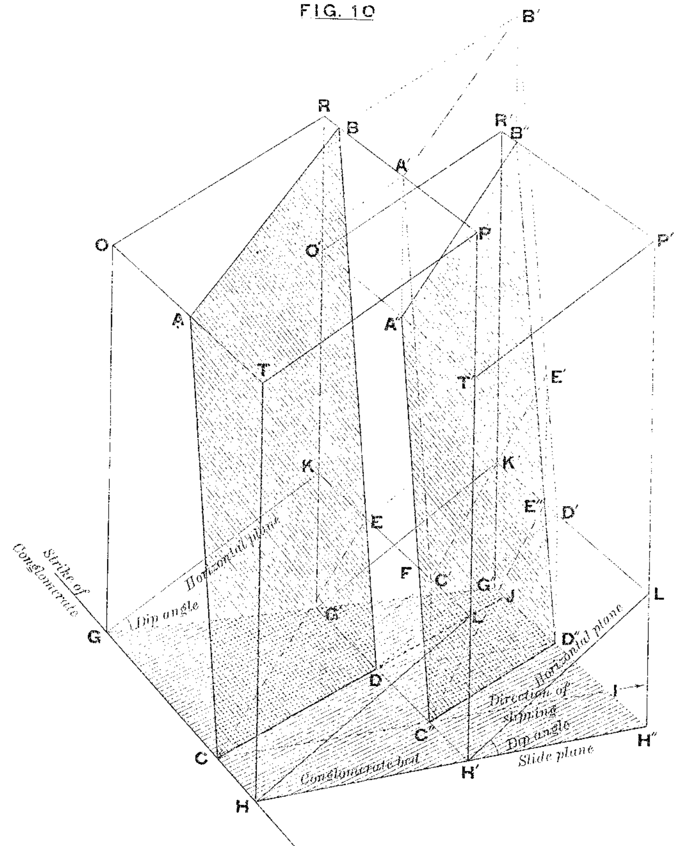
In order to represent the conditions noted in the Central mine, let A B D C, in Figure 10, represent a vein dipping to the right, or east, and extending downwards through a bed G H G″ H″ at C D. Let G H, a horizontal line, represent the strike of this bed, and G H K L

FIG. 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.

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 differ-

ence 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 the 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.

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 C 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=3° 18′, ∠ CC′E=90°. C′E : CC′ = sin 3° 18′ : 1, CC′ = $\frac{1}{\sin 3° 18′}$ = 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=0.095408 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′=17.3432 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 southwest 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. 33, according to the same authority, there is a

*Geol. Sur. Mich., I. Pt. 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.

4-foot belt of fluccan interbedded in the Keweenaw series (Fig. 9).

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. Irving 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.

§ 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

*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.

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 preglacial 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.*

§ 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

*See page 62.

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. To-day 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 in-

*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.

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trusive, 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 stated 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 explanation of many questions that have thus far been difficult of solution. In the following pages I shall have occasion to enter somewhat 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.

*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

*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 further 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.

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 (32) 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

* Copper-Bearing Rocks of L. S., p. 196.
† Geol. Sur. Mich., I, Atlas, Pl. XIV b.

further south, throughout the series, and whether each one is similarly acid elsewhere.

§ 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

* Bull. U. S. G. S., No. 23, p. 28. According to Foster & Whitney, the dip here is 42°.
† *Ibid.*, p. 49.

are exposed in the stream bed, westerly, as far as the Calumet road.

§ 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°-38° 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 amygdaloids 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. 21, 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 southwest, 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 Marvine'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., I, 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. 8 (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.§

On the north side of Portage Lake a cupriferous bed, supposed to be the continuation of the Isle Royale was opened in the Douglass, Concord and Arcadian mines, in Secs 30, 19 and 20, respectively,

* 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.

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 side 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 somewhere 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.

§ 6. Portage Lake as a fault line.

* This "jasper" bed I have never been able to find on the north side of the lake.
† *Ib d.*, p. 58.

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 having 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, and 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 Marvine's supposed fault in Portage Lake was derived, does not appear in his report, for the

* 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.

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.

§ 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

* Bull. U. S. G. S., No. 23, 1885, p. 18.
† *Loc. cit.*, p. 23
‡ *Loc. cit.*, p. 23.

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.

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 lakeward over the surface of the latter. At the east end no disturbance is apparent; the sandstone alone is exposed here in a solid mass.

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.

*Copper-Bearing Rocks of U. S., Pl. XVII.
†Bull. U. S. G. S., No. 23, Plate II.
‡*Loc. cit.*, page 17.
§Geol. Sur. Mich., V, Pt. I, page 136.

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.

§ 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

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

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 sandstone 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."¶

§ 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 horizontality of these

*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.

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 Marvine, 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

* The dip of the Allouez conglomerate at the Franklin Junior (Albany and B ston, 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°.

amount only, and may be due, for aught we know, to differential erosion.

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.

Anothar way in which subsidence may be 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

*Geology of the Henry Mountains, p. 2.

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.

On the south shore of Lake Superior opposite the Keweenaw peninsula rises a mass of Archean granite, outliers of which are seen in the lake at Granite Island and at the Huron Islands, indicating the extension of this area north under the waters of the lake 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 facies 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 superimposition 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 more 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

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

of this movement, whether in an independent subsidence of the trap series, or in an emergence of the Archean.

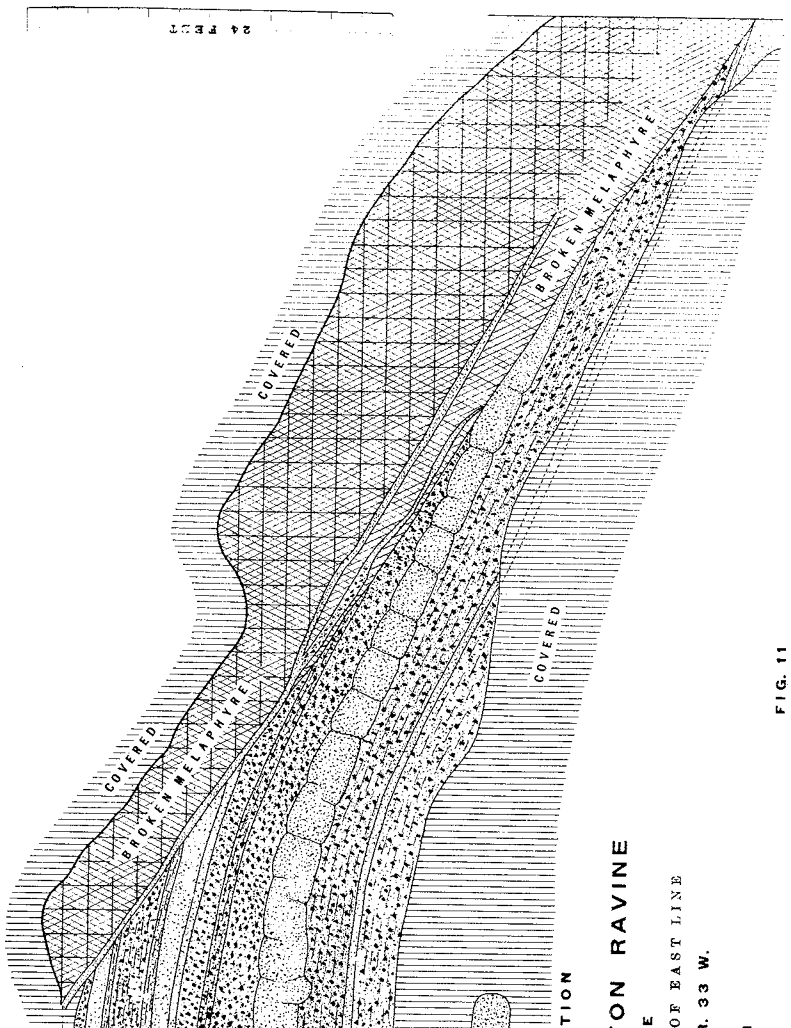
The evidence then seems to point to the early existence of an eroded line of steeply dipping and somewhat corrugated traps, against whose mural faces and over whose gentle slopes, respectively, the Eastern sandstone was laid down. Where the Keweenawan cliff overhung the sandstone, the weight of the former 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.

§ 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.

*Report State Board Geol. Sur., Mich., 1893, p. 164.



VERTICAL SECTION AT DOUGLASS HOUGHTON RAVINE SOUTH SIDE ABOUT 125 PACES WEST OF EAST LINE SEC. 36, T. 56 N., R. 33 W. BY A. E. SEAMAN 1889

FIG. 11

The diagram indicates that there might have been a slight overthrust movement of the traps.

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

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

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.

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*.

§ 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 Bay. (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:

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

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. Chamberlin. 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 9–50: (S. 17275). *Melaphyre*, **amygdaloid;** calcitic. The upper
(31) 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.

113 230.5–343.5: (S. 17282). **Melaphyre,** ophite. At 27 feet from the
(85) 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.**

28 505.25–533.25; (Ss. 17288–9). **Conglomerate,** basic. These three
(51) beds constitute the **Houghton** conglomerate. The upper 39
(389) 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 1423–1470.5; (Ss. 17318–26). **Conglomerate.** The bed is capped by 4 inches of fluccan, and near the hanging is brecciated and

47 seamed with calcite. For about 14 feet from the hanging it is

(36) largely of sandstone, changing in five feet to a more basic and

(719) 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) 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-

(451) 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) 2049.5-2068.5; (S. 17637). *Melaphyre*, **amygdaloid.** This bed 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 amygdaloid, in a

(863) 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°.

