brown colored melaphyre. Several masses of copper were found in the felsite, which at the contact is very much altered and contains abundant calcite.

Near the bottom of a second mass of felsite the shaft went through 30 feet of green stained felsite said to assay 22 pounds copper to the ton in the form of carbonate of copper. The carbonate, with some silicate, occurs as minute veinlets and patches in the dense felsite.

ISLE ROYALE LODE.

General character.—The Isle Royale lode is an amygdaloid worked extensively at the Isle Royale mine. What is supposed to be a con-

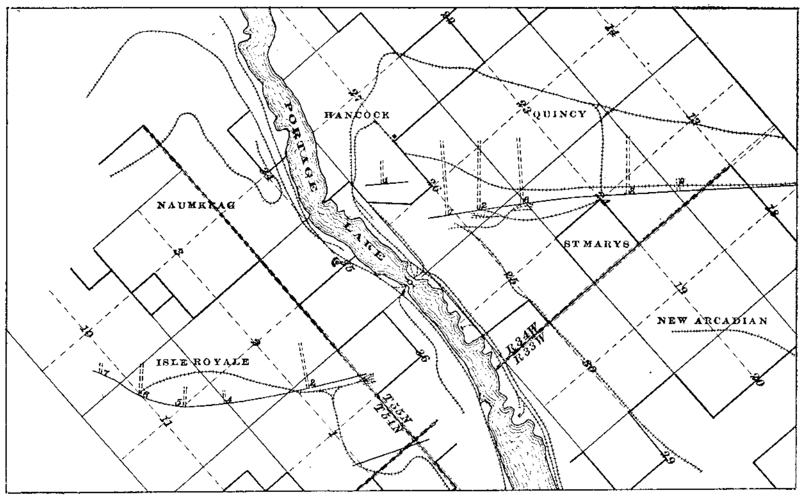


Figure 11. Map showing mines on Isle Royale and Quincy lodes.

tinuation of the lode was unsuccessfully opened up at several points by the Arcadian Mining Company north of Portage Lake. Further south the Winona is, in Dr. Lane's opinion, on the same lode.

At the Isle Royale mine the lode has commonly a gray, greenish or brownish ground mass which is rather distinctly though finely grained. In this are scattered amygdules composed of many species of minerals. Common among these are calcite, quartz, epidote, chlorite, prehnite and laumonite. Cracks in the rock have in most cases been filled with chlorite, laumonite or thompsonite. Much of the ore is spotted green with chlorite and epidote. The rock is fairly hard, but not so hard as the Kearsarge.

The rock has the composition of an olivine diabase. It is somewhat

mottled like the ophites, but contains a rather high percentage of feldspar. Dr. Lane calls it feldspathic-ophite.

The ore thus far mined is low grade, but better results are being obtained now than in former years and the copper is being extracted at a good profit. For the years 1908 to 1911, the yield was 13.8, 14.3, 14.5, 16.5 pounds refined copper per ton. It was estimated in 1911 that the mine would produce 435,600,000 pounds of copper from ore averaging 14 pounds per ton. Mr. J. R. Finlay, for the State Tax Commission in 1911 estimated that it would produce 112,000,000 pounds copper from above the 4,000 foot level.

At the northern end of the Isle Royale property the lode strikes S. 38° W. and dips to the N. W. at an angle of 58°. Towards the south the lode curves westward to S. 58° W. Above the lode there is a similar deposit known as the Grand Portage. This has been mined for short distances at the old workings and is now being opened up again by crosscuts from the main workings. Where recently opened up at a point 700 feet north of No. 2 shaft at the 29th level the Grand Portage was cut at a distance of 125 feet from the Isle Royale lode. It proved to be 62 feet wide with good ore on hanging and foot sides separated by lean ground.

In the Isle Royale the copper is more irregularly distributed than in most of the other productive lodes, occurring in patches of various shapes separated by lean or barren ground. The lode is therefore commonly referred to as "bunchy."

T. Macfarlane's description.—Thos. Macfarlance in 1866 said of the Grand Portage lode. "About 260 feet west of the 'Isle Royale vein' occurs the bed upon which the Grand Portage mine is situated. The color of the matrix is light green, thus differing greatly from the beds hitherto described (Pewabic and South Pewabic). It has an uneven earthy fracture, and is uncrystalline, with small white spots here and there through it. It is fusible and gives water when heated in a glass tube. The amygdules are all of a dark green color, and frequently consist exclusively of delessite. Quite as frequently, however, they consist of that mineral with a kernal of quartz, or much more rarely, of calcspar. The copper is found oftener in the amygdules than in the matrix. As in other beds, larger aggregations of crystalline minerals occur, in which quartz generally preponderates, associated with calcspar, prehnite and native copper. Specks of native silver sometimes occur in this veinstone. The strike of the bed is N. 40° E. and the dip 52° north-westward."

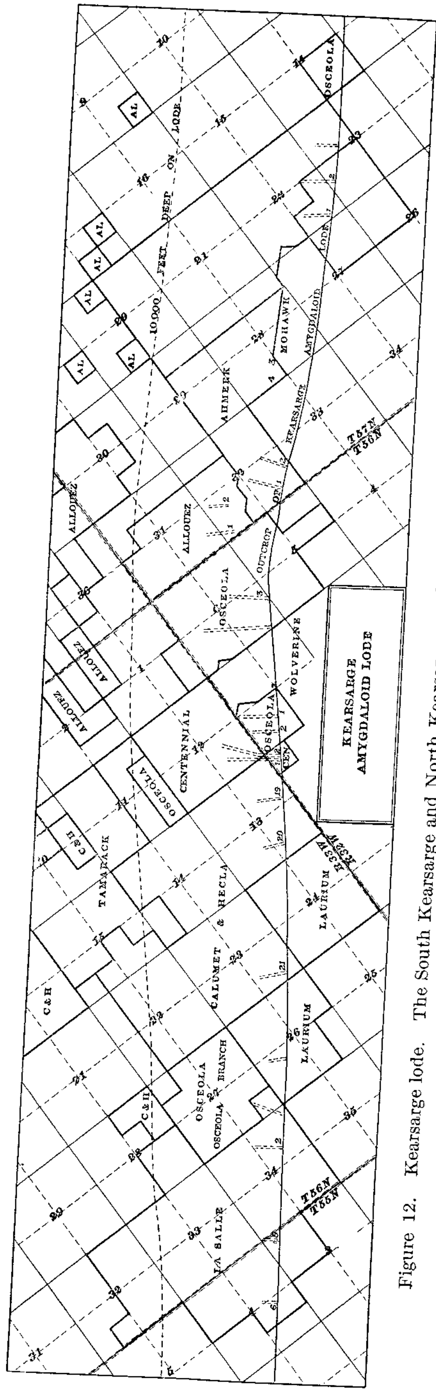


Figure 12. Kearsarge lode. The South Kearsarge and North Kearsarge are the Osceola properties on either side of the Wolverine.

KEARSARGE LODE.

General character.—The Kearsarge lode is the copper-bearing amygdaloidal upper portion of a bed of porphyritic melaphyre. Near the lode the bed is commonly a dark gray or brownish rock with large phenocrysts of feldspar, usually labradorite. This rock is commonly called by Dr. Lane and others, a labradorite porphyrite. Its porphyritic character is very pronounced wherever the lode has been opened, and it has served as a good horizon marker. The lower part of the bed shows numerous porphyritic crystals in a ground mass which has an ordinary ophite texture.

The lode itself is commonly a brownish amygdaloid showing numerous and large amygdules of calcite, quartz, red feldspar and green epidote in a dull, dense and fairly soft ground mass. In places the lode is greenish in color, containing much epidote and quartz, and is then quite hard. Some copper occurs in amygdules and may be a simple filling, but most of it is in irregular forms and has evidently replaced the rock.

As mined, the Kearsarge appears to be a remarkably uniform lode about 10 to 14 feet thick. The openings however, often give an incorrect idea of the distribution of the copper, as it is by no means so regular as the stope maps indicate. Compared with some of the other lodes, the Kearsarge is a very uniform bed and has, on some properties, been mined continuously for practically the same thickness from level to level. It is none the less true, however, that the lode varies considerably in thickness and the regularity of opening frequently indicates simply that the ore has not been always followed as closely as it might have been. In some places the openings are in barren rock and in others the full thickness of ore has not been broken. There are many and often very good reasons for this method of mining. It is mentioned here in order to call attention to the fact that the copper is much more irregularly distributed than some of the mine openings indicate. During the year 1912 at the South Kearsarge mine about 300,000 tons of ore was mined from deposits in the footwall and the company's president says in his report—"This rock (ore) consisted in part of vein matter which extended back into the footwall, and in part of foot trap which was found to contain copper. This rock can be mined cheaply, and it is hoped that a large part of the old stopes can be worked over in this way." It is not thought that all the mines on the lode have left as much ore in the foot as has the South Kearsarge, but it is frequently found in cleaning stopes of all broken ore that much copper has been left in irregular deposits in the foot. When this is broken out the Kearsarge will probably be found to more closely resemble the other amygdaloid lodes, though still by far the most regular and continuous amygdaloid.

Extent of lode.—The Kearsarge lode has been traced by mining operations, test pits and drill holes for a remarkable length. Dr. Lane says* of its character:

"For the 32 miles that the Kearsarge lode has been followed the large phenocrysts persist, sharply distinct from the ground mass and from each other, but very little agglomerated, * * * The porphyritic trap which is the foot of the Kearsarge lode is an ophite, but the mottling does not show close to the margin. * * * It is in some places one heavy bed 100 to over 200 feet thick. On top of this will be the well marked cupriferious amygdaloid which is the Kearsarge lode and then there will be no difficulty in identification. But this is not everywhere so. In places it will be broken up into successive gushes, each with its own amygdaloid and decrease of grain due to cooling. Besides this there may be irregular streaks of amydgaloid in the bottom of the trap. * * * At the Cliff mine the distance from the Kearsarge to the Wolverine sandstone was about 90 feet and the Kearsarge foot was thick and characteristic." At the Ojibway according to Dr. L. L. Hubbard, the trap is about 35 feet thick.

Dr. Lane states that the Kearsarge lode is clearly identifiable at the Mandan and well defined in the Manitou. It has been located at the Central and Miskwabik properties. It is being explored at the Ojibway and has been opened at the Gratiot and Seneca. It is being extensively mined at the Mohawk, Allouez, Ahmeek, North Kearsarge, Wolverine, South Kearsarge and Centennial mines. It is being opened up at one shaft on Calumet and Hecla and at one shaft on the Laurium property. At the La Salle two shafts have recently been put in shape for production. On the southern part of the La Salle property, according to Dr. Lane the Kearsarge shows a number of amygdaloids which are presumably overlapping gushes of the one flow. Dr. Hubbard, from observations at the Ojibway, believes that there was a marked geological internal between the foot-trap and later flows, although they are of similar character. Of its southern extension Dr. Lane says:† "The Kearsarge lode is, I think, also identifiable in the Rhode Island, Franklin and Arcadian sections. Beyond to the south I have not yet been able to identify it, which is the more strange since it is of good thickness at the Arcadian and it ought to be exposed somewhere between Houghton and Hurontown where I have made careful search at its horizon without identifying the peculiar and characteristic trap, though exposures are frequent."

*Michigan Geological Survey, 1909, pp. 314-315, Pub. 6.
†Pub. 6, Michigan Geological Survey, 1909, p. 327.

Distribution of copper.—To some extent the copper in the Kearsarge is distributed in courses or shoots, but the richer parts are as a rule of very irregular shape and better, though poorly, described as patches. Within these patches the copper is scattered in numerous smaller patches and streaks more or less separated by barren or low grade rock. Frequently the whole face of a stope shows no ore, but the rock is all broken to expose the ore beyond. At the Wolverine, which is a small property located on one of the richest portions of the Kearsarge lode, some of the stopes which were abandoned on account of the very poor showing on the face have been subsequently reopened and good ore found suddenly after cutting through a few feet of barren ground. It is frequently noticed that the ore contains more water than does the barren rock and in the openings it is regarded as a good sign when the face is wet. It is common experience to break into good ore close to such a face. Captain Pollard stated that in poor ground a wet drift has proven a good indication of good ore above the drift.

Parallel lodes.—Above and below the Kearsarge, there are other amygdaloids which carry some copper. These have been opened in a few cases by crosscuts from the main lode and have yielded a little copper but have, as a rule, not yet proven rich enough to pay for mining.

Masses.—The Kearsarge lode has yielded considerable mass copper, but the masses are not commonly over a few tons in weight. At the Wolverine, according to Captain Pollard, masses of two or three tons have been not infrequently mined, but none are met with so large as to require cutting. At the Mohawk and Ahmeek, as already stated, considerably larger masses have been encountered and cut up, but most of these were from fissure veins crossing the lode and not from the lode proper.

Two Lodes at North Kearsarge.—From the early reports it appears that in places at the North Kearsarge mine there are two lodes and numerous displacements were encountered.

Supt. John Daniell in his report on the operations at North Kearsarge mine in 1887 says:

"Development has shown that overlying the lode on which we commenced operations and usually distant 30 to 40 feet from it, there is another bed of amygdaloid from three to four feet wide, occasionally wider. This last runs in nearly a straight course, while the main lode, very irregular in size, takes a very circuitous course, sometimes approaching the west lode very closely, and again leaving a well-defined trap between. At more than one point we have found in cross-cutting from one bed to the other, that the intervening material is wholly

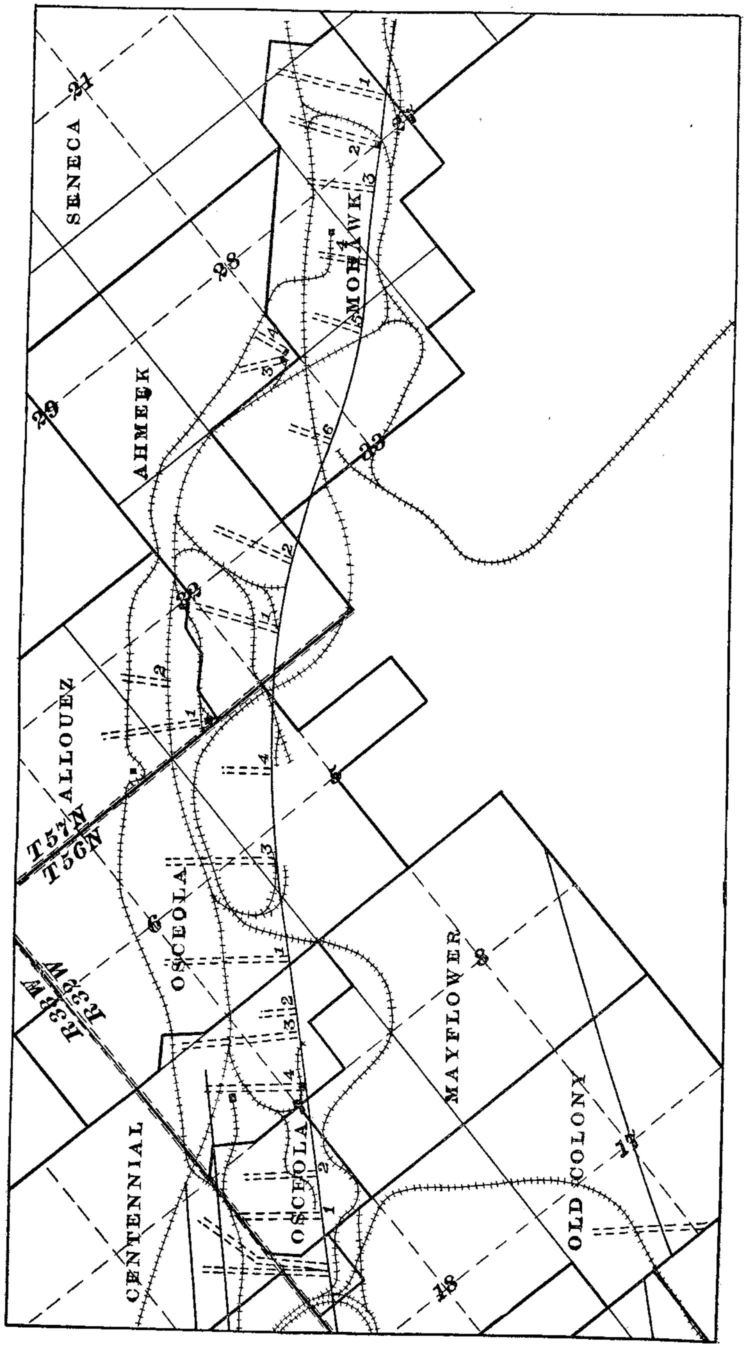


Figure 13. Map showing location of chief producing mines on Kearsarge lode.

amygdaloid, leading to the inference that both should be taken as one lode. At 5th level, No. 1 shaft, this is especially the case, but I cannot say that I am settled in opinion as to its correctness. Should this prove to be so, our chances of finding heavy deposits of copper in depth would be good. We look to early developments at 6th level to throw light on the question."

Supt. John Daniell says* further in his 1888 report:

"From all we see during the past year there is no doubt but that the two amygdaloids referred to in last report are separate lodes, each continuing its course. The eastern one, on which most of our work is done, continues as irregular in course in the deeper levels as was before noted. The number of crossings and faults that we encounter, which invariably throw the lode, are in excess of anything seen in the district, and have much to do with the disturbed character of the ground we meet with. The influence of some of these should grow less as we get deeper."

Dr. Hubbard has observed that at the Ojibway mine there are two lodes, very much as above described; but with a probable modification as described in his paper before the L. S. Mining Institute, Houghton, 1912.

C. Rominger's description.—C. Rominger says† of the lode where it was opened at the Wolverine mine:

"This belt is unusually rich in copper. It is a dark purplish brown rock, with dull earthy fracture, harder or softer, much shattered into fragments, which are recemented into seams of calcspar and of orthoclase in association with quartz, epidote and delessite. The amygdules are filled with laumonite, epidote, delessite and calcspar, usually several of them associated; in some parts of the rock the amygdules consist nearly all of a dark green amorphous serpentine-like mineral. Much of the amygdaloidal belt is transformed into a light green porous epidote rock, which principally carries the copper in ponderous hackly masses, so called barrel-copper. Near the surface the copper is much oxidized, coated over with red oxide, malachite and axurite. The same amygdaloid belt is laid open by numerous test-pits in the adjoining Kearsarge property.

"The foot-wall of the amygdaloid is a coarsely crystalline, dark colored diabase belt, about 100 feet wide."

In 1911 Mr. J. R. Finlay estimated the future production of the five leading mines on the Kearsarge lode would be 63,600,000 tons ore containing 986,000,000 pounds copper.

*Rep. Con. Min. Stat. Mich., 1888, p. 74.
†Vol. V, p. 118, Geol. Sur. Mich.

LAKE LODE.

General character.—The Lake lode is a wide amygdaloid opened at the Lake mine in Ontonagon County. Where first found and developed it has a strike of nearly due north, but subsequent development has proved that it curves to the west and near the South Lake boundary it strikes almost due west. Diamond drill holes on the latter property indicate that it there also strikes westerly and dips to the south.

At the No. 1 shaft of the Lake mine the lode dips to the west at an angle of about 34°. The South Lake drill cores, as interpreted by Dr. Hubbard, indicate the dip there to be southward at an angle of about 55°.

The general strike of beds in the properties further west is northeast and the dip northwest. It is probable that the discordance in structure has been partly brought about by extensive faulting along a zone traversing the South Lake property. One of the drill holes traversed broken ground here and this is possibly the location of a fault, or more likely a series of faults

The lode is a brown amygdaloid spotted with amygdules of chlorite, calcite and other minerals. The ground mass is poorly crystalline, but deeper in the bed the rock has the characters typical of ophites. The mottling is fairly distinct on the footwall, which is an ophite spotted with dark green chlorite giving it a pseudo-amygdaloidal character.

The copper is irregularly distributed along the lode, rich and wide portions alternating with stretches of poor ground. Some of the richer portions have been cut out for a width of 40 to 60 feet and should yield much good ore. The value of the lower grade portions is not yet very definitely known as the amount of stoping is as yet inconsiderable.

East lode.—About 100 feet east of the Lake lode there is another copper bearing amygdaloid known as the East lode. This is narrow, often only four or five feet thick, but is in places rich and occasionally there is a thickness of 10 feet of good ore. It is commonly greenish in color, partly from epidote but chiefly from abundance of a dull earthy green substance or green earth, and chlorite. The east lode follows the curves of the main lode, thus indicating that the structure as shown by the mine openings holds for a considerable thickness.

The Lake lode is fairly easily treated. It is soft and yields copper of good quality.

MASS MINE LODES.

At the Mass mine there are four parallel lodes a short distance apart which have been worked at various times. These are, in ascending order the Evergreen, Ogima, Butler and Knowlton. The Butler

has recently been extensively opened and is the chief producer. The Evergreen ranks second as a producer. The Ogima and Knowlton are not being worked at present.

The Evergreen lode is a greenish amygdaloid which contains copper in irregularly distributed deposits. The ore is often rich and masses are common in the lode, but as a rule there is much barren rock between the good portions. Continuous stopes of any considerable size are uncommon. It has yielded much copper, but mostly from "bunches" or "pockets."

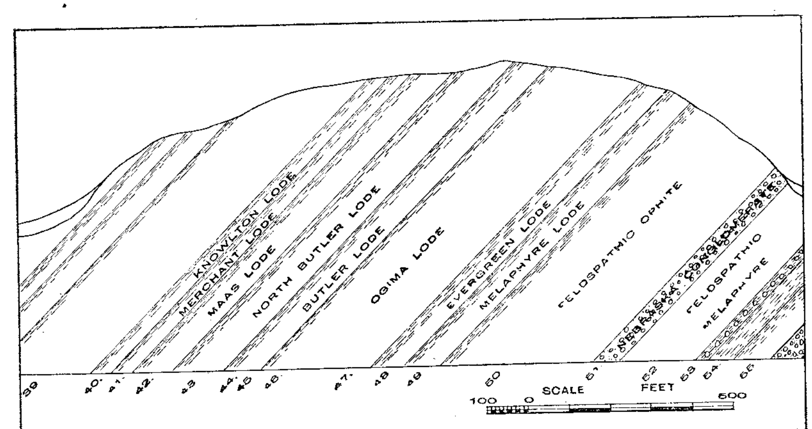


Figure 14. Cross section showing relationship of Butler, Mass, Ogima and Evergreen lodes at Mass mine (after Lane).

