is seen to have been retained in union with its fellow of the left side at the symphysis. The articulo-angular element is long, narrow in front, its superior border rising into a small median and a large posterior elevation, between which is a deep concavity; and its inferior border is nearly rectilinear. The superficial ornament of this piece has become well-nigh obliterated by weathering or abrasion, and of the two gular plates lying immediately underneath, nothing remains but an impression of their inner surfaces.

A notable peculiarity of the form under discussion consists in the arrangement of cheek-plates immediately in advance of the operculum. In all other Coelacanths, so far as known, two subequal postorbital plates are placed one above the other in the space between the orbit and operculum, their position being such as to exclude from contact with the latter the small triangular plate called "postmaxillary" by Huxley. The present species, however, has all three of these cheek-plates situated in vertical series, one overlapping the other from above downwards, and each of them overlapping the anterior border of the operculum. The lowermost cheek-plate, which corresponds to the so-called "postmaxillary" of Huxley, terminates below at a depth equal to that of the inferior border of the operculum, and its superficies covers the space immediately behind the inflected portion of the articulo-angular element of the lower jaw. Its antero-superior margin is apposed to the strongly arched and apparently semicircular suborbital element, of which only a small segment happens to have been preserved.

No indications are to be observed in the type specimen of a sclerotic ring, although one may be inferred to have been present as in other known Coelacanths. Neither is there any external indication of the presence of an ossified air-bladder, peculiar to members of this family. The caudal, anal, and pelvic fins are too imperfectly preserved for description, and the pectoral pair is entirely wanting. On the other hand the squamation is admirably displayed, especially in the posterior part of the trunk, where the fine longitudinal ridges of ganoine and concentric growth-lines are pyritized. The lateral line is rendered

conspicuous by a single large raised tubule of ganoine extending in a horizontal direction for nearly the total length of each scale in this row. The general appearance and some of the details of surface ornament of the type specimen are shown in the accompanying photographic illustration, which we owe to the kindness of Dr. Weller.

STUDIES FOR STUDENTS

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS—*Concluded*

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PART III. RELATIONS OF CLIMATE TO STREAM TRANSPORTATION

INTRODUCTION

It has been seen that climate exerts a primary control, only subordinate to topography, upon the rate and character of erosion on the one hand and on the other upon the chemical, structural, and organic characteristics developed in subaerial sedimentation. Between erosion and sedimentation intervenes transportation and the questions arise: To what extent is the carrying power of rivers dependent upon climate? To what degree may the ordinary stratigraphic textural variations between succeeding strata of clay, sand, and gravel be due not only to shiftings of currents and tectonic movements, but to climatic variations as well?

In a general way the influence of climate upon erosion and upon deposition is readily recognized and upon closer examination the

effects, as previously shown, are seen to be largely distinct from those which the topographic conditions alone can produce. The determination of the lithologic characters due to the climatic conditions of erosion and of deposition constitute therefore two more or less independent lines of evidence as to the climatic conditions of origin. With transportation, however, it is different. Any particular capacity for transportation is conditioned upon topography as well as climate and any change in the size or quantity of the material transported, even if due to climatic change, may conceivably be due also either to a lateral shifting of river currents, if on a small scale, or to some crustal movement if the changes occur on a greater. The proof of the climatic change must, therefore, depend primarily upon the nature of the erosion and deposition, but it will be argued in the course of this article that great climatic changes may result in transportative variations of such magnitude that the results become the most pronounced of the three divisions of climatic influence upon fluviatile sedimentation, and have sometimes been ascribed to tectonic revolutions.

For these reasons (because of the dependence of the proof of the climatic change upon the initial and final conditions of sedimentation, and also because of the great importance of such climatic change upon the power of transportation, and the resulting coarseness and thickness of the formation) this middle factor in the conditions governing fluviatile sedimentation is treated the last of the three and not in what at first sight might appear to be its more logical position.

Effects of Stream Transportation

laboratory experiments and laws of river action

The effect of transportation upon both the chemical and mechanical character of the material has been studied experimentally by Daubrée[1] who found upon submitting fresh and angular fragments of feldspar to prolonged trituration in the presence of distilled water that a very notable degree of decomposition was effected, as was shown by the presence in the water of silicate of potash which rendered the water alkaline.[2] The recent work of Cushman and Hubbard

[1] *Géologie expérimentale* (1879), pp. 248–88.

[2] *Op. cit.*, p. 271.

further shows that the decomposition occurring while undergoing abrasion due to movement in water takes place under exceptionally favorable circumstances, since if the initial film of decomposition is not continually removed the action of the water rapidly slows down;[1] and furthermore that the water alone, where the clogging films are continually removed, is well able thoroughly to decompose feldspar without the intervention of acid.[2] To the extent then to which mechanical abrasion occurs during river transportation decomposition is also favored and takes place at a vastly more rapid rate than in the normal weathering, which however persists through a far longer time while the material, owing to the lowering of the surface of erosion, is passing from the solid rock through the zone of soil. As to the mechanical effects:

In the series of experiments already referred to, Professor Daubrée made fragments of granite and quartz to slide over each other in a hollow cylinder partially filled with water, and rotating on its axis with a mean velocity of 0.80 to 1 metre in a second. He found that after the first 25 kilometres (about $15\frac{1}{2}$ English miles) the angular fragemnts of granite had lost $\frac{4}{10}$ of their weight while in the same distance fragments already well rounded had not lost more than $\frac{1}{100}$ to $\frac{1}{400}$. The fragments rounded by this journey of 25 kilometres in a cylinder could not be distinguished either in form or in general aspect from the natural detritus of a river-bed. A second product of these experiments was an extremely fine impalpable mud, which remained suspended in the water several days after the cessation of the movement. During the production of this fine sediment, the water, even though cold, was found in a day or two to have acted chemically upon the granite fragments. After a journey of 160 kilometres, 3 kilogrammes (about $6\frac{1}{2}$ lb. avoirdupois) yielded 3.3 grammes (about 50 grains) of soluble salts, consisting chiefly of silicate of potash. A third product was an extremely fine angular sand consisting almost wholly of quartz, with scarcely any feldspar, nearly the whole of the latter mineral having passed into the state of clay. The sand-grains, as they are continually pushed onward over each other upon the bottom of a river, become rounded as the larger pebbles do. But a limit is placed to this attrition by the size and specific gravity of the grains. As a rule, the smaller particles suffer proportionately less loss than the larger, since the friction on the bottom varies directly as the weight and therefore as the cube of the diameter, while the surface exposed to attrition varies as the square of the diameter. Mr. Sorby, in calling attention to this relation, remarks that a grain $\frac{1}{10}$ of an inch in diameter would be worn ten times as much as one $\frac{1}{100}$ of an inch in diameter, and

[1] "The Decomposition of the Feldspars," *U. S. Dept. of Agriculture, Office of Public Roads, Bull. No. 28,* 1907, p. 10.

[2] *Op. cit.*, p. 14.

a pebble 1 inch in diameter would be worn relatively more by being drifted a few hundred yards than a sand-grain $\frac{1}{1000}$ of an inch in diameter would be by being drifted for a hundred miles. So long as particles are borne along in suspension, they will not abrade each other, but remain angular. Professor Daubrée found that the milky tint of the Rhine at Strasburg in the months of July and August was due, not to mud, but to a fine angular sand (with grains about $\frac{1}{20}$ millimetre in diameter) which constitutes $\frac{2}{100000}$ of the total weight of water. Yet this sand had travelled in a rapidly flowing, tumultuous river from the Swiss mountains, and had been tossed over waterfalls and rapids in its journey. He ascertained also that sand-grains with a mean diameter of $\frac{1}{10}$ mm. will float in feebly agitated water; so that all sand of finer grain must remain angular. The same observer noticed that sand composed of grains with a mean diameter of $\frac{1}{2}$ mm. and carried along by water moving at a rate of 1 metre per second is rounded, and loses about $\frac{1}{10000}$ of its weight in every kilometre travelled.[1]

It is to be concluded from these statements that long transportation by reducing the size of the coarser fragments and dissolving much of the soluble matter tends to cause the material derived from mountainous regions or sub-arid climates finally to approach the chemical and mechanical nature of the waste derived from topographically gentler or climatically more humid regions. This conclusion is confirmed by observation of the beds of rivers.

Walther shows that the large rivers carry very different sediment in the different portions of their courses.

In the upper course the deposits show a complete assemblage of all kinds of rocks and minerals found within the reach of the river system. In the middle course the pebbles disappear, but the sand is still of various kinds and contains besides the original constituents, contributions from the neighboring streams. The first materials to disappear are those minerals soluble or readily disintegrated, but hardness is also important in exercising a selective action, since in the rubbing of stones together the softer are soon destroyed. In the upper course of the Avisio a great quantity of limestone pebbles may be detected between blocks of porphyry and syenite. In the lower valley, however, the limestone pebbles completely disappear and the eruptive rocks increase relatively in number. Consequently in the erosion of a mountain consisting of a schistose formation containing secondary quartz veins the entire matrix may by the transportation be transformed into fine clay and the quartz pebbles alone remain as the indestructible residue.[2]

Walther further states that

it may be directly observed upon the bed of the Rhine that sand and small fragments will be moved forwards several decimeters while a larger fragment lying

[1] A. Geikie, *Textbook of Geology*, 1903, pp. 496, 497.

[2] Translated from *Einleitung in die Geologie* (1893–94), p. 758.

in the same place will only be moved a few centimeters and therefore remains behind. Such unceasingly repeated shoving must necessarily lead to a classification along the stream course of the rolled material according to its size. So soon as the volume of a stream is altered through climatic change or tectonic movement the boundaries are immediately shifted to which large or small pebbles, sand, or clay are carried and laid down.[1]

Chamberlin and Salisbury[2] state that:

> Under certain circumstances, a stream may overload itself. Thus if a stream loaded with coarse detritus reaches a portion of its valley where fine material is accessible in abundance, some of the velocity which is helping to carry the coarse may be used in picking up and carrying the fine. This reduces the velocity and since the stream already had all the coarse material it could carry, reduction of velocity must result in deposition. It follows that when a stream fully loaded with coarse material picks up fine, it becomes overloaded, *so far as the coarse material is concerned.*

DISCUSSION OF THE DATA REGARDING RIVER TRANSPORTATION

Preliminary inductions.—From the preceding experiments, observations, and well-founded conclusions on the characteristics of river action the following inductions may be drawn.

First, the coarse material is not usually sufficiently strong or hard to stand long transportation by rivers, quartz, chert, or quartzite most effectively resisting the wear and alone being able to withstand transportation for distances of a hundred miles or more. It has sometimes been stated that the composition of a conglomerate of vein-quartz and quartzite pebbles indicates the erosion of a deeply and thoroughly decayed regolith, all but these constituents having been previously destroyed by weathering *in situ*. It is seen, however, that such a hypothesis is not necessary, since, if rivers existed sufficiently strong in current to sweep pebbles *long distances*, the quartz and quartzite would alone survive.

Second, rivers normally carry a large amount of finer material and a small amount of coarser, due to the disintegration and decomposition of the rock before it reaches the river, as well as the inherent weakness of the partially decomposed material which does reach the river in fragments. This loading up with fine material results in a lagging behind of the coarser more than if the fine was not present.

[1] *Op. cit.*, pp. 644, 645.

[2] *Geology* (1904), Vol. I, pp. 169, 170.

At times when for any reason, for example a climatic change, the fine material becomes deficient or the river volume becomes augmented, the river with the same grade may pick up the coarse material previously laid down and transport it with comparative rapidity to a lower portion of its course.

Third, Daubrée showed that upon revolving coarse and fine rock material in a barrel the coarser fragments, after being rounded, are reduced in size very slowly, so that a journey of several hundred miles would be required to reduce a pebble of 2 inches in diameter to 1 inch diameter. This may seem at first thought contradictory to the observations on river transportation, but the explanation is doubtless as follows:—The material which is of such a size that the current, which is already partially loaded with finer detritus, is just able to move it, is only moved with a fraction of the speed of the slightly smaller material. The result is that in being moved a mile down stream it may have moved ten or fifty miles relatively to the finer detritus. In so far as the rubbing and attrition are concerned, it has accomplished a journey many times the length of the actual distance moved. This lagging of the hardest coarse material under stable river conditions will be such that the added attrition due to the lagging is able to reduce it to that slightly smaller size which may be just handled by the slightly decreased velocity of the next lower portion of the river. With all but the hardest it appears, however, as previously stated, that the pebbles go to pieces faster than is called for by the necessities of transportation, so that in the lower portions of the valley there is an abnormal proportion of fine material—material which can be carried forward by a sluggish current—with the result that the condition for equilibrium is a flattened slope.

Fourth, the slope of a graded river is known to be in delicate adjustment between the volume of water, the quantity and fineness of load. These relations briefly stated are: (1) A more voluminous stream tends to flow down the same slope with greater velocity, the frictional resistence of the bed bearing a smaller ratio to the moving force. To remain in equilibrium upon such a slope the stream must carry more waste or coarser waste. Otherwise it will tend to load up its current by cutting down in the upper part of its course, building up in its lower until the grade is flattened, the velocity diminished and

equilibrium attained. The volume varies throughout the year and it is observed that in accordance with this principle by far the greater proportion of river detritus is moved in the seasons of flood. The same principle may be extended to apply to climatic cycles longer than that due to the revolution of the earth about the sun. (2) If through any climatic or tectonic change the forces of erosion are quickened and either a coarser or larger load of waste is poured into a stream of postulated constant volume, the stream must deposit the coarser of this material in place until the grade is steepened and the velocity consequently quickened sufficiently for transportation of a larger proportion. If the waste, on the contrary, becomes finer in grain or deficient in quantity, the stream responds by beginning to erode in its upper portions, tending to reach a new state of equilibrium by partially increasing its load and partly flattening its grade.

Relations of Stable Climates to Transportation

deductive conclusions with confirmatory illustrations

From the foregoing principles the relations, stated deductively, may be drawn between transportation and climate. The conclusions may then be tested by the examination of various regions which supply the requisite conditions. In sub-arid climates the streams in their upper portions have great temporary volumes and carrying power but the volume does not normally increase on the way. The result is that on escaping from the mountains the rivers in such climates are peculiarly liable to lay down a portion of their load, building piedmont slopes. The methods of erosion in an arid climate and the sudden tumultuous action of the streams result moreover in a large proportion of the deposit, consisting of a coarse and rather undecomposed waste, requiring relatively steep grades for its removal. The silt is swept farther out upon the flatter plains, while the clay and loess-like material may be carried to the front of the delta, provided the river waters are not absorbed on the way. The rivers of Argentina flowing eastward from the Andes furnish excellent examples, and to a lesser degree the rivers crossing the Great Plains of the United States. In both cases a condition of equilibrium is approached though never quite attained, between volume and waste upon a slope

which descends several thousand feet in a distance of several hundred miles.

The streams of a rainy climate on the other hand have greater carrying power over their lower and flatter courses, owing to the continually augmented volume with distance from source. The material carried is also more largely fine-grained than in the case of the sub-arid climate, a considerable portion consisting of true clay. There is consequently less tendency to build piedmont slopes and more to deliver the waste to the delta and the sea. In warm humid climates thoroughly oxidized and leached clays form a maximum percentage in the land waste, giving a river grade of maximum flatness after escaping from the mountains. The Amazon furnishes an excellent example, its bed being but 370 feet in elevation at the junction of the Marañon and Ucayali at a distance of about 1,800 miles from the ocean. The grade of the Amazon is doubtless, however, somewhat flatter and lower in its middle course than is called for by the present relations of volume and waste, since it is characterized by braided streams, distributaries, and shallow lakes. In cold rainy climates frost becomes a powerful disintegrating agent in mountainous regions, developing with great rapidity vertical cliffs skirted by coarse talus slopes and accentuating during the early portion of the cycle the steepness and roughness characteristic of such regions. The waste supplied to the rivers is coarser than that from a warmer region possessing the same broad topographic features, and the river consequently must flow on a somewhat steeper grade for the same volumetric relation of river water to sediment.

Effects of Varying Climates upon Transportation

In short streams of steep grade, such as those draining from the coast chains of California toward the ocean; or in longer ones of low grade, such as most of those of the Atlantic coast of the United States, the deposits of alluvium under all circumstances are largely marine and the chief effect of a change of climate upon the sedimentation is due to the resultant changes in the rate and kind of erosion rather than changes in the transportation. As pointed out under the subject of *the relation of topography and climate to erosion* this alone should lead to well marked differences in the sediment. In the larger

and longer river systems, however, especially those rising in mountain regions, influences of another character come in, of even greater stratigraphic importance.

CLIMATIC CHANGE FROM SEMI-ARID TO RAINY

To appreciate the maximum possible results imagine semi-arid alluvial plains such as the Pampas of Argentina and the High Plains of the United States to become the seats of a markedly rainy climate such as that of the Amazon basin. The rivers, constantly swelling in volume from additional drainage in crossing the inclined plains will erode the unconsolidated or semi-consolidated sands and gravels with immense rapidity, possibly sweeping such deposits entirely away and channeling into the rock formations below. In the case of the slopes cited from 500 to 1,000 feet of deposits could on a conservative estimate be swept off from large areas before the river currents would become sufficiently sluggish in consequence of the lowered grade of their middle courses to cease from the vigorous erosion. In the meantime over the headwaters erosion would not have increased in any such measure and might in some instances actually decrease in rate, since the vegetation if more luxuriant would hold the soil to the slopes on the one hand and on the other the corrasion of stream channels is measured by the volume of the occasional heavy floods rather than by the quantity of the constant rains. The increased fineness of the mountain waste, even if the same in quantity, and its less ratio to the greater volume of water will give the rivers still greater powers of erosion after escaping from the mountains.

In the normal topographic cycle the rivers which in their youthful stage build up piedmont slopes will in maturity begin to trench and remove them, owing to the decreased height in the region of the headwaters and the lessened rate of erosion. A strong climatic change from semi-arid to pluvial will therefore work with the normal topographic cycle and the results as recorded in the sedimentation over the lower portion of the system will be proportionately more marked than if the climatic change acted alone.

In this rapid erosion the coarse material constituting the piedmont slope will not be slowly rolled forward while being worn down *pari passu* by the friction of the smaller particles swept past, but will be

carried forward rapidly whenever reached by the tumultuous currents. It will therefore have moved relatively to the adjacent finer material but little farther than the actual distance; whereas, as previously pointed out, the coarser material usually moves relatively many times farther than the finer. Not only, therefore, will the final region of deposit undergo a sudden increase in sedimentation which may be called a veritable flood of waste, but it will be of phenomenal coarseness compared to that which preceded and that which will come after, the preceding sediment being fine in the delta region on account of the small carrying power of the rivers of the semi-arid plains; the succeeding sediment being fine because of the graded character of the mountain slopes and the more decomposed nature of the waste which they give to the streams in a time of more pluvial climate. The coarser material deposited on the delta region will, however, be finer than that previously deposited on the piedmont slopes since attrition and wear are inevitable during transportation. Such a climatic change from subarid to rainy will thus be marked by a shifting of the stored waste of the earlier epoch from the middle to the lowest portion of the river system. If it be assumed that the area of deposition in the second case is no larger than in the first, the amount will form a deposit on the average of equal thickness to the depth of the erosion in the piedmont plains. Thus it is within the limits of past possibilities that widespread sand or conglomerate formations intercalated between others of markedly different nature should be formed upon delta surfaces or over the bottoms of shallow seas, as the result of a rapid and profound climatic change. Such formations in the regions of their greater coarseness would be remarkably clean from clay and where reaching a maximum development might be several hundred or even a thousand feet in thickness. This possibility will become a probability in proportion as such arenaceous or conglomeratic formations are widespread, dissociated from the other evidences of origin through crustal movement, and correlated on other lines of evidence with climatic changes of the proper nature.

The most favorable period for the testing of these deductive statements is the Pleistocene, since the deposits are still preserved at the surface, they can be traced to their sources in the regions of erosion and great climatic oscillations are known to have taken place. The

complication, however, is that in many regions profound crustal movements are also known to have occurred. This correlation of climate with erosion and aggradation has been made by W. D. Johnson to explain the oscillations between stream-cutting and stream-building of the Great Plains region during the Quaternary. He notes that:

> There are two possible disturbing influences which may result in transformation of the gradation plane—deformation and change of climate. But it is not necessary, in order to account for change in behavior of the traversing streams, to appeal to deformation. A sufficient cause may be looked for in change of climate. There is record of erosion, with reversal to deposition and rebuilding, and reversal again finally to erosion, and there is reason for believing that this series of interruptions of the gradation cycle was an effect of climatic oscillation rather than of earth movement. The date of the building of the great débris sheet, so far as included fossil remains would seem to determine it, might range anywhere from middle Tertiary to early Pleistocene. However, the beginning of the final and present degradation stage, during which the smoothness of the Great Plains has been in large part destroyed and their surface lowered, with exception of the sod-covered plateaus of the central zone, doubtless dates from the opening of that period of climatic oscillations in the Pleistocene which, in the Great Basin region of Utah and Nevada, gave rise to repeated floodings of large areas and the creation of lakes. Indeed, it is not unlikely that the grading of certain of the minor plateau surfaces of the High Plains, which stand appreciably below the general level, is to be correlated with the several returns in the Great Basin to severe desert conditions during this period, which also are plainly recorded among the old lake evidences.[1]

In investigations of Pleistocene geology great attention is properly paid to the surface form, and in fluviatile and pluvial work erosion is more studied than sedimentation. In more distant geological times, however, it is the record of the deposits which must be almost entirely the basis of study. For such purposes, therefore, the relations of erosion and aggradation within the High Plains are not of so much final importance as the question, What was the nature of the deposit made by the erosion of the sands and gravels of the High Plains during times of wetter and colder climate? The suggested but not demonstrated answer is, that the landward edge of the corresponding deposit appears to be the Orange Sand Delta of Hilgard, now known as a Mississippian portion of the Lafayette formation.

[1] The High Plains and Their Utilization. *21st Ann. Rept.*, U. S. Geol. Survey, Pt. IV, 1901, p. 626, 628–30.

As shown by Hilgard,[1] this is a widespread, flood-made formation, extending along the great valley of the continent, the Mississippi, south of its junction with the Missouri and on the Gulf Coast reaching from Mobile Bay in Alabama to the Sabine River on the borders of Texas. The formation consists in large part of orange, rust colored, but sometimes purplish, white, or variegated sand, consisting almost entirely of quartz grains much rounded and smoothly polished, and very commonly encrusted with the rusty pigment. Near the great river channels, notably that of the Mississippi on either side, on the Tombigbee and Tennessee, as well as on the Sabine there is a steady increase of gravel. The beds are irregularly stratified, sometimes structureless for 20 feet of thickness, but have generally the flow-and-plunge structure. Hilgard considers that the formation as a whole is the outcome of fresh water in the state of violent flow. The "Orange Sand" increases in thickness toward the Gulf. In an artesian well near the Calcasieu River, 200 miles west of New Orleans, beds referred to the Lafayette are found to extend to a depth of 450 feet, beneath 160 feet of clay of the Port Hudson group; and at New Orleans the gravels have been found by borings to extend to 760 feet below the level of the sea. Hilgard showed that it overlaid the Grand Gulf beds and was in its turn covered by the Port Hudson or Columbia. He considers that it is latest Tertiary or earliest Quaternary, and he correlates this increase of fresh-water action with the melting and retreat of the first glacial stage. Chamberlin and Salisbury consider, however, that glacio-fluvial work is not concerned in the origin of this Mississippi portion, since upon careful search neither was able to find any pebbles referable to glacial action,[2] this origin being restricted to the Natchez formation which overlies it.[3] These authors favor the hypothesis that the Appalachian portions at least were developed by successive shiftings of river deposits toward the sea during Pliocene upward bowing of the partially developed Tertiary peneplain in the region of the Appalachians, but

[1] "The Age and Origin of the Lafayette Formation," *Amer. Journal of Science*, Vol. XLIII (1892), pp. 389–402.

[2] T. C. Chamberlin, "Some Additional Evidences Bearing on the Interval between the Glacial Epochs," *Bulletin of the Geological Society of America*, Vol. I, 1890, p. 470.

[3] *Geology*, Vol. III (1906), p. 308.

also recognize the influence which changes in precipitation and temperature may have had upon the rate of erosion.[1] Such shiftings of the gravels as were produced by the bowing would result in a progressively younger age of deposits found in going down the streams from the axis of bowing and therefore the Lafayette deposits of separated districts may not be of strictly contemporaneous origin.

As facts which have a bearing upon the relative influences of tectonic and climatic causes, it may be pointed out that according to Hershey erosion following a Pliocene uplift opened out basin valleys in the Ozark Highland from 75 to 100 and even 300 feet below the main Tertiary peneplain. These valleys are *floored* with Lafayette gravels which Hershey states represent the *end* (italics introduced) of deposition of the Lafayette formation, but the evidence for the latter statement is not given.[2] Following the development of these valleys another uplift, reaching in southern Missouri to at least several hundred feet, enabled the streams to excavate the inner canyon valleys of Ozarkian age. In this locality, then, the Lafayette appears to have been deposited at a time of crustal stability between two stages of uplift. While its presence could be explained by either a tectonic or climatic hypothesis, the latter is perhaps the easier, since at a time of crustal stability a climatic instability, by varying the ratio of erosion to transportation, could make itself most readily felt; now by an excess of erosion depositing material near the headwaters and steepening the grade, again by an excess of transporting power shifting the same to a lower portion of its course. Such a climatic instability marked the close of the Tertiary and increased in intensity until it resulted in the tremendous climatic reversals from glacial to interglacial intervals which marked the Pleistocene.

The chief criticisms which may be brought against this view lie in the entire lack of glacial material in the composition of the Lafayette formation and the good evidence of nearly related crustal movements of greater or lesser magnitude which affected the continent at about this time. But in continental interiors it is only land warpings

[1] *Op. cit.*, pp. 305–8.

[2] "Peneplains of the Ozark Highland," *American Geologist*, Vol XXVII, 1901, pp. 33, 41.

which can directly influence the rate of erosion unless the land uplift is sufficiently prolonged for the streams to steepen their grades from the sea backward to the headwaters, while glacial material would be absent until the increasing ice sheets actually invaded the headwaters of the streams building the formations. In the present connection it is desired to bring into more prominence the climatic factor, but without presuming to decide upon the relative importance in this case of the tectonic and climatic causes, as a final decision must be based upon broad field-work with both hypotheses in mind. It may be pointed out, however, that this quickening in erosion and transportation appears to have been very extensive over the United States and has been ascribed to a time of cool moist climate by a number of writers from several lines of evidence, such as the included bog deposits;[1] but there is also a suggestion by Chamberlin and Salisbury, from the oxidized character of the formation, that there were effective dry seasons.[2] This might simply imply, however, a more diversified climate while at the same time more rainy. A somewhat similar paradox is pointed out by Chamberlin and Salisbury in regard to the relationship of the loess to the Iowan ice invasion and the absence of gravel trains, "both phenomena, perhaps, implying aridity, strange as that may seem in a glacial epoch."[3]

In view of the diversity of opinion upon the origin, age, and extent of the Lafayette, an opinion in the present connection should be expressed with caution. It would seem, however, that the great development of sand and gravel on the margins of the Gulf and to a lesser extent up the Mississippi River corresponds with such an erosion of piedmont sands and gravels as is seen to have taken place from the High Plains. In each case there is the added volume of water required in the one region for erosion, in the other for the transportation of such material. Both events are known to have occurred near the close of the Tertiary or early opening of the Quaternary, and by correlating the two the necessity is avoided, either of assigning the flood waters to the melting and retreat of the ice sheet, or to a greater southward slope to the Mississippi Valley, or to local tilting of the High Plains in order to rejuvenate erosion. The climatic

[1] Hilgard, *op. cit.*, p. 401.

[2] *Op. cit.*, Vol. III, p. 304.

[3] *Op. cit.*, Vol. III, p. 412.

change which is known to have taken place at about that time seems a sufficient hypothesis, and renders the other necessary only where warping or tilting of previous base levels can be demonstrated. In graded rivers of considerable volume a slight increase of volume, by producing erosion along the whole stream course would seem competent to sweep sand and gravel to great distances, which previously could not be transported along the bottom, resulting in the deposit of hundreds of feet of gravels at New Orleans whither now the Mississippi carries chiefly clay and in its channel nothing coarser than sand.[1]

On the other hand, W. J. McGee points out that the Lafayette bordering the continent was laid down during an epoch of land subsidence and that these Quaternary gravels may therefore be reworked Lafayette gravels, owing to a Quaternary land elevation and rapid erosion in the lower portions of the rivers.[2] To account for the original Lafayette gravels of the lower Mississippi, carried seaward during a low stand of the land, a hypothesis of climatic change appears to the present writer to apply most readily. If the Quaternary gravels consist, however, of a redeposition during a low stand of the sea and not during a local and progressive subsidence of the lower Mississippi, then such a fluctuating sea level is sufficient to account for a Quaternary redeposition without invoking as a further aid a climatic cause, even if such may have been also in operation.

Irrespective as to whether or not, however, the orange sand of the Mississippi Valley is the formation which represents in part the prod-

[1] Since the above was written two further communications have appeared bearing upon the age and mode of origin of the "Lafayette beds" of Louisiana. G. D. Harris records the existence of sands, clays, and gravels, the latter of typical Lafayette type, extending to a depth of at least 1,500 feet; while a Quaternary molluscan fauna extends down to about 2,000 feet. The well records thus seem to indicate that the seaward continuation of the gravels in the central portion of Louisiana as well as in those states to the east and west are rather Quaternary than Pliocene. It would seem, then, that Hilgard's views as to the contemporaneousness and interrelationship of the coarse "Orange sands" in the south and the ice sheets in the north may prove correct in spite of the fact that certain "Lafayette" gravels are said to lie beneath glacial till farther north. (G. D. Harris, "Note on the 'Lafayette Beds' of Louisiana," *Science*, N. S., Vol. XXVII, 1908, p. 351.)

[2] *Science*, N. S., Vol. XXVII, 1908, p. 472.

uct of the erosion of the High Plains, the fact still remains that the erosion was concentrated into certain stages and that somewhere sediments of increased volume and coarser nature must have been deposited.

The same principles may be applied to the more distant past. Where the sediments by the chemical conditions of erosion and deposition give evidence of profound climatic change, such for instance as ushers in glacial periods, equally profound textural changes in regions beyond the reach of glaciation, whereby sand or even pebbles were swept to the delta regions or the seas beyond, may properly be ascribed to the change of climate and do not necessarily require any crustal movement for their origin, though they may be complicated by the presence of such movements. In this way periods of glaciation may make their existence felt far beyond the actual limits of the ice invasion. It is thought by the writer that the Pottsville conglomerate or Millstone grit which so commonly underlies the coal measures of the eastern United States and western Europe, sharply separating the Carboniferous from the sub-Carboniferous of those regions, owes its origin primarily to such climatic change.

CLIMATIC CHANGE FROM RAINY TO SEMI-ARID

Having given the previous analytical discussion, the reverse side of the problem may more briefly be stated. At a time of marked change from rainy to semi-arid the waste poured into the upper part of the streams may be rapidly increased in amount and in coarseness, owing to less efficient vegetation and more concentrated floods. In crossing the plains of the middle course, however, the rivers will diminish instead of gaining in volume. They will find their previous valleys much below grade with the result that a larger proportion of river sediment will be deposited upon the piedmont slopes than would even be the case under the same climate after the river grades had acquired slopes in equilibrium with the conditions. An accentuated deficiency of sediment will consequently be noted at the terminus of the river system. The stratigraphic effect of such a climatic change will depend, as in the previous instance, upon the quickness and amount of the change, the distance of the headwaters from the delta, and the height of the source. These factors measure the difference

in angle between the stable grades under the two conditions and the volume of sediments required to be shifted to cause one grade to pass into the other.

These deductive statements find perhaps their best illustration in Persia, a region which, while so arid as to have no outflowing drainage, yet is known from several lines of evidence to have undergone marked climatic desiccation during historical times. Blanford in 1873 called attention to the superficial gravels, sands, and clays of the valleys and deserts of Persia.[1] He notes that the margins of the valleys usually consist of a long slope composed of gravel and bowlders, and with a surface inclination of from 1° to 3°. Such slopes often extend for a distance of from 5 to 10 miles from the base of the hills bounding the plains, the difference in level between the top and bottom of the incline being frequently from 1000 to 2000 feet, or even more. The peculiarity of these slopes in Persia consists in their great breadth and in the enormous mass of detrital deposits which they contain. In the central portions of the valleys the surface usually consists of very fine, pale-colored, rather sandy earth, not unfrequently impregnated with salts.[2] In discussing the origin of these gravel deposits Blanford notes that it is usually the drier tracts in which accumulations of gravel attain their greatest dimensions while

Toward Shiráz the slopes of loose detritus on the sides of valleys are much less extensive, and in places, as in the valley of the Bandamir, above Persepolis, entirely wanting, the flat alluvium of the valley extending to the limestone ranges on each side. This may be due to a former extension of the existing salt lakes far into the valleys of Shiráz and Persepolis, and to the deposition of silt in the lakes in sufficient quantities to conceal any accumulation of detritus near the side of the valley; but there appeared to me to be a similar deficiency of gravel slopes on the sides of the higher valleys containing running streams, and I am much inclined to believe that their absence is connected with the heavier rainfall. . . . .

Probable origin of gravel accumulations.—This gives a clue to the origin of these immense spreads of recent or sub-recent deposits; and in connection with the last observations I may mention that usually, in Southern Asia, so far as I have seen, it is the drier tracts in which accumulations of gravel attain their greatest dimensions. . . . . Bearing in mind that all accumulations of detrital matter

[1] W. T. Blanford, "On the Nature and Probable Origin of the Superficial Deposits in the Valleys and Deserts of Central Persia," *Quarterly Journal of the Geological Society of London*, Vol. XXIX, 1873, pp. 493, 503.

[2] *Loc. cit.*, pp. 495, 496.

are due to arrest of motion, whether partial or total, in the transporting agent, we can easily understand that the rainfall on the Persian hills may suffice to wash down as far as the sides of the valleys those fragments which, by chemical agency or the action of frost, are loosened from the hill-sides; but when once the momentum given by the steepness of the incline is at an end, the quantity of water drained from the surface is insufficient to transport the débris to a lower level; all that it can do is to leave the detritus in a long slope, the surface of which is arranged by the wash of rain.[1]

These views receive further support from the observations of Medlicott and Blanford on the relations to the rainfall of the piedmont gravels which face the south slopes of the Himalayas. In this connection they state:

Bhábar is the slope of gravel along the foot of the Himalayas. Compared with the slopes in the dry regions of Central Asia, Tibet, Turkestan, Persia, etc., the gravel deposits at the foot of the great Indian ranges are insignificant, the difference in height between the top and bottom of the slope nowhere exceeding 1,000 feet. . . . . This difference is probably partly due to the much greater rainfall in India, and to streams being consequently able to carry away a much larger proportion of the detritus washed from the surface of the hills, partly also to the circumstance that the rocks in the lower regions of the hills are not subjected to the loosening effects of frost.

The *bhábar* slope of gravel along the foot of the Himalayas, although evidently of comparatively recent formation, has frequently, to the eastward, been cut into terraces by the streams from the hills. This is a necessary consequence of the streams cutting deeper channels in the rocks of the hilly ground. It is curious to note, however, that to the westward the *bhábar* is being raised instead of being cut through by streams. The difference is not improbably due to the much greater rainfall to the eastward, and to the streams being consequently able to carry away the gravel as they cut back their bed in the rock, whereas weaker streams are prevented from cutting back their channels by their inability to wash away the gravel they have already deposited. It may be, too, that from local causes the gravels to the westward are more easily percolated by water and therefore streams, instead of carrying away the *bhábar* deposits, sink into them; but, judging from the enormous development of the gravel slopes in regions of small rainfall, it is more probable that the first hypothesis is correct.[2]

In conclusion on this topic it is to be pointed out and emphasized that *the climatic significance of gravel deposits on piedmont slopes is precisely opposite in character to the same when found on the delta plain.* Climatic inferences cannot therefore be safely made unless,

[1] *Loc. cit.*, p. 498.

[2] Medlicott and Blanford, *Geology of India* (1879), Part I, pp. 403, 412, 413.

after the exclusion of the possibility of a tectonic origin, the synchronous relations of erosion and deposition are investigated for the three portions of the river system and the relative location of portions undergoing degradation and aggradation are determined. Even by those who have recognized the frequent climatic origin of changes in river grade the necessity of clearly stating these relations seems to have escaped attention.

CLIMATIC CHANGES DUE CHIEFLY TO TEMPERATURE

In the discussion of the relations of climate to erosion the characteristics of weathering in hot and cold climates were discussed. Under the present topic of the relations of climate to transportation it need only be said that a cooler climate, by producing less evaporation, will alone serve to increase the percentage run-off of the river systems. A change from a temperate to a rigorous climate tends, therefore, not only to increase the amount of waste given to the river in its upper portion, but will result to some extent in an increase of the coarseness and quantity of material carried through to the delta. A change from a temperate to a hot climate on the other hand will tend to diminish the percentage of run-off, and with it the coarseness of the waste which is transported. Provided that the waste becomes finer, however, from greater decomposition, the quantity carried by the stream may not be decreased. At the headwaters the amount of waste is presumably increased by more intense insolation or more rapid decomposition over the conditions of a milder climate, tending to build piedmont slopes.

Oscillations to climatic extremes of any sort may, therefore, be considered to accelerate rock destruction, but only oscillations toward a more concentrated or voluminous rainfall or toward marked coolness of climate will result over the regions of distant deltas and epicontinental seas, in an increased quantity or coarseness of deposit.

Conclusion

CONGLOMERATES AND SANDSTONES OF MARINE, TECTONIC, AND CLIMATIC ORIGIN

Summing up the preceding discussion it is to be concluded that conglomerates and sandstone formations intercalated between others of different nature may be due to three distinct causes:

First, marine conglomerates and sandstones.—Due to marine planation and transportation, enabled to reach wide horizontal extent over shallow seas through crustal movements shifting the zone of wave and current action.

Second, tectonic conglomerates and sandstones.—Due to subaerial erosion owing to a steepening of the river slopes, either from mountain making, crustal warping, or subsidence of the ocean level.

Third, climatic conglomerates and sandstones.—Due to climatic change without necessarily any new accompanying crustal deformation. In distant periods, when the change has been of such a nature that the accumulations of gravel and sand were local and deposited near the sources of the material there is less probability, on account of the smaller original area and its higher level of deposition, of such being observed, or separated and distinguished from deposits of purely tectonic origin made by erosion during a period of stable climate. When the change was of such a nature, however, either to a more rainy or colder climate, that the pebbly or arenaceous detritus was swept forward for hundreds of miles from previous sources of erosion and accumulation, formations which may be described as great sandstone plates must have resulted, intercalated between others of a finer and more argillaceous nature, conspicuous in the geologic column both from their areal extent and their physical contrast; a contrast due to the climatic change operating in the region of deposition as well as influencing the character of the transportation. Applying this principle to the geologic past, if the sections made by nature across the deposits of ancient deltas or shallow seas indicate a periodical fluctuation in kind and in coarseness of sediment, and if such variations can be correlated *on other grounds* with climatic changes of the proper nature, it is the simpler hypothesis to hold that the latter and not repeated synchronous deformations have been the causes of the changes in sedimentation.

In the history of geologic science it is to be noted that to marine action was once ascribed the greater part of planation of the land and the formation of conglomerates and sandstones from the débris; a natural stage in geologic theory, when it is considered that the earth science developed most largely upon the northwestern shores of Europe where there is a maximum of coast line, of coastal erosion, and of shallow sea. An awakened appreciation, however, by the following

generation, of the importance of repeated epeirogenic and orogenic movements in maintaining the land surface and supplying, through subaerial erosion and fluviatile transportation, the materials of the sedimentary rocks, has led to the recognition of the tectonic causes of many of the changes which distinguish and separate the series of sedimentary formations. But it is probable that tectonic causes have been too freely ascribed in explanation of the origin of formation differences in so far as a possible climatic origin has not been held in mind. An inspection of geological literature indicates that, although the possibility of such climatic causes has been increasingly appreciated in recent years by certain investigators, yet in general, geologists have not considered the possible effects of climatic changes when seeking the causes of variations in strata, especially such as are due to size of particles. Usually the climatic factor is only regarded when considering the characteristics of the fossil fauna and flora or when deposits are present of such obvious nature as those of salt and gypsum or the products of glacial action. It is desired here to call attention to climatic change as a cause of sedimentary variation in detrital deposits of co-ordinate importance with marine planation and crustal movement. In order to discriminate correctly between the three classes of deposits where occurring in the geologic record criteria must be employed for their separation, though it is doubtless true that a correct evaluation of the factors entering into the formation of many deposits may never be achieved.

It is natural that the influence of climatic change in producing shiftings of the sedimentary facies should be the last kind of action to reach a true appreciation. Marine and tectonic conglomerates and sandstones are now observed in the making, but the *shifting* of these regions of deposition through climatic changes and by which climatic deposits as distinct from the others are to be determined is only evident on comparing the present relations of erosion and deposition with those occurring in the recent past under the same tectonic but different climatic conditions.

In conclusion something may be said of the relations of the three classes of deposits to each other. The geologic environment of a land consists of three fundamental factors: the relations of land and sea, the relations of topography, and the relations of climate. Each of these may be practically stable for a time, being subject to minor oscillations

only, but ultimately great changes take place separating earth history into its periods and eras and giving to each an individual character.

Marine conglomerates and sandstones, but especially conglomerates restricted to those whose material is obtained and sorted by the waves and transported by bottom currents, where widely developed and intercalated between unlike formations, are indicative of broad movements of the beach line; that is, of the changing relations of land and sea.

Tectonic conglomerates and sandstones are of subaerial origin and result from vertical earth movements, ultimately from either horizontal or vertical forces. To separate them sharply from climatic conglomerates and sandstones, the climate is supposed to be unchanging during the progress of the following erosion.

Climatic conglomerates and sandstones are also of subaerial and fluviatile origin, but owe their contrasts with the superior and inferior formations to climatic and not tectonic changes. To separate them clearly from deposits of tectonic origin earth movements must be supposed quiescent while climatic variations of greater or less degree are supposed to occur, resulting in changes of the sedimentary facies and in shiftings of the regions of deposit of that land waste which arises primarily through the contest of tectonic and atmospheric forces. Where the climatic changes have been great and rapid, the nature of the erosion may be so changed and the regions of deposit so widely shifted that these climatic variations may be the cause of the most striking differences between formations. Climatic conglomerates and sandstones are here made distinct and independent from those of tectonic origin by the taxonomic elevation of the *shifting location* of deposits (in space) to co-ordinate importance with *intermittent uplift* and resulting pulses of erosion (in time).

Changes in volume of ocean waters, earth movements, and atmospheric activities are the three mixed and fundamental causes by which the three classes of deposits become possible, but the records which they embody are largely distinct and independent. By separating conglomerates and sandstones into these three classes the sedimentary rocks, therefore, present a threefold record, the marine conglomerates giving that of the variable relations of land and sea; the tectonic conglomerates, the record of variable vertical uplifts; the climatic conglomerates, the record of variable temperature and rainfall.

Reviews

La science séismologique: les tremblements de terre. By F. DE MONTESSUS DE BALLORE, with an Introduction by EDUARD SUESS. Paris: Armand Colin, 1907. Pp. 579, 222 figures, maps, and plates.

In the month of January, 1906, there came from the press of Armand Colin in Paris an illustrated monograph of some five hundred pages written by the Count de Montessus de Ballore and bearing the title, *Les tremblements de terre: géographie séismologique.* This important work grew out of almost a lifetime of labor and has laid the foundations for a branch of seismological science well described in the subtitle of the work, Seismic Geography. The present volume, which is uniform in style with and somewhat larger than its forerunner, was issued in December, 1907, or less than two years subsequent to the appearance of the *Seismic Geography.*

The earlier volume discussed the distribution upon the earth's surface of all recorded earthquake shocks, of which no less than 170,000 were brought under consideration. Not only were these shocks graded and compared by earthquake provinces, but within each province the distribution of seismicity was studied by a newly derived method, and maps were prepared on which all places which had been visited by important shocks were placed in relation with one another. Further, the geological structure of each district was inquired into and the relation of the so-called epicenters to lines of fracture and faulting was pointed out.

The new volume is a treatise upon seismology in all its aspects, and is at once the most comprehensive and the most authoritative work upon the subject which has yet appeared. Dr. de Montessus is an omniverous and very careful reader of the literature of the science, and in addition to the three principal languages of the scientific world, he has brought to his aid a reading knowledge of a number of others, notably Italian, Spanish, and Russian. It is to this fact as well as to the long period during which he has been collecting the data that the comprehensiveness and the broad perspective of the work are to be ascribed. If the data of seismology have been long in the assembling, the advance of the science is all comprised within a notably brief and recent period. The present is, in consequence, a time of transition as regards both the methods of study and the

fundamental theories of seismology. *Seismological Science* is for all these reasons a work to which the future student will often be compelled to refer.

The centrum or volcanic theory of earthquakes which has so long held the stage is here relegated to the lumber-room of the science, and for it is substituted the conception that earth shocks are directly due to a mutual adjustment of sections ("compartments") of the earth's crust which are moved individually like blocks between the faults which bound them. This new view-point is made the keynote of the entire work, and again and again in the pages of *Seismological Science* it is pointed out how facts before unintelligible or in direct conflict with others are now for the first time explained and brought into harmony. To this view Professor Suess has given his indorsement in the preface, where he has used the following language:

Seismic studies have passed by the same halting-places as the other branches of our knowledge. And if, in order to reach some summit of our great mountain chains, the Alpinist crouches upon a rock, not alone for the purpose of resting but that he may launch himself to greater heights after he has regained his breath; so seismology started out from a simple and perfectly schematic conception, that of the *epicenter*, the point of the earth's surface from which the earthquake seemed to emanate, and all efforts were directed toward fixing the position of this ideal geometric point; today seismology rejects this conception as too much simplified and valuable only for the shocks due to volcanic explosions, in order that it may rise to that of mutual adjustments within the design of the terrestrial marquetry.

De Montessus' classification of earthquakes is into *macroseisms* or sensible earthquakes, *microseisms* or unfelt earthquakes registered by instruments, and *megaseisms* or destructive earthquakes; and each of these is treated in a separate part of the work. Considerable confusion now exists as to the interpretation of the terms macroseisms and microseisms, and the reviewer is of the opinion that Milne's usage, making macroseisms the more destructive earthquakes and microseisms the weaker shocks, is better supported by derivation and practicability alike, though the other view has perhaps the larger following. In the Count's usage a microseism is a megaseism examined at a distance. The term microseism as applied by de Montessus is also likely to be further confused with those pulsational movements of pendulums which arise from causes other than those which produce earthquakes.

It is impossible in a brief review like the present to discuss the many subjects which are treated in this most important monograph. It will be

interesting to recall that de Montessus' interest in earthquakes was first awakened when he was a resident in Central America giving instruction in military science. The greater part of his work has, however, been accomplished in France as a major of artillery, for much of the time upon recruiting service. The last proofs of the present work he revised in South America, where he now directs the seismological service of the Republic of Chili. W. H. H.

Research in China. Vol. I, Pt. I: Descriptive Topography and Geology. By BAILEY WILLIS, ELIOT BLACKWELDER, AND R. H. SARGENT. Vol. I, Pt. II: Petrography and Zoölogy. By ELIOT BLACKWELDER; Syllabary of Chinese Sounds, by FRIEDRICH HIRTH. Vol. II: Systematic Geology. By BAILEY WILLIS; Atlas, by R. H. SARGENT. Washington, D. C.: Carnegie Institution, 1907.

These sumptuous volumes constitute a monumental contribution to Asiatic geology. They are signal productions not only in their substance and form, but in the fact that they are a gift of productive industry to progressive science, and a tribute of one of the newest phases of civilization to one of the oldest. They give expression also to a departure from inherited methods in that, though the work was circumscribed by limitations of time and means, and confessedly but expeditional, it was given a high degree of maturity so far as it went, with the definite expectation that other mature work, by some competent organization, will be duly fitted on to it on either hand. The territory attempted was mapped topographically as well as geologically, and both with a degree of fidelity, so far as one can judge, comparable to that of an official survey of the better order. The limitations of any survey made by such an expedition are necessarily great, but there is ground to believe that, in this case, these are chiefly limitations of area merely.

The ground covered embraced a selected tract in the province of Shantung in northeastern China, chosen because of its Cambro-Ordovician terranes, and a strip, of rather wandering course, reaching from the province of Chili in north-central China westward and southward and then southeastward, through the provinces of Shan-si, Shen-si, and Hu-peï, terminating at the lower cañon of the Yang-tsï-kiang. The formations involved range through the whole geological column, but the more notable phenomena brought to attention are those of the Cambro-Ordovician, the Siluro-Devonian, the Carboniferous, and the Tertiary-Quaternary. These are treated descriptively in Vol. I, and systematically and philosophically

in Vol. II. The descriptive contributions of Blackwelder are an important factor of the investigation and give evidence at once of fidelity and skill. The systematic and philosophic treatment by Willis presents in lucid form the larger deductions of the investigation, embracing at once the stratigraphic, the physiographic, and the dynamic. Although the order selected for presentation in these volumes is the natural and logical one, some will find it serviceable to read the systematic summation and the salient conclusions of Vol. II first and seek the details on which they are based afterward.

The previous work, of Richthofen, Pumpelly, and others have given us some familiarity with the stratigraphic series of central China, and have thus taken the flavor of freshness from some of the important lines of this research, but new features of critical interest have been brought forth by this investigation, more, indeed, than could have been anticipated, and some of these are distinct surprises. The analysis of the deformations by physiographic, as well as stratigraphic methods, and the determination of geological stages by the former method are among the most notable contributions. These cannot be reviewed in detail here, nor would it be best if practicable, since they can be appreciated at their full value only by reading at length the elegant verbal and graphic expositions which they have received at the hands of an artist at once with pen, pencil, and camera.

Perhaps the most startling and, in many respects, the most significant of the results of the investigation was the discovery, on the Yang-tsï-kiang, in about the latitude of New Orleans, of a thick glacial deposit lying below the trilobite horizon of the Lower Cambrian. This discovery, supported by evidences of similar formations at approximately the same horizons, as it would appear, in distant parts of the earth, added to Coleman's recent determination of a still earlier glacial formation at the base of the Huronian in North America, and supported by the general deductions from cosmogonic and physical data that have recently been advanced, makes it clear that a radical reversal of ancestral ideas as to atmospheric evolution and early climatic history is upon us.

The admirable topographic work of Sargent furnishes an excellent basis for the stratigraphic mapping and the physiographic induction.

T. C. C.

Glaciers of the Canadian Rockies and Selkirks. By William Hittell Sherzer. Smithsonian Institution, 1907. Quarto, pp. 135.

This elegant volume gives the results of a systematic examination of the Victoria and Wenkchemna glaciers in Alberta and of the Yoho, Asulkan, and Illecillewaet glaciers in British Columbia. The study embraced the

surface features of these glaciers, the nature of the ice movement, the temperature of the ice at various depths and its relations to the air temperatures, the amount of surface melting, the possible transference of material from the surface portion to lower portions, the rates of movement, the advances and recessions of the glacial extremities, and the structure of the ice. There is an accessory discussion of the physiographic changes of the region in Pleistocene and earlier times.

The points that stand out most in the discussion are those which relate to the precipitation of snow and rain, the effects of climatic cycles on glacial movements, the stratification and granulation of the ice, its shearing planes, blue bands, and the possible methods of their development. A notable result is the demonstration by daily measurements of the shearing of layers of ice over one another, a phenomenon announced by Chamberlin as a result of his Greenland observations, but questioned by Russell and others. The conclusions relative to glacial movement lie essentially in the lines toward which the more critical recent studies by different investigators seem to be quite surely tending, a composite mode of motion embracing as factors of varying efficiency granular growth, granular intermovement, shearing of the sliding planes of the ice crystals, and shearing of the glacial layers over one another. An unsatisfactory flavor is given this by an effort, italicized as though important, to make plasticity mean something which plasticity does not usually mean, for no other apparent reason than to justify the retention of an old term which is likely to be either misleading or meaningless. The movement of the gliding planes of an ice crystal over one another is a plastic movement only in the forced sense that the sliding of cards in a pack, or of boards in a lumber pile, is a plastic movement, and such a movement is better called something else.

The work is very amply illustrated by excellent photographs and maps, and is an important contribution to glacial science.

T. C. C.

The Fauna of the Salem Limestone of Indiana. By E. R. Cumings, J. W. Beede, E. B. Branson, and Essie A. Smith. Thirteenth Annual Report of the Department of Geology and Natural Resources of Indiana, 1906. Pp. 1187–1487, 47 plates.

The Salem limestone of Indiana is known generally to geologists and business men as the Bedford limestone, receiving its name from the town at which are located so many of the large quarries of this formation; but the name was preoccupied when given to this limestone, since Bedford had

already been used by Dr. Newberry for one of the important formations of Ohio. Several years ago the Indiana formation was renamed the Salem limestone by Dr. Cumings from another town in the Indiana district where the formation is also well shown.

The introduction to the report, written by Doctors Cumings and Beede, gives an interesting account of the occurrence of this fauna as well as of the localities at which it is most abundant. This formation occurs, stratigraphically, near the base of the Mississippian series of Indiana, resting in the northern part of its outcrop on the basal limestone of the Indiana Mississippian—known as the Harrodsburg—and, in a large portion of its southern outcrop, upon a shale. The formation is said to be rather lenticular in its occurrence, pinching out at two known localities, attaining a thickness of fifty or sixty feet in the vicinity of Bedford where it is typically developed, oölitic or semi-oölitic in structure, and frequently cross-bedded. In their typical development the fossils are characterized by their stunted form and extreme abundance. The authors state that "the cross-bedding of the rock, its water-worn fossils, the fact that they are stunted, and the oölitic or semi-oölitic character of the rock, wherever typically developed, preclude the idea of its pelagic origin and argue forcibly in favor of a semi-littoral or lagoonal origin, as is also indicated by its broadly lenticular occurrence. . . . .

"In general the gastropods and brachiopods found in the Salem limestone are forms indicative of shallow conditions, such forms as might inhabit coral reefs and lagoons where there is considerable agitation of the water." This part of the report is illustrated by five half-tones giving views of characteristic exposures of the limestone and a sixth plate showing a slab of the fossiliferous limestone from Bloomington.

The greater part of the report, however, is devoted to a systematic description of the fossils of this limestone which are here, for the first time, brought together, described, and illustrated in one work. As might naturally be expected, it contains a description of a considerable number of new varieties and species, and it is stated that, "The larger part of the time was spent in the study of the corals, bryozoans, etc., not represented in the works of Hall and Whitfield." The descriptions of the Protozoa, Pentremites, Echinoderma, Vermes, Brachiopoda, and Pelecypoda are by Dr. Beede. Miss Essie A. Smith contributes an interesting paper on the "Development and Variation of *Pentremites conoideus*," in the closing part of which she discusses the "dwarfing of the fauna of the Salem limestone." Miss Smith states that this limestone "was probably laid down in a lagoon or partially enclosed sea, and the dwarfing of the fauna was perhaps due in

part to the smallness of the body of water and to an overcrowding." It is also noted that the increased number of poral pieces connected with the hydrospires, which are regarded as the respiratory organs of Pentremites, "would indicate an effort of the animal to adapt itself to a depletion of oxygen in this ancient sea."

The descriptions of the Bryozoa and Gastropoda including Crustacea are by Dr. Cumings. The Bryozoa come from the top of the formation in an exceedingly soft, loose-grained, and greatly decomposed limestone, in which they are beautifully preserved. It is stated that, "Very few Bryozoa have ever been described from the famous oölitic limestones of Indiana," and that, "No better preserved fossils have ever been studied by the writer than these exquisite Fenestellids and other Bryozoa from the Dark Hollow quarries of Bedford." The descriptions of the Vertebrates, which consist of fish remains, were prepared by Professor Branson, of Oberlin College. This portion of the monograph is illustrated by forty-two plates which in their reproduction leave something to be desired, as is frequently the case in the illustrations of the fossils contained in the reports of state geological surveys similar to that of Indiana.

C. S. P.

Evidences of a Coblenzian Invasion in the Devonic of Eastern America. By JOHN M. CLARKE. *Festschrift zum siebzigsten Geburtstage von Adolf v. Koenen*, pp. 359–68.

Dr. Clarke has devoted a portion of each of several recent summers to the field examination and collection of fossils of the Devonian formations of eastern Canada. In connection with this investigation he has critically studied the Devonian faunas of Gaspé in eastern Quebec, Dalhousie in northern New Brunswick, and those of the eastern and central portions of Maine, and this paper contains a preliminary statement of the results which have been obtained. It will be remembered that the Lower Devonian of central Europe has generally been divided into two terranes, of which the Gedinnian is the older and the Coblenzian the younger.

It is stated that in Gaspé the Lower Devonian faunas are singularly profuse and are contained in a series of limestones reaching an approximate thickness of 1,500 feet. These limestones rest unconformably on Cambrian slates and have been divided into three terranes. The lowest one has been called the St. Alban beds by Dr. Clarke and its fauna "is an almost pure strain of the Helderbergian (especially Coeymans limestone and New Scotland beds) of New York." The middle division is the Cape Bon Ami beds with a sparse fauna which, however, has a similar relationship to that

of the lowest beds. The top division is the Grande Grève limestone which is "the seat of a profuse fauna with very strong Oriskany traits commingled with features of still later age." The species indicating later age are stated to be such as might be paralleled with members of the Onondaga fauna of New York in an incipient stage of development, and present evidence of an earlier stage than that of the Onondaga. It is noted that certain species of this fauna occur in a very different facies than in New York since "the large, heavy-valved species of brachiopods which characterize the loose and coarse sandy deposits of the Oriskany in central New York here occur without diminution of size or essential change of structure in entirely pure limestone deposits," and *Hipparionyx proximus*, *Spirifer arenosus*, and *Rensselaeria ovoides* are mentioned as examples. It is stated that during Devonian time:

> The evidence is complete of an unimpeded passage and migration [from this region] southwestward into the Appalachian basin of New York and of entire isolation from any communication far enough to the east to register itself in the transatlantic faunas. The succession and trend of outcrops of all paleozoic formations from New York eastward to the Gulf of St. Lawrence, a distance of 600 miles, conveys the impression that the deposits in question were laid down in a relatively narrow channel bounded by Appalachian folds of the older land and this impression is fortified by the detailed study of this fauna and of the almost denuded patches of paleozoics lying in the region between.

At Dalhousie on the upper reaches of the Bay of Chaleur "is an isolated series of soft calcareous shales with interbedded contemporaneous effusives." Dr. Clarke states that he has determined about seventy species which may be used in comparison and correlation with other faunas. Nearly one-half of these are identical or affiliated with the Helderbergian fauna of the Appalachian gulf and a few of them are also present in the St. Alban beds of the Gaspé section. The pelecypod element shows a noticeable affinity with that of the Coblenzian, which is indicated by certain positive identifications as *Pterinea pseudolaevis* and *Carydium gregarium.* Only a few species of the brachiopods, however, can be referred to the European rather than the American type.

In Aroostook County in northeastern Maine are the Chapman sandstones which occur in two separate localities, one covering the upper reaches of Presqu'isle stream and the other known as Edmund's hill. The faunas of the two localities, however, show a decided difference since in a total of seventy-two probable species, forty-nine constitute the Edmund's hill fauna and twenty-five that of the Presqu'isle stream, while but two species are common to both outcrops. The two faunas, however, are united by

the affinities of each with the Coblenzian faunas with which they show the closest agreement, which consists of three identical species and twenty-seven affiliated ones, while the next nearest is with the Helderbergian and Oriskany of the Appalachian gulf with eight identical and thirteen affiliated species. Dr. Clarke concludes that "the inference is unavoidable that the predominating influence expressed in the Chapman congeries is that of the trans-atlantic faunas of contemporary age."

Again in Piscataquis and Somerset counties in northern and western Maine to the west of Aroostook County are beds of quite fossiliferous sandstone and sandy shale. This fauna comprises about seventy species, some of which are identical with members of the New York Oriskany fauna, as *Rensselaeria ovoides*, *Spirifer arenosus*, *Hipparionyx proximus*, *Rhipidomella musculosa* (var.), etc.; others which are not identifiable with known members of contemporaneous faunas; and finally a Coblenzian contingent, which enforces and supplements that appearing in Aroostook County.

As a result of these studies Dr. Clarke states in conclusion: "The evidence then is fairly conclusive that during the period represented by the Coblenzian-Oriskany the arenaceous epicontinental sediments were the ground traversed by the Coblenz fauna westward along the North Atlantic continent. . . . . The immigrant fauna taken as a whole is the direct descendant of the Coblenzian faunas, changed in part by variation and by mutation, and hence contemporary therewith only in the sense of being homotaxial; the lines of passage westward through the regions indicated in New Brunswick and Maine were courses of migration only, not basins of sequestration, fertile propagation, and dispersion as was the northern or Gaspé passage."

C. S. P.

Age of the Pre-Volcanic Auriferous Gravels in California. By J. S. Diller. Proceedings Washington Academy of Sciences, Vol. VIII, pp. 405, 406. February 13, 1907.

The age of the auriferous gravels of the Sierra Nevada in California is generally given as late Miocene or Pliocene. This conclusion is based chiefly on fossil plants and a few animal forms. The auriferous gravel period in all probability was a long one and no considerable part of its flora has yet been connected directly with its contemporaneous marine fauna in the same region.

Mr. Diller has recently found a flora of ten species, determined by Dr. F. H. Knowlton, in beds that carry a large and definite Eocene marine fauna, studied by Dr. Wm. H. Dall. Three of these plants occur in the

auriferous gravels, indicating that the latter are, in part at least, Eocene. This discovery is important because the auriferous gravels have been relied upon in determining the age of the Sierra peneplain.

C. W. W.

The Drumlins of Southeastern Wisconsin. (Preliminary Paper.) By WILLIAM C. ALDEN. Pp. 46, 9 plates. Washington, D. C., 1905.

There are about 1,400 drumlins in this district, an area of some 4,200 square miles. The drumlins are distributed over the ground moraines of the Green Bay and Lake Michigan glaciers and have their longer axes in the direction of ice movement. They are all the product of the last ice invasion, at least so far as shaping is concerned. Over 90 per cent. of the drift in the drumlins of the Green Bay Glacier is of local derivation; about 9 per cent. must have been brought from the Canadian crystalline rocks.

C. W. W.

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OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

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"THE OLDEST KNOWN REPTILE."—*ISODECTES PUNCTULATUS* COPE

S. W. WILLISTON
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Recently M. Thevenin has described and figured a very interesting new air-breather from the Stephanian, or uppermost Carboniferous, of France, under the name *Sauravus costei*, referring it to the Reptilia. The form, of small size, has a long body, probably a long tail, vertebrae with persistent notochord, apparently no hypocentra, single-headed ribs attached intercentrally, two sacral vertebrae, ossified carpus and tarsus, and a phalangeal formula, for the hind feet of 2, 3, 4, ?, ?. There are twenty-three or twenty-four dorsal vertebrae; the humerus shows no epicondylar foramen; the tarsus has two bones in the proximal row, a centrale and four distalia; and slender ventral ribs are present. The author's conclusions are:

> En résumé, *Sauravus costei* du Houiller de Blanzy est le plus ancien Reptile trouvé jusqu'à présent en France. Malgré son ancienneté, il est déjà très évolué, car ses membres sont à peu près aussi parfaits que ceux des Sauriens actuels, quoique la coalescence des os du tarse soit moins achevée que chez ces derniers. Il a pourtant des charactères primitifs; par ses vertèbres ensablier à notochorde continue et par ses côtes ventrales, c'est un Rhynchocéphale. Il doit, jusqu'à ce que son crâne soit connu, être provisoirement placé dans le même ordre que *Palaeohatteria, Callibrachion, Kadaliosaurus*, qui sont d'âge un peu plus récent; il est plus perfectionné que le premier de ces genres.[1]

In the *American Naturalist* for April, 1896, Professor Cope, in a discussion of the Cotylosauria, made the following statement:

[1] *Annales de paléontologie* (1907), Pt. 3, p. 19.

A single genus has been found in the Coal Measures of Ohio, which is represented by a species which I shall call *Tuditanus punctulatus*. It is of small size, and the maxillary teeth are of equal length. I can not distinguish it from *Isodectes*, which belongs to the Pariotichidae. The other species which are referred to *Tuditanus* are Stegocephalia. *This is the first identification of a true reptile in the Coal Measures.*

In the following year (*Proc. Amer. Phil. Soc.* 1897, p. 88), under the heading Isodectes punctulatus, he said:

A collection from Linton, Jefferson County, Ohio, obtained from Mr. Samuel Houston, contains the greater part of the skeleton of what I suppose is this species. The head, scapular arch and [most of the] fore limbs are lost. The remainder agrees very well with the typical specimen which was obtained by Dr. Newberry from the same locality and horizon . . . . The specimen is of importance as pertaining to the oldest known reptile, and the only one which has been, thus far, positively identified from the Coal Measures.

The paper was not published till after Cope's death, and he did not see all the proofs.

Hay, in his catalogue, for what reason I do not know, refers the species back to *Tuditanus* and the amphibia, and there has been no further reference since of any kind to the species.

Very recently, through the kindness of Secretary Walcott of the Smithsonian Institution, and Professor Dean of Columbia University, the type specimen of *Tuditanus punctulatus*, and the specimen referred to above by Professor Cope, have come under my observation. The original type of *Tuditanus punctulatus* will be shortly discussed by Mr. Moodie of this university. The specimen which Professor Cope so positively and decisively referred to the Reptilia is of great interest in view of the recent discussions as to the origin of that class of vertebrates. Because of recent discoveries connecting so intimately the Stegocephalia with the primitive reptiles, it is somewhat hazardous to say with assurance that the specimen really is that of a true reptile. Perhaps all of significance that is now left as a distinguishing characteristic of the two classes is the greater or less development of the parasphenoid, and, as the skull is wanting in this particular specimen, as it also was in the specimen referred by Thevenin to the reptilia, we must await future discoveries for the final solution of the question. It is my opinion, however, that Cope was right, and the form should be, provisionally at least, referred to the reptilia.

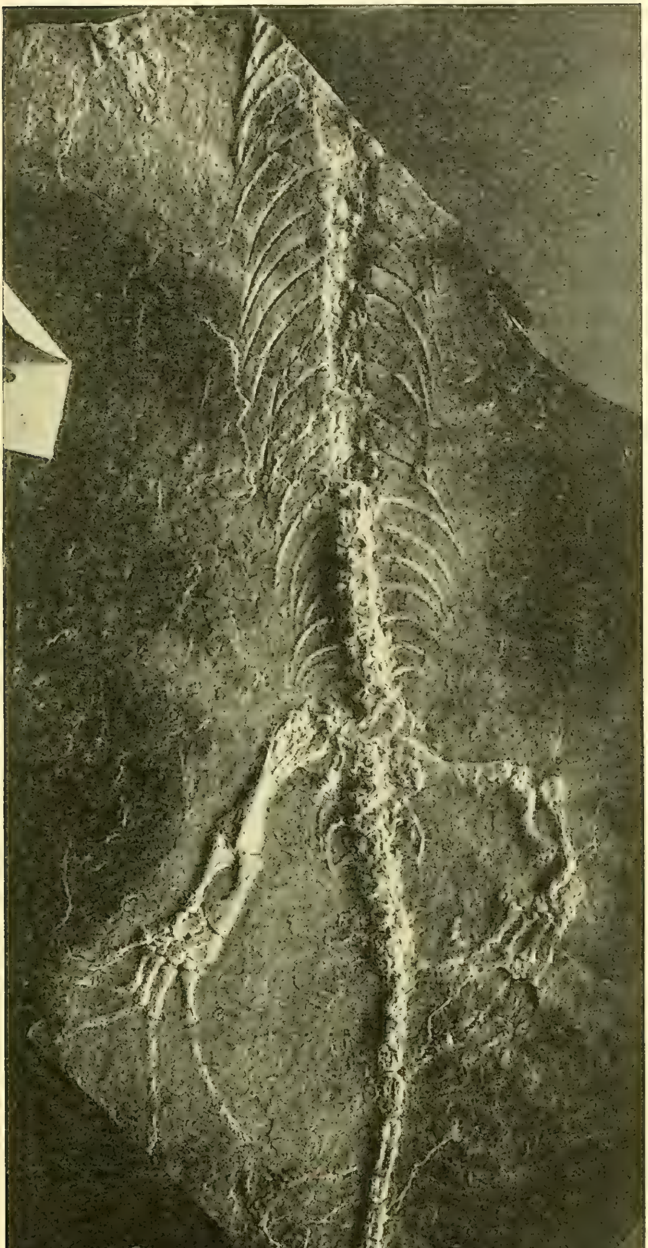

FIG. 1.—*Isodectes copei* Will., enlarged (plesiotype of *Tuditanus punctulatus* Cope).

I give herewith an enlarged photograph of the specimen, which will show, at a glance, the striking characteristics of the form; the figure given by Cope is in some things incorrect and obscure. In a very careful study of the specimen, I find no corrections of his rather brief description, but there are some facts that I can add with assurance. Positive indications of twenty-three dorsal vertebrae are present, and, since the left manus is doubtless in its normal position on the block, it is hardly possible that there could have been more than one or two more, that is, the number is doubtless the same as that of *Sauravus*. The ribs are small, slender, and curved, moderately dilated at the proximal extremity, but without real differentiation into head and tubercle; they are all attached intervertebrally. The vertebrae were certainly amphicoelous, and doubtless with persistent notochord, agreeing with those of *Sauravus*, and the Microsauria generally. The vertebral spines are rudimentary; and there are no indications of any kind of ventral ribs—one is safe in saying that the animal in life had none—in this respect differing from *Sauravus*. Nor is there any distinct evidence of hypocentra, though it is not impossible that such bones of small size may have been present. All the dorsal vertebrae bear ribs, and the first three of the caudal series also. Two vertebrae intervene without free ribs. On the left side the upper border of an ilium is discernible, close to the sides of the centra, and between them and the head of the femur. This ilium was certainly united to these two vertebrae. There were two sacral vertebrae, as in *Sauravus*, a reptilian character. The specimen lies on its ventral side, and the pubes and ischia, hence, are not visible. The tail, like the body, was evidently long and slender.

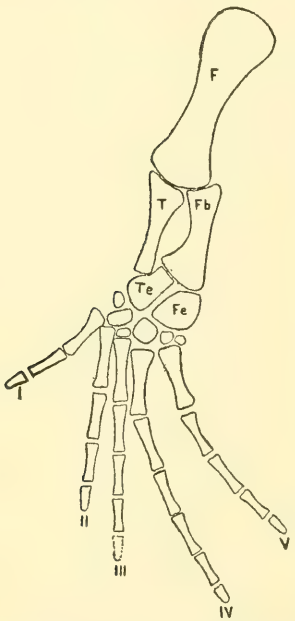

FIG. 2.—Left hind leg and foot of *Isodectes copei* Will., enlarged.

The perfection of the hind limbs is such that scarcely any thing

more could be wished for. I have no emendations to make of Cope's determinations, save to say that the phalangeal formula was certainly 2, 3, 4, 5, 4. I accept Cope's interpretation of the tarsus, as shown in the figure, with the proviso that possibly the proximal row may be composed of the three bones, tibiale, intermedium, and fibulare, but I do not think so. The bones exhibit full chondral ossification, and not perichondral alone, as is the case with the Branchiosauria, and many of the Microsauria also, probably. Whether microsaurian or reptilian in nature, the presence of such a tarsus, with its fusion of intermedium and centrale is of great interest, since *this is the oldest known tarsus and foot of an air-breather in existence*, the Linton horizon, of middle or lower Pennsylvanian being lower than others hitherto known yielding Microsaurian remains.

The imperfect left hand is the only part preserved of the fore limbs. Four metacarpals are, however, clearly shown, and two ossified carpals, together with several phalanges.

The apparent absence of ventral ribs and the possible absence of hypocentra would seem to remove our form from direct ancestral relationships with the later reptiles, but there is not a solitary character which can be discovered in the specimen that is not reptilian. That the specimen pertains to the same species, or even genus, as that represented by the type specimen of *Tuditanus punctulatus* is very doubtful, and Cope was not assured of the identity. That specimen indicates an imperfect chrondral ossification of the bones, and there are no signs of carpal bones, though the metacarpals are preserved. Until further evidence is forthcoming, the present specimen may be known as *Isodectes copei*, though the generic identity with the Permian form is very problematical.

M. Thevenin believes that his *Sauravus* is a rhynchocephalian; I cannot agree with him. In all probability the head of *Sauravus* will be found to be stegocrotaphous, of the Stegocephalian or Cotylosaurian type. If the parasphenoid is found to be considerably reduced in *Sauravus costei* and *Isodectes copei*, even though there be two occipital condyles, they must both be referred to the Reptilia; if not, they must be classified with the Microsauria. That the two forms are related one cannot doubt. But, wherever they may be finally placed, both clearly show reptilian characteristics. It is clear that the primi-

tive reptilian phalangeal formula was that now persistent in the lacertilia and *Sphenodon*, 2, 3, 4, 5, 4. In *Ceraterpeton*, a later form than *Isodectes copei*, Woodward has demonstrated the formula 2,3,4,4,3, in one species at least. The number 2,3,3,3,3, so characteristic of the mammals, is a late specialization, and can have, in my opinion, no genetic relations with the similar formula in most turtles. In other words the phalangeal formula is not of the great importance that some authors have attached to it.

The attachment of the ribs to the intercentral space is very hard to explain under the supposition that the amphibian centrum is the hypocentrum; if the vertebrae are really composed of the pleurocentra, the entire, or apparently entire, loss of the hypocentra in these the earliest known air-breathers offers another bewildering problem.

There are those who believe that the reptiles arose from two distinct groups of the amphibia, one from the Microsauria, the other from the Temnospondyli; and I must confess that *Isodectes* helps that theory materially, for its relationships with the Microsauria on the one side cannot be gainsaid. But, the close relationships between such forms as *Pariotichus*, *Procolophon*, *Telerpeton*, the Pelycosauria, the Cotylosauria, Pareiasauria, and Temnospondyli complicate matters here exceedingly, and leave the whole subject still in great obscurity.

THE ORIGIN OF AUGITE ANDESITE AND OF RELATED ULTRA-BASIC ROCKS

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CONTENTS

INTRODUCTION

Petrographers are in general agreement as to the existence of many close mineralogical and chemical similarities between augite andesite and basalt. It has, in fact, been found to be impossible to draw any sharp line between the two species. Nevertheless, the olivine basalts, volumetrically the most important class of lavas on the globe, are distinctly characterized by the great abundance of the basic phenocrysts, augite and olivine with which basic plagioclase and much magnetite are regularly associated as minerals of early generation. The list of phenocrysts in augite andesite normally includes the pyroxene and an average plagioclase which is more acid than that in the olivine basalts; olivine is absent and magnetite is less abundant than in the basalt.

These relations suggest the hypothesis that the andesite has been differentiated from the basalt by a process of fractional crystallization. This hypothesis is, in principle, nothing new, but it seems never to have been applied in detail to this particular pair of rock-species.

Vélain's observations at the isle of Réunion led him virtually to state the hypothesis, but, at the time of the publication of his memoir, very little was known as to the actual temperatures of crystallization in lavas, as to the degrees of fluidity which the lavas exhibit at those temperatures, nor as to the density of molten lava, phenocryst, or remelted phenocryst. It was, therefore, impossible for Vélain to show the exact conditions under which fractional crystallization can produce an andesitic lava from an original basalt. The experimental studies of the last twenty years have now made it possible to discuss the process of differentiation somewhat more fully.

It is one purpose of this paper to offer a brief statement of the hypothesis as viewed in the light of the experiments of Doelter and others on the properties of lavas during crystallization. A second purpose is to lay emphasis on the enormous scale in which this particular kind of differentiation of lavas has taken place. It appears to be a world-wide phenomenon. Thirdly, the hypothesis necessarily involves the correlative derivation of certain ultra-basic lavas and rocks from olivine basalt. The conception has thus become of practical value to the writer in helping to explain the recurrent field-association of olivine basalt, augite andesite, and various peridotitic rocks discovered in the Selkirk, Columbia, and Cascade mountain-ranges of British Columbia. The hypothesis will here be presented in a general form, for, while it appears to explain the field-occurrences actually studied by the writer, the conception, like all petrogenic hypotheses, should stand the test of geological experience throughout the world.

TEMPERATURES AND ORDER OF CRYSTALLIZATION IN BASALT

As a result of numerous experiments on artificial basic melts and on natural lavas, as observed under the microscope, Doelter has proved that olivine, augite, magnetite, and plagioclase crystallize in the order which has been deduced from the microscopic study of basalt by Rosenbusch, Zirkel, and other systematic petrographers.[1]

According to Doelter, both magnetite and phenocrystic olivine crystallize from artificial basic melts at temperatures ranging between 1200° and 1030° C. The olivine largely crystallizes between 1200°

[1] C. Doelter, "Die Silikatschmelzen," *Sitzungsberichte der k. Akad. d. Wissen.*, Vienna, Math.-naturw. Klasse, Bd. 103, 1904, p. 177.

and 1135° C.; the magnetite, largely between 1195° and 1100° C. The range for phenocrystic augite is 1190–960° C., with the most abundant crystallization between 1190° and 1100° C. The range for labradorite is 1125°–1075° C. He observed augite phenocrysts developed in molten basalt at the range, 1085°–920° C.; in molten limburgite at 1150°. Magnetite formed abundantly in molten basalt at 1095° C. and in molten limburgite at various temperatures ranging from 1170° to 1065° C. For rock-melts he records only one determination for olivine which "probably" crystallized out at 1085° C. in molten basalt.

Throughout most of the period of phenocrysitc development, that is, through a fall of temperature from 1200° to about 1080° C., basaltic lava is still notably fluid. Other experiments by Doelter have shown that strong fluidity characterizes various basic lavas at the following respective temperatures:

Etna basalt	1010° C.
Remagen basalt	1060
Vesuvian lava	1080
Limburgite	1050

It is fair to conclude that at the temperature of 1050° C. the average olivine basalt is fluid, and at 1100° C. quite thinly fluid. At the latter temperature its kinetic viscosity is probably comparable to that of the Hawaiian basaltic flow which Becker has calculated to have had, at the time of its emission, a viscosity about fifty times that of water.[1]

SINKING OF THE PHENOCRYSTS

In lava of such relatively high fluidity the olivine, augite, and magnetite crystals must slowly sink. Combining the results obtained by C. Barus[2] and, more recently, by J. A. Douglas,[3] on studies of volume changes as basic rock changes from the holocrystalline state to the glassy and then to the molten condition, the present writer has calculated that olivine basalt would have, at 1100° C. and at one atmosphere of pressure, a specific gravity averaging about 2.74; its groundmass, specific gravity ranging from 2.55 to 2.60. At the

[1] G. F. Becker, *Amer. Jour. of Sci.*, Vol. III, 1897, p. 29.

[2] *Bull. No. 103.*, U. S. Geological Survey, 1893.

[3] *Quart. Jour. Geol.*, Vol. LXIII, 1907, p. 145.

same temperature crystals of olivine (3.40), augite (3.30), magnetite (5.00), labradorite (2.70), and anorthite (2.75) would have specific gravities of, respectively, about 3.30, 3.20, 4.85, 2.61 and 2.66. These values are only approximate, but they show the order of the density differences to be expected between the phenocrysts and their mother-liquor. It appears probable that all the crystals except labradorite would slowly sink in the mother-liquor.

Some idea can be obtained of the rate at which the heavier phenocrysts would sink. For a spherical body the velocity of subsidence (x) at a time when steady motion is reached in a highly viscous fluid, may be found by solving the equation:

$$x=\frac{2g}{9}\times\frac{r^2(d-d')}{v},$$

where $g=$ the acceleration of gravity; r, the radius of the sphere; d, the density of the body; d', the density of the fluid; $v=$ viscosity.[1] This equation has been experimentally verified by Ladenburg who found that steel spheres, ranging from about 0.075 to about 0.2 cm. in radius took, respectively, from 570 seconds to 3,858 seconds to fall through a 20-centimeter column of Venetian turpentine—a substance a hundred thousand times more viscous than water.[2]

In an experiment by Jamin, pieces of stone sank through a layer of pitch in the course of several days (quelques jours), and corks simultaneously rose through the pitch, which, at 6° C, is much over 1,000,000,000,000 times as viscous as water.[3]

It is thus clear that even if the viscosity of the lava, within the temperature interval of early phenocrystic development, be many thousand times that of water, the phenocrysts must tend to sink. So long as such a crystallizing lava-column remains in its conduit and there undergoes cooling through the temperature interval, 1200°–1050° C.—a process necessarily involving a long period of time—the settling of the magnetite, olivine, and augite crystals will continue, though at a continuously slower rate. Theoretically the settlement

[1] Cf. Poynting and Thomson, *Textbook of Physics, Properties of Matter.* (London, 1902), p. 222.

[2] R. Ladenburg, *Annalen der Physik,* Vol. XXII, 1907, p. 287.

[3] Jamin et Bouty, *Cours de Physique* (Paris, 1888), Tome 1. 2e fascicule, 1888, p. 135.

will continue during the time occupied in the drop of temperature of another 100° C. or to the point when practical rigidity is established; but the rate of settlement must then be very considerably slower than in the interval, 1200°—1050° C. During the last-mentioned interval practically all of the olivine, much of the phenocrystic augite, and much of the magnetite of early generation has settled out of the upper part of the lava-column. Below 1050° C. the mother-liquor crystallizes. New crystals of magnetite and phenocrysts of augite and feldspar are formed but, because of the greatly increased viscosity, do not sensibly sink or rise in the freezing melt.

To estimate the chemical composition of the mother-liquor it would be necessary to know the composition of the original basalt and the quantity and composition of each settled-out phenocrystic material. The problem may be solved through a careful quantitative chemical study of a typical olivine basalt; the results are of the same order as those obtained from a comparison between the average compositions of the world's olivine basalt and of its phenocrysts. The result of these comparisons will be detailed on a later page.

FORMATION OF ULTRA-BASIC MAGMAS AND OF AN ANDESITIC MOTHER-LIQUOR

As the phenocrysts sink they enter levels in the conduit where the temperature is higher than near the surface, and where the basalt is as yet completely molten. Probably the lava-column grows slightly more dense toward its base, according to faint chemical differences in the successive strata. The sunk phenocrysts, at the lower levels and higher temperatures will, in turn, become re-dissolved or melted. Deville,[1] Doelter[2] and others have shown that both olivine and augite expand extraordinarily in passing from the crystalline state to the glassy. The specific gravities of a few typical specimens at room temperatures are indicated in the following table:

	Crystal	Glass	Molten at 1200° C.
Augite (Doelter)	3.30	2.92	2.83
Augite (Deville)	3.267	2.803	2.72
Olivine (Deville)	3.381	2.831	2.75

[1] Cf. F. Zirkel, *Lehrbuch der Petrographie* (Leipzig, 2d ed., 1893), Vol. I, p. 680.

[2] C. Doelter, *Physikalisch-chemische Mineralogie* (Leipzig, 1905), p. 8.

Each of these glasses would expand, with heating, at least as fast as diabase, e.g., 3 per cent. for 1200° C. (Barus). At 1200° C., therefore, the remelted crystals would have specific gravities at least as low as the values shown in the third column. The specific gravity of normal basalt at 1200° C. for a type which is holocrystalline at specific gravity of 3.00, is about 2.74; that for a type holocrystalline at 3.10 is about 2.83—both these values being calculated from the data of Barus and Douglas. There seems to be good reason to believe, therefore, that the remelted and more or less perfectly dissolved phenocrysts would not sink indefinitely deep in the lava column, but would come to rest, forming one or more ultra-basic layers in the conduit.

In an active volcano the time allowed for the growth and sinking of phenocrysts may be long enough for a complete differentiation, or it may suffice only to remove some of the olivine and magnetite from the cooling surface layer of the column, or it may be so short as to forbid the growth of phenocrysts in the vent. Eruption will necessarily arrest or greatly retard the process. Where the outflow is rapid and continuous the original olivine basalt appears at the earth's surface. There, of course, the rapid cooling generally prevents recognizable differentiation in the way possible, and, apparently necessary, in the vent itself when the basalt stands within it for a considerable time.

We have, then, to expect in nature a continuously graded series of lavas from pure olivine basalt, through olivine-free basalt, to those phases of the mother-liquor which must approximate a basic augite andesite and then an acid augite andesite. The last rock would thus represent the one phase, the more voluminous phase, of this kind of differentiation. In view of the notably uniform composition of olivine basalts throughout the world we must further expect, that, in all cases where the fractional crystallization has run a complete course, the more acid phase should be relatively uniform in chemical composition. Its phenocrysts form when the magma's viscosity is relatively high and sinking is very slow.

The other products of the differentiation must also show a very great variation in composition. According to the special thermal conditions and shape of each lava-column, the phenocrysts must sink

to different depths, and be segregated or dissolved in highly different proportions in different levels of the lava-column. From the original olivine basalt many types of ultra-basic basaltic magma and of peridotitic magma might be developed in the same conduit. During energetic eruption or intrusion into the walls of the conduit these might become mixed with each other and the resulting rocks present just such great variation as is actually observed in the peridotite family. Many peridotites, the picrites, limburgites (magma basalts), and abnormally olivinitic basalts are, in this view, the rocks derived from the fractional crystallization of olivine basalt, while augite andesite represents the other pole of the differentiation.

TESTS OF THE HYPOTHESIS

1. *Chemical relations.*—The view that olivine basalt may be the parent of augite andesite and of several ultra-basic igneous types is well supported by a comparison of Streng's total analysis of a dolerite and his analysis of its own glassy base.[1] The two are here quoted.

	Dolerite	Glassy base
SO_2	49.08	55.15
TiO_2	1.82	2.05
Al_2O_3	13.43	15.37
Fe_2O_3	6.49	4.66
FeO	5.92	5.73
MgO	9.58	4.20
CaO	8.92	7.62
Na_2O	3.42	3.45
K_2O	1.00	0.74
H_2O	0.32	0.80
P_2O_5	0.51	
	100.49	99.77

The phenocrysts of the dolerite include andesine, augite, enstatite, and olivine; and magnetite is, of course, a noteworthy constituent. The composition of the glassy base clearly tends toward that of an augite andesite, though the whole possible amount of phenocrystic development was, in the case of this dolerite, not attained. Streng observed that the phenocrysts were largely or altogether wanting in the upper-surface layer of the dolerite flow, but he thought it "improbable" that their absence was due to settlement of the crystals. He attributed the phenomenon rather to the operation of Soret's principle,

[1] *Neues Jahr. für Min., etc.*, 1888(2), p. 211.

the flow having undergone true magmatic splitting under the influence of a maximum rate of cooling at the surface. As a result of the magmatic differentiation the lava crystallized differently near the surface and within the main body of the flow. To petrologists of the present day this view must seem highly improbable, as it involves an impossible speed of molecular diffusion. The alternative view, rejected by Streng, that the andesitic, phenocryst-free surface phase is due to settlement of the olivine and pyroxene, certainly seems more worthy of belief.

Secondly, the hypothesis of fractional crystallization might be tested by a comparison of the analyses of the world's average olivine basalt, augite andesite, and ultra-basic rocks, along with the average analysis of each of the staple phenocrysts in olivine basalt. An approximation to most of these averages has been made possible through Osann's great compilation of the rock-analyses made between the years 1884 and 1900.[1] From his tables an average of all the available typical analyses for each rock-species has been calculated by the present writer.

In Table I, Column 1, the average composition of 161 typical basalts (largely olivine-bearing), is entered. In Columns 2 to 6 are entered, in order, the average compositions of 11 Hawaiian basalts, 17 olivine diabases, 9 dolerites, 11 melaphyres, and 17 olivine gabbros. In Column 7 is entered the average of the 198 analyses which include all but the olivine gabbros. Since some of the basalts are olivine-free (perhaps through settling out of the phenocryst) it seems probable that the addition of the 17 olivine gabbro analyses to the average total would render it more nearly representative of the true world-average than that shown in Column 7.

Column 8 of Table II indicates the result of averaging all 215 analyses given in partial averages in Columns 1, 3, 4, 5 and 6, Table I, and hence represents rather closely the mean composition of olivine basalt throughout the world.

Column 9 gives the result of averaging 33 of the most typical augite andesites in Osann's compilation. Columns 10, 11, and 12 give the similar averages of, respectively, 49 peridotites, 7 limburgites and 3 picrites.

[1] A. Osann, *Beiträge zur chemischen Petrographie*, Part 2, Stuttgart, 1905.

TABLE I

AVERAGE ANALYSES—BASALTS AND ALLIED ROCKS

	1 All Basalt	2 Hawaiian Basalt	3 Olivine Diabase	4 Dolerite	5 Melaphyre	6 Olivine Gabbro	7 First General Average
SiO_2	48.78	48.36	50.10	49.50	50.60	46.49	49.06
TiO_2	1.39	0.66	1.25	1.42	0.68	1.17	1.36
Al_2O_3	15.85	15.40	14.43	14.37	17.40	17.73	15.70
Fe_2O_3	5.37	6.48	5.06	6.55	4.57	3.66	5.38
FeO	6.34	10.07	6.31	5.84	6.29	6.17	6.37
MnO	0.29	0.80	0.25	0.17	0.46	0.17	0.31
MgO	6.03	4.19	7.32	7.75	4.89	8.86	6.17
CaO	8.91	8.69	9.53	9.96	8.09	11.48	8.95
Na_2O	3.18	3.34	2.75	2.50	3.23	2.16	3.11
K_2O	1.63	1.30	0.73	0.84	1.76	0.78	1.52
H_2O below 110° C	0.73	0.43 (both)	2.00 (both)	0.29	1.83 (both)	0.18	1.62 (both)
H_2O above 110° C	1.03			0.37		0.86	
P_2O_5	0.47	0.28	0.27	0.44	0.20	0.29	0.45
No. of analyses	161	11	17	9	11	17	198

Sum, 100.00 in each case.

Sum, 100.00 in all analyses.

TABLE II

AVERAGE AUGITE ANDESITE, OLIVINE BASALT, PERIDOTITE, LIMBURGITE AND PICRITE

	8 Second General Average Olivine Basalt	9 Augite Andesite	10 Peridotite	11 Limburgite	12 Picrite
SiO_2	48.84	57.50	44.39	41.69	43.24
TiO_2	1.35	0.79	0.88	0.67	.....
Al_2O_3	15.90	17.33	5.14	14.80	15.19
Fe_2O_3	5.23	3.78	3.88	15.04 (both)	8.62
FeO	6.30	3.62	6.70		7.89
MnO	.29	0.22	0.19	.....	.....
MgO	6.38	2.86	29.17	8.64	8.56
CaO	9.15	5.83	6.31	11.98	13.78
Na_2O	3.05	3.53	0.64	3.52	0.54
K_2O	1.46	2.36	0.76	1.17	0.48
H_2O	1.60	1.88	1.80	2.36	1.21
P_2O_5	0.45	0.30	0.14	0.13	0.49
No. of analyses	215	33	49	7	3

Sum, 100.00 in each case.

All of these averages were made after the method of Washington and Clarke in their latest determinations of the average rock-analysis for the world. Thus, the average for each oxide is based only on the

actual number of its determinations in the respective group; "trace" is taken to mean 0.01 per cent.

For the purpose of making a fair comparison among these averages it is necessary to recalculate them all as anhydrous; for, clearly, a large, though unknown, fraction of the water entered in the hundreds of analyses, must be regarded as mechanically absorbed water.

Table III, Columns 13, 14, 15, 16, and 17, shows these recalculated averages.

TABLE III

RECALCULATED AVERAGES, WATER EXCLUDED

	13 Olivine Basalt	14 Augite Andesite	15 Peridotite	16 Limburgite	17 Picrite
SiO_2	49.65	58.65	45.20	42.69	43.77
TiO_2	1.37	0.80	0.90	0.68	.....
Al_2O_3	16.16	17.67	5.25	15.18	15.37
Fe_2O_3	5.31	3.85	3.95	15.43 (Fe₂O₃ + FeO)	8.72
FeO	6.40	3.69	6.82		7.99
MnO	0.29	0.22	0.19	.....	.....
MgO	6.48	2.90	29.70	8.85	8.66
CaO	9.30	5.92	6.43	12.27	13.95
Na_2O	3.10	3.60	0.65	3.58	0.55
K_2O	1.48	2.40	0.77	1.19	0.49
P_2O_5	0.46	0.30	0.14	0.13	0.50

Sum, 100.00 in each case.

Table IV, Column 18, indicates the average composition of the olivine phenocrysts in basalt, according to Rammelsberg.[1] Column

TABLE IV

COMPOSITION OF PHENOCRYSTS IN OLIVINE BASALT

	18 Olivine (Rammelsberg)	19 Augite	20 Labradorite (Ab_1An_1)	21 Anorthite
SiO_2	41.01	47.72	55.55	43.16
TiO_2	.....	1.10	.....	.....
Al_2O_3	.....	6.31	28.35	36.72
Fe_2O_3	.....	3.12	.....	.....
FeO	9.83	5.31	.....	.....
MnO	.....	0.50	.....	.....
MgO	49.16	14.01	.....	.....
CaO	.....	20.71	10.36	20.12
Na_2O	.....	0.80	5.74	.....
K_2O	.....	0.42	.....	.....
Sp. gr. of crystal	ca. 3.40	ca. 3.30	2.700	2.75

[1] Quoted in Zirkel's *Lehrbuch der Petrographie*, 2d ed. (1893), Vol. I, p. 353.

19 gives the result of averaging 14 analyses of augite phenocrysts from basalt, dolerite, limburgite, and labradorite porphyrite, as stated in the appendix to Osann's compilation. Columns 20 and 21 represent typical analyses of labradorite and anorthite respectively.

By the settling-out of olivine, augite, and magnetite the molten lava or mother-liquor, must, when compared with the original basalt, be poorer in iron oxides, magnesia and lime, and richer in silica, alumina and the alkalies. The change in alumina might be slight, provided that the anorthite phenocrysts also settled out. Crystals of labradorite and andesine would slowly rise and enrich the upper part of the lava-column with silica, alumina, and soda. Chemically the average augite andesite appears to correspond to the mother-liquor, possibly bearing up-floated plagioclase crystals, while many of the ultra-basic rocks, picrite, limburgite, dunite, harzburgite, and other peridotites, correspond to those magmatic types developed deep within the lava-column by the settling of the phenocrysts.

2. *Observed cases of sunken and risen phenocrysts.*—A few instances of gravity differentiation accompanying the growth of phenocrysts in magma have been observed in rocks and also in artificial melts. Both Scrope, in 1825, and Charles Darwin, in 1844, published hypotheses, now classic, of such fractional crystallization in nature. Clarence King, in 1878, adopted their conclusion and added new examples studied by him at Kilauea. He broke asunder some of the thin, tongue-like flows of once very fluid basalt and found that in every case the bottom of the flow was thickly crowded with triclinic feldspars and augites, while the whole upper part of the stream was of nearly pure isotropic and acid glass.[1] He further remarked on the general absence of phenocrysts in some of the great Hawaiian flows; the crystals sank away into the conduit before eruption. Certain other Hawaiian flows described by E. S. Dana show the complementary feature of being ultra-basic and crowded with olivine crystals, which make up as much as 50 per cent. of the rock.[2] Neither at Kilauea nor at Mauna Loa, however, would one expect to find a notable differentiation of augite andesite. The extreme fluidity of lava-columns in both of the great pits seems to indicate general tempera-

[1] *U. S. Geol. Explor. 40th Parallel*, Sys. Geol., 1878, p. 716.

[2] J. D. Dana, *Characteristics of Volcanoes* (New York, 1891), p. 324.

tures above those at which even olivine can form. The "white" heat of the huge lava-fountains corresponds to a temperature of 1300° C. or over.[1] Granting that the Hawaiian conduits have always been so much superheated, it is not surprising that so few types of lava, other than olivine basalt, have been found on the island.

Iddings has described a striking case of the sinking of the augite phenocrysts, enriching a thick layer at the bottom of a 30-foot intrusive sheet on Electric Peak, Yellowstone Park.[2] It is not clear why so thin a sheet should have been differentiated and thus stand in contrast to hundreds of mapped sills of at least as great thickness, in which no differentiation is visible. Possibly the explanation is to be found in the fact that the Electric Peak sill is unusually rich in sulphur trioxide, chlorine, lithia, and "combined" water—substances which tend to lower the viscosity of magmas. In this case, though the magma was rather quickly chilled against the inclosing shales, the dissolved volatile matter maintained the fluidity long enough for the phenocrysts to fall to the bottom.

Against the hypothesis of fractional crystallization and gravitative sinking, it might be objected that the heavy minerals of early generation in gabbros and other plutonic types which have crystallized under slow-cooling conditions, are generally quite uniformly distributed through rock and show no concentration by gravity. There are, however, good reasons to believe that each plutonic magma, before any crystallization begins, is regularly cooled down several hundred degrees of the Centigrade scale below the melting-point of the rock resulting from the crystallization of the magma. The experiments of Oetling[3] and Amagat[4] show that pressure is a principal cause of this retardation of crystallization. According to Vélain[5] the retention of the volatile solvents, such as chlorides, would further tend to lower the temperature of crystallization in depth, while their escape at a volcanic vent would allow crystals to form at a higher

[1] Cf. H. Le Chatelier and O. Boudonard, High Temperature Measurements, trans. by G. Burgess, New York, 1904, p. 246.

[2] *Monograph* 32, Pt. 2, U. S. Geol. Surv., 1899, p. 82.

[3] *Tscher. min. u. petrog. Mitt.*, Vol. XVII, 1897, p. 332.

[4] *Comptes Rendus*, No. 16, 1893.

[5] *Op. cit.*, p. 181.

temperature and therefore during a less viscous stage of the magma's history. In an under-cooled silicate melt crystals must sink but slowly.

The crystallization of most plutonic magmas and of lavas at the earth's surface are thus believed to take place under strongly contrasted conditions. At the surface of a lava-column olivine, magnetite, augite, and plagioclase begin to form at high temperatures, when the viscosity is relatively low; the time-interval of crystallization for the whole magma is relatively long. Under plutonic conditions the same minerals crystallize at lower temperatures, when high viscosity is established and (because of under-cooling) the time-interval of crystallization is probably short.

Nevertheless, in some plutonic bodies of large size a certain amount of fractional crystallization and settlement of basic minerals may have actually taken place. Kemp has suggested that the anorthosites of the Adirondacks have been derived from more normal gabbro as a result of the sinking of the heavy constituents, either crystallized or still molten. He considers that the titaniferous magnetites of the region were erupted into the anorthosite after the anorthosite had consolidated, and implies that the molten ore has been derived from a *couche* which was formed from settled-out magnetite.[1] The relation of anorthosite and magnetite would, thus, be analogous to that postulated between augite andesite and certain olivine-rocks. Secondly, it is further possible that many basic contact-zones represent those parts of the respective intrusive masses where, on account of the relatively rapid cooling, the settling of basic minerals has been specially restrained, while the process has notably affected the composition of the slower-cooling interior of each mass. According to Kemp and Cushing[2] the huge anorthosite masses of the Adirondacks are characterized by wide contact-zones of rock relatively rich in pyroxene and magnetite (gabbro and anorthosite-gabbro). This gabbroid phase is usually finer grained and was presumably chilled more rapidly than the main body of the anorthosite.

[1] *Nineteenth Annual Report*, U. S. Geological Survey, pt. 3, 1899, p. 417.

[2] H. P. Cushing, *Geology of Franklin County*, 18th Report of the State Geologist (Albany, 1900), p. 101; *New York State Museum Bull. No. 95* (1905), p. 305 and *Bull. 115* (1907), p. 471.

It is obvious that the gravity-separation of phenocrysts in lava which has once escaped from its conduit and then cooled rapidly, will not be conspicuous in the average flow. The separation will be most pronounced in the upper levels of an active volcanic neck or lava-filled fissure.

The rising of phenocrysts in magma more dense than themselves has seldom been actually observed, partly for the reason that few phenocrysts are lighter than their matrix. Mercalli has described a case of the concentration of leucite phenocrysts (sp. gr. at 1100° C. about 2.42) in the surface layer of an 1883 flow of Vesuvian lava (sp. gr. molten at 1100° C. about 2.70).[1] An analogous instance is recorded by Morozewicz who found that tridymite (sp. gr. at 1300° C. 2.24), derived from converted quartz grains, floated to the top of a crucible in which he had melted two pounds of granite (sp. gr. at 1300° C. about 2.40).[2]

3. *Andesite actually observed to have been derived from basalt at an active volcano.*—But all deductive argument for the hypothesis must, in order to be entirely convincing, be supplemented with the positive facts of the field. The great value of Vélain's discovery in the Île de la Réunion (Bourbon) has surely never been adequately recognized in discussions on the origin of magmas.[3] A few weeks before his party reached Réunion the 8000-foot volcano at the southeastern end of the island erupted fluid lava at its summit and, simultaneously, other lava issued from a fissure on the flank of the volcano, a fissure which communicated with the main vent.

The lava issuing at the summit was relatively acid and had a composition apparently similar to that of the lava collected at the summit in the walls of the crater itself. The latter was analyzed by Vélain, with the following result:

SiO_2	57.49	Na_2O	3.64
Al_2O_3	16.41	K_2O	2.92
FeO	10.65	Loss on ignition	0.13
MnO	0.06		
MgO	1.23		100.05
CaO	7.52	Sp. gr.	2.79

[1] *Atti della Soc. ital. di scienze nat.*, Vol. XXVII, 1884.

[2] *Tscher. min. u. petrog. Mitt.*, Vol. XVIII, 1898, p. 332.

[3] C. Vélain, *Mission de l'île Saint-Paul* (Paris, 1888), pp. 101 ff.

This rock appeared to be quite holocrystalline and was essentially composed of feldspar microclites, augite and iron oxide; olivine was a rare accessory. The augite and feldspar appear in large part to have crystallized at the same time.

The lava from the flanking fissure was examined and found to be very dense (sp. gr. 2.97) and much more basic than the lavas at the edge of the crater "qui datent pourtant de la même phase éruptive." This basic lava carried only 48.98 per cent of silica. It is rich in olivine, magnetite and augite, with which less abundant crystals of anorthite are associated.