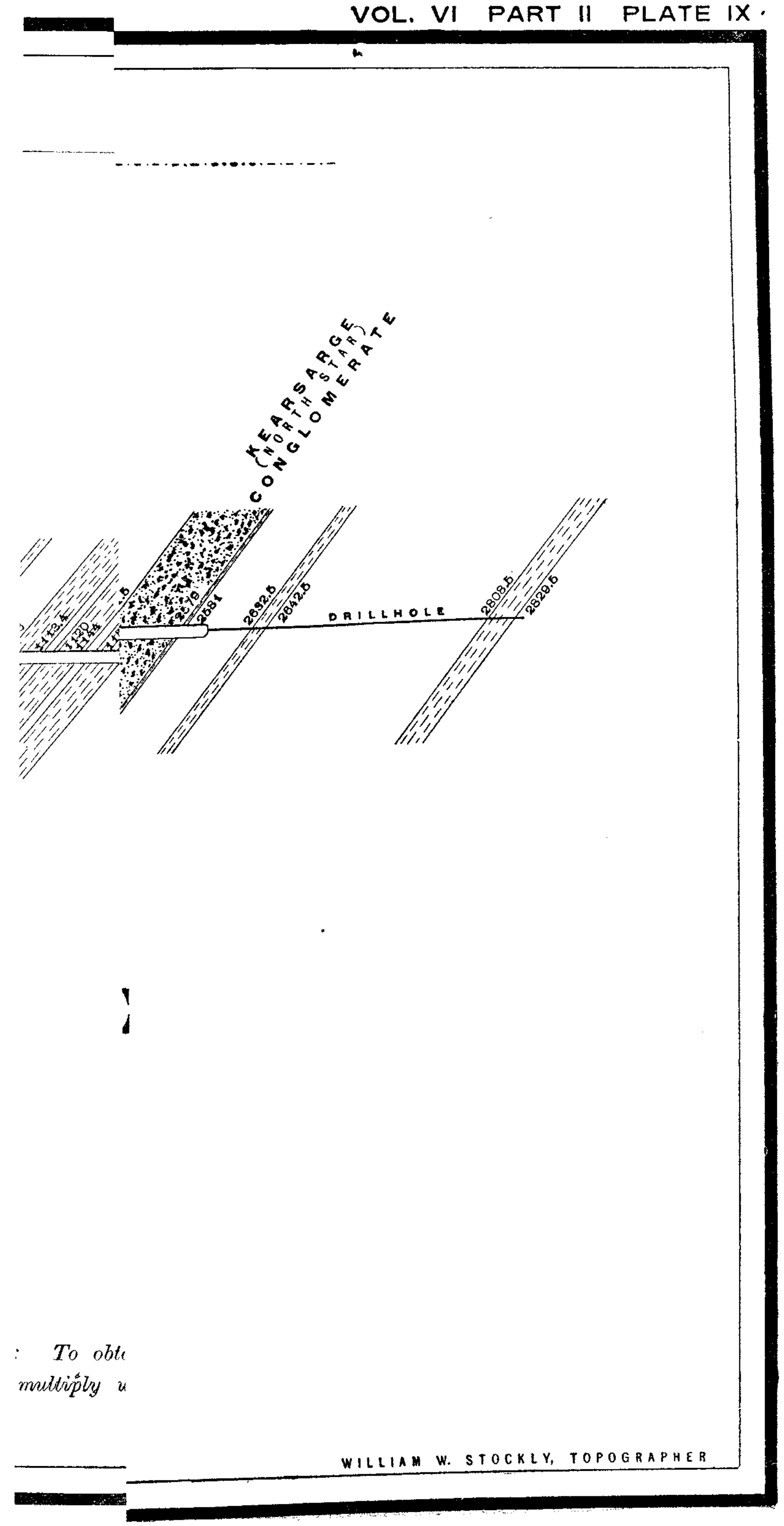
2 (2) 2588-2590; (Ss. 17652-3). *Melaphyre*, **amygdaloid.**

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.

VOL. VI PART II PLATE IX



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 $(5057 \times \overline{\sin 52° 11' = 0.78998})$, is 3,995 feet. With an average dip of 55°, the vertical distance between these two beds is then $(3995 \times \overline{\sin. 55° = 0.81915})$ 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

2,166 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 Royale 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. 16. 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 out-

* This bed appears in reality to be a double 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.).

crops 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.

§ 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 amygda-

* 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.

loid 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 corner 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 bove 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, $8\frac{1}{2}$°. 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

* Geol. Sur. Mich. I, Atlas. XIV a.
† Pumpelly's description tallies well with this designation. Ibid. I, Pt. II, p. 77.

one end to the other, that is, the dip of the Calumet conglomerate—$37\frac{1}{2}°$–$38°$. 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.

§ 6. Dips on Portage Lake beds.

1. Franklin Junior—Arcadian.

In the description of the cross-section 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 $52\frac{1}{2}°$ at the Kearsarge (No. 12). As previously stated, the dip of the Arcadian (Isle Royale) lode, still further east, is $56\frac{1}{2}°$. 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 $52\frac{1}{2}°$–$56\frac{1}{2}° = 54\frac{1}{2}°$, 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 $55\frac{1}{2}°$, 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. $\frac{1}{4}$ of Sec. 11, T. 54, R. 34, a dip of 56° was measured, and 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°.

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

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* See p. 105.

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

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°	3995† (3273)	55°		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 a 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.

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:

* Scaled 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.

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

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)	

We see, on examination of these figures, that the zone 8—C, 4838 feet, as computed, is just 150 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—14 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 Houghton 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

*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.

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.

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GEOLOGICAL SURVEY OF MICHIGAN

VOL. VI

PART II—APPENDIX

THE CRYSTALLIZATION OF THE CALCITE

FROM THE

COPPER MINES OF LAKE SUPERIOR

BY

CHARLES PALACHE

ACCOMPANIED BY SIX PLATES

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LAKE SUPERIOR CALCITES.

INTRODUCTION:—The copper mines of the Keweenaw Peninsula on the southern shore of Lake Superior have long been noted among mineralogists for their rich product of crystallized minerals, among which, after the native copper, calcite easily comes first in the interest and beauty of its specimens.

The present paper presents the results of an extended study of a large series of these calcite crystals. Such a study seemed desirable in view of the fact that the extremely rich crystallographic material here offered had been almost entirely neglected by American students; scattered papers in French and German contain with one exception the only published descriptions of Lake Superior calcites, and while these are excellent as far as they go, they were based on limited material and cover but a small portion of the field.

The material at the author's disposal for this study amounted in all to more than two hundred crystals, and he feels warranted in believing that among them were specimens of all the more important crystal types that have been found in the region. The bringing together of so large and fine a collection of these calcites was made possible only by the liberality of the owners and directors of many mineral cabinets, who allowed the author the free use of the material in their possession, and he desires here to express his thanks and obligations to all those who thus aided him. The following list will show the sources of the studied material. It includes only the number of the crystals actually measured; at least as many more were in hand and studied with less detail.

From the collection of :

C. S. Bement	10	crystals.
Brush Cabinet, Yale University	3	"
J. N. Cox	1	"
B. F. Chynoweth	1	"
G. L. English & Co.	4	"
L. L. Hubbard	22	"
Harvard Mineralogical Museum	21	"
J. H. Lathrop	5	"
R. Pumpelly	12	"
W. D. Schoonmaker	1	"
J. H. Sears	1	"
H. L. Smyth	2	"
Delia M. Stickney	1	"
U. S. National Museum	1	"
Geo. Vaux, Jr.	5	"
W. B. Whiting	21	"
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To Dr. L. L. Hubbard, the author owes a special measure of thanks for his unceasing kindness in supplying material as well as advice and assistance essential to the success of this study; and acknowledgments are due to Mr. W. W. Stockly for the care involved in the final preparation of the plates for publication.

In all of the crystallographic work the author has had the constant advice and aid of Professor Victor Goldschmidt of Heidelberg, for which he would here express his deep obligations.

LITERATURE:—The earlier writers who studied the Lake Superior copper mines make frequent mention of the abundant and beautiful crystallizations of calcite found in the veins; and the fact that these crystals were from the first valued and preserved by collectors is witnessed by the specimens in many collections bearing dates almost as far back as the beginning of mining in the region. But none of these earlier references to the Lake Superior calcites contain any crystallographic descriptions, save the most vague and general, and we are indebted to the German mineralogist, vom Rath, for the first detailed study of crystals from this locality. In a paper * published in 1867

* G. vom Rath, Mineralogische Mittheilungen. Poggendorf's Annalen, vol. 132, 1867, p. 387, vol. 152, 1874, p. 17.

he describes and figures four crystals which exhibit very well the commoner habits of calcite of this region; and his remarks on the dominant forms and on the twinning of these crystals have been fully confirmed by later studies. He published further a description of a complex twin crystal in 1874.

The next study of these crystals was made by Hessenberg* in 1870. He describes two combinations, of forms for the most part new and having highly complicated symbols. The crystals, which appear to have been rather poorly adapted to measurement, were afterwards re-examined by Irby† who altered and simplified many of the symbols found by Hessenberg, but found additional forms of quite as complex a character. But few of these forms of Irby's have been observed a second time and are probably to be considered as vicinal.

Des Cloizeaux figured a crystal of Lake Superior calcite in his Manuél de Minéralogie, Vol. 1, plate XLV, published in 1862; the text in which the figure is briefly described did not appear however until 1874. The crystal was similar to some of vom Rath's.

In 1891, Césaro‡ described a complex crystal with some rare planes.

In 1895 Palache§ described a specimen preserved in the Munich cabinet. A reproduction of his figure is given in figure 8, plate XII, and will be referred to later.

Thus in all, up to the present time, there have been described and figured ten combinations of Lake Superior calcites, exhibiting about twenty-eight well established forms and a number of more or less uncertain ones.

OCCURRENCE OF THE CALCITE :—Calcite occurs abundantly as a vein mineral throughout the copper deposits of Lake Superior. Its deposition appears not to have been confined sharply to any one period of vein filling, but continued through several stages of the process.

According to Pumpelly,‖ who gave special attention to the paragenetic relations of the various minerals, there were two well marked

* Hessenberg, Mineral. Notizen. Abhandlungen der Senckenbergischen naturforschenden Gesellschaft. Band VII, 1870, p. 257.

† J R. McD. Irby. On the Crystallography of Calcite. Inaugural Dissertation, Bonn, 1878. Abstract in Zeitschrift für Krystallographie. Vol. 3, 1879.

‡ Césaro, Calcite from Lake Superior. Annales de la Soc. geol. Belgique. 1891, Vol. 18.

§ C. Palache, Calcite von Lake Superior, Zeitschrift für Krystallographie. Vol. XXIV, 1895, p. 589.

‖ Raphael Pumpelly. The Paragenesis and Derivation of Copper and its Associates on Lake Superior. American Journal of Science, Vol. II, 1871. See also Geol. Sur. Mich., I, Pt. II, p.19.

periods of calcite deposition toward the end of the filling of both fissure veins and amygdaloidal cavities, between which was a period of copper and datolite deposition; while in rare cases there seems to have been an earlier calcite deposit, preceding almost wholly the copper deposit.

The double period of calcite deposition is well shown in the frequent crystals whose growth has been interrupted by the deposit of a coating of copper, the subsequent enclosure of which by a second generation of calcite material in perfect crystallographic continuity with the first often produces "shadow crystals" of great beauty. This interruption in the growth of the crystal is generally marked in addition by a decided change in habit, due to the altered conditions of growth during the two periods. Figure 15, Plate XIV, shows such a "shadow crystal," the inner crystal, outlined by copper, bounded by a positive scalenohedron and the basal plane, the outer one showing only negative scalenohedrons. The cleavage in such a crystal, however, extends unbroken through the whole mass, except for the slight irregularity apt to be caused by the thin layer of tough copper.

In a large number of cases it is certain that calcite was the last mineral to crystallize in the deposit, and to this fact we owe in large measure the great abundance of splendid crystals, the open spaces giving free opportunity for complete crystal development.