The Butler lode is an amygdaloid of peculiar reddish color, having abundant crystals of red feldspar, along with the more common minerals in the amygdules. The lode has been traced and opened up at intervals for several miles in Ontonagon County. It was mined by several of the old companies; but at present only at the Mass mine. The Butler is a wide bed containing ore at several horizons. At the Mass mine the bed is almost 350 feet wide with ore on the foot and hanging and in some places near the middle. The foot-wall lode is the main ore body and is known as the "Butler Vein." It averages about 10 feet but widens out in places to 30 feet. Frequently ore is followed up in irregular deposits in the hanging and in parts of the mine there are branches which have been followed and found to connect again with the main lode at some distance along the level or up in the stope. In other cases ore makes down into the foot and gives copper ground continuously down into the Ogima lode. Where the two lodes are close together, wide deposits of good ore have been mined, the copper continuing from one lode to the other. In some cases in following copper

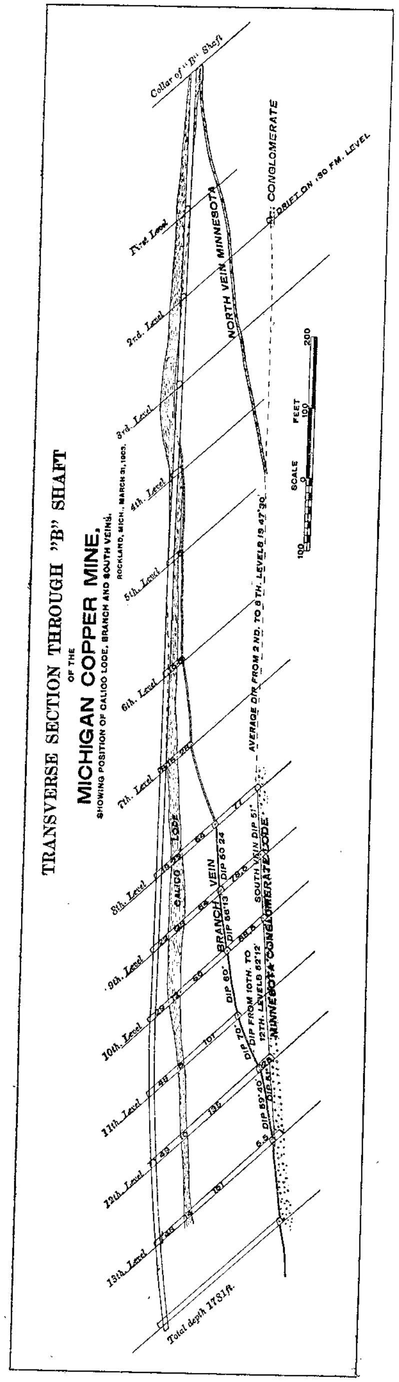


Figure 15.

without reference to character of the lode the miners have run in continuous good ore from the Butler into the Ogima lode.

The Ogima lode is comparatively dense and shows only occasional amygdules and is frequently referred to as a "trap" lode. It is a fine grained gray melaphyre spotted with epidote and chlorite. The copper occurs commonly in small grains or "shots" and masses are rarely found. Much of the lode seems dense and poor, but in places it is well mineralized and may in the future be profitably worked.

The Knowlton lode is a reddish amygdaloid resembling the Butler. Some large stopes were made in it years ago, but it is at present not a productive lode.

MICHIGAN MINE LODES.

At the Michigan mine several lodes have been worked. The chief producer was the Minesota vein elsewhere described but ore has also been taken from other veins and amygdaloids in its vicinity. The Branch and Contact veins and the Calico, North and South amygdaloids have contributed to the output. Some exploratory work has also been done on the Evergreen series of lodes now being worked further east at the Mass mine.

At the Michigan there has evidently been much fissuring. The main line of fracturing was along the bedding planes instead of across them as in Keweenaw County. From these main fissures, others of minor importance cut across the formation and in the mine these cross fissures were often found to contain ore. Some account of these is given under the heading Minesota lode.

MINESOTA LODE.

General character.—The Minesota lode is a vein rather than a bed. It strikes with the formation in which it occurs, but dips somewhat steeper and so gradually changes in horizon. The vein material is of greenish color, being chiefly made up of epidote, quartz and calcite. Copper occurs more largely in masses than it does in most of the lodes. Comparatively little of the copper produced was from stamp rock. The lode has been pretty well worked out and abandoned by the mining companies. For the past few years tributors have been doing some mining in the upper levels at the Michigan mine, especially on what is known as the Branch vein.

The first workings were on what is known as the "Minesota" vein which lies immediately above a bed of conglomerate known as the "Minesota conglomerate." From this the "Branch vein" diverges at a small angle cutting the upper beds, including an amygdaloid known as the Calico lode. Owing to the slight divergence between the vein and the Calico amygdaloid, the latter was the wall rock for a considerable distance and much of it was well mineralized and was profitably worked.

C. L. Lawton's description.—Chas. L. Lawton describing the deposit worked at the National mine says:*

"The old mine is in a vein of contact that outcrops along the side of the southerly slope of the bluff, and which is contained between an underlying conglomerate and the overlying trap; the gangue of this vein is chiefly quartz, calc-spar and epidote, and has afforded, in times past, many fine specimens of all these minerals. It is usually known as the conglomerate vein, and sometimes it is incorrectly supposed that the conglomerate yielded the copper; but the copper was invariably

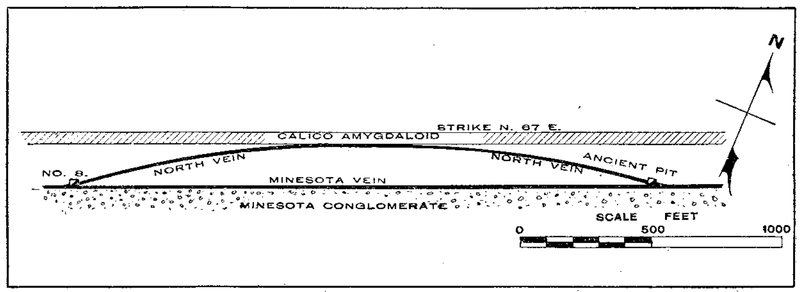


Figure 16. Ground plan sketch showing the relative position of Minesota conglomerate, Minesota vein, north vein of Minesota, and the calico amygdaloid.

the product of the vein. Sometimes the vein matter penetrated into the conglomerate, and masses of copper were obtained in such places; but not otherwise was copper found in the conglomerate. A prominent feature of the old mine was what was called the counter vein, a branch of the main vein, which extended diagonally, northwesterly, across the formation to intersect an amygdaloid belt that is situated 140 feet north of the conglomerate and runs parallel with it. This counter vein was also productive in copper, and especially so along its lines of intersection with the main vein and with the amygdaloid. In the vicinity of these lines of intersection, in the upper levels, were found the richest portions of the mine."

In another report Mr. Lawton gives further description of the lode as opened at the National and Minesota mines. He says:†

"The belts embraced within the limits of the workings of these mines are first, sandstone 40 feet wide; overlying this is a bed of conglomerate 30 or 40 feet wide, and upon this is a belt of trap 140 feet in width; but below the conglomerate and this trap is a belt of vein matter

*Report Com. Min. Stat., 1888, p. 20.
†Report Com. Min. Stat. Mich., 1885, p. 201.

—generally assumed to be a contact vein—having a variable width of from perhaps six feet to 15 feet wide. Overlying the trap is a belt of amygdaloid varying also from six feet to upwards in width, sometimes also making out into large pockets; this was called the north vein and was never much worked, as it is a stamp lode, though affording some mass copper and barrel work. So far as opened by the old company in former years it afforded some rich ground, about three feet wide along the foot wall, and thence to the hanging it was lean. Some of this foot wall part of the lode was very rich; 300 tons of it were stamped which yielded three per cent copper; a larger portion, which included the body of the lode, yielded a little under two per cent; these facts I got from Capt. Chynoweth who was an officer of the National at the mine for 25 years.

"Running through the trap from the conglomerate to the north vein are frequent fissures and in these and in their vicinity in the main vein the bulk of the copper was found. Especially was this true of a diagonal fissure that extends through the trap to the amygdaloid west of No. 2 shaft. This was found to be very rich in copper in all the levels; as it dips at a less angle than the formation it tends to intersect the conglomerate vein and in this line of intersection, it is probable, much copper may be found; the work now is towards reaching this result. This fissure was first found by a crosscut, at right angles to the formation, and was thought to be an independent vein, but upon following it in both directions it intersected the main lodes; other fissures, of less importance, also yielded copper in considerable quantity. The conglomerate does not hold any copper; masses of copper were sometimes found in the conglomerate where an opening or fissure in the conglomerate had become filled with vein matter. One of these openings extended through the conglomerate to the sandstone and was very productive in copper, in fact was almost completely filled with pure metal. It was in a fissure in the conglomerate that a 500-ton mass of pure copper was found in 1857, probably the largest native mass of copper ever discovered."

"The property (Minesota) is crossed by the same belts heretofore described and the formation is the same as in the National. Seventy per cent of the product of the Minesota mine was mass copper, the remainder, small pieces—'barrel work,' with a very few per cent of stamp copper.

"It was a wonderful deposit. Sometimes the only work was to cut up the masses of pure metal and hoist them to the surface. In places the stopes were nearly all copper.

"The map of the mine in Report Com. Min. Stat. Mich., 1885, p.

206 shows only the workings on the south vein—the conglomerate vein—as in the National; but lying north of this, between it and the amygdaloid, was a fissure vein running also east and west, but finally terminating in a cross-fissure to the west and intersecting the conglomerate vein to the east. In this longitudinal fissure the mine was first opened and worked before the fact of the existence of the other lodes had been ascertained. The National Company began on the conglomerate vein, and when they found that they were not working in the same vein as the Minesota people, they cross-cutted to find it, and came into a diagonal vein, as previously described. This middle vein in the Minesota mine lies north of the blank space shown on the section of the mine between No. 4 and No. 10 shafts. It dipped at a less angle than the conglomerate vein, and finally intersected it in the line indicated as the margin of the blank space on the map. Along this line of intersection of the conglomerate and the middle vein was the most productive ground found in the mine."

G. D. Emmerson's report.—The character of the ore mined is indicated by the description of Mr. Geo. D. Emmerson of conditions at the property in 1857. He says:*

"It was against the established rule that a vein could lie between two kinds of rock so dissimilar as trap and conglomerate." * * * "But they are finding immense masses of copper in the conglomerate under the vein. A few days ago this was showing in the most marked manner in several points. In the 20 fathom level, east of No. 5 shaft, in the south lode, the regular sheet of copper had been taken from the foot wall, and the yield at this point had been very great. The masses were from 12 to 18 inches thick. Strings of copper were cut off that seemed to branch into the conglomerate. These were followed and led immediately to very large masses, some of which were of the thickest copper ever before taken from the mine. One piece which was cut off presented a face of bright copper cut by the chisel three feet and nine inches in thickness. It was so thick that it could not be handled in the mine without again dividing longitudinally, or splitting. Thus the mass showed two flat surfaces, at right angles with each other, of bright copper cut by the chisel. This point in the mine has been extremely productive. Some 200 tons of large masses have been taken out of the conglomerate under the lode, besides the enormous yield of the vein itself overlying it. In one place the copper extended into the conglomerate as far as 16 feet south of the foot wall.

"An occurrence of copper in all respects similar is found to the west of No. 5 under the adit level. Besides the masses in the regular vein, which was also extremely rich at this point, they had taken only 40 or 50 tons out of the conglomerate, the foot wall was perfect as in the other case, and strings leading into the conglomerate were quite small, and very slightly attached. But by trifling labor they uncovered a series of masses going up and down, with an eastward indication, for the height of 70 or 80 feet and going out of sight both above and below. It was at once apparent that they had something very valuable, but they had no conception of the immense thing which a few days' work disclosed. At one convenient point they broke away behind the copper so as to get in a sand blast of five or six kegs of powder. They stripped the mass further and again fired without result. Again they fired nine kegs of powder and the mass remained unmoved. Bucking the rock around for a considerable distance 18 kegs of powder were shot off without effect, and again, 22 kegs, and the copper entirely undisturbed at any point. After further clearing, 25 kegs were shot off under the copper, and it was thought with some effect. But a final blast of 30 kegs, or 750 pounds, was securely tamped beneath the mass and fired. As soon as the smoke cleared away, a mass of copper 45 feet long and three to five feet in thickness, apparently very pure and which will probably weigh 300 tons had been shot out and was ready for cutting up. The blast had torn the immense body from its bed without exhibiting a sign of breaking or bending in any place, so great was its thickness and strength. It was torn off from other masses which still remain in the solid rock. About 100 feet to the east from this is another large mass which several parties are exposing, and from present appearances, it may exceed in size the last named one. These are near the point of the great counter lode from which 300 to 400 tons of copper have been taken; and the ground in the vicinity has unquestionably yielded the greatest amount of mineral ever taken from the earth in the same space. Its occurrence has been in three distinct forms: 1. In the counter lode; 2, in the regular vein; and 3, in the conglomerate rock under the vein.

"At No. 2 shaft they are sinking below the 60 fathom level, and are experiencing great difficulty in getting through the copper which they encounter. It was feared that they would be compelled to turn the shaft entirely out of the vein to enable them to sink. There are 1,000 tons of copper in sight—much of it ready for cutting."

Large masses.—A further extract, dated March 7, 1857, says: "There is now in the Minesota mine, between the adit and the 10-fathom level, a single detached mass of apparently pure metallic copper, which is some 45 feet in length, and in the thickest part as much as eight or nine feet in thickness. It contains probably more than 500 tons of pure metal, and is worth, as it lies, more than $150,000."

Mr. Wright further describes this mass as follows:

*Report of C. E. Wright, Com. Min. Statistics, Mich., 1880, pp. 75-76.

"This is believed to have been the largest complete mass of native copper ever discovered. The exact weight was not ascertained, but enough of it was weighed to ascertain that the total would not fall short of 500 tons. Its greatest length was 46 feet, and its greatest breadth, 18½ feet; greatest thickness, 8½ feet. The main width was 12½ feet, and the main thickness four feet. It took 20 men 15 months to remove it from out the rock. Some of the cut faces measured 16 square feet. The cutting up afforded 27 tons of copper chips."

(While the large mass described by Mr. Wright is often referred to as the largest mass mined, a still larger one of 520 tons is reported to have been taken out at the Phoenix mine. An enormous mass discovered recently at the Trimountain will probably prove still larger.)

The common occurrence of masses is illustrated by the following figures of production of the several classes of ore.

COPPER PRODUCTION OF MINESOTA MINE, 1857-1859.

	Mass copper.	Barrel copper.	Stamp copper.	Total product ore.	Per cent refined copper recovered.
1857	3,015,581	819,900	280,512	4,115,993	74.1
1858	2,429,989	903,871	333,352	3,667,212	70.1
1859	2,040,454	929,571	282,092	3,252,117	71

This does not show the character of the ore very faithfully as stamped rock was neglected while rich masses were plentiful. It serves however to indicate that the relative proportion of masses was much larger than in other lodes.

NONESUCH LODE.

General character.—The Nonesuch lode is a cupriferous bed occurring in the Upper Keweenawan in Ontonagon County. The bed carries native copper and chalcocite in small particles filling spaces between and sometimes forming a coating on the sand grains. The rock is a rather coarse sediment varying from sandstone to conglomerate. Much of it is a medium grained, gray colored sandstone, in part fairly hard, but as a rule not strongly cemented. It is very easily drilled and broken, but the rather flat dip increases cost of handling ore in the stopes. At the White Pine mine the dip varies from 18° to 35°. At the Nonesuch it is steeper than at the White Pine.

At Nonesuch mine.—Until recently the most extensive workings on the lode were at the Nonesuch mine. Good ore was found, but considerable difficulty was experienced in concentrating it, on account of the fineness of the copper. This difficulty was overcome and the

lode was tested to determine the extent of the ore body and the grade of ore. It is stated that good values were found, but it was not proved that there was much ore available.

At White Pine mine.—During the past few years promising results have been obtained at the White Pine mine. Here two beds known as the "First lode" and "Second lode" have been opened and found to be well mineralized. The beds are gray sandstone like that at the Nonesuch mine and are in places heavily loaded with copper and chalcocite. The First or Upper lode is the better. The beds average about six feet in thickness, varying from four to six feet. They lie parallel and close together, being separated by about five feet of dark colored slate. The hanging wall bed of the Upper lode is a thick bed of similar black slate. The foot wall of the lower lode is red sandstone, which at a depth of about 40 feet below the lode contains numerous pebbles. This conglomerate phase is fairly persistent and forms a good horizon marker.

It has been found that the lodes are much faulted. In many cases these faults, of the normal type, have allowed blocks to drop in such a way as to increase the apparent dip. In one place faulting of this character has brought the upper lode almost exactly into line with the lower lode.

R. D. Irving's description.—Dr. R. D. Irving has described* the ore bearing rock at the Nonesuch mine. He says: "At the Nonesuch mine, S. E. ¼ Sec. 1, T. 51, R. 43 West, the shale is seen with a thickness of over 200 feet, trending N. 45° 50° E., and dipping S. E. 28°. Near the base of the shale is the sandstone seam, four feet thick, worked at the Nonesuch mine for its copper. This rock is a dark greenish-gray, fine-grained sandstone, which in the thin section is seen to be composed in some measure of basic detritus, along with porphyry detritus, and numerous single quartzes. The basic detritus appears in the shape of much decomposed red and green-stained particles, showing both feldspathic and augitic ingredients. A good deal of magnetite is present, and native copper is very abundant, for the most part clustered around the magnetite particles. In a few places secondary calcite lies between the grains. Beneath the copper-bearing sandstone there come a few feet of shale, also carrying some copper, and beneath this some two and a half feet of a light-gray sandstone, harder than usual, beneath which again is the great sandstone layer previously described.

"The seam just mentioned as occurring at this junction has been traced for a number of miles in the valley of Iron River, and is the one which has attracted so much attention in this region for the silver it contains. Under the microscope it is seen to differ from the Nonesuch

*Monograph V. U. S. G. S., p. 221.

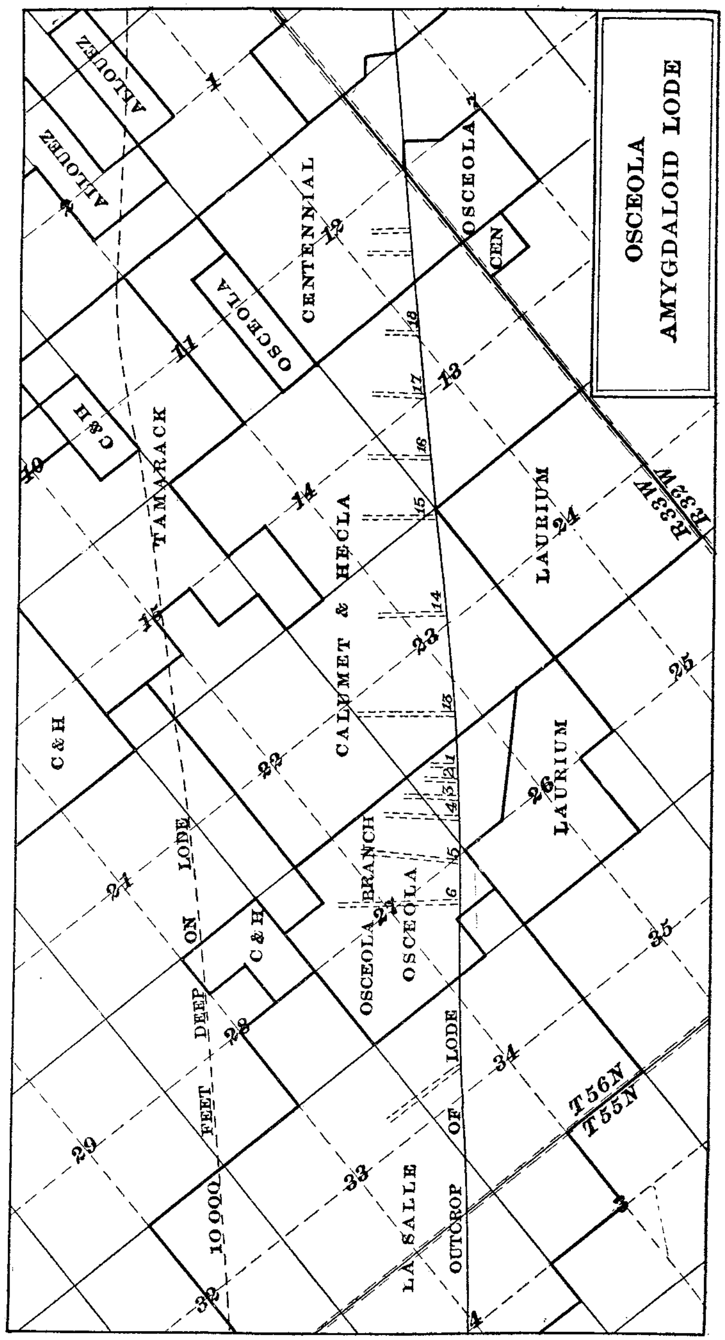


Figure 17.

copper sandstone, and, indeed, from the rock of the shale belt generally, in that it contains some water-deposited (secondary) quartz between the grains, which consist, as usual, of mingled porphyry and basic detritus and quartz particles. Calcite has also been deposited more or less plentifully in the interstices of the grains, and in some sections is the only indurating material."

