PART II

COPPER DISTRICT

BY

RAPHAEL PUMPELLY.

ASSISTANTS:

A. R. MARVINE, M.E., L. G. EMERSON, C.E., AND S. B. LADD.

ATLAS PLATES

REFERRED TO IN PART II

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To the Honorable Board of Geological Survey of the State of Michigan:

Gentlemen:—I have the honor to submit herewith a Report on the work done by the Geological Survey of the Copper District of the State, during the seasons of 1870 and 1872.

Yours very respectfully,

RAPHAEL PUMPELLY.

New York, *May* 1, 1873.

PREFACE.

THE work of the Geological Survey of the Copper District in 1870 and 1872 was confined chiefly to the construction of as perfect a series of cross-sections as circumstances would permit, in the Portage Lake, Calumet, and Eagle River districts. This seemed to be the most desirable method of expending the very limited annual appropriation of two thousand dollars. Any attempt to cover a wider field would have resulted in a simple reconnoissance of the district, without adding essentially to the previously existing information. To obtain the cross-sections which accompany this report, it was necessary to make an accurate triangulation of the country examined, without which it would have been impossible to represent in their relative positions, in a very uneven country, the outcroppings of the very numerous thin beds of nearly similar rocks, possessing varying thicknesses, an almost constantly changing course, and a high and varying degree of inclination. During 1870, the work was confined to the Portage Lake district, the survey of which was platted on a large working-map to the scale of 300 feet to one inch $= \frac{1}{3600}$. The cross-sections are on the scale of 90 feet to one inch. This scale appeared to be necessary in order to represent many beds of from two to six feet only in thickness, and especially to admit of adopting the same scale for both vertical and horizontal distances, without which it would not be possible to correlate the different sections as they are now exhibited. The cross-sections are accompanied by an accurate copy of the large working-map reduced to the scale of $\frac{1}{12,000}$, on which the various cross-section lines are delineated. This map represents only the work of the Geological Survey during the summers of 1870 and 1872, except the line of the northern shore of Portage Lake, which was taken from the United States Lake Survey Charts, and some results compiled from railroad surveys.

Both the maps and the cross-sections represent, with a few rare exceptions, only actual observations of rocks *in situ*. The Survey is indebted to Mr. A. B. Wood, Mr. R. J. Wood, and Mr. Mabbs (Agent of the Isle Royale Mine), for notes of measurements made by them in trenches dug under their supervision. These old explorations have been remeasured by the Survey, and where the rocks were not covered by the fallen *débris* they are described in the accompanying text. In the work of 1870 I was ably assisted by Mr. A. R. Marvine, M.E., and Mr. L. G. Emerson, C.E.

During the early part of the summer of 1872, Mr. Marvine was employed, in connection with Mr. Emerson, in completing some unfinished geological work on the north side of Portage Lake.

During the rest of the season, Mr. Marvine, assisted by Mr. S. B. Ladd, was engaged in making a cross-section in the Eagle River district. The results of this survey are embodied in the map and sheets of cross-section of the Eagle River district, which, like those of the Portage Lake district, are founded upon a careful trigonometrical survey, in which every pains was taken to insure extreme accuracy.

For comparison with the southern part of the Eagle River section I made a detailed geological section underground in the Central Mine.

Careful measurements were made by Mr. Marvine between the conglomerate beds at various points along the Range, in order to correlate stratigraphically the rocks of Portage Lake with those of Keweenaw County. The results of these measurements are given on the plate of "Grouped Sections," together with reduced sections of the Portage Lake and Eagle River districts, in order that the geological relations between the various sections may be more readily compared. The subject, which presents many difficulties, is ably discussed by Mr. Marvine in a separate chapter.

The chief aim of this report is to present to owners of mining properties a number of accurately determined geological landmarks, as guides in exploring for any given bed, and to establish an accurate base from which the Geological Survey may be prosecuted in Houghton and Keweenaw Counties on the one side, and toward Ontonagon on the other.

The chief portion of the present report is, therefore, to be found in the plates in the Atlas. I had intended to confine the text

simply to the limits of the description of the cross-sections; but as many interesting observations were made which throw light on the age of the copper-bearing rocks, and on the distribution and manner of occurrence of the copper, I have thought they might very properly be added to the text.

The Survey is indebted to Mr. Pietrie, agent of the Central Mine, Mr. J. Chassells, Mr. Bolton, C.E., and Col. J. H. Foster, in many ways for aiding in its progress.

R. P.

CHAPTER I.

ON THE AGE OF THE COPPER-BEARING ROCKS.

KEWEENAW POINT, from its beginning at the Montreal River to where its extreme point is beaten by the storms at the middle of the Great Lake, is formed by two, stratigraphically, and (for the greater part) lithologically, distinct formations. These are separated by a line dividing the peninsula longitudinally. On the eastern side of this line are beds of sandstone, sloping gently to the *south-east;* on the western side is an immense development of alternating "trappean" rocks and conglomerates, dipping to the north-west at an angle of 55° to 60° at Portage Lake, and of 23° to 33° at other points.

As the question of the relative age of these two formations has given rise to considerable discussion, I will give, as briefly as possible, the principal facts in the case, and certain observations made by Major T. B. Brooks and myself, which bear directly upon the subject. Both formations have been referred by Foster and Whitney to the Potsdam, by Sir William Logan to the Chazy, while Mr. Bell, of the Canadian Corps, considers the Cupriferous series to be Triassic, agreeing herein with Jackson and with the view afterwards abandoned by Owen.

The principal facts on the south shore of Lake Superior are as follows: A series of red sandstone and shales, lying everywhere nearly horizontally, borders the Michigan shore between the Sault St. Mary and Bête Gris Bay on Keweenaw Point. From the former place to west of Grand Island, this sandstone is overlaid on the south by other Silurian rocks, and between Grand Island and Marquette the whole series sweeps around to the south-west, on its way to form the western, as it had hitherto formed the northern rim of the great Michigan basin. Where this south-westerly bend begins, the outcrop-line of the sandstone divides, and from Marquette westward we find, with short interruptions, the sandstone beds flanking the northern foot of the Huron Mountains, and dipping gently, 5° to 15°, toward the trough of Lake Superior.

In this part of its course, where it may be said to belong to the Lake Superior basin proper, it forms a marginal band along the lake shore, varying in breadth from a few rods to one or two miles. But west of the Huron Islands it widens with the south-westerly curving of the topographical axis of the Huron mountains, and fills with its horizontal strata the broad trough lying between these hills and the range of copper-bearing rocks of Keweenaw Point. In this depression there still remain one or two hills formed by remnants of the younger Trenton limestone. The trough, partly occupied by the waters of Keweenaw Bay, has for its western slope the beds of this Lower Silurian sandstone, which rise, at what seems to be the original angle of deposition, from the waters of the bay, to form the broad belt of nearly level sandstone country, which makes up the eastern half of Keweenaw Point.

At the western edge of this belt, its nearly horizontal strata abut against the steep face of a wall formed by the upturned edges of beds of the Cupriferous series of melaphyr and conglomerate, which dip away from the sandstone, at angles of 40° to 60°, according to geographical position. This sharply defined and often nearly vertical plane of contact, having been seen by the earlier geologists at several points along a distance of many miles, and having been found to be often occupied by a thick bed of chloritic fluccan, which was looked upon as the product of faulting motion, was considered as a dislocation.

This idea seemed to gain corroboration in the fact that, on the western side of Keweenaw Point, sandstones bearing considerable resemblance to those of the eastern horizontal beds occur, apparently conformably overlying the Cupriferous series.* Both sandstones came to be considered as identical in age, and as forming the upper member of the group.

There are many circumstances which make it difficult for us to accept this conclusion. One obstacle lies in the enormous amount of dislocation required, for instance, at Portage Lake, where the strata of the Cupriferous series, with an actual thickness of several

* It is not yet known whether these sandstones on the west side of Keweenaw Point are upper members of the Cupriferous series or belong to the Lower Silurian.

miles, dip away from the supposed *longitudinal* fault at an angle of about 60°.

Again, there are at least two patches of sandstone lying on the upturned melaphyr beds near Houghton, though it was not easy to prove that they were not brought thither by glacial action. Mr. Alexander Agassiz informed me that he has found in the horizontal sandstones near this so-called "fault," abundant pebbles of the melaphyr and conglomerate of the Cupriferous series, a fact which I found abundantly confirmed on the spot.

Sir William Logan hints at a similar doubt as to the proximate equivalence in age of these two series of rocks.* But the most decided facts were gathered by Major Brooks and myself, during a reconnoissance of the country between Bad River in Wisconsin, and the middle branch of the Ontonagon, east of Lake Gogebic † in Michigan. Our route was chiefly confined to the surface of the upper member of the Michigan Azoic, which we have provisionally considered to be the equivalent of the Huronian.

From Penokie Gap, on Bad River, to near Lake Gogebic—a distance of nearly sixty miles—the quartzites and schists of this formation are tilted at high angles, and form a belt one-fourth to one-half mile in width, bordered on the south by Laurentian gneiss and schists. On the north it is everywhere overlaid by the bedded melaphyr (containing interstratified sandstones) of the Cupriferous series. These form ridges and peaks which rise 200 to 300 feet above the surface of the Huronian belt.

These ridges, forming the "South Mineral Range," unite at their western end with the Mineral Range proper, which forms really through its whole length the back-bone of the tongue of land known as Keweenaw Point. Between these two ranges lies the south-western part of the Silurian trough, which has been mentioned before as extending inland from Keweenaw Bay.

Here, as there, it is filled with the horizontally stratified Silurian sandstone, forming a generally level country. For a distance of nearly thirty miles, between the Montreal River in Town 47 and Lake Gogebic, we found the Cupriferous series apparently conform-

* Geol. of Canada, page 85. And again in Geol. Survey of Canada. Rep. of Progr., 1866–69, pp. 472–475. In the last-mentioned place, he protests strongly against the idea that the copper-bearing rocks of Lake Superior are Triassic.

† Wrongly written Agogebic on many maps.

ing in strike and dip with the Huronian schists, and both uniformly dipping to the north at angles of 50° to 70°.* But in approaching Lake Gogebic from the west, we find that erosion of Silurian or pre-Silurian age has made a deep indentation entirely across the Cupriferous series and the Huronian, and into the Laurentian, so that at a short distance west of the lake these rocks end in steep and high declivities, at the base of which lies the level country of the Silurian sandstone, in which is cut the basin of the lake. From this point eastward, this ancient erosion had made great inroads upon the continuity of the Cupriferous and older rocks before the deposition of the Silurian sandstone. The melaphyr ridges are broken into knobs, or are wanting, and no Huronian was found as far as the Ontonagon River, seven miles away, and the limit of our observations.

On this river, in the centre of the north-west quarter of Sec. 13, Town 46, Range 41, the Silurian sandstone was found exposed in cliffs 50 to 60 feet high. The strata are horizontal, or at most have a barely perceptible tendency to a northerly dip. About 150 steps from the base of this cliff, there are outcrops of Laurentian schists whose bedding trends north-east toward the cliff of horizontal sandstone, and dips 45° to 60° south-east. The nearest observed outcrop of the Cupriferous series is in the south-east corner of Sec. 5, about four miles distant. It is a characteristic amygdaloidal melaphyr, whose bedding planes strike nearly east and west, and dip 50° to north. In general terms, the conclusions we are drawn to are these :

I. The Cupriferous series was formed before the tilting of the Huronian beds upon which it rests conformably, and consequently before the elevation of the great Azoic area,† whose existence during the Potsdam period predetermined the Silurian basins of Michigan and Lake Superior.

II. After the elevation of these rocks, and after they had assumed their essential lithological characteristics, came the deposition of the sandstone, and its accompanying shales, as products of the

* We observed several dips in the Huronian of 25° to 40°, while in the overlying Cupriferous series none lower than 50° were found. While this may point toward non-conformability, the greater dip of the overlying beds would make it probable that the lower dips were of a local character and due to minor undulations in the Huronian.

† Islands of Laurentian gneiss, etc., existed in the Huronian sea over parts of this area.

erosion of these older rocks, and containing fossils which show them to belong to the Lower Silurian, though it is still uncertain whether they should be referred to the Potsdam, Calciferous or Chazy. The question would still seem to be an open one, whether the Cupriferous series is not more nearly related in point of time to the Huronian than to the Silurian.

Our observations have detected a lack of conformability between the Laurentian and Huronian, at several points on the Upper Peninsula. On the other hand, in the region we have been discussing, which is the only one where the Huronian and Cupriferous are seen in contact, there seems to be a well-marked concordance between these two. There is abundant evidence on the Upper Peninsula, that the Silurian sandstone was not deposited until after the Huronian beds had assumed both their present structural position and lithological characteristics, and after they had undergone an enormous amount of erosion.

Some of the most salient topographical features of the Upper Menominee had been sculptured to the depth of two hundred feet or more before that time, and were afterward buried and wholly obliterated by the Lower Silurian deposits, and have been partially restored by the subsequent erosion to which that valley now owes its features. We now find ridges, consisting of the nearly vertical beds of Huronian quartzite and iron ores, capped with the horizontal sandstone, of which last, patches still remain in place on the end and side declivities. Where the sandstone was deposited at the base of these cliffs, we find it consisting largely of a breccia of the debris of quartzite and iron ore, identical in character with these substances in the unbroken ledge. It would probably be perfectly safe to apply the same remark to the Cupriferous series. Its members were formed, as we have seen in the previous pages, before the elevation of the Huronian rocks. The deposition of the Silurian rocks bordering on Lake Superior, should seem to have taken place during the progress of a gradual depression, which caused the coast line of that part of the Silurian sea to be represented by the bold cliffs of the interior of the Azoic land. In the eastern declivity of the mineral range of Keweenaw Point, we may see, then, one of these shore cliffs instead of the exposed side of a gigantic fault.

It is probably to this process of deposition of the Silurian sandstone over an area, which, after having undergone an enormous amount of erosion, was being gradually submerged, that we owe the absence of outcrops of the Cupriferous series beneath the sandstone at so many points on the south shore. It would be difficult indeed to account for their total absence at L'Anse, for instance, by supposing them to have thinned out, when at a distance of eighteen miles they have a thickness measured by miles, a thickness they exhibit wherever they are known, at points hundreds of miles apart on the north and south shores.

CHAPTER II.

ON THE LITHOLOGY OF THE COPPER-BEARING ROCKS OF THE PORTAGE LAKE DISTRICT.

In the immediate neighborhood of Portage Lake, the strata composing the "Mineral Range" have a uniform trend of north 35° east, and a nearly equally regular dip of 55° to 60° to west-north-west.

The series consists of beds of melaphyr, varying in thickness from twenty feet to more than one hundred feet, the demarkation being frequently defined by the amygdaloidal or epidotic character of the upper portion of each bed.

At intervals, varying from a few yards to several thousand feet, beds of conglomerate occur intercalated in the series.

This is the general character of the country near Portage Lake for a distance of about three miles, measured west-north-west across the formation.

Still farther west-north-west the rocks are little known, but seem to consist chiefly of sandstones and conglomerates.

The trappean rocks of Portage Lake occur uniformly in beds varying from a few feet to one hundred feet, or more, in thickness. Frequently an appearance of subordinate bedding is observable, arising, perhaps, from the existence of joints lying parallel to the plane of stratification, which divide the rock into plates a few inches to several feet thick.

The texture of the many varieties varies from compact and sometimes porphyritic, through fine-grained subcrystalline or earthy, to coarse-grained and distinctly crystalline. In individual beds, the texture is usually found to undergo a more or less gradual change from compact or granular at the bottom, to a vesicular or amygdaloidal condition, in the neighborhood of the hanging wall.

Green, of various shades, is the dominating color, and next to this brown and dirty red. Light and dark green, mottled or speckled with brown; dirty brownish-green; reddish-gray; and dark green, almost black, are the usual colors.