It is unfortunate for our study of these calcites that in very many cases the exact locality or mine from which a crystal was obtained has not been recorded. The variety in mode of formation of the deposits that have been worked for copper in this region would give ground to hope that had more data been available it might have proved possible to trace a definite relation between them and the habit of the crystals formed under their various influences. The crystal habit varies in a striking manner, but we are hardly justified in saying more than that, while the crystals exhibit well-marked types in certain districts or groups of mines, slight dependence upon the nature of the deposit has been recognized. Reference to these "district types" will be found below under the description of crystal combinations.

General Description of the Calcite:—The calcite crystals are for the most part transparent, the colorless ones being sometimes absolutely pellucid and flawless even when quite large. The colorless condition is perhaps the most common; but very many are tinted a pale to deep wine yellow, and inclusions of native copper give to some a reddish color. Where the copper is in finely divided scales or spangles it makes a charming "aventurine" effect. Some of the "shadow crystals" mentioned above have the inner crystal of milky white material, while the exterior is colorless, thus heightening the contrast marked by the copper deposition. This milky condition is very common and characteristic in crystals from the Pewabic-Quincy lode, but is otherwise not common in the region. One crystal from the Bement collection was quite black and opaque through abundant inclusions of a powdery black material of undetermined nature.

It is rare to find a crystal other than the most minute in which cleavage cracks are not more or less developed, and the iris colors induced along these planes often add largely to the beauty of the specimen, expecially in water-clear crystals.

The crystal planes are for the most part of great perfection and high lustre, even in large crystals. Certain forms, however, tend to unevenness through striation, and etching phenomena are by no means rare. A discussion of these characters will be found below.

As would be expected there is a wide range in the size of the crystals, but they by no means rival those from other localities in the attainment of extremely large dimensions. The largest crystal from Lake Superior known to the writer is now in the Harvard Mineralogical Museum; it measures about six inches in height and in diameter. Crystals of from two to four inches in height are by no means uncommon and are often remarkable, as well for the perfection of their planes as for the symmetrical development of the many forms frequently found in combination upon them.

One character which lends these crystals a peculiar value both to the crystallographer and to the mineral collector is their tendency to develop as isolated crystals. Often implanted on a sheet of copper or on the wall of a cavity lined with copper or quartz, sits a single symmetrical crystal. Again the calcites are found implanted on delicate threads of copper, giving opportunity for the growth of doubly terminated crystals of more than ordinary completeness. Such perfect forms are, however, of exceptional occurrence and incrustations with occasional crystals rising from their midst, or drusy coatings are the rule.

CRYSTALLIZATION:—The table on the following pages contains a list of all the forms observed on crystals of calcite from Lake Superior. The letters there used to designate the forms are those used by Goldschmidt in the Index der Krystallformen der Mineralien, this being the only list published in which a complete enumeration of the multitude of calcite forms, together with letters for each one, has been attempted. In the column headed "D" are given the letters used by Dana in the System of Mineralogy, 1892, for such forms as appear in his incomplete list. In assigning letters to the many new forms found in this investigation, Goldschmidt's table, on page 141 of the above work, has been used. These letters* have been used both in the gnomonic projection plate and in the crystal drawings. The three columns containing for each form the symbol according to Goldschmidt, Naumann and Bravais-Miller, will facilitate reference to most works containing descriptions of calcite. The Goldschmidt symbol here given is that found under the heading "G_2" in his work.

All the forms named were observed by the author except where noted in the last column, which contains also the names of other observers who have described any of the forms. The word *new* opposite any form indicates that it is new to calcite.

A supplementary list contains all forms recorded for this region which can not be regarded as well established or have been called in question. Forms such as those of Hessenberg which have been revised by later study of the same crystals have not been included.

* In the case of the letter θ a different type has been used in text and plates.

Table of forms of Lake Superior Calcite.

No.	Letter		Symbol			Remarks
	Gld. Pat.	D.	Goldsch.	Naumann	Bravais-Miller	
1.	o	c	0	0R	0001	vom Rath, Hessenberg
2.	b	m	∞	∞R	$10\bar{1}0$	
3.	a	a	$\infty 0$	$\infty P2$	$11\bar{2}0$	vom Rath
4.	ζ	ζ	$\frac{5}{2}\infty$	$\infty R2$	$31\bar{4}0$	
5.	θ	—	4∞	$\infty R3$	$21\bar{3}0$	
6.	ψ	—	$\frac{4}{3}\infty$	$\infty R\frac{11}{9}$	$10.1.\overline{11}.0$	new
7.	π	π	10	$\frac{2}{3}P2$	$11\bar{2}3$	
8.	λ	—	20	$\frac{4}{3}P2$	$22\bar{4}3$	
9.	ν	—	30	2P2	$11\bar{2}1$	new
10.	ω	—	$\frac{16}{3}0$	$\frac{32}{9}P2$	$16.16.\overline{32}.9.$	new
11.	z·	ω	+28.28.	+28R	$28.0.\overline{28}.1.$	
12.	s·	ν	+13.13.	+13R	$13.0.\overline{13}.1.$	
13.	r·	θ	+10.10.	+10R	$10.0.\overline{10}.1.$	vom Rath
14.	m·	M	+4	+4R	$40\bar{4}1$	vom Rath, Hessenberg
15.	k·	k	$+\frac{5}{2}$	$+\frac{5}{2}R$	$50\bar{5}2$	vom Rath, Des Cloizeaux
16.	R·	—	+2	+2R	$20\bar{2}1$	new
17.	p·	r	+1	+R	$10\bar{1}1$	vom Rath, Hess., Des Cloiz.
18.	δ·	e	$-\frac{1}{2}$	$-\frac{1}{2}R$	$\bar{1}012$	vom Rath, Hess., Des Cloiz.
19.	θ· *	—	$-\frac{7}{8}$	$-\frac{7}{8}R$	$\bar{7}078$	
20.	λ·	L	$-\frac{8}{7}$	$-\frac{8}{7}R$	$\bar{8}087$	Irby
21.	ξ·	Λ	$-\frac{4}{3}$	$-\frac{4}{3}R$	$\bar{4}043$	
22.	π·	Π	$-\frac{7}{5}$	$-\frac{7}{5}R$	$\bar{7}075$	vom Rath, Des Cloizeaux
23.	ρ·	h	$-\frac{3}{2}$	$-\frac{3}{2}R$	$\bar{3}032$	
24.	σ·	—	$-\frac{11}{7}$	$-\frac{11}{7}R$	$\overline{11}.0.11.7.$	
25.	τ·	—	$-\frac{13}{8}$	$-\frac{13}{8}R$	$\overline{13}.0.13.8.$	
26.	φ·	f	−2	−2R	$\bar{2}021$	vom Rath, Des Cloizeaux
27.	ω·	—	$-\frac{11}{4}$	$-\frac{11}{4}R$	$\overline{11}.0.11.4.$	
28.	Γ·	ψ	−3	−3R	$\bar{3}031$	
29.	△·	χ	$-\frac{7}{2}$	$-\frac{7}{2}R$	$\bar{7}072$	vom Rath, Des Cloizeaux
30.	Π·	d	−8	−8R	$\bar{8}081$	vom Rath

* In the figures the other form of *theta* is used.

Table of forms of Lake Superior Calcite.—Continued.

No	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
31.	Σ·	Σ	$-11.11.$	$-11R$	$\bar{11}.0.11.1.$	
32.	u:	—	$-\frac{11}{13}\frac{2}{13}$	$-\frac{2}{13}R4$	$\bar{5}.\bar{3}.8.13.$	new
33.	v:	Ψ	$+1\frac{1}{5}$	$+\frac{1}{5}R\frac{11}{3}$	$7.4.\bar{11}.15.$	vom Rath
34.	g:	G	$+1\frac{1}{3}$	$+\frac{1}{3}R\frac{7}{3}$	$52\bar{7}9$	
35.	w:	w	$+1\frac{2}{5}$	$+\frac{2}{5}R2$	$31\bar{4}5$	vom Rath
36.	f:	—	$+1\frac{5}{11}$	$+\frac{5}{11}R\frac{9}{5}$	$7.2.\bar{9}.11.$	
37.	e:	E	$+1\frac{1}{2}$	$+\frac{1}{2}R\frac{5}{3}$	$41\bar{5}6$	
38.	b:	—	$+1\frac{2}{3}$	$+\frac{2}{3}R\frac{4}{3}$	$71\bar{8}9$	vom Rath only
39.	a:	—	$+1\frac{7}{10}$	$+\frac{7}{10}R\frac{9}{7}$	$8.1.\bar{9}.10.$	vom Rath only
40.	G:	—	$+\frac{11}{5}1$	$+R\frac{9}{5}$	$72\bar{9}5$	
41.	H:	λ	$+\frac{5}{2}1$	$+R2$	$31\bar{4}2$	
42.	J:	—	$+31$	$+R\frac{7}{3}$	$52\bar{7}3$	
43.	K:	v	$+41$	$+R3$	$21\bar{3}1$	vom Rath, Des Cloizeaux
44.	L:	—	$+\frac{35}{8}1$	$+R\frac{13}{4}$	$17.9.\bar{26}.8.$	
45.	M:	—	$+51$	$+R\frac{11}{3}$	$7.4.\bar{11}.3.$	
46.	N:	ϒ	$+\frac{11}{2}1$	$+R4$	$53\bar{8}2$	
47.	P·	—	$+\frac{13}{2}1$	$+R\frac{14}{3}$	$17.11.\bar{28}.6.$	new
48.	P:	y	$+71$	$+R5$	$32\bar{5}1$	
49.	T:	ζ	$+10.1$	$+R7$	$43\bar{7}1$	vom Rath
50.	U:	μ	$+13\ 1$	$+R9$	$54\bar{9}1$	vom Rath
51.	Π:	—	$+43$	$+3R\frac{11}{9}$	$10.1.\bar{11}.3$	new
52.	Γ:	—	$+\frac{19}{4}4$	$+4R\frac{9}{8}$	$17.1.\bar{18}.4.$	new
53.	Δ:	—	$+54$	$+4R\frac{7}{6}$	$13.1.\bar{14}.3.$	new
54.	Σ:	—	$+\frac{26}{5}4$	$+4R\frac{6}{5}$	$22.2.\bar{24}.5.$	new
55.	Θ:		$+\frac{16}{3}4$	$+4R\frac{11}{9}$	$40.4.\bar{44}.9.$	new
56.	Φ:	—	$+\frac{11}{2}4$	$+4R\frac{5}{4}$	$9.1.\bar{10}.2$	new
57.	Λ:	—	$+\frac{40}{7}4$	$+4R\frac{9}{7}$	$32.4.\bar{36}.7.$	new
58.	Ξ:	—	$+64$	$+4R\frac{4}{3}$	$14.2.\bar{16}.3.$	
59.	𝔓:	—	$+74$	$+4R\frac{3}{2}$	$51\bar{6}1$	
60.	ℑ:	—	$+10\ 4$	$+4R2$	$62\bar{8}1$	

Table of forms of Lake Superior Calcite.—Concluded.

