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LUCIUS L. HUBBARD, STATE GEOLOGIST

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KEWEENAW POINT WITH PARTICULAR REFERENCE TO THE FELSITES AND THEIR ASSOCIATED ROCKS

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ACCOMPANIED BY TEN PLATES AND ELEVEN FIGURES

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CHAPTER I. INTRODUCTORY

§ 1. Scope of field work.

During the progress of field work in late years by the Michigan Geological Survey on Keweenaw Point the observation was made, that the course of one or more conglomerate beds low down in the Keweenaw series was very irregular as compared with similar beds higher in the series, and this irregularity led to the belief that intrusions of igneous material might have taken place early in the geological history of the series, which, alone, might have produced an apparent unconformity or, in connection with subsequent erosion, a real unconformity which would call for a further subdivision of the series. Some phenomena observed on Isle Royale seemed to lend weight to the former, the simpler of these hypotheses, and plans were made to examine the lower or older parts of the formation to obtain evidence that might solve the problem, or that might throw light on the mutual relations of Keweenaw Point and Isle Royale. On a reconnoissance trip made to the end of Keweenaw Point in May, 1895, an area amounting to nearly one square mile, on the Little Montreal River, just above its mouth, was found to have been burnt over several years before, and the frequent exposures of rock there gave promise of yielding some facts which owing to the thick covering of forest had thitherto been inaccessible. The work during the remainder of the field season was prosecuted in that region and was confined largely to the two tiers of sections next north of Lake Superior, between Secs. 23 and 26, T. 58, R. 29, and the extreme end of Keweenaw Point. In 1896 the work was taken up at Mt. Houghton and was extended westward and southward along the same general horizon, particular attention being paid to the various outcrops of original acid rocks (and associated beds) which occur therein with greater or less frequency, as well as to the conglomerates.

In the prosecution of this work I have occasionally been assisted by the members of the Survey corps, and by Prof. A. E. Seaman to whose efficient aid I desire to express my indebtedness. I am also under obligations, for valuable old maps showing geological data, to R. R. Goodell, Esq., and to Mrs. Hill, widow of the late Hon. S. W. Hill, and for much useful information to Captains J. C. Hodgson and Johnson Vivian, and others.

§ 2. Structure of Keweenaw Point.

The geology of Keweenaw Point has been so often and so well described that a resume here, even of only its salient points, may seem superfluous, but in view of the fact that the literature on this subject may not be readily accessible to everyone, I venture to lay before my readers, very briefly, enough facts to enable them to follow, easily and intelligently, the course I shall take in commenting upon the conclusions of others and in recording my own observations.

The west end of the Lake Superior basin is a broad synclinal bordered by rocks both of the Keweenaw or copper-bearing and Potsdam series, the former of which terminates about a hundred miles southwest of the lake in Wisconsin. Keweenaw Point and Isle Royale, near the east end of the main complex (we thus exclude from consideration a few isolated areas of volcanic rocks and the sandstone, at the east end of the lake), form the principal subjects of this volume. They exemplify the synclinal structure, the beds of Isle Royale dipping southeast, and those of Keweenaw Point northwest and northerly, each towards the lake. Keweenaw Point is the more typically representative of the two, in that it shows numerous out- crops of the more add rocks and a contact, on the southeast, with sandstone recognized as Potsdam, and, what is of still greater interest, the relations of its rocks are such that they may enable us to explain some of the geological changes that have contributed directly to its topography and physical structure, and inferentially perhaps to the history of other parts of the Keweenaw series. The Minnesota coast northwest of Isle Royale corresponds more nearly to Keweenaw Point, in its general structure, but lies without the province of this report.

The Keweenaw peninsula extends about seventy miles north-easterly into Lake Superior from the fifth correction line at the head of Keweenaw Bay. A belt of rocks, in great part of volcanic origin, forming a plateau in many places 600 feet and upwards above lake level, dominates the central parts of this land spur, flanked by broad belts of sandstone whose drift-covered surface slopes on either side to the shores of Lake Superior. This plateau is cut in two, east and west, by the narrow bed of Portage Lake, and again sinks to within 250 feet of lake level at what I shall call Allouez Gap, near the headwaters of Trap Rock River. Prom this point rising again, it soon divides into two ranges separated by the valleys of Eagle River and the Little Montreal; the northern or Greenstone range with a very steep east-south escarpment skirts the lake shore on the west and north there, soon losing the broad belt of sandstone that formed its western flank further south, while the southern or Bohemian range continues in contact on the east and south with the great body of the Potsdam sandstone, or with isolated remnants thereof, almost to the extremity of the Point.

The Keweenaw series embraces volcanic rocks of different chemical and physical constitutions, from very basic to very acid, and from very fine grained to very coarse grained. With these are associated conglomerates and sandstones, which are also acid or basic, coarse grained or fine. The strike of these beds, with some notable exceptions, conforms nearly to the northerly coast line or trend of the Point, and their dip, which is variable in amount from place to place, is, as above stated, towards the main body of the lake.

Beginning near the end of the Point at the bottom of the series as exposed, at the contact with the Potsdam or Eastern sandstone, we find in the Bohemian Range a succession of both basic and acid volcanics, frequently in alternation with detrital beds of similar composition, the whole capped by an extensive and rather persistent bed of fairly coarse and rather acid conglomerate. This bed, which in the following pages I shall provisionally call the "Bohemia" conglomerate, skirts the northern side of this range near its summit. Above it geologically, on Keweenaw Point proper, no very acid rocks other than conglomerates have thus far been observed,"* and it is therefore important as marking the upper limit of the felsites of that district. Above it comparatively few conglomerates occur until we reach the so called Ashbed group above the Greenstone. From this horizon upward, conglomerates and sandstones predominate; the Great conglomerate, about 2,200 feet thick** at Eagle River, and the Outer conglomerate with the interbedded Lake Shore trap occupy the entire northern rim of the Point. It is foreign to the purposes of this sketch to enter into more minute details concerning the Keweenaw series otherwise than as they affect or are affected by the subject immediately in hand—the felsites or most acid rocks of Keweenaw Point. For further information the reader should consult the accompanying maps, but more particularly the extensive literature on the subject, to which references are given on subsequent pages.

*In the Tamarack and Franklin Junior (Peninsula) mines thin beds of "jasper" have been reported, but no samples from them have been seen by the writer. Marvine's "jasper" bed, No. 6, appears to be of sedimentary origin. See Geol. Sur. Mich., I, Pt. II, table opp. p. 60. *Infra*, Chap. V.

**According to Marvine. This may, however, include what I have called the Middle conglomerate. *Infra*, Chap. III.

§ 3. Conclusions of previous observers.

The literature relating to the acid rocks of Keweenaw Point is not very extensive. In drawing upon it in the following pages I may in one or two instances digress somewhat from the subject of the felsites, to touch incidentally upon some other subjects that have come under observation during the progress of our field work.

Douglass Houghton: The lower beds of the copper-bearing complex of Keweenaw Point, now known as the Keweenaw series, were by Dr. Houghton, Michigan's first State Geologist, considered as members of a series of metamorphosed rocks which passed gradually from the granite of the iron region into the greenstone and its associated amygdaloid.† Dr. Houghton did not attempt to differentiate the felsites from the more basic rocks, but covered both classes of rocks with the generic term "greenstone," applying it not to the amygdaloids but to the more *compact* of the "traps." The term "trap," too, in the usage of that time, and even later,‡ covered not only the basic rocks of the series but what have since been shown to be the non-sedimentary acid rocks as well.

†Third Annual Report, 1841, Mich. Joint Documents, pp. 487, 489. See opinion of Dr. John Locke, in Trans. Am. Phil. Soc., Phil, Apr. 19, 1844, IX, pp. 283-315. Bela Hubbard sees in an "imperfect sienitic granite" of Keweenaw Point (probably a porphyrite) a proof of the "identity of origin of the trap and granite rocks." "Mineral Region of

Lake Superior," by J. Houghton, Jr. and T. W. Bristol, 1846, p. 30; also Ann. Mess, and Accomp. Docs., 31st Congress, 1849-50, Pt. Ill, p. 837.

‡Foster & Whitney used the term "trappean" in the same sense, as late as 1850. Report on the Geol. and Topog. of a Portion of the L. S. Land Dist. in the State of Mich., Pt, I, p. 59. Hereafter in the following pages this report will be referred to as F. & W.

Overlying these compact and amygdaloidal metamorphosed rocks were (1) a conglomerate, (2) a mixed conglomerate and sandrock, and (3) a red sandstone. The first two which represent Irving's "Great" conglomerate and "Outer" conglomerate respectively, were considered by Dr. Houghton to be in effect one sedimentary* formation, divided by a trap dike, the "'Lake Shore" trap of Irving. Indeed, this phenomenon was according to Dr. Houghton not rare, for he alludes to the frequency of "dykes" in the series "of from fifty to four hundred or five hundred feet." To the action of "dykes" protruded between the strata and having with them a common inclination, Dr. Houghton attributed the metamorphism of many of the sedimentary rocks. From the context this statement should seem to refer to the amydaloids,† which in part Dr. Houghton considered due to the fusion of the lower parts of the sedimentary beds. Whether this statement is also meant to cover the felsites does not appear.

*loc. cit., pp. 491, 494.

†loc. cit., p. 490, See also p. 497.

U. S. Linear Survey: The geological work of the Linear Survey was begun under the direction of Dr. Houghton, after the publication of his report of 1841. On their maps of Keweenaw Point, which was not subdivided until 1845, the year of Dr. Houghton's death, we find noted the felsite‡ of Bare Hill, in Sec. 29, T. 58, R. 28, and other similar outcrops as "reddish hard trap" and the like.

‡This is designated as "hard compact reddish trap" and a felsitic conglomerate (or breccia?) as "porphyry trap."

Bela Hubbard: Bela Hubbard, Assistant State Geologist under Dr. Houghton, and Deputy U. S. Surveyor, speaks of the "trap" of Mt. Houghton,§ and mentions as occurring in the central portions of the South Range of Keweenaw Point, a

very hard and compact trap of a reddish color, which sometimes takes on the character of a trap-breccia, or aggregate of small cemented angular pieces of rock, and may perhaps he denominated a trap porphyry.‖

In his report for 1845 as Deputy Surveyor, he says:

Keweenaw point may he said to be made up of three rock formations—trap, trap conglomerate, and red sandrock: of these the first mainly gives its peculiar character to the country, giving to it its mountainous aspect and general configuration, having been protruded by the operation of igneous forces into its present position; while the other rocks are sedimentary in their origin, and are found surrounding and resting against the other;¶ and he refers to the trap exposed at Copper Harbor (the "Lake Shore" trap of Irving) as a dike.* On a preceding page (838) he had referred to the lower of the two conglomerates intruded and separated by this trap "dike," as having "been deposited around the base of the trap hills, beneath the waters" and having been subsequently elevated with them. These views agree substantially with those of Dr. Houghton and were evidently formed while Hubbard was acting as assistant to the former.†

During the season of 1846, however, while Hubbard was at work in the Ontonagon-Porcupine Mt. district, his views seem to have undergone a material change. It does not appear that Dr. Houghton ever examined this district in detail. The study of the structure of the Keweenaw series in the Ontonagon district, to which perhaps by reason of the early discovery there of mass copper, more attention was then being given than to the northern parts of Keweenaw Point, led Hubbard to the conclusion that the trap series was probably bedded. He says that the trap range between Portage Lake and the Ontonagon River is but a prolongation of that of Keweenaw Point, and

bears also a close analogy to the greenstone and amygdaloid of the latter. The high knobs are composed mostly of greenstone which is usually hard and compact. It sometimes approaches a crystalline structure, in which the feldspar and hornblende are aggregated in distinct grains, but generally the constituent parts of the mass are so blended as not to be separately discernible to the eye. This character of rock is, however, far from composing the whole great mass designated as trap, nor does it seem possible to consider the latter as a single dike or contemporaneous uplift; for though the compact variety usually composes the greater part of the cliff, the entire mass will be found to consist of *regularly disposed and alternating beds of greenstone and amygdaloid*, the latter sometimes giving place to epidote. * * * These alternating beds * * * give an appearance of stratification to the mass.

These observations will apply also to that portion of the surveyed district embracing the Porcupine mountains. Associated, however, with the greenstone and amygdaloid of that country, appears an argillaceous and silinous [silicious?] rock, which, though we have classed it among the trap rocks, is very distinguishable from all the other varieties of trap, and is therefore entitled to a separate description. This rock occurs in belts, alternating with those which make up the mass of the Porcupine ranges, and possibly may be regarded as a *volcanic mud*, altered and hardened by its vicinity to rocks of igneous origin.

§Min. Reg. of L. S., 1846, p. 28.

‖*Loc. cit*., p. 30.

¶Ann. Mess, and Accomp. Docs., 31st Congress, 1849-50, Pt. Ill, p. 836, et seq.

**Loc. cit*., p. 839.

†*Loc. cit*., p. 840.

The arrangement exhibited by these rocks has been alluded to as one of *apparent stratification*. While we desire to avoid any theoretical conclusions as to the mode of their formation, we cannot but observe that the character of the entire trap formation is rather that of a succession of overflows, than of simultaneous uplift in mass; in other words, it may be considered as made up of beds of the different kinds superimposed upon each other. It has been already observed that in the Porcupine ranges, the trap, sandstone, and conglomerate beds compose part of these alternations, in deposits of greatly varying thickness. It is difficult to reconcile the frequency of these interpositions, the comparative thicknesses of the beds, and the few signs of disturbance, with the supposition of a protrusion of the trap, as an igneous mass from beneath, through strata of the overlying sedimentary rocks. We would not be understood to assert that no uplift of the trap has taken place, but merely to distinguish between the mode of formation of the several rocks, and the subsequent and general uplift, by which the whole series has been thrown from a horizontal and inclined at the angle at which we now find them.*

It appears from the foregoing that Bela Hubbard was the first to call attention to the bedded nature of the trap series, and to the possible non-sedimentary origin of the acid rocks of that series. Of the latter he says,

It has been already mentioned, that; alternating with the several rocks that compose the Porcupine mountains is a hard rock of red color, fine grained, and sub-slaty in structure. It is evidently trappose in character, but is at the same time quite argillaceous, and sufficiently siliceous to strike fire under the hammer. Its color varies from a light to a dark brick red. In character and composition it bears a strong resemblance to the cementing portion of the conglomerate rock of the country.*

This rock is evidently the one previously referred to as a "volcanic mud," and from its description it appears to belong in the same group as the felsites.

*_Loc. cit_., pp. 886-887. I have quoted Bela Hubbard at some length, because Irving, both in his "Copper-Bearing Rocks of L. S.", Mon. V, U. S. Geol. Sur., and with Chamberlin in Bulletin No. 23, U. S. Geol. Sur., overlooks this suggestion as to the bedded nature of these rocks, a view, which, it will be observed, Irving adopted not only for the basic rocks, but for the acid rocks as well.

C. T. Jackson: Dr. Jackson speaks of the sandstone being sometimes

indurated into a flinty red rock resembling jasper * * * on the coast, Tp. 58, R. 28, Secs. 25 & 26 (25 & 35?), where the jasper-like rock forms bold cliffs projecting into the lake. This rock in some places passes into a distinct porphyry, and appears to have derived its feldspar from the adjacent porphyritic trap. In some instances it. seems to have been entirely fused and thrown up like a poryhyry dike.*

Since Dr. Jackson appears to have held the broad theory of Houghton that the basic rocks of Keweenaw Point were also of dike origin, this reference to the acid rocks is without special significance.

Speaking of Mt. Houghton, he says:

The rock at this place is a dull red jasper, stratified in structure, and splitting into thin sheets. It is supposed to be an indurated fine red sandstone, which has undergone partial igneous fusion by the heat of the trap rocks, which are in immediate contact with it.†

Dr. Jackson mentions a "porphyritic trap rock" at the Suffolk location, and another near the same locality, that has red feldspar crystals scattered through it.‡

The highest points of the Porcupine Mountains are by him said to be

made up entirely of massive quartz rock, or jasper. Its structure and texture vary considerably at different points. The greater portion of it, however, is a homogenous compact jasper of a deep brick red color. The whole appearance of the rock is that of an erupted mass. The jaspery mass is occasionally varied by numerous, delicate, light-colored streaks or bands contorted so as to form an imperfect ribbon jasper. At other points particles of white quartz are mingled with the red jaspery mass. The compact variety of quartz rock sometimes shows a gradual passage into quartzose porphyry, the jaspery mass showing here and there a crystal of feldspar imbedded in it.§

*_Loc. cit_. pp. 399, 400.

†_Loc. cit_. p. 414.

‡_Loc. cit_. pp, 430, 433.

§_Loc. cit_. p. 661.

J. D. Whitney, Assistant Geologist under Jackson, described an acid rock in the Porcupine Mountains as follows:

Found a low bluff on the southern side made up of a compact red jaspery mass, which may, perhaps, be nothing more than sandstone altered by the proximity of the trap. It is exactly similar to that found on Mount Houghton. In some places, even, it still seems to retain distinct marks of stratification; in others it seems to be entirely converted into jasper.‖

‖_Loc. cit_. p. 728.

Foster and Whitney say of the Bohemian Range:

The protrusion of so vast a mass of heated matter has changed in a marked degree the associated sedimentary rocks, causing them to resemble igneous products.*

Other references will be noted hereafter.

From the foregoing extracts it will be observed that by Jackson and by Whitney, and by Foster and Whitney the acid rocks of the trap series were looked upon as altered sandstones, except that Jackson, following Bela Hubbard, thought those of the Porcupine Mountains might be of volcanic origin.

*F. & W., 1850, Pt. I, p. 64.

Fr. C. L. Koch expressed doubts as to whether the amygdaloid rocks had been produced by the fusion of sandstone and trap, as advocated by Dr. Jackson (and previously by Dr. Houghton), and thought that the jasper-like masses and "jasper-porphyry" of the southeastern part of Keweenaw Point, as well as similar rocks in the Porcupine Mountains, were of a like origin with the traps, i. e., eruptive; that they had come up in a plastic (erweichtem) condition produced by chemical agencies—not in a molten condition—and cited the opinion of Hausmann on the Hartz Mountains. The quartz porphyries southeast of the Porcupine Mountains (Tps. 49 & 50, R. 42), he says, if they are identical with the silicious rocks of the Porcupine Mountains (as Irving admits they are†), must be later than the trap rocks on each side of them, that is to say, intrusive.‡

†Copper-Bearing Rocks of L. S., 1883, p. 208.

‡Die Mineral-Regionen der obern Halbmsel Michigan's am Lake Superior und die Isle Royale, 1852, pp. 121, 125.

Thomas MacFarlane observed reddish acidrocks on Michipicoten Island and considered them to be eruptive.§

§Geol. Survey of Canada, Rept. of Progress, 1863-66, p. 142.

R. D. Irving, while he was not the first to recognize as eruptive some of the felsites and porphyries of the Keweenaw series, is fairly entitled to his claim of being the first to recognize the fact that all of them are "original masses."‖ He describes many exposures of acid rocks around the rim of the Lake Superior basin, and while in some cases he admits the difficulty of reducing their structural relations to an "intelligible order," and in others admits that they are intrusive,* he nevertheless concludes that they are in general interbedded flows† and were extravasated in the early part of the formation of the Keweenaw series.‡ He describes acid rocks at the Palisades and at Baptism River in Minnesota, which he says are true layers of quartziferous porphyry between typical diabases and amygdaloids, and asserts that whenever less plain occurrences have been closely studied, it has become evident that in them, too, we have to do merely with interbedded porphyry masses.§

‖*Loc. cit*., p. 95. 2

**Loc. cit*., pp. 144, 206, 299, 306, 308, 309.

†*Loc. cit*., pp. 91, 145, 150, 240, 299, 435. The term "interbedded" has been used by different writers with different signification. Among the latest of these, Van Hise speaks of "interbedded sills" and of intrusive diabase which occurs as "interbedded sheets" (Principles of North American Pre-Cambrian Geology, U. S. G. S., Sixteenth Annual Report, 1896, p. 789). Emmons, however, earlier used the term as applicable only to a surface flow, that was subsequently covered by a later bed (Geology and Mining Industry of Leadville, U. S. G. S., Mon. XII, 1S86, p. 295) Irving used the term in the latter sense (supra, pp. 149, 299). This usage seems to correspond well with the idea of the deposition of a lava flow—a cover laid down on the top of a pre-existing surface, just as different parts of a sleeping-bed are made up. The term "intercalated" implies insertion between parts previously in existence, and to express the idea of "contemporaneousness" is for that reason as objectionable as "interbedded" is for an intrusive. "Interbedded." then, may be considered as equivalent to "interstratified," and applied to extrusive sheets, while "intercalated" is a proper term for an intrusive sheet.

‡*Loc. cit*., pp. 150, 186, 195, 198,:433.

§*Loc. cit*., pp.*H8, 149.

In accordance with these views Irving says that the Porcupine Mountains "owe their existence in all probability to a fold, the porphyry of the central portions being one of the usual embedded masses laid bare by subsequent denudation."‖

‖*Loc. cit*., p. 150.

Irving's monograph and Irving and Chamberlin's bulletin are among the most complete and elaborate works ever published on Lake Superior geology, and set forth views that not only are ably advocated by those eminent geologists, but have also, in part, found wide acceptance. On the soundness or unsoundness of Irving's views as to the relation of the felsites to the traps, may depend in some measure the correctness of his and Chamberlin's theory of the contact relations between the Keweenaw series and the Potsdam sandstone.

CHAPTER II. SCHLATTER LAKE AREA

§ 1. A. Definition of field names of rocks.

In the following pages I shall use the term *melaphyre* generically to cover the more basic and augitic effusive rocks, qualifying it by *doleritic* when coarse grained, *ophitic* when lustre mottled, *diabasic* when it discloses lath-shaped feldspars in an augitic matrix, and *amygdaloidal*, when it contains gas-formed cavities either empty or filled with foreign minerals. The term *porphyrite* will be used to designate rocks known to be of medium acidity, whether they carry feldspars visible to the naked eye or not. The word *trap*, commonly used by the miners, is a convenient field term and will include fine grained compact varieties of both melaphyre and porphyrite, where the exact character of the rock has not been determined and more often, perhaps, will be used in a still broader sense, to cover the entire Keweenaw series. The very fine grained and highly acid rocks, formerly also included under the term trap, will be called *felsite*, or when they carry feldspar or quartz crystals in some abundance, *porphyry*. (See Part I, p. 52).

B. Outcrops of acid rocks on Keweenaw Point.

The outcrops of acid rocks observed by the Survey occur in Sec. 30, T. 58, R. 27 (New England or Keystone location); Sec. 25 (?), Sec. 35 (Fish Cove), Secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; Secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom); Secs. 23 and 24, T. 58, R. 29 (Mt. Houghton) and both eastward and westward therefrom; Sec. 10, T. 57, R. 31 (Suffolk location, Praysville); Sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsarge and Wolverine mines); Sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); Sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and Sec. 1, T. 55, R. 33 (Hecla and Torch Lake R. R).

The northern limit of these acid rocks—felsites and porphyries—as far as they were observed and traced, is marked near the end of the Point by the Bohemia conglomerate, as above stated, which is in places quite thick, and is in near proximity to two other thinner and less extended beds of a like nature, all of which ultimately unite to form one bed. Below this conglomerate the felsites occur at different horizons down to the shore of Lake Superior, where in some instances they extend indefinitely beneath the waters of the lake.

The different felsite outcrops will be taken up in detail, as far west as Mt. Houghton, and the area thus comprised will be considered at length before proceeding to other areas further southwest. For convenience this area will be subdivided into the Schlatter Lake and the Bare Hill areas, the former comprising all the territory east of the mouth of the Little Montreal River together with a small part of Sec. 27, T. 58, R. 28, immediately west of the river.*

*See map, Pl. IV.

§ 2. A. Sec. 30, T. 58, R. 27.

The first reference I find in geological literature to acid rocks exposed in this section is by Foster and Whitney, who say, as quoted above:

> The protrusion of so vast a mass of heated matter [Bohemian Range] has changed in a marked degree the associated sedimentary rocks, causing them to resemble igneous products. Thus, on section 30, township 58, range 27, by the lake shore, is seen a metamorphosed sandstone resembling jasper. Its general bearing is east and west. In places it assumes a vesicular appearance, while other portions are brecciated, and take into their composition chlorite and feldspar. In some hard [hand?] specimens the lines of stratification can be recognized. The mass is about 100 feet thick, and surmounted by alternating bands of porphyry and a chlorite rock known as rotten trap, which may be regarded as a volcanic ash. These veins attain a thickness of only a few feet.†

On the shore, at the above named section, where in the early days of copper mining on Keweenaw Point a pit was sunk on what was called the Keystone location (New England?) at a point which according to the plat of the Linear Survey is about 400 to 600 paces west of the east line of Sec. 30, there are several outcrops of felsite covering a belt about 230 paces long, running east and west, and not over 30 paces wide as exposed. These outcrops, all of them in the water or at the water's edge, although to some extent separated, either by the water or by the sand and shingle of the beach, evidently belong together. The most easterly exposures are shown in the accompanying diagram, Figure 1. At the extreme east end a point, A, with an island opposite or south of it, rises about three or four feet above the water. The rock of this point is thinly jointed nearly north and south; that of the island about N. 33° W. The neck of this point where it joins the beach, flattens and is frequently covered by the water of the lake. Here the nature of the rock changes, apparently quite suddenly, and instead of a distinctly jointed, rather fresh-looking rock, we see a rock made up of reddish, light and dark patches of felsite, more or less surrounded by a white kaolinitic material. The latter is evidently the result of decomposition,* for on many of these outcrops the zone of the kaolinitic material is pretty sharply marked and is confined to their lower parts—those that are most subject to the alternating action of the atmosphere and the lake water. I have said that the line of demarcation between the fresh and the decomposed rocks is quite sharp, and yet along this line in places one can see the gradual transition from fresh to decomposed in what was originally one continuous band.

†F. & W., p. 64.

*Irving mentions "calcitic" decay of the felsites, *loc. cit.*, pp. 312, 319, and kaolinitic decay, *ibid*., p. 146.

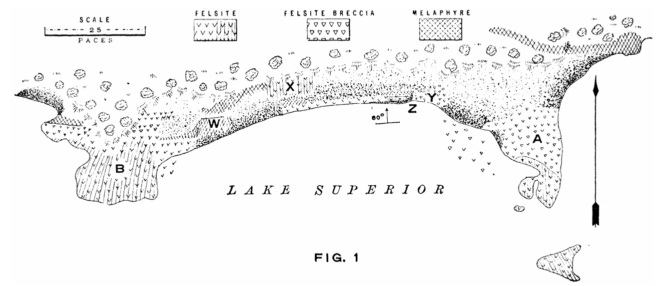

Figure 1. Exposures of felsite at Keystone or New England location, Sec. 30, T. 58, R. 27, Keweenaw Point, Michigan.

The zone of decomposed rock extends 25 or 30 paces north on the beach and can be seen in the shallow water extending some distance west of the rock, almost visibly connecting with an outcrop at **Y,** 40 paces west. The latter outcrop, level with the beach, holds abundant inclusions of basic rocks and on its north side is flanked by a dark-colored, boulder-like rock, possibly not in place, which is also largely basic. The inclusions in the rock at the water's edge are very distinct, owing to the gray and yellow alteration colors of the matrix. Six paces west a rock, **Z,** 4 feet high and over 4 feet thick rises from the water's edge, contains fragments of foreign rocks, and shows both in the hand specimen and in the thin section (17140) a distinct banding, east and west in the rock, due to flowage. It dips N. 80°, and strikes slightly north of west. It forms part of a wall which on the west falls gradually to the level of the beach and is flanked on the north, at its two extremities, by a thin layer of melaphyre in close contact. It disappears under the sand at its west end opposite a felsite, **X,** like that at **A,** which, like the latter is also thinly jointed north and south, and is more or less shattered. Ten paces further west, at **W,** two melaphyre outcrops separated by sand seem to lie in the way of the westward continuation of the felsite wall, but digging in the sand disclosed between them an east and west slip in line with the felsite wall, dipping like the latter, and carrying some fluccan and chloritized melaphyre.

Up to this point it was not clear whether the fragment-bearing felsite wall with east and west flow lines was a part of the decomposed bed under it, or an independent mass.

For about 6 paces west of the melaphyre at **W** sand arid shingle cover the rocks, but at 7 paces west occurs a small exposure of felsite jointed north and south.* Two paces further west is another felsite mass jutting into the lake, at **B.** It is like the felsite at **A,** and its outer or southern part is jointed and banded on the east side nearly north and south; as the west side of the ledge is approached, however, the jointing curves from southwest and west to east. The most northerly part of this ledge shows no distinct jointing, but otherwise closely resembles the southern jointed portion, the rock at each place being spherulitic. The spherulites are generally quite small (1-16 inch in diameter) but in some layers they are over an inch in diameter, and irregular in form. The jointing in these rocks, which is quite conspicuous, seems to coincide with a banding due to the disposition of the spherulites, not like the flow structure of the wall **Z.**

*In 1896 the rocks were exposed here, showing the eastern extensions of the felsite from B and the westward extension of the melaphyre north of it, to the east edge of B, also the eastward extension of the felsite north of the non-jointed portion—as shown in the diagram.

Near the north part of this ledge, **B,** and on a line with the felsite wall, **Z,** is a fairly well defined zone more than 5 feet thick that cuts off the jointing on the south, and carries fragments of felsite and of melaphyre, especially on the west side of the ledge. At this latter point the zone is in contact on the north with melaphyre. From here for 90 paces west the shore is lined with outcrops of basic rocks, to another ledge of felsite which juts into the lake. It much resembles the rocks at **A** and **B,** is decomposed below the water line, and contains a few small inclusions of dark-colored rocks and several larger ones of felsite, whose banding nearly always coincides with the longer axis of the ledge, east and west. There are many evidences of sliding in this outcrop. At its contact with the melaphyre on the north it contains numerous inclusions of melaphyre and shows an east and west banding, which dips 70° to 80° north. This banded portion is well marked for only three or four feet south of the con- tact with the melaphyre, but there is no such contact with the felsite south of it, as was observed at **B.**

Between **B** and **C** and in their line of strike several felsite masses rise from the water; and in the lake, a quarter of a mile east of **A,** there is another small island in the same line, the nature of which, however, was not ascertained.

The above facts make it not impossible that we have here two ages of felsitic rocks, the earlier of which appears to have intruded the basic rocks—*if the direction of its jointing is any indication of the direction of the flow*—and possibly to have been itself later intruded by a dike of felsite, which has taken up many fragments both of acid and of basic rocks. Whether this banded zone is simply the margin of the entire felsite mass or a later intrusion may perhaps be left an open question, but the jointing of the felsite, if it has any significance, and the irregular relations of the several felsitic, and basic outcrops to one another not satisfactorily explained by fault hypotheses, point to the intrusive nature of the main felsite mass.

The petrographic characters of these rocks were described by Rominger*, who noticed their spherulitic, banded and amygdaloidal structure, and their decomposition to kaolinite. The rock forming this fragmental zone he calls a "coarse breccia, of partly angular, partly rounded, water-worn felsite fragments," a name which evidently does not fully express his meaning, for although he does not differentiate between the different outcrops nor attach any significance to the different jointings, lie clearly recognizes in this "breccia" a rock of eruptive origin.

*Geol. Sur., Mich., V, Pt. I, p. 139.

B. Sec. 30, T. 58, R. 27. Westward.

Following the shore N. 76° W. from the last named locality, we find, about 1000 paces further wrest, another series of outcrops, also mentioned by Rominger* but not described by him. They are exposed on a narrow beach and are cut off on the east by melaphyre, the fault line apparently running southeasterly into the lake. This is evidently the outcrop described by Foster and Whitney as quoted above.

A curving band of red felsite with an average east and west strike, showing distinct flow lines, and containing lenticular fragments of felsite, which in its lower edge or footwall are very small, is in contact on the north or hanging side with melaphyre. Beneath it is a bed of reddish decomposed felsite, and below this a gray felsitic rock (S.17150).† Next below occurs a reddish rock containing angular fragments and calcite in coarse patches.

This latter bed strikes N. 78° W. and may mark a line of faulting or slipping along the edge of a banded belt filled with broken fragments which comes next under it, and which much resembles in structure a brecciated felsite (S.17149). This banded belt in turn gives place to a bed of amygdaloidal conglomerate under which is a melaphyre, more or less thinly platy and fractured, with some reddish matrix on its hanging, in seams, looking like angular felsitic fragments (S.17148). The west line of section 30, T. 58, R. 27, is probably on or near the east edge of a wide clearing used for banking logs, east of the brook from Hoar's Lake. Between this line and the gray outcrops on the east, just described, i. e. next under the latter, we find a series of melaphyres alternating with at least six melaphyre conglomerates.

The gray and the red rocks strike nearly east and west and amount to about 125 feet in width. Their dip is to the northward, about 70° or more. They show in places distinct flow lines conformable with the direction of their strike, and contain many angular fragments, being in all important respects like the hanging wall portion of the felsite in the same section further east. Like this, too, they are over- lain by a compact melaphyre.** The inference appears, therefore, to be justified that we have here a continuation of that felsite, separated by a fault of some 300 paces, the eastern portion being that much further south. This fault will be alluded to later, in connection with the discussion of the Greenstone Range.

**Ibid*.

†High numbers preceded by S, in parentheses, refer to thin sections of rocks in the collection of the Geological Survey, by Sp. to the hand specimens.

**No dips were observed in the overlying melaphyre at either of the above localities.

C. Sec. 25, T. 58, R. 28.

Following the shore south of west from the west line of Sec. 30, we find a continuation downward of traps and conglomerates, most of the latter being of the melaphyre or amygdaloidal variety, with, however, lower down in the series, some beds that contain also rounded pebbles of an acid rock. The first of these latter is about 1135 paces west of the east line of Sec. 25, T. 58, R. 28, or near the north and south center line of the section. It is made up of one foot of rounded amygdaloidal fragments in a calcitic matrix, above a three-foot layer of coarse sub-angular porphyritic pebbles in an abundant sandstone matrix, this in turn succeeded by five or six feet of rounded amygdaloidal fragments in a red matrix. About 90 paces further west we find, overlain by a mottled melaphyre, another conglomerate 5 feet thick, carrying rounded pebbles of melaphyre and fewer of an acid rock. The bed just below this conglomerate gave a strike of about N. 85° W. and a dip of 56° N. Near this point there is also exposed a series of rocks, more or less decomposed and red, containing laumonite, calcite and possibly some other zeolitic mineral, which alternate with fresher and more homogeneous rocks. Unless one of these beds be the brecciated felsite belt referred to by Rominger,† I did not see or did not recognize the latter.

Between the last point and the west line of Sec. 36, T. 58, R. 28, several conglomerates of varying thickness, and largely of basic material, occur interbedded with traps. One of the latter, a fine grained rock, shows distinct columnar structure. The thickest of the melaphyre conglomerates is 50 feet wide and is just south of the north line of Sec. 36.

†Loc. cit., p. 139. The beach sand and gravels shift from year to year, covering some outcrops and exposing others.

§ 3. Secs. 26 and 35, T. 58, R. 28. Fish Cove Knob.