OSCEOLA LODE.

General character.—The Osceola is an amygdaloid which has been mined extensively by the Osceola, Calumet and Hecla and Tamarack mining companies. On these properties it has been worked for a length of over three miles, openings extending completely across the Calumet and Hecla property and over a mile south on the Osceola. Further north the lode has been explored by the Centennial and Wolverine companies, and further south by the La Salle company, but operations on these properties were unsuccessful.

The lode underlies and runs parallel to about 400 feet east of the Calumet conglomerate striking N. 33° E. and dipping at the surface at Calumet at an angle of 38°. The workings on C. and H. property are as yet comparatively shallow, but the lode has been opened at greater depth by crosscuts from the conglomerate lode, and has been worked at considerable depth by the Tamarack Mining Company. The deepest shafts in the lode itself are No. 5 and No. 6 Osceola which are respectively 4,623 feet and 4,592 feet deep. The deepest shaft on C. and H. property is 3,232 feet deep.

The lode is a brown amygdaloid spotted and streaked with calcite. Most of the amygdules are calcite. The ground mass is softer than that of most lodes, and has commonly a dull and almost earthy appearance. It is easily crushed by the steam stamps and wears the stamp shoes much less than does the ore from most of the other lodes. Below the lode the rock becomes more crystalline in character and shows the mottling typical of the ophites.

Hanging and foot parts.—The Osceola lode varies in width and is in places very wide. The ore comes from two horizons known as hanging and foot parts. The chief and most regularly shaped and continuous ore body is the upper part of the bed. This hanging wall lode averages about nine feet in thickness and is fairly persistent and well defined. Below it there is commonly dense brown melaphyre succeeded by more amygdaloid in which are irregularly shaped ore bodies. These foot wall deposits are often richer and thicker than the hanging wall ore bodies, but they are of more pockety character and do not persist so regularly with strike and dip. In some places foot and hanging portions are continuous and there the lode is very wide, often 40 to 100 feet. More commonly there is 10 to 20 feet of so-called "vein trap" separating them. The amygdaloid encloses numerous lenticular masses of dense trap. Often a bar of trap runs across the amygdaloid and it has been frequently noticed that the rock on either side of such bars is unusually rich in copper. The copper in the lode shows up rather conspicuously and in good ore can be readily detected by the naked eye. A fairly satisfactory selection is made before breaking the ore and little sorting of broken rock is done underground. Some waste is sorted out at surface and with other poor rock sent down into the mine again to be used in filling stopes.

Future production.—In 1911 Mr. J. R. Finlay estimated the future yield of the Osceola lode on Calumet and Hecla property at 23,000,000 tons, yielding 330,000,000 pounds copper. There will also be a large output by the Osceola Mining Company and a small output by the Tamarack Company.

C. Rominger's description.—C. Rominger says* of the Osceola amygdaloid:

"The Osceola amygdaloid belt is about 35 feet wide; it dips in conformity with the other strata at an angle of 40° to the northwest; its color is reddish brown, dull, earthy; part of it is soft, porous, other parts hard, compact; its amygdules are principally filled with calcspar, delessite, prehnite and epidote; sometimes also with quartz, datolite, etc. The copper in the rock is mostly found in a network of fissure seams traversing the amygdaloid belt in association with calcspar, prehnite, datolite, quartz and epidote, filling the interstices between these minerals in hackly masses of smaller or larger size; sometimes the copper is found in druse cavities in very perfect, but rather small crystals; the spar crystals of such druses usually are bright red colored, being penetrated with an abundance of minute scales of copper.

"The datolite, which in the Portage Lake mines occurs only in amorphous porcelain-like concretionary masses, is here found in large crystals of pale greenish milky color, but rarely obtainable with free ends, as the crystals are densely agglomerated and enveloped with calcspar and prehnite.

"The hanging of the Osceola is a dark, blackish colored, fine-grained diabase, which incloses in its linear fissures sheets of copper, and is locally throughout its entire mass impregnated with minute scales of copper. Thin sections exhibit a large proportion of olivine grains in its composition, besides the ordinary constituents, plagioclase, augite, magnetite and interstitial masses of the green chlorite or serpentine-like mineral, which likewise fills distant globular amygdules."

*Geol. Survey of Michigan, Vol. V, pp. 110-111.

"In the hanging of the conglomerate belt at the Osceola location, a dark, fine-grained compact diabase belt occurs, which incloses irregular amygdaloidal rock masses rich in copper, most of it in coarser lumps—so called barrel work. They use the old shaft in the conglomerate belt to come to this rock belt and work it to advantage.

"The compact and the amygdaloidal rock are both olivine bearing; the copper is principally found in fissure seams associated with calcspar, prehnite and dark red orthoclase."

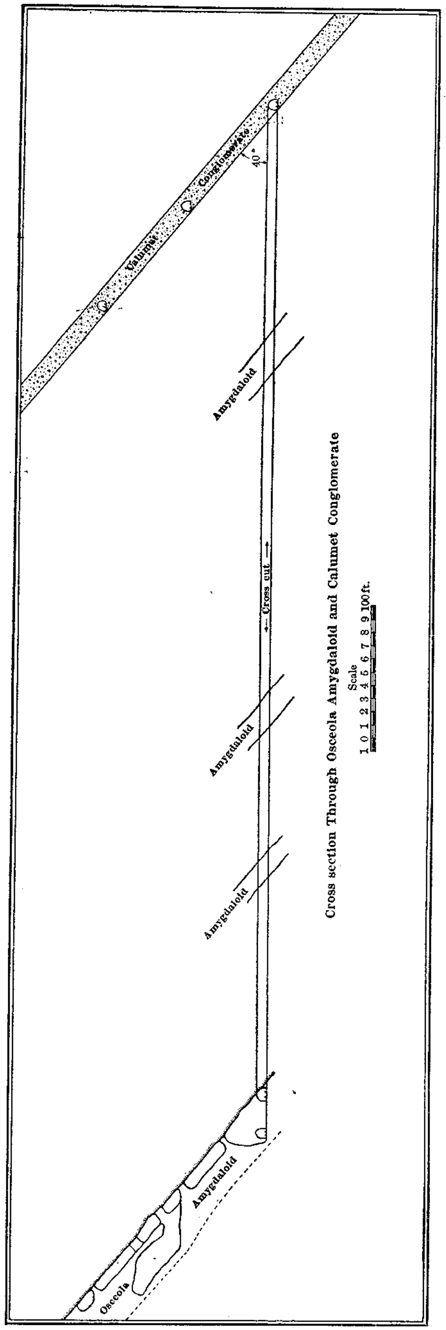
C. L. Lawton's description.—Chas. L. Lawton says* of the Osceola lode as opened at the Osceola mine in 1885:

"The lode possesses every degree of irregularity, and there is so much dead ground that the mine has had to be very largely opened in order to secure the product that has annually been made and the work has been done in a most effectual and economical manner. The misfortune in the Osceola mine is that the best ground is in the north end; the levels in this end are constantly shortening as the mine deepens. This is due to the fact that the Calumet and Hecla joins it on the north, and that the line of division of the properties, up to which the workings closely reach, bears north, 39° east, while the dip of the mine averages about 39° northwesterly, thus the boundary cuts diagonally across the lode, shortening it on the Osceola and lengthening it on the C. and H. The reverse is the case at the south end of the property, where the company has plenty of room to extend, but unfortunately the ground has not proved as productive in that direction. However there are signs of improvement; the south end is certainly better in the bottom than it has been heretofore."

At Tamarack mine.—The amygdaloid was opened up at the Tamarack mine by crosscuts from No. 1 shaft. Supt. John Daniell says in his 1893 report.

"On the Osceola amygdaloid we have drifted south of No. 1 crosscut, 14th level, 231 feet. At 15th level we have drifted south 172.7 and north 18 feet. In quality it has been irregular, but showing copper enough to indicate that it will pay to work. At 14th level we have stoped 490 fathoms of ground, the lode averaging 11 feet wide and affording a good grade of stamp rock, with an occasional piece of barrel work."

*Report Com. Min. Statistics, 1885, p. 246.



Cross section Through Osceola Amygdaloid and Calumet Conglomerate

Figure 18.

Chemical composition of Osceola lode.—Dr. Lane has published in his recent monograph the following analysis furnished by Mr. J. B. Cooper, of slime overflows from the trough classifiers between stamp-heads and jigs treating Osceola amygdaloid ore.

Loss on ignition	7.89%
SiO_2	41.31
Fe_2O_3	12.90
Al_2O_3 (+ Trace TiO_2)	22.46
CaO	11.08
MgO	4.07
Cl	0.11
SO_3	Trace
Cu	0.14
Na_2O and K_2O	Not determined.
	99.96

PEWABIC LODE.

General character.—The Pewabic lodes are the copper-bearing amygdaloids mined at the Quincy and Franklin Junior mines, and now being opened up at the Hancock mine. At the Quincy there is a zone about 300 feet thick in which are several lodes. These vary considerably in relative productivity in different parts of the mine. There is commonly one lode that continues more regularly than the others for some distance and then becomes known as the "main" lode. As the workings are extended this main lode frequently becomes locally quite subordinate in importance to one of the "east" or "west" lodes. According to General Manager Lawton, the lode called the "main" lode at one shaft is not the same bed as that which is called the "main" lode at another shaft.

For the most part the lodes run nearly parallel to one another and are separated by trap. A large ore body in the "east" lode was opened by crosscuts about 60 feet in length from openings on the "main" lode. Often two lodes are separated by only a few feet of dull brown trap and occasionally two come together and then form wide bodies of ore that are in many cases richer than the narrow parts. At the Quincy mine there are in most places two lodes being worked and in several places three. In one part of the mine four lodes are being extracted.

The lodes are highly altered portions of dark gray feldspathic lavas, porphyrites, known locally as the "Ashbed" type. They occur at the same horizon as similar rocks at Eagle River where the term "Ashbed" was applied to the scoriaceous top of a flow and subsequently to a whole series of feldspathic lavas. The amygdaloid shows chlorite, calcite, epidote, quartz, prehnite and native copper in a dark brown or gray ground mass. The trap is a fine but distinctly grained dark gray porphyrite, spotted with small particles of green chlorite.

Occurrence of the copper.—The copper occurs to some extent as a filling in cavities, but most of it has evidently replaced the rock, and forms irregularly defined masses, large and small. The larger masses are more abundant than in most of the lodes. While most of the copper is found in the main amygdaloidal parts of the bed, a large quantity is also mined from irregularly defined portions of the footwall trap. The lodes are crossed by a number of persistent calcite veins, but these are usually barren and in parts of the lode that are poor.

The distribution of copper in the lodes is very irregular and in stoping it is a common occurrence in fairly good ground to frequently expose a large face of very lean or barren rock. This is necessarily broken to get at the ore beyond and lowers the average yield per ton. Some of the waste, however, is sorted out underground and used in filling the stopes.

At the Quincy mine, the main lode is on the average about 10 feet thick, varying from three feet to 15 feet. The inclination, as with most of the lodes, becomes less with depth, being near the surface about 54° and in the lower workings, over a mile down on the slope, about 40°. In places in the northern part of the mine the dip at the low levels is about 38.°

At the Franklin Junior mine the lode being mined is about eight feet thick. Exploration has proven the existence here also of parallel lodes, but these have not yet been extensively opened. The yield at the Franklin Junior has been considerably lower than at the Quincy, but the recently opened lower levels show fairly good ore. The dip of the lode varies from 49° near surface to about 43° at the 32d level. At the Franklin there is a very characteristic hanging wall trap, unusually dark colored and dense.

The lodes strike N. 30° E. and at the Quincy are opened for a distance of about three miles. Between the northernmost Quincy shaft and the Franklin there is a long stretch of unknown ground which will doubtless be sometime explored. The Quincy first confined operations largely to one lode, but subsequently by exploratory crosscuts developed the others and has for years kept a diamond drill in operation probing foot and hanging walls.

Production.

The Pewabic lode had yielded at the Quincy in 1911 about 600,000,000 pounds of copper. In 1912 the Quincy mine produced 20,634,800 pounds and the Franklin Junior 1,710,651 pounds. If the yield per

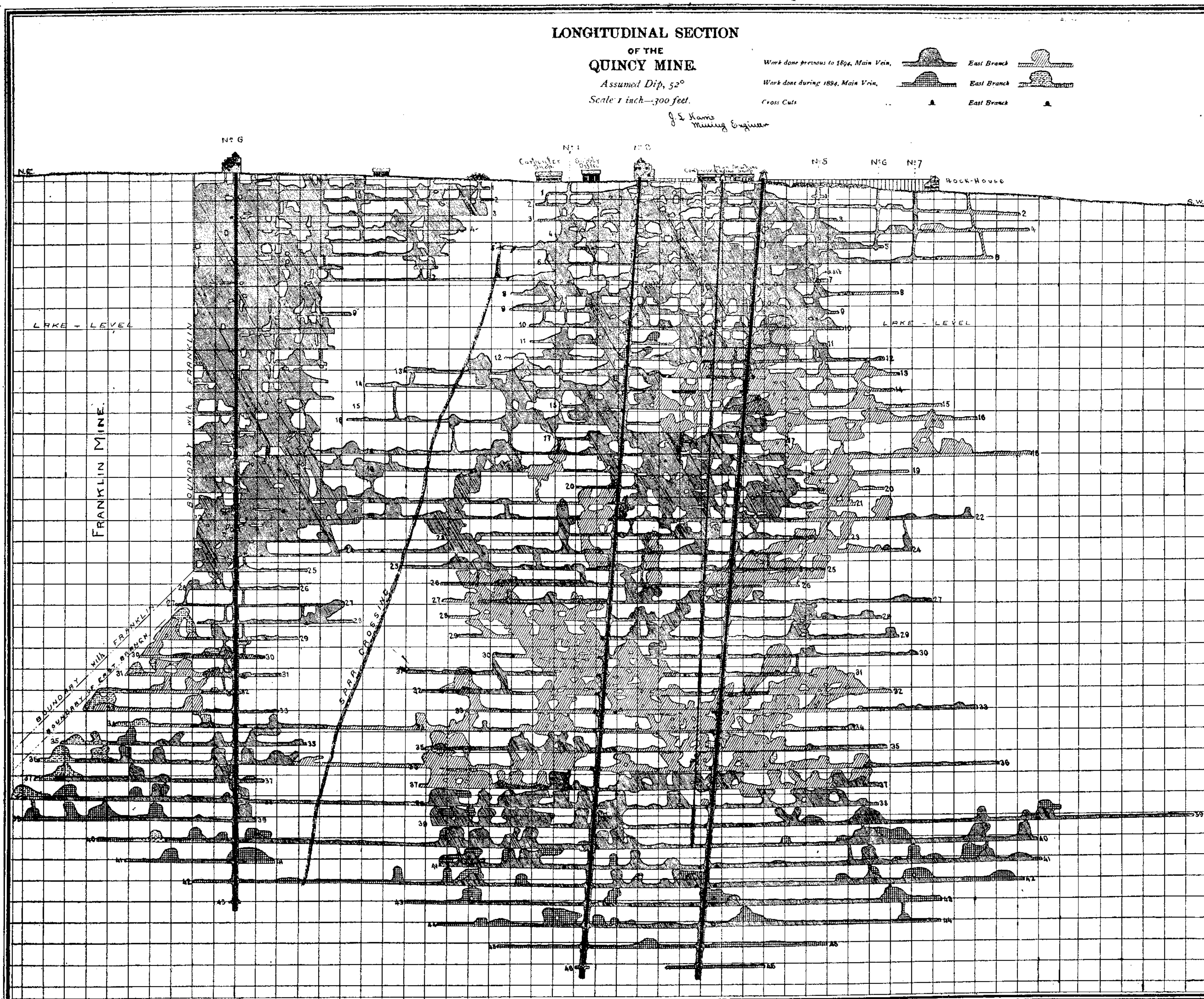

LONGITUDINAL SECTION
OF THE
QUINCY MINE.
Assumed Dip, 52°
Scale 1 inch—300 feet.
J. L. Harris
Mining Engineer
Work done previous to 1894, Main Vein,
East Branch
Work done during 1894, Main Vein,
East Branch
Cross Cuts
East Branch
N.E.
S.W.
No. 6
No. 5
No. 7
Rock-House
LAKE - LEVEL
LAKE - LEVEL
FRANKLIN MINE.
BOUNDARY with FRANKLIN
BOUNDARY with FRANKLIN
BOUNDARY OF EAST BRANCH
SPAR CROSSING

FIG. 19.

ton proves satisfactory the latter mine will show a much larger production in a few years. At the Quincy the southern workings are nearing the boundary, but the central and northern parts of the property have a long future before them.

Rich portion.—The best large body of ore at the Quincy appears to have been a portion of the "East" lode about 1,800 feet long and 300 feet wide, pitching southward from the 25th level 800 feet north of No. 2 shaft to the 36th level 300 feet south of No. 4 shaft. During the period that this section was being mined the yield was over two per cent and in 1882 when much of the ore was coming from the 25th to the 30th level the yield was 3.13 per cent. The 25th and 26th levels north of No. 2 shaft were exceptionally rich. At the shaft the best ore was at the 30th level, and further south it was deeper.

Present average.—At present and for some years past the ore mined has averaged about 16 pounds per ton. The lower yield is due largely to the lode being much less rich, but partly also to the fact that improved mining methods make it possible to remove profitably some very low grade ore.

Future production.—In 1911, for the State Tax Commission, Mr. J. R. Finlay estimated that Quincy mine would produce about 200,000,000 pounds more copper. The probable production of Franklin Junior and Hancock mines cannot be estimated yet. The area to be mined on these properties is large but the yield per ton at the Franklin has so far been low and the Hancock exploration is not yet far advanced.

T. Macfarlane's description.—Thomas Macfarlane of the Canadian Geological Survey, who examined the copper mines in 1865, thus described* the Pewabic lode and its wall rocks:

"It has a thickness of about 12 feet, and in places resembles the rock which constitutes the foot wall of the mines, into which it seems to graduate. In its characteristic varieties it differs, however, completely from that rock. It is a reddish-brown or chocolate colored uncrystalline rock, with amygdaloidal structure, and uneven, almost earthy fracture. The matrix sometimes contains some small amygdules, which are not always completely filled, and thus render the rock porous. The matrix is fusible to a black slightly magnetic glass. It is in places impregnated with grains of metallic copper, from the minutest size to those having a diameter of a tenth of an inch. Those of a larger size generally project from the matrix into the amygdules or form rounded particles lying entirely within these cavities, and filling them. The copper is here accompanied by a mineral of a light green color, very soft, and separable from the rock as a green powder. It is probably a variety of green earth. Some of the amygdules are altogether filled

*Report Geological Survey of Canada, 1866, pp. 152-154.

with it, in which case it frequently contains small isolated grains of metallic copper. Sometimes calcspar is found along with the green earth, the two minerals generally occupying separate parts of the cavity. Very frequently the green mineral merely lines the cavities and the rest is filled with calcspar.

"The foregoing description is of a specimen of the bed exceedingly rich in copper. At other places the matrix is more compact and darker colored, and the amygdules are exclusively filled with calcspar, without any enclosing film of green earth. Sometimes quartz, delessite, laumontite and prehnite occur, filling the cavities. In many parts of the bed large irregular patches and veins of calcspar are seen, through which, and through the adjoining rock, run large irregular masses of copper, frequently weighing several tons, with which small quantities of native silver are associated. Epidote is also often met with in the bed, generally unconnected with the amygdules and forming small irregular masses in the chocolate-colored rock."

"The rock which underlies the copper-bearing bed of the Quincy mine, is distinctly amygdaloidal [pseud-amygdaloidal?]. The matrix is fine-grained but it is crystalline, and is seen to consist of different constituents. Its color is dark reddish grey, and it is fusible to a black glass. The cavities, which seldom exceed the size of a pea, are filled with what appears to be the same chloritic mineral which occurs as a constituent in the rock above described. The specific gravity of the rock, including the amygdules, is 2.78."

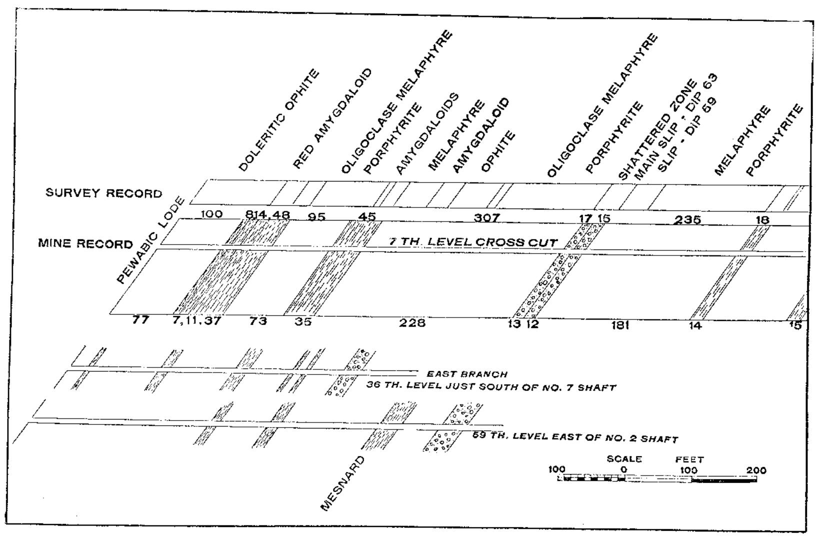


Figure 20. Sections at 7th, 36th and 59th levels of the Quincy mine (after Lane).