No.	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
61.	U	—	$+62$	$+2R\frac{7}{3}$	$10.4.\bar{14}.3.$	new
62.	𝔅:	Q	$+\frac{32}{5}\frac{8}{5}$	$+\frac{8}{5}R3$	$16.8.\bar{24}.5.$	
63.	P	—	$+92$	$+2R\frac{10}{3}$	$13.7.\bar{20}.3.$	new
64.	M	—	$+\frac{16}{5}\frac{4}{5}$	$+\frac{4}{5}R3$	$8.4.\bar{12}.5.$	new
65.	Z	—	$+\frac{8}{5}\frac{4}{5}$	$+\frac{4}{5}R\frac{5}{3}$	$16.4.\bar{20}.15.$	new
66.	N	—	$+\frac{20}{11}\frac{8}{11}$	$+\frac{8}{11}R2$	$12.4.\bar{16}.11.$	new
67.	𝔴:	—	$+\frac{5}{2}\frac{1}{2}$	$+\frac{1}{2}R\frac{11}{3}$	$7.4.\bar{11}.6.$	new
68.	𝔟	—	$+\frac{14}{5}\frac{3}{5}$	$+\frac{3}{5}R\frac{31}{9}$	$20.11.\bar{31}.15.$	new
69.	𝔞	—	$+\frac{25}{7}\frac{6}{7}$	$+\frac{6}{7}R\frac{28}{9}$	$37.19.\bar{56}.21.$	new
70.	b:	Γ	$-\frac{11}{4}\frac{1}{2}$	$-\frac{1}{2}R4$	$\bar{5}\bar{3}84$	vom Rath, Des Cloizeaux
71.	𝔉:	p	$-\frac{16}{5}\frac{4}{5}$	$-\frac{4}{5}R3$	$\bar{8}.\bar{4}.12.5.$	vom Rath, Irby, Des Cloiz.
72.	F	—	$-\frac{7}{2}1$	$-R\frac{8}{3}$	$\bar{11}.\bar{5}.16.6.$	new
73.	A	—	$-\frac{26}{7}\frac{8}{7}$	$-\frac{8}{7}R\frac{5}{2}$	$\bar{14}.\bar{6}.20\ 7.$	new
74.	I	—	$-\frac{31}{8}\frac{5}{4}$	$-\frac{5}{4}R\frac{12}{5}$	$\bar{17}.\bar{7}.24,8.$	new
75.	Y	—	$-\frac{56}{13}\frac{20}{13}$	$-\frac{20}{13}R\frac{11}{5}$	$\bar{32}.\bar{12}.44.13.$	
76.	𝔭:	x	-52	$-2R2$	$\bar{3}\bar{1}41$	vom Rath, Des Cloizeaux
77.	B	—	$-\frac{64}{11}\frac{28}{11}$	$-\frac{28}{11}R\frac{13}{7}$	$\bar{40}.\bar{12}.52.11.$	new
78.	𝔛:	N	-84	$-4R\frac{5}{3}$	$\bar{16}.\bar{4}.20.3.$	vom Rath
79.	C	—	$-\frac{18}{7}\frac{4}{7}$	$-\frac{4}{7}R\frac{10}{3}$	$\bar{26}.\bar{14}.40.21.$	Irby
80.	I·	—	$-3\frac{7}{8}$	$-\frac{7}{8}R\frac{55}{21}$	$\bar{38}.\bar{17}.55.24.$	new
81.	D	—	$-\frac{7}{2}\frac{5}{4}$	$-\frac{5}{4}R\frac{11}{5}$	$\bar{8}.\bar{3}.11.4.$	new
82.	E	—	$-\frac{7}{4}\frac{7}{22}$	$-\frac{7}{22}R4$	$\bar{35}.\bar{21}.56.44.$	new
83.	K	—	$-\frac{13}{8}\frac{5}{4}$	$-\frac{5}{4}R\frac{6}{5}$	$\bar{11}.\bar{1}.12.8.$	new
84.	𝔡	—	$-\frac{44}{31}\frac{32}{31}$	$-\frac{32}{31}R\frac{3}{2}$	$\bar{36}.\bar{4}.40.31.$	·new
85.	𝔠	—	$-\frac{28}{17}\frac{16}{17}$	$-\frac{16}{17}R\frac{3}{2}$	$\bar{20}.\bar{4}.24.17.$	new
86.	𝔣	—	$-\frac{32}{13}\frac{14}{13}$	$-\frac{14}{13}R\frac{13}{7}$	$\bar{20}.\bar{6}.26.13.$	new
87.	𝔤:	K	-21	$-R\frac{5}{3}$	$\bar{4}\bar{1}53$	

NOTE: The paper of Césaro op. cit was not accessible to the author and the forms observed by him are therefore not included above.

Supplementary List of uncertain forms of Lake Superior Calcite.

No.	Letter		Symbol: Goldsch.	Symbol: Naumann	Symbol: Bravais-Miller	Remarks
1.			$+18.18$	$+18R$	$18.0.\bar{18}.1.$	vom Rath Probably 19 R or $\frac{35}{2}$ R (Golds.), either of which conforms better with the series of rhombohedron forms.
2.			$+\frac{15}{6}\ \frac{1}{2}$	$+\frac{1}{2}R\frac{11}{3}$	$7.4.\bar{11}.6.$	Irby. Dull face, approx. readings.
3.			$+\frac{70}{27}\ \frac{14}{27}$	$+\frac{14}{27}R\frac{11}{3}$	$98.56.\bar{154}.81.$	Hess., Césaro. Probably same as No. 2.
4.			$-\frac{19}{11}\ \frac{16}{11}$	$-\frac{10}{11}R\frac{8}{5}$	$\bar{13}.\bar{3}.16.11$	Forms 4 to 8 inclusive were described by Irby. All were in striated zones, determined mostly from a single measurement, and are not established, especially as the author's study has shown the forms in this vicinity very subject to the formation of vicinal planes.
5.			$-\frac{32}{13}\ \frac{8}{13}$	$-\frac{8}{13}R3$	$\bar{16}.\bar{8}.24.13.$	
6.			$-\frac{23}{9}\ \frac{5}{9}$	$-\frac{5}{9}R\frac{17}{5}$	$\bar{11}.\bar{6}.17.9.$	
7.			$-\frac{109}{41}\ \frac{22}{41}$	$-\frac{22}{41}R\frac{40}{11}$	$\bar{51}.\bar{29}.80.41.$	
8.			$-\frac{129}{56}\ \frac{17}{28}$	$-\frac{17}{28}R\frac{52}{17}$	$\bar{69}.\bar{35}.104.56.$	

Gnomonic Projection of Calcite Forms:—In order to study the relations of a large number of crystal forms it is necessary to represent them as projected upon a plane. The method here used to do this is known as the *gnomonic projection.* It is constructed as follows: A sphere is imagined as described about the centre of the crystal and a radius of the sphere is drawn normal to each face of the crystal. These radii are extended to intersect a plane tangent to the sphere at the point where the normal to the basal plane emerges, which plane is made to coincide with the plane of the construction. The points of intersection of the face-normals with the plane of projection represent the faces of the crystal. In such a projection the points representing all the faces of a zone—that is, all faces that are parallel to a single direction and whose mutual intersections are therefore parallel—lie along a straight line; and it is this property of the projection which is most useful in the study of so large a number of forms as we have to do with here.

Plate XVI is a gnomonic projection of the forms observed on Lake Superior calcite. It will be noted that the basal plane appears in the centre of the projection; the rhombohedrons lie along six lines diverging at sixty degrees from the centre, positive and negative forms in alternate sectants; the scalenohedrons lie within the sectants; and the prisms are indicated by arrows at the margin pointing to their position, they not appearing as points since the normals to the prism planes are parallel to the plane of projection and hence do not intersect it.

It will at once be noted how certain zone lines stand out in the projection by reason of the number of planes distributed along them. A few words may well be devoted to the more important of these zones before the discussion of the individual forms is entered upon.

The most interesting zone, as being the most characteristic for this locality, is the one containing the planes δ., $-\frac{1}{2}$ R, b⁝ $-\frac{1}{2}$ R 4; and 𝔛 ⁝, −4R $\frac{5}{3}$, with many others between. Very few calcites from Lake Superior can be found which do not show one or more of the scalenohedrons of this zone; and on many crystals three or four may be present. Of the nine scalenohedrons in the zone four are new and peculiar to this locality, and the form b⁝, $-\frac{1}{2}$R4, is, as vom Rath first stated, the characteristic form for the region.

A second zone, notable for its richness in forms, is that stretching between m·, +4R, and 𝔍⁝, +4R 2, containing in this portion nine positive scalenohedrons, of which all but three are here observed for the first time.

The zones containing the various rhombohedrons are of course conspicuous from the great number of planes lying in them, but other localities exhibit the same richness in these forms. The same is true of the zone stretching between two faces of p·, the unit rhombohedron, and beyond in both directions. This is the most important zone among the calcite forms as a whole, containing the commonest scalenohedrons of the species; it is well represented in our crystals by numerous forms, but does not have the peculiar significance for this region possessed by some other zones.

Of the other less important zones that may be traced among the forms of the projection, those of most interest are the ones connecting the many new scalenohedrons grouped about λ·, $-\frac{8}{7}$R, and those near p·, +R, and K:, +R3.

It is probable that the more important zone lines represent directions along which the molecular forces were particularly active during the growth of the crystal. The activity of these forces is controlled in a way not at all understood as yet by the environment of the crystal during growth; according as the conditions favor the one set of forces or the other, faces of forms in the various zones come to bound the crystal, and that variety of combinations is produced which is described by the term "crystal habit." Molecular forces acting along lines transverse to the chief zones are also effective in producing faces upon the crystal, and the points where two or more zones intersect, very commonly mark the most frequently occurring and best developed forms.

FORMS AND COMBINATIONS:—The forms given above in the table, will now be described, singly or in groups as their relative importance and mode of occurrence on the crystals demand.

No. 1, *Basal Plane.* This form appears very rarely on crystals on which positive scalenohedrons dominate the combination, but where negative forms control the habit it is rarely absent, though often small. It is generally bright, but appears sensitive to etching agents and is one of the first planes to become dull when the crystal is attacked.

These observations do not agree with those of Pumpelly* who says: "The basal termination on scalenohedrons of calcite is as rare on Lake Superior as elsewhere, and in the few instances where I have seen it, it lacks the polish which indicates perfect growth."

The form will be observed in various degrees of development in several of the drawings.