> Ainsi, déversement d'une lave vitreuse, relativement riche en silice, par-dessus les bords du cratère comme un trop-plein, puis soutirage par des crevasses latérales, ouvertes à une assez grande distance du sommet, d'une lava tout à la fois plus basique et plus dense, chargée de péridot, mais se rapprochant de la précédente par la nature de son élément feldspathique (anorthite), tels sont les deux phénomènes consécutifs présentés par l'éruption de 1874. On peut les considérer comme représentant la marche habituelle des éruptions de ce volcan.[1]

The basic lava was observed to flow slowly, so that one may conclude that the temperature was well below 1200° C. or the point at which olivine begins to form in a cooling basalt. Other recorded flows of basaltic nature, such as that of 1812, ran with great speed, indicating higher temperatures and much lower kinetic viscosity. The temperature of the lavas within the vent is, thus, sufficiently variable to allow of their intermittent differentiation by the sinking of phenocrysts. In the process of time the island has been built up by alternating flows of olivine basalt, basic and acid augite andesites, and either true picritic rocks (described by Vélain) or their near relatives, ultrabasic basalts. Normal olivine basalt formed the original lava, whence, through fractional crystallization, the other types were derived.

4. *General field relations.*—The hypothesis implies that, in general, the derivation of augite andesite and olivine rocks from olivine basalt takes place in the relatively small openings represented by volcanic vents; secondly, that the effective differentiation occurs only when the lava column stands in the vent for a considerable time, and at temperatures ranging between 1200° and 1050° C.; thirdly, that the peri-

[1] C. Vélain, *op. cit.*, p. 182.

dotitic, limburgitic or picritic magma resulting from the remelting of the settled phenocrysts, would form at the base of the lava-column and would be considerably smaller in volume than the correlative andesite; fourthly, that the heavy, ultra-basic magma would oftener form intrusive than extrusive rocks, and would fill fissures either in the basal beds of the cone itself or in the older formations on which the cone rests; fifthly, that the primary basaltic magma is directly represented on the earth's surface where the lava was erupted rapidly in great volume, and at such temperatures that the phenocrysts of large size had not yet formed in abundance; and, sixthly, that augite andesite would be most often developed in and about the great volcanic cones, in the building of which the physical conditions and the duration of eruption were appropriate for pronounced fractional crystallization.

These various implications seem to be fairly matched by the facts of rock-distribution and rock-occurrence. The whole group of rocks here considered—basalts, andesites, peridotites, picrites, limburgites, etc., are consanguineous and several of them are commonly associated in the field. Where some of the derivatives are lacking in the existing outcrops, as in some of the British Columbia cases, the others may have been eroded away, or, on the other hand, have not yet been revealed by erosion. The ultrabasic rocks never form bodies of batholithic size but form dikes, sheets, "chonoliths,"[1] etc., and are thus always in such development as is explicable on this hypothesis. They form injected, not subjacent bodies. The olivine basalts are most largely developed in the vast lava-fields of the fissure-eruption type, where the emission of the primary lava has been too rapid for differentiation in the fissures. Augite andesite is most characteristically found in and about the greater cones, like those of the Andes mountain system or like most of the hundreds of very lofty cones rising from the floor of the deep sea. It has been already pointed out that the Hawaiian volcanoes carry superheated lavas, which, on account of the high temperature of the main body of each lava-column, cannot usually undergo pronounced fractional crystallization; yet the studies of J. D. and E. S. Dana show that some separation into olivine-free basalt and ultra-basic basalt has taken place before some of the

[1] *Journal of Geology*, Vol. XIII, 1905, p. 485 ff.

eruptions. King's observations warrant the belief that some differentiation by fractional crystallization occurs in the lava after it escapes from the calderas of Hawaii. However, the Hawaiian rocks are more allied to those of an Idaho or Oregon lava-flood than to the typical andesites of Ecuador. The poverty of Etna lava in phenocrysts may be explained as due to the partial differentiation of the primary olivine basalt.[1]

5. *Relation of augite andesite to other andesites.*—The hypothesis has been framed on the supposition that the primary basaltic magma has not been essentially affected by its solution or assimilation of chemically contrasted rock, material with which the lava makes contact as it rises or lies in the volcanic conduit. It is, however, most probable that the primary lava may in many cases absorb a certain amount of foreign material, either rock or fluid, and that the products of fractional crystallization must then vary notably from the few types so far mentioned. The process itself may be aided or retarded by such absorption, according as the absorption affects the temperatures of crystallization or the viscosity. Phenocrysts and ground-mass must change in chemical composition. Their separation by gravity would, then, produce magmatic materials not directly corresponding to augite andesite nor to any of the ultra-basic rocks formed directly from olivine basalt.

Hornblende andesites, mica andesites, dacites, etc., may, on this view, be derivatives of the primary basalt which has been modified by the assimilation of foreign rock-substance; while certain of the peridotites may represent some of the correlative differentiates of the compound lava. In a similar manner, one might possibly consider many lamprophyres and aplites as due to the analogous differentiation of their respective parent-magmas by the settling of basic minerals from the latter in its magmatic condition. It is not here the writer's purpose to discuss these possibilities in detail; they are noted rather to point to his belief that the commonly observed field associations and chemical relationships of augite andesite and other andesites are facts not opposed to the hypothesis outlined. It is, however, by no means intended to express the belief that *all* andesites or *all*

[1] Cf. H. Rosenbusch, *Mikros. Physiographie der massigen Gesteine,* 3d ed. (Leipzig, 1896), p. 1011.

peridotites have been formed through gravity separation of basic minerals; such a view is manifestly wrong.

6. *The rival hypothesis of magmatic differentiation.*—Finally, the hypothesis should meet the test of showing superiority over an obvious alternative suggestion. It might be conceived that augite andesite is due to the splitting of the basaltic magma before crystallization set in. In this view one must suppose that the splitting is due to a drastic change of physical conditions when the lava passes from abyssal levels to levels at or near the surface. The pressure is certainly very different in the two positions. However, no facts are in hand to show that a release of pressure causes immiscibility between two such magmas as molten andesite and molten peridotite, the two actually observed differentiates. If release of pressure alone caused the spontaneous splitting of olivine basalt into lighter andesite and heavier peridotite, we should very rarely expect to find true olivine basalt on the earth's surface, for most of these fluid lavas spend a considerable time in their conduits before being erupted. Against the idea is, further, the absence of any known physical reason why release of pressure should cause immiscibility. Experiments seem, on the contrary, to show that increase of pressure tends to promote immiscibility.

Immiscibility might conceivably ensue through a fall of temperature from a superheated condition, but there is no direct evidence that the phenomenon has a place in the history of volcanic cones or fissure-vents.

However probable may be the doctrine of immiscibility for certain magmas under plutonic conditions, we may regard the evidence on the problem as negative so far as volcanoes are concerned. The case may be summed up thus: The basaltic magma *may* split spontaneously into two or more magmas at a volcanic vent, but the phenocrysts of a molten basalt *must* sink while the lava undergoes the extremely slow cooling within the vent. Possibly both methods of differentiation are active. For the one advocated specially in this paper the physical conditions are quite simple and are largely understood quantitatively. The alternative view is at present a somewhat elusive conception for the petrologist and has few field-observations or compelling deductive considerations in its favor. It should, however, be added that the

writer believes in magmatic splitting under other conditions than those at the crater of a basalt volcano. Either hypothesis will, of course, recognize augite andesite as a derivative from olivine basalt; the balance of probability is here attributed to the hypothesis of fractional crystallization.

SUMMARY AND CONCLUSION

The purpose of the writer has been to state the results of correlating many scattered items of fact derived from experimental and field studies. The correlation seems strongly to support the early views of Scrope, Darwin, and others as to the efficiency of fractional crystallization in the formation of igneous rocks. It is only quite recently that this general hypothesis could be put on a quantitative basis. Even now there are needed many additional physical and chemical determinations before the hypothesis can reach its full measure of conviction for the petrologist. Nevertheless a compilation of the already established facts seems to show that the idea of rock-differentiation by the gravitative separation of certain minerals gains greatly in meaning, force, and usefulness when applied to actual rock-types and to actual petrographical provinces.

The hypothesis explains the origin of a considerable number of igneous rock-types. Augite andesite and many olivine-free basalts form what may be called one pole of the differentiation of olivine basalt. Picrite, limburgite, many peridotites and other ultra-basic types form the other polar group of differentiates. The conditions for the differentiation in the typical and general case, involve, in each case, a somewhat prolonged residence of the primary basalt in a volcanic vent in which the temperature varies from about 1200° to about 1050° C. The phenocrysts formed in the lava at these temperatures, must slowly but surely sink. They then collect in the lower part of the lava-column. While still undissolved, they may be erupted along with the fluid lava in which they rest, giving ultra-basic porphyritic lavas; or, as seems more probable, they are slowly dissolved in this lower, hotter part of the lava-column, forming one or more ultra-basic layers which, on injection, crystallize into peridotites or, following extrusion, develop picritic or limburgitic rocks.

The hypothesis is backed up by a comparison of the average olivine basalt and average augite andesite of the world; by a comparison of

the chemical nature of an individual and typical olivine basalt, its phenocrysts and its base; by the fortunate occurrence of simultaneous eruptions from the crater and low-lying lateral fissure at the Réunion volcano where Vélain shows the differentiation has taken place ideally; by the abundant proofs that heavy crystals do and must slowly sink and light crystals slowly rise in lavas, and in rock-melts; by the well-known facts of field-association and bodily development of augite andesite, olivine basalt and ultra-basic rocks throughout the different continents.

If the hypothesis correctly represents the facts and the augite andesites of the sea-floor volcanoes and of so many continental volcanoes are truly derivatives of olivine basalt, we have one more important link in the chain of argument leading to the belief that basaltic magma forms the universal substratum of the earth's crust today and has formed that substratum since Keewatin (early Archean) times. With this conception as a working theory the writer also connects the view that the crust overlying this basaltic substratum is stratified by density, so that the lower layer of the crust is crystallized basaltic magma (gabbro, possibly merging upward into anorthosite) and the upper layer is a composite of dominantly acid material. This latter is considered as made up largely of original granite or gneissic rock, similar to the staple fundamental gneiss of the pre-Cambrian—a layer probably less than thirty kilometers thick. This layer was crystallized in pre-Keewatin time; through it the basic Keewatin lavas were erupted; and through it basaltic magma has, from place to place and from time to time, ever since been erupted. The universal basaltic layer has thus been the effective source of the heat involved in the eruption of post-Keewatin igneous magmas. By the spontaneous differentiation of the primary basalt through fractional crystallization, the few rock-types specially discussed in this paper, have been locally derived. Most of the other eruptive rocks are, on this same working hypothesis, regarded as derived from the formation and differentiation of magmas which are the product of the solution of the acid, original gneissic shell and of its sedimentary veneer in the primary basalt. In other words, both the "syntectic"[1] (assimilation) theory and the fractional-crystallization theory seem to the writer to be essential and principal elements in the final solution of the genetic problem of the igneous rocks.

[1] F. Loewinson-Lessing, *Congrès géol. internat. Compte rendu*, 7th session, St. Petersburg, 1897, p. 375.

A TABLE OF INDEX OF REFRACTION AND BIREFRINGENCE OF ROCK-MAKING MINERALS

W. O. Hotchkiss

With regard to determining minerals in thin sections of rocks, index of refraction and birefringence are two of the most useful characteristics. These constants vary through wide ranges and comparatively few minerals possess the same or even nearly the same index. Consequently if the index can be determined even approximately the student has a most valuable starting-point to aid in his diagnosis of an unknown mineral.

The methods of determining the index described in Iddings' *Rock Minerals* furnish very delicate means of comparing the index of an unknown with that of a known mineral and sometimes will serve to determine the index closely enough for purposes of diagnosis, but it often occurs that the student would be able to determine a mineral much more readily if he had any means of actually measuring the index in a rough fashion. While instructing classes in petrology in the University of Wisconsin the writer spent some odd hours in trying to devise such a means, but did not succeed in finding anything simple enough for ordinary use. In connection with this work it was found somewhat difficult to get students to appreciate difference in index and make use of it in their studies, the temptation to identify a mineral simply by comparison—without a careful study of its constants—being too strong to resist. In the effort to overcome this tendency the accompanying table and diagram were constructed, and as they proved very satisfactory they are given here in the hope that others will find them as useful.

The diagram, as will be recognized, is simply an extension of Becke's diagram for the feldspars to include all minerals whose constants are known. The index is indicated by a short vertical line and the birefringence by a fine horizontal line. By giving all three indices for the optically biaxial minerals both the greatest and least possible birefrin-

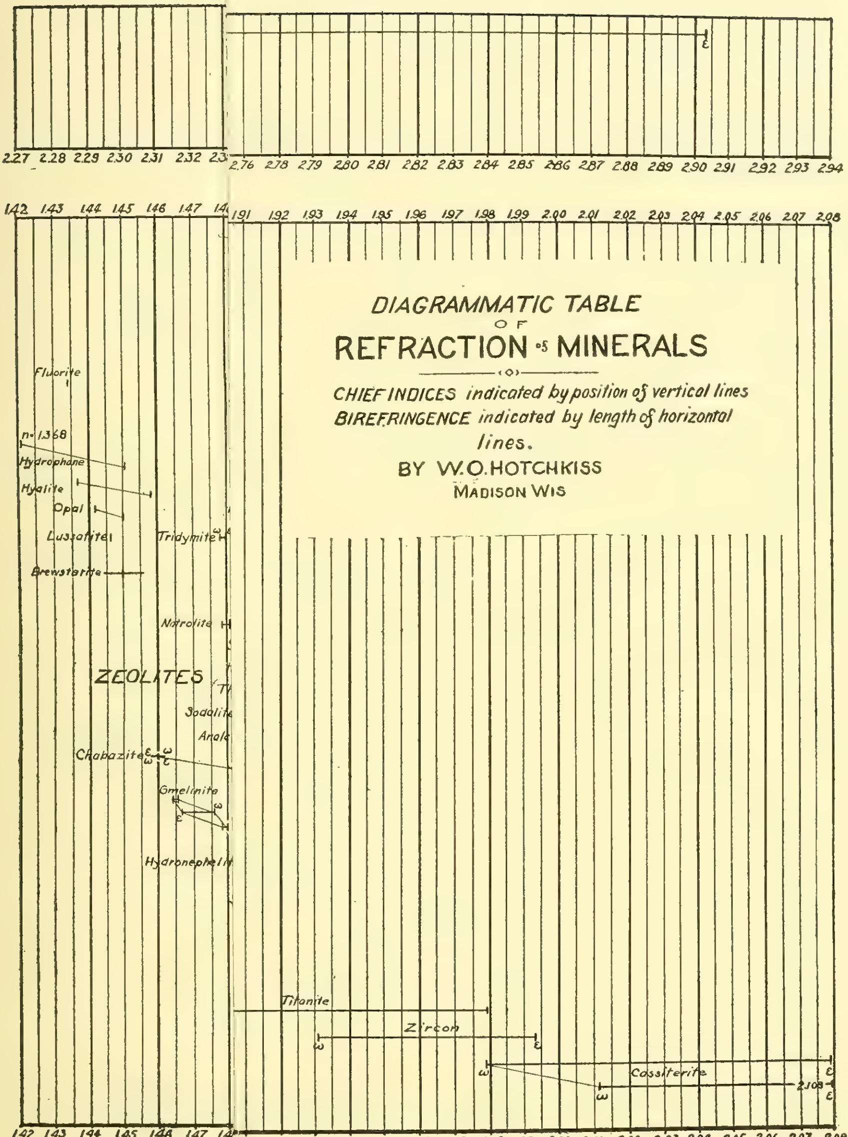
gence are shown. The total length of the line represents the maximum birefringence that any section of the mineral considered can possess. For many minerals the indices are only partly known. These are indicated by drawing the line representing the birefringence solid, when its approximate length is known, and any of the three indices is known. When an index is known, and the maximum birefringence is not known, it is represented by a dashed line either to the right or left or through the vertical line, according as the index is α, γ, or β, respectively. The first case is illustrated by Forsterite, $-\beta=1.659$, and the last three by Clinohumite, $-\beta=1.670$, in which the maximum birefringence is not known.

Minerals do not have constant unchangeable indices. The indices vary with composition and with change in physical conditions. These variations are indicated by giving both the lowest and highest sets of indices and connecting the similar indices by fine diagonal lines. This scheme serves to connect and group the various members of mineral series, such as the carbonates, the feldspars, the pyroxences, the olivine group, etc. It also serves to indicate change in sign of uniaxial minerals such as occurs in the eucolite-eudyalite series.

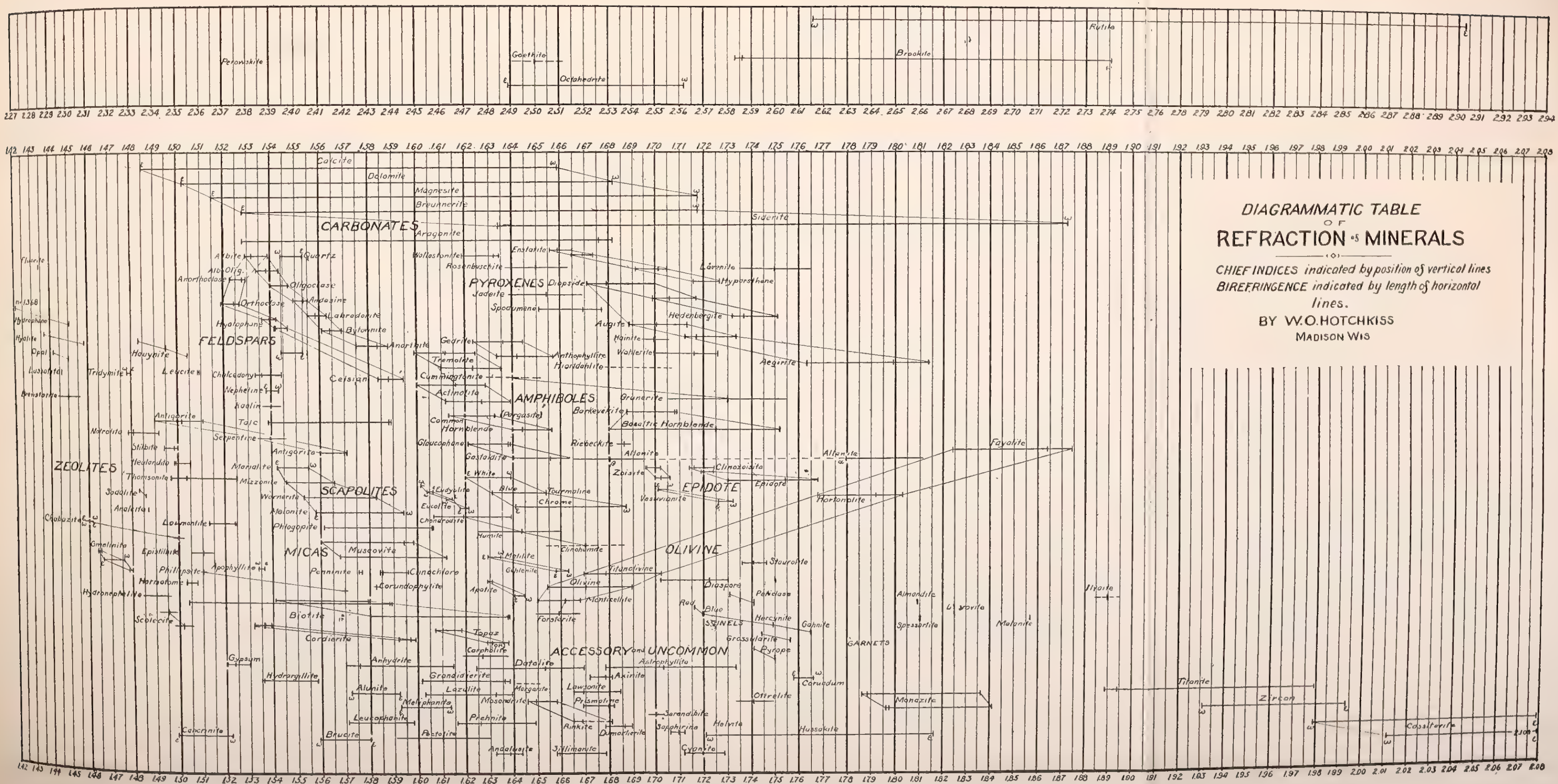
As far as possible the minerals are grouped in the diagram according to their relations. The most important rock-making groups are put together so as to facilitate comparison. Thus the carbonates are together, and similarily the amphiboles, pyroxenes, the olivine group, the mica group, the feldspars and quartz. About these are the other minerals—those with low indices, such as fluorite, leucite, and the zeolites at the left, and the large numbers of "accessory and uncommon" minerals to the right and below.

An inspection of the diagram will indicate its usefulness. The space between any two heavy vertical lines representing a difference in index of 0.020, or, roughly, two times the maximum birefringence of quartz, will be seen to contain comparatively few minerals, and usually there is a difference in the birefringence of these which serves for their easy distinction.

The diagram serves for the ready finding of any mineral corresponding to a known index. In order to find the indices of a known mineral a table arranged alphabetically is given. The table gives the indices



DIAGRAMMATIC TABLE
OF
REFRACTION OF MINERALS
CHIEF INDICES indicated by position of vertical lines
BIREFRINGENCE indicated by length of horizontal lines.
BY W.O. HOTCHKISS
MADISON WIS
2.27 2.28 2.29 2.30 2.31 2.32
2.76 2.78 2.79 2.80 2.81 2.82 2.83 2.84 2.85 2.86 2.87 2.88 2.89 2.90 2.91 2.92 2.93 2.94
1.42 1.43 1.44 1.45 1.46 1.47
1.91 1.92 1.93 1.94 1.95 1.96 1.97 1.98 1.99 2.00 2.01 2.02 2.03 2.04 2.05 2.06 2.07 2.08
Fluorite
n-1.368
Hydrophane
Hyalite
Opal
Lussatite
Tridymite
Brewsterite
Natrolite
ZEOLITES
Chabazite
Gmelinite
Titanite
Zircon
Cassiterite
2.108



DIAGRAMMATIC TABLE
OF
REFRACTION OF MINERALS
CHIEF INDICES indicated by position of vertical lines
BIREFRINGENCE indicated by length of horizontal lines.
BY W. O. HOTCHKISS
MADISON WIS
Rutile
Perowskite
Goethite
Brookite
Octahedrite
CARBONATES
Calcite
Dolomite
Magnesite
Breunnerite
Siderite
Aragonite
FELDSPARS
Albite
Quartz
Oligoclase
Andesine
Orthoclase
Labradorite
Hyalophane
Bytownite
Anorthite
Celsian
PYROXENES
Enstatite
Wollastonite
Rosenbuschite
Diopside
Jadeite
Spodumene
Augite
Hedenbergite
Hypersthene
Aegirite
AMPHIBOLES
Tremolite
Cummingtonite
Actinolite
Anthophyllite
Common Hornblende
Glaucophane
Gastaldite
Riebeckite
Basaltic Hornblende
Barkevikite
Grunerite
ZEOLITES
Natrolite
Stilbite
Heulandite
Thomsonite
Analcite
Chabazite
Laumontite
Gmelinite
Epistilbite
Phillipsite
Harmotome
Scolecite
SCAPOLITES
Marialite
Mizzonite
Wernerite
Meionite
MICAS
Phlogopite
Muscovite
Biotite
EPIDOTE
Allanite
Zoisite
Clinozoisite
Epidote
Vesuvianite
Tourmaline
OLIVINE
Fayalite
Hortonolite
Olivine
Monticellite
Forsterite
Titanolivine
ACCESSORY AND UNCOMMON
SPINELS
GARNETS
Almandite
Spessartite
Grossularite
Pyrope
Melanite
Corundum
Titanite
Zircon
Monazite
Cassiterite
Apatite
Topaz
Cordierite
Gypsum
Anhydrite
Hydrargillite
Alunite
Lazulite
Prehnite
Andalusite
Sillimanite
Cyanite
Staurolite
Diaspore
Periclase
Axinite
Datolite
Lawsonite
Ottrelite
Helvite
Hussakite
Ilvaite

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Actinolite	1.612	1.627	1.639	0.027
	1.600	1.616	1.628	0.028
Aegirite	1.763	1.799	1.813	0.040
Albite	1.529	1.532	1.539	0.010
Allanite	1.78	?	?	0.032
	?	1.68	?	.....
Almandite	1.809	.....	.....	.....
Alunite	1.592	1.572	.....	0.020
Analcite	1.487	.....	.....	.....
Andalusite	1.632	1.638	1.643	0.011
Andesine	1.549	1.553	1.555	0.006
Anhydrite	1.570	1.576	1.614	0.044
Anomite (Var. Biotite)	.....	.....	.....	.....
Anorthite	1.575	1.584	1.588	0.013
Anorthoclase	1.523	1.528	1.529	0.006
Antophyllite	1.633	1.642	1.657	0.024
	1.629	1.630	1.640	0.011
Antigorite	1.490	1.502	1.511	0.022
	1.560	1.570	1.571	0.011
Apatite	1.629	1.631	.....	0.002
	1.641	1.645	.....	0.004
Apophyllite	1.536	1.534	.....	0.002
Aragonite	1.528	1.676	1.681	0.153
	1.534	1.689	1.694	0.160
Astrophyllite	1.678	1.703	1.733	0.055
Augite	1.688	1.701	1.713	0.025
	1.712	1.717	1.733	0.021
Axinite	1.672	1.678	1.681	0.009
Barkevikite	1.687	1.707	1.708	0.021
Biotite	1.541	?	1.580	0.039
	1.580	?	1.638	0.058
	1.504	1.589	1.589	0.085
Breislakite (Var. Ilvaite)	.....	.....	.....	.....
Breunnerite	1.528	1.717	.....	0.189
Brewsterite	?	1.45	?	0.012
Bronzite (betw. Enstatite and Hypersthene)	.....	.....	.....	.....
Brookite	2.583	2.586	2.741	0.158
Brucite	1.580	1.559	.....	0.021
Bytownite	1.561	1.564	1.569	0.008
Calcite	1.486	1.658	.....	0.172
Cancrinite	1.499	1.522	.....	0.023
Carpholite	1.627	?	?	0.022
Cassiterite	1.979	2.080	.....	0.101
	2.012	2.108	.....	0.096
Celsian	1.584	1.587	1.594	0.010
Chabazite	1.5	?	.....	0.003
	1.46	?	.....	0.002
Chalcedony	1.533	1.536	1.544	0.011
Chiastolite (see Andalusite)	.....	.....	.....	.....
Chloritoid (see Ottrelite)	.....	.....	.....	.....
Chondrodite	1.607	1.619	1.639	0.030
Chrysolite (see Olivine)	.....	.....	.....	.....
Clinozoisite	1.714	1.716	1.724	0.010
Clinohumite	?	1.670	?	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Clinochlore	1.585	1.586	1.596	0.011
Cordierite	1.532	1.536	1.539	0.007
	1.592	1.597	1.599	0.007
Corundophilite	?	1.583	?	.....
Corundum	1.758	1.766	.....	0.008
Cummingtonite	?	1.64	?	.....
Cyanite	1.712	1.720	1.728	0.016
Danalite (see Helvite)	.....	.....	.....	.....
Datolite	1.624	1.653	1.669	0.045
Diallage (see Diopside, Hedenbergite, and Augite)	.....	.....	.....	.....
Diaspore	1.702	1.722	1.730	0.028
Diopside	1.699	1.706	1.717	0.018
	1.671	1.678	1.700	0.029
Dipyre (see Mizzonite)	.....	.....	.....	.....
Disthene (see Cyanite)	.....	.....	.....	.....
Dolomite	1.503	1.682	.....	0.179
Dumortierite	1.678	1.686	1.689	0.011
Enstatite	1.656	1.659	1.665	0.009
	1.665	1.669	1.674	0.009
Epidote	1.730	1.754	1.768	0.038
Epistilbite	?	1.51	?	0.010
Eucolite	1.618	1.621	.....	0.003
Eudyalite	1.614	1.612	.....	0.002
	1.606	1.604	.....	0.002
Fayalite	1.824	1.864	1.874	0.050
Fluorite	1.434	.....	.....	.....
Forsterite	?	1.659	?	.....
Gahnite	1.765	.....	.....	.....
Gastaldite	1.640	1.656	?	0.018
	.....	.....	.....	0.024
Gedrite	1.623	1.636	1.644	0.021
Gehlenite	1.658	1.663	.....	0.005
Gibbsite (see Hydrargillite)	.....	.....	.....	.....
Glaucophane	1.621	1.638	1.639	0.018
Gmelinite	1.467	1.476	.....	0.009
	1.464	1.465	.....	0.001
	1.478	1.480	.....	0.002
Goethite	?	2.5	?	.....
Grandidierite	1.602	1.636	1.638	0.036
Grossularite	1.744	.....	.....	.....
	1.757	.....	.....	.....
Grünerite	?	1.73	?	0.056
Gypsum	1.520	1.523	1.530	0.010
Hainite	?	1.7	?	0.012
Harmotome	1.503	?	1.508	0.005
Hiortdahlite	?	1.68	?	0.017
	?	1.71	?	0.020
Hedenbergite	1.732	1.737	1.751	0.019
Hauynite	1.496	.....	.....	.....
	1.504	.....	.....	.....
	1.483	.....	.....	.....
Helvite	1.739	.....	.....	.....
Hercynite	1.749	.....	.....	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ε; α	ω; β	γ	
Heulandite	1.498	1.499	1.505	0.007
Green Hornblende	1.640	1.643	1.656	0.016
Basaltic Hornblende	1.680	1.725	1.752	0.072
Hortonolite	1.768	1.792	1.803	0.035
Humite	?	1.643	?	0.038
Hussakite	1.816	1.721	.....	0.005
Hyalite	1.437	.....	.....	.....
	1.458	.....	.....	.....
Hyalophane: Or^4Ce^1	1.537	1.540	1.542	0.005
Or^7Ce^3	1.542	1.542	1.547	0.005
Hydrargillite	1.535	1.535	1.558	0.023
Hydronephelite	1.49	?	.....	0.012
Hydrophane	1.368	.....	.....	.....
	1.451	.....	.....	.....
Hypersthene	1.692	1.702	1.705	0.013
	1.716	?	1.727	0.011
Ilvaite	?	1.89	?	.....
Jadeite	?	1.654	?	0.029
Kaolin	1.54	?	?	0.008
Kornerupine (see Prismatine)	.....	.....	....	.....
Labradorite	1.555	1.558	1.563	0.008
Laumontite	1.513	1.524	1.525	0.012
Låvenite	?	1.750	?	0.030
Lawsonite	1.665	1.669	1.684	0.019
Lazulite	1.603	1.632	1.639	0.036
Leucite	1.509	1.508	.....	0.001
Leucophanite	1.571	1.595	1.598	0.027
Lievrite (see Ilvaite)	.....	.....	.....	.....
Lussatite	1.446	.....	.....	.....
Magnesite	1.515	1.717	.....	0.202
Margarite	?	1.64	?	0.009
	?	1.65	?	.....
Marialite	1.542	1.555	.....	0.013
Meionite	1.557	1.594	.....	0.037
Melanite	1.857	.....	.....	.....
Melilite	1.629	1.634	.....	0.005
Meliphanite	1.593	1.613	.....	0.020
Mizzonite	1.546	1.566	.....	0.020
Monazite	1.796	1.797	1.841	0.045
	1.786	1.789	1.837	0.051
Monticellite	1.650	1.662	1.668	0.018
Mosandrite	1.646	1.649	1.658	0.012
Muscovite	1.560	1.594	1.598	0.038
	1.569	1.605	1.612	0.043
Natrolite	1.478	1.482	1.492	0.014
Nephelite	1.538	1.543	.....	0.005
Noselite	1.483	.....	.....	.....
	1.504	.....	.....	.....
Octahedrite	2.489	2.562	.....	0.073
Oligoclase	1.540	1.544	1.547	0.007
Olivine	1.654	1.670	1.689	0.035
Opal	1.442	.....	.....	.....
	1.450	.....	.....	......
Orthite (see Allanite)	.....	.....	.....	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Orthoclase	1.519	1.524	1.527	0.008
Ottrelite	?	1.741	?	0.016
Pargasite (common Hornblende)	1.613	1.620	1.632	0.019
Pectolite	?	1.61	?	0.038
Penninite	1.576	1.577	.....	0.001
Periclase	1.731	.....	.....	.....
	1.741	.....	.....	.....
Perowskite	2.38	.....	.....	.....
Phillipsite	?	1.51	?	.....
	?	1.57	?	0.003
Phlogopite	1.562	1.606	1.606	0.044
Picotite (see Spinel)	.....	.....	.....	.....
Pleonaste (see Spinel)	.....	.....	.....	.....
Prismatine	1.669	1.680	1.682	0.013
Prehnite	1.616	1.626	1.649	0.033
Pyrope	1.741	.....	.....	.....
	1.750	.....	.....	.....
Quartz	1.553	1.544	.....	0.009
Riebeckite	1.687	?	?	0.005
Rinkite	1.665	1.668	?	0.003
Rosenbuschite	?	1.65	?	0.026
Rutile	2.903	2.616	.....	0.287
Sapphirine	1.706	1.709	1.712	0.006
Scapolite (see Wernerite)	.....	.....	.....	.....
Scolecite	?	1.495	?	0.008
	?	1.502	?	.....
Serendibite	?	1.7	?	weak
Serpentine	?	1.54	?	0.013
Siderite	1.634	1.872	.....	0.238
Sillimanite	1.658	1.659	1.678	0.020
Sismondine (see Ottrelite)	.....	.....	.....	.....
Sodalite	1.483	.....	.....	.....
	1.486	.....	.....	.....
Spessartite	1.810	.....	.....	.....
Spinels (Red)	1.716	.....	.....	.....
(Blue)	1.720	.....	.....	.....
Spodumene	1.651	1.669	1.677	0.026
Staurolite	1.736	1.741	1.746	0.010
Stilbite	1.494	1.498	1.500	0.006
Talc	1.539	1.589	1.589	0.050
Thomsonite	1.497	1.503	1.525	0.028
Titanite	1.888	1.894	1.979	0.091
Titanolivine	1.669	1.678	1.702	0.033
Topaz (Fl)	1.607	1.610	1.618	0.011
(OH)	1.629	1.631	1.638	0.009
Tourmaline (White)	1.620	1.639	.....	0.019
(Blue)	1.631	1.653	.....	0.022
(Chrome)	1.641	1.687	.....	0.046
Tremolite	1.599	1.612	1.624	0.025
	1.609	1.623	1.635	0.026
Tridymite	1.479	1.477	.....	0.002
Uvarovite	1.838	.....	.....	.....
Vesuvianite	1.701	1.705	.....	0.004
	1.726	1.732	.....	0.006

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Wernerite	1.553	1.583	.....	0.030
Wöhlerite	1.700	1.716	1.726	0.026
Wollastonite	1.619	1.632	1.634	0.015
Zircon	1.993	1.931	.....	0.062
Zoisite	1.696	1.696	1.702	0.006
	1.700	1.702	1.706	0.006

published in Rosenbusch-Wülfing, and all that are shown in the diagram. The first column gives n for isometric, ϵ for uniaxial, or α for biaxial minerals. The second column gives ω for uniaxial or β for biaxial minerals, as the case may be. The third column gives γ and the fourth gives the maximum birefringence. When an index is lacking the fact is indicated by a question mark.

The diagram illustrates very forcibly the need for some simple microscopic means of measuring the indices of minerals in thin sections. Various means are available at present for finding the index of mineral faces one or two millimeters in diameter, but no successful apparatus which will serve to use as an attachment to an ordinary petrographic microscope has been devised. The writer has had to give up any idea of working on such a help for students, as his interests are directed into other branches of the science, but it is hoped that this will fall into the hands of someone who will be interested enough to solve the problem.

HIGHLY FOLDED BETWEEN NON-FOLDED STRATA AT TRENTON FALLS, N. Y.

W. J. MILLER
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While engaged in field-work for the New York Geological Survey during the summer of 1907, excellent examples of highly folded between non-folded strata were observed at Trenton Falls, north of Utica, New York.[1] The phenomenon occurs in the classic Trenton limestone at its type locality. Vanuxem[2] and T. G. White[3] are the only ones who have described and attempted to explain the phenomenon at Trenton Falls.

Layers of highly folded and broken limestone included between perfectly straight and undisturbed limestone layers are well exhibited along the sides of the gorge at Trenton Falls. The impure limestone layers of both the folded and the non-folded portions average only a few inches in thickness and are separated by thin shale bands. The folded beds lie at two distinct horizons within the limestone formation which here shows a thickness of 270 feet. Prosser and Cummings[4] have made careful measurements of the thickness of the Trenton limestone at this locality. According to them the base of the lower folded zone lies 144 feet below the top of the Trenton. This contorted zone is about four or five feet thick and is visible only opposite the top of the lower part of High Fall and in the upper end of the gorge near Prospect village where the strata are highly inclined. It is well shown in Fig. A, Pl. III of White's article. Prosser and Cummings do not definitely refer to the upper folded zone in their paper,

[1] Published by permission of Dr. J. M. Clarke, State Geologist of New York.

[2] *Natural History of New York—Geology of the Third District*, p. 53.

[3] "The Faunas of the Upper Ordovician Strata at Trenton Falls, Oneida Co., N. Y.," *Transactions of the N. Y. Academy of Sciences*, Vol. XV, pp. 71–96.

[4] Prosser and Cummings, *Sections and Thickness of the Lower Silurian Formations on West Canada Creek and in the Mohawk Valley*, 15th Annual Report of the N. Y. State Geologist, pp. 615–27.

but its base occurs well down in their zone A^8 or about sixty-five to seventy feet below the top of the Trenton limestone. This contorted zone is about eight or ten feet thick and is well shown along the path opposite High Fall. From this point it may be traced along the sides of the gorge for nearly two miles to near the village of Prospect.

Within the folded zones the layers are, in rare instances, scarcely disturbed; sometimes they are only gently folded; most commonly they are highly twisted or contorted; while occasionally some of the layers are broken and pushed or faulted over others.

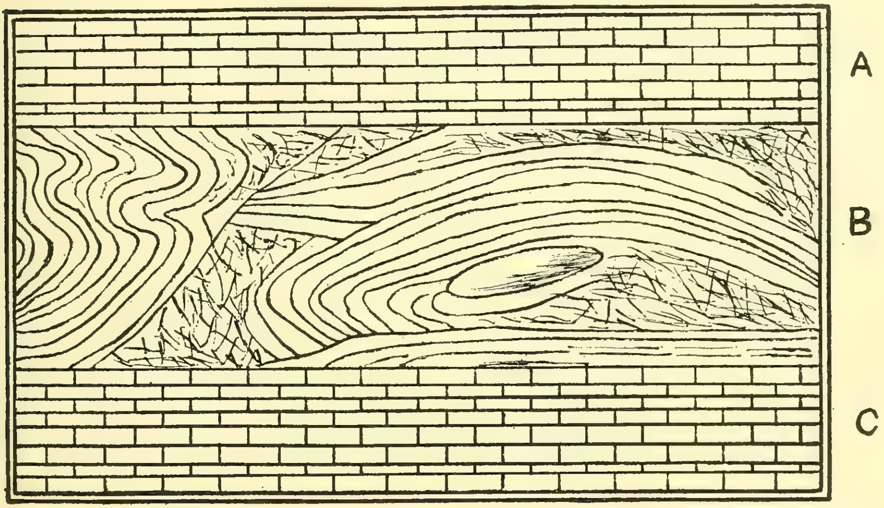

FIG. 1.—Sketch showing highly folded and broken limestone layers between undisturbed beds as seen along the foot-path opposite the top of High Fall, Trenton Falls, N. Y. Scale: one inch = six feet.

In those places where the folding has not been carried to an extreme, numerous observations show the axes of the folds to run generally from N. 50° E. to N. 65° E. The strike of these minor folds corresponds closely to the strike of a fault which the writer has found to extend from Prospect village past the village of Trenton. Also the whole Trenton limestone formation has, in this vicinity, been thrown into a number of very low folds which show about the same strike as above given.

It should be noted that these highly folded layers occur only in a

very local district. Numerous observations are not possible because of the heavy drift covered areas, but, as far as can be ascertained, these highly folded layers are visible only in the Trenton Falls gorge and in the bed of Cincinnati creek, one and one-half miles southwest of Prospect. Along Mill creek, near Gravesville, several miles to the southeast, most of the Trenton section is exposed but the folded layers have not been found there.

Similar phenomena of highly folded between non-folded strata have been observed in the stratified clay banks of Pleistocene age along Black River to the north of Trenton Falls and also in the banks along the canal feeder west of Forestport. The latter occurrence has been described and figured by Vanuxem.[1]

CAUSE OF THE FOLDING[2]

Vanuxem[3] states that the folded layers are more thoroughly crystalline than the undisturbed layers above and below and that as the material of the disturbed layers was being crystallized it caused an expansion which manifested itself laterally by throwing the layers into folds. However, a careful examination of the layers in the folded zone and those above and below fails to show any real difference in degree of crystallization. Even if such a difference in degree of crystallization were present, it is difficult to see how simple crystallization of the mass could bring about such a considerable lateral expansion.

T. G. White[4] cites Professor W. O. Crosby as suggesting that the folds may have been caused by the great weight of overlying strata. According to this view it is extremely difficult to explain the sharp and even overturned folds and the minor thrust faults which imply a distinct shortening of the layers within the folded zones.

In many places the structure of the upper folded zone greatly simulates cross-bedding and the writer was at first of the opinion that it, in reality, did show cross-bedding. The close association, in the same zone, of truly folded and broken strata soon caused this idea

[1] *Op. cit.*, pp. 214, 215.

[2] The writer here wishes to express his thanks to Dr. C. K. Swartz of the Johns Hopkins University for suggestions regarding the cause of the folding.

[3] *Loc. cit.*, p. 90.

[4] *Op. cit.*, pp. 88–90.

to be cast aside. White[1] gives photographs showing supposed overlap structure and channel filling. These structures appear to be merely parts of the disturbed zones, described in this paper, where the beds have been broken or only gently folded.

It has occurred to the writer that the phenomenon might have been due to a lateral compression within the region, which caused most of the limestone beds to become denser without being greatly folded, while certain other layers yielded to the compressive force by folding. Such an explanation would imply a difference in texture between the folded and non-folded strata, but such a difference is not noticeable. Also it would seem to assume that the folded zone was more rigid while the evidence appears to indicate, if anything, that it was less rigid.

It is thought that the folded structure at Trenton Falls was in reality caused by a differential movement within the mass of the Trenton limestone. That the whole body of the limestone has been moved is clearly demonstrated by the existence of a thrust fault, of considerable throw, passing Prospect village. The displacement was sufficient to cause beds of the middle Trenton to slide over beds of the upper Trenton. Near the fault-plane the beds on the upthrow side are bent upward at angles of from thirty to forty degrees. The following figure, shows the relation of the fault to the folded zones.

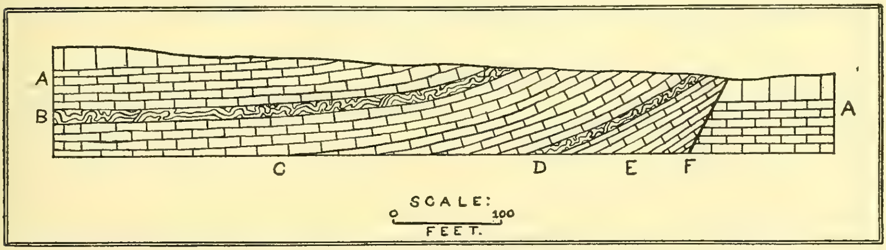

FIG. 2.—Section showing the position of the two folded zones in the Trenton limestone and their relation to the thrust fault at Prospect, near Trenton Falls, N. Y.

It is easy to see how when the force of compression was brought to bear in the region there would be a tendency for the upper Trenton beds on the upthrow side to move more easily and consequently faster than the lower Trenton beds. For instance the portion A in

[1] *Op. cit.*, Pl. III, Fig. B, and Pl. IV, Fig. B.

Fig. 2 being separated from C by an intermediate mass B of slightly less rigidity would slide over C and cause the portion B to become ruffled or folded. Occasionally parts of zone B would become fractured or faulted. The portion B would need to be only slightly less rigid than the adjacent portions. The somewhat thinner limestone layers separated by thicker shale partings would be sufficient to cause the part B to be thus less rigid. A similar explanation would also apply to the lower folded zone. The folded zones thus merely indicate horizons of weakness along which the differential movement has taken place.

As thus explained it is evident why the strike of the minor folds, the strike of the fault, and the strike of the large low folds of the region should all be parallel, since all these phenomena were produced by the same pressure. Also the local character of the phenomena under discussion is readily explained, since the conditions for their formation exist only in the vicinity of the fault.

Where phenomena of this kind occur even in regions of low folds, but without faults, it is thought that the above explanation will suffice, because during the process of folding there would be more or less of a tendency for certain strata to slide over others. Where the conditions of relative rigidity, etc., were favorable, certain strata just beneath the sliding masses might become ruffled or folded.

The locally folded clay layers between non-folded layers along Black River, above mentioned, are to be explained in a somewhat similar manner. Vanuxem says: "The layers show a series of contortions of different kinds, for which no cause can reasonably be assigned but different degress of lateral pressure." Since there is no noticeable difference between the characters of the disturbed and the undisturbed beds and since the intensity of the folding is often so great, Vanuxem's explanation is not at all satisfactory. The required differences in degree of lateral pressure are altogether too great. The writer believes that, in principle, the explanation given for the Trenton Falls occurrences applies here also, although in the case of the clay beds the movement of the upper over the lower masses may have been caused by ice action or by having been pulled down the hillsides by gravity. Or as Salisbury and Atwood[1] have suggested for such

[1] *Jour. Geol.*, Vol. V, 1897, p. 143.

a phenomenon in Pleistocene clay, the cause may have been lake ice or "the grounding of an iceberg on the surface before the overlying layers were deposited." In any case the cause of the movement in these superficial clays appears to be different from that of the ancient Trenton limestone.

GEOTECTONICS OF THE ESTANCIA PLAINS

CHARLES R. KEYES

Prefatory.—The Estancia Plains lie in central New Mexico. They form the extreme northern portion of the vast Mexican tableland. In length they extend a distance of 150 miles; in width about 30 miles.

Previous to the year 1900 the Estancia Plains were regarded as the highest and driest bolson east of the continental divide. For this reason, if for no other, the underground-water possibilities of this region offered a theme for consideration that was of great interest. Large industrial interests made possible the investigations necessary to decipher the geological structure. Three new lines of railway were under construction across these plains and good water-supplies became a matter of prime import.

General features.—Geographically the Estancia Plains are located at the juncture of the four greatest physiographic provinces of our continent: The Great Plains, the Rocky Mountains, the Mexican tableland, and the Colorado plateau. There are within the borders of the Estancia area three very distinct types of orogenic structures. These are superimposed upon a general and very remarkable epeirogenic uprase.

At the north and east is the Rocky Mountain type, illustrating tremendous compressive action. Over the west and south the basin-range type of structure is finely shown in the immense tilted block mountains. In the west-central portion is the laccolithic type, represented by four distinct dome-shaped masses which have spread apart Cretacic strata.

In the main, the geologic structure of the Estancia Plains is that of a broad trough, but there are many interruptions and local deformations (Fig. 1). As compared with the structure of the Jornada del Muerto[1] farther south there is not nearly the regularity (compare

[1] *Water Supply Paper No. 123*, U. S. Geological Survey, 1904.

with Fig. 2). As in the case of the latter plain the general aspect is that of a wide shallow valley which has a tendency to impart something of a synclinal character to the substructure. This apparent general relief feature, however, bears no relationship to the arrangement of the formations beneath. The surface of the plains is not a stratum-plane, as is naturally at first inferred, but a plane worn out in part at least on the beveled edges of the strata below, which lie at many different angles and dip in many different directions.

FIG. 1.—General structure of Estancia Plains.

This general structure of the plains appears to have been the characteristic feature of the region before their continuity was interrupted by the faulting which gave rise to the block mountains, and by the laccolithic intrusions.

In most of the parallel bolsons and valleys which are found in the high tableland region of New Mexico the bounding mountain blocks are so tilted that across some plains great fault-scarps face each other, as in the case of the Jarilla bolson immediately south of the Estancia district. Here the abrupt fault-scarp of the Sierra San Andreas, rising over 3,000 feet above the level of the plains, faces the equally abrupt scarp of the Sacramento Range to the east which rises even higher. In other instances, as in the Jornada to the southwest of the Estancia Plains, the main portion of the bolson is flanked on either side by the gentle backslopes of the monoclinal blocks. The fundamental plan of geologic structure is best indicated by diagram

FIG. 2.—Structure of the basin ranges in central New Mexico.

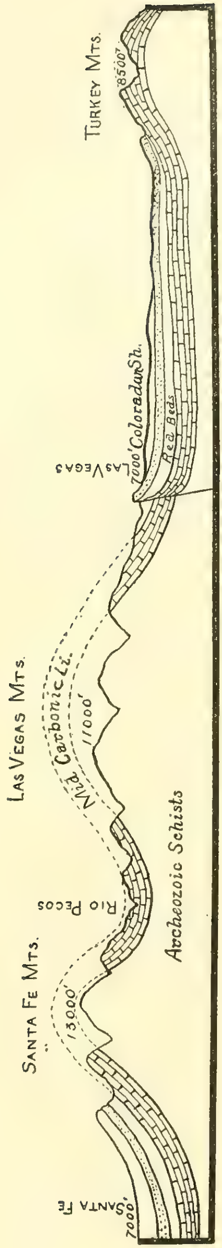

Fig. 3.—Geologic cross-section of the southern Rocky Mountains.

(Fig. 2). A similar arrangement representing the structure of the Estancia Plains is shown in Fig. 1.

The important factor to be taken into account in this region is the fact that the local geologic structure is not nearly so simple as it may at first glance appear. Everywhere there is greater or less complication. The great backslopes of the tilted mountain blocks, instead of being continuous stratum-planes, are found to be faulted at frequent intervals; and the dips of the rocks change within very short distances.

Rocky Mountain type of structure.—The compressive type of mountain structure finds expression in the Estancia Plains region only in the extreme northeastern part, where the Rocky Mountains end by plunging downward beneath the plains surface. Only a single southward-pitching arch is represented within the limits of the district under consideration. Farther to the eastward the details of structure are more complete. The cross-section to the plains of Las Vegas beyond is well worth much more consideration than can be given it here (Fig. 3).

There is abundant evidence of marked compressive action within the plains area here described, the geologic date of which is probably somewhat earlier than that which the southern nose of the Rockies represents. This period of compression was Early Cretacic. While the evidences are very clear within the limits of the Estancia region there are more abundant exemplifications a short distance outside of this area. On the

Chupadera Mesa just south of Estancia there is an unusually good exposure bearing directly upon this fact (Fig. 5). In some other examples the geologic dates of the compressure are not so clearly set off. In the Sierra de los Caballos where a thrust-plane is shown to advantage (Fig. 4), the movement may have been very recent.

Basin-range type of mountain structure.—In marked contradistinction to the type just described the basin ranges are the result of faulting on an enormous scale. The mountain blocks, rising 3,000 to 5,000 feet above the general level of the high plains which itself is 6,000 feet above the sea, appear tilted as ice cakes in a stream.

There are several instructive features relating to the structure of the Desert ranges that are shown better in and about the region under consideration than anywhere else in the Southwest. Recently a new interest has been awakened in the tectonics of the Great Basin by the publication of a number of more or less suggestive articles. The main structural features about which discussion centers appear to be whether the basin ranges are the result of normal faulting and form "block mountains;" or whether the "block" aspect is only apparent, the monoclinal "blocks" originally being, in reality, sharp asymmetric folds in which subsequent erosion has worn off the steeper limb faster than the other.

In the elucidation of the arguments by specific example, it is unfortunate that many of the illustrations selected have not been chosen with greater discernment. It is now well understood that some of the instances noted furnish the most conclusive proofs directly contrary to the purposes for which they were cited. Without entering into details in regard to many of these cited examples from other parts of the Great Basin region it seems pertinent at this time to call attention briefly to certain features displayed in the New Mexican part of the field. These may help to explain similar phenomena in other districts.

As has recently been noted, the geologic sequence in central New Mexico is especially noteworthy on account of the almost complete absence of the Paleozoic rocks and the enormous development of Mesozoic strata. The important member of the sequence above the Azoic metamorphics is the Mid Carbonic limestone which attains a normal thickness of over 2,000 feet.

No evidence has yet been found that would indicate that any of the present mountain blocks were produced by folding. All observations go to show on the other hand that only faulting is involved. To be sure the sedimentaries of some of these mountains are often folded and closely corrugated. Thrust-planes are plainly visible. Numerous other indications point to tremendous compression at some time or other. But the period of this compression has been found to be mainly a very different one from that during which the present mountains were formed. The compressive action was exerted long before the existing mountain blocks began to rear their heads above the vast plains. Chronologically this period of compressive

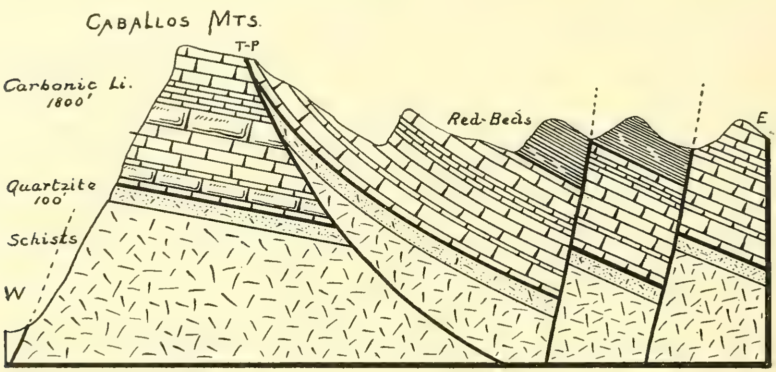

FIG. 4.—Old and modern faulting in Caballos Mountains.

conditions was manifestly subsequent to the Carbonic period because the rocks of this age are involved; but it was before the Late Cretacic period, since Cretacic strata are as clearly not affected.

Certain thrust-planes displayed in the Sierra de los Caballos, to the south of the Estancia region, the geologic sections of which have a bearing upon this point are particularly instructive while the production of others is thought to be somewhat later. Near the highest point of the range, known as Timber Peak, the fault-scarp is over 3,000 feet high and displays an excellent exposure of the rocks throughout this entire vertical distance. The transverse section of the mountain ridge, as shown a short distance to the north, is represented in diagram (Fig. 4). The heavy line, *T–P*, indicates the position of an exceedingly well-displayed thrust-plane. Along

it the beds are very much contorted. The inclination of this thrust-plane is now rather steep, but this is due partly to the fact that the present position of this structure is not the original one. Since the time of its formation the thrust-plane also has been tilted to a marked degree. In point of time the formation of the thrust-plane long antedates the uprising of the present mountain block.

There are in the Sierra de los Caballos at least three distinct periods of faulting. The first was before the formation of the present mountain ridge; the second was coeval with its formation; and the third was long subsequent to its uprising.

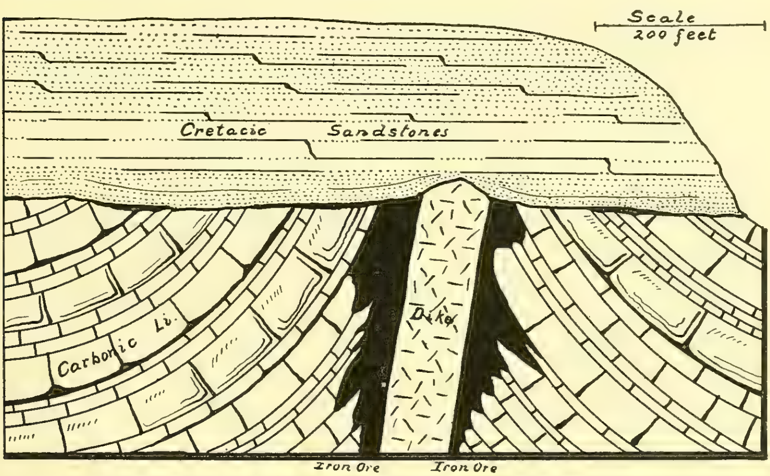

FIG. 5.—Unconformity of Cretaceous on Carboniferous, near Dios Springs.

Were it not for the exceptionally clear evidence to the contrary, casual examination could very easily lead to the conclusion that the Caballos mountain range had been produced by sharp folding, and that the crest of the asymmetric fold had been removed through erosion. The deduction is a natural one especially when in a view from the summit of the range there are plainly shown the strata dipping eastward to form a broad syncline, and coming up again with westerly dips in the great San Andreas block, 30 miles away.

It so happens that in the region under consideration the general sequence of geologic events is sufficiently well known to us to give a good insight into some of the actual conditions that have existed.[1]

[1] *American Journal of Science* (4), Vol. XVIII, pp. 356–58, 1904.

A number of observations lately made emphasizes the great importance of the unconformity at the base of the Cretacic strata of the region. For example, in the Chupadera Mesa in eastern Socorro County, there are found Carbonic limestones highly inclined on either side of huge trachyte dikes, over the whole of which recline nearly horizontally the Cretacic sandstones (Fig. 5). This surface of unconformity represents extensive land erosion. During the interval for which it stands the strata of the region were folded and planed off long before the later Cretacic sediments were laid down.

In nearly all of the basin ranges there are abundant evidences of marked compression producing the phenomena of folding. Yet in every instance personally observed the period of these movements is manifestly long prior to the elevation of the present mountains. The ancient tectonics of the basin ranges is a theme of very great interest.

There is another very deceptive feature connected with the formation of the blocklike mountains of some portions of the Mexican tableland. At the foot of the steeper slope the strata are often found to be tilted at a high angle and inclined away from the range. This attitude of the beds readily suggests at first the possibility of the mountain ridge's being a sharp anticline with the center completely removed through erosion, leaving the limbs of the arch unequally exposed. This condition might be easily fancied because of the fact that the greater part of the height of the mountains, 3,000 to 5,000 feet, is usually composed of massive crystallines and schists, while the crest and the backslope are of limestone.

There are many good reasons for believing that such phenomena as these instead of being ascribable to folding of the asymmetrical type are to be considered merely as an accompaniment of normal faulting. The displacement, however, is on a gigantic scale and under conditions not usually met with. When the hade is not vertical, or nearly so, the strata on the down-throw side to a greater or less degree lag, until a considerable zone is produced in which the beds become highly inclined and in many cases stand even nearly perpendicular. A typical instance is the Sandia Range, east of Albuquerque, as represented below (Fig. 6).

There are strong theoretical grounds for thinking that faulting

instead of folding is to be invoked to explain the structure of the so-called block mountains of the Great Basin region. The principle was clearly set forth by Le Conte[1] as long ago as 1889, when discussing the district between the Sierra Nevada and the Wasatch Mountains. As considered in his textbook[2] the same author has regarded the area in question as a region which was subjected to slow and general uprising but continually adjusted itself through normal faulting in great blocks. By the tilting of these blocks mountain ranges were produced on the elevated edge while on the depressed side were formed valleys which were subsequently filled with sediments. Lauterback[3] is inclined to modify this view

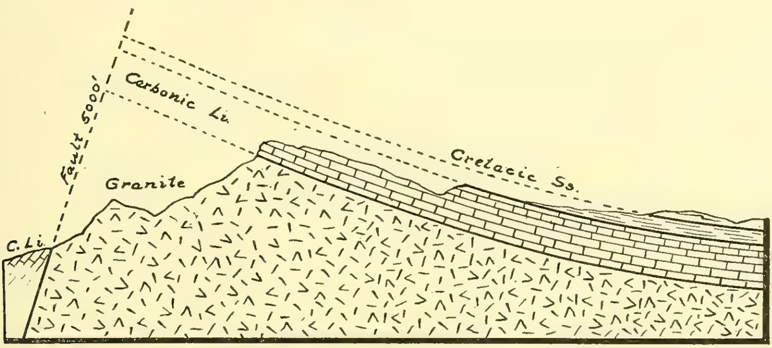

FIG. 6.—Fault-scarp of the Sandia Mountains.

somewhat by regarding the mountain block and the valley block as distinct.

The present relief features of the region are, however, mainly the product of general desert leveling, that is the result of eolian erosian under conditions of an arid climate, and the mountains are to be looked upon as remnantal ranges which are essentially monadnocks.

Laccolithic type of mountain structure.—In the northwestern part of the Estancia Plains there rise four isolated groups of lofty peaks. The several groups are five to six miles from one another and lie in a straight line trending nearly in a northeast and southwest direction. The southernmost group is known as the San Ysidro, or South

[1] *American Journal of Science* (3), Vol. XXXVIII, p. 259, 1889.

[2] *Elements of Geology*, 5th ed., p. 242, 1904.

[3] *Bulletin of the Geological Society of America*, Vol. XV, p. 343, 1904.

Mountains; then comes the Tuertos group; next, the Ortiz, Placer, or Gold mountains; and then, at the north, the Cerillos Hills.

At the present time each of these mountain groups is a huge, many-peaked boss of augitic and hornblendic andesite. Each also rises out of the Cretacic sandstones which are upturned all around. In some places great intrusive sheets extend out from the central mass to a distance of a dozen miles or more; and immense dikes radiate often to twice the distance named.

All evidence goes to show that each of the mountain groups is a laccolith. The molten material, forced upward from beneath, instead of reaching sky floated the overlying strata, forming enormous

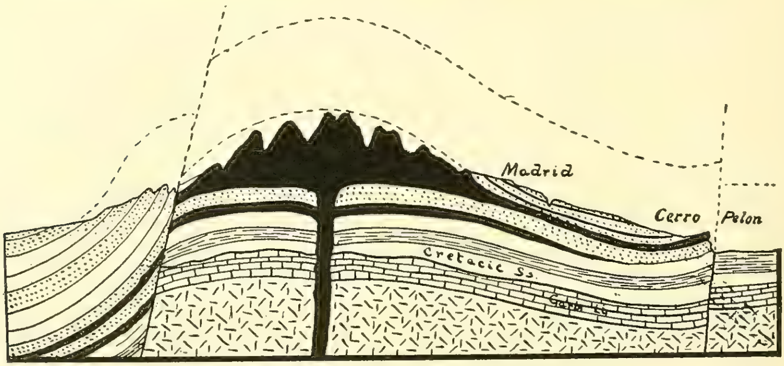

FIG. 7.—Structure of the Ortiz laccolith.

domes, the tops of which were subsequently removed through erosion. A cross-section of the Ortiz group indicates the structure as represented in Fig. 7.

The Ortiz group displays to best advantage the various phenomena of laccolithic nature. The Carbonic limestones have been completely changed by heat into garnet rock, as is well shown at the Lucas mine on the south side of the great dome. Many dikes and several sills have the Ortiz mass as a center. The largest sill extends southeastward to the Cerro Pelon, a distance of about twelve miles. This sill is more than 200 feet thick. The great intrusive sheet is of special interest in the present connection for reason of its penetrating the Cretacic coal measures. There are several important coal seams in close proximity to the intrusive sheet. Where the sill has come

directly into contact with the coal seam the latter has been entirely destroyed. When separated by a few feet of shale a fine grade of anthracite is produced. This variety of coal is extensively mined at the town of Madrid and elsewhere in the vicinity. Seams still farther removed from the sill are bituminous in character; while at a distance of 100 to 200 feet the coal seams are lignitic.

The relations of the sill to the coal seams suggest that the intrusive sheet itself may have followed along a large coal seam, perhaps the most extensive of all, as a horizon along which it was able to move

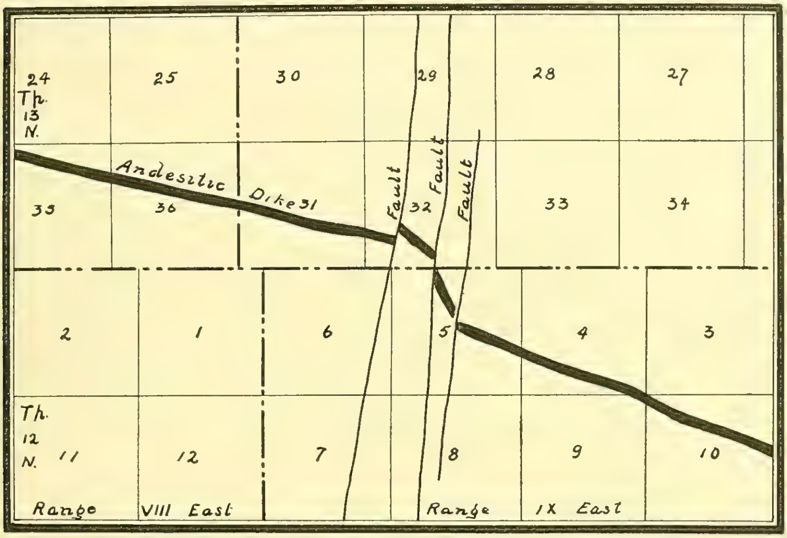

FIG. 8.—Plan of large dike cutting coal-field near Cerro Pelon.

most easily. Similar phenomena have been observed in the Scottish coal fields and in the coal fields of Germany and Hungary.

The dikes originating from the Ortiz mass often extend a score of miles across the plains as huge walls rising 100 to 200 feet above level surface. Some of these dikes show the amount of lateral displacement of the faults. One dike in particular has suffered movement in a remarkable way, as shown in the groundplan (Fig. 8). The squares in the cut are one mile in each direction.

Relations of the structure to the plains surface.—The even surface of the Estancia plains, vast as it is, is not, according to the strict physiographic usage of the term, that of a structural, or stratum-plane,

valley. While in general the rocks are only gently deformed they are locally sharply folded, highly inclined, or even standing on edge. As has been recently shown[1] bolson plains, of which the Estancia Plains are a type, have not the simple substructure that is commonly ascribed to them. They do not appear to be necessarily any newer or later than the plateau plains which overlook them. Their constructional detrital covering is no more important than that of the plateau plains. The wash-deposits brought down from the mountainous periphery are relatively of small importance.

On the other hand, it has been clearly demonstrated in a number of cases that the bedrock surface of the bolson plains, or that plane beneath the detrital covering, is a planation-surface worn out on the

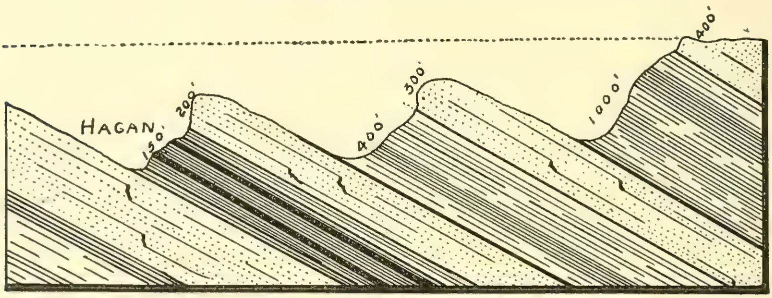

FIG. 9.—Alternation of Cretaceous shales and sandstones at Hagen, thickness about 4,000 feet.

beveled edges of the indurated sedimentaries. This feature is particularly well displayed in the plains between the Ortiz and Sandia mountains. At the Uña de Gato, near Hagan, the structure is as represented below (Fig. 9). The dotted line represents the plains surface; it extends to the right a distance of 20 miles.

The character of this beveling of highly inclined beds, in this case Cretacic sandstones, is admirably shown in the accompanying view near Los Cerrillos, from a photograph taken by Dr. D. W. Johnson. The horizontal beds at the top and above the old planed surface are composed of volcanic breccias, which in turn are overlain by late mesa clays and sands. (See Fig. 12.)

Characteristic rock-masses.—There are represented in the Estancia region five principal kinds of rock-masses. In the great fault-scarp

[1] *American Journal of Science* (4), Vol. XV, p. 207, 1903.

on the west face of the Sandia Mountains there are shown about 4,000 feet of schists, highly metamorphosed clastics, and old intruded granites. These are without much doubt Azoic in age.

Following the fundamental complex are blue limestones of great thickness. They are Mid-Carbonic in age. Above the limestones is normally a remarkable succession of red-beds consisting of shales and shaly sandstones which are doubtless, in great part at least, also of Mid-Carbonic age.

Then comes a prodigious mass of yellow sandstones and shales belonging to the Mid- and Late Cretacic Ages. Finally, are the surface loams, sands and gravels of variable thickness, of Tertiary and Quaternary ages.

Besides the five general classes of rock-masses referred to there is a variety of igneous types.

Geologic formations represented.—The general lithologic character, thickness, and stratigraphic relationships of the various geologic formations which are represented within the limits of the Estancia Plains area need not be described in detail at this time. Two terranal features should, however, be noted: The presence, in this region, of a great succession of "red-beds" fully 1,000 feet in thickness which is not the correlative homologe of the Kansas red-beds; and the remarkable sandstone forming the base of the Cretacic section of the region and to which the term Dakota sandstone has been long applied.

The red-beds of the Sandia side of the Estancia Plains have been termed the Bernalillo shales[1] and they represent the uppermost and third member of the Maderan series.[2] The fact that these "red-beds" are neither of Permian nor of Jura-Trias Age was first made known in 1900 by Herrick[3] who discovered in them a large and characteristic fauna, that clearly connected the section with the so-called Permo-Carboniferous section of central Kansas. The Kansas red-beds or Cimarronian series, and the Triassic red-beds have been shown to be entirely absent in central New Mexico.[4] The title Manzano formation which has been used for the beds in question is inapplicable.

[1] *Ores and Minerals*, Vol. XII, p. 48; also *Report of the Governor of New Mexico to Secretary of the Interior, for 1903*, p. 339, 1903.

[2] This *Journal*, Vol. XIV, p. 152, 1906.

[3] This *Journal*, Vol. VIII, p. 116, 1900.

[4] *American Journal of Science* (4), Vol. XX, p. 423, 1905.

To the eastward of the Estancia Plains there are three important "red-beds" formations, each nearly 1,000 feet thick, and superposed upon one another. They are of widely different geologic ages, and are separated by great erosional unconformities. One is of Mid-Carbonic Age, another of Late Carbonic Age, and the third of Triassic Age. Besides these red-beds there have been long recognized in the region other great red-colored terranes, in the Cretacic section, in the Tertiary section, and in the Devonic section.

At the base of the Cretacic section of this region the Rio Mora sandstone is an important member. It is the so-called Dakota formation of the early geologic reports of the Southwestern United States.

Unconformities.—All of the serial formations of New Mexico, as well as many of their minor members, are separated by marked planes of unconformity. Some of these indicate only notable oscillations of the old shorelines; but several of them are manifestly ancient erosion surfaces. Of the latter class may be mentioned the intervals represented by the sedimentation discordance between the Huronic crystallines and the Manzanan series, between the Cimmaronian and the Maderan, between the former and the Triassic, between the Triassic and the Cretacic, and between the last mentioned and the Cenozoic deposits.

In the interval between the top of the fundamental complex and the Manzanan limestones, there are missing all of the Cambric, the Ordovicic, the Siluric, the Devonic, and the Early Carbonic sequences. These are all very fully represented in the southern part of New Mexico. The interval between the Maderan series and the Cimmaronian shales and sandstones is occupied, a hundred miles south of the Estancia region, by about 3,500 feet of limestones and sandstones, known as the Guadalupan series and regarded as representing the true Permian of Russia. The great sequence of "red-beds," so long of uncertain geologic age, has thus lately been found to be partly of Mid-Carbonic, partly of Late Carbonic, and partly of Triassic Age; the three parts being separated by marked unconformities. A marked erosion unconformity also separates the Triassic shales from the Mid-Cretacic sandstones of the so-called Dakotan series. The missing terranes, represented by the Morrison beds of Jurassic Age and the

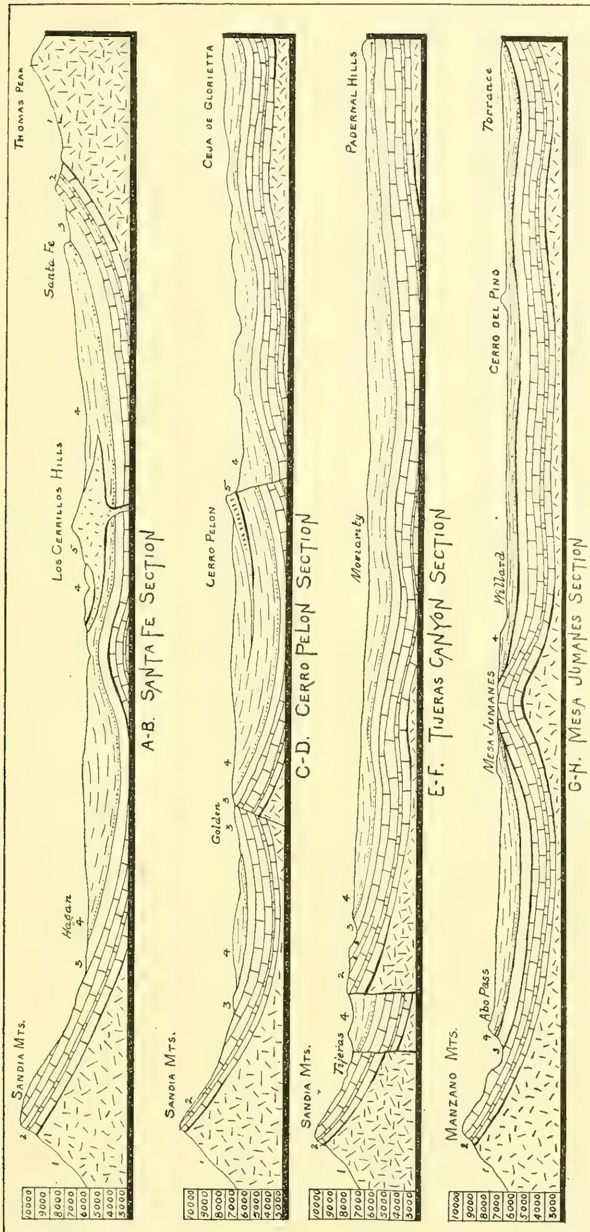

FIG. 10.—Geologic cross-sections of the Estancia Plains.

Comanche beds of Early Cretacic Age are both well displayed farther to the eastward near the Texas line.

General structural features.—The broader tectonic features of the region, as shown in the geologic cross-sections, offer some suggestive considerations regarding the forces which have been at work at the southern extremity of the Rocky Mountains. There are four cross-sections within the limits of the Estancia Plains that are particularly instructive. They may be called the northern section, the Cerro Pelon section, the typical plains section, and the southern section.

The northern, or Santa Fé, geologic cross-section extends from the Thomas Peak of the southern Rockies and a few miles southeast of the city of Santa Fé, in a southwesterly direction, to the Sandia Peak. The distance is 50 miles (section *A–B* of Group, Fig. 10). This section passes through the laccolithic dome of the Cerrillos Hills. In the main, the synclinal character is preserved between the Rocky Mountains and the Sandia Range. The blue Carbonic limestones are well displayed near both ends of the section. In the middle, a little to the south of the line of section, the limestones are also brought to the surface. All of the central part of the trough is occupied by Cretacic formations which are made up chiefly of sandstones.

The Cerro Pelon section trends nearly east and west (section *C–D*). The section is marked by two very pronounced faults which subdivide it into three nearly equal segments. The central portion owes its irregularities largely to the laccolithic disturbances of the neighborhood, the Ortiz group being on one side and the Tuertos group on the other. At the west end the section is monoclinal in character, there being very little if any rising of strata before the first fault is reached. Within this segment a short distance north of the section line several deep-drill wells have been put down.

The middle segment contains the Cerro Pelon, a sharp shoulder which is a feature of the landscape for a distance of many miles around. This hill rises 600 feet above the plain to the east. On its eastern face is a fault-scarp. The prominence of the elevation is due chiefly to the fact that it is capped by a plate of hornblendic andesite which has a thickness of over 400 feet. This capping-plate dips to the westward and is soon covered by the yellow sandstones of the Cre-

tacic Age. The andesitic plate is in reality a great sill, from the Ortiz laccolith, 12 miles to the westward, now bent into a broad syncline.

Some distance beneath the andesitic plate which crowns the Cerro Pelon dark clay-shales are exposed. The valley plain to the eastward is also occupied by soft black shales. At a point several hundred feet below the foot of the Pelon hill a core drill penetrated these shales to a distance of 800 feet without passing through them. They are therefore over 1,000 feet thick.

The dark shales dip to the westward—the valley plain being worn out on their beveled edges. Six miles to the east of the Cerro Pelon the bottom of the shale formation reaches the surface and then the underlying sandstones continue as the surface rocks to the edge of the Glorietta escarpment, forming the western cliff of the Rio Pecos.

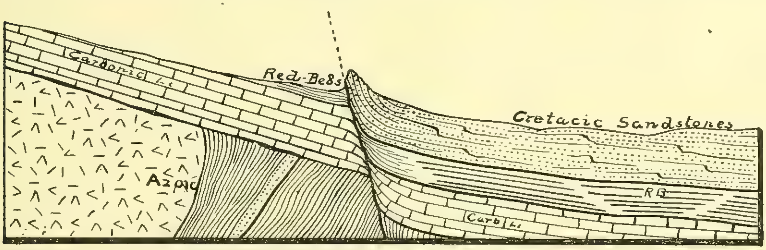

FIG. 11.—Fault bisecting the Sandia and Manzano ranges: displacement about 1,000 feet.

This eastern segment of the section is arching and is the pitching anticline by which the Rocky Mountains are terminated southward.

The Tijeras, or typical plains cross-section extends from the south end of the Sandia Range, at the upper end of the Tijeras Canyon, southeastwardly for a distance of 50 miles to the Padernal Hills, which form the drainage divide between the Estancia Plains and the Valley of the Pecos River (section *E–F* of Group, Fig. 10).

The most characteristic feature of this section is the even surface of the plains worn out on the beveled edges of the strata beneath. Only near the Sandia Range do the strata display any indications of marked dislocation. One of these faults has enabled the Tijeras Canyon to be formed between the Sandia and Manzano ranges. This fault (Fig. 11) has a throw of over 1,000 feet. At the hamlets of Tijeras and San Antonio it is well displayed. At the last-mentioned

FIG. 12.—Tilted Cretaceous sandstones overlain by horizontal volcanic breccia, near Los Cerrillos, height 400 feet.

place the line of movement is marked by a long, high ridge formed of Cretacic sandstones standing on edge.

The southern, or Mesa Jumanes, cross-section passes eastward from the crest of the Manzano Mountains, over the northern extremity of the plateau plain known as the Mesa Jumanes, to beyond the Cerro del Pino near Torrance (section *G–H*, Group, Fig. 10). The western part of the section is synclinal in character with Cretacic beds as the surface rock. The Mesa Jumanes is a tableland with even surface which is elevated 300 feet above the level of the surrounding plains. Its sides are very steep. It appears to have an anticlinal structure, with Carbonic limestones forming the central part. The margins are composed of Cretacic sandstones. The explanation of this remarkable plateau plain appears to be found in the physiography of the region farther to the northeastward. It is believed that the Estancia Plains once formed a part of the Las Vegas plateau which extends northward to the Colorado line, and that the elevated Mesa Jumanes is a remnant of the Ocate plateau so conspicuous to the north of the city of Las Vegas.

THE PHYSICAL ORIGIN OF CERTAIN CONCRETIONS[1]

JAMES H. GARDNER

The literature on the subject of concretions is somewhat limited in extent, and consists largely of descriptive rather than theoretical matter. It is safe to say, however, that distinct types present different problems for solution, and have resulted from divers combinations of chemical and physical laws. The forces brought to play in the forming of one kind may have played no part in the creation of another. Types vary to such a degree that a valid classification is difficult to prepare. Certain writers have made general classifications with reference to manner of growth; for instance, Dana[2] employs the terms "centrifugal" and "centripetal" concretions for growths to and from a center respectively. The latter includes principally concretions of a geodal character. In a similar way the terms "excretions" and "incretions" have been used.[3]

There can be no doubt as to the occurrence of these two general types, but it has been supposed, in many cases, that concretions have originated only through chemical phenomena. There are exceptions, however, in which certain forms of rounded nodules have been considered as resultant forms of physical forces. Kindle[4] accounts for certain concretions of the Chemung by pressure of rising gases of organic origin beneath impervious strata in a semi-plastic state. This idea was suggested by observation of Agassiz and Horsford on "raised hemispherical surfaces" in clayey mud near Cambridge.[5] Kindle makes use of this theory to account for a band of undistorted fossils along the vertical and lower horizontal surfaces of certain of

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

[2] J. D. Dana, *Manual of Geology*, 4th ed., p. 98.

[3] J. E. Todd, "Concretions and Their Geological Effects," *Bulletin of the Geological Society of America*, Vol. XIV, p. 361.

[4] E. M. Kindle, "Concretions in Chemung of Southern New York," *American Geology*, June, 1904.

[5] *American Association for the Advancement of Science*, Vol. IV, p. 12.

the Chemung concretions in southern New York. He supposes that the fossils once occupied a definite horizon and have been pushed upward and around the superjacent material which forms the body of the concretion. Kessler and Hamilton,[1] after giving an analysis of a certain gabbro and contained concretions, conclude with the remark: "This similarity in chemical composition seems to denote that the cause which set about the formation of the spheroids was not a chemical phenomenon." The writers refer to the explanation of Vogelsang[2] in the type locality, Corsica; the latter suggested that this concentric arrangement may be due to irregular areas of cooling and contraction. Blake[3] in referring to the concretionary structure in white volcanic lava of Tucson, Arizona, takes the view that concentric structure, in that case, has been formed by deposition around inclusions through action of permeating ground water.

It is apart from the discussion here, however, to deal with the concretionary and spheroidal structure of many eruptive rocks. The present article is intended to consider the origin of certain types of concretions common to sedimentary deposits only, and especially those concentric nodules of argillaceous composition containing, in many instances, noticeable percentages of calcareous and ferruginous constituents, and to show that possibly physical forces have played no little part in the forming of many of the common spherical, elliptical, discoidal, or irregular concretions in shales or clays. In some cases concretions are known to have originated entirely from chemical solution; an instance of this class is found in the well-known "loess kindchen" of the loess deposits. These calcareous nodules are formed often as incrustated deposits around roots and small plant stems. Other occurrences present equal evidences of purely chemical origin. But many of the more or less rounded nodules of concentric structure and smooth surfaces have merely been alluded to as products of an affinity for like to like with no definite explanation as to how or why they were so formed. The theory of attraction or affinity of like to

[1] H. H. Kessler and W. R. Hamilton, "Orbicular Gabbro of Dehesa Co., California," *American Geology*, Vol. XXXIV, pp. 133–40.

[2] *Sitzungsberichte der niederrheinischen Geschichte*, Vol. XIX, p. 185, 1862.

[3] "Origin of Orbicular and Concentric Structure," *Transactions of the American Institute of Mining Engineers*, Vol. XXXVII, p. 39.

segregate to like, subsequent to deposition of beds, is not sufficient to account for many alluminous concretions in clays and shales. Often the composition of inclosing sediments is closely similar to that of the included concretion but is usually variable.

The writer holds that many such concretions are contemporaneous with the strata in which they are contained; that they have resulted through adhesion of particles in overloaded water volumes disturbed by currents.

During the seasons of 1906 and 1907 the writer observed concretions so formed under natural conditions in alluvial beds of Present Age. This was in the desert region of the San Juan Basin, New Mexico. Conditions were met with here such as are not common to the present land areas. The Rio Chaco, some 40 miles above its confluence with the Rio San Juan, may be taken as a type locality. Here the bed of the stream is made up of alternating layers of sand and alluvial clay. Water flows along the bed only during the winter and spring months or after extensive rains. The fall of the river is very slight. During the flow, vast amounts of sand and clay, or mud, are transported along by the sluggish stream. The water, disappearing rapidly through evaporation and absorption in this arid region, is forced to deposit its sediments along the way; first the heavy sand grains or tiny pebbles, then the finer sand, then the coarse clayey material, and finally the very fine silt, which is held in suspension, becoming more and more concentrated as the water is soaked up or is evaporated. Often this moving mixture is a mere viscid fluid. After the water ceases to run and dries away, a thin coating of clay is left over the surface of the stream bed. Resting in and on this layer are often to be seen great numbers of round, concentric clay concretions. The accompanying plate indicates the manner in which they are collected into aggregations. These concretions are solid but may easily be broken with the hands. Some show nuclei in the form of small pebbles or angular fragments but many of them appear to be of similar material throughout with no recognizable nuclei. Cross-sections revealed that some of them contain small pebbles and sand grains in certain concentric shells of their makeup. The majority average about 1¼ inches in diameter.

The origin of these concretions is not difficult to explain. In

the super-concentrated or overloaded water carrying fine clay particles along a smooth bottom, an adhesion of those particles naturally results. They are pressed together as are finely disseminated particles of butter in the everyday illustration of churning. They may unite with or without a nucleus. A soft nodule will form, grow, and become round by being rotated along its different axes as boys roll snowballs. It will be propelled by the current, gathering as it goes. It will pass over slightly different characters of materials and may gather at intermittent periods; hence different concentric shells will

FIG. 1.—Clay balls in the bed of the Rio Chaco, New Mexico.

result. Should it pass over sandy particles or small pebbles, it will gather them up and may later cover them with additional coatings of clay. At eddies or acute bends in the stream the concretions aggregate and may become slightly welded together. There is a limit to their size depending on the strength of current flowage; they grow until the current is no longer able to transport them, then settle to become covered by subsequent deposition. It may occur that the upper or exposed portion while lying on the bottom receives additional material from the depositing sediments, resulting in an orbital form with a partly inclosing shell which, with modifications,

is a very common occurrence among concretions from sedimentary clay and shale beds. Or it is quite possible that a concretion formed as above may be subjected to stronger currents or clearer water and be eroded to any imaginable shape with smooth outlines. It may be carried to a distance and incorporated in a sediment of an entirely different character from that in which it had its origin. Its composition as a whole would likely in most instances vary from the material immediately surrounding it.

The following are analyses of a typical clay and inclosed concretion from the Champlain clays of the Connecticut Valley.[1]

DARK CLAY LAYER		INCLOSED CONCRETION	
Silica	51.90	Silica	42.93
Iron oxide	8.81	Iron oxide	13.66
Alumina	20.43	Alumina	25.49
Lime	.97	Lime	3.07
Magnesia	1.27	Magnesia	2.09
Manganese oxide	.94	Manganese oxide	1.10
Carbon dioxide	.30	Carbon dioxide	18

It will be observed that the silica and carbon dioxide of the concretion are somewhat lower than that of the clay, while the remaining constituents are higher. While the percentage of lime is 2.10 per cent. greater than in the clay, yet it is not in sufficient amount to justify the term "lime-concretion." The quantity of lime present in this type may vary from a small amount to more than 50 per cent.[2] From the presence of a high percentage of lime it does not follow that this constituent has been the prime factor in the origin of the concretion. Concretions of the character under discussion often show structure made up of very fine material such as would have resulted had they been formed from the adhering of minute particles. Clay and shale concretions have been known to contain gravels, coarse sand grains, or small organic relics as nuclei. Some show small pebbles and coarse sand grains in the form of interior concentric shells.[3] Similar structure has been pointed out as occurring among the concretions which form in the bed of the Rio Chaco.

[1] J. M. A. Sheldon, *The Champlain Clays of the Connecticut Valley.*

[2] C. B. Adams, "Concretions," *Second Annual Report on Geology of the State of Vermont,* pp. 111–18.

[3] "Champlain Clays," *loc. cit.*

Unfortunately the writer has no quantitative analysis of the specimens from the Chaco. They effervesce, however, in the presence of acids. One would expect them to contain a high percentage of soluble materials as is common to ordinary concretions. The last material laid down physically in the water volume is necessarily of a very fine character; furthermore, the water itself, being rapidly concentrated to the point of super-saturation, is forced to throw down its minerals in solution at the same time the concretions are being formed. If the water gains its clayey substances from ferruginous beds, iron oxides will prevail in the last stages of the concentrated solution. If calcareous, then lime will be prevalent in the fine silt at the time when conditions are favorable for the forming of concretions. The same will hold true in the case of other soluble minerals. It is reasonable to suppose that, in accordance with the theory of physical origin, most concretions of this class would be calcareous, since lime is most common. Hence it is seen that while the composition of a concretion so formed depends on chemical relationship, yet the concretionary process is itself a physical one.

Concretions often show flattened or discoid shapes with the greater axes parallel to the bedding planes of the containing strata. Writers have suggested that this is due to there being less resistance to growth in the horizontal than in the vertical planes. In some cases the strata seem to have been pushed away by the enlarging concretion. Such a flattening, however, may have been due entirely to pressure and the strata pushed back around the concretion through resistance to that pressure. There would also be a tendency toward development of cleavage in the concretion at right angles to the pressure and these planes might easily be confused with planes of stratification, the two in normal instances being parallel.

So far as the writer knows, attention was first called by Dr. George P. Merrill[1] to the balling tendency of mud under artificial conditions. He cites the phenomenon of concretionary balls having been formed in mud flowing quietly from the mouth of an iron pipe; the instance was that of pumping sediment from the bottom of the Potomac a few years ago for the purpose of deepening the channel and filling the so-called Potomac flats on the river front at Washington City.

[1] G. P. Merrill, *Rocks, Rock Weathering, and Soils*, p. 37.

Dr. Merrill states that this occurrence shows in an interesting way the manner in which certain concretions are formed.

Another example of the balling tendency of clay particles thickly suspended in current water is shown in the washing of brown iron ores in Alabama.[1] The clay in the log washers often adheres into balls or concretions and it is necessary to remove these by hand before the ore is sent to the furnaces. There may be serious loss of the finer ore particles due to the balls picking them up and carrying them to the waste dump. These mechanical illustrations of the balling tendency of clay are closely similar to those observed to occur under natural conditions in the bed of the Rio Chaco.

Is it not reasonable to suppose that causes which are now effective in producing concretionary structure have been in operation during past ages of the earth's history?[2]

[1] W. B. Phillips, "Iron Making in Alabama," *Alabama Geological Survey.*

[2] Since preparing the above article, the writer has been informed by Mr. Frank L. Hess that mud concretions have been observed by him along the Cuyama River and other localities in California and by Mr. H. S. Gale along a small tributary to White River, near Meeker, Colorado. No doubt the occurrence is familiar to most geologists.

In the Umpqua shales (marine Eocene) of Oregon, Mr. Chester W. Washburne reports having found concretions containing a concentric layer of marine shells; they were in such a position as to indicate that the concretions had been formed by a union of particles due to rolling.

A RECONSTRUCTION OF WATER PLANES OF THE EXTINCT GLACIAL LAKES IN THE LAKE MICHIGAN BASIN[1]

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CONTENTS

THE RAISED BEACHES

Around the borders of Lake Michigan are many fragments of abandoned shore lines, which stand at different heights above the present lake. They mark a series of stages of extinct lakes of late glacial times, known as Lake Chicago, Lake Algonquin, and the Nipissing Great Lakes. Near the south end of the lake, where erosion has been slight and the accumulation of shore drift has been going on since the earliest times, there is a record of nearly all the stages through which the lake has passed. On both the east and west sides of the lake, however, in Michigan and Wisconsin, where the cutting back of cliffs at the present level of Lake Michigan has been vigorous, the old shore lines have been partly or wholly destroyed for stretches of five to twenty-five miles. Even where the present lake has not cut away the record, it is usually incomplete, because the higher beaches have been destroyed by cliff recession during the lower of the extinct stages. It follows that the old shore lines preserved at one locality do not necessarily correspond with those at a neighboring locality, either in number or in order. The matter of correlation is not a very simple one; the highest beach at a given locality may not correspond with the highest at a neighboring locality, even though it may be less than a mile away. Moreover, while the

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

beaches around the south end of Lake Michigan are still horizontal, having been undisturbed by earth movements since they were formed, those in the more northerly portions have been affected by repeated differential uplifts. Each beach rises northward at a rate different from those above and below it, and at a rate which increases repeatedly in a northward direction. At one or more points, the planes marked by the inclined beaches split, vertically, so that a single stage in the southern part of the lake represents fifteen or twenty stages in the northern part. This is the result of the repeated tiltings of the northern district. The problem of proper correlation of the fragments, then, and of the complete reconstruction of the old water planes is a very difficult one. Not only must as many of these fragments as possible be discovered, but at each locality every beach and terrace of the series must be noted, its strength and peculiar characters recorded, and its altitude measured with all possible precision.

The raised beaches about the south end of Lake Michigan have been described in detail by Leverett,[1] Alden,[2] and others. The beaches along the west side of the lake, in eastern Wisconsin, were first studied in detail by the present writer,[3] in 1905. The planes which were recognized there have since been traced farther north in the upper peninsula of Michigan, by Hobbs.[4] On the east side of the lake, Taylor and Leverett have for several years been accumulating detailed information concerning the beaches. It was with the purpose of supplementing this work by a series of more detailed and precise measurements, and thus establishing more definitely the identity of certain beaches, and their relations, that the writer, under Mr. Taylor's direction, undertook a six weeks' survey of the shore lines along the east side of Lake Michigan in July and August, 1907,

[1] Frank Leverett, "The Illinois Glacial Lobe," *U. S. Geol. Surv.* (Monog. XXXVIII), 1899; also earlier papers (see *op. cit.*, p. 419).

[2] W. C. Alden, "Chicago Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 81, 1902; "The Delavan Lobe of the Lake Michigan Glacier of the Wisconsin Stage of Glaciation, and Associated Phenomena," *U. S. Geol. Surv.* (Prof. Paper 34), 1904; "Milwaukee Special Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 140. 1906.

[3] J. W. Goldthwait, "Correlation of the Raised Beaches on the West Side of Lake Michigan," *Jour. Geol.*, Vol. XIV, pp. 421–24, 1906. "Abandoned Shore-Lines of Eastern Wisconsin," *Wis. Geol. & Nat. Hist. Surv.* (Bull. xvii), 1907.

[4] For the Mich. Geol. Surv. Results not yet published.

for the U. S. Geological Survey. The method of measurement and of assembling the data secured in this study is the same which had been used in eastern Wisconsin in 1905. It was unnecessary in this case, however, to spend much time in exploration; for Mr. Taylor had selected a large number of localities where measurements could be made most advantageously. Considering the shortness of the season, therefore, the field covered was a large one, and the results obtained were unusually complete.

The old water planes, or imaginary surfaces of the extinct lakes, are marked by a variety of shore features. One type which is common on both the past and present shores is the cut bluff and bench. As developed along the present shore of Lake Michigan, the steeply sloping bluff or cliff rises from the water's edge, while the bench or terrace at its base reaches out under water. The point at the base of the bluff or the top of the bench is approximately the highest point at which erosion by storm waves is effective. It is usually a little above the normal lake level. Where bedrock cliffs instead of clay bluffs form the coast, however, the bench is perhaps likely to be a little lower than lake level. There is a constructional variation here of a few feet, but of only a few feet, in the case of Lake Michigan. In making measurements on such a bench, to determine the altitude of the old water plane, the base of the bluff was always taken. It is the only determinable point that one can take as a standard. Care was taken, of course, in making these measurements, to avoid places where the bench had been built up by landslides, or by alluvial wash down the face of the bluff, or where it had been gullied by streams. A range of error of five feet would probably be quite enough in this region to allow for discordances of benches due to original constructional variation in height.

Quite a different feature of topography is the beach or beach ridge —a line of shore drift banked up by the waves at or close to the water's edge, and rising only as high as storm waves can fling material. In exposed places on the shore of Lake Michigan, beaches have been observed whose crests stand fully six feet above calm water level. As a rule, however, they stand only three or four feet above it. In rare cases, where local conditions favor a heavy surf, the beaches probably attain a height of eight or even ten feet. The crest of a

beach, however, is the only point which one can take as a criterion for measuring a water plane; so in the study of these raised beaches it is the crest that has been measured each time. Care was taken to make sure of the presence of gravel on the surface of these beaches, in order to eliminate the effects of wind-blown sand, which often raises a beach, locally. If we allow a range of five feet for original variation in height of beach crests, we have probably satisfied all discordances except those which can be recognized as due to peculiar local conditions.

Other varieties of the beach need scarcely be mentioned, such as the bar or barrier, built between headlands, in comparatively deep water. Its height is liable to be more extreme on that account. The object in the foregoing remarks is to show that the points selected for measurement (the base of a bluff, or the crest of a beach or barrier) were chosen for convenience, not to say from necessity, and that an original constructional variation in height of about five feet is fully recognized.

METHOD OF INVESTIGATION

In the measurements the spirit- or Y-level was used almost exclusively, and to decided advantage. While much has been accomplished with the hand level and aneroid, in skilful hands, neither of these instruments has the accuracy or reliability of the Y-level. The influence of weather conditions, especially lake breezes, on the aneroid, and the personal equation in the hand level are liable to cause mistakes in such work as this. Where there is a whole series of shore lines to be measured in one locality and these beaches and benches follow one another in short vertical intervals, all possible accuracy in measurement is needed to correlate them, individually with members of a similar series at a neighboring locality. The Y-level, then, is almost indispensable for work in the central and southern portions of the Great Lake region, and desirable in all parts of it. Upham and Tyrrell used the Y-level[1] in measurements of altitude of the raised beaches of Lake Agassiz before 1890, Spencer[2] used it in

[1] Warren Upham, "The Glacial Lake Agassiz," *U. S. Geol. Surv.* (Monog., XXV), p. 9, 1896.

[2] J. W. Spencer, "Deformation of the Algonquin Beach and Birth of Lake Huron," *Am. Journ. Sci.* Vol. cxli, pp. 12–21, 1891, and other papers.

Ontario at about the same time. Lawson[1] used it along the north coast of Lake Superior in 1891; but between that time and 1905, the hand level and aneroid were very generally used, instead; and accordingly the correlation and identity of the beaches of the Lake Michigan basin were imperfectly known.

Absolute accuracy is of course impossible even with the Y-level. On the one hand are original variations in height of the beaches and benches, due to local conditions under which they were constructed or cut; for which five feet has been allowed. On the other hand a certain amount of error is involved in the process of leveling; first, through the slight inaccuracy in the use of the instruments, and second, through the use of Lake Michigan as the datum or starting-point. It frequently happened, on days when levels had to be run, that a strong on-shore wind was blowing and the waves were running high, so that one could not tell within half a foot what the normal level of the lake would be at that place. To be quite fair, then, we must expect in these measurements occasional discordances due to a combination of these errors of six feet or so.

THE SHORE LINES OF LAKE CHICAGO

The old shore lines fall into two distinct groups. There is an earlier group, well registered around the south part of Lake Michigan, but unknown in the northern part. These belong to the so-called Lake Chicago, a lake which was confined to the Michigan basin, with its outlet at the extreme southwest corner, into the Desplaines valley at Chicago. A later group, represented by but a single shore line in the southern part of the basin, below the beaches of Lake Chicago, but rising to a considerable height northward, and splitting into a large vertical series, records the complex history of Lake Algonquin and the Nipissing Great Lakes.

The shore lines of Lake Chicago, as distinguished at the south end of the basin, and described by Leverett and Alden, mark three distinct stages, to which the names Glenwood (or 60-foot), Calumet (or 40-foot) and Toleston (or 20-foot) stages have been given. To be more exact, the average altitudes of these three shore lines are 55,

[1] A. C. Lawson, "Sketch of the Coastal Topography of the North Shore of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren," *Minn. Geol. Surv.*, 20th Ann. Rept. p. 231.

38, and 23 feet above Lake Michigan, or approximately 636, 619, and 604 feet above sea level. In the following table, the altitudes of these beaches is given for six selected localities, where spirit-level measurements have been made by the writer.

Locality	Miles North of Chicago	Glenwood	Calumet	Toleston
Evanston and Niles Center, Ill.	15	636′	619′	605′
Zion City, Ill.	43	634′	621′	x
State Line, Ill., and Wis.	46	634′	616′	x
Line between Racine and Kenosha counties, Wis.	57	637′	621′	...
Holland, Mich.	65	638′	621′	605′
Spring Lake and Eastmanville, Mich.	87	633′	(613′)	602′

It will be noticed that the first four localities are on the west side of Lake Michigan. The last two are on the east side. Spring Lake and Eastmanville are near Grand Haven. The symbol "x" in the table indicates that the shore line is missing because of destructive cliff cutting at a lower stage. Other measurements might be given, less accurate than these, but confirming them, almost without exception. They indicate that as far north as a line through Grand Haven, Mich., and Milwaukee, Wis., the three beaches of Lake Chicago are horizontal. The terrace at Eastmanville, given at 613′ in the table above, is so obscure a feature that its exact altitude cannot be estimated within several feet. Disregarding this one measurement, then, the data show a remarkable accordance in the altitude of beaches, the variation being not more than five feet for each stage. That much ariation, as has already been remarked, must be expected in the original construction of the beaches. There is no indication of system in the slight departures from uniformity of height from north to south, hence no reason to suppose that any of these water planes are inclined at all south of Grand Haven and Milwaukee. Apparently, then, these beaches, representing the earliest stages of the lakes of late glacial times have been unaffected by any of the earth movements which are known to have deformed the central and northern portions of the Great Lake region since the ice withdrew.

On the accompanying map (Fig. 1) the northern limit of horizontality for these beaches of Lake Chicago is indicated by a line;

and this line is extended east and southeast through Lake St. Clair and Ashtabula, Ohio, so as to mark the corresponding limit for the beaches of Lakes Maumee and Whittlesey in the Erie basin, as determined by Leverett and Taylor. South of this line, then, there seems to have been no subsequent deformation in either the Michigan or the Erie basins.

Beyond Grand Haven, on the east side of the lake, the data recently collected at several localities, as far north as Ludington,

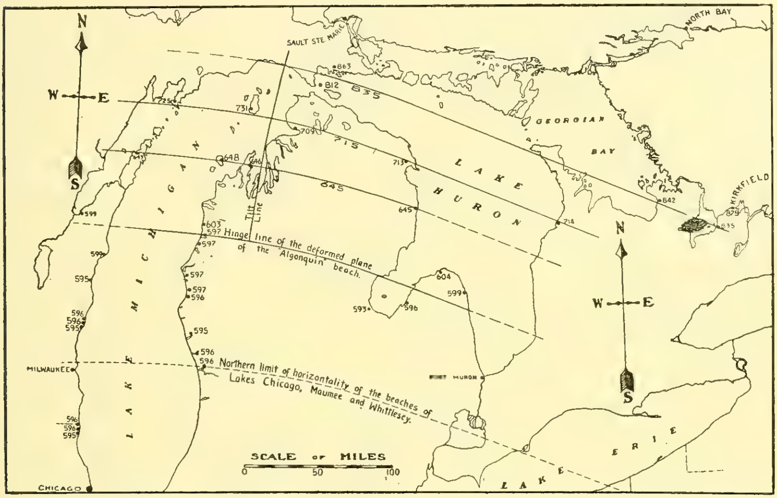


FIG. 1.—Map of Lakes Michigan and Huron, showing northern limit of horizontality of the beaches of Lakes Chicago, Maumee and Whittlesey, altitudes of the Algonquin beach at selected localities, and isobases of deformation and line of maximum inclination of the warped Algonquin water plane.

indicates that the beaches rise northward and increase in number; but the precise correlation has not been possible for several reasons. The measurements are as follows:

Locality	Distinct Beaches at
Muskegon	604′, 609′, 613′–616′, 628′
Montague	632′, 634′, 656′, 658.
Bass Lake	628′–630′, 639′, 642′, 649′–650′.
Ludington and Amber	636′–640′, 673′–675′.