Of the next two felsite outcrops met as one goes west along the shore, one lies partly in Sec. 35 and partly in Sec. 26, T. 58, R. 28; the other wholly in the latter section. These outcrops Hank a small bay known in early geological literature as "Fish Cove," and for convenience the larger outcrop on the east side of the bay will in the following pages be referred to as "Fish Cove Knob." Dr. Jackson speaks of it as a sandstone "indurated into a flinty red rock resembling jasper," in T. 58, R. 28, Secs. 25 (35?) and 26.* J. W. Foster refers to it as a "red jasper,"† and Foster and Whitney as a "metamorphosed rock."‡ Rominger speaks of the smaller and more westerly of these two exposures as "a large isolated outcrop of felsitic rock masses," that "projects in high cliffs at the shore." This outcrop consists of two narrow ledges about 8 feet high, jutting into the water, but together being not more than 25 paces long, as exposed, nearly north and south. On the west they are in close proximity to the trap. They Hank the west end of a beach about 350 paces long, thickly strewn with felsite pebbles. At the east end of the beach rises the other felsite mass, Fish Cove Knob, which is really an aggregate of several knobs of different sizes and altitudes. They are described by Rominger as a "belt" 500 feet thick, overlain on the north by a belt of porphyritic diabase.§ The limits of this felsite and of the group of knobs of which it forms a part, are shown on Plate I. The shore east of it, as far as the point on the line between Secs. 35 and 26, is lined with outcrops of the coarse grained diabase porphyrite described by Rominger,§ overlain by a fine grained almost aphanitic porphyrite, possibly the top of the coarse bed (S. 16972), resembling in the hand specimen in places a very dark felsite, and containing some minute amygdules. In the thin section it shows large oligoclase crystals with some iddingsite [Lane] and magnetite in a very fine feltlike groundmass, and resembles a rock from Michipicoten Island described by Irving.‖

*Ann. Mess, and Exec. Doc., 31st Congress, 1849-50, pp. 399, 400.

†*Loc. cit.*, p. 767.

‡F. & W., p. 65.

§Geol. Sur. Mich., V, Pt. I, p. 138.

‖Copper-Bearing Rocks of L. S., Pl. X, Fig. 2.

The strike of this latter bed at this point is N. 72° W., which is in close agreement with the prevailing strike higher in the formation, in Secs. 26 and 27 of the same township. Where it approaches the east end of the aforesaid felsite knob, the bed of coarse diabase porphyrite that lines the shore is covered by a beach terrace, but this bed, or a similar one, appears on the east face of the knob, where the well defined contact between felsite and porphyrite strikes N. 57° —60° W. The hanging side of the porphyrite, however, strikes N. 70° W., and the bed soon tapers out against the felsite wall on the west. Immediately above the coarse porphyrite at this point is the fine grained porphyrite already noted in an outcrop further east; it dips northerly 70° and carries some copper. A thin bed of conglomerate, also seen on the point further east, overlies the latter porphyrite. From the western termination of the above beds the felsite, turning abruptly, runs about N. 10° E. and N. 30° W. for nearly 200 paces, its immediate contact with the basic rocks being covered by drift. Fifty paces east, however, on the adjacent knob a thick bed of doleritic melaphyre is exposed in the upward continuation of the series. It seems quite evident, therefore, that the felsite cuts off the bedded rocks. The wedgelike termination of the coarse diabase porphyrite and the absence of any marked disturbance in the overlying beds, so far as observed, might possibly be looked upon as the natural result of a series of flows around the flanks of an earlier extrusive mass, but on this hypothesis we cannot well account for the east-facing cliff unless there was a considerable cutting away of the base of the felsite during the formation of the abutting beds, and that this was not the case is made probable by the rarity,—in fact, entire absence,—-so far as observed, of felsitic conglomerates at this horizon. The dip of the fine grained porphyrite noted above (N. 70°) which is 16° steeper than the prevailing dip of the beds in the interior of Sec. 26 on the north, is also significant.

Along the shore the felsite appears roughly columnar, and is also in a general way jointed parallel with the strike of the bedded rocks, the joints dipping like the latter to the north. It is also slightly brecciated near the east end of Fish Cove beach.

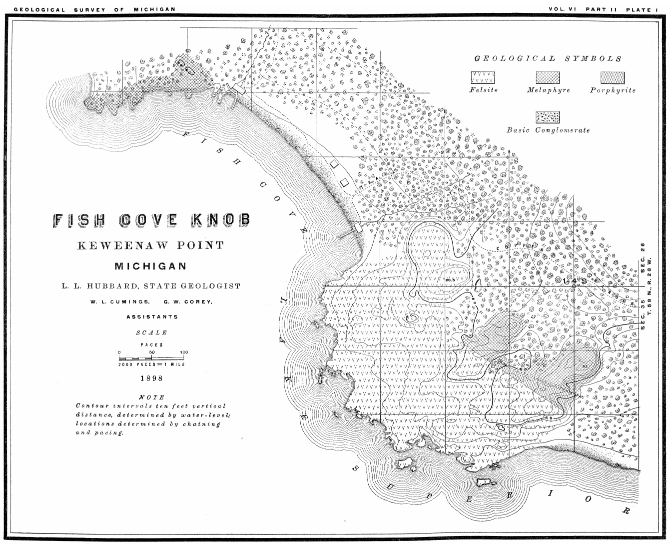

Plate I. Fish Cove Knob, Keweenaw Point, Michigan.

§ 4. Secs. 26 and 27, T. 58, R. 28. Interior.

A. General description.

The ground for 350 paces north of the beach between the last two mentioned felsite outcrops is low, flat, sandy and forest-covered. Beyond that limit, however, for nearly a mile east and west, is the burnt area above mentioned, that extends across parts of Secs. 26 and 27.

The surface of this tract is very uneven, being broken into a succession of short ridges and knobs which rise to a height of 150 to 180 feet above Lake Superior. These are separated by narrow valleys, in some of which vegetation was not affected by the fires. The ridges and knobs, however, many of them, are almost bare, even of soil, and the different rocks that compose them can, in some cases, be followed uninterruptedly for long distances. (See Pl. II.)

B. Cross-section in Sec. 27, T. 58, R. 28.

In order better to understand the relations of the rocks that occur beneath the most northerly felsites of these two sections and the disturbances that have taken place there, it may be well to introduce here a cross-section (Pl. III) and brief descriptions of the principal beds.

Following up the Little Montreal River from its mouth, where it falls over slightly corraded trap beds* about 25 feet above the lake, we soon reach a pool where the river bed makes a sharp turn to the east (Pl. II). Between this point and the lake shore the surface is more or less drift-covered, and was not examined in detail; it was seen to be underlain by lustre mottled melaphyres, or ophites, and melaphyre conglomerates, and by at least one small conglomerate that carries rounded pebbles of a more acid rock. The cross-section runs north from the pool at 50 paces S., 400 paces W., of the E. quarter-post of Sec. 27. (R—S, Pl. II.)

*Well marked glacial striae were found in the river bed here.

1. Basic eruptives. Beginning at the south end of the cross-section at the lowest or oldest part of the formation, we find on the south or left bank of the river a bed of coarse ophite, **A**, much altered, and peculiarly banded. This bed, as we shall see, plays an important part in our subsequent correlation. Above it, in the river bed is an amygdaloidal conglomerate which is overlain by a melaphyre and, succeeding these, are other sheets of similar basic eruptive and fragmental rocks. The original or eruptive rocks in the series occur in beds from 10 to 140 feet wide, or from 8 to 112 feet thick, four of them being upwards of 55 feet thick, and each bed varies more or less in width from place to place. As a rule they are compact and homogeneous, but many of them carry rounded or lenticular amygdules of quartz or of agate in sufficient quantities to be quite noticeable, but not always to form a typical amygdaloidal structure. This character in beds of the lower-middle part of the Keweenaw series has been noticed at many points between the Little Montreal River and the Portage Lake area.*

The compact melaphyre beds exposed along the middle parts of our line of section are in general narrow. No attempt was made to trace these beds in detail on the west side of the river, or to determine the amount and direction of the faults which are supposed to cross them, but which are probably of less magnitude and frequency than those found on the east side. Indeed, the narrowness of some of the beds and the amount of drift in places, would probably render such an attempt fruitless. Between beds **A** and **E** no absolute correlation was established with beds further east. **B**, **C** and **D** denote simply horizons that correspond approximately.

*"It must be expected that currents of lava which have flowed at great depths under water, will present comparatively few scoriform parts. * * * Vesicles or air-bubbles, on the contrary, should be expected to abound in the interior of the rock, whenever its liquidity was sufficient to permit the agglomeration of the vapor into parcels; the extreme tension of the elastic fluid causing the expansion of the bubbles as the lava flows on; while, for the reason mentioned above, very few will make their escape by rising outwardly." Scrope Considerations on Volcanos, London, 1825, p. 177.

2. Basic conglomerates. A marked feature of most of these melaphyres (below an acid zone soon to be

considered), is that the amygdaloidal portion or top of the flow no longer forms an integral part of its underlying bed, but has in most cases been broken up into a breccia-conglomerate with a reddish matrix. For over 200 paces immediately above the crowning acid conglomerate in this area basic conglomerates were not noticed. Within a like distance lower in the series, however, there are at least six of them if not more. Indeed it is the exception to find a compact melaphyre without its capping, more or less scoriaceous, conglomerate. This, in connection with the width of some of these detrital beds should seem to indicate that the earlier beds were formed at longer intervals than occurred between the outpouring of the beds above the acid zone, or that the beds above the acid zone were not submerged. It is characteristic of these conglomerates that they contain no acid pebbles such as are found in the better known conglomerates of Portage Lake. Roughly rounded to sub-angular fragments of amygdaloidal rock lie imbedded in a copious cement of a fine reddish material which consists of a mixture of quartz grains and of both basic and acid rock fragments. In color this cement is in marked contrast with the pebbles, which have a bluish green cast, possibly from the presence of salts of copper, and this matrix often stands out on an exposed surface, like the pointing in a wall of masonry. Figure 2 from a photograph of bed **F** shows well its character. In the figure the handle of the hammer is a foot long. It is quite noticeable that the line of demarcation between these conglomerates and the underlying parent bed—melaphyre—seldom exhibits the characteristics of an eroded surface.

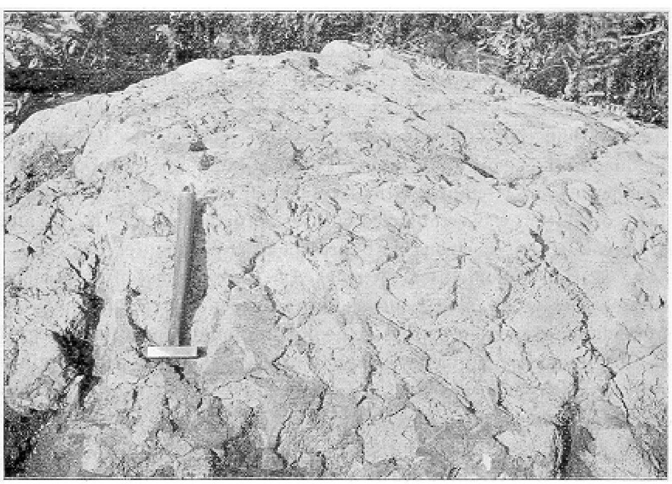

Figure 2. Melaphyre conglomerate.

Trying has described three types of conglomerate of diabase and diabase-amygdaloid:

one in which the pebbles are distinctly waterworn, and another in which there is no such distinct evidence of water action, and in which the vesicular exteriors of the halls suggest their possible origin as volcanic scoriae that have become buried in the accumulating detritus. The first of these varieties has been noted on the North or Minnesota shore only. The other has been observed on both the South and North shores, and is often hard to distinguish from a kind in which the red shaly material is most confusedly mingled with the vesicular amygdaloidal diabase, which at times seems to grade into the detrital matrix, and again to be separated from it in more or less distinctly defined balls; an appearance suggesting the deposition of detrital material upon and within the extremely scoriaceous upper portion of a lava flow.*

*Copper-Bearing Rocks of L. S., 1883, pp. 29, 30.

The peculiar type of amygdaloid characterizing the so-called Ashbed of Keweenaw Point * * * appears as a peculiar and irregular mixture of red sand and amygdaloidal material, and bears at first sight some resemblance to those conglomerates already described, in which the pebbles are amygdaloidal. But in the Ashbed the apparent pebbles appear on close observation to be mostly connected, and I am disposed to follow Wadsworth (Notes on the Iron and Copper District of Lake Superior, p. 112) in considering that it represents a very scoriaceous and open layer, upon and within which more or less sand was subsequently deposited.*

The basic conglomerates under consideration belong probably to the second and third classes. Their separation is at times difficult, for the same bed near its hanging and near its foot may have the characters of the two classes respectively. They occur from 5 to 50 feet thick, which fact alone, so far as the thickest beds are concerned, should seem to lend probability to the foregoing supposition; in some of the thinner ones, too, it is hard to determine whether we have before us a true conglomerate or a scoriaceous breccia bed with sand. They vary somewhat in width, from point to point, less so, perhaps, than do the original beds associated with them, and it is very noticeable but not strange that, corresponding to a conglomerate at one point, we find in apparently the same horizon elsewhere two thin beds, conglomerate and melaphyre, amounting to the width of the former, or we appear to find one thick bed of melaphyre corresponding to a series of alternate melaphyres and conglomerates. Indeed, the thinner beds in Sec. 27, below bed **E**, cannot satisfactorily be correlated off hand with beds in Sec. 26, unless we assume either that more flows spread over the former area than over the latter, or that disturbances known to have occurred in the latter area have obscured the relations between the two. These scoriaceous melaphyres and conglomerates were not subjected to a more critical examination by the Survey.†

**Loc. cit.*, p. 138.

†An amygdaloidal bed is generally considered as a part of the underlying trap, but since the under side of a trap bed may also be amygdaloidal, two amygdaloids of different ages may thus occur together, apparently as one bed. Scrope ascribes the fragmentary scoriae on the lower side of a lava bed to a breaking up and rolling over on itself of the consolidated top of the flow. This, he says, is possible only in very liquid (i. e. basic) lavas, for all liquids of great viscosity move down an inclined plane *en masse*, "the component particles retaining almost completely their relative positions, without rolling over one another in that free and voluble manner which characterises the motion of more perfectly liquid bodies." This gives rise to the so-called flow-structure, more often noticed in acid rocks; "the crystalline particles of lava move against one another rather as a sliding or slipping of their plane surfaces over each other." *Loc. cit.*, pp. 102, 103. See, also, B. K. Emerson, Diabase Pitchstone and Mud Enclosures of the Triassic Trap of New England, Bull. Geol. Soc. Am., 1897, VIII, p. 64.

Immediately overlying the principal conglomerate bed, **M,** of the acid zone in the higher part of our cross-section, a melaphyre, **N,** occurs which shows, at several points in Secs. 26 and 27, small patches of sandstone on its upper side, and in the former section (1466 paces N., 1786 paces W.) the same bed shows a number of seams that run from the hanging towards the foot, also filled with sandstone. These phenomena indicate the extrusive nature of this melaphyre. Marvine has described a similar occurrence at Eagle River.*

3. Acid rocks. Beginning with bed **E,** we meet a group of rocks that deserve more than passing notice, for they constitute a horizon easily recognized and of great persistence, which ultimately forms the backbone of the Bohemian Range to the western end of the latter in T. 57, R. 31. As previously stated, their northern edge, a conglomerate, marks, so far as observed, the upper limit of the original felsites of this area. This is evidently the belt represented on the map of Stevens, Hill and Williams,† as "Belt of Jasper," "Highly metamorphosed sandstone and conglomerate," and on Irving's map as "Quartz-porphyry and Felsite."‡

Bed **E,** the lowest in this belt, is about 60 paces wide where it crosses the line of our cross-section, and is traceable to the eastern limit of the map (Pl. II), and in the other direction is found in frequent outcrops as far as the western limits of the range. In general this rock is of a dark reddish brown color, weathering to reddish gray. It shows very minute, almost hairlike, feldspar laths in great abundance in a very fine groundmass. Its fracture is irregular, inclining to sub-conchoidal, and so tough and tenacious is the rock that in many places it is exceedingly hard to break. It is because of this quality that this bed has so successfully resisted erosion and now occupies some of the highest elevations on Keweenaw Point. It and a lustre mottled melaphyre, or ophite, apparently in the same horizon as bed **A,** previously mentioned (page 10), appear to have been the main protecting bulwarks of the Bohemian Range. The microscope brings out well in the thin section (S. 17000; 940 paces N., 1000 paces W., Sec. 28, T. 58, R. 28) the minute, almost microlitic lath shaped feldspars, among which appear some larger ones not so idiomorphic. The feldspars are all more or less pierced with sericite leaflets, and the section is dotted with epidote and iron oxide. Flow structure is quite noticeable in some sections made from rocks in the same horizon.

*Geol. Sur. Mich., I, Pt. II, p. 119. Cf. Irving, *loc. cit*., pp. 139, 292.

†Geol. Map of the Trap Range of Keweenaw Point, L. S., Phila., 1863.

‡*Loc. cit*., Pl. XVII.

An analysis of this rock (Sp. 17033, from near the hanging, 1098 paces N, 1685 paces W., Sec. 26, T. 58, R. 28) by F. P. Burrall, M. E., gave the following results:—

SiO_2	52.83
Al_2O_3	16.30
Fe_2O_3	9.60
FeO	2.48
CaO	2.98
Mn_3O_4	trace
MgO	3.98
K_2O	2.49
Na_2O	6.54
H_2O	2.76
	99.96

"It fused over Bunsen blast lamp (about 900° C.) to a very dark brown glass. Apparently about as fusible as No. 17039".

This is therefore one of Irving's diabase-porphyrites.* The hand specimen analyzed showed one or two feldspar phenocrysts about ⅛ inch long, an occurrence rare in this bed, but common in the felsite porphyrite soon to be, described.

Overlying the preceding is a conglomerate, bed **F,** easily traceable. It outwardly resembles most of the other fragmental beds in this area, being composed largely of reddish gray, more or less scoriaceous and amygdaloidal, subangular fragments, in a reddish matrix of fine material. It is the bed represented in Figure 2.

Next in ascending order is a rock, bed **G,** whose outward character corresponds to that of a rock from this locality described by Rominger as a

very fine grained, dark purplish brown colored, hard but very brittle rock, which under the microscope shows the structure of the so called Ashbed diabase; its irregular splintery cleavage makes it somewhat resemble very dark colored specimens of a felsitic rock.†

Loc. cit., p. 77.

†Geol. Sur. Mich., V, Pt. I, p. 137.

This rock differs from the porphyrite of bed **E,** in having an exceedingly fine granular texture visible under a pocket lens. It carries a few scattered feldspar phenocrysts ⅛ inch long or more, but few or none of the minute feldspar laths seen in the former. It is much more brittle than the diabase porphyrite and while it has an irregular fracture, under the hammer it breaks readily into small angular blocks. Its principal joint planes are generally parallel with the local strike and dip of the formation, which in the area under consideration are about N. 72° W. and 54° N., respectively. These joint planes are frequently not more than an inch apart. Aside from its darker color, it differs from the usual felsite of this region in not showing microscopically on weathered surfaces any flow structure. Under the microscope (S. 17039) a fine grained groundmass of andesitic feldspar in patches, in general without definable form, but sometimes roughly lath shaped, is sprinkled thickly with fine black patches of iron oxide, and red-stained blotches of epidote. The number of feldspar laths is variable in different sections, though never as abundant as those that characterize the porphyrite, and this seems also to differentiate it from the Ashbed diabase, to which Rominger likened it. Possibly Rominger's specimen came from the next lower bed.

Analyses by Mr. Burrall, of specimens of this rock (Sp. 17039; 1340 paces N., 360 paces W., Sec. 27, T. 58, R.

28; Sp. 17007; 915 paces N., 1060 paces W., Sec. 20, T. 58, R. 28) gave the following results:—

	No. 17039.	No. 17007.
SiO_2	59.52	57.45
Al_2O_3	15.58	15.75
Fe_2O_3	7.24	11.12
FeO	1.86	1.74
CaO	1.81	0.12
MgO	2.11	1.94
K_2O	3.48	3.51
Na_2O	6.82	7.84
H_2O	2.23	1.23
	100.65	100.70

No. 17039 "at 900° C. fused to a dark brown globule;" No. 17007 "at 900° C. melted to a very dark brown glassy globule. Not quite as fusible as No. 17039."

In S.17007 the feldspar seems to be near albite and is more porphyritic than in S.17039. [Lane.]

Chemically this rock belongs in the porphyrite group, being high in silica, very high in iron and low in lime and magnesia, but its structure and fineness of grain are such that it cannot strictly be classed with the diabase porphyrites. All things considered, it may be regarded as a middle form between the porphyrites and the felsites or porphyries, and in the following pages will be referred to as a felsite porphyrite. It is probably one of Irving's quartzless porphyries.*

Next above the felsite porphyrite is a bed of conglomerate, **H,** which towards the hanging changes gradually into a fine breccia, the latter forming about one-fourth of the total width. The larger fragments in the conglomerate, derived principally from the underlying felsite porphyrite, are more or less angular and the lower part of the bed contains a good deal of the red matrix common to the basic conglomerates heretofore described.

Apparently in contact with the breccia on its north side, 40 paces from the hanging of the felsite porphyrite, appears a small outcrop of felsite, **J,** in the bottom of the ravine on the south bank of the brook. This rock is of a pinkish gray color, in whose fine grained to aphanitic groundmass there appears, here and there, a feldspar phenocryst less than ⅛ inch in length.

Under the microscope this rock (S. 17036A) shows a fine mosaic of feldspar and quartz, with a few small roughly lath shaped phenocrysts of feldspar, both orthoclase and plagioclase. Iron oxide is rather abundant in small dots and apparently also as a stain. The section also shows irregular patches of a slightly darker color and finer grain. These patches seem to be largely non-polarizing, and may represent early cooled and partly devitrified portions of felsite magma.

The structure of this rock and that of the porphyrite, so far as the feldspar is concerned, are thus seen to form two extremes, with the felsite porphyrite between the two, sometimes nearer the felsite, and sometimes more like the porphyrite, with the addition of free quartz (Cf. S. 17007).

*The Praysville porphyry described by Irving (*loc. cit.*, p. 176) contains 59.52% of silica, but is much more porphyritic.

An analysis of this rock, (S. 17036A, 1440 paces N., 430 paces W., Sec. 27, T. 58, R. 28) by Mr. Burrall, gave the following results:—

SiO_2	75.67
Al_2O_3	12.43
Fe_2O_3	2.27
FeO	0.15
CaO	trace
MnO	trace
MgO	0.00
K_2O	6.73
Na_2O	2.01
H_2O	0.41
	99.67

"At 900° C. did" (not?) "fuse, but caked and lost its color."

On the north side of the brook, along the line of our cross-section, drift covers the surface for 40 or 50 paces, but 100 paces further east we find outcrops of fine breccia like the bed just south of the last felsite, this breccia, like the other, also forming the hanging of a conglomerate bed which is well exposed near the river in a ledge, **K,** about 70 paces long by 20 paces wide. It is noteworthy, that this conglomerate, in places quite coarse, shows its finest breccia near its contact with a tongue of felsite supposed to connect with the large lens of the same rock, **L,** further west. Under the microscope the breccia (S. 17037) shows very angular and mostly quite small fragments of porphyrite and of felsite or felsite porphyrite material and one well defined crystal of feldspar in a very fine groundmass, apparently sedimentary. It also encloses some ophitic fragments.

Along the line of cross-section, the felsite lens, **I,** is over 100 paces wide; and is overlain by a heavy felsitic conglomerate, **M,** which in some places attains a width of 240 paces. This bed and a thinner one, **O,** of very similar material north of it, are separated by a belt of basic rocks, **N,** nearly 50 paces wide, which in one place appears to consist of only one bed, and in another of several.

The three conglomerates just mentioned eventually merge into one bed (see Fig. 3). For 200 paces north of the uppermost conglomerate, **O,** beds of trap and amygdaloid were the only rocks noted.

Plate III. Keweenaw Point, Michigan. Cross-section, Sec. 27, T. 58, R. 28.

The consideration of this zone of acid rocks will be resumed later. Enough has now been said to enable us to take up more in detail the felsites in the interior of Secs. 26 and 27, and to discuss the general relations of the rocks in that area. For this purpose it will be more convenient to begin with the higher beds.

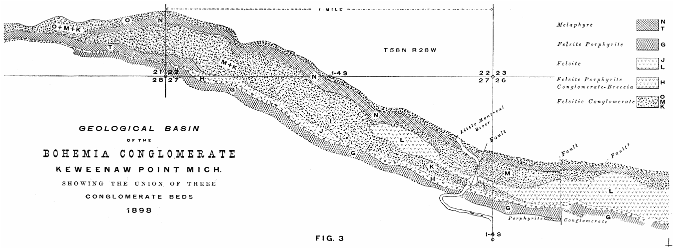

Figure 3. Geological basin of the Bohemia conglomerate, Keweenaw Point, Michigan.

C. Structure.

1. Bohemia conglomerate. The triple conglomerate complex, which I have provisionally called the Bohemia Conglomerate, is exposed on the east side of the Little Montreal River in the same relationship to other rocks as on the west side—a thin upper bed, **O,** underlain by melaphyre, **N,** a second thick bed, **M,** underlain by a thin tongue of felsite, **L,** well exposed at the foot of the upper falls, and a third bed, **K,** whose contact with its underlying rocks is not exposed. The conglomerate bed, **O,** is exposed here at three points, on an east and west line, in what appears once to have been a continuous ridge, separated from the main conglomerate on the south by a narrow valley in which lies the melaphyre **N.** The latter bed is not exposed at the most easterly outcrop of conglomerate, but the topographic conditions here are identical with those in the same horizon at the other two outcrops and the melaphyre probably lies buried here under the drift. The strike of the upper conglomerate at the middle outcrop is N. 80°-85° W., and here and at the western outcrop there are off-sets along fissures that strike N. W. and S. E., the more easterly parts of the bed being the further north.

The middle or main conglomerate bed, **M,** near the Little Montreal is seen (Pl. II) to rest on a thin bed of felsite which is probably a continuation of the lens, **L**W, on the west side of the river. This conglomerate and the lowest bed, for aught one can see, may or may not unite east of the felsite tongue and rest against the sides of the felsite **L**E. The main conglomerate bed along its northern declivity shows several offsets in the same sense as those noted in the upper bed, and its pebbles are much fractured.

2. Felsite lens, Little Montreal River. The felsite **L**E, on which rests the middle conglomerate bed, is a prominent outcrop well exposed for half a mile and traceable to the east line of Sec. 26, beyond which point a thick layer of coarse gray sand, together with the gradual flattening of the land, effectually conceals it. This massive outcrop, at one point 200 paces wide, consists of three roughly oval knobs, from 150 to 175 feet above lake level—the highest land in the section. It strikes nearly east and west, and its position and trend are such that it is probably in about the same horizon as one of the felsite outcrops in Sec. 30, T. 58, R. 27.

This rock is similar in appearance and character to the other felsites of this area, including the occurrence at Fish Cove, but, unlike the latter, it does not show a columnar structure. At several points along its south side it is brecciated and carries inclusions of basic rocks (Ss. 17225, 17197). It seems to be in contact on the south with a conglomerate or breccia like those above and beneath the bed **J,** on the west side of the river. Some north and south fractures are noticeable in this lens, and one fact that appears to have some significance is the relative trend of the three principal knobs into which the exposed part of the lens is divided. The axes of the east and west knobs trend nearly east and west, while that of the middle knob trends more northwesterly and southeasterly. The western knob slopes rapidly to the west down to level ground, where for several hundred paces in the same direction no rock exposures occur. That it is connected with the thin bed of felsite, **J,** on the west side of the river, and not with the lens **L**W by means of the tongue of felsite between the main and lowest conglomerates at the upper falls, at one time seemed probable, but the occurrence of the felsite **J**E with an overlying conglomerate immediately beneath the lens **L**E, near the north and south center line of Sec. 26, seems to mark **J**E and **J** as parts of the same bed.

In the last sentence I have taken for granted the extrusive nature of the felsite. In the absence of evidence to the contrary I must regard both the west and east felsite lenses as a flow. Their relations to the surrounding rocks are such as to satisfy this hypothesis; the mere fact of their being overlain by a heavy bed of felsitic conglomerate might alone justify it.

Briefly reviewing the facts above set forth, we find the earliest flows of the Keweenaw series in this area to consist of a succession of basic lavas, each of which, possibly with a few exceptions, passes gradually upwards into, or is capped by, a bed of more or less scoriaceous angular fragments of similar material mixed with sand. The frequency and character of these beds, and the fact made evident by the Bohemia conglomerate that there was here an ancient basin filled with water, make it highly probable that the early lava streams flowed into or under water. Their surfaces, thus suddenly cooled were cracked and broken up, and if they were at some depth below water level the resulting fragments were less subject to the rounding action characteristic of those of most shore-formed conglomerates. That they were at some distance below the surface of the water is possible, not only from their distance below the Bohemia conglomerate, but also from the amount of sand deposited between the fragments, and the general absence from them of foreign material of greater size, although these features in a sedimentary bed might point to formation in a shallow protected bay.

As we ascend in the series a change appears in the chemical nature of the beds. They are seen to be progressively more acid until we find near the top a rhyolite—the felsite—occupying prominent positions near the center of the basin and filling a large part of it. With the upbuilding of the series and the attendant increasing shallowness of the water the formation of a pebble conglomerate became possible and continued, perhaps, until the level of the basin was raised to that of adjacent areas. Just how widespread was this marked sequence from basic to acid rocks is not yet determinable. That it extended some distance west of the area in question is positively known. That it may not be common to the whole Lake Superior region should not surprise us, when we reflect that the lavas of the series probably came from widely separated vents, and were to some extent guided in their course towards the lower part of the Lake Superior basin by the contours of the surface over which they flowed; that probably not many of the beds, if, indeed, any one of them, spread out over the entire Keweenawan area, and that many of them probably solidified without even reaching the bottom of the basin. The sequence of beds at any one point might not therefore be an exact index of all the chemical changes that had taken place even in one volcanic focus during the period in which the beds in a small area were being extravasated. Any argument based on sequence of beds in the Keweenaw series, either for or against the theory of Von Richthoven, ought, therefore, to be made with reserve.

3. West Pond felsite. Between 300 and 400 paces south of the felsite **L**E, a broken ridge runs about 300 paces easterly from the southeast edge of West Pond. It is made up principally of a coarse grained ophite, much altered [serpentine? Lane] and peculiarly banded in the direction of its strike.

This rock very closely resembles that of bed **A,** previously noted, and that the two belong together appears probable from the following considerations. The horizontal width of the former bed is markedly greater than that of any other melaphyre (the width of the other bed was not measured) in the area under discussion. Its dip, measured on the planes of its bandings, is 80° N., which makes its actual thickness even greater in proportion, the prevailing dip west and northwest being but 54°. Except bed **A,** no other rock has been observed in the area covered by the map (Pl. II) that corresponds to this ophite. That this belt within the limits just stated cannot be regarded as an isolated occurrence, is evident from its great comparative thickness and short lateral extent, such occurrences not having been noted among the basic rocks of the Keweenaw series. That it should be out of line of the similar bed on the south side of the river is probably due to faulting, by which it and the beds north of it have apparently been crowded into a space narrower by one-third than the corresponding zone further west.

Outcrops of felsite flank this ophite belt both on the east and on the west, apparently uniting south of it. On the east side the felsite, $\mathbf{P}_1$, outcrops a few paces west of East Pond, there underlying a melaphyre and partially filling an embayment that runs north along the east side of the ophite. On the west the felsite, **P,** extends 200 paces north along the east shore of West Pond, almost if not quite to the north end of the latter where in a low valley that runs north the rocks are covered. On each side of the valley, however, the structure is well enough exposed to mark the presence of a fault that strikes nearly north and south, or in continuation of the general trend of the felsite mass last mentioned. The porphyrite, **E,** its overlying conglomerate and the felsite porphyrite, **G,** on the east side of the fault are thrown north some 60 paces or more. This appears to be the maximum measure of faulting in this particular zone and is the only case observed excepting at the upper falls, where the direction of the faulting is nearly north and south. Indeed, the fault here may be of a compound nature, the bed **F** appearing to have been thrust northeast past a part of its overlying bed **G.** In Sec. 26 at least a dozen faults were noted, the majority of which run east of north and the others west of north. The irregular course of the bed **F,** in the western part of the section, points to several faults of the former nature, a conclusion that seems to be verified by an examination of the lower beds. It was east of the principal fault, however, that the evidences of disturbance were strongest and most frequent. In an area about 500 paces square immediately south of the great felsite lens **L**E, at least eight faults were distinctly traceable, and although outcrops were located only by pacing, it is believed that the different beds were correlated with sufficient approximation to render the work correct as a whole, if not altogether in detail. Some difficulty was experienced from the occurrence of patches of basic conglomerate within what was supposed to be one bed of compact melaphyre. In other cases the thinner interbedded sheet was a compact melaphyre, those on each side of it, conglomerate. Bed **E** belongs under the former head, bed **F** under the latter. A detailed description of these beds is deemed unnecessary. They can be followed by reference to the map, Plate II.

The most noticeable feature of this area is the broken condition of the higher beds. The more basic rocks, except where faulted or jointed, appear in general quite compact. As we go up in the series, however, and reach the more acid rocks, we find the latter in many places so broken by shearing as often to be almost indistinguishable from conglomerates. The angularity of the fragments and their close resemblance to the material of the seams serves, however, to determine their brecciated nature. In places this brecciation seems to have affected only the lower, or only the upper parts of a bed; in others the entire bed is shattered. Again the brecciation is most noticeable along the fault lines.

The marked disturbance of the beds in the immediate area of the West Pond felsite, **P,** their apparent greater regularity as they recede from that area, and the relation of this felsite to the adjoining beds find their most rational interpretation in the intrusive nature of the felsite. The latter appears to have lifted the former, broken them into segments, and during the process to have converted the more brittle of them into typical breccias. This lifting of the overlying beds has also tilted them, so that their dips are steeper there than elsewhere. On the west side of the river and at the upper falls the dip, as previously noted, is 54° to the north. The ophite, **A,** dips 80° and at several points, further north, vertical dips were observed. In fact the bed **F** shows overturned dips of 80° (to the south). This increase of dips thus accounts for the horizontal narrowing of the disturbed zone and the northerly position of the bed **A.**

The relative age of the intrusion seems also to be apparent. It will be seen by reference to the map, Plate II, that a small embayment in low ground south of the felsite, **L**E, affords space for the westward extension of the bed **G** to the line of the principal fault. This fact and the phenomena already noted in the felsite and overlying beds to the north—direction of axis of middle felsite knob, fracture of conglomerate pebbles, offsets in the conglomerate beds, easterly strike of upper conglomerate—are in harmony, not with the hypothesis that the felsite, **L**E, was laid down unconformably on the upturned edges of the underlying beds, but that the felsite and overlying conglomerates shared the disturbance caused by the intrusion of the West Pond felsite, and that the age of the latter was later than that of the Bohemia conglomerate. How much later this disturbance occurred no facts are at hand to determine.

The West Pond felsite, **P,** on a fresh fracture surface is of a terra cotta color, very compact and aphanitic. It resembles in all important respects the felsites previously noted. In the burnt area they all weather white and their debris is abundantly scattered over the surface in small sharply angular fragments. Spherulites occur near West Pond to the size of an inch in diameter. At several points the margin of this mass is lined with a band of rather fine breccia, like that of beds **H** and **K** previously noted.

What appears to be significant of the origin of this felsite, is the direction of the joint planes along the margins of several of the outcrops. In the acid and intermediate rocks of this area, in general, where they are conformable with adjacent beds, the joint planes, when present, usually show a parallelism more or less strictly in accord with the strike and dip of the adjacent beds, as well as with the direction of the flow planes. Whether these joints are in general due to contraction on cooling or to subsequent pressure or shearing, or to both, we may not be able to determine, but in the case immediately before us we see them near the margins, following the contact and turning with the latter at an angle of 90° or less. Two such occurrences can be seen, respectively at 950 paces N., 1,420 paces W., and at 810 paces N., 1,440 paces W., Sec. 26, T. 58, R. 28. Pressure might produce joints on each side of a sharp wedge, but it would hardly make these joints unite in a curve around its edge. This phenomenon, then, of which we have already noted an example in Sec. 30, T. 58, R. 27, (p. 14), is more likely due to cooling as we sometimes see it exemplified in basic rocks, near contacts and parallel to them. It thus forms another link in the chain of evidence that points to the intrusive nature of this felsite.