Nos. 2 to 6, *Prisms.* The prismatic development is notably rare on Lake Superior calcites. Figure 8, plate XII, reproduces a crystal of prismatic habit, as does figure 21, plate XIV. But these are exceptional types, and generally where prisms occur they are subordinate to other forms, as in figure 20, plate XV. The prism of the second order, $\infty P2$, was noted more often than was ∞R; but the commonest of the prism forms is the new one, ψ, $\infty R\,\frac{1}{9}^{1}$, which is shown in figure 3, plate XI, and elsewhere. Its faces, often rounded, were sharp and bright on many crystals, and the form may be taken as well established and as rather characteristic for the region.

* loc. cit. p. 21.

Nos. 7 to 10. *Pyramids of second order.* These are of minor importance, none of them having been observed more than once. Of the two that are new, ω, $\frac{3}{9}^{2}P2$, is shown in figure 9, plate XIII; the other occurred on a crystal not here figured.

Nos. 11 to 16. *Positive rhombohedrons.* While rarely dominant, these forms are highly characteristic for the region, and are seldom entirely lacking. The steeper forms, Nos. 11, 12, and 13, are of rare occurrence.

m· ,+4R, is however the commonest form of all and plays an important part in the development of the crystals. Rarely very large, it is still present on almost every crystal, is always of the most perfect quality and its admirable reflections were very commonly used to orient the crystal for measuring. About it, as is well shown in the projection and in such crystals as are illustrated by figures 5 and 7, plate XII, are clustered many zones and forms, evidencing the importance of the form. Its characteristic deltoid or triangular shape may be seen in figure 14, plate XIII, and figures 20 and 24, plate XV.

k·, $+\frac{5}{2}R$, occurs rather often as a narrow truncation of the obtuse edge of the common scalenohedron K:,+R3.

R· ,+2R. This new rhombohedron is the dominant form on a magnificent crystal of the Hubbard collection, shown in figure 6, plate XII. It was not observed elsewhere, but the size and perfection of the faces left nothing to be desired in its determination.

p· ,+R. This form occurs only less frequently than +4R on Lake Superior crystals, a notable fact since it is not a common form for most localities. Its faces are generally good, though sometimes dulled by etching. As it is the cleavage rhombohedron, it was always used to orient the forms—that is to determine whether positive or negative—and as few crystals are so fortunate as to have escaped some slight bruise, sufficient, with the easy cleavage of calcite, to develop cracks or to break off a corner, faces of +R were hardly ever absent even when not present as crystal planes.

Nos. 18 to 31. *Negative Rhombohedrons.*

δ· ,$-\frac{1}{2}R$, appears very frequently as a terminal plane, sometimes alone, and with plane faces, more often striated deeply by oscillatory combination with scalenohedrons of the principal zone, a feature not of course confined to this locality.

λ· , $-\frac{8}{7}$R, occupies an important place in the zonal development of these calcites, and appears with sharp, plane faces on many crystals, examples of which may be seen in figure 5, plate XII, figure 10, plate XIII, and figure 16, plate XIV. It seems to be confined to crystals of negative scalenohedral habit.

The forms numbered 19, 21 to 25, and 27 are for the most part limited to a few crystals on which they form zones striking in the sharpness which these slightly differing forms may be recognized. Figure 1, plate XI, a beautiful specimen from the Bement collection, and figure 20 plate XV, from the same source, are the best representatives of this type; in others they merge together more or less, forming rounded surfaces with horizontal striations.

φ· , –2R, is the most common of the negative rhombohedrons. It is generally of brilliant lustre, and its ordinary position, truncating the acute edge of the scalenohedron K:, +R3, as in figure 3, plate XI, makes its identification easy in many cases. Its appearance is very different on crystals of the negative scalenohedral type, such as shown in figures 9 and 13, plate XIII.

Γ· , –3R, forms rhombohedral crystals, the polar edges obliquely truncated by +R, the lateral edges rounded by an indeterminate scalenohedron, which is often deeply etched.

△· , $-\frac{7}{2}$R, was observed on several crystals.

Π· , –8R, occurs in a variety of combinations. See figures 24 and 22, plate XV, where it is the bearer of a simple combination of unusual type, the crystals being quite opaque from the abundance of inclusions as described above, page 165.

Σ· , –11R, was observed only once.

No. 32. *u*:, $-\frac{2}{13}$R4. This new negative scalenohedron in the principal zone is of interest as occurring on several crystals as a narrow plane truncating the edge between the basal plane and the scalenohedron $-\frac{1}{2}$R4, in the manner shown in figure 23, plate XV.

Nos. 33 to 50. *Positive Scalenohedrons of the principal zone.* These forms fall naturally into two groups, comprising, 1st: those between two faces of +R (see projection) Nos. 33 to 39; 2nd: those lying beyond +R in the zone, Nos. 40 to 50. In the first group the forms are very prone to merge together, forming with $-\frac{1}{2}$R, a rounded surface giving a continuous train of reflections in the goniometer. The forms named were, however, well determined; some of them are nearly always present, as the terminations, with $-\frac{1}{2}$R, of crystals having the positive scalenohedral habit. Rarely the crystal is shortened in the direction of the chief axis, and the terminal planes become enlarged so as to give them the importance of dominant forms.

It is to forms of the second group, Nos. 40 to 50, that the crystals so frequently referred to as of positive scalenohedral habit owe their shape. The form K:, +R3, is generally the bearer of these combinations, as is well shown in figure 3, plate XI; upon it the steeper forms of the zone, including the prism of the second order (∞P2) appear as a series of narrow faces parallel to the lateral edges, often merged into a striated, rounded surface. The same is true of the flatter forms which are, however, less numerous, forming a transition to +R and through this form to the series of the first group. Crystals of this habit, more or less modified by negative forms and rhombohedrons, are very abundant, comprising perhaps more than a third of those studied. To this type belonged all the crystals described by vom Rath. They are the characteristic product of the mines of the Ontonagon District, of which the old Minnesota and the National are among the best known. The perfection of symmetrical development of some of the calcites of this type, the abundance and brilliancy of their planes and their transparency combine to place them among the most remarkable crystals known to mineralogy.

H:, +R2, beside occurring as above described, was observed frequently with small, bright faces on crystals of negative type as shown in figure 17, plate XIV.

K:, +R3, is rarely absent from Lake Superior calcites. Either it is dominant as above, or it is in equally balanced development with negative forms, as in figure 1, plate XI, or it occurs as a subordinate form on crystals of negative habit, as in figure 13, plate XIII. In whatever manner it occurs, its faces are always of the finest, remaining bright after most of the other forms have suffered from etching.

P· , +R$\frac{14}{3}$. New, observed on two crystals not here figured.

U:, +R9, is figured by vom Rath as the dominant form on one of his crystals. Though not so observed by the writer, it was found on several specimens as a narrow face.

The remaining forms of this group were not observed except as subordinate members of the principal zone.

Nos. 51 to 60. *Positive scalenohedrons of the parallel zone, $+4R$ to $-2R$.*

The interest attaching to this zone has been pointed out under a previous heading. Representatives of the zone are found on many crystals, and it appears specially characteristic of the water-clear specimens from the Central mine which, except for these forms, display a negative scalenohedral habit. Figure 2, plate XI, and figure 17, plate XIV, show typical combinations in which these forms are prominent and their relations will be best understood by examination of these drawings.

𝔗: , $+3R\frac{11}{9}$, stands apart from the rest of the group as falling within $+4R$ in the zone. It was observed on but two crystals, one of which is shown in figure 5, plate XII. The faces were particularly bright and plane.

ℑ: , $+4R2$ was the most frequently observed of these forms; its bright faces occurred sometimes without any other member of the group, but generally between it and $+4R$ is a series of the intermediate forms.

Nos. 52 to 57 are all new; Nos. 58 and 59 had been before observed by Hessenberg. Although these nine forms lie so near together their faces were always sufficiently distinct to give sharp reflections in the goniometer, and as all but one of them were observed at least once quite alone, each member of the very complete series may be accepted as established.

Nos. 61 to 69. *Positive scalenohedrons of various zones.*

U, $+2R\frac{7}{3}$, new to calcite, is a very common and characteristic form for the Lake Superior crystals. Always with brilliant faces, and lying in a zone with $+4R$, its recognition is generally easy. Figure 4, plate XI, shows it as the dominant form of the combination; more often it is subordinate in size as in figure 2, plate XI, figure 7, plate XII, and figure 14, plate XIII.

𝔙: , $+\frac{8}{5}R3$. Observed but once on the crystal shown in figure 9, plate XIII.

P, $+2R\frac{10}{3}$. New—a small face observed only on the crystal shown in figure 7, plate XII.

M, $+\frac{4}{5}R3$, New—well developed on one orystal as shown in figure 9, plate XIII.

Z , $\frac{4}{5}R\frac{5}{3}$. New—observed on several crystals, but generally somewhat rounded and tending to pass over to the next form. Shown in figure 17, plate XIV.

N, $+-\frac{8}{11}R2$. New—a common form on crystals of negative habit, with smooth faces, often quite large. It is nearly in the zone of the acute edge of $-\frac{1}{2}R4$, which makes it easily recognizable in most cases Shown in figure 6, plate XII, and in figure 19, plate XIV.

𝔴: , $+\frac{1}{2}R\frac{11}{3}$; 𝔟, $+\frac{3}{5}R\frac{31}{9}$; 𝔞, $+\frac{6}{7}R\frac{28}{9}$; These three new forms lie in a zone between $+R3$ and $+R$. They occur with small, bright faces, sometimes altogether as in figure 5, plate XII, or separately, as in figure 7, plate XII, on a few crystals of negative scalenohedral habit.

Nos. 70 to 78. *Negative scalenohedrons of the zone $-\frac{1}{2}R4$ to $-4R\frac{5}{3}$*

This zone has already been pointed out as the most characteristic for the region. Many crystals are combinations exclusively of forms of this zone, a feature the more marked, as negative scalenohedrons as a rule play a subordinate part in the crystallization of calcite, and though certain of the forms here prominent are of common occurrence elsewhere, on no other crystals does the zone as a whole assume any importance.

b: , $-\frac{1}{2}R4$, is the form which fills the most noteworthy role in the development of Lake Superior calcites. Its faces are usually plane and lustrous, giving good reflections in the goniometer. But in crystals where its planes are of relatively large size, it is often much facetted and broken by numerous vicinal planes, most of them very near it in position, and some of sufficiently constant recurrence to be established as independent forms. They will be discussed on a subsequent page. It was the occurrence of these forms on the crystals measured first by Hessenburg, and re-examined by Irby, that occasioned the large discrepancies in their results. Only by examination of a larger suite of crystals could their true character be determined.