The fragments north of Grand Haven are scarce and generally obscure, becoming sandy and irregular as they go north. It appears as if they were approaching the ice border for those stages, and fading

away among the moraines. Those beaches which locally show strong development cannot be grouped into a single system of diverging planes like the Algonquin beaches presently to be described. The rate of inclination from south to north is hardly one foot per mile. It is possible, then, that the southward slant of these beaches is due wholly to ice attraction, according to the calculations of R. S. Woodward.[1] Assuming an ice sheet of reasonable extent and thickness, Woodward found that its attraction might be sufficient to raise the surface of the lake nearby into a curve, concave upward, with an apparent inclination of several inches to the mile for the first fifty miles or so from the ice border. If this be the right explanation for the Lake Chicago beaches north of Grand Haven, it accounts for the apparent lack of harmony between the measurements; for the relation of successive water planes to each other would be similar to the branchings of a feather (see Fig. 2) and the few points where

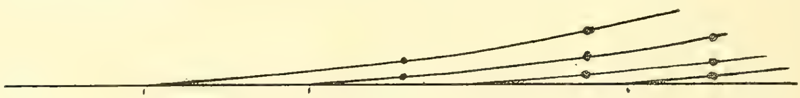


FIG. 2.—Diagram showing how a series of ice-attracted water planes might look, in profile.

measurements have been made might happen to lie on several different divergent surfaces. If, on the other hand, the northward ascent of the beaches is due to a series of differential uplifts of the region, these uplifts must have occurred before the formation of the next lower beach, the "Algonquin" beach, for that beach is horizontal over the whole southern half of the Michigan basin.

North of Ludington little is known of these beaches, and no measurements have been made. While the Glenwood and Calumet shore lines might expectedly terminate at any place, against a moraine, the Toleston or lowest shore line of Lake Chicago ought to extend northward to the place where the ice border first uncovered a low pass leading across Michigan into the adjoining Huron basin, probably east of Little Traverse Bay. No traces of such a beach are known. It is probable that the record is too weak and obscure to be recognized.

[1] R. S. Woodward, "On the Form and Position of the Sea Level," *U. S. Geol. Surv.* (Bull. 48. p. 88), 1888.

THE ALGONQUIN BEACH

Below the beaches of Lake Chicago, encircling the south end of Lake Michigan, is the Algonquin beach. It rises northward, in the central and northern part of the basin, as shown by the map, Fig. 1. The identity of this beach, the highest shore line on Mackinac Island, as the "Algonquin" beach[1] of Spencer was long ago recognized by Taylor. On the map, Fig. 1, can be seen the altitude of this Algonquin beach at about thirty-five selected localities in the Huron and Michigan basins. The warped attitude of the water plane which passes through these points is indicated by the system of isobases and the line of maximum inclination which runs perpendicular to them. The data have been taken from several sources. The measurement on the Garden peninsula (725′) is one of many made by Hobbs in 1907. The twenty or more remaining measurements around Lake Michigan and the Straits of Mackinac were made by the present writer, in company with F. B. Taylor, in 1907. On the west side of Lake Huron the measurements were made by Frank Leverett, A. C. Lane, W. M. Gregory, W. F. Cooper, and C. A. Davis. East of Lake Huron the measurements are all Spencer's except the one at Beaverton, which was recently made by Taylor.

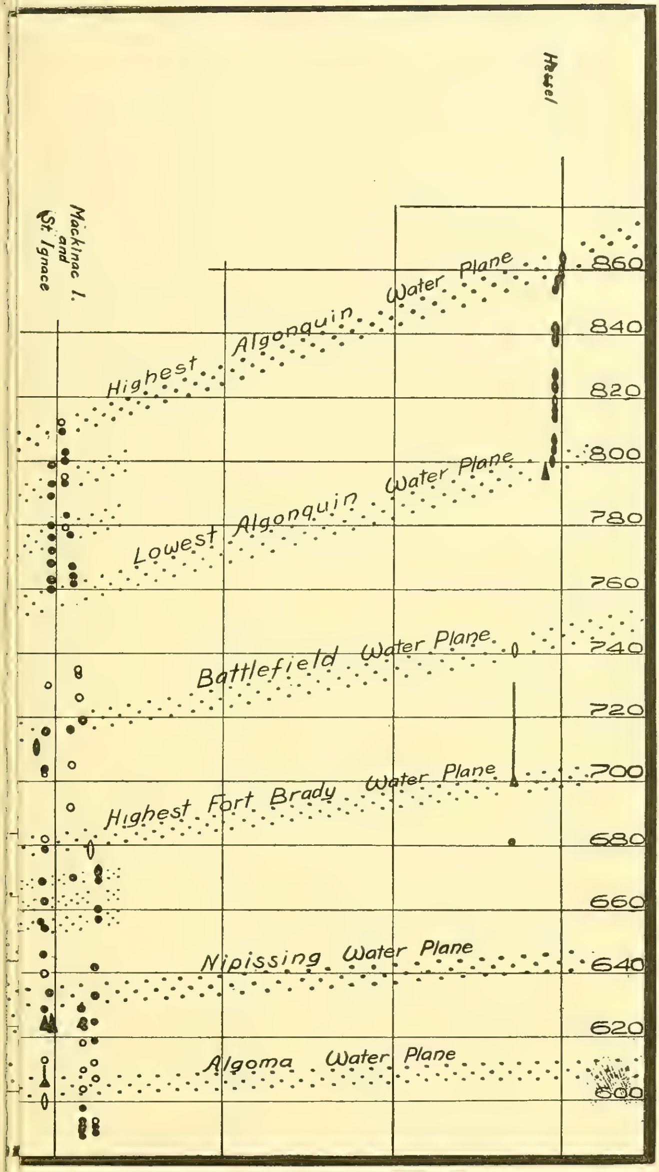
Recent investigations by Taylor in Ontario, supplementing earlier studies, indicate that this beach marks a period of activity of *two* outlets, one at Port Huron and one east of Kirkfield, Ontario, where there was an overflow into the valley of the Trent River. This Algonquin beach, of the "two-outlet" stage, seems to be the highest beach common to the Huron and Michigan basins. This gives reason to conclude that when the ice border south of the Straits of Mackinac withdrew so as to let the waters of the Michigan basin merge with those of the Huron basin, the "Trent outlet" was already running. Had the lakes merged before the Trent pass was uncovered and while the Port Huron outlet alone was active, then the plane of that beach, adjusted to the Port Huron outlet, would have been temporarily abandoned when the Trent pass was uncovered, and the waters fell to a low level; and the subsequent uplifts which raised the

[1] J. W. Spencer, "Notes on the Origin and History of the Great Lakes of North America" (abstract), *Am. Assoc. Adv. Sci., Proc.*, Vol. XXXVII, pp. 197–99, 1889, and later papers.

Trent pass up to the level of the one at Port Huron would have raised this old plane (within this region of deformation) well above any subsequent level of the waters. No such plane above the Algonquin beach of the "two-outlet stage" is known, unless it be the Toleston beach. As already noted, this beach is lost, north of Ludington, and no beach is known in the Huron basin which connects with this in the northern part of the lower peninsula of Michigan.

CONSTRUCTION OF A PROFILE OF WATER PLANES

The altitudes of the Algonquin beach at about fifty localities in the northern part of the Michigan basin is shown in Fig. 3. This is a miniature copy of a large scale chart (composed of sheets of the U. S. Lake Survey) on which the data collected in 1905 and 1907 were plotted for final inspection. Through and among these points, a series of isobases was drawn with a vertical interval of ten feet. These were found to be parallel to each other, and to be in harmony with the similar lines across the Huron basin, as shown in Fig. 1. Across the isobases was then drawn a line in the direction of maximum inclination—a gentle curve that changes gradually from N. 15° E. near the Straits of Mackinac to N. 5° E. south of Grand Traverse Bay. With this map as a basis for locating points, a profile of the Algonquin beach and the complex series of shore lines below it was then drawn, as follows: Upon the line of maximum inclination was plotted the position of each station on the east side of the lake where measurements had been made. Each one was then transferred directly to a sheet of co-ordinate paper, on which distances from left to right represented distances from south to north. A horizontal line at the base was taken to represent the present level of Lake Michigan (581.5 feet A. T. in July and August, 1907). With a vertical scale of 20 feet to the inch (500 times as large as the horizontal) the altitude of every beach and bench was recorded by an ordinate. These ordinates served to reconstruct the water plane in profile. A reduced copy of this profile constitutes Plate I. In it, between Hessel and Onekama, a distance of 125 miles, over 25 different lines of levels at as many localities along the east side of Lake Michigan are represented. In other words, the stations are on the average 5 miles apart. About 190 measurements are on well-formed beaches or benches, and



Mackinac I. and St. Ignace
Hessel
Highest Algonquin Water Plane
Lowest Algonquin Water Plane
Battlefield Water Plane
Highest Fort Brady Water Plane
Nipissing Water Plane
Algoma Water Plane
860
840
820
800
780
760
740
720
700
680
660
640
620
600

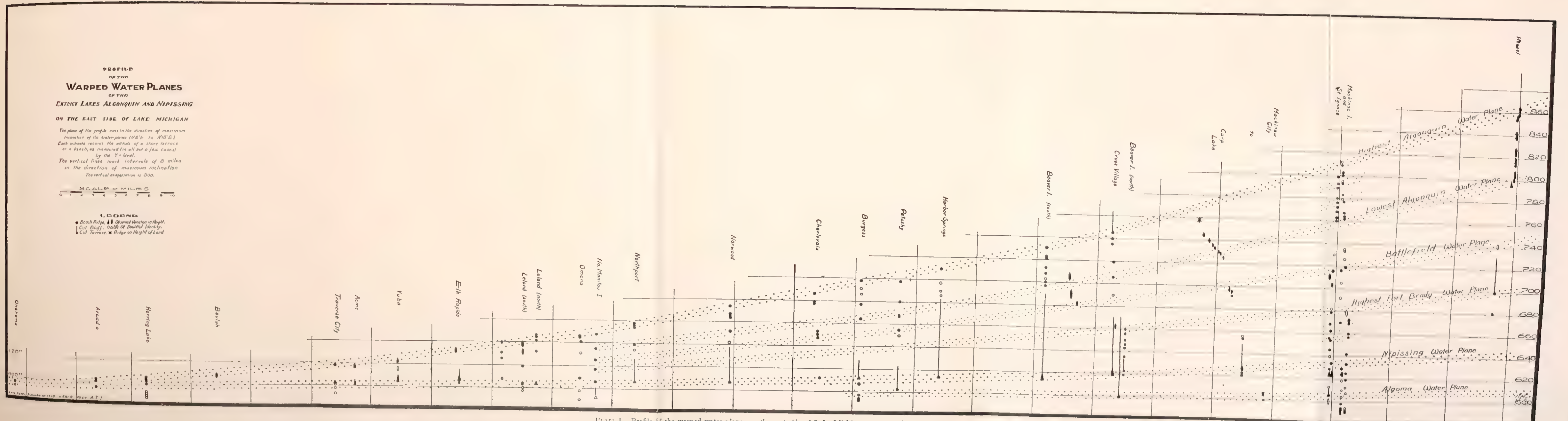


PLATE I.—Profile of the warped water planes on the east side of Lake Michigan, north of Onekama.

about 50 on beaches or benches that are less distinct, though not to be neglected in a fair consideration of evidence. A distinctive symbol is used for the two contrasted types of topography, benches and beaches; and the symbol for a well-formed beach or bench is different from the one for a beach or bench that is faint. The size of the spot is intended to cover the probable range of error in measurement. The height of a cut bluff is shown by a wriggling vertical line.

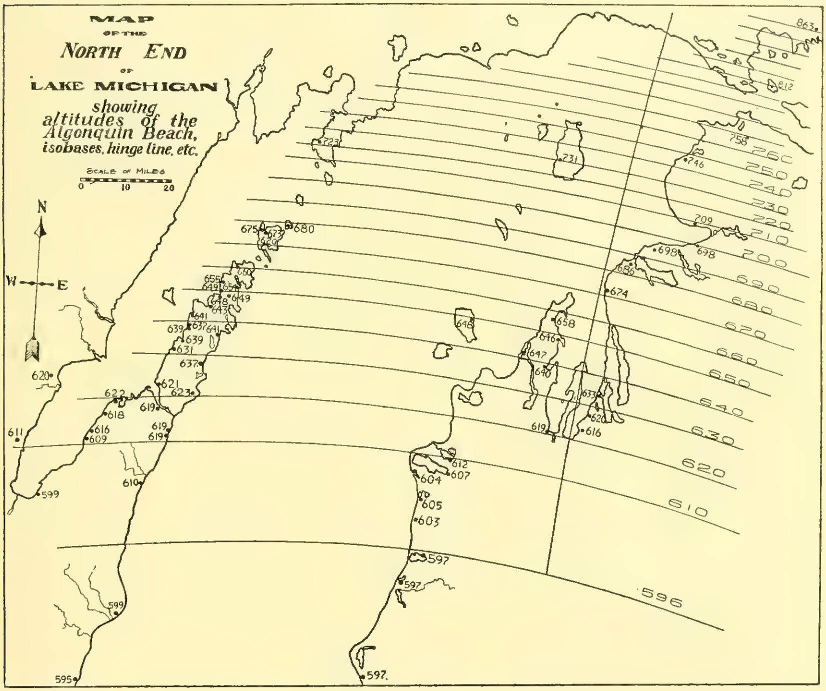


FIG. 3.—Map of the north end of Lake Michigan, showing the warped attitude of the Algonquin water plane.

Through the highest beach thus recorded a line or band was drawn with a thickness (according to the scale) of 6 feet, to represent the range of variation in height to be expected in the original construction of the beach or bench. The line or band, when drawn as a gentle curve, so as to pass most directly through the highest ordinates, includes 21 out of 24 of them. Of the 3 which are either too high or too low, to fall within it, one at Carp Lake, fully 8 feet too low, is

easily accounted for. It is a beach ridge on a height of land, where no opportunity exists for the record of a higher stage. The other two discordant points, one at Petoskey and one at Leland, are five feet below and 4 feet above the center of the band, respectively, instead of being within 3 feet of it. This discordance of one or two feet is not a serious one; for it might be due to an error in leveling which augments an original variation in height, instead of being included in that variation.

The rate of inclination of this Algonquin plane measured from Hessel (at the ancient "Munuscong Islands") southward to Mackinac Island (15 miles) is 3.73 feet per mile. From Mackinac Island to Beaver Island (24 miles) it is 3.30 feet per mile. A rather rapid change of inclination near the isobase of Beaver Island introduces a tilt rate of about 2.00 feet per mile. Over the southern part of Grand Traverse Bay the rate again decreases, perhaps more gradually than in the former case, so that near Traverse City it is about 1.00 foot per mile. The further change from an incline to a horizontal position, which is accomplished near Onekama, seems to be a rather rapid one; for Onekama is only 25 miles south of Traverse City, where, as we have just remarked, the tilt rate is one foot per mile. The abruptness of the changes near Beaver Island and Onekam could be emphasized by representing the plane on the profile by a bent line rather than a curved one. The curve has been used here merely for simplicity, without meaning to imply that the deformation is necessarily a warping rather than an uplift by the tipping or jostling of large fault blocks. Either sort of uplift seems admissable, when due weight is given to the opportunity for variation in the height of the beaches or benches.

Below the highest shore line are a number of others. Some of them are equal to the Algonquin in strength; others are comparatively faint. They can best be recognized in the northern part of the region, where the vertical space between them is greater. On Mackinac Island, for instance, strong benches and beaches record ten lower stages of considerable importance. The Algonquin beach is the highest of a closely spaced group of ridges which are well displayed on the short target range back of Fort Mackinac. This "Algonquin group" of beaches occupies an interval at that place of about 50 feet.

The lowest of them and two intermediate ones are especially prominent. Forty feet below the Algonquins, and separated from them by an interval in which there are no plainly developed beaches or benches, is a beach of remarkable strength, called by Taylor the "Battlefield beach." It was so named because of its conspicuous development as a great ridge of cobblestones and gravel on the old battlefield, on the north slope of the island. Below the Battlefield beach another interval of 40 feet, unoccupied by any very persistent beaches, leads down to the group known as the "Fort Brady beaches." There are several of these ridges. Four of them fill a vertical interval of 25 feet; below them are at least two others of which we have a distinct record. A little below the Fort Brady beaches is the "Nipissing shore line," one of very remarkable strength. It is probably the most conspicuous of all the shore lines, and it is peculiar in consisting usually of a bench and bluff rather than a beach ridge. On Mackinac Island it stands 53 feet above Lake Huron, being represented there, however, by a great deep-water barrier which runs southwest from the Episcopal church. Below the Nipissing is one stage of importance, marked by the "Algoma shore line." At the Straits of Mackinac this stands about 25 feet above the lake.

All these shore lines and groups of shore lines—the Algonquin group, Battlefield beach, Fort Brady beaches, Nipissing shore line, and Algoma shore line—can be traced southward from the Straits of Mackinac, on this profile (Pl. I), with certainty for at least twenty miles, to Beaver Island, where they are all represented. But as they are followed further southward the record of them is found to become more and more imperfect and incomplete. The planes gradually converge until the discrimination between them becomes difficult; and what is more troublesome, in the development of cliffs at the lower stages (especially the Nipissing and the present stage) many of the higher beaches have been cut away and no record of them is left. The exact position of the planes between the Algonquin and the Nipissing, therefore, cannot be absolutely demonstrated, though a reasonable amount of confidence is placed in the reconstruction here given. In the case of the Nipissing shore line, however, there is no uncertainty. Its exceptional strength and peculiar character make it possible to follow this plane southward, down its gentle inclination

of 0.75 feet per mile, diminishing to less than 0.50 feet per mile near Beaver Island, to Onekama, where it becomes horizontal and seems to unite with the Algonquin plane to form the single 596-foot plane already mentioned. While the data for the intermediate planes do not permit an unqualified statement, they seem to indicate that the lowest of the Algonquins, the Battlefield, and the Fort Brady beaches all converge to the same point, Onekama, instead of being overlapped, one after another, by the Nipissing. The Algoma plane seems to constitute another member of this split series; but its exact position south of Petoskey is somewhat in doubt.

It is perhaps possible that the highest Algonquin beach becomes horizontal at about 24 feet above Lake Michigan, near Herring Lake. This is suggested by the work of the present writer in eastern Wisconsin, and by the data thus far collected by those who have worked in the Huron basin. If so, the 14-foot "Nipissing shore line" seems to have very generally destroyed the 24-foot "Algonquin shore line" along the east side of Lake Michigan, south of Herring Lake. The evidence here seems rather to indicate that the Algonquin and Nipissing shore lines coincide to form the single 14-foot shore line. Figures 1, 3, and 5, and Plate I, embody this idea.

SIGNIFICANCE OF THE FAN-LIKE PROFILE

The steepness of inclination of these water planes, and their convergence to a single point, affords a basis for choosing between differential uplifts and ice attraction, to explain their present condition. At the Straits of Mackinac the calculated rate of inclination for the highest Algonquin is 3.73 feet per mile; for the lowest of the Algonquin group, 3.00 feet; for the Battlefield, 2.10 feet; for the highest Fort Brady, 1.29 feet; for the Nipissing, 0.75 feet; and for the Algoma, 0.33 feet. All those above the Nipissing slant too steeply to be accounted for by ice attraction. They must be explained by a series of earth movements which repeatedly raised the shore line of this region out of water. The Nipissing and the Algoma shore lines are inclined no more steeply than the surface of the lake close to the ice border might be inclined by ice attraction; but they are probably inclined more steeply than they could be so far from the ice border for the stages they represent. The ice front must have been at least

200 miles to the northeast of this region; for it had withdrawn from the Mattawa valley, east of North Bay (see Fig. 1), and at this distance its attraction on the waters would hardly have raised the lake surface more than an inch or two to the mile, according to Woodward's computations. Furthermore, the water planes come together at a single point. They should converge in turn to a series of points, feather fashion, if they marked the attraction of the lake to successive positions of the retreating ice front (see Fig. 2). Evidently, then, the inclined position of the planes, and their fan-like relation, must be attributed to earth movements.

The line from which the planes diverge (the "hinge line" on the map, Fig. 1), or as seen on the profile (Plate I) the point at which they split, might be determined, it seems, in either of two ways. It might mark the southern limit of a series of deformations, acting thus as a hinge on which the tiltings took place. If so, it is evident that here were no less than ten or fifteen distinct tilting or warping movements, all of which hinged on the same line. On the other hand, the point of splitting might be located at an outlet (or along the line of equal deformation through an outlet), which together with the region north of it had been raised by tiltings; for as the outlet rose, the horizontal surface of the lake would rise, south of it, drowning the old shore lines there, while to the north the former shore lines would be raised out of water each time and would come to form a fan-like series. This process is illustrated diagrammatically by Fig. 4.

The choice between these two explanations for the case at hand may be quickly made, if one considers the information shown on the map (Fig. 1). There are two outlets, only, which could possibly be associated with the splitting, viz., the Kirkfield and the Port Huron outlets. The isobase through the former (if it were drawn an 875-foot line, parallel to the 835-foot isobase on the map) would pass nowhere near Onekama, but rather through the upper peninsula of Michigan. That is a district as yet not critically examined. The Port Huron pass lies south of the "no tilt" line (or "hinge line" as it is called in Fig. 1); that is, it lies within the district which has been unaffected by uplifts; consequently no fan-like splitting can occur at it or in line with it. It seems necessary to conclude that Onekama lies on the hinge line of the tiltings which raised all the planes into their

inclined positions. That so many tiltings, separated no doubt by considerable intervals of time, should have had the same hinge suggests that this line, for reasons unknown, is one of structural weakness.

In order to show the significance of the fan-like profile of water planes, in Plate I the following series of diagrams (Fig. 5) is introduced. These present in a very conventional and much simplified way the relation which the successive planes of Lake Algonquin and the Nipissing Great Lakes should bear to each other according to the present generally accepted interpretation of the history of the great Lakes, worked out by Mr. Taylor. Since that history is

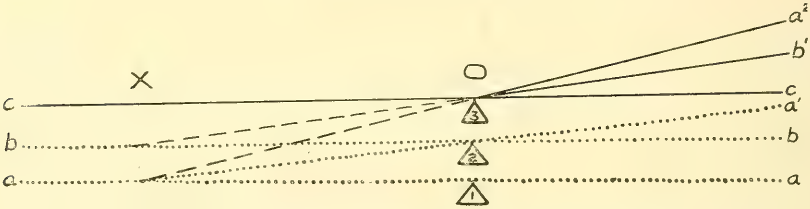


FIG. 4.—Diagram showing in profile how a fan-like group of water planes might be produced by a number of differential uplifts which tilted a lake basin and its outlet. Outlet at *O*. Uplifts affect region to the right of *X*. Three stages are shown. First stage, outlet at *1;* horizontal water plane of the lake at *aa*. Second stage, tilting on right side of *X* has raised outlet to *2;* water plane *aa* has been inclined to aa^1; the lake has risen to plane *bb*, drowning that part of it which lies on left side of outlet. Third stage, another uplift has raised outlet to *3;* has tilted *bb* to bb^1, and increased tilt of aa^1 to aa^2; lake has risen to *cc;* on left side of outlet planes *a* and *b* have been drowned; on right side, they rise, splitting at outlet, fan-fashion.

recognized as subject to revision, through further study, the diagrams should be taken to represent simply the conditions which seem most probable, in the light of the evidence already at hand. Although in the actual case the planes have been warped to curved profiles, as shown in Plate I, they are represented in the diagrams as simply tilted. This is wholly for the sake of simplicity, and must not be thought to imply that the crustal movements were actually tiltings instead of warpings.

The final diagram (6, in Fig. 5) shows the present position of these planes. That portion which lies south of the Trent outlet is based on recent detailed work in the Michigan and Huron basins, including that described in this paper. The large profile, Plate I,

corresponds with that part of Diagram 6. The remaining part, north of the Trent outlet, covers a large field in which studies have been less detailed and the reconstruction on that account cannot be regarded

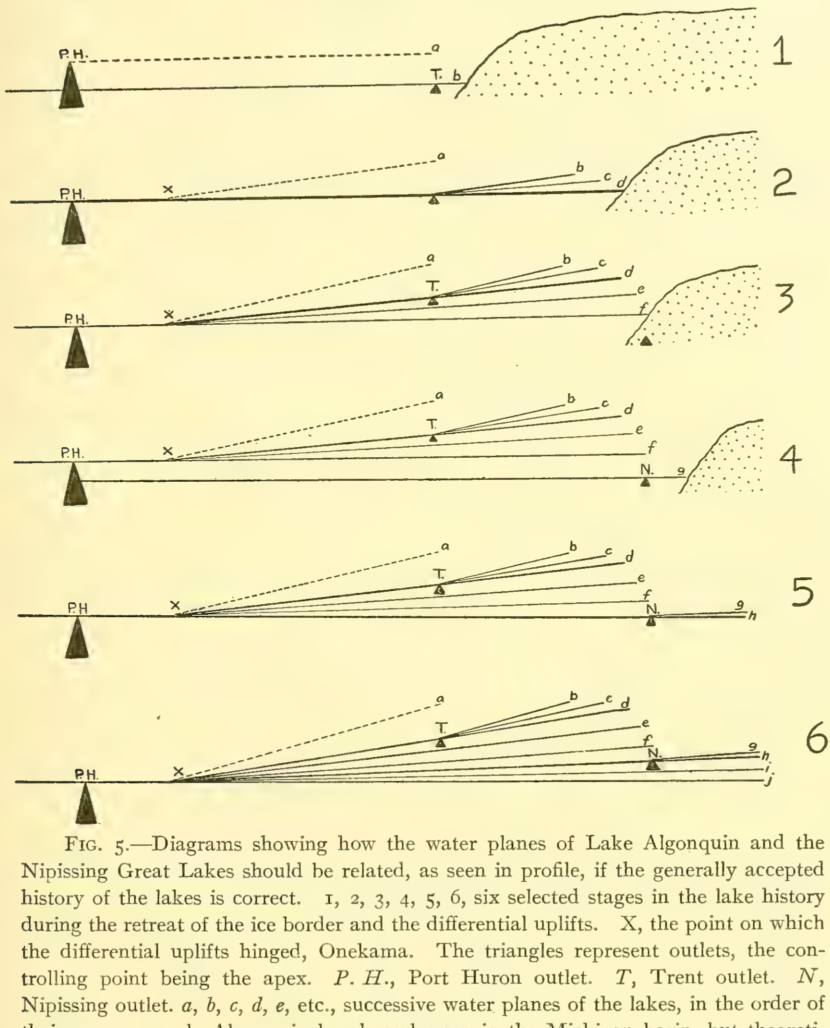


FIG. 5.—Diagrams showing how the water planes of Lake Algonquin and the Nipissing Great Lakes should be related, as seen in profile, if the generally accepted history of the lakes is correct. 1, 2, 3, 4, 5, 6, six selected stages in the lake history during the retreat of the ice border and the differential uplifts. X, the point on which the differential uplifts hinged, Onekama. The triangles represent outlets, the controlling point being the apex. *P. H.*, Port Huron outlet. *T*, Trent outlet. *N*, Nipissing outlet. *a*, *b*, *c*, *d*, *e*, etc., successive water planes of the lakes, in the order of their age. *a*, early Algonquin beach, unknown in the Michigan basin, but theoretically necessary in the Huron basin, *b*, *c*, planes of temporary low water stages through the Trent outlet; *d*, plane of the "Algonquin beach;" *e*, plane of the Battlefield beach *f*, plane of a Fort Brady beach; *g*, plane of a temporary low-water stage through the Nipissing pass, possibly marine submergence; *h*, plane of the Nipissing shore line; *i*, plane of the Algoma shore line; *j*, present plane of the Lake Michigan.

as actually established. From this series of diagrams it may be seen that (1) the "Algonquin" beach of the Michigan basin marks the "two outlet" stage when the discharge was shared between the pass at Port Huron and that at Kirkfield. Before it there had been a "low-water" stage, adjusted to the Trent (i. e., Kirkfield) outlet in its original low position; but earth movements had lifted the outlet, and consequently the lake level south of it to the level of the Port Huron pass. The records of this low water stage (southern continuations of planes *b* and *c*) have been drowned in the Michigan and Huron basins. The lower members of the group of Lake Algonquin beaches, the Battlefield and Fort Brady beaches, represent successive stages after the restoration of the Port Huron outlet (planes *e* and *f*). Each seems to record a differential uplift in which the northern part of the region was raised out of water, from a hinge near Onekama. The Nipissing plane (*h*) represents, like the Algonquin, a "two-outlet" stage, with the discharge divided between Port Huron and North Bay. Previous to it the low Nipissing pass east of North Bay had been opened and a second low water stage had occurred. The data thus far collected seem to admit a possibility that this was a stage of temporary marine submergence; but further careful studies and more accurate measurements in that most critical field will be needed before the truth is known. With repeated uplifts, the waters of the Huron and Michigan basins rose from this low level, the "low water" beaches were drowned (except north of the Nipissing pass), and the Port Huron outlet was re-established. Since then the Nipissing plane has been raised far out of water. The Algoma beach (*i*) seems to mark the most important pause in this period of comparatively recent uplift.

Reviews

Earthquakes: An Introduction to Seismic Geology. By William Herbert Hobbs. New York: D. Appleton and Co., 1907.

Recent earthquake phenomena in North America have aroused such general interest in the subject that there has arisen a well-defined demand for clearly written books on earthquakes, in which one could find the latest knowledge in such a form as to be intelligible even to the layman. Professor Hobbs has set himself the task of supplying this demand, and has been very successful in his effort. He has given us a book which, though brief, outlines the main facts, theories, and conclusions in a clear, direct, and simple manner. Moreover, he brings the information down to date, which is a matter of great importance in a science that has felt the impulse of new methods that, within a decade, have almost revolutionized certain phases of the subject.

In the first chapter there is a brief summary of early theories for earthquakes, including the simple notions of the ancient philosophers, and a tracing of the steps by which the centrum theory has been gradually abandoned. The next six chapters deal with various topics, among them the cause and distribution of earthquakes, the nature of the shocks, the effect of earthquakes on surface and underground water, and the earthquake faults and fissures and their relation to earth lineaments.

The latter topic, which is the author's special contribution, though touched upon at various points in the book, receives special treatment in chapter vi. The main points in this chapter are already familiar to American geologists from the special articles by Professor Hobbs, and there has been a widespread dissent from his views as to the relation between what he calls earth "lineaments" and seismotectonic lines. To the reviewer it seems that, while Professor Hobbs undoubtedly has a good point here, applied in moderation, he has given it a far greater application than any facts he presents will warrant. There is much reason to believe that many geologists have, in large measure, overlooked the significance of joint planes, faults, and other lines of earth weakness in topographic expression; and the facts presented by Professor Hobbs in this chapter, and in his special articles, clearly show that there is a more definite and wide-spread relation between earth lineaments and seismotectonic lines than has generally been recognized. At the same time, it seems equally clear that Professor Hobbs has read into earth lineaments a relationship to faults and fissures which no facts so far presented will warrant.

To be specific, selecting but one of a number of instances, the city of Elmira, in central southern New York, is, according to Professor Hobbs, one of the greatest centers of intersection of earth lineaments in northeastern United States, no less than five lines centering there. Here, as in other maps, the data upon which

these conclusions are based are almost wholly arbitrary, and totally unconvincing. In some cases it amounts to little more than drawing straight lines connecting two or more places from which one or more earthquakes have been reported. It is to be regretted that so much stress has been placed upon such doubtful cases, for it is liable to discredit the whole theory, by attracting attention to the weak parts and thereby throwing doubts even on the strong parts.

Following these chapters are four in which are presented summary statements of phenomena associated with notable earthquakes in North America and other parts of the world; and this is followed by a chapter on earthquake danger spots within the United States. It is to be hoped that the intimation that the large coastal cities, from Washington to Boston, are on a danger line will not be verified by future earthquake phenomena.

The next chapter deals rather fully with the sounds, or *brontidi*, accompanying earthquakes, and a discussion of the significance of noises from the earth when there are no sensible shocks. Then comes a chapter on the "Study of Earthquakes on the Ground," in which there are some suggestions that will doubtless be of decided value to amateur observers, as well as to others, who have the opportunity of studying an earthquake and its results. The last four chapters deal respectively with disturbances in the ocean, seismographs, interpretation of seismograph records, and disturbances of gravity and earth magnetism. In the last two chapters the importance of distant seismographic records is clearly shown, and the main results so far attained are stated.

Each of the chapters is closed with a selected series of references to original papers, which will be of use to those who wish to pursue the subject further. The book is well printed and adequately illustrated with one hundred and twelve figures and maps, and twenty-four pages of half tone plates, on most of which there are two pictures.

To prepare a general summary of a large subject, in the compass of a little over three hundred pages, and to present the matter clearly and scientifically, and yet in such a manner as to interest both the lay reader and the student of science, is one of the most difficult forms of writing, and the author of this book is to be congratulated on the success which he has attained in his effort to accomplish this end. He has given us a readable book, and yet one in which even the geologist will find new matter, unless he has followed all the latest literature on the subject of earthquakes from the standpoint of both the physicist and the geologist. The student of geology, as well as the layman, will find the book interesting, suggestive, and informing. It takes rank with the best of the general books on seismology.

Ralph S. Tarr

The Iron Ores of the Salisbury District of Connecticut, New York, and Massachusetts. By William Herbert Hobbs. (Reprint from *Economic Geology*, Vol. II, No. 2, March-April, 1907, pp. 153–81.)

From the low-grade limonite ore of this district a superior grade of

manganese iron, especially well adapted for car-wheels, has long been prepared by the old charcoal process. Iron has been mined almost continuously since 1734. Most of the mines are located at or near the boundary of the areas of Hudson schist with those of the Stockbridge dolomite, both of which are Cambro-Ordovician sedimentaries. The more important of the exploited ore beds form a nearly continuous series encircling the base of Mt. Washington. The author believes that the ore was derived from pyrite in the Berkshire schists of the adjacent elevated territory, and that the ore bodies have been formed by the replacement of Berkshire schist and Stockbridge dolomite.

C. W. W.

Lead and Zinc Deposits of Virginia. By THOMAS LEONARD WATSON. (Geological Survey of Virginia, Geological Series, Bulletin No. 1. Pp. 156, 14 plates. Published by the Board of Agriculture and Immigration, Richmond, Va., 1905.)

Galenite and sphalerite are associated in all the mining districts, generally as replacement deposits in limestone breccia near faults, and on anticlinal axes. The sulphide ores show no secondary enrichment. The most interesting feature of this region is the secondary oxidized ore which occurs in depressions of the weathered surface of the limestone beneath several feet of residual clay. This ore consists of predominant calamine, associated with smithsonite, and cerrusite, and toward the bottom there is generally some galenite. Commercial ores are limited to the Shenandoah Limestone.

C. W. W.

The Paragenesis of the Minerals in the Glaucophane-Bearing Rocks of California. By JAMES PERRIN SMITH. (Proceedings of the American Philosophical Society, Vol. XLV, 1906, pp. 183–242.)

This paper, and the one by H. S. Washington published last year, make a nearly complete study of the glaucophane schists and related rocks. Professor Smith shows that the glaucophane rocks of the Coast Ranges have been derived from siliceous fragmental sediments, deposits of organic silica, acid arkoses, medium-basic clay shales, basic tuffs, syenites, diorites, diabases, gabbros, and probably pyroxenites. The origin may be determined by study of the chemical composition. Metamorphism has consisted merely in recrystallization, no material has been added or taken away, except that the water which once existed in the pore spaces has been included as water of crystallization. The paper includes thirty-two chemical analyses, and petrographic descriptions of the minerals and rocks.

C. W. W.

The Charleston Earthquake of 1886 in a New Light. By William Herbert Hobbs. (Reprint from *Geological Magazine*, N. S., Decade V, Vol. IV, May, 1907, pp. 197–202.)

The linear distribution of craterlets and of points of special damage to railroad tracks, as determined by Dutton, leads the author to the conclusion that these phenomena indicate the position of faults in the rocks below the coastal series. There are two main sets of faults, one treading about N. 65° E., the other about N. 10° W.

C. W. W.

Some Topographic Features Formed at the Time of Earthquakes and the Origin of Mounds in the Gulf Plain. By Wm. H. Hobbs. (Reprint from *American Journal of Science*, Vol. XXIII, pp. 245–56, April, 1907.)

In areas of subsidence, especially during earthquakes, water is squeezed upward through fissures and gives rise to forms such as the mud cones and craterlets in the deltas of great rivers, to the sandstone dikes and pipes observed in many rocks, and to mounds of the "spindle-top" type observed in the Texas and the Baku oil-fields.

C. W. W.

Itinéraires dans le Haut Atlas Marocain. By Louis Gentil. La Géographie, Bulletin de la Société de Géographie, 15 mars, 1908, pp. 177–200, map.

M. Gentil has furnished us a sketch of the topographic and geologic observations made during his journeys in a difficult and dangerous area which includes Cape R'ir and Marrakech in Morocco. Most of the systems of sedimentary rocks are represented in this region, together with volcanic and metamorphic formations of somewhat uncertain age. It is a striking fact that the rocks show in most cases the features which are characteristic of contemporaneous deposits in the greater part of the surface of the earth. Thus the lower Carboniferous contains limestones with numerous crinoids and bryozoans and the Permo-Trias consists of red-beds with gypsum and salt and of other deposits formed on land or in shallow lagoons. As elsewhere, the Cretaceous marks a period of extensive sea transgression and may easily be separated into a lower and an upper division. The shelly sandstones of the Tertiary occupy a tract along the Atlantic coast. The author concludes with a summary of the general orography of the northwestern corner of Africa. His observations confirm the conclusion of Suess, that there is essential continuity between the structures of northern Africa and southern Spain.

H. H.

Lehrbuch der geologischen Formationskunde. By DR. EMMANUEL KAYSER. Dritte Auflage, 1908. Stuttgart: Verlag von Ferdinand Enke.

The third edition of this very useful textbook contains many changes of a minor character which were rendered necessary by the recent rapid strides in statigraphical research. A few sections have been extensively revised and rewritten. The volume is one-sixth larger than the second edition, and contains over 100 additional illustrations of fossils, besides new figures and plates. H. H.

Physical Geography of the Evanston-Waukegan Region. By W. W. ATWOOD AND J. W. GOLDTHWAIT. Urbana, Ill.: Illinois State Geological Survey, Bulletin No. 7, 1908.

This forms the first of a series of "Educational Bulletins" descriptive of various parts of Illinois, and should be of particular interest to teachers of physiography and geology. Excellent accounts of the work and deposits of continental glaciers and of the evolution of lake shore-lines are given, as well as summaries of the history of the greater Great Lakes and of the features characteristic of the various stages of an erosion cycle.

H. H.

The Evolution of the Falls of Niagara. By J. W. SPENCER. 470 pp., 43 pls., 30 figs. Ottawa: Canadian Geological Survey, 1907.

From 1842 to 1905 the average recession of the Canadian Falls was found to be 4.2 ft. per year, and of the American Falls only 0.6 foot per year. G. K. Gilbert (U. S. G. S., Bull. 306) calculated the retreat for the two falls at 5 ft. and 3 in. respectively. The former breadth of the Canadian Falls has been reduced nearly one-seventh by commercial operations, and if the whole amount of water granted by the present franchises for power purposes be utilized these falls will shrink from 3,000 ft. to 1,600 ft., while on the American side there will remain but a few disconnected streams. New soundings show a depth of 92 ft. below the level of Lake Ontario at the head of the Whirlpool Rapids and furnish equally interesting figures for other parts of the river. Much new light is thrown on the history of the Whirlpool—St. David buried channel, and the truth about this feature seems finally to have been made clear. The ancient stream which flowed in it never drained the Erie basin, nor does it account for much of the gorge above the Whirlpool, as has been sometimes stated. To its great depth, however, it caused the formation of the Whirlpool. A small, superficial,

post-Glacial valley diverted the old Niagara above the Whirlpool and concentrated the flow in such a manner that a deep, narrow gorge was excavated. Afterward this was partially filled with blocks of stone and the present Whirlpool Rapids were formed. The basin at the site of the present falls is part of the shallow valley of a former tributary of an old outlet of the Erie basin. The Upper Rapids owe their existence to the fact that the falls, in working back, are climbing the bank of this refilled channel. Below the Whirlpool the well-known Foster Flats indicate the position of the floors of the Niagara River at the time when there were two falls, one in advance of the other. A third cataract existed still farther down the gorge and persisted long after the other two had become united. When the falls had retreated just beyond Foster Flats the drainage from the three upper Great Lakes was added to that of the Erie basin, which had already found an outlet through the Niagara. A study of the fluctuations of the lake levels shows that the tilting of the Great Lakes area has not operated during the last 50 years. The above are only a few of the features connected with Niagara and its history which are discussed in this very complete study of the river. Mr. Spencer places the age of the falls at 39,000 years.

H. H.

Transvaal Mines Department. Report of the Geological Survey for the Year 1906. Pretoria, 1907. 140 pp., 37 pl.

The plan of the Transvaal Survey is to publish separate sheet maps of definite portions of the Colony, together with descriptions of the geology of these areas. The report for 1906 contains descriptions of the structure, topography, and stratigraphy of nearly 5,000 square miles of territory and pays especial attention to deposits of economic value. Occurrences of magnesite, coal, magnetite, hematite, antimony, and gold are cited. In connection with the non-detrital auriferous deposits in the Lyndenburg and Carolina districts it is of interest to note that they are of the bedded ore-sheet type: water with gold in solution traveled along bedding planes until the precious metal was precipitated by ferrous compounds. Many of the illustrations in this volume will be appreciated by those who delight in grandly wild scenery.

H. H.

Maryland Geological Survey. Vol. VI. 572 pp., 51 pls., 19 figs., map. Baltimore, 1906.

Part I of this report contains a complete summary of the physical features of Maryland, describing the physiography, geology, mineral resources, soils, climate, hydrography, terrestrial magnetism, and forestry of the

state, together with six plates illustrating characteristic fossils of the various formations. A new and well-executed geological and soil map of the state is also included. Part II gives an account of the exhibits made by the Survey at recent expositions. The remaining half of the volume comprises reports on highways and highway construction, and an historical account of the counties and election districts. H. H.

Congrès géologique international. Compte rendu de la dixième session, Mexico, 1906. Imprenta y fototipia de la Secretaria de Fomento, Mexico, 1907.

The report of this session is in two large volumes, containing 1,350 pages and 52 plates. Besides the lists of members, minutes of the meetings, accounts of the excursions taken, etc., 46 papers communicated to the Congress are printed in full. The chief topics discussed are those relating to earthquake and volcanic phenomena and to geological climates. Those relating to the latter subject are: "Interglacial Periods in Canada," by A. P. Coleman; "Glaciation in Lower Cambrian Time" and "Conditions of Climate at Different Geological Epochs," by T. W. E. David; "Ueber die Klima-Aenderungen der geologischen Vergangenheit," by F. Frech; "Climatic Variations," by J. W. Gregory; "The Causes of the Glacial Epoch," by E. W. Hilgard; "Le climate de l'Afrique du Nord pendant le Pliocène supérieur et le Pleistocène," by L. de Lamothe; and "Climats des temps géologiques," by M. Manson. Among the papers on ore deposits may be mentioned: "Ore Deposits at the Contacts of Intrusive Rocks and Limestones," by J. F. Kemp; "The Relation of Ore-Deposition to Physical Conditions," by W. Lindgren; and "Some Relations of Paleogeography to Ore Deposition," by H. F. Bain. H. H.

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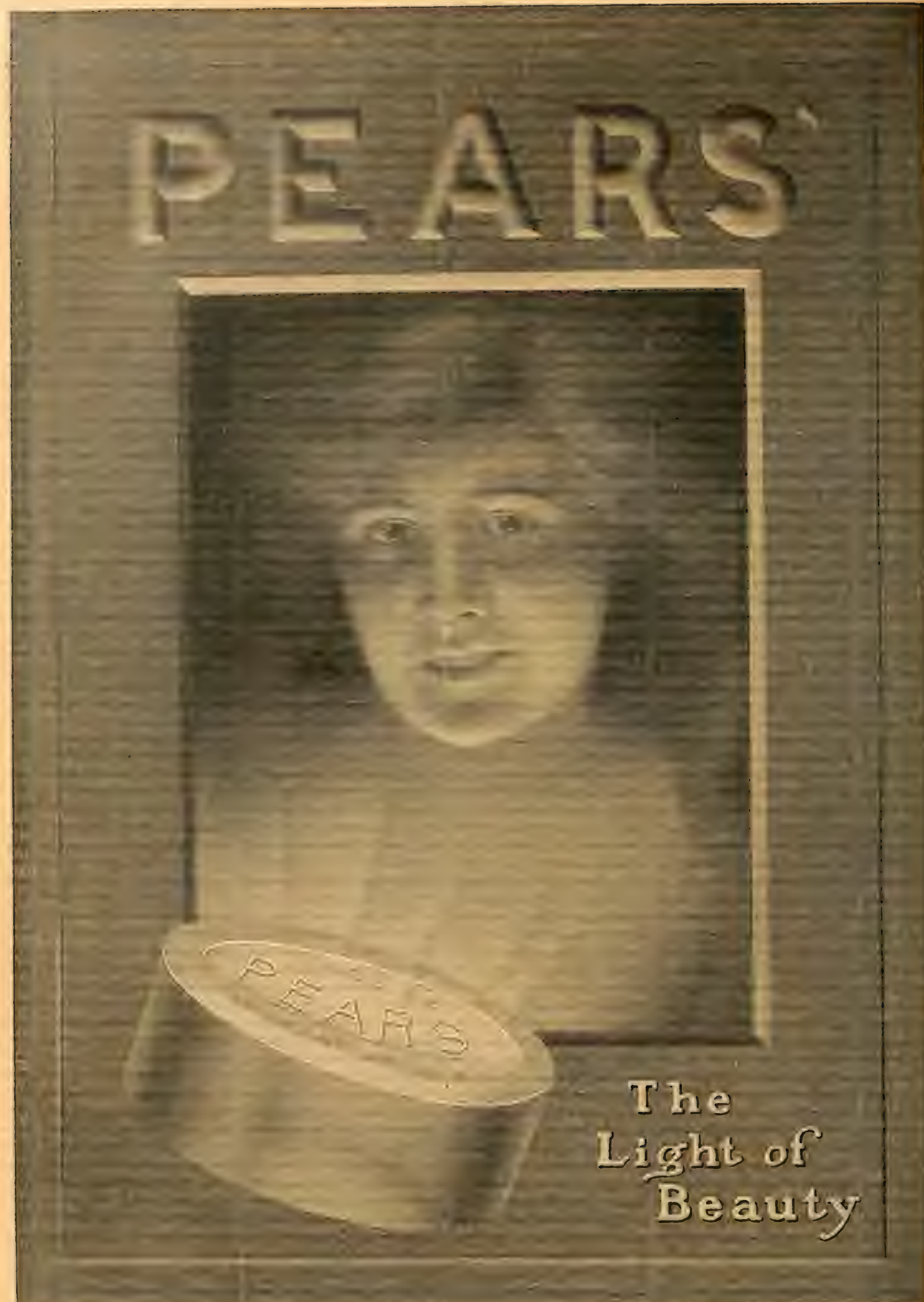
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THE RED BEDS OF NORTHERN COLORADO[1]

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The perennial problem of the age of the so-called Red Beds of Colorado received some attention from the State Geological Survey during the field season of 1907, and owing to the uncertainty as to when the results may be published by the survey, it is deemed best at this time to give to the public a brief statement of the important facts. These beds were designated Jura-Trias by the early surveys, chiefly on account of lithologic resemblances to formations found elsewhere. Since it became evident that at least the lower portion in many places is much earlier, the term Red Beds has come into general use. Our work on these formations in 1907 was confined to the foothill region north of Boulder. At the northern boundary of Colorado we found a chert concretion zone containing *Spirifer centronatus* Winchell, *Cranaena subelliptica* var. *hardingensis* Girty, and *Spiriferina solidirostris* White, a fauna which is considered Mississippian and is found on the east side of the Front Range at Canyon City and elsewhere. The first-named species and others of like age were long ago reported from that region, but the record had little value because the position in the formation was not given. We traced the chert zone for eight or nine miles southward, finding it everywhere within a few feet of the contact of the conglomerate with the granite and uniformly containing fossils, but found none farther south. The coarse sandstone and conglomerate series in which this fossiliferous zone occurs appears

[1] By permission of the State Geologist of Colorado.

to be stratigraphically continuous with the Fountain formation in the Boulder District as defined by Dr. Fenneman,[1] who correlates it with the Fountain of the Colorado Springs region. We have traced the formation in the field the entire distance from the Wyoming line to Boulder and find no reason to doubt that the horizon containing the chert fossils is the equivalent of the base of the Fountain as represented at Boulder, or possibly even much higher than the base as it occurs immediately north of Boulder, where the formation is much thicker than near the Wyoming line.

In limestones at a much higher horizon we found a Pennsylvanian fauna (tentatively considered older than Knight's so-called "Permian" of Wyoming), consisting of *Productus cora* D'Orb., *P. nebrascensis* Owen, *Spirifer rockymontana* Marcou, *Squamularia perplexa* McCh., *Derbya* n. sp. ?, *Phillipsia* aff. *major* Shumard, *Myalina swallowi* McCh., abundant crinoid stems and others. These limestones were said by Darton[2] to pass into the Fountain conglomerates in traveling southward. Of this we are by no means certain without further investigation, but they seem certainly to belong at the very top of the Fountain or base of the overlying Lyons formation of Fenneman's bulletin. These limestones nearly disappear at the Cache la Poudre, and a little work just north of that stream is necessary to determine their exact position. We have traced the contact of the Fountain and Lyons all the way from the northern line of the state to Boulder except two or three miles between the Cache la Poudre and Owl Canyon, and believe the Ten Sleep sandstone of Darton's paper to be the stratigraphic equivalent of Fenneman's Lyons.

It seems very clear that all of the Fountain sandstones and conglomerates of northern Colorado are Carboniferous, the base being probably Mississippian (certainly so in the northern portion of the field) and the upper portion possibly as late as Pennsylvanian. It also seems likely that the Lyons is Pennsylvanian.

The fossils were, through the kindness of Dr. T. W. Stanton, of the United States Geological Survey, submitted to Dr. G. H. Girty, whose determinations are followed in this paper.

[1] N. M. Fenneman, *Geology of the Boulder District, Colorado,* U. S. Geol. Sur., Bull. No. 265, 1905.

[2] N. H. Darton, *Geology and Underground Water Resources of the Central Great Plains,* U. S. Geol. Sur., Professional Paper No. 32, 1905.

GLACIAL DRIFT UNDER THE SAINT LOUIS LOESS

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Glacial drift in the vicinity of St. Louis seems to have been described first by Professor A. H. Worthen, in 1866.[1] In 1890, Professor G. Frederick Wright[2] reported glacial drift in the following localities within the city limits: (1) Near Forest Park, on the road to Ferguson, beneath 20 feet of loess was a bed of gravel 2 or 3 feet thick, which contained granite and other pebbles two to three inches in diameter, some finely striated; (2) at Hyde Park a similar section was seen; (3) in the vicinity of Shaw's Garden. Loess had been removed for brick making, uncovering extensively a gravelly stratum which contained many granite pebbles. Striae were found on angular limestone fragments. The elevation was 150 feet above the Mississippi River.

H. A. Wheeler, in a paper "On Glacial Drift in St. Louis," in 1895,[3] reported blue glacial clay or till 12 feet thick, at West Pine Boulevard and Taylor Avenue, extending westward to Euclid, underneath 10 to 15 feet of loess. The diameter of the bowlders is said not to exceed one foot. Among the erratics reported were red and gray granite, diorite, dolerite, and quartz-porphyry.

In 1896 James E. Todd[4] described bowlder clay in St. Louis. His section may still be seen on Laclede Ave. near Sarah St. The till is 8 feet thick, "a reddish brown or a waxy red clay," containing granite and other foreign pebbles. The overlying loess is 16 feet thick.

Frank Leverett, in his monograph on the *Illinois Glacial Lobe*,[5] reported deposits of glacial derivation underlying the loess for a few

[1] A. H. Worthen, *Geology of Illinois*, Vol. I, p. 314, 1866.

[2] G. F. Wright, "The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois," *Bulletin 58, U. S. Geological Survey*, p. 72, 1890.

[3] H. A. Wheeler, "On Glacial Drift in St. Louis," *Transactions of the St. Louis Academy of Science*, Vol. VII, pp. 121, 122, 1895.

[4] J. E. Todd, *Missouri Geological Survey*, Vol. X, pp. 162, 163, 1896.

[5] F. Leverett, *The Illinois Glacial Lobe*, Monograph XXXVIII, pp. 64, 71, 1899.

miles back from the Mississippi River in northern St. Louis County. While he recognized the glacial nature of the deposits, he favored the

FIG. 1.—Exposure of loess and underlying till on the south side of the quarry at Grand Ave. and Rutger St. 1, St. Louis limestone, much decayed at the top; 2, bowlder clay; 3, loess.

idea that they were water-laid, basing his opinion on the water-worn appearance of the pebbles and cobbles, and the presence of pebbles

which had evidently come from outcrops in Calhoun and Lincoln counties, a few miles up the valley. "It remains an open question whether the ice sheet reached into northern St. Louis County from the Illinois side of the river."

So far as the writer knows, the foregoing is the sum total of reported investigation of a glacial drift under the St. Louis loess. It is the purpose of this paper to present additional evidence of a true drift in the above-mentioned region.

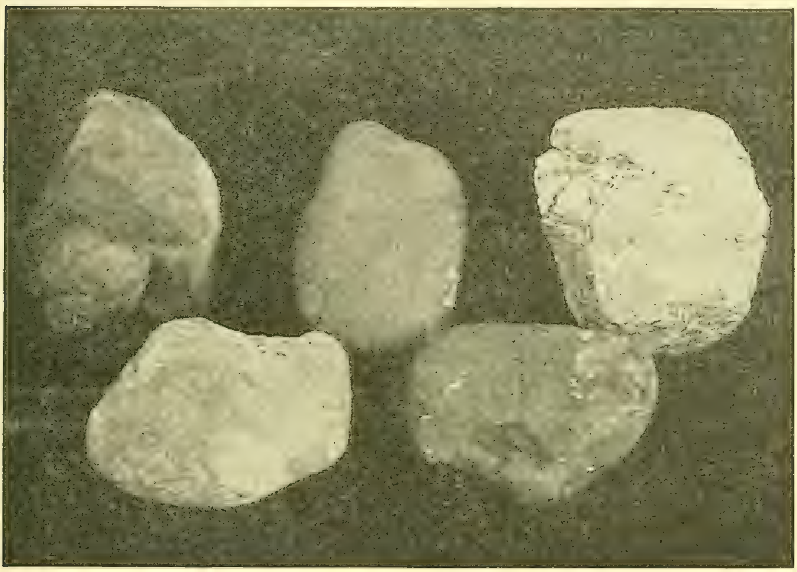

FIG. 2.—Pebbles from the bowlder clay at St. Louis. *A* and *B*, quartzite; *C* and *D*, greenstone; *E*, chert. Reduced to less than three-eighths natural size.

At the quarry near Grand Ave. and Rutger St. may be seen a section of till resembling the material described by Todd. On the south side of the quarry the drift sheet is 4 feet thick, and lies on the deeply decayed St. Louis limestone. On the west side of the quarry the till is from 2 to 3 feet thick. The overlying loess has a thickness of from 12 to 17 feet. In places the contact between the loess and the clay is sharply defined (see Fig. 1). This clay differs from the loess in color, texture, and composition. It is red rather than buff colored, compact, and very sticky when moist. The upper portion

of it has a sheet of small water-worn pebbles. Occasional subangular and planed bowlders are found in the clay beneath the pebbly sheet. The largest pebble found in this section by the writer is a chert shown in Fig. 2, *E*. Its dimensions are 13 by 10 by 8 centimeters.

On Meramec St., north of the Workhouse quarry, there is an outcrop of till on the south and east faces of the bluff. The deposit lies on the St. Louis limestone, and beneath loess 20 to 25 feet thick. The line of contact between loess and till is a sharp one. With the possible

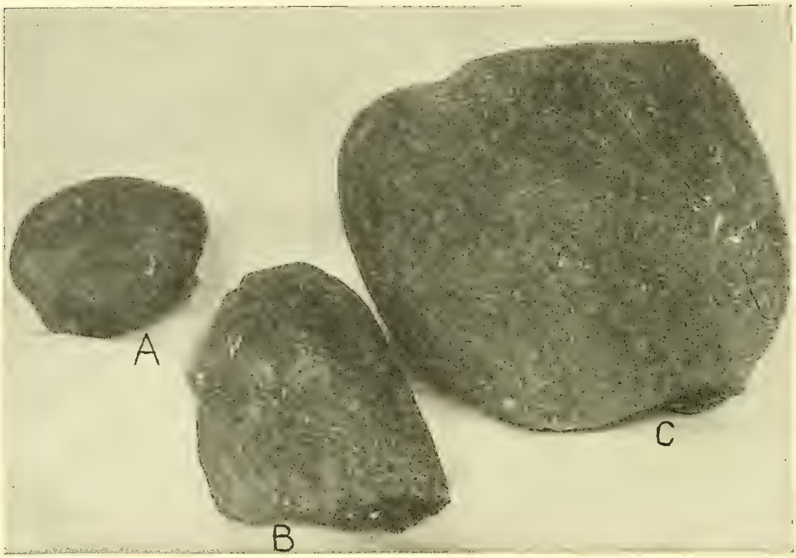

FIG. 3.—Pebbles from the bowlder clay of St. Louis. *A*, ferruginous chert; *B*, felsite; *C*, sandstone. Reduced to about one-fourth natural size.

exception of Wheeler's section at West Pine Boulevard and Taylor Ave., the material at Meramec St. is more pebbly and bowldery than any till heretofore described as lying beneath the St. Louis loess. The sheet in the Meramec St. section is 2 to 3 feet thick, and contains bowlders a foot in diameter. Bowlders from 8 to 12 inches are quite numerous. Some of them show both planed and polished surfaces. Several bowlders of granite, including a biotite granite of medium texture and others of a coarse, pegmatitic nature, have been found here. They not infrequently show planing, but are always much weathered inside.

Several pebbles of characteristic subangular shape and of a composition which shows them to be erratics are shown in Figs. 2 and 3. Fig. 3, *A*, is a ferruginous chert. It bears a resemblance to pebbles in a conglomerate at the base of the Sioux quartzite of southern Minnesota and northern Iowa. Cherts of this sort are also found, however, in the Mesabi and Penokee iron ranges of northern Michigan. Fig. 3, *B*, is a planed and polished pebble of dark-blue felsite which contains phenocrysts of feldspar and quartz. Fig. 3, *C*, is a sandstone with hematite cement, approaching a quartzite. In Fig. 2, *A* and *B* are quartzite resembling that at Sioux Falls, Ia.; *C* and *D* are medium-grained greenstone, planed on three faces. Pebbles and bowlders representing the following rocks are found in this section: coarse sandstone, almost a quartzite, with silica and limonite cement; sandstone with hematite cement; quartzite; vein quartz; quartz porphyry; felsite; greenstone; biotite granite; pegmatite. While all these varieties might have come either from the southern Minnesota district or the Lake Superior district, it seems rather probable that the drift came from the former direction. This district is nearer than that of northern Michigan; and a southward direction of transportation would agree with Leverett's observations of pebbles from Calhoun and Lincoln counties.

From Meramec St. southward for several blocks exposures of bowlder clay of varying thickness may be seen. Near the Hoffman-Hogan quarry is an outcrop resembling the one at Grand Ave. and Rutger St., described in this paper. Rhyolite, granite, and diabase pebbles have been found by the writer in these exposures.

While it is possible that in certain places the thin sheet of gravelly material under the St. Louis loess is glacial gravel, as described by some authors, rather than till, the sections described in this paper are without doubt true bowlder clay. The variety in composition of the pebbles and bowlders indicates collection from distant and scattered sources, and transportation by an ice sheet. The presence of many subangular pebbles with smooth and planed sides, associated with pebbles of less characteristic shapes, the heterogeneous mixture of bowlders, pebbles, and fine clay, and the compactness and general consistency of this clay, are all indicative of till rather than of a water-made deposit. This sheet of drift has been observed by the writer

in the northwest, central, and southeast portions of the city. Considering these sections and those previously described, it seems that the sheet underlying the St. Louis loess is true glacial drift. It seems not unlikely that in other places as well as here the old drift sheets beneath the loess extend farther south than they have heretofore been fully recognized

THE JAPANESE VOLCANO ASO AND ITS LARGE CALDERA[1]

ROBERT ANDERSON
Washington, D. C.

CONTENTS

BRIEF DESCRIPTION

Aso-san is a volcano in the center of Kiushiu, Japan, within twenty-nine miles of the western, and forty-five miles of the eastern, coast of the island. It consists of a huge mound-shaped cone on the summit of which is sunk an oval bowl measuring about ten miles in width, fourteen miles in length, and 1,000 to 2,000 feet in depth, the bottom being some 1,500 feet above sea-level. Within this bowl a range of mountains, attaining an altitude above sea of 5,600 feet and overtopping the rim more than 2,000 feet, runs from east to west across its short diameter and divides it into 2 crescent-shaped basins. On the summit of this dividing range is a low modern cone with active

[1] Read before the Geological Society of Washington, January, 1907.

crater; and at the foot of the range on either side a fairly level plain stretches off to a steep mountain wall that surrounds the bowl. At only one point a break occurs in this wall. The central range is so high and broad, and so completely shuts off the inclosed plain on the south from the one on the north, that one does not at once recognize the two plains as parts of a single great oval floor. But each of the basins is so perfectly the complement of the other that little doubt can exist of their being the two halves of a large crateral depression partitioned off by mountains of subsequent growth. The bowl has a typical caldera form, and it has most probably originated through the subsidence of a formerly overlying mountain mass. It is one of the very largest, if not the largest, of the craters known on this planet, and without doubt the largest having such perfect preservation.

SOURCES OF INFORMATION

The observations upon which this article are based were made in the spring of 1905, when I made a visit to the volcano and lived for nearly two weeks within the caldera.[1]

Little has been known or published concerning Aso-san. John Milne many years ago made a hasty visit to it and published a narrative and descriptive article in the *Popular Science Review*.[2] He has also discussed the history of the eruptions of the new crater and noted other features of the volcano in the *Transactions of the Seismological Society of Japan*.[3] Aso-san is briefly described by Edmund Naumann in his paper "Ueber den Bau und die Entstehung der japanischen Inseln,"[4] and there is an article in Japanese on the subject in the Tokio *Journal of Geography*, written by T. Iki.[5]

No detailed maps are available upon which to base statements regarding Aso. The altitudes and other measurements here given are approximate but are based on careful estimates, on barometric measurements, and on general maps of Kiushiu. The accompany-

[1] In company with my brother, Malcolm Anderson, and friend, Kiyoshi Kanai, to both of whom I am indebted for photographs and information.

[2] New Series, Vol. IV, No. 16, October, 1880.

[3] Vol. IX, Pt. II, 1886.

[4] Berlin, R. Friedländer & Sohn, 1885.

[5] Published by the Tokio Geog. Soc.; Vol. XIII, No. 149, April, 1901.

ing diagram is largely from memory and is intended merely to convey a general idea of the caldera.

GEOLOGY OF KIUSHIU

The island Kiushiu, which covers about 17,000 square miles, has a foundation of rocks of Paleozoic age and possibly some belonging to the Archaean. These are largely sedimentary, and frequently metamorphic; but associated with them are many varieties of igneous rocks. Less altered strata of supposed Mesozoic age, but possibly

FIG. 1.—Sakura-jima, an andesitic cone of medium slope, in the bay of Kagoshima at the southern end of Kiushiu. Its last eruption was in 1779. Its altitude is 3,850 feet.

in part representative of the early Tertiary, overlie these extensively; and fossiliferous, much-disturbed Tertiary formations occur in numerous relatively small detached basins. Over these basement rocks a superstructure of eruptives has been built up during the Quaternary, having probably been begun before the close of Tertiary time. About one-half of the island is now covered by these volcanic rocks. In some places the covering has the nature of a thin layer of ash or volcanic mud or lava over the old surface, whereas in others it has a great thickness. The whole of the north-central part of the

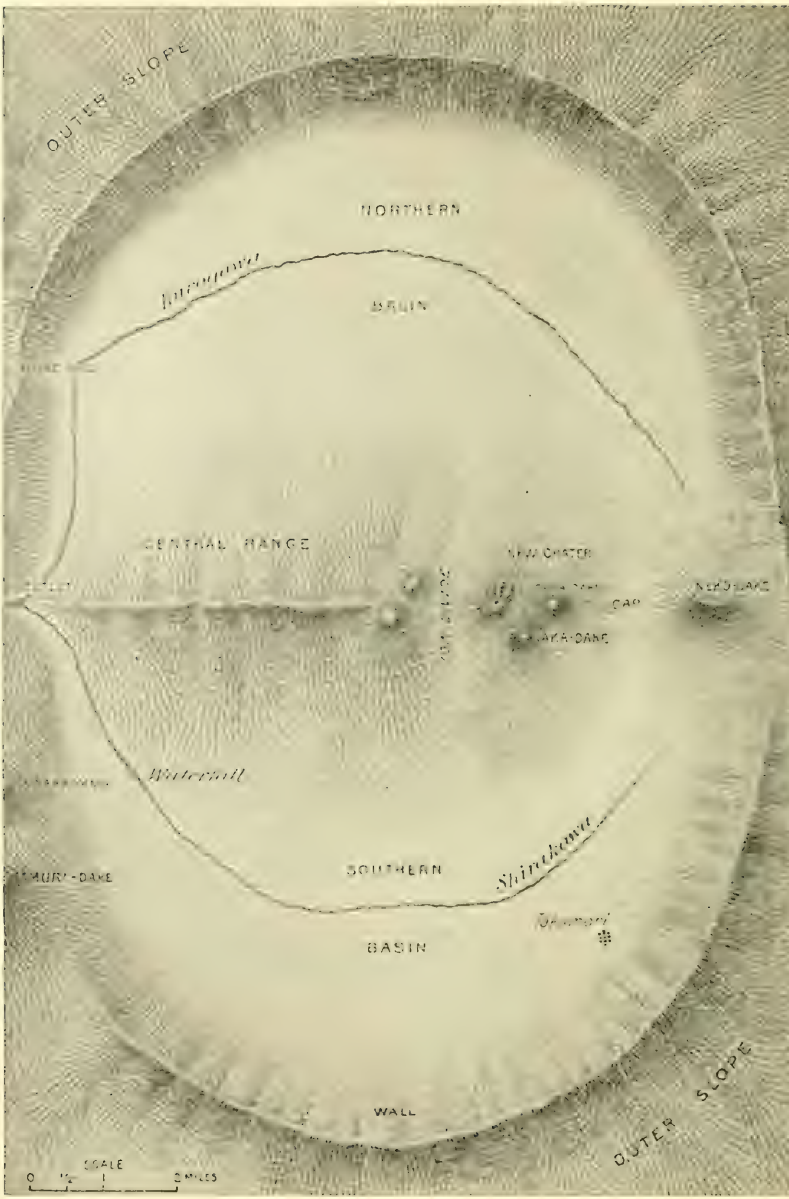

FIG. 2.—Rough diagram of the Aso caldera.

island and much of the southern part is volcanic. The Japanese geologists count twenty volcanoes in Kiushiu, including two that form small islands near the coast on the south. The period of volcanic construction extends into the present—eight of the twenty volcanoes being still living—but the general activity seems to be on the decline. The volcanic forces must have reached their climax sometime during the middle Quaternary, to judge from the amount of erosion that has taken place since the greatest outpourings occurred; and it is probably from this period that the long since extinct crater of Aso dates. In its prime Aso doubtless held a position of pre-eminence among the volcanoes and mountains of Kiushiu, as is indicated by the extent of territory that is covered by material derived from its eruptions, and by the grandeur of the scale upon which the crater was built and the probability that a cone formerly rose to a great height above it. Its present peaks are surpassed by a few others in the island, the highest of which is the non-volcanic mountain Sobo-san, 6,600 feet in altitude.

APPROACH TO THE CALDERA

Aso-san may be most easily reached from Kumamoto, a city situated on the coastal plain near the western coast of Kiushiu. From there a road runs up into the mountains and down into the caldera, which is about twenty miles away. The volcano does not form a prominent cone as seen from this side and appears merely as a high portion of the mountain mass that occupies the island's interior. The caldera becomes apparent only on an approach to its very edge, or from the summit of one of the high mountains within a score of miles of Aso. From such a summit one looks down upon it and obtains an impressive view of the huge bowl and the high volcanic peaks that spring from within it.

THE FLOOR

Viewed broadly, the floors of the two basins into which the caldera is divided are level plains lying at the same elevation. They slope gently upward from west to east. On the east they break into low sweeping ridges and knolls that rise gradually and merge with the wall and central range, which are there convergent. (See Fig. 3). Throughout the centra portion of each of the two basins the floor

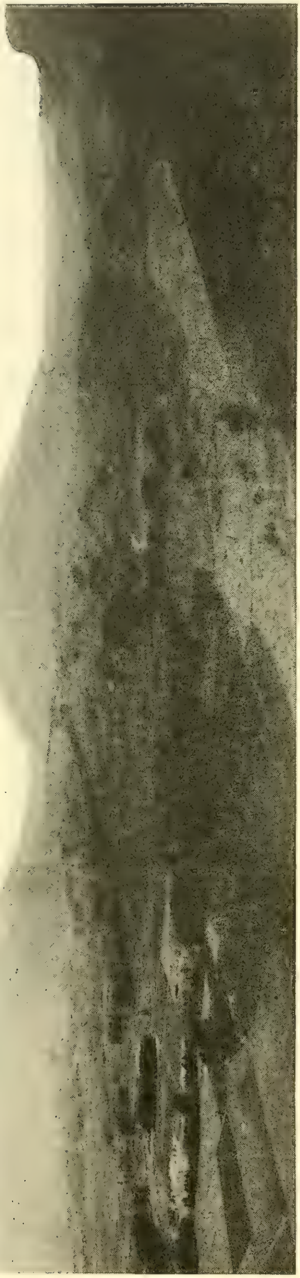

Fig. 3.—Panorama of the southeastern portion of the caldera. Looking north and northeast from near Takamori. Naka-dake and Taka-dake on the left, Nekodake in the center, and the ring wall on the right. Photo by Malcolm Anderson.

except for gentle undulations, is almost level and has an average elevation of about 1,500 feet. On the inner side of each it slopes gently up to the central range, and on the outer side to the wall. Each half of the caldera is traversed by a stream that follows a shallow curving course from east to west. The stream in the southern basin is called "Shirakawa" (*kawa* or *gawa* means river); that in the northern, the "Kurogawa." The usually dry, branching, tributary runnels in the upper course of the former are shown in the middle foreground of Fig. 3. The Kurogawa carries considerably more water than the former and is worthy to be called a small river. (See Fig. 5.) These streams unite around the western end of the central range, which just fails to reach the wall there, and flow out through a canyon or barranco. The single stream thus formed, called the Shirakawa, runs westward down the mountains and across the Kumamoto plain to the sea. The point of outlet is at an elevation of about 1,000 feet above the sea, and on approaching it the streams leave their gentle

course over the comparatively flat plain and tumble down to their junction at the outlet with gradients of 4 to 8 per cent. or more. The northern one makes the descent the more rapidly. The southern one on leaving the upper level of the floor drops over a picturesque waterfall.

The northern basin appears to be larger and rounder than the southern one and its floor is even more level. Small parts of it were

Fig. 4.—A portion of the ring wall, looking southwest across the cultivated floor of the southern basin. The wall in this portion is considerably worn. The town of Takamori shows in the distance on the left. Photo by Malcolm Anderson.

flooded or marshy during April, 1905. Several small isolated and fairly steep hills rise out of the northern basin. They were not observed closely but looked as if they were composed of the same material as the wall.

The surface deposits of the floor appear to be chiefly fine sandy material and coarse yellow sand and gravel in horizontal layers, covered with black, slightly sandy soil. The deposits were probably

formed by a mingling of the products of eruptions and erosion. The low slopes and hillocks where the plain rises into the wall are, as far as observed, composed of lava both vesicular and compact, and it is most likely that the floor within no great depth below the surface is composed of the same material.

The floor of the caldera is everywhere cultivated, and supports a population that may be roughly estimated as amounting to at least 5,000 people. Many villages and groups of dwellings are scattered over the plain, and clusters of trees stand here and there. The whole scene is a remarkable one, being especially brilliant when the spring crops, which consist chiefly of green wheat and mustard with yellow flowers are maturing. There is a legend that the mountain-girt bowl of Aso was once occupied by a lake, until the god of the mountain kicked a hole in the wall where the present outlet is and allowed the water to flow out. There may have been in former times flooded areas of more wide extent than those noted above, but it does not seem probable that a real lake ever occupied the caldera.

THE WALL

The caldera has an oval shape and its rim forms a smooth sweeping curve around the whole circumference, broken only at the cleft on the west where the streams pass out, and on the east where the wall is joined by the descending slope forming the extremity of the central range. The curvature of the wall is so slight that it appears at a glance like the face of a straight mountain range. On the basis of a rough estimate it may be said that the average slope from the floor to the top of the wall would nowhere exceed 25 or 30°, although rocky almost vertical precipices occur at points on its face. The wall is furrowed by gulches that have in places eaten back to the summit and notched the skyline of the rim. In general, however, its top is fairly even. Between the gulches sharp ridges run out into the floor. The wall varies in appearance from point to point, and the ridges and prominences on its face have a variety of picturesque shapes. The wall of the southern basin, exposed to the north, is much more worn than that of the northern one. Forms resembling the remains of terraces appear in places. The lower portion of the wall has a gentle slope, and at some places is deeply soil-covered

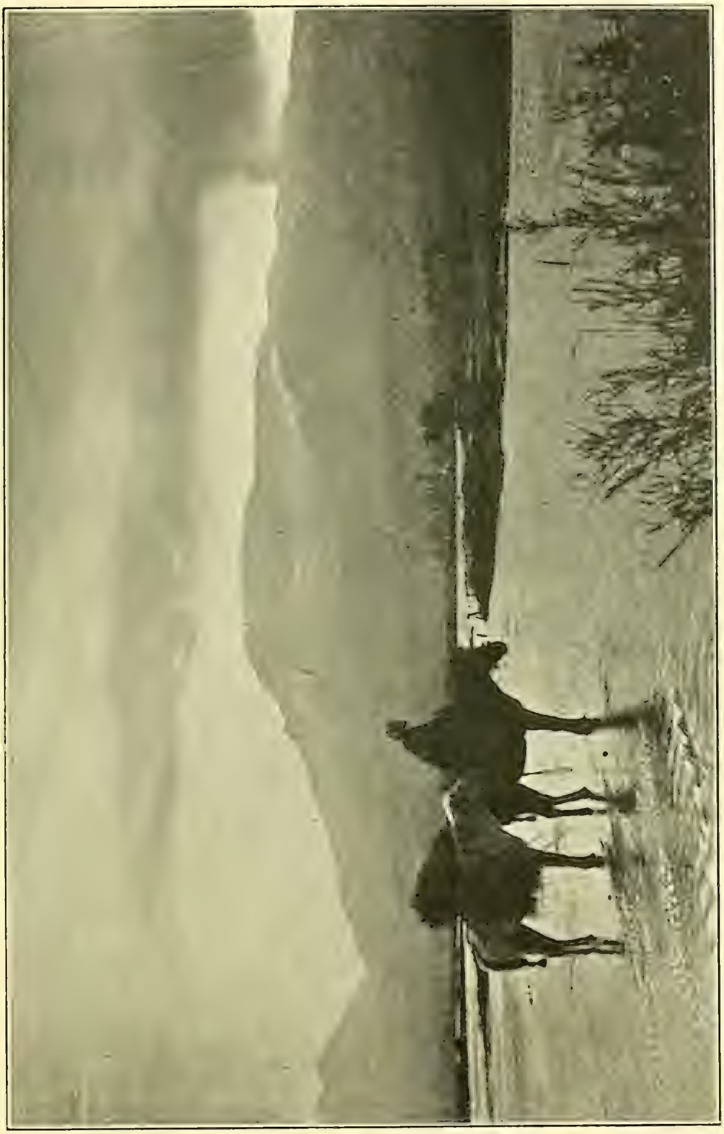

Fig. 5.—The central range from the floor of the northern basin. In the foreground flows the Kurogawa; on the right a vapor cloud rises from the modern crater; in the center is Taka-dake, 3,000 feet above the foreground; and on the left is a portion of Neko-dake. Looking southeast.

and supports a fine grove of trees. The higher portion is precipitous and exposes best the material of which it is made. It is formed of roughly bedded flows of basaltic andesite, interbedded and intermingled with mixtures of vesicular lava, scoriae, pumice, and volcanic sand. The lava predominates, and the harder layers project with vertical rocky faces, while between them softer zones have weathered way into débris slopes. The height of the wall is on the average about 1,300 to 1,500 feet. It decreases toward the eastern side owing to the gradual rise of the floor in that direction, but increases at some points, as on the southwest and west sides, where mountains break the regularity of the horizon line.

The only opening in the ring wall is the barranco on the eastern side through which the streams have their outlet. Cliffs of roughly columnar lava form the sides of this gorge up to a height of several hundred feet and are continued upward by densely wooded slopes that rise over 1,500 feet above the stream bed. The span of the canyon where it begins to widen out above the cliffs is less than half a mile.

Probably the next lowest point upon the rim is at a point three miles north of the outlet, where the "Futaetoge" (*toge* means "pass"), which has an elevation of about 2,500 feet above the sea, is less than 1,000 feet above the caldera floor. Another stream running down the outer slope to the sea heads at this low point. The highest portion of the watershed on the rim is on Tawara-yama and Kamuri-dake, two mountains that form the wall at the western end of the southern basin. They rise 2,000 to 2,700 above the floor of the caldera. The former is between two and three miles south of the outlet of the streams, the latter four miles or more. The summit of each and the high ridge connecting them is about two miles back from the floor.

THE CENTRAL RANGE

The ridge or range that divides the caldera is, properly speaking, Mount Aso. From the floor on the south, or the one on the north, it appears as a massive rugged barrier the summit of which is roughened by several dominating peaks. (See Figs. 3 and 5.) Looking up at it from either basin one would never imagine the existence of a second and almost identical pit with level floor and encircling outer wall at

its base on the opposite side. It is only from one of the peaks in the range or from a distant mountain top that a conception of the whole as a unit and as a single vast caldera may be obtained.

There are three main peaks, all along the eastern half of the range. The western end is lower, has less bold outlines, and declines gradually toward the west. The most striking of the peaks in the range is Neko-dake at the very eastern end. (The word *dake* which forms

FIG. 6.—Recent-looking lava with smooth flow structure, high on the south side of Naka-dake. Looking south toward the southern wall, which shows dimly far across the caldera.

part of the name of many Japanese mountains means "peak.") Its slopes have the graceful curving outlines characteristic of volcanic cones and its summit is serrated with pinnacles of lava. Its eastern flank drops down and ends the range by merging with the outer wall. There is no sign of any continuation of the range beyond into the outer region, it being distinctly a line of peaks belonging inside of the caldera. The slopes of Neko-dake are steep, being in the main 25 to 30 degrees. A part of the summit is easily accessible, but the

highest point cannot be reached as it is an isolated monument of andesitic lava 100 feet high and having slopes of from 60 to 75 degrees on its sides.

The western flank of Neko-dake extends down most of the way to the crater floor, forming a depression in the central ridge 2,000 to 2,500 feet deep, so that the peak is left as an isolated pyramid with truncated, broken summit. The top is 4,800 feet above the level of the sea, and not much over 2,500 feet above the highest portion of the floor.

Beyond the gap just mentioned the central ridge continues westward and rises immediately into Taka-dake, the highest peak of all. It has an elevation of 5,600 feet, and rises some 4,000 feet above the plain at its base. The next peak, Naka-dake, is a somewhat lower one, on the southwest flank of Taka-dake, slightly out of line with the general east and west summit line of the ridge. Its shape is somewhat like that of a half dome, and it presents on the south side of its summit a broken precipice of black lava.

At the western base of the last two peaks the modern crater is situated, at an altitude of about 4,000 feet above the sea. The range declines still more just west of this, forming a depression in its central portion. (See left of Fig. 3 and right of Fig. 5.) This depression is by no means as low, however, as the one between Neko-dake and Taka-dake, and does not tend to break the continuity of the range as that one does. The surface of the range here is a wide upland covered with curious small steep mounds of volcanic débris.

The north and south flanks of the range sweep down with concave slopes into the wide level floor. They are furrowed by sharp ravines and intervening ridges that gradually lose their prominence among the gentler slopes toward the base. The slopes are not usually very steep, and are for the most part covered with soil and long grass. They afford little water, and are uncultivated and uninhabited.

Basaltic andesite of varying compact, cystalline and scoriaceous texture is the chief material of which the central ridge is built up. In the vicinity of the higher peaks exposures of lava are very prominent Over the lower, more gentle slopes, outcrops are infrequent. Deposits of ashes and pumice are scattered far and wide.

THE MODERN CRATER

The cone upon which the modern crater of Aso is situated has a slope of about 15 degrees and is only a couple of hundred feet high.

FIG. 7 —The modern Tuff cone on the summit of the central range, after a rain; looking northeast. The vapors issue from the northern end of the new crater. Young drainage lines are forming in the soft mud and cinders. In the foreground is a temple to the god Aso.

(See Fig. 7.) The cone is largely composed of fine-grained gray mud, which on drying becomes compacted into tuff. It is irregularly interbedded with lava and coarse fragmentary matter. This modern center of the activity of Aso is about one mile nearer the eastern than the western side of the old outer crater, but its position is roughly central with respect to the whole great oval.

The new crater is a black, ragged pit, constantly roaring and steaming. (See Figs. 8 and 9.) It has sheer walls of roughly stratified mud, the layers of which appear to dip inward, and a depth of three hundred feet or more. It is oblong in shape, and is at a rough estimate nine hundred feet across from east to west and two thousand feet long from north to south, the long axis being in the same direction as that of the outer crater. Its rim is very uneven, being much higher on the north and east than on the other sides. It is divided into five compartments or vents arranged along the long axis, each separated from the next by a steep wall of mud one hundred feet or more high. The two most northerly vents are the deepest and the only active ones. Occasionally when the vapor column diminishes one can look to the bottom of the northern vent and see the burning sulphur that plasters the lower walls and floor. The bottom is a round flat disk of cracked mud looking like the dried bottom of a pond, and there is no appearance of a hole or conduit descending to greater depths. The one next south of it is deeper and pours forth the most steam. No glimpse of its bottom could be obtained by the writer from any point upon the rim. The existence of activity in a decadent stage is indicated at other points, all in the western half of the Aso range, by jets of steam and hot springs. (See Fig. 11.)

DOUBLE RIM OF THE NEW CRATER

An interesting feature of the modern cone is a small ridge of mud that circles around the western side of the summit at a distance of about one hundred feet from the crater's edge. On climbing the cone one reaches what appears to be the summit only to find that one must descend some twenty feet into a moat and rise again a similar amount before reaching the lip of the crater. The moat acts as a line of drainage and carries the rain water southward along the summit of the cone, parallel with its long axis, to an outlet down the

mountains. On the east side there is no similar moat but the crater borders the cliffs at the foot of the peaks Taka and Naka and is separated from them by a stream channel, as shown in Fig. 10. A small double rim and moat was observed by the writer in the loose cinders for part of the way around the crater at the summit of Vesuvius in September, 1905.

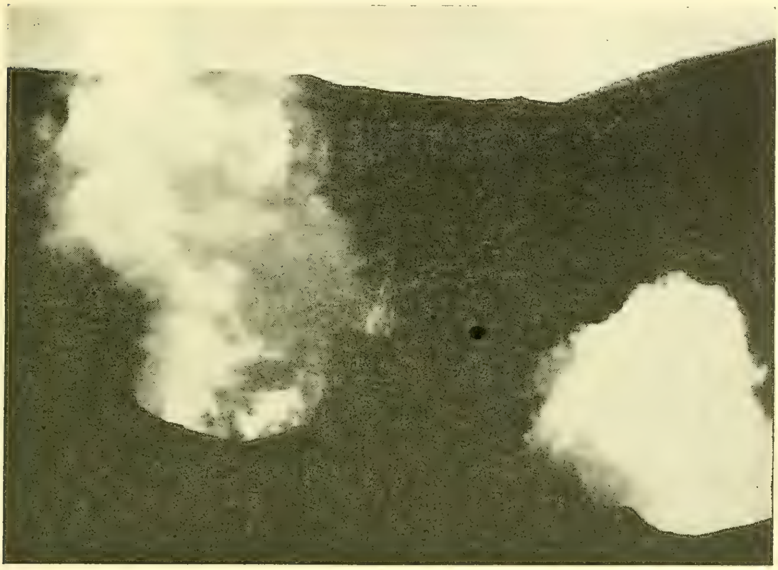

Fig. 8.—Looking northeast into the modern crater of Aso, showing the two most northerly vents and the stratified wall. These are the only active vents, the one on the right being more active and deeper. Photo by Malcolm Anderson.

HISTORY OF THE NEW CRATER

Aso-san has been in continual activity during the historical period. A detailed account of its history has been compiled by John Milne from interesting contemporaneous Japanese records.[1]

The greatest eruptions of very recent times were in the winter of 1873–74, when unusual activity continued during several months and ashes covered the ground to a distance of eighteen miles; in the winter of 1884 when ashes were blown over Kumamoto, making it so dark there at a distance of twenty-five miles that lamps had to be

[1] *Transactions of the Seismological Society of Japan*, Vol. IX, Pt. II, 1886.

used for three days; in 1889 during the year of the Kumamoto earthquake, which was the year following the great explosions of Bandai-san in central Japan; and lastly in 1894, when the floor of the modern crater was somewhat altered.

THE OUTER SLOPES

The vast open bowl of Aso occupies the summit of a great mound, the flanks of which, sloping gently away from the top of the interior wall, form a rolling hilly upland of low relief among the mountains of Kiushiu. This low dome-shaped mountain taken as a whole occupies at least 450 square miles. From above, the outer slope appears as an inclined plateau wrinkled with knolls and ridges and little valleys. All of these hillocks are of similar height, and destruction through erosion has not gone far. The general angle of slope away from the edge of the caldera is about 3 to 5°, but it is even less than this in places. On the northwest side it is very slight, because the flanks of the mound, which reach so far in other directions, there give place to a plateau between the rim and the not far distant volcanic mountains Kura-take and Ona-take. Within five to ten miles of the rim on most sides, at an elevation above the sea about the same as that of the bottom of the caldera, the outer slopes reach the foot of high mountains that almost completely encircle the upland, much as the caldera wall surrounds the plain formed by its floor. The surrounding mountain barrier is not volcanic on the east and south, where ancient sedimentary and igneous rocks form Sobo-san and other prominent peaks. The whole volcanic mass of Aso and of the mountains to the north is of the nature of a filling within a depression in the topography of the older formations.

The surface material of the outer slopes is largely fragmental débris. At a few places where it was observed exposed it appeared as massive deposits of sandy material, or as soft tuff, or as agglomerate composed of coarser fragments. Some of the hills many miles from Aso are entirely composed of fragmental volcanic deposits of this kind. Lava is frequently exposed on the western slope down to the Kumamoto plain; and in the upland region about Aso, toward the foot of the surrounding mountains, where dissection has advanced farthest, lava is much in evidence. It is most probable that

lava predominates beneath the surface throughout this whole region.

RADIATING LAVA FLOWS

Some miles to the south and east of Aso-san the surface covering of volcanic ejectamenta which has filled up and blotted out the ancient features of the landscape in this portion of Kiushiu ceases to be a solid sheet, and the underlying older formations come to light. But beyond

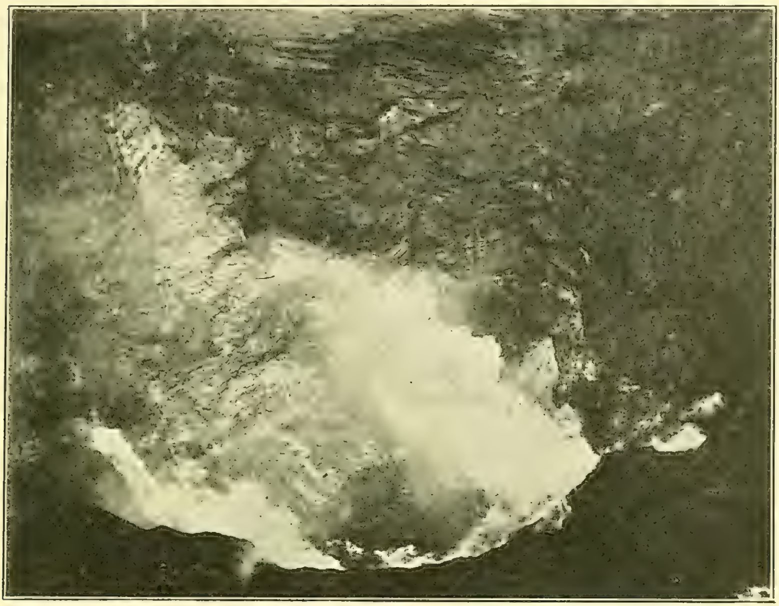

Fig. 9.—Looking down into the northernmost vent of the modern crater, showing the bottom and the sharp ridge of mud on the right between this and the next vent. The vapor comes chiefly from burning sulphur. Taken from the rim on the west side. Photo by Malcolm Anderson.

the line of contact, lava streams continue for great distances, partly burying the old river channels that radiate away from the region occupied by Aso-san, this region being the source of most of the large rivers of the island. Aso has evidently been the center of the volcanic activity of central Kiushiu and the source of supply of the erupted material mantling the region. The longest of the lava arms extends down the Gokase-gawa southeast of Aso, and was followed

by the writer to its termination on the east coast. The contact of the volcanic sheet and the older rocks in that direction is about twenty miles from the center of Aso, beyond which the lava extends down the canyon about thirty miles, almost to the sea. The width of the present lava filling of the canyon is on the average two and one-half to three miles, and the depth amounts certainly to several hundred feet. Nearly twenty-five miles away from the center of Aso the Gokase is joined by another large canyon from the north that issues from mountains in the Paleozoic formation. The lava flowed up this canyon for a distance of at least eight miles, filling its bottom likewise with a wide, deep stream. The source of the lava in this branch was the main stream that occupied the Gokase canyon. It could not have come down as a tributary flow because no volcanoes exist anywhere about.

High mountains formed of Paleozoic rocks inclose the valley of the Gokase-gawa, rising steeply above the fairly flat surface of the lava filling. In the center of this the river has cut an abrupt square canyon, and has already reached a depth of several hundred feet without coming to the level of its old course. The depth of the channel is at least three hundred feet in some places and its width is hardly more. Its sides are cliffs of basalt-andesite, usually with imperfect columnar structure. The columns, which average a foot or more in thickness, are sometimes four-sided, sometimes five-sided, the sides and angles being of irregular dimensions. They stand in the main perpendicular, but locally show deflections of a few degrees from this attitude.

CHARACTER OF THE LAVA

In the field the lava of the interior range, the ring wall and the surrounding region appeared to be the same. The rock is intermediate between andesite and basalt. That it is by no means of the most basic composition is indicated by the angle of the slopes presented in the interior range, and by the fact that explosive eruptions, with the ejection of abundant ashes and scoriae, have taken place in association with effusive eruptions throughout the history of the volcano. On the other hand, the recent-looking flows observable on the higher portion of the central range exhibit a smooth flow structure that is evidence of considerable fluidity and a prolonged state of fusion.

Three samples of lava from Aso were examined by Dr. Albert Johannsen of the U. S. Geological Survey, and the following description of these is based on the report which he kindly furnished. Specimen 1 is hypersthene-bearing basalt from the foot of the wall of the caldera near the town of Takamori on the south-east side. It is medium gray in color, compact, and highly porphyritic. The phenocrysts are about 55 to 60 per cent. labradorite, about 10 per cent. augite, and the rest hypersthene, magnetite, and olivine in decreasingly lesser amounts. The groundmass is made up of plagioclase, augite, and magnetite, with possibly a little glass. Specimen 2 is basalt from the same locality. It is mottled black and white, is somewhat vesicular, highly porphyritic, and strongly resembles specimen 1, especially under the microscope. The phenocrysts are about 80 per cent. labradorite, 15 per cent. augite, and the rest hornblende, magnetite, and olivine in decreasingly smaller amounts. The ground-

FIG. 10.—Stream channel on the east side of the modern cone. The lip of the crater is immediately on the right, and the cliffs at the foot of the highest Aso peaks on the left. The fine gray mud is fast eroded by rains. Looking south, parallel to the long axis of the crater. Photo by Malcolm Anderson.

mass contains plagioclase, brown glass, magnetite, augite, and possibly a little olivine. Specimen 3 is a very vesicular fragment of hypersthene andesite blown from the new crater. It is composed of phenocrysts —labradorite and hypersthene in a groundmass of brown glass. Regarding these specimens Doctor Johannsen says as follows: "At best the amount of olivine in any of the rocks is slight, and with its absence I would name them all andesite."

A SUPPOSED FORMER MT. ASO

The roughly bedded strata in the walls of the big crater seem to dip away on all sides at a low angle, and their inclination is probably reflected in the gentle outer slopes that form the sides of the mound or cone of Aso. It seems likely that this mound is the basal remnant of a conical volcano that once continued upward to a culminating point high above the center of what is now the crater bowl.

If such a mountain existed it is probable that its upper portion rose with a gradually increasing slope into a summit cone. Judging from the character of the lava and the analogy afforded by the steep slopes of the present interior peaks of Aso, which seem to be constructed of materials similar to those of the wall, as well as by other volcanoes of Kiushiu (see Fig. 1), which are mostly built of similar andesitic lava and its fragmental products, the ancient cone may have risen in its upper portion even as steeply as 20° or 30°. But assuming that it rose with a constant slope no greater than now in places exhibited in the base, say 7°, its summit would have been over 7,000 feet in altitude above the sea. If it steepened above it may have been 10,000 feet or much more.

The amount of rock material that must have been removed to cause the disappearance of the whole upper portion of the cone and the opening of a wide bowl upon its site may be roughly estimated as at least fifty-four cubic miles, counting the volume of the caldera as twenty-five cubic miles—not subtracting the interior range—and the volume of the overlying cone as twenty-nine cubic miles.[1] If the cone rose steeply above, as it probably did, the volume must have been considerably more.

[1] The figures printed in the article by the writer in the *Popular Science Monthly*, Vol. LXXI, July, 1907, are incorrect.

ORIGIN OF THE CALDERA

There are three ways in which the old crater may be conceived as having originated, namely, by being built up around a vent of great magnitude, by the explosive removal of a volcanic mountain mass, or by the subsidence of the area now inclosed within the wall.

The most acceptable conclusion is that the bowl of Aso is a caldera produced by the sinking in of a volcano, as the result of the escape of

FIG. 11.—Hot springs at Yunotani near the western end of the central range. There is said to be a small geyser here that spouts out boiling water and red mud.

lava from an underlying reservoir at low points of discharge and the consequent undermining of the mountain flanks. The process was probably one of the gradual enlargement of an original summit crater.

There are three main reasons why this supposition seems to apply. In the first place, the bowl has a wide extent of almost level floor, a symmetrical oval shape, and a practically continuous ring wall of regular form. It is difficult to conceive of a violent explosion destroy-

ing the whole upper part of a mountain of such size and leaving such regular remains, whereas they might well be the outcome of a comparatively gentle process of sinking taking place simultaneously at all points around a common center. In the second place, the great lava flows radiating from the volcano are the quantitative equivalent of the mass that has disappeared from the old cone of Mount Aso, and may be reasonably considered as derived from the space in which the mountain became engulfed, having vacated this space through channels that opened at low points on the flanks of the cone. In the third place, the lava, although it is not of the most fusible variety, is of such a character that it would be capable of forming large, easily flowing and slowly cooling streams; and would not be of such viscosity as to offer the utmost resistance to explosive forces and to cause explosions of the greatest magnitude.

As regards the possibility of an explosive origin for the crater, it is to be expected that a prominent rim of débris would have accumulated around the brink of the cavity had such an immense block of the earth's surface been removed in this manner. Although it is true that a vast amount of fragmental material is present in the wide region surrounding Aso-san, no such rim is to be found. The balance of probability favors the conclusion that upward discharges of material did not play a chief part in excavating the bowl, but that the masses of ejectmenta covering much of the region around the volcano were thrown out partly before the destruction of the ancient mountain and partly during the period in which the process of engulfment was progressing, as a secondary phenomenon attending that catastrophe. The strata in the wall tell of explosive eruptions that took place contemporaneously with the emission of lava streams in the early history of the volcano, but it appears that the erupted material was chiefly in the form of lava flows. On the other hand, the decadent stages of the volcano have been marked chiefly by explosive eruptions as witnessed by the new cone and the deposits in its vicinity, and by the historical accounts.

As regards the other hypothetical mode of origin, the low cone of Aso may be thought of as having been formed by a process of cone building, through the overflowing of lava from a very large vent and the accumulation round about of material explosively removed.

But it is scarcely conceivable that a process alone of building up could have produced such forms as those of Aso.

John Milne discusses the origin of the Aso crater in the account of his visit to it before mentioned.[1] He considers unfavorably the theory of an explosive origin and comes to the following conclusion:

> I should be inclined to look upon it as being now, as it ever was, the upper crater of an old volcano, inside which in more recent times a cone has grown. Although at the commencement of the mountain the action may have been cataclysmic in its nature, subsequently, however, I should think that it grew up higher, partly by the accumulation of ashes, but now perhaps by the boiling over of a highly liquid trachytic lava. That this latter action has taken place seems to be testified by the roughly stratified appearances which are exhibited in the ring walls; the growth has in fact been probably something like the growth of Mauna Loa in the Sandwich Islands or as a geyser tube in Iceland.

ORIGIN OF THE CENTRAL RANGE

The theory of a subsequent origin for the interior range is the only acceptable one. The caldera may have originated over the intersection of 2 fissures, one running north and south parallel to the long axis of Kiushiu determining the long axis, and one at right angles determining the shorter axis and affording a line of activity along which a ridge of cones was later built.

ORIGIN OF THE BARRANCO

The single opening in the wall has been described as immediately opposite the western end of the central range. It may be that its origin is due to the line of weakness supposed to exist along the diameter occupied by this range, and that it was contemporaneous in origin with the caldera. Or it is possible that forces aided in the destruction of this point in the wall at the time that great eruptions were taking place along the central line and the new range was being built.

Another supposition is that it is a truncated canyon of the former Mount Aso, which has cut back and tapped the floor since the caldera was formed. There is not much evidence that the flanks of the former Mount Aso had become deeply dissected during the interval between its construction and its disappearance, and there is no other canyon making a comparably deep gap in the wall. Therefore the outlet

[1] *Popular Science Review*, New Series, Vol. IV, No. 16, October, 1880.

of the streams owes its origin more probably to one of the first-mentioned causes, or to the aid afforded by structural weakness to erosional work.

LIST OF LARGE CRATERS

A review of the literature on volcanoes reveals the fact that there are very many craters and volcanic depressions comparable with the Aso caldera in form and origin. The frequency of occurrence and importance of this type has not received adequate recognition in most of the textbooks. The following list gives the dimensions of some of the largest known craters, and of a few smaller ones that are typical calderas, out of the hundreds of large craters that might be cited. It is probable that the majority of these mentioned are volcanic sinks—have resulted, that is, from the subsidence of portions of volcanic mountains—and may therefore be termed calderas.

Monte Albano, in Italy, has a ring wall inclosing a crater 7 by 6 miles in dimensions.

Lago di Bolsena and Lago di Bracciano are crater lakes in Italy, the former measuring 8.5 by 7.5 miles, and the latter being round and with a diameter of 5.5 miles.

On Vesuvius, the old crater of Somma must have been nearly circular and 3 miles in diameter.

Val del Bove, on Mt. Aetna in Sicily, is a caldera 4 or 5 miles in diameter.[1]

Pantellaria, between Sicily and Africa, has traces of a crater ring 12 miles in diameter.[2]

Santorin, in the Mediterranean, is a volcanic ring 18 miles in circumference.

Palandökan, in Armenia, has a crater with long axis of 6 miles.[3]

Dyngufjöll, in Iceland, has a crater about 8 by 4 miles in dimensions with an area of 25 square miles.[4]

[1] Charles Lyell, *Principles of Geology*, 10th ed., Vol. I, p. 630.

[2] G. Poulett Scrope, *Volcanos*, 1872, p. 429.

[3] Hermann Abich, *Geol. Forschungen in den kaukasischen Ländern*, Theil II, Vienna, A. Hölder, 1878–87.

[4] Th. Thoroddsen, *Geog. Journ.* (London), Vol. XIII, Nos. 3 and 5, March and May, 1899.

Palma, in the Canary Islands, has a crater that has been reported as 9 miles in diameter.[1]

Teneriffe, in the same group, has a crater with longest diameter of 8 miles.[1]

St. Helena Island preserves the wreck of a crater which according to Darwin[2] may have measured 8 or 9 by 4 miles. From other descriptions the longest diameter does not appear to have been more than 4 or 5 miles.[3]

Mauritius according to Darwin has remnants of an oval crateral ring with shorter diameter of 13 miles.[2 and 4]

San Thiago (St. Jago) Island has a remnant resembling in character and size that of Mauritius.[2]

Réunion has a central, crater-like depression that is approximately round and 6 miles in diameter.[5]

Antandroy, in Madagascar, has a partially destroyed crater with diameter of 15 miles.[6]

In the District of Ngorongo, in East Africa, an apparently crateral depression measuring over 12 miles across has recently been described.[7]

Kamtschatka is said to contain a crateriform lake 15 miles in diameter surrounded by the Palan Mountains, and another large lake, called Kranosk, probably crateral.