Mr. Macfarlane analyzed the rock and found it to consist essentially of labradorite and delessite (a variety of chlorite). He states of the hanging-wall rock that "It is a fine-grained mixture of reddish-gray feldspar, and dark green delessite, the former predominating. In this mixture larger crystals of feldspar, and larger rounded grains of the ferruginous chlorite are occasionally discernible. Its specific gravity is 2.83."

Mr. Macfarlane says* further concerning the lode.

"The width of the bed is from 6 to 30 feet and the average thickness 10 feet. According to the general experience at the mine, the thicker the bed the richer is the rock in copper. About two-thirds of the area of the bed is removed as remunerative, the other third, although it may contain some copper, is left standing, as unworthy of excavation. The amount of ingot copper yielded by the ground actually removed in 1864 was 562 pounds per cubic fathom. Assuming the specific gravity of the rock of the lode to be 2.7, it thus yielded 1.4 per cent. Of course the copper was unequally distributed through the rock and the true percentage would be at many places above, and at others below that just mentioned."

Mass copper.—Mr. C. E. Wright says† of the occurrence of mass copper at the Quincy mine:

"The largest mass ever found in the mine is now being cut up in the 170-fathom level, about 50 feet north of No. 2 shaft, and will weigh about 20 tons. The masses usually found are not to exceed five tons in weight. The product is about 40 per cent mass and barrel work and 60 per cent stamp rock."

C. E. Wright's description.—Mr. Wright says‡ of this lode as it was known at the Quincy in 1881, where it had then been opened to a depth of 2,200 feet.

"The Pewabic lode, as developed in the Quincy, is a broad belt, 200 or more feet in width, through which runs a bunchy deposit or a series of connected deposits of amygdaloid; laterally, in the foot and hanging are also pockets of amygdaloid, which, when worked, are reached by cross-cuts from the main drifts. Altogether these make up the belt. The main lode is tolerably well defined and is followed, and the diamond drill, which for years has been employed in the mine, discovers the lateral pockets, many of which prove greatly productive in copper. They are sometimes in the foot, and as frequently in the hanging side. Nearly 300 borings have been made in the mine with the diamond drill, having an average length of 120 feet."

In another report Mr. Wright says:§

*Report Geological Survey of Canada, 1866, p. 162.
†Report Com. Min. Stat. Michigan, 1880, p. 131.
‡Report Com. Min. Stat. Michigan, 1881, p. 110.
§Report Com. Min. Stat. Mich., 1882, p. 121.

"The Quincy mine is in the same lode with the Pewabic and the Franklin, but it differs materially from either of them in some important features that redound greatly to the advantage of the Quincy. The chief of these peculiarities are the so-called east and west branches which are found in the Quincy mine, and from which so great a portion of the product comes. They have been mainly found with the diamond drill and do not seem to occur in the mines west of the Quincy. The ground plan of the levels from the 80th down, show the main branch flanked by these laterals. Of these the east branch—the line of pockets found from the foot-wall—is by far the best. These lateral pockets, those which are the best, are from 60 to 100 feet from the main branch, and sometimes they prove very rich. The westerly pockets, or west branch, do not produce so well. The amygdaloid is harder, more "trappy," too much so to pay to work. Some of the pockets which make up the east branch are 200 to 300 feet in length, and all good stoping vein matter."

Early workings at Franklin mine.—At the old Franklin mine the testing for east and west lodes met for some time with little success, but a valuable deposit was opened up in 1888 at the 30th level. Supt. J. Vivian describes this lode in his report. He says:*

"From time to time, for the last four or five years we have been exploring each side of the main lode with a diamond drill without the least success until July last, when we discovered, at the 30th level, 47 feet east of the main lode, an amygdaloid, 20 feet wide, bearing stamp and barrel copper in paying quantities. This lode has been opened at this level 288 feet, which has exposed some good stoping ground for at least 200 feet in length. The last eighty feet opened is not showing anything of value. In sinking a winze from the 30th to the 31st level some very rich stamp and barrel copper was met with. At the 31st level this lode has been cut into with a crosscut which has shown it to be copper-bearing for fifteen feet in width. Some good stamp rock and some barrel copper is being taken out at this point daily. At the 29th level this lode has been intersected with a crosscut, and opened on its line 128 feet. On the whole it is less productive than it is in the levels below, but some portions of it will afford some fair stamp rock, and will doubtless pay to stope. There is a large amount of ground ready for stoping on this lode that will yield in ingot copper above the average of the main lode."

Variations in yield.—The yield of refined copper per ton of ore mined at the Quincy in the years 1870-1881 is given in the following table from Chas. E. Wright's report for 1881.

*Rept. 1888, p. 52.

	Tons mass copper produced.	Tons of ore stamped.	Tons concentrate produced.	Yield of refined copper per ton of ore stamped, per cent.
1870	86	55,027	1,437	2.61
1871	96	59,757	1,370	2.29
1872	100	60,828	1,302	2.17
1873	67.5	63,272	1,644.5	2.60
1874	58	67,112	1,752.7	2.61
1875	46	70,501	1,717.6	2.44
1876	65.75	74,717	1,765.5	2.38
1877	65.75	75,307	1,586.5	2.11
1878	70.25	92,800	1,634.25	1.76
1879	59.5	89,817	1,608	1.80
1880	83.5	84,426	2,355.75	2.50
1881	314.25	98,869	3,096.5	3.13

The figures for this period show that a fairly uniform grade of ore was being stamped. In the years 1861-1869, the average yield varied

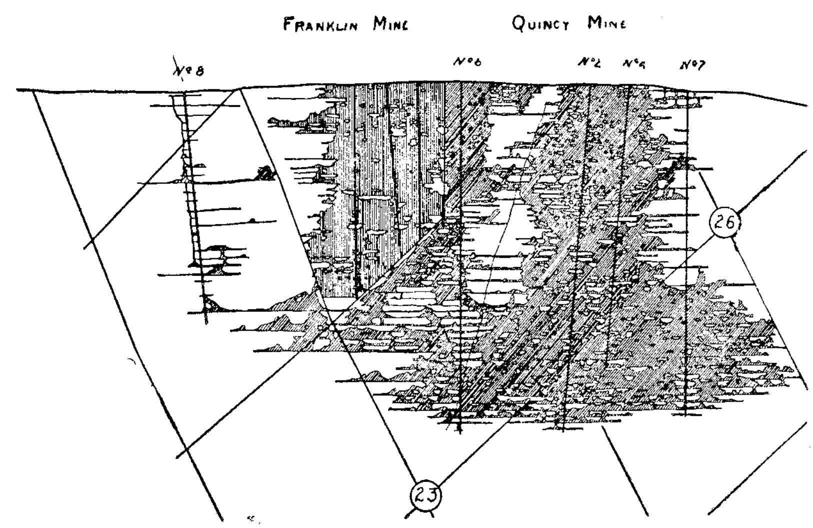


Figure 21. Stope map showing extent of workings at Quincy mine in 1893.

from 2.03 to 2.96 per cent, being lowest in 1862 and 1868. For the whole period of 21 years therefore, the yield was fairly uniform. In view of the richness of the ore mined in 1881 it is noteworthy that the mine was then 2,200 feet deep on the slope of the lode, and practically all of the ore was coming from below the 1,000 foot level.

For several years following the encountering of rich ore at depth the grade of ore mined continued high. As may be seen from the following table the period 1881-1891 was the best in the early history of the mine. Later, the rich ore body having been worked out, the grade fell off again and for the past five years the yield has been only about 16 pounds copper per ton.

Change in grade with depth.—The change in character with depth is shown by the following table. In general the ore came from deeper levels each year, but there were other causes of variation in yield as will be noted in column headed remarks. The data are taken from the annual reports. The figures for succeeding years have not been made public.

YIELD OF QUINCY MINE ORE, 1864-1893.

	Average yield of copper per cubic fathom mined.	Remarks.
1864	562 pounds	
1865	501 pounds	
1866	451 pounds	
1867	526 pounds	
1868	427 pounds	The lode separated into two parts the larger and more productive dipping nearly vertically while openings had been made in the leaner branch.
1869	446 pounds	Increased yield resulted from opening main branch.
1870	528 pounds	Increased yield resulted from opening main branch.
1871	441 pounds	Decrease in richness of main lode.
1872	391 pounds	Falling off due to "pockety" character of the lode which was rich in places, with stretches of barren ground. At the 170 and 180 fathom levels, which were worked at this time, the lode was comparatively lean in copper.
1873	491 pounds	Increase due to opening up of rich lode to east of lode being worked. At No. 1 shaft a cross-cut at the 180 fathom level cut this lode at 60 feet east. This lode proved wide and rich. At No. 2 shaft also, the lode having become thin and poor, a cross-cut was run east at the 210 fathom level through 60 feet of hard compact trap and good ore was found.
1874	577 pounds	Increase largely to good ore from east lode but main lode also improved somewhat with depth.
1875	485 pounds	The lode at the points which had been relied on for the year's product proved much narrower than was expected and much more extensive openings were made to find new ore bodies. Drilling north at the 180 fathom level after passing through 80 feet of poor ground the lode became wide and rich.
1876	507 pounds	Ore largely from new ground opened north at No. 1 shaft and from the east branch at No. 2 shaft.
1877	467 pounds	No additional sinking was done in this year, the extension being by drifting to north and south.
1878	397 pounds	Ore chiefly from north and south extensions. The pockety character of the lode was unusually manifest, mass and barrel work being 48 per cent of the whole product. Many of the new openings were in unproductive ground.
1879	403 pounds	Openings were in poor ground and a large extent of hard narrow lode was encountered.
1880	563 pounds	Good ground was opened south of No. 4 shaft and also north of No. 2 shaft at the 24th level. Rich ore was also taken from south of No. 4 shaft at 14th level.
1881	767 pounds	Twenty-fifth and 26th levels were remarkably rich. All the levels below the 19th level and several above the 13th contributed to the product.
1882	800 pounds	The greatest yield per ton since opening of the mine. No. 2 shaft was 2,150 feet and No. 4, 2,090 feet deep. Several stopes were above average notably on 22d, 27th, 28th and 29th levels, though not so rich as 25th and 26th.
1883	850 pounds	Stoping of the past several years north of No. 2 shaft plainly indicates that the copper bodies have a decided pitch to the south. The best ore at No. 2 shaft at the 25th level was a considerable distance north, but at the 30th level it was close to the shaft.

YIELD OF QUINCY MINE ORE, 1864-1893.—*Concluded.*

	Average yield of copper per cubic fathom mined.	Remarks.
1884	722 pounds	The principal and most productive ground worked was at the 29th, 30th, 31st, and 32d levels at distance ranging from 300 feet south to 700 feet north at No. 2 shaft.
1885	710 pounds	The stoping done in the northern part of the mine was at various places between the 22d and 34th levels. The most productive ground worked was at the 32d, 33d and 34th levels. Most of the stoping done in the southern part of the mine was at the 31st, 32d, and 33d levels north and south of No. 4 shaft. The 32d, 33d and 34th levels were opened on the "East lode," about 50 feet east of the line of the old workings.
1886	638 pounds	Stoping chiefly in same parts of mine as in 1885.
1887	781 pounds	The principal stoping done at No. 2 shaft was at 30th, 31st, 32d, 34th and 35th levels north and in a rich block of ground at 33d level south; at No. 4 shaft principal stoping was between 31st and 35th levels north and south.
1889	690 pounds	Stoping at No. 2 shaft was at 37th and 38th levels north and south of shaft, at 36th, 35th, 34th and 33d levels north; at 32d, 31st, 30th and 20th north and south of shaft. Stoping done at No. 4 shaft was at 37th level south; at 36th, 35th and 34th north and south; at 33d, 32d and 31st south; at 27th north and south; at 25th south and 16th north and south.
1890	769 pounds	Principal stoping at No. 2 shaft was at 39th, 32d and 30th north; at 38th, 37th, 36th, 35th, 31st and 30th north and south at 33d, 26th and 25th levels south. Principal stoping at No. 4 shaft was at 40th and 29th north; at 39th, 38th, 37th, 36th, 34th, 27th and 16th north and south at 23d, 32d, 31st and 30th levels south.
1891	685 pounds	Stoping at No. 2 shaft was at 41st, 40th, 39th and 38th north and south; at 37th, 36th, 35th and 34th north; at 26th south and 24th north. Stoping at No. 4 shaft was at 16th north and south; 30th, 31st, 32d, 33d south; at 34th, 35th, 37th, 38th and 39th north and south; 40th south and 41st south.
1892	572 pounds	Stoping at No. 2 shaft at 41st, 40th, 39th, 38th, 37th, 36th, 35th, 34th, 33d, 32d, 31st north; 41st, 40th, 39th, 33d, 32d, south. Stoping at No. 4 shaft at 41st, 40th, 38th, 37th, 35th, 32d, 26th north; 41st, 40th, 39, 38th, 37th, 36th, 34th, 33d, 32d, 31st, 30th, 29th, 28th, 16th south. Some stoping was done at No. 6 shaft.
1893	574 pounds	Stoping at No. 2 shaft at 44th, 42d, 41st, 40th, 39th, 38th, 37th, 36th, 35th, 34th, 33d, 32d north; 44th, 43d, 42d, 41st, 37th, 36th, 34th and 26th south. Stoping at No. 4 shaft at 44th, 43d, 42d, 41st, 39th, 38th, 37th, 36th, 35th, 33d, 32d, 16th and 10th south; 43d, 42d, 41st, 40th, 38th, 37th, 34th, 33d north. Stoping at No. 6 shaft at 40th, 39th, 38th, 36th, 35th north and south.

In considering the above figures it should be borne in mind that the amount of rock discarded varied. In 1880 about 20 per cent of the rock broken was discarded. However, the figures show fairly well the variation with depth.

At greater depth the ore is leaner; but the writer has not figures to show how much leaner. It is doubtful whether there are any records to show the yield of copper from the section of the lode immediately under that which had been mined in 1893. In subsequent years the workings were extended far to the north and the lowering in grade that one might deduce from inspection of the annual statement is an exaggerated one. Poorer ore was, however, encountered at lower levels as well as north and south.

PHOENIX MINE VEIN.

Chas. L. Lawton quotes the following figures showing yield of copper from the Phoenix mine vein for successive years:

Year.	Total ground broken fathoms.	Yield copper per fathom broken. (Pounds.)	Per cent ingot in rock hoisted.
1872	965.81	363	.0086
1873	1,468.65	441	.0087
1874	1,835.62	749	.0145
1875	2,469.76	599	.0135
1876	2,865.46	413	.0110
1877	2,799.51	312	.0078
1878	1,802.46	246	.0073
1879	2,274.57	243	.0109
1880	1,543.59	289	.0077
1881	1,260.40	359	.0090
1882	1,489.63	346	.0085
1883	2,000.24	319	.0092
1884	1,388.93	409	.0133
1885	768.92	457	.0151

SUPERIOR LODE.

The Superior mine lodes are comparatively rich and are being mined very profitably. The main lode is quite thick; but the ore bodies so far developed are not of great length. At present the mine is regarded as a one-shaft producer.

Much of the Superior lode is a dense reddish brown rock seamed with calcite. In the dark colored rock there are numerous light colored streaks and patches and in these much of the copper occurs. Thin sections of the brown rock are almost opaque, showing very numerous black grains and red dust, probably iron oxides, and large patches of nonmetallic semi-opaque light colored aggregates stained with red iron oxide. Between these patches are clear grains of quartz. In places the semi-opaque aggregates show a finely matted structure possibly due originally to feldspar laths now altered to calcite, etc. The aggregate when treated with H Cl effervesces readily and is evidently largely made up of granular calcite.

The pale colored streaks and patches seem to have formed by alteration starting at joints or minor cracks in the rock. In several cases a string of copper runs down the middle of the aggregate in the position of the original joint. The microscope shows in very thin sections that calcite is the chief constituent. Thicker sections are semi-opaque and resemble sections of the red rock except for the absence of blackand red iron oxides.

Other specimens of the lode show a rock with dense brown colored ground mass enclosing remarkably numerous amygdules that are mostly quartz and calcite. One section shows numerous calcite veinlets in one of which are several elongated grains of copper. On either side of the veinlet are several large copper grains in rock which has evidently been altered and is largely made up of very fine granules of quartz and feldspar. In the part containing most copper the well rounded amygdules are lacking, but the amygdules closest to these much altered portions contain some small copper grains. The copper bearing portion of the section is much lighter in color than is the main mass of the rock. One section shows numerous light colored bands in a part without amygdules and down the middle of the light bands is a rib of copper. Irregular light colored patches near these bands enclose occasional grains of copper. Many of the specimens are traversed by thin calcite veins. One section of the brown rock shows a remarkable rounded plagioclase crystal which has the appearance of being corroded. It has been broken and the fracture sealed with quartz.

One section shows a calcite veinlet traversing a distinctly amygdaloidal portion of the rock. The veinlet contains several elongated grains of copper. On either side of the veinlet the rock is much fissured and altered and contains grains of copper. Further away the rock is less altered and shows no copper.

Specimens of ore from the Houghton mine are remarkably similar to those from the Superior mine and it is probably the same lode. A dull brown or greenish rock containing much calcite and enclosing numerous or few amygdules of calcite and quartz is the common type. A section of the greenish ground mass seems to be largely chlorite and calcite with numerous opaque non-metallic particles. The amygdules of quartz and calcite enclose numerous very small grains of copper. One amygdule shows a border of clear quartz without copper enclosing a dull aggregate of calcite containing several grains of copper. Other amygdules show grains of copper in clear quartz.

Dr. Hubbard calls attention to the evidence of fracturing having preceded the deposition of copper. He states that at the Houghton mine another lode, east of the Superior lode, shows brecciation on a large scale with subsequent deposition of copper.

SUPERIOR WEST LODE.

This is partly brown and red, partly grey and green colored. Both types contain abundant calcite and quartz. The brown rock has very numerous areas, amygdules and irregular fillings, that are largely composed of brick-red feldspar. In many cases the filling is nearly all feldspar; but more commonly the feldspar occurs as a red border enclosing coarsely crystalline quartz or calcite. Yellow-green epidote is the chief constituent of several amygdules. Scattered irregularly through the brown rock are patches of a dull dark green serpentinous or chloritic substance.

The grey ore shows a dense grey rock containing numerous amygdules which are chiefly calcite, and enclosing patches of a soft light green serpentine-like substance which is studded with native copper.

Thin sections of the brown ore show a dense ground mass with numerous grains and patches of red and black opaque minerals. The black occurs as metallic grains and is probably magnetite. The red is not in well defined grains and is probably secondary hematite. Feldspar occurs in lath-like shapes as in the diabases. There are grains of copper in this ground mass, some isolated and some in ill defined veinlets of quartz, chlorite, etc. The secondary red feldspar is much decomposed and is stained with red iron oxide. It appears to be orthoclase. One feldspar crystal encloses numerous microscopic grains of copper. With the quartz in amygdules and veinlets there are small green crystals which show the properties of delessite. The delessite in some cases occurs as nested aggregates enclosed in coarse quartz grains, in other cases the green crystals form the border and project from the brown ground mass out into the clear quartz. In each case the quartz is younger than the delessite. One amygdule shows a border of yellowish epidote enclosing quartz, delessite and calcite. Several amygdules are composed of a pale green chloritic aggregate. In a clear quartz veinlet copper occurs both as isolated grains and in string-like forms.

WINONA LODE.

The Winona lode is the productive amygdaloid of the Winona mine. According to Dr. Lane it is probably a continuation of the Isle Royale lode. It is low grade and has not yet been very successfully worked, but has been recently opened up for production on a larger scale and may soon prove profitable if good prices are obtained for the metal. Much of the copper is unusually fine and is not readily saved by the concentrating apparatus. For 1911 and 1912 the yield was about 13 pounds per ton. It is hoped that a better yield can be profitably obtained by finer grinding.

The ore contains a very high percentage of epidote and is almost all of green color. Copper occurs frequently in fine particles in quartz and calcite.

The lode averages about 24 feet in width, but in places is 30 feet wide. It is easily distinguished from the darker colored trap hanging,

but owing to the readiness with which the latter breaks a good deal of waste is mined with the ore. Above the lode and parallel to it there is a well defined fissure which has a soft clay filling and which is evidently a surface along which much movement has taken place. This slipping plane is in places just above the lode, but is sometimes 10 feet back in the hanging. That portion of the hanging trap under the slip is naturally heavy ground and falls easily after exposure to the air.

The lode is not a simple amygdaloid top, but, as stated by Dr. Hubbard, has many vein-like characters as though it had filled fissures

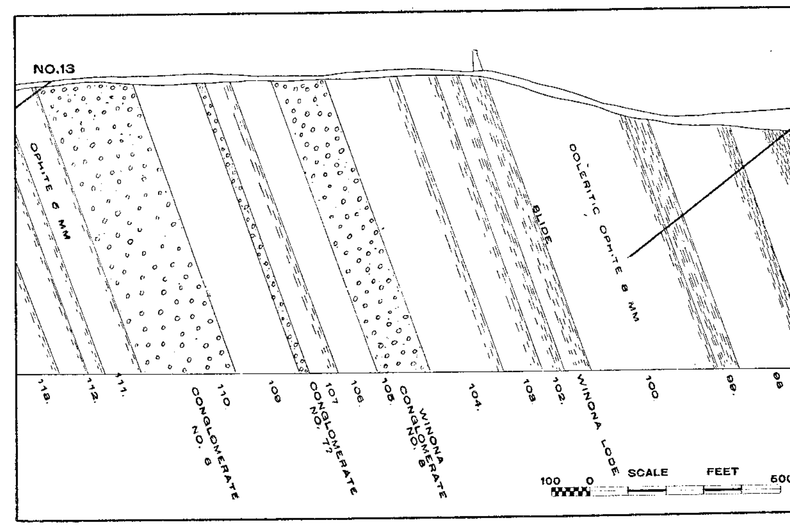


Figure 22. Section at Winona mine (after Lane).

more or less parallel to the bedding. The ore bodies do not continue very regularly and are separated by blocks of dense trap which generally contains very little or no copper, though in places it is fairly well mineralized. In mining the lode continuously therefore, much waste is broken and the practice is to sort out and discard about half the broken rock underground. In following the lode numerous slips are encountered and blocks of good ground are frequently found to be faulted into the footside of the main workings. Mr. Seeber says that many of these offset blocks of the lode are good ore, though some of them are lean. The main productive part of the lode shows a pitch to the southward.