On the west side of the bed **A** there are two occurrences of what might be called a conglomerate dike or vein, running northerly to northeasterly nearly at right angles to the strike of the bed. They are irregular in width, ranging from a mere seam to 4 feet, and are filled with fragments, largely of basic rock, with a few pieces of felsite among them—in a finer grained matrix. For such occurrences Wadsworth has proposed the name "clasolite."* They were probably originally fissures filled with fragments from above, like the sandstone seams mentioned on page 24. They strike in the direction of the prevailing faults in this area and like these are probably a product of the intrusion of the felsite. Other similar occurrences, or possibly apophyses from the intrusive felsite, are found at points northeast of the principal felsite outcrop, **P.**

* Report of Board of Geological Survey of Mich., 1892, p. 130.

CHAPTER III. BARE HILL AREA

§ 1. Acid zone from Little Montreal River to Mt. Houghton.

The acid zone in Sec. 26, T. 58, R. 28, as described in the preceding pages, comprises the following beds, beginning with the lowest; (1) porphyrite and conglomerate, (2) felsite porphyrite and conglomerate-breccia, (3) felsite and conglomerate-breccia, (4) felsite and conglomerate, (5) melaphyre, and (6) acid conglomerate. (See cross- section, Pl. III). This horizon was examined carefully and the contacts of the several beds were located by pacing.* The regular recurrence of the above beds was noted in a belt trending northwesterly from Sec. 26. Inasmuch as the altitudes, toward the west, rise to upwards of 300 feet above Lake Superior, the actual strike of the beds there is slightly more to the north than as indicated on the map (Pl. IV) and it thus appears that immediately west of the Little Montreal this zone—probably also the beds under it—begins to curve slightly more to the north, passing through the southwest quarter of Sec. 22 (T. 58, R. 28). From the west line of this section, however, the strike is west to the center of Sec. 21, thence successively northwesterly, west and southwesterly, to the felsite mass of Mt. Houghton. It thus describes a curve, interrupted by one flexure of rather wide extent, and, as appears by reference to Plate IV and to Figure 3, by several flexures of only local extent.

The two beds of the Bohemia conglomerate, **K** and **M** unite at the west end of the felsite lens **L**W, their combined thickness thence westward for three-fourths of a mile being upwards of 200 paces (nearly 550 feet). This is the maximum thickness of the felsite lens **L**E (Pl. II), and measures, as well, the distance between the bed **J,** and the top of the other lens, **L,** so that it is plain that the conglomerate filled a basin in which these two felsite masses had towered above the other surface rocks, and into which their material was eventually washed.

In Sec. 21, T. 58, R. 28, about 500 paces west, the combined lower conglomerate beds appear to unite (Fig. 3) with the third or uppermost bed. From this point west to Mt. Houghton and beyond it, we find evidence of only one, rather thin bed, which from near the west line of Sec. 22 westward is underlain by a doleritic melaphyre which thereafter constitutes a persistent and characteristic bed of the series, developing further west into a typical coarse ophite.

The Bohemia conglomerate outcrops west of the center of Sec. 21 at intervals only, until it reaches Secs. 20 and 19, where it is exposed frequently for 1,300 paces, striking east and west, immediately underlain by the doleritic melaphyre above noted. On the west line of Sec. 19 it is again exposed in several broken outcrops, with the melaphyre 75 paces and the porphyrite (S. 16967) 150 paces south of it. Fifty paces south of the latter is a fine grained ophite (S. 16964). From here westward the porphyrite is well exposed for 300 paces, striking south of west. Since this same bed is in almost immediate contact with the south edge of the felsite of Mt. Houghton at the west line of Sec. 24, and the Mt. Houghton lens can be traced eastward to a point 50 paces N., and 200 paces W. of the porphyrite, it is evident that the former occupies a position between the dolerite on the north and the porphyrite on the south, equivalent to that of the felsite porphyrite and its overlying felsites further east.

We have here, then, a very interesting illustration of the progress of geological events during the early part of the Keweenawan history. The lowest of the lava sheets appear to have flowed into a trough in the Lake Superior basin, *under water*. Successive flows, after a time, increased in acidity. The accumulation of lava sheets together with the products of erosive agencies rendered the trough or basin gradually more shallow, until its upper parts were filled with acid fragmental material and a thin interbedded zone of basic lava. From this point no further accessions of very acid lavas occurred in the Keweenaw series in this area, and up to the horizon of the Greenstone there are only four known well marked conglomerate horizons, which extend with almost unbroken continuity as far southwest as Portage Lake and are essentially acid. Their material was evidently derived from the earlier acid rocks of the series or perhaps from other similar rocks south and southeast, that belonged to an earlier series.

*To the accurate pacing of Mr. D. C. Forbes much of the value of our maps is due.

§ 2. Mt. Houghton.

Foster and Whitney say of Mt. Houghton:

> Its summit is jasper for the distance of 150 feet, and it is difficult to trace any well-characterized lines of stratification in the mass. On the southern flank the mass apparently dips to the SSW. On the northern slope a perpendicular ledge, 20 feet in height, is observed, dipping slightly to the east; to the northeast two low ridges of jasper are seen bearing nearly east and west, and connecting with the Bare Hills by the lake shore [!] * * * In tracing it west, it gradually passes into a compact trap, with here and there an almond-shaped cavity, filled with quartz or calcspar.*

Irving describes the mountain and notes—

> abundant irregular parallel bandings in the rock of the top of the mountain. The appearance of lamination is produced by waving bands of lighter and darker shading, which are often emphasized by minute quartz seams following their direction.†

Rominger also noted the banded, laminated structure of the Mt. Houghton rock, and described it microscopically.

Mt. Houghton, 877‡ feet above Lake Superior, is a forest-covered mass of felsite of lenticular form lying east and west in Secs. 23 and 24, T. 58, R. 29, the line between which runs about 50 paces east of its summit. Along this line it is about 400 paces wide, and tapers off rapidly toward each end. (Fig. 4.) The north side, for 300 feet below the summit, has an average slope of about 30°, the south side, 200 feet below the summit, at the contact is vertical, the cliff beginning 125 paces west of the section line and extending some distance east of it. The east side of the mountain, 300 paces from the summit, is also steep, but from that point runs off in a low spur. The west side, more or less drift-covered, slopes more gradually to the middle of Sec. 23. The summit of the mountain thus forms a dome, slightly oblong, surmounting a steep east and west ridge. The immediate contact with the surrounding beds, although not often uncovered, is well enough defined to determine accurately the shape of the lens, which at 1,000 paces east of the summit appears to have narrowed from 400 paces to 50 paces or less in width. A similar decrease in width takes place towards the west, at about 200 paces west of the center line of Sec. 23, or 1,200 paces west of the summit. At 518 paces N., 768 paces W., Sec, 23, T. 58, R. 29, in the line of extension of the mountain westwardly, occurs an outcrop of felsite that merges on the south gradually into a breccia of the same material. From this point west for nearly 200 paces this breccia is well exposed but no more of the compact felsite. The south side of the mountain is brecciated and shattered also further east. Forty paces west of the westernmost breccia an ophitic melaphyre comes in, and fifty paces south of it is the porphyrite, so that the Mt. Houghton mass probably ends near here as above stated.

*F. & W., p. 65.

†Copper-Bearing Rocks of L. S., p. 181 *et seq*.

‡Map of J. R. Mayer. See footnote, p. 44.

At 697 paces N., 1076 paces W., Sec. 23, the first exposure of the Bohemia conglomerate west of the east line of Sec. 24 was noted. Large blocks of conglomerate, possibly from this bed, were found at several points on the north side of Mt. Houghton, but diligent search and some digging failed to disclose the bed in place. The melaphyre immediately north of the mountain is a doleritic ophite (S. 16947, 950 paces N., 150 paces W.) like the bed that underlies the conglomerate both to the east and to the west, but since the conglomerate is also overlain by a very similar bed, indistinguishable from the former, no positive evidence could be secured to determine the relative ages of the comglomerate and felsite. All that can be said on this point with any degree of positiveness is that the Mt. Houghton felsite immediately overlies the porphyrite, **E,** and is itself probably overlain, in part at least, by the melaphyre immediately under the Bohemia conglomerate. The conglomerate, then, may have been formed above the melaphyre on the higher exposed flanks of the Mt. Houghton felsite, in like manner as the lower part of the same conglomerate was laid down against the sides of the felsite lenses at the Little Montreal River. Mt. Houghton may thus be, like these, extrusive, and may have furnished part of the material found in the Bohemia conglomerate.

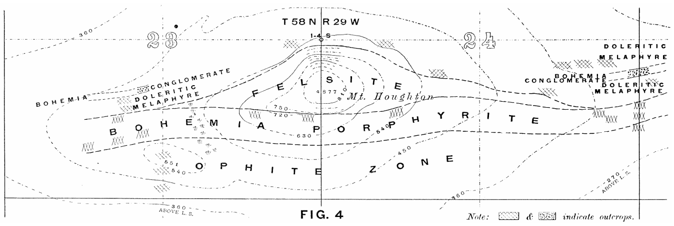

Figure 4. Sketch map of the Mt. Houghton area, Keweenaw Point.

A question of rather greater difficulty is the relation of the Mt. Houghton felsite to the felsite porphyrite of Secs. 26 and 27, T. 58, R. 28. Approaching the mountain from the east we last find the felsite porphyrite (Ss. 17007, 17013, 17163) in Sec. 20, T. 58, R. 28, a mile and a quarter east of the nearest known outcrop of the Mt. Houghton lens. Further west, near the east end of the lens, in Sec. 24, T. 58, R. 29, we find the porphyrite, **E,** (Ss. 16967, 17194), just below the felsite and the melaphyre just above it, so that the Mt. Houghton felsite is in the horizon occupied further east both by the felsite porphyrite and by the felsites. The felsite porphyrite, like the more acid felsite, thus appears to be of limited lateral extent. The felsite of Mt. Houghton, in the thin section, differs in no noticeable respect from the felsites already described.

On the north side of the mountain large spherulites* were found and on this side the banded structure is plainer than on the south side. Joints, nearly vertical, were also visible at different points, striking east and west.

An analysis of the Mt. Houghton rock (S. 16951), by F. P. Burrall, M. E., gave the following results:

No. 16951. (Felsite, south side of Mt Houghton.)

SiO_2	69.76
Al_2O_3	13.14
Fe_2O_3	1.44
FeO	0.66
CaO	0.36
MgO	0.18
K_2O	11.90
Na_2O	2.52
H_2O	0.42
	100.38

The rock "at 900° C. was infusible." The specimen analyzed was homogeneous and came from 50 paces north of the south contact, or 525 paces N., 55 paces W., Sec. 23, T. 58, R. 29.

The silica present is in excess of that required for a non-quartziferous porphyry. Irving gives the silica of this rock as 76.9%† and appears to infer the presence in the latter of free quartz.

An analysis by Mr. Burrall, of a specimen from 655 paces N., 635 paces W., Sec. 24, T. 58, R. 28, near the east end of the Mt. Houghton lens, gave the following results:

No. 17193 A. (Felsite, east end of Mt. Houghton.)

SiO_2	80.05
Al_2O_3	9.73
Fe_2O_3	1.72
FeO	0.18
CaO	0.83
MnO	trace
MgO	0.00
K_2O	4.43
Na_2O	2.19
H_2O	1.03
	100.16

"At a temperature of about 900° C. this rock caked, but did not fuse."

*Irving remarks on the apparent absence of spherulitic structure in the Lake Superior felsites. Copper-Bearing Rocks of L. S., 1883, p. 100.

†*Loc. cit.*, p. 182.

The small amount of potash, compared with that shown in the previous analysis, together with the large amount of quartz, indicates a relatively smaller amount of feldspar, and the probable presence of infiltrated quartz. The latter hypothesis is confirmed by the thin-section. If we consider 10% of the silica to be in the form of free quartz, we get the following figures:

SiO	70.00
Al_2O_3	14.59
Fe_2O_3	2.58
FeO	.27
CaO	1.24
K_2O	6.64
Na_2O	3.28
H_2O	1.54
	100.14

Except for the slight difference in soda and potash these correspond fairly well with those of the preceding analysis, but not with the composition of the felsite porphyrite. From the above analyses and those of the felsite porphyrite (p. 26) it should seem likely that the two rocks would not grade into each other, and in the absence of further evidence they may be considered as independent masses.

§ 3. The felsite of Bare Hill.

Several of the felsitic masses described in the preceding pages have been seen to be of greater lateral extent than thickness, and may properly be classed as sheets and regarded as interbedded with the more basic eruptives and their associated fragmental beds. Several other masses, however, appear, on many grounds, to be in all probability intrusive. They are not, however, very extensive, and the disturbance caused by them in the neighboring rocks, in the form of faults and shearing, does not seem to have been very violent or very far reaching.

We now come to a felsite complex, whose dimensions at the surface appear to be nearly equal in all directions. This felsite out- crops in Sec. 29, T. 58, R. 28, on and near the lake shore, and is known as Bare Hill. The first reference to it that I have been able to find in geological works is one by J. W. Foster in his report to Dr. Jackson,* in the laconic form "*Bare rock*—Jasper above, trap at the water's edge." Foster and Whitney say of this locality:

In section 30 [29?] township 58, range 27 [28?] west of the Little Montreal River, * * * The Bare Hills here approach the coast and rise up in overhanging cliffs to the height of 80 feet, and jasper appears to be the prevailing rock. From this point it can be traced [?] inland in a westerly direction, through sections 29 and 80, in the same township and range, to the west line of section 24, township 58, range 29, expanding to a width of about half a mile.**

Irving, after having spoken of Mt. Houghton, says:

The same felsite shows in the Bare Hills, in Sec. 29, T. 58, R. 28 W., and beyond on the lake shore in section 28. Similar rocks appear on the east point of the bay† into which the Little Montreal River empties [!], * * * and it would appear probable that the Mount Houghton rock, along with some smaller elevations leading off from it in an easterly direction, belong with the more easterly of the exposures on the coast, while the Bare Hills belong to another belt.

Irving maps the Mt. Houghton belt as extending some distance east and west from Mt. Houghton, and a second belt of quartz-porphyry and felsite as running through the southern part of Bare Hill eastwardly in such a direction as probably to include the Fish Cove felsite in Sec. 35, T. 58, R. 28. Rominger does not appear to have examined Bare Hill except from the shore.‡

The rounded mass of this mountain rises rather rapidly from the shore of Bête Grise Bay to a height of 584 feet.§ It is flanked on the south by a shore cliff about 180 feet in height, which extends, probably with a varying altitude, more or less regularly along the south face of the Bohemian Range, within a hundred paces of the water's edge, from the middle of Sec. 26, T. 58, R. 29, to Sec. 26 of the range next east. This shore cliff, vertical in Sec. 29, here marks the edge of a fairly well defined terrace which runs back until it meets the main cliff which on the southeast side rises thence vertically almost to the summit of the mountain. The rounded mass of the latter at this point is less covered with vegetation than further north, and stands out as one of the prominent landmarks on this part of the coast. The annexed illustration (Fig. 5), from a photograph taken from the shore just east of the mouth of Little Montreal River, brings out the relation between the shore cliff and the main mass, and the relation of the latter to other parts of the range. In the background, down the range, Mt. Bohemia also rises into prominence.

*Ann. Mess, and Ace. Docs., 31st Congress, 1849-50, Pt. Ill, p. 767.

**F. & W., p. 65.

†Copper-Bearing Rocks of L. S., p. 182. Irving evidently refers to the felsites of Fish Cove which is half a mile east of the river.

‡Geol. Sur. Mich., V, Pt. I, p. 136.

§According to map of J. R. Mayer, 1865. "Survey of the North and Northwestern Lakes." This map is on file in the War Department, Washington.

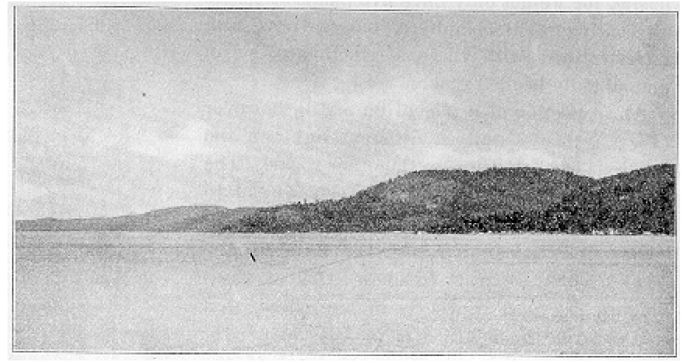

Figure 5. Bare Hill, from mouth of Little Montreal River.

Under the microscope this rock (S. 17017) shows a mosaic of closely interlocking quartz and feldspar, stained red and dotted with iron oxide. Interspersed in the groundmass are roughly shaped feldspar laths with small extinction angles. Grains of fresh quartz, in part if not wholly secondary, are scattered over the section.

The steep sides and much of the eastern summit of Bare Hill are well exposed, and the frequency of outcrops fortunately makes the geology of this hitherto neglected and interesting mass quite plain. The felsite prominent in the principal cliff appears in a belt 275 paces wide, forming the western summit of the mountain along the west line of Sec. 29. It is bordered by melaphyre both north and south. Cross-section. Figure 6, adapted from the contour sheets of the U. S. Lake Survey, is drawn through the mountain north and south about 500 paces east of the west line of Sec. 29. An inspection of this cross-section might seem to confirm the conclusions drawn by Irving from a similar phenomenon on the Minnesota coast,* where a band of quartz porphyry was found between two beds of diabase, as if interbedded, i. e., extrusive. If we imagine the rocks in the above section dipping at a small angle instead of a large one, we have a striking counterpart of Irving's example, and in fact seem to have a much more convincing illustration of the extrusive character of the felsite, for we not only have five bands of felsite alternating with melaphyre, but we have also interstratified with these a conglomerate—an undoubtedly bedded rock.

**Loc. cit.*, p. 314 et seq.

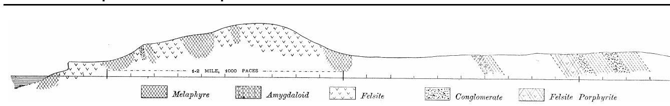

Figure 6. Cross-section, Bare Hill, Keweenaw Point.

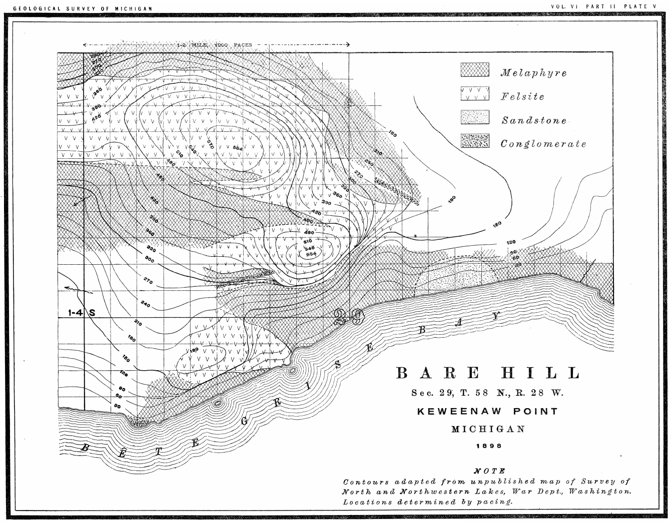

Plate V. Bare Hill, Keweenaw Point, Michigan.

An inspection of a *plan* of Bare Hill, however (Pl. V). throws quite a different light on the relations of the felsites to the other rocks. The broad belt of felsite is seen to sweep around to the southeast and to cut off a bed or beds of coarse ophite, running into the latter in the form of three separate tongues. One of these tongues, the most southerly of the three, well exposed on the south rim of the main cliff, rises on its north side above the level of the adjacent ophite, and may possibly be genetically independent of the overlying felsite. Near the edge of the cliff this tongue of felsite extends around and below a conglomerate, leaving on the south side of the latter an isolated pyramid of felsite some rods distant from the main body. The conglomerate and a bed of melaphyre north of it are thus cut off obliquely on the east, the contacts being well exposed and the relations of the rocks—the felsite intrusive in the others—unmistakable. This conglomerate strikes about N. 75° E., and dips north 80°. On the east side of the mountain nearly in the line of this strike a bed of conglomerate is found near the felsite, but striking apparently about S. 64° E The true strike is somewhat less to the east. Here the conglomerate is underlain by a coarse grained melaphyre and overlain by a porphyrite. The conglomerate was not traced to contact with the felsite.* In some places on the east side of the mountain, the melaphyre in contact with the felsite is much shattered. The felsite thus for 2000 feet is flanked by the melaphyres and conglomerates, and has cut across them at right angles to their strike and lifted the beds on the east side. These melaphyres, as far as observed, are mostly of the ophitic variety, and in places are very coarse grained. They evidently belong to the broad belt of this rock heretofore noted, which is prominent at many points along the south side of the Bohemian Range.

*This bed was located in 1897 from the west end of the sand- stone outcrop on the shore and its distance from the felsite may not be exactly as appears on Pl. V.

No connection was seen between the lake shore felsite and that of the higher parts of the mountain. The former is seldom exposed except on the south edge of the cliff, and elsewhere in huge blocks near the water, under which, for some 200 feet from shore, its eastern end extends. Here it shows a good contact under water, with basic rocks on the east, nearly at right angles with the shore line. At this point, in a small cove, we find the felsite on one side brecciated, and between it and the felsite on the other side there is a small outcrop of melaphyre, which appears to extend northeast through a small cleft to the melaphyre on the other (northeast) side. These large blocks of felsite were thought by Rominger* to be "loosened masses, slid down," which is possibly true also of the principal shore cliff.

The contour lines in the above plat (Pl. V) are adapted from the Lake Survey map,† with some modifications sketched from memory, to indicate a few minor details not shown on that map.

*Geol. Sur. Mich., V, Pt. I, p. 136.

†J. R. Mayer. Survey of the North and Northwestern Lakes, War Department, Washington.

§ 4. Evidences of disturbance along the shore.

The main masses of the Bare Hill felsite being thus evidently intrusive, a few observations made along the adjacent shore and elsewhere may be not without interest.

The north shore of Bête Grise Bay as far east as Fish Cove is in general difficult of access—from the land side on account of thick underbrush and lack of trails, and from the water side on account of scarcity of landing places and because of the heavy surf that dashes against the rock-bound margin in any but the calmest of weather. It is evidently for these reasons that this part of the Keweenaw series has perforce received so little attention, the observations there having been in most cases made from row boats skirting the shore at a safe distance from the breakers. This is particularly true of that part of the shore immediately south of Bare Hill.

In general the basic rocks that line the bay show signs of disturbance and of weathering. They are much broken and fissured, carrying veins of laumonite and calcite, and sometimes of prehnite and copper. No regularity is apparent in these fissures. They strike in many different directions. The trap rocks exhibit no uniform bedding, sometimes none at all. Sometimes one can easily make out such a bedding as one's theories may require. There are, however, frequent and positive signs of slipping of the rocks lakeward at angles of 45° or steeper. One such occurrence is especially noticeable, west of the sandstone and east of the felsite, near the center line of Sec. 29, T. 58, R. 28, along a melaphyre conglomerate, which shows a lakeward slipping of both foot and hanging walls, there being several inches of fluccan on the foot. Near the same locality a block of trap apparently in place projects into the water. On its west side is seen a band of amygdaloid between two bands of more compact trap, all striking about N. 20° E. and dipping 45° S. E.

On the west side of Bare Hill no evidences of unusual disturbance were noted along the contact with the felsite. On the east side evidence already noted indicates that the beds there have a northwesterly-southeasterly strike. This and the cases just noted along the shore, together with the fallen masses of felsite near by, should seem to indicate that these phenomena, otherwise rare in the Keweenaw series, are due, in part, to the protrusion of the felsite, and in part to undercutting by wave action, and subsequent sliding into the lake of immense rock masses. At a center of disturbance like Bare Hill, the adjacent rocks would be particularly susceptible to movements of this nature. To such movements also is attributed the presence of the conglomerate outcrops on the shore west of the above point, or about 150 paces east of the west line of Sec. 29. Further reference will be made to them on a subsequent page.

§ 5. Flexure of beds north of Bare Hill,

We have already seen (Pl. IV) that the Bohemia conglomerate in its westward course from the Little Montreal River, in Sec. 27, T. 58, R. 28, begins to swing more to the north, and when within a mile of Bare Hill it and its immediately underlying beds—the acid zone—curve around the mountain in a direction parallel with the north and east faces of the latter, as outlined along the felsite outcrops. So far as the observations of the Survey go, there is no reason to doubt that, excepting the conglomerate above noted, the melaphyres and fragmental rocks beneath this acid zone practically are conformable with the latter, except that the dip increases as we approach the older beds of the formation on the south. Dips of 72° were noted in the melaphyre on the east side of Bare Hill, and of about 80°, in the conglomerate on the west side, as already stated. The northern side of the Bohemian Range is rather more drift-covered than the southern, and falls away gradually into the Little Montreal River valley, the opposite or northern side of which is shut in by the Greenstone Range. It was along the southern face of the latter that exploration was dominant in the early days of mining on Keweenaw Point. From Mosquito Lake eastward, the Wyoming, Empire, Bluff, Iron City, Etna, Hanover, Montreal, Star, Copper Harbor, Philadelphia and Boston, and Keweenaw Companies worked upon or explored for fissure veins that in general crossed the formation in a direction slightly west of north, frequently if not always disclosing their whereabouts by topographical breaks in the range. The Allouez conglomerate lies immediately under the Greenstone, and its exposures on the surface and in the works of the mines serve to mark the south boundary of the lustre mottled "greenstone" or ophite, whose coarsely warty weathered surface is well seen in ledges, and in detached blocks that are strewn along the sides of the ridge. (See Part I, Pl. VII).

§ 6. Strike and dip of beds above the Bohemia conglomerate.

A. Strikes.

For some miles west of Mosquito Lake the Greenstone Range runs east and west. At the east end of the lake, however, in the north-west corner of Sec. 14, T. 58, R. 29, a mile and a half north and a little west of Mt. Houghton, it trends more northerly, then swings east again, and then more southerly (Pl. IV). In Sec. 13, T. 58, R. 28, on the property of the Keweenaw Mining Company, the course of the Allouez conglomerate as taken from an old map of the location by H. F. Quarré d'Aligny, and by Wm. H. Stevens, one of the Keweenaw pioneers, is from about 1650 paces north, on the west line of the section, to 120 paces west of the southeast corner on the south line of the section—an apparent strike of about S. 49° E. From below the latter point in the north part of Sec. 24, immediately south, the above map shows the conglomerate swinging more to the east around the east flank of the range and falling rapidly away with the latter.*

The range sinks to the general level of the country, which is comparatively low from here to the end of Keweenaw Point. Former geologists† and old geological maps,‡ because of this decided eastward curve in the course of the conglomerate outcrop or for other reasons, mark the Greenstone bed as running to the east part of Sec. 21, T. 58, R. 27, but the flat northeast dip of the conglomerate (35° according to the above map of the Keweenaw location§) and the rapid decrease in altitude of its outcrop, and possibly some faulting,¶ have a good deal to do with its apparent eastward trend at the point indicated. A careful examination of the shore in Sec. 21, where the old maps indicate the emergence of the Greenstone, failed to show any rock that corresponds in character with it. Furthermore, the only rock on the beach there that might be taken for a conglomerate is an amygdaloid more or less scoriaceous, whose top in places appears to be slightly conglomeratic, but without evidence of sandy matrix, such as is common in melaphyre conglomerates in this district. This bed strikes N. 65° to 67° W. Noteworthy is the fact that very few fragments of lustre mottled melaphyre are to be seen along this shore east to the end of the Point and no beds of that rock until we reach a spot 600 or 700 paces north of the extreme southeast point. If the Greenstone does take the course laid down on the old maps, it must have wedged out and disappeared west of here.

*Cf. contour map of J. R. Mayer, 1865. Survey of the North and Northwestern Lakes, War Department, Washington.

†F. & W., *loc. cit.*, p. 62, say: "A few yards south of the extremity of the point, and near the north line of Sec. 27, a band of conglomerate is observed, attaining a thickness of sixty feet, bearing N. 70° W. and dipping NE. 16°. The underlying trap differs from that which overlies the detrital rocks, being more amygdaloidal, and offering less adhesion between the particles. This is supposed to be a continuation of the great metalliferous belt, as developed at the Cliff, North American, and Northwest mines," i. e. the belt next below the Allouez conglomerate.

‡Map of Stevens, Hill and Williams, also Pl. XVII, Copper-Bearing Rocks of L. S.

§F. & W. give the dip of the conglomerate in range 28 as 40°. *Loc. cit*., p. 62.

¶See p. 17.

On the other hand, an examination of the shore immediately south of the north line of Sec. 29, T. 58, R. 27, showed a bed of coarsely lustre mottled melaphyre or ophite, 150 paces wide, capped by an amygdaloid with another ophite and amygdaloid over it, the whole being 225 paces wide. This may not be the full measure of the ophite belt, which may have suffered from erosion on the north. Under the lower of these two ophites is a well characterized amygdaloidal conglomerate, which, it is true, does not resemble the Allouez conglomerate as we usually find it elsewhere, but conglomerate beds change from point to point. This ophite complex runs back from the shore in a well marked ridge crossing the north line of Sec. 29, about 300 paces west of the center, and disappears in low ground southeast of a grassy meadow in the S. E. ¼ of the northwest adjoining Sec. 19, thus leaving a gap of less than a mile to the end of the Greenstone ridge in Sec. 24. What is very significant, however, is the occurrence along the southwest side of this ophite ridge of large, smoothly waterworn boulders of ophite, very coarse grained, and in all respects like the blocks that line the south face of the Greenstone further west. No such coarse grained ophite beds are known at greater distances than two hundred or three hundred feet south of the Greenstone, until we reach the Bohemian Range, and even here they are hardly as coarse grained. These circumstances might not be conclusive evidence of the identity of the shore outcrops with the Greenstone, but the trend of both ridges and the short gap between them are circumstances that cannot be overlooked. They should seem to outweigh former inferences grounded not even on lithological resemblances, and I have no hesitation in marking the course of the Greenstone in accordance therewith.

The curves of the Bohemia conglomerate and of the Greenstone, east of Mt. Houghton and Mosquito Lake respectively, are thus seen to be in close correspondence. These curves will be slightly more accentuated if projected to lake level. That the general symmetry of these curves has not been disturbed to any great extent is positively known of the Bohemia conglomerate and is made probable of the Greenstone by the best attainable evidence on record. Old mine location and other maps indicate faults in the Greenstone, generally striking west of north, but they also indicate only slight disturbances. If we select as a center of disturbance a point at Bare Hill or further south, the curves above noted would be the natural result of an uplifting force acting at that point, or of an obstruction around which the overlying strata were bowed. The lines of fracture caused by such flexing, not as radii from the center of upheaval but more or less inclined to these radii, are also in accord with similar phenomena observed elsewhere.*

The Bare Hill massif may be only a part of a greater mass not now exposed to view. We find west of it. in Sec. 30 at the foot of the shore cliff, about 100 paces back from the lake, another smaller outcrop of acid rock just under a pebble conglomerate that is undoubtedly the same bed as the cut-off conglomerate at Bare Hill. This rock contains some phenocrysts of feldspar and corroded quartz, in a groundmass in which the feldspar does not interlock with the quartz as intimately as in the Bare Hill felsite, and the feldspar laths here are rather more abundant and better defined. It is a quartz porphyry.

The relations of the rocks here are confused, but an acid porphyrite also occurs above the conglomerates. Whether the porphyry (compare page 45) is intrusive or not could not be determined. It is, at all events, another indication that we are here in a zone of acid rocks that may be laccolitic sheets, offshoots from a parent mass that once may have existed further south.

*See Woodworth, On the Fracture System of Joints, B. S. Nat. His., 1897, pp. 163-184, and authorities cited.

B. Dips.

As already noted, the prevailing dip of the Bohemia conglomerate is 54°. North of that horizon we have no records of the dip of overlying beds until we reach the Allouez conglomerate immediately under the Greenstone. Foster and Whitney, as previously stated, give the dip of the Allouez conglomerate as 40°.† This evidently refers to the area here under consideration, but is greater by about 0° than the dip measured by the writer on the Allouez conglomerate and on the foot wall of the Greenstone in an adit on the Star location in Sec. 9, T. 58, R. 28. Further west, at the old Pennsylvania location‡ (Sec. 15, T. 58, R. 30), and possibly at Mosquito Lake also, the dip is 23°.

†*Loc. cit*., p. 62.

‡Geol. Sur. Mich., V, Pt, I, p. 130.

The dip of the Great conglomerate opposite the last two points accords nearly with that of the Allouez. At Manganese Lake, however, according to Foster and Whitney* it is 25°, which may be a misprint for 35°, for on the old road that runs from there east to the manganese deposit in the northeast quarter of Sec. 4, next adjoining, it is 35°-36° in the same horizon as at Manganese Lake, and at several points west of the latter dips of 27°-30° were noted. Dips of 34°-36° were also measured on a sandstone of the group above the Greenstone, west of the Clarke location, near the south line of Sec. 4, and almost equally steep dips in the Outer conglomerate on the lake shore west of Copper Harbor.

There appears, therefore, to be a belt of which the Greenstone forms a part, in which the dips are flatter than those of the overlying beds. Similar relations appear to hold good in the same zone opposite the Central mine,† and at Eagle River gap where the increased dip, going northwest from the Greenstone, amounts to at least 6°.‡ (See Chap. IV.)

At the extreme end of the Point, beginning on the lake shore in Sec. 10, T. 58, R. 27 at the hanging of the Lake Shore trap group of Irving, which is exposed for one mile north and south, we find the strike about N. 60° W., and the dip 23° N. E. Near the hanging of the conglomerate ledge that forms the north side of High Rock Bay, the dip is 22°-23°. A conglomerate 60 paces wide, south of the center line of Sec. 22, gave dips of 23° and 24°, and another conglomerate 13 paces wide, about 250 paces north of the south line of Sec. 22, gave a dip of 23°. This is the lowest pebble conglomerate observed by the Survey in this section and appears to be the one of which Foster and Whitney record an observed dip of only 16°, and a strike N. 70° W. Foster and Whitney evidently considered this the Allouez conglomerate.§ The hanging is a chloritic melaphyre (Sp. 17619), in no wise like the Greenstone.

It thus appears that the average dip across the extreme end of the Point is not greater than about 23°.

On the lake shore in Sec. 29 of the same township, between the most easterly felsite and the conglomerate immediately under the ophite that we have assumed as the east end of the Greenstone, no conglomerates were seen. The joint planes in the melaphyres and the contacts between melaphyre and conglomerate gave no very satisfactory dips, but approximate dips of 51° to 57° were noted, the steeper dips being the further south, i. e. nearer the felsite horizon. The average strike of the beds was N. 65° to 70° W.

**Loc. cit*., p, 103.

†Copper-Bearing Rocks of L. S., Pl. XVII.

‡Cf. Marvine, Geol. Sur. Mich., I, Pt. II, p. 96.

§See foot note, page 50.

§ 7. Significance of strike and dip.

It may be remembered that the dip of the contact at the hanging of the felsite in Sec. 30, T. 58, R. 27, first described, was 80° N. The overlying beds along the lake shore appear, then, to decrease in dip, in a distance equivalent to one mile at right angles to the strike of the formation, i. e., as far as the Greenstone, from some indeterminable figure (80° or less) to something like 31°. From the Greenstone east for another mile no outcrops appear, but at a mile and a quarter above the Greenstone, still at right angles to the strike, we reach a horizon in which further east on the lake shore the dips have decreased to 23°, an inclination they steadily maintain for an additional two miles, up to the Outer conglomerate. Whether the change of dip from the Greenstone north (from 31° or more to 23°) is gradual, as at other points further west, or whether it takes place immediately above that bed, in the nature of an unconformity, may never be known, for the area in question is flat with few or no outcrops. If it does, however, the unconformity is purely local and may be due to the intrusion of a small mass like that in Sec. 30, T. 58, R. 27, whose age would thus be marked as just subsequent to that of the Greenstone.

