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MINERAL RESOURCES OF MICHIGAN

WITH

STATISTICAL TABLES OF PRODUCTION AND VALUE OF MINERAL PRODUCTS

FOR

1914 AND PRIOR YEARS.

WITH A TREATISE ON MICHIGAN COPPER DEPOSITS BY

R. E. HORE.

PREPARED UNDER THE DIRECTION OF

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LETTER OF TRANSMITTAL.

To the Honorable, the Board of Geological and Biological Survey of the State of Michigan:

Gov. Woodbridge N. Ferris.
Hon. Wm. J. McKone.
Hon. Fred L. Keeler.

Gentlemen:—Under authority of act number seven, Public Acts of Michigan, Session of 1911, I have the honor to present herewith Publication 19, Geological Series 16, the fourth of a series of annual statements of the production and value of the mineral products of Michigan, with a special article by R. E. Hore on Michigan Copper Deposits.

Very respectfully,
R. C. ALLEN,
Director.

CONTENTS.

CHAPTER V.

The Copper Deposits or Lodes.

CHAPTER VI.

Origin of the Deposits.

The Copper Industry in 1914, Walter E. Hopper.

Statistical Tables.

PART II.

Non-Metallic Minerals, R. A. Smith.

Coal in Michigan.

APPENDIX.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES.

PART I. METALLIC MINERALS.

MICHIGAN COPPER DEPOSITS.

REGINALD E. HORE.

CHAPTER I.

LOCATION OF THE COPPER MINES.

Michigan's copper mines are located in the northwestern part of the state close to the south shore of Lake Superior. Most of them are in Houghton and Keweenaw counties on Keweenaw Point and the others are in Ontonagon County, which adjoins Houghton County on the south and west.

The district is easily reached by rail from the south, east and west. From Chicago trains to Houghton and Calumet are run by the Chicago, Milwaukee and St. Paul and the Chicago and Northwestern Railways. These enter the Copper Country on the tracks of the local railway companies, the Copper Range and the Mineral Range. From Sault Ste. Marie, St. Ignace and Duluth the copper mines are reached by the Duluth, South Shore and Atlantic Railway.

Keweenaw Point is also readily accessible by steamer. Portage Lake and a ship canal afford ready passage for the lake boats across the point and Houghton is a regular port of call for all passenger steamers running between Duluth and Sault Ste. Marie. The unusual transportation facilities are an important factor in the Michigan copper industry. Fuel and supplies from lower lake ports are brought to the mines at low cost.

Most of the copper produced is from Houghton County; but Keweenaw and Ontonagon also make important outputs and the richest of the younger mines, the Ahmeek, is in Keweenaw County. The deepest mines, the Calumet and Hecla and the Quincy, are both in Houghton County. According to B. S. Butler of the U. S. Geological Survey, 82.2% of the copper produced by Michigan mines in 1912 was credited to Houghton County. In the early days of the industry the chief production was from fissure-vein mines in Keweenaw County and bedded-vein mines in Ontonagon County.

Most of the important producers of today are located on a portion of the Copper Range about 25 miles long, extending from Painesdale in Houghton County to Mohawk in Keweenaw County. In order from southwest to northeast are the following well known mines: Champion, Trimountain, Baltic, Atlantic, Superior, Houghton, Isle Royale, Hancock, Quincy, Franklin, Osceola, LaSalle, Calumet and

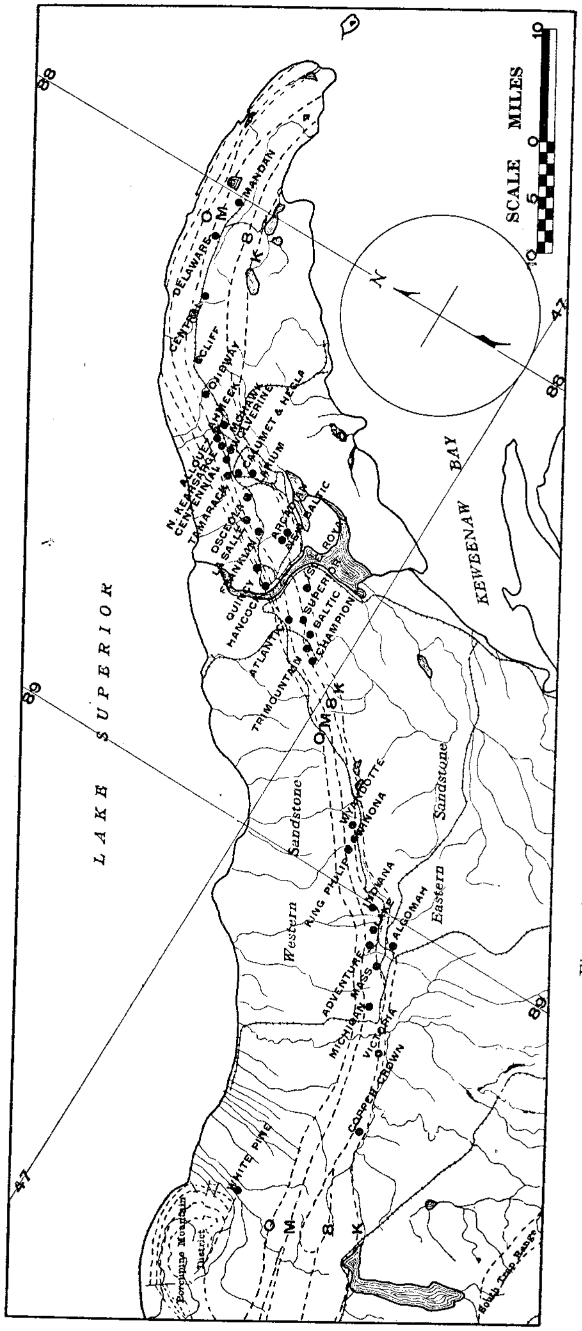

Figure 1. Outline map of Keweenaw Point showing location of mines.