The lode dips at somewhat less than 70°. The shafts are inclined at 70°, but extension of the workings has shown that the lode is not quite as steep as this. The strike is N. 58° E. and the dip S. W.

PRODUCTION OF MICHIGAN COPPER DEPOSITS IN 1912.

(By lodes.)

	Tons of ore treated.	Pounds refined copper produced.	Yield in pounds per ton ore.
Calumet conglomerate lode.			
Calumet & Hecla Mine	1,746,960	51,935,245	29.3
Tamarack Mine (Including a small tonnage of Osceola amygdaloid ore)	421,385	7,908,745	18.8
Osceola amygdaloid lode.			
Calumet & Hecla Mine	1,040,600	15,692,199	15.08
Tamarack Mine (A small tonnage included with conglomerate ore)	....	....	....
Osceola Mine	115,511	1,479,642	12.80
Kearsarge amygdaloid lode.			
Centennial Mine	106,517	1,742,338	16.36
Osceola (South Kearsarge) Mine	458,651	8,322,025	18.15
Wolverine Mine (1911-1912)	401,308	9,408,960	23.45
Osceola (North Kearsarge)Mine	672,231	8,611,720	12.81
Allouez Mine	333,618	5,525,455	16.56
Ahmeek Mine	652,260	16,455,769	25.2
Mohawk Mine	787,941	11,995,598	15.22
Calumet & Hecla Mine	19,050	228,985	10.2
Pewabic amygdaloid lodes.			
Quincy Mine	1,309,253	20,634,800	15.8
Franklin Jr. Mine	176,462	1,710,651	9.8
Isle Royale amygdaloid lode.			
Isle Royale Mine	531,105	8,186,957	15.4
Superior amygdaloid lodes.			
Superior Mine	172,322	3,921,974	22.76
Baltic amygdaloid lode.			
Baltic Mine	652,433	13,373,961	20.50
Trimountain Mine	366,663	6,980,713	19.04
Champion Mine	765,306	17,225,508	22.51
Winona amygdaloid lode.			
Winona Mine	181,148	2,307,237	12.74
Lake amygdaloid lode.			
Lake Mine	....	....	....
Butler and Evergreen amygdaloid lodes.			
Mass Mine	132,891	2,045,006	15.39
Forest amygdaloid lode.			
Victoria Mine	131,955	1,224,911	9.04

CHAPTER VI.

ORIGIN OF THE DEPOSITS.

VIEWS OF GEOLOGISTS.

Many geologists have discussed the origin of the Michigan copper deposits. It is proposed here to summarize what has been written and then briefly to present the writers' views. The descriptions and deductions made by Dr. R. Pumpelly are especially worthy of study. Both are remarkable for clearness and accuracy.

Dr. R. Pumpelly from his studies drew among others the following conclusions:* "1. The chlorite of the melaphyre, 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 melaphyre 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 the 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 comes 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.

*Michigan Geological Survey, Vol. I, Part II, pp. 39-42.

"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 englargement 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 one-fourth per cent to three 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."

Dr. R. Pumpelly says further with reference to the origin of the copper deposits:*

"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 constituents of the rock, and before those which were formed by the destruction of the feldspar. Now this is what we should expect if we supposé the pyroxenic rock to have been altered to its present condition under the cooperation 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 seem at 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 state of the process from the first

*Michigan Geological Survey, Vol. I, Part II, pp. 44-45.
†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.

green discoloration on the cleavage planes to the amygdules 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 congolmerate, while calcite very frequently replaces the cement in barren portions of the bed.

"The cement of the conglomerate 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."

R. D. Irving in Mono. X, U. S. G. S. says: "The differences in origin of the several classes of copper deposits—conglomerate beds, cupriferous amygdaloids, epidote veins parallel to the bedding and 'fissure' veins transverse to it—which at first sight seem to be great, on closer inspection for the most part disappear. They are all the result of the percolation of carbonated waters, which, in the lines of fissure, the open textured amygdaloids, and the nearly equally open conglomerates, found the least resistance to their passage, and at the same time the greatest susceptibility to their altering power. This susceptibility depended partly upon the very openness of these different rocks, but also, in the case of the amygdaloids, in the presence of a large proportion of glass basis, the most readily alterable substance among rock constituents.

"The source and the cause of the arrest of the copper which was carried in with the altering waters are other and more difficult questions. Its home has commonly been regarded as being within the mass of the trappean flows themselves, with which it is supposed to have come to the surface. Another view is that it was originally deposited in a sulphuretted form along with the detrital members of the series, from which it was subsequently leached, partly in the shape of a sulphate, but principally as a carbonate and silicate. The latter is the view which Pumpelly has elaborated;* to whom also is due the credit of having advanced the only satisfactory view as to the cause of arrest of the copper in the places where it is now found. He has shown the existence of an intimate relation between the precipitation of the copper and the peroxidation of the ferrous oxide of the augitic constituent of the basic rocks; a relation so constant as to render irresistible the conclusion that in this ferrous oxide is to be found the precipitating agent of the copper. To this I would add that the ferrous oxide of the magnetite and of the unindividualized magma of the vesicular layers, has also been concerned in this reaction."

M. E. Wadsworth in a paper presented at the Lake Superior Meeting of the American Institute of Mining Engineers in 1897 considers the copper to have been derived from the volcanic rocks by percolating waters. He says:†

"From the fact that the copper is generally found most abundantly under the heavy lava flows, and associated with minerals evidently the product of the decomposed lavas, it appears probable that the copper was once finely disseminated through the lavas, and has since been concentrated by waters percolating through them. This view is advocated by Muller, Bauermann, Marvine and myself, while a similar view has been advanced by S. F. Emmons to account for the origin and concentration of the Leadville ore-deposits."

He says of the deposition of the metal:

"The means by which the copper was concentrated and deposited as native copper, instead of occurring in the form of the usual copper ores, is an interesting and unsolved problem that awaits the attention of the chemist who is willing to give his time and thought to the subject, although Pumpelly advocates the idea that the principal agent is the oxide of iron. In this he has much to sustain him, and his view is generally adopted."

Dr. Wadsworth considered that the evidence shows that deposition of metal took place after the Keweenawan Series was complete. He says:‡

"That the copper was deposited after the copper-bearing series was complete is shown by the fact that it is found in fissures extending across the beds that could only have been produced after the beds were in place; by the fact that the copper was deposited subsequently to the jointing of the lavas, owing to its now being found wrapped around the pieces formed by jointing; and by the extension of the copper from one flow down into another as a continuous mass."

*Geology of Michigan, Vol. I, Part III, p. 43.
†Trans. A. I. M. E. Vol. XXVII, 1897, pp. 694-695.
‡Trans. A. I. M. E., Vol. XXVII, 1897, p. 695. Also stated in Dr. Wadsworth's report, M. G. S., 1891.

C. R. Van Hise in his paper on "Some Principles Controlling Deposition of Ores" discusses the Michigan deposits as an example of ore bodies which have remained practically unchanged since their first concentration. He says:*

"We have now seen that the zone of fracture is searched by the percolating waters; that metalliferous materials taken into solution by the downward and lateral moving waters are carried to the trunk channels of underground circulation. that in these trunk channels the metalliferous materials are precipitated in various ways. Thus a first concentration, by ascending waters giving sulphurets and metals of some of the elements, is fully accounted for.

"In some cases the deposits thus produced are sufficiently rich, so that they are of economic importance. In these cases, which undoubtedly exist, but which perhaps are less numerous than one might at first think, a concentration by ascending waters has been sufficient.

"A conspicuous illustration of ore-deposits of this class which may be mentioned are the metallic copper deposits of the Lake Superior region. The copper was in all probability reduced and precipitated directly as metallic copper from upward moving cupriferous solutions. The reducing agents were the ferrous compounds in the solid form, in part as magnetite and as solutions derived from the iron-bearing silicates. When the copper was precipitated, the iron was changed into the ferric condition.† It is well known that metallic copper once formed is but slowly affected by the oxidizing action. Oxidation has in fact, occurred in the Lake Superior region, but from the facts now to be observed, not to an important extent. An oxidized belt may have formed in pre-glacial times, but if so, it was swept away by glacial erosion, and sufficient time has not since elapsed to form another. The ore-deposits now worked, have apparently remained practically unchanged since the time of their first concentration. In this fact we have the explanation of the great richness of these deposits to extraordinary depths."

C. R. Van Hise in his paper on "Some Principles Controlling Deposition of Ores" says‡ of the Michigan copper deposits:

"A still clearer case of precipitation resulting from the influence of the wall rock is the well known occurrence of metallic copper about grains of magnetite and in the openings of sandstones, conglomerates and amygdaloid of Keweenaw Point. Where the copper is about the magnetite, it seems perfectly clear that the protoxide of iron in the magnetite was the reducing agent which precipitated the metallic

*Trans. A. I. M. E. Genesis of ore Deposits, p. 353.
†"Paragenesis and Derivation of copper and its associates on Lake Superior," by R. Pumpelly, Am. Jour. Sci., Third Series, Vol. II, 1871, p. 353.
‡Genesis of Ore Deposits, Trans. A. I. M. E., 1901, p. 344.

copper. The metallic copper between the particles was doubtless precipitated by ferrous solutions furnished by the wall-rocks, which in many cases are basic volcanics."

Franz Posepny in his well known treatise on "The Genesis of Ore Deposits" says* of the origin of the Michigan Copper deposits:

"Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore-depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive flows between the sedimentary strata, so that the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all the deposits, suits also the exceptional case cited by R. D. Irving, namely, the Nonesuch copper-bed in the sandstone of Porcupine Mountain, far from an eruptive outflow."

Waldemar Lindgren in a paper† entitled "Metasomatic Processes in Fissure Veins, says of the Michigan copper deposits which he discusses under the heading of Zeolitic Copper Veins.

"The copper-deposits of Michigan are in part fissure veins cutting across the beds of melaphyre and other basic igneous rocks as common in that district. It is true, however, that the ore bodies of the large mines are not to be considered as fissure-veins, but rather as beds or strata along which copper has been deposited by a process of replacement."

He summarizes the descriptions and theoretical deductions of Raphael Pumpelly and R. D. Irving and states in conclusion:

"Especially remarkable is the series of replacements which, as shown by Pumpelly, has taken place in these veins. Prehnite is pseudomorphic after plagioclase; and many amygdaloids are largely prehnitized. The prehnite is again replaced by otrhoclase; and finally, the latter may change into epidote and quartz. Sericite is absent.

"These copper-bearing veins are clearly very different from the majority of fissure-veins, and have been formed under very different conditions—in fact, probably not by the thermal waters. Of other classes, the orthoclase-albite-zeolite veins of the Alps are most closely related; while a certain slight resemblance also exists to the propylitic veins, emphasized by the chloritic alteration and the presence of orthoclase."

Dr. Lindgren in his recently published book on Mineral Deposits discusses the origin of the native copper and of the zeolites which occur with the copper in basic lavas. He points out that of all the occurrences of zeolites the most abundant and conspicuous is that in

*Trans. A. I. M. E., 1901, p. 145.
†Trans. A. I. M. E., Genesis of Ore Deposits, 1901, pp. 606-608.

the blowholes of volcanic flows, and states that in many occurrences it can be shown that the zeolites formed as the last phase of consolidation of a magma. He discredits the frequently made statement that zeolites are formed as the result of leaching by surface waters and says:

"Zeolites are manifestly unstable in the zone of weathering and must have been formed at some depth. Of late years the opinion has been gaining ground that zeolitization, in basic volcanic rocks is distinctly connected with the cooling processes and in fact should be regarded as an after effect of volcanism, their deposition taking place in the still hot rocks."

He believes, with Knopf, that any theory accounting satisfactorily for the zeolites will also account for the copper. He believes that the copper was first present in the rocks as a silicate and says:

"Following Lane, I believe that waters of seas or lakes, mingling with the exhalations from the magma, decomposed the copper silicate contained in the pyroxenes, and that the resulting chlorides of iron and copper were decomposed by silicates or carbonates of calcium, with the formation of native copper, ferric oxide, and calcium chloride."

J. H. L. Vogt—It is interesting to note that J. H. L. Vogt who argues in favor of the theory of magmatic origin of many ore deposits, considers the Michigan copper as a deposition from underground waters as described by Van Hise. He says in his paper* on "Problems in the Geology of Ore Deposits:"

"That the ore-deposits first mentioned above, viz., the titanic iron-ores in gabbro, the chromite-occurrences in peridotites, the nickel-pyrrhotite deposits in gabbro, etc. were formed by magmatic extraction, I think I have scientifically proved beyond doubt; and I believe that the magmatic-extraction theory advanced for the cassiterite and apatite-veins is in its main proposition correct. For the ore-deposits subsequently considered—the contact-deposits, the pyritic deposits, the gold-veins, silver-lead veins, copper-ore veins, etc.—the views here offered become confessedly more and more hypothetical. But they have much in their favor; and even if, following in particular the French observers, I have ascribed to magmatic-extraction too great a significance, I believe, nevertheless, that the hypothesis is worthy of thorough scientific discussion.

"At the same time, I wish to add emphatically that, beyond doubt, numerous ore-deposits may have been formed by the action of underground waters, so comprehensively investigated and described by Van Hise; e. g., many deposits of iron and manganese-ores; the veins

*Trans. A. I. M. E., Genesis of Ore Deposits, 1901, p. 658.

of nickel silicate (garnierite); pretty certainly also the native copper of Lake Superior; and many other occurrences."

H. L. Smyth, in a paper presented at Harvard University in 1896, discussed the origin of the Keweenaw Point deposits and a summary of his paper has been published in Science, February, 1896, p. 251. He points out that from the consideration of the conditions of formation of the separate flows, with their subordinate intercalated conglomerates, it is probable that each flow after consolidation was immediately subjected to the action of meteoric waters. "Afterwards by slow subsidence, each bed would eventually sink beneath their reach..... Afterwards came the northerly and northwesterly tilting, and the formation and filling of the fissures, and the impregnation and partial replacement of the amygdaloids and conglomerates. The new minerals of this period are sharply separated from the alteration product of the first (which they often replace) by their richness in alkalies, and the presence of flourine and boron. The two periods, therefore, are far separated in time as well as by the character of the chemical agents at work and do not, as Pumpelly supposed, represent a continuous march of alteration." Prof. Smyth concludes that neither Pumpelly's view, that the copper had been brought down from the sandstones of the upper division of the series, nor Wadsworth's, that it had come from the lava flows themselves, is probable. On the other hand, the mineral associates of the copper, the time of formation and, in the case of the veins, the evident arrest of the copper-bearing solutions below the relatively impervious greenstone, all point to a deep-seated source and to ascending solutions as the transporting agent. As to the precipitating agent, Smyth does not accept the view that it was electrolytic in its nature, because the deposition was manifestly accompanied in so many cases by the chemical destruction of the cathode. He concludes that in spite of lack of confirmation by laboratory experiment, no theory so well explains the invariable deposition of copper to great depths as Pumpelly's viz., that it was effected by the reduction of copper salts by the ferrous oxide in the universally present chlorite.

J. F. Kemp has summarized and commented on some of the published views on the origin of the deposits as follows:*

"The original source of the copper was thought by the earlier investigators to be in the eruptive rocks themselves, and that with them it had come in some form to the surface, and had been subsequently concentrated in the cavities. Pumpelly has referred it to copper sulphides distributed through the sedimentary, as well as the massive rocks from which the circulating waters have leached it out as carbonate,

*Ore Deposits of United States and Canada, pp. 209-211.

silicate and sulphate. Although the traps are said by Irving to be devoid of copper, except as a secondary introduction, it would be interesting to test their basic minerals for the metal in a large way, as has been so successfully done by Sandberger on other rocks. It is probable that these may be its source.

"Irving states that the coarse basic gabbros of the system contain chalcopyrite, but they do not occur near the productive mines. The electro-chemical hypothesis of deposition was earliest advocated (Foster and Whitney), and on account of the electrolytic properties of the two metals copper and silver, at first thought, it seems to be a reasonable explanation. Still, the unsatisfactory character of all experiments made in other regions to detect such action militates against it. Pumpelly, however, has worked out an explanation much more likely to be the true one. He found, on studying the mineralogical changes which have taken place in the rocks, that the alteration had been very thorough, and that it had involved a most interesting series of minerals, which are now chiefly manifested in the cavity fillings. It is to be appreciated, as has been especially well shown by the recent detailed geological sections of L. L. Hubbard,* that in the productive region, the Keweenawan rocks consist of a vast series of basic lava flows, with a few of more acidic types, and with occasional intercalated conglomerates. H. L. Smyth† has also emphasized the fact that these successive lava sheets must have remained for protracted periods after their outpourings, exposed to the atmospheric agents, and to weathering, before they sank beneath the sea, and were buried under the conglomerates. As a matter of observation, the upper portions of the sheets are notably more cellular and decomposed than are the lower. Two kinds of amygdaloids were indeed recognized by Pumpelly,‡ brown ones, or true amygdaloids, in which the alteration was excessive, and which were probably derived from cellular lava sheets; and green ones, or pseudo-amygdaloids, which are hard and dense, and probably owe their apparent amygdules to the decomposition of pyroxene, olivine or feldspar crystals. Pumpelly traces out the following series of minerals. The first to develop was chlorite. Either contemporaneously with the chlorite or next after it, laumontite, a hydrated basic silicate of calcium and aluminum resulted. Laumontite, prehnite and epidote, all non-alkaline silicates, next segregated in the cavities, and were followed by quartz. They are thought to correspond to the decay of the pyroxenic minerals in the lavas. The copper manifestly came in after this, and its deposition seems to have proceeded along with the formation of a green chloritic mineral, or green-

*Geological Survey of Michigan, V., opp. p. 166.
†Science, February 14, 1896, p. 251.
‡Geological Survey of Michigan, I, Part II, 14 Amer. Jour. Sci., September, 1871. Proc. Amer. Acad. Arts and Sciences, XIII, p. 268, 1878. Geol. Wisconsin, III, 31.

earth, which has displaced the prehnite, quartz and calcite of the earlier stages. Calcite, it should be added, marks almost every stage of the paragenesis. Presumably the reducing action produced by the oxidation of FeO to Fe_2O_3 in the production of the chloritic 'green-earth,' caused the reduction and precipitation of the copper from some aqueous solution of sulphate, carbonate or silicate. After all this had occurred a quite different series of minerals (except that calcite continued to form) was introduced, which are characteristically alkaline silicates. Analcite, apophyllite, datolite, and last, of all orthoclase, are the chief members. Pumpelly regards them as produced by the alteration of the feldspars of the basalts, and in a continuous succession of changes following those just cited, but H. L. Smyth advances the view that they and the copper came in after the tilting and faulting of the strata, and probably in uprising solutions along the fissures, which are illustrated in the vein mines. He remarks that apophylite contains fluorine, and datolite boron, and that the mineralization of the fissure veins is often extended in lateral enrichments, where the fissures cut porous beds. Pumpelly specially favored the overlying sandstones and descending solutions as sources of the copper. Wadsworth gives a resume of all the views advanced up to 1880* and himself favors a derivation by leaching of the neighboring and overlying trap.

"As stated in mentioning the great ore-shoots above, the circulations must have followed the general lines indicated by them, so that it is evident that the rich currents were of limited extent. The anomalous condition presents itself of native copper, a mineral that is usually characteristic of the oxidized zone of deposits of sulphides, extending to great depths below the ground-water level.

"It is natural to raise the query as to the possible passage of the native copper into sulphides in depth, but there is as yet no evidence of this change. Any minerals in the nature of sulphides are extraordinarily rare. A little whitneyite and domeykite (copper arsenides) and chalcocite occur in the amygdaloid, formerly worked at the Huron mine; chalcocite has been found in the Bohemian Mountains and in the Copper Falls mine. Native copper changes to chalcocite 90 feet down in the Mamaisne mine, near the Sault (L. L. Hubbard). A pocket of melaconite, the black oxide, was opened in the early days at Copper Harbor.

Van Hise, Leith and Steidtmann.—A brief statement of the views of several geologists who have discussed the origin of the ores is given by

*M. E. Wadsworth, "Notes on the Geology of the Iron and Copper Districts," Bull. Mus. of Comp. Zool., VII, 76, 123. Report of the State Geologist of Michigan, 1892, 167-170, and especially 169. Rec. also in a pamphlet of the Duluth, South Shore & Atlantic R. R., 1890. "Origin and Mode of Occurrence of the Lake Superior Copper Deposits." Trans. Amer. Inst. Min. Eng., XXVII, 669.

Van Hise, Leith and Steidtmann in Monograph No. 52, pp. 580-581. They say:

"Irving,[1] Wadsworth,[2] and nearly all other geologists who have studied the copper-bearing rocks believe that the source of the copper was in the basic igneous rocks, and that so far as it was derived from the sediments, its ultimate source was still the basic igneous rocks, because the sediments came from those rocks. This belief is founded principally on the uniform and close association of copper with the basic igneous rocks and the known existance of copper sulphides minutely disseminated through some of the coarser igneous rocks. The source, of the copper was believed by Pumpelly[3] to be the overlying sediments.

"Smyth[4] believed that the ores did not come from the adjacent wall rocks but from a deep-seated source, the nature of which does not appear from this report.