Even in the fresh state these rocks may be easily scratched with a knife, but they are exceedingly tough under the hammer, and the force which crushes a fragment often leaves the powder very firmly compacted.

The fracture is generally uneven, or hackly, to imperfectly conchoidal, but in the freshest, and especially in the compact varieties, it is often highly conchoidal. They have an earthy odor often even without having been breathed upon.

Some varieties yield a thick beard of a magnetic iron ore to the magnet, while others contain very little of this mineral.

The ingredients which are visible under the glass, and which seem to be common to all varieties, are a light *green triclinic feldspar*, apparently labradorite and chloritic mineral of different shades of green, while the magnet reveals a very variable percentage of a magnetic iron; and in some of the coarser-grained varieties small jet black crystals, apparently of augite or hornblende, are occasionally visible. The accessory minerals observed, many or all of which are probably products of the alteration of the above constituents, are:

A brick-red foliaceous mineral resembling rubellan, occurring as very minute specks in some fine-grained varieties; it lends a soft rusty-brown appearance to the weathered surface, and speckles the interior with red.

Specular-iron in minute flakes, seemingly more frequent in the coarser-grained varieties.

Calcite in seams, and more frequently in grains and amygdules, especially in the amygdaloidal portion of the beds.

Epidote rarely crystallized; most common in the amygdaloidal varieties, but frequently in seams and impregnations, and nearly always associated with quartz.

Quartz which occurs in amygdules and seams, and also as an indurating medium near the hanging wall of many beds.

Prehnite in amygdules and seams, mostly confined to the amygdaloidal portion of the beds.

A chlorite-like mineral, soft, compact, amorphous, greenish-black, sometimes altered to brick-red, occurring in grains from pin-head to walnut size.

A yellowish-green soft earthy mineral, probably a green earth.

Laumontite and leonhardite in seams and amygdules.

Analcite in amygdules.

Orthoclase in small crystals and massive; in amygdaloidal cavities.

Native copper sometimes in fine impregnations in the fine-grained rock, also in thin sheets in jointing cracks, but chiefly in the amygdules, masses, sheets and impregnations which form the metalliferous deposits in the amygdaloids, where it is occasionally associated with native silver.

Native silver.

Datholite massive in the amygdaloidal portion of some beds, and also in small aggregations of microscopical crystals in the same positions.

We have fortunately several recent analyses of different and typical varieties of these rocks, made by Mr. Thomas Macfarlane.*

Of one of the coarser-grained varieties which forms very thick beds several hundred feet west of the Quincy "vein," Mr. Macfarlane says: "It is distinctly of a compound nature, but all its constituent minerals are not large enough to be accurately determined. Conspicuous among them is a dark green chloritic mineral, the grains of which vary from the smallest size to one-fourth of an inch in diameter. In the latter case they are irregularly shaped, with rounded angles, but they are never quite round or amygdaloidal [?]. They frequently consist in the centre of dark green laminæ. The mineral is very soft, and has a light greenish-gray streak. It fuses readily before the blowpipe to a black magnetic glass, and it would seem to be the preponderating element in the rock. The other constituents are in very fine grains, and consist of a reddish-gray feldspathic mineral, with distinct cleavage planes, and another closely resembling it, in light greenish-gray particles, but whether of a feldspathic, pyroxenic or hornblendic nature could not be determined.

"The prevailing color of the rock is dark grayish-green. Hydrochloric acid produces no effervescence with it, even when in the state of fine powder. Its specific gravity is 2.83, and the magnet attracts a very small quantity of magnetite from its powder. The color of the powder when fine is light greenish-gray.

"When ignited it loses 3.09 per cent. of its weight, and changes to a light brown color. When digested with nitric acid, and afterwards with a weak solution of caustic potash (to remove free silica), it experiences, including the loss by ignition, a loss of 46.36 per cent. This consists of

* Canadian Geological Survey, Report of Progress, 1863–1866, p. 149.

Silica	14.73
Alumina	7.17
Peroxide of iron	14.87
Lime	4.47
Magnesia	2.03
Water	3.09
	46.36

"In the undecomposed residue light-red and dark-colored particles are discernible. On digesting it with hydrochloric acid, and subsequently with a weak solution of potash, it sustains a further loss of 10.6 per cent., which consists of

Silica	3.48
Alumina	3.03
Peroxide of iron	1.98
Lime	1.76
Magnesia	.35
	10.60

"The undecomposed residue was still found to consist of a light-red and a dark-colored constituent. The latter was the heavier, and an approximate separation was accomplished by washing. The dark-colored particles, which could not, however, be freed wholly from the light-colored feldspathic constituent, fused readily to a dark-brown glass. To judge from its gravity and fusibility, it would not appear unreasonable to regard it as either pyroxene or hornblende. In quantity it did not, however, exceed one-eighth of the feldspar. The latter fused easily before the blowpipe to a colorless glass, tinging the flame strongly yellow. It would therefore seem to be of the nature of labradorite, although it is only slightly decomposed by hydrochloric acid. Since, according to Girard, neither labradorite, pyroxene nor magnetite are decomposable by nitric acid, it may reasonably be concluded that the constituents removed by the nitric acid are those of the chloritic mineral. On treating the rock previous to ignition, much of the iron is removed as protoxide.

"Although some peroxide is also possibly present, I have calculated the whole of the iron as protoxide, and have, moreover, added the difference of the weight between it and the iron estimated as peroxide to the loss sustained by ignition, and put it down as water. In this way the composition of the chloritic mineral, calculated to 100 parts, would be

Silica	31.78
Alumina	15.47
Protoxide of iron	28.87
Lime	9.64
Magnesia	4.37
Water	9.87
	100.00

"In these figures the quantity of iron is much greater and that of magnesia much less than in ordinary chlorite. In its composition, and in being easily decomposed by acids, the mineral most closely resembles the ferruginous chlorite of Delesse (the delessite of Naumann), but differs from it in containing a considerable amount of lime, and in being readily fused before the blowpipe. Assuming, nevertheless, that the chloritic constituent is delessite, and that one-half of the iron removed by hydrochloric acid belongs to the magnetite, then the rock would be composed mineralogically of

Delessite	46.36
Labradorite	47.43
Pyroxene or hornblende	5.26
Magnetite	0.95
	100.00"

By the same method of analysis, Mr. Macfarlane found the rock underlying the copper-bearing bed of the Quincy mine to consist of

Delessite in amygdules and grains	38.00
Labradorite	62.00
	100.00

This rock is distinctly amygdaloidal. "The matrix is fine-grained, but it is crystalline, and is seen to consist of different constituents. Its color is dark reddish-gray." Its cavities, rarely the size of a pea, are filled with what seems to be the same chloritic mineral which occurs as a constituent of the rock above described.

Mr. Macfarlane also examined the rock which overlies the Albany and Boston conglomerate at the Albany and Boston mine. "It is a fine-grained mixture of dark-green delessite, greenish-gray feldspar, and reddish-brown mica, some of the laminæ of the latter showing ruby-red reflections. Its specific gravity is 2.81, and the smallest trace only of its powder is attracted by the magnet." He considers the mineralogical composition of this rock to be

Delessite	40.00
Mica	20.00
Labradorite	40.00
	100.00

The rocks to which the above given analyses refer are representatives of the three predominating types of the melaphyr of Portage Lake. Mr. Macfarlane's results agree very closely with my own observations on several hundred specimens, aided by the blowpipe and examination of external characteristics.

Everything goes to show that the normal, essential constituents of these rocks are, in their present condition, a triclinic feldspar, probably labradorite, and a ferruginous chlorite closely allied to delessite. This composition places these rocks among the typical melaphyrs, the greater specific gravity of the Portage Lake varieties being accounted for by the fact that the sp. gr. of delessite is 2.89, while that of ordinary chlorite ranges from 2.65 to 2.78.

Although the name melaphyr is an unfortunate one, having been first used to designate an entirely different rock, and having been successively applied to others of very various characters, it is now the only distinctive name for the class we have under consideration. All the trap rocks and associated amygdaloids of Portage Lake are varieties of melaphyr.

But I do not doubt that any one who will carefully study the melaphyrs of Portage Lake, and compare them with their equivalents in Keweenaw County, will feel convinced that the melaphyr owes its distinctive character to a process of metamorphism, in

which the chlorite resulted, largely or wholly, from the alteration of hornblende or pyroxene. In the more distinctly crystallized traps of Keweenaw County, the pseudomorphic occurrence of chlorite after the hornblende or pyroxene constituent of the trap, may be traced through all the stages to a complete replacement of the latter by chlorite.

The principal varieties of melaphyr on Portage Lake are:—

1. *Coarse-grained;* in which the crystals of feldspar and grains of delessite are more or less distinct. The color is greenish-gray. It contains generally grains of magnetite and small tabular crystals of specular iron.

2. *Fine-grained;* the constituents, light-green or reddish triclinic feldspar and dark-green delessite, are sometimes distinguishable, but more generally they are not so. The usual color is grayish-green, but it sometimes is speckled with brown, through the presence of small flakes of rubellan; or mixed green and brown, from the oxide of iron produced in the decomposition of some of the constituents. As a rule, the greater the amount of rubellan the less there seems to be of magnetite. In some instances, especially in some of the beds east of the Isle Royale copper-bearing bed, the rock is fine-grained and subcrystalline, brilliant black-green, sometimes purplish; slightly shimmering; easily scratched with the knife; contains considerable magnetite, small pieces of rock adhering to the magnet. It weathers rusty gray.

3. *Melaphyr-porphyry;* dark-green, often nearly black; compact, with perfect conchoidal fracture; very hard; contains minute crystals of triclinic feldspar.

AMYGDALOIDS.

The amygdaloids are merely varieties of the melaphyr. On Portage Lake they always form the upper or hanging-wall portion of beds of trap, into which they pass by a more or less gradual transition.

It is rare that one finds a bed of trap which does not contain, here and there, scattered segregations of secondary minerals, especially delessite, but often calcite, laumontite, quartz, or chalcedony, or prehnite, occupying cavities which are often well defined and spherical or ovoidal, but sometimes wholly irregular in shape, and without definite walls. These enclosures usually become more frequent in ascending from the foot-wall of a bed toward the hanging wall. The plane of demarkation between the amygdaloidal upper portion of a bed and the overlying rock is always well defined. Where they are sufficiently numerous to impress a distinctive character upon the rock, while at the same time the matrix retains the essential features, in regard to color and texture of the parent trap, I have designated the variety

AMYGDALOIDAL MELAPHYR.

All the varieties of melaphyr on Portage Lake are subject to this modification, but there is a considerable variation among different beds in regard to the nature of the minerals in the amygdaloidal cavities. In all the varieties, amygdules of delessite, or calcite, or quartz coated with delessite, or again spots of epidote, occur here and there in the body of the rock. In some beds the rock is characterized throughout by the presence of laumontite in small amygdules and minute seams.

In the belt occupying 1,000 feet or more on either side of the Isle Royale copper-bearing bed, many of the beds assume towards the top amygdules of delessite and of a green flinty mineral, resembling chrysoprase, coated with delessite. These are gradually succeeded nearer the top by ovoidal, lenticular, or irregular amygdules, from the size of a bean to several inches in diameter, of prehnite, greenish-white, or tinged with pink generally amorphous, but often with a radiating structure, and sometimes slightly impregnated with native copper.

The portion of the bed nearest the hanging wall is often highly amygdaloidal, while the matrix has at the same time a different degree of hardness, texture and color, and often a different mineralogical constitution from the parent trap. These varieties form the

AMYGDALOIDS PROPER.

The amygdaloids are the most highly altered form of the melaphyr, and present themselves under a variety of characters in different beds and in different parts of the same bed. The colors of the matrix are different shades of brown or red, and of green, or of these mixed; its texture varies from fine-grained or sometimes subcrystalline to compact; and its hardness ranges from that of limestone to that of quartz.

Two quite different kinds of amygdaloid occur on Portage Lake, both separately, and intimately associated in the same bed, and are easily distinguished by their different colors, the one being brown and the other green.

The brown, which exhibits the amygdaloidal character in its highest development, has a chocolate-brown to dirty red matrix, which generally is easily scratched with the knife, but is sometimes indurated and hard; it has a fine-grained to subcrystalline texture, and now and then contains minute reddish crystals of feldspar, and fuses easily to a dark-green and somewhat magnetic glass.

The amygdules in this variety are more generally spherical, but often somewhat irregular and connected, and more rarely long-cylindrical, and then usually perpendicular to the plane of bedding. The contents of these cavities, for they are very rarely empty, are laumontite, leonhardite, calcite, quartz, a soft green mineral, apparently green-earth, delessite (more rarely), native copper, epidote, prehnite, analcite, orthoclase. In places one, in others another, of these predominates; generally several are associated.

The green variety is a very fine-grained to compact light grayish-green rock. It is generally very hard, striking fire under the steel. Its constituents are very largely free silica, and a green mineral which has been generally taken for epidote, but which is so minutely disseminated as to render it difficult of determination. Small pieces of the rock fuse easily on the edges to a dark enamel which gelatinizes with acids. These beds are called epidote "veins," and they are probably, in many instances, at least, an intimate mixture of quartz and epidote, though in otherwise nearly similar beds the green mineral is soft, and is probably either a green-earth or a chlorite. The cavities in this variety are often less regularly defined in shape than in the brown amygdaloid. The enclosed minerals are quartz, epidote, calcite, delessite, prehnite, laumontite, green-earth, analcite, native copper, orthoclase. These two varieties of amygdaloids often occur together without any well defined lines of separation, the bed being made up of irregular masses of the two rocks. In places, however, the brown amygdaloid forms a band one to two feet thick on the hanging wall, with a rather abrupt transition into the green amygdaloid underlying it; I have never observed the reverse.

Some beds have an exceedingly mixed character; the amygdaloidal portions are associated with massive segregations of calcite, quartz and epidote, and are traversed by seams and irregular veins of these minerals; this structure is especially noticeable in the beds worked for copper. A somewhat similar structure occurs in other beds on a smaller scale, giving to them a brecciated or even a conglomerate-like appearance, which seems, however, to be due to purely metamorphic action; the best example of this is in the "Ancient Pit" bed, on the Shelden and Columbian property.

CONGLOMERATES.

The conglomerates of Portage Lake differ from each other but little, if at all, in lithological characteristics. The pebbles vary from the size of a pea to one foot or more in diameter, being coarser in some beds than in others. The different beds vary in thickness from mere seams to several hundred feet, and the same bed often varies greatly in width.

The pebbles, in most of the beds on Portage Lake, consist almost exclusively of varieties of non-quartziferous felsitic porphyry; two kinds predominate; one of these has a chocolate-brown to liver-brown, subcrystalline to compact almost vitreous matrix containing very scattered minute crystals of triclinic feldspar of the same color as the base. The other and rarer variety, also non-quartziferous, has a chocolate-brown, compact to minutely crystalline matrix, in which lie crystals, ⅛ to ½ inch long, of a flesh-colored triclinic feldspar.

In some beds there appear pebbles of a flesh-red rock, composed almost entirely of granular feldspar, containing small specks of a black undetermined mineral. In some instances the feldspar is wholly triclinic, in others the twin-striation is frequently absent. This variety of pebble is altogether absent in some beds, at least where they are opened, while in others they predominate, as in the

Albany and Boston Conglomerate. Pebbles of compact melaphyr, and of melaphyr amygdaloid also occur, but are quite subordinate in number to those already enumerated.

The normal form of cement is a fine-grained sandstone, composed apparently of the same material as the pebbles. Often the cement is very subordinate in volume, the pebbles touching each other. Frequently, however, the reverse is the case, and often, the sandstone forms layers from less than an inch to many feet in thickness.