It is evident, however, that whatever may have been the force that tilted the beds in this immediate area (Secs. 19, 20, 29 and 30, T. 58, R. 27), the visible effect of that force—excepting the steeper zone above the Greenstone—decreases in intensity from south to north. The uncertainty of the exact nature of the felsite in Sec. 30, whether intrusive or extrusive, the absence of other positive data, and the probability that, owing to topographical conditions, no more positive and convincing evidence can be gathered here, render unsatisfactory any inferences we might draw as to what the tilting force at this point may have been.

From the Bare Hill massif, however, dips decreasing towards the northwest, north and northeast, and, so far as known, steeper towards the north than in corresponding horizons further west and further east; beds swinging out of their previously regular course to curve symmetrically and in approximate conformity around the northern flank of a mass of felsite known to be intrusive—these are phenomena that may be readily and naturally explained, in great part, at least, as those of effect and cause—the flexure of beds above and around an intruding mass.

That all of the known beds of the copper-bearing series on Keweenaw Point above the Bare Hill horizon were affected by this agency, if any of them were, also seems probable from their apparent close conformity. This is well shown immediately east of Mosquito Lake (Pl. IV) where the courses of the beds are easily followed. The age of the Bare Hill intrusives, if these be connected with the above phenomena, may then be later than that of all the rocks that overlie them in the series on Keweenaw Point. But this conclusion may not be accepted as final until we know that the later, flatter-dipping part of the series, does not now occupy a position approximately the same as that in which it was laid down.

§ 8. Relation of lava flows to contemporaneous conglomerates.

In order better to understand the chain of events that may have led to the establishment of the beds of the Keweenaw series in the positions in which we now find them, and to explain, if possible, some apparent anomalies that we shall meet on subsequent pages, a few considerations of a general nature may properly here claim our attention. The components of that series are, (1) lava sheets, which are the so called original product of volcanic action and were extravasated from the interior of the earth, either with or without violence, from craters or more probably from fissures, and spread over parts of its surface as flows (we are not here considering dikes), and—(2) conglomerates or sandstones, secondary products, which are made up of the more or less rounded debris of the volcanic, and to a less extent of the other, rocks. These two classes of rocks, the eruptives and the fragmentals, while in some respects they both belong in the domain of fluvial and of sedimentary geology, such, for example, as in their attainment of, and distribution over, the lower parts of a basin, and in the tendency of their upper surfaces, under favorable conditions to preserve or to assume a position approaching horizontality, appear to have some divergent tendencies that can not be overlooked. An overflow of lava, if sufficiently liquid, will, like an overflow of water, seek the nearest depression or channel and will discharge itself through this if the latter be of sufficient width and depth, without rising over its sides. Such a lava stream is called a *coulée*. Lava issuing simultaneously from different parts of a fissure on a mountain side might find several such channels and build several distinct coulées, or, if the discharge were sufficiently copious the result might be one broad sheet, of varying thickness according to the furrows in the slope over which it flowed.

A lava flow, however, unlike a flow of water, may find its fluidity impeded if not altogether checked by its rapid loss of heat and consequent increasing viscidity and may finally come to rest on a downward slope without having reached the lowest level. If such a lava stream were quite acid, its lateral flow like its downward flow might proceed but a short distance and it might solidify in a mass thick at the center and tapering out at the sides—lens-shaped. Such seem to have been the forms of some of the felsite extrusions. The slope of a consolidated lava stream may be of almost any angle up to 40° and even 45°, and Geikie says that, "Even when it consolidates on a steep slope, a stream of lava forms a sheet with parallel upper and under surfaces, a general uniformity of thickness, and often greater evenness of surface than where the angle of descent is low."* In trying to account for the structure of the Keweenaw series we can therefore agree with Irving that the lava beds may have had their source in the rim of the Lake Superior basin—a trough of pre-Keweenawan origin†—and aside from the probability that the less basic flows, by more rapid cooling, contributed to raise the rim of the basin relatively to its center, and thus gave a steeper gradient to some of the subsequent flows, there must even in earlier Keweenawan times have been a difference of altitude between the basin rim and its center, and we cannot therefore follow Irving and Chamberlin in their conclusion that the Keweenawan beds were originally laid down in a position of almost absolute horizontality,‡ if these writers mean this to apply equally to all parts of the beds, or, especially, to those beds that may not have reached the lowest part of the basin. The "rim of the basin" is a somewhat indefinite term, but we know that many dikes of similar character to the melaphyres of the Keweenaw series cut the Archean in the high land of the Gogebic Range and northeasterly as far as the vicinity of Marquette. The presence of dikes in those areas is as marked as is their absence on Keweenaw Point, and while the sources of some of the earlier Keweenawan flows may possibly now be buried under Keweenaw Point, the assumption that the Gogebic and other known dikes are the sources of at least a part of the flows, can certainly not be regarded as improbable.

*Geikie's Geology, 1885, p. 211; 1893, p. 226. This is evidently not meant to apply to the most acid extrusions. See also Dana, Characteristics of Volcanoes, 1890, pp. 13, 148.

†Copper-Bearing Rocks of L. S., p. 418.

‡Bull. 23, U. S. G. S., p. 101.

It is admitted by more than one writer that the basin now occupied by the Keweenaw series was formed in pre-Keweenawan time, but in order to account for the dips of the Keweenaw series from all parts of the basin rim towards its center, a further gradual subsidence of the basin center is assumed to have gone hand in hand with the upbuilding of the series, and this, too, in face of the fact that the basin lies in what is characterized as the "stable Azoic."* If such a subsidence has taken place, we have no satisfactory measure for it, because we do not know how deep the basin was in pre-Keweenawan time, and, moreover, the admitted previous existence of such a basin weakens, *ipso facto*, the argument that a great subsidence must have taken place in its central parts during the accumulation of the Keweenaw series—in consequence of that accumulation. If the extravasation of the lavas was from the rim, there should seem to be no conclusive reason for placing the source of the extravasated material immediately under the middle parts of the present hydrographic basin rather than without the area of extravasation and immediately contiguous to it, and if the greatest accumulations of volcanic material were in the rim of the basin on the underlying Archean, there should seem to be more reason to suppose a regional subsidence involving the rim of the basin and known areas of the Archean, than a local subsidence of the center of the basin where these accumulations should seem to have been of less magnitude.† The differential subsidence, therefore, can at most be regarded as a relative change of level of different portions of the beds, due to plication or folding of the beds in the general process of mountain building, a process that had already begun in pre-Keweenawan time.

*Dana's Manual of Geol., 1869, p. 199. Irving supposes the granite-gneiss complex of the Huron mountains to run across Lake Superior to the Canadian shore. Geol. Sur. Wis., II, p. 458.

†Compare the difference of thickness of the series on opposite sides of Lake Superior (this volume, Part I, p. 101). See also *infra*, Chapter IV.

Whether we believe in a subsidence of the middle parts of the basin, due to the accumulation of Keweenawan material in them, or to the emergence of the Archean on either side of them, due to folding or otherwise, we must consider the Keweenawan lavas in great part as issuing from sources situated at some distance above their ultimate level, for the degradation of the original vents of the lava flows in post-Keweenawan times, which amounts to several thousand feet, must also be taken into account. The lavas, then, in order to reach the bottom of the basin must have had a very appreciable gradient and could therefore not show throughout every part of their course even a close approximation to horizontality. The higher the elevation of their source, *ceteris paribus*, the steeper their gradient was likely to be. In studying the lower beds of the Keweenaw series near Portage Lake we shall find many irregularities that point to this area as being a part of the basin rim over whose slopes the early lavas poured with different degrees of steepness, rather than as belonging to that part of the basin over which the earliest lavas and conglomerates were spread in a nearly horizontal position. If this conclusion be well founded, its importance is great, for if the edges of the Keweenawan beds now exposed along the contact with the Eastern sandstone are but the eroded margins of these beds where they rested on the slopes of the basin rim, we are here near the eastern limits of the lower levels of the pre-Keweenawan basin, and whatever parts of the Keweenaw series lay still to the eastward must have been at higher levels and therefore were involved in the post-Keweenawan erosion that cut out Keweenaw Bay. In short, by accepting some such theory we shall not have to expand the thickness of the series indefinitely to the east beyond its visible limits, or to suppose the presence of a great reverse fault that caused the depression—not of the basin center, but of its margin.

That the surface of the earth in the Lake Superior region showed in pre-Keweenawan times the usual diversities of an eroded landscape may well be assumed when we reflect that some 14,000 feet of Huronian rocks had been carried away and that some folding of the strata had taken place, before the lava flows began.* Whether the area now covered by the waters of Lake Superior was then one great trough, or formed two distinct basins, into each of which flowed lava streams from their several sources, north, south, east and west, is a matter that can never perhaps be determined. With the exception of a few marginal remains on the eastern shore and on Michipicoten Island, we now find the Keweenawan lavas of Lake Superior confined to the western part of the basin whose axis lies nearly northeast and southwest, in general terms parallel with the axes of Isle Roy ale and Keweenaw Point, and also with a series of troughs† northwest of the lake in Canada, in which appear remnants of folded Huronian rocks. That Keweenaw Point formed the southeast margin of the western basin at an early period of Keweenawan time, is made probable by the irregularities and apparent unconformities observed between strata in the lower part of the series, and by the character of some of the older conglomerates, whose angular fragments indicate proximity to the shore line on which they were laid down.‡ This inference should also seem to be strengthened by the immense thickness of the Great conglomerate on Keweenaw Point and its marked and rapid decrease in thickness§ where it diverges from the Greenstone Range at the end of the Point, and the indication that this bed is therefore following a course that would make its section at lake-level parallel with the outline of the Archean terrane of the Huron Mts. on the south.

Lava streams issuing from fissures in the margin of the basin flowed down the valleys toward the bottom of the basin, consolidating in their channels or finally spreading over the bottom in wider sheets, until having filled the valleys with beds of varying thickness and finally covered the highest projections of the older formations they built up a series of strata that show an almost ever decreasing divergence of dip and strike, that is, a more widespread uniformity towards the end of the period, when the latest beds were practically conformable over wide areas. Some such hypothesis should seem to be in accord with facts observed in other volcanic regions and seems to offer an explanation of phenomena that in the light of these facts presents no inherent difficulties.

*Irving and Van Hise, The Penokee Iron-Bearing Series of Michigan and Wisconsin, Mon. XIX, U. S. G. S., 1890, p. 460.

†See 5th Annual Report, U. S. G. S., Pl. XXII.

‡See Chapter V.

§See *infra*., § 9.

It thus appears that there is no reason to believe, from the present position of the Keweenaw lava beds, that they must originally have been everywhere horizontal, and that the dips now observed in the later beds are due wholly to a subsequent tilting. Let us see if the testimony of the conglomerates militates against the above conclusions. The lavas and interbedded conglomerates of the Keweenaw series are closely parallel, if we except some cases of discordance, already alluded to, that will be taken up later. Therefore the original positions of these two classes of strata must have been similarly parallel. If the lavas were horizontal, the conglomerates must have been almost equally horizontal, or both may have been originally laid down at an angle to horizontality. It is well known that conglomerates, made up of rocks that occur along a shore line, are built up, within the limits of wave and current action, on the shelving sea bottom sometimes at an angle receding from the shore, an angle that may be as high as 24°* if not higher, and it should not seem to need proof that as distance from the shore—the source of the pebbles—increases, these beds (as contradistinguished from sandstones) must grow thinner,† and probably do then become more nearly horizontal, conforming to some extent, perhaps, to the irregularities of the bottom. The possible angle of deposition of the conglomerates near their margins thus falls within the gradient limit of the lava flows and there is therefore no reason why a lava stream flowing into a sea and spreading over its bottom may not be approximately conformable with a conglomerate formed either below or above it, and yet neither of them at the shore may originally have been horizontal.

From the above it follows that a conglomerate may be laid down on the margin of a sea bottom whose shore line may describe a curve with a short radius, the dip of the conglomerate remaining the same at all parts of the curve, its strike, however, changing constantly, so that from being north and south at one point, it may be east and west at another. A lava sheet flowing over this bed might spread laterally over a considerable segment of it, but might not and probably would not be co-extensive with it, especially if the convexity of the shore line were great. Several flows of lava of similar character might, however, overlap and together cover adjacent segments of the conglomerate for a great distance laterally, and if these several sheets could not be differentiated, we might be left in doubt whether to ascribe the tilted position of the several beds to an origin similar to that just described, or to a subsequent earth movement. This is perhaps the greatest difficulty against which we have to contend on Keweenaw Point, and we cannot hope in every case to reach a conclusion that will be free from uncertainty. We may also note here the effect, that a subsequent tilting of the formation would have on the dip at different points. In Fig. 7, suppose the dips in the conglomerate at C and D and at all points between them were originally equal, and that the strikes at those two points differ by 90°. If the beds are tilted towards C around the axis A B, they must turn at least 90° before the dip plane at D becomes vertical, but less than 90° to make the dip plane at C vertical. In other words a certain amount of tilting has its maximum effect at C and on all planes parallel to C, the effect being less for every point of the curve from C to D.

*Gilbert, Geol. of the Henry Mountains, p. 52.

†Cf. Russell, Bull. U. S. G. S., No. 108, p. 33.

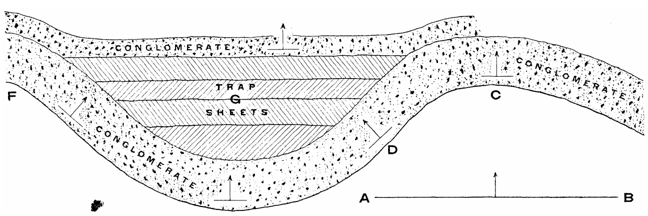

Figure 7. Ideal sketch, to show difference of strike in beds of the same series.

Again, a shore line might consist of two adjacent convex portions, C and F, and a lava sheet or sheets might be deposited in the trough formed by these curves, G, and covered by a later conglomerate. These beds would then be apparently unconformable, laterally, with an underlying conglomerate, although belonging in the same series.

There seems to be nothing in the foregoing discussion that would militate against the conclusion reached on a former page, that the Bare Hill intrusion may be connected with intrusive phenomena later than the Outer conglomerate of Keweenaw Point. If, however, this and the Great conglomerate were laid down against the sides of the older formations after the flexure of the latter, we might, perhaps, in the absence of marked disturbances, expect a greater uniformity of dip in these conglomerates between Eagle River and the end of Keweenaw Point than we now find there. But if this difference in dip be due to irregularities in the surfaces of underlying beds, or if another phenomenon, slide-faulting,* should be found to have prevailed to a great extent in the area west of Copper Harbor, by which the dips of the beds there have been reduced subsequently, the questions of the relative ages of the Bare Hill felsite and the Great conglomerate, and of the conformity of the Great conglomerate with lower members of the series, must still be left open. This phenomenon will be taken up in the next chapter.

*See Chap. IV.

§ 9. Thickness of the Great conglomerate and underlying formations.

In order to compare the higher beds of the series in the Schlatter Lake area at the extremity of Keweenaw Point with corresponding beds at Eagle River, as measured and described by Marvine, some figures may be of service. They are based on the following facts and assumptions. The strata between the Outer conglomerate (Pl. IV) and the lowest observed conglomerate in Sec. 22, T. 58, R. 27, as already stated, have a very uniform dip, averaging not over 23°. The strike observed uniformly throughout the Lake Shore trap here was N. 60° W. Lower in the formation the strike, based on less satisfactory observations, was thought to be nearly the same, although Foster and Whitney give it as N. 70° W. We have seen that the probable strike of the beds under the Greenstone in Sec. 29, T. 58, R. 27, is about N. 65°-67° W. We may therefore safely assume for the Greenstone itself a strike of N. 67° W. What dips prevail in the beds between the lowest conglomerate in Sec. 22 and the Greenstone, is not known, but if we take the average (27°) between the extreme observations (23° and 31°; see preceding pages) and multiply the horizontal distance, 7200 feet (including that across the Greenstone), by the sine of the dip (0.454), we find the hypothetical thickness for the beds next above the Greenstone to be 3270 feet. The thickness of the beds between these and the Great conglomerate can be measured with a near approach to accuracy. Scaled from the map (Pl. IV) they are 3353 feet wide or (x sin 23° = 0.39) 1308 feet thick. The thickness of the Great conglomerate (Pl. IV; Great and Middle conglomerates and Lower Lake Shore trap), computed in like manner, is (4594 x sin 23° = 0.39) 1792 feet; that of the (Upper) Lake Shore trap, (2724 x sin 23° = 0.39) 1062 feet.

In the preceding paragraph I have included within the Great conglomerate formation a number of melaphyre beds grouped by Irving with the Lake Shore trap, together with a thick bed of conglomerate that overlies them and separates them from the higher beds of the same group.* This was temporarily necessary for comparison's sake, for between the end of Keweenaw Point and Eagle River no distinction has ever been made between the Great conglomerate and the bed just mentioned, which I take to be the same bed that lies between Copper Harbor and Lake Fanny Hooe. Both have been regarded and mapped by previous geologists as the Great conglomerate, and Marvine's measurements at Eagle River, were made on this assumption. This higher conglomerate bed I have called the Middle conglomerate, as will be explained later.

At Copper Harbor the Lake Shore trap, within the limits and with the dip (35°) usually ascribed to it, is about 1100 feet thick, and the Great conglomerate (embracing the limits heretofore assigned to it at that point), with the same dip, must be upwards of 2500 feet thick—not far from its calculated thickness at Eagle River and other intervening points.

Tabulating the above figures on the basis of the foregoing correlation, we have the following:

	End of Keweenaw Point.		Copper Harbor.		Eagle River.
	Dip.	Thickness.	Dip.	Thickness.	Thickness.
Lake Shore trap. (Upper)	23°	1062	35°	±1100	Not exposed.
Great congl. (including Middle congl. and L. S. trap.)	23°	1792	35°	2500+	±2200?
Beds between foot of Great congl. and foot of Greenstone.	23°	1308	—	—	4120
	27°	3270?			
Totals.		6370			±6320

Loc. cit., map, Pl. XVII.

From these figures we thus find the total thickness of that part of our column at the end of Keweenaw Point, between the top of the Great conglomerate as above determined, and the bottom of the Greenstone, to be 6370 feet, which is practically the same as the thickness of the same zone at Eagle River, as determined by Marvine. But, inasmuch as the Great conglomerate, as above delimited,* is between 400 and 700 feet thinner at the end of Keweenaw Point than at either of the other points mentioned, the zone below it to the bottom of the Greenstone, *on our assumed dip of 27°*, must therefore be almost as many hundred feet thicker there than elsewhere. We are thus assured that unless the latter zone is in reality much thicker at the end of Keweenaw Point than further west, for which there is no evidence, the assumed dip of 27° for that zone is if anything too steep, and that the flat dips noticed at the end of the Point probably extend nearly if not quite as far down as the Greenstone. Thus we are enabled to assume, with a strong degree of probability, that the dips are similarly disposed in the overlying beds both east and west of the Bare Hill core, and that if the average dip for the zone under the Great conglomerate be in reality less than assumed (27°) the thickness of that zone is in fact less than as above computed.

On reference to the map, Plate IV, it will be seen that in the Schlatter Lake area at the extremity of Keweenaw Point, within the zone hitherto known as the Lake Shore trap, there is a conglomerate which I have designated as the Middle conglomerate. On old maps this bed is represented as rapidly wedging out on the west, but the same maps† mark a conglomerate in similar position south of Eagle River. The interval between this bed and the Great conglomerate at points still further south is indicated by a well marked depression. Beginning near the end of Keweenaw Point one can follow westward a similar depression, even more marked, between conglomerate ridges that, as above stated, have heretofore been considered parts of the Great conglomerate. This is the valley down into which the county road to Copper Harbor descends just before reaching the village of that name, and is the same depression in which lie lakes Fanny Hooe, Upson and Bailey. Were not this topographic feature so striking, the relations of the conglomerate and trap beds at the end of the Point might alone suggest a trap horizon along this depression, but the inference becomes a certainty by the observation by Messrs. R. T. Mason and C. F. Moore of a bed or beds of melaphyre in the deep valley just west of Copper Harbor. The outcrops of melaphyre seen here at distances a mile apart, east and west, are near the southern base of the north conglomerate ridge—"Brockway's Nose"—and undoubtedly mark the continuation of similarly placed beds observed at the end of the Point. The "Middle" conglomerate is then the same as the bed north of Lake Fanny Hooe, and the Lower Lake Shore trap under this lake, from its more feeble resistance to erosion, has been degraded more rapidly than the overlying and underlying conglomerates.

*I. e., including the Lower Lake Shore trap and the Middle conglomerate.

†Stevens, Hill and Williams's, and Irving's.

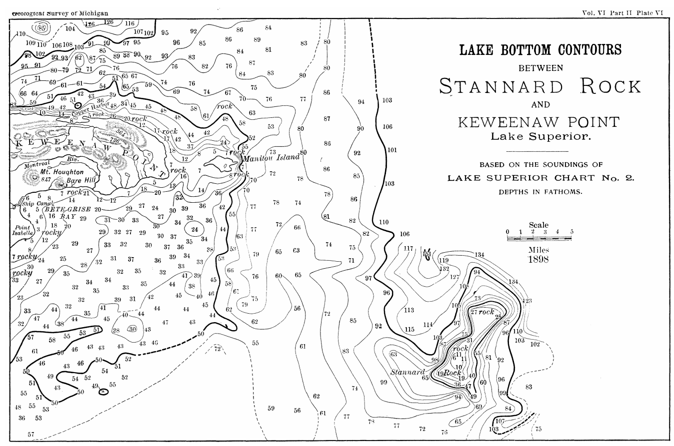

Plate VI. Lake bottom contours between Stannard Rock and Keweenaw Point, Lake Superior.

Under the waters of Lake Superior opposite Eagle River there is a reef which by general consent is held to be trap. I have met with no statement by any one that has actually seen a sample from this reef, and if the latter should prove not to be trap, it would in that case probably be the continuation of the Middle conglomerate.

For the apparent rapid decrease in thickness of the Great conglomerate eastward from Copper Harbor—some 400 to 700 feet in 7 miles—two explanations are possible, either (1) that when the conglomerate first began to form, the land where the end of Keweenaw Point now is was not submerged, or, (2) that the conglomerate as it goes east recedes from the old shore line against which it was laid down, and from which it has since been eroded. It is only necessary to bear in mind, as already pointed out, that in general a conglomerate is thicker near the shore (but not of necessity immediately next to it) from which it derives its material, and grows thinner towards deeper water, where it may also gradually change into sediment of a finer character. If, therefore, we find a heavy conglomerate outcrop preserving the same thickness for miles, we may assume that the line of outcrop is substantially parallel to the original shore line on which the conglomerate was formed, but if the outcrop over long distances shows a regular and progressive decrease in thickness, we may assume that in following it we may possibly be going from the original shore line towards the deeper parts of the original basin. Under this assumption, were the eroded edges of the Great conglomerate and its underlying beds restored, we should probably see the former increased to its normal thickness, and much nearer the east flank of the Greenstone range, thus restoring also, in a measure, the eroded symmetry of the Bare Hill complex. Such a thickening of the conglomerate might be assumed without increasing the total thickness of the combined formations, for we have seen that the calculated thickness of the underlying zone may have been too great by the assumption of too steep a dip.

From the above considerations we have an alternative hypothesis, (1) that an intrusion near Bare Hill may have lifted the later of the Keweenawan strata and bowed them, or, (2) that some of these strata may have been laid down more or less symmetrically around a pre-existing eminence at that point.

§ 10. Bohemia conglomerate west of Mt. Houghton.

West of Mt. Houghton the Bohemia conglomerate, as previously noted, is first seen in an outcrop at about 697 paces N., 1076 paces W., Sec. 23, T. 58, R. 29, about 190 paces north of the brecciated zone that marks the boundary between the Mt. Houghton felsite and the underlying porphyrite. Immediately underlying the conglomerate here is the coarse grained melaphyre belt, which is thus seen to have increased in thick- ness from the east. Along the west line of Secs. 22 and 27, north of Paddy pond in the same township, both the conglomerate and the underlying doleritic rock are still thicker, the former being apparently 80 paces wide, and the latter about 200 paces wide, but consisting of two beds; the upper coarse grained, and the lower a basic porphyrite resembling fragments in the breccia further east. Under the latter porphyrite and separated from it by a thin layer of conglomeratic material, is the porphyrite that we have followed from the Little Montreal River. This bed here is about 100 paces wide. A north and south fault may run along the stream that empties into Paddy pond from the north, throwing the west side slightly north. The felsite porphyrite does not appear to occur here. In fact, from here westward this felsite porphyrite, or a similar rock, is seen only in the neighborhood of Gratiot bluff.

The doleritic belt under the Bohemia conglomerate continues to increase in width westward, being 300 paces wide in Secs. 27 and 34, T. 58, R. 30, north of Gratiot bluff. In the next section west, Sec. 33, the conglomerate is seen in low ground at 738 paces N., 925 paces W. The underlying doleritic belt is here about 330 paces wide, underlain by the porphyrite, and at 580 paces N., 1925 paces W., in Sec. 31, T. 58, R. 30, seems to have developed into or to be replaced by a coarse ophite. Careful search along the limits of this bed failed to disclose further outcrops of the conglomerate, and the fact that the latter was growing narrower where last seen and the underlying doleritic belt wider, makes the conclusion probable or at least plausible, that the conglomerate has wedged out along the flanks of the massive ophite, which in this area probably rose above the sea in which the conglomerate was laid down, turning the course of the conglomerate northward, where its edge probably lies concealed below the surface under overlapping beds. That this explanation probably accounts for the disappearance of the conglomerate at the surface is strengthened by the analogy of the Kearsarge conglomerate, as will appear more fully when we come to speak of the Central mine, two miles to the northwest.

The beds of the Bohemia belt immediately under the last named ophite are easily traceable southwest into Sec. 9, T. 57, R. 31, where they still form the crest of the Bohemian Range, which here appears to reach its highest elevation, some 900 feet above Lake Superior. The ridge falls away rapidly from here southwest and merges into a more or less drift-covered plateau. Between the above point and Sec. 30, T. 56, R. 32, nine miles south and eight miles west, probably on account of the heavy drift-covering, no beds other than a conglomerate have been noticed by the Survey that appear to be the continuation of the great Bohemia belt. In Sec. 30, T. 56, R. 32, there come to the surface acid rocks which if not the counterpart of those of the Bohemian Range, seem at least to mark the same horizon. These rocks will be referred to later.

§ 11. Lac la Belle conglomerate.

In the diagram of Bare Hill (Pl. V) the conglomerate cut off by the felsite at the southwest is only about 8 paces wide and is made up largely of rounded pebbles of medium acid and of basic rocks. As already noted, it dips about 80° to the north and strikes about N. 75° E. About half a mile west, in the adjoining Sec. 30, two similar conglomerates are exposed in the face of the vertical shore cliff, the upper one being here only about 2½ feet thick and separated from the lower, which is thicker, by a bed 10 to 12 paces wide (about 25 feet thick) of melaphyre so chloritic and slickensided as to be almost unrecognizable as such. The latter also contains numerous seams of epidote. These beds dip at 69° to 71° N. and strike N. 84° E., i. e., directly towards the conglomerate at Bare Hill, last above mentioned. Further west in the bed of the brook that flows through the west part of the same section, the same beds are again exposed, the upper conglomerate being from 3 to 5 feet wide, the melaphyre below it 20 feet wide, and containing seams of epidote nearly a foot wide. The foot of the lower conglomerate is not exposed. In the cliff on the west line of the same section the same beds occur again. These conglomerate beds are cut out about 70 paces west of the point last above mentioned, by acid rocks,* but seem to appear again 250 paces further west. The several conglomerate outcrops above traced are all in the line of strike with two similar conglomerates further west in Sec. 25, T. 58, R. 29, where they form the face of a cliff at least 120 feet high, that almost overhangs the water of Bête Grise Bay. Going west from the bay, towards Lac la Belle, on the road that skirts the terrace (110 (?) feet high), we find traces of conglomerates in the same general horizon in several streams that flow south. They are well exposed along the south side of Mt. Bohemia, on the terrace 110 feet above lake level. At the Lac la Belle stamp mill two conglomerate beds occur, here thicker than those further east, with an interbedded melaphyre, their character and mode of occurrence being such as to leave little doubt in one's mind that they are identical with the conglomerate horizon just traced from Bare Hill. Between these extreme points the conglomerates are everywhere overlain by the ophite, which is known to be quite thick, being on the west line of Sec. 30, T. 58, R. 29, probably not less than 350 paces wide. From Lac la Belle westward no outcrops -of conglomerate were found, until in Sec. 20, T, 57, R. 31, where at 650 paces N., 350 paces W. and at 290 paces N., 990 paces W., ill exposed conglomerates occur, which may be a continuation of one or both of the Lac la Belle beds. Unless cut out, these beds probably run under the waters of Gratiot Lake.

On the east side of Bare Hill we have seen what may be the lower of these two beds, in a faulted position. Further east, near the Little Montreal River, a conglomerate near the top of the low cliff back of the shore may also be the eastward continuation of this belt, but in this case, since this bed is horizontally much nearer the Bohemia conglomerate than at Bare Hill, the dips north of the latter would have to be flatter than those at the Little Montreal River. Another thin bed of pebble conglomerate is also exposed on the east end of the small bay between the mouth of the river and Fish Cove, (See Pl. IV.)

*See p. 52.

§ 12. Other conglomerates south of the Bohemia conglomerate.

The map of Stevens, Hill and Williams and other old maps mark a higher or younger conglomerate that runs west from Bare Hill, through the centers of Secs. 30, 25, 26, 27 and 28, and wedging out east of Mt. Bohemia. No such bed was noticed by the Survey. A large block of conglomerate near the bed of the brook about 1075 paces N., 400 paces W. in Sec. 27, T. 58, R. 29, may have been taken to indicate the position of a conglomerate bed here, but this block is not in place.

On the point on the lake shore southwest of Bare Hill, Sec. 29, T. 58, R. 28, there is rather a wide bed or rather group of immense fragments of a rather basic conglomerate carrying very few distinctly rounded pebbles, but looking like a shattered and sheared melaphyre, much like a part of the Lac la Belle conglomerate north of the Lac la Belle stamp mill. It dips north. Below it on the east side of the point are several large blocks of a regular pebble conglomerate lying in the water. They dip steeply to the north. They may have been disturbed somewhat or detached, but are approximately in line southwest and northeast. The line runs on the east into the wall of rock on the shore behind some melaphyres that show a slipping nearly vertical towards the lake. It probably does not reappear immediately east of this point, for broken masses of the shore felsite (p. 20) come down to the water's edge at the east end of the shore cliff and appear to rest on melaphyre upon which they have fallen. Going west from this line of conglomerate masses, on the south side of the ledge 30 or 40 paces out in the lake some conglomerate appears, like the melaphyre portion of the conglomerate bed above mentioned. The evidence seems to favor the conclusion either that these conglomerates belong to a different horizon from the pair of conglomerates that run west along the shore cliff, or, what seems more probable and has already been suggested, that they are parts of the Lac la Belle conglomerate broken off and faulted from the line of those beds nearer the top of the cliff.

It thus appears that in the areas heretofore considered we find two horizons of well defined pebble conglomerates,—from half a mile to a mile apart on the surface,—between which a large number of basic conglomerates occur. Associated with the lower horizon— the Lac la Belle conglomerate—one small outcrop of quartz porphyry has been found, that may or may not be a flow interbedded with the traps. Above this horizon the only acid rocks noted are intrusive, until we come near the horizon of the Bohemia conglomerate, where the successive beds show greater acidity and culminate in several outflows of felsite that furnished the material for the thickest conglomerate known on Keweenaw Point below the Great conglomerate.

§ 13. Stannard Rock.

That there is thus low down in the Keweenaw series a well characterized horizon of acid rocks, original and secondary, in which the former are extrusive, and that this horizon has a considerable lateral extent is beyond question. That there is a similar horizon near the top of the series in the Rockland district is also well known. The occurrence of original acid rocks elsewhere in the series, rocks that are now recognized as intrusive, leaves open the classification of other acid rocks as extrusive or intrusive, according to the evidence that may govern each case. When, therefore, Irving places the felsite of Stannard Rock (a submerged reef in Lake Superior about 29 miles southeast of Keweenaw Point) in the same "belt" as Mt. Houghton, "or rather as belonging near the same general horizon,"* this cannot be taken as conclusive evidence of the interbedded nature of this rock. A contour sheet (Pl. VI), constructed from Chart No. 2, Survey of the North and Northwestern Lakes,† shows the configuration of the lake bottom southeast from the end of Keweenaw Point to Stannard Rock. The reef of which the latter is the highest part appears as a steep north and south ridge about eight miles long and from one to three miles wide, sharply separated from Keweenaw Point by a valley some 400 feet deep and eight miles broad. That this reef may represent an independent focus of eruption, or perhaps the remains of a mountain around and over which the Keewenaw lavas flowed, thus seems quite as probable as that it once formed an integral part of the Mt. Houghton "belt" or that it "marks for us the course of the Keweenaw Point Range," with all that this statement implies.

*Copper-bearing Rocks of L. S., p. 198.

†Issued by the War Department, Washington.

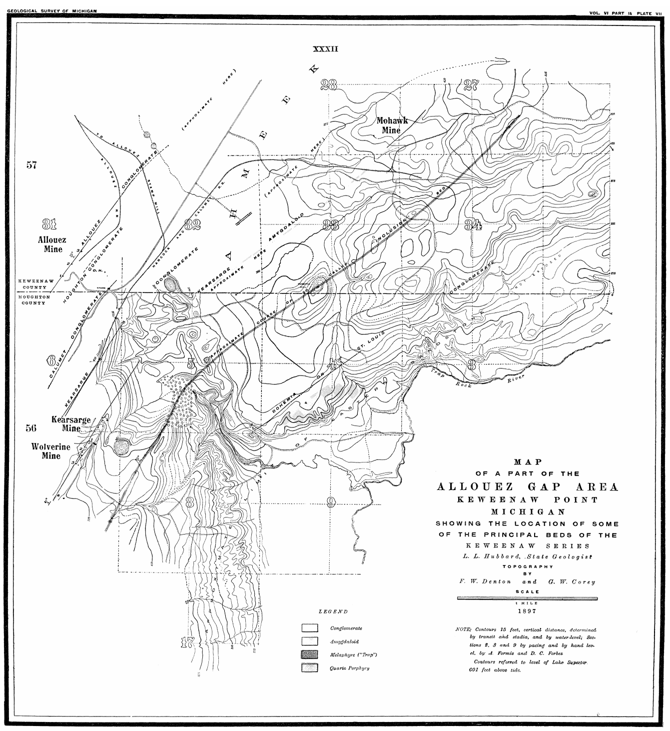

Plate VII. Map of a part of the Allouez Gap area, Keweenaw Point, Michigan.

§ 14. Rocks of Mt. Bohemia.