Japanese lakes.—The following lakes of northern Japan may occupy calderas:

Tazawa, about 60 miles west of Morioka, Hondo. It is 6 miles in diameter, and the volcano Komago-take is within 10 miles of it.

[1] Leopold von Buch, *Physikalische Beschreibung der canarischen Inseln*, Berlin, 1825; also, *Ges. Schriften*, herausgeg. von Ewald, Roth und Dames, Vol. III, 1877, p. 150.

[2] Charles Darwin, *Geological Observations on Volcanic Islands*, London, Smith, Elder & Co., 1851, pp. 29–30.

[3] J. C. Meliss, *St. Helena*, London, L. Reeve & Co., 1875.

[4] M. Bailly, *Voyage aux Terres Australes*, tome I, p. 54.

[5] Charles Vélain, *Description Géologique de l'Ile de la Réunion, etc.*, Paris, Typographie A. Hennuyer, 1878.

[6] E. F. Gautier, *Madagascar*, Paris, Libraire Maritime et Coloniale, 1902.

[7] Fritz Jaeger, *Mitteilungen aus den deutschen Schutzgebieten*, Nos. 2 & 3, 1907. See also a review of this in the *Geog. Journ.* (London), Vol. XXX, 5, November, 1907, p. 560.

Towada, about 60 miles south of Aomori, Hondo. It is 10 miles in diameter and irregular.

Toya, near the coast north of Volcano Bay in Hokkaido. It is round and over 10 miles broad, and contains two islands. The volcano Usu-dake rises just south of it.

Shikots, over 60 miles south of Sapporo, Hokkaido. It is an irregular lake nearly 14 miles long and 7 broad surrounded by high mountains. There are volcanoes within 5 miles both northwest and southeast of it.

Kutcharo, over 50 miles south of the southernmost part of the north coast, in the northeast corner of Hokkaido. It is irregular, with approximate dimensions of 15 by 8 miles, and surrounded by mountains. A volcano and hot spring are just east of it.

Bombom, Luzon, is a rudely oval crater lake with mean diameter of 12 miles.[1]

Java[2] contains the following large craters: Ringguit, a remnant of a ring that may have had a diameter of 13 miles; Idien, a remnant with possible diameter of 10 miles; Hiiang, faint traces of an outer crater of 10 miles diameter; Tengguer, an entire summit crater over 5 miles across; there are also 3 other adjoining craters, and the 4 together seem to form a single elliptical depression measuring 7 by 5 miles; Ngadipouro, a remnant of a ring 6.5 in diameter; Tounggoul and related craters, 3 large rings that together seem to form a depression 15 miles long, and 12 miles wide at one end and 4 miles at the other; Danou, one remnant indicates a formerly existent ring 9 miles across, and 3 other rings together seem to form a crateral inclosure measuring 8 miles by 3; Prinsen-eiland between Java and Sumatra forms a partial ring 6.5 miles across; and the 4 islands of Parang, north of Java, make up a possibly crateral ring with diameter of 6 miles.

Maniendjoe and Singkarah are 2 lakes in Sumatra that probably

[1] Richard von Drasche, *Fragmente zu einer Geologie der Insel Luzon*, Vienna, Verlag von Karl Gerold's Sohn, 1878. Also, G. F. Becker, *Twenty-first Ann. Rept.*, U. S. Geol. Survey, 1899–1900, Pt. III.

[2] Franz Junghuhn, *Java;* German translation, Leipzig, Arnoldische Buchhandlung, 1857. Also, Verbeek and Fennema, *Description géologique de Java et Madoura*, Amsterdam, Joh. G. Stemler, 1896.

occupy crater basins; the greatest dimensions of the former are 14.5 by 7 miles, and of the latter 13 by 4.5 miles.[1]

Deception Island, in the South Shetland group, contains an oval crateriform harbor 6 miles long and 4 miles wide.

The well-known craters of the Hawaiian Islands are representative of the caldera type. The largest of them is Haleakala, which is of irregular shape and covers 16 square miles. It has 2 arms, each of which is about 6 miles long and 2 miles wide.[2] Mohokea caldera on the side of Mauna Loa measures about 6 by 5 miles.[3]

In Galapagos Islands there are 5 large craters on Albemarle Island. The largest is at the south end and has a length of about 12 and a width of about 6 miles. The others vary in size down to a length of 3 miles or less.[4]

The Central American lakes,[5] Atitlan and Amatitlan in Guatemala, and Ilopango in San Salvador, are 3 lakes whose origin was probably due to volcanic subsidence, although there is a difference of opinion regarding them. The first is 12.5 by 9 miles in greatest dimensions, the second, 9.5 by 3.5, and the third, 12.5 by 5 miles.

Masaya-Nindiri volcano, in Nicaragua, is surrounded by the remains of a crater that must have had a long diameter of 5 or 6 miles.[5, 6]

Crater Lake, in Oregon, occupies a deep caldera measuring 6 or more by 4.5 miles and having an area of 20.5 square miles.[7]

[1] R. D. M. Verbeek, *Topographische en Geologische Beschrijing Sumatra's Westkust*, Batavia, Landsdrukkerij, 1883.

[2] J. D. Dana, *Characteristics of Volcanoes*, New York, Dodd, Mead & Co., 1890. Also, Clarence Dutton, *Hawaiian Volcanoes*, Extract from 4th Ann, Rept., U. S. Geol. Survey, 1882–83, pp. 126–28.

[3] C. H. Hitchcock, *Bull. Geol. Soc. Am.*, Vol. CXII, October, 1906, pp. 485–96.

[4] This information was kindly furnished by Mr. W. H. Ochsner, of Stanford University and the California Academy of Sciences, who recently returned from a geological trip to these islands.

[5] E. G. Squier, *The States of Central America, etc.*, New York, Harper & Bros., 1858. Also, A. Dollfuss and E. de Montserrat, *Voyage géologique dans les républiques de Guatemala et de Salvador*, Paris, Imprimerie Impériale, 1868.

[6] Karl von Seebach, *Ueber Vulkane Centralamerikas;* aus den 38sten Bande der *Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, Dieterichsche Verlags-Buchhandlung, 1892.

[7] J. S. Diller, *Professional Paper, No.* 3, U. S. Geol. Survey, 1902.

SUMMARY

The caldera of Aso is a great depression at the summit of a low mound-shaped cone in the center of the island Kiushiu, within 22 to 35 miles of the sea and only 1,000 to 3,000 feet above it. It has been the center of vast outpourings of lava and fragmental material that have filled a depressed area in the topography of the older formations during Quaternary time. It is one of the largest, if not the largest, of craters known on the earth.

The caldera has been worn considerably, but the wall has not been removed by erosion at any point, the single barranco being considered as due chiefly to structural weakness or subsequent disruption. The floor has been built up as well as worn down and probably retains fairly well its original level. The caldera appears to date from about middle Quaternary time.

In the history of the volcano both effusive and explosive eruptions have been characteristic, and have occurred contemporaneously, the amount of material emitted as lava flows having probably been greater.

The lava is intermediate between andesite and basalt, and is of comparatively easy fusibility.

There existed formerly a volcanic cone above the site of the present caldera, of which the truncated base is preserved in the outer slopes. The caldera grew as a result of the discharge of great lava flows and the collapse of this cone. The process was probably one of gradual enlargement of a summit crater.

A high, continuous interior range was later built up by eruptions along a fissure at right angles to the long axis of the caldera; and the cone building still continues, though with diminishing vigor, in a modern crater centrally situated with respect to the old one.

MARGINAL GLACIAL DRAINAGE FEATURES IN THE FINGER LAKE REGION[1]

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A study of a considerable number of the channels or scourways formed by streams associated with the Pleistocene ice sheet in the southern Finger Lake region of New York has served to bring out many features of more than local interest and importance, both as to the broader phases of glaciation in this part of New York State, and as to the value of a study of such channels as an aid in working out the glacial geology of a region.

This study has a distinct bearing on the interglacial problem in that several of these channels give conclusive evidence of more than one stage of glaciation, while one points strongly to three or more such stages with corresponding interglacial epochs, some of which seem to have been considerably longer than post-glacial time. Other channels are so situated as to make possible a fairly accurate estimate of the slope of the ice margin along the valley tongues. Still another furnishes proof of an extensive sinking of the surface consequent upon the melting-out of a large block of buried ice—a phenomenon, the importance of which seems not to be fully appreciated.

The Finger Lake region, lying as it does along the belt of the great recessional moraines of the Wisconsin ice sheet, is especially favorable for the study of marginal glacial drainage features. The long halts of the glacier, while the moraines were building, gave ample time for the associated streams to carve for themselves distinct channels which, now that the ice is gone, are in most cases left dry and entirely out of harmony with the present drainage.

[1] This paper is an abstract of a thesis presented to the faculty of Cornell University in June, 1907, as a requirement for a major in Physiography. The work was undertaken at the suggestion of Professor R. S. Tarr, to whom the writer is indebted for helpful suggestions, and for the location of many of the channels herein described. In the course of folio work for the U. S. Geological Survey, Professor Tarr discovered several of these channels, some of which are described in his report soon to be published by the Geological Survey.

CHANNEL TYPES

The glacial channels of the Finger Lake region are of several different types, representing various conditions of formation, ranging from small streams at the ice margin to the outlet streams of large glacial lakes. It has been found desirable in describing these channels to classify them into five groups, based on the most common conditions of formation. The following five types have been selected:

I. *Marginal.*—Channels formed by streams flowing close along the ice margin.

II. *Submarginal.*—Channels of a broadly marginal nature; not, however, following closely the edge of the ice; cutting across hill spurs or behind small outlying hills.

III. *Lateral.*—Channels formed by streams leaving the glacier through a notch in the bordering hills and flowing laterally away from the ice.

IV. *Morainic channels.*—Channels formed while a moraine is building by contemporaneous streams issuing from the ice. Often indistinct; best developed in flat moraine near the end of an ice-lobe.

V. *Glacial lake outlets.*—Channels formed by the outlet streams of glacier-dammed lakes.

It must be borne in mind that it is often difficult, if not impossible, to draw sharp lines of distinction in all cases. This is necessarily so because of the variations in conditions under which the channels were formed.

In this paper only selected examples of each type are described. In so far as possible channels have been selected which illustrate well the type, and at the same time show features of more than local interest.

TYPE I. MARGINAL

Slaterville channels.—One of the most typical channels of the marginal type is found about two miles east-northeast of Slaterville Springs (Dryden sheet, U.S.G.S.) on the east side of Six Mile Creek valley at an elevation of about 1,640 feet near the top of the southmost hill. The channel starts as a slight trimming of the hill slope. This increases gradually until at first a flat bench, and later a two-sided channel is cut in the slope (Fig. 1). The channel bottom has a width of about one hundred feet and is very flat and swampy. A profusion

of trunks and branches of hemlock trees is scattered over the bottom; a rather characteristic feature of such channels in this region. The lower bank, or the one which was nearest the ice, is low, varying from two to ten feet in height. The opposite bank, formed by trimming of the hillside, is very steep, and thirty or forty feet high in places. The

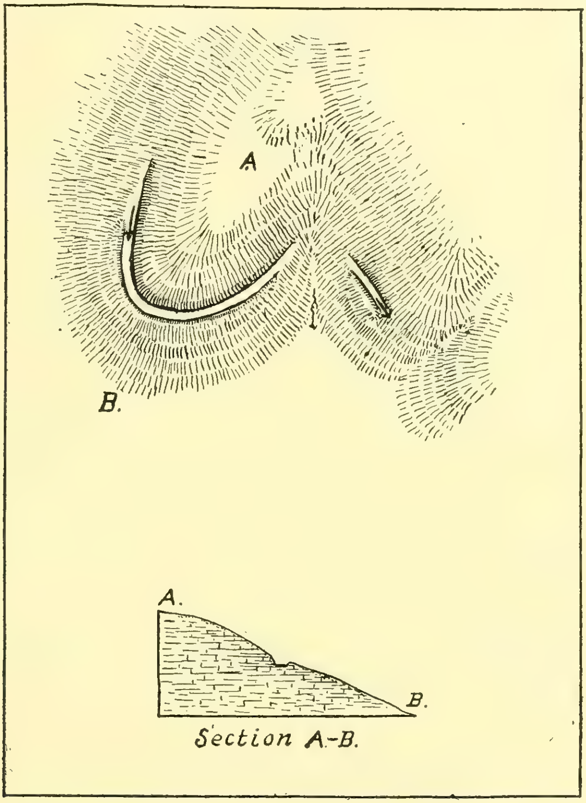

FIG. 1.—Sketch of Slaterville Springs channel, showing its contour-like character.

channel, beginning on the west side of the hill, follows closely the contours around the south end to the east side, where it becomes lost for a short distance as it crosses a small valley or gully, but reappears again, though less distinctly, beyond.

An interesting feature is the disappearance of the channel in crossing the small valley, and its re-appearance on the opposite side. It may be that a block of stagnant ice, probably more or less buried, lay

in the valley and formed the stream bottom. If such were the case we would expect to find no distinct channel after the ice had melted.

At an elevation two hundred feet lower on the same hill, and almost due southwest of the channel just described is another of the same general type. It begins on the west slope of the hill as a shallow, indistinct, slightly swampy channel with banks varying in height from one to three feet. After continuing thus for about 150 feet it suddenly changes, at the site of an ancient waterfall, to a deep partly rock-sided gorge which contours the hill for a distance of about one-fourth mile. Its depth here is approximately forty feet. A short distance east of the mouth of this channel is another shorter one cut in the rock at the base of the hill. The two were probably contemporaneously formed by the same stream.

Several features of this channel show that it was formed previous to, or during the *advance* of the last ice-sheet, and that streams associated with the *retreating* Wisconsin ice did little more than to clear out a part of the débris with which the channel had been filled. The lines of evidence pointing to this are: (1) the present V-shape of the gorge, (2) the presence of considerable drift within the gorge, and (3) the only occasional outcrop of rock in the gorge walls. The bottom is not flat as would be expected if the gorge had been cut by the last stream which flowed through it. The flat portion of the bottom is very narrow; only a fraction of the width of the gorge, and in no part of the bottom is rock visible.

This is one of two channels among the large number studied, in which the sites of waterfalls were found.

Wedgwood channel.—One and one-half miles west-southwest of Wedgwood Station (No. 1, Fig. 2, from Watkins sheet, U. S. G. S.) is a marginal channel distinctly older than the final retreat of the last ice-sheet. It is now largely drift-filled and shows no trace of the presence of a stream since it was uncovered by the ice. It is not flat bottomed, as are the undisturbed channels, but has a decided V-shape. East of the channel a small rock hill has been isolated by the channel cutting. Rock is exposed in the walls in only a few places. One exposure at *X* (Fig. 3) shows an approximately vertical rock wall buried beneath the glacial drift which partially fills the gorge. A few feet north of *X* the channel bottom rises several feet to a drift divide

which is distinctly *within* the main channel, but shows no trace of stream action. Beyond the divide a hummocky deposit continues nearly to the small stream which here crosses nearly at right angles to the direction of the channel. In this stream, approximately in line with the west channel wall, is a waterfall probably formed by the

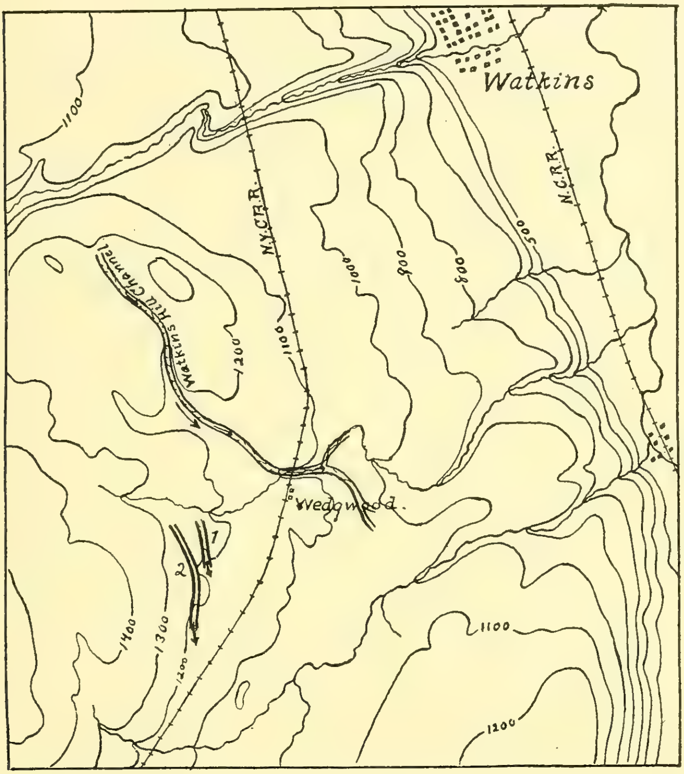

FIG. 2.—Wedgwood and Watkins Hill channels. These channels were formed at the margin of an ice-lobe moving southward through the Seneca Lake valley shown on the eastern side of the map. Scale 1/62,500.

present stream encountering the rock wall of the buried gorge. A short distance below the fall the conditions shown in *A–B* (Fig. 3) may be seen. There is a rock terrace about thirty feet wide at a level three feet above the present stream. The stream, however, is not flowing on rock. It seems to have discovered a buried channel, for both its bottom and its southwestern side are composed of drift.

This condition of the stream, together with the occurrence of the falls a short distance above and the rocks walls at X, indicates the presence of a buried gorge extending at least as far north as the stream, beyond which, if present, it is entirely concealed by drift.

Only a few hundred feet west of the channel just described, and a

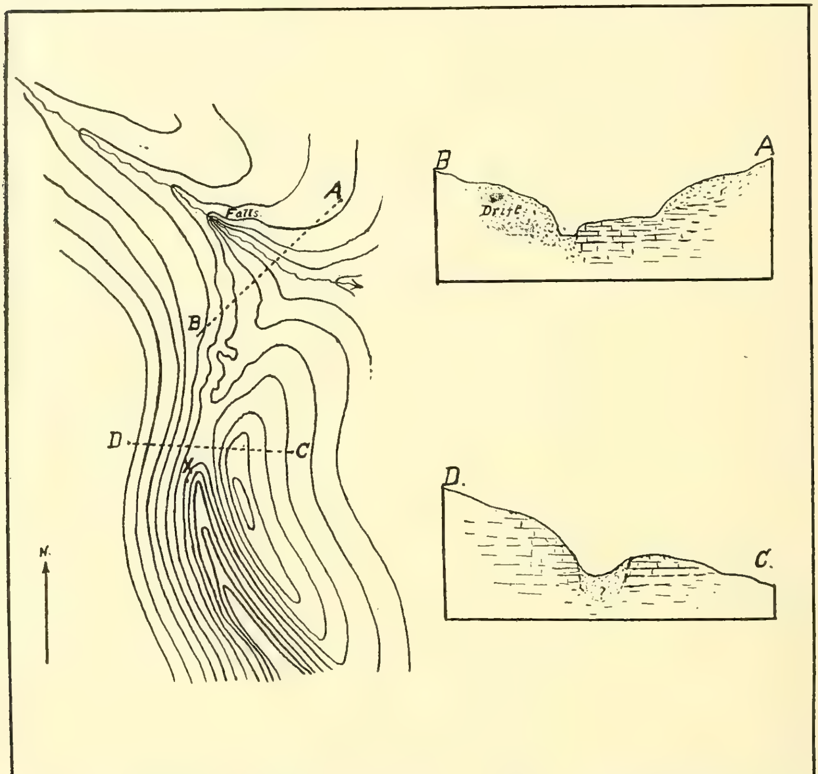

FIG. 3.—Sketch of Wedgwood channel (1). Scale of contour sketch about six hundred feet to the inch. The profiles are slightly exaggerated to bring out essential features.

little further up on the hillside (2, Fig. 2) is another of a strictly marginal type which follows for over one-half mile along the hill. There is here distinctly a channel within a channel; the smaller and later one formed during the final retreat of the ice; the other at an earlier date. The older channel is partially drift-filled, yet maintains distinct banks throughout most of its course. The banks are not

sharply trimmed. In the lower end are several hummocks, apparently of a morainic nature. This older channel was occupied during the retreat of the last ice-sheet by a small stream which formed a second channel twenty or thirty feet wide within the older one, which has a width of about 125 feet. The smaller channel has distinctly trimmed though low banks, and a characteristically swampy bottom. At its upper end the older channel is buried in a gently undulating moraine in which the smaller and later stream seems to have originated.

TYPE II. SUBMARGINAL

Cayuta Gorge channel.—An excellent example of this type is Cayuta Gorge at the outlet of Cayuta Lake (Fig. 4; Ithaca sheet, U. S. G. S.). The lake lies in a broad, mature valley trending a little south of southwest. At its southern end a glacial deposit, about forty feet in average height stretching across the valley, forms the dam to which the lake owes its origin. In one place on the west side of the valley near the schoolhouse the top of this barrier is less than twenty feet, and probably not more than ten feet above lake level. Through this gap to the south is free communication with Catlin Mill Creek, and thence with Seneca valley; yet the lake waters, instead of finding an outlet through this low pass, turn eastward and escape through a rock gorge cut to a depth of over three hundred feet through the hill bordering Cayuta valley on the east (Fig. 4). That this outlet is no normal valley, is shown by its almost perpendicular rock sides and its lack of harmony with the surrounding topography. Clearly nothing but the intervention of a glacier could have produced such an abnormal drainage condition in a region of horizontal and comparatively homogeneous rocks.

As is show by a map of the moraines of this region,[1] a lobe of ice from the great Seneca valley tongue lay for a long time across the lower end of Cayuta Lake valley. Such an ice-lobe would obstruct the normal drainage and cause the water to escape over the lowest point in the valley side. This, in this case, clearly must have been the site of the present gorge. In order to permit the cutting of so profound a gorge, the glacier must have stood nearly stationary for a long time. It might have been melting away as fast as the gorge was being cut

[1] Tarr, *Bul. Geol. Soc. Am.*, Vol. XVI, 1905, pp. 215–28.

down, but no faster, for if melting were more rapid than downcutting, a new channel farther down the hillside would at once be begun.

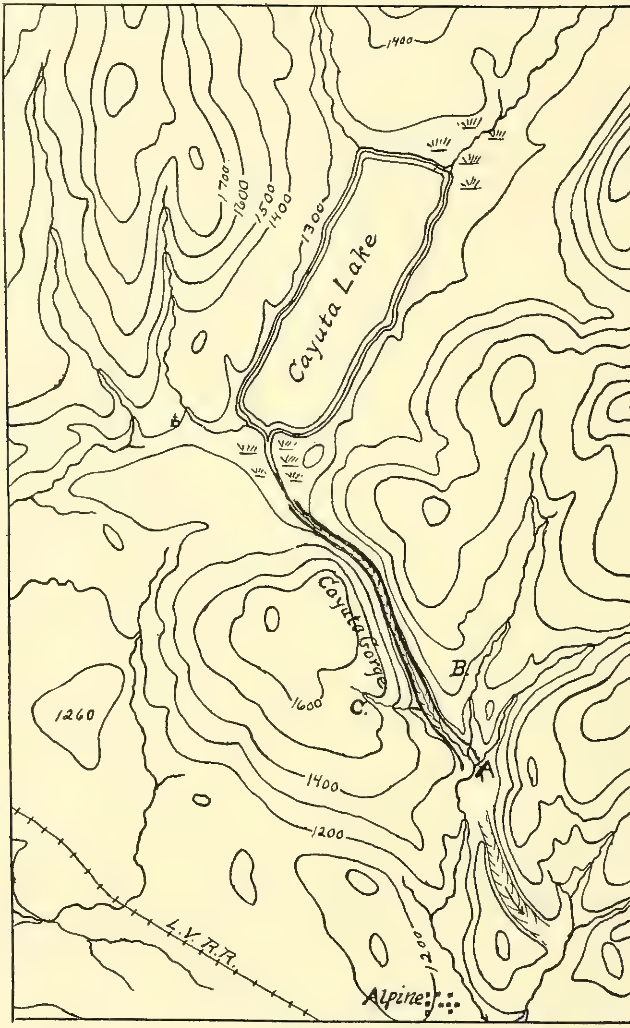

FIG. 4.—Cayuta Gorge and vicinity. Note tributary streams *A*, *B*, and *C*, referred to in the text. Scale 1/62,500.

A channel of this type could be formed only in connection with a *retreating* or possibly stationary phase of ice-movement; never in connection with an advancing movement, for, since the initial stage

of such a channel begins high up on the hill, if after the channel had been started the ice continued to advance, the channel would soon be covered and another farther up the hill slope would be begun. Such reasoning strongly supports the belief that this channel was formed by waters associated with a retreating ice-sheet. It was not, however, formed during the final retreat of the last ice, for within the gorge itself are deposits of glacial drift which the stream is still engaged in removing. It has nowhere as yet reached rock bottom. The presence of the drift clearly proves that, after the gorge had been cut to a depth greater than the present, it was subjected to glacial action.

The cutting of the gorge has introduced a hanging condition in the streams *A*, *B*, and *C* (Fig. 4). The stream *C*, which, as the map shows, has only a small drainage area, enters Cayuta Gorge without falls through a drift-filled rock gorge thirty or forty feet in width. The stream bottom, at least in the lower part of the gorge, is entirely on drift. The presence of this drift-filled tributary gorge shows that, since the glacial epoch during which Cayuta Gorge was formed, there came an erosion interval long enough for a small stream to cut a good-sized rock gorge. After this period of erosion came another epoch of glaciation during which the gorges were filled with drift. Since glacial times this stream, working over a very steep grade, has been unable to remove the drift from the gorge which in the interglacial interval it had cut in solid rock. This would indicate that the ratio of interglacial to postglacial time is roughly that of the time taken by a stream to cut a gorge in rock to that taken by the same stream to cut a gorge of about equal size in drift.

Stream *B* shows an even more complex history. It enters Cayuta Gorge at a rather steep grade through a gorge which is distinctly interglacial in character. Its walls are veneered with drift and appear much weathered. The stream, which flows in a series of cascades over a rock bottom seems to have deepened its channel in the rock by about six feet since glacial times. One-fifth of a mile above its mouth the gorge widens out into a nearly circular amphitheater (Fig. 5) at which there is an abrupt change in direction and an absolute change in the character of the gorge. For one-half mile or more above the amphitheater the stream flows with an even grade through a rock-walled, partly drift-filled gorge at least three times wider than

that below. The gorge bottom in this upper part is about 120 feet wide and shows rock in only one or two places, then not sufficiently to cause falls or rapids. The walls show marked decay. In line with this upper gorge and running from the amphitheater to the side of Cayuta Gorge is a sag of about fifteen feet in the surface which undoubtedly marks the drift-filled continuation of the gorge above (see Fig. 5).

The Stream *B*, then, above the amphitheater, is flowing in a gorge distinctly broader and older than the interglacial one which it follows from the amphitheater to its junction with Cayuta Gorge. If this larger gorge is due to a hanging condition initiated by the cutting of Cayuta Gorge then, in order to explain the facts, appeal must be made to three periods of glaciation; for what but the intervention of a glacier would account for the diversion of the stream from its broader gorge to the one, itself interglacial, which it occupies in the lower part of its course? It has been suggested however, that the older gorge may be the result of a regional rejuvenation antedating the appearance of the first ice-sheet. Such a rejuvenation, evidence of which has been found by Tarr in many of the streams of this region, might account for the conditions here found without appeal to more than two periods of glaciation.

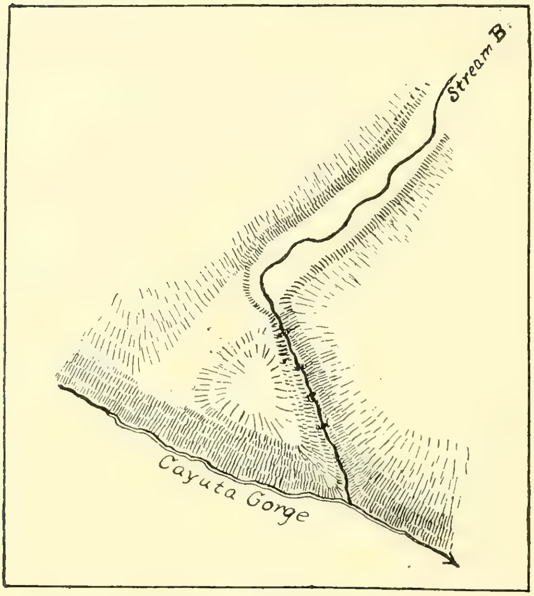

FIG. 5.—Sketch of tributary Stream B. Note the broad upper gorge, and the narrower one, itself interglacial, through which the stream reaches Cayuta Gorge.

It seems probable, however, if Stream *B* cut a gorge due to regional

rejuvenation that it was tributary to the neighboring Stream *A* rather than to Cayuta Gorge. This belief is based on the fact that the drift-filled gorge at the mouth of *B* appears to be hanging well above the present stream in Cayuta Gorge, and that in *A*, about one-third of a mile above its mouth, there is a break in the continuity of the rock wall on the west side, above which the gorge is decidedly narrower; a condition which suggests strongly the entrance of a large tributary gorge from the west.

For these reasons, though one gorge may be due to rejuvenation, it is believed that the others represent at least three ice invasions with corresponding intervals of deglaciation.

Evidence as to the interglacial nature of these gorges is of considerable importance, owing to the fact that while the multiplicity of glacial epochs has been proven in many parts of the United States, it has not been fully recognized for this region. As late as 1905 we have the following statement from Fairchild[1]: "It is safe to discuss the history of the region as involving only the Wisconsin glacial epoch, for no evidences of any earlier and more forceful and extended ice sheet have been found." Previous to 1906, Tarr[2] held that there was no direct evidence of more than the Wisconsin ice invasion. In that year, however, he published evidence based on the buried gorges which led him to the conclusion that there have been at least two epochs of glaciation.[3] Maston[4] in 1904 described a series of buried gorges in Buttermilk valley near Ithaca which led him to the belief that at least two and perhaps four ice-sheets had invaded this region.

TYPE III. LATERAL

Spencer Summit channel.—A typical lateral channel is found one and one-half miles east of the Lehigh Valley railway station at Spencer Summit, a short distance south of the Thompkins County line and one-fourth mile east of Michigan Creek (Dryden sheet, U.S.G.S., Fig. 6). Beginning just beyond the divide in the deep notch through which the road passes, it follows a southeasterly course along the preglacial valley heading near the notch. For the

[1] *Bul. Geol. Soc. Amer.*, Vol. XVI, p. 67.

[2] *Ibid.*, pp. 217, 237–42.

[3] *Jour. Geol.*, Vol. XIV, 1906, pp. 18–21.

[4] *Ibid.*, pp. 133–51

first mile of its course the channel is very distinct, flat bottomed and from 100 to 150 feet in width. Farther down it is less distinct owing to the entrance of tributary valleys whose streams have modified the old channel bottom.

Contrary to what would be expected, the channel does not begin at the divide. Here the notch is V-shaped in cross-section, and at the bottom scarcely wider than the highway. Rock is visible in the walls, but there is a considerable drift filling. About two hundred feet

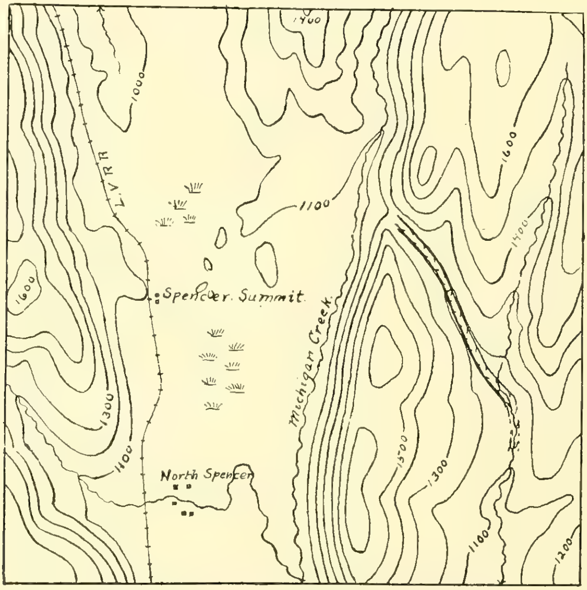

FIG. 6.—Spencer Summit channel. A typical lateral channel. The ice-tongue moved southward through the deep, steep-walled valley in which Spencer Summit is situated. Scale 1/62,500.

east of the divide the channel begins suddenly. It is very swampy and attains almost its full width at the very beginning.

A probable explanation of the absence of the channel at the divide is that a small ice-lobe from the main Cayuga valley tongue pushed partly through the notch, and from its terminus discharged the stream which formed the channel. This is a condition almost exactly similar to that found by Tarr at Floral Pass, along the eastern border of Hayden Glacier, Alaska.

Johnson Hollow channel.—Two and one-half miles north of the town of Millport, and an equal distance east-southeast of Moreland is the beginning of another interesting lateral channel. It was formed by a stream from a small lateral lobe which pushed from the great Seneca valley ice-tongue for a short distance through the gap in the hills on the west side of the valley. The stream flowed for a little over a mile in a northeasterly direction, almost opposite to that of the ice-motion in the adjacent valley. It then turned and flowed a little south of west for another mile, then southward through Johnson Hollow and finally back to the ice three miles below the starting point. (See Fig. 9.)

This channel, like those already described, has a flat, swampy bottom and distinctly trimmed banks. For the first mile of its course its width varies from 100 to 150 feet. The elevation at the beginning is 1,200 feet, and at the foot of Johnson Hollow, where it again reached the ice tongue, 1,000 feet. This gives a drop of two hundred feet in a distance of three miles, or an ice-slope of sixty-six feet per mile.

At the head of Johnson Hollow is a series of several channels of which this is one. The entire series will be fully described on a later page with special reference to the relation of the various channels to each other and to the ice-front.

Watkins Hill channel.—Beginning on the west side of Watkins Hill (Fig. 2, Watkins Sheet, U. S. G. S.) is another lateral channel which after a course of about two and one-fourth miles, again reached the ice-tongue, against which it built a distinct gravel plain. The difference in elevation of the two ends of this channel is approximately 150 feet. This, in two and one-fourth miles, gives an ice slope of sixty-seven feet per mile; practically the same as that determined for the Johnson Hollow channel.

Remarks.—The condition favorable for the formation of a lateral channel is the presence of an ice-tongue lying in a valley bordered by hills. Under these conditions the marginal drainage is apt to be diverted by any low gap in the valley sides, giving rise to a lateral channel. It often happens that a stream after thus leaving the ice finds itself in a valley tributary to that in which the ice-tongue lies. It will then, after a longer or shorter course, return to the main

valley. If it finds this still occupied by the ice, a marginal deposit, either a gravel plain or a delta, will be formed. Which of the latter is formed will depend on whether or not a marginal lake is held up in the tributary valley. When such a deposit is preserved the two points, one where the stream leaves the ice, and the other where it again reaches it, furnish valuable data as to the position and slope of the glacier tongue at the time the deposits were forming.

TYPE IV. MORAINIC CHANNELS

None of the morainic channels studied show features worthy of separate description. A short summary of the most characteristic features of such channels is therefore given instead of detailed descriptions of individual channels.

Morainic channels as seen in the region of the Finger Lakes are characteristically weakly developed. They are often short, irregular, and marked in many cases by scarcely more than a modification of the drift into flat, stream-bottom form. Such a condition is what should be expected. The ice while a moraine is building is subject to more or less backward and forward oscillation. Temporary streams are developed here and there, and under most conditions the great amount of morainic débris supplied to these streams causes them to aggrade rather than to degrade; to build up the channel bottom rather than to cut it deeper. Hence the prevalence of broad, flat-bottomed channels with ill-defined banks.

TYPE V. GLACIAL LAKE OUTLETS

Watkins Lake outlet.[1]—The outlet of Lake Watkins, held up by the glacier in Seneca valley, has already been described in part by Fairchild[2] and later by Watson.[3] Both, however, failed to see and describe the most interesting part of the channel—its beginning and the first one and one-half miles of its course. Both described the channel as beginning at Pine Valley (Fig. 7; Elmira sheet, U. S. G. S.) and continuing southward past Horseheads to the Chemung River at Elmira. Pine Valley was considered the site of the lake outlet as is shown by the following from Watson:[4] "This channel has an equally

[1] In connection with his folio work, Tarr first discovered the part of this channel above Pine Valley.

[2] *Bul. Geol. Soc. Am.*, Vol. VI, 1894–95, pp. 365–68.

[3] *N. Y. State Museum Rept.*, Vol. LI, 1897, p. 74.

[4] *Loc. cit.*, p. 74.

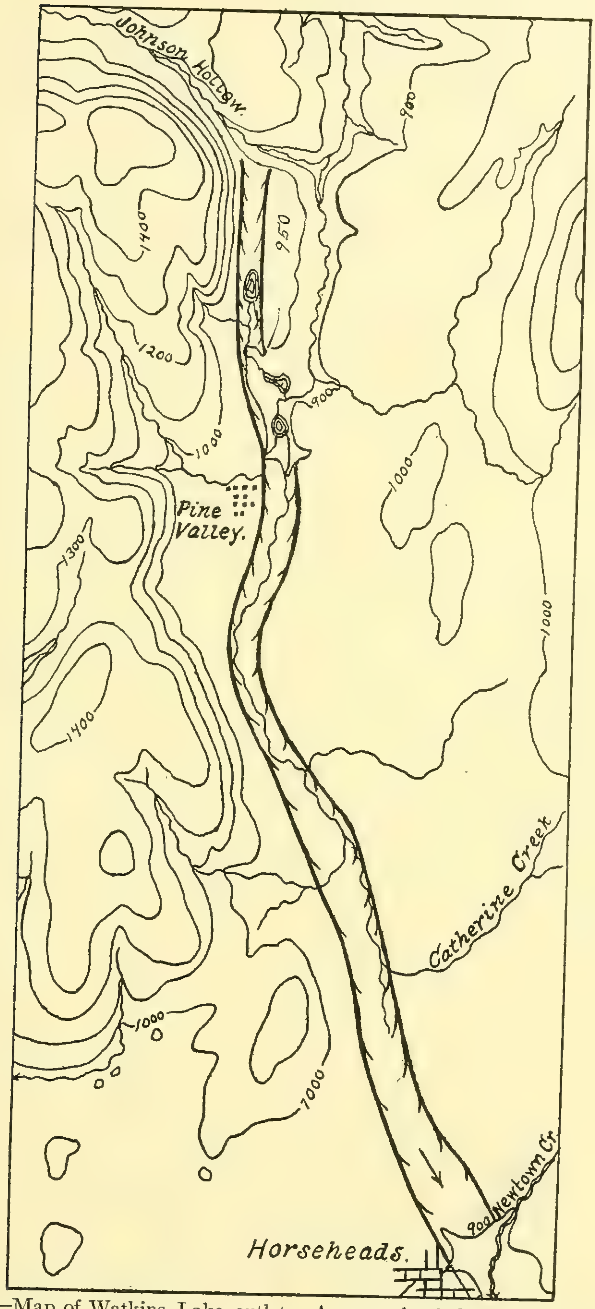

FIG. 7.—Map of Watkins Lake outlet. As a result of the melting-out of buried ice after the outlet waters had ceased flowing, one side and a part of the bottom of the channel just north of Pine Valley has dropped out. Scale 1/62,500.

slight gradient northward as far as Pine Valley where the glacial lake properly began, as to the south into Elmira."

The failure of these authors to recognize the true beginning of the channel is probably due to the peculiar drainage condition now prevalent in the channel. Two miles north of Horseheads, Catherine Creek enters the old channel and, turning northward, follows it with very slight gradient as far as Pine Valley, where, one-half mile north of the village, its grade suddenly becomes steeper as it leaves the channel and flows the remainder of the distance to Seneca Lake delta through a deep drift valley (Fig. 7).

The question at once suggests itself: Why does Catherine Creek flow northward in the channel in a direction opposite to that taken by the glacial waters? Tilting of the land may be suggested as an explanation, for it is well known from the studies of Gilbert that this part of New York has suffered deformation since glacial times. Tilting, however, does not offer a solution of the problem, for the land was tilted toward the south, with uplift in the north. This would increase the grade of the channel rather than decrease it sufficiently to cause a reversal of drainage. A more satisfactory explanation may be found in the fact that Newtown Creek, which enters the channel at Horseheads, has built a fan across it, and by ponding back the normal stream in the channel has caused the reversal of drainage. Were it not for this fan, if a lake were now held up in Seneca valley, it would outflow at Pine Valley. Nevertheless, in glacial times the outlet was not here but was one and one-half miles north of the village close to the base of the steep hill at the mouth of Johnson Hollow.

The channel at the beginning has a width of 700 feet; gravelly bottom and distinct, clear cut, and approximately straight banks from fifteen to forty feet in height. At the first road crossing, one mile below the beginning, a small stream entering from the hills on the west has built a very perfect alluvial fan entirely across the channel and caused the formation of the shallow pond shown in Fig. 8. Below this the channel continues for about one-half mile to near the road leading into Pine Valley. For the next half-mile southward through the village one side of the channel and a part of the bottom have literally dropped out. Near the road the west bank and the west half of the channel are intact; the east half of the bottom and the

east bank have dropped down, leaving a depression now occupied in part by a pond at a level three or four feet below that of the channel bottom. Into this depression and its continuation northward Catherine Creek now flows. It is here that Watson and Fairchild evidently placed the outlet of Lake Watkins.

Obviously there has occurred here a settling-down of a portion of the drift in the central part of the valley since glacial times; cer-

FIG. 8.—Watkins Lake outlet. Looking up-stream from a point one mile below the beginning. The shallow pond in the foreground is caused by the blocking of the channel by an alluvial fan.

tainly since the waters of glacial lake Watkins ceased flowing through the channel, for had the settling occurred while the stream was still flowing, the depression thus formed would immediately have been filled with gravel. Besides, had the depression existed then as now the lake would have overflowed at this point rather than at a higher level farther north.

The melting of an ice mass buried beneath glacial gravels is sug-

gested as the cause of the settling.[1] Ice thus buried would melt away very slowly. In this case it must have remained at least until the glacier had withdrawn far enough to permit the waters of Lake Watkins to find an outlet at a lower level.

The conditions at Pine Valley and northward to Seneca Lake are especially favorable for the burial of an ice block. In this part of Seneca valley, which is comparatively narrow and gorge-like, there lay a long tongue of ice. The valley is now drift-filled to an unknown, but certainly great, depth, at least several hundred feet as is indicated by borings at Watkins and Pine Valley. Presumably at the time of maximum glaciation the ice completely filled the valley down to the rock at the bottom. As the glacier retreated, melting would take place largely at the surface, or at least more rapidly at the surface; with the result that at the surface retreat would be more rapid than deep in the valley bottom. Since the glacial waters escaped to the south at a level certainly considerably higher than that of the bottom of the ice, outwash gravels from the more rapidly melting upper part would spread over and bury the lower ice. Ice thus buried would melt away slowly and in melting allow the settling of the overlying drift; producing conditions like those actually found at Pine Valley.

The topography strongly indicates that the axis of Seneca valley for several miles north of Pine Valley was occupied by an ice-block which in melting allowed the slumping of the overlying drift.

THE JOHNSON HOLLOW CHANNELS

At the head of Johnson Hollow (Watkins sheet), is an important series of connected channels illustrating four of the types described in the preceding pages, and showing their relations to each other and to the ice front. (See map, Fig. 9.)

At the time the channels were forming, a lobe of ice from the main Seneca valley tongue pushed into the Moreland valley; ending near the head of Johnson Hollow. At the same time the ice in the Seneca valley extended several miles farther south. The drainage from the margin and end of the Moreland lobe, together with a lateral stream (*E*) from the Seneca valley tongue, united at the head of Johnson

[1] The agency of a buried ice mass had been suggested by Tarr as an explanation of this particular condition, even before the direct evidence of the sinking of the channel bottom had been found.

Hollow and flowed as a single large stream, southward and southeastward to the foot of the hollow where it emptied into a marginal lake held up by the ice of the Seneca valley tongue.

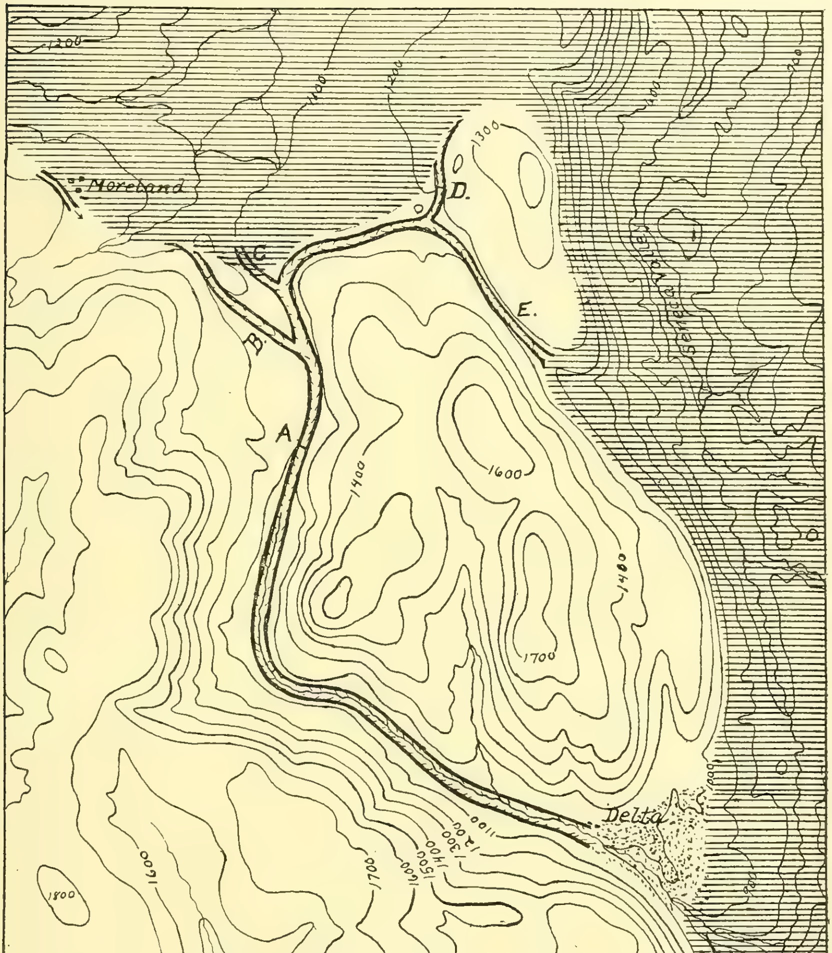

FIG. 9.—Johnson Hollow Channels. The probable position of the ice at the time the channels and delta were forming is shown by the ruled area. The Watkins Lake outlet begins at the base of the hill near the southeast corner of the map. Scale 1/62,500.

Four of the channel types, *marginal*, *lateral*, *morainic*, and *lake outlets*, are represented in this series. Channel *B*, at the beginning,

is strictly marginal. Farther down it swings behind a low knoll probably of rock; then takes a straight course southeastward to the main channel. *C*, which was probably initiated by a stream flowing from the end of the ice-lobe, seems later to have developed into a lake outlet, draining a lake held up in the Moreland valley by the retreating Moreland lobe. Channel *D*, formed along the eastern margin of the Moreland lobe, may be classed as marginal-morainic. It enters the main channel *E* as a rather deep trench with banks only moderately trimmed. Its lower portion might well be mistaken for a small valley cut by a post-glacial stream were it not for the fact that the only stream, a very small one, which enters it has built a fan across it. In its upper part the channel becomes shallower and finally one bank, the western, disappears. The other continues for considerable distance farther, gradually becoming less and less distinct.

E has already been described (p. 539). The main channel below A, is very pronounced, flat bottomed, and from four hundred to six hundred feet in width, with sharply trimmed drift banks twenty to thirty feet high.

An interesting drainage condition is found in connection with these channels. One-half mile below the junction of *A* and *B* a stream from the hills on the east has built a fan entirely across the channel. This has completely reversed the drainage of the channels above the fan, causing all the water to flow out northward through *C*, and thence to the stream in the Moreland valley. The grade of *C*, which was doubtless a lake outlet, is so low that a slight blocking of the channel three-fourths of a mile below was sufficient to reverse its stream.

In so far as could be determined, these channels were practically contemporaneous in origin, except that *C* must have persisted longer than the others. There is no apparent hanging condition at the junction of any of the channels with the main one as might be expected if the stream in one ceased flowing for any considerable time before that in the others.

At the foot of Johnson Hollow is a large delta formed, apparently in a marginal lake, by the stream flowing down the channel. The top of the delta is at the 1,000 feet contour, with the northern part slightly lower than the southern. The delta is very perfect, with

an even slope eastward toward the ice. There is evidence that this delta was built against the ice. Its eastern margin shows several deep kettles and other signs of the melting out of buried ice.

The top of the delta is one hundred feet higher than the Watkins Lake outlet channel, which began only three-fourths of a mile distant. This indicates clearly the deposition of the delta material in a marginal lake rather than in Lake Watkins. There is good evidence that while a large stream was still coming down Johnson Hollow, the ice melted out sufficiently from Seneca valley to cause the draining of this marginal lake and to bring about the initial stage of Lake Watkins at a level one hundred feet lower. At this level, just opposite the beginning of the outlet channel is a second delta built into Lake Watkins by a stream from Johnson Hollow. While forming the lower delta the stream cut a broad channel though the one first formed.

The Johnson Hollow series of channels presents many features of interest. It shows that while an ice-tongue lay in Seneca valley, at least as far as Millport, a lobe pushed westward into the Moreland valley and ended approximately at the head of Johnson Hollow. It also illustrates the case of a stream leaving the ice at one point and returning to it at a lower level several miles distant. This gives a means of estimating the ice slope, which seems to have been about sixty-six feet per mile. There is a possibility, however, though from the evidence it seems very improbable, that, while the upper delta was building in the marginal lake, the ice-lobe from which the stream came pushed for considerable distance into Johnson Hollow; and that it was only during the building of the later delta in the early stage of Lake Watkins that the channels at the head of Johnson Hollow were formed. If this were the case, the ice margin might have had a considerably greater slope, for the ice-tongue would not then necessarily reach as far south as the delta.

SUMMARY

Our study of the Finger Lake channels has brought out some features of interest and importance. It has shown, in the first place, the large number of these channels. It has shown also that, although from their nature the greater number of the channels now visible were formed during the final retreat of the ice, a considerable per-

centage have an earlier origin. In some of these cases all that can be said concerning the time of their formation is that they antedate the final retreat of the last ice-sheet. In others, notably Cayuta Gorge channel, the development of tributary gorges subsequent to the channel cutting points unquestionably to one or more interglacial intervals at least several times longer than post-glacial time.

Clear evidence of the burial and subsequent melting of large ice masses, with consequent settling of the overlying drift, has been found in one of the channels. Under ordinary conditions it would be difficult to obtain conclusive evidence of settling caused by melting ice because of the difficulty of distinguishing the resulting depressions from normal morainic topography. When, however, such a sinking lowers a portion of the bottom of a large stream channel, the evidence is clear.

One of the most important features of these channels is that they show the direction of the ice flow, and in this are of great value in the mapping of the glacial geology of a region. In favorable cases, especially in connection with *lateral* channels, it is possible to ascertain the slope of the ice with a very fair degree of accuracy.

Glacial channels are easily recognized. They are characteristically flat bottomed and are usually swampy. The banks, in almost all cases, are distinct and, except where disturbed by cultivation, show little effect of post-glacial degradation.

RELATION OF WIND TO TOPOGRAPHY OF COASTAL DRIFT SANDS

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Mexico City

The work on which this paper is based covers a number of years and a variety of marine sea-coasts. Sand formations have been studied by the writer on different coasts in Europe, on sea-shores in Australia, South Sea Islands, North and Central America. In a recent paper[1] the origin and development of such sand formations have been discussed and it is the intention to present here some observations on the wind in its relation to the topographical features of these sands.

As a geological agent the wind exercises a considerable modifying power, although its character is very unsteady. It manifests its influence by carrying fine particles of soil, depositing these, denuding rocks that stand in its way, and indirectly affecting the topography of the earth's surface by distributing moisture and limiting vegetation.

The moving sands of sea-shores afford ample opportunity for study of the methods of the wind in its work of denudation. It can often be seen how the sand carried over the surface of rocks sometimes wears them quite smooth, or covers them with scratches and furrow marks. This abrasion by the wind-transported material is always noticeable in dune districts, at least on the wind-worn pebbles, but also on the remains of trees which have been partly buried by the drifting sand, and then the protruding parts have been slowly carved and worn by the sand (Fig. 2).

In its weathering action wind has a constant tendency to break down the stones, gravel, and coarser soil particles into fine dust, and it is assisted in this work by the moisture. If it was not for the looseness of the sand, which allows the rain to percolate rapidly and thus to carry the fine dust deep into the ground, the persistent combined action of wind and moisture would suffice to prepare the quantity of

[1] Pehr Olsson-Seffer, "Genesis and Development of Sand Formations on Marine Coasts," *Boletin de la Sociedad de Geográfia y Estadistica*, Mexico (in press).

fine material needed to supply plants with soluble substances, and thus to allow a cover of vegetation to gain a foothold.

The action of wind as a transporting agent when removing the denuded rock material, whether soluble or insoluble, as soon as it appears at the surface is one of the most important factors in the denudation processes. Walther[1] calls this phenomenon *deflation* and he considers it to be of even more consequence than abrasion. Through deflation fresh rock is consequently exposed to the eroding forces, and it is evident that this action must be considerable, especially on the coasts with their moist climate.

The softer strata of rocks are worn more deeply by deflation, co-

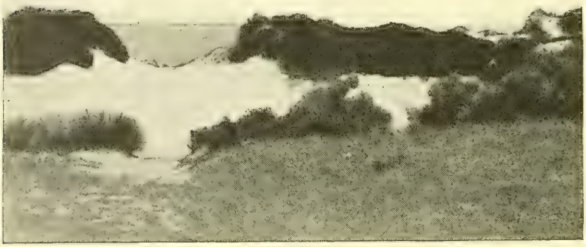

FIG. 1.—Established and rejuvenated dune surface at Fremantle, Western Australia.

operating with abrasion, and the harder layers are left to form cornices. On account of the abrasion being greater near the surface where the wind current carries a greater load of sand, the lower parts of rocks are often eroded more rapidly than the upper. Evidence of this can be seen in the "balancing rocks" not infrequently occurring in the neighborhood of extensive sand formations. The writer has seen such rocks on many coastal sands, near Port Fairy in Victoria, for instance, on the West Australian coast, at Port Said in Egypt, and at Carmel Bay in California.

It is especially the fine particles of sand which are liable to be transported by the wind; but as the fine sand retains its moisture better

[1] *Das Gesetz der Wüstenbildung*, 1900.

than that of coarser texture, because of its greater capillarity, it is evident that, if some means are furnished which increase the amount of moisture, or rather lessen the evaporation, the action of wind will be in a measure counterbalanced. This is accomplished by a vegetative covering, which fixes the sand and thus protects it against the influence of the air currents. The climatic conditions, especially a larger or smaller degree of moisture, is therefore a great factor in the development of eolian sand formations.

It is a matter of everyday observation that the velocity of the wind changes rapidly and varies considerably. A wind which appears to be very uniform is, when subjected to close observation, only a series of gusts following each other with intervals of lesser velocity, and even of complete calm. The carrying capacity of the wind is, therefore, also very variable. The wind that one moment carries and drops pebbles, a few minutes later carries only sand for deposition, and finer sand follows coarser.

A series of observations made by the writer in this connection will here be referred to.

Methods of observation.—The experiments were conducted on the sandy beach north of Fremantle in Western Australia during September and October, 1902, and they were intended to ascertain the carrying capacity of wind of certain velocities, as well as the effect of these winds on the movements of the sand.

For measuring the velocity of wind I used anemometers of Crova type, purchased from Negretti and Zambra in London. The instrument was placed on a support steadily secured in the sand, and elevated 5 cm. above the ground. It was not practicable to lower the apparatus more, because nearer the surface the amount of sand particles carried by the air current was still greater than at the elevation chosen, and I found that the results were somewhat influenced by the density of the sand-shower.

Samples of sand of different grain sizes were secured by sifting through sieves with meshes of known diameter. Three sizes were used, 0.2 mm. (fine sand), 0.3 (medium sand), and 0.6 (coarse sand).

Of each kind of sand a quantity of about 5 cu. dm. was dyed with different colors, black, bright blue, and orange being considered the most suitable and best distinguishable from the natural sand. The

sand was dyed in colored water and then thoroughly dried. By weighing the colored sand I satisfied myself that the weight had not materially increased through this process. At the time the observations were made, this colored sand was laid out in ridges transverse or parallel to the direction of the wind or in small heaps, the different results being noted in each case.

In order to ascertain the height to which different grades of sand were lifted by the wind I devised a simple contrivance, which seemed

FIG. 2.—Established dune destroyed by the wind. Near Southport, Queensland.

to fill the purpose. Five sheets of corrugated iron held together by a frame, were placed above each other at a distance of 2 cm. with the lowest floor resting on the ground, and with the wrinkles at right angles to the direction in which the sand moved. The front of each sheet was flattened for about 12 cm., so as not to give any obstruction to the wind or sand. These sharp, parallel edges divided the sand-shower, and the grains were collected in the folds of the apparatus. By closing the front and sweeping the different "floors" samples for examination were secured. For the sake of brevity I have in the following pages spoken of this apparatus as the "sand separator."

As my object was principally to find out the influence of wind in the layers near the surface or those which carry the greatest quantity of sand and come into contact with the lowest strata of the vegetation, I did not have the sand separator arranged to receive sand which was lifted higher than 8 cm. above the surface.

It seemed, further, to be of considerable interest to know how great the difference of the velocity of wind was on level and broken ground, and consequently to what extent a rough surface influenced the movement of sand. On a vacant lot, south of Fremantle, where the sand had been covered with a layer of loam for agricultural purposes, I had opportunity to make some observations in that direction, and subsequently I measured the surface velocity of air on a grassy plot adjoining a field of drifting sand.

Day after day the experiments were continued under different conditions of wind and humidity, and with the aid of an assistant I was able to make careful observations of the tactics of the moving sand, and to secure some results which are not without interest.

Velocity of wind.—Of the hourly registrations made, those for six days will be given as samples. The place of observation was on an open beach, 40 m. from shore. Angle of sloping about 12°. The following table indicates the result. Velocity in meters per second.

	I	II	III	IV	V	VI
7 A.M.	0.6	11.3	10.9	8.6	3.1	10.4
8	1.3	12.5	12.3	12.7	3.9	10.9
9	1.9	13.1	14.2	14.1	4.7	11.5
10	2.4	13.8	15.7	14.9	5.6	14.2
11	2.1	14.6	18.2	23.7	7.1	15.7
12	4.5	15.9	19.5	22.5	7.6	18.6
1 P.M.	4.9	17.6	16.3	23.2	7.9	18.9
2	6.0	19.4	14.9	14.1	8.7	17.2
3	12.8	22.4	15.1	22.6	12.3	18.4
4	13.9	21.2	15.6	22.3	14.1	20.2
5	13.7	19.6	13.2	14.7	11.6	19.7
6	13.3	18.3	12.9	20.4	8.7	16.1

Result of experiments on carrying capacity.—A few of the observations made will here be given to show the details obtained. The Roman numerals refer to corresponding days in the table of velocities.

I. No drifting was observed in the forenoon. Slight movement was noticed between 1 and 2 o'clock. During the next hour the sand

separator had received a quantity of grains on each floor. Mechanical analysis of these grains showed that on the lowest floor A, on a level with the surrounding ground where the greatest quantity of sand had collected, many different grades were represented. This is self-evident as the grains here had only rolled and not been lifted by the wind; at least not higher than 2 cm., in which case they were intercepted by the next higher floor B. The wind was gusty, but the force of the separate gusts was comparatively uniform, and the intervals of wind of lesser velocity, brief and somewhat regular in length.

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.	0.02–0.05	trace
	0.05–0.1	2.2
	0.1 –0.2	13.1
	0.2 –0.3	56.2
	0.3 –0.5	21.5
	0.5 –1	5.6
	1 –2	1.4
Floor B.	0.02–0.05	0.8
	0.05–0.1	5.2
	0.1 –0.2	42.9
	0.2 –0.3	44.5
	0.3 –0.5	6.6
Floor C.	0.02–0.05	12.3
	0.05–0.1	16.6
	0.1 –0.2	58.4
	0.2 –0.3	10.7
	0.3 –0.5	2.0
Floor D.	0.02–0.05	37.4
	0.05–0.1	56.7
	0.1 –0.2	5.9
Floor E.	0.02–0.05	72.5
	0.05–0.1	26.3
	0.1 –0.2	1.2

The coarsest material with certainty lifted by a wind of a velocity of 12.8 m. per second was, as indicated by the above table, medium sand, and the greatest height to which this sand was lifted, 4–6 cm.

During the same period of time the colored sand samples exposed to the wind were distributed as follows:

Fine sand	12 m.
Medium sand	12
Coarse sand	7.5

II. During morning hours the drifting was insignificant as the surface of the ground was still somewhat moist with the abundant

dew fall. But at 9 o'clock, although the force of wind had not increased much, the sand was moving briskly and the shifting continued through the day.

The sand separator was kept at the same distance from shore as on day I, but the ground was so slightly sloping as to be almost horizontal. The day was warm and the sand quite dry. From 2 to 3 o'clock the separator was in action, and subsequent analysis gave the following result:

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.	0.02–0.5	trace
	0.05–0.1	6.4
	0.1 –0.2	10.2
	0.2 –0.3	41.3
	0.3 –0.5	28.4
	0.5 –1	9.6
	1 –2	3.5
	2 –4	0.6
Floor B.	0.02–0.05	1.7
	0.05–0.1	3.3
	0.1 –0.2	26.5
	0.2 –0.3	47.8
	0.3 –0.5	14.1
	0.5 –1	6.6
Floor C.	0.02–0.05	5.1
	0.05–0.1	10.0
	0.1 –0.2	23.4
	0.2 –0.3	41.2
	0.3 –0.5	6.7
	0.5 –1	3.6
Floor D.	0.02–0.05	16.3
	0.05–0.1	34.7
	0.1 –0.2	28.5
	0.2 –0.3	12.1
	0.3 –0.5	8.4
Floor E.	0.02–0.05	32.5
	0.05–0.1	34.1
	0.1 –0.2	16.8
	0.2 –0.3	5.4
	0.3 –0.5	1.2

A wind with a velocity of 22.4 m. per second was thus able to lift medium sand at least 8 cm. and coarse sand 4–6 cm. The coarsest grains at all raised above the surface had a diameter of 1 mm.

As for the distance to which the wind was able to transport colored grains I found grains 4.3 m. away from the original place of exposure after 15 minutes, while grains of 0.2 mm. diameter were carried at

least as far as 12 m. where they were intercepted by a white canvas sheet. These distances are only relative values of the carrying capacity, as they show only what has been observed with the crude methods employed; a number of grains are, no doubt, carried much farther but cannot be distinguished on the sandy ground.

IV. From about 8:15 A. M. the sand was drifting slowly, increasing by degrees with the increase of force of wind and the rise of temperature and consequent desiccation of the sand. Shortly after noon a damp fog came driving inland from the ocean, and a decrease in the movement of the sand was at once evident. A small shower of rain followed and drifting ceased completely. Evaporation was not sufficient to dry the sand during the rest of the day, and in spite of the comparatively high wind no more drifting was observed.

VI. Between 10 and 11 o'clock in the forenoon the separator was at work, and collected samples of sand, the mechanical analysis of which is given below. The sand was completely dry to a depth of about 5 cm. and the separator was placed on ground sloping in an angle of 25 degrees.

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.—	0.02–0.05	trace
	0.05–0.1	1.6
	0.1 –0.2	10.5
	0.2 –0.3	60.1
	0.3 –0.5	17.8
	0.5 –1	6.7
	1. –2.	3.3
Floor B.—	0.02–0.05	trace
	0.05–0.1	3.8
	0.1 –0.2	37.3
	0.2 –0.3	51.9
	0.3 –0.5	7.0
Floor C.—	0.02–0.05	5.7
	0.05–0.1	12.4
	0.1 –0.2	61.3
	0.2 –0.3	14.5
	0.3 –0.5	6.1
Floor D.—	0.02–0.05	21.3
	0.05–0.1	63.9
	0.1 –0.2	12.6
	0.2 –0.3	3.2
Floor E.—	0.02–0.05	64.8
	0.05–0.1	28.6
	0.1 –0.2	5.1
	0.2 –0.3	1.5

A wind with a velocity of 15.7 m. per second was thus able to lift grains of 9.3 mm. diameter to a height of 6–8 cm., and experiments for ascertaining the distance to which such grains were carried by the same wind showed this to be 8.6 m. in 30 minutes.

The few examples given are typical of a larger number (24) of mechanical analyses of series of samples collected with the sand separator during wind of different strength, but it is hardly necessary to furnish additional data, as a discussion of the facts given will bring out the points wanted for our present purpose.

For the solution of the problem of the carrying capacity of the wind, it is of primary importance to know whether the velocity is changing on or near the surface. Among the observations on velocity of wind in different heights, which have been recorded, we may mention those by Stevenson, Montaigny, Ragona, and Sokoloff. All these experiments show that *the velocity increases considerably with the height.*

A very significant feature of the above tables is that the bulk of sand on the two lowest floors is of such uniform size. I take this to indicate that the velocity of the lowest layers of air must be comparatively uniform, while the higher currents are of a more gusty character and are able to pick up the smaller grades of grains and lift them higher. It is an accepted fact that a current, which carries a load, is retarded, and the retardation is greater the larger the particles moved. Nearest to the ground there is a layer which on account of the friction against the uneven surface is comparatively inert, and we know that the velocity of the current in this layer increases only at a very slow rate with an increase in the speed of the layers next above it.[1] These circumstances put together tend to support the above theory that the movement of the lowest layer of the atmosphere is more uniform than the higher.

Although the bulk of sand on the lowest floor of the separator is greater than on any of the higher, the difference between the quantity of sand on A and B is not very remarkable. I understand this to prove that the larger part of sand moved by the wind is lifted from the ground, if only for a short distance. It seems at first sight as if all the material on the lowest floor or on the same level as the ground,

[1] J. A. Udden, *The Mechanical Composition of Wind Deposits*, 1898, p. 24.

had been pushed forward or rolled on the surface. But the opening between the floors is high enough to allow a considerable part of the grains to be lifted above ground. It seems most likely to me that the sand is moving in short jumps.

Different opinions have been expressed on this question. Brémontier considered that the sand is not lifted to any considerable height as he says:

Chacun des grains de sable dont elles (les dunes) sont composées n'est pas assez gros pour résister aux vents d'une certaine force; ni assez petit pour être enlevé comme de la poussière, ils ne font que rouler sur la surface dont ils sont arrachés, s'élèvent rarement à plus de 3 à 4 pouces d'hauteur.[1]

Andersen[2] also maintains that the grains are mostly rolled on the surface. Berendt, Hagen, and Sokoloff, among others, admit that it is lifted quite high; the latter[3] correctly assumes that the many different theories on this question most likely depend on the fact that the observations refer to different places on the dunes sometimes to the front slope, in other cases to the summit or to the leeward side.

Udden[4] discusses this question in following words:

Materials finer than dune sand are wholly lifted up into swifter currents which promptly move them. The dune sand itself, on the other hand, is partly lifted and also partly rolled just as the grains of the nearest larger sizes. Working in this last manner the transporting power of the wind varies more nearly in approximation to its erosive force than to its lifting force. With changes in velocities the latter varies as the sixth power while the erosive force varies as the square. It is therefore much easier for the coarser ingredients to be rolled along with the dune sand than it is for the dune sand to be picked up and carried away with the finer ingredients.

This holds true and the cause of the greater resistance of the finer material is simply the greater coherence of the finer soil particles. In drawing any inferences with regard to these matters we must not forget, however, the influence which is exerted by the slope. On a horizontal surface the effect of wind is not so great as on a slope.

[1] "Mémoire sur les dunes," *Ann. des ponts et chaussées* (1), 1883, p. 148.

[2] *Om Klitformationen*, 1861, p. 57.

[3] Sokoloff, *Die Dünen*, 1894, p. 79.

[4] *The Mechanical Composition of Wind Deposits*, 1888, pp. 24 ff.

This has been shown by Sokoloff[1] and two of the experiments already described, those on days I and II, illustrate the same fact. Although in the latter case the wind was swifter with nearly 10 meters per second the quantity of material moved as well as the percentage of the coarser grades was only very little larger than in the former case, when the separator was placed on a sloping surface.

Any obstruction that comes in the path of the wind will greatly reduce its force and consequently lessen the movements of the sand. It is on this principle that some of the methods of arresting drift sand are based. Planting rows of grasses or trees, or the making of fences of sticks and other material on the dunes are means employed for this purpose. Scanty rows of grasses act more effectively as windbreaks than as regular binders of the soil, and in planting such "sandstays" it is important to get the right distance between the rows, which varies at different localities with the exposure to wind and coarseness of the sand. If the local conditions have not been studied and if the disposal of the windbreaks has not been done properly, the results will be unsatisfactory. Too long distance between the rows will not prevent drifting, and too close planting is unnecessarily expensive.

The experiments conducted for the purpose of ascertaining difference in velocity of wind on an even and a rough surface gave the results shown below:

Number of Series	Number of Observations	Mean Velocity per Second in Meter		
		On Even Surface	On Rough Surface	On Grass Covered Surface
I	7	8.4	5.2	4.3
II	11	10.2	6.8	5.8
III	5	4.6	3.1	2.6
IV	6	9.8	6.3	5.1
V	3	16.2	10.6	8.7
VI	6	5.4	3.7	3.0

The following compilation of these results will show the actual difference of velocities as well as the proportion expressed in per cent. of velocity on the even surface.

[1] *Die Dünen*, 1894, p. 289.

DIFFERENCE OF WIND VELOCITIES PER SECOND IN METER

Number of Series	Between Even and Rough Surface		Between Even and Grassy Surface		Between Rough and Grassy Surface	
	Actual Difference	Per Cent.	Actual Difference	Per Cent.	Actual Difference	Per Cent.
I	3.2	61.9	4.1	51.1	0.9	82.6
II	3.4	66.6	4.4	56.8	1.0	85.2
III	1.5	67.5	2.0	56.3	0.5	83.8
IV	3.5	64.2	4.7	52.0	1.2	80.9
V	5.6	65.4	7.5	53.7	1.9	82.0
VI	1.7	68.5	2.4	55.5	0.7	81.0

In these experiments the anemometers were placed on a board on the ground, thus raised 3 cm. above the surface. The centrum of the instrument was on a level with the top of the low grass turf in the case of the grassy surface.

We find from these accumulated facts that the mean velocity on the even surface surpassed that on the rough ground by 3.15 m. per second or 34.7 per cent. F. H. King[1] gives the velocity over smooth ground as more than 40 per cent. greater than that on a rough surface. The difference in my results may have been caused by different conditions under which the experiments were conducted. King does not give any information about the method by which his results were obtained so that actual comparison is impossible. I consider the difference as being of minor importance, as by both these series of experiments it is clearly shown that the velocity of wind over a smooth surface is *at least* 34.7 per cent. greater than on uneven ground. Again, the velocity on grassy ground is still less than on bare rough surface. This is a fact of some practical importance in connection with planting on sandy soils, and it has a bearing of considerable weight on the vegetation on sand formations.

Through the investigation of Kihlman,[2] Warming,[3] Hansen,[4]

[1] *Destructive Effects of Winds on Sandy Soils and Light Sandy Loams with Methods of Prevention*, Eleventh Annual Report of Agricultural Experiment Station of Wisconsin University, 1895, p. 332.

[2] Pflanzenbiologische Studien aus Russisch Lappland," *Acta Soc. F. Fl. F.*, VI, 1890.

[3] *Plantesamfund*, 1895; "Der Wind als pflanzengeographischer Faktor," *Engl. bot. Jahrb.*, Vol. XXXI, 1902.

[4] *Die Vegetation der ostfriesischen Inseln*, 1901.

and others, it is now a well-established fact that the movements of the atmosphere are of the greatest importance for the plants, especially because of the influence of winds on the transpiration processes. With regard to vegetation on coastal sands wind is a factor of particular moment. The difference in wind velocities on open soil, on a surface more or less uneven, or covered with a more or less dense vegetation, is therefore of great significance, and we shall be able to show some effects of this eolian influence in the following pages.

The direction of wind on different shores is further a factor which must not be overlooked as it plays an important rôle, not only in the development and topography of the sand formations, but also in the distribution of plants on the coast.

As a general rule we can lay down the law that on every coast where sand dunes occur the offshore wind is prevailing. There are, however, a great many exceptions to this rule, where the local topography or other factors have been the cause of dune development.

On some coasts, as that of Jutland, where the supply of marine sand seems to be inexhaustible, the prevailing westerly winds from the sea drive the sand inland from the beach, continuously adding to the volume of sand. On other coasts, as that of Gascony, strong land winds occur, which often return considerable quantities of sand to the sea.

On the Pacific coast of America near San Francisco, and near Salina Cruz in Mexico I noticed that the sand cast upon the beach by the northerly and westerly winds was again driven back into the sea by the winds from the south and east. Similar conditions exist on many other coasts where the topography is favorable to such a forward and backward movement.

The force of the wind is augmented or diminished according to the season, but the result as regards sand formations depends greatly upon the direction of the coast. On the windward side of many islands high dunes are formed, as for instance on the northern coast of Oahu in the Hawaii group where they reach about 30 feet.

Typical coastal sand formations.—Very little variation is noticed in the formation of sand drifts on marine coasts. Wherever the drifting sand encounters an obstacle in its way such as a shrub or a piece of wood, or a rock, there it deposits on the leeward side. Gener-

ally we meet, however, with a level beach of a varying width, and then the coastal dune rises slowly at an angle varying from 4–16° on the wind side. Its height varies on different coasts according to the supply of material and the prevailing direction of the wind.

On very long, straight, and open coasts the wind strikes the sand over a long distance with the same force and under almost identical conditions. On such coasts we find long stretches of dunes showing a little diversified topography. As a rule the dunes are very little curved and run at right angles to the direction of the wind.

The diurnal variation of direction and force of winds which always is considerable on marine coasts exercises some influence upon the development of the drift-sand formations. The angle of deflection from the direction of the annual wind resultant differs in summer and winter, and from observations of these meteorological data in a locality with drift sands it is possible to calculate to some extent as to the annual movement and changes of the sand formations.

Usually the downward eddy behind the coastal dune sweeps over the stretch of land immediately following, and regular dunes are not formed before some distance from the coastal dune. These first dunes are formed round some obstacle, and their form is usually oval, pointing toward the wind and the coast, but sometimes crescentic, and convex to the wind. These small advance dunes are followed by trains of large dunes, nearly uniform in shape. The wind sweeps with brisk velocity upward along the gentle gradient and carries the sand to the brink where it is deposited on the steep lee-side which is further increased by the undercutting of the eddy.

Beyond the reach and influence of the strong sea breeze the dunes are more irregular, and lateral inequalities are formed connecting the various individual dunes into long ridges. These travel forward in a continuous march, slowly but surely. The form and location of the drift changes gradually.

A dune region shows a more or less undulating surface, which suddenly may be broken up into quite high hills or ridges. Sometimes, when the forward march of the dunes has been stopped the dune belt is continued inland in a gently undulating sand field.

In a dune region many different stages of dune development are observed, from the embryonic living dune to the large established

mountain-like sand dune covered with vegetation. Very often such finished dunes are again broken up by the wind (Fig. 1). On these rejuvenated dunes the usual series of development takes place from the very beginning, and they have often a peculiar character, resulting from the remaining remnants of the old vegetation covering and the new plant immigrants which have arrived after the complete or partial destruction of the dune.

It is a rule that the inner dunes in a complex are higher than those nearer the beach because the horizontal directions of wind are deflected.[1]

Dunes do not travel extensively. Those in Brittany are said to move 27 feet a year for 200 years. On the coast of Norfolk facing the North Sea the dunes travel 150–80 feet a year, according to Lapparent. I have not been able to find conclusive evidence regarding a more rapid advance of dunes than 42 feet in one year, which is the rate of advance of some dunes near Vera Cruz in Mexico.

Dr. Baschin[2] reports a mean drift of moving sand ridges on the west coast of Fanö, the northernmost of the islands of North Friesland, of about 10 feet a day. The author's explanation is that on a large dune more material must be driven to the lee-side before any displacement of the crest becomes evident, while the small sand ridges on which his experiments were made moved more rapidly. He also maintains that the slope on the leeward side is due simply to the fall of the sand as the crest of the dune moves forward. I hold with Bertoldy that the steep slope is due not only to the fall of the sand but also to the effect of the vortex of air round a horizontal axis formed on the lee-side of the dune.

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AN INTERGLACIAL FAUNA FOUND IN CAYUGA VALLEY AND ITS RELATION TO THE PLEISTOCENE OF TORONTO

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On the western shore of Cayuga Lake, in central New York, is an interglacial fossiliferous deposit which is of interest because of the rarity of similar beds which contain traces of Pleistocene life.

The deposit is between Taughannock Falls and Frontenac Beach in a small ravine which has cut through one of the delta terraces so common in Cayuga valley. It was first noticed some time since by Professor R. S. Tarr and was later examined by Professor G. D. Harris and the writer. The following is a vertical section of the locality.

Drift	20 to 30 feet
Gravel and sand	several inches
Fossiliferous clay	5 to 8 feet
Bowlder clay	10 to 15 feet
Devonian shales	10 feet exposed above lake level

The bowlder clay in its uppermost part passes into gravel and sand which are decidedly oxidized, indicating a period of erosion and weathering.

The clay in which the fossils are imbedded is a slaty blue color, loose and very peaty at the base where it is composed almost wholly of the remains of plants, but in the center it becomes compact and is a very fine-grained, blue clay. It is distinctly stratified and splits easily along the plane of bedding but not in any other direction.

Above the fossiliferous blue clay are a few inches of sand and gravel pointing to a short period of erosion at the close of the warm interglacial period before the return of the ice and the deposition of the great mass of overlying drift.

The fossils are all fresh-water shells. Unios, Anodontas, and Sphaeriums are common and of large size, showing that conditions were favorable for their growth, but few are well preserved.

The following species have been identified and are in the geological museum of Cornell University.

Anodonta fragilis Lam. (*marginata* Say)	*Limnaea elodes* Say
Anodonta grandis Say	*Physa heterostropha* Say
Anodonta grandis var. *footiana* Lea	*Planorbis bicarinatus* Say
Lampsilis luteolus Lam.	*Planorbis deflectus* Say
Lampsilis ventricosus Barnes	*Planorbis lentus?* Say
Sphaerium simile Say	*Planorbis parvus* Say
Pisidium compressum Prime	*Amnicola limosa* Say
Pisidium virginicum Bourg.	*Valvata tricarinata* Say
Limnaea palustris Mull.	*Campeloma decisa* Say

Of these species *Sphaerium simile*, *Pisidium compressum*, *Planorbis deflectus*, *Amnicola limosa*, and *Valvata tricarinata* are the commonest forms.

Every one of the species listed has been found, by the writer, now living in Cayuga Lake. But of the five Unionidae, four are Mississippi species which are, however, also living now in the St. Lawrence system. *Anodonta fragilis* is the only one that strictly belongs to the St. Lawrence. *Luteolus* though originally a Mississippi species has secured such a foothold in the St. Lawrence system as to have become one of the commonest shells of the Finger Lakes.

On comparing the Cayuga Valley Pleistocene shells with those of the well-known interglacial beds near Toronto, about 170 miles to the northwest of Ithaca, we find the following species common to both deposits.

Lampsilis luteolus Lam.	*Planorbis bicarinatus* Say
Anodonta grandis Say	*Amnicola limosa* Say
Sphaerium simile Say	*Physa heterostropha* Say
Pisidium compressum Prime	*Valvata tricarinata* Say
Limnaea elodes Say	*Campeloma desisa* Say
Planorbis parvus Say	

Thus more than half the interglacial species found in Cayuga Valley have also been identified in the warm climate or Don valley beds of the Toronto formation.[1]

But while we find that every one of the interglacial species of Cayuga Valley are now re-established in Cayuga Lake, on the con-

[1] See A. P. Coleman, *Amer. Geol.*, Vol. XIII (1894), pp. 85–95; *Journ. Geol.*, Vol. IX (1901), pp. 285–310; also C. T. Simpson, *Proc. U. S. Nat. Mus.*, Vol. XVI, pp. 591–95.

trary, two-thirds of the Unios in the Don valley beds withdrew permanently from Lake Ontario after the destruction of their colonies. These forms required a milder climate and could only live in Ontario during the warm interglacial period when, as Coleman has shown, the climate of Toronto was so mild as to permit the growth of the paw-paw and the osage orange.

In addition to the similarity of faunas of the Don and Cayuga valley deposits, there is a great similarity of levels. According to Mr. Coleman the lowest of the Don valley beds was formed when the water stood 19 feet above the present level of Lake Ontario. The Cayuga valley deposit began to be formed with the water about twenty feet above the present lake level.

It is unfortunate that the plant remains in the Cayuga valley interglacial bed are too decayed and fragmentary for identification, but the lowest layers of the fossiliferous blue clay, like the lowest of the Don valley beds, are formed of sheets of vegetable matter consisting of twigs, fragments of leaves, and reeds.

In conclusion we may say that (1) the Cayuga interglacial colony was established by Mississippi and St. Lawrence molluscs which came down from the north and west; (2) this would have required a very considerable period of time after their widespread destruction in the preceding ice invasions; (3) the colony could not have been established during a slight oscillation northward of the ice (as might have been the case if the species had come in from the Susquehanna system); (4) more than one-half the molluscs found in the Cayuga valley deposit are reported from the Don valley beds of the Toronto formation; (5) the Cayuga and Don valley fossiliferous beds both began to be formed when the water stood about twenty feet above the present lake levels; (6) it is very probable that the Cayuga fossiliferous deposit corresponds approximately in time with the Don valley, or warm climate beds, of the Toronto Pleistocene formation which is regarded as representing the Peorian, or fourth, interglacial period.

AN EXAMPLE OF DISRUPTION OF ROCK BY LIGHTNING ON ONE OF THE LUCITE HILLS IN WYOMING[1]

V. H. BARNETT

The accompanying picture (Fig. 1) is a view on the summit of Cross Mesa,[2] one of the Lucite Hills near Rock Springs, Wyoming.

This mesa, like most of the group, is quite barren and flat on top, the volcanic rock of which it is composed being unprotected by soil and vegetation. Like the other Lucite Hills it is a very prominent landmark standing well above the surrounding country.

The angular bowlders seen in the picture have been torn by some apparently violent force from the surface of the lava and some of them still lie in the cavity formed. The space from which the rock fragments were torn is roughly a half-saucer in shape, having the east rim nearly vertical while on the opposite side it is more gently sloping. Two or three cracks, one of which may be observed near the right lower corner of the picture, radiate from the saucer-shaped depression. Whether some of these cracks may not have occurred before the disruption the writer was not able to judge, but it is not likely that all of them did so occur. The rock fragments range in size from an inch or two in diameter up to about two feet and a half, and are sharply angular with fresh surfaces. From the size of the cavity the amount of rock removed is approximately twelve cubic feet and lies within a radius of about ten feet from the fracture and exclusively to the west of it. No fragments were observed to have been thrown very far.

Two hypotheses at once present themselves in explanation of this phenomenon: first, that of an artificial explosion as dynamite or blasting powder; second, that of lightning.

The probabilities of this being due to the first hypothesis seem very slight since it is so far removed from human activities of any

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

[2] J. F. Kemp and W. C. Knight, "Lucite Hills of Wyoming," *Bull. Geol. Soc. Amer.*, Vol. XIV, 1902, p. 317.

kind. The nearest trail is in Long Cañon, one mile northwest and four hundred feet lower down. Over this trail there is perhaps not more than one person a week during summer and probably fewer in winter. Several coal prospects have been opened, however, during the last five or six years, in Back Cañon and also in Long Cañon, not more than five miles to the south, but giant powder only was used in shooting. Had a prospector been so disposed it is the writer's opinion he could not have produced the effect shown in this photograph with

FIG. 1.—View on top of Cross Mesa, Wyoming, showing fragments torn from the lava by lightning.

ordinary blasting powder. He certainly could not have done it without a drill hole and no evidence of holes were observed. Even with a drill hole it would have been very hard, if not impossible, to have confined the powder sufficiently well. Furthermore, from the very nature of the rock (lava), a prospector would not have been looking for minerals in this place, and if he had been doing it for amusement he almost certainly would have selected a crevice at the limiting cliff of the mesa where the explosion would have loosened a large mass of

rock and sent it tumbling down the steep slope which falls away from the escarpment.

The other hypothesis, that of lightning, seems the more probable, and the writer wishes to call attention to it as an example of a kind of phenomenon rather rarely noted in geological literature. A few instances of the disruptive effects of lightning are on record.

Hibbert[1] describes as follows the effect of lightning on the cliffs of micaceous schist on the east side of the island of Fetlar, one of the Shetland Islands.

A rock 105 feet long, 10 feet broad, and in some places more than 4 feet thick, was, in an instant, torn from its bed, and broken into three large and several lesser fragments. One of these, 26 feet long, 10 feet broad, and 4 feet thick, simply turned over. The second, which was 28 feet long, 17 feet broad, and 5 feet in thickness, was hurled across a high point of a rock to the distance of 50 yards. Another broken mass, about 40 feet long, was thrown still farther but in the same direction, quite into the sea. There were also many lesser fragments scattered up and down.

T. R. Dakyns, in his paper on "Modern Denudation in N. Wales,"[2] says:

During the great thunderstorm that occurred in N. Wales in the middle of August, 1898, a mass of rock was broken and thrown down the Llyn Teyrn. This is known to have been done by lightning, as it was not there until after the storm.

In a conversation with the writer, George Otis Smith has stated that during a thunderstorm in 1904, he observed lightning strike on the summit of Mt. Battie, in the northern portion of the Rockland quadrangle[3] (Maine), and a mass of quartzitic conglomerate several feet in diameter was broken from the glaciated surface and thrown out.

While the most commonly observed effects of lightning on rocks seems to be that of fusion resulting in the production of fulgurites or glassy coatings,[4] no evidence of fulgurites nor of glassy coatings was observed either on these fragments or in the cavity from which they were thrown, but since lightning of the disruptive type is apparently

[1] Samuel Hibbert, *Description of the Shetland Islands*, 1822, p. 389. For this account of lightning effect Hibbert says he is indebted to Geo. Low, *M. S. of Rev.*

[2] *Geological Magazine*, new series, Vol. VII, 1900, No. 1, p. 19.

[3] *Rockland Folio No. 158*, U. S. Geol. Survey, May, 1908.

[4] R. R. Julian, "A Study of the Structure of Fulgurites," *Jour. Geol.*, Vol. IX, 1901, pp. 673–93.

not always accompanied by high temperatures, it does not follow that this phenomenon may not have been caused by lightning.

The most evident effect of lightning is of the disruptive type observed almost every day in the form of splintered telegraph poles and shattered trees and buildings. Lightning, producing this class of results, does not seem always to be accompanied by high temperatures. The writer has observed one instance at least in which a perfectly dry wooden building was shattered without a tendency to firing it.

ON THE VALUE OF THE EVIDENCE FURNISHED BY VERTEBRATE FOSSILS OF AGE OF CERTAIN SO-CALLED PERMIAN BEDS IN AMERICA

E. C. CASE

In 1876–77 Cope referred certain beds in Illinois and Texas, bearing vertebrate fossils, to the Permian Age. This has stood almost without challenge until very recently and has had a very considerable effect on the literature of the Permian. The recent discovery by Mr. Raymond of reptilian remains, of the same character as those referred to the Permian from Illinois and Texas, in the Coal Measures of Pennsylvania[1] renders it desirable to re-examine the evidence upon which the position of the beds was determined. The conflicting evidence of invertebrates and plants will not be discussed as they will be considered in the accompanying papers.

In re-examining the evidence for the age of these beds it seems necessary to consider two points:

1. The morphological comparison of the North American forms with those of known Permian Age from Europe and other continents.

2. The possibility of the introduction of reptilian life at an age earlier than the Permian.

In discussing the first question it will be best to pass in review the evidence upon which Cope based his determination of the Permian Age of the beds. The scope of the article will not permit discussion of the details of comparative anatomy and so the arguments will be based on conclusions which have been reached by various anatomists, leaving the details to another time and place should a discussion arise.

Cope's evidence: The first mention of vertebrate remains from Illinois was in 1875:[2]

A remarkable peculiarity of the vertebrae of the series is the longitudinal perforation axial of the centrum. They present the character observed in *Arche-*

[1] *Science*, Vol. XXVI, December 13, 1907.

[2] *Proc. Acad. Nat. Sci. Phil.*, 1875, p. 440.

gosaurus and other stegocephalous Batrachia, but which also exists, according to Gunther, in the living Rhynchocephalous lizard, the *Sphenodon* of New Zealand. The bones of the limbs and the scapular arches are decidedly reptilian, and so unlike those of any Batrachia with which we are yet acquainted, that I am disposed to refer them to the former class. And as there are several points in which the fossils resemble the order *Rhynchocephalia*, I refer them provisionally to that neighborhood. They constitute the first definite indication of animals of that type in the western hemisphere.

Associated with these saurians were found the teeth of two species of fishes which are important in evidence of the position of the beds in which they occur. One of these is a new species of *Ceratodus*, Ag., and the other a *Diplodus*. The former genus is characteristic of the Triassic period in Europe, one species having been found in the Oolite. It still lives in North Australia. In both of these respects the Rhynchocephalian lizards present a remarkable coincidence. They also belong to the horizon of the Trias in Europe; and the only living species is found in New Zealand. Thus it would seem that a fragment of this fauna, so ancient in the northern hemisphere, and so remarkably preserved in the southern, has been brought to light in Illinois. It must be added in reference to the geological age of the fossils, that the genus *Diplodus* has not yet been discovered above the Carboniferous, and that one genus of the *Rhynchocephalia* belongs to the Permian of Germany. We therefore wait further material before venturing to decide whether they belong to Triassic or Permian time.

In May, 1877, he read a paper before the American Philosophical Society in which he reaffirmed the probable Permian character of the beds:[1]

After an examination of the first fossils from this fauna which came under my observation, I left the question undecided as to whether its characters pointed to the Triassic or Permian Age. The Reptilia and a *Ceratodus* pointed to the former; the *Diplodus* pointed even to the Coal Measures. The additional evidence adduced in this paper adds weight to both sides of the question. Of the fishes added, *Ctenodus* is a genus of the Coal Measures, and while *Strigilina* is new, its affinities are to the Petalodont genera of that formation. On the other hand the reptilian character of *Clepsydrops* is established, and the number of its species is increased. Now the Coal Measures have nowhere disclosed reptilian remains, so far as we have determinations of a reliable character; Batrachia were the only type of air-breathing vertebrata known to that epoch. The present fauna must then be placed above the Coal Measures, and the horizon will correspond more nearly with the Permian than with any other embraced in the system.

From its most characteristic fossil, the bed might be called the *Clepsydrops* shale. Its position according to Dr. Winslow is near the top of the Coal Measures, and is marked No. 15, in Professor F. H. Bradley's section of the Coal

[1] *Am. Phil. Soc. Proc.*, 1877, Vol. XVII, p. 64.

Measures of Vermillion Co., in the *Report* of the Geological Survey of Illinois by A. H. Worthen, Vol. IV, p. 245. It is about 111 feet, averaging different localities, from the summit of the series, and 2,099½ feet from the base. Two insignificant beds of corals [misprint for *coal*] occur above and the following genera of invertebrate fossils: *Productus*, *Spirifer*, *Athyris*, *Terebratula*, *Hemipronites*, *Retzia*, *Zeacrinus*, *Cyathaxonia*, *Discinia*, *Lingula*, *Cardiomorpha*, *Orthoceras*, and *Nautilus*. Several of these genera are found in the Zechstein, while others belong to the Coal Measures and below them.

In another paper of the same year he says:[1]

Twenty species have now been obtained from the *Clepsydrops* shale, the exact geological position of which remains to be accurately determined. Dr. Winslow informed me that they are the bed No. 15 of Professor Bradley's section of the Carboniferous rocks of Vermillion Co., Illinois. This places them at the summit of the Carboniferous series, below two thin beds of coal. I am now informed that this portion of Professor Bradley's report is not correct, and that No. 15 occupies a much higher position than he assigns to it. It lies unconformably above the meron sandstone of Mr. Collett, which deposit is above the Coal Measures and unconformable to them. The stratigraphic evidence is thus confirmatory of that derived from paleontology, that the *Clepsydrops* shale occupies a position in the scale above the Coal Measures.

A page or two farther on in the same article he correlates the Texas and Illinois horizons (p. 193):

The discovery of a species of the genus *Clepsydrops* in Texas, in a formation hitherto regarded as Triassic, adds weight to the view above expressed, that the *Clepsydrops* shales of Illinois belong either to the Triassic or Permian formations.

In 1878 he definitely asserted the Permian Age of the beds:[2]

The Texan genera of this group (Pelycosauria), so far as yet known, are about equally related to the Ural and South African types. The age of the former deposit is the Permian, which includes, according to Murchison, the Todtliegende and the Zechstein of Thuringia. The age of the South African beds is uncertain but is suspected by some authors to be Triassic, and by Owen to be Paleozoic. In discussing the *Clepsydrops* shales of Illinois, which had been referred to the Coal Measures by previous investigators, I left the question open as to whether they should be referred to the Triassic or the Permian formations. The evidence now adduced is sufficient to assign the formation, as represented in Illinois and Texas, to the Permian. Besides the saurian genera mentioned above, the existence of the icthyic genera *Janassa*, *Ctenodus*, and *Diplodus*, in both localities, renders this course necessary.

[1] *Am. Phil. Soc. Proc.*, 1877, Vol. XVII, p. 182.

[2] *Ibid.*, p. 350.

THESES

1. The horizon of the *Clepsydrops* shales of Illinois and the corresponding beds in Texas is Permian.

Finally in 1879, in a comparison of the vertebrate horizons of Europe and America,[1] he gave the following table:

West Europe		North America
Thuringian	Permian	*Clepsydrops* shale
Lodevian		*Eryops* beds

And says:

The Permian vertebrate fauna which I discovered in Illinois and Texas exhibit close parallels, but not yet generic identity, in the two continents. Thus the American *Clepsydrops* and *Dimetrodon* are near to the *Deuterosaurus* of the Perm of Russia, and the *Lycosaurus* of the mountains of South Africa. The Texan genus *Pariotichus* may, with further information, prove to be identical with the *Procolophon* Ow. from the Tafelberg. Humeri of the type discovered by Kutorga in Russia and by Owen in South Africa, are found in North America, and the same remarkable type has recently been discovered by Gaudry in France. The peculiar type of Labyrinthodont vertebae described by me under the genus *Rhachitomus* from Texas has been discovered by Gaudry in France. The present indications are that close similarity between the faunae of this period in Europe and America will be discovered. Nevertheless up to the present time no representatives of the striking American forms, *Diadectes*, *Bolosaurus*, *Empedocles*, and *Cricotus*, have yet been found in any other continent (p. 34).

The oldest of these I have called the *Eryops* beds, from the most abundant genus of Labyrinthodonts which is found in it. They contain also abundance of other vertebrata, none of which are higher than the reptilia (order *Theromorpha*), with plants, mollusks, etc. They consist of sandstones, alternating with beds of red clay and coarse conglomerate and sphaerosiderite, etc. They are chiefly distributed in Northern Texas and Southern Indian Territory.

The *Clepsydrops* shale named by me in 1865 [misprint for 1875] forms a thin stratum, in southeast Illinois and southwest Indiana, consisting of black and rarely reddish carbonaceous shales and clays. These appear in some places to lie conformably upon the Coal Measures, to which they have been referred by previous geologists, but Collett, Gibson, and others have shown that it is unconformable over considerable areas. It does not belong to the Coal Measures (p. 52).

After this paper Cope consistently referred to the beds as Permian.

Reviewing the evidence cited above we find that the beds were so referred on—

1. The presence of reptiles.

[1] *Bull. Geol. and Geog. Survey of the Terrs.*, 1878–79, pp. 33–54.

2. The similarity of the *Poliosauridae*[1] and the *Clepsydropidae* to the reptiles from the known Permian of Europe and Africa.

3. The similarity of certain amphibians, especially *Eryops* and *Trimerorhachis*, to known Permian forms.

4. The presence of *Janassa, Ceratodus, Ctenodus, Diplodus,* and *Strigilina.*

5. He suggests the similarity of *Pariotichus* of Texas and *Procolophon* of South Africa.

These points will be discussed *seriatim.*

1. The argument from the presence of reptiles may be rejected at once as this is part of the question on trial. In a later paper (*Proc. Am. Phil. Soc.*, 1897, p. 88) Cope identifies one of his Permian reptiles from Illinois, *Isodectes,* in a form that he previously considered as an amphibian, *Tuditanus* from the Coal Measures of Linton, Ohio. So that he himself recognized the possibility of reptiles occurring below the Permian. The validity of this identification may be questioned, however.

2. The morphological similarity between the reptiles from the Illinois and Texas beds and reptiles from known Permian beds of Europe and Africa.

Cope depends on three points in particular.

a) The resemblance between *Clepsydrops* and *Lycosaurus* from the Permian of South Africa. This, with all other comparisons between the reptiles of the two continents (except perhaps the *Cotylosauria*) may be dismissed, as the forms have been shown to be so radically different (Diapsidan in North America and Synapsidan in South Africa) as to preclude any possibility of their use in indicating the contemporaneity of the beds.

b) The resemblance of *Clepsydrops* to *Deuterosaurus* of Russia. The skulls of *Deuterosaurus* and *Rhopalodon* have repeatedly been described, but their condition is such that no definite conclusions can be drawn, but the weight of evidence seems to be that they are nearer to the South African forms than to the North American.

c) The notochordal condition of the vertebrae, and the resemblance of certain humeri to humeri from the Permian of France. The first character cannot be considered as distinctive of the Permian;

[1] Case, *Publication 55*, Carnegie Institution, Washington.

it is characteristic of the most primitive type of reptiles and persists even to the present (*Sphenodon*).

The humerus mentioned by Cope was that of an amphibian or one of the *Diadectidae* and the French form was probably *Euchirosaurus*.

3. With regard to the amphibians the evidence is scarcely better. Cope emphasizes the rhachitomous character of the vertebrae and compares the condition of *Eryops* and *Trimerorhachis* with similar rhachitomous forms from the French Permian, the genus is not mentioned but it is evident that he had *Euchirosaurus* in mind. This character of the vertebrae comes nearer to being a determinant character than anything mentioned by Cope, but it is open to question because the same form of vertebrae occurs in the Carboniferous amphibian, *Dendrerpeton*.

4. The fishes mentioned by Cope have the distribution shown below:

Sagenodus—Carboniferous and Lower Permian.
Janassa—Carboniferous to Triassic.
Strigilina—A petalodont selachian of Carboniferous affinities.
Diplodus (*Orthocanthus*)—Carboniferous and Permian.

Evidently the fishes are of little more value than the amphibians and the reptiles.

5. The *Cotylosauria* common to North America and South Africa. The similarity of *Pariotichus* and *Procolophon* was suggested by Cope; this has been shown to be impossible, but Williston has very recently (*Journal of Geology*, Vol. XVI, No. 2, 1908, p. 148) attempted to show that *Labidosaurus*, a form very closely related to *Pariotichus*, is also very closely related to *Procolophon*.

However, even if this should be accepted, the presence of two distinct genera of this extremely primitive order could not prove the contemporaneity of two beds in such distant regions.

The evidence adduced by Cope is not sufficient to prove the Permian Age of the Illinois and Texas beds as against a possible Carboniferous Age.

It now remains to examine the evidence discovered since 1877. Undoubtedly Cope regarded much of this as directly confirmatory of his ideas.

1. There have repeatedly been suggestions that reptiles occur in beds below the Permian. Two examples suffice:

As cited above, Cope identified a reptile in the beds of Linton, Ohio. Following is a quotation from a letter written to the author by the late Dr. Baur, dated June 20, 1897:

> I have found out that *Hylonomus* Dawson, and *Dendrerpeton* Owen, and *Petrobates* Credner, are reptiles and not Stegocephalians. All these forms are Carboniferous with the exception of *Hylonomous*, which is also found in the Permian, and *Petrobates*, which belongs to the Permian alone. The vertebrae are elongate and biconcave, chevrons intercentral, ribs two-headed, long, slender, and bent. Teeth smooth, with large pulpa. Two sacral vertebrae, the second with small sacral rib. No cleithrum. Interclavicle T-shaped, clavicle slender. Ribs of caudal vertebrae bent backward. These forms are directly ancestral to the *Paleohateriidae*. *Microsauria* Dawson is the proper name for them. This fact, of course, makes the *Microsauria* the oldest reptiles, from which the *Paleohateriidae* and the *Rhyncocephalia* are directly developed.

The position taken in this letter was defended in the *Anatomischer Anzeiger*, Bd. IV, pp. 146–51.

2. The difficulty in distinguishing between the primitive reptilia and the amphibia has steadily increased by the discovery of intermediate forms, so that it is practically impossible to draw a line between the two today. The presence of a distinct parasphenoid bone distinguishes the amphibia, and in the Texas beds the presence of an entepicondylar foramen in the humerus distinguishes the reptiles, but this cannot, perhaps, be depended on as a general character of value.

We now proceed to the consideration of smaller groups.

Poliosauridae.—These may be related to the *Proterosauridae* rather more closely than to the *Pelycosauria* with which they have been described. *Proterosaurus* and *Paleohatteria* are typical members of the *Proterosauria* from the Permian.

Clepsydropidae.—No forms of this family occur in the Permian of Europe. *Ctenosaurus*, an aberrant, related form, is from the Bunter Sandstein and *Anomosaurus*, a doubtfully related form, is from the Muschelkalk.

Naosauridae.—A single species of this genus has been found in the Permian of Bohemia.

Pariotichidae.—No forms are known outside of the Texas beds.