The original character of the cement is often entirely lost; the interstices between the pebbles are sometimes, though rarely, empty; in places, the sand is associated with oxide of iron, chlorite, a white talc-like mineral, and carbonate of lime, or it is entirely replaced by calcite, chlorite, epidote or even native copper.

It is a remarkable fact that while all the conglomerate beds near Portage Lake are free from pebbles of quartz-porphyry, those in the neighborhood of Calumet are characterized by pebbles rich in grains of quartz. This abrupt change takes place about six miles northeast from the lake.

Different horizons of the Portage Lake series of rocks are marked by certain distinguishing lithological characteristics, which, without in any instance being peculiar to a given horizon, still serve to mark decidedly those parts of the series where they are, respectively, most frequent.

Thus, to begin toward the eastern part of the field, from the neighborhood of "Mabbs' vein" to within, say, 1,000 feet east of the Isle Royale "vein," there is a tendency, among the different traps, to a compact or fine-grained texture with a dark-green, almost black color, sometimes slightly mottled, especially on the weathered surface. The fracture is brilliant, and the trap contains enough magnetite to cause small bits of the rock to adhere to the magnet.

From this region till 1,500 feet or more west of the Isle Royale copper-bearing bed, the upper portions of very many of the beds have the amygdaloidal cavities filled with a light-greenish white or pale pink prehnite, which sometimes, for a width of 2 to 6 feet, form from 10 to 40 per cent. of the rock, and lend it a very characteristic spotted appearance.

During the next 2,000 feet or more, the traps have frequent seams 3 to 20 inches thick, consisting of distinctly individualized triclinic feldspar, delessite, prehnite and specular iron; these occur both parallel to the plane of bedding and oblique to it. The traps through a portion of this distance are frequently impregnated with epidote, as is also the cement of the conglomerate beds.

On the "Dacotah" property we come to a belt of the formation in which many beds have a tendency to a coarse-grained, crystalline texture, and in some, the character is highly developed, giving the rock, at a distance, almost the appearance of a chloritic granite. Still farther west, on the "Southside" property, the brown amygdaloids often present a scoriaceous appearance which is quite characteristic.

Some, at least, of these features are traceable for miles in the longitudinal extension of the zones in which they occur. Thus, the prehnite amygdaloid of the Isle Royale series is found in the north-east extension of this zone, near where the road to Eagle River crosses the line between Townships 55 and 56 north, or about 7 miles from Portage Lake.

The coarse-grained melaphyr of the "Dacotah" is found extensively developed in the extension of the same zone on the South-Pewabic, Quincy and St. Mary's properties. The brown amygdaloids of the "Southside" reappear with their peculiar scoriaceous structure in the South-Pewabic and Hancock beds, and in the trenches on the St. Mary's, and are unquestionably the equivalents of the "Ash-bed" rocks of Keweenaw County, which they resemble.

CHAPTER III.

PARAGENESIS OF THE MINERALS ASSOCIATED WITH COPPER.

(*With a Comparative Table.*)

No. 1. CAPEN VEIN.—This is apparently a true fissure vein. It occurs in a compact and very tough melaphyr, which is exceedingly chloritic near the vein. All the joints within a distance of several yards from the vein are covered with a coating $\frac{1}{10}$ to $\frac{1}{2}$ inch thick, of dark-green and bluish-green chlorite, having a combined fibrous and foliated structure oblique to the joint surfaces. The melaphyr is rich in magnetite. Sheet copper was found in mining, but not in paying quantity.

1. *Laumontite*, in thin seams.

2. *Prehnite*, in seams which cut through those of laumontite, also between symmetrically arranged bands of laumontite.

3. *Chlorite*, as destroyer and replacer of prehnite, and as lining of cavities in the latter.

4. *Analcite*, in clear crystals on the prehnite and chlorite.

5. *Calcite*.

No. 2. HURON MINE.—1. *Laumontite*, in thin crystalline bands on the sides of a cavity; the free ends of the opposed crystals nearly meet.

2. *Prehnite*, filling the space between the bands of laumontite.

No. 3.* COPPER FALLS MINE.—Fissure vein. 1. (?) *Natrolite*. 2. *Laumontite*. 3. *Analcite*.

No. 4. PHŒNIX MINE.—(Fissure vein.)

1. *Datholite*, on rock.—2. *Calcite*, scalenohedrons on the datholite.—3. *Feldspar*, crystals on both the datholite and calcite.—4. *Apophyllite*, in very clear crystals on datholite, calcite, and feldspar.

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* Taken from a list given by Hilary Bauerman, Quart. Journ. Geol. Society, Nov., 1866.

No. 5.* BAY STATE MINE.—1. *Prehnite.* 2. *Quartz.* 3. *Copper.* 4. (?) *Laumontite.*

No. 6. * PHŒNIX MINE.—Fissure vein. 1. *Laumontite.* 2. *Quartz.* 3. " *Green-Earth.*"

No. 7.* BAY STATE MINE.—Fissure vein. 1. *Quartz.* 2. *Apophyllite.* 3. *Calcite.*

No. 8.* BOHEMIAN MINE.—1. *Analcite.* 2. *Copper.* 3. *Orthoclase.*

No. 9. AMYGDALOID MINE.—Fissure vein. 1. *Prehnite,* in its characteristic reniform shape.

2. *Quartz,* in small crystals on the prehnite.

3. *Analcite* crystals, covering the quartz.

4. *Orthoclase* crystals, on the analcite and quartz.

No. 10. BAY STATE MINE.—Fissure veins. On the soft brown gangue: 1. *Analcite,* lining part of a vugg. The crystals are $\frac{1}{4}$ inch in diameter, often white and transparent, but very much fractured. Near the contact with the rock they are often reddened internally and much altered, and then surmounted by the next member.

2. *Orthoclase,* in the usual minute crystals, some of which are scattered over the altered analcites.

No. 11. AMYGDALOID MINE.—Fissure vein. 1. *Prehnite,* in the characteristic reniform shape, forming the body of the specimen; fresh-looking on the free surface, but on the under broken side somewhat porous, with earthy fracture, and then rather intimately associated with datolite and a soft green (chloritic?) mineral.

2. *Copper,* in films traversing the prehnite, and moulded to the reniform surface. While the under surface of the copper bears the impression of the prehnite, the upper surface, now free, bears that of some mineral that is gone; threads of copper rising from this free surface $\frac{1}{4}$ inch are crystallized at the tips, where they stood above the mineral that has disappeared.

3. Minute grains of a hard yellowish-white mineral, sprinkled like meal over the prehnite and copper; under the microscope appear to consist of sheaf-like clusters of minute rhomboidal plates; fuses with difficulty.

4. *Datolite,* in microscopic crystals on No. 3; others, one line in diameter, rosy, with suspended flakes of copper, lie upon the prehnite.

No. 12. AMYGDALOID MINE.—(Fissure vein.) On the gangue—here chloritic—lie, 1. *Calcite,* imbedded between the gangue and No. 2.

2. *Prehnite,* forming the greater part of the specimen, and having a tolerably fresh lustre.

3. *Copper,* in grains, flakes and threads conforming to the radiating cleavage planes of the prehnite.

4. *Datolite;* compact amorphous, white, translucent mass, covering the prehnite with a layer of which $\frac{3}{4}$ inch thickness still remains. The copper threads do not penetrate it.

No. 13. PEWABIC COPPER-BEARING BED.—This specimen—about $2\frac{1}{2}$ inches by $3\frac{1}{2}$ by $\frac{3}{4}$—is evidently from the interior of a druse, to whose wall it was attached by only a small part of its surface. The body of the specimen is copper, very cavernous, much of it pseudomorphous after laumontite. The copper is very thickly bestrewn with small green crystals of quartz—prisms terminated at both ends—which are, however, *older* than the copper. On the sides and around the edges of the specimen there are beautifully modified scalenohedrons of calcite. The successions are:

1. *The rock or mineral* to which the laumontite was originally attached, and which has disappeared.

2. *Laumontite* or leonhardite; has also disappeared; the prisms were $\frac{1}{8}$ to $\frac{1}{2}$ inch long, terminated at one end with a hemidome.

3. *A mineral,* now gone, which must have been present to support the quartz crystals (see Quartz). It may perhaps have been the alteration-product of the laumontite or an enclosing mineral.*

4. *Quartz,* in prisms $\frac{1}{20}$ to $\frac{1}{5}$ inch long, often terminated at both ends. They occur on parts of nearly every one of the pseudomorphs after laumontite; the copper is moulded to them, giving casts even of the striæ on the prisms, and they frequently pass entirely through the pseudomorphs after laumontite, so that the two ends of a quartz prism frequently just appear on opposite sides of the pseudomorph and transmit light. In some instances, the quartz crystals are so numerous as to touch each other, but they are often wholly isolated, and supported only by the copper which is younger.

The quartz crystals contain minute, brilliant particles of copper, wholly isolated, in the interior.

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* Laumontite crystals often occur enveloped in younger calcite, except at the base.

5. *Copper*, in the form of laumontite, preserving often the sharpness of the angles and smoothness of the faces of the original mineral, when seen by the naked eye; under the glass the surface is less even. The pseudomorphs are not solid copper, as will appear in describing other specimens.

6. *Chlorite?* a soft, light-green mineral in minute hemispherical forms, with radiating structure, scattered over the quartz and copper. Wherever this mineral lies upon the quartz crystals, these are more or less penetrated by it, and some of them are eaten through and through to such an extent that the crystalline form is no longer recognizable.

7. *2d Copper and Calcite;* Calcite crystals—scalenohedrons—⅛ to ¾ of an inch long, lie on the sides and around the edges of the specimen. These crystals, in forming, adapted themselves with partially entering faces to the rough surface of the preëxisting quartz and copper. Some of the calcite crystals contain brilliant isolated films of copper, which must have been formed at least after the calcite had begun to crystallize, and is therefore younger than the copper previously mentioned.

8. *Datolite*, in exceedingly minute crystals, lying on both the chlorite and calcite; they are less than $\frac{1}{200}$ inch in diameter, but the datolite form is distinctly visible under the microscope; they fuse easily with the characteristic green flame.

No. 14. Pewabic Copper-bearing Bed.—1. *The rock* or mineral to which the laumontite was originally attached, which has disappeared, copper now forming the support of all the members.

2. *Laumontite*, of which only the form now remains.

3. *A mineral*, now gone, which seems necessarily to have been present to support the isolated crystals of quartz.

4. *Quartz*, in minute prisms, containing brilliant particles of copper.

5. ? *Calcite*, represented only by impressions in the copper. This calcite may, perhaps, be older than some of the foregoing members.

6. *Copper*, now forming the body of the specimen. It is very cavernous, and besides forming in places pseudomorphs after laumontite, it is the support of every member of the series. That it is younger than the quartz crystals is shown by the fact that

on removing these, perfect casts of them are visible in the copper. The copper also contains impressions of calcite crystals (see above).

7. *Chlorite?* the same mineral as the 6th member of No. 13, and occurring in the same manner.

8. *Calcite;* a few small scalenohedrons planted on the copper in the impressions of the older calcite = 5th above.

No. 14 (*a*). *Copper after laumontite*, from the Pewabic Copper-bearing Bed.

The upper face of this specimen is part of a partially filled cavity in a cupriferous and highly altered amygdaloid; the lower or broken face is a portion of the altered amygdaloid itself. The general appearance of the specimen at first glance is that of a drusy cavity, nearly filled, except in the middle, with broken crystals of calcite, whose interiors contain many thin plates and threads of native copper.

The amygdaloid is a soft compact brown and green rock with earthy fracture—an altered amygdaloidal melaphyr. The small amygdules near the wall of the larger cavity are of calcite.

The pseudomorphs of copper after laumontite are prisms ⅛ to ½ inch long and about ⅛ of an inch square, and are terminated with a hemidome; they are each attached by one end to the wall of the cavity and project out toward the interior. The angles are often sharp, though in some instances the junction of two faces of a prism presents something of the appearance of a copper cast made in a mould whose two halves fit only imperfectly together. Sometimes, under a strong glass, the joining is clearly imperfect, and the pseudomorph has the effect of a prism built with four badly-soldered plates of metal.

Minute prisms of quartz (colored green by the chlorite-like mineral mentioned in specimens No. 13 and 14) project from the interior of the pseudomorphs, through the copper, to $\frac{1}{100}$ of an inch above the surface.

In one place I cut to the depth of $\frac{1}{12}$ of an inch in solid copper; but a cross fracture in another prism showed that the copper was, there, a mere superficial film, while the interior was occupied by a confused and rather porous mass of quartz prisms, copper, and the green chlorite-like mineral mentioned above. It is these quartz crystals whose ends just pierce the copper coating. In some instances, a prism of quartz terminated at both ends passes entirely through the pseudomorph and appears on both sides, and allows the light to pass through. After removing a quartz crystal from the copper, a perfect cast, even to the horizontal prism-striæ, is found in the copper.

The copper-surface of the pseudomorphs seems nearly smooth to the naked eye, but under a strong glass it appears not only often perforated with holes, but it often shows flakes of copper rising on edge to a height of $\frac{1}{100}$ of an inch above the face.

These pseudomorphs before the breaking of the specimen were imbedded in the interior of scalenohedrons of calcite, except at the attached ends of the prisms. At the contact planes between the calcite and the pseudomorphs, the former seems to adapt itself fully to all the irregularities of surface of the latter.

On the bottom of the specimen the calcite amygdules exhibit marked signs of change to datolite. The transparent crystals become gradually opaque, with a pearly lustre on the cleavage planes, and a little farther away this condition merges almost insensibly into a lustreless white mass composed of an aggregation of exceedingly minute crystals, which exhibit the datolite form under the microscope, and fuse easily with the characteristic green flame before the blowpipe. The same change is visible, in places, on the crystals of calcite enveloping the pseudomorphs after laumontite.

The relative ages here appear to be, 1, *The amygdaloid*, though probably not in its present condition; 2, *Laumontite;* 3, *Quartz;* 4, *Copper, chlorite-like mineral;* 5, *Calcite;* 6, *Datolite.*

No. 14 (*b*). *Another specimen* from the same locality exhibits—besides pseudomorphs of copper after laumontite—pseudomorphs of quartz after laumontite. In these last, the ends of the pseudomorphs are broken off, leaving only the prism. The faces are formed by a tolerably even mass of quartz, on the outer surface of which a crystalline form appears here and there under the glass. The interior of the prism is not a compact mass of quartz, but is merely filled with quartz prisms projecting from all sides toward the middle, and containing minute brilliant and isolated particles of copper.

Near these are the copper pseudomorphs; they are mere hollow shells, scarcely as thick as paper; the angles are sharp and the faces tolerably smooth, but often pierced with holes. The hemidome of one of these is studded with the ends of minute quartz prisms, which

occupy the interior of that part of the pseudomorph and project through the copper shell.

In this specimen, also, some of the pseudomorphs are imbedded in scalenohedrons of calcite, which sparkle with brilliant particles of copper swimming in the transparent crystals.

In these remarkable pseudomorphs, the quartz is undoubtedly the oldest existing intruder, while the copper, which far more generally preserves the crystalline form of the laumontite, seems to be pseudomorphous in, at least, the second degree of removal. Yet in nearly all instances the older quartz is present, occupying a part of the space originally belonging to the laumontite crystal; and very often these quartz crystals are wholly separate from each other and supported only by the younger copper. Something which is now gone must have existed to perform this office of support before the copper was deposited.

No. 15. "RAGGED AMYGDALOID," ALBANY AND BOSTON M.—On the rock lie: 1, *Prehnite*—2, *Orthoclase*, in minute crystals on the prehnite.

No. 16. "EPIDOTE LODE," ST. MARY'S.—In a cavity in the quartz-epidote rock, which forms a frequent feature of this bed, lie: 1, *Prehnite* crystals, disposed as a reniform lining of the cavity—2, *Quartz*, in transparent prisms on the prehnite—3, *Analcite*, crystal $\frac{1}{2}$ inch in diameter, slightly opaque and somewhat cavernous internally, planted on the quartz—4, *Orthoclase* crystals planted on the prehnite, quartz, and analcite.