On the south face of Mt. Bohemia, above the Lac la Belle conglomerate, occur rocks described by Irving as syenite and gabbro and which, so far as observed, are like no other rocks on Keweenaw Point, but resemble many rocks found in place on the Minnesota shore of Lake Superior. The relations of these rocks to the basic flows of the Keweenaw series never have been fully determined; even Irving leaves the matter in doubt, for he says of the augitic syenites and orthoclase-gabbro:

> The former of these two is seen on the upper part of the mountain and its relation to the adjoining rocks was not satisfactorily made out, though it seems more probable that it is intersecting. The other rock shows lower down on the southeast side of the mountain and seems to constitute an interstratified belt (not impossibly an intersecting mass).†

In company with Messrs. A. E. Seaman and W. T. Sutton, the writer, in 1895, spent a day on Mt. Bohemia, tracing on the summit and south face of the mountain the contact of Irving's gabbro-syenite aggregate, the perception of whose relations to the adjoining melaphyres was due to the keenness of Mr. Seaman. The strike of the traps in this vicinity is probably conformable with that of the conglomerate at the south base of the mountain, i. e., slightly north of east, although we had no opportunity to determine the former. The combined gabbro and syenite are thus seen to cut the traps nearly at right angles (Fig. 8). The relations of the two former rocks to each other were not investigated. The augite syenite occurs at the lowest part of the narrow neck, and possibly elsewhere. The rocks at several places on each side of the contact are much altered, and some of them contain a good deal of fibrous hornblende. The conclusion might be drawn that the gabbro has been altered by contact with the massive ophite. The latter then would be the younger rock, and if so, the gabbro-syenite complex would have formed a peak around which the later flows of the Keweenaw series were laid down. Examination of the contact rocks at different points, however, and a study of several thin sections under the microscope by Dr. Lane, lead to the belief that it is the Keweenawan rocks that have undergone the greatest alteration and that the so called gabbro-syenite complex is a deep-seated intrusive in them. This, too, may in turn have been intruded and altered.**

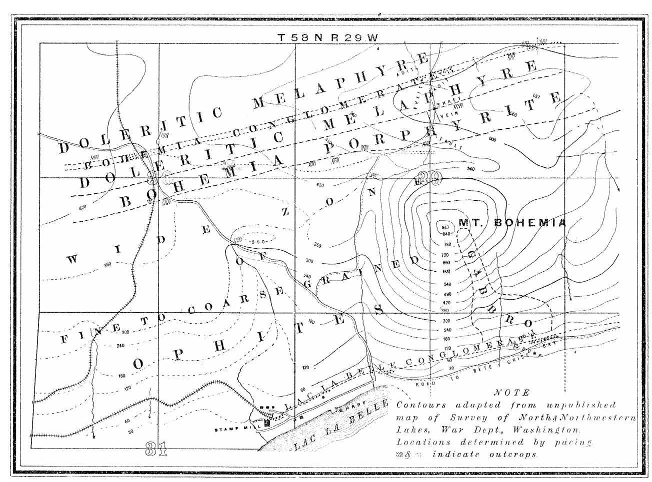

Figure 8. Sketch map of the Mt. Bohemia area, Keweenaw Point.

The following notes by Dr. Lane are on the specimens from Mt. Bohemia, Sec, 29, T. 58, R. 29.

S. 16920 from the Keweenawan outside the gabbro, 650 paces N., 900 paces W., is an illustration of a slightly altered melaphyre. The eye cannot recognize the feldspars any more, and instead of the flashing patches of ophitic augite are patches with a satin sheen. The rock has become more uniform in color. Under the microscope the feldspar is seen to be largely changed to sericite, probably mixed with carbonates, epidote and chlorite, though enough is left to show that it was labradorite. The olivine is all gone, and a tendency for idiomorphic magnetites to develop from it can be traced. The augite proves to be still largely present in patches 4 to 8 mm. across and more, but is changing to blue-green hornblende and chlorite. This uralitic alteration of the ophite appears to be due to the gabbro contact. (Rosenbusch iii, pp. 121, 265.)

In S. 16925, close to the contact with the gabbro, 150 paces N., 700 paces W., the change of the augite is complete but the original areas can be distinguished more or less, partly by common orientation of the uralitic hornblende, and—especially when the secondary hornblende fibres are at random—by the relative scarcity and finer grain of the magnetite within these patches—corresponding to the original scarcity and absence of olivine.

S. 17408, from near the north end of the gabbro tongue, and sections like it, are as much altered as the above, but lack the traces of ophitic texture. They have areas with no hornblende and with finer magnetite, which appear to replace feldspar phenocrysts, and are probably from melaphyres of the contact zone which were more decomposed or less characteristic originally.

S. 16923, 450 paces N., 700 paces W., differs from the foregoing in composition and in texture. It is coarser. The texture is that of a plutonic rock, the interstices being filled with clear quartz which occasionally shows traces of granophyric intergrowth with the red-margined feldspar. The feldspar has lower refraction than the quartz, generally it shows low extinction angles, occurs in laths 1 to 2 mm. broad and 4 to 5 long, and is distinctly oligoclase. The hornblende is about equal in quantity to the feldspar and in equally large areas, generally with a uniform orientation, but more or less intermingled with calcite and chlorite. Some of the hornblende is undoubtedly secondary, but waiving the question whether there may not have been some primary hornblende the nature of the feldspar and the character of the texture and relative proportions of the constituents would lead me to class it with Rosenbusch's diorites according to his third edition, pp. 241, 244. It is a type of Irving's orthoclase gabbro. It has riot at all the texture of an effusive, but is plutonic in texture -with a leaning toward dike texture, and is closely akin to the salite diorite described in the footnote to p. 257, of Part I.

S. 16924, 160 paces N., 600 paces W., which is a brick-red granular rock with a few green specks, is an aplitic facies of 16923, that is, the ferro-magnesian constituents are almost gone. The heavily red clouded idiomorphic oligoclase laths (75% + Ab) are smaller, 0.1—0.3 mm., and shorter. The quartz is in even smaller granules but shows the aplitic tendency to idiomorphism. Rectangular sections with diagonal extinctions are abundant, but we have also traces of granophyric intergrowth with quartz. There are rare altered phenocrysts which may have been pyroxene. This is a dioritic aplite. It is the same type of rock as the red rock of the Duluth gabbro, *i. e.*, U. S. Grant's soda granite, Irving's augite syenite and granitell, and by increase in granophyric character (micro-pegmatite) would become the granophyrite which occurs so abundantly in the Keweenawan conglomerates, e. g., in S. 16933, from the base of Mt. Bohemia.

*Irving, *loc. cit*., pp. 198. 414.

†*Loc. cit.*, p. 184.

**Cf. Bayley, The Basic Massive Rocks of the Lake Superior Region, Journal of Geology Vol. I, No. 7, p. 714.

CHAPTER IV. OTHER OCCURRENCES OF ACID ROCKS.

§ 1. Curvature of the Greenstone at Eagle River gap.

From the area north of Bare Hill, last under consideration, the course of the Greenstone lies about S. 80° W. for upwards of 15 miles, to a point near Eagle River gap, where it curves rapidly to the south, and after describing to the west another slight curve whose crest is near the Allouez location, it runs, no one knows how far, in a direction varying little from S. 33° W.

The Greenstone belt at Eagle River is upwards of a thousand feet thick. At Allouez gap it is very much thinner and eroded down to within about 225 feet of lake level. Between Allouez (Sec. 31, T. 57, R. 32) and Calumet (Sec. 13, T. 56, R. 33) it is again marked by a ridge, less in contrast, however, with the adjoining areas than further north, and in the shafts of the Tamarack, and Calumet and Hecla mines it appears to be from 190 to 277 feet thick. At the Franklin Junior mine, Sec. 8, T. 55, R. 33, there is no belt above the Allouez conglomerate recognizable by its thickness as the Greenstone, the ophite next under that conglomerate there having, on the contrary, attained to a thickness of about 134 feet.* On Isle Royale it appears to be thicker at the east end than at the west end of the island. Whether regarded as a single bed† or as a group of several beds, it thus evidently filled a north and south depression between a point or points near Eagle River and the North Shore, overflowing on the southwest into another narrower and shallower channel. The crest in the Allouez curve was therefore apparently in existence prior to the Greenstone flow, for the bed at the Allouez resembles the hanging of the Greenstone further north.

The course of the Greenstone from the Bare Hill area west and southwest as far as Eagle River gap is in accord although not strictly parallel with that of the Bohemian Range, which we have previously traced through Sec. 9, T. 57, R. 31. No intrusive rock masses have been noticed that would account for the curvature of the two ranges at and opposite Eagle River gap, and the structure here may, perhaps, be explained by some other hypothesis—a subject that may best be taken up later.

*See Plate IX.

†Dr. Lane, after personal examination of the Greenstone at Eagle River gap, believes that it consists of a series of flows that followed one another in such rapid succession as to constitute practically a single bed—a point on which at present I have no opinion to offer. See this volume, Part I, p. 75.

§ 2. The Allouez curve.

In a reference previously made to the gap near the Allouez mine I have said that the gap marks the southern termination of the Greenstone and Bohemian ranges, and their separation from the broad plateau-like area that extends south to Portage Lake and beyond. This gap also marks the crest of a mass of quartz porphyry, at the bottom of the Keweenaw series as exposed here, near the junction of the latter with the Eastern sandstone. The porphyry, first observed in a small outcrop by Messrs. Seaman and Lane of the Michigan Survey in 1889, was laid bare by the clearing of the land in subsequent years, and is now seen to extend from near the south- west corner of Sec. 4, T. 56, R. 32, diagonally half way across the section, and to be at least 300 paces wide (Pl. VII). The rock is light gray, and where weathered, white. It contains small scattered phenochrysts of light colored feldspar and corroded grains and dihexahedra of quartz in a fine grained groundmass dotted with minute dark colored inclusions (S. 17525).

For some distance south of the Allouez mine the positions and curves of the principal beds between the Allouez conglomerate and the Kearsarge amygdaloid have been accurately determined from surface outcrops and by pits and mine shafts. At Calumet, in Secs. 13 and 23, T. 56, R. 33, these beds maintain an almost parallel course, about N. 33° E., and a north westerly dip which at the surface varies from about 38° on the Calumet conglomerate at the north end of the Calumet and Hecla mine to 39° on the Allouez conglomerate at the Allouez mine (See note, page 117.) Taking up these beds in order we see, what has already been stated, that the highest conglomerate, the **Allouez**, describes a curve convex towards the west, across the Allouez gap (Sec. 31, T. 57, R. 32). As marked on the map (Pl. VII) this curve appears slightly more accentuated than it really is, owing to the lower altitude of the gap.* In Sec. 29, T. 57, R. 32, the strike is about N. 39° E., the dip not measurable with certainty but probably flatter than at the Allouez mine, from which point it probably decreases as we go north. At Eagle River gap it is probably between 26° and 27°.†

Omitting the Calumet and the Houghton conglomerates, which are supposed to be in almost strict conformity with the Allouez conglomerate but which have not been found immediately north of the area under discussion, unless it be on the Seneca location, we come to the **Kearsarge conglomerate.** This bed is exposed at the surface on the Kearsarge location, north of the latter in several pits east of the railroad, and at the Ahmeek location, near the east quarter-post of Sec. 32, T. 57, R, 32. At the last named point the strike is about N. 45°-50° E. The dip measured on the shaft stringers is 44½° N. W., these figures being only one-half degree less than the dip as - determined by the relation of width (75 ft.) to thickness (52 ft.)‡ In any event the convexity of the curve of this conglomerate appears to be greater than that of the higher lying Allouez conglomerate. On the hanging of the former bed at the Ahmeek there is a layer of fluccan, which, according to Capt. J. C. Hodgson is two feet thick, with the next three feet cupriferous.

The **Kearsarge amygdaloid**, the bed worked at the Kearsarge and Wolverine mines in Secs. 6 and 7, T. 58, R. 82, is at these mines about 1250 feet horizontally southeasterly from the Kearsarge conglomerate, measured at right angles to the strike. In the Kearsarge mine, according to R. M. Edwards, Mining Engineer of the Tamarack Mining Company, the strike of this bed as the latter is followed north curves 5° to the east in the drifts of the mine. Outcrops of the footwall of this bed are well exposed in Sec. 27, T, 57, R. 32, on the Fulton location, where the Kearsarge amygdaloid has been uncovered by several pits near the southwest corner of the section (Pl. VII), and has been shown to be cupriferous§. The footwall rock is a thick bed of ophite characterized by large phenocrysts of labradorite. According to the location of these outcrops the bed is found here to be curving rapidly to the west as it is followed south.

*Probably more than 200 feet.

†The dip of the "slide" or Allouez conglomerate at the Cliff mine according to Hulbert and Lum (1857) is 24°, according to P. H. Updegraff (1870) between 24° and 25°. The Cliff mine is about two miles south of Eagle River gap.

‡Capt. J. C. Hodgson. This dip seems abnormally steep for this point.

§This property is now known as the Mohawk mine.

Underlying the Wolverine ophite is a bed of **Sandstone** mapped by Marvine and Ladd,* and also mentioned by Rominger.† According to Capt. Hodgson this bed, 265 feet east of the Kearsarge amygdaloid, is an altered conglomerate, chiefly of dark colored sandstone, 40 feet wide, with 2 feet of fluccan on the footwall. So far as known to the writer, no outcrops of this sandstone have been noted else- where in this immediate area. It may correspond to Marvine's conglomerate No. 9 exposed (?) near Portage Lake. It may at other points be an amygdaloid conglomerate. A large boulder of such a conglomerate lies by the roadside in the hollow east of the line of the bed in Sec. 7, T. 56, R. 32.

East of the Wolverine mine (about 950 paces, measured east on the north line of Secs. 7 and 8, T. 56, R. 32), there is exposed for several hundred paces in a low ridge an outcrop of a rather light colored melaphyre containing numerous apparent inclusions, of amygdaloidal character, that carry calcite. This bed strongly resembles the footwall of the Isle Royale cupriferous bed back of Houghton, as well as another bed about 400 paces above it on the old Huron location‡ (Sec. 2, T. 54, R, 34). With an average dip of 46° for the intervening strata (which I am inclined to believe is too steep), it is 1521 feet vertically below the Kearsarge amygdaloid—a measurement that is some 700 feet less than the vertical distance between the position of the supposed Kearsarge amygdaloid at the Franklin Junior and the Douglass-Arcadian (Isle Royale) bed east of it.§ The same bed outcrops in two places about 15 paces apart on the Fulton location, at about 375 paces north, 490 paces west, Sec. 27, T. 57, R. 32. (See Pl. VII.) Just beneath it here is a dark brown crumbly ophite the lower part of which, or the next lower bed, carries large amygdules of stellar quartz. Next above the bed with inclusions is another dark brown decomposed ophite. At the point first indicated, east of the Wolverine mine, the light colored, "inclusion" bed strikes N. 38°-40° E. and dips N. W. about 50°—possibly less—and here, as at the Fulton location, is overlain and underlain respectively by darker, brown colored ophites, that are crumbly towards their hanging walls. The course of this bed as indicated by the two sets of outcrops, shows a close conformity with the higher beds previously described and must run very near—possibly to the west of—the old workings of the Forsyth mine, near the south quarter-post of Sec. 33, T. 57, R. 32. Beneath the "inclusion" bed occur alternations of amygdaloids and very coarse grained or doleritic melaphyres, well exposed on Sec. 4, T. 56, R. 32. They carry more or less quartz in amygdules and show considerable epidote, points of resemblance with beds above and beds below the Arcadian Isle Royale horizon at Portage Lake.

At the base of these beds we find a rather wide bed of a very tough and very coarse grained basic rock that merges on the southeast or footwall side into a coarse ophite, immediately beneath which—between it and the quartz porphyry—is a **conglomerate**, exposed at short intervals between the southeast corner of Sec. 5, T. 56, R. 32, in low ground, and a point in Sec. 4, about 1125 paces north, 525 paces west, of the southeast corner. This bed strikes uniformly about N. 55° E. and dips N. W. 58°. At its most southerly exposure in Sec. 5, however, the strike appears to be N. 50° E., and the dip about N. W. 70°. In Sec. 35 in the next township north, a similar conglomerate is exposed at 1425 paces north 1235 paces west in a prominent knob, here underlain by a coarse grained melaphyre like that under the Bohemia conglomerate further east. This outcrop, it will be observed, is only slightly east of the direct line of apparent strike of the conglomerate in Sec. 4, which is some 200 feet lower. The latter bed is about 24 paces wide at its greatest exposure and may be still wider, for there is a covered space of 100 to 150 paces between it and the underlying porphyry. It carries rounded to angular fragments—some as large as a man's head—predominatingly of acid rocks of felsitic or of porphyritic structure, quite dark colored, containing phenocrysts of red feldspar and much like the Praysville porphyry. There is very little matrix present at some points, other than calcite; at other points the matrix is coarse. One fragment of the felsitic kind showed spherulites.

*Geol. Sur. Mich., T. Atlas, Pl. XIX. No. 9. Gray slaty sandstone and fine red sandstone.

†*Ibid*., V, Pt. I, p. 118.

‡Other similar beds have been noted lower in the series, south of Portage Lake.

§See Chapter VI and Plate IX.

A. Identity of the St. Louis conglomerate with the conglomerate of Sec. 4, T. 56, R. 32.

In the next section southwest, Sec. 8, T. 56, R. 32, the land rises rather rapidly some 200 feet from the valley of the Trap Rock River, whose west branch here flows southeast through the northeast quarter of the section. Massive outcrops, often in rounded knobs, of rocks similar to the belt noticed in Sec. 4 above the conglomerate, appear in a broad plateau which falls off to the east abruptly in places, for three-fourths of the way south through Sec. 8. On the edge of this plateau at about 750 paces N., 865 paces W. is a knob of very coarse grained rock, which over small areas shows a distinctly ophitic structure. This rock very closely resembles that of the nearest exposed bed above the conglomerate in Sec. 4. Careful search failed to find rock east of it where it is exposed in Sec. 8, except in a line of pits that extend a hundred paces to the east, a heavy deposit of drift material lying over them. Basic rocks had probably been found in some of these pits. There are also indications that the Eastern sandstone is probably in place near here, under the drift. In Sec. 17, next south, however, at 1600 paces north, 1025 paces west, in a ravine, a conglomerate bed is in place that closely resembles the so called **St. Louis conglomerate** which has been traced through Secs, 20, 19 and 30, southwesterly. An extensive group of large fragments of the same conglomerate was found in Sec. 17, about 900 paces N., 1325 paces W., which occurrence makes it fairly presumable that the course of the St. Louis conglomerate in this section is slightly east of north, and that the St. Louis conglomerate and the bed in Sec. 4 are one and the same bed. This conclusion is rendered still more probable by the occurrence at 874 paces N., 134 paces W., Sec. 19, T. 56, R. 32, of a very coarse grained and ophitic rock (Sp. 17538), like the bed immediately above the horizon of the latter conglomerate, already twice described, once from Sec. 4 and again from Sec. 8, T. 56, R. 32. Here this bed is exposed about 140 paces horizontally above the conglomerate; the dip is growing flatter as we go south. Although the St. Louis conglomerate in Sec. 20 (Wall Ravine) and further south contains some pebbles that are fairly large, most of its fragments are small and many are sub-angular to very angular, much resembling a tuff, this being a very characteristic feature of this bed along here and indicating proximity to the bed or beds from which its material was derived. The matrix is rather coarse and fairly abundant, and many of the pebbles resemble the porphyrite of the Bohemian Range, being less porphyritic than the Praysville porphyry. The rock, so far as pebbles and matrix are concerned, is firmly coherent; but is much jointed.

In the appended diagram, Figure 9, are given the results of trenching done under the superintendence of Capt. J. C. Hodgson, to whose kindness I am indebted for the sketch from which the diagram was copied as well as for much other information. It shows the course of the beds at this point, and the occurrence of sandstone and conglomerate higher in the series, but what is the nature of these beds, I am not informed.

FIG. 9

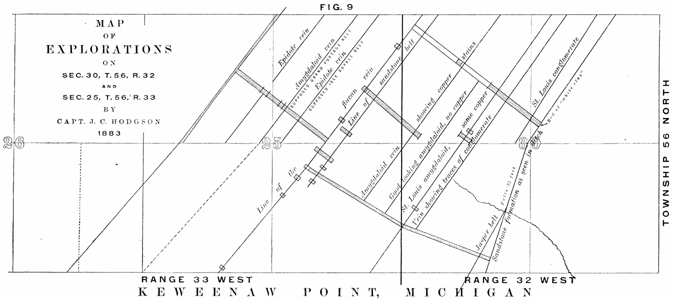

Figure 9. Map of explorations on Sec. 30, T. 56, R. 32, and Sec. 25, T. 56, R. 33.

On Plate XIX, published with Vol. I, Geological Survey of Michigan, a cross-section at the Kearsarge mine, by Marvine and Ladd, shows three conglomerate beds and a bed of "jasper" east of the Wolverine sandstone which are stated to have been scaled from a small map made by Capt. William Newcombe. The position of the most easterly of these beds on the cross-section and its identity are queried. The other beds (Nos. 4, 5 and 6 of Marvine's Portage Lake conglomerates) are horizontally 8598, 3298 and 2930 feet, respectively, from the Wolverine sandstone and would fall within the zone occupied by the belt of coarse grained rocks above the horizon of the St. Louis conglomerate, but none of them has been seen by the present members of the Survey, and they do not appear, from the measurements above given, to correspond to the beds located by Capt. Hodgson.

B. Relations of beds.

Plate VII shows a horizontal section, approximately correct, of the beds above described. We see at the base of the section, arching over a mass of quartz porphyry, a conglomerate which dips 70°-58° and strikes from about due north on the south side of the arch to N. 55° E. on the north side. Up to the horizon of the Greenstone each successive bed on which observations were made shows a gradually decreasing dip and perhaps less divergence in its strikes, on the two sides of the arch. This divergence, however, is still quite marked as far up as the Kearsarge conglomerate. That the dip of each individual bed also flattens—to the north, at least—is probably also true; the amount of decrease—if any—south for the higher beds is comparatively small.

The above relations of the several beds make difficult any very positive conclusion as to the cause of the rapid change of strike. The porphyry may be intrusive. Pebbles from the overlying conglomerate resemble it, but they are not thought to be abundant enough or scarce enough to serve as an argument either way. If the porphyry is intrusive, it is probably older than the Greenstone, if, as should seem natural, it was the cause of the ridge in the lower strata that separates the two lateral extensions of the Greenstone north and south of Allouez gap (p. 31). In this case we should expect to find in the immediate vicinity of the porphyry evidences of disturbance in a faulting of the overlying beds. Only one such fault* is known in the vicinity—the Seneca fault—between the Seneca location (Sec. 29, T. 57, R. 32) and Forsyth Hill and possibly extending southeast of the latter. This fault, however, is supposed also to cross the Greenstone, but cannot have caused any marked dislocation there. Little is known about it, but if it does cross the formation and was caused by the intrusion of the porphyry, the latter would then be younger than the Greenstone.

At the Allouez mine two fissures cross the formation, one of which shows two or three feet of fluccan, but neither seems to be accompanied by any heave in the adjoining beds.

*This fault-"vein"—is said to strike N. 22° W.

On the other hand, the curvature of the overlying beds is such that they might have been laid down, over the sloping sides of the porphyry, and subsequently tilted, as discussed in the preceding chapter. If reduced to lake level the curves of the different beds would not appear as marked as in Plate VII, so that it is not inconceivable that the same or similar lava sheets may have flowed over a flat conical projection of porphyry and arranged themselves as we now see these beds. There is apparently no flexure of the overlying beds immediately south of the porphyry. As above re- marked, no contact is visible between the porphyry and the under- lying conglomerate, but at Wall Ravine the St. Louis conglomerate, near its *hanging*, is found in contact with a mass of decomposed porphyry, and Capt. Hodgson found in the next section southwest of Wall Ravine, 50 feet or more below the conglomerate, a bed of "white clay," evidently the kaolinized decomposition product of a porphyry.* If this is a product of slide-faulting, like much of the fine material we find along the contact of the traps and Eastern sandstone, we may be right in refusing to assign to this porphyry an intrusive character. If it is older than the overlying beds, it may even belong to an older series.

*Between these two points there are trap rocks 200 paces in width below the conglomerate, but the porphyry may intervene.

§ 3. Identity of the Bohemia and St. Louis conglomerates.

The beds from the Greenstone to the St. Louis conglomerate, as we have just seen, disclose a more or less increasingly easterly strike, towards the north across the Allouez gap. The Greenstone and the Kearsarge amygdaloid on the Fulton location soon begin to swing back, more towards the north. In an unpublished cross-section of beds at the Cliff mine, by F. Klepetko, we find three conglomerates approximately at the same distance from, one another, in which the Allouez, Calumet and Kearsarge conglomerates occur between Calumet and the Allouez mine.† In other words, they have followed the Greenstone in its curving back towards the north. The same relative position of the above conglomerate beds is also found to be true in the Central mine. It is thus a matter of fairly strong inference, that the St. Louis conglomerate, in like manner with the higher conglomerates, must swing to the north from its last observed outcrop in Sec. 35, T. 57, R. 32, and that its course must curve in harmony with theirs, passing west of the ophite that caps the Bohemia belt, where the latter appears along the crest of the Bohemian Range in Sec. 9 of the township next east. This conglomerate bed may here wedge out or be overlapped by higher beds, as was supposed to be the case with the Bohemia conglomerate further northeast. It is thus apparent that the St. Louis conglomerate and the Bohemia conglomerate must eventually approach the same horizon. Their characters, their position with reference to other horizons, and the absence of other conglomerates near each of them in areas where they are separately exposed may justify us in the conclusion that they are in all probability one and the same bed.

†The Houghton conglomerate is not positively known to occur in the Calumet and Tamarack mine shafts.

§ 4. Conglomerates exposed in the Central mine.

The Central mine, in the south half of Sec. 23, T. 58, R. 31, close under the Greenstone, is in a Assure vein that strikes N. 13° 07' W. and hades vertically from the surface to the 9th level—nearly 700 feet. From the latter point the apparent hade* of the vein averages about 7° 42' east, to the conglomerate bed found near the bottom of the mine, or including the vertical part of the vein its average apparent hade from the surface is 5° 27'.†

Four conglomerate beds are encountered in this mine at vertical distances that correspond with the four conglomerates next below the Greenstone near the Allouez gap.

It thus appears that the lowest conglomerate is the Kearsarge, with whose character at Calumet, on the Kearsarge location and at the Ahmeek location it here also agrees, except that its pebbles show less porphyritic feldspar. It is composed largely of pebbles of varying size, of a hard brownish rock, in whose aphanitic ground- mass there is much quartz in large grains or crystals. These pebbles lie in a cement of similar material, and near its footwall in several places the texture of the rock is so fine as hardly to be recognizable to the naked eye as conglomerate, but resembles rather that of a bed of compact quartz porphyry. This may be due to a crushing of large masses of the enclosed rock. Similar phenomena occur in conglomerate bed No. 7 (Marvine, Geol. Bur, Mich. I, Atlas, Pl. XIVa) on the south side of Portage Lake, which, according to Capt. J. C. Hodgson runs into a bed of "jasper" on the north side of the lake.

*Measured in a plane that cuts the plane of the vein at an angle of 86° 42'. The hade, underlie or underlay of a vein, is its inclination from the vertical—the complement of the dip. This explanation may seem superfluous, but the two terms, bade and dip, have recently been used as synonymous.

†See paper on "The Relation of the Vein at the Central mine. Keweenaw Point, to the Kearsarge Conglomerate", Proc. L. S. Min. Inst., 1895.

§ 5. Flattening of dips vertically.

On Pumpelly's cross-section of the Central mine (*Ibid,* Pl. XXIII) the beds show a general decrease of dip from south to north. Measurements by the writer in the lowest levels of the mine, near the Kearsarge conglomerate, show that the dip along the top of this bed decreases, in a distance of 500 to 600 feet, from about 27° at the south or higher end of the bed, to about 21° at the lowest part of the bed exposed in the mine. It also appears that this conglomerate bed is a mere seam of sandstone in the mine near the 27th level, its thickness increasing gradually from that point downwards until in the 32nd level—about 1300 feet on the slope—it is 57 feet. A similar wedging out, it will be remembered, was suspected to occur in the Bohemia conglomerate, southeast of this place. This difference of 6° in curvature of the top of the conglomerate may be due to the fact that we are here at the rim of the basin in which the conglomerate was laid down. In those parts of such a basin that are nearer its center, or farther down from its rim, the dip of the conglomerate probably represents its true niveau or relationship to other conglomerate horizons in the same series, more nearly than do parts of the conglomerate near its margin, and in the present case the dip of 21° establishes a flatter niveau for the lower beds of the series than for overlying horizons which near the surface, in this area, both south of the Greenstone and for a mile or more north of it, have a well established dip of between 26° and 27°. This observation, so far as it goes, is important. If it should be found to be generally applicable throughout the Keweenaw series, it would tend to negative the assumption of a gradual differential subsidence of those parts of the beds nearest the central parts of the Lake Superior basin, during the formation of the later overlying beds, for in the latter case the lower beds would dip *more steeply* than those parts of the higher ones, that were originally vertically above the former, or if the subsidence took place by the simultaneous and equal sinking of large areas, the successive conglomerate beds, other things being equal, would be *parallel*. The relations actually observed are, on the contrary, quite in harmony (1) with the general effect of an uplifting agency acting on the south side of Keweenaw Point, or (2) with the deposition of beds on a gradually decreasing slope.

§ 6. So called Kingston conglomerate,

"Marvine records an outcrop of a conglomerate 45 feet wide, 500 feet south of the center of Sec. 33, T. 58, R. 31.* He recognized the similarity of this bed in character to the Kearsarge conglomerate, further south, but on an assumed average dip of 28° between the Greenstone and the point of exposure, 5870** feet horizontally, he figured that this bed must lie 600-700 feet east of the Kearsarge. He says that if the dip were about 25° it would be the same bed as the Kearsarge. Now, with a dip of 26°, the vertical distance between the Greenstone and the "Kingston" is only 2573 feet, as against 2599 feet between the Greenstone and the Kearsarge in the Central mine. At the Cliff mine, about 2½ miles southwest, the Kearsarge conglomerate is according to Klepetko 40 feet thick, and horizontal and vertical measurements between beds there, made on Klepetko's cross-section, show that the assumed dip of the formation there is less than 26°. As I have already noted, the dip of the "slide" under the Greenstone at the Cliff mine is about 24°.† Marvine says that along a line between Eagle River village and the Phoenix mine, near the Greenstone, the dips decrease, coming south,‡ i. e., towards the lower beds of the formation.

We have just seen that in the Central mine, less than three miles northeast from the "Kingston" conglomerate, we find the Kearsarge conglomerate showing, where thickest, a dip of 21°. From the foregoing indications it is probable that Marvine, and Irving after him, assumed too steep a dip for the strata opposite and east of Eagle River gap, which resulted in making the estimates there too thick and in confounding the Kearsarge conglomerate with a bed which Marvine supposed lay east of it. It seems, therefore, no longer a question of doubt, that the so called Kingston conglomerate is not an independent bed, and as such must henceforth be dropped from the list of conglomerates.

*Geol. Sur. Mich , I, Pt. II. p. 114 In Marvine's description the township is erroneously printed as T. 57, and in Irving's the location is given as 500 paces south of the center of Sec. 37, T. 57, (Copper-Bearing Rocks of L. S., p. 176).

**Irving makes the distance 4650 feet, but this must surely be another typographical error for he would have no motive to remeasure the distance.

†See foot note, p. 76.

‡*Loc. cit*., p. 96.

§ 7. Fault in the Central mine.

The top of the Kearsarge conglomerate in the Central mine marks the bottom of the so called east vein, where the latter has evidently been faulted to the east above the conglomerate. What was formerly the downward continuation of this vein is found penetrating upwards to the hanging of the conglomerate at a point farther west which would make the amount of heave of the vein 284 feet. The upper part of the formation west of the vein is also thrown about 35 feet north.*

The top of the Kearsarge conglomerate is in places for three or four feet down much decomposed, and altered to epidote, calcite and prehnite—an alteration that seems to be more general at points where there are numerous indications of fissuring and brecciation of the conglomerate. Above this bed is generally found a layer of fluccan, reddish clayey material, sometimes hard and compact, but usually moist and soft, and in places containing small ellipsoidal† forms as of pebbles, which also seem to be of similar decomposed character to the clay that encloses them. Above this clayey material is a bed of blacker brecciated material, very fine and chloritic near the fluccan, but growing coarser towards its upper side where it merges gradually into a bed of compact ophite. This breccia bed is in many places 10 to 15 feet thick, and together with the faulting of the vein is evidence that there has been a shearing movement or slide-faulting along the upper surface of the conglomerate. The strike and dip of the conglomerate and the strike of the vein being known, it is possible to compute the amount of sliding down the conglomerate in the direction of greatest dip, necessary to produce the given amount of heave of the vein. This is one of only two cases,‡ so far as known to the writer, where the posssible amount of sliding along beds of the Keweenaw series can be established, and in view of the probable prevalence of this phenomenon throughout the series, and its intimate connection with the structure of Keweenaw Point, a somewhat detailed discussion may not be out of place, although it might more properly belong in a later chapter.

*In the article above referred to (p. 102), I thought from an inspection of the west level that the ground west of the west vein had been faulted downwards, but later work by the miners showed the rock west of the vein in the 30th level to be a porphyrite, like the bed under the conglomerate. This would make the throw on this side up instead of down.

†This phenomenon is very common along slide-faults on Keweenaw Point, especially between the traps and the eastern sandstone. See discussion by N. H. Winchell, Geol. and Nat. Hist. Sur., Minn., 23rd Ann. Rep., p. 15.

‡The other case is that of the Armstrong vein at Eagle River, where Marvine computed a fault of 150 feet. Geol. Sur. Mich., I, Pt. II, p. 128. He does not give the data on which his computation is based.

§ 8. Slide-faulting on the Kearsarge conglomerate.

In order to represent the conditions noted in the Central mine, let A B D C, in Figure 10, represent a vein dipping to the right, or east, and extending downwards through a bed G H G’’ H’’ at C D. Let G H, a horizontal line, represent the strike of this bed, and G H K L a horizontal plane cut by the vein along C E, which latter is thus the direction of the strike of the vein. The angles K G G’ and C’ C C’’ will represent the dip of the bed G H G’’ H’’; the angle T A C the dip of the vein; the horizontal angle E C C’ the amount of difference between the direction of strike of the vein, and the "dip-plane" of the bed G H G’’ H’’, which is at right angles to the strike of the bed, and may be represented by the plane C’ C C", or any plane parallel to it.

If we imagine a block of “ground” OH’RH as sliding down the plane of the bed GHG’H’’, in the direction of steepest inclination, i. e., of its “dip-plane,” CC’’I, this block will come to rest at O’H’’R’H’, and the vein *above* the bed will assume the position A’’B’’D’’C’’. C’’D will then represent the distance apart of the original and new positions of the vein measured along the strike of the bed GHG''H'', a measure which we may here, for convenience, call the "lateral displacement" of the vein. If this line, C''D, were at right angles to the plane of the vein, ABCD, it would represent the true heave of the vein. The smaller angle DCC'', the more nearly do the amount of heave and the "lateral displacement" coincide. CD and C''D'' represent the two intersections of the vein with the slide-plane. If C''D, and the angles C'CC'' (the dip of the bed GHG''H'') and TAC=ACG (dip of the vein) are known, we can determine CC'', i. e., the amount of slipping or slide-faulting, CI, necessary to produce a lateral displacement equal to C''D.

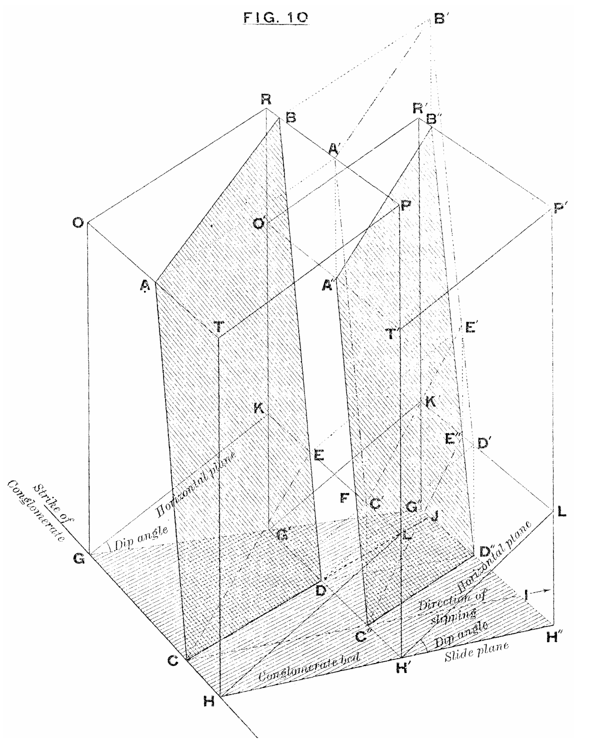

Figure 10. To determine the amount of slide-faulting along a tilted bed, necessary to effect a certain amount of heave in a vein cutting that bed.