$-\frac{1}{2}R4$ appears often as the bearer of the combination, as in figures 23 and 19, plate XV. More frequently it is in balanced development with the form $-2R2$, as in figures 15 and 18, plate XIV. In such crystals its bright faces are in marked contrast to the deeply striated faces of the steeper form. It is this type of crystal that is found most abundantly at the present day, chiefly from the Quincy mine and others in the Pewabic belt. Quite as often it is found as a subordinate form, both on crystals of a negative habit, as in figures 1 and 2, plate XI, and on those of positive habit, as figure 3, plate

XI. In short, it occurs in all possible varieties of development, and is rarely absent.

$\mathfrak{F}$: ,$-\frac{4}{5}R3$, is far less common than the last, but is still a frequent form. Figure 12, plate XIII, shows it as the dominant form of a combination, and it plays the same part in Irby's figure 6. This, however, is rare, and it is more apt to appear as a subordinate face of the negative zone on crystals of positive scalenohedral habit, like that figured by Des Cloizeaux. Its faces are of good quality.

F,$-R\frac{8}{3}$. New—observed but once, as shown in figure 11, plate XIII.

A,$-\frac{8}{7}R\frac{5}{2}$ New—observed but once, as a striated face, but well determined by the zonal relations, as shown in figure 6, plate XII.

I,$-\frac{5}{4}R\frac{12}{5}$. New—observed but once as a narrow face in the chief zone, as shown in figure 14, plate XIII.

Y,$-\frac{20}{13}R\frac{11}{5}$, was first observed by vom Rath on Bergen Hill calcite, and had not again been recognized. Here it is of frequent occurrence, sometimes, as in figure 4, plate XI, of dominant character, more often as a narrow face in the zone. Faces generally deeply striated or dull.

$\mathfrak{v}$: ,$-2R2$, is only less common than $-\frac{1}{2}R4$, with which it is nearly always associated. Its faces are not always striated, as described above, but are plane and lustrous.

B,$-\frac{28}{11}R\frac{13}{7}$. New—observed on two crystals as a narrow face in the zone, as shown in figure 17, plate XIV.

$\mathfrak{X}$: ,$-4R\frac{5}{3}$, was often observed, and sometimes with large faces; always of good lustre. Shown in figure 8, plate XII, and in several of vom Rath's figures.

Nos. 79 to 87. *Negative scalenohedrons of other zones.*

The three forms, Nos. 79, 80 and 81, belong to a zone which is of peculiar interest from its nearness, both, in position and direction to the principal negative zone just described. It is as though some disturbing force had been active during crystal growth, pulling the faces slightly out of their normal positions. It is doubtless to such abnormal forces that we are to ascribe the formation of the so-called "vicinal planes," and as such, these are to be regarded, though they are here sufficiently definite in their occurrence to be recognized as independent forms.

C,$-\frac{4}{7}R\frac{10}{3}$, was one of the many planes, near to $-\frac{1}{2}R4$, observed by Irby on a single crystal. It alone has been confirmed by the study of the larger series at the author's command. It is a very common form, either as the bearer of rich combinations like those shown in figure 5, plate XII, and in figure 17, plate XIV; or as a vicinal to $-\frac{1}{2}R4$ in the shape of facets as shown in figure 19, plate XIV, and in figure 7, plate XII. Figure 10, plate XIII, reproduces a crystal of special interest as exhibiting all the forms of this abnormal zone without any of the typical forms being present. The crystal sufficiently defines the character of the two new forms of the zone, I·,$-\frac{7}{8}R\frac{55}{21}$, and D,$-\frac{5}{4}R\frac{11}{5}$, neither of which was observed more than twice.

No. 82, E, $-\frac{7}{22}R4$. New—observed on but one crystal, as a narrow truncation of the edge between 0P and C, $-\frac{4}{7}R\frac{10}{3}$, as shown in figure 5, plate XII. The faces were somewhat uneven.

No. 83, K,$-\frac{5}{4}R\frac{6}{5}$, is a new form of special interest, and is very characteristic for the region. Many crystals had been examined which were very nearly cubical in outline, but their faces so rounded and broken that it was impossible even to say whether the dominant form was a rhombohedron or a scalenohedron. At length the crystal reproduced in figure 13, plate XIII, was sent to the author as a very rare form from the Ridge mine, and it gave a satisfactory solution of most of the problematic crystals. The dominant form was the scalenohedron in question, $-\frac{5}{4}R\frac{6}{5}$; it approximates so closely to the rhombohedron $-\frac{7}{5}R$, whose angles are within less than a degree of 90 degrees, that the cubical appearance of the rough crystals on which it occurred is readily understood. Owing to the selection of the point of view, this effect is unfortunately rather poor in the drawing. On this crystal the planes were highly polished and gave excellent reflections; it was not observed in measurable condition on other specimens.

No. 84, $\mathfrak{d}$,$-\frac{32}{31}R\frac{3}{2}$, and No. 85, $\mathfrak{c}$,$-\frac{16}{17}R\frac{3}{2}$, are new forms in a zone with $-\frac{8}{7}R$ and $-\frac{1}{2}R4$. The crystal on which they were observed was etched in parts, and it is possible that these are etch faces, which would in a measure explain their complex symbols. They are shown in figure 12, plate XIII. The second of the two was also observed on other crystals.

No. 86, $\mathfrak{f}$, $-\frac{14}{13}R\frac{13}{7}$, a new form, and No. 87, $\mathfrak{g}$: , $-R\frac{5}{3}$, occur, together with No. 85, in a zone on three crystals of the type shown in figure 16, plate XIV. The large development of these forms on several splendid crystals, and the perfect quality of their faces establish them as good forms despite the complex symbols which must be employed to satisfy the measured position. The crystal figured is also remarkable for its twinning, described below.

RÉSUMÉ:—A brief review of the foregoing descriptions shows the following facts. Of the 85 crystal forms observed by the author on Lake Superior calcites, 59 have not been before described from that locality, and 32 are new to the species.

The forms most prominent by reason of their common occurrence, are $-\frac{1}{2}R4$, $+R3$, $+4R$, $+R$, $-2R2$, and 0P.

As peculiarly characteristic of the locality, the following forms may be named: $-\frac{1}{2}R4$, $+4R$, $+2R\frac{7}{3}$, $+\frac{8}{11}R2$, $-\frac{8}{7}R$, $\infty R\frac{11}{9}$, and the forms having the general symbol 4Rn.

Two general types of habit are recognized in which the positive and the negative scalenohedrons dominate respectively, but there are many crystals of intermediate habit in which both groups of forms occur in balanced development. The prismatic and rhombohedral habits are rare.

There are but few exceptions to the rule that the crystal planes are of good quality, and give excellent reflections for measurements.

The formation of vicinal planes is most marked in the neighborhood of the form $-\frac{1}{2}R4$.

TWINNING:—Twinned crystals are a common feature of Lake Superior calcites. Twinning occurs according to two laws: first, the twin and composition face is 0P; second, the twin and composition face is $-\frac{1}{2}R$. Of these two laws the first is exemplified in a far greater number of cases.

A simple twin on 0P is shown in figure 20, plate XV, reproducing a remarkably perfect and symmetrical crystal from the Bement collection. In this crystal the twinning has not resulted in the appearance of any re-entrant angles as is so often the case; it is simply expressed in the horizontal boundary dividing the upper and lower portions of the crystal, and in the reversal of the ordinary alternate relation of the faces above and below. Such simple twins were also shown by the fine crystal in the U. S. National Museum at Washington, by a splendid specimen in the Hubbard collection, and by the crystal in the Harvard Cabinet, already mentioned as of unusual dimensions. They do not, however, seem to be of common occurrence.

A much more frequent expression of this twinning, is that shown in figure 17, plate XIV. Here a thin band or lamella through the centre of the crystal is alone in twinning position, the portions above and below it retaining their normal relation. This layer is parallel to 0P, and occupies almost invariably the very centre of the vertical dimension of the crystal. Sometimes it is of no greater thickness than a very thin sheet of paper, and may be traced as a fine hair-line or seam on the glassy surface of the crystal. Figure 17 shows such a case, the cross-section accompanying it aiding to show the interruption in the crystal growth caused by the twinning. The various faces are cut off sharply by this almost invisible boundary, some forms, however, such as m· , continuing their growth beyond the re-entrant caused by the twin lamella.

Again, the twin lamella may be of greater thickness, showing crystal planes on its surface as in figure 19, plate XIV. And in very exceptional cases the lamella grows outward along the edges, beyond the boundaries of the main crystal, producing wing-like segments of a second crystal in twin position to the parts of the first above and below. Two such specimens were studied, one of which, a superb crystal over two inches in height, from the Hubbard collection, is figured in figure 16, plate XIV. The other was from the Pumpelly collection, and was much smaller and less perfect, but was bounded by the same rare planes as the first named. Very often, too, several lamellae in alternate twin position are intercalated in the crystal centre.

The occurrence of this twin seam or "Naht" was first described by vom Rath, and is a characteristic feature of the Lake Superior crystals, not known elsewhere.

Twins on the face of $-\frac{1}{2}R$ are not rare, and often take the form shown in figure 18, plate XIV, the distortion of the faces of $-2R2$, there indicated, being a common feature. This form of twin was observed only on crystals of negative type, chiefly from the Quincy mine; the finest example seen was a very large specimen in the Hubbard collection not here figured. Many crystals show numerous twin lamellae parallel to $-\frac{1}{2}R$, and on some such, sent to me by Dr. Hubbard, he pointed out that the summits were injured in such a way as to suggest a blow or impediment during growth sufficient perhaps to produce a pressure on the crystal through which the twinning was induced in the well-known manner. In a few cases these fine twin lamellae traverse the crystal in such numbers and with such regularity as to produce a marked striation on the bounding faces.

STRIATION AND ETCHING:—Both phases of crystal imperfection are commonly illustrated on these calcites. Several cases of characteristic striation have already been cited, for example, that parallel to the combination edges of the planes of the principal negative zone; this affects all the faces of the zone, but particularly the forms b: and Y.

Other examples may here be noted. In figure 5, plate XII, striations are well marked parallel to the edge between λ· and C. In figure 14, plate XIII, v-shaped striations will be seen on m· parallel to its intersection edges with the faces of 4Rn. Deep striations are frequent parallel to the edges of intersection of N with b: or its vicinals. In figure 2, plate XI, is shown a horizontally striated face lying between m· and U; it is found to be produced by the oscillatory combination of the forms θ :, $+4R\frac{11}{9}$, and Π: , $+3R\frac{11}{9}$. In the same way, in figure 9, plate XIII, the striation face between 𝔙: and C is caused by combination of ω and m.

The effects of etching have not been introduced into the figures, though many of the crystals studied showed interesting samples of that process. As the faces produced by it are almost always rounded or rough, and of variable position, they cannot for the most part be given places as independent forms. Some of the features may, however, be noted.