The prehnite is partially altered, containing cavities lined or filled with a soft green mineral, chlorite or green-earth. There is also a greenish-yellow chlorite-like mineral which incrusts and has eaten away the surface of the quartz crystals.

No. 17. AMYGDALOID ON THE KEARSARGE LOCATION.—On the rock lie: 1, *Prehnite*—2, *Quartz* on the prehnite.

No. 18. HURON MINE.—On the rock lie: 1, *Analcite*, in a continuous band $\frac{1}{2}$ inch thick, crystallized on the inner face; it is reddish and perhaps much altered, though still hard—2, *Calcite* incrusting the analcite crystals, and occupying cavities in their interior.

No. 19. ALBANY AND BOSTON AMYGDALOID.—The rock of this bed is a wholly irregular mixture of hard light-green amygdaloid, and soft-brown amygdaloid, in which the vesicular form is frequently lost, from the fact that the cavities containing secondary minerals have extended and become merged together, forming a confused patch-and-vein structure: 1, *Prehnite*, amorphous and altered to a slightly cavernous appearance on the surface—2, *Quartz* in prisms—3, *Orthoclase* in minute crystals chiefly on the altered prehnite, with which its formation is probably connected, and also on the quartz.

No. 20. SAME BED.—On the amygdaloid, which contains quartz amygdules, lie: 1, *Prehnite* penetrated with strings and films of copper—2, *Quartz* in prisms; *Chlorite-like mineral* in hemispherical forms, with radiating structure; *Orthoclase* in minute crystals; all these lie separately on the prehnite—3, *Calcite* covering all the above-mentioned members.

No. 21. SAME BED.—1, *Quartz* in prisms—2, *Chlorite-like mineral* in hemispherical forms, with radiating structure; wherever it is in contact with the quartz it has pitted it and eaten into it—3, *Calcite*.

No. 22. SAME BED.—On the amygdaloid lie: 1, *Prehnite* crystals in reniforn masses—2, *Quartz*, in prisms on the prehnite crystals—3, *Orthoclase; Calcite;* the orthoclase is in minute crystals on the prehnite and quartz.

No. 23. SAME BED.—The amygdaloid on which the following succession occurs consists of quartz and chlorite, and is wholly altered, so much so that the quartz which now composes a large part of it is evidently of the same age as that which follows the prehnite: 1, *Prehnite*, in crystalline reniform masses—2, *Quartz* prisms—3, *Copper* in cubes, with octahedral modifications, planted on, and moulded to, the quartz crystals.

No. 24. SAME BED.—1, *Prehnite*—2, *Quartz*—3, *Calcite*.

No. 25. SAME BED.—*Analcite* in pellucid crystals—2, *Calcite; Orthoclase;* in this specimen the analcite appears to have incrusted some mineral which has disappeared, and the feldspar crystals occur in the cavity thus formed as well as on the outer surface of the analcite.

No. 26. SAME BED.—1, *Prehnite*—2, *Quartz*—3, *Copper*, in threads often moulded to the quartz—4, *Orthoclase* in minute crystals planted on the prehnite, quartz and copper.

No. 27. SAME BED.—1, *Prehnite*, penetrated with copper threads—2, *Quartz* in prisms—3, *Chlorite-like mineral* mentioned in Nos. 20 and 21; here also it has eaten into the faces of the quartz crystals—4, *Analcite* crystals, much fractured and eaten away, and sometimes quite hollow.

No. 28. SAME BED.—1, *Prehnite* in places cavernous—2, *Quartz* in prisms in the cavities in the altered prehnite—3, *Orthoclase* crystals planted on the quartz.

No. 29. SAME BED.—1, *Prehnite*—2, *Copper* traversing the prehnite in the form of threads, etc., ending in crystals which adapt themselves to the crystalline surface of the prehnite.

No. 30. SAME BED.—1, *Prehnite*—2, *Analcite*—3, *Copper* in flakes on the analcite—4, *Orthoclase; chlorite-like mineral*.

No. 31. SAME BED.—*Quartz* in prisms—2, *Orthoclase* crystals, planted on the quartz.

No. 32. SAME BED.—1, *Prehnite*—2, *Copper* in crystals whose under surfaces are moulded to the crystalline surface of the prehnite.

No. 33. HURON MINE.—On the amygdaloid containing smaller amygdules of delessite and quartz, lie: 1, *Laumontite*, a crystalline layer with projecting crystals—2, *Calcite* crystallized upon and wholly enveloping the laumontite crystals.

No. 34. WESTERNMOST ADIT ON THE "SOUTHSIDE."—1, *Analcite*, in opaque crystals $\frac{1}{8}$ to $\frac{1}{2}$ inch in diameter—2, *Orthoclase* crystals planted on the analcite. (The rock containing this is chocolate-brown, and filled with small amygdules of 1st, Laumontite, 2d, Calcite).

No. 35. "RAGGED AMYGDALOID." ST. MARY'S.—This is a soft brown amygdaloid with brown streak, in which the cavities have assumed the most irregular shapes, and merge into each other in a manner which gives to the rock a highly brecciated appearance. The cavities are generally partially open at their wider points; and the minerals occupying them are chiefly the following, often accompanied by a white clay: On the rock lie, 1, *Analcite*—2, *Orthoclase* crystals on the analcite—3, *Calcite* over both the foregoing members.

No. 36. SAME BED.—On the rock lies *Calcite*. *Orthoclase* crystals on the calcite.

No. 37. SAME BED. On the rock are scattered: 1, *Analcite* crystals—2, *Calcite* on the analcite.

No. 38. SAME BED.—1, *Analcite* in large crystals; much altered—2, *Orthoclase* crystals planted upon the outer surface of (and in cavities in) the analcite.

No. 39. PEWABIC COPPER-BEARING BED.—On the amygdaloidal rock lie: 1, *Calcite; Copper*—2, *Datolite* in a granular mass incrusting the calcite crystals.

No. 40. SAME BED?—1, *Calcite* in scalenohedrons—2, *Datolite*, a granular mass of microscopical crystals. Here the datolite has partially displaced the calcite; only the points of the crystals of the latter were exposed, all the rest being imbedded in the younger datolite. These free-standing points remain perfect in glance and form, while wherever the calcite crystals are in contact with the datolite, their surfaces are roughened and perceptibly eaten into. The calcite crystals rest upon a granular mass of the same variety of datolite, which is perhaps the result of a displacement of calcite.

No. 41. "EVERGREEN BLUFF."—1, *Quartz* prism—2, *Orthoclase* in minute crystals—3, *Calcite* in simple and twin scalenohedrons.

No. 42. "AMYGDALOID" MINE.—(Fissure vein). 1, *Copper*—2, *Compact datolite*.

No. 43. SAME VEIN.—1, *Prehnite* in its characteristic form—2, *Copper* conforming to the radiating cleavage-structure of the prehnite—3, *Datolite*, compact.

No. 44. LOCALITY UNKNOWN.—1, *Prehnite* in its characteristic form—2, *Quartz* in prisms on the prehnite—3, *Analcite* crystals on the quartz—4, *Orthoclase* crystals on the analcite.

No. 45. WESTERNMOST ADIT. "SOUTHSIDE."—Small amygdules consist of: 1, *Laumontite*—2, *Quartz* surrounded by the laumontite.

No. 46. MICHIGAN MINE.—(Fissure vein). On the veinstone, which is here a greenish-gray, hardened clay-like material with flakes of chlorite and copper, and which becomes brown and soft near the contact with No. 1, lies: 1, *Datolite* in a uniformly distributed layer $\frac{1}{10}$ of a line to 2 lines thick, with the free surface highly crystallized. The crystals are transparent and rose-colored from the presence of minute particles of copper. The datolite appears quite fresh, and the copper seems to be confined to it—2, *Calcite*, four small slightly yellowish semi-transparent rhombohedrons, modified with steeper scalenohedron faces, lie upon the datolite—3, *Orthoclase*, yellowish crystals, $\frac{1}{20}$ of an inch long, are scattered over the surface of the specimen, some lying upon the calcite and some upon the datolite.

No. 47. MANY LOCALITIES.—1, *Prehnite*—2, *Delessite*. The prehnite which occurs as the solid filling of amygdaloidal cavities in the upper part of many beds, is subject to alteration to chlorite. It is very common to see the prehnite soft and green to a slight depth from the outer surface of the amygdule, without any line of separation between this portion and the hard centre; and in the interior the prehnite often passes gradually into spots and flakes of chlorite. In these amygdules the prehnite is characterized by a radiating structure starting from a single centre. It is along these planes of radiation that the change begins. Every possible gradation is observable. The resulting product is sometimes a mass of foliated chlorite, but more generally, it is an amygdule of compact chlorite, exhibiting in its fracture the same radiating structure as the prehnite.

No. 48. SHELDEN AND COLUMBIAN LOCATION.—1, *Prehnite*, which is the general filling of the cavities in the upper part of the amygdaloid of this locality—2, *Feldspar*, red. It is quite an exceptional occurrence in this neighborhood, and it is intimately associated with the prehnite in a manner that makes it seem to be pseudomorphous after it.

Crystals of epidote and of quartz occur on this feldspar, but the specimen gives no insight into their relation, as regards age, either to each other, or to the feldspar, as a secondary product.

No. 49. SOUTH PEWABIC MINE.—In this bed, a frequent form of the rock is a compact amygdaloid, of which 50 or 60 per cent. of the volume consists of amygdules from the size of a pin-head to $\frac{1}{3}$ inch in diameter. The matrix in a specimen before me is brown, and too hard to be scratched with a knife. The amygdules are sometimes of calcite, but more generally contain, 1, *Quartz*, clear and filling the cavity—2, *Chlorite; copper*. The chlorite (apparently delessite) appears to displace the quartz; in some amygdules, it merely penetrates the fissures of the quartz, giving to this a green color; in others, nothing remains but a cavernous mass of quartz and chlorite usually well charged with copper; indeed the copper occurs here only with this chlorite.

The series to which this bed belongs is represented on the "Southside," and again on the St. Mary's, by amygdaloids which resemble this one in all essential particulars, except that the amygdules are there filled chiefly with laumontite, and are free from copper and nearly free from chlorite.

No. 50. "OSSIPEE AMYGDALOID."—The rock is compact, spotted green and brown, and contains small *separate* amygdules of prehnite, quartz, epidote, calcite, chlorite. The chlorite appears as a destroyer of prehnite, quartz and calcite. A larger cavity shows the following succession: 1, *Prehnite;* a lining $\frac{1}{8}$ to $\frac{1}{3}$ inch thick, much altered and in places changed to chlorite—2, *Orthoclase,* minute crystal—3, *Epidote* on the feldspar.

No. 51. HURON MINE.—In places, the Isle Royale copper-bearing bed consists largely of a light grayish-green, fine-grained rock of epidote and chlorite indurated with quartz; small, irregular cavities in this contain: 1, *Epidote;* crystalline lining $\frac{1}{4}$ inch thick—2, *Quartz* filling the interior.

No. 52. SHELDEN AND COLUMBIAN MINE.—In cavities, in a brown and green amygdaloid, lie: 1, *Quartz* in well-shaped prisms —2, *Calcite; Quartz.* This second quartz is in small and very much distorted crystals, which are often partially imbedded in the calcite, and are also often planted on the older quartz, from which they can be easily removed without fracture.

No. 53. HURON MINE.—1, *Quartz* with more or less crystalline structure—2, *Copper* moulded on the quartz and filling cracks and interstices in it.

No. 54. RAGGED AMYGDALOID. ST. MARY'S.—In the rock (see No. 35), some of the smaller cavities contain: 1, *Orthoclase* as a thin crystalline lining—2, *Calcite* filling the interior—3, *Chlorite-like mineral* penetrating and apparently replacing the calcite.

In a larger cavity occur the following:

No. 55.—1, *Analcite* crystals ¼ inch to 2 inches in diameter, much reddened—2, *Orthoclase;* small crystals on the analcite—3, *Clay?* a soft white mineral, apparently the result of continued decomposition of the analcite under conditions unfavorable for the formation of new silicates as feldspar.

No. 56. "ANCIENT PIT" BED. DOUGLASS LOCATION.—1, *Epidote* forming a crystalline lining of a cavity—2, *Quartz* filling the interior.

No. 57. SULPHURET VEIN (Fissure vein). HURON LOCATION.—

The vein (6 to 8 inches wide) consists of the following: 1, *Ankerite?* (crystalline, massive, white on fresh surface, but rusty brown on exposed fractures) forming the member nearest the wall on each side—2, *Quartz,* in two symmetrical comby bands on the dolomite, and in thin seams in the dolomite connected by cross-seams with the quartz-comb—3, *Chalcocite,* black—bluish-black *with distinct cleavage.* It resembles the pseudomorphous chalcocite of the Lac la Belle mine. Bornite occurs sprinkled through the chalcocite in minute specks; in places it predominates, sometimes to the exclusion of the latter.

These sulphurets form the central member, and bunches of them are often surrounded by the older members, giving the "cockade" structure to the vein.

No. 58. UNKNOWN.—A specimen (in Mr. W. H. Stevens' collection at Copper Harbor) consisting chiefly of prehnite and containing beautiful cast-impressions of calcite.

1st. *Calcite* scalenohedrons 1½ inches long, represented now only by perfect casts.

2d. *Prehnite* massive and botryoidal containing the casts of calcite.

3d. *Quartz* upon the upper surface of the prehnite.

No. 59. SCHOOLCRAFT MINE.—(See cut on next page). Small amygdules in the brown amygdaloid immediately overlying the conglomerate bed. This rock is very rich in copper surrounding amygdules and filling their cracks.

1st. *Copper* forming outer shell of amygdule.

2d. *Delessite.*

No. 60. IBID.—(See cut on next page). In same specimen with No. 59.

1st. *Copper* forming the outer shell of a large amygdule.

2d. *Red feldspar,* forming the next inner layer.

3d. Calcite filling the interior.

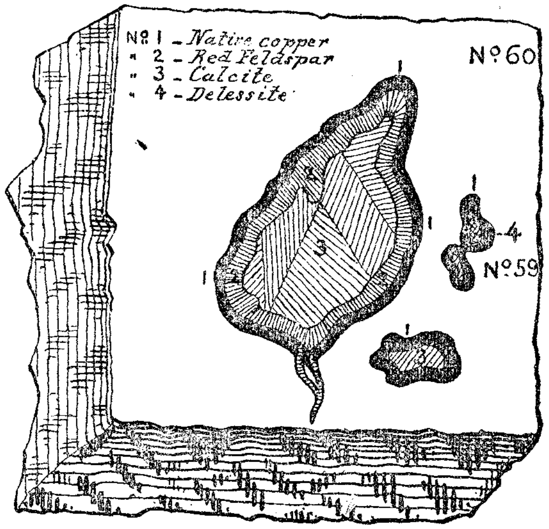
No. 61. PHŒNIX MINE.—(Fissure vein). A specimen of purple and green vein rock, 5 inches by 4 inches, is covered on one side by

1st. *Datholite?* crystals closely studded over the whole surface.

NOTE.—It is in another portion of this vein that the arseniurets, whitneyite and domeykite are found.

2d. *Green-earth or chlorite?* forming a thin film over much of the datholite.

3d. *Analcite* in numerous $\frac{1}{3}$ inch semi-limpid crystals, often very cavernous.



4th. *Feldspar* in small limpid crystals scattered profusely over the datholite and green-earth, but rarely sitting on the analcite.

5th. *Calcite* in scalenohedrons sitting on the green-earth and feldspar.

6th. *Apophyllite* in countless $\frac{1}{16}$ inch crystals perfectly transparent, and sitting on 2, 3, 4 and 5; where it occurs on calcite the crystals are pure and colorless; elsewhere they are colored red, possibly through particles of oxide of copper.