On the principle of the parallelogram of forces, the motion of the block down the slide-plane may be resolved into two motions, one horizontal and the other vertical. The points C, A, and B may be considered as moving first to C'A' and B' respectively, and thence to C", A" and B" respectively. The vein would then theoretically first assume the position A'B'D'C', and would then have a lateral displacement represented by C'E. In moving vertically downwards, however, owing to its eastward dip the vein again approaches its line of intersection with the conglomerate further north, or reduces the amount of the lateral displacement gained by its horizontal movement. It cannot altogether overcome the displacement when the dip of the vein in the direction of the dip of the conglomerate is steeper than that of the conglomerate. The effect of a dip of the vein may best be appreciated by following the point G in its assumed movement to C' and then to C". Between C and C' it is constantly going further from the original plane of the vein, but from C' to C" it again approaches the original position of the plane of the vein, but (in the case in hand) at a slower rate. During the latter movement it loses an amount represented by C'F.

In order to ascertain the amount of sliding necessary to produce a given displacement, we must determine:—

1. The amount of horizontal movement, x, along CC', necessary to gain one foot laterally in the direction EC'.

2. The amount of lateral displacement, y, lost for every foot of vertical movement along C'C".

y = tan hade of vein.

3. (a) The amount of vertical movement, z, corresponding to the horizontal movement, x.

This depends altogether on the dip of the slide-plane, and equals x times tan dip of slide-plane.

(b) The amount of lateral displacement lost during the vertical movement, z, or during its corresponding horizontal movement x, equals yz, and

(c) The net amount of lateral displacement corresponding to x, equals 1 — yz.

4. The amount of movement down the slide-plane, corresponding to the horizontal movement x, equals $\frac{x}{\text{cos dip of slide-plane}}$.

The amount of lateral displacement corresponding to the sliding movement is the same as that which corresponds to x, as found under 3 (c).

5. The ratio of lateral displacement to motion down the slide-plane, when the total amount of the former is known, determines the total amount of the sliding.

By applying the foregoing to the data gathered at the Central mine, we find

1. In the triangle CC'E, if we make C'E=1 ft., C'CE=:30 18', ∠ CC'E = 90°. C 'E:CC' = sin 8° 18' : 1, CO' = $\frac{1}{\sin 3° 18'}$ = 17.3432 ft =x.

2. In the triangle FC'C", ∠ FC''C'=5°27' (the apparent hade* of the vein), and FC'C'' = 90°.

Then C'F = tan 5° 27'=0.095408 ft.=y.

3. (a) In the triangle CC'C'', ∠C'CC'' = 20° 48', CC'=17.3432 ft, C'C'' = tan 20° 48' times 17.3432 = 6.588 ft.

*The apparent hade is greater than the true hade by a very small quantity which for this demonstration may be neglected,

(b) yz = 0.095103 times 6.588 = 0/62855 ft.

(c) 1-yz = 1-0.62855 = 0.37145 ft.

4. In the triangle CC'C'', ∠ CC'C" = 20° 48', CC' = 17.3412 ft., CC'' = $\frac{17.3432 \text{ ft.}}{\cos 20° 48'}$ =18.55 ft. =z. This motion down the slide-plane corresponds to a lateral displacement of the vein of 0.37145 feet.

5. 18.55 : 0.37145 = x : 285 x: = 14,233 feet.

It is thus possible, under the conditions stated, that the part of the Keweenaw series that lies above the Kearsarge conglomerate has moved from its original position, in a northerly direction, horizontally, about 2.7 miles, or along an inclined plane its equivalent distance of about 2.9 miles. These conditions are, first of all, that this movement took place down the steepest part of the conglomerate bed, and further, that the measurements of strike, dip, etc., of the conglomerate and of the vein—on which this result is based—are free from error. These measurements were made in part by Mr. Theodore Dengler, with instruments of precision, and in part by the Geological Survey, the latter being by pacing, but reasonably accurate.

In the foregoing computation the most conservative figures were taken, so that it is confidently believed that the result is not to any great extent exaggerated. If the dip angle of the conglomerate had been taken as 26° 56/, instead of 20° 48', the possible amount of horizontal motion would have been nearly 35,000 feet, or if the hade of the vein had been taken as 7° 42', which it actually is from the 9th level down, this amount would have been over 44,000 feet. Without attaching any great importance to these figures as indexes of the actual or even approximate amount of sliding that has taken place along the plane of the Kearsarge conglomerate, the demonstration is important as establishing, as above stated, a phenomenon thought to have been frequent on Keweenaw Point, and one that may have been to some extent a factor in the shaping of its topography, and intimately connected with its copper deposits.

§ 9. Conditions necessary to sliding of beds.

It needs no argument to show that for the explanation of a sliding movement such as that above described between beds of the same series, no recourse need be had to complicated causes. Planes of weakness in or between beds of the formation and a tilted position of the beds, whether from original deposition, or from a force acting at one point which depresses them (sedimentation), or from a force acting at another point which lifts them (intrusion), or from a folding which lifts or which depresses different parts unequally, are all that are necessary. If the dip be steep enough, gravity or the principle known as isostasy will tend to restore equilibrium, and the higher parts of a series will shear or slide over the lower parts or one series will shear, over a lower one. The tops of sandstone and of conglomerate beds, from their evenness, afford planes of greatest weakness for the accomplishment of this movement.

Whether the fluccan of a conglomerate bed is in every case to be regarded, in whole or in part, as a product of some such sliding or shearing movement, or altogether as a layer of mud which covered the conglomerate at the time the overlying lava bed flowed over it, can not well be determined, but the sudden transition from coarse, solid conglomerate to fluccan should seem to indicate a different origin for the latter than as a mere stage in the conditions of deposition under which the conglomerate was laid down. Besides, we have the analogy of cross-fissures in which the presence of fluccan in connection with slickensides is clearly referrible to a sliding, or rubbing together of the two walls.

Having shown one sliding movement to have occurred in the Keweenaw series in connection with more or less finely ground rock material, we may naturally and logically infer that similar movements have taken place along other conglomerate planes where we now find fluccans. Indeed, the several conditions above set forth, as preliminary to slide-faulting, are such as to carry with them the conviction, without need of demonstration, that where these conditions exist in so marked a degree as on Keweenaw Point, extensive shearing must have taken place.

§ 10. Occurrence of fluccan.

A. Within the Keweenaw series. In the various cross-sections and literature of the Keweenaw series that have heretofore been published, there are found frequent references to beds of "chlorite," fluccan, clay, and to "slips," nearly all of which, like the fluccan in. the Kearsarge conglomerate, are conformable with the ordinary beds of the series. Thus the Allouez conglomerate, as already noted,* is represented at Eagle River by a red clay seam six inches thick, called in early reports "the slide." This bed about two miles south- west of Eagle River gap, between the Cliff and Albion locations, is characterized by Foster and Whitney as a "thin belt of slaty chlorite about twelve feet in thickness."† At the Allouez mine this conglomerate shows about 6 inches of fluccan (clay) on the hanging wall, and in places itself attains a maximum thickness of 30 feet. About 16 feet from the foot wall there is a "sandstone slip."‡ At Calumet this bed varies from 6 inches to 8 feet in thickness and is designated in a cross-section§ by the officials of the Calumet and Hecla mine simply as a conglomerate, no mention being made of any fluccan. At the Peninsula (Albany and Boston) mine, latterly called the "Franklin Junior," about 4½ miles southwesterly from Calumet, the hanging of the Allouez conglomerate is described as fluccan 5½ feet thick. In the new adit southeast of the Quincy mine, about 4½ miles southwest of the Franklin Junior mine, the same bed is represented by a well marked seam of clay, within 50 feet of which and parallel to it, there are several "slips" in the contiguous beds.

The Houghton conglomerate does not appear at Calumet. At the Franklin Junior mine it has 3 inches of fluccan and at the Quincy mine adit a seam of clay, 1½ feet thick, on its hanging wall. In the Franklin Junior mine also, the Calumet and Kearsarge conglomerates are capped by fluccans respectively 4 and 16 inches thick.

Above the Greenstone at Eagle River a "slide" is noted by Marvine on the hanging of the first sandstone above the Ashbed and a similar slide occurs at about the same horizon in the Copper Falls mine.‖ The Kearsarge conglomerate at the Ahmeek location, as already stated, has 2 feet of fluccan on its hanging wall. None is recorded on the same bed at Calumet. Capt. J. C. Hodgson, reports two feet of fluccan on the *footwall* of the Wolverine sandstone. In Sec. 25, T. 56, R. 83, according to the same authority, there is a 4-foot belt of fluccan interbedded in the Keweenaw series (Fig. 9).

*Geol. Sur. Mich.. I. Pl. II. p, 115.

†F. and W., Pt. II, p. 127.

‡According to Mr. Fred Smith, the Agent.

§Geol. Sur. Mich., V, Pt. I, Plate.

‖Capt. J. Vivian says this runs into the Ashbed at the Phoenix, so that it is not strictly parallel to the formation.

B. Along the contact with the Eastern sandstone. Beside the above occurrences, within the Keweenaw series, similar material has been noted by many observers at different points along the junction between this series and the Eastern sandstone. Foster and Whitney early called attention to the belt of "fissile chlorite rocks"* which continues from Mt Bohemia "almost uninterruptedly to Portage Lake and always preserving the same relation to the trap and sandstone," that is, between them. Trying and Chamberlin have described in detail an occurrance of this kind at Bête Grise Bay.† Wadsworth mentions a fault breccia 2 feet thick in Sec. 6,-T. 54, R. 33.‡ In the same section at another exposure (further south) this breccia band is at least 9 feet thick. Not at all points of contact between the two series is the amount of breccia or fluccan equal, and there are even some points, particularly near the end of Keweenaw Point, where no fault breccia is noticeable between the sandstone and traps. The dips noted at these various points are in general steep, and there is no reason to doubt that the same sliding movements noted within the Keweenaw series, have taken place also at its edge, along the contact with the Eastern sandstone, at some points greater, at others less, and at others again, perhaps not at all.

*Loc. cit., pp. 65, 66.

†Bull. U. S. G. S., No. 23, page 20.

‡Report of the State Board of Geol. Sur., Mich., 1893. p. 163.

§ 11. Topography as affected by slide-faulting.

The Kearsarge slide-fault, which was not confined within the limits of the east and west veins at the Central mine, but extended beyond them, to the east and to the west respectively, no one knows how far, and possibly other similar slides higher or lower in the formation, may have left their impress on the topography of Keweenaw Point. The Central mine lies under the southern face of the Greenstone bluff, which from near the east line of T. 58, R. 28, forms the northern escarpment of the valley of Little Montreal River, and of Eagle River further west, thence curving southwards to the headwaters of the Trap Rock River near the Allouez gap. These two valleys of the Little Montreal and Eagle rivers form a depression between the Bohemian Range and the Greenstone Range that is 250 to 350 feet below the summit of the latter, and even more than that below the summit of the former. This depression is to a great extent covered by glacial drift, and is itself the result of pre- glacial erosion, and possibly, in some measure, of the sliding that took place along different horizons. From figures already given we can show that the plane of the Kearsarge conglomerate, if extended upwards from the edge of the bed as exposed in the Central mine, with a dip of 27°, which is about that observed on the highest part of the bed, would make the horizontal distance between the Allouez conglomerate at the base of the Greenstone and the extension of the Kearsarge plane opposite the Central mine, 5775 feet, or upwards of a mile. This would bring the plane of the Kearsarge conglomerate to the surface there, if the latter has the altitude of the Allouez conglomerate at the Central mine, at a point somewhere near the southeast corner of Sec. 26, T. 58, R. 31.

If the Greenstone ridge has actually moved respectively northward and westward by an amount equivalent to 2.7 miles horizontally, its southern face must previously have been nearly as far south as the center of Sec. 1, T. 67, R. 31, or immediately above the summit of the Bohemian Range. This would bring the south and east face of the Greenstone Range nearly if not quite into coincidence with the southeast slope of the Bohemian Range, the two forming one continuous mountain slope. In suggesting a theoretically possible former continuity of the eastern faces of these two ranges, I wish simply to point to the probability that, even if no such continuity existed, there may at least have been a large amount of movement of the upper part of the series away from the present line of contact with the Eastern sandstone, and that the greater the amount of this movement, the deeper and wider would be the resulting valley between the two ranges and the less would be the amount of succeeding erosion required both to carve out the valley and to reduce the crest of the sliding portion to its present level. The dip of the Kearsarge fault, where we now find the latter, is comparatively flat. With an increase of the angle of dip of the fault plane a correspondingly less amount of sliding would be necessary to reduce the altitude of the surface to a similar level, so that corresponding faults nearer the contact with the Eastern sandstone, where the dips are in general steeper, and where we should therefore naturally expect slide-faulting to be of more frequent occurrence, would, other conditions being favorable, tend to lower the general altitude of the series in a much more marked degree.

On the other hand, if the shearing in evidence along the Kearsarge conglomerate and other beds be only an incident in the process of folding to which the Keweenaw series has been subjected, we may have to attribute the valley of Eagle River and the Little Montreal largely if not entirely to the corrasive force of the ancestors of those streams, which, sinking along the slope of the formation, have attacked the softer beds under the Greenstone and gradually undercut the latter and carried away its debris. We may then derive from this alternative some idea of the magnitude of the erosive agencies that have been at work since the emergence of Keweenaw Point took place. The two forces, erosion and slide-faulting, thus seem to have worked to a common end, the one as a complement of the other. The greater the one, the less necessity was there for the other. Together they have reduced the level of Keweenaw Point to its present altitude. Slide-faulting along the planes of the Kearsarge and Allouez conglomerates, in the Eagle and Little Montreal River areas, would carry the higher beds north and west down towards the lake, in decreasing curves, which would have the effect of extending the shore line somewhat northwest and exposing in those areas flatter dips than if such faulting had not occurred. Whether this may be the explanation of the curve of Keweenaw Point and the contrast in dips between its northern area and the Portage Lake area, or whether these phenomena are due to other causes, cannot be determined more definitely as yet.*

*See page 62.

§ 12. Structure of the Lake Superior basin.

We have thus far confined ourselves to the Keweenaw series as seen practically from one side of the basin only, and have laid down some broad principles, and have stated some facts not heretofore generally known. Let us extend our observations for a moment over the entire series. We know, as already stated, that dikes of eruptive rocks occur on the North Shore as well as on the South Shore. We may, therefore, suppose that some of the Keweenawan, lava sheets originated on the North Shore. In the earlier part of this volume Dr. Lane has shown that the succession of rocks appears to be closely similar on each side of the lake, but that the thickness of the series on the North Shore is only two-thirds of its thickness on the South Shore. Unless we suppose that for almost every lava flow from the South Shore, an outflow of similar character occurred contemporaneously on the opposite shore—which is not likely—we must conclude that at least the basic flows came principally but not necessarily altogether from the same shore; that those beds that reached the bottom of the basin may have spread out to its opposite side, and encroached upon the shore line there from time to time. If the slope on the opposite side were gentler than on the side from which the majority of flows came, the beds at the former point would spread out thinner than at the latter point—a section through them would be shorter.

Now, unless we conceive it probable that a conglomerate bed, as such, can form *continuously* across a deep basin 30 or 40 miles wide, we must assume that the conglomerates of the Keweenaw series are merely marginal facies of deposition in the Lake Superior basin, i. e., that their rims were built up either on earlier lava beds or on the underlying Archean higher up the basin sides. The latter, therefore, as the name indeed implies, must have sloped towards the basin center and the lavas that formed a part of them must also originally have had a gradient, as has already been assumed. That conglomerates were thus laid down on lava beds is additional evidence that many of the latter must have flowed into or under water. If we assume that originally the steeper gradient was on the south side of the basin, and the gentler gradient on the north side, lava flows from one side or the other, if thick enough, could cover the basin floor and encroach more widely on the north or flatter shore, becoming thinner towards their margin. We should then probably find steeper original dips on the South Shore for beds extravasated there* and a thicker aggregate of beds than on the North Shore. Today we find the beds of the Keweenaw series dipping from each side of the lake towards its center, the lower, or earlier beds more steeply at their highest points than the later beds. Along the southern edge of the series, we find acid rocks, distinctly intrusive, that may have contributed to these steeper dips and some others that may be a part of the underlying Archean. Near the northern margin of the series, on Pigeon Point, we find similar acid rocks of undoubted intrusive nature, and on Isle Royale acid rocks of probably similar origin.** Further back, on each side of the lake we find the Archean. Thus in their main features the two sides of the basin appear to be similar in the character of their rocks and in their structure. The flat dips of the North Shore lavas to the south may be due to intrusions and to folding.

I have now slated the principal observations (anticipating several) on which I have endeavored, in passing, to erect the frame of a working hypothesis. These observations have been given in great part in the order in which they were made. The systematic arrangement of field observations covering so large an area, and suggesting so many deductions, must always be a matter of great difficulty, and I cannot claim to have succeeded in this particular to the extent that the subject demands. Parts of this hypothesis are offered with some diffidence, because they are opposed to the views of some very eminent and very experienced investigators of Lake Superior geology, and, on the other hand, with some confidence, because I believe them to involve fewer assumptions, and to be the more natural deduction from certain observed phenomena, than some views heretofore advanced. Owing to the fact that the examination of the copper district in Michigan is not yet completed—much less that of the other parts of the series in neighboring states—it would be very venturesome to state in precise terms any theory as to the life history of the Keweenaw series, or to claim infallibility for it, when stated. I have, therefore, in submitting the facts observed by the Survey, drawn certain inferences, which I wish to be considered largely as tentative. If they should bear the test of time we may finally, when all the facts are in, arrive at a satisfactory ex- planation of many questions that have thus far been difficult of solution. In the following pages I shall have occasion to enter some- what further into a discussion of the same subject and shall reserve until later a résumé of the conclusions to which my investigations thus far have led me.

*The steeper dips above the Greenstone at Eagle River may be due to this cause, or these beds may originally have had a steeper gradient than the underlying Greenstone because of their greater acidity and consequently greater viscidity. See Chapter III.

**Bayley. The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and their Contact Phenomena. Bull. U. S. G. S., No. 109, 1893.

CHAPTER V. ACID ROCKS OF THE PORTAGE LAKE AREA.

§ 1. Wall Ravine to Douglass Houghton Falls.

In Wall Ravine, Sec. 20, T. 56, R. 32, near the hanging of the St. Louis conglomerate, we find a few ill exposed outcrops of a felsitic rock carrying large numbers of small spherulites. The exact relations of this rock to the conglomerate cannot satisfactorily be made out; there are no positive indications that it is intrusive. Its presence here, at one point near the hanging of the conglomerate and at another near its footwall, may, however, be taken as a point of resemblance of this horizon to that of the Bohemia conglomerate at the Little Montreal River, where we found conglomerate beds and acid flows in alternation, and above which no original felsites have thus far been noted. This bed is thus an additional indication of the probable identity of the two conglomerates, the Bohemia and the St. Louis. Apparently below this horizon (Fig. 9) there is a bed of "jasper," exposed in the face of the water-fall in the next section southwest (Sec. 30), which is probably the northward continuation of the quartz porphyry noticed by Merriam below Douglass Houghton Falls,* in Sec. 36, next southwest.† It is a fine grained dark red rock, resembling much the felsites of the Bare Hill area, but carrying more free quartz (S. 12887), and is underlain by a fine grained porphyrite. At the point of exposure it dips westerly about 33°. No outcrop that closely resembles this bed has been seen except the one at Douglass Houghton Falls, but in Sec. 36, T. 56, R. 33, a short distance southwest of the latter falls, in the ditch on the west side of the Torch Lake and Calumet R. R., there is a small outcrop of coarse quartz porphyry, described by Irving.** It is a similar rock, as Irving pointed out, to the pebbles that characterize the Allouez conglomerate at the Albany and Boston (Peninsula, Franklin Junior) mine in Sec. 8, T. 55, R. 33, as well as the Calumet conglomerate at Calumet. No outcrop of original acid rocks has been found between here and Portage Lake unless a thin bed of "jasper" be such, that is marked as No. 6 (7?) of Marvine's conglomerates.††

On a previous page (82) reference was made to the theory of Von Richthofen. We have seen that the felsites interbedded with the Bohemia conglomerate mark the culmination of acid eruptions and flow on Keweenaw Point in this part of the Keweenaw series. We have traced this horizon, not everywhere equally acid, and marked by rocks that vary from fine grained to coarse, down to the vicinity of Torch Lake. Above this horizon lies the vast mass of the known Keweenawan, but nowhere in the latter, in this area, do we find original rocks of equally high acidity. The intrusive felsites of Fish Cove, of West Pond and of Bare Hill, being later than those of the Bohemia belt, can therefore not be connected with any known similar rock elsewhere that is interbedded with the melaphyres and conglomerates (i. e. extrusive). Whether they reached the surface other than by denudation we do not know. They are important only as marking a second period during which very acid magmas were active within the crust of the earth, or better, perhaps, the end of the period of activity of very acid magmas that began back in the Huronian.

We know, however, of several horizons in the series on Keweenaw Point that are marked by rocks of medium acidity. The porphyrite on the east side of Fish Cove Knob is one of these. Another is the porphyrite above the Lac la Belle conglomerate at Bare Hill and in Sec. 30, west of the latter, probably also under bed A, Sec. 26, T. 58, R, 28 (Pl. II). Above the Bohemia belt we find next below the Kearsarge conglomerate another rock of medium acidity, followed, higher in the series, by the porphyrites of the Ashbed group. Thus there are already known on Keweenaw Point at least five, more or less well-marked horizons of medium acid to very acid rocks. It will be of interest to see whether these horizons are persistent further south, throughout the series, and whether each one is similarly acid elsewhere.

*Bull. U. S. G. S., No. 23, p. 43.

†There is an apparent discrepancy between the location of this porphyry by the Survey and that of Capt. Hodgson's map. According to the former the falls in Sec. 30 are further west, and the porphyry between the falls and the point where exposed in a trench farther south, strikes more southerly than in Fig. 9. In either case, however, the horizon of the conglomerate in Sec. 30 appears to be above that of the porphyry.

**Copper-Bearing Rocks of L. S., p. 196.

††Geol. Sur. Mich, I, Atlas, Pl. XIV b.

§ 2. St. Louis conglomerate south of Wall Ravine.

The St. Louis conglomerate has its greatest observed thickness at Wall Ravine, in Sec. 20, T. 56, R. 32, where it is exposed for about 70 paces along the sides and bed of the ravine. At this point it is in contact with the Eastern sandstone, and near the line of junction it is so much shattered and altered as to be, in places, almost unrecognizable as a conglomerate. From here southwesterly it is seen at frequent intervals in natural exposures and in mine pits and adits as far as the St. Louis ravine near the south line of Sec. 19. Here, at the old stamp mill it is only 6½ feet thick, dips 47° N. W. and strikes N. 36° E.*

The next indications of a detrital bed southwest of Sec. 30 in this general horizon are at Douglass Houghton Falls, where, about 40 feet above the bottom of the ravine, in the face of the wall over which the stream is precipitated, there is a 4-inch seam of sandstone that appears thus far to have escaped the notice of the many geologists that have examined this historic spot. It dips northwest about 22°-23°, and apparently strikes N. 20° E., or even more to the east. It is medium fine grained, with a dark red basic matrix. This seam lies between beds that are very much brecciated, the lower one being apparently the thicker and the more brecciated. They are very chloritic and red, and one cannot say positively what the rock was originally, whether conglomerate or trap. There are so many slips in the formation here that the position of the sandstone with reference to the quartz porphyry could not be positively determined, but the latter seems to be below the former. This brecciated zone with its sandstone may possibly be the horizon of the St. Louis conglomerate, which, as we have seen, was thinning out rapidly towards the southwest and lay above the porphyry. The foot of Douglass Houghton Falls is about 130 paces from the contact with the Eastern sandstone down stream. We have already noted just south of Wall Ravine the occurrence of trap for about 200 paces below the conglomerate. The joint planes of the trap beds at the top of the falls, dip northwesterly about 24°. From this point, which is 368 feet above the level of Torch Lake,† only basic rocks are exposed in the stream bed, westerly, as far as the Calumet road.

*Bull. U. S. G. S., No. 23, p. 28. According to Foster & Whitney, the dip here is 42°.

†*Ibid*., p. 49.

§ 3. Conglomerates southwest of Douglass Houghton Falls.

From the Allouez gap to Sec. 30, T. 56, R. 32, the section northeast of Douglass Houghton Falls, the course of the St. Louis conglomerate has been very close to that of the contact between the Keweenaw series and the Eastern sandstone. That course, if continued southwest, would carry the conglomerate near the horizon of the Torch Lake quartz porphyry, but as indicated above, the conglomerate has probably wedged out before reaching the porphyry. The latter outcrop is only a few feet in diameter, but whether it is, (1) intrusive, (2) Interbedded, or, (3) belongs to the underlying Archean, we have as yet no means of knowing. If intrusive, the porphyry is probably older than the Kearsarge conglomerate, because the latter and subsequent beds contain many pebbles that resemble this porphyry; probably younger than the St. Louis conglomerate and the contact conglomerate further south, for these do not seem, to contain a similar rock. Moreover, it is quite apparent from the regularity of the strike of the beds higher in the series opposite this point, that the intrusion, if there was one, was either quite early in the history of the series, or else its effects were either not violent or not far reaching.

The next conglomerate outcrop southwest near the Eastern sandstone contact is found in Sec. 11, T. 55, R. 33, at 1400 paces N. 400 paces W., of the southeast corner, or about 1 2-3 miles from the Torch Lake porphyry. (See Pl. VIII.) It is well exposed here on each side of a stream for about 8 paces in width, dips westerly 36°- S8° and strikes N. 15° W. The position and strike of this bed are in harmony with the suggestion (1) that it curves around the Torch Lake porphyry, that Is, that it was lifted and flexed by the latter. If It shall be found not to contain pebbles of this porphyry—the Survey has noted none—the above suggestion will have the force of strong probability. On the other hand, should fragments of this porphyry be found in these conglomerate beds the porphyry may be (2) interbedded, or (3) it may belong to the Archean.

We appear to have entered here an area that differs from that immediately adjacent to the St. Louis conglomerate north of the Torch Lake porphyry. The overlying melaphyres seem to be less crystalline and more amygdaloidal than the beds at the more northerly point, and the conglomerate itself, as we shall see, follows a very irregular course. That we may be in a different horizon and that the conglomerate here may not be a continuation of the St. Louis bed is quite possible. For this reason I shall provisionally, at least, call the former the "contact" conglomerate.

About half a mile almost due south of the above outcrop the conglomerate next appears at the upper falls on Hungarian River, almost in contact with the sandstone, only a bed of trap separating them. It dips westerly about 33° and strikes about N. 12°' E. For nearly half a mile above the falls the melaphyres and amygdaloid^ are much shattered. No other conglomerate was observed there.

From this point southwest the same conglomerate is found exposed in the beds of small streams, and probably at about 800 paces N., 1875 paces W., of the southeast corner of Sec. 14, T. 55, R. 33. In Sec. 22, about 750 paces W., near the north line of the section occur outcrops of sandstone and of a conglomerate with a very sandy matrix. The pebbles in the conglomerate are subangular and some of them are of quartz porphyry. The dip is about 50°-54° N. W., strike about N. 45°-50° E. The stream is full of slabs of these rocks and one or two hundred paces up the stream there are several large blocks of red sandstone on the east bank. I believe that this conglomerate is a part of the Eastern, sandstone series.

Further west, along the north line of Sec. 22, near the north quarter-post, a larger stream shows exposures of a conglomerate that carries many rounded pebbles, principally of acid material, with a small amount of quite coarse matrix. No bedding is noticeable and the rock looks much like a recent deposit except that the pebbles are more abundant, and the cementing material harder, than usual. This may be a part of the bed we have traced from the northeast. About 75 paces west of the north quarter-post of Sec. 22, just south of the line, and also higher up the stream in Sec. 15, there are several outcrops of rock with very abundant amygdules, largely of calcite, and to a less degree of an amorphous white substance. The dip of these beds is apparently very flat, as low as 15° or less.

The junction of the Keweenaw series and Eastern sandstone is next seen about a mile further west (1750 paces N., 850 paces W.) in Sec. 2.1, T. 55, R. 33, on the banks of a small stream that flows south. A conglomerate here, underlain by trap, strikes N. 72° E., and dips northerly 44°, the trap being in contact on the south with the sandstone, which is much broken and disturbed but appears to dip rather flat to the N. E. The sandstone here is 414 feet above the level of Portage Lake. From this point the sandstone contact can be traced south west; past the west quarter-post of Section 21 (Alt. 416 feet above Portage Lake); through Sec. 20, into Sec. 29; thus making a sweeping curve to the south (Pl. VIII). At several points along this contact in Sec. 20 a conglomerate outcrops and is in places underlain by trap, compact or amygdaloidal, and appears to run very nearly parallel with the contact line, but whether it is the same bed in all cases can not be positively affirmed. Further south in Sec. 29, in very nearly the same horizon, occur three outcrops of conglomerate, two of which may possibly belong to one and the same bed. No satisfactory correlation has thus far been made between any of these and the bed in Sec. 21. The strike of these beds, however, corresponds more nearly though not exactly with that of beds higher in the series, and is thus in contrast with the strike of the former—N. 72° E. Whether the latter bed be the continuation of the "contact" conglomerate followed from Sec. 11 north of Hungarian Falls through Secs. 14 and 22 is a matter of inference.

If we follow the courses of several conglomerates where they can be traced connectedly, we see that from Wall Ravine the St. Louis conglomerate appears to have run southwest with the usual strike of the overlying beds and probably to have wedged out somewhere north of the Torch Lake quartz porphyry; that a conglomerate close to the contact of the traps and Eastern sandstone first again comes to view in Sec. 11, 1 5-8 miles south of the porphyry. Here, however, the conglomerate strikes S. 15° E., and must soon curve westward as it goes south, for at the next exposure at Hungarian Falls, it strikes S. 12° W. and continues from this point through Sec. 14 with a strike about S. 40° W. If the conglomerate seen on the north line of Sec. 22 is a continuation of this bed, the latter is certainly swinging enough more to the west to merge with the conglomerate in Sec. 21 (1750 paces N., and 850 paces W.), and must there have a strike nearly east and west. That it should swing back from this point, into line with some of the conglomerate outcrops of Secs. 20 and 29 is no more improbable than that it here runs east and west. Whether or not we accept the latter correlation of this contact conglomerate, we are at least positive of its course in Sec. 11 (S. 15° E.), and see that this is quite out of conformity with the higher beds of the series. This is not the only case of the kind that we shall meet in this part of the series and in this area. We may account for it by supposing that a wide section of the trap series between Sec. 21, T. 55, R. 33, and the head of Torch Lake has been faulted east and let down against the Eastern sandstone. The presence of a small north and south fault in Sec. 21, and other evidences of disturbance in the traps, the flexure of the Eastern sandstone at the contact, and the fact that it *apparently* underlies the traps, the flatter dips and irregular course of the contact conglomerate, all lend color to this suggestion, and that some such movement has in fact taken place in this area is not at all improbable, but that it was on such a scale as to account for the apparent flexure in the contact conglomerate—its deflection from parallelism with overlying beds—is improbable. Besides, the different character of the beds immediately above the conglomerate—more amygdaloidal than those above the St. Louis conglomerate opposite Wall Ravine—should seem to indicate, as previously remarked, a difference of horizon for the two conglomerates, or, if these are in fact coeval, it may indicate either that the more southerly portion was deposited along the margin of an embayment (See Fig. 7), or was flexed by some orogenic movement early in the history of the series. Whether the two conglomerates represent the same or different horizons is, so far as the present discussion is concerned, of little moment. The curve of the contact conglomerate represents a trough that was filled by a series of rather thin lava flows, before the period of the more massive flows began that we find above Mar vine's conglomerate bed No. 3. (Geol. Sur. Mich., I, Atlas, Pl. XIVa). The question arises: Can not this trough have been in the rim of an early Keweenawan or pre-Keweenawan basin, and are not the low dips of the early beds and the high dips of the later beds and the irregular course of the contact conglomerate thus best accounted for? If this area had been near the center of a basin, would not the lava beds that flowed into it, and the conglomerates that lined it, be more nearly conformable? If early intrusions be answerable for the flexure of the conglomerate, such intrusions, lifting the strata, would thereby form raised margins to the surrounding depressions, and the resulting structure would be the same. The locus of the intrusions would thus become the rim of a basin.

§ 4. Conglomerates south of Portage Lake.

In Sec. 31, T. 55, R. 33 and in Sec. 6, T. 54, R. 33, next south of the former on the south side of Portage Lake, two conglomerate beds have been traced, one of which seems to be the continuation of the bed we have been following. They are Nos. 1, 2, and 3 of Marvine.* His beds Nos. 1 and 2 are thought to be one and the same bed, which appears to run nearly north and south through Sec. 6, and outcrops on the north line of that section, 500 paces E. of the N. W. corner.

The divergence of the two conglomerate beds is seen on the map (Pl. VIII), and the curvature of No. 1 marks this bed as being possibly the southward extension of the so called contact conglomerate, which we have traced on the opposite side of the lake. It at least calls to mind the sinuous course of that bed. A heavy covering of drift conceals the respective positions of these beds nearer Portage Lake. Between these two conglomerates, that is, No. 1 and No. 3, occur a succession of scoriaceous beds uncovered in a line of trenches in Sec. 6, T. 54, R. 33, dug by Mr. Mabbs† across the property of the Isle Royale, Mining Company, as far east as the sandstone contact. No conglomerate was found in these trenches below No. 3 until the contact conglomerate was reached—an additional piece of evidence—so far as it goes—for considering Marvine's conglomerate No. 2 as the northward extension of No. 1. The space between conglomerate No. 3 and the contact conglomerate is thus seen to be bowl-shaped like, the embayment in Secs. 11, 14 and 15 on the opposite side of the lake (Pl. VIII) and to be filled, like the latter, with rocks that differ radically from the coarsely crystalline rocks immediately above conglomerate No. 3, and similarly, from those above the St. Louis conglomerate at points north of the Torch Lake porphyry. Conglomerate bed No. 3, then, seems to mark for the south side of Portage Lake the bottom of that part of the series whose beds show a widespread conformity of dip and strike, as well as a more massive and crystalline character. It thus marks an era when this part of the Keweenawan area was being leveled up by the filling of pre-existing channels in the rim of the basin. That area was gradually thickening and expanding eastward, up the side of the basin, only to suffer periods of degradation and contraction during which material from the higher parts of the basin rim was transported to and accumulated in the conglomerate beds nearer the basin center. Let us see if we can find the equivalent of conglomerate No. 3 on the north side of Portage Lake.

*Geol. Sur. Mich., I, Atlas, Pl. XIVa.

†Geol. Sur. Mich., 1, Pt II, p. 62.

§ 5. Correlation of some Portage Lake conglomerates.