Many crystals of positive habit show among their terminal planes more or less even faces lying slightly out of the principal zone. This is probably an etch form, as measurements on various crystals gave very discordant results for its position. The crystals which show this form have very often suffered a deep corrosion of the upper parts of the faces of K:, +R3; these parts are roughened and pitted while the remainder of the crystal is unharmed. The portion of the face affected is generally bounded below by a curve which is symmetrically located on all the faces.

On one fine specimen from the collection of Mr. Whiting, deep triangular etch figures appeared on the faces of the form U, $-2R\frac{7}{3}$; unfortunately the crystal was too large to mount on the goniometer, and the position of the sharp faces which bounded the pits within, could not be determined.

In the description of the form K, $-\frac{5}{4}R\frac{6}{5}$, mention was made of the many rough and rounded crystals whose form was probably determined by it. The rough surfaces of these crystals give evidence of having been produced by etching processes.

Nothing is known as to the agents producing these etching effects in this region; nor can they be correlated with any particular period of deposition, or mode of formation.

COURSE OF INVESTIGATION:—The crystallographic studies, the results of which have here been given in brief form, have extended over a period of nearly three years, during which new material has constantly been obtained. Some of the new forms discovered have already been announced in the pages of Goldschmidt's Krystallographische Winkeltabellen, Berlin, 1897, p. 396, and table, pp. 82-86, but many more have been added to the list since the publication of that work. It will be noted that the measurements and tables of angles on the basis of which the new forms have been established, are not given in this paper. Those who desire to consult these data are referred to a paper shortly to appear in the Zeitschrift für Krystallographie, where a full discussion will be given.

The measurements were made for the most part on a goniometer with two circles (Goldschmidt Model 1895), which proved itself especially effective in the study of the complex crystals in hand. Small crystals were generally available, and where such were not to be had, and specimens too large to be mounted on the two-circle instrument were to be measured, recourse was had to the ordinary horizontal goniometer (Fuess, No. 2.)

Mineralogical Museum, Harvard University, July 1898.

EXPLANATION OF PLATES.

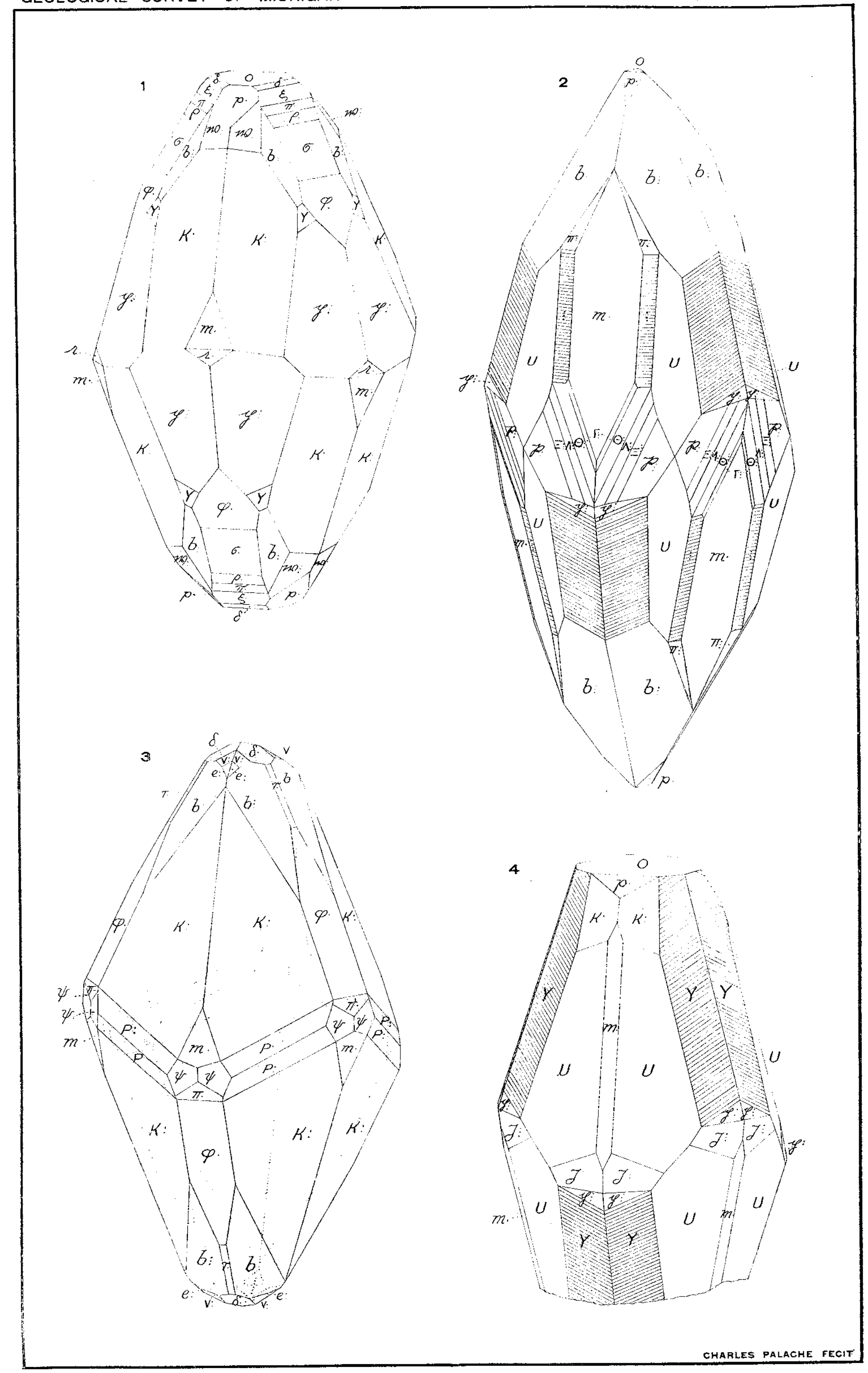
Fig. 1. Bement Coll. (171). Locality not stated, but similar crystals in the coll. come from Owl Creek Vein, Copper Falls Mine. Transparent, yellowish, 1 inch high.

Fig. 2. Hubbard Coll. (86). Central Mine. Colorless, ½ inch high.

Fig. 3. Harvard Cabinet, (33). Minnesota Mine, Ontonagon district. Transparent, yellowish, 1 inch high.

Fig. 4. Whiting Coll. (9). Colorless, ¼ inch high.

Fig. 5. Whiting Coll. (3). Colorless, minute. The face C which occurs on this crystal, and is referred to twice on page 179, is the face running diagonally down from p·.
Fig. 6. Hubbard Coll. (268). Colorless, 3 inches high.
Fig. 7. Whiting Coll. (54). Colorless, 1 inch high.
Fig. 8. Munich Cabinet. Reproduced from Zeit. für Kryst., *loc. cit.* p. 589.
Fig. 9. Brush Coll. (127). Twin lamella parallel to 0P. Colorless, $1\frac{1}{2}$ inch high.
Fig. 10. Pumpelly Coll. (168). Phœnix Mine. Colorless, etched, small.
Fig. 11. Harvard Cabinet (129). Some faces etched, copper inclusions. Under $\frac{1}{2}$ inch.
Fig. 12. Hubbard Coll. (258). Minute, colorless, etched in part.
Fig. 13. B. F. Chynoweth (259). Ridge Mine, Ontonagon district. Yellowish, 1 inch high.
Fig. 14 Whiting Coll. (18). Water-clear, 2 inches high.
Fig. 15. Harvard Cabinet (30). Central Mine. "Shadow Crystal," with copper inclusions, 1 inch high.
Fig. 16. Hubbard Coll. (266). Yellowish, $2\frac{1}{2}$ inches high. Twin on 0P.
Fig. 17. Vaux Coll. (136). Water-clear, $2\frac{1}{2}$ inches high (with vertical section). Twin lamella parallel to 0P shown.
Fig. 18. Hubbard Coll. Quincy Mine. Twin on $-\frac{1}{2}$R, copper inclusions, 2 inches high.
Fig. 19. Hubbard Coll. (75). (Drawn in orthographic projection.) Twin on 0P. Yellowish, 1 inch high.
Fig. 20. Bement Coll. (164). Owl Creek Vein, Copper Falls Mine. Yellowish crystal, 2 inches high. Twin on 0P.
Fig. 21. Harvard Cabinet (143). Colorless, minute.
Fig. 22. Bement Coll. (165). Ridge Mine, Ontonagon district, 1 inch high, black from inclusions.
Fig. 23. H. L. Smyth (124). Colorless, $\frac{1}{4}$ inch high.
Fig. 24. W. D. Schoonmaker (139). One corner of large crystal 2 inches high, transparent.



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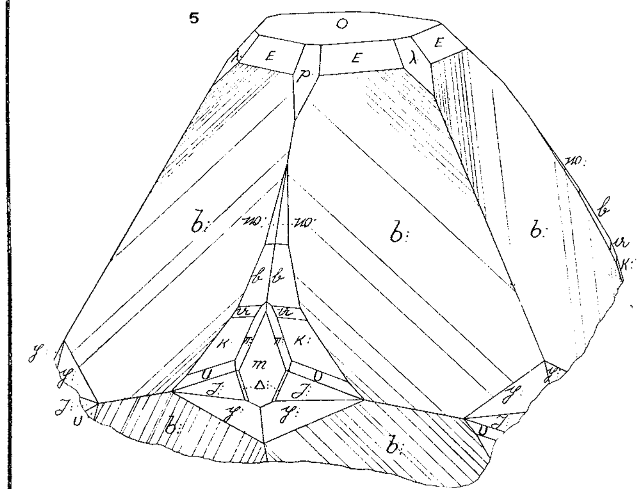

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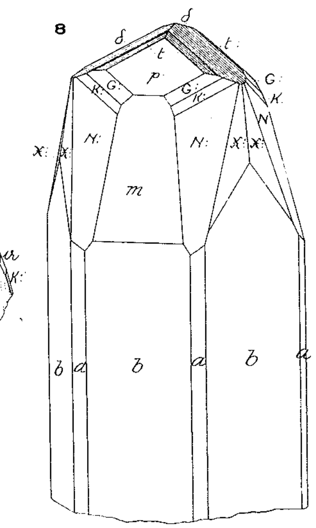

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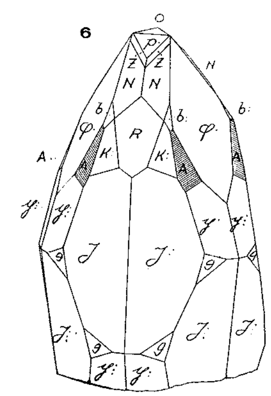