I have attempted to bring the foregoing observations into the following tabular form for greater convenience of comparison. The table is unavoidably imperfect, owing to the necessary difficulties which arise in attempting to compare the successions of different localities. The detailed observations, however, will serve for a check upon the imperfections of the schedule.

COPPER AND CALCITE.—In many of the instances in which calcite crystals are found enclosing copper, it is difficult and often impossible to distinguish as to the relative ages of the two. But

Cape
Hur
Copp
Phœ
Bay
Phœ
Bay
Bohe
Amy
Bay
Amy
Pewa
"
Alb.
" Ep
Amy
Huro
Alb.
Huro
" Sou
" Ra
Pewa
"
Ever
Amy
Unkn
" Sou
Mich
Many
Sheld
South
Ossip
Huro
Sheld
Huro
Ragg
"
" An
" Sul
Unkn
Scho
Phœn

COMPARATIVE TABLE.

Capen Vein	1	Laumontite		Prehnite				Chlorite				Analcite	Calcite				
Huron Mine	2	Laumontite		Prehnite													
Copper Falls Mine	3	Laumontite										Analcite					
Phœnix Mine	4								Calcite		Datolite						Apophyllite
Bay State Mine	5			Prehnite	Quartz		Copper										
Phœnix Mine	6	Laumontite			Quartz			Green-earth									
Bay State Mine	7				Quartz							Apophyllite	Calcite				
Bohemian Mine	8											Analcite		Copper	Orthoclase		
Amygdaloid Mine	9			Prehnite	Quartz							Analcite			Orthoclase		
Bay State Mine	10											Analcite			Orthoclase		
Amygdaloid Mine	11			Prehnite, Cu *							Datolite						
" "	12		Calcite	Prehnite, Cu							Datolite						
Pewabic Lode	13	Laumontite			Quartz		Copper	Chlorite or Green-earth	{ Calcite / Copper }		Datolite						
" "	14	Laumontite			Quartz	Calcite	Copper	Chlorite or Green-earth					Calcite		Orthoclase		
Alb. & Bost. "Ragged Amygd."	15			Prehnite											Orthoclase		
"Epidote Lode," St. Mary's	16			Prehnite	Quartz			Chlorite or Green-earth				Analcite					
Amygd. Kearsarge	17			Prehnite	Quartz												
Huron Mine	18											Analcite	Calcite				
Alb. & Bost. Amygd	19			Prehnite	Quartz										Orthoclase		
" "	20			Prehnite	Quartz			Chlorite or Green-earth							Orthoclase	Calcite	
" "	21				Quartz			Chlorite or Green-earth								Calcite	
" "	22			Prehnite	Quartz										Orthoclase		
" "	23			Prehnite	Quartz, Cu												
" "	24			Prehnite	Quartz											Calcite	
" "	25											Analcite			Calcite / Orthoclase		
" "	26			Prehnite	Quartz, Cu										Orthoclase		
" "	27			Prehnite	Quartz			Chlorite or Green-earth				Analcite					
" "	28			Prehnite	Quartz										Orthoclase		
" "	29			Prehnite, Cu													
" "	30			Prehnite								Analcite		Copper	{ Green-earth or Chlorite / Orthoclase		
" "	31				Quartz										Orthoclase		
" "	32			Prehnite, Cu													
Huron Mine	33	Laumontite	Calcite														
"Southside"	34											Analcite			Orthoclase		
"	"	Laumontite	Calcite														
"Ragged Amygdaloid"	35											Analcite			Orthoclase	Calcite	
" "	36												Calcite		Orthoclase		
" "	37											Analcite	Calcite				
" "	38											Analcite			Orthoclase		
Pewabic Bed	39								Calcite	Copper	Datolite						
" "	40								Calcite		Datolite						
Evergreen Bluff	41				Quartz										Orthoclase	Calcite	
Amygdaloid Mine	42									Copper	Datolite						
" "	43			Prehnite						Copper	Datolite						
Unknown locality	44			Prehnite	Quartz							Analcite			Orthoclase		
"Southside"	45	Laumontite			Quartz												
Michigan Mine	46										Datolite		Calcite		Orthoclase		
Many localities	47			Prehnite	Delessite												
Shelden & Columbian	48			Prehnite											Feldspar		
South Pewabic Mine	49				Quartz			{ Chlorite or Green-earth / Copper									
Ossipee Amygdaloid	50			Prehnite											Orthoclase	Epidote	
Huron Mine	51		Epidote		Quartz												
Shelden & Columbian	52				Quartz	Calcite / Quartz											
Huron Mine	53				Quartz		Copper										
Ragged Amygdaloid	54														Orthoclase	Calcite / Chlorite	
" "	55											Analcite				Clay	
"Ancient Pit" Bed, Douglass	56		Epidote		Quartz										Orthoclase		
"Sulphuret Vein," Huron	57		Ankerite?		Quartz		{ Bornite / Chalcocite										
Unknown	58		Calcite	Prehnite	Quartz												
Schoolcraft Mine	59						Copper	Delessite								Calcite	
" "	60						Copper								Feldspar	Calcite	
Phœnix Mine	61										Datolite / Gr.-earth	Analcite			Feldspar	Calcite	Apophyllite

* The symbol Cu occurring in the same column with another mineral indicates merely that the copper is younger than the prehnite or quartz and older than the datolite or orthoclase.

specimens in my collection offer conclusive proof that each of the following cases occur:

I.—*The copper was present before the calcite began to form, and became enclosed in the growing crystal.*

In this case the copper and its associated minerals generally form the basis on which the calcite rests, and the crystals of the latter exhibit entering faces wherever the surface of the crystal is in contact with the copper; it should seem to indicate an effort at those points to crystallize free from the foreign substance, by forming separate individuals. But on the finished crystal the traces of this tendency are visible, generally, only in the comparatively very small entering faces at the contact with the copper.

In this way calcite crystals, formed in a cavernous mass of copper, are intersected internally by a perfect network of thin plates of the metal, and yet preserve their cleavage unaffected; but wherever the copper comes in contact with the surface of the crystal, the small entering faces are present.

II.—*The crystal of calcite was partly formed, then became incrusted with copper, and was finished by a new growth of calcite over the metallic film.*

A most remarkable instance of this case is that of a crystal about 2 inches long—a steep scalenohedron—with a basal termination of about 1 square inch surface. At this stage of its growth it was covered, over nearly the whole surface, with a thin coating of copper. 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 tendency to complete the point of the scalenohedron is well shown on this specimen; over the partially copper-coated basal plane there are scattered a large number of perfectly pointed scalenohedrons—two or three of these are ⅓ to ½ inch high—and others are scattered over the side-faces. All of these younger crystals are arranged in perfect uniformity with the plan of the underlying, older individual.

Those portions of the surface on which the copper-coating is perfect have no younger calcite crystals; these occur where the metallic film is thinnest and more or less perforated.

The copper is not confined absolutely to the surface of the crystal on which it lies; it penetrates to a slight distance along the cleavage-planes, and the result is an exceedingly delicate reticulation on its under surface. The calcites which are planted on the copper contain brilliant particles of the metals swimming, if one may use the word, in the interior of the crystals; and these are so disposed as to lead to the idea that, throughout the growth of the younger crystals, they had to contend with the continued deposition of the metal. Thus one of the new scalenohedrons, after growing to the height of ¼ inch, was, like the underlying one, also ended with a basal termination, on which again smaller new and well-pointed individuals were built up.

III.—*The copper has entered the calcite crystal since its growth was finished.*

A specimen, in my collection, illustrates this remarkably well. It is a cleavage-rhombohedron of opaque calcite, traversed by intersecting sheets of copper, which are wholly independent of the cleavage planes. On detaching the copper from the calcite, the surface of the latter appears rough; it is a fracture oblique to the cleavage, and the face of the fracture is formed by countless corners, or solid angles, of minute cleavage-rhombohedrons, as is fully proved by the reflection of the light. The copper-sheets, which are about $\frac{1}{40}$ inch thick, reproduce this very completely.

Another very remarkable specimen is from the cement of the Albany and Boston conglomerate. It is about 1 inch in diameter, and consists of opaque white calcite. The continuity of the cleavage shows it to be a single individual, though it passes on the edges without any sharp demarkation into the common cement of the conglomerate. This calcite is traversed by continuous sheets of copper $\frac{1}{200}$ to $\frac{1}{40}$ inch thick, which are perfectly straight. These sheets are parallel to several planes (nearly all of which are independent of the cleavage), and intersect each other. In each of the sets thus formed the sheets are perfectly parallel, and are separated by plates of calcite, which are, in places, as thin as the copper itself. Where three such sets intersect each other, the resulting solid appears composed of concentrically arranged laminæ of copper and calcite. In some parts of the specimen, the copper predominated over the calcite. Wherever the faces of the copper laminæ are exposed, they are marked with a delicate, reticulated tracery, indicating the lines of intersection of the sheet with the cleavage planes of the crystal. The cement in the vicinity of the calcite is impregnated with copper; in places it is almost wholly replaced by the metal in the fine granular condition called "brick copper," and into this the laminæ of metal extend, without break, from the calcite. This specimen is really a pseudomorph of copper after calcite.

Copper and Silver.—It is a well-known fact that these two metals occur in the metallic state, in the Lake Superior deposits, in the most intimate contact with each other, and yet without being mutually alloyed. Even at the contact they are not absolutely joined together, for after rolling out a piece of copper containing spots of silver, the two metals become more or less separated, and may often be readily detached from each other.

In all the instances that have come under my observation the silver appears to be younger than the associated copper, and seems to have been directly precipitated by copper, and to have replaced the latter.

Chalcocite, Bornite, Whitneyite, Domeykite.—Two fissure-veins are known in the neighborhood of Portage Lake which carry these ores. They have been examined only very superficially; but it is a remarkable fact that the amygdaloids traversed by these veins contain only native copper. One of the fissure-veins, bearing both sulphides and arsenides of copper, enters the Grand Portage cupriferous amygdaloid bed, which bears only native copper, and remains in it with a changed direction for a short distance. The gangue of these veins is quartz, calcite, and a carbonate of lime containing some iron and magnesia—ankerite?

The only other instance I have observed of the occurrence of copper in combination with sulphur, is in the fissure-vein of the Mendota property, near Lac la Belle. This vein appears to traverse the entire trappean series from Agate Harbor on the north to Lac la Belle.

Wherever this vein has been opened or uncovered, along the greater part of its course, north of the Mendota property, only *native* copper has been found; but when it enters a bed of conglomerate on the north flank of Mt. Bohemia, the little copper it contains is combined with sulphur in a very pure chalcocite. Where the vein passes from the conglomerate into the underlying amygdaloid, a fine deposit of chalcocite with calcite was found to have been formed, for a short distance, on both sides of the vein, between the two beds.

Still farther south the vein enters a mass of syenite, consisting of a pink triclinic feldspar, some hornblende and much chlorite, as an alteration-product of hornblende, and containing frequent impregnations of chalcopyrite, bornite, and, more rarely, chalcocite. In this syenite the vein and its many feeders carry bornite and considerable quantities of a bluish sulphuret of copper, in sheets ⅓ to ¾ inch thick, which has a very crystalline structure and exhibits octahedral cleavage.*

Near the contact between the syenite and trap, the latter rock is impregnated with magnetite, specular iron, chalcopyrite, and bornite. Excepting the syenite, wherever copper is found in the traps and amygdaloids on the Mendota property, it is in the metallic state. The occurrence of the sulphides and arsenides of copper in this isolated manner and in fissure-veins traversing rocks more or less impregnated with metallic copper, seems to show a diversity of origin for the sulphur and arsenic on the one hand, and the copper on the other. It does not seem unreasonable to suppose the copper to have entered the vein-fissure from the adjoining rocks in solution, as carbonate, sulphate, or silicate, and to have been then precipitated by sulphuretted hydrogen and arseniuretted hydrogen respectively. Or the copper may have been deposited in these as in other veins, in the metallic state, and have been subsequently changed by the same gases. In the case of the pseudomorphous chalcocite, where the Mendota vein traverses syenite, cuprite must have been formed by the oxidation of chalcocite or of native copper, and the oxide must have been subsequently decomposed by sulphuretted hydrogen.

The Huronian formation, which probably underlies all this region, contains in its upper members large amounts of carbonaceous matter in the form of graphite; the gases may have originated in a reduction of sulphates and arseniates by the carbon of these beds.

* Prof. Cooke, after a casual examination of this mineral, suggests that it is probably a pseudomorph of chalcocite after cuprite.

REPLACEMENT OF PORPHYRY MATRIX BY CHLORITE AND COPPER.

Among the pebbles in the Calumet conglomerate there is a variety of quartz porphyry, with a brown, compact, almost jaspery matrix, which only glazes slightly before the blowpipe. In this paste there are numerous grains of dark quartz $\frac{1}{20}$ to $\frac{1}{4}$ inch in diameter, and often more frequent crystals of flesh-red feldspar, apparently orthoclase,—$\frac{1}{10}$ to $\frac{7}{10}$ inch in length.

It not rarely happens, that in these flesh-red crystals there appear dirty green portions exhibiting the twin-striation of a triclinic variety. The feldspar is hard and brilliant, but is nevertheless no longer intact; under the glass the crystals appear cavernous, 10 per cent. or more of the substance being gone. This is the character of this porphyry in the freshest pebbles.

I have before me a pebble 4 inches in diameter, broken through the middle. It was the same variety of porphyry I have just described—the same brown matrix, with the same grains of quartz, and the same large crystals of orthoclase, often enclosing crystals of triclinic feldspar. But this pebble carries on its face the history of an extreme change. In the interior, where it is freshest, the matrix, still of the same brown color, has become so soft as to be easily scratched with the point of a needle. The quartz grains are highly fissured, and the surfaces of the fissures are covered with a soft, light-green magnesian mineral. The feldspar, although it still resists the point of the steel needle, has generally lost its glance, and has an almost earthy fracture; it is lighter colored, and tends to spotted dirty-red and white. In places, specks of chlorite are visible in the holes in the altered feldspar, and the cleavage planes often glisten with flakes of copper. As we go farther from the middle of the specimen toward the original surface of the pebble, the matrix becomes much softer, though still with brown color and brown streak, and then changes to a soft, green, chloritic mineral, which whitens before the blowpipe, and fuses on the edges to a gray glass. A little farther from the centre there is no longer a trace of the porphyry matrix: it is altered wholly to chlorite. The feldspar crystals are somewhat more altered here than they are in the middle of the pebble, but the quartz grains seem to have been in part replaced by chlorite. The change to chlorite is accompanied throughout by the presence of a large amount of copper. While in the interior of the pebble, the flakes of copper are confined to the cleavage planes of the feldspar, and the porphyry matrix exhibits scarcely a trace of the metal, the chlorite which has replaced the matrix contains in different parts of the specimen from 10 to 60 per cent., by weight, of copper.

In another pebble of the same porphyry, not only is the original matrix gone, but the usurping chlorite has been almost, if not wholly, replaced by copper; and we have as the remarkable result a quartz-porphyry, whose crystals of feldspar and grains of quartz lie in a matrix of metallic copper. There is still a very small amount of chlorite present, but it seems to have come from the change of the feldspar crystals and quartz grains.

In other pebbles of the same quartz-porphyry, containing, perhaps, less quartz, the alteration seems to have taken a somewhat different direction, or at least the result before us is different. In the interior of the pebble, the matrix is of a darker and dirtier brown than in the previous cases, which may be due to the presence of manganese in the alteration-product. Going from the middle, the brown color changes rather abruptly to a dirty greenish-gray; the material also becomes softer, but it is earthy, with an earthy odor, and gritty to the touch. The change seems here to be in the direction of kaolinization.