Pareiasauridae.—Very doubtfully present in North America.

Among the amphibians—

Eryops.—Closely related in the rhachitomous character of the vertebrae to *Actinodon* and *Euchirosaurus* from the Permian of France.

Trimerorhachis.—No close relative of this form is known except in the character of the vertebrae.

Cricotus.—This resembles *Archegosaurus* in the embolomerous character of the vertebrae which occurs in the caudal series of *Archegosaurus* and throughout the column in *Cricotus.*

Dissorhophus and *Diplocaulus.*—Have no equivalents.

Crossotelos, Case.—This shows the characters of fringed dorsal and haemal spines in the caudal series such as occurs in *Urycordylus* and *Oesteocephalus* both from the Carboniferous.

The numerous smaller amphibians from Texas are so imperfectly known that it is impossible to make profitable comparisons with other forms.

Among the fishes—*Janassa* (*Thoracodus*), *Orthacanthus*, *Ctenodus*, *Ptyonodus* (*Sagenodus*), have been discussed above.

Didymodus.—Known from the Carboniferous of Europe.

Gnathorhiza.—Known from Texas only.

Sagenodus pertenuis, Eastman.—Known from the Permian of Russia (*fide* Broili).

Ectosteorhachis.—Known from Texas only.

We may now reject all the evidence furnished by the fishes except *Sagenodus pertenuis,* because they occur both in the Carboniferous and Permian, or because they do not occur outside of North America.

We may reject all of the amphibians except *Eryops* and *Cricotus* for the same reason.

We may reject all of the solid-roofed forms, *Cotylosauria* (*Chelydosauria*), *Pariotichidae,* etc., because they have no close relatives known outside of North America.

We may reject the *Clepsydropidae* as the only possible European representative is Triassic.

There remains only the family *Poliosauridae,* the genus *Naosaurus,* and *Sagenodus pertenuis,* worthy of consideration. *Sagenodus* has been identified from Texas (Eastman) and from Russia (Broili). The latter locality, the banks of the Lusa, a tributary of

the North Dwina, carries a fauna typical of the South African region.

As is well known, the genus *Naosaurus* occurs in the Permian of Bohemia.

The resemblance between the *Poliosauridae* and the *Proterosauridae* is in just such primitive and generalized characters as would persist from one formation to another.

The evidence for the Permian character of the beds rests then on the presence of a single genus, *Naosaurus*, common to the Permian of North America and Europe and on the community of many very primitive characters and numerous more specialized ones, which, however, reach either down into the Carboniferous below or up into the Triassic above.

CONCLUSION

1. The evidence from vertebrates is not sufficient to demonstrate the Permian Age of the beds in Illinois and Texas, they may reach down into the Carboniferous or they may extend upward into the Triassic.

2. There is no unlikelihood that reptilian life began in the Carboniferous. The evidence is rather affirmative than otherwise.

It is becoming more and more evident from the vertebrate paleontology that the Red Beds of North America and their eastern equivalents represent an enormous interval of emergence which may well have begun while Carboniferous (Pennsylvanian) forms still lingered in the waters and have continued until Triassic types were well established.

Reviews

Fourth Biennial Report of the State Geological Survey of North Dakota. By A. G. Leonard, State Geologist, E. J. Babcock, and C. H. Clapp. 312 pp., 37 pls., map. Grand Forks, 1906.

This volume continues the systematic descriptions of the economic possibilities of the state which have been published in previous years. North Dakota possesses extensive deposits of high-grade clays, as was well shown in the exhibits of the School of Mines at the St. Louis and Portland Expositions. The report contains chapters on the origin, chemistry, value, and physical properties of clays in general, and on the stratigraphy and economic geology of North Dakota clays in particular, together with a description of the methods of mining and manufacture now employed. H. H.

The Production of Gold and Silver in 1906. By Waldemar Lindgren, and Others. Advance chapter from *Mineral Resources* for 1906. U. S. Geol. Surv. 265 pp. Washington, 1907.

The total of these two metals mined in the United States, amounting in value to $132,630,200, showed an increase of over $10,000,000 for the year. Colorado, Alaska, and California were the chief producers of gold, and Montana, Colorado, and Utah of silver. H. H.

Iowa Geological Survey. Vol. XVII. Annual Report for 1906. 588 pp., 62 pls., 44 figs. Des Moines, 1907.

The major portion of this volume consists of a description of the quarry products of Iowa. Special stress is laid on cements and cement materials, and the careful general treatment of the properties, uses, and preparation of different grades of cement will be found valuable by economic geologists, and those commercially interested, in all parts of the country. H. H.

The Grenville-Hastings Unconformity. By Willet G. Miller and Cyril W. Knight. An extract from the Sixteenth Report of the Ontario Bureau of Mines, 1907. Part I, pp. 221–23.

The authors find themselves unable to agree with certain of the conclusions of the International Committee of 1906 in regard to southeastern

Ontario and the neighboring portions of Quebec. They object especially to the statement that the Hastings series is in reality only a less altered phase of the Grenville series. They have found that in eastern Ontario many of the limestones, conglomerates, and other fragmental rocks, which have been called the Hastings series, are much younger than the typical limestones of the Grenville series proper, and overlie the latter unconformably. The Grenville limestone, which rests in places on the ropy surfaces of Keewatin lavas, may be correlated with the Keewatin Iron Formation of the Lake Superior region; while the younger sedimentaries of the Hastings series are probably Huronian in age. H. H.

The Pre-Cambrian Volcanic and Intrusive Rocks of the Fox River Valley, Wisconsin. By WILLIAM HERBERT HOBBS AND CHARLES KENNETH LEITH. Bulletin of the University of Wisconsin, No. 158, pp. 247–78. 21 figs. Madison, May, 1907.

The Fox River Valley area of south-central Wisconsin presents several well-defined exposures of crystalline rocks of quite uniform chemical and mineralogical composition, but of varying textures. In passing outward from the granitic centers, intermediate textures and then surface volcanics are encountered, indicating the truncation of a volcanic region. The age of these rocks is certainly pre-Cambrian and probably Archean; for they occur as monadnocks projecting above the pre-Cambrian peneplain. The various rock types which are found in the area are fully described in the report. H. H.

Abandoned Shore Lines of Eastern Wisconsin. By JAMES WALTER GOLDTHWAIT. Wisconsin Geological and Natural History Survey, Bulletin No. XVII. 126 pp., 37 pls., 37 figs. Madison, 1907.

While the history of the greater Great Lakes which existed during the late stages of the Glacial period has been well blocked out by various investigators, detailed study of the ancient shore lines has been undertaken in only a few areas. This bulletin contains a very complete description of the old shore lines in Wisconsin, together with a review of all the previous work done in developing the history of the lakes, and a useful bibliography. Light is thrown on several controverted questions, and among the more important conclusions reached may be mentioned the following:

The 60-foot and 40-foot beaches of Lake Chicago seem to extend as far north as Sheboygan. It seems probable that the more northerly portions of them were

obliterated by the advance of the ice to the Manistee moraine. These higher beaches seem to have suffered little or no tilting.

The Lake Algonquin beaches seem to extend southward through Wisconsin with rapidly diminishing inclination south of Sturgeon Bay, becoming horizontal near Two Rivers, and encircling the southern half of Lake Michigan as the "Toleston" beach. This makes the Chicago outlet an outlet for Lake Algonquin at its highest stage.

The Nipissing water-plane seems to stand nearly horizontal along the whole Wisconsin shore—absolutely horizontal, and 10 or 15 feet above the lake, south of Manitowoc.

The elevation of the various beaches was determined by means of the wye level, thus reducing the chances for misinterpretation to a minimum.

H. H.

Some Characteristics of the Glacial Period in Non-Glaciated Regions. By ELLSWORTH HUNTINGTON. Bull. Geol. Soc. of Am., Vol. XVIII, pp. 351–88, pls. XXXI–XXXIX. New York, 1907.

This significant article is rendered particularly valuable because of the author's exceptional opportunities for the observation of arid conditions in two continents. It is evident, the whole earth considered, that fluctuations of the ice-edge were far from being the only effects of the climatic changes of the Pleistocene. In some of the now desert basins of central Asia are evidences of a surprising number of oscillations of lacustrine and arid conditions, some apparently coinciding with the known alternations of glacial and interglacial stages of the so-called Glacial period, and others preceding them. H. H.

The Clays of Mississippi. By WILLIAM N. LOGAN. Mississippi Geological Survey, Bulletin No. 2. 250 pp., 42 pls., 14 figs. Jackson, 1907.

This bulletin contains chapters on the origin, classification, chemical and physical properties, and processes of manufacture of clays, on the properties and imperfections of brick, on the geology of Mississippi clays, and on the clay industries of the northern part of that state. H. H.

A Theory of Continental Structure Applied to North America. By BAILEY WILLIS. Bull. Geol. Soc. of Am., Vol. XVIII, pp. 389–412. New York, 1907.

An analysis of the North American continent is taken to show that it may be resolved into a number of positive, or lighter, and of negative, or

denser, components. The negative elements have, because of the relatively greater density which they inherited from an original state, been able to force the positive into higher positions during much of geologic time, so that they are characterized by a greater thickness of fairly continuous sediments. The positive elements found their levels of isostatic adjustment to be higher, so that they have more often constituted our land masses. The original relations of these components to one another has been greatly modified by tangential pressure and igneous intrusions, making occasional readjustments necessary; though the continent as a whole has maintained its equilibrium with the exceptionally heavy oceanic segments. H. H.

Peat, Essays on Its Origin, Uses, and Distribution in Michigan. By CHARLES A. DAVIS. A part of the report for 1906 of the Michigan Geological Survey, pp. 105–360, pls. XIII–XXXI, figs. 2–20. Lansing, 1907.

The author has very properly taken up the study of peat from a botanical standpoint, though geological factors are by no means ignored. Michigan peat is composed largely of the remains of plants which grew below or near the water-level; sphagnum forms only shallow superficial deposits. The living plant society varies as the development of a bog advances, for the changed conditions created by one group of species may enable an invading group to obtain a foothold where it was unable to live before the introduction of the earlier group. We cannot, therefore, expect the flora at present living in a swamp to indicate the quality of the underlying peat. A peculiar type of structureless peat was found which consisted largely of algal remains with occasional diatoms and an abundance of the three-celled pollen grains of conifers. Under proper conditions peat of this character would form a deposit like the structureless cannel coals of the Carboniferous. Many uses for which peat could be profitably employed are pointed out. In Michigan, especially, peat coke might be made to bear a close relationship to the iron industry. H. H.

The California Earthquake of 1906. By DAVID STARR JORDAN and Others. San Francisco: A. M. Robertson, 1907.

This volume contains a collection of articles, partly of a semi-popular nature, by D. S. Jordan, J. C. Branner, G. K. Gilbert, S. Tabor, F. Omori, H. W. Fairbanks, and Mary Austin, which had previously appeared in various publications, together with a new essay by Charles Derleth, Jr., on the effects produced by the earthquake on structures and structural

materials. Both scientific and non-scientific readers will find much to interest them in it. The illustrations, of which the book contains 143, are noteworthy. H. H.

Contributions to the Geology of the Falkland Islands. By J. G. ANDERSSON. With 9 plates, and maps. Wissenschaftiche Ergebnisse der schwedischen Südpolar-Expedition, 1901–03, Band III, Lieferung 2. London: Dulau & Co.

In their deeply indented coast lines with numerous drowned valleys, the Falklands show a recent submergence of about 100 meters. During the ice age they stood at about their present height above the sea, while in pre-Glacial times they were somewhat higher and carried considerable rivers. A striking feature on East Falkland is the so-called "stone-rivers," which are level sheets of huge, angular bowlders streaming down the hillsides and reaching far out on almost level surfaces. This phenomenon is the product of solifluction, i. e., of gradual creep down the slopes of masses of waste saturated with water. Glacial action has not been the direct agent; for the islands seem never to have possessed a large ice cap. Thick peat deposits in this region furnish yet another instance of notable accumulations of vegetation in *cool*, moist climates. Devonian sandstone is found in the islands, resting on an Archean basement, while younger Paleozoic rocks are also present. H. H.

The Meteor Crater of Canyon Diablo, Arizona; Its History, Origin, and Associated Meteoric Irons. By GEORGE P. MERRILL. Reprinted from Smithsonian Miscellaneous Collections (Quarterly Issue), Vol. L, Part 4, pp. 461–98, pls. LXI–LXXV, figs. 124–29. Washington, January 27, 1908.

The author inclines strongly to the view that the peculiar topographic feature commonly known as Coon Butte owes its origin to the impact of a meteorite of unprecedented size. The crater, which is 4,000 feet in diameter and 500 feet deep, lies in a region of undisturbed sedimentary rocks which are horizontally bedded except in the immediate vicinity of the crater itself, where they show a strong quaquaversal dip. Extensive development work, now being carried on by a mining company in the field, fails to substantiate the theory that volcanic action has been the factor involved, but shows that the disturbance was essentially superficial. Microscopic and megascopic studies of the fragmental materials in and about the crater indi-

cate the action of a force which caused considerable crushing, and which may have been due to meteoritic impact, followed, perhaps, by an intense explosion. H. H.

The Geology of the Compostela-Danao Coal Field. By WARREN D. SMITH. From the *Philippine Journal of Science*, Vol. II, No. 6, pp. 377–403. 15 pls., 3 maps. Manila, 1907.

The area mapped covers 36 square miles of mountainous country on the Island of Cebu which is quite generally underlain with coal, probably of Eocene age. In the area under consideration there are indications of the presence of several million workable tons of coal, and these are now being partially developed. The lack of suitable timber to support a rather weak roof, and the high inclination of the beds offer great, but not insuperable, difficulties for profitable mining. An igneous base underlies the region and on it were deposited the coal measure shales, and the sandstones and conglomerates of the Eocene. The Oligocene and Miocene are represented by interesting deposits of limestone. H. H.

Meteorite Studies, II. By OLIVER CUMMINGS FARRINGTON. Field Columbian Museum, Publication 122. 18 pp., 14 pls. Chicago, 1907.

Complete descriptions are here given of a number of meteorites and of the conditions under which they were discovered. Photographs of the rocks and plans of various localities add to the clearness of the exposition. It will be remembered that the same author gave an excellent summary of the constituents, structure, and theoretical origins of meteorites in this Journal, Vol. IX, pp. 51, 174, 393, 522, and 623. H. H.

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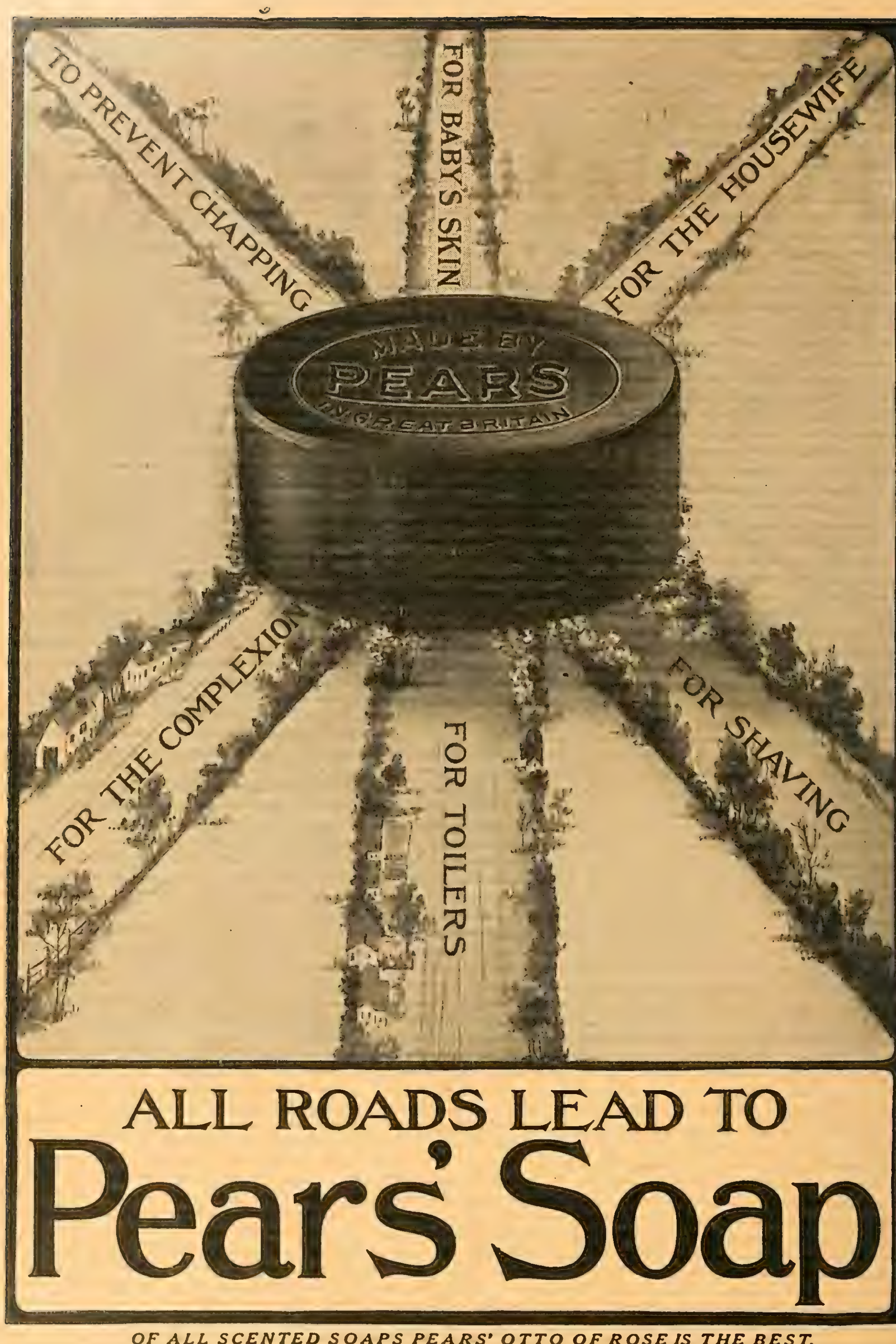

OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

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STRUCTURAL GEOLOGY OF THE MIDDLE YANG-TZÏ-KIANG GORGES

E. C. ABENDANON

During the first half of the year 1904 I made an exploration trip in the province Ssï-ch'uan of West China, which I reached by going up the Middle Yang-tzï-kiang from I-ch'ang to Chung-king. The results of this journey are published in the *Revue Universelle des Mines* (1906), of which a separate edition[1] also appeared. The reason why I now return to this subject is to compare my results with those obtained by Messrs. Bailey Willis and Eliot Blackwelder, who—and this is a curious coincidence—reached I-ch'ang on the same day (June 9, 1904) as I did, after our travels in China. To my regret this coincidence did not lead to our meeting, either at I-ch'ang or on board the steamer to Hankow. Their researches and personal views were published in the splendid work, *Research in China*, under the auspices of the Carnegie Institution of Washington, in April, 1907.

In this description of the structural geology of the Middle Yang-tzï-kiang[2] I shall go much more into details than in my publication about the Red Basin. On the other hand, I shall only cursorily describe the encountered formations and not enter into the peculiarities of the separate strata. In contrast to my former description I shall not this time mention my observations in an upriver direction, but in a downstream one, this manner having the advantage, as we shall

[1] *Géologie du Bassin Rouge de la province Se-Tchouan en Chine.*

[2] The accompanying map has been put together, as far as topography is concerned, from those of Arthur Kniep and R. H. Sargent.

presently see, that the windings of the river can be explained in detail from the geological structure of the country.

From K'ui-chóu-fu to I-ch'ang the Yang-tzï flows, for a distance of 135 km. through the ranges of mountains bordering the Red Basin of Ssï-ch'uan. Formerly I have already observed that the anticlines, which in the Red Basin strike almost NNE–SSW, are bent round in the north and east toward the NE, ENE, and E. To explain this, I assumed that the Red Basin had been forcibly pressed up against the old mountain ranges of Kuen-lun and Tsin-ling-shan trending in almost equatorial direction. The trends in these border ranges of the Red Basin do not therefore conform to the normal in the basin itself.

From K'ui-chóu-fu to I-ch'ang the Yang-tzï-kiang cuts the following formations:

1. A granitic formation intersected by numerous dykes of granite, diorite,[1] and melaphyre, all of them striking almost N–S.

2. Metamorphic schist, consisting of hornblende, chlorite, and mica schists, alternating with layers of nearly pure quartz.

3. Purplish-brown limestone with fossils, among which is a coiled nautilus, which, according to Professor Frech, of Breslau, marks the Lower Silurian. The most striking are, however, the numerous and very large casts of Orthoceratites. This is, I believe, the Cambro-Ordovician Ki-sin-ling limestone of Blackwelder and Willis.

4. Green shales of about 900 m. thickness; this the Middle Paleozoic Sin-t'an shale of the afore-named gentlemen.

5. The gorges-limestone formation, 1,600 m. thick, called by the two other explorers Wu-shan limestone.

As, according to my researches, not only a part of the Wu-shan gorge but all the gorges are built up of this formation, I consider the name gorges-limestone better than Wu-shan limestone. This formation is considered as belonging to the "Upper Carboniferous" by said gentlemen.

What Blackwelder comprises in the K'ui-chóu series, has been divided by me as follows:

6. The reddish-brown sandstone and argillite formation, 300 m. thick.

[1] Under these names are comprised various kinds of aplitic and lamprophyric "Ganggesteine" of granito-dioritic character.

7. The slaty limestone formation, 300 to 400 m.

8. The sandstone formation, with layers of coal, whose flora belongs to the Rhetian, 600 m.

9. A formation, 1,800 to 2,500 m., of alternating strata of sandstone and argillite, the former of which are generally of eolian origin. This has been named by me the K'ui-chóu formation.

Between 8 and 9 there is, in the middle of the Red Basin, a series of marls, 50 m. thick, but this is lacking in the bordering part.

The formations 7 and 8 I believe I may count as belonging to the Permian or to the Lower Triassic, and to the Upper Triassic.

The stratum between 8 and 9 seems to belong to the chalk formation, so that the K'ui-chóu formation, in which I did not find any organic remains, may be considered as belonging to the chalk formation, and, taking into account the thickness of the formation, it might be assumed that the deposit continued into the Tertiary Period.

The folds of the Red Basin of Ssï-ch'uan are of later date than the K'ui-chóu formation. As latest formation must be named the following:

10. A conglomerate bank, which I have encountered in several parts along the Yang-tzï-kiang. The bowlders and pebbles in this conglomerate generally are of eruptive origin whereas the cement consists of a calcareous siliceous tufa. This must therefore be the latest formation, whose origin dates after the folding of the Red Basin.

We will now describe the structural geology of the Middle Yang-tzï-kiang gorges going downstream from K'ui-chóu to I-ch'ang. Coming from the synclinal area, west of K'ui-chóu-fu, the Yang-tzï for the first time encounters the high gorges-limestone mountain ranges, to the east of that place. On the left bank the river tries to penetrate the softer upper strata so that a creek is formed there. But as the softer layers, which formerly spread out like a mantle over the anticlinal gorges-limestone mountain range, and nowadays have been washed away from the crests of this range, still, as a whole, form a kind of dam, the Yang-tzï is forced to make a bend toward the first of the great gorges: the Fong-hiang-hia or gorge of K'ui-chóu-fu. This gorge being a deep incision of the big river through the mountain range east of K'ui-chóu-fu, clearly shows its structure.

The gorges-limestone strata strike about ENE–WSW and dip

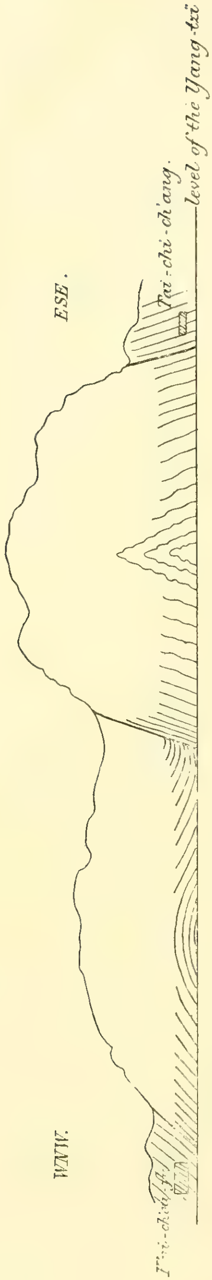


FIG. 1

40° WNW. The river narrows considerably and the banks at once rise to double the height of what they were outside the gorge. Soon the dip decreases to 25°, and in the deeper levels of the formation to 7° or 8°. Now soon follows the anticlinal flattening of the layers, and after a pretty long distance with the strata in horizontal position the southerly inclined limb also makes an angle of 7° to 8°. This is a broad and low fold. Suddenly the strata, with a faint southerly dip, bend round sharply and get a northerly dip, and now the layers rise to the south under an angle of 70°. This time the anticlinal folding follows much sharper, and the southern limb dips 75° south. In both limbs, and in the crest of the anticline itself the layers are not straight, but waved, and show many secondary plications. All this points to a strong compression and forcing outward of this anticline.

The structure of this first limestone mountain range as it appears in the gorge of K'ui-chóu-fu, therefore, is that of two folds strongly pressed together, each of which takes up just one-half of the length of the gorge on the river level (see Fig. 1).

As soon as the river, a little way above Tai-chi-ch'ang, issues from the gorge, it re-obtains a double width in the syncline area of Wu-shan. To the north and to the south the river is inclosed by the lofty gorges-limestone mountains, and the next gorge is already perceptible in the range south of the Yang-tzï. In this syncline nothing is left of the later formations but the reddish-brown and the slaty limestone formations,

with a slight relic of the sandstone formation. It is a strongly compressed syncline, by reason of which compression a commencement of dynamo-metamorphosis is observable, especially the reddish-brown formation, recognizable by the far greater hardness of its sandstone layers, and, besides that, by their becoming slaty on account of the greater amount of mica they contain.

In the following description of the different strata and their position in the synclinal area of Wu-shan, I must neglect details and shall merely describe the structure in general features.

The Yang-tzï, which in the K'ui-chóu-fu gorge flowed almost vertically to the trend of the strata, downstream Tai-chi, transects the reddish-brown and the slaty limestone formations which also dip SSE, and, after a wedge-like compressed syncline, it strikes against the 25° NNW-dipping limb of the anticline south of the river. This causes the river near K'ui-ché-pan to bend from its ESE course into a NE direction. In this part the layers are much disturbed, and a relic of the sandstone formation is found among the slaty limestones. Near Tan-tia-wan the river has again gone too far north and has abutted, in steeply SSE-dipping layers, against the southern limb of the northern anticline. The river is now again forced to bend, and flows in a WNW direction through the strata of the slaty limestone formation, which, at first dipping faintly SSE, soon becomes almost horizontal, and then again dips 50° NNW; and lastly the river forces its way into the reddish-brown formation, which also dips precipitously north. Near Wu-shan the river has thus, for the second time after Tai-chi, entered the northern limb of the southern anticline, which it has again transected in a gorge just below Wu-shan.

Before describing this gorge, being another magnificent section through a high mountain range, I will just discuss the profile of the Ta-ning-ho, a tributary river, which flows into the Yang-tzï near Wu-shan. Going in a NNW and N direction from Wu-shan, along very hilly territory, in whose narrow synclinal valleys I only found relics of the reddish-brown and of the slaty limestone formations, I reached the place Ta-ch'ang or Kiu-shï-li-p'u on the Ta-ning-ho. This swift narrow mountain stream I followed to its confluence with the Yang-tzï. Owing to the imposing gorges through which we passed, and to the remarkable skill and proficiency in navigation with which

the skippers of the river craft guided their boats over rapids and along an almost rectangular bend in the river, where the current set straight upon the steep cliffs, this was certainly one of the finest and most stirring of my water trips in China. The rapids are generally formed in synclinal territory by bars of bowlders; here the river is broad and its banks are generally lower. Only once there was a fall of a few feet in the bed of the river itself. In the limestone gorges the river is much narrower and confined between high steep cliffs.

My observations there coincide pretty well with those of Willis and Blackwelder. On pp. 277, 278 of their work[1] they say: "Along the Ta-ning-ho the red series seems to be devoid of coal which may lie higher in the system than any strata remaining in those synclines." As I have already observed before, there only remain in these synclines the strata that lie far below the sandstone formation with its layers of coal.

Ta-ch'ang is situated in a rather wide synclinal area. If we go down the Ta-ning-ho, a very winding river, along whose course many pebble banks form small rapids, we reach after a sharp bend the first gorge, the Lao-men-hia.[2] Here again the gorges-limestone strata is folded up in an anticline of which the northern limb dips steeply and the southern limb but faintly. It took us a little more than an hour to pass this gorge. During twenty minutes we next float down through a synclinal, more open area, with a dangerous rapid, which leaves but a narrow passage-way between banks of pebbles; and then we reach the next gorge, which exposes two lower folds pressed together. The southern limb of the second of these folds dips 20°–30° SSE. The gorge, called "Lung-chin-hu-cho-hia," or "gorge of the dragon and tiger," is passed in fifty minutes. Sin-t'an-hia[3] is situated at the lower end of the gorge, which again opens on a second synclinal area, in which the river makes almost a loop. Here again was a very difficult rapid, at least when the water is at the height encountered by me. The next and fourth anticline is less broad, and then, after a short synclinal area, there again follows a gorges-limestone anticline, in which the now very swiftly flowing Ta-ning-ho has excavated a narrow gorge. To reach this gorge we had to pass a very

[1] *Research in China.*

[2] Old Gate Gorge.

[3] Literally, New Rapid Gorge.

difficult rapid, just at a place where the river made a rectangular turn. This too was negotiated with remarkable skill by the two steersmen standing, the one fore and the other aft; these two men and myself being the only members of the party to remain on board the sloop, the others preferring to walk along the river banks.

These last two anticlines must be considered as the easterly prolongation of those of the gorge of K'ui-chóu-fu. We see that these two anticlines, having diverged east of K'ui-chóu-fu, have got limbs of almost equal dip, and have therefore become lower from west to east, especially the southern one.

It takes nearly two hours to go down stream from Sin-t'an-hia to the lower end of the last gorge and twenty minutes more through the synclinal area to Wu-shan.

From K'ui-shï-li-p'u to Wu-shan five anticlines with an almost equatorial direction, which lie close together, are thus transected by the Ta-ning-ho. Just below Wu-shan the Yang-tzï makes a bend like the one below K'ui-chóu-fu, and leaves the steeply NNW-dipping reddish-brown formation, to enter the 80° NNW-dipping gorges-limestone formation. In this second of the grand gorges of the middle Yang-tzï the river flows at first almost in the trend of the layers, only gradually reaching deeper levels. This already points to the sinking of the anticline, to which this limb belongs, viz., in an easterly direction. Just upstream before the hamlet Klao-che, the river, which in this part of the gorge has but slightly narrowed, enters the underlying formation, the olive-green Sin-t'an shale, of which the upper part is brownish red. We now perceive on the left bank a very fine dome[1] in the gorges-limestone formation, below which the observed Sin-t'an shale are situated (see Fig. 2). We also observed that from west to east the Sin-t'an shale remains much lower, which also points to a sinking of the anticline toward the east. After having for a short distance transected the southern limb of this anticline in the gorges-limestone, below Wen-che-chi we find very markedly plicated

[1] Willis and Blackwelder, *op. cit.*, Vol. I, p. 287: "Northwest of the grand arch of the Wu-shan limestone, probably one of the most superb exposures of a fold in the world, the K'ui-chóu red beds occur in the syncline, and the Yang-tzï valley is developed in them for some miles westward." From the above it is clear that in this case under the K'ui-chóu red beds must be understood the reddish-brown and the slaty limestone formation, but not the proper K'ui-chóu series.

layers in the same formation, which eventually dip 65° NW near Sui-che-t'an. The Yang-tzï is bent round to the SSE and cuts almost vertically the next anticline, the upper strata of the northern limb of which are, as just mentioned, strongly compressed. The NW dip of the layers at first increases to 80° and then diminishes to 25°. And then the anticlinal arch in both of the limestone walls becomes beautifully visible. This very fine section, in the middle of which the two limbs of the anticline, both dipping 25°–30°, are most clearly exposed, stretches over almost the whole length of the SSE-directed course, in which the narrow Yang-tzï flows below Wen-che-chi. In the last part of the SE limb the layers dip 70° south.

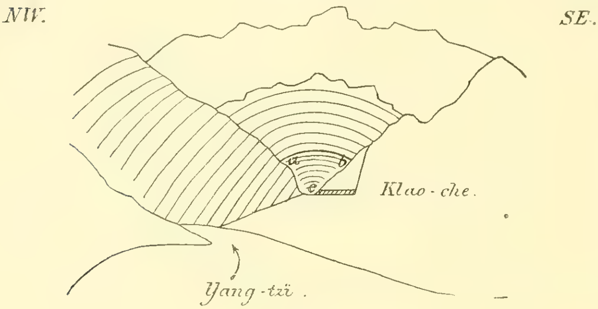


FIG. 2

Near Ts'ing-shï-tung the Yang-tzï turns sharply to the east, and flows through the eastern continuation of a valley, formed by a wedge-shaped syncline (like that reproduced in Fig. 3). Inside the valley looking west, we could see a series of south-dipping layers of the reddish-brown formation, but soon below Ts'ing-shï-tung the river banks are formed of 50° to 55° north-dipping layers of gorges-limestone, which shows that the river, emerging from the wedge-formed connection of the two anticlinal limbs, has pierced into the northern limb of a southern anticline, which, in this part, trends nearly EW. From Ts'ing-shï-tung to Fu-li-chi, the Yang-tzï remains in the upper part of the gorges-limestone formation, which auses

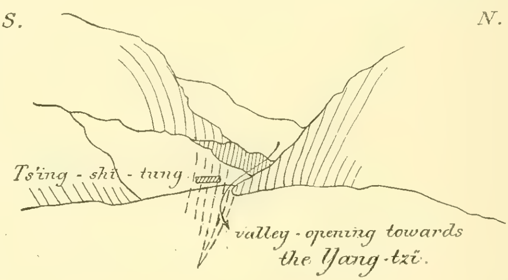


FIG. 3

the river to become broader and the banks, especially the left bank, less high. The right bank rises much higher, according to the dip of the layers toward the north. Before Pei-chi the gorges-limestone limb bends slightly toward the SE, visible by the NE dip of the layers. After a short transversal fault, the EW trend of the anticline reappears. Before a cleft in the river bank near Leng-sui-chi, where the layers show many plications, a bar of stones has been formed, and in the gorge itself there is a small rapid, a thing which is very rare in the gorges. A little farther on, we see in front of a cleft in the left bank a bar, formed by many reddish-brown and gray pebbles, which reveals the existence, to the north of the river, of a synclinal area of the reddish-brown formation. In fact, I found to the north of Fu-li-chi, the reddish-brown, and also part of the slaty limestone formation, with very slaty layers, caused by the strong compression of the narrow syncline. These show, especially in the slaty limestone, all the colors ranging from reddish-brown, orange, yellow, and olive green to grayish-blue. Just before Fu-li-chi there again appears in the mountains to the south of the Yang-tzï a fine dome, standing almost vertically on the river, which thus points to the existence of a third anticline (see Fig. 4). Below Fu-li-chi, till Nan-mu-yüan, the river again penetrates the deeper levels of the gorges-limestone formation. The secondary plications accompanied by small faults, are continued in the layers, which have a general EW trend and dip 60° N. Below Yang-chi-p'ong the river, which was flowing ESE and E, turns to the NE. For this fact we soon find the explication in the NW-dipping layers, which therefore point to a turning of the anticlinal axis from an EW to a NSW–NE direction. In this latter portion of the gorge the layers show many small secondary folds and faults, while to the south of the Yang-tzï, in the higher mountains, once more an indication of the anticline is given in the layers that are bent round to a horizontal position. At last, near Kuan-tu-k'ou, we emerge from

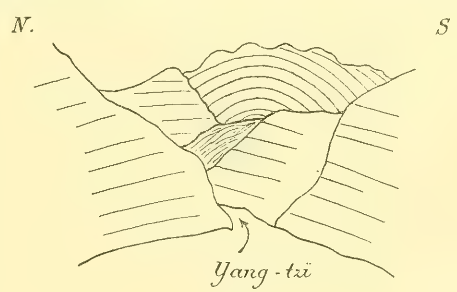


FIG. 4

the 45 km. long Wu-shan gorge, through layers, dipping rather steeply N, of the upper levels of the gorges-limestone which show a turning of the anticlinal axis toward W–E.

To recapitulate we see that as far as the Wu-shan gorge exposes the structure of the mountain range south and east of Wu-shan, this range appears to be formed by three anticlines, closely pressed together. Of these the anticline farthest upstream rises highest, for in that we see the green slaty formation underlying the gorges-limestone formation. (Fig. 5 gives a sketch of my conception of the geological structure of this gorge.) The Yang-tzï has cut its course quite through the northern two anticlines, and then through part of the northern limb of the southernmost one.

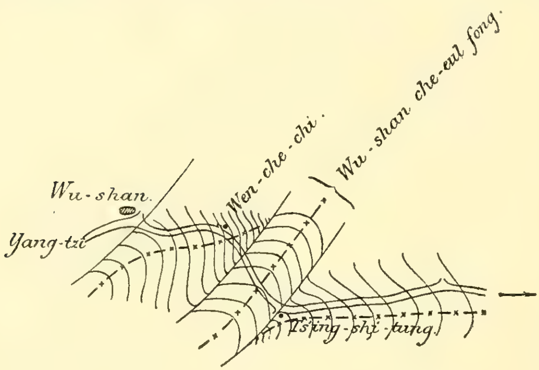


FIG. 5

From the above it will appear that my observations, which were taken while going upstream, at the rate of 25 km. a day, differ in many particulars from those of Willis, which were taken during the so much swifter course downstream.

The principal difference is, that Willis considers a great part of the Wu-shan gorge to be formed of Ki-sin-ling limestone, while I maintain that nothing but the gorges-limestone, Willis' Wu-shan limestone, appears in that gorge.

Willis writes: "Below Nan-mu-yüan the base of the Wu-shan limestone is marked by the occurrence of black cherts and it may be assumed that the Sin-t'an (middle Paleozoic) shale occurs in its proper place below the limestone, but we did not see it."[1]

From what I have written above, it appears, that the thick Sin-t'an shale formation was not observed by me either in that place, although it would have been almost an impossibility to overlook it (had it been there) going, as I did, so slowly upstream. Besides, in

[1] *Op. cit.*, Vol. I, Part 1, pp. 286, 287.

connection with the rest of my researches, it could not be expected to occur there. Willis continues:

Between Nan-mu-yüan and Wu-shan-hien the Yang-tzï flows across a sequence of smaller and larger folds, chiefly of the Ki-sin-ling limestone, but, at the head of the gorge, consisting only of the Wu-shan limestone. The sequence will best be understood by reference to the section [see his Fig. 61], which was sketched, as we floated past the magnificent cliffs in which it was exposed. As we could not measure distances, the distribution along the river was noted and has since been adjusted to "Chevalier's map of the Yang-tzï." Two anticlines and a syncline bring the top of the Ki-sin-ling limestone high above the stream, above and below Nan-mu-yüan. For several miles below Ts'ing-shi-tung the course is in the axis of a carinate syncline, a position determined by the Sin-t'an shale, although the canyon is now sunk below that formation in the Ki-sin-ling limestone. The thin beds of the latter dip very steeply, but above them, in a nearly flat position, the Wu-shan forms the upper cliffs. From half a mile above Ts'ing-shï-tung the synclinal valley extends westward but it is occupied only by a small tributary. The lower part of the Wu-shan gorge is cut across a great anticline of the Ki-sin-ling, the arch extending up to the mountain tops 3,000 feet or more above the river. The inner part of the anticline in the thin-bedded strata, near the base of the formation, is therefore exposed along the water level, and is seen to be characterized by many sharp folds and possibly by minor overthrusts. The details could not be followed as we passed, but the major structure was clear. Finally, toward the west, the dip is continuous on the northwestern limb of the arch, and the Sin-t'an shale comes in above the limestone.[1] The shale is overlaid by the Wu-shan limestone with characteristic black chert of the lowest beds. There is a repetition of the shale and limestone with black chert, occasioned by a slight overthrust at this horizon of adjustment, and then follows the mass of the Wu-shan limestone forming the upper part of the Wu-shan gorge.

We see that this description differs very materially from my researches. In confirmation of my own views I must remark that it is far more difficult to take careful observations while going rapidly downstream than during the slow course upriver. I myself experienced this on my return journey.

If we now continue the course of the Yang-tzï, below K'uan-tu-k'ou, it will appear that an ever-widening synclinal area is occasioned between two anticlines, viz., the middle anticline of the Wu-shan gorge with its NE–SW trend, which in the NE is probably bent ENE–WSW, and the almost true equatorial trend of the southernmost of

[1] This was not observed by me.

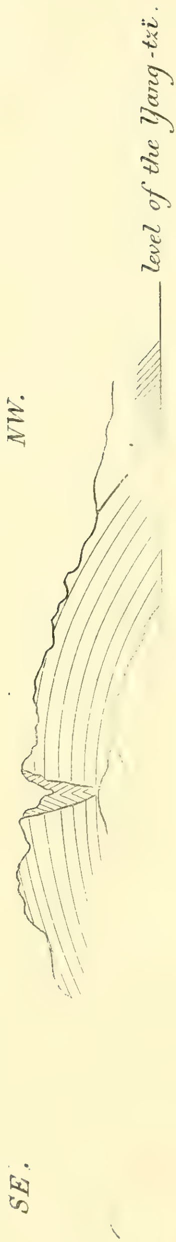


Fig. 6

the three anticlines of the Wu-shan gorge. In this synclinal area occurs for the first time downstream since K'ui-chóu-fu besides the reddish-brown and the slaty limestone formations, the sandstone formation and that of K'ui-chóu-hien. After K'uan-tu-k'ou the Yang-tzï, much wider now, flows through a narrow ENE–WSW trending syncline, in the reddish-brown and the slaty limestone formations, until upstream from Wan-h'ou-two, it strikes a 30° south-dipping limb, and so again is turned toward the east and the south-east. Another bend in the trend of the layers is also observable in their dip. From the south-dipping layers the river is headed into north-dipping ones, which again become NE-dipping, the layers being thereby much fractured. Before Pa-tung-hien the dip is again toward the north and then northwest. Just below Pa-tung-hien the Yang-tzï cuts across the upper part of a local fold in the gorges-limestone formation, thus showing in the right river bank the section as represented in Fig. 6. It is still the same north-dipping limb of the most southerly Wu-shan gorge anticline; and the layers, dipping consecutively NW, N, and NE, plainly reproduce the fold in the limb.

The Yang-tzï then continues its way in the 30°–40° north-dipping layers of the reddish-brown formation, trending ESE–WNW, and then in the slaty limestone formation, which here has much diminished in thickness and individuality. Near the Niu-k'ou-t'an the river reaches the base of the sandstone formation, consisting of dark-green slaty sandstones. The river now flows almost in the trend of the layers.

Near Pa-t'ou-t'an, the right bank consists of the reddish-brown formation, above which still lie a few slaty limestone beds; the left bank is of the

sandstone formation, overlying which soon appears the K'ui-chóu-hien formation. Near Che-men then we see on the right bank the reddish-brown, on the left the sandstone and K'ui-cóuh formations.

We must observe the thinning out of the slaty limestone formation. A little farther downstream we see the layers to the right dipping south, and those to the left dipping north, and this fold goes from the right bank to the left just above the Yeh-t'an. This fold occurs in the reddish-brown formation, and thus we have come out of the northern limb into the anticline itself. It we now consider that the same anticlinal crest, which, a little above Fu-li-chi, was estimated at a height of some 500 m. in the gorges-limestone formation (Fig. 4) was at a height of 10 m. near Yeh-t'an in the stratigraphically much higher reddish-brown formation, then the conclusion is patent, *that this anticline of Pa-tung* (as I shall call it) *has greatly diminished in height from west to east.*

The sandstone formation near Yeh-t'an contains layers of coal, as is the case in the Red Basin itself. It rests on the fold in the reddish-brown formation and supports the K'ui-chóu layers. Immediately below the Yeh-t'an the fold commences to turn toward the south, and, going downstream, we find the NNE-dipping limb of the sandstone formation, to which soon succeeds the K'ui-chóu formation, trending already SE–NW with a dip NE. In the thick sandstone beds, about ten in number, of the K'ui-chóu formation which appear typically, especially on the left bank till close to K'ui-chóu, we see how the trend gradually becomes NS and the dip 60° east. This plainly shows *the deviation of the anticline of Pa-tung, which in general traits has an equatorial direction, to a meridional one, the convex side of the bend being turned toward the NE.* The significance of this deviation I have set forth on pp. 180, 181 of my *Géologie du Bassin Rouge*, where I wrote:

> Another deviation was observed upstream from K'ui-chóu; it is the one, to the south, of the anticline which extends from the middle of the Wu-shan gorge in a more or less equatorial direction toward the east. This deviation must have been caused by the powerful anticline of Nan-t'ou, about which later.

And again on p. 190:

> I must finally assume that the anticline of Nan-t'ou must have formed the line of resistance for the anticlines of the Red Basin, which, in its NE part trend

ENE–WSW. Very interesting in connection with this appears the deviation of the anticline, which extends from the middle of the Wu-shan gorge toward the east. This deviation takes place a little farther upstream, above K'ui-chóu, from a direction about EW to a more or less meridional one, so that the convex side is turned toward the NE. This fact shows, firstly, the capacity of resistance of the anticline of Nan-t'ou, which resistance would seem to me impossible, if a great fault[1] really existed. And, secondly, that the origin of the anticline of Nan-t'ou must date from before the folding of the Red Basin.

According to my idea the sinking from west to east and the deviation of the anticline of Pa-tung, have in the structural geology of the land, a very special and interesting signification, representing as they do the relation of a fold of the Red Basin with regard to the anticline of Nan-t'ou.

This deviation of the anticline of Pa-tung has not been observed by Willis. Pumpelly however does mention it, although this explorer also failed to observe its signification. Pumpelly[2] writes:

> The trend of the beds, which near the gorge (of Mi-t'an) was NNE, with a dip of about 40° to WNW, changes here to N with a dip to E and farther up opposite Kwei (K'ui-chóu-hien) it is N by W with an inclination of 70° E by N. Here is the beginning of a series of those angular plications so common to coal measures in all countries. Small beds of limestone and red argillite alternate with sandstone until, about two miles above Kwei, the first coal seems to crop out and with the appearance of these, the trend changes to NW by W, more than 90° from its normal direction of NE–SW.

If we look at the hills of the K'ui-chóu formation near K'ui-chóu, we see (as Fig. 7 shows) for the last time the indication of the Pa-tung anticline through steep ENE-dipping layers on the left bank of the Yang-tzï, by the beginning of the anticlinal arch in the top of the massive hilly landscape at the place, and through steep WSW-dipping layers in the hindmost hill-tops on the right bank of the river.

Below K'ui-chóu the trend of the layers is NNE–SSW, and the dip still steep ESE, but this soon becomes less, and it coincides with a decrease in height of the surrounding hills. Neither do the hard sandstone beds occur in the upper levels of the K'ui-chóu formation.

[1] This remark refers to my observation of the anticline of Nan-t'ou, in contrast with von Richthofen's *Gebirgsbruch bei I-tsch'ang*. Willis too remarks (p. 286 of his work): "von Richthofen was thereby led to consider it a fault-scarp, but there is no fault such as he inferred."

[2] *Smithsonian Contributions to Knowledge*, Vol. XV, "Geological Researches in China, Mongolia, and Japan," p. 6.

Near Lao-K'ui-chóu, a deserted place, on the right bank, we are in the synclinal area and then soon follow 45° WNW-dipping layers, and the river again enters into the levels of the K'ui-chóu formation, which here, however, do not contain so many sandstone beds as in the western limb of the syncline.

We must therefore remark the thinning out of the hard sandstone beds of the K'ui-chóu formation from west to east. And they no longer crop out so typically from the river banks as above K'ui-chóu-hien. Under the K'ui-chóu formation the river penetrates the slaty sand-

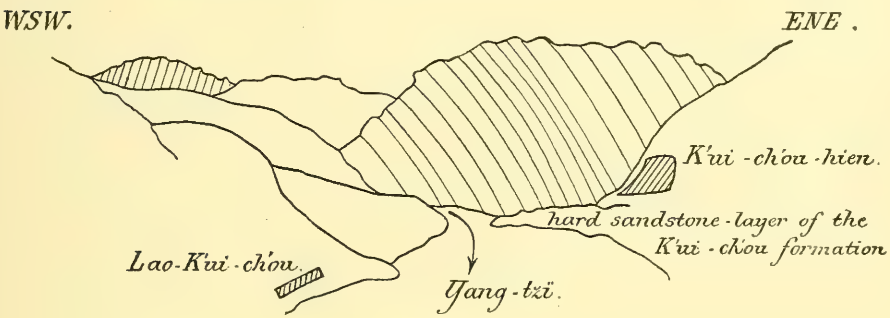


FIG. 7

stone layers of the sandstone formation, which has here greatly diminished in thickness and does not contain any coal measures.

We must observe the thinning out of the coal layers in the sandstone formation, and the thinning out of the formation itself toward the east.

Directly beneath the sandstone lies the gorges-limestone formation, which, rising up in an anticlinal limb, has again been transected by the Yang-tzï in a magnificent and grand gorge.

We therefore observe that the reddish-brown formation is also thinned out toward the east.

In the Mi-t'an gorge the Yang-tzï cuts across 30° to 40° WNW-dipping layers of the gorges-limestone formation. The massive mountains rise to more than double the height of these in the preceding sandstone area of Hsiang-chi. Only there, where a softer slaty layer complex occurs in this formation, we find a small valley on both sides of the river. This same layer complex, we shall see, plays an important part in the direction of the course of the Yang-tzï in the

I-ch'ang gorges. In the Mi-t'an gorge we see before us a west-dipping limb of the gorges-limestone formation, beneath which appears the green shale formation, "Blackwelder and Willis' Sin-t'an shale."

Between the Mi-t'an and Niu-kan-ma-fei or Ox-liver gorges, we find the Sin-t'an area. In about the middle of this area, which is bordered in the W, S, and E by the high gorges-limestone mountains, occurs the low and sharp fold of Lung-tchoe of which a photo appears on p. 43 of my publication on the Red Basin. This fold which has a 45° W-dipping and a 10° E-dipping limb, *itself dips steeply south* (see Fig. 8). It exposes a reddish-brown limestone, in which I found lower Silurian nautili, and many fine and very large Orthoceratite casts. I therefore believe that this must be the same limestone as the Ki-sin-ling limestone of Blackwelder and Willis. On this limestone rests the green shale formation (Sin-t'an-shale) and above that the gorges-limestone formation. All this as far as the right bank is concerned.

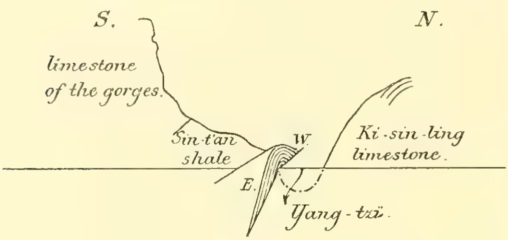


FIG. 8

On the left bank, on the contrary, the Ki-sin-ling limestone rises to much higher levels, and we find under the reddish-brown limestone a crystalline dark blue one, in layers, that are often separated by several centimeters, as a result of the plication. The closing of the narrow Sin-t'an basin by the gorges-limestone formation was not observed by me toward the north, looking from the right bank. We must still mention that, on the north bank, occurs, on top of the horizontally cut off and W-dipping Sin-t'an shales a thick conglomerate bed with large rounded-off pebbles, which must be originally from the valley in the north. This bed is of a recent date and was formed after the plication of the Red Basin, and while the Yang-tzï was cutting its way deeper and deeper into the mountains. In the eastern limb of the fold of Lung-tchoe the green Sin-t'an shale formation contains more hard quartzy sandstone beds than in the western limb. The formation also diminishes in thickness in that direction. The incline of the layers decreases and the Yang-tzï again enters the

overlying limestone formation, rising to mountain-heights, in which is cut the Niu-kan-ma-fei-hia.

In this gorge the dip of the layers soon again becomes W, and so, going down-stream, we find ever deeper levels, until, immediately after the end of the gorge near Miao-ho, the green shales reappear, but now in very much thinner beds.

This shale formation (Sin-t'an shale) thins out, in the western limb of the anticline of Nan-t'ou, from west to east.

The Ki-sin-ling limestone, which was exposed by the fold of Lung-tchoe, in the Sin-t'an area, does not again show itself east of the Niu-kan-ma-fei-hia.

As Blackwelder and Willis have observed in the upper course of the Ta-ning-ho the Sin-t'an shale to be in conformity with the Ki-sin-ling limestone, so that this limestone formation appears to extend as far as Sin-t'an, the thinning out of both formations toward the east would increase the signification of age of the anticline of Nan-t'ou. More about this later.

About the geoglogical structure of the Niu-kan-ma-fei-hia or Lu-kan gorge and the Mi-t'an gorge Willis again gives a description greatly differing from my own. He writes:[1]

> The Lu-kan gorge is a canyon across the Ki-sin-ling limestone, which dips NW. Above Sin-t'an the overlying middle Paleozoic shale, which we have named from its occurrence at this point, is succeeded by the Wu-shan limestone, dipping 40° NW and giving rise to the Mi-t'an gorge.

I presume that while going so swiftly downstream the fold of Lung-tchoe was overlooked, and so the whole structure was wrongly interpreted. According to Willis, a deep valley would have to occur between the two limestone formations. The photo on p. 43 of my *Géologie du Bassin Rouge* shows instead of a valley a high mountain range of gorges-limestone.

At the lower end of the Lu-kan gorge the trend of the layers is NNW–SSE. Underlying the but slightly developed green shale formation appear the crystalline schists, which trend NS and dip 20° W. They consist of mica, chlorite, and hornblende schists, alternating with nearly pure quartz beds and intersected by dykes of melaphyre. Near the lower opening of the Lu-kan gorge (Niu-kan-

[1] *Research in China,* Vol. II, Part 1, p. 286.

ma-fei-hia) there occurs a broad dyke of dioritic "Ganggestein" straight across the river, which, having left, by incomplete river-erosion, a couple of cliffs in the river bed, has caused the Kung-ling-t'an (a dangerous rapid).

A little way upstream from Mei-lin-to this crystalline schist formation stops, and it becomes apparent that it overlies a granite formation. The granite extends in a range of low rounded-off cliffs to the I-ch'ang gorge and northerly as far as one can see. Toward the south, however, we see the gorges-limestone mountains, which overlie the granite, stretching in one angular but continuous line to the next gorge.

This fact, taken in connection with a like occurrence in the Sin-t'an area, makes me draw the conclusion that there must have existed, to the south of Nan-t'ou,[1] a more or less equatorially trending fold, which therefore stretched about vertically on the anticline of Nan-t'ou. The synclinal area, which, according to my view, and in connection with this fold, exists to the south of the Yang-tzï shows a continuous gorges-limestone formation, both near Sin-t'an with the steeply S-dipping fold of Lung-tchoe, and between the Lu-kan and I-ch'ang gorges. The anticlinal parts, which, in connection with the foregoing, must have existed to the north of the Yang-tzï have disappeared through erosion.

This continuation of the gorges-limestone formation overlying the granite south of the Yang-tzï is not reproduced on Willis' map.

Pumpelly, on the other hand, writes:

> In the immediate neighborhood of the river, over an area of forty or fifty square miles, the limestone has disappeared but, in the distance, on both sides of the Yang-tzï, its yellow cliffs are seen towering to a height of more than 2,000 feet above the water.

As far as the granite area extends, the course of the Yang-tzï shows, with regard to the anticlinal axis which must run through it, a typically symmetrical line, which consists of two, about equally long WNW–ESE pieces, connected by a bend toward the south. In the middle part of the granite area there occur many dykes trending

[1] On the map of my *Géologie du Bassin Rouge*, Nan-t'ou has not been given the right location as is also not the case in the map of Yi-tschang-fu (*Plankammer der Königl. Preuss. Landes*, Aufnahme), from which it was copied.

about N–S of aplite, pegmatite and melaphyre, which have only been partly eroded in the river bed, thus leaving obstacles, which give rise to rapids.

As I already found occasion to remark in my former publication, these dykes of eruptive matter in the granite and crystalline schists, I bring into genetical connection with the plication of the anticline of Nan-t'ou.

Just below Nan-t'ou finally begins the last or I-ch'ang gorge. Pumpelly[1] here mentions to the east of the granite area of Nan-t'ou, once more metamorphic strata and says: "Those to the eastward, which could not be closely examined, seemed to be gneiss trending E–W and dipping about 30° to S."

Blackwelder[2] relates the following about a formation named by him "the Nan-t'ou formation" which is indicated on Willis' map to the north of the Yang-tzï:

On account of the absence of fossils the age of the Nan-t'ou formation is not accurately known. It lies at the base of the Cambro-Ordovician limestone from which we obtained lower and middle Cambrian fossils within less than 100 miles, 160 km., from Nan-t'ou. Hence it is highly probable that these glacial beds on the Yang-tzï are of early Cambrian age.

Little is known at present regarding the areal distribution of the Nan-t'ou glacial beds. The horizon at which they occur is exposed many miles both north and south of the Yang-tzï, at the base of the escarpment which is crowned by the Cambro-Ordovician limestone; but the river crosses it at one point only and we had no other opportunity to see it. At the lower entrance to the Lu-kan gorge Pumpelly examined the base of the limestone system, and reported 50 feet, 15 m., of quartzite, overlain by limestones, which contain layers and lenticular masses of flint. It is probable therefore that the glacial beds do not occur in that locality.

I have not observed anything of all this, and only saw that the gorges-limestone rests direct on the granite which may eventually have become gneissy. "The glacial beds of early Cambrian age," I am, however, at a loss to reconcile with my own observations.

The first portion of the I-ch'ang gorge shows 10° SE-dipping layers, which the river crosses almost vertically. At the same place, where a diminution in the incline of the layers occur together with their more slaty condition, the Yang-tzï bends round to the SSW.

[1] *Smithsonian Contributions to Knowledge*, Vol. XV, p. 4.

[2] *Research in China*, Vol. I, Part 1, p. 264.

In the Mi-t'an gorge we saw that this level of the gorges-limestone formation was steeply inclined, and on both sides of the river had been excavated into deeply grooved cross valleys. In the eastern limb of the Nan-t'ou anticline which has a much fainter dip, the river has completely altered its course, where it reached this softer level in the hard limestone formation. Afterward it again bends round to an ESE course, and cuts through ever-higher levels of the gorges-limestone formation, until, at the end of the I-ch'ang gorge, it makes a sharp curve to the south. In this latter part of the gorge occur many minor plications in the layers which, as a whole, continue to dip 10° SE. The limestone strata, gently sloping away, disappear under the I-ch'ang series.

Although I did not perceive it, Willis again assumed the existence of the Sin-t'an shale and the Ki-sin-ling limestone in the I-ch'ang gorge. He writes:

> The lowest or I-ch'ang gorge of the Yang-tzï is cut across the Wu-shan limestone which rises at the rate of about 1,000 feet a mile till the Sin-t'an (middle Paleozoic) shale appears from beneath it. Further upstream the Ki-sin-ling (Cambro-Ordovician) limestone forms a second gorge, and passing from a dip of 10° to a nearly horizontal position, gives rise to the mesa like heights above Huang-ling-miau.[1]

But the deep erosive valleys in the Sin-t'an shale altogether fail to prove that the above quoted view of the structure of the I-ch'ang gorge is correct. The photo published by me on p. 25 of my *Géologie du Bassin Rouge* shows high rising cliffs of limestone on the left side of the Yang-tzï, where, according to Willis, a deep erosive valley of Sin-t'an shale ought to exist. My photos on p. 28 sufficiently prove that Willis' idea, that the Ki-sin-ling limestone borders the right side of the Yang-tzï from Nan-t'ou till Huang-ling-miau, is not in accordance with the reality.

Below the I-ch'ang gorge the Yang-tzï enters upon its lower course, and, to far below I-tu, it cuts across a formation of sandstone and red argillite layers, which between I-ch'ang and I-tu are folded into a broad and flat anticline.

Blackwelder calls this "apparently a recurrence of the K'ui-chóu formation."[2]

[1] *Research in China*, Vol. I, p. 286.

[2] *Op. cit.*, p. 287.

In the *Géologie du Bassin Rouge*, pp. 163, 164, I remarked concerning this:

Although the formation of I-ch'ang misses the characteristic appearance of the K'ui-chóu formation, we may safely presume that both are of the same geological age, especially as concerns the formation of I-ch'ang and the upper levels of those of K'ui-chóu. In the syncline of Lao-k'ui-chóu we have observed similar red and white more or less sandy argillites and we might imagine that the coarser material was deposited in the Basin, while the finer matter was collected on the outside.

Finally I must still mention the occurrence of a thick conglomerate bed with pebbles of a size ranging from that of a marble to that of a fist and more, which is found on both sides of the river above the present water level, and which point to an old river formation. It therefore dates after the plication of the Red Basin, and has been formed by the action of the hydrographical system, which appeared after the plication.

According to my idea Pumpelly has wrongly interpreted the signification of the conglomerate layer. He writes:

Near the city of I-ch'ang, at the eastern mouth of the gorge, the limestone strata, trending here NE and dipping about 80° to SE, are covered by apparently conformable beds of fine-grained gray sandstone, which toward the top soon merges into a coarse conglomerate. . . . . This conglomerate is followed by a red sandstone, which, above I-tu, dips easterly, and below that place westerly.[1]

Hence Pumpelly considers this conglomerate as a level in the I-ch'ang formation.

From K'ui-chóu to I-ch'ang, the Yang-tzï thus cuts through the high mountain ranges, here rising to 1,200 m, which form the boundary between the Red Basin of Ssï-ch'uan and the East China plain. The structure of these mountain ranges, may appear clear from the geological map and the different sketches. The deep gully, cut out by the Yang-tzï in these ranges exposes a succession of the finest and most interesting pictures of its inner structure. It is, as we see, a succession of folds, in which faults only play a secondary part.

The above suggests the following questions which I shall consider consecutively:

1. The tectonic signification of these folds.

[1] *Smithsonian Contributions to Knowledge*, Vol. XV, "Geological Researches in China, Mongolia, and Japan," p. 7.

2. The signification of the anticline of Nan-t'ou.

3. The causes which have enabled the Yang-tzï to cut through these high-limit ranges.

Concerning the first point I must remark that the folds here are not sinial folds taken in the sense von Richthofen attached to old Paleozoic ENE–WNW trending folds, in North China (Liau-tung). The folds[1] of the Red Basin of Ssï-ch'uan are of much younger date, in fact, younger than the K'ui-chóu formation, which has been plicated together with the lower layers. The almost equatorial trend in the easterly border area of the Red Basin I have already explained through the deviation of these later folds against the so much older folded mountain ranges of the Tsin-ling-shan and Kuen-lun. In the *Monatsberichte* of the German Geological Society, No. 9, p. 202, I wrote:

> We can therefore describe that part of the earth's crust in southwest China in the following manner: Firstly, in the south a widely extending upheaval of the earth's crust in broad, flat folds; then, toward the north an increase in height and number of the regular and parallel folds; finally, the deviation of the whole series from the NNE–SSW direction, to an ENE–WSW and EW one, in consequence of the "Anschaarung" of this system of folds against the equatorially trending Kuen-lun or Tsin-ling-shan system.

Formerly I wrote concerning this:

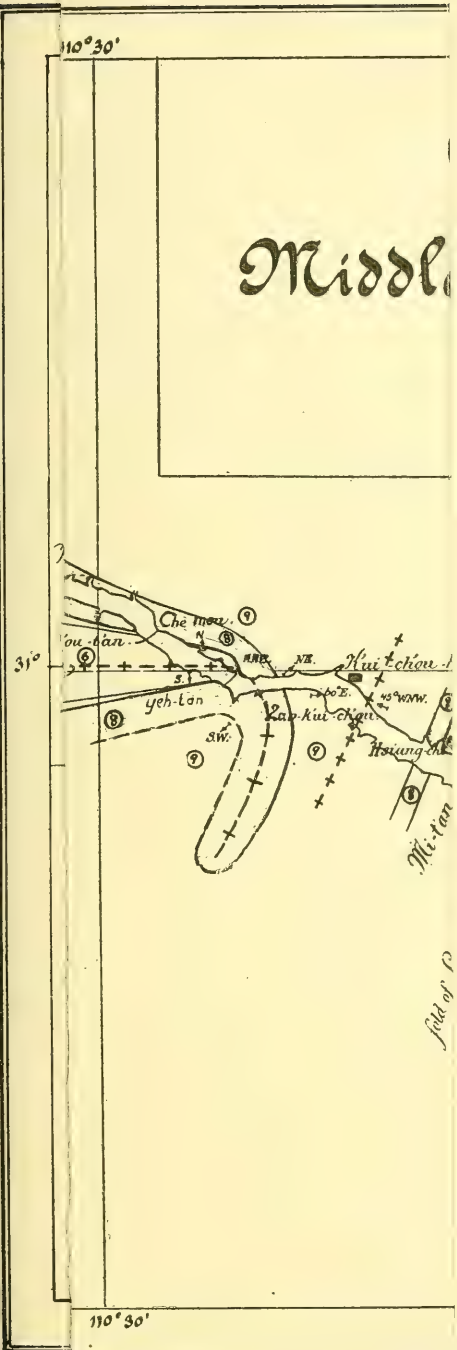
> It is quite possible that this pressure will have left visible traces north of Wu-shan and K'ui-chóu-fu in this old mountain range (the Tsin-ling-shan).[2]

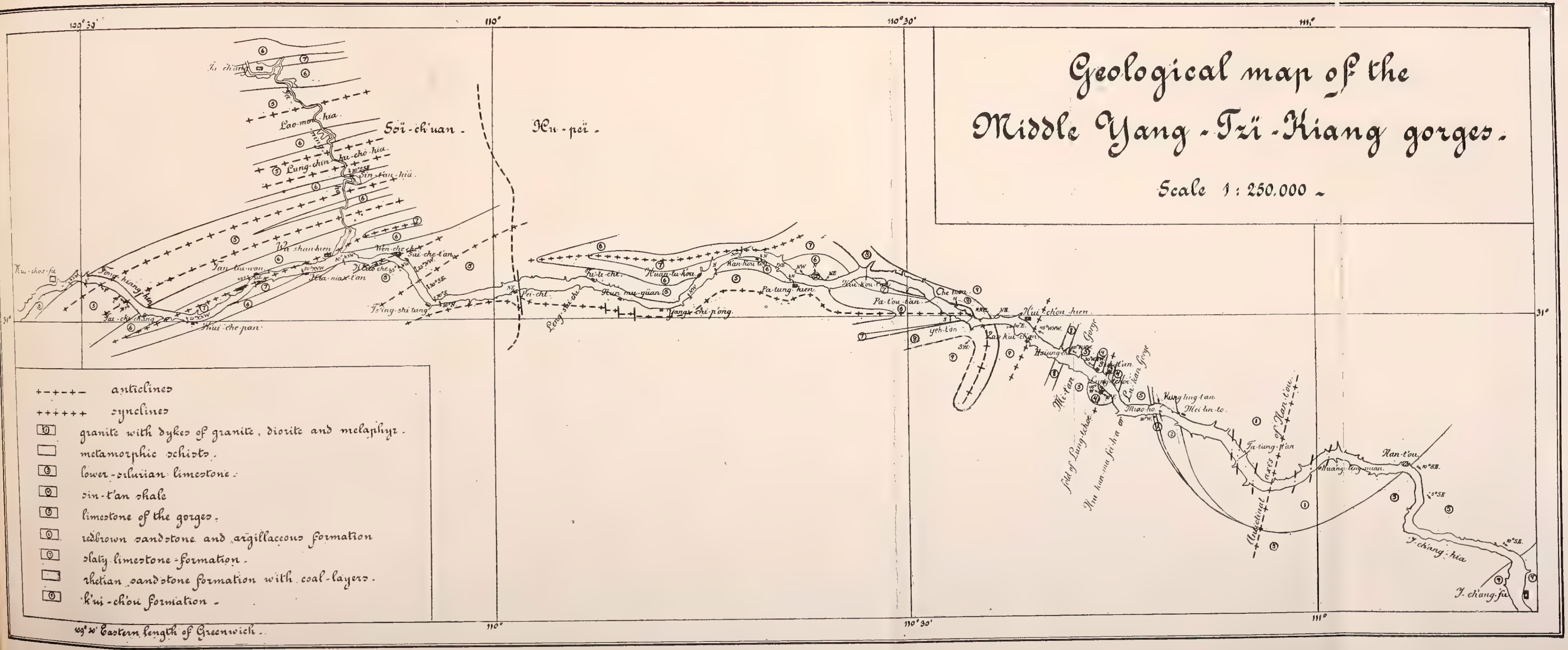
As a fact Willis, who passed through the land north of Wu-shan, along the Ta-ning-ho, gives, in his oft-mentioned work (pp. 288, 289) a section, which shows that the folds, from S to N, to the north of the Yang-tzï, become more and more sharp and high, while, finally, a little to the north of Sü-kia-pa, 65 km north of Wu-shan, he depicts a great overthrust, about which he writes (p. 291):

> Northward from Sü-kia-pa, there is, however, a complexity of structure which we did not fully understand in the field, but now interpret as an overthrust fault.

[1] Whether these folds are younger or older than those of the Jura mountains cannot be said for the present moment; but we may point out that they very materially output the latter as concerns regularity and simplicity.

[2] *Géologie du Bassin Rouge*, p. 181.


110°30'
Middl
Chê mou
ou-tan
31°
yeh-tan
Kui-chou
Lao-kui-chou
Hsiung-ch
Mi-t'an
field of
110°30'



Geological map of the Middle Yang-Tzï-Kiang gorges.
Scale 1 : 250.000
anticlines
synclines
granite with dykes of granite, diorite and melaphyr.
metamorphic schists.
lower-silurian limestone.
sin-t'an shale
limestone of the gorges.
redbrown sandstone and argillaceous formation
slaty limestone-formation.
rhetian sandstone formation with coal-layers.
k'ui-ch'ou formation.
109° 30' Eastern length of Greenwich.
110°
110° 30'
111°
31°
Soï-ch'uan
Hu-peï
Lao-mo-hia
Lung-chin
Sin-tan-hia
Wu-shan-hien
Wen-che-che
Sai-che-t'an
Kui-chou-fu
Fong-hiang-hia
Tai-chi-chang
Hui-che-pan
Tan-tiu-wan
Hia-niao-t'an
Ts'ing-shi tang
Pei-chi
Lung-shi-che
Hua-mu-güan
Yang-chi-p'ong
Kuan-tu-kou
Wan-kou-tü
Pa-tung-hien
Kui-kou-tsü
Pa-t'ou-tan
Che mau
Kui-chou-hien
yeh-tan
Hsiung-K.
Mi-tan
Lu-kan Gorge
Kung ling tan
Mei tin-to
Miao-ho
Ta-tung-t'an
Han-t'ou
Huang-ling-miau
I-chang-hia
I-chang-fu

From the foregoing it is clear that I cannot agree with the views expressed by von Richthofen[1] in the following quotations:

> In this way it becomes plain that an immense area, situated to the south of the easterly Kuen-lun, whose basal structure in the parts known to us (and probably in its entirety), consists of the paleozoic formations, and which is folded together according to the sinial trend of the strata, can yet show great variety in its separate parts.

Although I fully agree with the description of the geological structure given in the next passage, I can by no means agree with the example von Richthofen adduces to illustrate the event of the welding together of the Kuen-lun mountains with the southern system of plication. On p. 638 we read:

> One of the most remarkable circumstances is the firmly growing together of the sinial zone of plication with that of the Kuen-lun in the Tsin-ling-shan. Just as when upon a cloth, folded into parallel folds, were laid a heavy bar at an oblique angle to the direction of those folds, and this bar were moved, at right angles, to its axis toward those folds until they were so bent round as to completely take the direction of the bar, in the same way the stiff stem of the Kuen-lun leans against the sinial folds. While at a distance from the Kuen-lun they strike from SW to NE, they gradually bend round toward the Kuen-lun, to a WSW–ENE trend. At the same time they press so closely, and the strata attain such a steep dip, that they become joined with the principal stem into one solid mass.[2]

From this example of the bar on the folded cloth we might draw the conclusion that von Richthofen assumes that the Kuen-lun mountains are of later formation than the area to the south of it, considered by him as occupied by mountain ranges folded up according to the sinial system. I need not reiterate what I wrote above, for I

[1] *China*, Vol. II, p. 637: "So erklärt es sich, dass ein ausserordentlich ausgedehntes, im Süden des östlichen Kwen-lun gelegenes Gebeit, dessen Grundbau in den uns bekannten Theilen, und wahrscheinlich in seiner Gesammtheit, aus paläozoischen Formationen besteht, und nach der sinischen Streichrichtung zusammen gefaltet ist, doch in seinen einzelnen Strecken grosze Verschiedenheit darbietet."

[2] *China*, Vol. II, p. 638: "Zu den bemerkenswerthesten Umständen gehört das feste Verwachsen der sinischen Faltungszonen mit denen des Kwen-lun im Tsin-ling-shan. Wie, wenn man einen schweren Stab auf ein in parallele Falten geworfenes Tuch unter schiefem Winkel zur Richtung dieser Falten legt und ihn gegen dieselben hin rechtwinklig zu seiner Axe fortscheibt, die Falten sich bis zur völligen Anschaarung umbiegen, so schmiegt sich der starre Stamm des Kwen-lun an die sinischen Falten. In grösserem Abstand von ihm von SW nach NO gerichtet, biegen sie an ihm zu einen WSW–ONO Streichen um! Zugleich drängen sie sich so dicht, und die Schichten nehmen eine so steile Stellung an, dass sie sich zu einer einzigen starren Masse mit dem Hauptstamm verbinden."

made it clear enough there that I believe the relation to have been exactly the contrary, namely: an older Kuen-lun range, against which the almost meridionally directed recent folds of the Red Basin struck —like the surf of the ocean beating against the firm land—thereby causing them to rise and to bend round, and thus to assume, only locally and incidentally, a trend in accordance with that of the sinial system of folding.

Another confirmation of my idea of the forcing-up of the Red Basin folds, as I was able to observe it in the northeastern parts, I find far to the westward, described in the following communication by von Richthofen:

> The outermost southern branch of the sinial system, which to the south of Kwang-yuen is still hidden under the formations of the Basin (see Fig. 111*c*) now appears in ever mightier lines, striking at first WSW and then SW, and forms (as beforesaid) the lofty northwestern wall of the plain of Tschöng-tu-fu. It here bears the name of San-miën-shan and Kiu-ting-shan.[1]

According to my opinion, the tension, which caused the Red Basin to be folded and to be pressed up against the Kuen-lun, became less in this westerly part, so that a basin fold still could be deviated by the Kuen-lun from its normal direction but at the same time (the fold) became flatter and vanished, instead of running high up against the Kuen-lun mountains, as is the case in the eastern part.

As concerns the signification of the Nan-t'ou anticline, we may conclude from the foregoing:

1. The crystalline schists are found to the west of the granite area of Nan-t'ou. Originally they will also probably have occurred to the east, but they are washed away, while sediments were deposited in a basin forming itself to the westward.

2. To the visibly oldest sediments belongs my lower Silurian brown limestone of Sin-t'an, with its fossils, the Cambro-Ordovician Ki-sin-ling limestone of Blackwelder and Willis. As we saw, this formation does not extend as far to the east as the lower entrance of the Ox-liver gorge. It does not seem to occur to the east of the Nan-t'ou anticline.

[1] *China*, Vol. II, p. 639: "Der äusserste Südzweig des sinischen Systems, welcher nördlich von Kwang-yuen noch unter den Beckengebilden verschwindet (fig. 111*c*) hebt sich in seinen erst nach WSW, und dann nach SW gerichteten Streichen immer mächtiger hervor und bildet wie erwähnt, die erhabene Nordwestmauer der Ebene von Tschöng-tu-fu. Er führt hier die Namen San-miën-shan und Kiu-ting-shan."

3. In transgression for some kilometers toward the east we find my green shale formation, Blackwelder's middle Paleozoic Sin-t'an shale, which thins out not far to the east of Miao-ho at the lower entrance of the Ox-liver gorge. To the east of the Nan-t'ou anticline this formation does not seem to occur either.

4. To the Sin-t'an shale succeeds my gorges-limestone formation, Blackwelder's Upper Carboniferous Wu-shan limestone.

Now we see the remarkable fact that the Nan-t'ou area, which proved to be an eastern land-ridge for the older formation, becomes a sea, together with the eastern part, during the Upper Carboniferous period. *This sea very probably in transgression spread over a great part of China.* After the limestone formation the area of Nan-t'ou again resumes its rôle of boundary wall between an eastern and a western basin.

5. The (probably) Permian and Lower Triassic reddish-brown formation only occurs in an eastern part of the Red Basin, not in its center. It extends along the Yang-tzï as far downstream as Yeh-t'an, but not as far as Hsiang-chi.

6. The (probably) Upper Triassic slaty limestone formation extends even less far toward the east. It thins out already above Yeh-t'an. Neither of these formations occur to the east of the Nan-t'ou anticline.

7. Overlying this transgrades the Rhetian sandstone formation in the Red Basin itself far to the west. Although the area of Nan-t'ou is again a land limit against which the sandstone formation thins out, this same Rhetian sandstone, which contains coal measures, occurs in the East China Basin and also in other parts of China. We already noticed before that the formation itself extends farther east than the coal layers, which occur in higher levels.

8. This retrogression of the sediments westward is continued, and we find the shell-marl strata of probably Cretaceous age only in the middle of the Red Basin, whilst it thins out in more or less extensive lenticular layers between Wan-hien and K'ui-chóu-fu.

9. After this again comes a period of transgression. The K'ui-chóu formation extends to the western limb of the Nan-t'ou anticline. It seems that this anticline did not act as dividing line for the upper levels of this formation, for we find the I-ch'ang formation overlying its eastern limb, as far as it has not been washed away by ero-

sion. The very highest level which consists of very coarse-grained and micaceous sandstone, however, again only occurs in the center of the Red Basin.

In resuming the above we must come to the important conclusion that the area of Nan-t'ou must have played the part of a dividing line ever since the Cambro-Ordovician, or perhaps still earlier ages, until after the depositing of the K'ui-chóu formation (Cretaceous formation or later ?). During all that time, however, it twice gave up this rôle: once during the Upper Carboniferous and for a second time, let me say, during the upper K'ui-chóu time. At last the broad mighty anticline of Nan-t'ou was completely formed as we see it nowadays, partly destroyed by erosion.

The later formed folds of the Red Basin are therefore of younger date, and although we might assume an earlier date for the beginning of their growth, which a more careful research may possibly teach us from the trend of the extension of the reddish-brown and the slaty limestone formations, it must be inferred that their growth proper must have taken place much faster than that of the Nan-t'ou anticline.

As I already remarked above, these NNE–SSW folds of the Red Basin are bent up against the Tsin-ling-shan which I regarded as the consequence of the Red Basin having been pressed to the north.

Finally, I again refer to the deviation of the anticline of Pa-tung against that of Nan-t'ou, which fact agrees with the greater age and capacity of resistance of the latter.

And now I have still to consider the question of what were the reasons which caused the hydrographic system that originates nowadays on the eastern slope of the highlands of Tibet south of the Kuen-lun mountains, to force its way through the high mountain ranges from K'ui-chóu-fu to I-ch'ang. Until the present moment I have not fully considered this point. In the literature that I have consulted, on this subject I only find an explanation from Arthur Kniep[1] which, however, seems so strange to me that I shall not discuss it here.

[1] "Der Yang-tzï-kiang als Weg zwischen den Westlichen und Ostlichen China," *Gerlands Beiträge zur Geophysik*, Band VII, Heft I, pp. 22, 23. The explanation of

Of all the existing theories those of antecedent and regressed or beheaded rivers seem the most probable to me. Even in a developed and grand river system as that of the Yang-tzï-kiang it seems quite possible that both factors combined to produce such a system.

When we look at the map of China, we are impressed by the fact that the whole basin of the Upper and Middle Yang-tzï finds an outlet through the most northerly area which borders, to the south, the high dividing mountain range of north and south China. It readily appears to us that whilst the Kuen-lun is the divide between the Upper Yang-tzï and the Upper Hwang-ho, its eastern prolongation, the Tsin-lin-shan, remains the divide of a southerly developed Yang-tzï system and a northerly developed Hwang-ho system. Thus, in very general features, facts can be understood by a glance at the map.

But to return to the Middle Yang-tzï itself. We must first of all bear in mind that the anticlines of the Red Basin, and with them, of course, its entire area decline from N to S. This fact must be inferred from the observations that in consequence of an intensive erosion the anticlines in the northern parts of the Red Basin have been weathered away to a thickness of at least 2,500 m. down the gorges-limestone, which now still rises in mountains of 1,500 m. and more. These arch cores of limestone are only to half their height concealed under anticlinal limbs of the younger formations. More to the south the limestone cores have lowered to the level of the Yang-tzï and the cores of the sandstone formation, lying over the limestone, rise to anticlinal ridges of some 300 m., whilst there the overlying mighty K'ui-chóu formation has been washed away and has only remained in place in the synclinal areas, where it is dissected by numerous narrow cross and length valleys. At last, south of Ki-kiang, a place some 100 km. in right line south of Chung-king, I encountered an anticline which up to the height of 500 m. still consisted of the youngest or K'ui-chóu formation, the sandstone formation there being very much lower than it is in the country of Chung-king.

the antecedent theory, to which I shall also appeal, seems to him very improbable. Kniep speaks of a peneplain between Wan-hien and I-ch'ang, where the Ta-kiang (a local name for this part of the Yang-tzï) should have taken its meandering course without close connection to the rock structure.

Thus, when we appeal to the antecedent theory we must accept the fact that this antecedent river not only had the power of cutting its course through a succession of parallel folds but even could keep the better of a general rising of the land contrary to its way from south to north, from far upstream Chung-king till Wan-hien. Nothing opposes itself to this combined movement of the earth's crust, viz., its being folded and at the same time pressed up against the Tsin-ling-shan; on the contrary the observations lead to this inference as is explained in the above. To account for the last-mentioned discrepancy we must suppose that the river had a sufficient power, as the result of a considerable fall anywhere in its course and that there was no possibility of going another way, for a river does its work only when it is forced to it. Now, it is almost certain that east of I-ch'ang, where nowadays still exists the low east China plain with its many lakes (Tung-ting, Po-yang, etc.,) ever since the filling up of the Red Basin there was a considerable difference in height from west to east. Might any obstruction have occurred in the antecedent river by the rising of the country from south to north, it still would be possible that a more intensive erosion in the watercourse took place from I-ch'ang in an upriver direction. But here we already appeal to the regression theory, for it may be that the rate of land-folding and uplifting have been the same as that of the cutting-power of the river water, or the first may have stopped the last till regression of the old watercourse redressed the former river-way, which then could continue its work in the old direction.

As to the second condition necessary for the absolute maintenance of the antecedent theory, viz., the impossibility for the river water of going another way, we cannot say very much because of the very incomplete geographical and geological investigations of southern China. When we look at the map we see that all great tributaries of the Yang-tzï, and its headwaters too, run in general lines from north to south. This makes me feel quite inclined to suppose that the hydrographical system of the province Ssï-ch'uan once must have found an outlet toward the south according to the general incline of the earth's surface from north to south. If this is true, then we must consider one or more of southwestern China's big rivers as beheaded ones by a retrogressed river system, which now is that of the Middle

Yang-tzï. That the effect of retrogression proved to be most powerful as near as possible to the Tsin-ling-shan appears most natural. The open sides of the Nan-t'ou and Sin-t'an areas toward the north quite accord with a retrogression theory for this last part of the Middle Yang-tzï.

All the grand gorges of the Middle Yang-tzï are very interesting when one could see in them the fixed image of the relation between the rate of movement of the earth's crust in the folding process and of the cutting-power of a river. Although from Chung-king to I-ch'ang the Yang-tzï cuts through the anticlinal mountain ranges nearly perpendicularly, there is a sufficient number of exceptions, for instance, where the river has a meandering course in the gorges; so from this point of view we cannot find either a proof to support the antecedent theory, nor one against it. The indifference of the Middle Yang-tzï to the general land-structure, rising from south to north, might account to the antecedent theory. On the other hand the bending round of the Yang-tzï, near Wan-hien, from a general NNE to an ENE course, in complete correspondence to the turn of the anticlines of the Red Basin against the Tsin-ling-shan, seems to bear against this theory, for here the river has followed the mountain structure. If there has been any antecedent watercourse in this region, it must anyhow have been considerably affected by the folding process, probably being restored only after a retrogression process of a watercourse more downstream from this point.

From the above it is clear that by reason of the present condition of the investigation of the whole of the Yang-tzï basin we cannot come to a decisive opinion to attribute the origin of the grand gorges of the Middle Yang-tzï-kiang either exclusively to the antecedent river theory or to that of the retrogression process.

Contrary to Kniep, however, I must point out that the meanders of the Yang-tzï in the synclinal valleys and even in the eastern limb of the Nan-t'ou anticline were exclusively caused by the geological and the rock structure. Another important example of this kind can be seen in the part of the river between Wan-hien and K'ui-chóu-fu, where the Yang-tzï, having lowered its course to one of the thick sandstone layers of the K'ui-chóu formation, here being in a horizontal

position, has cut its way in a straight canal-like bed, obliged to do so by the rock structure.

The Middle Yang-tzï might be called a mature river, and this even after it has been revived, as seems to have been the case only once. The conglomerate bank of principally eruptive pebbles, mentioned above, shows the remains of the floor of a former Yang-tzï valley, in which the river has cut its narrower trench of nowadays. The mighty work here already accomplished by Nature has rendered the Yang-tzï navigable to far above Chung-king, thus making it for a length of more than 2,500 km. one of the most important highroads for traffic. That which Nature has left undone would be no serious obstacle for the amelioration of this waterway because the obstructions do not consist of falls, but only of rapids as the result of not-yet-washed-away detritus accumulations and partly uneroded dykes of eruptive rocks in the Nan-t'ou granite area. These obstructions, that make steam navigation on the Middle Yang-tzï not yet economically practicable, can, according to my idea, easily be overcome by human technics, and it is by no means beyond financial possibility. This has already been set forth in detail by me in an article, "La navigabilité du haut Yang-tzï-kiang par bateaux à vapeur," published in the *Revue universelle des Mines*, at Liège, tome XII, 4e série, p. 149.

No doubt the geology of the mountain ranges which are cut by the Yang-tzï between K'ui-chóu-fu and I-ch'ang still offer many interesting problems and points of view. But I believe to have given in the foregoing, in general features, the geological structure of this most interesting area as it appears in reality. Indeed, all that I saw of the Red Basin of Ssï-ch'uan and its border parts, leads me to the conviction, that, as for structural geology, this is one of the classic parts of the earth's crust, showing its inner and outer structure in a way to allow of the finest detail studies of folding and erosion, which appear in a pattern of the utmost simplicity and regularity.

RECENT STUDIES IN THE GRENVILLE SERIES OF EASTERN NORTH AMERICA[1]

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In a paper which has recently appeared[2] a summary of the chief results of a geological study of a large area on the margin of the Laurentian protaxis in eastern Ontario, by Dr. Barlow and the writer, has been presented. The area in question, whose study has just been completed, is one of the largest areas of the protaxis which has hitherto been examined, comprising 4,200 square miles, and the study has furthermore been carried out in much greater detail than in the case of areas formerly examined in Canada, the field work extending over a period of eight years. In a second paper[3] now in press a more detailed account of the great development of nepheline and corundum-bearing syenites found in the area is given.

The area lies near the border of the Laurentian protaxis, north of Lake Ontario and east of Lake Huron, and one of the most conspicuous features of its geology is the great development in it of Logan's Grenville series. It is proposed in the present paper to present certain new facts which have been discovered concerning this series in the area in question, as well as certain general considerations relative to this, which is one of the most extensive and important series of pre-Cambrian Age in North America. A complete description of the area will appear in the form of a report to be issued by the Geological Survey of Canada during the present year.

In *The Geology of Canada*,[4] published in 1863, which contains a statement of the results of the work of the Canadian Survey up to that date, Logan commences the chapter dealing with these rocks as follows:

[1] Communicated by permission of the Director of the Geological Survey of Canada,

[2] Frank D. Adams, "On the Structure and Relations of the Laurentian System in Eastern Canada," *Quarterly Journal of the Geological Society*, May, 1908, p. 127.

[3] "On the Nepheline and Alkali Syenites of Eastern Ontario," *Transactions of the Royal Society of Canada*, 1908.

[4] P. 22.

The rocks which compose the Laurentian Mountains were shown by the Geological Survey in 1846 to consist of a series of metamorphic sedimentary strata underlying the fossiliferous rocks of the Province. They have since been recognized by Sir Roderick Murchison as forming the so-called "Fundamental Gneiss" of the western islands of Scotland and parts of Rosshire and Sutherlandshire, and the name of the Laurentian system as applied in Canada has now been extended to them in Great Britain where, as well as in this country, they are the oldest rocks known and lie at the base of the sedimentary series. They are highly altered to a crystalline condition and are composed of feldspathic rocks interstratified with important masses of limestone and quartzite. The great vertical thicknesses of the series are composed of gneiss containing chiefly orthoclase or potash feldspar, while other great portions are destitute of quartz and composed chiefly of a lime soda feldspar, varying in composition from andesine to anorthite and associated with pyroxene or hypersthene. This rock we shall distinguish by the name of anorthosite.

Logan's exploratory work showed that these ancient rocks underlie enormous areas in Canada. It is now known that they occupy an area of about two million square miles. As their structure is very complicated, he found it impossible to make a detailed study of the whole Canadian shield and therefore decided to select a comparatively limited area in which the Laurentian system had a typical development, and there, by careful mapping, to ascertain its structure and relations. The district which he selected had an area of about fifteen hundred square miles and was situated on the margin of the northern protaxis in the vicinity of the little town of Grenville, some forty miles to the west of the city of Montreal. His map of this area appeared in the atlas which accompained *The Geology of Canada*. This area has come to be known as the "Original Laurentian Area" of Logan, and the succession which he worked out there has found its way into most textbooks.

Since that time other members of the staff of the Geological Survey of Canada, notably Vennor and Ells, have extended our knowledge of this portion of the Laurentian area by mapping large tracts along the margin of the protaxis to the west of the Original Laurentian Area as far as the western border of the Province of Quebec, and thence over into eastern Ontario. In 1897[1] the writer published the results

[1] "Report on the Geology of a Portion of the Laurentian Area lying to the North of the Island of Montreal," with appendices and map, *Annual Report of the Geological Survey of Canada*, Vol. VIII, p. 184.

of a study of a large area lying to the east of the Original Laurentian Area and extending as far as the St. Maurice River, which flows into the St. Lawrence about half-way between Quebec and Montreal. Our knowledge of the Laurentian has also been very considerably extended by the researches of Kemp, Cushing, and others in the Adirondack Mountains, as well as by the extended explorations of Low and others in the far north and by the work of Lawson in the west.

SIR WILLIAM LOGAN'S WORK IN THE LAURENTIAN OF CANADA

Before considering the results of these recent studies it will be of interest to look very briefly at the work done by Logan in the Original Laurentian Area.

This master of stratigraphy found that the Laurentian system, instead of presenting a chaotic mass of crystalline rocks from which no order could be evolved, constituted as a matter of fact a great series of rocks largely stratiform, if not stratified, in character, and which almost everywhere exhibited a foliated structure. Among these rocks he found great bodies of limestone, the importance and significance of which he at once recognized. This limestone was, it is true, frequently very impure and always coarsely crystalline, constituting in fact a true marble. Its chemical composition, however, led him to conclude that it was of sedimentary origin. The limestone occurred in the form of belts or bands, and, being easily recognized in the field, was used by him as a basis for working out the complicated stratigraphy of the district. Being soft and easily disintegrated, it frequently occupies low drift-covered ground, and over considerable tracts of country he was obliged to determine its existence beneath the drift by driving down a sharply pointed iron rod and testing the powder brought up by the rod, by means of acid. He was enabled by the use of this geological cheese-taster to determine the existence of the limestone beneath the drift in many places where its occurrence could not be otherwise ascertained.

Associated with the limestones he found in places bands of quartzite. Bands of hornblendic rocks, now termed amphibolites, often of great thickness, also formed part of the series. He ascertained, however, that orthoclase gneiss was the most abundant rock in the Laurentian. This, he states, varies greatly in character, being

sometimes almost massive and granitic, while elsewhere it is well foliated. It sometimes occurs in great bodies free from all admixture of other rocks, while at other times it is found intimately associated or interbanded with the limestones or other rocks making up the series.

The highly contorted character of this series of rocks made it very difficult to determine its thickness, but Logan regarded the following ascending section as representing approximately the succession and thickness of the various elements constituting the Laurentian in the original area examined by him.

		FEET
1.	Anorthosite, above the Morin band of limestone, the thickness is wholly conjectural	10,000
2.	Orthoclase gneiss, passing gradually into anorthosite, probably includes the quartzite of Quartz Mountain, the anorthosite above it and the gneiss of passage	3,400
3.	Proctor's Lake limestone	20
4.	Orthoclase gneiss	1,580
5.	Crystalline limestone of Grenville, in some parts interstratified with a band of gneiss about	750
6.	Orthoclase gneiss, with several bands of garnetiferous gneiss and quartzite, and with much coarse-grained porphyroid gneiss	3,500
7.	Crystalline limestone of Great Beaver Lake and Green Lake, including two bands of interstratified garnetiferous rock and hornblendic orthoclase gneiss	2,500
8.	Orthoclase gneiss	4,000
9.	Crystalline limestone of Trembling Lake	1,500
10.	Orthoclase gneiss composing Trembling Mountain, lower limit not ascertained, thickness probably exceeds	5,000
		32,250

The base of the series was thus a great body of orthoclase gneiss —the Trembling Mountain gneiss—above which were four belts of limestone, certain of them of great thickness, alternating with orthoclase gneiss; the whole succeeded by a great development of anorthosite.

The alternation of limestone with gneiss was considered by Logan as proving that the whole series represented a great body of highly altered sediments, the oldest sediments recognizable in the earth's history. The foliation exhibited by the bodies of orthoclase gneiss

lying between and below the limestones, as well as that exhibited by the anorthosite, was regarded as the survival of an almost obliterated bedding, and this foliation, as has been mentioned, extended down to the very base of the whole series. The existence of this great thickness of anorthosite superimposed upon, and, therefore, presumably younger than the orthoclase gneiss, was in a brilliant paper by Sterry Hunt, explained as due to a succession of chemical reactions which must necessarily have been developed during the cooling of the earth from whose primeval ocean the whole series was supposed to have been deposited in the order of their succession.[1]

Since Logan's time, however, the great advance in our knowledge of petrography has thrown a flood of light upon the nature of the crystalline schists and a study of the area lying immediately to the east of that mapped by Logan made it evident that Logan's conclusions must be in part revised.

The Fundamental Gneiss, in the first place, is found to be a great body of uniform, fine-grained, foliated granite, showing under the microscope excellent protoclastic structure. It is clearly an igneous intrusion in which foliation has been developed by movement under pressure. The suggestion of stratification which it presents owing to its foliation, is enhanced by the presence in it of occasional lenticular bands of dark amphibolite. These, of course, lie parallel to the foliation, that is, to the direction of movement in the rock, but are evidently inclusions of the overlying rock which was intruded by the granite. The thickness of this fundamental gneiss (5,000 feet), considered even by Logan to be wholly conjectural, must therefore be deducted from the total thickness given in the above section.

The anorthosite, when traced to the east, is also proved beyond doubt to consist of a great body of igneous rock having a pronounced foliation, especially near its margin, and which cuts off the limestone bands where it meets them. Its thickness (10,000 feet), which was also considered by Logan to be wholly conjectural, must also be deducted.

It is furthermore certain, as the result of recent work, that the gneisses associated with the limestones are in part of igneous origin

[1] "The Chemistry of Metamorphic Rocks," *Chemical Geological Essays*, Boston, 1875.

and in part represent highly altered sediments. It is impossible in all cases to distinguish these two classes of rocks, but the distinction can in many cases be made with certainty.

The sedimentary gneisses (paragneiss) are fine in grain and usually occur intimately associated or interstratified with the limestones and quartzites, and very frequently weather to a rusty color. From the thickness of the limestone bands given above, there must be deducted that of the igneous gneiss included in or associated with them.

It is also by no means certain that the four limestones mapped by Logan are all separate bands, seeing that the intervening belts of gneiss, being largely igneous in origin, can no longer be regarded as representing separate stratigraphical elements, but may be intrusions separating portions of one and the same body of limestone. Whether or not this latter presumption represents the truth, can, however, only be determined by a complete re-examination of Logan's work in this area. In the meantime it is certain that the highest and lowest members of his series are bodies of intrusive rock in which a foliation has been induced by pressure. The deduction of these reduces the thickness of the series by 15,000 feet, and that a much greater reduction than this must be made if the true thickness of the sedimentary portion of the series is to be ascertained, is evident from what has been already stated.

In his map of this area, Logan separated the anorthosite and designated it as Upper Laurentian, while the other rocks of the series were classed as Lower Laurentian or Grenville series. In after years the lowest gneiss came to be known as the Fundamental Gneiss or Ottawa Gneiss, while the name "Grenville series" was restricted to the limestone-bearing portion of Logan's Laurentian.

This work of Logan, while in many respects imperfect, was nevertheless a first approximation to a true knowledge of the Laurentian and served as an excellent basis for the work of subsequent investigators.

Logan subsequently found in eastern Ontario a series of rocks which he considered in all probability to represent the Grenville series in a less altered form, and to these he gave the name of the "Hastings series."

THE HALIBURTON-BANCROFT AREA IN EASTERN ONTARIO

The Haliburton-Bancroft area in eastern Ontario, the mapping of which has just been completed, occupies a position on the margin of the protaxis corresponding to that of the "Original Laurentian Area" but is some 175 miles further west. It is very similar in petrographical character to Logan's area but presents a somewhat greater variety of rock types, the distribution of twenty different rock types being represented on the Bancroft sheet accompanying the report on the area in question.

The Grenville series in this area presents a diversified series of undoubted stratified rocks among which limestones preponderate, but they rest upon and are invaded by an enormous body of gneissic granite.

To the southeast, toward the margin of the Paleozoic cover, the sedimentary series is largely developed and is comparatively free from igneous intrusions. Toward the northwest, however, the granite, in ever increasing amount, arches up the sedimentary series and wells up through it, in places disintegrating it into a breccia composed of shreds and patches of the invaded rock scattered through the invading granite, until eventually connected areas of the sedimentary series disappear entirely and over hundreds of square miles the granite and granite gneiss alone are seen, holding, however, in almost every exposure, inclusions which represent the last scattered remnants of the invaded rocks.

The type of structure presented by the invading granite is that of a bathylith.

The limestones.—The limestones in this Laurentian district are very thick and underlie a large part of the area. In their more altered form they exactly resemble those described by Logan in the areas examined by him, but to the southeast of the Bancroft sheet, where the invading granite is less abundant and the alteration of the invaded strata is correspondingly less pronounced, the limestones appear in less-altered forms and eventually pass into fine-grained, grayish-blue varieties in which the bedding is perfectly preserved and concerning whose truly sedimentary character there can be absolutely no doubt. The gradual transition of the comparatively unaltered bluish limestone into the coarsely crystalline white marble takes place by the develop-

ment in the former of little strings or irregular patches of coarsely crystalline white calcite, usually following the bedding planes. These become larger and more numerous on going north in the area toward the granite intrusions, until eventually the whole are transformed into great bodies of white marble. Here and there through this marble, where it is very thick, small remnants of the original blue limestone can occasionally be found.

Enormous bodies of nearly pure limestone or marble occur in many parts of the area, but elsewhere it becomes impure, owing to the presence of numerous scales and granules of various silicates distributed through it, or owing to the appearance of numerous little bands of silicates representing impurities in the original limestones, which, under the influence of metamorphism, develop into gneisses and amphibolites of various kinds. Where these little gneiss or amphibolite bands become increasingly abundant, the limestone passes over into paragneiss or into some one of the varieties of amphibolite.

The limestone in what may be called its usual development, that is, in its highly crystalline form, is a white, cream-colored, or pinkish marble, and is generally very coarse in grain. The little grains or scales of foreign minerals scattered through it are usually arranged so as to indicate the lines of the original bedding. No less than thirty-seven species of these minerals have been found in the limestones in this area, of which phlogopite, malacolite, serpentine, scapolite, graphite, and pyrite are the most common.

That the limestone has in many places been subjected to great movements can be distinctly seen on the face of any high cliffs or where other large surfaces of the limestone are exposed. Here the interstratified bands of gneiss or amphibolite can be seen winding to and fro over the exposed surface, often folded back upon themselves or broken into fragments which have become widely separated from one another by the movements, the more plastic limestone having flowed in between them, the rock often in this way taking on the appearance of a coarse conglomerate.

The quartzites.—Quartzite is not common in this area. Where it occurs it is found interstratified with the crystalline limestones and rusty weathering paragneisses. It is well foliated and rather fine

in grain, sometimes containing a certain amount of feldspar as an accessory constituent, and elsewhere containing some pale-green pyroxene, which is evidently derived from the alteration of a certain amount of calcareous matter originally present.

Under the microscope the quartz of these quartzites is seen to have the form of elongated grains arranged in the direction of the foliation and showing very marked strain shadows, sometimes passing into a distinct cataclastic structure. There is every reason to believe that these quartzites represent, in most cases at least, altered sandy sediments.

The gneisses of sedimentary origin (*paragneiss*).—These gneisses differ distinctly in appearance from the foliated granite gneisses already referred to, and which constitute the bathylithic intrusions. They are fine in grain and show no protoclastic or cataclastic structure, the original material having been completely recrystallized. They have an allotriomorphic structure, with a tendency of certain of the constituent minerals to elongate themselves in the direction of the original bedding. While quartz, feldspar, and biotite are among the constituents present, the mica is usually more abundant than in the granite gneisses, and, in addition, garnet, sillimanite, graphite, and pyrite are very frequently present, the last giving rise to a prevailingly rusty color on the weathered surface. These gneisses occur in the form of well-defined beds and are usually found intimately associated with the limestones. They resemble in many respects the hornstones which are found in granite contact zones, but are rather more coarsely crystalline than is usual in this class of rocks.