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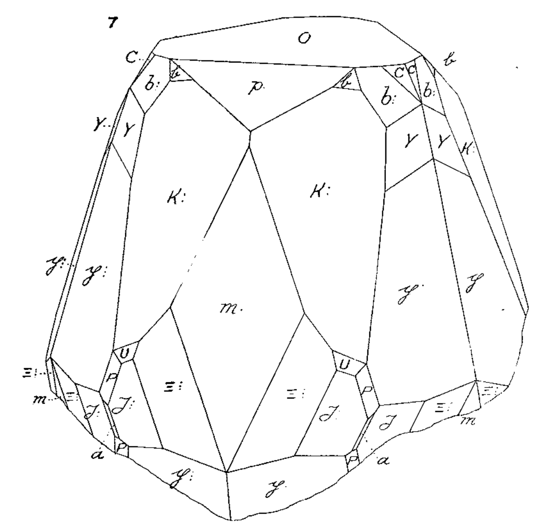
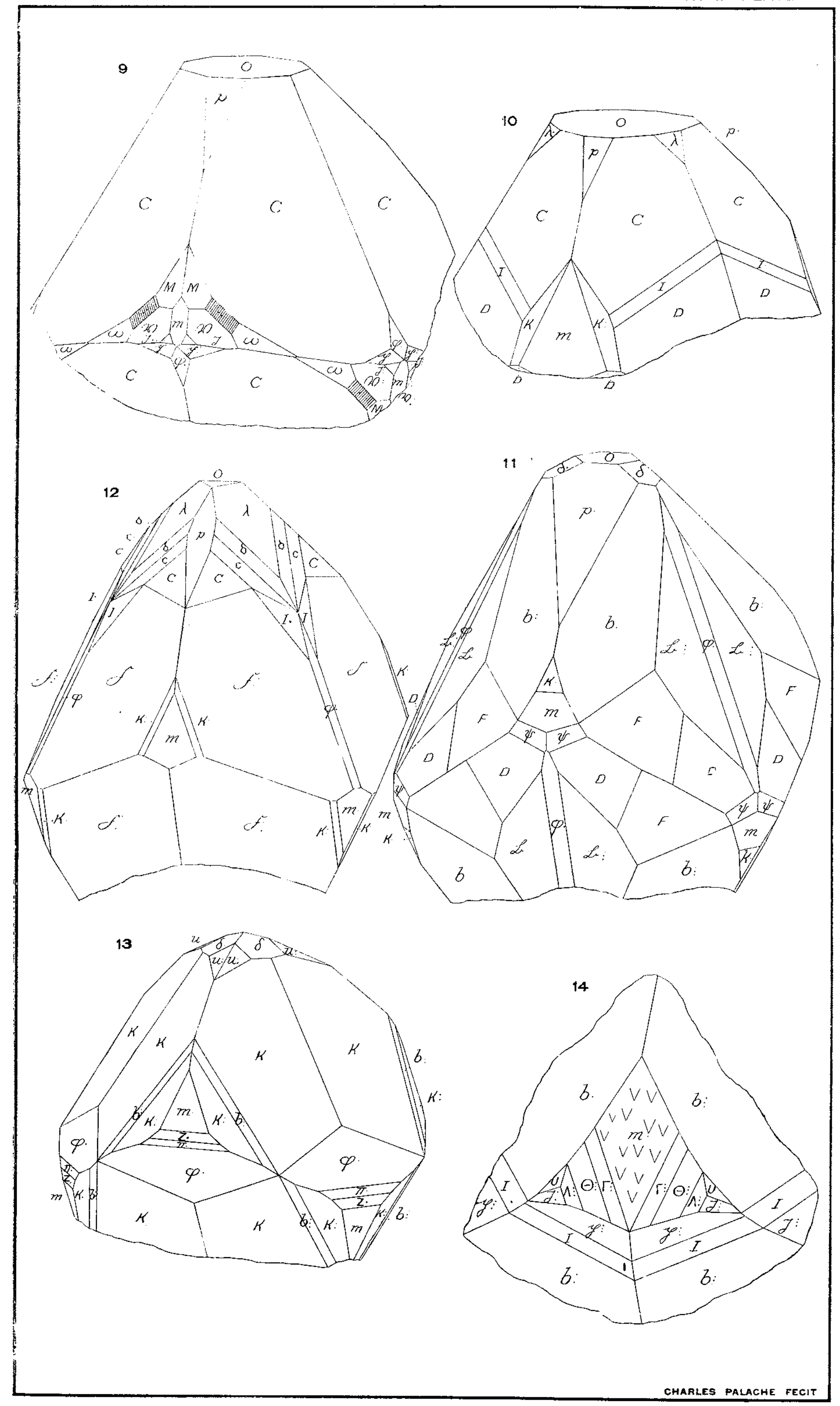


CHARLES PALACHE FECIT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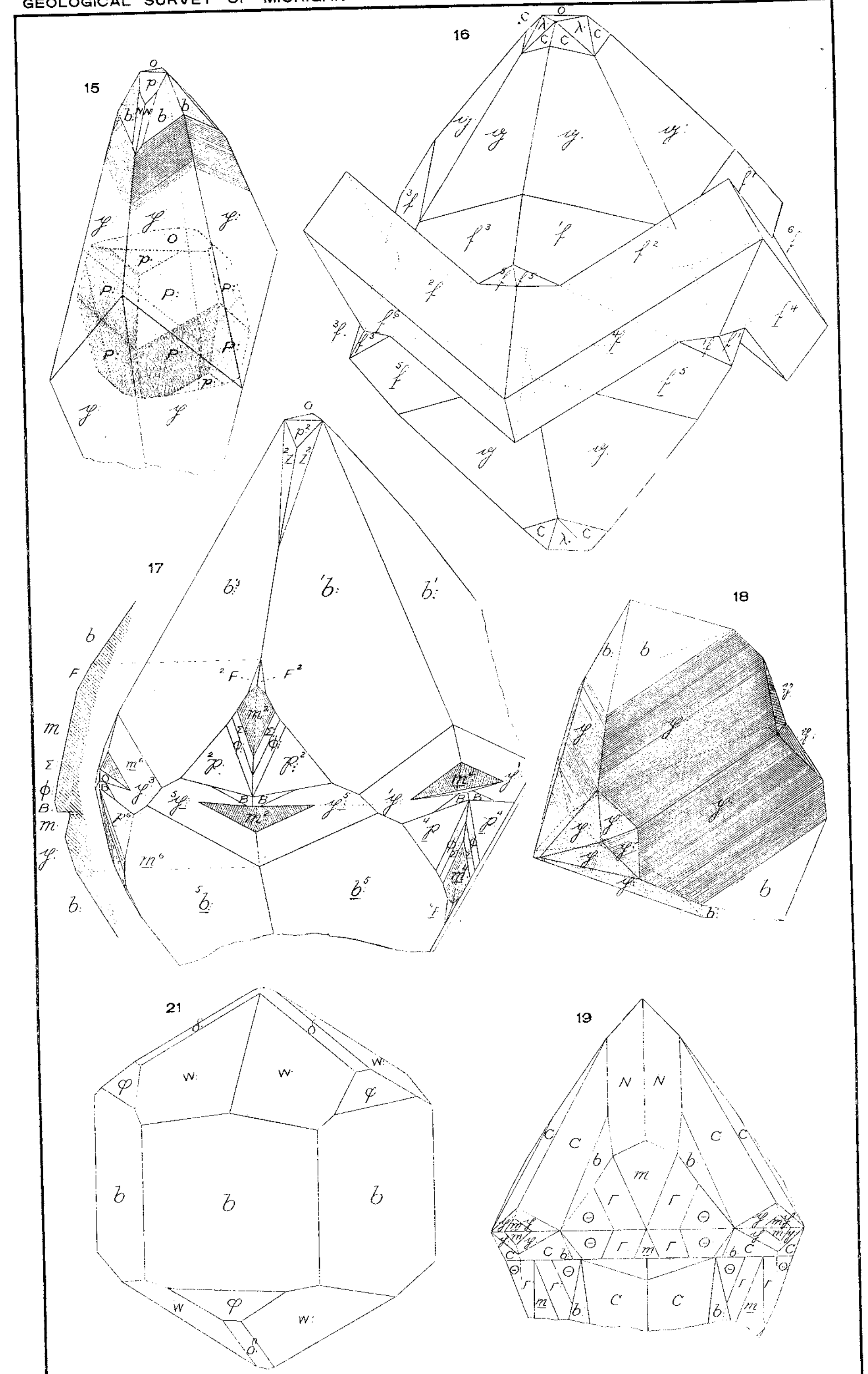

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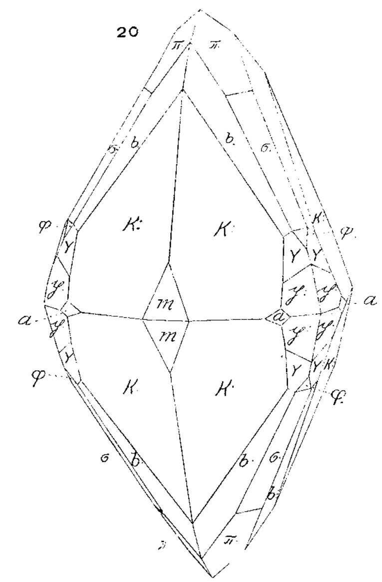

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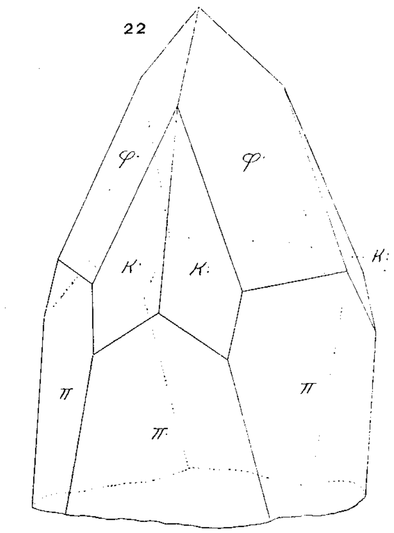

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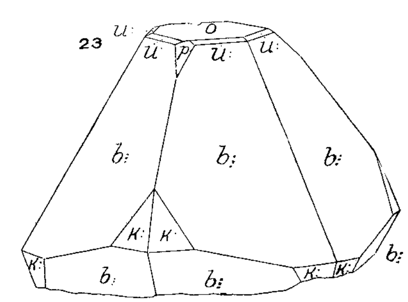

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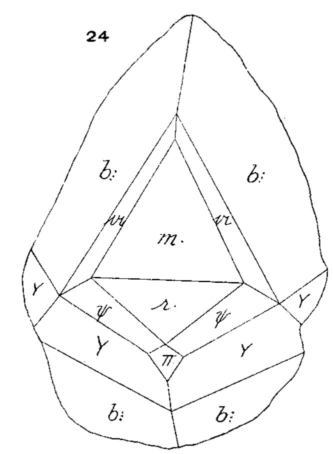

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