The entire pebble is permeated with minute shining threads and plates of carbonate of lime. The lighter-colored portion contains considerable copper, while nearer the surface of the pebble it is largely replaced by that metal. Pebbles showing the various alterations described above are by no means rare. Many of them, from 1 inch to 1 foot in diameter, are found every day.

A very interesting occurrence of copper and silver is visible in specimens, in my collection, from the abandoned Suffolk mine in the "South Range," south of Eagle River.

There is here an extensive development of feldspathic porphyry (without visible free quartz). In this rock a vein carrying sulphuret of copper was once worked. The specimens referred to were

found loose in a gorge near the vein, but are porphyry. They have a dark purplish brown compact matrix, with uneven to semi-conchoidal fracture, and contain numerous amber-colored to flesh-colored crystals of triclinic feldspar, averaging ¼ inch in diameter by ½ inch thick, and occupying about $\frac{1}{5}$ of the surface area of fracture.

The rock contains, disseminated through the matrix, small particles of black sulphuret of copper. The feldspar crystals often contain minute flakes of native copper, and in some instances flakes of native silver occur in the same manner in the cleavage planes of the feldspar. The chain of changes was, perhaps, initiated by the forming of chloritic substance in the feldspar crystals, the ferrous oxide then reduced the copper from solution, and the copper precipitated the silver.

CONCLUSIONS.

We may be permitted to draw a few conclusions from the facts brought out in the observations thrown together in the foregoing pages.

I. The *Chlorite* of the melaphyr, and consequently the distinctive character of that rock, is due to the alteration of hornblende or pyroxene. This seems to have been the first step toward the production of melaphyr proper. *Laumontite*, which we find alike in the beds containing the least and in those containing the most chlorite, and occurring both diffused and concentrated in seams, appears to have been formed either contemporaneously with the chlorite, or as the next step in the process.

In the fissure-veins of Keweenaw County, laumontite is most abundant near and under the "Greenstone," as in the north end of the Central Mine. Here the great body of overlying rock is one in which the hornblende has undergone but little change.

The next step appears to have been the individualization, in amygdaloidal cavities, of *non-alkaline silicates*, viz., *laumontite*, *prehnite*, *epidote* respectively, according as the conditions favored the formation of one or the other of these.

In the fissure-veins of Keweenaw County, prehnite is the most abundant silicate found in depth, *i.e.*, below the 80 or 90 fathom level. The alkaline silicates are found chiefly in the upper levels.

Following the non-alkaline silicates came the individualization of *quartz* in these cavities.

Perhaps we may be warranted in considering these minerals, together with the lime of the calcite that more rarely occurs in this portion of the series, as chiefly due to the decomposition of the pyroxenic ingredient of the rock.

So far as we may infer from the tabulated results, the concentration of *copper* in the amygdaloidal cavities does not appear to have begun till after the formation of the quartz.

In this part of the series falls also the formation of a chloritic or green-earth mineral, which in some manner has displaced prehnite, quartz, calcite, and with which copper, when present, appears to stand in intimate relation. Subsequently to this came the individualization of the alkaline silicates, viz., analcite, apophyllite, orthoclase. Here also seems to belong the formation of datolite.

The alkaline silicates represent the period of decomposition of the labradorite ingredient of the original rock, and when they occur in the mass of the rock (as distinguished from veins), it is only where the alteration of the rock has proceeded so far that the amygdaloidal form has merged into the brecciated through the enlargement and union of the cavities.

In the fissure-veins of Keweenaw County, the alkaline silicates, as before stated, abound in the upper levels, and are rare in depth; in other words, they are abundant in that zone of the veins which lies between walls of those portions of the beds of melaphyr in which we should look for the most advanced stages of alteration in the components of the melaphyr, supposing such alteration to be due to the action of *descending* solutions.

The fact that calcite occurs at almost every step in the paragenetic series, and forms one of the most common of the secondary minerals, is proof that carbonic acid was very generally present throughout the whole period of metamorphism; it was probably the chief mediating agent in the processes, without being sufficiently abundant to prevent the formation of silicates.

II. The change of pyroxene to chlorite, as illustrated on an immense scale in the formation of the melaphyr, and the displacement of feldspar and quartz—quartz-porphyry—by chlorite, as exhibited in pebbles of the conglomerate, point to an extremely important line of investigation for the chemical geologist. The alteration of the pebbles appears to have followed two different directions according to the ruling conditions, viz., either toward chlorite or toward kaolinization; and as the result of the latter process is impregnated with calcite, while the result of the former is free from carbonates, it would seem that the direction was determined by the presence or relative freedom from free carbonic acid. The deposition of calcite, if formed from the acid carbonate, would set free sufficient carbonic acid to prevent the formation of silicates of iron and magnesia.

III. *Copper*, wherever we can detect it with the eye, has already gone through a partial concentration. The presence of this metal in minute quantity in the sandstones of Lake Superior, is made evident by the stains of carbonate which form on the cliffs of the "Pictured Rocks."

It has also been found in the form of thin sheets of native copper occupying thin vertical fissures in the cliffs of Lower Silurian sandstone on the lake shore north of the Huron mountains. It is found here and there in the less amygdaloidal melaphyr in minute specks and impregnations, or even in a more concentrated form, as thin sheets occupying the joint-cracks.

These occurrences increase in frequency in proportion as the rock is more amygdaloidal; in other words, the copper is more concentrated in those portions of the beds where the chemical change has been greatest. Where the rock has not passed beyond the strictly amygdaloidal stage, the copper occurs in the amygdules, traversing these in flakes, or coating them in a film of greater or less thickness, to such an extent as to form from ¼ per cent. to 3 per cent., by weight, of the rock over considerable areas. Finally, in those beds where the metamorphism has proceeded to such an extent as to wholly replace large portions of the amygdaloid by secondary minerals, epidote, calcite, quartz, chlorite, laumontite, etc., there the copper occurs in masses of many pounds, and sometimes of several tons weight, and in forms equalled in their irregularity only by those of the masses of secondary minerals accompanying the metal.

In each and all of these positions we find that the deposition of the copper took place subsequently to the decomposition and removal of a portion of the rocks, and subsequently to the deposition of laumontite, epidote, prehnite, and quartz, where these accompany it

In all this we have direct evidence of the movement of some salt of copper in wet solution, and the concentration of the metal by accumulating deposition in places where the precipitating agent existed.

In the fissure-veins of Keweenaw County, the widening of the vein is frequently due to "splicing," *i.e.*, a portion of the wall rock became detached and split by countless small cracks having a general parallelism to the main vein. Thus, instead of forming a solid "horse of ground," it consists of myriads of small and large lenses of often wholly decomposed rock, surrounded by films and seams of chlorite, laumontite, calcite, and clay. These places are often the home of large "masses" of copper, which then also have a spliced structure. Where the masses occur in a gangue of calcite, they are not spliced, but have a solid texture and the most irregular shapes. These facts point, perhaps, toward the formation of "masses" by replacement.

According to Mr. Pietrie, the superintendent of the Central mine (fissure-vein), where a "horse" occurs in the vein, the regular vein filling follows the foot-wall side of the "horse," and the younger fissure on the hanging-wall side is filled with calcspar and mass-copper. The foot-wall branch contains (like the regular filling elsewhere) prehnite, one of the earlier-formed minerals.

Except in the melaphyrs of Lake Superior, the copper so widely diffused in the Palæozoic and older stratified rocks, exists either in the various sulphurets, or as oxidation products of these. Indeed, we cannot well suppose the copper to have been deposited in submarine formations in any other condition than as sulphuret. Nor can we suppose it to have taken any other form permanently, so long as unoxidized organic matter remained in the beds. An oxidation of the sulphuret would be followed by reduction of the resulting sulphate to new sulphurets around the organic remains. In this way we may suppose the simplest and most common form of concentrated deposits—the impregnations—to have originated, as well as the farther enrichment of particular beds or zones—*fahlbands*—which may represent strata which were originally richer in organic substances, or which may have retained these longer than the other beds.

The trappean series of Keweenaw Point differ from all the other cupriferous rocks of the Northwest in lithological constitution, and

in having the copper in the metallic state. It is still an open question whether the trap which formed the parent rock of the melaphyr was an eruptive or a purely metamorphic rock. If it was eruptive, it was spread over the bottom of the sea in beds of great regularity, and with intervals which were occupied by the deposition of the beds of conglomerate and sandstones.

It should seem probable that the copper in the melaphyrs was derived by concentration from the whole thickness of the sedimentary members of the group, including the thousands of feet of sandstones, conglomerates, and shales which overlie the melaphyrs, and including melaphyrs also—and especially, if these are purely metamorphic.

Among the most interesting questions connected with the occurrence of the copper are those touching its condition previous to concentration during the amygdaloidal stage of metamorphism, the chemical combination by which this concentration was effected, and the character of the precipitating agent.

The great persistency of metallic sulphurets through the usual processes of metamorphism, and the almost universal association of sulphur with copper in crystalline rocks, renders it perhaps probable that this was here also the combination in which the metal was diffused, or rather, very partially concentrated. Traces of sulphur detected by Mr. Hochstetter in the melaphyr contiguous to the Hecla conglomerate point also in this direction, considering that the only acids generally present in the melaphyrs are silicic and carbonic acids, and if we add sulphuric acid as an oxidation product of the sulphurets, our choice of the form of solution, by which the final concentration was effected, should seem to be limited to silicates, carbonates, and sulphates of copper. Probably all of these combinations took part in the process, but while we may consider the translocation of the copper to have been initiated by the sulphate, this salt must have been so soon decomposed by the abundant acid carbonate of lime,* as well as by the alkaline silicates, that we cannot readily suppose the sulphate † to have

* A coating of gypsum covering very thin sheets of copper from the jointing-cracks of the melaphyr contiguous to the Hecla conglomerate, may be due to this decomposition, followed by the reduction of the copper.

† Compare Bischof, Chem. u. Phys. Geol., I., p. 52, and III., p. 716.

generally effected the final concentration of large deposits. It is more probable that this was accomplished by the more permanent solutions of carbonate and silicate of copper respectively, as the circumstances favored. The position of the metallic copper in the paragenetic series, shows it to have been deposited after the non-alkaline silicates, and before the formation of the alkaline silicates, *i.e.*, after those minerals which resulted from the decomposition of the pyroxenic constituent of the rock, and before those which were formed by the destruction of the feldspar. Now this is what we should expect if we suppose the pyroxenic rock to have been altered to its present condition under the co-operation of water carrying carbonic acid and some free oxygen, because the oxygen must have been employed in oxidizing the carbonate of iron resulting from the decomposition of the pyroxene;* the oxidation of the sulphuret of copper could not, therefore, take place until the pyroxene had so far disappeared as to leave a relative excess of oxygen as compared with the amount of ferrous salts exposed to a higher oxidation. Throughout its deposits the copper exhibits a decidedly intimate connection with delessite, epidote, and green-earth silicates, containing a considerable percentage of peroxide of iron as a more or less essential constituent; while among the other silicates, viz., analcite, laumontite, datolite, prehnite, only the last named, which alone seems subject to a considerable replacement of its alumina by ferric oxide, is especially favored by copper. This association is so invariable and so intimate that one is forced to the conclusion that there exists a close genetic relation between the metallic state of the copper and the ferric condition of the iron oxide in the associated silicates; that the higher oxidation of the iron was effected through the reduction of the oxide of copper and at the expense of the oxygen of the latter.

As regards the green-earth and that variety of chlorite or delessite which is intimately associated with the copper, they either immediately follow the copper in point of age or are contemporaneous with it, and they may be looked upon as having been formed under the influence of this reduction. Where copper is associated with prehnite it is invariably younger than the latter, a fact which would

* The result of this oxidation is seen in the brick-red color of the amygdaloids and in the brown color and spots of many of the melaphyr beds.

seem at the first glance to oppose the supposition that there is any relation between the peroxide of iron in the zeolite and the deposition of the copper. But we have seen that prehnite undergoes a change to delessite; we find these pseudomorphs in every stage of the process from the first green discoloration on the cleavage planes to the amygdule of delessite with prehnite structure. Now, may we not consider the presence of iron in prehnite generally to be due to a beginning change, and the deposition of native copper in the Lake Superior prehnites to be partially or wholly correlated with the higher oxidation of the iron?

In at least very many instances, if not in all, the deposition of the copper has been a result of a process of displacement of pre-existing minerals. In some rare instances the metal retains the form of its more or less remote predecessor, as in the pseudomorphs after some mineral (clay?) after laumontite.

Nowhere is this displacement more apparent than in the cupriferous conglomerates. In these, the cement is the home of the metal, and in some places, as in portions of the Hecla and Calumet mines, it is wholly replaced by it; copper forming 20 to 50 per cent., by weight, of the rock. In these instances, either chlorite or epidote is associated with the copper as minerals formed since the deposition of the conglomerate, while calcite very frequently replaces the cement in barren portions of the bed.

The cement of the conglomerates is of the same materials as the pebbles in a more comminuted form. The displacement of the whole mass of quartz porphyry in large pebbles by chlorite and copper described above, is probably an illustration of the manner in which the cement was displaced on a more extended scale.

The absence of the ores of the baser metals—lead, zinc, nickel, etc., from the deposits of the trappean series, while they are present in the less metamorphosed rocks of the Quebec group in other localities—may be due to the greater intensity of the chemical action to which the melaphyrs have been subjected; an intensity which may be measured by the extent to which the process of concentration has been carried. Concentration is a process of removal, relatively speaking, and concentrated deposits are accumulated masses of material arrested in the drainage channels of rock masses by the action of competent forces; if the arresting cause is absent from a given region, the removal will continue to another where it is present. If causes exist which are able to arrest one class of the substances in the passing solution, and are powerless as regards another class, then a separation will occur between the two classes.

Now, copper and silver belong to a class distinct from the baser metals, in that, by reason of their smaller affinity for oxygen, they are more readily reduced to the metallic state, the condition of greatest permanence in presence of the usual reagents to which they are exposed. If the arresting cause of these metals was, as we have supposed, their reduction by protoxide of iron, it is a cause which would have been powerless as regards the salts of the baser metals, and we may suppose these to have continued in solution till they reached some region where they were arrested by the presence of organic matter, or of sulphuretted hydrogen, etc.

CHAPTER IV.

CORRELATION OF THE ROCKS OF HOUGHTON AND KEWEENAW COUNTIES.

BY A. R. MARVINE.

(See table at the end of this chapter.)

UPON the Plate of Grouped Sections are gathered the various sections that have been made by the Geological Survey in the years 1870 and 1872, that their relations may be more readily studied. They are placed down the Plate in the order in which they occur, going from south to north. All the sections but I. and II. are taken very nearly across the formation. I. and II. of the Portage Lake District, however, contain many points scattered along the formation, as well as across it, as may be seen by reference to the map; the two being connected by the Roman numerals.

In Section I., the exposures have been projected upon the plane of section from the various points at which they occur along such lines of strike, as near as may be, that the formation has at them. In Section II. (which stands in a relation to Section I. to be hereafter explained) the "Albany and Boston" conglomerate, No. 15, has been assumed as a straight line between the Pewabic and Rhode Island mines, and the remaining beds plotted off from it at right angles, at the distances which they were found to have at those points where they happened to be exposed. Under these circumstances, both in Sections I. and II., points exposed directly across the formation from one another, would appear upon the sections as having the same geological relations to one another that they have along the line at which they actually occur. Exposures not lying directly across the formation from one another would also carry with them to the section their true relations, provided that the intervening beds had neither thickened nor thinned in going along the formation from one point to the other. But if thickening or thinning has taken place, two points so exposed would be projected upon the section, either farther apart or nearer together than they would if either point had been exposed directly across the formation from the other; while they might or might not appear as they would, supposing the beds prolonged till they actually intersected the plane of section.