"The conditions and agents under which the copper has been taken from the adjacent rocks and concentrated have been variously interpreted. Irving[5], Pumpelly[6], Wadsworth,[7] Lane[8], and others have been inclined more or less strongly to the theory of concentration under the direct downward movement of meteoric waters. Pumpelly has also implied that concentration may have occurred when sediments were still below sea level. Lane[9] has suggested that the waters were sale waters of the type now found in the deep copper mines and that they represent fossil sea waters or fossil desert waters, which in the tilting of the series have migrated downward. Van Hise[10] has argued that while metoric waters have done the work, it has been during their upward escape after a long underground course. Smyth assigned the first concentration of the ores to ascending solutions from a deep-seated source not specified."

Messrs. Van Hise, Leith and Steidtmann outline their own hypothesis of origin as follows:

"The copper ores are characteristically associated with basic igneous rocks. The source of the copper-bearing solutions lies in these igneous rocks. The original copper-bearing solutions were not. These solutions

[1]Idem. pp. 425-426.
[2]Wadsworth, M. E. The origin and mode of occurrence of the Lake Superior copper deposits: Trans. Am. Inst. Min. Eng., Vol. 27, 1898, pp. 694-696. See also Muller, Albert Verhandl, Naturf. Gesell. Basel, 1857, pp. 411-438; Bauermann, Hilary, Quart. Jour. Geol. Soc., Vol. 22, 1866, pp. 448-463; Wadsworth, M. E., notes on the iron and copper districts of Lake Superior; Bull. Mus. Comp. Zool. Harvard Coll., Geol. Ser., Vol. I, 1880, p. 126.
[3]Pumpelly, Raphael, The paragenesis and derivation of copper and its associates on Lake Superior; Am. Jour. Sci. 3d ser., Vol. 2, 1871, pp. 188-198; 243-258; 347-355.
[4]Smyth, H. L., Theory of origin of the copper ores of the Lake Superior district; Science, new ser., Vol. 3, 1896, p. 251.
[5]Irving, R. D., op. cit., pp. 419-426.
[6]Pumpelly, Raphael, op. cit., pp. 353-355.
[7]Wadsworth, M. E. The origin and mode of occurrence of the Lake Superior copper deposits; Trans. Am. Inst. Min. Eng., Vol. 27, 1898, p. 695.
[8]Lane, A. C. The theory of copper deposition; Am. Geologist, Vol. 34, 1904, pp. 297-309.
[9]Lane, A. C. The chemical evolution of the ocean; Jour. Geology, Vol. 14, 1906, pp. 221-225.
[10]Van Hise, C. R., A treatise on metamorphism; Mon. U. S. Geol. Survey, Vol. 47, 1904, p. 1136.
[11]Op. cit., p. 251.

may be partly direct contributions of juvenile water from the magma, partly the result of the action of meteoric waters on crystallized hot rocks."

Van Hise, Leith and Steidtmann believe* that the original deposition of the copper was limited mainly to middle Keweenawan time, or, if not, at least to the cooling period of the igneous rocks of that time. They consider some of the gangue minerals to be hot-water deposits and state that the wall rock alterations associated with the ores seem to be such as are characteristic of hot water rather than meteoric solutions. They believe that part of the copper was deposited soon after the extrusion of the associated igneous rocks, but that much of the deposition of the copper followed the folding and deformation of the Keweenawan rocks, which accompanied and immediately followed the deposition of the Keweenawan series. They discuss the source of the thermal solutions, pointing out that the localization of the deposits in time and place seems to be something more characteristic of highly concentrated magmatic solutions than of a universally acting agent like metoric waters working down from the surface, but that the juvenile waters were naturally more or less mixed with meteoric waters.

They say† in conclusion on this point:

"On the whole the evidence is taken to point to a probable original concentration of copper by hot solutions largely of juvenile contribution, but more or less mixed, necessarily, with meteoric waters and a later working over of the deposits by water dominantly of meteoric source. In any case there is a high degree of probability that the associated basic igneous rocks are the source of the copper deposits. The doubt arises only as to the manner of their derivation from these wall rocks —whether they are due to the escape of solutions of a juvenile nature before or during the crystallization of the lavas, or whether on the breaking up of the crystalized rocks by katamorphic alterations the minute portions of copper they contained were concentrated in the deposits."

In the same report Van Hise, Leith and Steidtmann discuss the chemistry of deposition of the ore and advance‡ the following hypothesis:

"Hot solutions containing copper chlorides, boron, and fluorine compounds, CO_2, and possibly other magmatic emanations entered the porous parts of the formations, where they began the work of deposition and the solution and replacement of the wall rock. Hot solutions, in general, remove lime and soda with great rapidity. Pressure and CO_2 alone could cause the solution of alumina.§ In

*Monograph No. 52, U. S. G. S., p. 582.
†Monograph No. 52, U. S. G. S., p. 587.
‡U. S. G. S. Mono. No. 52, p. 589-590.
§Gawalowski, A., Chem. Centalbl., pt. 1, 1906, p. 640.

general, there would be a tendancy for the decomposition of all minerals in the wall rocks, and a consequent enrichment of the solutions in the constituents taken out of the wall rocks. However, as Lane* suggests, the calcium silicate and sodium silicate in the solution would tend to keep magnesium out of solution. These processes would tend to develop chlorite by replacement and to keep magnesia permanently out of the solution. In general, chlorite is the most stable mineral from which magnesia assumes in the presence of hot solutions.† The first step in the cycle of deposition thus accounted for left the solution rich in lime, iron, and aluminum silicates. Changing conditions, perhaps, of concentration, heat, and pressure brought about the saturation of these constituents, and a generation of laumontite, prehnite, and epidote followed the development of chlorite. Silica became insoluble in this solution after the deposition of the lime-aluminum silicates, which resulted in the precipitation of quartz. The individualization of quartz was followed by the deposition of copper. It is suggested that the solutions were relatively rich in alkalies, probably the carbonates and chlorides both, when the period of copper deposition began, for the deposition of copper accompanied the solution of quartz and was followed by the deposition of alkaline silicates. Under these conditions copper-bearing solutions reacting with the ferrous silicates of the wall rock and perhaps with ferrous salts in solution in presence of alkaline carbonates caused the precipitation of copper. It is furthermore suggested that the deposition of calcite, coeval with the deposition of copper, was due to the interaction of alkaline carbonate and calcium chloride. As calcium chloride is a solvent of copper, its precipitation as a carbonate would give additional impetus to the precipitation of copper."

R. Beck and W. H. Weed conclude‡ that:

"Genetically these deposits are best explicable by the assumption of a lateral secretion of the copper ores, which were originally finely distributed in the malaphyre. The only enigma is, why the resecretion and concentration took the form of native copper."

Frank F. Grout in a paper§ on Keweenaw Copper Deposits of Minnesota shows that the copper occurs very commonly in the Keweenawan lavas. In the specimens examined he found that the more altered ores contained less copper than the fresh types, and he states that the copper occurs in the form of an insoluble silicate rather than as sulphide or native metal. Of the several types of lavas he considers the mottled melaphyres (ophites) to be specially favorable,

*Lane, A. C., Econ. Geology, Vol. 4, 1909, p. 166.
†Steidtmann, Edward A., Graphic comparison of the alterations of rocks by weathering with their alterations by hot solutions; Econ. Geology, Vol. 3, 1908, p. 398.
‡Nature of Ore Deposits, p. 233.
§Econ. Geol., Vol. V, 1910, pp. 471-476.

stating that they furnish not only a high per cent of the copper, but more ferrous iron for a reducing agent than the other types.

He gives the following analyses:

	Per cent copper.
1. Hackley diabase, Pine City, Minn., very fresh	0.029
2. Hackley diabase, Crooked Creek, Minn., average alteration	0.020
3. Hackley diabase, McDermott Creek, Minn., extreme alteration	0.013
4. Mottled diabase, Taylors Falls, Minn	0.019
5. Hackley diabase, Crooked Creek, Minn	0.020
6. Conchoidal diabase, Crooked Creek, Minn	0.012

A. C. Lane has, in his monograph on the Keweenawan Series, summed up a number of facts bearing on the question of origin of the deposits. He calls attention* to:

"1. The dissemination of copper in small quantities throughout the formation. The average from several thousand feet of drilling at the Clark-Montreal was 0.02 per cent. Hardly a single amygdaloid fails to carry less than .02 per cent copper, and when the copper content reaches .50 per cent it is nearly an ore.

2. The occurrence of native copper in similar formations of red rock associated with salt waters and lavas elsewhere—notably the New Jersey Triassic, in the Bolivian Puca sandstone, in Nova Scotia, around Oberstein in the Nahe melaphyre region, and in Alaska.

3. The general absence of native copper outside the Keweenawan, in the Lake Superior region but—

4. Native copper has been found in iron ores (generally thought to be formed by the action of downward working waters) in a few places.†

5. The water in the formation is of three kinds:

a. At and near the surface, soft and fresh with sodium in quantities more than sufficient to combine with the chlorine

b. At some distance (generally 500 to 2,000 feet, before it attracts attention, unless especially sought), the chlorine is higher and the water is charged with common salt. The line between the two classes of waters is often quite sharp.

c. At great depths a strong solution of calcium chloride containing some copper.

6. The middle water (b) often contains more salt than it could possibly have were it a mixture of a and c.

7. The lines between the different kinds of waters are not regular, yet the lowest water probably always comes within two or three thousand feet.

*Publication 6, Michigan Geological and Biological Survey, 1912, pp. 41-43.
†Report for 1903, p. 247.

8. The amygdaloids seem, other things being equal, to contain rather stronger (more saline) water than the conglomerates.

9. An unequally heated solution corresponding in composition to mine water (c) will precipitate copper on the same minerals, prehnite, datolite, etc. on which it occurs in the mines, as Fernekes has shown.

10. The traps contain combustible gasses, as R. T. Chamberlain has shown.

11. Certain beds are abnormally high in copper for many miles.

12. Copper often replaces chlorite, and in the Calumet and Hecla pebbles chlorite replaces felsite, and the copper the chlorite.

13. Copper may even replace vein quartz.

14. Copper is formed generally after those minerals which are the products of alteration and contain lime, and before those secondary minerals which are the products of alteration and contain soda and potash.

15. Therefore, at the time the copper formed the mine water might have lost lime but could not have lost sodium. The rock might have lost both.

16. The Calumet and Hecla lode averages less rich (very rich in spots) near the surface, attains its greatest richness at a certain depth say about 2,000 feet, and then gradually decreases in richness.

17. The silver occurs more abundantly in the upper levels."

He then states: "The conclusion to which these facts have forced me is that the copper was in the Keweenawan formation as a whole, before being introduced into the particular places where we find it and that the deposits have gathered together by migration of the particles known as ions in the chloride solution, just as in the formation of electrolytic copper in an electrolytic bath the copper goes toward the electro negative pole and the more electro positive or alkaline parts of the solution, and as in Fernekes' experiments, toward the hotter parts of the solution."

Dr. Lane in concluding his remarks on the formation of the copper says:* "It will be seen that my studies have led to no radical change in the views as to the origin of copper expressed by me in annual report for 1903 and by Wadsworth in the Transactions of the American Institute of Mining Engineers (XXVII p. 669) and by Pumpelly earlier.

"Copper should then be looked for not merely along pervious lines but near pervious lines, with a strong tendency to appear in hanging and foot and the mineral crest or richest part of a lode will be in the salt water belt, adjacent, either to right, left or below where the downward absorption has gone deeply."

*Keweenaw Series of Michigan. Mich. Geol., Survey, 1912, p. 873.

In summing up his studies on alteration of the minerals and composition of the mine waters, Dr. Lane states:* "Pumpelly's theories seem to be altogether confirmed except that chlorine rather than sulphuric anhydride was the acid radical."

THE DEPOSITION OF COPPER BY SOLUTIONS OF FERROUS SALTS.

H. C. Biddle has discussed† the conditions under which copper may be deposited by solutions of ferrous salts. He cites several reactions by which copper has been deposited in the laboratory. He shows that in a solution containing few ferric ions and in which the reaction does not result in their appreciable increase a sufficient concentration of ferrous and copper ions will result in the deposition of metallic copper. He concludes from his results that the conditions under which the oxidation of ferrous salts may result in the deposition of copper are those which obtain, in underground waters and that the theory of Pumpelly and others based on paragenetic relations is thus fully sustained by chemical evidence.

H. N. Stokes.—Among the experimental investigations on solutions containing copper, those described in a paper‡ by Mr. H. N. Stokes are also of a nature to corroberate the views of Pumpelly. Stokes devised a simple apparatus to illustrate the behavior of hot ascending solutions. In the lower and warmer part the reaction between the mineral or metal and the solution was brought about, while in the upper cooler part the reaction was reversed, with deposition of the metal. The apparatus was filled with a solution of ferrous sulphate and cupric sulphate and the lower limb heated at 200° C. After an hour a crystalline deposit of copper was observed in the upper limb, and after 20 hours there was an abundant crystallization of copper. Hematite was deposited in the lower limb.

The reactions are represented by the equations.

$$2\,Cu\,SO_4 + 2\,Fe\,SO_4 = Cu_2\,SO_4 + Fe_2\,(SO_4)_3.$$
$$Cu_2\,SO_4 = Cu + Cu\,SO_4.$$

The fact that a solution saturated with cuprous sulphate will deposit metallic copper on cooling, as represented in the second equation, had been previously shown by several investigators as stated by Mr. Stokes.

DEPOSITION OF COPPER FROM CHLORIDE SOLUTIONS.

G. Fernekes.—Having in view the fact that the copper mine waters are essentially chlorides with only traces of sulphates, Gustave Fernekes

*Loc. cit., p. 868.
†Jour. Geol. Vol. IX, 1901, pp. 430-438.
‡Economic Geology, Vol. I, 1906, p. 644.

carried out experiments to determine whether copper would be deposited from chloride solutions in the same way as Dr. Stokes had found copper to be precipitated from copper sulphate solution by means of ferrous sulphate. In the preliminary experiments, carried out according to the method of Stokes, no copper was precipitated. This failure to precipitate copper from chloride solution Dr. Fernekes attributed to the fact that metallic copper is soluble in hot dilute hydrochloric acid whereas dilute sulphuric acid which was set free in Stokes' experiments has absolutely no effect upon the copper. The reactions which take place are—

1. $2\,FeSl_2 + 2\,Cu\,2l_2 = Cu_2\,Cl_2 + 2\,Fe\,Cl_3.$
2. $2\,Fe\,Cl_2 + 2\,Cu\,Cl = 2\,Cu + 2\,Fe\,Cl_3.$
3. $Fe\,Cl_3 + 2\,H_2O = Fe\,(O\,H)_2\,Cl + 2\,H\,Cl.$

Reaction three takes place at high temperatures and fairly dilute solutions.

Having determined that copper is deposited only when the acid liberated in this reaction is neutralized, Dr. Fernekes then added some of the minerals common in the ores and repeated the experiments. He found that in the presence of prehnite or datolite, copper is deposited. As these minerals are very common in the ores, the experiment has very important significance. Dr. Fernekes' description, as given in Economic Geology Vol. II, p. 581 is as follows:

"To make the precipitation of copper possible according to the above reactions, the hydrochloric acid must be constantly neutralized. This neutralization can be brought about by the carbonates or silicates of calcium and sodium. Calcium hydroxide was first tried, then calcium carbonate and finally calcium silicate in the form of the mineral wollastonite. The experiments were successful, the copper being deposited in from ten to fifteen minutes heating at 200° C.

"Complete precipitation required a somewhat longer time. It is evident that the more soluble the neutralizing mineral is in hydrochloric acid the more efficient it is for rapid neutralization and consequent precipitation of the copper. It also seems probable that we would be able to obtain crystalline copper more readily if a slower neutralization took place than in the above experiments where in fact the copper came down in a fluffy condition.

"At this point Dr. Lane suggested the following minerals, common in this region, which may have taken part in the neutralization of the free acid; labradorite, prehnite, laumontite, datolite, analcite and pectolite. Of these minerals the first there were present in the rocks before the copper deposits were formed and the last three are closely associated with the metal. The first four minerals were tried but positive results were obtained only with prehnite and datolite. Since the conditions of the experiments, as finally carried out, were slightly different from those described by Stokes, it may be well to mention a few of the modifications introduced. Instead of employing a metal bath as did Stokes, an ordinary sand bath was used. The thermometer was placed alongside of the sealed tube containing the solutions. As explosions are not frequent this arrangement is perfectly satisfactory. The total length of the tubes employed was also greater, being about eighteen inches. The upper limb of the tube was surrounded by a water jacket. The temperature of the lower limb ranged from 200° C. to 280° C. The material was introduced into the tube in the following order; first about five grams of the neutralizing mineral, finely ground and freed from possible admixture of copper by treatment with nitric acid; then 0.2 grams of copper chloride; and finally a solution of ferrous chloride, containing an excess over that required to precipitate all of the copper. A few crystals of potassium bromide were also added. The solution which was always slightly acid, due to the ferrous chloride, was then almost neutralized by the action of sodium carbonate, filled to the top with water and sealed.

"In the case of prehnite, perfect circulation of the liquid about the mineral continued for about five hours when heated to 200° C. At the end of this time the basic iron salt formed in the reaction covered the small surface of the exposed prehnite to the height of two to three centimeters and consequently further action proceeded very slowly. Occasional cooling of the lower limb of the tube was therefore resorted to and by this means the solution was drawn back into the mineral, constantly exposing new surfaces. The tubes were heated intermittently for ten hours during the day. The heat was removed in the evening and again applied the next morning. After heating the solution and prehnite in this manner for five days an explosion took place at about 250° C. A portion of the side of the tube about five centimeters from the bottom was blown off, leaving a fairly hard cake underneath. On examining this cake of mineral with a small hand lens, it was found to be interspersed with shiny particles of crystalline copper. A few chemical tests were made. The particles were soluble in nitric acid with the evolution of brown fumes. They were insoluble in dilute hydrochloric acid, which fact distinguished them from cuprous oxide, and they precipitated metallic silver from neutral silver nitrate solution. The prehnite had become much darkened and the particles of the mineral were stained red in places with iron oxide.

"Datolite was acted upon in a similar manner for six days, at the end of which time minute crystals of copper could be detected throughout

the mass of the mineral. Experiments with laumontite and labradorite have up to the present time been unsuccessful."

AUTHOR'S CONCLUSIONS AS TO ORIGIN OF THE DEPOSITS.

Some characteristics of the deposits to be considered in any hypothesis of origin may be here briefly restated.

The copper occurs almost entirely as native metal. A little copper occurs as arsenides and sulphides in fissure veins.

The associated minerals are chiefly calcite, quartz, delessite, chlorite, epidote, prehnite and iron oxides.

The copper occurs in parts of the rock which show abundant evidence of decomposition.

Some copper occurs as a filling in fissures or porous beds.

Some copper occurs in fractures which extend along the beds, and also in minor fractures extending in all directions.

Most of the copper occurs as a replacement deposit.

In the amygdaloids some copper occurs in the amygdules; but most of it does not.

In the conglomerates most of the copper occurs in the matrix, but some in the pebbles.

The deposits are confined to the Keweenaw series and all but one of the important ones are in the lower part, which is very largely igneous.

Most of the workable deposits are amygdaloids, but the richest* of all is the Calumet conglomerate which is interbedded with volcanic rocks.

Many of the deposits have thick and relatively impervious traps overlying them.

The amygdaloid lodes are parts of thick beds, mostly ophites. The lode rock seldom has a fresh crystalline appearance and is commonly a dull brownish or greenish mass of secondary minerals containing amygdules, seams and shapeless masses of calcite, quartz, epidote, delessite, and chlorite.

A consideration of these and other facts and a study of the literature leads the writer to the following conclusions:

The copper and the Keweenawan igneous rocks had a common origin. Two hypotheses present themselves: (1) the copper was deposited with the rock constituents, as silicate or other minerals, and subsequently dissolved and reprecipitated in the lodes as native copper, and (2) the copper was never so disseminated through the rocks and the native copper is essentially a primary deposit from solutions which accompanied and followed the extrusion of lava.

Abundance of chlorides in the mine waters indicates that the native

*Exception must be made of the very rich but much smaller deposits in fissure veins.

copper was deposited from a chloride solution rather than from a sulphate solution. Sulphides are rare in the copper deposits and sulphates are only very occasionally found and it is therefore unlikely that sulphur was an abundant constituent of the solutions from which copper was deposited.

The copper is essentially a replacement deposit. Some has doubtless simply filled cavities in the porous rocks; but most of it has taken the place of other minerals which were decomposed and removed.

This replacement is not to be regarded as a secondary concentration long after the formation of the Keweenawan rocks, but rather as a result of reactions which took place while the rocks were still hot, though solid and fractured. The deposits are of Keweenawan age.

The occurrence of the same minerals with the native copper is remarkably characteristic of all the deposits and leads directly to the conclusion of a common origin for the copper of all the lodes, conglomerate beds, amygdaloid beds and fissure veins alike, as suggested by Pumpelly, Irving and Wadsworth.

Almost invariably there occur with copper the following minerals: Chlorite, epidote, calcite, quartz, prehnite and hematite. These, as Pumpelly has shown have, like the copper, replaced other minerals, and their formation was doubtless due in part at least to the copper-bearing solutions. Their constituents were for the most part present in the rocks in which they are now found and they are to be regarded as secondary minerals formed by the action not of ordinary meteoric solutions but by solutions partly of magmatic origin containing considerable copper and probably hot.

The deposition of the copper as native metal was probably due to reactions similar to those of Stoke's experiments with sulphate solutions; but from chloride solutions in presence of a neutralizing mineral as in Fernekes' experiments. The abundance of ferrous iron in the minerals in the original rocks and of ferric iron in the altered rocks indicates clearly the presence of an efficient reducing agent as suggested by Pumpelly.

There is very little evidence in favor of the view that the deposits were formed by meteoric waters.

Because in many districts native copper occurs near the surface of sulphide deposits under such conditions that it is believed to have resulted from oxidation of sulphides, some geologists express the opinion that the native copper of the Michigan deposits has been formed as a secondary product by the oxidation of sulphides. In the opinion of the author there is no good reason to believe that the copper was first formed as a sulphide or that the copper was formed from any other mineral by meteoric waters near the surface.