These gneisses, while presenting a general similarity in appearance, show a considerable diversity in composition and are evidently derived from the recrystallization of sediments which varied considerably in character. The two following analyses show extreme cases of this variation.

No. I occurs interstratified with beds of white garnetiferous quartzite at St. Jean de Matha in the Laurentian district to the north of Montreal. It is composed of quartz, orthoclase, garnet (in large amount), and sillimanite, with smaller amounts of rutile, biotite, pyrite, graphite, and serpentine, the latter mineral resulting from the

alteration of some constituent which has now entirely disappeared. As will be seen, the rock has the composition of an ordinary clay slate, possessing the characteristic high content of alumina with a low percentage of alkalis and a great preponderance of magnesia over lime, which is characteristic of these rocks.[1]

	No. I	No. II
SiO_2	61.96	79.70
TiO_2	1.66	.30
Al_2O_3	19.73	8.29
Fe_2O_3		.41
FeO	4.60	1.17
FeS_2	4.33	Not det.
MnO	Trace	.03
CaO	.35	.67
BaO		.08
MgO	1.81	.76
Na_2O	.79	1.43
K_2O	2.50	4.11
P_2O_5		.04
Graphite	Not det.	3.00
Water	1.82	.70
	99.55	100.69

No. II is from the township of Stanhope in the Haliburton area and is distinctly different in composition. If the "Mode" or percentage mineral composition of this rock be calculated, it is found to be as follows:

	PER CENT.
Quartz	55.20
Orthoclase	18.94
Oligoclase	14.46
Biotite	3.45
Muscovite	3.50
Rutile	.30
Apatite	.09
Calcite	.28
Graphite	3.00
Water	.54
	99.76

[1] See F. D. Adams, "A Further Contribution to our Knowledge of the Laurentian," *American Journal of Science*, July, 1895.

If the quantitative classification be adopted, this rock would find its place as a Tehamose, a division which includes many granites and liparites, and, so far as its chemical composition is concerned, might be of igneous origin, although few liparites contain so high a percentage of silica. Its mode of occurrence and structure, however, indicate that it is of sedimentary origin and it evidently results from the recrystallization of some arkose-like material derived from the disintegration of granite rocks.

These sedimentary gneisses (paragneisses) clearly represent deposits of argillaceous, or in some cases arenaceous sediment, often more or less calcareous, which were laid down in the same sea in which the limestones were accumulated.

In a extreme southern portion of the Bancroft area there is a considerable development of clay stones (often siliceous or calcareous) which probably represent these gneisses in a less altered form, but which probably, at the same time, hold a considerable admixture of volcanic material.

The amphibolites.—Intimately associated with these sedimentary gneisses and the limestones on one hand, and with the gabbros and diorites on the other, are other rocks which are grouped under the name of amphibolite. While many varieties of these rocks occur in the area, differing considerably from one another in appearance, they have as common characteristics a dark color and a basic composition. Quartz, which is one of the commonest constituents in the gneisses, is absent, or is present only in very small amount, while hornblende and feldspar, the latter chiefly plagioclase, are the chief constituents of the rock. Pyroxene or biotite often replaces the hornblende in part. In places the sedimentary gneisses fade away into occurrence of amphibolite when traced along the strike. Masses of amphibolite also, as has been mentioned, abound as inclusions throughout the granite of the bathyliths.

These amphibolites, furthermore, are not peculiar to this area but occur abundantly everywhere in the Laurentian. They have always proved to be one of the chief difficulties in the way of a correct understanding of the geology of this system, seeing that it has been impossible to do more than indulge in conjectures concerning their origin. The same difficulty has been met with in the case of these and allied

rocks occurring elsewhere, as for instance the trap granulites of the Saxon Granulitgebirge or the amphibolites of the crystalline complex of certain portions of the Alps, whose origin remains in doubt while that of the rocks with which they are associated has been definitely determined.

As the result of a very careful examination, it has been possible to prove conclusively that in this area the amphibolites have originated in three entirely different ways, the resulting rocks, although of such diverse origin, often being identical in appearance and composition. This remarkable convergence of type, whereby rocks of widely different origin come to assume identity of character, explains the difficulty which has been experienced up to the present time in arriving at a satisfactory conclusion concerning their genetic relations. These three ways are: (*a*) By the metamorphism and recrystallization of impure calcareous sediments; (*b*) By the alteration of basic dykes and similar igneous intrusions; and (*c*) By the contact action of the granite bathyliths on the limestones through which they cut. The question of the origin of these amphibolites is discussed elsewhere.[1]

THICKNESS OF THE GRENVILLE SERIES IN THE HALIBURTON-BANCROFT AREA

While in most parts of this area the Grenville series is so torn to pieces by igneous intrusions that no development of it can be found sufficiently continuous to enable its thickness to be measured, there are in certain parts of the area developments where these intrusions are distinctly subordinate and in which such measurements can be made with at least the same degree of accuracy as in the case of any other pre-Cambrian series.

One such district is that where the four townships of Anstruther, Burleigh, Chandos, and Methuen meet. Here a well-defined synclinal is succeeded to the east by an anticlinal, and the following succession of strata, which however does not represent a complete section through the Grenville series of this area, is expressed in descending order (Burleigh-Chandos section).

[1] *Journal of Geology*, Vol. XVII, No. 1.

	FEET
Limestone of Jack's Lake	6,770
Rusty weathering gneiss with associated amphibolites, crossing Lots 29–35 of Range I of Anstruther	5,754
Limestone with bands of sedimentary ("feather") amphibolite north of Loon Lake	3,060
Amphibolite north of Loon Lake	2,190
Limestone at Duck Lake (nearly flat, only surface exposed), say	50
	17,824

Another line of section along which the Grenville series is excellently exposed and along which measurements with a view to determining the thickness of the series may be made, is furnished by the Hastings road. This is one of the most striking sections of strata of pre-Cambrian Age to be found anywhere in the world. The road was constructed many years ago by the government for the purpose of enabling settlers to penetrate into what was then a very wild, remote, and inaccessible portion of the Dominion. A line was drawn on a map and orders were given to lay out the road along the line in question. The result was that a long road was constructed, starting from the rear line of the township of Madoc, running in an almost straight line to the Madawaska River, holding throughout almost its entire course a direction of N. 20° W. This road, which traverses the whole width of the Bancroft sheet and almost the whole width of the area embraced by the Haliburton sheet, fortunately for students of geology, runs about at right angles to the strike of the country rock, and throughout the whole southern portion of its course traverses the Grenville series, affording excellent exposures. The selection of this course for the road was, however, correspondingly unfortunate for the settlers who took up land in the district, since the road holds its course quite irrespective of hill or valley, and in its course passes directly across several great gabbro intrusions which give rise to an exceedingly rough type of country, and which might easily have been avoided had a slightly different line been adopted.

As will be seen by consulting the Bancroft sheet of the Ontario series of maps now being issued by the Geological Survey of Canada, throughout a distance of 25.3 miles from lot 30 of the township of Madoc to 60 in the township of Faraday, except where it crosses the gabbro intrusions above mentioned, whose width has been

deducted in arriving at the measurement just given, the Hastings road passes continuously across the limestone and amphibolites of the Grenville series, and throughout this whole distance crosses these latter practically at right angles to their strike.

Furthermore, throughout the whole distance these strata dip in a southerly direction at high angles. Here and there, at long intervals and for a few yards, a reversed or northerly dip can be observed, but this is merely local owing to a minor undulation in the strata which has no stratigraphical significance.

The angle of dip naturally varies somewhat from place to place, but the average dip may be taken as 45°. This is a minimum estimate, the average dip along the whole section being in all probability somewhat higher. Taking this value we obtain the following result:

Apparent thickness of the Grenville series along the line of section
=25.3 miles=133,584 feet.
True thickness of the Grenville series along this line of section
=17.88 miles=94,406 feet.

It must be noted that the series is one which along the whole length of this section presents a continuous alternation of beds of varying character, so that it is not a foliation but a true bedding that is observed and measured.

It is, moreover, to be noted that while this thickness is so great as to suggest reduplication of some sort by isoclinal folding or by faulting, there is no stratigraphical evidence that such reduplication exists, and a fact of very great importance to be noted is that if there be such reduplication, the basement upon which the series was deposited is nowhere brought up along the whole line of section as would undoubtedly be the case unless the series reduplicated by folding was of enormous thickness.

For purposes of comparison the estimated thicknesses of some of the other great developments of pre-Cambrian rocks in North America are presented on a later page.

In all these districts there is, as in that at present under consideration, a possible error due to partial repetition by folding.

In the Grenville series, as has been stated, limestones predominate,

and these sections afford data for determining the relative proportion of limestone present.

In the Burleigh-Chandos section given above the Jack Lake limestone is essentially a body of pure limestone, while the Loon Lake limestone band may be estimated to be about half limestone. This gives a thickness of about 8,350 feet of limestone in that section out of a total of 17,824 feet, that is to say, 46.8 per cent. of pure limestone.

The estimated thicknesses above referred to are as follows:

	FEET
Huronian-Marquette Iron Range, Michigan, U. S. A.[1]	12,590
Huronian-Menominee Iron Range, Michigan, U. S. A.[2]	4,650 to 6,400
Huronian-Penokee Iron Range, Michigan, U. S. A.[3]	13,950
Huronian-Mesabi Iron Range, Minnesota, U. S. A.[4]	6,800 to 8,800
Huronian & Keewatin-Vermilion Iron Range, Minnesota, U. S. A.[5]	13,350 to 15,550
Couchiching series in Rainy Lake District, Ontario, Canada[6]	23,760 to 28,754

With these may be compared:

Belt Formation in Montana, U. S. A.[7]	12,000
Pre-Cambrian of Lewis & Livingstone Ranges, Montana, U. S. A.[8]	9,900 to 10,700

[1] C. R. Van Hise, and W. S. Bayley, "The Marquette Iron-bearing District of Michigan" (Monograph), *U. S. Geol. Survey*, 1897.

[2] W. S. Bayley, "The Menominee Iron-bearing District of Michigan" (Monograph), *U. S. Geol. Survey*, 1904.

[3] R. S. Irving and C. R. Van Hise, "The Penokee Iron-bearing Series of Northern Wisconsin and Michigan" (Monograph), *U. S. Geol. Survey*, 1892. This thickness is arrived at by adding to the aggregate thickness of 1,950 ft., given for cherty limestone, quartz slate, and iron-bearing member an additional thickness of 12,000 ft. for the upper slate member, which thickness is that of the Hanbury slate, which in the Menominee Range is its equivalent.

[4] C. K. Leith, "The Mesabi Iron-bearing District of Minnesota" (Monograph), *U. S. Geol. Survey*, 1903.

[5] J. M. Clements, "The Vermilion Iron-bearing District of Minnesota" (Monograph), *U. S. Geol. Survey*, 1903.

[6] A. C. Lawson, "Annual Report of Progress," *Geol. Survey of Canada*, 1885, p. 108 c. c.

[7] "Pre-Cambrian Fossiliferous Formations," *Bull. Geol. Soc. Am.*, Vol. X, pp. 201–15.

[8] Bailey Willis, "Stratigraphy and Structure of Lewis and Livingstone Ranges, Montana," *Bull. Geol. Soc. Am.*, Vol. XIII, pp. 316–24.

In the section along the line of the Hastings road, it is estimated that the "blue limestone" and the "limestone and amphibolite," which represent the calcareous part of the series, contain about two-thirds of their thickness of pure limestone. This would give a thickness of 50,286 feet of pure limestone out of a total thickness of 94,406 feet, equal to 53.3 per cent. This latter section, being a much longer one, probably represents more nearly the average proportion of limestone in the Grenville series as developed in this area, which in its turn affords a representative area of the series as it occurs in Canada, so that it may be stated that the Grenville series, as a whole, contains rather more than one-half its thickness of pure limestone. The thickest development of limestone in any occurrence of the Huronian in America is the Randville dolomite in the Menominee Range, which attains a thickness of 1,500 feet. In the Belt Formation and in the series of pre-Cambrian rocks in the Lewis and Livingstone Ranges, there is a thickness of limestone amounting to 4,400 and 5,400 feet respectively.

As will be seen, the thickness of limestone in the Grenville series is much greater than in any of these.

It may be safely stated that the Grenville series presents by far the thickest development of pre-Cambrian limestones in North America, and that it presents at the same time one of the thickest, if not the thickest, series of pre-Cambrian rocks on this continent.

AREAL EXTENT OF THE GRENVILLE SERIES

Not only has the Grenville series a great thickness, but it has a very wide areal distribution. It is exposed along the southern border of the protaxis from the Georgian Bay eastward to a point considerably beyond the St. Maurice River, which flows into the St. Lawrence at the town of Three Rivers. It extends to the northward in the Laurentian Highlands at least as far as the latitude of Cobalt, although not reaching so far west as this point, which lies in a Keewatin and Huronian district. To the southeast it is stated by Professor H. P. Cushing to be exposed at intervals over the whole Adirondack area, while to the southwest deep borings under the city of Toronto have brought up, from beneath the Paleozoic, cores of a white crystalline limestone which evidently belongs to the same series. The area thus

outlined embraces 83,000 square miles. In areal extent, therefore, it can be compared only with certain of the greatest developments of the Paleozoic limestones in North America as for instance the Knox Dolomite of the Southern Appalachians. Over this area of 83,000 square miles, the Grenville series is not, of course, now continuously exposed. It is penetrated in many places by great intrusions of granite and anorthosite. This is especially true of the Adirondack Mountains in which these intrusives are especially numerous. This area, however, is one which was originally undoubtedly covered by a continuous development of the Grenville series.

In all probability, however, the areal distribution of the Grenville series is much greater than this. In many parts of the Laurentian Highlands far to the north of the limit here taken as the boundary of the Grenville series, areas of white crystalline limestone and associated rocks are found which are identical in character with that of this series. Enormous developments of such limestones, identical in all respects with the Grenville series, are, for instance, found about the shores of Hudson Straits. Whether these northern limestones belong to the same series is however not at present known with certainty. Definite information on this point may be obtained as our knowledge of this great northern country becomes more complete. It is furthermore very highly probable, as the Grenville series along the southern margin of the protaxis everywhere disappears to the south beneath the Paleozoic cover, that in this direction it originally had a very much greater extent than that over which it is at present exposed. In this connection it is important to note that the pre-Cambrian limestone series of the Highlands of New Jersey, which has recently been studied by Bayley, has by him been correlated with the Grenville series.[1] The facts, however, in our possession at present show that the Grenville series is one of the greatest limestone series in North America and that it presents, as has been mentioned, the greatest development of limestone known in the pre-Cambrian.

CORRELATION OF THE GRENVILLE SERIES

In connection with the Grenville series one other question presents itself, namely, whether this great series represents a continuous suc-

[1] "Preliminary Account of the Geology of the Highlands of New Jersey," *Science*, May 8, 1908, p. 722.

cession of strata or whether in it there may be two series of identical petrographical character, intimately associated, and which have been subjected to the same intense and widespread metamorphism. The information hitherto accumulated and bearing on the question may be briefly stated. In the report upon the Haliburton-Bancroft area, by Dr. Barlow and the writer, to which reference has already been made, the occurrence of conglomerates at a few separated points in the southern portion of the area is described and the conclusion is reached that certain of these are probably of epiclastic origin and indicate an unconformity in the series. If two series be present, however, the intense metamorphism and folding has rendered it impossible to delimit them in the area embraced by the report in question. When the international committee representing the geological surveys of the United States and Canada (appointed for the purpose of effecting a correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "Original Laurentian Area" and Eastern Ontario) visited the Madoc district, which lies to the south of the Haliburton-Bancroft area, they examined a conglomerate near the town of Madoc and concluded that it probably represented a break in the pre-Cambrian sedimentary limestone series as there developed. Miller and Knight, who visited the district in the autumn of last year, stated in a short paper which appeared in the *Report of the Ontario Bureau of Mines* for 1907 (p. 202), and which was afterward read before the American Geological Society, that "a few days in the field has made the relationship of the sedimentary series quite plain, and the view that the Grenville and Hastings series constitute one series, the former being a more highly altered phase of the latter, is no longer tenable." A careful study extending over many months, however, shows that Logan was quite right and that the comparatively unaltered strata of what he mapped as the Hastings series pass over imperceptibly into the typical Grenville series. What the committee saw, and Messrs. Miller and Knight have substantiated, is that within this unaltered "Hastings series" of Logan, as also probably in the more altered "Grenville" phase of the same rocks, there are two series which are petrographically identical. These series, when worked out, should be distinguished by specific names, as Upper and Lower Grenville, or one may be termed the "Madoc series." Logan's "Hast-

ings series" is the less altered phase of both and to employ it now, to designate either, is to use it in a new sense differing from that of Logan and thereby introduce confusion in the nomenclature. Messrs. Miller and Knight conjecturally set down the lower of these two series, with its enormous body of limestone and other sediments, as Keewatin and as the equivalent to the Keewatin iron formation of Lake Superior, correlating the upper series with the Huronian.

Van Hise in his recent "Presidential Address,"[1] however, very properly declines to accept this view until some evidence has been adduced in favor of such a supposition.

In fact, if conjecture must be indulged in, it is much more reasonable to correlate the whole series, being, as it is, essentially a great sedimentary limestone series, with the Huronian, owing to the fact that as we come east in the Huronian developments of the iron ranges of Lake Superior, limestones become more abundant. The thickest and greatest bodies of limestone in the whole western pre-Cambrian are those of the Menominee Range. It may easily be that still further east the Huronian becomes still more highly calcareous and takes on essentially a limestone facies, while the Keewatin has essentially a pyroclastic development.

But it must be borne in mind that so far as is known at present, the Grenville series may be a distinct entity, separate from either and differing in age from both. This can only be ascertained by a further detailed examination of the intervening areas.

Whatever may be the result of future studies—whether it be established that the Grenville series is to be correlated with members of the pre-Cambrian development in the west or whether it proves to be a series differing in age from any of these—it remains the greatest development of limestone known in the pre-Cambrian of North America and one of the greatest limestone developments of any age.

[1] *Bull. Geol. Soc. of America,* March 30, 1908.

A STUDY OF THE DAMAGE TO BRIDGES DURING EARTHQUAKES.[1]

WM. HERBERT HOBBS

To the study of the damage sustained by buildings during earthquakes a vast amount of attention has been devoted, while other structures, better suited to reveal the nature of the disturbance have hardly been examined at all from the scientific standpoint. This is in part to be explained because the damage has been supposed to result wholly from elastic waves, but in part it has been determined by the obvious necessity of safeguarding the lives of the inmates of the buildings. Adopting the newer viewpoint that the vibrations felt at the surface of the earth are genetically at least a secondary rather than a primary cause of the disturbance, our attention must be turned in a different direction. In place of high structures we must study low ones, and from inspecting damage at isolated points we must note the distribution of the damage along complete sections crossing the affected district. Buildings thus give place in importance to railways, pipe lines, and to metal cables, and in fact to any *continuous* structures of fairly uniform strength and rigidity over long distances. Such structures are suited to register either tensional or compressional stresses.

Railway tracks, now the most generally available of these structures, preserve a record of tension in the tearing out of fish-plates and separation of rail ends, and of compression in the jamming of the joints and the buckling or kinking of the metals. The first and most striking result of observation of the damage to such structures, is the common occurrence of distinctly local maxima of deformation (see Fig. 1, *C* and *D*). The zones of deformation are not always, however, so narrow as in these instances, but may be betrayed by a sinuous course of the rails extending over a considerable fraction of a mile (see Fig. 1, *A*).

[1] A paper read before the American Association for the Advancement of Science at the Chicago Meeting, December, 1907.

There is a type of structure whose sensitiveness for recording earth movements seems never to have been given its due weight, for we look in vain for any grouping of the evidence from damage sustained

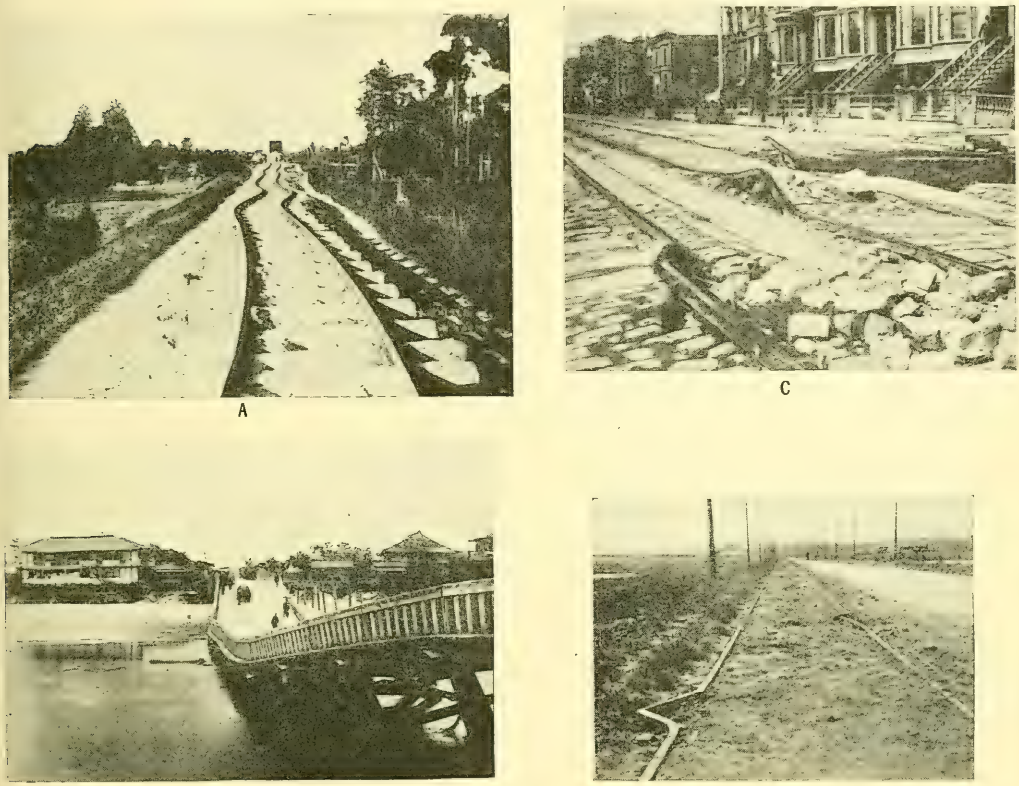


FIG. 1.—(*A*) Compressed railway tracks in the approach to the Kisogawa Railway bridge after the Japanese earthquake of 1891 (after Milne and Burton). (*B*) Biwajima Road bridge thrown into a serpentine form during the Japanese earthquake of 1891 (after Milne and Burton). (*C*) Car tracks which have sustained a sharp local compression along an oblique intersecting line. California earthquake of 1906 (after H. W. Fairbanks). (*D*) Electric railway tracks near San Francisco, showing a sharp local compression along an oblique intersecting line. California earthquake of 1906 (after Moran).

by bridges at the time of earthquakes. The writer has recently noted in a brief statement the rather common observation that the abut-

ments of bridges have approached each other during earthquakes,[1] and it is now proposed to assemble the evidence on which the statement was based and to suggest an explanation of the phenomenon. It is to the descriptions of destructive earthquakes of comparatively recent date and in countries of considerable industrial development that we must go for our evidence, since it is the bridges of better construction, and the railroad bridges especially, which furnish the most satisfactory evidence. Data are available from the Charleston earthquake of 1886, the Japanese earthquakes of 1891 and 1894, the Indian earthquake of 1897, the California earthquake of 1906, the Kingston earthquake of 1907, and probably others.

THE "CHARLESTON" EARTHQUAKE OF AUGUST 31, 1886

A typical illustration is here furnished by the Charleston and Savannah Railway bridge over the Ashley River after the earthquake of August 31, 1886.[2] The diagrammatic sketch after Dutton, which is reproduced here in Fig. 2, is especially valuable, since it well illustrates a characteristic distortion of the abutments of bridges observed after a destructive earthquake. Of this bridge Dutton says:

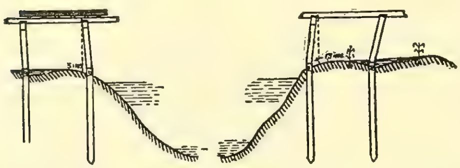


FIG. 2.—Bridge over the Ashley River, South Carolina, as it appeared after the earthquake of August 31, 1886 (after Dutton).

> The approach to the bridge is by a long embankment, traversing a marshy flat with an ascending grade, giving place near the bridge to a high trestle. An embankment and trestle lead to the bridge from the opposite side. The draw-bridge was closely jammed by the earthquake, the immediate cause being the sliding or creeping of both river banks toward the center of the stream, carrying the trestle with them. West of the river the joints of the rails were torn open by tension produced in this sliding motion. (P. 304.)

The only other railroad bridge within the so-called "epicentral tract" of this earthquake was on the same line of railway near Rantowles Station:

[1] *Earthquakes, An Introduction to Seismic Geology* (D. Appleton & Co.), 1907, p. 230.

[2] C. E. Dutton, "The Charleston Earthquake," *9th Annual Report*, U. S. Geol. Survey, p. 231.

The piling, which affords no indication of relative movement from inclosing earth, has dragged attached bents from vertical positions and jerked the superstructure from opposite sides to the center line with violence, wrecking rails, bulging up stringers, forcing up the caps of bents which were mortised with four-inch tenons, and in general affording liberal indications of shortening of the distance separating banks. (Pp. 304, 305.)

Of culverts and trestles there were many which received serious damage at the time of this earthquake, and all appear to have been deformed by a longitudinal compression.[1]

THE MINO-OWARI EARTHQUAKE OF OCTOBER 28, 1891[2]

This earthquake has furnished some of the best illustrations anywhere available of the nature of damage to bridges during a destructive earthquake.

The Biwajima-Bashi, a wide wooden carriage bridge across the Schonaigawa, was completely wrecked. It lies in the bed of the river in a curious serpent-like twisted form. The river is very low, and the continuity of the bridge was nowhere actually broken, so it was possible to walk across, though the feat was not an easy one on account of the angle at which the footway was canted. (See Fig. 1, *B.*)

A brick railway bridge near the Biwajima River presented a singular appearance. The abutments which ordinarily had been perpendicular, had apparently been pushed backward to the right and left, and the arch which they ordinarily supported lay in two huge quadrant shaped masses blocking up the roadway between them. (See Fig. 3, *D.*)

Speaking of the Kisogawa bridge, Milne and Burton say:

a) *Approaches.*—A more important feature is, however, the serpent-like bending of the line. Not only have the metals been deflected, but the embankment has suffered a parallel deformation. It seems as if the country here—and similar appearances are presented at other places—had been subjected to a permanent longitudinal compression. At each of these bends, although not shown in the present picture, to the right and left of the line, there is generally a slight compression in the general contour of the country which possibly may mark the line of an ancient watercourse, in which we may imagine that the materials are softer than elsewhere. (See Fig. 1, *A.*)

b) *Bridge.*—The lateral shifting of the foundations by which the distances between the piers have been reduced, has been the result of a permanent compression which, had the bridge been represented by a line across the river bed, would have been contorted into one or more snake-like bends. (See Fig. 3, *A.*)

[1] *Loc. cit.*, pp 286, 290.

[2] John Milne and W. K. Burton, *The Great Earthquake in Japan*, 1891, Yokohama, (Lane, Crawford & Co., 1892), 2d ed.

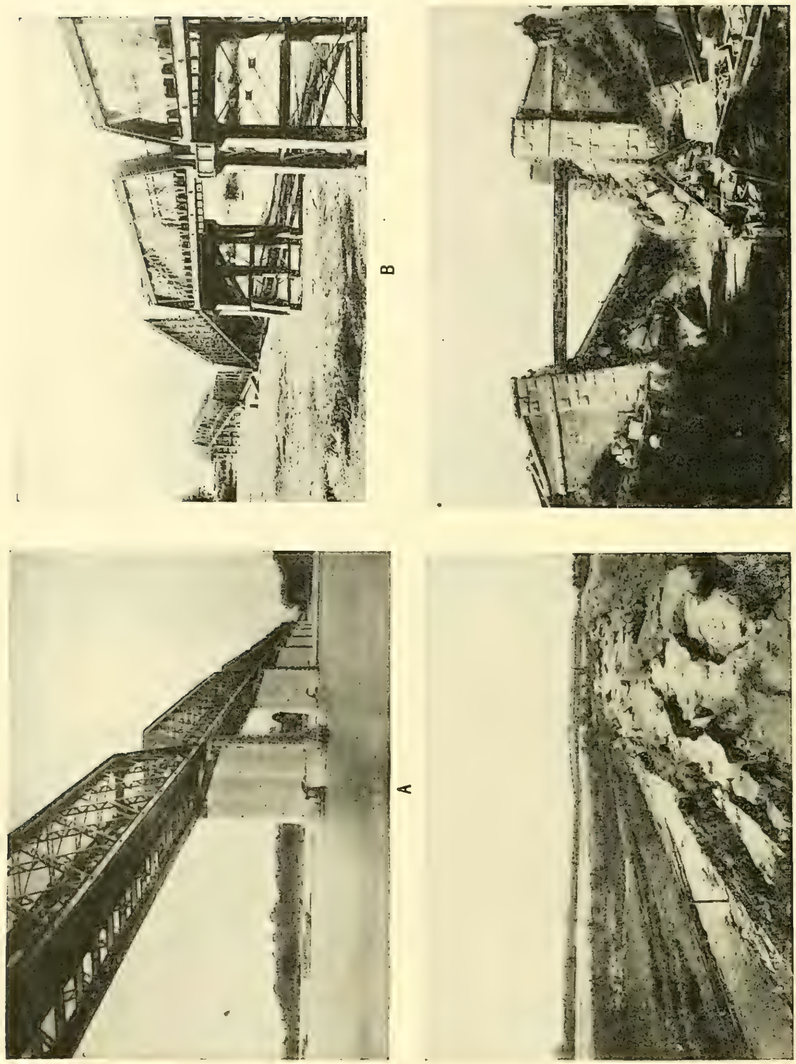


FIG. 3.—Damage sustained by bridges during the Japanese earthquake of 1891 (after Milne and Burton). (*A*) Kisogawa Railway bridge with fractured piers. (*B*) Nagaragawa Railway bridge fallen in part into the river bed but still continuous. (*C*) Nagaragawa bridge (in distance) with fissured river banks in foreground. (*D*) Biwajima Railway bridge showing distorted abutments and fallen arch.

Speaking of a bridge near the Kiso River and also near the great Kisogawa bridge just referred to, the authors state that this bridge consists of two spans of 70-foot plate girders, and add:

The end walls or abutments are cut through horizontally, and the solid brick "well" which supported the central pier between the spans is broken across like a stick. The upper portion of the well has moved three feet sideways on the line of fracture.

From the photograph it will be seen that while the south abutment is broken through horizontally, the side walls are cracked diagonally.

At the end of the crack where it rises from the ground it was discovered, on taking the brick work down for reconstruction that the earthquake had thrown the foundations of each wing wall 10 inches away from the well formation of the abutment which originally was touching the foundations. (See Fig. 5, *A*.)

Thus in this case, also, it appears that the abutments showed evidences of the shortening of the distance between them in their tilting back from the river.

Probably the most interesting and instructive example yet furnished of the deformation of bridges during earthquakes is that of the railway bridge over the Nagara River (See Fig. 3, *B* and *C*).

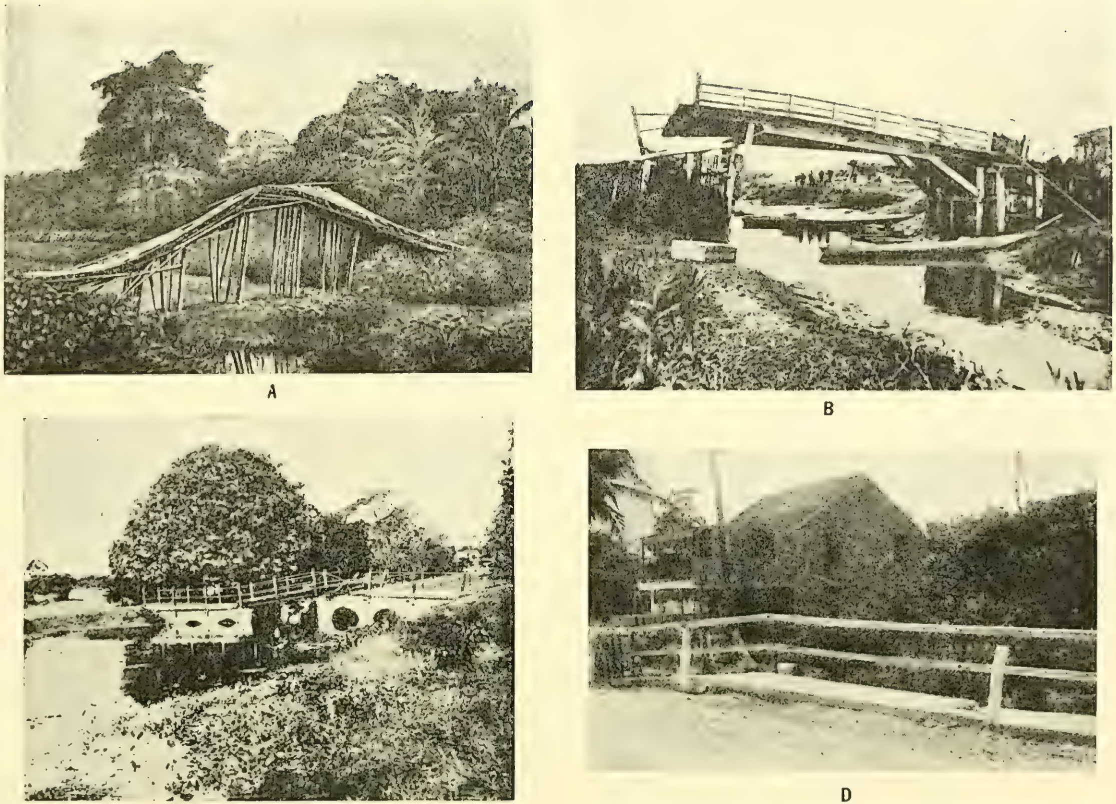
The main part of the bridge consists of five independent thrust girders of wide span. The piers at the two ends of one of these girders are completely wrecked and the girders have fallen bodily into the bed of the river. The piers on either side of the two mentioned are partly wrecked, and the girders between them and the first-mentioned girders rest, each with one end in the river bed, the other on the top of the partly destroyed pier. The remaining girders are in their original positions or nearly so.

It will again be observed that the portion of the bridge which has fallen relative to the part which remains standing, has been thrown some distance out of a straight line.

Examination has shown that this displacement is not simply a displacement of the upper-work of the bridge, but the ground with the screw-pile foundations has been shifted a distance of several feet up the stream.

The embanked approach to the Nagaragawa bridge has been thrown into a regular series of undulations of such extent that, looking along the line eastward from the eastern abutment, the appearance is almost that of looking along a switch-back railway.

It will not fail of observation that the bridge spans, though fallen in some instances from their foundations, and further shifted some distance up stream, approximate to curved sections, in both horizontal and vertical planes, yet maintain their continuity across the river



A B C D

FIG. 4.—(*A*) Bridge over a stream at Rangpur after the Assam earthquake of 1897. The center of the stream channel has been raised (after R. D. Oldham). (*B*) A rustic bridge after the Schonai (Japan) earthquake of 1894, with its girder pushed up over the abutment (after Kikuchi). (*C*) Bridge over a canal at Rangpur after the Assam earthquake of 1897. Girder pushed up over abutment (after R. D. Oldham). (*D*) Bridge near Kingston damaged by approach of abutments during the Jamaica earthquake of 1907 (after Fuller).

from bank to bank. The narrowing of the distance between banks which is thus indicated is considerable. This is shown in Fig. 3, *B* and *C*.

EARTHQUAKE OF SCHONAI, JAPAN, IN 1894

An interesting illustration of the approach of the abutments of a rustic bridge during the Schonai earthquake is seen in Fig. 4, *B*. In this case the girder has slid up over one of the abutments so as to allow the latter to move toward the stream.[1]

GREAT ASSAM EARTHQUAKE OF JUNE 12, 1897[2]

Next to the Mino-Owari earthquake this great disturbance has furnished perhaps the largest number of examples of wrecked bridges. These will be discussed, therefore, in some detail:

Bridge on Grand Trunk Railroad west of Gauhati:

At the western end of the Gauhati Bazar is a bridge of three girders carrying the Grand Trunk Road over a small stream, which here joins the Brahmaputra. The original length of the bridge, as measured along the hand rail, was 99 feet, 4 inches, while the present length, between the same points, is 97 feet, 10 inches. The bridge has therefore been shortened 18 inches. This has been caused by fissuring of the banks on both sides of the stream, the abutments having been carried forward. One of the piers has been tilted over probably by the thrust of the girder. There are no cracks in the abutments. (P. 266.)

Assam Bengal Railway (Reported by T. D. Latouche):

I went out along this line as far as the bridge over the Kapili River about forty-one miles from Gauhati. The rock cuttings, in gneiss, have not been affected in the slightest degree by the shock, but where the line passes over alluvium, the embankment has settled down, carrying the rails with it. Many of the culverts are badly cracked, apparently from the same cause as has affected the bridge mentioned above at Gauhati, viz., the fissuring of the banks of the streams and the consequent sliding forward of the abutments and wing walls. The piers of the large bridge over the Kapili are cracked through horizontally at about 2 feet above the ground level, and the girders have shifted lengthwise on top of the piers. (P. 267.)

Bridge over the Bara Khal (Reported by G. E. Grimes):

In the case of the bridge over the Bara Khal the piers have fallen right over into the river and disappeared entirely; before the earthquake this bridge had

[1] D. Kikuchi, *Recent Seismological Investigations in Japan*, Pub. E. I. C., No. 19 (Tokyo), 1904, Fig. 46.

[2] R. D. Oldham, *Mem. Geol. Surv. India*, Vol. XXIX, (1899).

eleven piers standing, each with 9000 cubic feet of masonry, there being three spans of sixty feet and six spans of forty feet, but after the shock only two piers on each bank were left standing and the intermediate space is quite blank. At the time of the shock the two embankments are said by those who were present to have moved toward one another and then apart, when the telegraph wires were snapped across and some of the insulators were hurled violently for a considerable distance backward from the river. (P. 295.)

The damage to the bridges on the Assam Bengal Railway is thus summarized by Mr. Grimes:

The abutment walls are cracked or broken and have come to, shortening the span. . . . This coming-to of the abutment walls is often quite considerable, and in spans of twenty feet it is sometimes as much as a foot. Accompanying this movement we, in almost every case, see that on one or both sides of the bridge the embankment has sunk several feet. When the bridges have wing walls to the abutment, this forward movement has cracked and considerably damaged them, but where, as in the case of many of the smaller bridges, there are straight return walls, the pressure has acted along the length of the walls and not across them, and so the bridges have mostly escaped with little or no damage. The coming to of the abutments and consequent shortening of the span has either resulted in the buckling up of the girders in the center, or the girders have pushed back on and broken off the balance walls of the abutments. In a few cases the piers of the bridges have been tilted over to the side, but in most cases only inwards. (P. 296.)

Gauhati Road Bridge over Umkra River:

The large bridge on the Gauhati Road about one and one-half miles from Shillong, over the Umkra River, has suffered severely. The abutment on the southeast side fell entirely, carrying the girders with it. The two piers and the abutment on the northwest side, which are of more recent construction, remained standing, though somewhat cracked. (P. 271.)

Bridge near Shampur on Kuch Bihar Railway:

Near Shampur, also, the hexagonal brick piers of one of the bridges have been broken through horizontally and the upper portion has shifted slightly: this form of fracture appears to have been rather common, and though at first supposed to be of no great moment, was subsequently found to render the bridges unsafe for either rapid or heavy traffic. (P. 284.)

Bamboo bridges over canal (reported by H. H. Hayden):

The canal being, as already stated, a line of weakness, it is not surprising to find that the banks on each side are cut up by fissures, while its bed has risen in some cases through several feet, the central portion being now above the water: this is well shown by the bamboo bridges which have been shot up in the center (see Fig. 4, *A*). The same effect is seen in numerous places between Rangpur and Kuch Bihar, where bridges of small span cross canals or swamps. If the

bridge has a central pier then the pier has been shot up and the bridge broken. This is, however, in some cases due partly to a sinking of the abutments as well. (P. 285.)

Manshai Bridge:

In the neighborhood of Dewan Hat, however, the line has suffered severely, and the bridges, particularly that over the Manshai River, have been broken

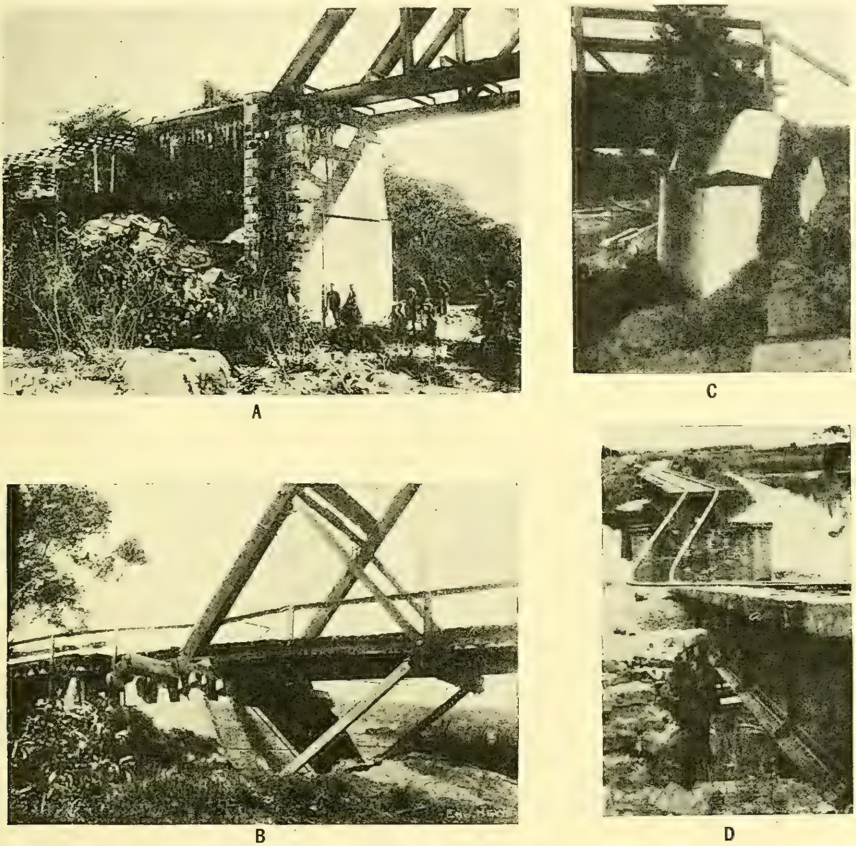


FIG. 5.—(*A*) Bridge of Tokaido Railway near the Kisogawa with abutment broken by the approach of river banks during Japan earthquake of 1891 (after Milne and Burton). (*B*) Bridge over Salinas River with distorted abutment damaged during California earthquake of 1906 (after Derleth). (*C*) County bridge over Pajaro River at Chittenden, California, after the California earthquake of 1906 (after Dudley). (*D*) Manshai bridge after the Assam earthquake of 1897 (after Oldham).

(see Fig. 5, *D*). At about seven miles south of Kuch Bihar, a small bridge passing over a water channel in swampy land has been damaged by the thrusting-up of the central pier. (P. 287.)

Examination of the photograph of the Manshai bridge reproduced in Fig. 5, *D*, will show in the lateral kink of the rails and the dropping of the span conformity with the general rule that there is a shortening of the distance between piers.

CALIFORNIA EARTHQUAKE OF APRIL 18, 1906

The report upon this earthquake[1] purporting to discuss the effect on structures particularly is a disappointment in that a single bridge only is mentioned, and this in such ambiguous language that the nature of the damage sustained can only be guessed.[2] The bridge referred to is that of the Southern Pacific Railway where it crosses the Pajaro River near Chittenden Station. Abundant material for a study of the damage to bridges existed, and we are fortunate in having been able to collect the data concerning some interesting examples. One of these is illustrated by a photograph of the county bridge over the Pajaro River at Chittenden, which, as well as any we have seen, illustrates a typical effect of earthquakes upon such structures (see Fig. 5, *C*).[3]

The damage sustained by the Salinas Highway Bridge in the same province has been described and photographed by Derleth[4] (see Fig. 5, *B*), and is shown to conform to the rule which elsewhere obtains. The bridge rests on pile-bent abutments. The north abutment was not disturbed, but the south abutment was bent back from the river at the top and it is stated that the ground moved out toward the river beneath it a distance of six feet. A three-inch oil pipe-line crossing the bridge was bent into an *S* and ruptured.

In the same article Derleth has given us a clear account of the damage to the Southern Pacific Railway bridge over the Pajaro River, from which it appears that this case is an unique exception to

1 Grove Carl Gilbert, Richard Lewis Humphrey, John Stephen Sewell, and Frank Soulé, *The San Francisco Earthquake and Fire of April 18, 1906, and Their Effect on Structures and Structural Material*, Bull. 324, U. S. Geol. Surv., 1907, pp. 170, pls. 56.

2 *Loc. cit.*, p. 20, Pl. XI *A*.

3 Reproduced in Salisbury's *Physiography* (New York, Holt & Co., 1907), p. 424.

4 Charles Derleth, Jr., C. E., "The Destructive Effect of the San Francisco Earthquake of 1906," *Engineering News*, Vol. LV, No. 26 (June 28, 1906), p. 712, Figs. 15 and 16.

the general rule. The bridge lies across the rift line of California at a very acute angle and it is probable that the large shiftings on this line have here played an important rôle in producing the damage.[1] The pulling of the girder out of its seat on the south abutment apparently indicates a widening of the distance between banks during the earthquake, and this would appear to show that the shear on the rift plane is here in a contrary sense to that which has generally obtained at other places.

Through inquiry of the engineering department of the Southern Pacific Railway Company it was found that in addition to the Pajaro bridge above mentioned slight damage was sustained in other sections of the road. Some few trestles were thrown out of line and "two small drawbridges were affected slightly by the movement of the landing piers toward the center piers—just enough in each case to bind the bridge."[2] On the Atchison, Topeka and Santa Fe Railway there was a Bascule bridge in which the two leaves approached each other so closely, as a result of the disturbance, that the bridge was rendered inoperative until changes were made. This gradual approach of the two abutments has continued in the absence of sensible shocks during the succeeding two years.[3]

In the report of the subcommittee on railway structures to the General Committee of the American Society of Civil Engineers[4] it is stated that embankments crossing marshy ground generally sank (sometimes as much as eleven feet), and that trestles in soft material moved or were thrown down. Railway drawbridges across little creeks and inlets about the Bay of San Francisco "were affected by a slight movement of their piers, in many cases resulting in the bridge binding so that it could not be opened until some repairs were made." On the California and Northwestern Railway the bridge at Bohemia and the one over the Russian River at Healdsburg were

[1] *Loc. cit.*, p. 711.

[2] Letter from J. H. Wallace, Assistant Chief Engineer, Southern Pacific Company.

[3] Letter from H. C. Phillips, Chief Engineer, A. T. and S. F. Ry. Co.

[4] "The Effects of the San Francisco Earthquake of April 18, 1906, on Engineering Constructions," Report of a general committee and six special committees of the San Francisco Association of Members of the American Society of Civil Engineers (with discussions by twenty-three others, Ed.), *Trans. Am. Soc. Civ. Eng.*, Vol. LIX, (December, 1907), pp. 208–329.

both slightly shifted on their piers at one end. At Duncan's Mills on the North Shore Railroad a combination span a hundred and twenty feet long "had the eye-bars in the lower chord buckled by movement of the abutments toward each other" (see Fig. 6, *B*).[1]

The sub-committee appointed to investigate highway structures in lieu of a report offered the statement that such structures had been singularly immune from damage. This meager statement is curiously contradicted by the evidence furnished in the printed discussions. The highway bridge across a creek tributary to Tomales Bay near Port Reyes Station, which had eight panels or sections, had its north abutment sink two to three feet and approach the south abutment so much that in reconstruction the north end panel was not used but was in part replaced by an apron (see Fig. 6, *C*).[2] At Watsonville was a bridge which according to Derleth was distorted in the same manner as the Salinas bridge above described and with which it is compared.[3] In each case the deformation was ascribed to "differential surface movement distinct from elastic vibration."

Two additional instances have been mentioned in the report with illustrations by Galloway,[4] to wit: the Alder Creek bridge north of Point Arena in Mendocino County, the other the Gualala bridge south of the same point. The first mentioned (Fig. 6, *D*) now lies on the bed of the stream across the rift line, the other, a steel structure, had one end of the girder dropped twenty-eight feet. These bridges were not examined by the engineers, and the views afford the only evidence at hand.

KINGSTON EARTHQUAKE OF JANUARY 14, 1907

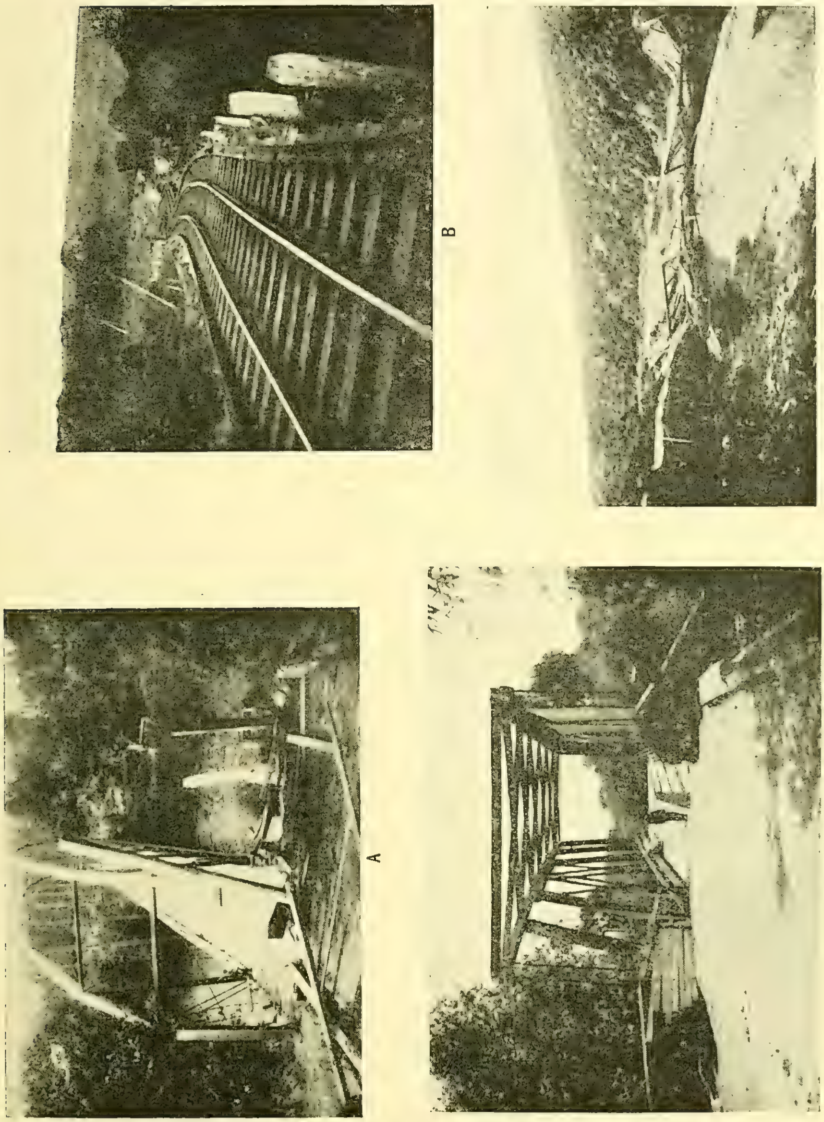
A very recent example which illustrates the usual deformation of a bridge at the time of a destructive earthquake, has been furnished

[1] J. H. Wallace, H. C. Phillips, R. M. Drake, and E. M. Boggs, sub-committee, *loc. cit.* p. 259, Pl. 53, Fig. 1.

[2] H. H. Wadsworth, *M. Am. Soc., loc. cit.*, p. 270.

[3] Charles Derleth, *loc. cit.*, pp. 311–15.

[4] John D. Galloway, *M. Am. Soc. C. E., loc. cit.*, Pls. 57, 58. From a personal letter from Mr. Galloway it is learned that Alder Creek enters the ocean some twenty miles north of Point Arena. The Gualala River is a mountain stream which enters the ocean about the same distance south of Point Arena. The Gualala bridge, which was built some ten years ago, gave trouble from the fact that the ground beneath the piers showed a tendency to slide so that it was necessary to put the bridge up upon a false work and realign the piers.



A B C D

Fig 6

by Fuller's account of the Jamaican earthquake of January 14, 1907.[1] A cement culvert at the mouth of a stream was buckled up and broken through the movement of its walls toward the center of the valley (see Fig. 4, *D*).

It is believed that the above data are sufficiently full and decisive to warrant the conclusion that during a destructive earthquake the banks of valleys generally draw together so as to shorten the intervening distance. The examples of deformed bridges which have been offered in evidence, have not been selected for the purpose of proving a point, but include all which have come to the writer's attention. The unique exception to the law which otherwise controls, is furnished by the railway bridge over the Pajaro River damaged during the California earthquake of 1906; and, inasmuch as this bridge lies across the rift line at an acute angle it seems likely that special shearing movements along the rift plane have here been of larger measure than the normal contraction of the valley.

It appears, further, to be a fact of general observation, that a fissure or series of parallel fissures open during earthquakes along the banks of rivers parallel to their courses (see Fig. 3, *C*). According to Milne[2] within the Aichi prefecture in Japan, after the earthquake of 1891, more than four hundred miles of river banks, water trenches, and roads were found destroyed through action of this kind. On river banks the fissured zone and hummocky ground looked as though gigantic plows had torn out furrows several feet in width and sometimes as much as twenty feet in depth, and this character of the surface extended from ten to fifty yards from the river. Such structures can be only in part explained through the shaking down of loose material such as is found in a railway embankment on which the tracks approach bridges, for the reason that such mere removal of support to rails should give the effect of tension rather than compression.

Thomas Oldham, who first seriously studied the fissured river banks in connection with the Cachar (Indian) earthquake of January 10, 1869,[3] went out from the conception of an earthquake centrum

[1] M. L. Fuller, "Notes on the Jamaica Earthquake," *Jour. Geol.*, Vol. XV, 1907, pp. 718, 719.

[2] John Milne, *Seismology*, p. 148.

[3] *Quart. Jour. Geol. Soc. Lond.*, Vol. XXVIII (1872), p. 255. See also *Mem. Geol. Surv. India*, Vol. XIX, Pt. 1, pp. 52–56, Pl. vi.

explained the cracks as due to earth waves, and assumed that a single crack, if one only was formed, opened just a half-wave-length back from the river's edge on either side.

When we take into account the observed effect of the earth movements upon bridges, it is clear that something quite different from the mere passage of an earth wave must be invoked in order to explain these geological changes. Not only is the space between valley walls in part closed up, but for a considerable distance back from the banks the bridge approaches show the effect of compression (see especially Fig. 1, *A*). The piers of the bridge which rest upon the stream bed also suffer changes not explainable, upon Oldham's theory (see Fig. 3, *A* and *B*). Whether occupied by streams or not (see Fig. 3, *D*) it seems to be clear that the vicinity of valleys is marked by unusual surface compression in a direction at right angles to the valleys.

It is perhaps unnecessary to here bring forward the evidence obtained from observations of a different kind that local compression of the ground actually occurs during earthquakes. On the one hand, there are the continuous stone curbings and buried metal pipes which are found buckled up from the surface of the ground; and on the other, there are the many variations in the longitudinal shear along fault lines which must be accounted for either through differential contraction, expansion, or both.[1] On the Baishiko fault opened in Formosa on March 17, 1906, a change in the direction of the longitudinal shear between two stations less than three-fourths of a mile apart, indicated a change in linear distance between the two points before equally distant of about fourteen feet.[2]

That the changes of superficies to which we have called attention are wholly restricted to the mantle of unconsolidated rock material is most improbable; though, as we shall see, there is reason for supposing that it is locally much larger within the mantle than within the underlying rock. To account for an extension of surface of any portion of the consolidated outer shell of the lithosphere, it is only necessary to assume a very slight increase of each of the joint spaces present within the rock. A contraction of the surface area may,

[1] For examples see the author's *Earthquakes*, pp. 62, 66, 73–75, 228–31.

[2] Omori, *Bull. E. I. C.*, Vol. I, No. 2, Pl. xvii.

perhaps, likewise be best explained through a change, and here a reduction in width, of individual joint spaces. To this change may be added the effect of some actual compression of the unfractured

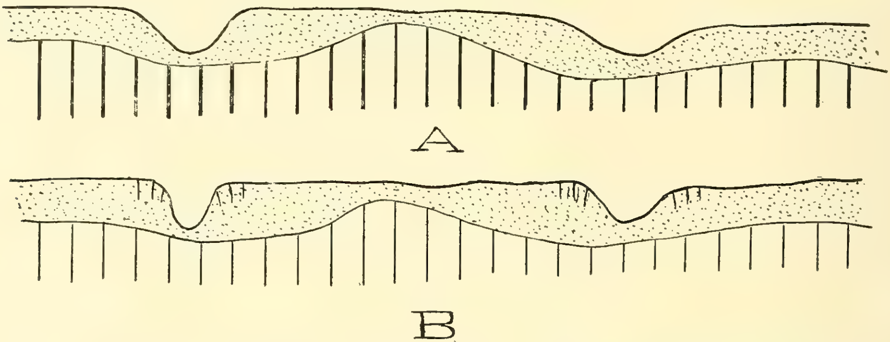


FIG. 7.—Diagram to illustrate the narrowing of valleys during earthquakes as a result of crustal contraction, (*A*) before contraction; (*B*) after contraction.

portions of the shell. In Fig. 7 let *A* represent in its lower portion a section of the outermost consolidated shell of the lithosphere, and in its upper portion the mantle of unconsolidated deposits in which the

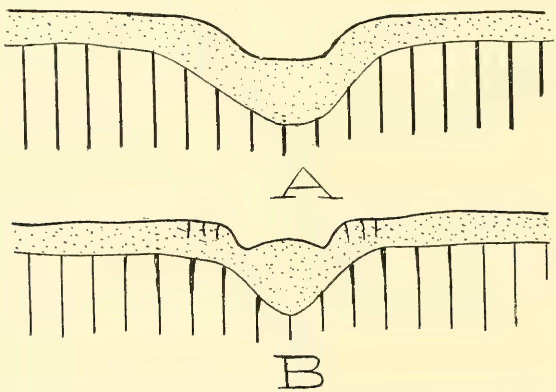


FIG. 8.—Diagram to illustrate the pushing up of the beds of rivers during earthquakes as a consequence of crustal contraction, (*A*) before contraction; (*B*) after contraction.

valleys have been cut. As the compression of the shell reduces the width of the joint spaces and otherwise diminishes the superficies of the shell, its envelop of loose material by reason of its lack of

rigidity is incompetent to transmit the same stresses, and hence tends to remain in *status quo*. In the mantle a slip over the basement floor of rock will take the place of a more uniformly distributed adjustment within the floor. The valleys which intersect the mantle, must, in consequence, reveal an amount of crustal contraction far in excess of the average for the district (see Fig. 7, *B*).

Wherever rock valleys interrupt the surface of the shell beneath a newer valley in the mantle of loose soil (see Fig. 8, *A*), that portion of the shell which lies outside the level of the bottom of the rock valley, will by reason of the breaks in its continuity be less capable of transmitting the compressive stresses. This may otherwise be expressed by saying that this outer layer is not fully included in the pinch to which the layer immediately below it is subjected. A consequent reduction of its competency to transmit the earth's stresses will be greatest for the immediate vicinity of the valleys, and hence the joints will there be closed by a portion only of the average amount. The walls of the rock valley must therefore tend to approach with the result that they will push up the center of the river bed into a definite ridge, and further give the effect of a settlement at the banks where abutments are placed (see Fig. 8, *B*). Next to the narrowing of the distance between banks and the accompanying parallel fissuring, these changes are, as we have seen, the ones most frequently observed along rivers after a destructive earthquake.

UNIVERSITY OF MICHIGAN
May 3, 1908.

THE DEVELOPMENT OF A CARBONIFEROUS BRACHIOPOD, *CHONETES GRANULIFER* OWEN

F. C. GREENE

INTRODUCTION

Through the kindness of Professor J. W. Beede the writer had placed at his disposal for study a large collection of *Chonetes granulifer*, the adults alone probably numbering two thousand specimens. The majority of these specimens are finely preserved and this together with the great range in their size, gives an excellent opportunity for a study of the development of the species.

Chonetes granulifer has been found in the following horizons arranged in descending order:

Permian Series	Ft. Riley limestone. Wreford limestone.
Pennsylvanian Series	Neosho shale. Florena shale. Cottonwood limestone. Eskridge shale. Neva limestone. Elmdale formation. Americus limestone. Emporia limestone. Burlingame shale. Howard limestone. Severy shale. Topeka limestone. Deer Creek limestone. Lecompton limestone. Oread limestone. Kickapoo limestone. Stanton limestone.

First will be taken up a study of the form from the Florena shales at Florena and Grand Summit, from which a complete series was obtained, and then a study of the development based on this series. This study has been under the direction of Professors E. R. Cumings and J. W. Beede of Indiana University, and the author wishes to

express his deep gratitude for their aid and assistance. The photographs for the plates were also made by Professor Cumings.

Owen's type specimen of *C. granulifer* came from the Carboniferous limestone, near the mouth of Keg Creek, Iowa.[1] This locality has never been definitely correlated with the Kansas section, but as near as can be made out from Meek's discussion of the rocks of the Missouri River section[2] and Owen's description[3] of the locality from which the type specimens were taken, as correlated by Beede and Prosser,[4] it appears to come from some horizon between the Topeka and the Tecumseh limestones, probably nearer the Deer Creek limestone than any other. The material which the writer used, contained specimens covering practically the entire range of the species, including the equivalent of the horizon from which the types were taken.

SPECIFIC CHARACTERS

Mature form.—Shell semi-circular in outline, having the greatest breadth at the hinge-line, with cardinal angles somewhat attenuate. The size of the shell varies greatly. Size of largest specimen, 33 mm in width by 19 mm in length. Average size of adult, 28 mm in width by 15 mm in length. The shape also varies in that the cardinal angles of some specimens are much more mucronate than in others (Plate I) and in some specimens there is a tendency to develop a mesial sinus in the ventral valve. Both of these characters are seen in Plate I, rows 3, 4.

Dorsal valve.—In the Grand Summit specimens (the most perfectly preserved in the lot) the dorsal valve is concave to the extent of two or three mm. This valve is ornamented with radiating striae and concentric lines of growth around the margin. The striae number about fifty near the beak but at the frontal margin increase to about one hundred and fifty by implantation. The shell is punctate in the furrows between the striae. The striae become obscure on approach-

[1] Owen, *Geol. Rep. Wis., Iowa, and Minn.*, p. 583.

[2] Meek, *U. S. Geol. Surv. Nebr.*

[3] Owen, *Geol. Rep. Wis., Iowa, and Minn.*

[4] Prosser, "Comparison of the Carb. and Penn. Form. of Neb. and Kans.," *Jour. Geol.*, Vol. V, pp. 1–16, 148–72.

ing the hinge-line. Immediately under the beak, this valve is at first convex, but becomes concave farther forward.

Ventral valve.—The convexity of this valve exceeds the concavity of the dorsal valve to a very great extent in some specimens. In other specimens this valve follows the dorsal valve closely. The striae of this valve are similar to those of the dorsal. Shell punctate in the furrows between the striae. What appear to be large punctae are scattered over the surface of this valve. These are lighter in color than the rest of the surface and are largest at the anterior margin, growing smaller and more thickly set toward the beak. They possibly correspond to the spines of Producti.

The beak projects slightly over the hinge-line. Cardinal area long and narrow; longer than the greatest width of the shell farther forward. It lies at an angle of 45° to the plane of the shell (Plate II, Fig. 12, 13) grooved with horizontal striae; the greater part of the area is on the ventral valve. The hinge areas of the two valves form an obtuse angle.

Two plates of the cardinal process of the opposite valve partially close the delthyrium. The hinge area of this valve is bordered by a row of seven to eleven spines on each side of the beak, growing larger toward the cardinal extremities. This valve is the larger of the two (Plate IV, Fig. 4).

Interior of dorsal valve (Plate II, rows 3, 4).—Convex. Hinge-line straight. The cardinal process is bifid, stands at an angle of 120° with the plane of the valve and is one millimeter in length. On the ventral side of this process is a pit which corresponds to the convexity mentioned just in front of the beak on the exterior of the dorsal valve. From the base of the cardinal process five septal ridges radiate. Two of these pass forward at an angle of 25° or 30° to the hinge-line. They also unite back of the cardinal process to form a little lip over the process. Just back and above them are the two sockets for the hinge teeth.

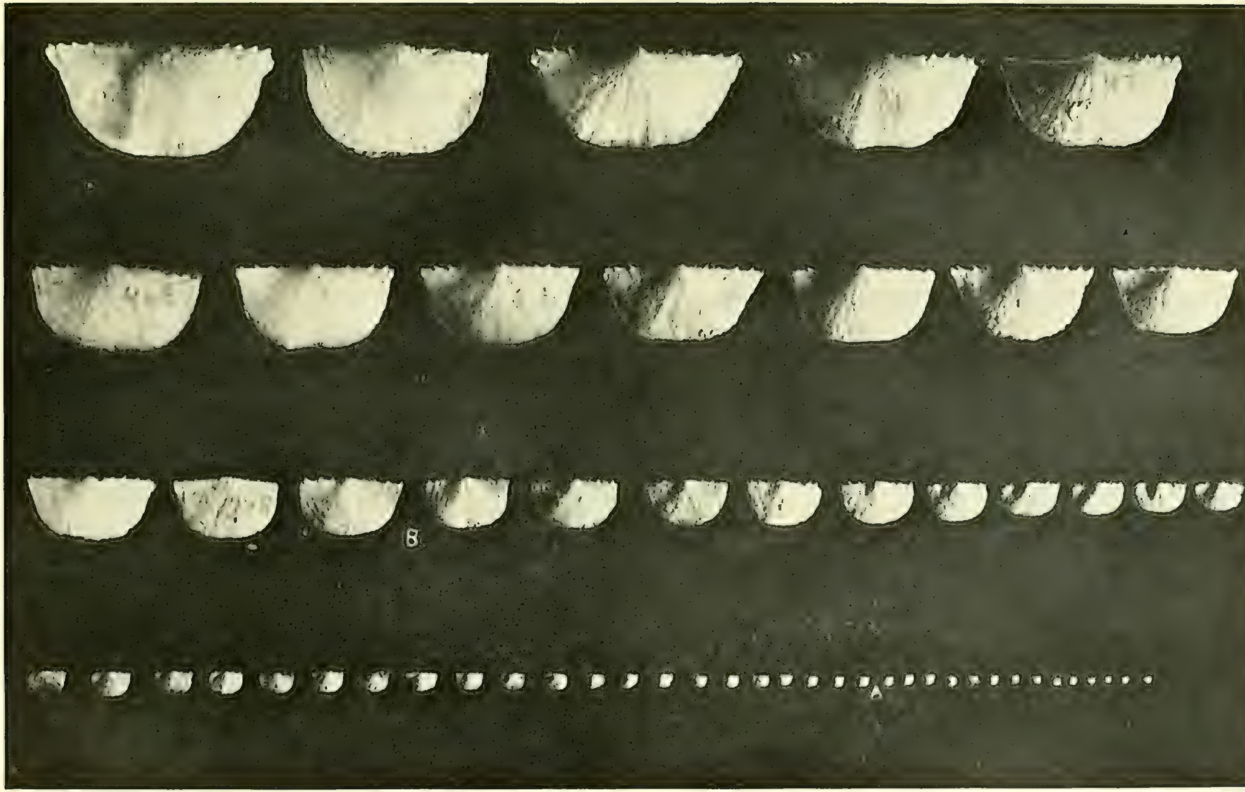
Two other lateral septa pass forward from the edge of the pit at an angle of 70° with the hinge-line. The fifth ridge is the mesial septum. It is at right angles to the hinge-line and extends forward half the length of the shell. With the other four septa it forms the boundaries of the pit. This pit was probably formed at a very young stage, and

Row IV

Row III

Row II

Row I



therefore the septa do not extend to the cardinal process as in some of the Productidae. The scars of the adductor muscles lie on each side of the mesial septum, extending over the next ridge. The brachial markings, shown on a few specimens of this valve, are somewhat obscure, and reniform in shape, pointed at the front. They lie on each side of the mesial septum, just within the row of granules marking the limits of the visceral cavity.

This valve is ornamented with granules (from which the species derives its name of *granulifer*). These are largest and most numerous at the forward edge of the visceral cavity, and the mesial sinus, growing fainter and more thinly scattered posterially. At the anterior margin they also grow fainter until they form distinct radiating rows.

Interior of ventral valve.—Very concave. Granules similar to those of dorsal valve, except that instead of having a group of granules on the anterior end of the mesial septum, they are arranged along its sides and help to form the partition between the long, median adductor muscle scars and the subovate diductor muscle scars. Hinge-line straight, with the exception of the delthyrium. There are two teeth on each side of this opening. The deltidium extends to the beak.

Nepionic form—dorsal valve.—Length 1 mm and breadth 1 mm. Longitudinally semi-elliptical in shape; concavity greater than in mature form in proportion to the size. The convexity mentioned as being opposite the beak near the hinge on the dorsal valve of the mature form, is the most prominent feature of this valve of the incipient form. Here it nearly equals the length of the shell and is more elongate than in the adult. Surface without striae.

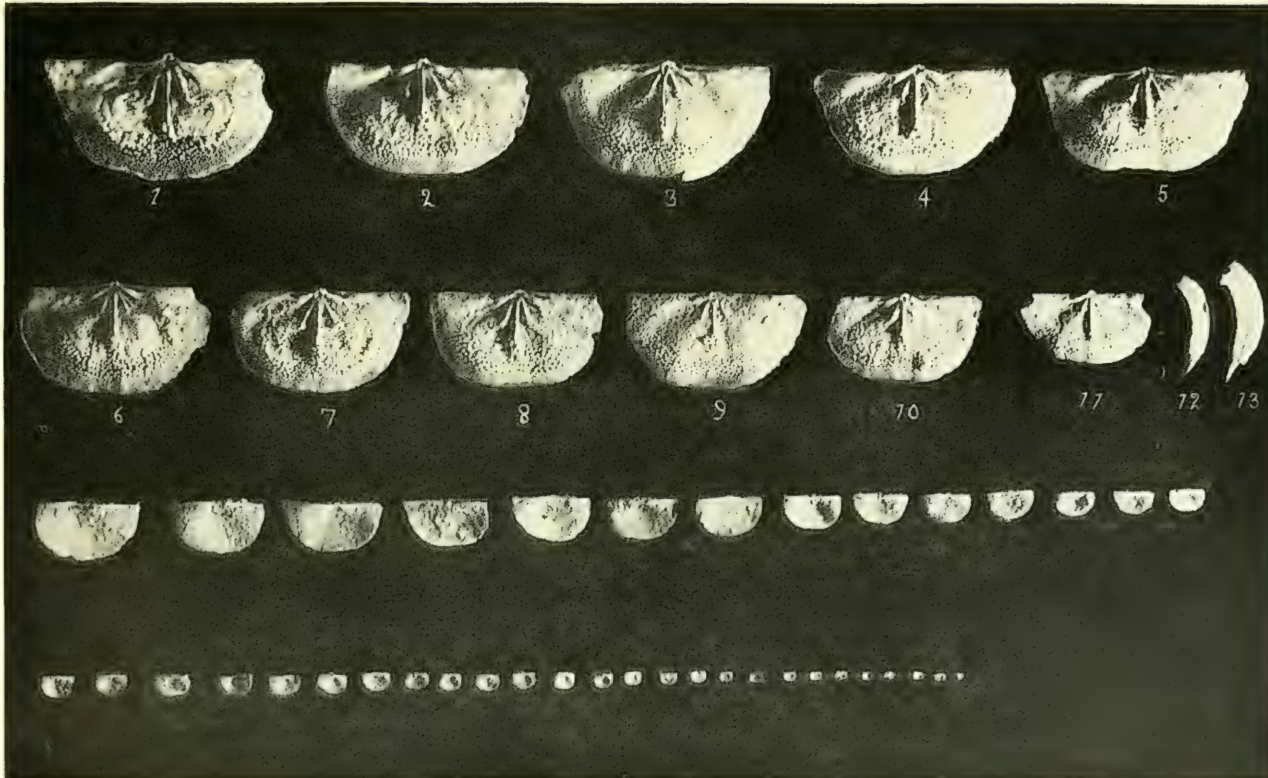
Nepionic form—ventral valve.—This valve is also without striae. On each extremity of the hinge-line is a spine pointed laterally and posteriorly. The ventral mesial sinus is a regular feature of this valve. A sharply outlined pit also occurs regularly on this valve just anterior to the beak.

DEVELOPMENTAL CHANGES

The change in shape may be seen from the following table of the measurements of a series of specimens (not the series shown in Plate I).

1.	0.9 mm×1.0 mm
2.	1.0 mm×1.0 mm
3.	1.0 mm×1.0 mm
4.	1.1 mm×1.1 mm
5.	1.2 mm×1.2 mm
6.	1.3 mm×1.2 mm
7.	1.5 mm×1.25 mm
8.	1.5 mm×1.4 mm
9.	1.5 mm×1.2 mm
10.	1.9 mm×1.4 mm
11.	1.9 mm×1.5 mm
12.	2.0 mm×1.5 mm
13.	2.25 mm×1.5 mm
14.	2.25 mm×1.6 mm
15.	2.5 mm×1.75 mm
16.	2.75 mm×1.5 mm
17.	2.8 mm×1.75 mm
18.	3.0 mm×2.0 mm
19.	3.25 mm×2.25 mm
20.	3.5 mm×2.25 mm
21.	4.0 mm×2.4 mm
22.	3.9 mm×2.5 mm
23.	3.9 mm×2.75 mm
24.	4.0 mm×2.5 mm
25.	4.25 mm×2.9 mm
26.	4.6 mm×2.9 mm
27.	4.75 mm×3.25 mm
28.	5.5 mm× 3.5 mm
29.	6.0 mm× 3.5 mm
30.	6.5 mm× 3.5 mm
31.	6.8 mm× 3.9 mm
32.	7.0 mm× 4.0 mm
33.	8.0 mm× 4.0 mm
34.	9.5 mm× 5.5 mm
35.	10.25 mm× 5.5 mm
36.	11.0 mm× 6.0 mm
37.	11.0 mm× 6.5 mm
38.	13.0 mm× 7.0 mm
39.	13.25 mm× 7.5 mm
40.	16.5 mm× 8.0 mm
41.	16.25 mm× 8.5 mm
42.	18.5 mm× 9.5 mm
43.	19.0 mm× 9.5 mm
44.	21.0 mm× 9.5 mm
45.	20.5 mm×10.5 mm
46.	21.0 mm×10.5 mm
47.	22.0 mm×11.5 mm
48.	23.5 mm×12.0 mm
49.	24.5 mm×13.0 mm
50.	28.0 mm×13.0 mm
51.	24.0 mm×14.0 mm
52.	30.0 mm×15.0 mm
53.	33.0 mm×19.0 mm

Ventral valve (*Plate I*).—The mesial sinus in the youngest specimen is a deep, narrow groove near the beak. This occurs regularly up to the 16th specimen, that is, one about 1.6 mm×1.2 mm in size, after which it occurs only at irregular intervals. From the youngest up, it moves forward so that in the older specimens it is seen on the anterior margin. The striae appear distinctly for the first time on the fifteenth specimen (size 1.6 mm×1.1 mm). On the youngest specimens there are two cardinal spines (Plate IV, Figs. 1–3, 6–8) one on each side of the beak. These are located on the extremity of the hinge-line in the youngest specimen, but as the hinge-line becomes longer, the spines are added successively at the extremities. No. 15 in this series shows the first traces of an additional spine, the new spine appearing, of course, between the original spine and the lateral margin. The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number of spines increases about every eighth or ninth specimen, until it reaches the maximum of eleven on one side of the beak, or twenty-two on the entire hinge-line, which was the largest number noticed.

The shape of the youngest specimen is nearly square, while in the oldest the breadth is nearly twice the length. As will be seen by the above table of measurements, this change from one to the other is somewhat irregular.

The angle formed by the hinge-line and the sides of the shell gradually changes from an angle of 90° to a more and more acute angle, although, as has been pointed out before, the angle varies greatly in the adult (Plate I).

Dorsal valve.—The striae do not appear distinctly on this valve until the twenty-fifth specimen, (4.3 mm×2.5 mm) but this is probably due to the fact that some of the earlier stages have been omitted from this series, and that some are incrusted in the concavity or water-worn, which renders the striae invisible in them.

The most notable thing about the developmental changes in this valve concerns the small convexity mentioned in the description of the incipient form. In the smallest specimen this occupies one-half the space of this valve and extends from the hinge-line forward three-quarters of the length of the shell. In the twenty-eighth specimen it is crowded well up under the hinge-line and is so small in comparison to the size of the shell, that it is hardly distinguishable. In the oldest forms, it is so close up under the hinge-line as to be entirely obscured.

Interior of dorsal valve.—In the interior of this valve, the granules in the visceral cavity continually become fewer as the specimens become larger after the beginning of the ephibic stage. The muscular and brachial markings also become stronger as the size increases.

DEVELOPMENT

As a complete series was obtained from the Florena shales at Florena and Grand Summit, this is used as a basis of comparison. A complete series might have been obtained from Florena alone, but as the adults were compressed, Grand Summit specimens were substituted for them.

STAGES IN DEVELOPMENT

As in any series, the division into stages is more or less arbitrary, but there are several factors which determine approximately the different stages. In the series of ventral valves (Plate I, rows 1 and 2) it will be seen that all stages prior to specimen 14 (point *A* in the plate) are not marked with striae and have only the one spine (Plate IV, 1–3, 6–8) while beyond this point the striae appear and increase in number regularly (Plate IV, fig. 5). This point is taken to mark the end of the nepionic and the beginning of the neanic stage. The latter stage continues until the shell takes on its adult characters, such as the number and strength of the striae, the shape of the cardinal angles, a widening of the hinge area causing the beak to project and the hinge to appear bent. The point *B* about marks this division although it cannot be drawn with the same precision as the division between the first two stages.

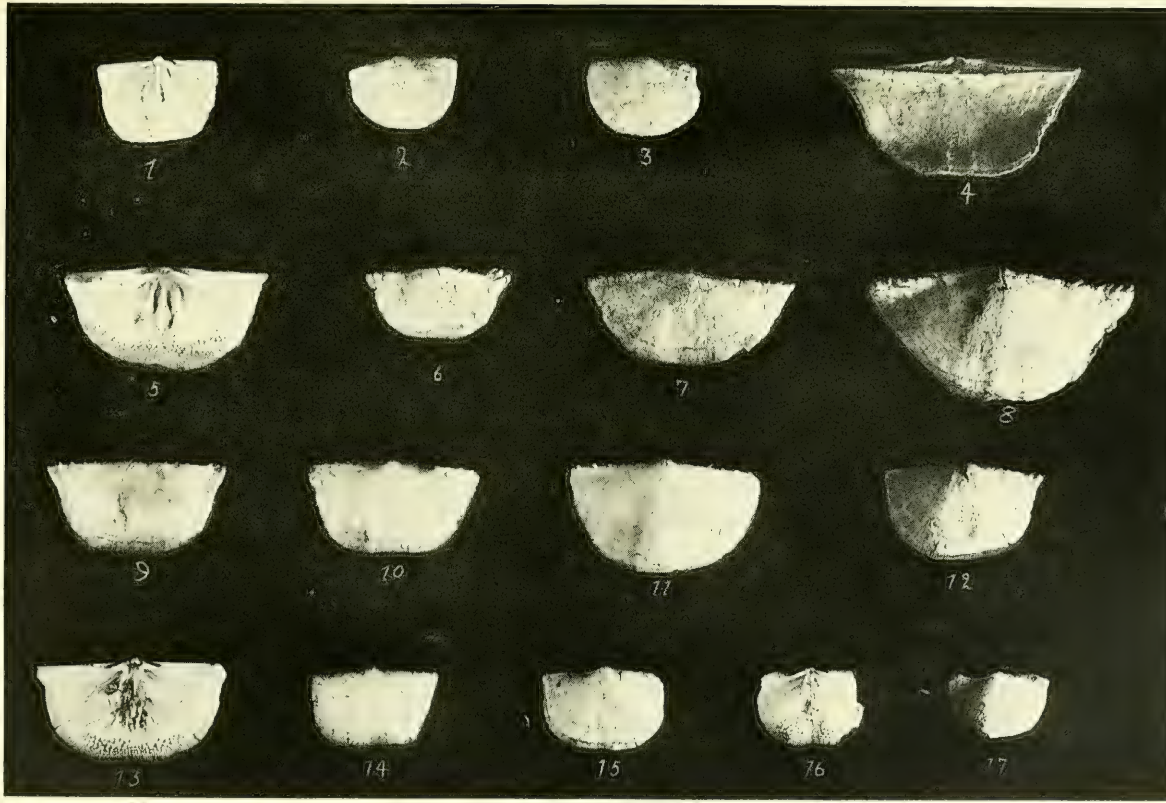
The last two (and largest) specimens in the series represent the old age or gerontic stage. The intervening specimens represent the adult or ephibic stage.

Another series is made to show further the last two stages. This is the series of specimens of the interior of the dorsal valve (Plate II, rows 3 and 4). Here the last specimen represents the gerontic stage. This shows (1) a great thickening of the shell; (2) prominence of the muscular and brachial markings; (3) greater length of hinge-line; (4) a lesser number of granules within the visceral cavity. These characters in this brachiopod are indications of old age.

COMPARISON OF THIS SERIES WITH SPECIMENS OF THE GENUS *CHONETES*, OLDER AND YOUNGER GEOLOGICALLY

It will be noted from the measurements discussed under "Developmental Changes," that the length and breadth of the shell of the nepionic stage are about equal. *This is true of practically all the Silurian and early Devonian species of Chonetes in the adult stages.*

The acceleration in the development of this species is illustrated by the appearance of a pair of spines in the nepionic stage in specimens less than 1 mm in diameter instead of in the neanic stage as in *C. scitulus*, where they first appear on specimens about 2 mm in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diameter.[1] In *C. granulifer* the youngest form obtainable has the spines on the extreme outer edge of the hinge-line.

As mentioned under the description of the Specific Characters in the incipient form of this shell, there is a deep pit or sinus just in front of the beak on the ventral side, and a corresponding convexity just in front of the hinge-line on the dorsal side. This would be an indication of an early species with these characters and also the two preceding. This form is found in the species *Chonetes lepidus* from the Marcellus shale[2] which represents the probable type of shell from which *C. granulifer* is descended.

The figure,[3] which is a ventral view, shows a deep sinus and in the description, it is stated that the dorsal side follows the curves of the ventral. It will be noted that *C. lepidus* is a striated species, while the nepionic stage of *C. granulifer* is glabrous. This has little bearing, as it is a general characteristic of the incipient shells of brachiopods to be glabrous.

Ephibic stage.—Following the laws of development, we could assume the great bulk of adults of *C. granulifer* in the upper Carboniferous of Kansas and below the Florena members of the Garrison formation to be like the ephibic stage in the Florena—Grand Summit series, and upon investigation, this proves to be the case, while above and below these limits, they should be more like the gerontic and late neanic stages respectively. This holds true in nearly every instance.

As was stated in the introduction, the type specimens probably came from a horizon between the Topeka and Tecumseh limestones. Specimens from these horizons correspond with the typical ephibic form, so that the type specimens represent just about the normal form of the species.

We find Norwood and Pratten's species, *C. smithii*,[4] that of Meek and Worthen,[5] and that of Hall and Clark[6] to be a short-eared form

[1] Raymond, *The Developmental Change in Some Common Devonian Brachiopods*, Vol. XVII, pp. 277–300. Pls. XII–XVIII.

[2] Hall, *Pal. N. Y.*, IV, Pt. 1, pp. 132 and 142, Pl. XXII, Fig. 12.

[3] *Ibid.*

[4] Norwood and Pratten, *Jour. Acad. Nat. Sci. Phil.* (2), Vol. III, p. 24, Pl. II, Figs. 2a–c.

[5] Meek and Worthen, *Geol. Surv. Illinois*, Vol. V, 1873, p. 570, Pl. XXV, Fig. 11.

[6] Hall and Clark, *Pal. N. Y.*, VIII, Pt. 1, 1892, XV B, Fig. 12.

with a relatively short hinge-line and the shell longer and narrower than the adult of *C. granulifer* from Grand Summit, and it is found that all these come from a much lower horizon. Thus it will be seen that they correspond to the early ephibic stage of our series. This throws them into the species *C. granulifer* as already done by Schuchert and Weller.

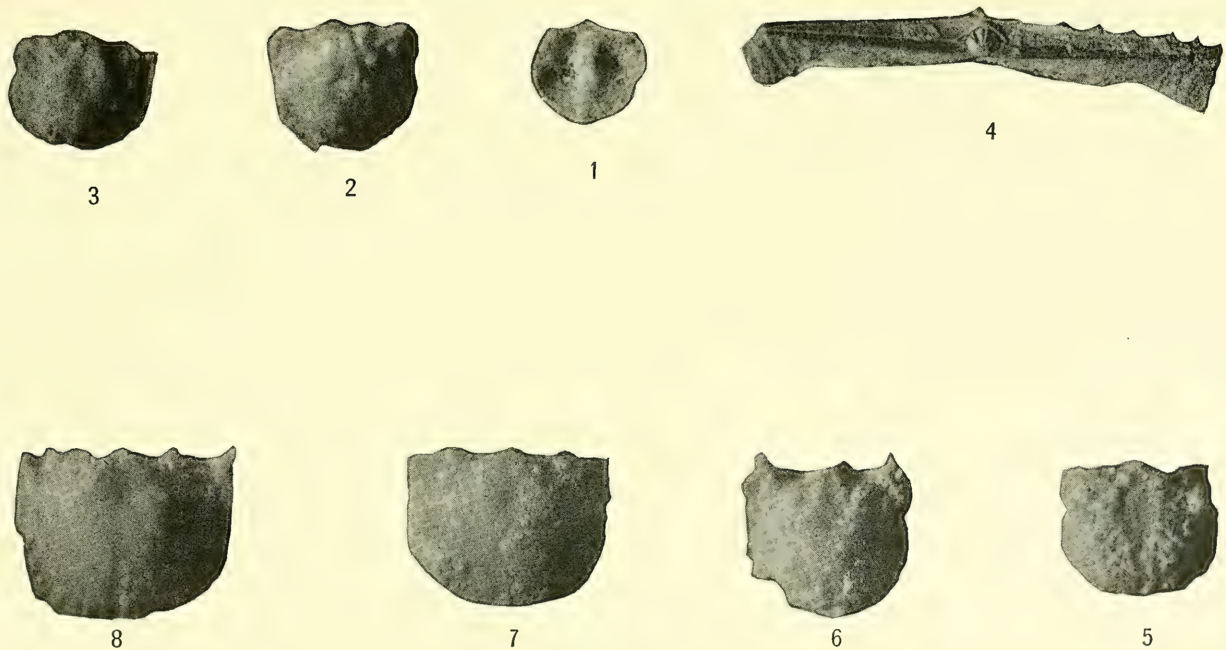
Gerontic stage.—In the case of the gerontic form we find the same thing to be true. Meek and Hayden[1] finding a form with mucronate cardinal angles, longer hinge-line, much thicker valves, and, as they say, "the area of its smaller valve ranges more nearly at right angles to the plane of the shell, than in the Illinois species"[2] (*C. smithii*), they called it a new species, although they suspected it of being allied to, or possibly the same species as, *C. smithii*. The above characters are found in the gerontic stage of the Grand Summit specimens, and Meek and Hayden's material was from a higher horizon than the Florena shales. The fact that the area of its smaller valve ranges more nearly at right angles to the plane of the shell than in the Illinois species, is due directly to the fact that it is a gerontic form. One of the characteristics of this stage is the thickening of the shell, especially in the pedicle valve, material being added to the inner surface of the shell. To compensate for this, and keep the visceral cavity its normal size, shell material is added at the hinge-line, which thickens the cardinal area of the pedicle valve and forces the pedicle valve back, making the hinge-line of this valve more nearly at right angles to that of the brachial valve (Plate II, Fig. 12–13).

In Prosser's collection from the Neosho (the next horizon above the Florena) near Strong, Kansas, the majority of the specimens exhibit a form remarkably like the gerontic stage in the Grand Summit series.

A collection from the Oread limestone at University Hill, Lawrence, Kans., made by Mr. Chas. D. Ise, bears out the foregoing conclusions to a remarkable degree. The figures (Plate III, Figs. 14–17) show a form identical in shape with the early ephibic stage in the series. The hinge-line is short and the cardinal angle is nearly or quite 90°. There is a tendency in many of the specimens to develop

[1] Meek and Hayden, *Pal. Up. Mo.*, [illegible], Pl. I, Fig. 5 *a–e*

[2] *Ibid.*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a comparatively deep sinus. In the interior of the dorsal valve, the granules are arranged around the margin of the visceral cavity alone. The septa are very weak when compared to the later forms.

In the Permian rocks (Ft. Riley limestone) we find that the species has reverted. This form is much smaller, has many granules on the interior, brachial and muscle markings weak, is thin shelled and approaches very nearly in shape to the nepionic stage of *C. granulifer* and therefore the earlier species of the genus. So far as is known, this is the last of the species of *Chonetes* in the Mississippi basin (Plate III, Figs. 1–3).

CONCLUSION

The writer has endeavored to show that, by taking as a basis a series of *Chonetes* from the horizon of the Upper Carboniferous, forms corresponding to the different stages may be found in the rocks above and below this. Thus the nepionic stage represents species from the Silurian and Devonian; the neanic and early ephibic species from the Carboniferous; and the later ephibic and gerontic species from the Upper Carboniferous, while the Permian or last form reverts back again in form to the early species.

EXPLANATION OF PLATES

PLATE I.—Series showing ventral view, Florena shales, at Florena and Grand Summit.

PLATE II.—Rows 1, 2, Series showing dorsal view, Florena shales, at Florena; cross-section of Grand Summit specimen; cross-section of Prosser's Neosha specimen. Rows 3, 4, Interior of dorsal valves, Florena shales at Florena.

PLATE III.—1, Ft. Riley Limestone; 2, Ft. Riley Limestone; 3, Ft. Riley Limestone; 4, Ft. Riley, No. 10, top of Neosho; 5, Neosho, Prosser's Collection; 6, Neosho, Prosser's Collection; 7, Neosho, Prosser's Collection; 8, No. 6 Crusher Hill, bottom of Neosho; 9, Florena at Grand Summit; 10, Florena at Grand Summit; 11, Florena, Ulrich's Quarries near Manhatten, Kan.; 12, Topeka, at Topeka; 13, Topeka, at Topeka; 14, Oread, University Hill, Lawrence, Kan.; 15, Oread, University Hill, Lawrence, Kan.; 16, Oread, University Hill, Lawrence Kan.; 17, Oread, University Hill, Lawrence, Kan.

PLATE IV.—1, 2, 3, 5, 6, 7, 8, specimens from the series shown in Plate I, enlarged ×20, to show details of marking ventral vein. 4, hinge area enlarged ×3. Florena shales at Florena.

THE VARIATIONS OF GLACIERS. XIII[1]

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Johns Hopkins University

The following is a summary of the *Twelfth Annual Report* of the International Committee on Glaciers.[2]

REPORT ON GLACIERS FOR 1906

Swiss Alps.—Of the sixty-three glaciers observed in 1906, fifty-three were retreating and ten were doubtful. Of the doubtful glaciers nine seemed to show a slight advance but it was not sufficient to establish a true change of phase.[3]

Eastern Alps.—Only thirty glaciers were measured in 1906; they were in the Ubergossene Alm, the Silvretta, Oetztal, Stubai, Zillertal, Venediger, Glockner, Ankogel, and Ortler groups and in southern Tyrol. Twenty-six glaciers were retreating, three were stationary, and one was advancing. The general retreat was stronger than in 1905. Of the five glaciers reported as advancing and three as stationary in the Oetztal in 1905, five are now retreating. The Grosselendkees in the Ankogel, which was stationary in 1905, shows a marked advance. It is the only advancing glacier amongst those observed.[4]

Italian Alps.—All the glaciers that were observed in 1906 in Val Tournache, in Val Formazza, and in the Lombard Alps were retreating. The Forno glacier in Valfurva retreated rapidly between 1864 and 1895, and a little later became stationary. Its névé-fields seem to have diminished in the last ten years, suggesting a coming retreat.[5]

French Alps.—An examination of earlier observations has brought to light the changes which took place in the Glacier des Bossons between 1818 and 1904. At the later date the glacier was 600 meters

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XVI.

[2] *Zeitschrift für Gletscherkunde*, 1908, Vol. II, pp. 161–98.

[3] *Report* of Professor F. A. Forel and M. E. Muret.

[4] *Report* of Professor E. Brückner.

[5] *Report* of Professor O. Marinelli.

shorter than in 1818. It seems to be advancing slightly at the present, although the other glaciers of the region, and those in the nearby regions of Maurienne and Tarantaise are retreating. Large-scale maps of the ends of several glaciers have been made for future comparisons. Several small glaciers have entirely disappeared. A number of glaciers measured in the Dauphiné are retreating rapidly and some small ones have disappeared.

Pyrenees.—The glaciers are retreating but the precipitation was heavy during the previous winter, and two glaciers are getting thicker in their upper portions.[1]

Norway.—The four glaciers measured in the Folgefon and in the Jostedal have advanced from 15 to 33 meters since 1905. In the Jotunheim seven glaciers have advanced and nine have retreated during the year. The greatest advance was 12.8 meters and the greatest retreat 22.5 meters.[2]

Russia.—Two glaciers on the northern slope of the mountain chain of Peter the Great, Boukhara, are rapidly melting back, whereas a glacier on the southern slope of the same chain is, according to observations in 1905, notably advancing. A number of glaciers are reported in the Tian Chan mountains and, although not measured, several seem to be advancing.[3]

Canada.—The report contains an interesting summary of the observations of the Messrs. Vaux on the Illecillewaet, Asulkan, Wenkchemna, Victoria, Wapta, and Horseshoe Glaciers, since 1898. It will be unnecessary to repeat the details here as the article has been published in extenso in this country.[4] Suffice to say that these glaciers have in general retreated, but at a diminishing rate; the Asulkan has advanced slightly, but has retreated again to its position of 1899; the Illecillewaet continues to retreat, but photographs show that the upper part is getting thicker, and it will be interesting to determine how soon this will affect the end.[5]

[1] *Report* of M. Ch. Rabot.

[2] *Report* of M. P. A. Oyen.

[3] *Report* of Colonel J. de Schokalsky.

[4] "Observations made in 1906 on Glaciers in Alberta and British Columbia," *Proc. Philad. Acad. Nat. Sci.*, 1906, pp. 568–79.

[5] *Report* of MM. George and William S. Vaux.

Himalayan Glaciers.—Steps have been taken by the Geological Survey of India to survey and mark the positions of the ends of several glaciers; photographs will be taken and observations made at future times, which will determine the changes they undergo.[1]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1907[2]

The snow fall in the Rocky Mountains was so great during the previous winter that the Hallet glacier in Colorado was not uncovered during the summer of 1907, and therefore it is probable that it has made a small advance (*Mills*). Three small glaciers are reported in the Crazy Mountains of Montana, one each in Big Timber, in Sweet Grass and Rock Creek canyons, respectively (*Wolfe* and *Mansfield*). There is no report on the Californian glaciers, but the snow-fall in the Sierra Nevadas was unusually great during the preceding two winters (*Le Conte*).

The snow fall seems also to have been excessive in the Cascade Mountains of Oregon, though the annual precipitation at Portland, Oregon, was but normal (*Montgomery*). The Eliot Glacier, on the northern side of Mt. Hood, continues to retreat. A comparison of a photograph taken in 1907, with earlier ones, shows a marked recession, and the slope at the end of the glacier is much diminished, (*Langille*). Mr. A. H. Sylvester[3] has made a topographic map of Mt. Hood and the region west of it which is to be published by the United States Geological Survey. He observed glacial scratches and old moraines at a considerable distance from the mountain. He reports evidences of a small advance in most of the glaciers which is referable to the heavy precipitation during recent years, but he thinks the Zig Zag and White River glaciers are retreating on account of the greater activity of the fumarole at their heads, which has melted a large quantity of snow in the old crater of the mountain. In the canyon below White River Glacier he has found ice buried in places by more

[1] *Report* of M. Douglas W. Freshfield.

[2] A synopsis of this report will appear in the *Thirteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1906 was given in this *Journal,* Vol. XVI, pp. 51–55.

[3] "Is Our Noblest Volcano Awakening to New Life?" *Nat. Geog. Mag.*, July, 1908, Vol. XIX, pp. 515–25.

than 200 feet of débris, which he takes to be all morainic. This ice occurs under what has been called the Moraine Mesa, as its surface is covered by a well marked ground moraine. Mr. Sylvester looks upon the material below this moraine as an earlier moraine; between the two is a confused mass of forest humus and broken trees, some of which seems still to be in place; and he infers two periods of glaciation separated by a long interval with a mild climate. The present writer, who visited the mountain in 1901,[1] looks upon the lower material as ejecta. The presence of ice under it would then indicate that an older glacier was buried under the material thrown out during a period of great activity; and the steam which would continue to escape, in gradually diminishing quantities, would prevent the formation of glaciers for a long time; even after the snow again began to accumulate, it would require a century or more before the White River Glacier would extend to the region of the Moraine Mesa; and no great variations of the climate would be necessary to account for the buried forest. It is not improbable that the great outburst was the cause of the disappearance of the southern wall of Mt. Hood's crater.

Mr. George Davidson made a trip in southeastern Alaska in 1907 and noticed a general retreat of the glaciers and diminution of the snow-fields since his earlier visits in 1867–69. The only definite information we have regarding Glacier Bay is contained in two short notes by members of the International Boundary Survey.[2] A small sketch map of Muir and Reid Inlets accompanies Mr. Morse's report. These notes show that between 1894 and 1907, Muir Glacier has retreated eight miles, Grand Pacific Glacier, seven and one-half miles, and Johns Hopkins Glaciers, three miles. Only a small part of the end of Muir Glacier is discharging ice-bergs.[3] That the rapid retreat common to all the glaciers of the bay was in

[1] "The Glaciers of Mt. Hood and Mt. Adams," *Mazama*, 1905, Vol. II, pp. 194–200; and "Studies of the Glaciers of Mt. Hood and Mt. Adams," *Zeitschrift für Gletscherkunde*, 1906, Vol. I, pp. 113–32.

[2] Otto J. Klotz, "Recession of Alaskan Glaciers," *Geog. Jour.*, 1907, Vol. XXX, pp. 419–21; Fremont Morse, "The Recession of the Glaciers of Glacier Bay, Alaska," *Nat. Geog. Mag.*, 1908, Vol. XIX, pp. 76–78.

[3] It is to be noted that Mr. Klotz interchanges the names of the Grand Pacific and the Johns Hopkins glaciers.

some cases started, and in others helped, by the earthquake of September, 1899, has been the general belief on account of the great quantity of floating ice which the excursion steamers encountered the following summer, and which has ever since filled the bay, especially from Muir Inlet southward. This belief is confirmed by the experience of Mr. August Buschmann, who was in charge of the cannery at the mouth of the bay in 1899. He reports that immediately after the earthquake the quantity of drift ice in the bay increased and made navigation very difficult for his small steamers.

The glaciers descending from the Brabazon range of mountains, facing the coast between the Fairweather Range and Yakutat Bay, give evidence that they are retreating by the existence of moraines at some distance from the ice; the intervening region is barren, but trees in general grow on the outer side of the moraines. One glacier, the Yakutat, has its origin in the great snow fields behind the mountains and passes completely through the range; it is retreating like the others.[1]

The interpretation heretofore put upon the narratives of Malaspina and of Vancouver, regarding the ice in Disenchantment Bay, has been that the glaciers actually filled the bay as far as Haenke Island in 1792 and 1794. But Messrs. Tarr and Martin,[2] by a consideration of the general character of the vegetation, the absence of lacustrine deposits in the lower part of Russell Fiord, the strongly marked shore lines in Disenchantment Bay, and finally by a critical examination of the accounts of the two early explorers, have concluded that they merely encountered compact floating ice in the neighborhood of Haenke Island, and that the glaciers did not, at the time of their explorations, extend to this island.

In the Aleutian Islands, the volcano of Makushin, Unalaska, and the volcanic mountains of Atka, carry large névé-fields with radiating glaciers; they do not show any signs of retreat; it is probable that they are advancing, for the Aleutian Islands are unquestionably in process of elevation (*Jaggar*).

[1] Eliot Blackwelder, "Glacial Features of the Alaskan Coast between Yakutat Bay and the Alsek River," *Journal of Geology*, 1907, Vol. XV, pp. 415–33.

[2] "Position of the Hubbard Glacier Front in 1792 and 1794," *Bull. Am. Geog. Soc.*, 1907, Vol. XXXIX, pp. 129–36.

Reviews

The Stratigraphy of the Western American Trias. By J. P. Smith. Sonderabdruck aus der Festschrift zum siebzigsten Geburtstage von Adolph v. Koenen gewidm. v. seinen Schülern. Stuttgart: E. Schweizerbartsche Verlagsbuchhandlung, 1907.

Since Lower Triassic times, and perhaps earlier, the marine faunas of western America have shown a close relationship with those of eastern Asia, except when modified by the periodical invasions of Boreal forms and the occasional interruptions of Mediterranean types which gained access through Atlantic waters. At the present time the living marine faunas of Japan and our Pacific coast show a large number of identical species, though the intermingling of the shallow-water forms is prohibited by deep water east of Kamchatka and by the cold current from Bering Sea. A rise of 200 meters would close Bering strait and shut off the cold water from the north, while a greater elevation would allow easy communication between the shore forms of Kamchatka and the Aleutian Islands. It is probable that the recurrence of comparatively small elevations and subsidences of the North Pacific border accounts for the similarity of the faunas of the eastern Asiatic and the western American coasts during some stages and the invasions of Boreal types during others. This hypothesis assumes that a uniform temperature did not necessarily exist over the entire earth previous to the Tertiary, and it aims to show that the intervention of a Pacific continent during Mesozoic time is unnecessary for the explanation of the similarity of Asiatic and American faunas. An analysis of the Triassic formations of western America and a summary of later stratigraphy forms the basis for these conclusions. H. H.