Thus Sections I. and II. show the relations the beds have at the various points along the range at which they happen to be exposed. Were it an object to form a true section across the range at some one point, the rates of thickening or thinning of the beds would have to be first ascertained and a correction—depending on those rates and the distances of the exposures from the section—applied to the various beds, as shown upon the printed sections, thus reducing them to their proper places upon the ideal section.*

The differences in dip which occur along the mineral range are apt to lead to very deceptive results in comparing the distances between beds as shown upon the surface. Two beds, whose dip angle is growing less as we follow them along the formation, will appear to gradually separate from one another, while the actual distance between them, measured perpendicular to the plane of bedding, remains the same or may even diminish. Thus, the horizontal distance between the Allouez and first conglomerate, south at the Central mine, is more than four times the horizontal distance between the Albany and Boston and Houghton conglomerates as exposed on the Mesnard property. The dip at the former, however, is twice as flat as at the latter, thus accounting for most of the difference in distance; while if allowance be made for the rate at which we know the intervening beds to be actually widening at the Mesnard, the remaining discrepancy is entirely accounted for.

In order, then, to impartially compare different portions of the

* It is with the object of avoiding the publication of a number of such sections, while at the same time affording data for forming them when necessary, that the table which is to follow has been prepared. Having some known bed to measure from, this table, in connection with the accompanying sections, enables the positions of beds, covered upon the property in question, but known elsewhere, to be ascertained with considerable accuracy.

mineral range, the perpendicular distances between the beds only must be regarded.*

The number and lithological similarity of the amygdaloids, together with the fact that they are prone to wholly disappear, as may be readily seen from the sections, render them unfit for the purpose of tracing the formation. The great similarity among the melaphyrs renders them also doubtful guides; though in both amygdaloids and melaphyrs there are certain broad features obtaining over more or less wide belts, which are serviceable in correlating, in a general way, different parts of the range. Such are the coarse-grained melaphyr belt of the Dacotah, and the belt containing scoriaceous beds to the west.

The relative infrequency of the conglomerates, notwithstanding their lithological similarity, renders them, therefore, the only reliable stratigraphical guides of the formation.

The measurements between the conglomerates, to which the survey paid much attention, have therefore been discussed, and the results gathered into the accompanying table, (opposite page 60) a description of which follows:—

The right-hand column contains the names of the various properties along the range on or opposite to which the various measurements were made. These, in going down the page, read from south to north. The strip across the paper opposite each is supposed to represent a narrow strip running directly across the formation. Column two contains the dip of the formation, as near as

* The perpendicular distance between two beds equals their horizontal distance multiplied by the sine of the dip angle. A measurement made between two beds that are exposed at different heights does not give the horizontal distance between them. With strata dipping to the north-west, if the north-west point is the higher the measurement will be shorter than it should be,—if lower, longer than it should be. The correction to be added or subtracted, as the case may be, to a measurement itself reduced to the horizontal, in order to give the horizontal distance between the beds, equals the difference in height of the observed points divided by the tangent of the dip angle. The following table gives the natural sines and tangents of the dips of the principal mining locations:—

Dip angle.	56°	55	54	53½	53	52¾	52	45	43	39¼	31	30	26
Sine......	.82904	.81915	.80902	.80386	.79864	.79600	.78801	.70711	.68200	.63271	.51504	.50000	.43837
Tangent..	1.48256	1.42815	1.37638	1.35142	1.32704	1.31507	1.27994	1.00000	.93252	.81703	.60086	.57735	.48773

could be ascertained, on the property it is opposite. Column three contains the approximate distances, in feet, along the formation of the various strips from the southernmost one; and subtraction of the numbers opposite any two measurements enables one to obtain the distance along the formation between them. The conglomerates are numbered uniformly with the grouped sections. The names of several near Portage Lake are placed along the top of the table, of several in Keweenaw County, along the bottom.

The Albany and Boston and the Allouez conglomerates being represented by a straight line (No. 15), the various other conglomerates are plotted off from it, and from one another, to a scale of 1,600 feet to one inch, the distances from foot-wall to foot-wall * perpendicular to the formation being taken. This part of the table, then, may be taken to represent the appearance the outcrops of the conglomerates would present, on the supposition that the mineral range, instead of being tilted into its present position, had been tipped up, without faulting, until the strata at all points stood vertical, and then straightened out until the Albany and Boston and the Allouez conglomerates formed one straight line.†

The horizontal measurements between the conglomerates are placed opposite the points in column 1, at which they were made, and between the lines representing the conglomerates, their direction and limits being indicated by the fine dotted lines. Under each of these, in a parenthesis, is placed the resulting perpendicular distance between the beds. It is those numbers which are drawn to a scale of 1,600 feet to an inch. Numbers in parentheses which stand alone are not derived from horizontal measurements, but are obtained indirectly either by subtracting adjacent parenthetical numbers, or by applying a correction to direct or diagonal measurements on account of thickening or thinning of the formation. Placed between those numbers in parentheses, which represent the perpendicular distances between the same two conglomerates at different points of the range, are numbers in brackets. These represent the number of feet of thickening or thinning, per each

* Except No. 14, in which the hanging-wall is taken, the foot-wall not being observed.

† The distances across the table being drawn to scale, it may be cut in two, just above the Kearsarge, when, by moving the lower part back or forth upon the upper, any other apposition of the conglomerates than that here adopted may be made.

thousand feet along the formation between the measurements, that has taken place in the beds lying between the conglomerates in question. They are obtained by subtracting the perpendicular distances between two conglomerates at different points, and dividing the difference by the number of thousand feet lying between the points, as obtained from column 3. Thus, take conglomerates 14 and 15, between the Mesnard and Albany and Boston, when measurements between them were made. At the former place the two are 411 feet apart, and having a dip of about 53°, the perpendicular distance between them would be (328) feet. At the latter, these distances are 460 and (362) feet respectively. The total thickening is, therefore, 34 feet, which has taken place in a distance along the range (column 3) of 12,800 feet, or at the rate of [2.7] feet per thousand. Thickening toward the north is indicated by the simple rate; thinning toward the north, by the minus sign,—thus [−1.6].

Rates that are derived from measurements made directly across the formation are the most reliable. Having these we may correct diagonal measurements, or calculate the distances between the same beds at other points, and from these obtain rates of thickening of beds not directly measured. Thus, at the Pewabic we have a measurement (3,166) between 9 and 15, but no direct one elsewhere. At the Montezuma, however, we have from 9 to 12, and at the Dacotah from 12–14 (1467), which, corrected for the rate [3] to the Montezuma, becomes 1,480. Reducing the distance between 14–15 at the Mesnard for the rate [2.7] gives (297) feet at the Montezuma, or, in all, from 9 to 15 at the Montezuma (3,151) feet. Comparing this with (3,166) at the Pewabic, gives a rate of widening, per 1,000 feet, of [2.8] feet for the total space between conglomerates 9 and 15. If we add the rates of widening given in the table for the spaces included between 10 and 15, we have for this whole space [−1.8] feet which would leave [4.6] for the space 9–10. It will be observed that between the Montezuma and the Kearsarge, a rate of [4.1] was obtained for this same space. It may be objected that in the above calculation the rate [2.7] which 14–15 has between the Albany and Boston and the Mesnard was assumed to continue to the Montezuma.

The projected distance in Sec. I. between 14 and 15, corrected, for a reason not readily explained, for the rate [6.4] between 15 and 17 gives [285] at the Montezuma, and this number, compared with the distance at the Mesnard, gives the same rate of widening as from there to the Albany and Boston, or, indeed, from the latter point to the central. But be this as it may, the assumption may be avoided by regarding the region between 9 and 14 only, and considering that the rate [2.7] holds good only so far as the Pewabic. Here 14 and 15 would therefore be (310) feet apart, leaving (2,856) feet between 14 and 9. Proceeding as before, we find that between the Montezuma and the Pewabic the zone 9-14 is widening at the rate of [0.3] per thousand, leaving [4.8] for the zone 9-10, or [0.2] larger than before. These examples, taken at random, serve to show the manner of obtaining rates not entered in the table, for the purpose of ascertaining the approximate positions of unexposed conglomerates, and, with the help of the sections, of intermediate beds, should there be reason to suppose them continuous. It must be observed that numbers thus derived from the table are *thicknesses*, or distances perpendicular to the plane of bedding. To reduce them to the horizontal, they must be divided by the sine of the dip on the property on which a bed is sought (p. 3), and this number should be increased if the ground slopes downward to the west, or decreased to the east.

General Conclusions.—Regarding, first, the region lying between the South Pewabic and the Albany and Boston, we see that there is a very general thickening of the beds in going north along the formation.* In only one zone does the reverse take place, viz., between conglomerates 11 and 12. The large rate here obtained [—10] may be somewhat in excess owing to some error. It could not be varied much, however, and shows that there is a very decided narrowing going on in this belt. Eastward of No. 9 the thickening toward the north is small throughout, while west of it, excepting the narrowing zone, it is much greater, being especially marked west of 14. The rate [5.9] between 15 and 16, derived from a measurement probably not reduced to the horizontal, must be inaccurate; but it serves to show that most of the total thickening [6.4] between 15 and 16 is taking place in the zone 15-16.

* Upon the table, a sudden bend or widening in the lines representing the conglomerates does not indicate a similar change in the formation, for distances up and down the page are not drawn to any scale, so that some parts of the Range are much crowded together compared with others. Two lines that are separating indicate a thickening, the actual amount of which, however, must be obtained from the numbers between them.

Identity of the Allouez and Albany and Boston Conglomerates.—It will be observed that in the table the Albany and Boston conglomerate has been assumed to be the same as the Allouez. We may seek the proof of this in three separate groups of facts—geographical, stratigraphical, and lithological.

1. *Geographical.*—The extension of the line between the Albany and Boston and Rhode Island shafts northward would intersect the line of the Calumet conglomerate near the line between the Calumet and Hecla properties, at an angle of about 5¾ degrees, and it has been supposed that by curving in a peculiar way they might be the same bed. The extension of the Calumet base, however, passes over 2,400 feet east of the Rhode Island, and not far from where the North Star conglomerate (No. 12) should be; while the extension of the line of strike of the Allouez conglomerate from the Allouez mine would intersect the Albany and Boston conglomerate not far from the Rhode Island. Might not a curving throw either of these two together?* The Albany and Boston conglomerate, between the Pewabic and Albany and Boston mines, is bending eastward toward the Calumet, partly in virtue of the flattening of the dip which is here taking place. This effect is much exaggerated upon the map by the depression of the Albany and Boston Creek, which throws the outcrop here too far to the westward. Reduced to Lake Livet, the line of the bed still shows considerable eastward curvature, which, however, notably diminishes at the Albany and Boston, and is hardly apparent at the Rhode Island, where there seems to be almost a slight reversal of the curve. It is a line bearing eastward of this which fails to intersect the Calumet till reaching that mine. A bend at the Rhode Island, similar to that which takes place between the South Pewabic and Portage Lake, or at the Pewabic mine, would throw the Albany and Boston conglomerate west even of the Allouez. The Calumet conglomerate, in going south, also swings westward toward the Albany and Boston. Here, fortunately, we have data which give an approximate idea of the amount

* The Calumet base line was extended by Mr. L. G. Emerson southward to the Rhode Island. Mr. A. B. Wood prolonged the Albany and Boston strike, as a picket line, northward toward the Calumet, while the Allouez was prolonged, as a transit line, from the Allouez mine to Calumet by Mr. Harry Beaseley, formerly county surveyor. A line nearly parallel with, but about 900 feet west of, the latter was afterwards run by Mr. L. G. Emerson, southward, I believe, to the Rhode Island.

of curving. Explorations on the Ossipee and Sawabic show that at about one-fourth of the distance toward the Rhode Island, the Calumet has swerved 60 feet westward from the extended Calumet Base Line, not taking difference in height into account, which might or might not increase this distance. Supposing that this rate continued, not directly as the distance from Calumet, which would give a departure from the extended line at the Rhode Island of 300 feet, but as the *square* of the distance, a most liberal estimate, and which would give a departure of 960 feet, still leaving the bed over 1,400 feet east of the Albany and Boston. Upon previous considerations, it has been seen to be between 1,600 and 1,700 feet east of the Albany and Boston. So far as curvature goes, these two cannot be identical, while placing the Calumet where curvature would probably carry it, leaves the Allouez the same as the Albany and Boston.

At the Calumet mine, the dip, according to Mr. G. D. Bolton, is 39° 15′. Both toward the north and south it is increasing, becoming, according to Mr. E. J. Hulburt, 52° at the Albany and Boston, and, according to Mr. G. D. Bolton, 46° at the Allouez, while the survey obtained 43° in several observations on the Kearsarge. It is partly in virtue of this steepening in the dip that the Calumet curves toward the Albany and Boston as we have seen. But if this curvature is small, smaller than is due to the mere steepening of the dip, it shows a bending in the opposite direction of the whole formation, in which case the widening upon the surface between outcrops, also due to decreasing dip, would increase the curvature of beds to the east, while it would diminish it to the west, and at a point far enough off in this direction actually reversing it. This is what takes place. The Allouez conglomerate, as exposed at Calumet, notwithstanding the flattening dip and difference in height between the two, is exposed 120 feet *west* of the extended Allouez base. If, with a flattening dip, this bed has swerved from the line, with a steepening dip it would again approach it, and, with the thinning of the strata, at the Rhode Island could not be far from the Albany and Boston conglomerate. The Pewabic West conglomerate (No. 16) is too far west to be it, and between the latter and the Albany and Boston the explorations on the St. Mary's show that no conglomerate exists. It must either be the Albany and Boston, or have vanished. It is hardly possible that a dislocation of the strata could have affected this reasoning. The glacial, or pre-

ceding eroding agencies, which have so strongly modified the surface of this region, have selected those weak points formed by all known faults of any magnitude upon which to leave their deepest impress. No such surface evidence of any fault exists between Calumet and the Rhode Island.

2d. *Stratigraphical.*—*a.* Number of beds. It will be seen from the table that, considering the Albany and Boston the same as the Allouez, only four, out of fifteen conglomerates considered, are not found in both districts, and these would all pass, supposing them persistent beds, through regions as yet not uncovered from the "drift," unless it be the Calumet. This could easily escape notice on the south shore of Portage Lake under the covered portions of the Dacotah and Huron Properties;* but on the north shore of the lake, certain now-filled-up explorations on the Pewabic should have passed near it. The Survey has been unable to obtain any definite information of these, except that the deep "drift" upon the surface was not always penetrated, and the bed may have been thus not uncovered.

b. Thickening of beds. It is unfortunate that more exposures of the various beds are not known in Keweenaw County, in order that rates of thickening could here be obtained to compare with those of the Portage Lake District. Between Calumet and Kearsarge thickening continues, and also between the Central and the Delaware, though the latter is approximate. The rates of thickening, however, obtained in the Portage Lake District are singularly in harmony with those obtained by comparing Portage Lake distances with those north, and which are placed in the table between the Albany and Boston and Calumet properties. We have already referred to the widening in the zone 14–15 between the Albany and Boston and Central as being the same as that from the Albany and Boston southward, and also to the similarity of rates between 9 and 10. The rate [3–3] between Nos. 7 and 10 is small when the thickness between these beds is considered,—though larger than the rate that exists between these beds from the Huron to the Douglass (which may be obtained by taking the rate before derived [4.6] between 9 and 10 and deriving the distance 6–9 at the Huron, to

* Fragments of a conglomerate resembling the Calumet have been seen near the road following up the valley of "Huron Creek."

compare with (2,756) at the Douglass). The distance between 6 and 9 on the Kearsarge is probably also somewhat in error, being scaled from a small map made from measurements by Capt. Newcomb.