Because numerous investigators have found that copper is a very common constituent of the Keweenawan rocks and occurs in small quantities in nearly all localities there is some reason to believe that there may be some copper present in the silicates, probably in the pyroxenes. Analyses of numerous specimens of so called "fresh" Keweenawan rocks have shown copper to be almost universally present. It does not follow that the copper is present in the silicates, however, as it is just as probably present as native copper. It is folly to assume that because native copper is not visible to the naked eye that it is not present.

The numerous Keweenawan rocks examined by the writer are all more or less altered. Some are called "fresh" because they appear comparatively little altered. It is merely a matter of degree.

The author is therefore of the opinion that while the copper may be present in the form of a silicate is is just as probably present as microscopic particles of the native metal.

To state that the copper was first present as a silicate therefore only results in bringing into the question another unknown. There are unknowns enough already. The simpler hypothesis is by the author regarded as the better one. Of the two hypotheses (1) and (2) mentioned early in this discussion the author prefers (2) that the native copper is essentially a primary deposit from solutions which accompanied and followed the extrusion of the lava. The rocks were certainly fractured and possibly tilted before deposition of native copper ceased. It is possible that very little deposition took place before the rocks were extensively fractured.

It has been frequently stated that the ore bodies become gradually lower in grade with depth and that this points to formation of the deposits by descending waters. Before any useful deductions regarding the deposition of the copper can be made from the falling off in values with depth it is necessary to consider the facts more carefully. It is true that the ore now being mined at great depth is much leaner than that mined at some higher levels; but reference to descriptions of the various lodes will convince the reader of the inaccuracy of the general statements of gradual decrease with depth. The richer portions have terminated at some depth of course; but they terminate laterally in just the same way. There is no marked difference between the falling off in values with increase in depth and the falling off in values that is found in extending the openings laterally. Because some of the lodes are being mined for several miles it must not be imagined that the ore bodies are continuous. Rich and poor ground alternate. At and near the surface the lodes have been tested at intervals and the richer minable portions discovered. There is unfortunately no similar means of locating any ore bodies which may lie at some distance below the present mine openings. The statement that the deep openings on the most productive lodes are in much leaner ore than was mined years ago is unfortunately only too true. It is not however a characteristic peculiar to depth alone. It is one that has taken longer to determine for depth than for length.

There is a remarkable similarity between the ore from near the surface and ore from depths of several thousand feet. Minor differences are noted, disintegration and some weathering has taken place near the surface. It is common experience that the lodes for the first few hundred feet are rather softer and more fractured than at greater depth. Yet the peculiar feature is that the ore is essentially the same; the same minerals occuring in the same way.

This uniformity in the character of the ore leads the writer to the conclusion that little change has taken place in the distribution of the copper since the deposits were first formed in Keweenawan time. The formation has been further tilted and faulted since deposition of copper ceased, and some secondary deposits have filled the later fractures formed; but the ore bodies themselves have been little changed. The lodes and enclosing rocks have been weathered and then glaciated. There is no reason to believe that the formation of the ore bodies has been in any way dependent on the present surface. The latter is the result of changes which took place long after the formation of the ore deposits.

Summary of Author's Conclusion as to Origin of the Copper Deposits

The native copper deposits were formed in Keweenawan time and have been but slightly altered since.

The native copper and the Keweenawan igneous rocks had a common origin.

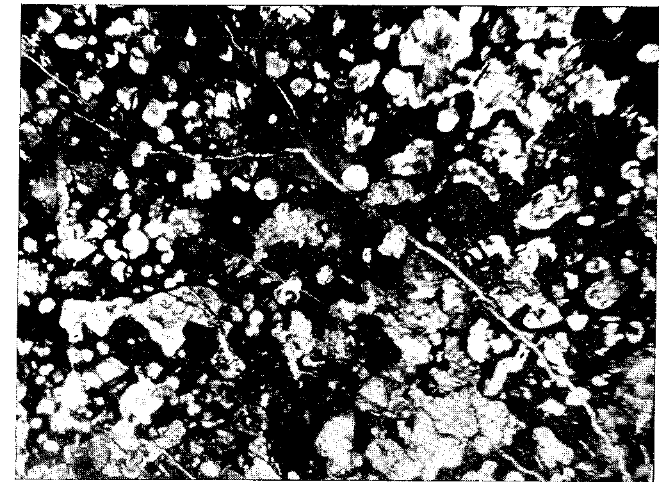
The native copper is essentially a primary deposit from solutions which accompanied and followed the extrusion of lava.

Deposition took place while the rocks were still hot; but after they were fractured.

As pointed out by Dr. Hubbard, fracturing along or nearly along the bedding planes had occurred before deposition of copper ceased and possibly before any considerable deposition had taken place. The fracturing of the rocks was an important factor in determining the nature of the deposits, the fractures affording continuous channels for movement of solutions.

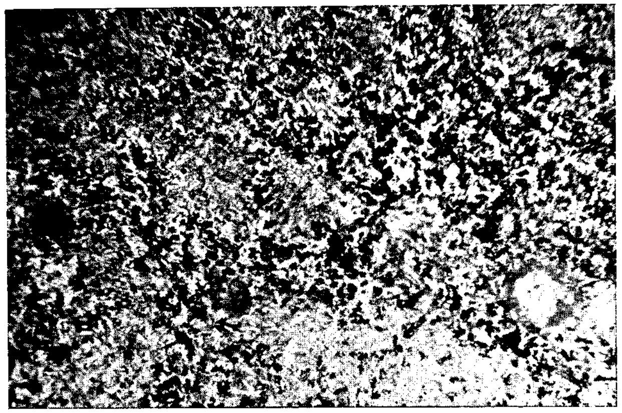
The deposits are replacement deposits.

The native copper was probably precipitated from a chloride solution.

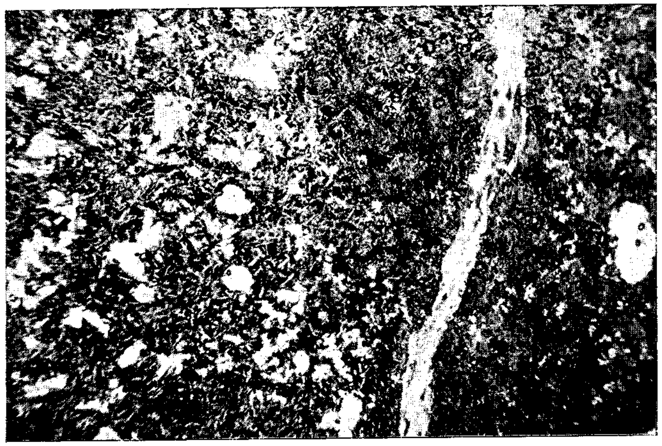


A. ALGOMAH LODE, ALGOMAH MINE, ONTONAGON COUNTY. PHOTOMICROGRAPH X 10. THIS IS A VERY VESICULAR PORTION OF THE LODE. SOME OF THE BLACK AREAS ARE MELACONITE, OTHERS THE DARK BROWN GROUND MASS OF THE ROCK. THE VEINLET AND SOME OF THE IRREGULAR AREAS ARE CHRYSOCOLLA.

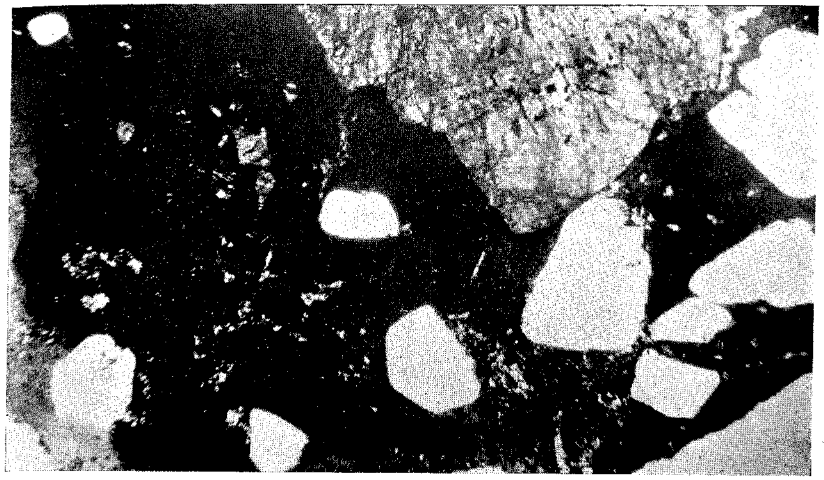
B. BUTLER LODE, MASS MINE, ONTONAGON COUNTY. PHOTOMICROGRAPH X 10. THIS MICROSCOPIC SECTION SHOWS A FINE TEXTURED GROUND MASS AND AMYGDULES. THE LATTER ARE CHIEFLY COMPOSED OF RED FELDSPAR, QUARTZ AND CALCITE. THE DARK RED AND STAINED SEMIOPAQUE FELDSPAR FORMS THE OUTER PART OF THE AMYGDULE. THE CLEAR TRANSPARENT CALCITE AND QUARTZ WERE DEPOSITED AFTER THE FELDSPAR AND FILLED THE CENTRAL PART OF THE CAVITIES. THE COPPER IN THIS SECTION OCCURS IN FINE GRAINED GROUND MASS AND NOT IN THE AMYGDULES.



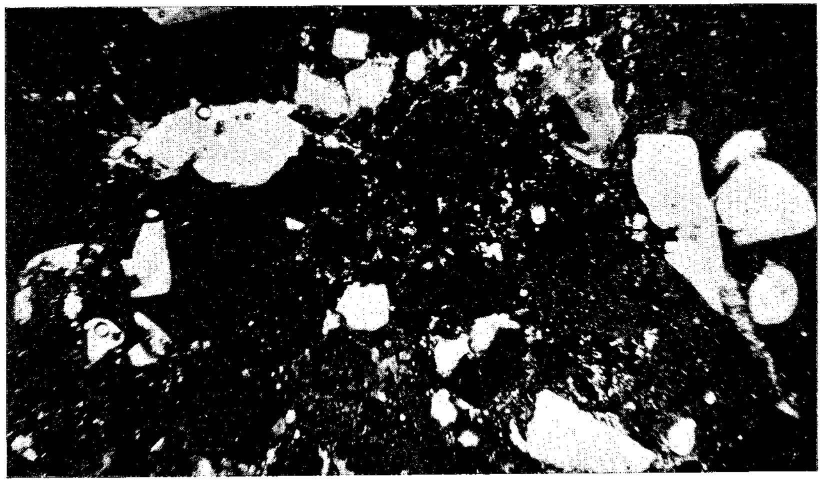
A. BALTIC LODE, BALTIC MINE. PHOTOMICROGRAPH X 10. THIS THIN SECTION SHOWS FINE GRAINED ROCK WITH VERY FEW CAVITIES. IT ILLUSTRATES THE TEXTURE OF A LARGE PORTION OF THE BALTIC LODE.



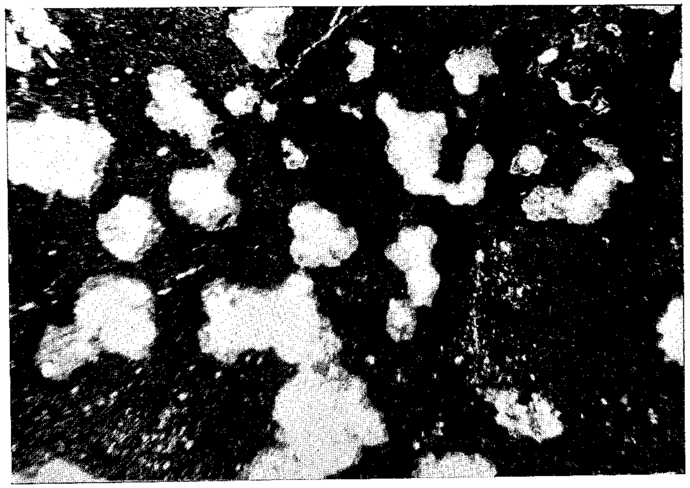
B. BALTIC LODE. PHOTOMICROGRAPH X 8. THIS SECTION SHOWS THE VESICULAR PORTION OF THE BALTIC LODE AND A VEINLET OF CALCITE. A CONSIDERABLE PORTION OF THE COPPER IS IN ROCK WHICH HAS BEEN FRACTURED AND LATER CEMENTED WITH CALCITE AND OTHER MINERALS. COPPER OCCURS IN FRACTURE FILLINGS BUT MORE LARGELY IN THE ALTERED ROCK NEAR THE FRACTURES.



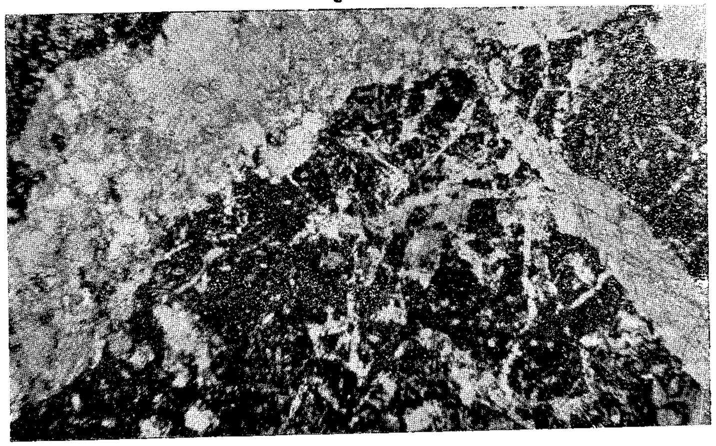
A. CALUMET CONGLOMERATE, CALUMET AND HECLA MINE. PHOTOMICROGRAPH X 12. THIS IS A TYPICAL SECTION OF THE QUARTZ PORPHYRY OF THE CALUMET CONGLOMERATE SHOWING NUMEROUS CLEAR CRYSTALS OF QUARTZ IN A NEARLY OPAQUE FELSITE GROUND MASS. THE QUARTZ PORPHYRY PEBBLES CONTAIN SUCH NUMEROUS RED PARTICLES THAT THE GROUND MASS IS TRANSPARENT ONLY IN VERY THIN SECTIONS.



B. CALUMET CONGLOMERATE. PHOTOMICROGRAPH X 8. THE CONGLOMERATE IS MADE UP LARGELY OF FRAGMENTS OF QUARTZ PORPHYRY BUT THE ROCK CONTAINS SO MANY MINUTE RED PARTICLES THAT IT IS NEARLY OPAQUE IN THIN SECTION. THE CLEAR TRANSPARENT AREAS ARE QUARTZ.

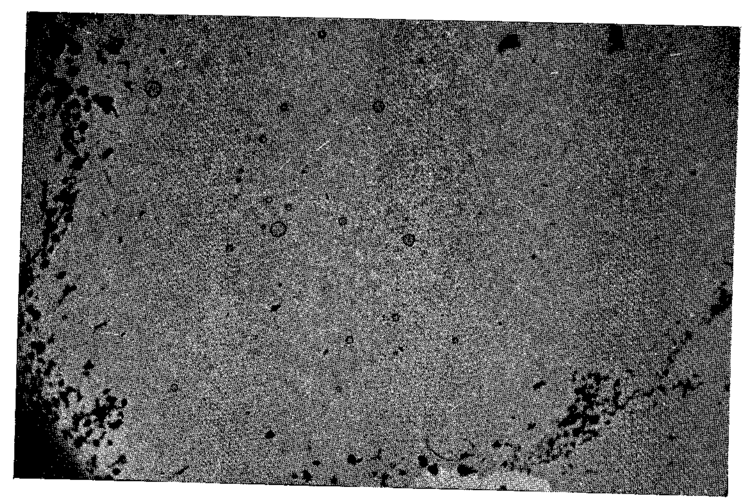


A. HANCOCK NO. 3 LODE, HANCOCK MINE. PHOTOMICROGRAPH X 10. THIS LODE IS A TYPICAL AMYGDALOID. THE AMYGDULES IN THIS PARTICULAR SECTION ARE COMPOSED OF CHLORITE, QUARTZ AND CALCITE. MOST OF THE SEMI-OPAQUE CHLORITE HAS BEEN DEPOSITED EARLIER THAN THE CLEAR TRANSPARENT QUARTZ AND CALCITE.



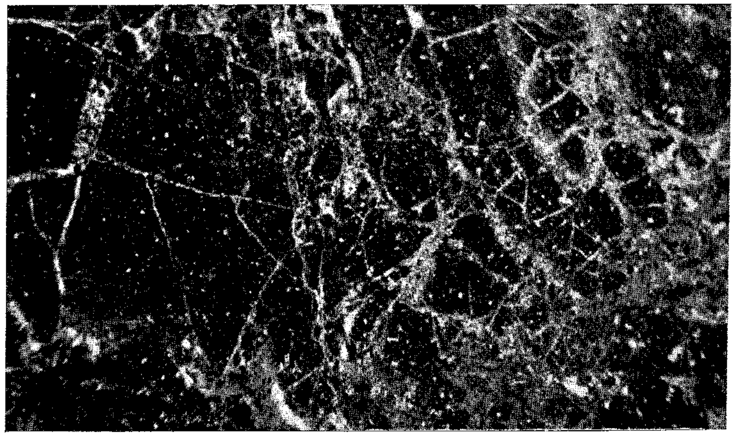
B. HANCOCK LODE NO. 4, 34TH LEVEL. PHOTOMICROGRAPH X 8. THIS SECTION SHOWS VEINLETS OF CALCITE IN A NEARLY OPAQUE ROCK WHICH IS AN ALTERED PORPHYRITE.

A. HANCOCK LODE. PHOTOMICROGRAPH. THIS SECTION SHOWS NATIVE COPPER IN RATHER LARGE PARTICLES ALONG THE MIDDLE OF A VEIN OF PREHNITE. COPPER OCCURS ALSO IN SMALL PARTICLES IN THE ROCK ON EITHER SIDE OF THE VEIN.

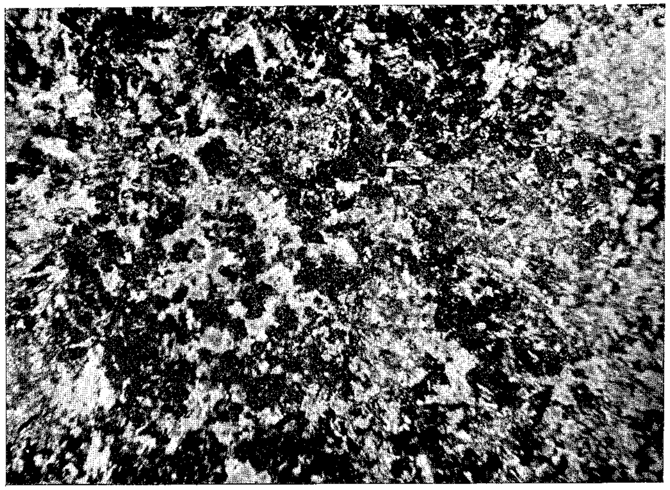


B. PHOTOMICROGRAPH X 9. THIS SECTION SHOWS MODE OF OCCURENCE OF NATIVE COPPER (BLACK) IN DATOLITE (WHITE). (RINGS ARE AIR BUBBLES IN THE BALSAM ON WHICH THE SECTION IS MOUNTED). FRANKLIN JUNIOR MINE.

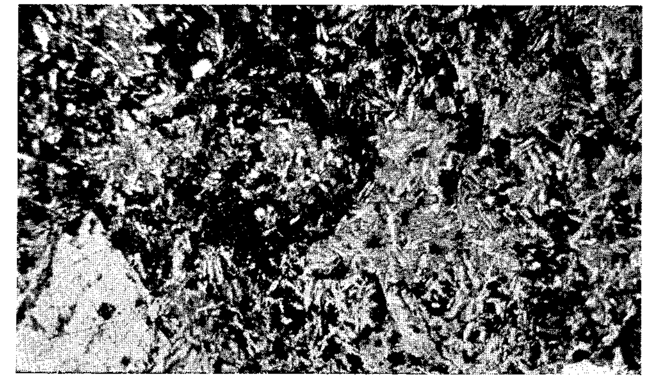
THE DATOLITE OF THE FRANKLIN MINE IS A WHITE VARIETY. IT OCCURS FREQUENTLY AS ROUNDED MASSES SEVERAL INCHES IN DIAMETER. THE CENTRAL PART OF THESE MASSES IS OFTEN FREE FROM COPPER. NEAR THE OUTER EDGE, HOWEVER, NUMEROUS SMALL PARTICLES OF COPPER OF IRREGULAR SHAPE, AS SHOWN IN THIS HALFTONE, ARE GENERALLY FOUND.



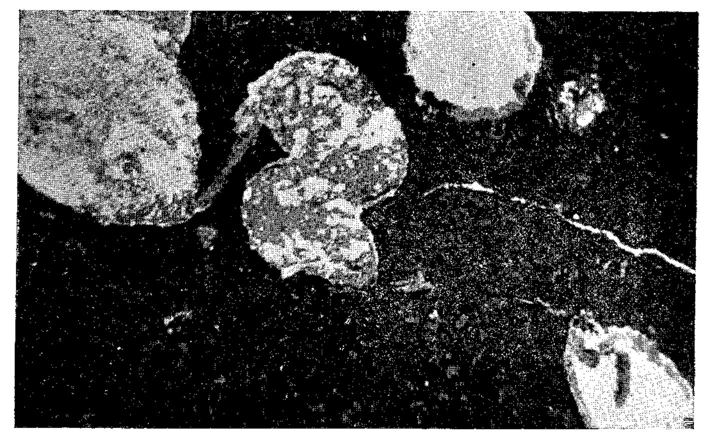
A. FELSITE, INDIANA MINE, ONTONAGON COUNTY. PHOTOMICROGRAPH X 10. THE FELSITE IS SEMI-OPAQUE OWING TO THE ABUNDANCE OF DARK RED COLORED PARTICLES. SEVERE FRACTURING IS INDICATED BY NUMEROUS VEINLETS OF COLORED MINERALS WHICH HAVE FILLED THE FRACTURES.