On a previous page I have indicated the probability that Marvine's conglomerate bed No. 2 is identical with bed No. 1—the contact conglomerate. Marvine and Emerson located* between the contact and the Isle Royale cupriferous bed six other conglomerate beds, which, in order to avoid confusion we shall continue to designate by their numbers, 3 to 8. Bed No. 3 (scaled from Marvine and Emerson's plat, not allowing for a small difference of elevation which will slightly reduce the horizontal distance) lies 670 feet horizontally† east of the Isle Royale bed. This bed and No. 6 are characteristic pebble conglomerates. Number 7, 510 feet east of No. 8 and 350 feet west‡ of No. 6, is a very characteristic seam of fine grained indurated sandstone, called by mining men "jasper," and at one or two points appears to be closely associated with a conglomerate of porphyritic material. The position and course of these three beds have been satisfactorily determined by the Survey as far south of Houghton as Five Mile Hill in Sec. 16, T. 54, R. 34. The course of the Isle Royale cupriferous bed, as laid down by Marvine and Emerson for a mile back of Houghton, appears to be closely in conformity with that of the above conglomerates, while the course of the Grand Portage bed west of the former appears according to the same authorities to approach the Isle Royale as it comes north.§

*Geol. Sur. Mich., I, Atlas, Pl. XIVa.

†Mr. R. C. Pryor by actual measurement, allowing for difference of elevation, makes the horizontal distance 650 feet.

‡Measured by the Survey on the Isle Royale location,

§The relations of these two beds to each other must be left to a future report.

On the north side of Portage Lake a cupriferous bed, supposed to be the continuation of the Isle Royals was opened in the Douglass, Concord and Arcadian mines, in Secs 30, 19 and 20, respectively, in T. 55, R. 33. *Six hundred and sixty* feet horizontally east of this bed, a conglomerate closely parallel with it, has been traced for nearly a mile and a half. Marvine and Emerson correlate this bed with No. 7, with whose predominant characteristic, "jasper," it does not however agree, and locate 360 feet (scaled) east of it bed No. 6, which they designate "jasper" and which thus appears to correspond in character although not, by 150 feet, in position to No. 7 on the south side of the lake.* Marvine says "the bed on which the Concord and Douglass mines are situated is some distance east of either the Isle Royale or Grand Portage beds,"† but gives no reason for his opinion. If this opinion be well founded, conglomerate No. 8, unless cut out, should occur within 160 feet east of the Douglass-Arcadian cupriferous bed (for the distance between No. 7 and No. 8 on the south side of Portage Lake is 503 feet), but no such bed has ever been seen.

The above evidence is entitled to great weight in deciding as to the correctness of Marvine's correlation. If the latter is wrong and if as above suggested, the conglomerate next east of the Douglass-Arcadian bed is in fact No. 8, then the Douglass-Arcadian bed must be the extension either of the Isle Royale or of the Grand Portage bed, or possibly of the union of these two.

Lying not more than 350 paces (not over 1000 feet horizontally) east of the above conglomerate in Sec. 20, T. 55, R. 33, is another well marked conglomerate which follows a course parallel with that of the above beds into the north half of the same section. This may be bed No. 5, for it corresponds closely to the position of No. 5 on the opposite slide of the lake. No other conglomerates have been noted in this area until we reach the eastern part of the northwest quarter of Sec. 29 in the same township. The course of the latter beds is at an angle to that of the others above noted, so that some- where between their horizon and that of No. 5 must be the horizon that corresponds to conglomerate No. 3 and to the sub-crystalline traps on the south side of Portage Lake. The last named conglomerate may, then, be the extension of the St. Louis or Bohemia conglomerate.

*This "jasper " bed I have never been able to find on the north side of the lake.

†*Ibid*., p. 58.

§ 6. Portage Lake as a fault line.

Marvine thought that Portage Lake represents an old fault line and that the north side has been heaved about 720 feet to the west,* his determination haying evidently been made from observations on the Albany and Boston (Allouez) conglomerate, higher in the series. The correlation from one side of the lake to the other, and the possible location of deposits on one side known to exist on the other, made it desirable to do some work to determine whether this dislocation, if it really exists, affects as well the lower beds of the series, and if so, to what extent. This work was confided to Mr. W. W. Stockly, who established his stations by triangulation by means of the transit, with reference to the north quarter-post of Sec. 30, T. 55, R. 33, and also to the S. W. corner of Sec. 36, in Hurontown, in the section next southwest. The altitude of the different stations was determined with a wye level by Mr. Stockly on the north side, arid by Mr. W. L. Cumings on the south side of the lake.

The outcrop of the conglomerate (No. 8) next east of the Douglass-Arcadian bed was followed and located for 4152 feet. The difference of elevation (106 ft.) between extreme stations, with a dip of 54° gave the true strike of the bed N. 36° E.,† which was platted to lake level. The line of apparent strike was then carried across the lake, and from it outcrops of conglomerate No. 8 were located, and their altitudes determined by leveling. These points, taking the same dip, were also platted to lake level and all the points joined, as in Plate VIII. The resulting line represents a true strike that varies, between points A and D, only 3° 20'. The distance between A and D is about 15,000 feet, and were the lines of strike at these points produced until they met in Portage Lake, the horizontal distance between them could not be greater than 275 feet. These figures then must represent the maximum of faulting possible at this horizon, in offsets distributed over a distance of about 15,000 feet. There is no evidence to show that the offsets all occur within the limits of Portage Lake itself, and for the distance across the lake, 1,500 feet, the apportionable amount would not be greater than 27.5 feet‡. From just what correlation the amount of Mar vine's supposed fault in Portage Lake was derived, does not appear in his report, for the Albany and Boston conglomerate on which most of his work was done does not seem to have been recognized by him on the south side of the lake. That so marked an increase in the amount of dislocation should have taken place between the horizon of the latter bed and that of No. 8, within the limits of Portage Lake, while it may be possible, does not seem probable, unless the fault be one that cuts the series diagonally and is not disclosed in the areas thus far explored. Any more decided opinion on the subject, however, may well await the result of further investigation.

*Geol. Sur. Mich. I, Pt II, p. 61

†With a dip of 57°, the strike would be N. 36° 53 E. This dip is probably more nearly correct than the one above assumed (54°), but the difference in the curve would be very slight.

‡With a steeper dip, as above suggested, this amount would be still less.

§ 7. EASTERN SANDSTONE.

A. End of Keweenaw Point. The Eastern sandstone outcrops at several places along the southern shore of Keweenaw Point, notably in Sec. 26, T. 58, R. 29, where Irving and Chamberlin examined and described it in detail (Pl. IV, points A and B*); about the middle of Sec. 30, T. 58, R. 28, (point B2) where it is exposed for about 100 paces, and was noted by the United States Linear Survey; east of the center of Sec. 29, T. 58, R. 28 (point C)† where it is exposed for some 300 paces; and on Sec. 35, T. 58, R. 28 (point D), where it covers the bed of the lake for several hundred paces, and runs up to the low shore cliff but does not appear above the water. In each of these places it has similar characteristics, being rather coarse grained, quartzose, whitish and somewhat feldspathic. On Sec. 26, T. 58, R. 29, it is associated with beds of basic and acid rock-fragments of small size, generally angular, in a red shaly matrix. At the other points, further east, beds of exactly similar character to these last do not appear to occur in connection with the sandstone. The latter is arranged in folds dipping lakeward, and erosion of their upper edges has produced the effect of making it appear to approach and recede from the shore in distinct curves which from high points on the shore may be seen to extend far out under the waters of the lake. The dip of these beds varies from 30° to vertical, and in fact, in one place (point B) the beds are supposed to be overturned, and dip to the north.‡

During the work of the Survey in 1895 and 1896, beside the occurrence of sandstone on the lake shore in Sec. 35, T. 58, R. 28, that of two others was noticed. One of these was in Sec. 27, T. 58, R. 28, at 1190 paces north, 280 paces west. In a small basin inclined slightly to the north on the right bank of the Little Montreal River, the ground for 20 paces north and south and 12 paces east and west, is strewn with slabs and thick fragments of the characteristic white, round grained and coarse grained sandstone, like that on Sec. 26, T. 58, R. 29. These slabs are very crumbly, a part of their constituents being largely decomposed kaolinite. The elevation here, above Lake Superior, is from 80 to 85 feet.

The other occurrence of sandstone is in Sec. 26, T. 58, R. 28, about 760 to 780 paces north, 1420 paces west. Three or four pieces of the same coarse, whitish to reddish sandstone are exposed at the southern base of the hill at the southeast end of West Pond (Pl. II). One of these outcrops, more reddish than the others, somewhat finer grained and containing no kaolinitic matter, alone of all of them appears as if it might be in place. Excavation alone can settle this point. This outcrop is exposed for 6 or 8 feet east and west and is 3 feet or more thick, and seems to lie very nearly horizontally. The others are more or less discordant, smaller in extent and have evidently been disturbed. In one of them were noticed inclusions of quartz and of quartzite, and of fragments of what seemed to be quartz porphyry, now reduced to kaolinite. It is somewhat significant that this sandstone is near the 80-foot contour line, or at about the same horizon with the fragments in Sec. 27, previously described. This fact and the apparent total absence of other blocks or even fragments of similar sandstone in this entire burnt area lead one to believe that these sandstones are on or near the place of original deposition. All through these two sections as far as examined, and especially around the pond near the outcrops last mentioned, the soil seems to be largely, if not altogether, of whitish sand, the upper limits of which are between the 80-foot and 90-foot intervals. The very nearly horizontal position of the last named sandstone, near an intrusive felsite, as contrasted with the disturbed condition of the sandstone on the lake shore in other places, is an argument in favor of the conclusion that the disturbance in the latter areas is not due to the gentle and simultaneous tilting of the series, but rather to local movements, such, for example, as the lakeward slipping of the traps. The prevailing dip of the traps in Sec. 26, T. 58, R. 28 is 54°, nearly the maximum known for the corresponding horizon throughout the series, and yet that dip and the steeper dip of the beds affected by the intrusive felsite of West Pond had been assumed before the deposition of the sandstone—if, at least, we can rely on the outcrop in Sec. 26 as being in place.

*Bull. U. S. G. S , No. 23, 1885, p 18.

†*Loc. cit*, p. 23

‡*Loc. cit*., p. 23.

B. Bare Hill. By far the most interesting occurrence of Eastern sandstone in this, or perhaps any other area, is that which lines the shore near the foot of Bare Hill, in Sec. 29, T. 58, R. 28. From a distance this outcrop might easily be mistaken for felsite. Indeed, Irving appears to have included it in his Bare Hill felsite belt,* although later, on Rominger's authority† he and Chamberlin corrected the error.

Irving and Chamberlin quote from manuscript notes of Dr. Rominger, 1884,‡ the following description of this outcrop:

> Further east another large patch of sandstone occurs on the shore near the center of section 29, township 58, range 28. In the outer portion of this patch the strata dip under an angle of about 20° south, but, following the exposures along the shore eastward, this inclination decreases, and finally, near the spot where the sandstones come in contiguity with the diabase, they are horizontal.

In his report as finally printed§ Rominger says of these sandstone beds that—

> They have a distinct southern dip, steepest off shore, and diminishing toward the shore, near their contact line with the diabase, where the strata have an. almost completely horizontal position, which circumstance makes me suggest as the possible cause of the inclined position of the strata an underwashing of the beds in the lake-bottom and the subsequent breaking down of the more superficial strata. Their discordance with the diabasic rock belt is here just as plainly observable as in the former place; crevices in the diabase are often found replenished with sandrock.

The above observations are substantially in accord with those made by the writer. The outcrop in question extends along the shore from near the center of Sec. 29, between 300 and 400 paces eastward. (Pl. IV). At its west end it overlies the trap—an ophite—and dips about 25° to the southeast, looking exactly as if it had slipped lake- ward over the surface of the latter. At the east end no disturbance is apparent; the sandstone alone is exposed here in a solid mass.

*Copper-Bearing Rocks of L S., Pl. XVII.

†Bull. U.S. G. S, No. 23, Plate II.

‡*Loc. cit*., page 17.

§Geol. Sur. Mich., V, Pt. I, page 136.

Following the contact on the west, back from the shore up the slope for 75 paces, we pass large blocks of sandstone, some of them many tons in weight, disturbed and evidently out of place. Near the top of the shore ridge (100-180 feet above lake level) that evidently corresponds to the terrace back of the shore-felsite further west, we find just east of the trap, a vertical wall of sandstone about 50 feet high that extends 50 to 75 paces east. It has here the appearance of a compact original mass in place, and while no conclusive evidence of bedding was seen, the sandstone has all the appearances of horizontality. The contact of the sandstone with trap in the shore ridge on the east side of this hill is marked by a small spur of sandstone running lakeward and apparently somewhat harder than the same rock elsewhere at this place. This outcrop thus has an approximately semi-circular form, and lies in an embayment on and against a steep wall of trap where it has been protected from total erosion. Its position is such as to make the conclusion irresistible that it was laid down against the shore cliff unconformably on the trap series, after the tilting of the latter and probably after the intrusion of the Bare Hill felsite. This is the view early advanced by Agassiz, Pumpelly* and others, as to the relations of the Eastern sandstone and the Keweenaw series in general.

Before adding any further observations on the relative ages of the sandstone and the trap series, it seems more properly in place to consider certain contact phenomena from which have been drawn some quite important conclusions as to the structure of the two series.

*Geol. Sur. Mich., I., Pt. II, page 4.

§ 8. Theory of a deep-seated fissure in the Keweenaw series.

The theory of Irving and Chamberlin, briefly stated, is that the Keweenaw series is essentially bedded, built up by lava flows extravasated near the margin of the Lake Superior basin, and by horizontally deposed conglomerates and sandstones alternating with the former; that the more basic flows, from their greater fluidity, spread out over a wider extent than the more acid and viscous extrusions, which tended to accumulate in "thick embossments" near the loci of eruption, where they were the more exposed to rapid degradation; that the accumulation of this material was accompanied by a slow and progressive subsidence of the beds near the center of the basin and their elevation in the districts of eruption, that is, the Marquette-Gogebic region and the northwestern shore of the lake in Minnesota and Canada; that thus the uplifted margins of the lava sheets were themselves supplying the material for the conglomerates and sandstones that were from time to time interbedded with them. Irving and Chamberlin believed that the dips of the Keweenaw series are uniform and steady, and that the junction line between that series and the overlying Eastern sandstone is gently undulating. They point with emphasis to the disturbed condition of the Eastern sandstone along the line of contact, and to the presence of a fault plane at many points on that line, and believe that these phenomena can best be explained by supposing the long contact line between traps and sandstone to be the result of "ancient faulting," that is, by faulting that took place before the Eastern sand- stone was laid down, "modified by subsequent erosion and by still more recent slight faulting," but they entertain no very confident conclusions as to the precise nature of the earlier fault. In this contention they assume the existence, *within the Keweenaw series*, of a deep seated, hidden fault plane of whose existence they freely say they have no direct evidence. The cause of the faulting lies, they think, in the expanded condition of the earth's crust in the districts of volcanic activity (the Marquette-Gogebic region) during the long process of eruption—a progressive elevation—followed by contraction, which may have caused a differential subsidence between the Keweenaw Point area and the region south and east of it. The upward curving of the sandstone, noticed at many points, was caused, they conclude, by the depression of the sandstone or by an upward thrust of the Keweenaw series—a reverse fault.

While both the upward curves and the downward curves of the sandstone at the immediate contact, together with the character of the overlying and underlying contacts themselves, may be the results of a reverse or thrust fault as just noted, Irving and Chamberlin point out that similar results might be produced by an individual movement of beds in the Keweenaw series on each other, during the last faulting. "That faulting may be distributed along several planes that offer comparatively small shearing resistance," they say, "is affirmed by theoretical considerations, experimentation and observations in nature. "We have," they say, "at times been inclined to believe that the post-Potsdam disturbance was due to a slight irregular movement of this kind, but the increased evidence now at command seems to strengthen the probability that there was a definite, and not inconsiderable, faulting movement somewhat of the kind above indicated."* To the foregoing Irving and Chamberlin add a number of arguments why the Eastern sandstone should be considered as having been laid down unconformably on and against the Keweenaw series, a conclusion which the recent work of the Michigan Survey seems to verify.

Irving and Chamberlin's views with reference to the fault along the junction of the two series do not, however, seem fully to satisfy certain observed phenomena described in the previous pages. The fault or fissure theory has had many advocates. Foster and Whitney thought there was no doubt of the existence of a deep seated fissure between the end of Keweenaw Point and the western limits of the district along the line of which was protruded the Bohemian Range.† Rominger thought the trap range had been subjected to a submarine upheaval, subsequent rupture, and that its western horizon finally emerged from the water.‡ Wadsworth§ thought that the first lava of the Keweenaw series "flowed over the Eastern sandstone, which is older than the copper-bearing or Keweenawan series. Subsequently a fault line or fissure was formed, running near what is now the point of contact of the sandstone and lavas, sometimes exactly at that point, sometimes on the lava side, and probably sometimes on the sandstone side of it. Along the fissure it is probable that a normal fault occurred * * * * *." The same general idea of a deep seated fissure penetrating the series itself, the Keweenaw series in the one case, and the Potsdam in the other, seems to have been held in common by the above investigators. Pumpelly and Brooks, among the geologists that have expressed an opinion on the subject, are the only ones to reject the fissure theory. In the eastern declivity along the contact with the Eastern sandstone on Keweenaw Point they see a "shore cliff" and not the "exposed side of a gigantic fault."¶

*Bull. U. S. G. S., No. 23, p. 115,

†F. and W., p. 68.

‡Geol. Sur. Mich., I, Pt. III, pp. 96-98.

§Rept. of Board of Geol. Sur. Mich., 1892, p. 164.

¶Geol. Sur. Mich., I, Pt . II, p. 5.

§ 9. Subsidence of Keweenawan beds.

In previous pages the origin and final deposition of the lava sheets of the Keweenaw series and of their interbedded conglomerates have been discussed with reference to the original horizontally of these beds. The position there taken involves also the subject of a subsidence of the beds near the basin center or axis, that Irving and Chamberlin contend was due to the weight of accumulating rock material.

That there may have been a slow and progressive subsidence of the Keweenawan beds near the axis of the present Lake Superior basin is perhaps possible, but in view of the fact that the dips now seen along the shore adjacent to that axis are almost without exception within the limit of the angle of deposition of lava flows and of conglomerates, and that the dips of underlying beds in the Lake basin are inaccessible, there is no evidence of a convincing nature that would make such a subsidence necessary. The dip of the traps and interbedded conglomerate beds from older to younger, so far as yet observed, is, at its maximum, from near verticality in the former to a minimum of about 21° in the latter, 2500 feet below the surface, or to about 23° at the surface, and if by subsidence we are to understand a differential sinking of the beds, by which those parts of each formation near the basin center sank from time to time as other beds were deposited above them, we should expect to find at least in and near the central parts of the basin a steeper dip prevailing in the lower beds than in the higher ones, at points vertically above them. Thus far, in our deep mines, we have found no evidence to show such a relation of the strata, but what little evidence we have points in the other direction, that the dips are flatter as we go down vertically. It is as if, in addition to the natural decrease in the angle of deposition of the beds away from their point of origin, some force had been applied at the southern margin of the beds, which had the effect of lifting them—faulting, intrusion, or folding? I am aware that an apparent thickening of the beds from Portage Lake northeasterly, as suggested by Mar- vine, might be used as an argument in support of the above theory of subsidence, but in view of recent and more accurate observations* on the dips that were an essential part of Marvine's calculations, any far reaching conclusions from the latter should be accepted with reserve, for this thickening is, in the aggregate, of a trivial amount only, and may be due, for aught we know, to differential erosion.

*The dip of the Allouez conglomerate at the Franklin Junior (Albany and Boston, Peninsula) mine was by Marvine supposed to be 52°. In reality it is but 48°. For the same bed at the Allouez mine Marvine used a dip of 46°. Mr. Fred Smith, agent of the mine, tells me the dip is 39°.

It may be observed here that an extensive sliding of the formations north and west in the Eagle River area may have brought thicker parts of beds horizontally lower and contributed to the apparent thickening northward of certain zones.

Another way in which subsidence maybe regarded is as a simultaneous sinking of extensive areas of the series In a vertical or nearly vertical direction. This implies a kind of faulting that has seldom been observed on Keweenaw Point,* although apparently not uncommon on Isle Royale.

If by subsidence, however, we are to understand that phenomenon of gravity by which the beds of a series standing at high angles, owing either to their original deposition or to folding or to intrusion, should seek a state of equilibrium by a shearing motion along planes of weakness, whether between different beds or approximately parallel to their surfaces within a single bed, and the higher beds should slide over the lower in gradually decreasing curves until the equilibrium should be restored, then we have in the phenomena of Keweenaw Point many evidences of subsidence.

Such movements would expose to erosion at successive periods wider segments of the deeper and of the thicker beds as well, and especially of the lenses of acid rock, and we might expect to find in successive conglomerates abundant pebbles from the same bed or beds—perhaps also from rock masses intrusive in these beds, and in the earlier beds pebbles from older formations under them. Such movements doubtless agree in great part with those advocated by Irving and Chamberlin, but they do not necessarily presuppose a differential subsidence of all of those parts of the Keweenaw series along and near the axis of the present hydrographic basin of Lake Superior as due primarily to sedimentation—a subsidence that would imply a steepening of the dips of the older beds along that axis. This steepening might also be, and in some parts of the Keweenawan area probably was, increased by later intrusions near the margin of the series.

*Capt. W. Clarke says there is an occurrence of this kind in the Copper Falls mine, with a throw of 22 feet

§ 10. Junction line between the Keweenaw series and the Eastern sandstone.

The work of the Michigan Survey under Dr. Wadsworth showed that the line of contact between the Keweenaw series and the Eastern sandstone, although a curve which follows in a general way the trend of Keweenaw Point, is marked at several points by embayments more or less deep which interrupt the directness of the course of the contact. Where the outline of these embayments is coincident with the course of the conglomerates interbedded in the Keweenaw series near the contact, we have already suggested that the embayments may mark the former position either of eroded early intrusive, or of eroded pre-Keweenawan rocks, in either case representing the margin of a basin. The erosive agencies that wore away these ancient rock masses attacked also the edges of the later, steeply dipping Keweenawan beds, forming cliffs in some places and gentle slopes in others. Against these cliffs and on these slopes the Eastern sandstone was laid down. The present plane of contact between the traps and the Eastern sandstone is therefore variable, inclining sometimes westerly to northerly, sometimes easterly to southerly. It is not often exposed, but at some points between Wall Ravine (Sec. 20, T. 56, R. 32) and Sec. 6, T. 54, R. 33, south of Houghton, its prevailing hade or inclination seems to be west. At Wall Ravine according to Irving it is vertical near the surface, and lower down hades to the west. At Douglass Houghton Falls it is 30°, at Hungarian Falls 35°, west. At these and other points of contact the edges of the Eastern sandstone are much bowed, either up or down, a phenomenon ascribed to faulting. There seems to be no doubt that between the sandstones and the traps there has been a good deal of faulting at some points, notably where the plane of contact is highly inclined or where the traps overhang the sandstone. It is by no means so certain that where this plane dips gently eastward there are equally conclusive signs of faulting or that at every point where faulting has occurred, its amount has been equally great. We have only to recall the phenomena at Bare Hill and elsewhere on Bête Grise Bay where the mural character of the trap is not even as pronounced as it appears to have been in the Torch Lake area. The undercutting of the beds and the lakeward faulting of masses from the Keweenawan cliffs are plainly seen there, and the flexure of the abutting sandstone at several points at and near the contact is like that at other points further south and is exactly what might be expected to result from similar rock movements. In some areas of sandstone embayments, however, the sandstone clearly appears to be an overlap on the trap; in other cases, where the deeply dissected topography is strongly suggestive of a sandstone formation, it is not unusual to find at the heads of corraded channels large fragments of sandstone that may be and probably are remnants of a former edge of the Potsdam series. In these areas we must infer either that the eroded edges of the traps slope gently to the eastward, or, if they be of mural character, that the Eastern sandstone conceals them by extending above their steepest parts. Here, then, the mural contact with its pronounced fault features is not exposed. Any faulting we may observe between the eastward or southward sloping traps and the overlying sandstone is simply a contact phenomenon. The junction line, therefore, as evidence of a deep seated fissure in the Keweenaw series, must lose much of its importance. To use the terms "sandstone contact" and "fault line" as in this sense synonymous, is therefore incorrect.

If the mural character of the traps at points near the contact with the Eastern sandstone be considered as by itself evidence of a great fault in the trap series, one need only point to the Greenstone escarpment as an example of what erosive agencies have done in this area, and that, too, on very resistant rocks exposed to their attacks in a much less degree than the fractured rocks along the great Keweenawan cliff, and yet there is no evidence that the eastern face of the Greenstone ridge is a fault scarp.

The presence of masses of porphyry of indeterminable age and character, that is of rocks that may possibly be intrusive, along the contact between traps and sandstone might point to a line of weakness and to a deep seated fissure along that horizon, through which these rocks, if intrusive, reached their present position, but in the absence of other evidence such an inference can have the force of an inference only. Gilbert says of the Henry Mountain laccolitic intrusions that they mark "no discernible arrangement."* A part of the Little Montreal River felsite and the Bare Hill felsite show that the trap series was invaded at those points by intrusive masses, but thus far no evidence of a longitudinal fissure has been connected with these masses. The Allouez Gap and the Torch Lake porphyries, if intrusive, are not known positively to penetrate the trap series. If they were intruded along a, line of weakness, that line may equally well be the contact plane between traps and sandstone.

*Geology of the Henry Mountains, p. 2.

On the south shore of Lake Superior opposite the Keweenaw peninsula rises a mass of Archean granite, outliers of which are seen in the hike at Granite Island and at the Huron Islands, indicating the extension of this area north under the waters of the Sake within the present area of the Eastern sandstone. The acid rocks found along the contact of the Eastern sandstone and Keweenaw series on Keweenaw Point, aside from the possibility of their being interbedded in the Keweenaw series, may be peripheral fades of this granite, or, like the granite near the Minnesota coast, according to some authorities,* they may be parts of a younger granite, intrusive between the Archean and the Keweenawan. In the latter case it may be to these intrusives that we must ascribe the final tilting and a large part of the slide-faulting of the Keweenawan; in the former, these phenomena, may be simply the result of a differential elevation or subsidence of the two series along their plane of contact.

I have tried to emphasize the idea that the tendency to establish an equilibrium in the steeply dipping beds by slide-faulting need not be confined to the beds of the Keweenaw series, but if circumstances were favorable would probably extend to the contact planes between that series and intrusive masses, or between that series and an older* one. The super-imposition of a newer series on the latter, and their common movements are only incidents in the phenomena that began at an earlier period. Indeed, one might rather expect such a faulting to occur between an intruded and a steeply inclined intruding body more easily than between beds of a series that have become move or less firmly welded, and quite as easily along a steeply inclined contact between unconformable series. It is a matter of less consequence what may have been the ultimate cause of this movement, whether in an independent subsidence of the trap series, or in an emergence of the Archean.

The evidence then seems to point to the early existence of an eroded line of steeply dipping and somewhat corrugated traps, against whose mural faces and over whose gentle slopes, respectively, the Eastern sandstone was laid down. Where the Keweenawan cliff overhung the sandstone, the weight of the former pressing on the more yielding sandstone would in time cause a deformation of its edges, the effects of which would be greatly increased, if segments of the trap were locally separated from the parent mass by normal faulting, as suggested by Wadsworth.** This would naturally follow where the Keweenawan cliff had been deeply undercut by wave action, and might more naturally occur than what I have termed slide-faulting, at points where the trap series was not steeply inclined, notably in the Torch Lake area. Indeed, the flatness of the dips in the trap series at points near the contact may in part be due to such a faulting, but that this cannot wholly account for the difference in structure between the lower part and the upper part of the series is manifest from the difference in character of the two horizons, as has already been pointed out.

The mural character of the contact plane between traps and sandstone and the contact phenomena between these two series do not therefore seem sufficient to establish the existence of a deep-seated fissure *in the Keweenaw series*, but leave open the alternate hypotheses of extensive erosion, and of faulting between the traps on the one side and the sandstone and the Archean on the other.

*J. Edward Spurr, The Iron-Bearing Rocks of the Mesabi Range in Minnesota, Geol. and Nat. Hist. Sur. Minn., Bull, No. X, 2; U. S. Grant, *ibid*, 20th Ann. Rept., pp. 35-95, and 21st Ann. Rept., pp. 36. 37.

**Report State Board Geol. Sur., Mich., 1898, p. 164.

§ 11. Unconformity of Keweenaw series and Eastern sandstone at Douglass Houghton Falls.

As confirmatory evidence of the unconformity between traps and sandstone, as exhibited near Bare Hill, I append here a section (Fig. 11) at Douglass Houghton Falls, made by Mr. A. E. Seaman after an examination in 1889—the locality where such portions of the two series at the contact as were exposed appeared to be most nearly conformable. It thus appears that Mr. Seaman at that early date, by deeper excavation than had been made by previous investigators, was able to demonstrate, as will be evident to the unprejudiced, that the series there are not by any means conformable. The diagram indicates that there might have been a slight over-thrust movement of the traps.

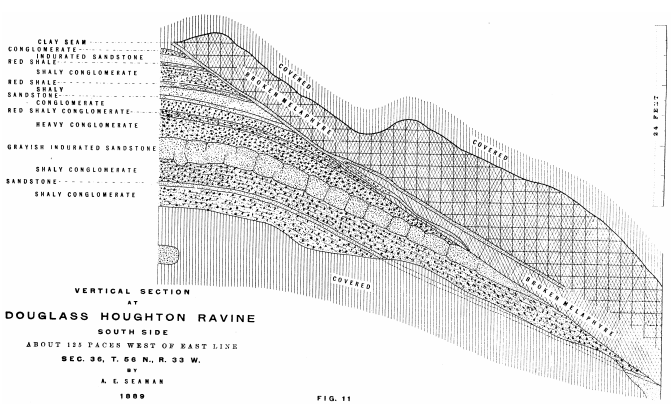

Figure 11. Vertical section at Douglass Houghton Ravine.

If the exposures in the Douglass-Houghton and Hungarian ravines were the only ones where the Eastern sandstone and the traps are seen in contact, the explanation that the former series underlies the latter conformably and that its former westward extension together with the overlying traps has been faulted normally against the sandstone on the east, would doubtless be plausible, but such an explanation is irreconcilable with the evidence at Bare Hill and elsewhere. On the other hand the evident superposition of the sandstone on the traps at Bare Hill calls for an explanation of the phenomena of Douglass Houghton ravine that shall be consistent with the later age of the sandstone. If it be objected by the opponents of the latter view that the sandstone along the contact may be of two different ages, one older and the other younger than the trap, it should seem that the burden of proof of the assertion must fall upon these objectors, for the sandstones agree in all essential characteristics and have thus far never been shown to be of different ages.

§ 12. Altitude of the Eastern sandstone.

The junction line of traps and sandstone, as appears by the foregoing pages, shows an overhanging of the traps in the Torch Lake area, as far north as Wall Ravine. The sandstone, if it formerly rose above the level of the trap escarpment and overlay it, has here been removed by erosion. This appears to be not improbable from remnants of sandstone on the eastward slope of the traps near the contact in the area immediately north of Wall Ravine, although it is quite true that such fragments might have been deposited there by glacial action. At Bête Grise Bay we find both classes of contact with evidence that goes to show that they were originally alike—the sandstone overlay the traps. In the latter area the sandstone is now found in place about 100 feet above Lake Superior; near Portage Lake it is more than 400 feet above the lake.* If the highest strata now found at these different points are in the same horizon, and if the dip of these strata continues at the same angle further southwest, it is probable that the sandstone formerly stood at a much higher elevation there, relatively to the traps. If, on the other hand, the highest sandstone strata near Portage Lake are above the horizon of those at Bare Hill, the sandstone formerly may have covered a large part of the northern area of Keweenaw Point.

*Opposite the Belt mine, in Sec. 32, T. 51, R, 37, it is about 500 feet.

It is not impossible, therefore, that the reputed sandstone fragments formerly found back of Houghton, and cited by early geologists* as possibly *in situ,* were in fact at or near the place of their original deposition. These blocks have in great part long since been broken up and used for building purposes; only their extreme lower parts are left. One of them lay at what is known to be at or very near the junction line between sandstone and traps, 220 paces north, 1450 paces west, Sec. 31, T. 55, R. 33, on or near conglomerate bed No. 1 (Marvine's No. 2). The other was at 265 paces north, 485 paces west, Sec. 1, T. 54, R. 34. On digging through the remnants of this mass the latter was found to have under it about one inch of red sand, immediately beneath which lay trap in place. The sandstone here dipped at a small angle to the east. The absence of drift material between the sandstone and the underlying trap is evidence, so far as it goes, that the sandstone is not an erratic block. It is only half a mile west of the other so called fragment. Its altitude, 307 feet above Portage Lake, is a hundred feet lower than that of the Eastern sandstone less than three miles away. Thus there was nothing in the altitude of this block, or in its relations to the traps that militates against its having been *in situ*.

*Geol. Sur. Mich., I, Pt. II, p. 3 and Pl. III. p. 96.

§ 13. Summary of hypotheses.

The facts gathered by the Survey and set forth in the preceding pages, together with observations made by previous investigators, have led to the formation of several hypotheses, of which the most recent may be briefly summed up as follows:

1. The eroded conformable downward extension of the Keweenaw series continues eastward under the Eastern sandstone of Keweenaw Ray. (Pumpelly and Brooks.)

2. The eastern face of the Keweenaw series, as now exposed, represents a fault scarp. The downthrown part of the series lies under the Eastern sandstone of Keweenaw Bay. (Irving and Chamberlin; Rominger.)

To these suggestions of previous observers I may add:

3. *a*—The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the higher part of the series, suggest that in this area near the contact between the Keweenaw series and the Eastern sandstone we are on the edge of an early-Keweenawan or pre-Keweenawan basin.

b—If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the South Trap Range, were eroded in pre-Potsdam time together, possibly, with a part of the underlying Archean.

c—The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,—

(1) Marginal facies of the underlying Archean;

(2) Intrusive in the early Keweenawan;

(3) Early interbedded flows of the Keweenaw series; or,

(4) Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

The above may for the present be regarded as multiple working hypotheses.* The ultimate decision as to which hypothesis carries with it the greatest probability may await the result of future study in other parts of the range.

*Cf. Chamberlln, Am. J. G., 1897, Vol. V, No. 7, p. 837.

CHAPTER VI. RECENT WORK NEAR PORTAGE LAKE.

§ 1. The Franklin Junior.

With the end of the preceding chapter, bringing the work of the survey down to the close of 1897, this report was intended to finish, but during the two years that have elapsed since the latter was prepared for the press, some developments in mining have been made in the vicinity of Portage Lake that justify a departure from that plan, if only to make brief mention of them.

One of the earliest of these developments was the resumption of work at the Franklin Junior location, formerly known as the Peninsula and earlier still as the Albany and Boston, on Sec. 8, T. 55, R. 33. At this place a cupriferous bed supposed to be the Pewabic, 475 feet horizontally west of the Allouez conglomerate (dip 48°) has been opened by two shafts to the depth of some 900 feet. Details of the work on this bed are given in the report for 1897-98 of the Commissioner of Mineral Statistics, to which the reader is referred.

From a geological standpoint the most interesting work performed on the location by direction of Mr. Graham Pope, the enterprising agent, is the extension of the old cross-cut that runs from the Allouez conglomerate easterly. This and a drill hole were carried to a point some 250 feet east of a conglomerate that corresponds to the Kearsarge, known on the surface and in mine workings further north. This bed is thus seen to be the same as the conglomerate opened near the south quarter-post of Sec. 18, in the same township, known as the North Star (Pl. VIII), which, like the Kingston, must now as a separate bed be stricken from Marvine's list of conglomerates. In the same cross-cut are also exposed the Houghton and the Calumet conglomerates and the Osceola amygdaloid. All of the beds in the cross-cut are shown in the annexed section (Pl. IX), the widths having been measured with a tape by the Geological Survey. Their equivalent thicknesses and characters are noted in the following record:*

*The difference in level between the two ends of the cross-cut is about 36 feet. An allowance for this was made in the aggregate thicknesses between conglomerates, but not in the separate beds. The direction of the cross-cut is so nearly at right angles to the strike of the formation that no correction was thought necessary for the slight error thereby included in the computed thicknesses. The distances between conglomerates noted on Plate IX are approximate surface measurements.