Though No. 12 has not been opened to the north, the narrowing zone between it and 11 still continues through. The absence of 12 makes it impossible to directly ascertain the amount of narrowing, but we may approximate to it. Regarding the zone 11–14, we may obtain the rate of widening in it in two ways: first, 14 not being exposed on the Kearsarge, we may calculate its distance from 15 by the rate [2.7] between the two. This gives (462) leaving (2,034) between 14 and 11, which may be compared with the distance between them at the Montezuma:—or, second, we may obtain the rate in the zone 11–15 between the Montezuma and the Kearsarge, and subtract the rate due to the zone 14–15 [2.7]. These two methods give [−1.6] and [−1.7] feet per thousand, respectively, as the rate of narrowing that has taken place between 14 and 11 from the Montezuma to the Kearsarge. This is made up of a widening between 12 and 14, and a narrowing between 11 and 12. At the Kearsarge the rate between 13 and 14 would be about [3.8]—[2.7] or [1.1], leaving [−2.7] between 11 and 14. Supposing the [3] between 12 and 14 to the south continues through, it would leave [1.9] for the zone 12–13 or [−4.6] for the zone 11-12, giving, as at the south, a very decided narrowing going on in this one belt. In the Eagle River District, the "slide" lying some sixty feet above the so-called "Ash-bed," has unmistakable patches of sandstone in it, and is the only bed corresponding with No. 17 in the Portage Lake District. It gives a rate of [7.2] between Eagle River and St. Mary's,—the rate from St. Mary's to the South Pewabic being [6.4]. No. 16 would be represented at Eagle River by two thin sandstone seams, giving a rate of [4.7] between 15 and 16 from St. Mary's to Eagle River. These seams widen to true sandstones at Copper Falls, six miles farther north-east.

It appears, then, that this particular apposition of the conglomerates, gives rates of widening from the Portage Lake District northward differing but very little from those obtained from actual measurements between known beds in that district,—so little, in fact, that it seems absolutely impossible that it could be owing to mere chance.

3. *Lithological.*—I am unprepared to enter into a detailed correlation of the lithological characters of individual beds, and can only speak of broader distinctions extending over wider areas. Among the conglomerates themselves too much similarity prevails on any one line across the formation to give any conclusive evidence. At Portage Lake, all are much alike. At Calumet, all have gained in addition to their components at Portage Lake, a greater or less per-cent. of pebbles, of grains of quartz in the pebbles. The representative of the "greenstone" series of Keweenaw County would be the "coarse-grained melaphyrs" occurring between the Albany and Boston and Pewabic west conglomerates in the Portage Lake District. In some beds of the latter, as for instance a belt exposed in a ravine just east of the Hancock Mine, hornblende crystals are abundant, and they closely resemble some of the upper strata of the greenstone series as exposed near Eagle River. There is a decided dissimilarity, however, between the beds lying immediately above conglomerate 15, in Sections II. and V. This can be no argument against the correlation, however, as the change has taken place before the space to be spanned is reached. At the Allouez mine, the lower greenstone beds have lost much of their character, while at the Kearsarge and at Calumet the beds just above No. 15 are more like the beds above it at the St. Mary's than at the Allouez. West of 16, however, the accordance in the general characters of the formations north and south is very striking.

The lithology of the formation lying at any distance south of the greenstone in Keweenaw County, is too little known to compare with equivalents in Houghton County.

Thus, three separate lines of evidence converge to establish the fact that the Albany and Boston and the Allouez conglomerates are one and the same bed.

1. Geographically, they are either identical or else one disappears toward the south, the other probably to the north.

2. Stratigraphically, 11 out of 15 conglomerates have equivalents in both regions, and in such a way that the rates of thickening observed in the Portage Lake District are so nearly reproduced as to render it most improbable that it can be due to chance.

If the alternative of reason 1 is accepted, but few beds would have equivalents, and there would be no general harmony in rates of thickening.

3. Lithologically, conditions, so far as known, are satisfied.

It will be observed, that under these circumstances, the "ash-bed" of Keweenaw County becomes the equivalent of the Hancock, or South Pewabic bed of Houghton County, a correlation that has been suggested by several, and arising, no doubt, from their general lithological resemblance. It is an exception to the general rule, however, of non-persistence of individual amygdaloid beds, and is not a proof of the general reliability of the correlation of individual beds based on individual lithological characters. The family resemblance, as it were, often existing between the beds of certain zones, while it may enable one to say that a distant bed belongs to the zone in question, renders it impossible for any one to prove, on mere lithological evidence, that it is the equivalent of any one certain bed of that zone. In its minerals and peculiar structure, as well as in the accompanying trap, the South Pewabic amygdaloid and the "ash-bed" are much alike. Yet these facts, judging from the interchange of characters sometimes occurring between neighboring beds in other parts of the range, as well as the thinning out of beds and replacement by others, would not prove them to be identical; a fact, the probability of which is made much greater by their occupying the same horizon beneath the same conglomerate.

The Pewabic Lode, which, judged by lithological characters, has been found by different persons at such a variety of points in Keweenaw County, probably does not pass far beyond the Kearsarge; while the bed on which the Concord and Douglass mines are situated, is some distance east of either the Isle Royale or Grand Portage beds. The amygdaloid over conglomerate 9 on the Kearsarge, which is opened on the Huel Vivien, and which is thought by some to resemble the Douglass or Isle Royale bed, must be some 3,000 feet west of them.

The Calumet conglomerate furnishes an instance of a bed, of which there is perhaps a more general desire in the Copper region to trace than any other bed. While, as will appear in the sequel, there is reason to suppose that it is persistent, there is a possibility that it may continue as a mere seam, and no reason to suppose that it should carry with it the remarkable richness which it has at the Calumet and Hecla mines. The short distance which it has been traced renders prediction as to its place probably more uncertain than of almost any other bed. The only two measurements to it are near together, so that any error in either would strongly affect the rate of widening, and there are no minor facts which can serve to indicate in which way the rate may err. However, its place upon various properties has been calculated, with such data as the table gives, with the following results, which are probably correct within 50 to 150 feet, either one way or the other, depending on the distance of the point from Calumet.

At South Pewabic, 1,390 feet east of conglomerate No. 15 (Albany and Boston) or 3,070 feet (about) east of the South Pewabic amygdaloid.

Huron and Montezuma, between 750 and 850 feet west of No. 12.

On the Huron, 12 is exposed near the Slaughter House, and is the third conglomerate west of Huron Finishing Mills.

On the Montezuma, 12 is exposed on the Lake Side Road, west of Houghton. (See map.)

Pewabic, 1,500 feet east of the Albany and Boston conglomerate.
Mesnard, 1,560 " " " "
St. Mary's, 1,590 " " " "
Albany and Boston, 1,640 " " " "

Phoenix Mine, 3,290 (about) south of the "slide" under the "greenstone."

Central (dip 26?) 2,245 (about) south of second conglomerate south of the greenstone.

These are approximately the horizontal distances between the beds, and, with a flat dip and much difference in height, should be amended accordingly.

General Conclusions.—There are certain general conclusions which result from the facts presented in the table, and which may be of interest, concerning the original structure of the range. The very uniform thinning of the zones included between the conglomerates toward the south-west, excepting always the zone 11–12, shows that when first laid down in a nearly horizontal position, whatever may have been their mode of origin, the *source* from which the material forming them came, was toward the north-east. I believe that near the extremity of Keweenaw Point the formation is said to be again thinning. If so, it would place this source somewhere abreast of the centre of the Point, and probably to the south or south-east, rather than north of it.

The conglomerates do not seem subject to the general thinning toward the south characteristic of the intermediate beds. In fact, their thickness seems to follow no well-defined law, but to be wholly irregular, some seeming to thin or thicken in one direction as well as another. This fact, together with a pretty general uniform coarseness, would seem to show that the direction of the source from which they were derived was different from that of the melaphyrs, and that the source must have been a shore line not far from parallel to what is now Keweenaw Point. Upon this shore, opposite and north of Calumet, a quartz-porphyry must have predominated among the rocks, and which did not exist further south. This shore line, however, was variable. Conglomerate 9, on the Pewabic, is of the normal Portage Lake type, while at the Kearsarge it is 50 feet wide, and is composed of two parts, a lower of dark gray, more or less fine shaly sandstone, some layers approaching slate in character, an upper of a red, exceedingly fine arenaceous non-shaly sandstone. This portion of the bed must have been further from the shore than that near Portage Lake. The reverse takes place in the first broad conglomerate skirting the north-west border of the range—a heavy conglomerate all along the upper point, near Portage Lake it is composed of sandstones and fine arenaceous shales, which must have been a deep-water deposit compared with the conglomerate.

The conglomerate beds of Keweenaw Point have been generally considered as mere local deposits, rapidly fading out in either direction. The table would seem to show, on the contrary, that for conglomerates they are unusually persistent, and that while a bed may thin out and lose its character as a conglomerate, it may still exist even as a mere seam. Thus the Allouez conglomerate has a thickness of from 15 to 20 feet at the Central and Allouez mines, while near the Phœnix mine, between them, it does not appear, being replaced by what is locally known as the "slide," a layer of soft red clay 2 to 6 inches thick. We gather from those facts that when the beds composing the trappean range were being originally formed, the agencies, whatever they were, which formed what are now the melaphyrs, ceased to act not only over limited but over extended areas, in once instance at least over fifty (50)

Table : Giv[illegible]

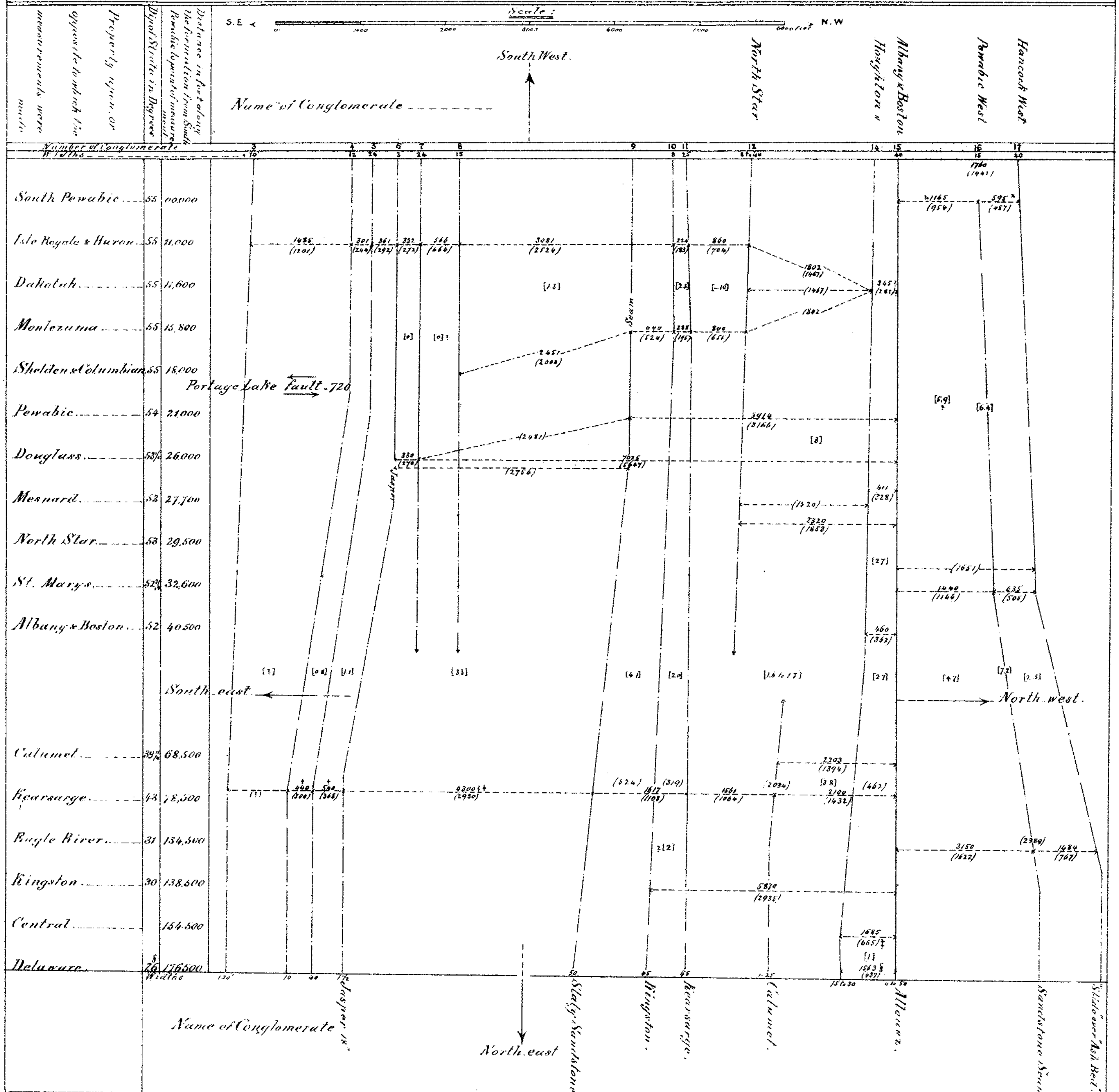
Property upon, or opposite to which the measurements were made	Dip of Strata in Degrees
Number of Conglomer[illegible]	
Widths	
South Pewabic	55
Isle Royale & Huron	55
Dakotah	55
Montezuma	55
Shelden & Columbian	55
Pewabic	54
Douglass	53½
Mesnard	53
North Star	53
St. Marys	52¾
Albany & Boston	52
Calumet	39½
Kearsarge	43
Eagle River	31
Kingston	30
Central	
Delaware	26

× Measurement by

‡ Scaled

Table: Giving the horizontal and perpendicular distances between the foot-walls of various beds of Conglomerates in Houghton and Keweenaw Counties, the rates of thickening of the included beds, and the correlation of the formations of the two Counties.

A. R. Marvine.



× Measurement by Mr. A. B. Wood, not reduced to horizontal and too large.

* Scaled from an approximate map, by Capt. Newcomb.

‡ Scaled from the large working map of the Central Mine.

§ Scaled from a small map of the Delaware Mine - approximate.

‖ The hanging wall of conglomerate No. 14 has been taken, as its foot-wall was not observed.

miles, and for periods of time long enough to allow of the accumulation of beds of conglomerate from a few to over 75 feet—in one instance over half a mile—in thickness.

In the Portage Lake District, commencing upon the eastern limit, so far as known of the range, the trappean zones have considerable thickness, which are separated by three beds of conglomerate about 50 feet thick. Then follows a zone of about 1,300 feet thick, in which there are five conglomerates from 2 to 20 feet thick. Twenty-five hundred feet of melaphyrs and amygdaloids then follow, with no known conglomerate, and then, for 5,000 feet in thickness, nine conglomerates from 200 to 1,000 feet apart, and from almost 0 to 30 feet thick occur. West of these, conglomerates and sandstones frequently occur, in aggregate thickness probably equalling that of the interstratified melaphyrs, until the wide conglomerate (slates and sandstones) is reached.

Fault in Portage Lake: Section II. stands in the relation to Section I. that it would have, supposing the Albany and Boston conglomerate were accurately projected from the Pewabic mine, with the line of strike it then has, until it intersected Section I., and then plotted off from the point so obtained, and moved down into its present position. If the Albany and Boston conglomerate were exposed upon the south shore, there would be shown a fault in this conglomerate of about 710 feet horizontal. Applying corrections for widening to the apparent faults in other conglomerates, gives from 705 to 720 feet, excepting the extreme east and west ones, which give nearly 740 feet. The discrepancies are due to the bending of the formation in crossing the lake, a source of error not easily eliminated. The numbers serve to show, however, that the actual amount of faulting is probably not far from 720 feet, the north shore having been raised or the south shore depressed, giving the effect of the north shore having been moved westward upon the southern one. If the fact that the north shore is generally over a hundred feet higher than the south shore is not wholly due to erosion, it may be in part due to this fault. The dislocation is probably made up of many lines of fracture, as several pass through the Hancock property.