The Green Schists and Associated Granites and Porphyries of Rhode Island. By Benjamin K. Emerson and Joseph H. Perry. U. S. Geological Survey, Bulletin No. 311; 71 pp., map. Washington, 1907.

This paper deals principally with the interesting Cambrian remnants which occur in Rhode Island as broad isolated patches, and with the surrounding eruptives. Special emphasis is placed on the remarkable series

of fresh porphyritic rocks which extend westward from the town of East Greenwich, although the Cambrian and Carboniferous sedimentaries and the various Paleozoic igneous rocks of this difficult area are not neglected. A complex collection of igneous rocks was intruded into the Cambrian schists, in Carboniferous times or earlier, as a laccolithic mass. A narrow basic border on the northern side of this mass passes on the south into a broad band of the granitic nucleus, while still farther south are extensive microgranites and graphic microgranites. The microgranites and the basic rocks of the narrow border seem to be portions of a common mantle over the granite. Fragments of the graphic microgranite in a blue quartz-porphyry cement constitute a breccia in the central area. After the consolidation of the granite and the rocks of its mantle, microgranite dikes penetrated the mass; then an explosive eruption blew off this microgranitic capping and furnished the numerous fragments of that rock found in the adjacent Carboniferous conglomerate. A portion of the magma left in the conduit solidified to form the central mass of porphyry; while another part, already partially crystallized, cemented shattered fragments of the graphic microgranite when a sudden transference to a higher level caused a rapid consolidation. In the comparatively quiet period following this eruption, the Carboniferous conglomerates containing bowlders of these igneous rocks were spread still more widely over the region. The conglomerates afterward suffered considerable metamorphism, so that their paste was converted into a coarse muscovite schist and many secondary minerals were developed. The publication of this bulletin will go a long way toward clearing up the very complex geological history of Rhode Island.

H. H.

Some Principles of Seismic Geology. The Geotectonic and Geodynamic Aspects of Calabria and Northeastern Sicily. By William Herbert Hobbs. Sonderabdruck aus Gerlands Beiträgen zur Geophysik. Bd. VIII, Heft 2, s. 219–362. Leipzig: Wilhelm Engelmann, 1907.

The author of these two articles, in an endeavor to gain more light on the crustal architecture of regions like the New England states, was on his way to Calabria when the disastrous earthquake of 1905 occurred in that province. His observations were thereby greatly facilitated. The first monograph deals in a broad way with seismic phenomena and their relation to certain geological problems. Data gathered from the communes damaged by earthquakes leads to the conclusion that they are usually arranged along

essentially straight lines which bear some relationship to geologic boundaries, coast lines, mountain borders, etc., which are parallel to one another in series, and which often intersect volcanic vents. Seismic intensity does not vary with distance from any point or points within the earth, but is greatest at or near the intersections of these seismotectonic lines. In only a very few cases can seisms be said to owe their origin to vulcanism; the great majority of shocks are due to faulting of the normal type and it is along fractures that the earth-waves are propagated. Places situated even a short distance from fracture lines along which disturbances have repeatedly occurred have escaped serious injury. It is interesting to note also that brontidi, the deep rumblings heard commonly in certain localities, occur on lines along which much seismic disturbance has taken place, indicating that these noises are due to slipping along fracture planes. A survey of recorded earthquake scarps and fissures seems to show that notable surface dislocations are formed only at times of notable shocks; that they are sharply divided into two orders of magnitude; that the faults are of the nearly vertical normal type, and that all the movements are due to an adjustment in position of individual blocks. Thus a careful study of the earth movements of a region may furnish data from which the position of otherwise undeterminable fault planes and systems may be derived. The topography and hydrography of many areas is also modified along seismotectonic lines, as is illustrated in the United States by the Northern and Southern Fall lines, the Carolina coast line, the Connecticut line, and other lineaments. The three most prominent seismic areas of the United States—the Atlantic border, the middle Mississippi basin, and the bay of San Francisco—are also sinking areas. Briefly stated, the law of the distribution of seismic phenomena is that seismicity is localized along faults and is greatest at their intersections.

The second article deals more in detail with the southernmost portion of the Italian peninsula and with the neighboring parts of Sicily. In this region the relationship between the topography and crustal dislocations is particularly well marked and the rectilinear stretches of coast are often lines of great seismicity. Even the separation of Sicily from Calabria and from Africa is a comparatively recent event due to subsidence along fault planes. The well-known Italian volcanic vents are often situated at the intersections of fracture planes, while the destructive intensity of Calabrian quakes is greatly augmented at similar points. A striking fact in connection with the best-known earthquakes of Calabria is the nearly constant relative intensity shown at a number of the affected communes, indicating that these shocks have been the results of successive

slippings along the same fault planes or that the elastic waves have been transmitted mainly along these planes. Adjustments of smaller amplitude have occurred along other planes but in no case is there any evident relation to an epicenter. H. H.

Drumlins of Central Western New York. By H. L. FAIRCHILD. New York State Museum, Bulletin 111; 76 pp., 20 pl., map. Albany, 1907.

New York possesses the most remarkable group of drumlins in the world, and this bulletin, with its excellently prepared maps, photographs, and descriptive matter, will be a welcome addition to a glaciologist's library. The distribution of the New York drumlins shows that they were formed during the latest phase of glaciation by the spreading of the ice from the Ontario basin. A sliding movement of the lower ice caused by a horizontal thrust from behind seems to be essential to drumlin formation, though the quality, position, and volume of the drift material, and the degree of the vertical pressure and of the mobility of the ice are also factors. The shales of central New York furnished a peculiarly adhesive drift from which the drumlins were *constructed* by a plastering-on process. These masses of drift were thus given their peculiar shapes by the rubbing action of the ice movement during the final stages of diminished pressure and lagging flow. The presence of open spaces in the midst of strongly drumlinized areas is difficult of explanation. In some cases depressions may have lain at such a low level that a plane of shearing was formed in the ice above them so as to leave a mass of stagnant ice beneath. An earlier ice invasion may have localized the drift of the ground moraine that was to be shaped into drumlins by the next invasion; but no drumlin was observed, the internal structure of which revealed a direct derivation from terminal moraine material.

H. H.

Geology and Water Resources of the Bighorn Basin, Wyoming. By CASSIUS A. FISHER. U. S. Geological Survey, Professional Paper, No. 53; 51 pp., 20 pl., map. Washington, 1906.

The region described comprises about 8,500 square miles, situated mainly in Bighorn County in northwestern Wyoming. The most striking topographic feature is a broad structural valley bounded on nearly all sides by high mountain ranges and containing in its interior high badland slopes. The amount of water in the principal streams varies greatly with the season of the year, being greatest in early summer; but irrigation has been prac-

ticed for over twenty years. A storage reservoir and canals under construction by the Government will reclaim 282,000 acres more. The study of the stratigraphy of the region shows that all the younger systems are represented down as far as the Devonian, and below that the Ordovician, Cambrian, and pre-Cambrian occur. The Laramie has a much greater development than any other co-ordinate division, although the Colorado, the Pierre shale, and the Wasatch also show considerable thicknesses. Coal has a widespread distribution in the Laramie and associated formations and is mined at numerous points along the streams. Gypsum deposits are extensively developed, but are not utilized except in a small way.

H. H.

Geology of the Long Lake Quadrangle. By H. P. CUSHING. New York State Museum, Bulletin 115; 88 pp., 20 pl., map. Albany, 1907.

The Long Lake quadrangle is situated on the western border of the more rugged portion of the Adirondack Mountains. The topography of the area is greatly diversified, for portions of both the high Adirondack region and the lower "lake belt" are included. Fifty-seven lakes and ponds, many being rapidly converted into marshes, are shown. All the rocks of the quadrangle are of pre-Cambrian age and most of them belong to the early portion of that long interval. Four groups have been differentiated, most of them strongly metamorphosed: (1) A series of sedimentary rocks, the Grenville series, with contemporaneous intrusions; (2) a series of gneisses of igneous origin, perhaps older than the Grenville; (3) a series of igneous rocks less profoundly altered and certainly younger than the preceding; (4) a series of still younger igneous rocks of very slightly altered character. Probably Ordovician deposits were laid down on the older rocks but, if so, have been entirely removed by erosion. A full account of the geological history of the northern Adirondack region is given by the same author in New York State Museum Bulletin No. 95.

H. H.

Mineral Solution and Fusion under High Temperatures and Pressures. By ARTHUR L. DAY. From the *Fifth Year-book* of the Carnegie Institution of Washington, pp. 177–85. Washington, 1907.

This paper is a summary of the work accomplished in geophysical research by the Carnegie Institution of Washington in 1906. The work

has now passed beyond the preliminary stage. Important results have already been obtained and much more may be expected in the future, especially since the occupation of new quarters by the laboratory will make possible the investigations of mineral behavior under high pressures originally contemplated. The study of the feldspars and other minerals resulted in the location of several cases of reversible changes and one of irreversible change. Wollastonite possesses one crystal form below 1,200° and another above that temperature and either of these forms may be changed to the other. Three forms of magnesium metasilicate may be changed into a fourth by heating, but the reverse change does not occur; and yet enstatite, the magnesium silicate compound common in rocks, is not this stable form. Quartz was found to change over to tridymite at 800°, if given time enough; showing that this mineral, so common in nature, has been formed at a relatively low temperature. "Quartz-glass," a most useful material which can be raised to a white heat without melting and subjected to sudden changes of temperature without breaking, was successfully prepared, though quite high temperatures (above 1,600° C.) and some pressure were necessary. The valuable properties of Portland cement have been attributed to tricalcic silicate, but this compound was found not to exist; further study may reveal the true chemical relations which determine the action of this cement. Textures similar to those of certain schistose metamorphic rocks were produced in the laboratory by submitting crystallizing substances to unequal stresses; thus confirming the conclusions of Van Hise in regard to the cause of schistosity in rocks. The published work of the laboratory has appeared in various scientific journals, as enumerated in the paper.

H. H.

The Mountains of Southernmost Africa. By W. M. Davis. Reprinted from Bulletin of the American Geographical Society, Vol. XXXVIII, October, 1906.

One of the best-defined physiographic features of South Africa is the mountain system, occupying the southern border and here referred to as the Cape Colony ranges. It comprises a number of nearly parallel east and west ridges and longitudinal valleys which do not conform in direction to the trend of the southern sea coast but are cut irregularly by it. The sea has advanced on these mountains, leaving but a remnant of the whole system, and this remnant has itself suffered extensive denudation. Americans will be particularly interested to learn that the Cape Colony ranges are in many respects similar to the Alleghenies. The strata, with the exception

of a few Mesozoic formations in South Africa, are Paleozoic in both cases, and were originally spread out in horizontally uniform sheets of great vertical diversity. Great thicknesses of rock were laid down on slowly subsiding peneplains until compressional forces crowded them into parallel folds with overturns directed toward the continental center and with essentially flat plateaus on the landward side of the systems. In both cases, therefore, the mountain-making forces produced thrusts directed from the ocean toward the land masses. The massive Karroo formations in southernmost Africa, as the Carboniferous strata in the Appalachians, have been almost entirely removed from the folded area by a long period of erosion, which produced a partial peneplanation; while the renewal of deep erosion since that period is the result of another relative uplift. The present configuration of the mountains is in no sense due to the form the country received originally as a result of the action of the compressional forces, though the prevalence of anticlinal ridges and synclinal valleys has proved a snare to some observers. The synclinal valleys are occupied by *resequent,* not *consequent,* streams; the early consequent streams were diverted to the anticlines at one period, but were forced back into synclinal positions by the resistance of a second deep-lying hard stratum. Where the beds of a regularly folded region are of great vertical diversity and the geologic history is similar to that of the Alleghenies or the Cape Colony ranges, the resequent type of valley is the one which theoretical considerations indicate as the natural result of the conditions prevailing. H. H.

Drainage Modifications in the Tallulah District. By DOUGLAS WILSON JOHNSON. Proceedings of the Boston Society of Natural History, Vol. XXXIII, No. 5; pp. 211–48. Boston, February, 1907.

The Chattooga River flows southwest between Georgia and South Carolina to the westernmost point in the latter state, where it receives the Tallulah River as a tributary from the northwest and then turns abruptly to the southeast and flows to the Atlantic Ocean under the names of the Tugaloo and Savannah rivers. A few miles from this abrupt bend, Deep Creek, one of the headwaters of the Chattahoochie system, continues the course started by the Chattooga to the southwest.

The conclusion is reached that, by a process of "remote capture," the Chattooga River, which formerly flowed southwest into the Gulf of Mexico as a part of the Chattahoochie system, was captured by a member of the Savannah system. The Atlantic drainage gained this victory over that of

the Gulf by virtue of its shorter course to the sea, aided perhaps by favorable crustal warping. The place of the capture was just below the junction of the Tallulah and Chattooga Rivers. The falls and gorge of the Tallulah, difficulties in the paths of many former observers, are explained as the result of the presence of a rock barrier in that river more resistant than the formations the Chattooga was forced to cut through. Other physiographers, notably Hayes and Campbell, had reached essentially the same conclusions in regard to this capture, but it remained for this masterly exposition of the case to set at rest all doubts on the subject. H. H.

Postglacial Faults of Eastern New York. By J. B. WOODWORTH. From New York State Museum, Bulletin 107, Geological Papers. Albany, 1907.

At a number of points in and near the Hudson River Valley, as well as in various points in New England, the relation to one another of glacial striae on each side of certain fault planes shows that the displacements have taken place since glacial times. The so-called tilting of the land after the retreat of the ice has, therefore, been accompanied in this region by the fracturing of rocks in certain zones where the strata have yielded by numerous small step-faults. These have a downthrow to the southwest where the strike of the structures is normal to that direction, and to the south where the strike is east and west. The observations so far made indicate that the ancient shore lines on the eastern side of the Hudson gorge north of the Highlands have been raised a few feet more than those of the western side. Confirmation is also given to the supposition that there has been a relative uplift in the north and a downthrow in the south of this area, though it is uncertain whether the degree of faulting is a measure of the extent of the change of level. Further examination of these displacements may furnish data for the exact determination of the amount and nature of the postglacial warping to which the northeastern states have been subjected.

H. H.

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Good morning!
Have you used
Pears' soap?


JAMES HALL
STATE GEOLOGIST OF NEW YORK
1837 – 1898
ESTABLISHED IN THIS
FOURTH GEOLOGICAL DISTRICT
THE CLASSIFICATION OF A LARGE PART OF THE
NEW YORK SYSTEM OF GEOLOGICAL FORMATIONS
WHICH GAVE ENDURING REPUTE TO THE GEOLOGY OF NEW YORK
THIS GORGE EXHIBITS THE TYPICAL EXPRESSION OF HALL'S
PORTAGE GROUP
WHOSE ROCKS CARRY AN ASSEMBLAGE OF ORGANIC
REMAINS MOST WIDELY DIFFUSED THROUGHOUT THE WORLD
THIS TABLET HAS BEEN ERECTED BY
1908

THE
JOURNAL OF GEOLOGY

NOVEMBER-DECEMBER, 1908

THE GOLD REGIONS OF THE STRAIT OF MAGELLAN AND TIERRA DEL FUEGO

R. A. F. PENROSE, JR.

LOCATION OF THE REGION[1]

The Strait of Magellan intersects the southern end of South America from east to west. To the north of the strait is Patagonia, to the south of it is the archipelago of Tierra del Fuego. Both these regions are owned partly by Chile and partly by the Argentine Republic. The dividing line follows the Andes southward in Patagonia to the Strait of Magellan, thence eastward for some distance along the strait, and thence southward again through Tierra del Fuego, giving most of that archipelago to Chile, but an important part on the eastern side to Argentine. The Chilean possessions in the Magellan region, on both sides of the strait, are officially known as the Territory of Magallanes, a term locally abbreviated to simply "Magallanes."

Patagonia represents the southern end of the mainland of South America, terminating at Cape Froward, in the Strait of Magellan. The name Tierra del Fuego properly belongs to the whole archipelago of islands lying south of the Strait of Magellan and north of Cape Horn, though sometimes it is applied to the one large island which comprises most of the land area of the group and which is often

[1] During the year 1907 the writer twice visited the Strait of Magellan and had an opportunity to learn something of the gold-mining industry of that region. Other researches in South America prevented his making a special study of the deposits on which this industry has been built up, but it is hoped that the following general account of the occurrence and environment of the gold in this little-known region may be of some interest.

locally known as "the island," in distinction from the others. In the present paper the name Tierra del Fuego will be used to indicate the whole archipelago, and, as thus defined, it consists of one large island and many smaller ones. It comprises an area extending about 500 miles in a direction from northwest to southeast and about 200 miles in a direction from northeast to southwest, and from about 52° 30′ to almost 56° south latitude. The two main tidewater channels are the Strait of Magellan on the north and Beagle Channel near the southern part, intersecting the region from east to west. Between these two, and also south of Beagle Channel, are numerous other minor and transverse channels, dividing the archipelago into the many islands of which it is composed. (See map.)

GEOLOGY AND TOPOGRAPHY OF THE REGION

The western part of Patagonia is comprised in the main range of the Andes, dropping off abruptly on the Pacific side, while the eastern part is comprised in the low rolling country known as the pampas, sloping gradually to the Atlantic. South of the Strait of Magellan, in Tierra del Fuego, the western and southern parts of the archipelago are rugged and mountainous, some of the peaks rising from about 3,000 to about 7,000 feet above the sea. (See Fig. 2.) This region represents the southern extension of the Andes, which here turn from their usual north-and-south course to a northwest-and-southeast course, and then to an east-and-west course, finally terminating in the rugged Staten Island, the most easterly member of the archipelago. The northeastern part of the main island of Tierra del Fuego, however, is a more or less flat or rolling country, and partakes of the nature of the pampas of eastern Patagonia. In fact, just as the mountainous districts of Tierra del Fuego are the southerly extension of the Andes, so this part of the main island is geologically the southern extension of the pampas.

Tierra del Fuego probably owes its condition as a group of islands, instead of as a continuous land area, to a partial submergence of the southern end of South America. The numerous small but high and mountainous islands dropping off precipitously into the sea, following each other in quick succession along certain directions and separated by deep but narrow tidewater channels, strongly suggest what the

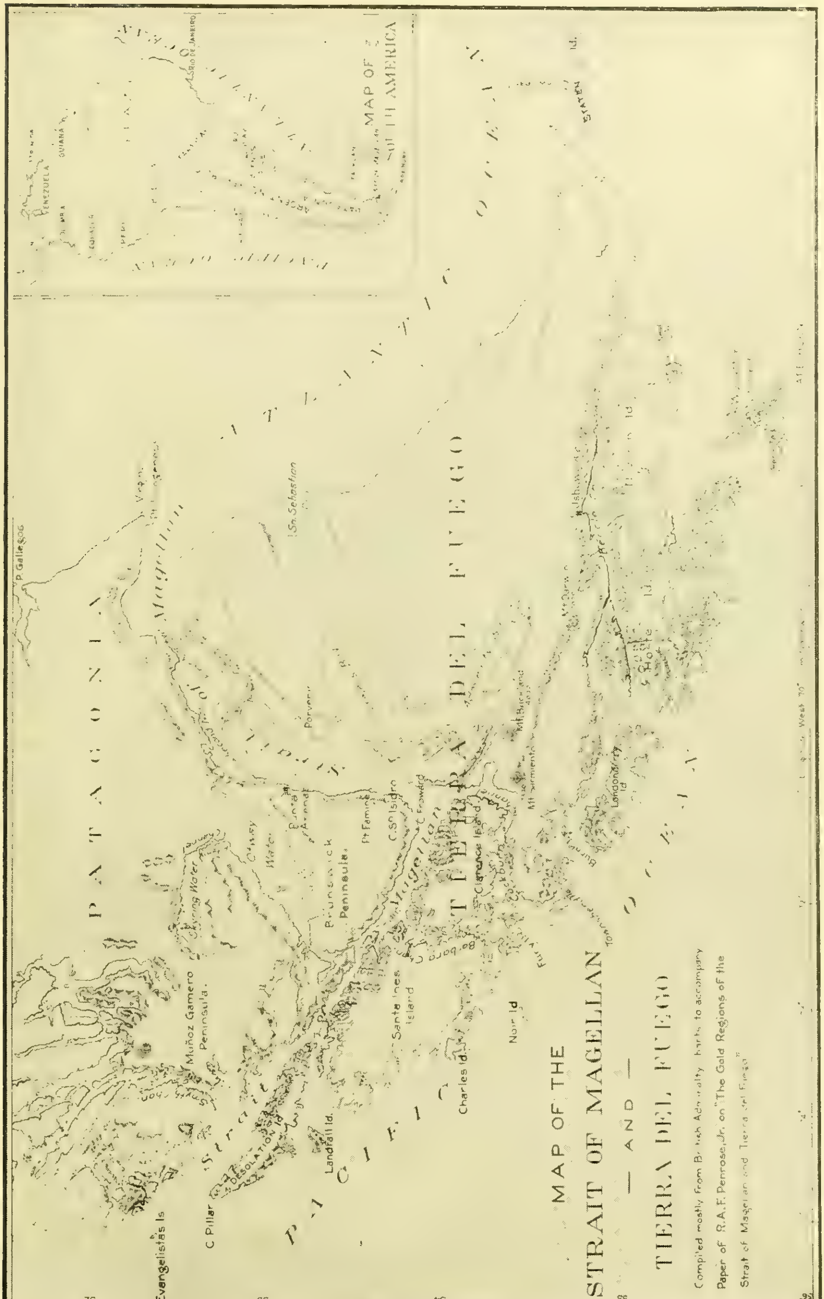

FIG. 1.—Map of the Strait of Magellan and Tierra del Fuego.

higher Andes range to the north would look like if it were submerged sufficiently to permit the sea to invade its lower parts. The islands appear to be the upper parts of old mountain peaks, and the numerous straits, channels, and bays, with their great depth and precipitous sides, appear to mark the courses of the old canyons and valleys now submerged. Whether the submergence is now at the maximum depth to which it has ever reached, or whether there has been some uplifting since the period of maximum submergence, is a question which cannot be fully discussed within the limits of the present article.

The rocks of southern Patagonia and Tierra del Fuego have not been much studied, but from the little that is known of them, it may be said that in the mountainous areas they are much like those of other parts of the southern Andes, granites, various igneous rocks, and slates being common; while in the low pampas country in eastern Patagonia and the northeast part of the main island of Tierra del Fuego, more or less soft, sandy and argillaceous strata predominate, probably belonging mostly to the Mesozoic and Cenozoic eras. Not only in its geology but in other respects, a large part of southern Patagonia and Tierra del Fuego is a little-known country. Various expeditions, especially those of the British ships the Adventure and the Beagle, have prepared good charts of the strait and neighboring waters, with accurate measurements of the depth of water and other nautical data most valuable to the navigator. These observations have been supplemented by later Chilean, American, French, and other expeditions. The outlines of most of the land-areas have also been fairly accurately mapped, and some of the mountains have been plotted and measured, but there are vast areas of country almost unknown beyond their shore lines. The advent of the sheep-raiser and the miner are rapidly giving us knowledge of some of these regions, but such information, though better than nothing, is necessarily vague.

DISCOVERY AND DISTRIBUTION OF THE GOLD DEPOSITS

Gold is said to have been discovered in southern Patagonia by the Chileans over forty years ago, and is supposed to have been known to the native Indians at a much earlier date, but it has been

produced in quantities sufficient to attract general attention only in the last twenty to twenty-five years. The gold in the gravels of Rio de las Minas, near Punta Arenas, was one of the earliest discoveries, and a number of miners soon began to work there. Another early discovery was the gold in the beach sands near Cape Virgins, at the eastern entrance of the Strait of Magellan, which was first discovered about 1876, but not actively worked until 1884. Then considerable excitement followed and prospecting parties overran a large part of southern Patagonia and Tierra del Fuego. An Austrian named Mr. Julius Popper was among the most active operators at that time, especially on the east coast of the main island of Tierra del Fuego. The search continued for several years with more or less activity,

FIG. 2.—A view in the Strait of Magellan.

sometimes the excitement subsiding, and sometimes breaking forth again when an especially rich discovery was made.

During this time, gold was found and actively worked in many places on both sides of the Strait of Magellan, but the principal localities were the following: the gravels in the Rio de las Minas near Punta Arenas; the beaches at Cape Virgins and from there southwestward along the shore to Point Dungeness; the gravels on several small streams to the eastward of where Porvenir now stands, across the strait from Punta Arenas; the beach at Paramo northeast of San Sebastian Bay, on the east coast of the main island of Tierra del Fuego; Navarin Island, Lennox Island, New Island, and Sloggett Bay in the extreme southern part of the archipelago near Cape Horn; New Year Island which lies north of Staten Island, at the eastern end of the archipelago; and several localities in the western islands of the archipelago. In fact, gold has been found to be very generally distributed almost all through the Magellan region, though

only in certain localities has it been profitably worked. Most of the important localities yet discovered are in the archipelago of Tierra del Fuego, though a few, such as on the beaches at Cape Virgins and Point Dungeness, are in Patagonia, on the north shore of the Strait of Magellan; and gold is also found in places along the southern coast of Chile, for some distance north of the Strait of Magellan.

About the year 1904 the preparations to use steam dredges in handling the gold-bearing gravel started afresh the boom that had

FIG. 3.—The town of Porvenir, Tierra del Fuego.

for a time been more or less quiescent. The old method of working the mines had been by hand, gathering the gold in pans, sluice-boxes, or other similar appliances. With the introduction of steam dredges, however, it became possible to handle the gravel much more cheaply and in much larger quantities. From all over Chile and Argentine again came the gold-seekers, with some from a still greater distance, and the usually almost deserted Strait of Magellan became animated with small craft. Since that time, though the excitement has subsided, work on the gold deposits has steadily progressed, and in a much more systematic manner than formerly. There were in

1907 some twelve or thirteen dredges in operation or being constructed, and the gold industry of the region promises soon to become a far more important business than in the days of handwork. The most active man in introducing the dredges has been an American, Mr. John D. Roberts, who for some years has been engaged in developing the gold industry of this region. The dredges are not used in handling the beach deposits, as the fury of the storms would soon batter them to pieces, and their use has so far been confined to the inland deposits.

FIG. 4.—The town of Punta Arenas, Strait of Magellan.

Until recently the largest gold-mining operations were at Paramo and Lennox Island, but since the introduction of the dredges, the most active operations are on the northwestern part of the main island of Tierra del Fuego, just across the strait from Punta Arenas. Here the town of Porvenir is the headquarters of the industry. This town has been a small settlement for some years, but it jumped into prominence in the gold boom of 1904, and is now a prosperous mining center of about 800 people. (See Fig. 3.) The mines are mostly some miles, and often many miles, from Porvenir, but the town is the supply point and the port at which the boats of the miners land.

In addition to the Porvenir region, mining on a smaller scale, but of more or less importance, is still going on at some of the other localities already mentioned.

The chief center of civilization in the whole region is the Chilean town of Punta Arenas, a name which in English means Sandy Point, and which refers to the spit of sandy land on which it is built. The town is on the Patagonian side of the Strait of Magellan and has a fairly good harbor. It is the seat of government in this part of the

FIG. 5.—Gold-bearing alluvium on the Rio del Oro, Tierra del Fuego.

Chilean possessions and is a very active place of some 12,000 people. (See Fig. 4.) It is the only large town in the Magellan region. The settlement of Ushuwaia, which is the seat of government of the Argentine part of Tierra del Fuego, is only a very small place, while several small mining or fishing camps, of which Porvenir is the largest, together with a few missionary posts, none of them containing more than a few persons, complete the list of settlements in this region. Punta Arenas is in 53° 9′ 42″ south latitude, and has the distinction of being the most southerly town of any considerable size in the southern hemisphere. Some of the places mentioned above are still

further south, and Ushuwaia is in almost 55° south latitude, but they are all very small settlements.

Punta Arenas was started by the Chilean government as a penal colony in 1843, but its location at that time was somewhat further south than at present. A few years later, in 1849, the settlement was moved to where it now stands. In the early days of Punta Arenas it was the scene of much disturbance, and on more than one occasion frightful bloodshed and massacre on the part of the convicts have

FIG. 6.—Gold-bearing alluvium on the Rio Pararich, Tierra del Fuego.

blackened its history. The Chilean government finally ceased using it as a penal colony and encouraged its settlement by free Chileans. For a long time it was the headquarters for sealing and whaling vessels, until the seals and whales became so nearly exterminated that the industry began to wane. It was also the wrecking headquarters for the Magellan region, and the many ships that were in distress or were dashed to pieces in the storms of this inhospitable region received the attention of the Punta Arenas wreckers.

In recent years, however, Punta Arenas has prospered greatly along other lines, first by the development of the sheep industry in Patagonia

and later by the advent of the gold miner. Its population is of a most cosmopolitan character, comprising, besides the native Chileans, many Austrians and a considerable number of Argentines, Germans, and English, as well as some Americans, French, and others. Punta Arenas bears much the same relation to the Far South as Dawson City, on the Yukon River, does to the Far North, both being isolated settlements on the borders of opposite polar regions, where, for vast distances, there is no other civilization; and though they are not

FIG. 7.—Gold-bearing alluvium on the Rio Verde, Tierra del Fuego.

large cities, their very isolation gives them a metropolitan air, for they are dependent on themselves for protection, amusement, and the general facilities of civilization. The one is the Antarctic metropolis and the other the Arctic metropolis of the Western Hemisphere; beyond both, civilization ceases.

MODE OF OCCURRENCE OF THE GOLD DEPOSITS

The gold of the Magellan region, including the Strait of Magellan and Tierra del Fuego, is, so far as at present known, most all in alluvial, or placer, deposits. Very few gold-bearing veins have been

found, though it may be said that, in a region so difficult as this is to prospect, gold-bearing veins might readily be overlooked. The alluvial deposits may be divided into two classes, those in beds of creeks or on hillsides, and those on sea beaches where they are subject to the action of the sea during rising and falling tides and during storms.

The alluvial deposits in beds of streams or on hillsides vary in gold contents from a few cents to a dollar or more per cubic yard,

FIG. 8.—Gold-bearing alluvium on the Rio Verde, Tierra del Fuego.

and sometimes, though less commonly, are considerably richer, but most of the ground that is now worked is said to range from twenty-five cents to fifty cents per yard. Under the conditions existing in the region, it is difficult to make very low grade ground pay, but some of the operators expect eventually, with steam dredges, to make a profit on very considerably lower-grade ground than they are working now. The gold-bearing beds vary from a few feet to many feet in thickness, ten to thirty feet or more being not uncommon. (See Figs. 5, 6, 7, 8, and 9.) An "overburden," or capping of barren ground, of variable thickness often occurs.

The gold on the beaches is sometimes on the immediate surface and sometimes covered by from a few inches to several feet of barren sand. On some beaches it is well up on the shore, on others it is near the water level and on still others it is below the water level. The sandy strata carrying the gold are rarely over a few inches in thickness, but often very rich. The gold is associated with large quantities of black sand, which seems to be mostly magnetite, and numerous small garnets.

FIG. 9.—Gold-bearing alluvium on the Rio Santa Maria, Tierra del Fuego.

The gold, whether from the creeks, hillsides, or beaches, is said to be quite pure, though it contains often a little copper and silver. It occurs generally in rather fine particles, but sometimes small nuggets, often flat and about the size of lima beans, occur, and occasionally still larger ones are found, but no very great nuggets have yet been discovered. The rarer minerals which occur in some other gold districts, like diamond, sapphire, topaz, etc., are said not to be found in this region, though a closer study of the deposits might reveal the presence of some of them.

As regards the origin of the gold deposits of the Magellan region,

it may be said that the alluvial deposits in the creeks and on the hillsides have doubtless been derived from the erosion of gold-bearing rocks, and though such rocks have not yet been found to any great extent in the region, they nevertheless probably exist and may sometime be discovered. If the Magellan region represents the partly submerged southern end of the continent, as already mentioned in this paper, many of these deposits may have been originally formed as ordinary alluvial deposits high up in the mountains, and brought down during the sinking era to a much lower level, while some of them may have been completely submerged in the sea. The gold in the beaches probably came largely from the later erosion of the alluvium in the creek beds and on the hillsides, and perhaps partly from old submerged alluvium from which the gold was thrown up by the sea. In either case the gold has been further concentrated by being washed over and over again on the beaches. It is said that the beaches, after having been carefully worked for gold, seem again to become rich in that metal after a storm or an unusually high tide.[1] This phenomenon is probably due partly to the action of the waves and currents in concentrating the gold which the imperfect methods of the miners have left behind in the sand, and partly to the washing up of fresh gold-bearing sand from depths that are undisturbed in ordinary weather or by ordinary tides. So well recognized is this enriching of the beaches, that the miners, after working all the sand that can be profitably handled, wait for the next storm or very high tide to come, and then wash the same spots over again with a good profit.

The ordinary tides in the eastern part of the Strait of Magellan have a rise and fall of 30 feet or more, and the spring tide, 45 or 50 feet, though in the western part of the strait the tides have a much less rise and fall. The great rise and fall of the tides on the Atlantic side cause rapid currents in the strait, often with a velocity of 7 or 8 knots an hour, and these, scouring the beaches backward and forward, must have a very marked effect in concentrating the gold. When we consider that a river, flowing always in one direction, has a wonderful power to concentrate gold in the gravel in its bed, a much

[1] A similar phenomenon is observable in the gold-bearing beach sands of Cape Nome, Alaska.

greater concentrating power would seem to be possessed by a channel like the Strait of Magellan, where the tides run as fast as a very swift river, and where they reverse their direction four times a day; for in water running always one way, gold may become covered and protected from further concentrating action, but in water running first one way and then another, gold that may be covered when the water runs in one direction, may be uncovered and moved about when the direction is reversed, eventually becoming more closely concentrated. In fact, the conditions in the Strait of Magellan represent a natural process of concentration, not at all unlike some of the artificial processes that man has found best suited for concentrating gold.

METHODS OF PROSPECTING

Prospecting in the Strait of Magellan and Tierra del Fuego is a more difficult task than in most places, and many a man has lost his life in his search for gold in that bleak, inhospitable region, while many more have rapidly become discouraged and returned to milder climates. Most of the traveling is done in boats, as the land is much cut up by deep tidewater channels and bays, and covered with dense underbrush or immense peat bogs; while everywhere, even on the mountain sides, the soil is soft and boggy, so that walking is difficult and often impossible. Hence traveling in boats and stopping from place to place along the shore is the most practical way of prospecting; but here again another difficulty comes in, as the storms are frequent and violent, and many a vessel has been hurled on the rocks and everyone in her lost. The climate, however, though stormy, is not extreme in temperature, the thermometer rarely going much below zero or much above 60° Fahrenheit. The mean winter temperature is about 33° F. and the mean summer temperature is about 50° F.

The natives, until recently, have been a considerable check to the progress of mining. Many of them still use the bow and arrow of their ancestors, and have fiercely opposed the invasion of the white man; yet the sad fate of most American Indians is rapidly overtaking them, and they will probably soon vanish before the miners and the cattlemen.

Aside from the difficulties of prospecting, the industrial conditions under which gold is worked in this region are not as expensive as

might at first be supposed. General supplies can be obtained at Punta Arenas at reasonable prices, for it is a seaport and supplies are brought there by ocean steamers at fairly cheap rates. The most expensive item is coal, and this is brought mostly from foreign countries. There is a small deposit of lignitic coal worked at what is known as the Loreto mine, a short distance from Punta Arenas, but the production is very limited and does not go far toward supplying the needs. There is also coal near Coronel and Lota on the Chilean coast, south of Valparaiso, but this is mostly used locally and by ocean steamers. In some parts of Tierra del Fuego there is a good deal of timber of the magnolia, beech, and other varieties, which can be used as fuel, but in other localities it is scarce. All over the region there is a great deal of peat, and efforts are now being made to use this as fuel.

The season during which mining can profitably be carried on is about eight or nine months, from August to May, while during the rest of the year frost and snow hinder operations. The capital at present invested in the industry is mostly Chilean and Argentine, but it seems probable that, as the region becomes better known, other capital may be attracted to the gold deposits of this far-south country. No very definite statistics of the production of gold in the early days in the region are obtainable, but until recently it has been small, and probably not very many hundreds of thousands of dollars had been produced up to the time of the introduction of the steam dredges. With these, however, the production will probably be greatly increased.

THE CAMBRO-ORDOVICIAN LIMESTONES OF THE APPALACHIAN VALLEY IN SOUTHERN PENNSYLVANIA[1]

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Washington, D. C.

The limestones of the Appalachian Valley, which in the South are separated into many formations, have generally been treated as a unit in the North under the name Shenandoah, or other local terms, such as Valley, Lancaster, Kittatinny, and York. These rocks include all the strata between the Cambrian quartzites of Georgian age and the Martinsburg ("Hudson") shale of Ordovician age.

In a paper on the sedimentary rocks of South Mountain[2] the author briefly described the formations comprising the Shenandoah group in southern Pennsylvania. Later studies of these rocks in the Cumberland Valley of Pennsylvania have furnished data for a more complete description of the group, including the faunal content and correlation, based on determinations by E. O. Ulrich.

The formations comprising the Shenandoah group in southern Pennsylvania are as follows:

	Martinsburg formation		Eden Utica Upper Trenton	Ordovician
Shenandoah group	Chambersburg limestone	100–600 feet	Lower Trenton Black River Lowville Upper Chazy	Ordovician
Shenandoah group	Stones River limestone	800–1000 feet	Lower and middle Chazy	Ordovician
Shenandoah group	Beekmantown limestone	2250–2300 feet	Beekmantown	Ordovician
Shenandoah group	Conococheague limestone	1635 ± feet	Saratogan	Cambrian
Shenandoah group	Elbrook formation	3000 ± feet	Acadian	Cambrian
Shenandoah group	Waynesboro formation	1250 ± feet	Acadian	Cambrian
Shenandoah group	Tomstown limestone	1000 ± feet	Georgian	Cambrian
	Antietam sandstone		Georgian	Cambrian

The general structure of the Cumberland Valley is a monocline, the oldest rocks of the Shenandoah group resting against the Cam-

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

[2] *Jour. of Geol.*, Vol. XIV, 1906, pp. 201–20.

brian quartzites of South Mountain on the east, and the youngest rocks passing beneath the Ordovician shales and sandstones of North Mountain and its associated ridges on the west. The monocline is not simple, however, but is modified by numerous folds and faults that either repeat the strata or conceal them.

The following detailed descriptions relate chiefly to the portion of the Valley in the Mercersburg and Chambersburg 15-minute quadrangles, which lie just north of the Maryland state line, but brief references are made to the Carlisle quadrangle at the north end of South Mountain.

TOMSTOWN LIMESTONE

The Tomstown limestone is not well exposed because of its nearness to South Mountain, where the surface is thickly covered by wash. It is composed largely of limestone, both massive and thin bedded, in part cherty, with some shale interbedded near the base. On account of its relative solubility it forms a depression or valley between the mountain and the irregular line of low ridges and knobs of the Waynesboro formation. Its thickness, computed from the width of its outcrop and the dip of its beds, is about 1,000 feet.

The base of the formation is largely concealed but comprises some hydromica shale interbedded with the limestones resting on the uppermost beds of Antietam sandstone. The top of the formation is placed at the first sandstones of the Waynesboro formation.

In the eastern or Chambersburg quadrangle the Tomstown limestone forms a belt about one mile wide along the foot of South Mountain, spreading out to nearly double that width in places. At Little Antietam Creek it is offset by a diagonal fault and extends up the Antietam Valley into the mountains several miles.

But few fossils have been found in this formation. At Roadside, in the upper limestones of the formation, excellent specimens of *Salterella* sp. undet., with the characteristic invaginate structure, were obtained. Mr. Walcott also found in this limestone, at the foot of the mountain east of Little Antietam Creek, *Kutorginia* n. sp. and fragments of *Olenellus*. These definitely determine its age as Georgian (Lower Cambrian).

In central Virginia a formation 1,600 to 1,800 feet thick, occupying

about the same interval but apparently including beds which in the Chambersburg area are calcareous sandstones and are mapped with the overlying Waynesboro formation, has been named Sherwood limestone by H. D. Campbell. The new name Tomstown is from a village in the Chambersburg quadrangle. The formation has been recognized also in the Carlisle quadrangle to the north, where it forms a deeply weathered belt about the foot of the mountain, largely covered by wash.

WAYNESBORO FORMATION

The Waynesboro formation is a series of sandstones, purple shales, and limestones overlying the Tomstown formation. Because of its resistant siliceous character it forms hills and knobs, parallel to the mountain front. At the base are very siliceous gray limestones that weather to slabby porous sandstone, large round masses of rugose chert, and white vein quartz.

In the middle of the formation are dark-blue to white subcrystalline limestones and dolomites, which become siliceous upward and merge into mottled slabby sandstone and dark-purple siliceous shale at the top. The thickness of the formation, computed from the width of outcrop and dips, and allowing for minor folding, is 1,250 feet.

The formation occupies a belt about one-half mile wide along the east side of the Cumberland Valley in the Chambersburg quadrangle. Its most complete development is in the hills northeast of Waynesboro, from which its name is taken. It has been traced northward beyond Mt. Holly Springs in the Carlisle quadrangle, but is there seldom exposed.

The only fossils found in this formation are a few poorly preserved shells, two of which are identified as *Obolus* (*Lingulella*) sp. undet. They were obtained from sandy shale at the very top of the formation, just east of Waynesboro. They suggest Acadian (Middle Cambrian) age but are not conclusive.

In central Virginia the Buena Vista shale, described by H. D. Campbell, is at this general horizon, but, as previously stated, apparently has a different lower limit. It is described as bright variegated shale, 600 to 900 feet thick, with mottled limestone and shale in the lower part. Mr. Walcott found in it a species of *Ptychoparia* related to Acadian (Middle Cambrian) species of Tennessee.

ELBROOK FORMATION

The Elbrook formation is the thick series of gray to light-blue shaly limestone and calcareous shale that overlies the purple Waynesboro formation.

The formation is decidedly shaly, most of the included limestones being minutely laminated and weather readily into calcareous shaly plates. When unweathered the limestone appears massive and homogeneous and in places is quarried.

Near the middle of the formation are massive beds of dolomite and very siliceous or quartzitic limestone that weathers to porous slabby sandstone and frequently forms knobs and ridges. The formation is limited above by limestone conglomerates containing rounded vitreous quartz grains and others containing tabular fragments of limestone, which characterize the base of the overlying formation.

The thickness of the Elbrook, determined on the two limbs of the unsymmetrical syncline west of Quincy, is about 3,000 feet.

The Elbrook formation crosses the Chambersburg quadrangle in a belt about 2 miles wide, with numerous projections and re-entrants due to intricate folding. It has also been traced across the Carlisle quadrangle where the character of the limestones is the same, but shales increase in prominence.

The only fossils found in this formation were fragments of trilobites obtained from rather pure limestone near the base northeast of Waynesboro. The age of the rocks could not be determined from these fragments, but they suggest Acadian.

The limestone was once extensively quarried for ballast for the Western Maryland Railroad at Elbrook, in the Chambersburg quadrangle, from which the name of the formation is taken.

CONOCOCHEAGUE LIMESTONE

The Conococheague limestone is characterized by beds containing thin sandy laminae and quartz grains that weather into hard shale fragments and thin slabby sandstones which generally give rise to rocky hills and rugged topography.

The base of the formation is usually easily determined because it is marked by siliceous beds and conglomerates that produce a ridge. The conglomerates are of two kinds; one is composed of rounded

limestone pebbles, 1 inch or more in size, in a matrix containing numerous round coarse grains of vitreous quartz; the other is composed of long slender fragments of limestone in a calcareous matrix, which, because the fragments are tilted at various angles, is called "edgewise" bed. Interbedded with the conglomerates are oolites and dark shaly limestones with red clay partings.

The body of the formation is a closely banded dark blue limestone, the bands varying from one-half inch in width to minute laminae. The banding is inconspicuous in the fresh rock but is brought out in weathering as yellowish sandy streaks across a light-blue or gray surface. Toward the top these partings become more numerous and sandy, and weather into hard sandy plates and sheets. Chert is not an important constituent of the formation in the Chambersburg and Mercersburg quadrangles.

The thickness of the formation is about 1,600 feet.

A section measured at Scotland is as follows:

	Rather pure, light, shelly or platy limestone, probably Beekmantown-
90 feet.	Granular crystalline limestone containing coarse "edgewise" con. glomerate, oolite, and pink marble, with numerous slaty partings weathering to glistening shale particles.
300 feet.	Covered.
15 feet.	Fine-grained, pure, light limestone, "edgewise" conglomerate and cross-bedded limestone containing quartz grains
390 feet.	Covered. Lower portion contains impure dark limestone and large banded chert.
10 feet.	Banded, dark and light limestone.
270 feet.	Dark, rather pure limestone containing trilobites and oolite, with argillaceous partings weathering to soft shale or slaty partings.
40 feet.	Massive light-colored, dense, even-grained limestone, with few fluted siliceous partings.
70 feet.	Covered.
180 feet.	Corrugated impure siliceous banded limestone and hackly shaly limestone.
30 feet.	Dense, black, rather pure limestone.
40 feet.	Massive beds of crumpled, siliceous banded limestone.
200±feet.	Dense siliceous banded limestone with "edgewise" conglomerate, cryptozoan, and sandstone beds at the base.

1635 feet, total.

The Conococheague limestone occurs in a broad sinuous belt crossing the Chambersburg quadrangle from south to north. It is plicated into many folds northwest of Waynesboro, marked by ridges of rough topography, and just south of the Chambersburg pike its

basal member forms a high elbow ridge, which is faulted off on the west side.

A wedge-shaped inlier of Conococheague is brought to the surface by an anticline in the vicinity of Welsh Run, in the Mercersburg quadrangle, where the rocks are similar to those in the Chambersburg area, but the siliceous banding is less pronounced. In the Carlisle quadrangle neither the basal siliceous beds nor the sandy laminated beds at the top are prominently developed.

Few fossils have been found in this formation, and such as have been collected are poorly preserved and difficult of determination. At the base a few good specimens of trilobites and brachiopods were obtained in the western portion of Scotland, and fragments of the same were seen in the basal conglomerate. These comprise *Dikelocephalus hartii* Walcott; *D.* sp. undet.; and *Billingsella* like *B. desmopleura.* The trilobites place this part of the formation definitely in the Saratogan (Upper Cambrian). In the basal conglomeratic beds a species of *Cryptozoan*, probably *C. proliferum* Hall, characterized by a mammiferous surface, the elevations ½ to 1 inch in diameter, is rather generally present. In cross section the fossil appears to consist of thin closely folded laminae, and is illustrated in the writer's former paper.[1]

These siliceous banded limestones, together with overlying finely laminated purer rocks, were previously described by the writer under the name Knox limestone. The differentiation of the upper rocks as a separate formation, next to be described, necessitates the giving of a new name to these lower beds, and Conococheague, the name of the large stream on the banks of which, in the town of Scotland, the best exposures occur, has been selected. The Conococheague and the overlying Beekmantown, therefore, comprise the Knox group.

BEEKMANTOWN LIMESTONE

The Beekmantown is a rather pure limestone lying between the siliceous Conococheague below and the very pure Stones River above. A minutely laminated appearance on weathered surfaces of many of the beds, due to their impurities, and pink to white fine-grained limestone or marble are characteristic features of the formation. Near

[1] *Loc. cit.* p. 217.

the base are siliceous banded beds and large "edgewise" conglomerate, closely resembling the Conococheague formation. These have been separated as a transition phase under the name Stonehenge member of the Beekmantown.

The best exposure of the formation in the Chambersburg quadrangle is adjoining the Chambersburg-Gettysburg pike, where the following composite section has been measured by Mr. Ulrich and the writer.

Beekmantown Section, 1 Mile East of Chambersburg.

	Base of Stones River containing fine limestone conglomerate and laminar and oolitic chert.	
600 feet.	Interbedded fine-grained pure limestones and magnesian limestones, finely laminated in part and containing small quartz geodes. Porous sandy chert near top. Dark layers near base, mottled by magnesian material that weathers out, leaving pits and holes, contain numerous gasteropods and ostracoda.	
375 feet.	Alternating pure dove and gray limestones and magnesian limestones, with layer of sandy chert.	
100 feet.	Bluish to dove fine-grained fossiliferous limestone, at the base containing rounded quartz grains.	
275 feet.	Pink, fine grained marble, containing layers of milky quartz chert. Gasteropods of the genus Ophileta, Maclurea, and Eccyliopterus rather abundant.	
285 feet.	Pure dove and blue, fine-grained limestone, with some pink limestones. Contains fragments of Trilobites.	
145 feet.	Fine-grained dove to dark-gray limestone with fine conglomeratic and oolitic beds. Abundant chert in upper portion, in part oolitic and conglomeratic.	
225 feet.	Fine-grained light- to dark-gray limestone containing contorted laminae of sandy matter, that stand in relief or fall to sandy shale on weathering, and thick beds of "edgewise" conglomerate. Contain Gasteropods in upper portion and fine fragments of Trilobites in lower part.	Stonehenge member
260 feet.	Dark- to light-gray limestone, with sandy laminae less developed than in overlying beds. Contain Orthis, Ophileta, and Trilobite fragments.	Stonehenge member
	Top of Conococheague, containing contorted sandy laminae and beds of coarse limestone conglomerate.	

2,265 feet total.

In the Mercersburg quadrangle an excellent section of the Beek-

mantown occurs on Licking Creek near its mouth. Unfortunately the upper part of the formation is not exposed in the creek bank and is complicated by folding. The section measured by Mr. Ulrich and the writer is as follows:

Beekmantown Section, near Mouth of Licking Creek.

	Interbedded pure and magnesian limestones of Stones River type.
340 feet.	Light gray finely laminated magnesian limestone and white dolomite, with cherts of rosette type at the top.
140 feet.	Dark and light, coarse dolomite.
	Rocks here folded and largely covered; contains white domolite, dark-blue oolitic limestone, and dark coarse dolomite with yellow blocky sandstone fragments and rosette cherts. Exact continuity indeterminable, but the previous beds are apparently repeated by folding.
350 feet.	Interbedded pure and magnesian limestones, with beds of coarse dark dolomite, and in the lower part beds of "edgewise" conglomerate; at base contains Gasteropods, Cephalopods, and Trilobites.
170 feet.	Largely finely banded magnesian limestone with few pure limestones. Contains fine conglomerate beds and Gasteropods.
130 feet.	Largely dolomite, some coarse and dark. Large scoriaceous black chert and coarse sandstone at the base.
290 feet.	Chiefly dolomite, coarse and dark in upper part, with occasional pure fossiliferous limestone. Bed of granular limestone with numerous Ophileta and pinkish fine-grained limestone near middle, crossbedded banded limestone at base locally unconformable on underlying beds.
65 feet.	Fine-grained limestone seamed with calcite and dolomite beds, with flinty chert containing Cryptozoan at the base.
130 feet.	Partly covered. Lower part pure dark limestone with few beds of finely laminated magnesian limestone and fine white oolite near base. Small rough chert with casts of crystal at the base.
165 feet.	Light-blue limestone with fine contorted sandy laminae that weather in relief. Contains fine dark conglomerate with red limestone pebbles and fragments of Trilobites.
530 feet.	Purer fine even-grain limestone with few sandy partings.
	Sandy laminated limestone, much contorted, of the Conococheague formation.
2,310 feet, total.	

The details of the sections in the two areas are quite unlike. Whereas beds of pure limestone and marble are common and chert infrequent in the Chambersburg section, the reverse is true in the Licking Creek section. The pure limestones have been extensively

quarried at Stoufferstown and Stonehenge east of Chambersburg. In the Mercersburg quadrangle, chert is sufficiently plentiful in the soil derived from the Beekmantown to produce low ridges. One horizon is just above the siliceous banded limestone of the Stonehenge member and in the Mercersburg area is included with the siliceous phase. The cherts are of various forms. Some are large, rough, scoriaceous masses, others are flinty in texture, banded, brecciated, granular, and oolitic; while the most unique forms are composed of super-imposed rosettes resembling heads of cauliflower. A Cryptozoan, apparently of the species described by Winchell as *C. minnesotensae*, occurs in these cherts.

An upper horizon of cherts, many of the small rosette form, occurs at the top of the Beekmantown in both areas, but is a ridge maker in the Mercersburg quadrangle.

The Beekmantown limestone is one of the most widely distributed formations in the area, occurring in a broad belt across the western half of the Chambersburg quadrangle, and in several anticlinal areas in the Mercersburg quadrangle. Its outcrops are generally deeply covered with soil with infrequent exposures, and furnish excellent farm land.

In the eastern belt it is closely folded in common with the enclosing limestones, and its outcrop is consequently very irregular in outline and width. In the Mercersburg quadrangle it forms large lens-shaped areas in the anticlinal uplifts of Welsh Run-Edenville, Mercersburg, Foltz, and McConnellsburg.

Although its fauna has been previously observed at various places in the Appalachian Valley, the Beekmantown has not heretofore been recognized as a distinct formation in this region, and little is known of its extent beyond the immediate vicinity of the area. It is known to maintain its lithologic and faunal characters as far northeast as Mechanicsburg, Pa. Although sparingly fossiliferous as a whole, a rather large variety of forms have been collected in this area.

The lower portion of the formation, including the Stonehenge member, is characterized by *Ophileta complanata* and of the 13 species collected the following have been identified by Mr. Ulrich:

Rhabdaria, cf. R. fragilis Billings.
Calathium sp. undet.
Orthis wemplei?
Ophileta complanata.
Maclurea affinis.
Eccyliopterus.
E. triangulus.
Bathyurus near B. conicus.

In the middle of the formation two faunas have been distinguished. The lower one, characterized by horn-like *Opercula*, small *Isochilina*, *Hormotoma artemesia*, and large thin-shelled *Maclurea*, occurs in both quadrangles and good collections were made at Licking Creek and near McConnellsburg. 15 species were collected of which the following have been tentatively determined:

Orthis cf. electra.
Maclurea affinis.
Horn-like opercula of an otherwise unknown gasteropod for which Mr. Ulrich suggests the generic name *Ceratopea*.
Liospira canadensis.
Eccyliopterus, cf. triangulus.
Isotelus canalis.
Bathyurus cf. conicus.
B. caudatus.
Amphion cf. salteri.
Leperditia cf. Primitia gregaria Whitfield.

The upper fauna of the middle division, characterized by *Syntrophia lateralis* and found only at Stoufferstown, is as follows:

Syntrophia lateralis.
Maclurea? sordida.
Liospira cf. laurentina.
Orthoceras cf. primigenium.

In the upper part of the formation, which is characterized by high-spired turritelloid gasteropods and by *Ophileta disjuncta*, 17 species have been collected from the quarry at Stoufferstown, and the following tentatively identified by Mr. Ulrich:

Orthis (? Dalmanella) electra.
Maclurea cf. M. oceana.
Ophileta ? disjuncta.
Solenospira cf. prisca.
Turritoma acrea?
Hormotoma gracilens.
Lophospira cf. Murchisonia gregaria Billings.
Cyrtocerina cf. mercurius.
Trocholites internestriatus.

Mr. Ulrich, who determined all the fossils described under this and succeeding headings, correlates the foregoing lists with the Beekmantown of New York, and that name is therefore applied to the formation.

STONES RIVER LIMESTONE

Above the Beekmantown is a considerable thickness of very pure limestones with occasional magnesian layers. The greater portion of the limestone that is burned for lime in this area is obtained from

this formation. In general the formation is composed of three divisions:—a middle band of massive pure granular limestone containing the large gasteropod *Maclurea magna* and thin beds of black chert that weather into small rectangular blocks; an upper series of thin-bedded pure limestone; a lower series of interbedded massive pure beds and magnesian layers.

These divisions cannot be readily distinguished in all parts of the area, and at no place can the complete section be seen because the beds are several times repeated by folding and the outcrops are not continuously exposed.

The following is a composite section of the formation in the Chambersburg belt:

	Feet
Thin-bedded, fine-grained, pure, dove limestone.	275+
Massive pure limestone containing Maclurea magna and black chert layers. Upper part, compact, blue to dark; lower part, light gray, granular and oolitic	150–200
Massive and thin-bedded limestone interbedded with magnesian layers .	600+
Total	1050+

In the western belts the cherty Maclurea horizon was not clearly observed and the three-fold division could not be made. At West Branch of Conococheague Creek, south of the Mercersburg-Greencastle pike, its thickness was determined at 800 to 1,000 feet.

In McConnellsburg Cove, west of Tuscarora Mountain, the exposures are exceptionally meager. At a quarry south of the Mercersburg pike the formation as exposed comprises about 575 feet of interbedded, pure and banded magnesian beds with very pure fine-grained dove limestone at the top.

The formation crosses the Mercersburg and Chambersburg quadrangles from north to south in five belts. The eastern belt lying in the Chambersburg quadrangle is intricately folded and faulted, and comprises several parallel strips.

In the next limestone belt to the west, the Welsh Run-Edenville anticline, the Stones River forms a narrow strip about ¼ mile in width on either side of the Beekmantown. In the Mercersburg belt it occurs as two narrow faulted strips. In the Foltz and McConnellsburg limestone belts, its outcrops are largely covered.

Few fossils have been found in this formation, except in the middle chert-bearing portion. These consist chiefly of gasteropods, ostracoda, cephalopods, and bryozoa. A few ostracoda (*Leperditia fabulites*) and *Tetradium "syringoporoides"* can usually be obtained from the fine even-grained beds in all parts of the formation; 22 species were obtained from the subgranular beds of the middle division, and the following have been tentatively identified by Mr. Ulrich:

Stromatocerium sp. nov.
Tetradium "syringoporoides"—the single-tubed form of this genus so characteristic of the Stones River.
Glyptocystites sp. undet.
Lingulella ? belli (Billings)
Hebertella borealis.
H. vulgaris
Dinorthis cf. platys.
Strophomena aff. S. charlottae.
Bucania sulcatina.
Maclurea magna.
Lophospira bicincta.
Isochilina cf. amiana.
Ampyx halli.

The massive shells and opercula of *Maclurea magna* are the most characteristic fossils of this division. From the standpoint of correlation the most noteworthy feature of the above list is that no less than eight of the species occur in the middle Chazy of the Champlain Valley.

Although only *Leperditia fabulites*, L. cf. *amiana, and Lingula manteli* were obtained from the lower beds of this formation in this area, 12 species were collected 30 miles down the valley at Martinsburg, W. Va., by Mr. Ulrich and the writer, of which the following have been determined:

Solenopora compacta var.
Cyrtodonta sp. nov.
Matheria sp. nov.
Liospira cf. obtusa.
Lophospira cf. perangulata.
Helicotoma ? sp. nov.
Oncoceras ? sp. undet.
Leperditia fabulites.

The fossils as well as the lithologic character of this formation are so nearly the same as those of the Stones River limestone of Tennessee that they are regarded by Mr. Ulrich as identical, and the name Stones River is therefore applied.

CHAMBERSBURG LIMESTONE

The Chambersburg limestone is the uppermost division of the Shenandoah limestone. It is characterized throughout the area by

fossiliferous thin-bedded limestones with argillaceous partings. It varies in thickness across the strike from a maximum of 600 feet in the Chambersburg belt to about 100 feet in the McConnellsburg Cove.

Its most typical development is in the Chambersburg belt throughout which fossils are abundant. The following section in the railroad cut 1½ miles west of Kauffman is the most complete continuous section in this belt.

	Feet
Black shale (Martinsburg)	
Largely concealed, but probably chiefly shale (near the top are black carbonaceous limestone with conchoidal fracture, shaly dark crystalline limestone, thin sandstone, and 10 feet of coarse crystalline limestone containing Lingulas)	150
Calcareous shale and limestone	100
Nodular clayey limestone	50
Dark platy limestone	94
Compact dark limestone, very fossiliferous	108
Cobbly limestone containing numerous Nidulites, bryozoa, and a layer of cystid heads	105
Total	607

The "cobbly" character of the weathered outcrop of certain of the beds, due to a wavy lamination or clay parting that crosses the bedding at a high angle and, on weathering, gives rise to rounded lenticular masses resembling rough cobbles, is one of the noticeable features of this formation. The upper 200 feet of the formation is composed largely of shale with interbedded thin fossiliferous limestones.

In the Welsh Run-Edenville belt, 2½ miles southeast of Mercersburg, the following section occurs on the banks of West Branch of Conococheague Creek.

		Feet
Fissile shale containing graptolites and lingulas	Martinsburg shale.	
Calcareous black shale and hard thin black carbonaceous limestones, 80 feet.	Martinsburg shale.	
Granocrystalline limestone, fossiliferous		2
Cobbly dark subcrystalline limestone, both massive and thin-bedded		73
Coarse massive granocrystalline limestone with massive beds of pure fine-grained limestone		75

Platy granocrystalline limestone, fossiliferous	25
Dark, subcrystalline limestone with wavy partings of shale, fossiliferous	150
Very thin-bedded pure fine-grained drab limestone followed by more massive pure beds with magnesian layers and fine laminations (Stones River)	
Total	325

The following section was measured 1½ miles west of Markes on the west side of the Mercersburg belt:

	Feet
Fissile and calcareous shale (Martinsburg)	
Thick bed of coarse crystalline gray limestone, fossiliferous	5
Thin bedded and cobbly dark limestone with Nidulites and *Monotrypa hemisphericus* in upper part	45
More massive limestone, banded in part	45
Pure fine-grained dark limestone with large Beatricea	20
Dark compact limestone	20
Covered	60+
Thin-bedded pure fine even-grained drab limestone (Stones River)	150
Total	195+

In the McConnellsburg Cove, few outcrops of the Chambersburg limestone occur, and but one measured section was secured, 2 miles northeast of McConnellsburg, as follows:

	Feet
Fissile shale containing graptolites	
Hard black slate and thin slaty black limestone, (Martinsburg)	84
Covered	10
Gray marble and massive blue-veined limestone	20
Dark shaly limestone with argillaceous partings, containing solenopora and bryozoa	68
Pure fine even-grained limestone (Stones River)	
Total	182

The Chambersburg formation forms a narrow band along the margin of the overlying Martinsburg shale throughout the Mercersburg and Chambersburg quadrangles except where it is cut out by faults. It is present also along this contact throughout the Carlisle quadrangle, but details of its character and thickness there are not known.

Nearly everywhere this formation yields on careful search an abundance and great variety of fossils, and those from the Chambersburg quadrangle differ from those obtained in the Mercersburg quad-

rangle. In the Chambersburg belt the formation may be divided into 4 faunal zones.

From the lower zone, characterized by *Dinorthis pectinella*, 20 species were collected, of which the following have been determined by Mr. Ulrich:

Receptaculites cf. occidentalis.
Echinosphaerites sp. undet.
Orocystites?
? Chaetetes cumulata.
Hemiphragma irrasum.
Dalmanella testudinaria, small n. var.
Dinorthis pectinella.
Hebertella bellarugosa.
H. cf. borealis and vulgaris.
Rafinesquina inquassa?
Plectambonites pisum var.
Triplesia n. sp.
Leperditia fabulites pinguis.
Ampyx normalis.

In the second division, characterized by Nidulites, 38 species were collected and the following tentatively identified:

Nidulites cf. favus.
New genus of Amygdalocystidae.
New genus of Pleurocystidae.
Bolboporites n. sp.
Praspora contigua.
P. cf. lenticularis.
Stromatotrypa (? Diplotryna) sp. undet.
Hemiphragma irrasum?
Stomatopora inflata.
S. proutana.
Orthis sp. undet.
Plectorthis n. sp.
Dalmanella testudinaria var.
Dalmanella n. sp. (aff. D. subaequata).
Scenidium anthonense.
Strophomena cf. filitexta.
Rafinesquina cf. inquassa.
R. cf. incrassata.
Leptaena n. sp.
Plectambonites cf. pisum.
P. asper (Reudemann).
Triplesia n. sp.
Ampyx n. sp. (cf. A. normalis and A. halli).
Pterygometopus cf. callicephalus (variety approaching P. schmidti).
Ceraurus pleuraxanthemus.

In the third division, which is often crowded with fossils, 43 species were collected, of which the following have been determined:

Diplotrypa sp. undet.
Rhinidictya cf. neglecta.
Plectambonites n. sp.
Leptaena n. sp.
Parastrophia cf. hemiplicata.
Ulrichospira n. sp.
Echinosphaerites sp.
Hemiphragma cf. irrasum and ottawaensis.
Arthropora cf. bifurcata.
Rhinidictya cf. neglecta.
cf. Trematopora ? primigenia.
Orbiculoidea cf. lamellosa.
Orthis cf. tricenaria.
Scenidium cf. (Merope).
Dinorthis n. sp. (aff. D. subquadrata).
Strophomena n. sp.

Strophomena (? Leptaena) cf. charlottae.
Plectambonites asper.
P. pisum.
P. n. sp. (near P. pisum).
P. n. sp.
Christiania trentonensis.
C. n. sp.
Triplesia n. sp.
T. cf. nucleus.
Protozyga exigua.
Orthoceras cf. junceum.
O. cf. arcuoliratum.
Lepidocoleus 2 undet. species (near L. jamesi).
Isotelus cf. gigas.
Illaenus consimilis.
Fragments of Trinucleus or Tretaspis.

In the upper, or Sinuites, zone, which is immediately beneath graptolite-bearing shales, 31 species were collected, and the following determined:

Diplograptus sp. undet.
Lingula riciniformis ?
Lingulops sp. nov. ?
Conotreta rusti.
Rafinesquina cf. ulrichi.
Sinuites cancellatus.
Cyclora minuta.
C. parvula.
Microceras cf. inornatum.
Coleolus cf.
Trocholites sp. undet.
Caryocaris sp. undet.
Turrilepas sp. undet.
Ctenobolbina sp. undet.
Ampyx n. sp.
Trinucleus concentricus ?
Harpina ottawaensis ?
Triarthrus becki.
T. fischeri.
Calymene senaria ?
Bumastus sp. ?
Bronteopsis ? sp. undet.
Proetus latimarginatus.
Cyphapis matutina.

In the Mercersburg quadrangle 4 faunal zones are also distinguished but they do not correspond with those of the Chambersburg belt. The lower zone comprises 20 species, largely new and undescribed, of which the following are tentatively listed:

Licrophycus cf. ottawaensis.
Lockeia sp. undet.
Cliocrinus n. sp. ?
Raphanocrinus ? n. sp.
Echinosphaerites sp. ? plates only.
Helopora spiniformis ?
Rhinidictya neglecta.
Escharopora ramosa.
Dalmanella cf. testudinaria.
D. subaequata.
Rafinesquina minnesotensis.
Strophomena cf. filitexta.
Plectambonites asper.
Gonioceras chazyense.
Thaleops ovatus.
Pterygometopus cf. schmidti.

Of the 48 species collected in the second zone, the brachiopods and bryozoa that have been identified by Mr. Ulrich are regarded by him as suggesting the upper Chazy of New York:—

Solenopora compacta.
Camarocladia cf. rugosum.
Columnaria halli.
Tetradium columnare.
T. cellulosum.
Caryocystites sp. nov.
Anolotichia impolita.
Nicholsonella laminata.
Batostoma cf. magnopora.
Hemiphragma irrasum.
Helopora divaricata ?
Rhinidictya fidelis.
Pachydictya cf. foliata and robusta.
Escharopora confluens.
Phylloporina reticulata.
Hebertella borealis.
H. vulgaris.
H. bellarugosa ?
Rafinesquina sp. undet.
Strophomena (? Leptaena) charlottae.
Plectambonites asper.
Rhynchonella plena.
Zygospira recurvirostris.
Leperditia cf. fabulites.
Isochilina cf. gracilis.
Platymetopus cf. trentonensis.

The third zone, characterized by Beatricea, is regarded as representing the Lowville ("Birdseye") of New York. Of the 37 species, the following have been identified.

Beatricea n. sp.
Tetradium cellulosum.
Echinosphaerites sp.
Mesotrypa ? sp. undet.
Diplotrypa ? sp. undet.
Stictoporella sp. undet.
Dinorthis cf. meedsi.
Triplesia sp. nov.
Zygospira uphami.
Helicotoma planulatoides.
H. verticalis ?
Omospira cf. alexandra.
Leperditia cf. fabulites.
Isochilina n. sp. (cf. I. gracilis).
I. n. sp. (cf. I. ottawa).
Macronotella ulrichi.
Drepanella macra.

The upper division is the Sinuites zone, and although it corresponds with the upper zone of the Chambersburg belt, it is not succeeded directly by the graptolite-bearing shale but by a considerable thickness of intervening barren calcareous shales and thin black limestones. Of the 32 species the following have been identified by Mr. Ulrich, who correlates them with the Normanskill division of the Trenton of New York.

Hindia sp. undet.
Lingula riciniformis.
Lingulops n. sp.
Dalmanella n. sp.
Dinorthis cf. germana and subquadrata.
Plectambonites pisum.
P. n. sp. (1) (aff. P. transversalis).
P. n. sp. (1) (aff. P. sericea).
Christiania n. sp.
Triplesia n. sp.
Sinuites cancellatus.
Cyrtolitina nitidula.
Eccyliomphalus spiralis.
Strophostylus textilis.
Cyclora minuta.
C. depressa ?
Orthoceras junceum.
Trinucleus concentricus ?
Cyphaspis matutina.

NORTH AMERICAN PLESIOSAURS
TRINACROMERUM

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In previous papers[1] I have discussed the known characters of *Elasmosaurus*, *Cimoliasaurus*, *Brachauchenius* and *Polycotylus*, and *Trinacromerum*, as derived from the species *T.* (*Dolichorhynchops*) *osborni.* The brief and somewhat erroneous description of the type of *Trinacromerum* by its author has hitherto prevented its recognition with much certainty. Its relationships with *Dolichorhynchops* I recognized at the time that I proposed that genus, and suggested the possible identity, but it was not until I had the opportunity of examining the type specimen of *Trinacromerum*, which was kindly granted by the president of Colorado College, where the specimen is now preserved, that I became assured of the synonymy, an acknowledgment of which was made in the third volume of Chamberlin and Salisbury's *Geology*, and, later, in the second of the papers cited below. Furthermore, I am now nearly as well assured of the synonymy of *Trinacromerum* with *Polycotylus*, but am yet hesitant to abandon the name *Trinacromerum* until the skull of the type species of *Polycotylus*, (*P. latipennis* Cope) shall be better known and have been more thoroughly studied. The only differences that I can so far discover are the deeper concavity of the vertebral centra, the number of epipodials and the manner of attachment of chevrons—of doubtful value. The name *Trinacromerum*, therefore, is used provisionally until such time as more positive evidence is forthcoming.

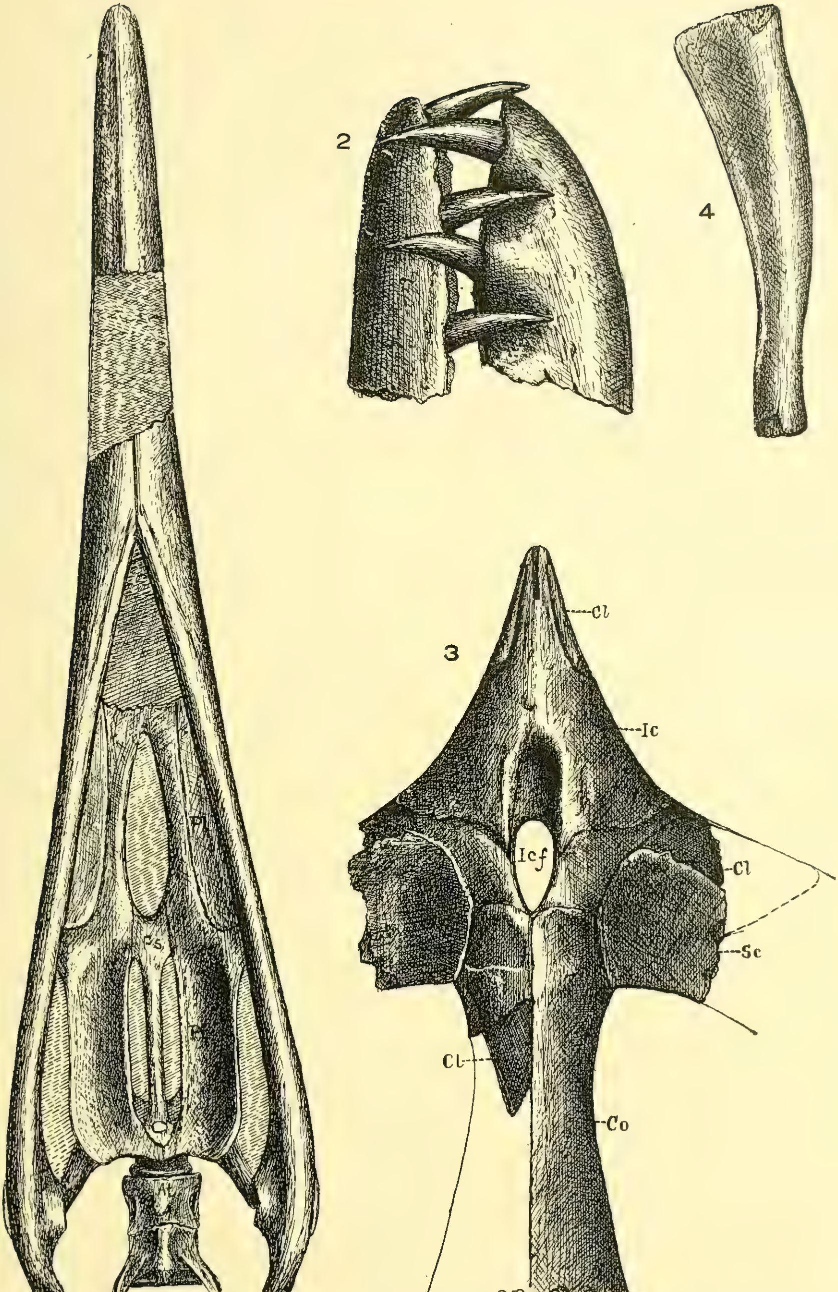
Very recently, through the courtesy of Professor Sclater, I have had the opportunity of further study of certain important parts of the type specimen of *Trinacromerum bentonianum*, kindly sent me for that purpose. I am thus enabled to give a number of figures and a more complete description of this important species.

[1] *Publication No. 73* of the Field Columbian Museum, 1903; *American Journal of Science*, XXI, 221, 1906; *Proc. U. S. Nat. Mus.*, XXXII, 477, 1907.

Trinacromerum bentonianum Cragin

Skull.—In his original description Cragin speaks of three skulls referred by him to his typical species. One of his skulls, however, proves to be a part of the pectoral girdle of his original type, an error resulting from the confusion of the interclavicular foramen with the pineal foramen, an error not so great as it would seem, since such a foramen in the pectoral girdle was unknown previously among plesiosaurs. A close comparison of the two skulls, both from the same horizon and adjacent localities, leaves no doubt of their identity, both generically and specifically. Skull "No. 2," the better specimen, shows the underside nearly complete, with the hyoids and jaws in place, a small part of the facial portion only, wanting. The upper part of the skull is so badly compressed and mutilated that but little decisive can be made out from it, but the palatal structure, perhaps the most important of the plesiosaur cranial anatomy, has been determined from this specimen almost perfectly, the relations of the vomers only being doubtful (figs. 1, 2).

The slender parasphenoid separates two long and narrow openings between the pterygoids, which openings may properly be called the parasphenoidal vacuities for the present. On either side, the long, broad, gently concave plate of the pterygoid fills up nearly all the free space between the vacuity and the mandible, and thence extends forward as a slender process on either side of the real interpterygoidal vacuity to articulate externally with the palatine, and anteriorly, doubtless as in *T. osborni*, with the vomer. The true interpterygoidal vacuity is an elongated ovate opening, obtuse posteriorly, acute in front, bounded by thickened, rounded margins; posteriorly it is bordered by the slightly expanded anterior end of the parasphenoid, which is here concave in outline and thick, the pterygoid suture extending forward on each side from the front end of each parasphenoidal vacuity. In the type specimen of *T. osborni* the anterior end of this bone was somewhat mutilated, and I was not quite certain that it was not produced forward to fill up this vacuity as in other known plesiosaurs. This, however, is not the case. This extraordinary opening is therefore unique for this genus and *Polycotylus* among plesiosaurs, and indeed among all known reptiles, if it be merely a vacuity. And I venture the opinion that it may be compared with a similar opening



FIGS. 1–4.— *Trinacromerum bentonianum* Cragin. 1, skull from below, one-sixth natural size; 2, extremity of beak, one-half natural size; 3, pectoral girdle in part one-sixth natural size; 4, left hyoid from below. At, atlas; Cl, clavicle, Co, coracoid; Ic, interclavicle; Icf, interclavicular foramen; Pl, palatine; Ps, parasphenoid; Pt, pterygoid; Sc, scapula.

in the skull of *Nyctosaurus* and *Pteranodon*, the American Cretaceous pterodactyls. This would suggest that the supposed elongated basisphenoid of *Nyctosaurus* is really the parasphenoid, against which view we have the improbability of the survival of so large a parasphenoid in this type of reptiles, as well as the mode of attachment of the pterygoids on either side.

The junction of the transpalatine is seen in the specimen on the left side, but the shape and relations of the bone are obscured by the mandible, though certainly there is no posterior palatine foramen; doubtless the relations of the bone are quite as I have figured them in *T. osborni*.

The relations of the pterygoids posteriorly cannot certainly be made

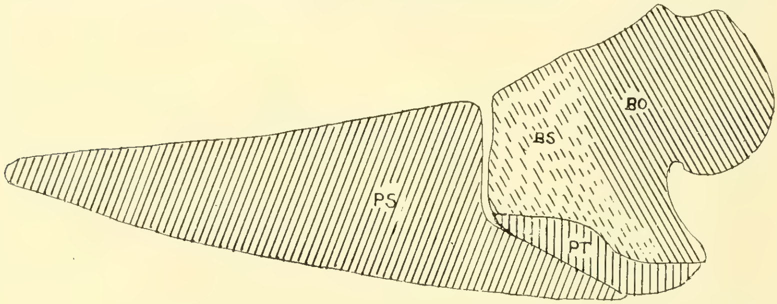


FIG. 5.—*T. bentonianum*. Section through basioccipital and parasphenoid, one-half natural size. BO basioccipital; BS, basisphenoid; PS, parasphenoid; PT, pterygoid.

out in skull "No. 2" nor were they in the type of *T. osborni*. Very fortunately, however, the posterior part of skull "No. 1," the type specimen of the genus, gives nearly all the information that could be desired. In this specimen there is a longitudinal break or split through the occipital condyle, nearly in the middle line, to the interpterygoidal vacuity. I give this section in fig. 5. The distinction between the basioccipital and basisphenoid is not clear, but it must be as in *T. osborni* or nearly so, as has been indicated by the broken lines of the figure. In front of the basisphenoid the conical and thickened parasphenoid, or "presphenoid" narrows into a median, long, and vertically broad bone to the hind end of the interpterygoidal vacuity, which it bounds. Posteriorly it extends, by a squamous underlap, nearly to the hind margin of the basioccipital, the

united pterygoids clearly intercalated between them. Between the pterygoids and parasphenoid, and hollowed from the latter there appear to be two parallel canals, terminating on the free surface below. Along the middle of the rounded under surface of the parasphenoid there is seen a slender groove, as though the remains of a suture, a remarkable thing if it be really a suture. The parasphenoidal vacuities are bounded outwardly by the everted margins of the pterygoids, internally by the parasphenoid. The openings, however, do not quite reach to the hind end of the external boundaries, the pterygoids forming a floor to the grooves on the posterior fourth, as seen from below. So extraordinary a development of the parasphenoid in this group of reptiles as is shown in these specimens is of more than passing interest. If it be the true vomer of the mammals, one cannot understand the cause of its retention in so highly developed a condition unless the plesiosaurs sprang from reptiles that had not yet lost it. The Nothosauria are markedly different in the complete union of the pterygoids on the median line, to the exclusion, not only of the parasphenoid but the basisphenoid also; a condition, which, associated with the typical reptilian phalangeal formula, excludes the group I believe absolutely from direct and perhaps indirect genetic relationships with the plesiosaurs. Furthermore, the persistent retention of the parasphenoidal vacuities, so definitely bounded in all plesiosaurs, is puzzling, unless the explanation is that suggested by me in my earlier paper—that they are the real nareal openings.

The crushed condition of the upper part of the skull is such that little definite can be made out, though the resemblance to the same parts in *T. osborni* is evident. On the left side the jugal arch has been but little disturbed, showing the jugo-postorbito-squamosal sutures as in *T. osborni.* There is no indication whatever, and the parts are here intact, of a quadratojugal bone, the supposed suture of *T. osborni* being in no wise apparent. I believe that at last it may be definitely said that the quadratojugal bone is *absent in all plesiosaurs*, as a distinct element.

Unfortunately the jumbled condition of the frontal and prefrontal elements in these skulls has obliterated all sutures. An examination, however, of the various plesiosaur skulls in the British Museum and

at Cambridge, confirms me, in the determination of the elements in *Brachauchenius* and *Trinacromerum*. That this was not the frontal structure in all plesiosaurs is also quite certain. As I have stated before, the suture between the frontal bone and the element directly in front of it had never been positively determined. A suture has been given for the skull of *Plesiosaurus macrocephalus*, nearly transverse in position and immediately in front of the pineal opening, but this is incorrect. However, an isolated specimen of the frontal region of a species of *Plesiosaurus* in the British Museum, for the privilege of examining which I am indebted to Dr. Woodward, shows clearly a fronto-parietal suture, beginning some distance in front of the pineal opening, in the middle line, and extending obliquely outward and forward, clearly distinguishing a median frontal bone; and the one at either side of this true frontal is as clearly the prefrontal. In the later plesiosaurs, or some of them, I believe that the prolongation of this parietal projection forward to the backwardly produced premaxilla has separated the real frontals; and this interpretation is confirmed by the examination of the bones of this region in *T. anonymum* described farther on.

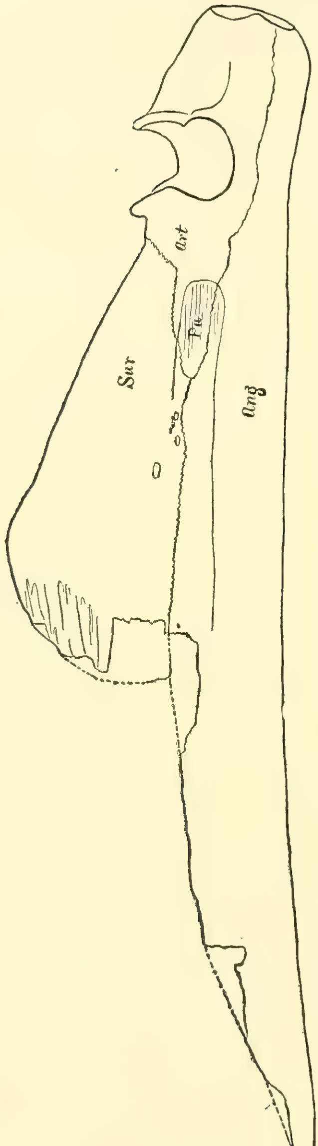


FIG. 6.—*Polycotylus latipinnis* Cope. Posterior part of right mandible, two-sevenths natural size. Art, articular; Ang, angular; Pa, prearticular; Sur, surangular.

Mandible.—The structure of the mandible is, for the first time, completely made out in a specimen (No. 1125) in the Yale Museum. Although the specimen belongs to the closely allied, possibly identical genus *Polycotylus*, it may be described here. The suture between the articular and surangular, never before determined, is here clearly shown, running obliquely downward and forward from just in front of the cotylus to connect with the angular-surangular suture beneath the proximal end of the prearticular (fig. 6). In the earlier of the cited papers I recognized the differentiation of this element in front of the articular, clearly homologous with the 'splenial' of the turtles, and gave to it the name prearticular. Baur, who had previously recognized this new element in the reptilian mandible unfortunately took for the type of structure that of the turtles, and changed the names of the other elements to conform thereto, giving to the splenial, as the name was originally applied, the name presplenial. This confusion was pointed out in a later publication by me, but without mentioning the fact that I had previously proposed the term prearticular for the newly discovered element.[1] Kingsley later, in reviewing the mandibular structure proposed for the same element the term dermarticular. In this separation of the prearticular from the articular the plesiosaurs show certain relationships with the turtles, but not important ones, since a like condition will probably be found in most of the early reptiles. The great elongation of the coronary, and its union in a median symphysis is the most striking characteristic of the plesiosaur mandible.

Hyoids.—Under each skull are preserved in perfect condition, and in undisturbed positions the hyoids. They lie below the concave lateral pterygoid plates, the anterior end reaching nearly as far forward as the hind end of the interpterygoidal opening. The bones of skull No. 2 (fig. 4) are a little less slender than those of skull No. 1. The posterior end is rounded, rod-like, and the mesial border is the thinner and more concave one. The hyoids have hitherto been unknown, so far as I am aware, in the plesiosaurs.

Vertebrae.—The atlas and axis are united with each other and with the occipital condyle in the type specimen. They resemble very closely the same bones in *T. osborni.* The axial rib is firmly attached.

[1] *Field Mus. Publ.*, No. 73, p. 30.

On the underside of the atlantal intercentrum, beyond the middle antero-posteriorly, there is an obtuse hypopophysis with the sides concave. The axial intercentrum has an obtuse keel, thicker posteriorly; this bone, also, is proportionally a little longer than in *T. osborni.* Ten or twelve other cervical vertebrae are preserved, but are, for the most part, without processes. They all have a conspicuously large vascular foramen on each side of a prominent ridge. A pair of smaller foramina for the centrum veins is seen in the floor of the neural canal. The ribs are single-headed, their sutures well indicated,

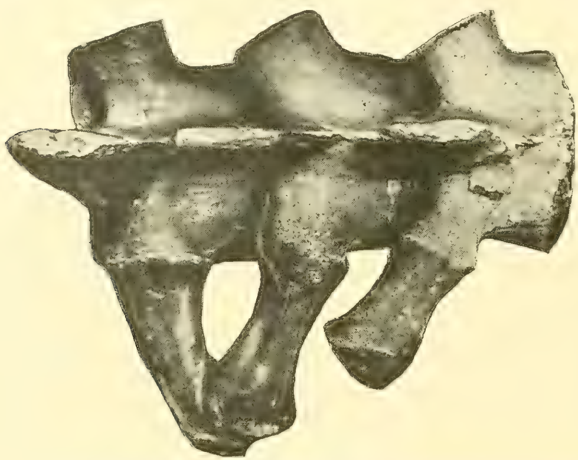


FIG. 7.— *T. bentonianum.* Sacrum, from above, one-fourth natural size.

though they, as also the neural arches, are firmly attached to the centrum.

Length of atlanto-axis	80 mm
Diameter of axis posteriorly	54
Lengths of vertebrae, as preserved	37, 37, 48, 50, 50, 50, 50
Transverse diameters of same	53, 75, 75, 75, 83, 86

There are fifteen dorsal vertebrae preserved in the type specimen, none of which is complete, though the preserved parts indicate well their structure. Two united anterior thoracic vertebrae have each a length of 63^{mm} and a width of 85^{mm}. The transverse processes, arising low down, are stout, and the zygapophyses are large and stout. The underside of the centrum is gently concave, and has the usual

two vascular foramina, but they are small, and the ridge between them is obsolete. Posteriorly the centra become more nearly circular in outline, and the articular surfaces are nearly flat, the under border also nearly straight. The transverse processes here are more slender and are directed more obliquely upward. The zygapophyses are smaller and weaker.

Lengths	63, 63, 66, 70, 72, 72, 72, 72
Widths	85, 85, 97, 97, 97, 97, 97, 97
Heights of centra	86, 86, ? 97, 97, 97

Sacrum.—The structure of the sacrum is so well shown in the figures (figs. 7, 8) that a detailed description is unnecessary. The specimen is of especial interest as for the first time giving a complete knowledge of this part of the vertebral column in the plesiosaurs. Three vertebrae, it is seen, take part in the structure of the sacrum. A fourth in front, probably, as in *Pantosaurus*, has its sacral rib arising from the centrum in part and participating in the support of the ilium, but if so it was not preserved with the remainder of this skeleton. The two posterior vertebrae are co-ossified, the front one not. The anterior sacral rib was connected with the ilium by ligamentous union, a rugosity for which is usually observed at a little distance from the extremity of the ilium.

FIG. 8.—T. *bentonianum.* Sacrum from right side, one-fourth natural size.

The opinion has been expressed at various times that the plesiosaurs are related to the turtles because of the position of the ilia, directed as they are downward and forward. But I see no necessity for such an explanation of the resemblances here. The hind limbs in the turtles, as in the plesiosaurs, are used chiefly as propelling organs. The strain upon the ilium at the acetabulum would be antero-posterior, inclining the ilium forward. While the union with

ilium was a strong one, as is shown by the large size of the sacral ribs, it was clearly a yielding, ligamentous one.

Pectoral girdle (Fig. 3).—The pectoral girdle lacks most of the scapulae, save their clavicular ends, the outer angles of the clavicles, and a portion of the coracoids. Otherwise it is in a remarkably undistorted and natural condition.

Scapula.—In the type specimen the extremity of the ventral process is preserved in relation with the clavicles and interclavicle. It is a flat, thin plate, underlapping the clavicle, meeting suturally the clavo-coracoid process for a short distance, with its distal mesial border slightly thickened, angularly, for cartilage. The outer part of the plate is missing on both sides; it doubtless covered the clavicle to the free border.

Interclavicle.—The interclavicle is a large, triangular bone, with a deep posterior emargination, and is strongly convex on its lower surface from side to side. As seen from below, there is an elongate process, with a small, narrow, slit-like emargination in the middle in front. The visible border widens gradually for a considerable distance, and then turns outward sinuously to the hind angle. The real border is underlapped in front by the clavicles, as is indicated by the interclavicle of *T. anonymum* (*Field Mus. Publ.*, No. 73, p. 44, f. 9), continuing in front of the anterior end of the clavicles as a seeming continuation of their borders. The posterior border is thin and squamous, directed outwardly nearly transversely on each side of the interclavicular foramen. It sends a pointed process back on each side a third of the distance of the foramen, apparently, though scarcely forming a part of the border of that opening. In the middle there is a deep emargination forming a fossa continuing the foramen anteriorly, its roof filled in by a thin bone suturally underlapping the interclavicle.

Clavicles.—The clavicles are elongate, triangular bones, in position and shape resembling those of *T. osborni.* The outer angle of each is lost in the specimen. On either side of the interclavicle they are visible in front. The posterior outer border is also concave, beginning in the angular depression lodged in the depression of the underside of the clavo-coracoid processes. Just in front of these processes is the arge interclavicular foramen, ovate in shape, rounded in front and

acute behind. The front border of the foramen is evidently formed by the clavicles, but no median suture is visible.

Coracoids.—The right coracoid has the proximal part of the scapula in position. The two coracoids formed a deep trough, with the anterior processes directed somewhat ventrad. The intergelenoid bar is very much thickened, with a deep concavity transversely above. The left bone shows, on the posterior side near the thickening, the margin of a foramen, as has been observed in species of *Polycotylus* and in *T. osborni.* It may be the real coracoid foramen. The glenoid fossa looks directly outward in the articulated position. The clavo-coracoid processes are elongate and flattened, the thickened inner border beveled obliquely for symphysial union. The sutural surface for the interclavicle extends on the visceral surface about two-fifths of the distance to the base of the process. The anterior ends are slightly thickened for cartilaginous attachment.

The united bones of the girdle are, as stated, in this specimen quite normal in position and shape, and, so far as they are preserved are in the relations of life. The under margin of the interclavicle turns upward at an angle of about ten degrees from the plane of the coracoids, and the girdle is very convex transversely on the under side. A much wider knowledge of the structure of the pectoral girdle in the older reptiles since the publication of my first paper convinces me of the correctness of the determination of the elements. The clavicles and interclavicle are assuredly the same elements, and not unlike those of the older reptiles. The ventral process is, furthermore, I am confident, not the united procoracoid, but merely a prolongation of the scapula, corresponding to the 'acromion' of such reptiles as *Dicynodon*, etc. What has become of the procoracoid we cannot positively say, but I believe that, as Seeley has suggested, it is represented by the portion of the coracoid in front of the foramina described. If this supposition be true, the immense size of the coracoid is chiefly due to the development of the procoracoid. And it is not unreasonable to suppose that such a development might have occurred; the two bones always meet normally in the middle, and do yet in the Monotremata, and the same propelling function of the fore limbs would tend to develop strongly these parts, as it has the pubes of the pelvic girdle. Furthermore, in the Elasmosauridae, the posterior

parts of the coracoids are broadly separated, their early, normal condition. The interclavicular foramen is a relatively late development, reaching its highest extreme in this genus and *Polycotylus*. Such a foramen, imperfectly understood, occurs in *Muraenosaurus*, and in a species described by me from the lower Cretaceous of Kansas provisionally, but incorrectly referred to *Plesiosaurus*.[1] What its function was it is difficult to say, if it had any, and its well-formed and thickened borders suggest that it did have some function.

Length of interclavicle	224 mm
Expanse of interclavicle	166
Width of foramen	33
Length of foramen	90
Length of clavicles	410

Pelvis.—The pelvis, though incomplete, has no distortion or malformation. The larger part of each ischium is present, the two united in the median line, and the left one has the ilium attached. The right ilium is quite perfect. Its upper extremity is flattened from within outward, and has a roughened surface on the inner side near the end for ligamentous attachment to the first of the sacral ribs. Below, the shaft is thicker, at its middle forming nearly a circle in cross-section. The lower extremity is thickened, club-shaped, with a large, flat, articular surface, broadly oval in shape, the anterior broad part looking more directly downward for the acetabulum; the posterior, more obliquely placed, smaller and subtriangular in shape, for articulation with the ischium. The anterior border of the bone is concave, with a slight convexity above, and a strong convexity at the lower end. The posterior border is convex except at the lower part, where there is a concavity.

Length of ilium	323 mm
Diameters of shaft at middle	37, 53
Greatest diameter of lower extremity	82
Antero-posterior diameter of lower extremity	100

Ischia.—The ischia are shaped very much as in *T. osborni*, that is, elongate and narrow, a characteristic of the group. Both ischia are present, attached to each other, and, as already stated, to the pubes.

[1] *Loc. cit.*, p. 44, Fig. 11.

The left ischium also is united with its ilium. The bones are somewhat concave longitudinally above, and considerably so from side to side. The blade is thin. In front view, when articulated, the interacetabular thickening lies nearly horizontal, with the acetabular thickening lying above the transverse plate so that the acetabulum looks upward and outward. Back of the thickening, the downward curvature of the thinned part leaves an obtuse keel in the middle.

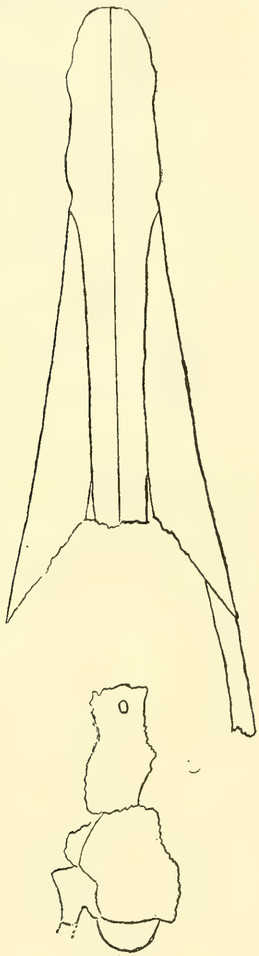
Pubes.—The pubes are incomplete, but their outline cannot differ materially from that of *T. osborni.* The right pubis is firmly attached to the ischium in its natural position. The sutural border is but little more than half the length of the acetabular border; thence to the symphysial angle the curve is smoothly and deeply concave, the immediate border for the most part somewhat thinned, though the bone is thickened a little in front of it. The external border, thinner, is not evenly concave as in *T. osborni*, but is sinuous, with a convexity in the middle of the concavity. The anterior external angle is somewhat thickened and rounded. Of the thin anterior border a part has been lost. The symphysial border is squarely truncated, showing a horizontal union. The upper surface of the bone is strongly concave, the external angle turned upward at about thirty degrees from the horizontal part. As is indicated in the pelvis of *T. osborni*, the whole bone turns downward distinctly from the plane of the ischium.

Width of pubes, from side to side, as articulated	682 mm
Antero-posterior extent of pubis, approximated	403
Width of neck of pubis	157
Length of symphysis	255
Length of ischium	600
Expanse of ischia	630

Paddles.—Parts of three paddles are preserved, one of them nearly complete, though, unfortunately there is no complete propodial among the material.

The proximal articular surface of the humerus forms nearly a hemisphere, the pitted cartilaginous surface limited sharply by a distinct rim. The tuberosity stands out prominently on the dorsal side, its top only has a distinctly limited cartilaginous surface connected with that of the head. The shaft below the head is somewhat oval. The distal extremity of one propodial has the epi-, meso-, and

metapodials and the first row of the phalanges attached, except that the epipodial supernumeraries are absent. Another, similarly united proximal series of the smaller bones has the first epipodial supernumerary in place, and there is possibly a place for a second one,



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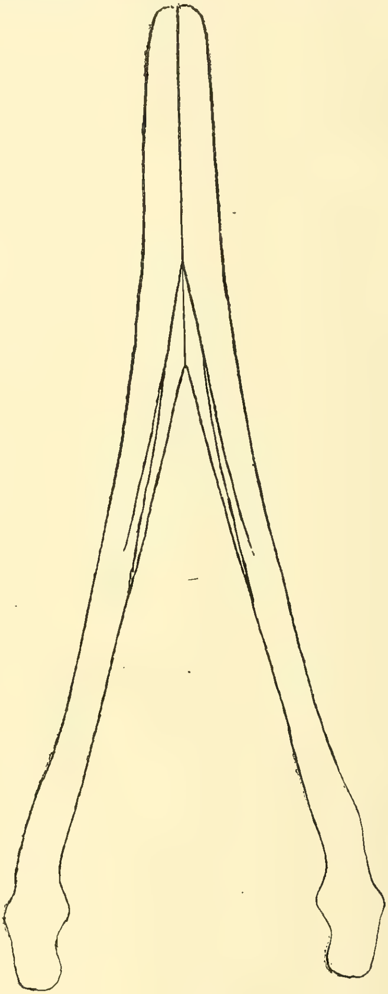

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FIG. 9.— *Trinacromerum anonymum* Williston. Outline of anterior part of skull, from above; a little less than one-sixth natural size.

FIG. 10.— *T. anonymum.* Outline of mandibles from below; a little less than one-sixth natural size.

as in *Polycotylus*. The generic name is derived from the belief that there were but three bones in the epipodial row. Beyond these connected series of bones there is another, and still a third includes the extreme tip of the paddle. In the first digit there are actually preserved ten phalanges, in the second twelve, and in the third fourteen—this last is the longest. The second digit could not have had less than fifteen and the third twenty. The three distal phalanges of the first digit seem to have been imperfectly ossified, and are closely related to, if not co-ossified with, the second digit. So, also, the distal four phalanges of the fifth digit are united, and are closely applied to the fourth digit, as are also the terminal three or four of the second with the third. The terminal phalanges of the third and fourth digits are flattened at the end, almost ungulate. The paddles are remarkably long and slender.

Trinacromerum anonymum Williston

A specimen in the Yale Museum (No. 1129), collected in 1873 by the late Mr. Joseph Savage from the Benton Cretaceous of Kansas "three miles south of the Solomon," is clearly identical with the species which I figured and partially described under the provisional name *Trinacromerum anonymum*, the type specimen collected by the late Professor Mudge from nearly the same locality and doubtless the same horizon in the Upper Benton. The species differs from the type species in its much smaller size, less slender skull, the different shape of the interclavicle and of the propodial bone. The Yale specimen must originally have been an excellent one, comprising the skull and vertebral column and portions of the paddles, but like so many of the specimens of those early days it suffered in its collection. The skull (figs. 9, 10), so far as it is preserved, bears a strong resemblance to *T. osborni*, but the attenuated portion of the face is shorter and the symphysis of the mandibles much shorter. The undersurface of the parietals with their attachments is clearly shown, and a little in front the opening into the deep median sinus or canal leading to the pineal foramen 50^{mm} in advance is clearly seen. Two tongue-like projections lie close together, projecting apparently as far forward as the end of the projection, the under surface with longitudinal striae like those of the upper surface. On each side there is a broad deep

fissure for the attachment of the so-called prefrontal or "frontal," but there is not the slightest indication of a suture either above or

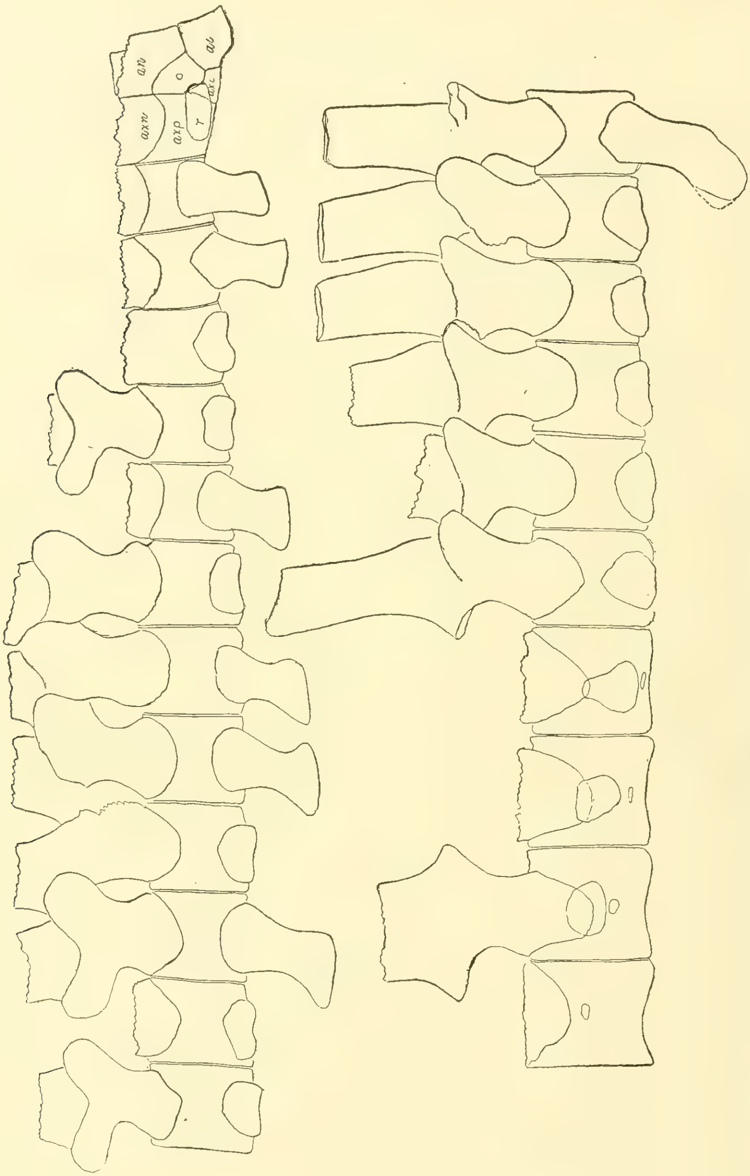

FIG. 11 — *T. anonymum.* Cervical vertebrae, three-eighths natural size. ai, atlantal intercentrum; axi, axial intercentrum; axp, axial pleurocentrum; o, odontoid (atlantal pleurocentrum); r, place of rib attachment.

below, separating this anterior projection, which goes forward to meet the premaxilla, from the true parietal.