RECORD OF CROSS-CUT.

9; **Allouez** (Albany and Boston) **Conglomerate;** ("The Slide" at Eagle River). Dip. 48°.

41 (31) 9-50; (S. 17275). *Melaphyre*, **amygdaloid;** calcitic. The upper 6 to 8 feet are much bedded and jointed as if by pressure (slipping?), and the thickest of the resulting layers, being rounded on the edges, look like lenticular boulders in a disintegrated cement.

67 (50) 50-117; (S. 17276). **Melaphyre,** ophite; feldspathic.

17 (13) 117-134; (S. 17277). *Melaphyre*, **amygdaloid**, calcitic.

21 (16) 134-155; (S. 17278). **Melaphyre,** ophite; feldspathic (?)

17 (13) 155-172; (S. 17279). *Melaphyre*, **amygdaloid.**

40 (30) 172-212; (S. 17280). **Melaphyre,** ophite.

18.5 (14) 212-230.5; (S. 17281). **Melaphyre,** altered, epidotic.

113 (85) 230.5-343.5; (S. 17282). **Melaphyre,** ophite. At 27 feet from the foot there is a seam of calcite and vein matter, from 2 to 4 inches thick.

6 (5) 343.5-349.5; (S. 17283). *Melaphyre*, **amygdaloid;** laumonitic.

48 (36) 349.5-397.5; (S. 17284). **Melaphyre,** ophite (?)

7 (5) 397.5-404.5; (S. 17285). *Melaphyre*, **amygdaloid.**

61 (46) 404.5-465.5; (S. 17286). **Melaphyre,** ophite.

38.5 465.5-504; (S. 17287). **Conglomerate,** acid.

1.25 504-505.25. **Sandstone.**

28 (51) (389) 505.25-533.25; (Ss. 17288-9). **Conglomerate,** basic. These three beds constitute the **Houghton** conglomerate. The upper 39 feet consist of rounded pebbles of felsitic and porphyritic rock, usually smaller than a goose egg, in a coarse cement of similar material, the whole being capped by three inches of fluccan and separated from the underlying basic part of the bed by a foot of sandstone. Dip 49°-50°. The lower 28 feet form a typical example of an amygdaloidal or scoriaceous conglomerate; more or less rounded fragments of amygdaloid, carrying calcite, are embedded in a dark red fine grained cement that consists largely of quartz and iron oxide.

This conglomerate complex is of interest, in that it appears to mark a very sudden change in the conditions of erosion and deposition that contributed to its growth. The basic part of the bed appears to have been derived from the immediately underlying melaphyres, and the upper or acid part to have been transported from a more distant source—as is indeed evident from the smallness of its pebbles.

This conglomerate does not appear to have been cut by any of the Calumet shafts.

78 (60) 533.25-611.25; (S. 17290). **Melaphyre,** ophite.

15 (12) 611.25-626.25; (Ss. 17291-2). *Melaphyre*, **amygdaloid,** brecciated, calcitic, epidotic. Drift to north.

96 (73) 626.25-722.25; (S. 17294). **Melaphyre,** ophite.

5 (4) 722.25-727.25; (S. 17294). *Melaphyre*, **amygdaloid;** calcitic.

11.67 (9) 727.25-738.92; (S. 17295). **Melaphyre,** ophite.

17 (13) 738.92-755.92; (S. 17296). *Melaphyre*, **amygdaloid.** The last two amygdaloids with intervening melaphyre appear to be one bed.

53 (41) 755.92-808.92; (S. 17297). **Melaphyre,** ophite. Near the hanging this bed is somewhat seamed and carries laumonite, etc.

43 (32) 808.92-851.92; (S. 17298). *Melaphyre*, **amygdaloid.** Seamed, brecciated and decomposed: carries abundant calcite. Drift to north. On the south face of the cross-cut the rock appears quite compact. There is here a steep slide striking northeast and southwest, and dipping southeast, which might involve some faulting.

75.5 (58) 851.92-927.42; (S. 17300). **Melaphyre,** ophite.

41.5 (32) 927.42-968.92; (Ss. 17301-2). *Melaphyre*, **amygdaloid.** Near the hanging this bed carries calcite and laumonite in large patches. Drift.

78 (60) 968.92-1046.92; (S. 17303). **Melaphyre,** ophite.

9 (7) 1046.92-1055.92; (S. 17304). *Melaphyre*, **amygdaloid;** brecciated.

39 (30) 1055.92-1094.92; (S. 17305). **Melaphyre,** ophite.

27.5 (21) 1094.92-1122.42; (S. 17306). *Melaphyre*, **amygdaloid.**

6.5 (5) 1122.42-1128.92; (S. 17307). **Melaphyre,** ophite.

23.67 (18) 1128.92-1152.59; (S. 17308). *Melaphyre*, **amygdaloid.**

7.5 (6) 1152.59-1160; (S. 17309). **Melaphyre,** ophite.

26 (20) 1160-1186; (S. 17310). *Melaphyre*, **amygdaloid;** possibly with a thin layer of basic conglomerate on the hanging.

87 (66) 1186-1273; (S. 17311). **Melaphyre,** ophite.

5 (4) 1273-1278; (S. 17312). *Melaphyre*, **amygdaloid.**

62 (48) 1278-1340; (S. 17313). **Melaphyre,** ophite.

2 (2) 1340-1342; (S. 17314). Seam of coarse, altered ophite, carrying copper.

20 (15) 1342-1362: (S. 17315). **Melaphyre,** ophite.

7 (5) 1362-1369; (S. 17316). *Melaphyre*, **amygdaloid;** highly altered, and very calcitic; bunchy.

54 (42) 1369-1423; (S. 17317). **Melaphyre,** ophite.

0.5 47 (36) (719) 1423-1470.5; (Ss. 17318-26). **Conglomerate.** The bed is capped by 4 inches of fluccan, and near the hanging is brecciated and seamed with calcite. For about 14 feet from the hanging it is largely of sandstone, changing in five feet to a more basic and scoriaceous character, which continues to the foot, terminating in a 6-inch seam of sandstone. This bed, according to accepted correlations must be the **Calumet** conglomerate, but the absence from it of rounded pebbles of acid rock is very noticeable, and shows a complete change of character in the few miles that intervene between this point and Osceola (N. E.).

3 (2) 1470.5-1473.5; (S. 17327). *Melaphyre*, **amygdaloid;** bunchy.

116.5 (90) 1473.5-1590; (Ss. 17328-9). **Melaphyre,** *porphyrite*; feldspathic. At 50 feet from the hanging there is a slip on the north side of the cross-cut, dipping south-east, and carrying a half inch of fluccan.

53.5 (42) 1590-1643.5; (Ss. 17330-2). *Melaphyre, porphyrite*, **amygdaloid.** Contains frequent cavities, some of them 3 feet in diameter, filled with a soft, clayey decomposition product. Sp. 17332, from near the foot of the bed, is a feldspathic porphyrite of the Ashbed variety.

133 (103) 1643.5-1776.5; (Ss. 17333-6). **Melaphyre,** ophite. At 65 feet from the hanging there is a seam of calcite, one foot thick, which dips about 56° to the west. Near by there are several similar thinner seams, which show marked evidences of faulting movements.

17 (13) 1776.5-1793.5; (S. 17337). *Melaphyre*, **amygdaloid;** carries quartz and epidote.

56 (44) 1793.5-1849.5; (S. 17338). **Melaphyre,** ophite verging on porphyrite. At the hanging is not well defined, but seems to pass, gradually into the overlying amygdaloid, which is more or less, shattered. A number of seams appear on the south side of the cross-cut, carrying laumonite and other alteration products. Dip of seams, about 45° east to southeast.

19 (15) 1849.5-1868.5; (S. 17339). *Melaphyre*, **amygdaloid.**

5 (4) 1968.5-1873.5; (S. 17340). **Melaphyre,** ophite.

20 (16) 1873.5-1893.5; (S. 17341). *Melaphyre*, **amygdaloid.**

156 (122) (451) 1893.5-2049.5; (Ss. 17342. 17636). **Melaphyre**, ophite. The highest 38 feet of this bed. together with the three preceding beds, show more or less disturbance—seams and slips. The lower part of the bed is compact and massive, and coarsely lustre-mottled. In places it shows spheroidal parting on a large scale, some of the joints dipping north about 45°, but with no signs of slipping.

19 (15) 192049.5-2068.5; (S. 17637). *Melaphyre*, **amygdaloid.** This bed (15) occupies the same relative position to the conglomerate next west of it, that the Osceola amygdaloid at Calumet does to the Calumet conglomerate, the vertical distances between the beds being, at the two localities, 451 and 449 feet, respectively. (See cross-section, Vol. V).

106 (83) 2068.5-2174.5; (S. 17638). **Melaphyre,** ophite.

6 (5) 2174.5-2180.5; (S. 17639). *Melaphyre*, **amygdaloid.** Not well defined at the foot, but passes gradually into the underlying bed.

75 (59) 2180.5-2255.5; (Ss. 17640-1). **Melaphyre,** ophite.

5 (4) 2255.5-2260.5; (S. 17642). *Melaphyre*, **amygdaloid.**

153 (121) 2260.5-2413.5; (S. 17643). **Melaphyre,** ophite.

10 (8) 2413.5-2423.5; (S. 17644). *Melaphyre*, **amygdaloid.**

107 (84) 2423.5-2530.5; (Ss. 17645-6). **Melaphyre,** ophite; shows some laumonitic seams near the foot, but is not brecciated to any great extent.

57.5 (45) 2530.5-2588; (S. 17647-50). **Conglomerate.** Capped by 16 inches of fluccan. Consists of medium sized to small, rounded pebbles of felsite and quartz porphyry with some

(863) amygdaloid, in a coarse matrix of similar material. The bottom of the bed consists of about 3 feet of sandstone, under which are 18 inches of an impure and very tough aggregate of calcite and ferruginous matter.

This bed corresponds to the Kearsarge conglomerate at the north, and to the North Star conglomerate at the south. Dip on fluccan, 52°-52½°.

2 (2) 2588-2590; (Ss. 17652-3). *Melaphyre*, **amygdaloid.**

51.5 40) 2590-2641.5; (S. 17653). **Melaphyre.**

10 (8) 2641.5-2651.5. *Melaphyre*, **amygdaloid.**

166 (132) 2651.5-2817.5. **Melaphyre,** ophite.

21 (16) 2817.5-2838.5. *Melaphyre*, **amygdaloid.**

The last three measurements and part of the next preceding were obtained from the drill record.

The above section is the only one in the possession of the Survey that combines accuracy of horizontal measurements with trustworthy observations of the dip of the beds from point to point. These were seen to increase gradually from west to east, being 48° on the Allouez conglomerate, 49°-50° on the Houghton conglomerate, and 52½° on the Kearsarge conglomerate. The dip on the Arcadian bed, still further to the east, is reported by Mr. R. C. Pryor to be 56½°, so that the progressive increase may be assumed to continue to that point, but at a more rapid rate as we approach the lower part of the series.

Mr. Pope also uncovered, on the same location, Sec. 8, T. 55, R. 33, what is thought to be the **Kearsarge amygdaloid.** The rock closely resembles the amygdaloid found at the Wolverine mine, carrying large characteristic amygdules of calcite and feldspar, and being associated with doleritic melaphyres. This bed, according to Mr. Pryor, is about (2425-1117) 1,308 feet horizontally east of the Kearsarge conglomerate. If we assume for it a dip of 54¼°, consistent with the regularly increasing dip observed in the cross-cut, we derive a vertical thickness of about 1,087 feet for the strata between the Kearsarge conglomerate and the Kearsarge amygdaloid. From figures now at hand we can also estimate very closely the thickness between the amygdaloid and the Arcadian bed. Along the section line between Secs. 18-17 and 19-20, the horizontal distance between the north quarter-post of Sec. 18, very near which lies the foot of the North Star (Kearsarge) conglomerate, and the Arcadian bed (210 feet west of the north quarter-post of Sec. 19)— chained by Mr. Pryor—is 5,057 feet. According to Mr. Pryor, the strike of the Arcadian bed is N". 38° 49' E. On Marvine and Emerson's map (Geol. Sur. Mich., I, Atlas, Pl. XIV b) the strike of the Allouez conglomerate is about N. 39° E., so that with this strike, applied also to the Kearsarge conglomerate, we find that the horizontal distance between the Kearsarge conglomerate and the Arcadian bed, at right angles to the strike (5057 X sin 52° 11' = 0.78998), is 3,995 feet. With an average dip of 55°, the vertical distance between these two beds is then (3995 X sin. 55° = 0.81915) 3,273 feet. Deducting the vertical distance between the Kearsarge conglomerate and the Kearsarge amygdaloid—1,087 feet—the vertical distance between the latter and the Arcadian bed is thus about 2,106 feet. The assertion is thus negatived that the Kearsarge amygdaloid and the Arcadian bed are one and the same. We also see that the vertical distance between the Kearsarge amygdaloid and the Arcadian is about 700 feet greater than the computed vertical distance between the former bed at the Wolverine and the "inclusion" bed east of it. The latter, then, is probably not the continuation of the Arcadian-Isle Roy ale horizon, unless the formation at the Wolverine mine is much thinner than at the Arcadian mine. See Chapter IV, p. 77.

§ 2. The Isle Royale Consolidated.

On Atlas sheet XIV a, published with Vol. I, Geological Survey of Michigan, Marvine and Emerson laid down several beds on the south side of Portage lake, whose strike is supposed to correspond with that of the other beds of the series, and several veins whose strike appears to lie more to the west as they are followed south. Of these the principal, beginning on the east, are the "Mabbs vein," the "New vein," and a "Fissure vein" that crosses the old Huron location, on Secs. 1 and 2, T. 54, R. 34. The "Capen vein," east of the Isle Royale bed, appears to strike conformably with the latter, and seems to correspond with the "Jasper" bed found associated at several points with conglomerate No. 7 (Pl. X). The Survey is in possession of little information regarding the exact nature of these occurrences other than what has been gained by a very limited surface inspection of them, but some of them appear at least to partake of the nature of veins and show signs of brecciation, with a frequent filling of calcite between the rock fragments. This brecciation is noticeable also in the Isle Royale bed, which seems to be an amygdaloid, underlain by a bed whose upper part for several feet contains many apparent inclusions of amygdaloid rock, similar to the "inclusion" bed referred to in preceding pages. There is no doubt that in this area, in which the beds dip at angles between 50° and 60°, there has been a good deal of shearing, and while these "veins" are most frequently found to coincide with the amygdaloid portion of the lava beds, which were probably the planes of least resistance, this was not invariably the case. Immediately south of the old Huron location, the entire formation bends more westerly (from about S. 38° W. to about S. 58° W.), and if this change in strike is even in part the result of dynamic action, the plication may easily have been attended with fractures as we now see them in these "veins." Along the sides of Huron Creek, in Sec. 35, T. 55, R. 34, we find many examples of similar brecciation in the scoriaceous parts of the beds exposed there.

With our present limited knowledge it would be perhaps premature to express any decided opinion as to the extent and permanence of the copper deposits that occur between Portage Lake and the Porcupine Mountains, but we must bear in mind that this area, being one of steep dips, if shearing or slide-faulting preceded the deposition of copper and was the chief factor in preparing the way for it by producing seams and cavities, there must be a limit in depth to the effects of this shearing, and consequently in the deposits of mass and barrel copper that followed it. What the limit is we do not know. Where shearing is not confined to a plane of marked weakness, like a sandstone or the top of a conglomerate, but takes place in the more resistant trap, its effects—laterally also—may be distributed over several ill defined planes, each of irregular extent. This possibility should be borne in mind.

Of the geological relation of the Isle Royale to the Grand Portage bed the writer has as yet no information, his intention having been to treat all the mines south of Portage Lake in a future report.

§ 3. Correlation south of Portage Lake.

In Chapter V we have seen that the course of conglomerate No. 8, next east of the Isle Royale—Arcadian bed, probably makes a slight curve across Portage Lake (Plates VIII and X) being found at almost exactly the same distance from the latter bed on each side of the lake. This conglomerate has been traced by frequent outcrops to about 175 paces south of the north line of Sec. 11, T. 54, R. 34, just south of the old Huron mine on the west side of the Ontonagon road. About 860 feet east of it on the Huron Hill, conglomerate No. 6 has been traced almost equally far south. For three-quarters of a mile southwest of the above points, however, no traces of either bed have been seen until one reaches the low swampy ground that forms the headwaters of Huron Creek to the north, and. of a small branch of the Pilgrim to the south. Here the road crosses a bed of conglomerate that has been traced over the crest of Frue Hill in Secs. 10 and 15, down to another branch of the Pilgrim on the Hennes farm about 400 paces east of the west quarter-post of Sec. 15. Here again for about 350 paces no more outcrops appear, although at an intermediate point on the last named stream many conglomerate blocks in the line of strike of the bed just followed from the northeast proclaim the nearness of the parent bed. Three-eighths of a mile beyond, on Five Mile Hill, three different conglomerate beds are exposed—two of them on the Baltic railroad—that pursue the same general course as the former bed nearly to the south line of Sec. 10. The highest* and lowest of these three beds are horizontally about 330 paces (871 ft.) apart, about the same interval that separates No. 6 and No. 8 on the Huron Hill. At this point two hypotheses face us. Either the formation is faulted some 330 paces, or the lowest of the three beds is the continuation of the conglomerate we have followed from the west side of Sec. 11. The invariable absence elsewhere in this area, of felsitic conglomerates for half a mile above No. 8 and the relative distances apart of the three beds on Five Mile Hill make it at least probable that we have here Nos. 6, 7 and 8. Moreover, in the Huron Creek hollow in Sec. 11 there is a large mass of conglomerate apparently in place, about 300 paces above the bed that is crossed by the road, and between the two, although apparently not at the proper interval in either case, there occur at least two thin beds of fine indurated sandstone, like the "jasper" that characterizes No. 7 nearer Portage Lake. However, waiving the question whether this conglomerate mass is in place, stronger evidence, perhaps, of the identity with No. 6, of the bed we have been tracing lies in the recurrence of characteristic amygdaloid conglomerates below it from Sec. 15 southwest, and in the apparent absence below it of any porphyry conglomerate that could correspond to No. 6, if this be No. 8. The reasons are not absolutely conclusive, but from all the facts that are now known, I feel fully justified in the belief that it is conglomerate No. 6 that has thus become prominent in Sec. 15, No. 8, with the possible exception of the isolated outcrop, being drift-covered or having wedged out until it reappears on Five Mile Hill.

The three porphyry conglomerate beds of Five Mile Hill were first opened by Capt. J. C. Hodgson in a series of trenches which are now to a great extent obscured by a growth of shrubbery. They have not been traced immediately south of Sec. 16, the range being heavily drift-covered for several miles in that direction, and few outcrops of any kind are visible beyond the Baltic mine until we reach the lower part of T. 53, R. 35. It is only by a critical study of the beds near Portage Lake that we may hope to recognize the different horizons when they reappear down the range.

In a former chapter attention was called to the irregularity of strike of the contact conglomerate on the south side of Portage Lake, the outcrops of this bed, together possibly with that of No. 2,** forming the sides and bottom of a bowl-shaped depression, capped by conglomerate No. 3, which appears to strike .in close conformity with the overlying beds of the series. Bed No. 3 can be traced only for a short distance back of Houghton, beyond the old workings of the Mabbs vein in Sec. 1, T. 54, R. 34. The conglomerate lies upwards of 100 feet east of the Mabbs vein; the course of the latter is supposed not to be parallel with the strike of the former. The horizontal distance between conglomerate No. 3 and conglomerate No. 6, scaled from Marvine and Emerson's map, is about 2,060 feet, the horizontal distance between. No. 3 and No. 4, being 1,300 feet. No dips have been noted here by the Survey on any of these lower beds, and in the following discussion we are obliged to rely on the assumed general conformity in strike of the beds above conglomerate No. 3, in order to arrive at any conclusions that shall have the force of probability.

*This bed appears in reality to be a doable conglomerate separated by a few feet of trap. There are surface indications of a similar condition in bed No. 8 near its intersection with the old Isle Royale tramway (Pl. X.).

**The possibility is by no means excluded that No. 2 may, after all, be conformable with No. 3, instead of being the northward extension of No. 1, the contact conglomerate.

§ 4. The Baltic.

The Baltic mine is in an amygdaloid bed, whose strike according to Mr. Theodore Dengler, Mining Engineer of the Atlantic and Baltic mines, is N. 60° 30' E. (magn.) This bed crosses the line between Secs. 20 and 21, T. 54, R. 34, about 200 feet north of the quarter-post. It shows some slight evidence of disturbance, in the nature of shearing or slide-faulting, in the presence of several small fissures that strike with the bed and are nearly vertical; they are filled with a carbonate of lime and carry some chalcocite. These fissures appear to wedge out at a short depth from the surface. Other irregular seams cross the rock, filled with calcite, this being also the usual filling of the amygdules. The latter are irregular in shape, and in places almost look as if they were secondary, i. e., pseudamygdules, due to the filling of irregular cavities or pores induced by chemical or by mechanical changes, or by both. The calcite is of earlier origin than the copper found associated with it, the latter showing the mould of the cleavage-and twin-planes in the former. On being exposed to weathering the calcite becomes yellow from a small percentage of iron in it. The dip of this bed is about 73° to the northwest.

About 114 feet southeasterly from the Baltic amygdaloid, we find a bed of porphyry conglomerate, beyond which extend trap and amygdaloid for about three-eighths of a mile to the edge of the Eastern sandstone. This conglomerate dips about 71° in the same direction as the amygdaloid. Above the conglomerate we find no other similar bed exposed in this immediate area until we reach No. 6, in Sec. 16. The horizontal distance between these two, allowing 20 feet for difference of altitude, is about 2,280 feet. In Sec. 15, next northeast, there is a fine exposure of conglomerate on the Hennes farm, which the Survey located by compass and by chaining, from the northeast corner of that section. It is about 2,440 feet horizontally southeast of No. 6, in the same section. These are the only two positive outcrops of porphyry conglomerate found by the Survey below No. 6 in this township west of Sec. 12, but it is noteworthy that near the southwest corner of Sec. 15, nearly in line with them, numerous fragments of conglomerate in the soil point to the probable nearness of the parent bed at that point.

Going back to Sec. 1, we have seen that the horizontal distance between conglomerates No. 6 and No. 3, near the Mabbs vein, scaled from Marvine and Emerson's map, is 2,060 feet. If then the dips in the various strata that make up the zone from Portage Lake to the Baltic mine are even approximately uniform in the same bed, the Baltic conglomerate, the conglomerate on the Hennes farm south of the center of Sec. 15 and bed No. 3, must be one and the same bed. The fact that bed No. 4 is 1,300 feet horizontally above No. 3 at once negatives any suggestion that either of the two former outcrops can correspond to No. 4. They must be No. 3, or else some other bed very near its horizon—a bed of which we have no indications elsewhere, unless it be bed No. 2. The differences in the above horizontal measurements may be due to differences of dip in the strata opposite the several points considered. In any event they are, under the circumstances, not great enough to vitiate the correlation.

The bearing of this evidence upon the extension of the Baltic amygdaloid northeast can be appreciated at once. The possible existence of a slight fault or of a sudden curve in the formation near the west line of Sec. 15, by which the beds of Sec. 15 may lie somewhat more to the east than the corresponding beds in Sec. 16, may account for the length of the cross-cut made by the Atlantic exploration near the southeast comer of Sec. 16. If the line of disturbance, if there be such, lies to the west of this cross-cut, the distance to the conglomerate may be in reality greater than was expected. Even if no such line of disturbance exist, the cross-cut is apparently not yet far enough advanced to cut the lode. Upon the extension or non-extension of the latter to this point there can therefore as yet be nothing authoritative.

§ 5. The Atlantic.

The Atlantic mine, formerly called the South Pewabic, has commonly been thought to be in the Ashbed horizon, the same in which the Copper Falls, Arnold and some other mines on Keweenaw point have worked, and was correlated by Marvine and Emerson* with beds just below conglomerate No. 17, the Hancock West. The bed worked by the Atlantic Mining Co. is in part a melaphyre conglomerate,† being made up of fragments of amygdaloidal melaphyre in a matrix of fine but more or less angular basic sandy material, in places altered to epidote. The copper-bearing belt extends down into the unbroken amygdaloid. This and the underlying trap belong to the more basic lavas and have no immediate resemblance to the typical Ashbed rock as we find it on Keweenaw Point as far south as the Tamarack mine, other than in the fine dissemination of the copper which it carries. The Ashbed rock shows abundant greenish to reddish crystals of feldspar.

The work of the Survey together with some work recently done at my request by the Atlantic Company, through its Engineer, Mr. Theodore Dengler, enables me to suggest a possible correlation for the Atlantic bed that differs radically from those previously accepted, but appears for several reasons to be worthy of consideration. In appoaching this subject the great drawback has been, and to a great extent still is, the want of positive knowledge as to the dip of the rocks that underlie, drift-covered, the considerable area between the immediate valley of Huron Creek and the Atlantic mine.

The total difference of dip between the extreme beds to be considered—conglomerate No. 6 and the conglomerate next above the Atlantic bed—is, from the best obtainable data, about 4°, which corresponds very closely with the difference of dip across the same interval as far north as the Quincy mine on the opposite side of Portage Lake. From here further north, however, the difference of dip must-soon increase materially, for opposite the Franklin Junior mine it is, as we have seen, 8½°. Whether the same conditions exist at Calumet, the Survey has no means of knowing, for the cross-sections furnished us by the Calumet and Hecla and Tamarack Mining Companies show a uniform dip from one end to the other, that is, the dip of the Calumet conglomerate—37½°-38°. According to these cross-sections the interval between the Kearsarge and Allouez conglomerates is 2303 feet vertically, as against 1971 feet at the Franklin Junior. The formation at Calumet, then, may be thicker than it is at Portage Lake. At the Central mine we know that it is thicker. We see, then, that as we go north from Portage Lake the dips in the Keweenaw series grow flatter in the higher or younger beds, and in the aggregate the beds themselves in certain zones are probably thicker.

The tracing and accurate locating of the position, among others, of conglomerate No. 6, near Portage Lake, has also established the fact that while the course of this bed is somewhat irregular there is no reasonable ground to suppose that in this part of the series there has been transverse faulting other than of a trivial character, and hence the horizontal distances that we are able to scale from the map represent very closely the actual widths of the different belts between conglomerates. Thus, by applying the dips observed and those fairly deducible from them, we can ascertain the probable thickness of each of the different belts. Mr. Pope's valuable work in extending the cross-cut at the Franklin Junior affords a reliable standard of comparison, nearer Portage Lake than any previously known. The measurements derived from this cross-section show that the formation on each side of and immediately adjacent to Portage Lake is practically identical in thickness, but we have just seen that it is there probably less thick than at Calumet.

*Geol. Sur. Mich. I, Atlas. XIV a.

†Pumpelly's description tallies well with this designation. Ibid. I, Pt. II, p. 77.

§ 6. Dips on Portage Lake beds.

1. Franklin Junior—Arcadian.

In the description of the cross-suction at the Franklin Junior mine attention was called to the fact, just alluded to, that the dips observed on the different conglomerates in the cross-cut increase from 48° at the Allouez conglomerate (No. 15) to 52½° at the Kearsarge (No. 12). As previously stated, the dip of the Arcadian (Isle Royale) lode, still further east, is 56½°. This dip—of a copper-bearing zone—in a melaphyre might not agree with that of an interbedded conglomerate, but we have an independent observation in conglomerate bed No. 8 only 660 feet (horizontally) to the east of the Arcadian lode, which nearly agrees with the above figures, so that the fact is apparent that the gradual increase of dip eastward from the Allouez conglomerate holds good as far as conglomerate No. 8.*

In the absence of faults that would materially change the normal thickness of the series here, the extension eastward of the Franklin Junior cross-section from the Kearsarge conglomerate with a dip whose inclination is the average of 52½°-56½° = 54½°, may be accepted as accurate within narrow limits of error.

2. Isle Royale Consolidated.

On the south side of Portage Lake observations on conglomerate No. 12* (Kearsarge, Sec. 2, T. 54, R. 34), by Dr. Lane give dips ranging from 53° to 55½°, the average being about 54°. On the Isle Royale bed the dip according to Capt. W. E. Parnall, is 56°. These dips thus agree very closely with those of the equivalent horizons on the north side of the lake and are another indication that the correspondence of the two parts of the range immediately adjacent to the lake has not been disturbed to any great extent by the hitherto supposed fault in the lake.

3. Atlantic.

On the lowest conglomerate shown in this cross-section, bed No. 6, at a point in the S. W. ¼ of Sec. 11, T. 54, R. 34, a dip of 56° was measured, arid a dip of 58° was noted on Frue Hill, in Sec. 10. The dip at the Atlantic mine at the other end of the cross-section is reported to be from 54° to 56°, an average of 55°.

*See p. 105.

*Correlated by Marvine and Emerson, Mich. Geol Sur, I. Atlas, XIV a.

Cross-Sections

Reducing horizontal width to thickness, we find the different zones as set forth in the following tables:

CROSS-SECTION, FRANKLIN JUNIOR TO ARCADIAN.

The measurements between beds are in feet, from footwall to footwall; those without parentheses denote *horizontal* width, those in parentheses denote *thickness*. No allowance is made for differences of altitude, which will not materially affect comparisons. Dips underscored have been actually observed.

Conglomerate beds.	6		8		Isle Royale bed		No. 11		12 Kearsarge.		13 Calumet.		14 Houghton.		15 Allouez.		16 Pewabic W.		17 Hancock W.
A. Douglass mine, Sec. 30, T. 55, R. 33.			57°	660† (552)	56½°														
B. Arcadian mine, Sec. 20, T. 55, R. 33, to North Star, Sec. 18, T. 55, R. 33.					56½°	55° 3995† (3273)			53½°?										
C. St. Mary's, Sec. 18, T. 55, R. 33.															47°?	1500* (1097)	46°?	640* (460)	
1. Franklin Junior mine, Sec. 8, T. 55, R. 33.							(3273+552=3825)		52½°	1118† (863)	50½°	937† (719)	49½°	524† (389)	48°				
2. Isle Royale Con.‡ mine, Sec. 1, T. 54, R. 34.	57°?	860† (722)		650† (542)	56°	2835 (2329)	54½°	898 (729)	54°		1980 (1592)		53°?						

† Numbers marked thus, †, indicate measured distances; all others are scaled from map. See Plates VIII, IX and X.
* Scaled from Marvine and Emerson's map.
‡ The beds noted in this cross-section were located and their identity was established by Marvine and Emerson under Pumpelly.

A comparison of the foregoing cross-sections, by zones, gives the following:

	Isle Royale Con.	Franklin Jr.-Arcadian.
Beds 8-12...............	3,600	3,825
Beds 12-14..............	1,592	1,582

The difference of elevation between beds 8 and 12 on the Isle Royale Consolidated (414-240) 174 feet, will reduce the vertical distance by 105 feet; that on the Arcadian (550-530) about 20 feet, will reduce the vertical distance between the same beds about 15 feet. In the Franklin Junior cross-cut the correction made for difference of altitude between beds 12 and 15 will increase the vertical distance 28 feet between beds 8 and 12. The corrected distances will then be

	Isle Royale Con.	Franklin Jr.-Arcadian.
Beds 8-12...............	3,495	3,838
Beds 12-14..............	1,592	1,582
Beds 8-14...............	5,087	5,420

These figures are probably within about 100 feet of accuracy,* and, in the absence of faults in the series, they point to ax slight thinning of the formation southwest of the Franklin Junior. Measurements scaled from the map (Pl. X), between the Douglass and Quincy locations show that the horizontal distance at lake level between conglomerate No. 8 and the Allouez conglomerate (No. 15) is 6,660 feet, which with an average dip of (57°, 52°) 54½° makes the vertical distance there 5,422 feet. The corresponding interval at the Franklin Junior being 5,809 feet, and at the Isle Royale Consolidated (derived by subtracting interval 14-15 at the Franklin Junior from measurements at the Isle Royale Consolidated) 5,491 feet, we see that the thinning, if it actually exists, is between the Franklin Junior and the Quincy, and that the formations, in thickness, as well as in dip, agree very closely on each side of and immediately adjacent to Portage Lake. This thinning, then, so far as the evidence goes, may not extend further south than Portage Lake.

*Scale from the map, Plate X, the total distance from No. 8 to No. 14 on the Isle Royale Consolidated is 5,096 feet *minus*, instead of 5,192 feet.

If, now, we construct a cross-section on similar lines to the above, from the Atlantic mine to conglomerate No. 6 in Sec. 15, T. 54, R. 34, lettering the three conglomerate beds† in Secs. 4 and 9 (Atlantic) A, B and C, from the highest down, we get the following:

Conglomerate beds	6		8		C (13)		B (14)		A (15)
3. Atlantic mine. Secs. 4 and 9, T. 54, R. 34, to Sec. 15, T. 54, R 34.		58°		57°		56°		55°	
						1205		571	
		(722)*		(5560—722=4838)		(999)		(468)	

†The locations of these conglomerates were determined by Mr. F. McM. Stanton.

We see, on examination of these figures, that the zone 8—C, 4838 feet, as computed, is just 1.50 feet thicker than the zone 8—13 of the Franklin Junior-Arcadian cross-section, or not greater than what we should expect would be the thickness of the same zone at Calumet. On the other hand, it is 375 feet thicker than the corresponding zone opposite the Isle Royale Consolidated, or 250 feet thinner than the zone 8 —U at the last point (5087 feet). That the bed C cannot well be No. 14, the Houghton conglomerate, is apparent when we try to reconcile the positions of beds B and A† with those of conglomerates next above the Hough ton at other points. This bed C, then, should be the Calumet conglomerate, and if the dips used in our computations be correct, the formation south of Portage Lake may thicken instead of continuing to grow thinner. In order to bring this bed into line with the Allouez conglomerate—which it has been supposed to be—we should have to use a dip of 66° or more on conglomerate No. 6 at Frue Hill, and while there is indeed evidence that the dip on this bed is probably nearly that steep on Five Mile Hill, a mile further southwest, we have no evidence that the same conditions obtain at the point of our cross-section. In candor, however, I must say that the dip assumed for that point has not been determined beyond a reasonable doubt.

A circumstance of some importance that bears on the possible identity of conglomerate C with the Calumet lies in the fact that at about 440 feet vertically under this bed, on the Atlantic location, occurs an amygdaloid bed that carries considerable copper. This may be merely a coincidence, but at Calumet and at the Franklin Junior the Osceola amygdaloid lies 450 feet vertically under the Calumet conglomerate.

If the above considerations and conclusions are just, the Atlantic bed lies between the Houghton and the Allouez conglomerates.‡ There is at least enough of probability in this conclusion to warrant a search for the Quincy bed in ground west of the Atlantic. A more positive statement would perhaps be unwarranted, for in a drift-covered area it is impossible to know whether exceptional conditions exist in the hidden rocks, by which the most careful calculations may be vitiated, and in the present case I have been forced to conclude that conditions may have been reversed that held from Calumet to Portage Lake.

If the conglomerate that I have assumed to be No. 6 were in reality No. 8, bed C would then occupy a position about 250 feet short of that of No. 15 (the Allouez) at the Franklin Junior, but this is a correlation for the older beds that I am loath to admit.

*Derived from cross-section No. 2. The altitude at the Atlantic mine (436 feet above Portage Lake) is about the same as that on conglomerate No. 6 on Frue Hill.

†The intervals respectively between C and B and B and A correspond closely with those respectively between beds 15 and 16 and 16 and 17 at the St. Mary's, but in view of the other facts noted in the text, undue weight should not be given to this circumstance.

‡The interval between them here, 468 feet, is 87 feet greater than that at the Franklin Junior, but the latter is abnormally small. See Proc. L. S. Min. Inst., 1895, p. 76.