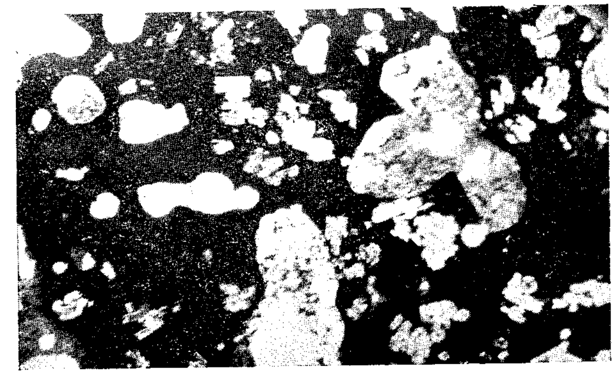
B. ISLE ROYALE LODE, ISLE ROYALE MINE. PHOTOMICROGRAPH X 8. THIS SECTION SHOWS A FINE TEXTURED ROCK WITH NO AMYGDULES. A CONSIDERABLE PORTION OF THE ORE HAS THIS TEXTURE. OTHER PARTS ARE QUITE VESICULAR.



A. KEARSARGE LODE, MOHAWK MINE. PHOTOMICROGRAPH X 8. THIS SECTION SHOWS A RATHER DISTINCTLY CRYSTALLIZED PORPHYRITIC ROCK. THE SPECIMEN WAS TAKEN NEAR THE FOOT WALL OF THE LODE.

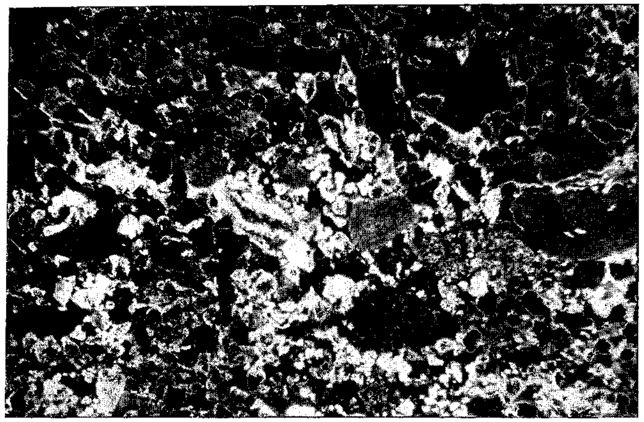


B. ISLE ROYALE LODE, ISLE ROYALE MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS LARGE AMYGDULES AND A VERY FINE GRAINED GROUND MASS. THE SEMI-OPAQUE MINERAL IN THE AMYGDULES IS EPIDOTE. THE CLEAR COLORLESS MINERAL IS QUARTZ. IN TWO CASES THE EPIDOTE FORMS THE MARGIN; IN THE OTHERS IT IS IRREGULARLY INTERGROWN WITH QUARTZ.

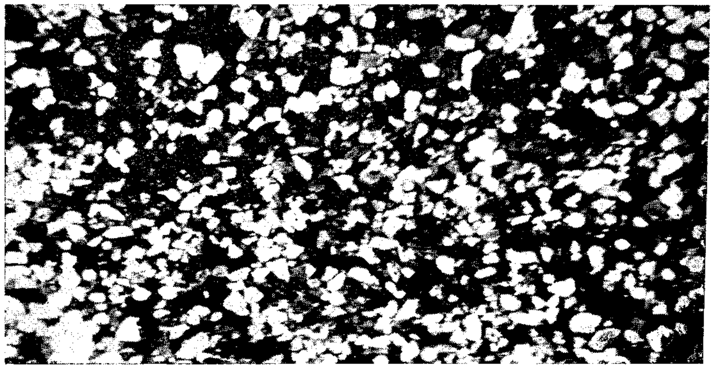


A. LAKE LODE, LAKE MINE. PHOTOMICROGRAPH X 12. THIS SECTION SHOWS BOTH AMYGDULES AND PORPHYRITIC FELDSPAR CRYSTALS IN AN OPAQUE GROUND MASS. THE AMYGDULES SHOW CLEAR TRANSPARENT QUARTZ AND CALCITE AND SEMI-TRANSPARENT CHLORITE.

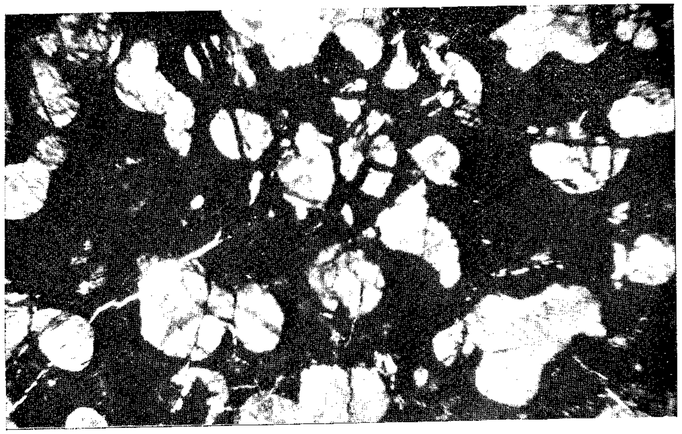
B. LAKE LODE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A PSEUDOAMYGDALOIDAL PORTION OF THE LODE. THE CLEAR TRANSPARENT AREAS ARE CHIEFLY PALE GREEN CHLORITE. THE GROUND MASS IS DISTINCTLY CRYSTALLINE.



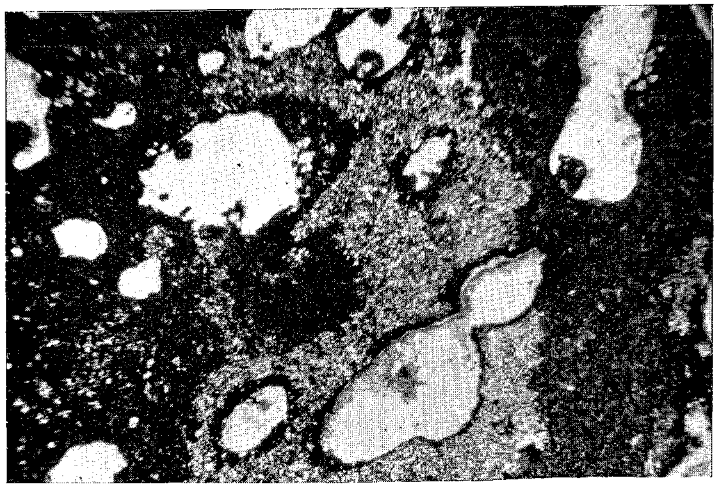
A. NONSUCH SANDSTONE, WHITE PINE MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A FINE GRAINED CONGLOMERATIC ROCK. THE COLORLESS PEBBLES ARE QUARTZ. THE LARGE GRAINS ARE FELSITE AND MELAPHYRE. SOME OF THE SMALL OPAQUE PARTICLES ARE NATIVE COPPER.



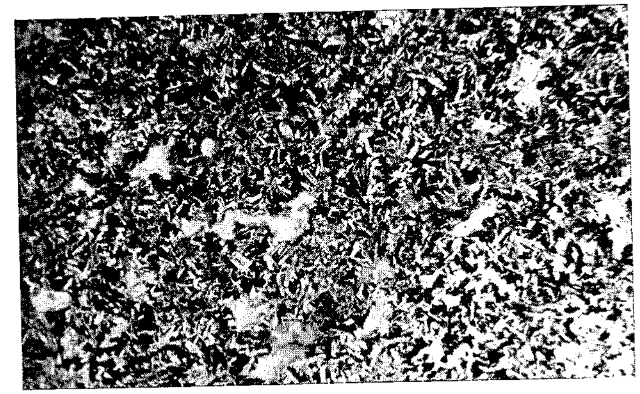
B. NONSUCH SANDSTONE, WHITE PINE MINE. THIS SECTION SHOWS A FINE GRAINED SEDIMENTARY ROCK COMPOSED CHIEFLY OF CLEAR COLORLESS GRAINS OF QUARTZ AND DARK COLORED ROCK PARTICLES. SOME OF THE OPAQUE PARTICLES ARE NATIVE COPPER AND SOME ARE MAGNETITE.



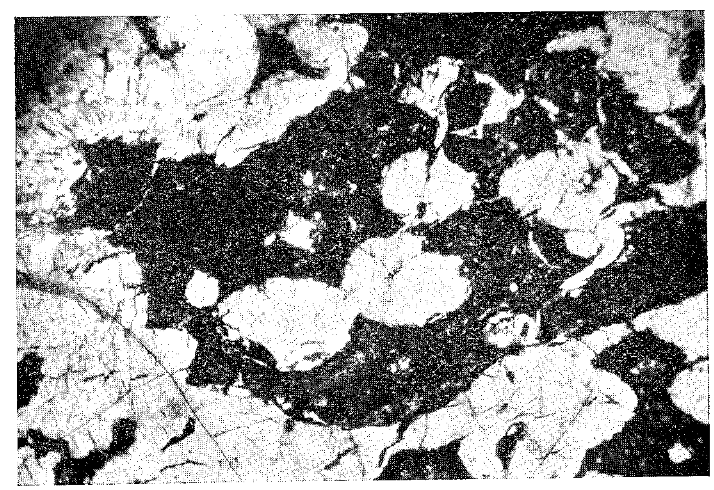
A. PEWABIC LODE. QUINCY MINE. PHOTOMICROGRAPH X 8. PREHNITE IS VERY ABUNDANT IN THE ORE AT THE QUINCY MINE. THIS SECTION SHOWS NUMEROUS AMYGDULES OF PREHNITE IN THE OPAQUE GROUND MASS. SOME OF THE OPAQUE PARTICLES IN THE PREHNITE ARE NATIVE COPPER.



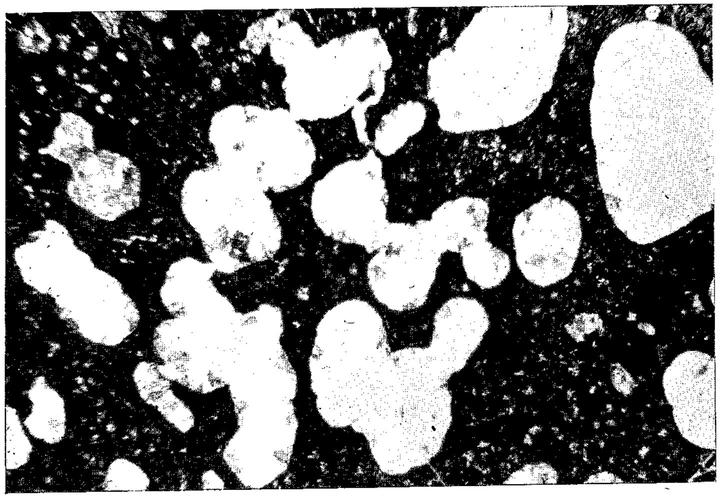
B. PEWABIC LODE, FRANKLIN JUNIOR MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A TRUE AMYGDALOIDAL PORTION OF THE LODE. CRYSTALS OF DELESSITE (SEMI-OPAQUE) APPEAR AT THE BORDER OF CLEAR TRANSPARENT QUARTZ WHICH IS THE CHIEF CONSTITUENT OF THE AMYGDULES IN THIS SECTION.



A. PEWABIC LODE, QUINCY MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A PSEUDO-AMYGDALOIDAL PORTION OF THE LODE FROM NEAR THE FOOTWALL. THE LARGE TRANSPARENT PATCHES ARE SECONDARY CHLORITE. THEY HAVE NOT THE CHARACTER OF TRUE AMYGDULES.

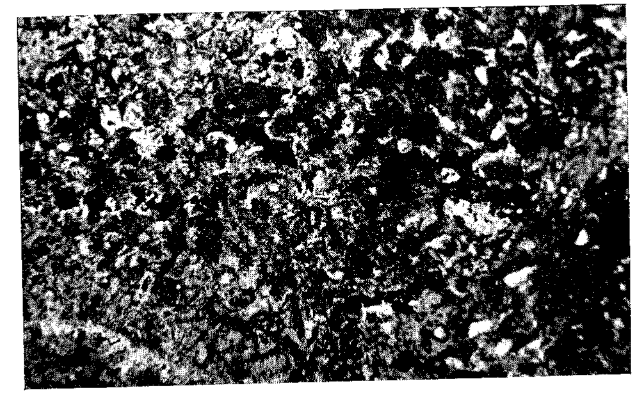


B. PEWABIC LODE, QUINCY MINE. PHOTOMICROGRAPH X 8. NATIVE COPPER IN PREHNITE. THIS IS A PORTION OF THE LODE WHICH HAS BEEN LARGELY REPLACED BY PREHNITE (WHITE IN PHOTOGRAPH). IN THE WHITE PREHNITE ARE SEVERAL IRREGULAR PARTICLES OF COPPER. THE MAIN DARK COLORED PART OF THE SECTION IS ALTERED ROCK CONTAINING PARTICLES OF NATIVE COPPER.

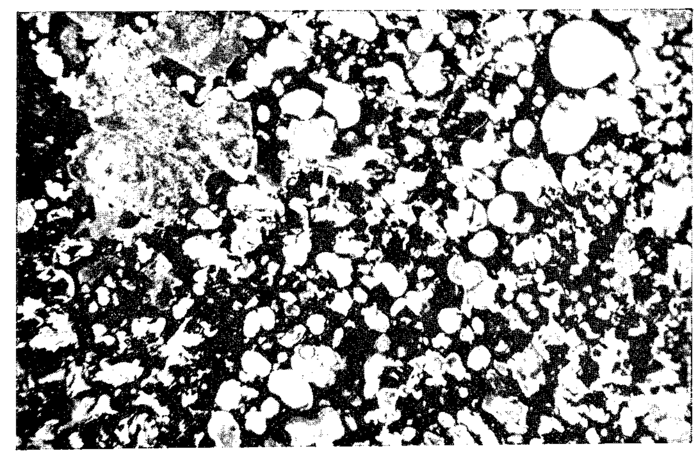


A. KEARSARGE LODE. WOLVERINE MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A TYPICAL AMYGDALOID WITH NUMEROUS LARGE AMYGDULES. THE CLEAR COLORLESS MINERAL IS QUARTZ. THE SEMI-OPAQUE CRYSTALS NEAR THE EDGE OF THE AMYGDULES ARE EPIDOTE.

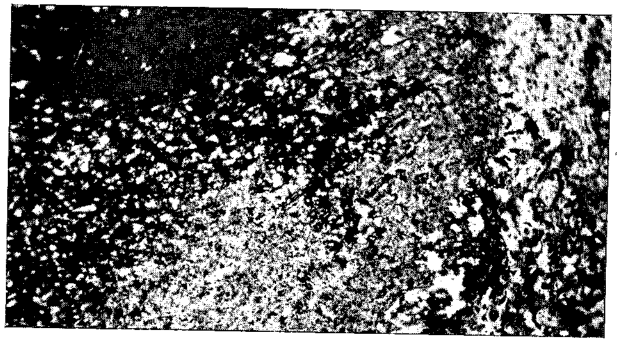
B. SUPERIOR LODE, HOUGHTON MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS COARSE PARTICLES OF NATIVE COPPER IN LARGE AMYGDULES. IN THE DARK GROUND MASS THERE ARE NUMEROUS FINE PARTICLES OF METAL. THE LACK OF CRYSTALLINE STRUCTURE IN THE GROUND MASS IS NOTEWORTHY.



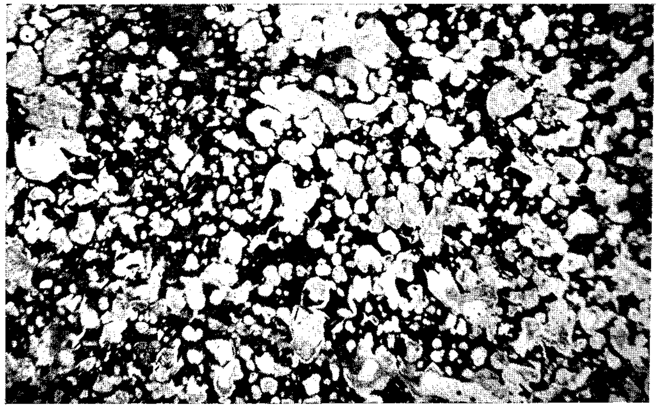
A. SUPERIOR LODE, SUPERIOR MINE. PHOTOMICROGRAPH X 12. THE COPPER IN THIS SECTION IS IN VERY SMALL PARTICLES SCATTERED THROUGH A FINE GRAINED ROCK.



B. SUPERIOR LODE, SUPERIOR MINE. PHOTOMICROGRAPH X 10. THIS IS A REMARKABLY VESICULAR COPPER BEARING ROCK. THE AMYGDULES ARE CHIEFLY CALCITE. THE OPAQUE GROUND MASS IS MADE UP OF A CONFUSED AGGREGATE OF PARTICLES TOO SMALL FOR IDENTIFICATION.



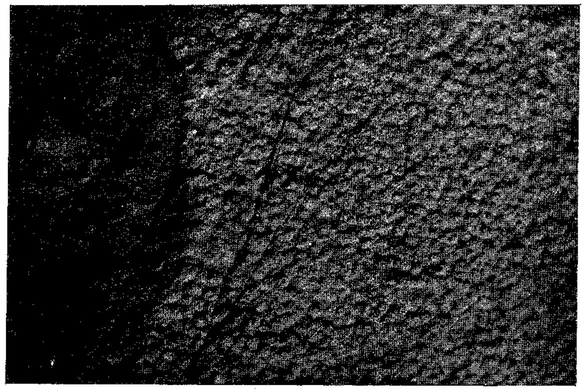
A. SUPERIOR LODE, SUPERIOR MINE. PHOTOMICROGRAPH X 10. THIS IS A DULL BROWN MASSIVE ROCK SHOWING NO COPPER TO THE NAKED EYE. NUMEROUS SMALL GRAINS OF COPPER ARE, HOWEVER, READILY OBSERVED UNDER THE MICROSCOPE. THE ORIGINAL TEXTURE OF THE ROCK HAS BEEN OBSCURED BY SECONDARY ALTERATION.



B. SUPERIOR LODE, SUPERIOR MINE. PHOTOMICROGRAPH X 10. THIS SECTION SHOWS A VERY VESICULAR ROCK. AMYGDULES ARE CHIEFLY CALCITE AND CONTAIN LITTLE COPPER. NATIVE COPPER OCCURS ABUNDANTLY IN VERY SMALL PARTICLES IN THE DARK GROUND MASS.

A. ALLOUEZ CONGLOMERATE, FRANKLIN JUNIOR MINE.

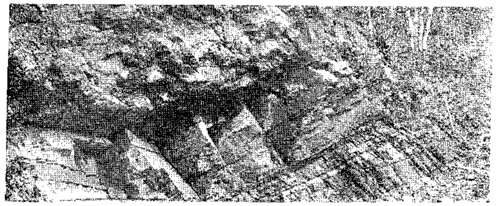
B. CALUMET CONGLOMERATE, TAMARACK MINE.



C. OPHITE, WEATHERED AND FRESH SURFACES. FRESH FRACTURE SURFACE AT LEFT.

A. COPPER SHELLS FROM CALUMET CONGLOMERATE.

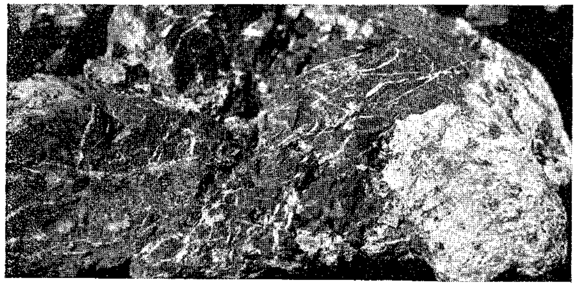
B. MASS COPPER, AHMEEK MINE.



C. SANDSTONE OVERLAIN BY TRAP, EAGLE RIVER.

D. EXPOSURE OF TRAP BED, HOUGHTON.

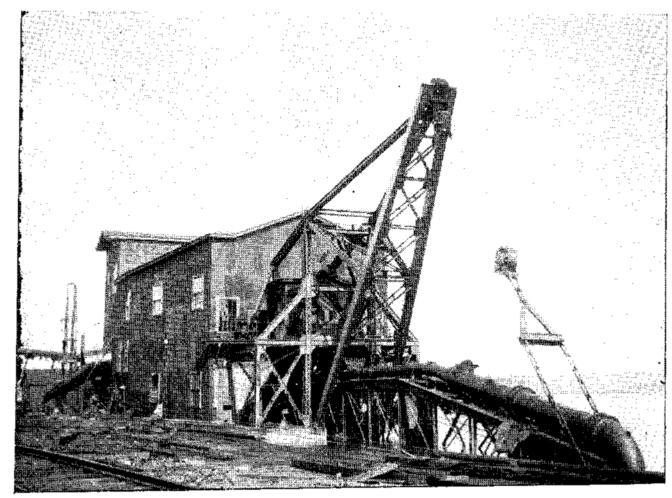
A. DOMEYKITE VEIN, ISLE ROYALE MINE.



B. MASS COPPER AND FISSURED COUNTRY ROCK,
AHMEEK MINE.

C. MASS COPPER, MICHIGAN SMELTER.

A. FOUNDATIONS OF THE TAMARACK RECRUSHING PLANT AND THE STAMP SAND IN TORCH LAKE.



B. THE LARGE DREDGE FOR HOISTING THE CALUMET AND HECLA STAMP SAND FROM TORCH LAKE.