The supraoccipitals are shaped nearly as *T. osborni*, though they may meet for a short distance above.

Twenty-three cervicals in a continuous series are present, their processes for the most part lost. As this is the first absolutely positive

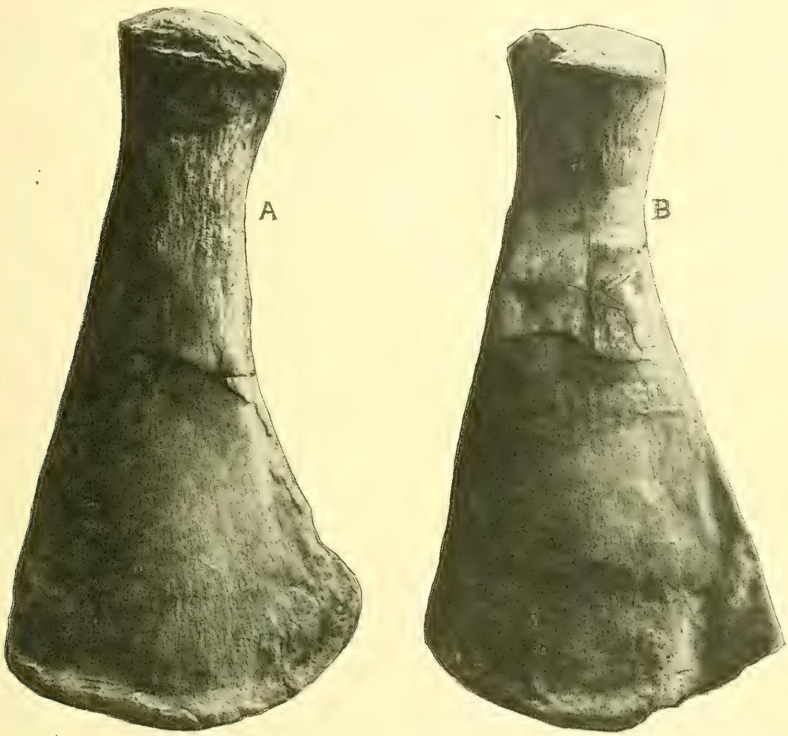

FIG. 12.— *T. anonymum.* A, left humerus; B, left femur, No. 1129 Yale Museum.

determination of the number of cervical vertebrae in this genus, I give careful outline figures of the series (fig. 11). The centrum of the third vertebra measures 23^{mm} in length, 32 in height, and 40 in width. The tenth vertebra has for its corresponding measurements 32, 34, 42; the twentieth, 32, 40, 58. The zygapophyses are heavy and large, placed nearly at right angles with each other, and are nearly plane. The twenty-fourth has the diapophyses wholly on the

arch, and is, hence, a true dorsal vertebra, leaving twenty as the number of true cervicals, and three pectorals. The characteristic structure of the cervical and dorsal vertebrae of *Polycotylus latipinnis* is shown in fig. 13.

Twenty-three presacral centra follow. They are all depressed from pressure. The largest measures 42^{mm} in length and the series $1,300^{mm}$. The length of the neck is 700^{mm}, that of the skull 700^{mm}, giving a total length of the animal in life as about eleven feet, or a little greater than that of the type specimen of *T. Osborni.*

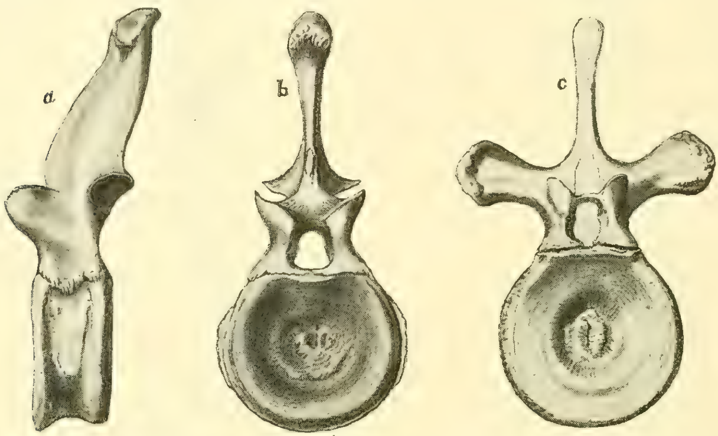

FIG. 13.—*Polycotylus latipinnis.* a, twenty-sixth (last) cervical vertebra from the side; b, the same vertebra, from in front; c, dorsal vertebra (forty-fourth of series) from in front. All one-fourth natural size.

Trinacromerum latimanus, n. sp.

Among the collections of the University of Chicago from the Hailey Shales of the Upper Benton of Wyoming, are parts of two individuals which I refer to an undescribed species of *Trinacromerum* chiefly because of the absence of the second supernumerary epipodial in the limbs and the character of the vertebrae. One of these specimens has the posterior part of the skull, a number of vertebrae and portions of the limbs; the other, which may be taken as the type, is an isolated humerus in perfect condition, collected by Mr. Roy Moodie (fig. 15). From the humeri of *T. bentonianum* and *T. anonymum* it differs conspicuously in its greater expansion distally. From the humerus of *Polycotylus latipinnis*, which I here figure for the first

time (fig. 14), it differs in the absence of the fourth epipodial, the greater concavity of the ulnar border, the convexity of the distal radial border, etc.

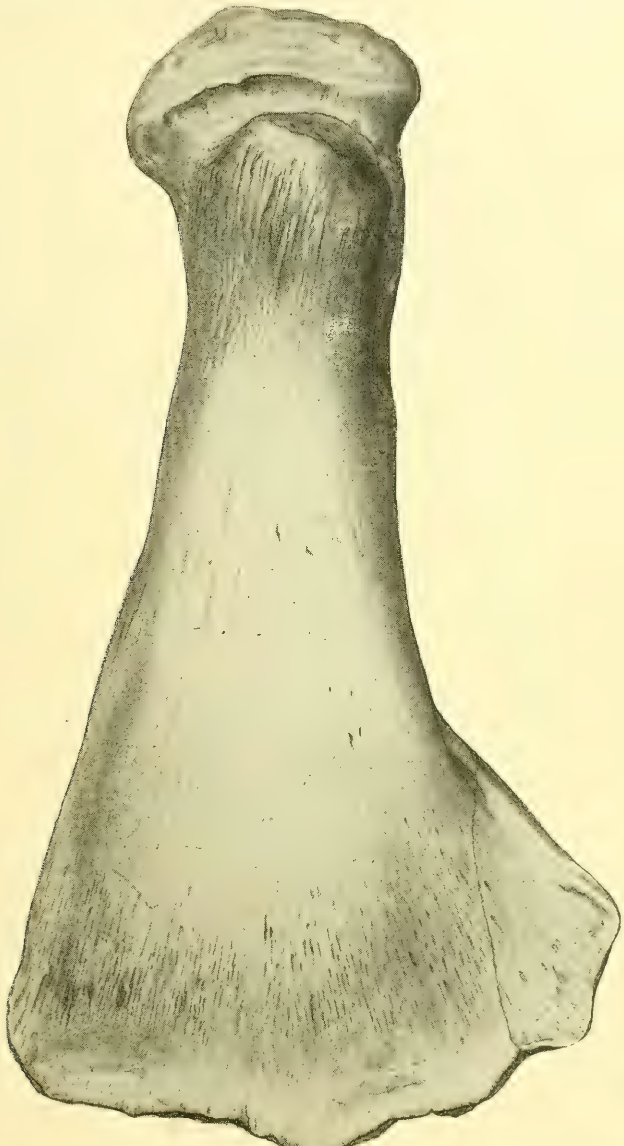

FIG. 14.—*P. latipinnis.* Left humerus, dorsal side, three-sevenths natural size.

Length	351 mm
Least diameter of shaft	87
Greatest width	250

The next paper of this series will be devoted to a discussion of the Jurassic species.

FIG. 15.— *Trinacromerum latimanus.* Left humerus, dorsal side, three-sevenths natural size.

Family POLYCOTYLIDAE Cope

Skull with long facial rostrum and thin, high parietal crest. Supraoccipital bones separated. Palate with large interpterygoidal vacuity, the pterygoids articulating with vomers, and meeting in the middle line posteriorly; no palatine foramina. Neck but little longer than head, the vertebrae all short; ribs single headed. Coracoids meeting throughout in symphysis, with long clavicular processes articulating with clavicles and scapulae, the interclavicle present; a large interclavicular foramen; ischia elongate. Three or four epipodial bones, all broader than long. Colorado Cretaceous, North America.

Polycotylus

Cope, *Proc. Amer. Phil. Soc.*, XI, 117, 1869; Williston, *Amer. Journ. Sci.*, XXI, 233, March, 1906.

P.) *latipinnis* Cope, *loc. cit.; Ext. Batrachia*, etc., 36, pl. 1, ff. 1–12; *An. Rep.*, U. S. Geol. Surv., 1871, 388; *ibid.*, 1872, 320, 335; *Bull.*, U. S. Geol. Surv. Terr., 27, 1874; *Cretac. Vert.*, 45, 72, 255, pls. I, VII, ff. 7, 7*a;* Leidy, *Ext. Vert. Fauna*, 279; Williston, *Field Mus. Publ.*, No. 73, p. 67, pl. XXI; *Amer. Journ. Sci.*, 2, 234, pl. III, Niobrara Cretaceous, Kansas.

P.) *dolichopus* Williston, *Amer. Journ. Sci.*, XXI, 235, pl. III, f. 2; Niobrara Cretaceous, Kansas and Wyoming.

Trinacromerum

Cragin, *Amer. Geologist*, December, 1888, p. 404; September, 1891, p. 171; Williston, *Amer. Journ. Sci.*, XXI, 236; *Dolichorhynchops* Williston, *Kans. Univ. Sci. Bull.*, No. 9, p. 141, September, 1902; *Field Mus. Publ.*, etc.

T.) *bentonianum* Cragin, *loc. cit.* Fencepost horizon of Benton Cretaceous Downs, Kansas.

T.) *osborni* Williston, *loc. cit.; Amer. Journ. Sci.*, XXI, 234; *Field Mus. Publ.*, No. 73, pp. 1–51, pls. I–XVII (*Dolichorhynchops*). Niobrara Cretaceous, Kansas.

T.) *anonymum* Williston, *loc. cit.*, p. 45, pl. XVIII. Upper Benton Cretaceous, Kansas.

T.) *latimanus* Williston, *antea.*—Hailey Shales, Upper Benton, Wyoming.

Piratosaurus

Leidy, *Cretac. Rept. N. Amer.*, p. 29, 1865.

P.) *plicatus* Leidy, *loc. cit.*, pl. XIX, f. 8. Cretaceous, Manitoba.

As has been suggested, this genus is perhaps identical with *Polycotylus* or *Trinacromerum*, in which case the name must take priority. If so, the determination cannot be made with certainty until such time as more complete specimens from the type, locality, and horizon have been studied.

The above species are all that are known belonging to the group. It is possible that other forms from the Fort Pierre may eventually be found, perhaps some have been described under other names. I may add here that the type of *Nothosaurops occiduus* Leidy is unquestionably a *Champsosaurus* Cope, as was suggested by Zittel, and that name should take precedence.

LIST OF DESCRIBED NORTH AMERICAN PLESIOSAURS

JURASSIC (BAPTANODON BEDS)

Plesiosaurus shirleyensis Knight.—Wyoming.
Pantosaurus striatus Marsh.—Wyoming.
Megalneusaurus rex Knight.—Wyoming.
Cimoliasaurus laramiensis Knight.—Wyoming.

LOWER CRETACEOUS (COMANCHE)

Plesiosaurus mudgei Cragin.—Kansas.
Plesiosaurus gouldi Williston.—Kansas.

BENTON CRETACEOUS

Trinacromerum bentonianum Cragin.—Upper, Kansas.
Trinacromerum anonymum Williston.—Upper, Kansas.
Trinacromerum latimanus Williston.—Upper, Wyoming.
Brachauchenius lucasii Williston.—Middle or Lower, Kansas, Texas.
Elasmosaurus, n. sp. Williston.—Middle, Kansas.

NIOBRARA CRETACEOUS

Elasmosaurus snowii Williston.—Middle, Kansas.
Elasmosaurus serpentinus Cope.—Nebraska, Wyoming.
Elasmosaurus marshii Williston.—Middle, Kansas.
Elasmosaurus ischiadicus Williston.—Upper, Kansas.
Elasmosaurus nobilis Williston.—Basal, Kansas.
Elasmosaurus sternbergi Williston.—Middle, Kansas.
Polycotylus latipinnis Cope.—Kansas.
Polycotylus dolichopus Williston.—Kansas, Wyoming.

FORT PIERRE CRETACEOUS

Plesiosaurus gulo Cope.—Kansas.
Elasmosaurus platyurus Cope.—Basal, Kansas.
Elasmosaurus intermedius Cope.—South Dakota.
Uronautes cetiformis Cope.—Montana.
Ophrosaurus pauciporus Cope.—Fox Hills, New Mexico.
Piptomerus megaloporus Cope.—Fox Hills, New Mexico.
Piptomerus microporus Cope.—Fox Hills, New Mexico.
Piptomerus hexagonus Cope.—Fox Hills, New Mexico.
Embaphias circulosus Cope.—South Dakota.

CRETACEOUS OF NEW JERSEY AND THE SOUTH

Plesiosaurus brevifemur Cope.—Greensand No. 5, New Jersey.
Cimoliasaurus magnus Leidy.—Greensand No. 5, New Jersey.
Discosaurus planior Leidy.—Mississippi, New Jersey.
Brimosaurus grandis Leidy.—Arkansas.
Elasmosaurus orientalis Cope.—New Jersey.
Taphrosaurus lockwoodi Cope.—No. 1, New Jersey.

OF DOUBTFUL RELATIONS AND HORIZON

Oligosimus primaevus Leidy.—Green River, Wyoming.
Piratosaurus plicatus Leidy.—Cretaceous.

THE LOCALITIES AND HORIZONS OF PERMIAN VERTEBRATE FOSSILS IN TEXAS

W. F. CUMMINS

The vertebrate fossils from the Permian formation in Texas described by Professor E. D. Cope were collected by myself and others before any stratigraphic work had been done in the part of the state in which that formation occurs, and the only thing that could be done by the collector was to give the locality from which the specimen was taken. Whether the different localities were of the same horizon or whether they were entirely different beds was not known, and consequently could not be given.

At a subsequent period, as a member of the Texas Geological Survey, I made a thorough examination of the country and complete stratigraphic sections across the entire Permian area. These sections were published in the *Second Annual Report* of the Survey.

After the stratigraphic work had been done, I took up, with Proessor Cope, the work of giving the horizon of each of his described forms and the study of the development of the forms of life. Unfortunately, before the completion of this work the death of Professor Cope occurred, and his collection passed into other hands and the paper was not prepared. Later, I asked Professor Osborne, into whose hands most of Professor Cope's Permian fossils had gone, to send me the localities as given on the labels with the fossils collected from Texas. The request was referred to Professor E. C. Case, who very kindly furnished me with such facts as the labels disclosed.

More recently, Dr. W. D. Matthews, of the American Museum of Natural History, New York, sent me the card list and the original lists sent to Professor Cope by the collectors, together with the original correspondence relating to the collections.

From these sources I have been enabled to give the localities of most of the vertebrate fossils collected.

After these fossils had been collected, Dr. C. A. White, of the United States Geological Survey, came to Texas, and together we

visited the Permian beds and made a collection of the invertebrate fossils. Part of these occurred at some of the same localities as those from which Cope's vertebrate forms were taken. These invertebrates were afterward described by Dr. White (*Amer. Nat.*, 1889, p. 128, and United States Geological Survey, *Bull. No. 77*).

Subsequently further collections of invertebrate fossils were made by myself and other members of the Texas Survey. The cephalopods were placed in the hands of Professor Alpheus Hyatt for determination and description. His reports were published as parts of the *Second* and *Fourth Annual Reports* of the Texas Geological Survey.

The fossil flora was sent to Professors Fontaine and I. C. White for their determination. A paper was published by them (*Bulletin of the Geological Society of America*, Vol. III, pp. 217, 218), giving the results of their study.

It is the purpose of this paper to describe more accurately the various localities from which the fossils were taken, to indicate their stratigraphic relation to the general section, and bring together a list of the vertebrate forms[1] so far described from each locality, as nearly as it is possible to give it from existing data.

THE GENERAL SECTION

The Permian deposits were described and separated into divisions in the several reports of the Geological Survey of Texas. As a whole, the formation comprises a series of sands and clays with interbedded sandstones, limestones, and gypsum, lying conformably and with a gentle westward dip upon the Coal Measures to the east and stretching to the foot of the Staked Plains on the west. Three divisions are recognized, the earliest and most easterly being the Wichita, followed successively by the Clear Fork and Double Mountain.

The Wichita division comprises a series of sandstones, sandy shales, clays, and conglomerate, which passes gradually to the southward into sandstones, clays, and limestone. In the earlier reports, there being no apparent stratigraphic break between it and the underlying Coal Measures and its materials being quite different from the Wichita, these beds in the southern part of this field were

[1] The lists sent me include batrachia and reptilia only. The fish will, therefore, not be included in this.

called the Albany beds and were assigned to the Coal Measures. Subsequent study, however (*Texas Academy of Science Trans.*, Vol. II, pp. 93–98), disclosed the fact that the beds were stratigraphically continuous with the Wichita, being simply deposits in deeper waters, and in all subsequent publications they have been included in the Wichita, referred to the Permian, and the name Albany dropped.

The Clear Fork beds are composed of bedded limestone, magnesian and earthy, followed by clays, limestones, and shales, and are more sandy toward the top.

The Double Mountain beds comprise sandstones, sandy shales, earthy limestone, clays, and thick beds of gypsum.

For details of the sections reference is made to the *Second Annual Report* of the Geological Survey of Texas, pp. 402 ff.

So far as our collections show, the first vertebrate fossils are found in beds which are a little below the middle of the Wichita division. The beds below these, while not differing materially in character, are possibly the representatives of the transition beds of the territory north, as Adams suggests,[1] but from the evidence here given it is plain that such a reference cannot apply to any beds west of Onion Creek.

In describing these localities I have begun with those nearest the base and have given them as nearly in stratigraphic sequence as our present knowledge will permit.

I have tried to give all localities at which we made collections of vertebrate fossils, whether the forms have been identified or not.

LOCALITIES OF WICHITA DIVISION

Onion Creek.—A few miles east of Archer City there is a small tributary on the south side of the Little Wichita River called Onion Creek. Near the mouth of this stream, the first fossil vertebrate of the Texas Permian was found by Professor Jacob Boll, who afterwards sent it to Professor Cope.

Cottonwood Creek.—This creek is about ten miles south of Archer City and is a tributary of the South Fork of Little Wichita.

Fire Place.—This is on the west side of the South Fork of the Little Wichita about six miles south of Archer City. It is one of Boll's localities.

[1] *Bulletin of the Geological Society of America*, Vol. XIV, pp. 191–200.

Elm Creek.—A tributary of the South Fork of the Little Wichita, about twelve miles southwest of Archer City. Collections were made on east side of creek.

Fossils: *Dimetrodon gigas, D. dollovianus*

Post Oak Pens.—This locality is south of the head of Kickapoo Creek, on the head of the South Fork of the Little Wichita River about fifteen miles southwest of Archer City. From here I took quite a collection of the teeth of fishes. The horizon is below that of Tit Mountain, or Corn Hill.

Copper Mines.—About one-half mile east of the copper mines there is a small area of "bad lands" at which place I collected some fragments of vertebrates and many teeth. This is about the same horizon as Post Oak Pens. This locality is four miles west of Archer City.

Long Creek.—This creek runs into the Little Wichita on the north side, just a little west of the copper mines.

Fossils: *Empedias alatus, Dimetrodon incisivus, Naosaurus cruciger*

Mount Barry.—This is a prominent hill in the valley of the Big Wichita about ten miles west of Wichita Falls. This is about the middle of the Wichita division.

Fossils: *Empedias alatus*

Briar Creek.—A small branch running into the North Fork from the south side, a few miles west of Kickapoo Creek.

Fossils: *Naosaurus cruciger*

Slippery Creek.—This is a small creek that runs into the North Fork of the Little Wichita from the north side almost directly south of the town of Dundee, and a little above the mouth of Briar Creek on the south side.

Fossils: *Trimerorhachis sp., Eryops sp., Dimetrodon incisivus, D. giganhomogenes, Ctenosaurus sp.*

Cox's Camp.—A few miles east of the mouth of Godwin Creek, when the collections for Cope were being made, the Harrold Brothers had a line riders' camp, known as Cox's camp. Just east of that camp, on the north side of the Little Wichita River, there is a small area of "bad lands." At this place one of the best-preserved fossils in the entire Cope collection was found.

Fossils: *Trimerorhachis sp., Eryops sp., Empedias sp.*

Headquarters.—The first headquarters established by Harrold Brothers for their extensive ranch was on the north side of the North Fork of the Little Wichita River, a mile or two from the mouth of Kickapoo Creek, a tributary of the North Fork from the south side. Some of Cope's fossils were taken from this locality.

Corn Hill.—Corn Hill, formerly called Tit Mountain, is No. 31 of our section and is about a mile north of Dundee, and is higher in the formation than the beds at Mount Barry.

Fossils: *Trimerorhachis bilobatus, T. sp., Dimetrodon incisivus, D. macrospondylus, D. longiramus*

Godwin's Creek.—A tributary of the Little Wichita River from the south side. It runs from a southwestward direction nearly on the strike of the beds, having its source in the limestone hills of the Clear Fork Division ten miles away. From its mouth to the crossing of the road from Archer City to Seymour there is quite a body of "bad lands." Several specimens of Cope's fossils were taken from this place. About one-half mile east of the crossing of the Archer and Seymour road is Dr. C. A. White's Godwin Creek invertebrate locality. About two miles up the creek, on the south side above the road crossing, is the locality from which the fossil flora was taken described by Dr. I. C. White as coming from Godwin's Creek. The Antelope locality in the same paper is Carboniferous.

Fossils: *Diadectis sp., Empedias fissus, Dimetrodon platycentrus*

Hackberry Creek.—This is a small tributary of the Little Wichita river, about three miles southeast of Fulda. It is one of Mr. Sternberg's localities.

Fossils: *Eryops sp., Diadectes sp.*

Deep Red Run.—There was at one time a small fort called Fort Auger on the north side of Red River about opposite where the town of Iowa Park is now located. There was a road leading from Fort Auger to Fort Sill. Near the crossing of Deep Red Creek by this old road is the locality at which I collected the vertebrates in Cope's collection labelled "Indian Territory." The horizon is about the same as that of Corn Hill.

Fossils: *Cricotus hypantricus, Dimetrodon gigas, D. macrospondylus, D. dollovianus, D. platycentrus, Naosaurus cruciger*

Camp Creek.—About four miles west of Tit Mountain. It was named from the fact that Harrold Brothers had one of their line camps on it. At this place appears the first limestone as we go up the south side of the Big Wichita River. It is one of Dr. C. A. White's invertebrate localities.

Big Wichita.—Going west from Camp Creek and before reaching the locality designated as Military Crossing, there is an exposure of the beds given as No. 29 in the Section on p. 403, *Second Annual Report* Texas Geological Survey. This is not "Big Wichita" of Boll's collections. He used the term for various localities along the river.

Fossils: *Eryops sp.*, *Clepsydrops leptocephalus*, *Theropleura retroversa*

Moonshine.—A small creek that runs into the Big Wichita River near the east line of Baylor County has the name of Moonshine. At this place I found a few vertebrate fossils.

Fossils: *Chilonyx rapidens*, *Dimetrodon gigas*

Military Crossing.—Before there were any other roads through this country or crossings on the Big Wichita River, Maj. Van Dorn made a road from Fort Belknap to old Fort Radminski, at the western end of the Wichita Mountains near Otter Creek. This road crossed the north fork of the Little Wichita River near its head. It crossed the Big Wichita River at the eastern foot of the hills a little west of north of Fulda and near where, at a later date, the west line of the "99" pasture fence was built. This crossing has been abandoned for a great number of years and the locality must not be confused with the old cattle trail made several years later, nor the county road made between the two crossings at a still later date. About one and a half miles north of this crossing, on the Big Wichita River, is a small dry creek. On the north side of that creek, about one-fourth of a mile from the old road, is the locality known as Military Crossing. This horizon is near the top of the Wichita Division. This locality furnished the greater number of the invertebrates collected by Dr. White.

In addition to the forms given under the above localities, the following were collected within the area occupied by the Wichita division, but the localities are not given closely enough to permit their being referred to any definite horizon: *Zatrachys seratus*, *Eryops*

megacephalus, Cricotus crassidiscus, Diadectes phaseolinus, D. latibuccatus, Empedias molaris, Pariotichus brachyops, Pantylus cordatus, Clepsydrops natalis, C. limbatus, Dimetrodon semiradicatus, Metamosaurus fosssatus, Paleosaurus uniformis, Embolobus[ritillus

So far as known none of these species occur above the Wichita beds.

As has been stated, the continuations of these beds to the south comprise deposits of deeper water and carry a large invertebrate fauna. The details of the stratigraphy and fossils of this division on the Colorado river are given by Dr. Drake in the *Fourth Ann. Rep. Geol. Sur. Tex.*, pp. 421 ff.

Ballinger and North of Abilene, the localities of Professor Hyatt's cephalopods, are well known. They are the same horizon as that of Military Crossing.

LOCALITIES OF CLEAR FORK DIVISION

Coffee Creek.—In the northeastern corner of Baylor County, about four miles west of Military Crossing, a small stream, generally dry, runs into the Big Wichita River from the north. The old cattle trail crossed the Big Wichita River about three miles above the mouth of Coffee Creek. As will be seen, this was a very prolific locality for collectors:

Fossils: *Diplocaulus magnicornis, D. limbatus, D. sp., Trimerorhachis mesops, Zatrachys micropthalmus, Eryops sp., Acheloma cumminsi, Anisodexis imbrocarius, Diadectes phaseolinus, D. sp., Pariotichus aguti, Captorhinus angusticeps, Pantylus tryptychus, P. coicodus, Labradosaurus hamatus, L. sp., Dimetrodon gigas, D. dollovianus, Naosaurus claviger, N. cruciger, N. macrodus, Edaphosaurus pagonias*

Boneyard.—The old cattle trail from the south to the north, at the time the Cope collections were made, crossed the Big Wichita River about two and a half miles above Coffee Creek. Just east of that road, on the north side of the river, is an area of "bad lands." At this place there were a great number of fragments of vertebrates, so much so that Mr. Sternberg gave it the name of "Boneyard" and so labelled many of the fossils collected by him.

Fossils: *Diadectes sp., Empedias sp.*

Beaver Creek.—At the crossing on Beaver Creek of the old cattle trail mentioned elsewhere as crossing the Big Wichita River west of Coffee Creek is another locality at which I collected fossils for Cope. Boll's locality "Beaver Creek" was at its mouth and in the Wichita Beds.

Brushy Creek.—Six miles northwest of Seymour is the head of Brushy Creek, which runs into the Big Wichita River on the south side.

Fossils: *Eryops sp., Diadectes sp.*

Indian Creek.—This creek runs into the Big Wichita River on the north side nearly opposite the mouth of Brushy Creek.

Fossils: *Diplocaulus sp., Trimerorhachis conangulus, Eryops sp., Diadectes sp., Pariotichus isolomus, Isodectes megalops, Dimetrodon giganhomogenes, Naosaurus claviger*

Gray Creek.—In same vicinity, south of river.

Fossils: *Otocoelus testudineus, Conodectes favosus*

Crooked Creek and Hog Creek.—Same vicinity, south of river.

Fossils: *Diplocaulus sp., Labidosaurus sp., Naosaurus claviger*

Stamford.—While connected with the Texas Geological Survey, I collected some vertebrates from the Clear Fork beds in Haskell County, Texas, near Otey's Creek, not far from the present town of Stamford (*Second Ann. Rept. Tex. Geol. Surv.*, p. 405.)

Other forms described from the Clear Fork division but not localized are: *Zatrachys conchigerus, Dissorhopus multicinctus, Bolbodon tenuitectus, Pariotichus isolomus, Hypopnous squaliceps, Otocoelus mimeticus*

The forms described from this region which we cannot certainly assign to either division comprise: *Trimerorhachis insignis, Zatrachys apicalis, Eryops erythroliticus, E. ferricolus, E. reticulatus Diadectes sideroplicus, D. biculminatus, Helodectes pandius, Pariotichus ordinatus, P. incisivus*

LOCALITIES OF DOUBLE MOUNTAIN DIVISION

Kiowa Peak.—A few years ago I procured a sandstone slab with impressions of tracks of a reptile, which is now in my collection at Dallas, Texas, but no attempt has been made to identify the animal making them. This slab was procured from a gulch a few miles

south of Kiowa Peak in Stonewall County, Texas (*Second Ann. Rept. Tex. Geol. Sur.* No. 15, p. 406). This would be about the base of the Double Mountain Division.

DISTRIBUTION

Of the eight genera of *Stegocephalia* only four, *Trimerorhachis*, *Zatrachys*, *Eryops* and *Cricotus*, have been found in the Wichita. The first three, together with *Diplocaulus*, *Dissorhopus*, *Acheloma*, and *Anisodexis*, are found also in the Clear Fork, *Cricotus* alone being absent from the latter beds. In all cases, however, the species occurring in the two divisions are different.

Of the *Cotylosauria*, *Diadectes*, *Empedias*, *Pariotichus*, and *Pantylus* are common to both divisions, but only a single species, *Diadectes phaseolinus*, occurs in both. In all other cases the genera are represented by distinct species. *Chilonyx* and *Bolosaurus* are confined to the Wichita, while *Bolbodon*, *Isodectes*, *Hypopnous* and *Labidosaurus* appear only in the Clear Fork.

The *Chelydosauria* are found only in the Clear Fork.

The distribution of the *Pelycosauria* is equally distinctive. While three species of *Dimetrodon* and two of *Naosaurus* extend through both divisions, we have as characteristic genera of the Wichita, *Cleopsydrops*, *Ctenosaurus*, *Theropleura*, *Metamosaurus*, *Paleosaurus* and *Embolophorus* and of the Clear Fork *Edaphosaurus* only.

It is therefore evident that the divisions of Wichita and Clear Fork which were proposed at first on purely stratigraphic grounds are fully warranted and upheld by the fossils found in them. And it will be found when the invertebrate forms collected from these divisions on the Colorado shall have been studied that this separation is equally warranted there.

SOME FEATURES OF EROSION BY UNCONCENTRATED WASH

N. M. FENNEMAN
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Erosion without valleys appears frequently to be regarded as due to the absence of all initial inequalities which might tend toward concentration of the run-off. It should follow as a corollary (and this too seems quite as often to be tacitly accepted), that such erosion cannot of itself perform a great geologic task, for, in nature, conditions of absolute equality are rare. If exemption from valley-cutting is due to such an exceptional condition, the wonder is that any broad slopes remain and that valleys do not branch indefinitely. Yet the observation is common that in loose and homogeneous material, the head of a gully is a perfectly definite thing, and that while some large gullies do arise from the union of smaller ones, this subdivision in a headward direction is not carried to microscopic dimensions.

If a broad slope without valleys is possible only with a nice equality of rills, its existence must be highly precarious, but it must be recognized that for every dissecting land surface there is a degree of minuteness beyond which dissection will not go, and when this degree is reached the slopes are in no danger whatever of further dissection. The exact degree of minuteness of dissection (or what has sometimes been called the *texture* of the topography) depends on a number of factors not here discussed. The purpose of this paper is to point out and account for that limitation and to examine some of the topographic effects of erosion without valleys. It should be made clear that such erosion is not in the main dependent on equality of conditions, and that among rills or runnels on a broad hillside there is not always a tendency to grow larger, hence not always a contest for mastery or a struggle for existence.

Conditions assumed.—The simplest and typical case for the study of this principle is that of the plowed field or other surface of homogeneous material. A sod cover may temporarily hold its own against

channeling, even where steamlets are sufficiently concentrated to carry their loads and have some power to spare. Even here, however, the failure to cut channels may be due less to the actual withstanding of wear than to the retardation of currents and their continued subdivision, that is, the power which would result from concentration of the water is *prevented* rather than *withstood.* This case and all others which are complicated by the nature of the material or by special initial slopes are omitted from this discussion, which is concerned only with the simplest and most typical case of gradual concentration of run-off and its effects. If there is any categorical difference between the wash above the gully-head and that below, it must appear best where there is perfect freedom for either mode of activity to occur.

Loss of power due to subdivision of stream.—It is a well-recognized principle that the carrying power of a given flow of water is greater when concentrated into a single stream than when subdivided into several streams. Its application to deltas is familiar, in which case it might be shown that although the united stream were able to carry its entire load, a sufficient degree of subdivision into distributaries would bring about a condition in which no one of these could transport its sediment; in other words, while the volume of water and sediment are divided arithmetically, the power of the water decreases in a greater ratio.

The same principle applies equally well to the opposite case, that is, to the union of several streams into one. Applied to this case it may be stated thus: Given a stream whose power is more than necessary to carry its load; suppose this to be formed by the union of smaller streams, each of which in turn was similarly formed, and so on back to the origin of all in unconcentrated wash; previous to a certain degree of concentration, when all streams were below a certain size, all were overloaded and hence unable to cut definite channels. It is a commonplace observation that definite and continuous channels cannot be cut until a certain degree of concentration is reached; but the point here emphasized is that this condition may be and often is due to actual overloading of the primary streamlets with sediment.

Sudden change from overloaded to cutting condition.—There is

apparently a tacit assumption that the gully differs only in degree from the rill-mark, or what amounts to the same thing, that the behavior of the water in gully-making is the same in kind but differing in degree from the behavior of water in rills. The attendant assumption is that the change from the earlier condition to the later is gradual. A point to be emphasized is that the two conditions differ fundamentally, not in degree but in kind, and that the change from one to the other is sudden. It will be seen that this harmonizes with the common observation that heads of gullies in homogeneous unconsolidated material and having a simple history, are perfectly definite as to form and location.

All streamlets above the point where continuous valley-cutting begins, are here conceived of as overloaded, hence wandering, braiding, etc., according to well-known habits. Their union is, however, to some extent progressive, and when a certain stage is passed, the power is more than necessary for the load, and then definite, progressive down-cutting begins. It is unnecessary to show just how such down-cutting favors further concentration of rills at that point and therefore when once begun, goes on at an increasing rate. It may, however, be said that the progressive union of overloaded rills is to a large extent fortuitous.

Terms.—The characteristic suddenness of the change from the overloaded condition of the small streamlets to the cutting condition after a certain degree of concentration has been reached, makes it desirable that these conditions should be designated by distinctive names. No such distinctive names are in use, for the good reason that the distinctive character of the streamlets previous to this degree of concentration, seems not to be generally recognized. In the vast majority of cases the word "rill" seems to be applied to such cases, but no essential characteristic is implied by that term except smallness. In the absence of a more specific term, and for the purposes of this discussion, the word "rill" will be used to indicate such a streamlet in an overloaded condition, that is previous to the degree of concentration necessary to cut a gully. It is not necessary to specify the want of permanence since that is a necessary corollary. The condition succeeding that of the rill is equally without a distinctive term and there seems to be nothing to do but to use the word "gully stream'

for one in that condition, since the making of a gully is its characteristic function.

The whole area over which rills alone are formed may well be spoken of as subject to "unconcentrated wash." This term is necessarily relative, for even a drop of water represents a degree of concentration and there is no categorical distinction until the cutting stage is reached. The terms "sheet flood" and "sheet wash" are appropriate both in a descriptive and a technical sense for certain phenomena, generally in arid regions, where the run-off from torrential rains descends a slope in visible sheets. The same terms are misleading when applied to the ordinary phenomena of unconcentrated wash. The "sheet" in this latter case is rather a net work of constantly changing pattern.

Down-cutting by unconcentrated wash and "overloaded streams."— It will probably not be questioned that unconcentrated wash may and commonly (perhaps universally) does degrade that part of a slope which lies above gully-heads. If the assumption made above be correct, we then have the case of degradation being performed by currents which, according to our accepted terminology, are overloaded. It is difficult to deny that this is the case. If it seems to involve a contradiction of terms, it may be necessary to define an overloaded stream (if the term be retained) not as one which deposits at a certain place more than it removes but as one which behaves in a certain way with reference to its load. The main features of such behavior are the building of bars, the shifting of channels, subdivision and braiding, and above all, the inability of the streams to incise any one channel beneath the level upon which it wanders.

It would be a mistake to assume that all streams which build bars, anastomose, shift their channels and "braid" are of necessity aggrading their valleys or even that they are not degrading them. The relations between these phenomena of "overloaded streams" on the one hand and aggradation on the other is not so simple as that. It may safely be assumed however that some of the conditions which favor anastomosing, etc., are also favorable to aggradation. The classical example of an "overloaded stream" (the Platte) is quite probably aggrading its valley at the present time in that part where the phenomena listed above are most pronounced, and it has surely

aggraded it recently, but locally the same phenomena are well exemplified where the valley is distinctly terraced, the terraces and flood-plain all sloping toward the stream indicating progressive down-cutting.

If rills running over loose materials may be regarded as overloaded streamlets, and if it be assumed that the surface of a ridge is washed by such streamlets behaving as here described, and capable of carrying away from a given point more material than they bring, we have the conditions for the continued down-cutting of broad slopes without cutting valleys and for the lowering of a ridge without its subdivision into hills; it may be at a rate which is uniform throughout its length. Thus a broad area consisting of hills and ridges of uniform height may be cut down in such a manner as approximately to preserve their uniformity of height and the flatness of the sky line.

St. Louis peneplain.—Before going further it may be stated that this discussion was not begun with an academic interest, but in an attempt to explain what appears to be a case of just such uniform down-cutting as is here assumed. The area in question is the St. Louis quadrangle and adjacent territory. It is a low plateau with a mature drainage system. The ridges and very narrow remnants of upland rise to such a uniform height that no physiographer would hesitate to pronounce them the remnants of a former plain of very faint relief (in this case a peneplain as shown by abundant evidence). Furthermore the supposition would be that the horizon of the former plain was approximately that of the present hilltops.

Above the uniform level of the hilltops are a few exceptional elevations of fifty feet or more. Capping these are deposits of typical Lafayette gravels from ten to twenty feet thick. No theory of the origin of the Lafayette formation which receives any credence, admits the supposition that these gravels might have been deposited on exceptionally high points in preference to a lower surrounding plain. If the elevations on which they now rest existed as such when the gravels were deposited, it would seem necessary to assume that the entire surrounding plain was buried by gravel to a depth equal to the height of these hills plus the thickness of the deposit on the hills. It must then be assumed that subsequent erosion was guided in such a manner as to strip practically the whole of this thick bed of gravel from the surrounding plain while leaving the thin deposit on

the hilltops. To avoid this improbable supposition it might be assumed that the gravels were laid down on a plain whose elevation is represented by that of the present exceptional hills and that a post-Lafayette peneplain was developed 50 or more feet lower.

Hypothesis of rill-wash applied to the St. Louis region.—As a modification of, or substitute for this last hypothesis, the following is suggested: After the deposition of the Lafayette gravels on a nearly flat surface, uplift followed and the area was maturely dissected by a drainage system which was to some extent ready made, having held over from former conditions and which, therefore, to a certain degree, began its work simultaneously on the entire area. The gravel was in the main removed, except from a few patches between the head waters of streams flowing northwest to the Missouri and others flowing southeast to the Mississippi. It remained in these places partly because they were flatter and therefore less subject to erosion, and partly because, lying between headwaters, they were the last to be reached by erosion. With the exception of these spots the topography of the area was then one of comparatively even-topped ridges and valleys, but without flat uplands. Both while this dissection was in progress and subsequently, unconcentrated wash (as described above) lowered these ridges fifty or more feet. This was not effective on the gravel-covered hills, partly because of their relative flatness, but largely because percolation obviated wash.

The difficulty in such a conception lies in the uniformity of the down-cutting of all the ridges and the consequent preservation of the typical form of a dissected peneplain. This arises from our habit of thinking of rills as small rivers, each incising its own little valley and absorbing its neighbors as soon as a slight advantage has been gained. If the above theoretical reasoning pertaining to rill-wash be correct, this difficulty disappears. The struggle for existence (so characteristic of gullies) disappears from the community of rills as soon as each is seen to be overloaded. Stability then takes the place of instability and there is no longer any difficulty in maintaining an undissected slope while degradation proceeds. Under these conditions a large number of subequal ridges constituting a dissected plain will be degraded at a subequal rate.

It should be made clear that the correctness of the theoretical

reasoning above is not dependent on its application to the St. Louis region. This illustration is not brought forward to prove the argument but to show the nature of the problem in which the question occurs.

It should also be noted that the case of uniform down-cutting over a wide area implies a mature drainage system throughout. In the first dissection of a plateau this condition is reached first near the edge, hence the whole plateau cannot be simultaneously lowered. The erosion of an uplifted peneplain may, however, begin with a ready-made drainage system, the whole of which soon becomes incised. The whole area has, therefore, something of an even start in down-cutting.

Bearing of these principles on profile, and cross-section of valleys.— Returning to the principles, let us examine their bearing on the profile and cross-section of the young valley. Whether there is or is not any progressive union of overloaded rills, the power of such wash increases as the slope is descended, though it is not necessary to assume that the rills become less overloaded, for their load is likewise increasing. The reason for the increase of power lies in the increased amount of water. It is to be assumed that the fall of rain is equal throughout the slope, but since some of the descending water fails to percolate, the amount which joins the run-off is cumulative as the slope is descended. The effect of increasing power in this case is *increasing slope.*

Increase of slope as the result of increase of power is contrary to our customary conceptions gained from constant attention to rivers in which the reverse is usually true. A brief statement of the geometrical principle involved may therefore be necessary. Where a current is limited in its down-cutting by a certain level beneath which it cannot cut, additional power results in cutting nearer to that level and flattening the profile. Where the opportunity for down-cutting is not thus limited, the current is free to cut downward in proportion to its power and the effect of progressively increasing power is *a progressively steepening profile.* This is the case where a cutting stream encounters a fall. Both the principle and the form are illustrated in the rapids above all falls. However low the fall may be, it removes the upper stream entirely from the influence of the limiting level

below, and that level has no existence for the current above the fall. Nor is it necessary that the fall be vertical; the principle is the same in the approach to a cataract or cascade or other exceptionally steep slope, though its application is less simple.

Applying this principle to the case of rill-wash, we recall that the end of the overloaded condition and the beginning of gully-cutting is sudden. The effect of this is a steep offset which allows the rills to cut down without reference to any lower limit. The effect of this, in turn, is progressively increased slope as the fall at the gully-head is approached. This gives, above the gully-head, a profile which is convex upward, which gives way in the young valley itself to a profile of decreasing slope, that is, one which is concave upward. It will readily be seen that this description fits the case of the simple gully developed on a simple slope. Indeed the compound curve thus formed is very general despite all complexities due to sod covering and initially complex slopes.

A similar convexity of the upper slope is seen in the cross-section of a young valley. The existence of the valley removes from the wash on at least the upper part of the slope, the influence of the level which limits down-cutting. In all cases, therefore, except where peculiar conditions are assumed, the wash increases in power for a small distance at least, while the slope is concurrently steepened, producing a curve which is convex upward. If the valley be deepening, this convexity approaches more or less close to the axis, and, if the deepening be sufficiently rapid, the convexity reaches the channel making the entire slope from hilltop to stream convex upward. Where this is the case, the down-cutting of the valley axis is sufficient to leave the rill-wash on the entire slope free from the influence of a lower limiting level. Where down-cutting is less rapid, the wash near the stream comes within the influence of a lower limit and shapes its profile according to the laws of streams, that is, it becomes concave upward. The result is the U-shaped valley. The point to be emphasized here is that not only does this form *not* imply a cessation of down-cutting, but that it does not even imply lateral corrasion by the stream. The only requisite is that the stream shall cut down slowly enough so as *not* to remove from the wash on the side slopes the influence of a lower limit. In the area mentioned near St. Louis

it is quite the rule that the sides of the smaller valleys are upwardly convex from top to bottom.

In the course of its development the young valley whose cross-section shows simple curves increasing in steepness as the axis is approached, exchanges these for compound curves as described above. The stage of development at which this exchange is made depends partly on the absolute rate of down-cutting of the axis and partly on the behavior of the wash. A full explanation of the latter would involve discussion of materials composing the surface. Observation indicates that with a given rate of down-cutting a loess cover is specially favorable to valleys, whose sides increase in steepness down to the axis, that is, are simple curves and upwardly convex.

A STUDY OF RIVER MEANDERS ON THE MIDDLE ROUGE[1]

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Given a stream flowing on a flat surface of homogeneous material, will it meander? If so, will the meanders develop at once, or will they be formed only after considerable time has elapsed? The answer to these questions was actually encountered in a millpond which had silted up for many years till its floor was level. Then the dam broke causing the river to flow in a narrow channel through the deposits. It is hoped that the behavior of the stream under these conditions may shed some light on the general question of the origin of meanders.

The conception generally held is, that the stage in the lives of rivers when they meander in broad arcs is reached late, when they flow sluggishly, as swift streams are less easily turned aside than those which flow less impetuously.

This supposes a turning aside from a straight course due to irregularities or obstructions in the path of the stream. The breaking out of ditches into meanders is held to support this view. This view of the origin of meanders is the one stated by Geikie, Russell, Davis, Chamberlin and Salisbury, and other authorities. It is also held in some quarters that meandering is a direct result of loading of the stream and deposition of the sediment.[2]

This paper concerns itself with a discussion of an actual case of meander development and shows that meanders may develop in a swift stream, that they are not always the result of a long process; but may develop immediately, and that inequalities of bed or obstructions in the path of the stream are not necessary for their formation.

The river on which meander development was studied was the Middle Rouge, one of the three upper branches of the River Rouge,

[1] This case of meandering was discovered when on a field trip with Professor M. S. W. Jefferson of the Ypsilanti State Normal.

[2] Griggs, *Bull. Am. Geog. Soc.*, Vol XXXVIII, pp. 168–76.

a stream emptying into the Detroit River, as shown on the accompanying map of the vicinity, designed to show the relation of the locality to the surrounding country.

Some seventy-five years ago a dam was built across the Middle Rouge near Pikes Peak. Since that time the dam has been maintained continuously, except that it broke in 1895. It was, however, immediately repaired so that to all intents and purposes the water has been ponded up continuously for about three quarters of a century.

The floor of the pond is composed of silt of very uniform char-

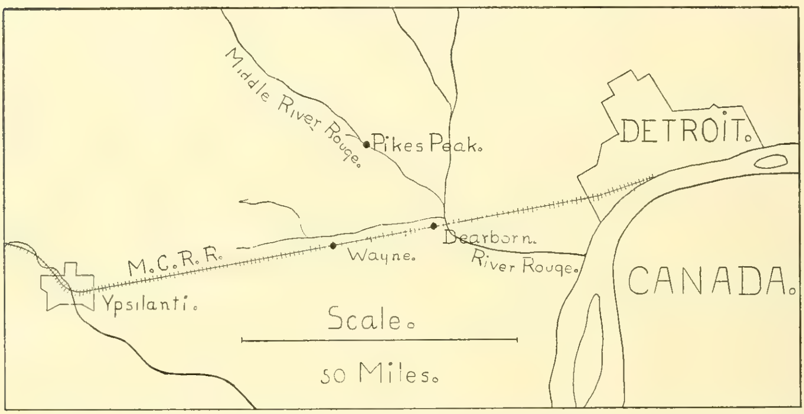

Fig. 1.—Map of the vicinity to show the relation of the locality to the surrounding country.

acter. Deposited under water as it was, and attaining a thickness of several feet, it presented a material of exceptional character for the river to cut into when the water was withdrawn from the surface by the break in the dam. The uniform character of the deposit, so far as any illustration can show it, is shown in Fig. 3, taken about 600 ft. above the dam on the right-hand bank of the stream.

The deposit, which is a fine even clay with absolutely no bowlders or stones, has cracked extensively, and to considerable depths since the withdrawal of the water, and these cracks show plainly in the photograph. The vegetation (*Polygonum*) also shows; but as the picture was taken after snow had fallen, late in November, the luxuriance of its growth is not apparent.

The margins of the pond when first the dam was built, must have been the bluffs on either side of the flood plain and the pond must have extended back half a mile from the dam as is shown by the deposits. The pond when the dam broke, was much smaller, due to deposits of silt, its limits at the head of the valley being marked by the peculiar hummock or mound configuration built up by the sedge

Fig. 2.—Break in Dam (looking S. E.). During high water on May 30, 1905, the dam gave way leaving a break at the end of the waste weir and bridge as shown in Fig. 2. When the water was drawn off, the floor of the pond was almost entirely covered with Knotweed (*Polygonum Muhlenbergii*) standing from three to five feet high.

(*Carex stricta*) and added to later by turf-forming grasses.[1] These tuft formations mark off sharply the limits of the pond on the margins away from the dam and shown in Fig. 4. Here the stream has cut a narrow channel in the bed of the old, wider course, but preserved the old bed, the banks of the old course being marked off sharply, the

[1] Brown, *Bot. Gaz.*, October, 1905, p. 270.

hummock configuration showing on either shore, but better on the right.

The same is shown in the view of the entire valley (Fig. 5) in the foreground, where the present stream has inherited an old meander. This view down the river shows the bridge in the background and the bluffs on the left hand side of the valley. The wagon road

FIG. 3.—Section of silt where stream has cut seven feet into old pond floor.

also shows, and over to the left the houses at Pikes Peak may be seen. The character of the surface, with its tuft formations, the land reclaimed from the original pond by silting and subsequent additions by the growth of vegetation, also shows very well.

The meander which shows is an inherited one, cut by the river in silt laid down in the original pond while the water was still ponded up, and deepened in a narrower channel since. The old banks show plainly on either side.

The bars on the inner side of the curves are of small extent and

relatively steep slope, as the lateral cutting of the stream has as yet been very little. One of these bars shows in the foreground. They are in general composed of coarse material (sand and gravel), differing in composition from the banks of the stream.

The Rouge is so called from its color, which is owing to the sediment carried. The Middle Rouge, even though a small stream here, carries a great amount of sediment. A large portion of this was

FIG. 4.—Present stream in an inherited wider bed.

dropped in the pond while the dam was intact, the deposits reaching a depth of eight feet at the dam and extending back a distance of nearly half a mile.

The map accompanying the paper (Fig. 6) shows the meandering course of the stream in the old floor of the pond and extends back far enough to show all the meanders which have developed since the withdrawal of the water as well as one (the first of the series), which was developed earlier and has since simply been deepened.

The map has been constructed with considerable care, the principal

points being located accurately, and the width of the stream measured carefully in many places.

At the present time, the river has cut through the old deposits and has regraded its floor so that the deposits stand out eight feet thick at the dam and thin out to nothing half a mile up stream.

Assuming that the floor of the pond is level, and it must be very nearly level when we consider that the top of the waste weir is

FIG. 5.—View down the river taken from bluffs at the head of the old mill pond.

only eleven feet above the bed of the stream and the silt reaches to within three feet of its top, we can see that when the dam gave way the river was flowing on a nearly level surface, certainly more nearly level than any other portion of the flood plain in the vicinity. It immediately began to cut into this deposit, however, and soon had a fall in half a mile of a trifle more than the thickness of the deposits, or something over ten feet.

To have been there and seen the events as they actually occurred would have been exceedingly interesting. Nothing could be learned

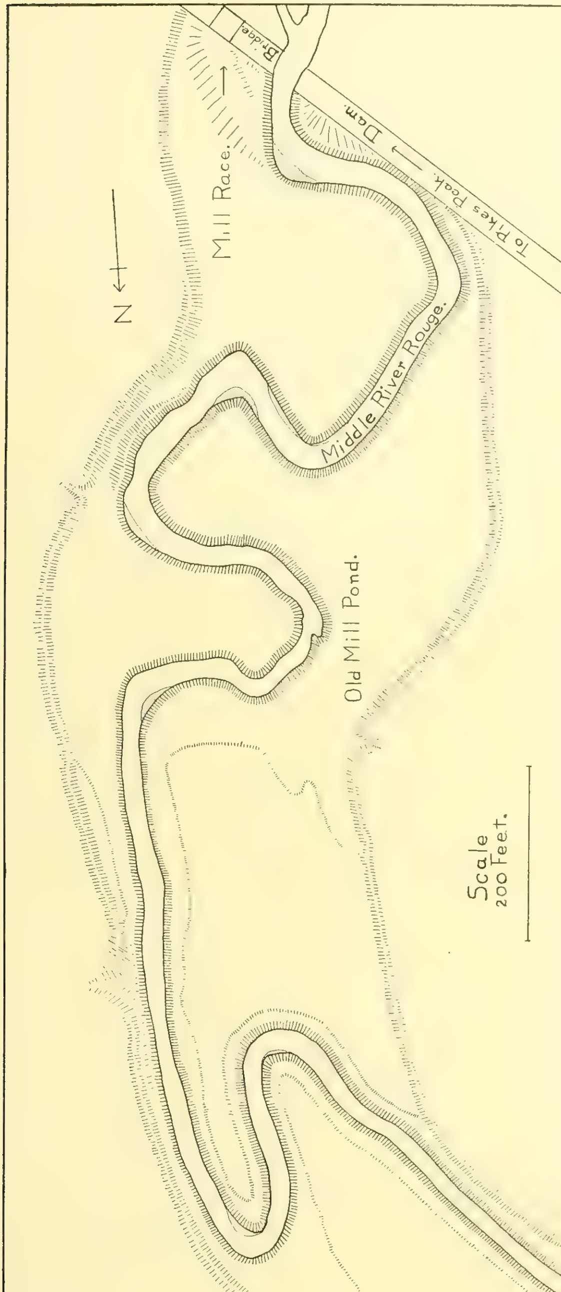

Fig. 6.—Map of the mill-pond at Pikes Peak.

in the vicinity, however, which seemed reliable enough to be taken as authority as regards the course of events, so it will be necessary to imagine what actually did occur from the final results.

The river, when first the dam broke, must have been free to flow on a practically flat surface, at least not uneven enough to cause it to swing from one side of the plain to the other. Neither can the character of the deposits have been the cause of the meandering which actually occurred. These meanders may or may not have been assumed practically as soon as the dam broke and deepened and made permanent since.

The meanders developed on the withdrawal of the water from the pond are not the old ones which the stream simply resumed with slight deviation. The old meanders were completely obliterated by silting. If this were not so, we should expect to find traces of old meanders which the present stream does not occupy, but which would be plainly visible as slight depressions in the valley floor. These we do not find in the floor of the old pond, though they occur both above and below in the valley floor. In fact, several "cut offs" have had time to form in the old deposits above water at the time the dam broke, farther up stream than shown on Fig. 6, but still in silt laid down in the original pond.

The old topography of the valley floor was not reproduced on the withdrawal of the water due to pressing out of the water entrapped in the subaqueous deposit by the increased gravity of the mass. It this were so, it would be peculiar that only one set of meanders should be produced and the stream should follow them. Others would show as well. The material deposited was a very fine, even clay and the amount of settling which it would undergo on the withdrawal of the water, from a shallow pond perhaps three or four feet deep would be problematical, and perhaps of more theoretical than practical importance in the determination of the course of a stream whose course was determined within a few hours after the break in the dam.

The silting up of the pond was certainly complete enough to obliterate entirely the old stream courses and the settling of the mass which would occur in 24 hours did not reproduce them. The new meanders are independent of the old.

The probability is, that while the water of the pond was draining

off, the flat character of the bottom caused the water to flow in a thin broad stream, and that the meanders were caused or formed as the narrower stream cut back from the dam. This is rendered probable by the fact that near the dam, in so far as there are any inequalities of surface, the water does not occupy the lowest land. This would tend to show that inequality of surface was not the determining factor in causing the meandering. The question naturally arises: What did cause the stream to meander?

According to the U. S. contour map of the locality, the average fall of the stream per mile is about ten feet above the old pond and about six feet below. If the stream had assumed a straight path, it would have had a fall of over thirty feet to the mile in the floor of the old pond. As a matter of fact, it, by its meandering course, reduces the fall to about fifteen feet to the mile. These numbers are only approximations; but can be verified by consulting the accompanying map. Even this is more than the average fall per mile in the course of the stream. This is what we should expect, as while in the old pond the stream has graded its course, it is still cutting down to conform to the grade of the stream as a whole, which it will reach in time.

Considering the width of the flood plain, however, it will be seen that it would be impossible for the stream to decrease its rate of fall farther by meandering, as it already swings from side to side, cutting into both boundary bluffs. In so far as the conditions permit, the stream has apparently endeavored to conform to the general grade of its course in its path across the floor of the old pond. This gives rise to some very interesting questions.

What does meandering mean? Does it mean a response to surface configuration? Is it dependent upon the nature of the material in which the river is cutting its course? Does it bear any relation to stream velocity? Is it necessarily associated with the lower courses of streams because of a decrease in velocity, or is it because of a decrease in freedom to meander due to the width of the flood plain caused by lateral cutting?

These meanders are not inherited, neither are they the result of lateral cutting. Most of the work done by the river since the dam gave way has been vertical cutting. The banks are vertical and remain so on account of the fine, homogeneous clay of which they are

composed. Only in an occasional place, and then only in small amount, has any lateral cutting whatever occurred.

What then does meandering mean? It would seem from this one case, that meandering is rather an expression of the river's attempt to establish a certain grade and fix a certain relation between its slope and the amount of sediment carried, that meandering is not dependent upon the character of the material and may proceed in deposits in which there are no obstructions to start meandering, that meanders are not always the result of a long process, but that a meandering course may be the one first chosen, and that a swift stream, when free to assume the path it chooses, will meander.

This is, of course, more in the nature of a suggestion than a definite statement as to the cause of meandering, as one case is not sufficient to establish the point, but it should be possible to find many other examples of character similar to this, and a careful study of such cases would certainly help us to a better understanding of the behavior of meandering streams.

REVIEW OF NOMENCLATURE OF KEWEENAWAN IGNEOUS ROCKS[1]

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The Keweenawan igneous rocks of the Lake Superior region have been studied and discussed by many geologists during the past thirty years. At the beginning of that period microscopical petrography was in its infancy, and minor errors due to faulty methods inevitably resulted. In the course of the years these have been gradually corrected, involving changes of nomenclature. Some variations in nomenclature have resulted from the varying points of views of the authors. But the general progress of petrography has brought more numerous and important modifications.

In order to make the names used by the prominent writers on the subject more readily intelligible, a correlation of these is presented herewith. It must be remembered that, since the basis of petrographic classification used by the authors has varied somewhat, such a correlation can be only an approximation, but it will nevertheless serve the purpose of showing the various changes that have occurred, and of presenting, at least in its outlines, the main facts of nomenclature of each writer.

In order to give precision to such a correlation, it is desirable that the nomenclature of each writer be compared, not simply with that used by other authors, but also with an expressed and definite classification. Therefore the following classification has been prepared, on the basis of textures and mineral composition. It is not a general classification of igneous rocks, but is intended to include merely the types represented in the Keweenawan of the Lake Superior region.

Macfarlane,[2] in 1866, described the Keweenawan rocks of Michipicoten Island. He found melaphyre, trap, amygdaloid, quartz porphyry, porphyrite, and trachytic phonolite. His "quartz porphyry,"

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

[2] Thos. Macfarlane, *Geol. Surv. of Canada, 1863–66,* 1866.

which occurred at the contact of the sandstone and trap, was doubtless a modified quartzite. His "trachytic phonolite" is not fully described, and correlation is uncertain.

J. H. Kloos,[1] in 1871, described gabbro or hypersthenite, black porphyry or melaphyre, porphyry and amygdaloid. The first named was probably a gabbro and the second a diabase.

Pumpelly,[2] in 1873, described melaphyre, trap, and amygdaloid without microscopic study; he distinguished three kinds of melaphyre, coarse-grained, fine-grained, and melaphyre porphyry. Correlations of these names are impracticable, and would be misleading rather than helpful.

Marvine,[3] in the same year, described melaphyre, trap, diorite, and amygdaloid. Pumpelly later claimed, probably correctly, that Marvine's diorite included samples of diabase, melaphyre, and gabbro but no true diorite.

Streng,[4] in 1877, described melaphyre, melaphyre porphyry, and hornblende gabbro from the Keweenawan of Minnesota. He published chemical analyses of two of these which permit their correlation on the quantitative basis (see Table III).

Pumpelly,[5] in 1878, described the alterations which some of the Keweenawan rocks had suffered in great detail, but brought to light no additional varieties of the unaltered rocks.

The same author,[6] in 1880, identified eight or ten kinds of igneous rocks in the Keweenawan (see the correlation table). He distinguished diallage from augite by means of the parting in the former, and, in accordance with the usage at that time, called a massive igneous rock containing plagioclase and diallage a gabbro, while one containing plagioclase and augite he called a diabase. But in his descriptions and illustrations, his diabase seems to have an ophitic texture in all cases. His identifications of the various plagioclase feldspars were all based on incorrect methods, so that his so-called

[1] J. H. Kloos, *Zeitschrift der deutschen geologischen Gesellschaft*, p. 417, 1871.

[2] R. Pumpelly, *Geol. of Mich.*, Vol. I, Pt. 2, 1873.

[3] A. R. Marvine, *ibid.*

[4] A. Streng, *N. J. Min. Geol.*, 1877.

[5] R. Pumpelly, *Proc. Amer. Acad.*, Vol. XIII, p. 285, 1878.

[6] R. Pumpelly, *Geol. Wis.*, Vol. III, pp. 27–49, 1880.

…cation of Keewenawa…

			No feldspar	
	N…	+Olivine	±Pyroxene±Amphibole ±Biotite	
+Amphibole ±Biotite	…ne		−Olivine	+Olivine
Quartz Diorite	…he …e	Troctolite	Pyroxenite	Peridotite
Dacite				

TABLE I.—Mineralogical Classification of Keweenawan Igneous Rocks of the Lake Superior Region

<table>
<tr><td rowspan="4">Textures</td><td colspan="3">Chief feldspar orthoclase</td><td>Orthoclase with equal plagioclase</td><td colspan="12">Chief feldspar plagioclase</td><td colspan="2">No feldspar</td></tr>
<tr><td colspan="2">+Quartz</td><td colspan="2">−Quartz</td><td colspan="4">With quartz</td><td colspan="7">Without quartz</td><td rowspan="3">+Olivine</td><td colspan="2" rowspan="2">±Pyroxene±Amphibole ±Biotite</td></tr>
<tr><td colspan="4">±Mica±Amphibole±Pyroxene</td><td colspan="2">+Monoclinic pyroxene</td><td rowspan="2">+Orthorhombic Pyroxene</td><td rowspan="2">+Amphibole ±Biotite</td><td rowspan="2">No ferro-magnesian mineral</td><td rowspan="2">+Amphibole ±Biotite</td><td colspan="2">+Monoclinic Pyroxene</td><td colspan="3">+Orthorhombic Pyroxene</td></tr>
<tr><td>±Microcline</td><td>+Anorthoclase</td><td colspan="2">±Microcline</td><td>+Orthoclase</td><td>−Orthoclase</td><td>−Olivine</td><td>+Olivine</td><td>+Monoclinic Pyroxene</td><td>−Olivine</td><td>+Olivine</td><td>−Olivine</td><td>+Olivine</td></tr>
<tr><td>Granitic</td><td>Granite</td><td>Soda granite</td><td>Syenite</td><td>Monzonite</td><td>Orthoclase Gabbro</td><td>Quartz Gabbro</td><td>Quartz Norite</td><td>Quartz Diorite</td><td>Plagioclasite</td><td>Diorite</td><td>Gabbro</td><td>Olivine Gabbro</td><td>Augite Norite</td><td>Norite</td><td>Olivine Norite</td><td>Troctolite</td><td>Pyroxenite</td><td>Peridotite</td></tr>
<tr><td>Ophitic</td><td></td><td></td><td></td><td></td><td>Orthoclase Diabase</td><td>Quartz Diabase</td><td>Quartz Enstatite diabase</td><td></td><td></td><td></td><td>Diabase</td><td>Olivine Diabase</td><td colspan="2">Hypersthene Diabase</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Porphyritic (Phenocrysts prominent)</td><td>Rhyolite Porphyry (Quartz porphyry)</td><td>Quartz Keratophyre</td><td>Trachyte Porphyry</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Andesite Porphyry</td><td>Augite Andesite Porphyry</td><td>Basalt Porphyry</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Felsitic or Porphyritic (Phenocrysts few)</td><td>Rhyolite</td><td>Quartz Keratophyre</td><td>Trachyte</td><td></td><td></td><td></td><td></td><td>Dacite</td><td></td><td>Andesite</td><td>Augite Andesite</td><td>Basalt</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fragmental</td><td colspan="11">Acid tuffs</td><td colspan="7">Basalt Tuffs</td></tr>
<tr><td>Glassy</td><td colspan="11">Obsidian</td><td colspan="7">Tachylyte</td></tr>
</table>

albite and oligoclase are actually andesine-oligoclase, his labradorite is andesine, and his anorthite is chiefly labradorite with some bytownite.

Irving[1] followed the practice of Pumpelly, but described about twice as many petrographic varieties. He protested against the practice of basing rock names on any such distinction as that between diallage and augite, but followed the custom, nevertheless, in the main, although he tried to discriminate between diabase and gabbro on the basis of coarseness of crystallization, assigning the name gabbro to the coarser grained varieties. Irving's orthoclase gabbro has been called hornblende gabbro by Wadsworth, and porphyritic gabbro by N. H. Winchell; it is nearly the same as Lane's gabbro aplite; recently it has been called oligoclase gabbro by F. E. Wright.[2]

N. H. Winchell,[3] in 1881, described thin sections of dolerite, labradorite rock, hyperite, and gabbro. He made the name "dolerite" so general in meaning as to include gabbro, diabase, olivine gabbro, olivine diabase, augite andesite, and basalt. His "labradorite rock" was called "anorthite rock" by Irving, and is now called plagioclasite (or anorthosite), while his hyperite is now known as norite.

Wadsworth,[4] in 1887, proposed a new classification of the Keweenawan igneous rocks on the basis of the alterations which a given type has undergone. Thus, a gabbro whose augite had altered to hornblende he would call a gabbro, diorite. A peridotite may by alteration become a serpentine or a talc schist; in either case Wadsworth would call it still a peridotite, adding a name to indicate its present condition. Consequently, a rock called, for example, a gabbro by Wadsworth, may belong to any one of a dozen types as commonly recognized. Nevertheless, Wadsworth's names as actually applied in this case may be correlated approximately with the names of other writers, as shown in the table.

Wadsworth indorsed Irving's protest against using the distinction

[1] R. D. Irving, *Geol. Wis.*, Vol. III, pp. 167–206, 1880; *Mon.* V. *U. S. G. S.*, 1883, and *Geol. Wis.*, Vol. I, p. 340, 1883.

[2] F. E. Wright, *Science*, Vol. XXVII, p. 892, June, 1908.

[3] N. H. Winchell, *Proc. A. A. A. S.*, Vol. XXX, p. 160, 1881.

[4] M. E. Wadsworth, *G N. H. S. Minn.*, Bull. 2, 1887.

between augite and diallage as a basis of rock classification, and yet, like Irving, he used it. He did not discriminate sharply between the ophitic and the poikilitic textures, both of which may be found, sometimes together, in Minnesota diabases.

Bayley,[1] in 1889–97, described the gabbro bathylith of Minnesota in considerable detail, and also studied the peripheral phases of the gabbro. To emphasize the close connection in origin between the peridotite and the gabbro of the district, he called the former nonfeldspathic gabbro. Although some of the peripheral phases described by Bayley may be of later date than the gabbro, if we assume that they all belong in the Keweenawan, we find that Bayley recognizes not only augite syenite of Irving, but also a porphyritic equivalent which he calls quartz keratophyre on account of the presence of anorthoclase. He speaks of olivine pyroxene aggregates which should apparently be correlated with wehrlite, dunite, and pyroxenite.

In the peripheral phases he finds a texture which he considers somewhat characteristic; it consists of the presence of many rounded grains of the more important constituents inclosed by other minerals. Bayley calls it the granulitic texture. It has been called the contact structure by Salomon, and the globular by Fouqué. It is well described by the term globular or globulitic.

Grant,[2] in 1893 and 1894, described gabbro, diabase, granite, and fine-grained rocks previously called muscovadites in the Minnesota reports. Grant's granite is the equivalent of Irving's augite syenite, later called soda augite granite by Bayley (see the correlation table). The fine-grained rocks, called muscovadites, include border facies of the gabbro mass of various types, but especially norite, fine grained gabbro often with hypersthene, olivine norite, cordierite norite, etc.

Hubbard,[3] in 1898, described various types of the Keweenawan of Keweenaw Point. His melaphyre is chiefly andesite or basalt;

[1] W. S. Bayley, *Am. J. Sc.*, Vol. XXXVII, p. 54, 1889; Vol. XXXIX, p. 273, 1890; *U. S. G. S.*, Bull. 109, 1893; *J. G.*, Vol. I, p. 433, 1893; Vol. II, p. 814, 1894; Vol. III, p. 1, 1895; *U. S. G. S.*, Mon. 28, p. 519, 1897.

[2] U. S. Grant, *G. N. H. S. Minn.*, 21st Ann. Rep., p. 5, 1893; 22d Ann Rep., p. 76, 1894.

[3] L. L. Hubbard, *Geol. Surv. Mich.*, Vol. VI, Pt. 2, 1898.

R. Pumpelly 1880		N. H. Winchell and U. S. Grant 1900	Mineralogical Classification
	Grani	Granite	Granite
Quartz porphyry	Quart	Quartz porphyry	Rhyolite porphyry
		Rhyolite	Rhyolite
		Tuff	Acid tuffs
		Obsidian and apobsidian	Obsidian
	1 Au 2 Gr	1 Granite 2 Soda granite	Soda granite
	Gran	Quartz keratophyre	Quartz keratophyre
		Syenite ?	Syenite
	Quar		Trachyte porphyry
Felsite porphyry	1 Fe 2 Fe	Trachyte	Trachyte
		Syenite or Granophyre	Monzonite
1 Augite diorite 2 Melaphyre	1 Ho 2 Or	Porphyritic gabbro	Orthoclase gabbro
	Orth		Orthoclase diabase
		Quartz gabbro	Quartz gabbro
		Diabase	Quartz diabase
		Quartz norite	Quartz norite
		Diabase with hypersthene	Quartz enstatite diabase
		Quartz diorite	Quartz diorite

TABLE II

CORRELATION OF NOMENCLATURES OF KEWEENAWAN IGNEOUS ROCKS

R. Pumpelly 1880	R. D. Irving 1880–1883	M. E. Wadsworth 1887–1893	W. S. Bayley 1889–1897	L. L. Hubbard 1898	A. C. Lane 1898–1906	A. N. Winchell 1900	N. H. Winchell and U. S. Grant 1900	Mineralogical Classification
	Granite						Granite	Granite
Quartz porphyry	Quartz porphyry			Porphyry	Quartz porphyry		Quartz porphyry	Rhyolite porphyry
				Felsite	1 Felsite 2 Felsophyre 3 Orthophyre		Rhyolite	Rhyolite
							Tuff	Acid tuffs
							Obsidian and apobsidian	Obsidian
	1 Augite syenite 2 Granitell		1 Granite 2 Soda augite granite		1 Augite-porphyrite? 2 Granophyre 3 Augite syenite 4 Gabbro aplite		1 Granite 2 Soda granite	Soda granite
	Granitic porphyry		Quartz keratophyre				Quartz keratophyre	Quartz keratophyre
							Syenite?	Syenite
	Quartzless porphyry				Quartzless porphyry			Trachyte porphyry
Felsite porphyry	1 Felsite? 2 Felsitic porphyry			Felsite	1 Felsite 2 Orthophyre		Trachyte	Trachyte
		Quartz biotite diorite					Syenite or Granophyre	Monzonite
1 Augite diorite 2 Melaphyre	1 Hornblende gabbro 2 Orthoclase gabbro	Altered gabbro	Hornblendic gabbro		Gabbro aplite?	Orthoclase gabbro	Porphyritic gabbro	Orthoclase gabbro
	Orthoclase diabase							Orthoclase diabase
						Quartz gabbro	Quartz gabbro	Quartz gabbro
			Quartz diabase		1 Quartz diabase 2 Diabase granophyrite		Diabase	Quartz diabase
							Quartz norite	Quartz norite
					Enstatite diabase		Diabase with hypersthene	Quartz enstatite diabase
		1 Gabbro? 2 Quartz diorite	Quartz diorite				Quartz diorite	Quartz diorite
					Quartz porphyrite			Dacite
	Anorthite rock					Plagioclasite	Anorthosite	Plagioclasite
	Diorite?						1 Diorite 2 Gabbro	Diorite
	Quartzless porphyry			Doleritic melaphyre			Porphyrite	Andesite Porphyry
	Diabase porphyrite	1 Augite Andesite 2 Hornblende porphyrite		1 Felsite porphyrite 2 Melaphyre	1 Felsite porphyrite 2 Felsophyrite		Andesite	Andesite
1 Diabase 2 Gabbro	1 Diabase 2 Gabbro			Doleritic melaphyre		Gabbro	1 Gabbro 2 Diabase	Gabbro
1 Diabase 2 Gabbro	1 Diabase 2 Gabbro	Diabase	Diabase	Diabasic melaphyre	Diabase (in dikes)	Diabase	Diabase	Diabase
Porphyritic diabase	Diabase porphyrite				1 Porphyrite 2 Labradorite porphyrite		1 Diorite porphyrite 2 Diabase porphyrite	Augite andesite porphyry
	1 "Ashbed" diabase 2 Diabase porphyrite		Porphyrite	Porphyrite	Augite andesite		Basalt	Augite andesite
	1 Olivine diabase 2 Olivine gabbro		Olivine gabbro			Olivine gabbro	Olivine gabbro	Olivine gabbro
1 Chrysolitic diabase 2 Melaphyre	1 Olivine diabase 2 Olivine gabbro 3 Melaphyre	1 Diabase 2 Granophyrite	1 Olivine diabase 2 Olivine gabbro	Ophitic melaphyre	1 Melaphyre ophite 2 Melaphyre porphyrite 3 Olivine diabase (in dikes)	Olivine diabase	Diabase with olivine	Olivine diabase
	Diabase porphyrite			Doleritic melaphyre	Melaphyre dolerite		Porphyritic basalt or zirkelite	Basalt porphyry
"Ashbed" Diabase	1 Diabase porphyrite 2 Melaphyre	1 Basalt 2 Melaphyre		Melaphyre	1 Felsite 2 Melaphyre porphyrite 3 Labradorite porphyrite	Basalt	Basalt	Basalt
							Tuff or zirkelite	Basalt tuffs
							Zirkelite	Tachylyte
			Hypersthene gabbro				Hypersthene gabbro	Augite norite
	Norite						Norite (muscovadite)	Norite
					Enstatite diabase		Hypersthene diabase	Hypersthene diabase
							Norite with olivine	Olivine norite
		1 Forellenstein 2 Troctolite			Troctolite	Troctolite	Forellenstein or troctolite	Troctolite
			Granulitic pyroxene rock				Pyroxenite	Pyroxenite
			Nonfeldspathic gabbro			Peridotite	Peridotite	Peridotite

his doleritic melaphyre is a coarser basalt, or a gabbro; his ophitic melaphyre is a poikilitic and luster-mottled diabase; and his porphyrite is chiefly andesite and trachyte.

Lane,[1] in 1898–1906, described the Keweenawan rocks of Isle Royale and northern Michigan. His melaphyre porphyrite is the equivalent of Pumpelly's "Ashbed" diabase and Irving's diabase porphyrite, Lane's melaphyre ophite is an olivine diabase, luster-mottled by means of poikilitic textures; his doleritic melaphyre is a basalt porphyry. Lane would confine the name diabase to dike rocks. His augite syenite is said to be at least in part an equivalent of Bayley's quartz diabase. He uses the term "ophitic" in a narrow sense, not justified by the original definition of Michel Lévy,[2] nor by his usage.[3] He applies it to those luster-mottled rocks in which single pyroxene individuals inclose several plagioclase crystals, usually lath-shaped and irregularly placed. It is, thus, for Lane, a variety of the poikilitic texture. In its original meaning, still commonly used by many, and adopted here, it refers to that texture of a basic igneous rock produced when the plagioclase crystallizes in lath-shaped forms before the pyroxene solidifies.

A. N. Winchell,[4] in 1900, described in detail a few samples of the Keweenawan rocks of Minnesota. He used the new term plagioclasite for the rocks previously known usually as anorthosites.

N. H. Winchell and U. S. Grant[5] published in 1900 by far the most complete accounts of the petrography of the Keweenawan igneous rocks. Their nomenclature varies very little from that commonly in use at present. They described practically all the petrographic types of the Keweenawan previously known and added some half dozen new varieties. They used diorite porphyrite or diabase porphyrite to designate more or less ophitic types of andesite porphyry or augite andesite porphyry. They used Wadsworth's

[1] A. C. Lane, *Geol. Surv. Mich.*, Vol. VI, Pt. 1, 1898; *Geol. Soc. Amer.*, Bull., Vol. XIV, pp. 369, 385, 1903; *J. G.*, Vol. XII, p. 83, 1904; *Geol. Surv. Mich.*, Ann. Rep., 1903, pp. 205, 239, 1905; *Geol. Surv. Mich.*, Ann. Rep., 1904, p. 113, 1905; *Proc. L. Sup. Mg. Inst.*, Vol. XII, p. 85, 1906.

[2] *Bull. Soc. Geol. Fr.*, Vol. VI, 1878, p. 158.

[3] *Minéralogie micrographique*, 1879, Pl. XXXVI. See also p. 153.

[4] A. N. Winchell, *Amer. Geol.*, Vol. XXVI, pp. 151 (197), 261, 348 (1900).

[5] N. H. Winchell and U. S. Grant, *G. N. H. S. Minn.*, Fin. Rep., Vol. V, 1900.

name zirkelite for a devitrified basalt, basaltic tuff, or tachylyte; devitrified obsidian they called an apobsidian, and a devitrified rhyolite an aporhyolite, as suggested by Bascom. Wadsworth's quartz biotite diorite is called syenite by Grant. It is an intermediate type corresponding to a monzonite.

The quantitative classification of igneous rocks as proposed by Cross, Iddings, Pirsson, and Washington may be used as the basis of a correlation of the Keweenawan igneous rocks. From a chemical point of view such a correlation (see Table III) is more exact than one based upon the mineral composition and texture, but it can include only those rock types of which satisfactory quantitative analyses are available.

An examination of the table of correlation on this basis will reveal the fact that the number of satisfactory analyses available is not great, especially when compared with the descriptions previously mentioned. Several of the early analyses are not included in the tabulation because of manifest inaccuracy or incompleteness.

The analyses of Streng and Pumpelly are good for the time at which they were made. The norm of Pumpelly's andose is: or 7.78, ab 42.44, an 17.24, hy 1.30, ol 17.97, mt 4.41, il 4.41. The norm of his camptonose is: or 7.23, ab 22.01, an 23.91, ne 4.26, di 22.55, ol 7.47, mt 4.18, il 5.32. The norm of his auvergnose is: or 0.56, ab 16.24, an 36.97, di 15.88, hy 20.34, ol 1.11, mt 3.71, il 1.98. Sweet published two analyses of Keweenawan rocks; the one of diabase from the Ashland mine, Ashland Co., Wis., is wholly unsatisfactory; the other is approximately correct, and classifies as hessose. The analyses of gabbros published by Wadsworth are recalculated in Washington's tables[1] of chemical analyses of igneous rocks; the norm of his diabase granophyrite from the Cleveland mine is: Q 5.10, or 8.34, ab 16.77, an 32.25, di 11.02, hy 9.90, mt 8.45, il 5.17; the norm of his sample from Houghton Co. is: Q 8.46, or 8.90, ab 23.06, an 16.40, di 13.75, hy 20.82, mt 5.80, ap 0.34. Washington's tables give full details regarding the recalculation of the analyses of Keweenawan rocks published by Van Hise, N. H. Winchell, and Bayley. The norms of the analyses reported by Hubbard may be summarized as follows:

[1] H. S. Washington, *U. S. G. S.*, P. P. 14, 1903.

1 A. Stren[illegible] 1877	13–16 [illegible]. Hubbard 1898	17–18 A. N. Winchell 1900–1908	19–21 A. C. Lane 1905–1906	Quantitative Classification
	[illegible]te (13) Keweenaw Pt., Mich.			I. 3. 1. 2. Magdeburgose
	elsite (14) (No. 17193A) Keweenaw Pt., Mich.			I. 3. 2. 3. Tehamose
	elsite (14) (No. 16951) Keweenaw Pt., Mich.			I. 4. 1. 1. Lebachose
				I. 4. 1. 3. Liparose
				I. 4. 2. 3. Toscanose
		Plagioclasite (17) Carlton Peak, Minn.		I. 5. 4. 4,5. Labradorose
				II. 4. 2. 3. Adamellose
			Gabbro-aplite (19) Mt. Bohemia, Mich.	II. 4. 3–2. 4. Tonalose-dacose
	elsite porphyrite (15) Keweenaw Pt., Mich.			II. 5. 1. 4. Umptekose
	orphyrite (16) Keweenaw Pt., Mich.			II. 5. 2. 4. Akerose
Hornblend[illegible] Duluth,		Orthoclase gabbro (17) Duluth, Minn.		II. 5. 3. 4. Andose
Melaphyre Duluth,				II. 5. 3. 5–4. Beerbachose-andose

TABLE III

CORRELATION OF NOMENCLATURES OF KEWEENAWAN IGNEOUS ROCKS OF THE LAKE SUPERIOR REGION

1 A. Streng 1877	2 R. Pumpelly 1878	3 E. T. Sweet 1880	4–5 M. E. Wadsworth 1887–1893	6 C. R. Van Hise 1892	7 N. H. Winchell 1893	8–11 W. S. Bayley 1889–1895	12 A. C. Lane 1898	13–16 L. L. Hubbard 1898	17–18 A. N. Winchell 1900–1908	19–21 A. C. Lane 1905–1906	Quantitative Classification
								Felsite (13) Keweenaw Pt., Mich.			I. 3. 1. 2. Magdeburgose
								Felsite (14) (No. 17193A) Keweenaw Pt., Mich.			I. 3. 2. 3. Tehamose
								Felsite (14) (No. 16951) Keweenaw Pt., Mich.			I. 4. 1. 1. Lebachose
						Granite (8) Pigeon Pt., Minn. Soda granite (9) Pigeon Pt., Minn. Quartz keratophyre (8) Pigeon Pt., Minn.					I. 4. 1. 3. Liparose
						Quartz keratophyre (9) Pigeon Pt., Minn.					I. 4. 2. 3. Toscanose
									Plagioclasite (17) Carlton Peak, Minn.		I. 5. 4. 4,5. Labradorose
			Gabbro (4)? Pigeon Pt., Minn.			Quartz diorite (9) Pigeon Pt., Minn.					II. 4. 2. 3. Adamellose
										Gabbro-aplite (19) Mt. Bohemia, Mich.	II. 4. 3–2. 4. Tonalose-dacose
								Felsite porphyrite (15) Keweenaw Pt., Mich.			II. 5. 1. 4. Umptekose
								Porphyrite (16) Keweenaw Pt., Mich.			II. 5. 2. 4. Akerose
Hornblende gabbro Duluth, Minn.	Melaphyre Middle of bed 87 Eagle River section, Mich.						Porphyrite (V and VI) Isle Royale, Mich.		Orthoclase gabbro (17) Duluth, Minn.		II. 5. 3. 4. Andose
Melaphyre porphyry Duluth, Minn.			Gabbro (4) Baptism River, Minn.								II. 5. 3. 5–4. Beerbachose-andose
									Quartz gabbro (17) Little Saganaga Lake, Minn.		II. 4–5. 3. 5. Placerose-beerbachose
							Porphyrite (I) Isle Royale, Mich.				II. 5. 3. 5. Beerbachose
		Diabase Fond du Lac Mine, Douglas Co., Wis.	Diabase granophyrite (5) Cleveland Mine, Keweenaw Pt., Mich.			Olivine gabbro (9) Pigeon Pt., Minn. Olivine gabbro (10) T. 61 N. R. 12 W., Minn.	Porphyrite (IV) Ophite (VII) Isle Royale, Mich.		Olivine gabbro (17) Birch Lake, Minn. Diabase (17) Birch Lake, Minn.		II. 5. 4. 4.5. Hessose
			Diabase granophyrite (5) Sec. 2, T. 49 N. R. 27 W. Houghton Co., Mich.								III. 4. 3. 4. Vaalose
									"Ashbed diabase" (18) Bed 65, Eagle River section, Keweenaw Pt., Mich.		III. 5. 2–3. 4. Kilauose-camptonose
	Melaphyre Bottom of bed 87, Eagle River section, Keweenaw Pt., Mich.								Orthoclase gabbro (17) (Basic part) Duluth, Minn.		III. 5. 3. 4. Camptonose
	Melaphyre Lower part Bed 64, Eagle River section, Keweenaw Pt., Mich.			Diabase Sec. 13, T. 47 N. R. 46 W. Gogebic Co., Mich.	Gabbro (granular) Bashitanaquab Lake, Minn.	Olivine gabbro (10) Birch Lake, Minn. Gabbro (11) T. 64 N. R. 8 W., Minn.			Troctolite (17) Duluth, Minn. Olivine diabase (18) Bed 108, Eagle River section, Greenstone Cliff, Keweenaw Pt., Mich.	Ophite (19) Mt. Bohemia, Mich. Diabase (20) Lighthouse Pt., Mich. Ophite (21) St. Mary Land Co., Keweenaw Pt., Mich.	III. 5. 4. 4, 5. Auvergnose
						Hypersthene gabbro (11) Gunflint Lake, Minn.					IV. 1^1. 1^1. 2. Cookose

1–21 See references on page 774.

[1] H. S. Washington, *U. S. G. S.*, P. P. 14, 1903.

	Magdeburgose	Tehamose	Lebachose	Umptekose		Akerose
				No. 17,039	No. 17,007	
Q	38.58	48.90	18.60	1.14	.....	.....
C	1.94	.....	.....	.....	.....	.....
or	39.48	26.13	70.61	20.57	20.57	15.01
ab	16.77	18.34	0.52	57.64	57.64	48.21
an	.....	3.61	.....	1.67	.....	7.78
ne	.....	.....	.....	.....	2.27	3.69
ac	.....	.....	4.16	.....	3.70	.....
ns	.....	.....	3.66	.....	.....	.....
di	.....	0.12	1.43	5.62	0.43	5.18
hy	.....	.....	0.86	2.70	.....	.....
ol	.....	.....	.....	.....	3.22	5.32
mt	0.46	0.70	.....	6.03	5.57	8.12
hm	1.92	1.28	.....	3.04	5.92	4.00
H_2O	0.41	1.03	0.42	2.23	1.23	2.76
Total	99.56	100.11	100.27	100.64	100.55	100.07

It is to be remarked that not one of these rock types described by Hubbard corresponds chemically with any variety described by any other author. The fact suggests possible inaccuracies in Hubbard's analyses.

Lane's analyses, as well as Hubbard's were overlooked and omitted from Washington's tables. Recalculations of the analyses given by Lane yield the following norms:

	Tonalosedacose	Andose		Beerbachose	Hessose		Auvergnose		
		No. V	No. VI		No. IV	No. VII	No. 8 Lighth. Pt.	St. M. Land Co.	Mt. Bohemia
Q	13.08	.....	.....	.....	.....	.....	.....	1.80	.....
C	1.02	.....	.....	.....	.....	.....	.....	.....	.....
or	17.79	6.12	6.12	2.78	1.67	2.78	3.89	1.67	10.01
ab	36.15	28.82	23.58	45.59	28.82	21.48	18.35	20.96	18.34
an	16.96	24.19	30.30	20.02	34.19	41.14	36.14	31.41	31.69
ne	.....	2.84	4.26	.....	.....	.....	.....	.....	.....
di	.....	3.80	18.41	1.30	10.66	10.64	13.52	12.74	1.36
hy	11.06	.....	.....	2.76	1.56	5.76	10.77	12.20	21.62
ol	.....	23.25	2.10	12.58	12.97	6.01	13.06	.....	2.08
mt	2.32	3.94	11.14	11.37	6.50	10.44	3.71	10.67	7.42
hm	.....	.....	.....	.....	.....	.....	.....	2.24	.....
il	1.98	.....	.....	.....	.....	.....	.....	4.10	4.71
ap	.....	.....	.....	.....	.....	.....	0.34	0.34	.....
cc	.....	0.90	2.30	2.00	.....	0.70	.....	1.10	.....
pr	.....	.....	.....	.....	.....	.....	0.36	0.10	.....
H_2O	.....	5.01	3.49	2.82	3.90	1.83	.....	0.67	.....
Total	100.36	98.87	101.62	101.22	100.27	100.78	100.14	100.00	97.23

Lane's gabbro aplite differs in its norm from the orthoclase gabbro of Duluth by a greater abundance of quartz, and also by a greater proportion of alkalies as compared with salic lime. His porphyrite (VI), on the contrary, belongs to the same type (andose) as the orthoclase gabbro. His porphyrite (No. 1) is a beerbachose; the others belong to the classes, hessose and auvergnose, so well represented in the Keweenawan.

The analyses published by A. N. Winchell in 1900 were recalculated by Washington with the exception of that of the troctolite, the norm of which is: or 2.22, ab 7.86, an 28.63, ne 5.11, di 5.91, ol 30.21, mt 10.67, il 4.41, MnO 0.08, H_2O 5.23.

In view of the scarcity of analyses of the typical volcanic rocks of the Keweenawan the following new analyses are of much interest. They were made by George Steiger in the laboratory of the Survey.

ANALYSES OF KEWEENAWAN DIABASE

	No. 1*	No. 2†
SO_2	47.69	50.07
Al_2O_3	16.02	12.63
Fe_2O_3	2.41	3.84
FeO	8.70	10.30
MgO	8.31	5.23
CaO	10.54	6.55
Na_2O	2.44	3.53
K_2O	none	1.90
H_2O-	0.44	0.86
H_2O+	2.04	1.96
TiO_2	1.38	2.50
ZrO_2	none	none
CO_2	none	none
P_2O_5	0.06	0.22
SO_3	none	none
S	none	none
MnO	0.26	0.42
BaO	none	0.02
SrO	none	none
Total	100.29	100.03

* Olivine diabase from Bed 108, Eagle River section, Greenstone Cliff, Keweenaw Point, Mich Sample No. 5 of Rohn's collection of Lake Superior rocks. Rock powdered to pass a 100-mesh sieve before analysis.

† "Ashbed" diabase from Bed 65, Eagle River section, Keweenaw Point, Mich. Sample No. of Rohn's collection of Lake Superior rocks. Rock powdered to pass a 100-mesh sieve before analysis, thus improving the accuracy of the figures for ferrous iron and water.

Recalculation of these analyses on the basis of the quantitative classification gives the following norms:

	1. Olivine diabase	2. Ashbed diabase
or	.....	11.12
ab	20.44	29.87
an	32.80	13.07
di	15.60	15.12
hy	15.64	15.32
ol	7.06	2.00
mt	3.48	5.57
il	2.74	4.71
ap	0.14	0.50
H_2O	2.48	2.82
Total	100.38	100.10

The olivine diabase belongs to the same class as the Birch Lake olivine gabbros, the Lighthouse Point diabase, and several others, that is, to the auvergnose type, which seems to be the dominant type of the Keweenawan, although the hessose type, which differs only in having a greater proportion of salic minerals, is also quite abundant. But the "ashbed" diabase classifies as a camptonose, very near a kilauose. It is therefore related to Irving's melaphyre of Bed 87 of the Eagle River section, and to the more basic phases of the orthoclase gabbro of Duluth.

It is to be expected that additional analyses of the Keweenawan volcanic rocks would disclose still other types, especially such as would parallel the known plutonic types. The parallelism in composition already established is quite remarkable, considering the relatively small number of analyses available. Thus, it appears that Lane's porphyrite (No. IV) and ophite (No. VII), as well as Sweet's Douglas County diabase and Wadsworth's diabase granophyrite from the Cleveland mine, are the chemical equivalents among the volcanic and dike rocks of Bayley's olivine gabbro from Pigeon Point and from T. 61 N. R. 12 W., and of A. N. Winchell's olivine gabbro and diabase from Birch Lake among the plutonic rocks. Again, Pumpelly's melaphyre from the middle of Bed 87 and Lane's porphyrite (Nos. V and VII) from Isle Royale correspond chemically with the coarse hornblende gabbro and orthoclase gabbro from Duluth. Finally, the same chemical type, viz., auvergnose, includes plutonic rocks such as Bayley's gabbro and olivine gabbro from Birch Lake, N. H. Winchell's gabbro from Bashitanaquab Lake, and A. N. Winchell's troctolite, together with volcanic or dike rocks

such as Pumpelly's melaphyre from Bed 64, Van Hise's Gogebic County diabase, and Lane's ophite from the property of the St. Mary's Land Company, and from Mt. Bohemia.

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Reviews

Triassic Ichthyosauria, with Special Reference to the American Forms. By JOHN C. MERRIAM. Memoirs of the University of California, Vol. I, No. 1, pp. 1–196, pls. 1–18, 1908.

Just forty years ago the late Professor Leidy described some fragmentary remains of ichthyosaurs from the Triassic of Nevada, the first known representatives of the order from America. About ten years later Professor Marsh made known a much more highly specialized form, *Baptanodon*, from the Jura-Cretaceous of Wyoming, a form which has been recently well described by Mr. Gilmore. Until 1895, nothing was added to our very meager knowledge of the early types from America and not much from other parts of the world. Since that time, however, Professor Merriam, the author of the present memoir, has been engaged almost continuously in the collection and study of the abundant, but often refractory remains of these animals from the Trias of the Pacific region, the final and praiseworthy results of which are embodied in the present work. In addition to the description of Leidy's *Cymbospondylus* he has founded no less than four other genera, *Torotocnemus*, *Merriamia*, *Delphinosaurus*, and *Shastosaurus*. *Mixosaurus*, *Ophthalmosaurus*, and *Ichthyosaurus* are the only other known genera of the order, hitherto unknown from America with certainty.

From the time when Scheuchser two centuries ago made known some vertebrae of an ichthyosaur from Altorf as those of a human being who had come to grief in the Noachian deluge, the gropthe ichthyosaurs have been of special interest to all classes, and much has been written about them in literature both grave and light. So perfectly were they adapted for aquatic life that it had been generally assumed, until 1887, that they were directly derived from the fishes. Baur it was, who, in the year mentioned, showed conclusively from the study of the only, and imperfectly known European Triassic form, *Mixosaurus*, that the animals must have sprung from some terrestrial crawling reptiles. A further knowledge, therefore, of the unexpectedly rich and varied ichthyosaurian fauna which has been brought to light by Dr. Merriam from the Triassic deposits of the Pacific region since 1895 when he began his energetic studies of this group, are peculiarly welcome to all interested in extinct animals and their evolution. So important are the many positive demonstrations of evolution in these forms which the

author's studies disclose, that it will be of interest briefly to summarize the more noteworthy of them. Perhaps no more familiar type of an aquatic carnivorous vertebrate can be suggested than the common gar-pike of America, a long, smooth body, short neck, propelling tail, guiding, loosely connecting fins, slender jaws, etc. The later ichthyosaurs approach such a type more closely than do or have any other air-breathing animals, in their long body, short neck, extraordinary tail-fin, paddle-like limbs, long jaws, large eyes, etc., and it is very evident that in the transition from forms not unlike a common lizard in external appearance, the animals must have passed through very great changes. In the Triassic forms chiefly those from California, Dr. Merriam has demonstrated a progressive adaptation in all these and in other characters. The locomotion of these early forms was more by aid of the limbs and less by the tail, the limbs were larger, with fewer bones, more elongated arm bones, the hind limbs were larger to supply the deficiency of a weaker tail, their connection with the trunk was stronger, the pelvis was heavier, the connection of the vertebrae with each other was more of the terrestrial kind—the vertebrae were more elongated, that is, less fish-like, etc. The skull was shorter, the jaws relatively less elongated, the teeth were more firmly fixed, the eyes were smaller, the ears less well adapted for deep diving, and the neck was less short. But it is in the tail that the most interesting progressive adaptation is seen. Every one knows how remarkable was the terminal caudal fin of the late ichthyosaurs. Dr. Merriam shows that the early forms were progressively modified from the simple flattened tail, as in the crocodile, to a tail with a preterminal dilatation like that of the mosasaurs having little or no downward bend; to the gradual turning downward of the distal end and the great expanse of the terminal, quite fish-like caudal fin. It is only in the ribs that modifications seem to have arisen not in conformity with the laws of aquatic specialization. The early forms had them attached to the centrum by a single head, while the laters ones are predominantly bicipital. However, the writer has little doubt that this primitive branch of the reptilian stem began with single-headed ribs, and that the acquisition of a double-headed attachment of a kind almost peculiarly their own, has been an independently acquired character. On the other hand, it seems very certain that a similar mode of attachment in the neck ribs of the plesiosaurs was a primitive character which has been lost in all the late forms. As the author says: "Not only is the stage of development of the Triassic representatives nearer the stem or semi-aquatic reptilian type than in the later ones, but a definite and fairly regular gradation or progressive specialization from the earliest forms to the latest seems to be recognizable in many parts of the skeleton."

But alas, notwithstanding all these conclusive evidences of evolution from a still earlier terrestrial type the Triassic forms offer no conclusive evidence of the origin of the order. The author can see no especial rhynchocephalian characters in the ichthyosaurs, so strongly urged by Baur, and he rejects the conclusions of McGregor that the ichthyosaurs are nearly related to the phytosaurs, and in both these conclusions the writer concurs. He believes that the ichthyosaurs arose from very primitive or the most primitive reptiles. Hay, recently in his extensive work on the turtles has reached the same conclusion for that order of reptiles. In other words, the results of both these authors, based upon exhaustive studies, go to support the phylogenic views expressed by Cope in his *Factors of Evolution*, published not long before his death. It seems to the writer they also destroy every shred of support remaining for the primary division of the reptilia into two chief classes, and the writer further protests against the use of the terms "Synapsida" and "Diapsida" as practically synonyms of Cope's Synaptosauria and Archosauria, proposed and sustained by him years before his death.

Briefly stated in conclusion, Dr. Merriam gives a full discussion of the geological and geographical distribution of the ichthyosaurs, their classification (he accepts Baur's two families only, the Mixosauridae and Ichthyosauridae), evolution, and structure, with especial reference to the Triassic forms, which are fully described so far as the known material has permitted. The work is well illustrated by text figures and plates.

Both the author and the University of California are to be congratulated upon the issuance of this volume, and not the least is the university to be commended for the inauguration of the handsome series of quarto memoirs of which this is the beginning; other institutions might well profit by the example.

S. W. W.

Skeletal Remains Suggesting or Attributed to Early Man in North America. By Aleš Hadlička. Bureau of American Ethnology, Bulletin No. 38, Washington, D. C., 1907.

This is a very careful, dispassionate review of the skeletal remains found at New Orleans, Quebec, Natchez, Lake Monroe (Florida) Soda, Creek, Charleston, Galaveras, Rock Bluff, Penon, Trenton, Burlington, Riverview, Lansing, Osprey, Hanson Landing, and Nebraska. The discussion of the Nebraska "loess man," which is based on personal examination of the grounds as well as study of the remains, is the climacteric point of interest, because of the low, retreating foreheads of some of the skulls. Hadlička's general conclusion (p. 98) is as follows:

The various finds of human remains in North America for which geological antiquity has been claimed have been thus briefly passed under review. It is seen that, irrespective of other considerations, in every instance where enough of the bones is preserved for comparison the somatological evidence bears witness against the geological antiquity of the remains and for their close affinity to or identity with those of the modern Indian. Under these circumstances but one conclusion is justified, which is that thus far on this continent no human bones of undisputed geological antiquity are known. This must not be regarded as equivalent to a declaration that there was no early man in this country; it means only that if early man did exist in North America, convincing proof of the fact from the standpoint of physical anthropology still remains to be produced.

Referring particularly to the Nebraska "loess man," the mind searches in vain for solid ground on which to base an estimate of more than moderate antiquity for the Gilder Mound specimens. The evidence as a whole only strengthens the above conclusion, that the existence on this continent of a man of distinctly primitive type and of exceptional geological antiquity has not as yet been proved.

There may be discouragement in these repeated failures to obtain satisfactory evidence of man's antiquity in America, but there is in this also a stimulus to renewed, patient, careful, scientifically conducted and checked exploration; and, as Professor Barbour says in one of his papers on the Nebraska find, "the end to be attained is worth the energy to be expended." A satisfactory demonstration of the presence of a geologically ancient man on this continent would form an important link in the history of the American race, and of mankind in general. The Missouri and Mississippi drainage areas offer exceptional opportunities for the discovery of this link of humanity if such really exists.

T. C. C.

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BUFFALO LITHIA SPRINGS WATER

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