Hecla, Tamarack, Centennial, South Kearsarge, Wolverine, North Kearsarge, Allouez, Ahmeek, Mohawk and Ojibway. Further southwest in Ontonagon County are the Lake, Mass, Adventure, Michigan and Victoria mines. Other active properties in Houghton County are Winona, Wyandot, New Baltic, New Arcadian, St. Louis, Laurium, Oneco and Naumkeag. In Ontonagon County shafts have been started and development work carried on at South Lake, North Lake and Indiana properties. In the Porcupine Mountain district, further west, the White Pine mine is being thoroughly tested by the Calumet and Hecla Mining Co. In Keweenaw County the Keweenaw Copper Company is doing extensive exploratory work with diamond drills.

Among old mines once productive but now idle, are the Cliff and Central in Keweenaw County and the Minesota in Ontonagon County.

CHAPTER II.

STRUCTURAL FEATURES OF KEWEENAW POINT.*

GENERAL GEOLOGY OF KEWEENAW POINT.

The Keweenaw peninsula has in its central part a plateau at an elevation of 400 to 600 feet above the lake level. From this the ground slopes down on either side, gradually towards the west and more abruptly towards the east. A valley occupied by the narrow arm of Portage Lake cuts across this plateau, and gives ready access for lake ships. Further out on the point the plateau drops away, and there is a short gap of lower land followed by two long ridges which extend with occasional gaps well out to the end of the point. The northern ridge is called the Greenstone Range, and the southern is known as the Bohemian Range.

The plateau and ridges along the central part of the peninsula are formed by the copper-bearing, Keweenawan formation, bedded igneous and sedimentary rocks dipping to the northwest, and striking with the general trend of the point. The western slope down to Lake Superior is formed by the upper members of the same series. The easterly part is formed by gently inclined Upper Cambrian sandstone, separated from the Keweenawan formation by a great fault which extends nearly the whole length of the point. The fault is from the evidence at hand supposed to be of the reverse type, the older series slipping up and over on the sandstone.

STRUCTURE OF THE COPPER-BEARING SERIES.

The Copper Range of Keweenaw Point is comparatively simple in its larger geological features. The outcrop shows but the eroded edge of one limb of a synclinal formation, which dips under Lake Superior and appears again on the north shore. The beds strike with the general trend of the shore line northeast. Near the extremity of the point the strike is almost due east, and at the very extremity the formation bends south of east. In following the range out towards the point, there is found a lessening of the inclination of the beds. In going from lower to higher horizons the same change in dip is found, the lower beds dipping more steeply than the upper ones. On follow-

*In this chapter merely an outline of the structure is given. For details the reader is referred to the monograph by Dr. A. C. Lane published by the Michigan Geological Survey, Publication 6, Geological Series 4.

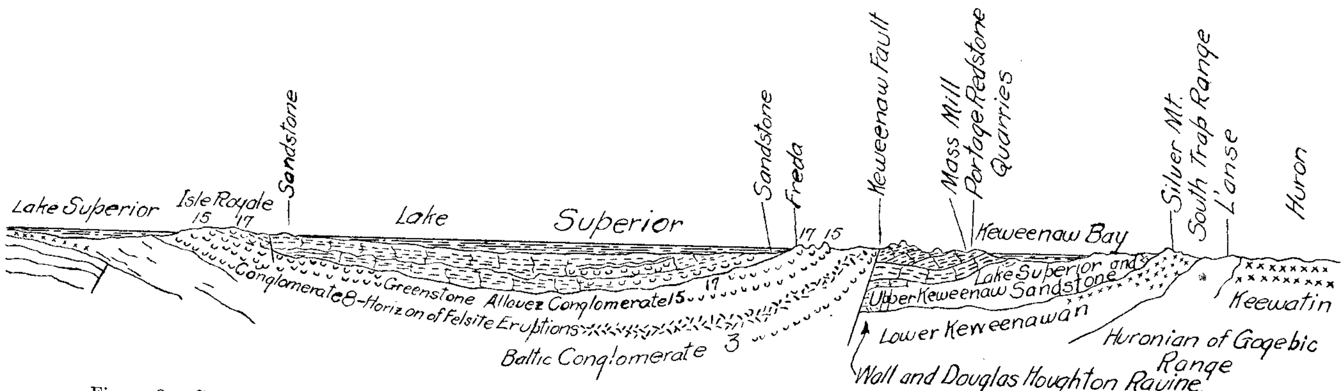

Figure 3. Cross section through Lake Superior from Huron mountains to Port Arthur (after A. C, Lane in Mines and Minerals).

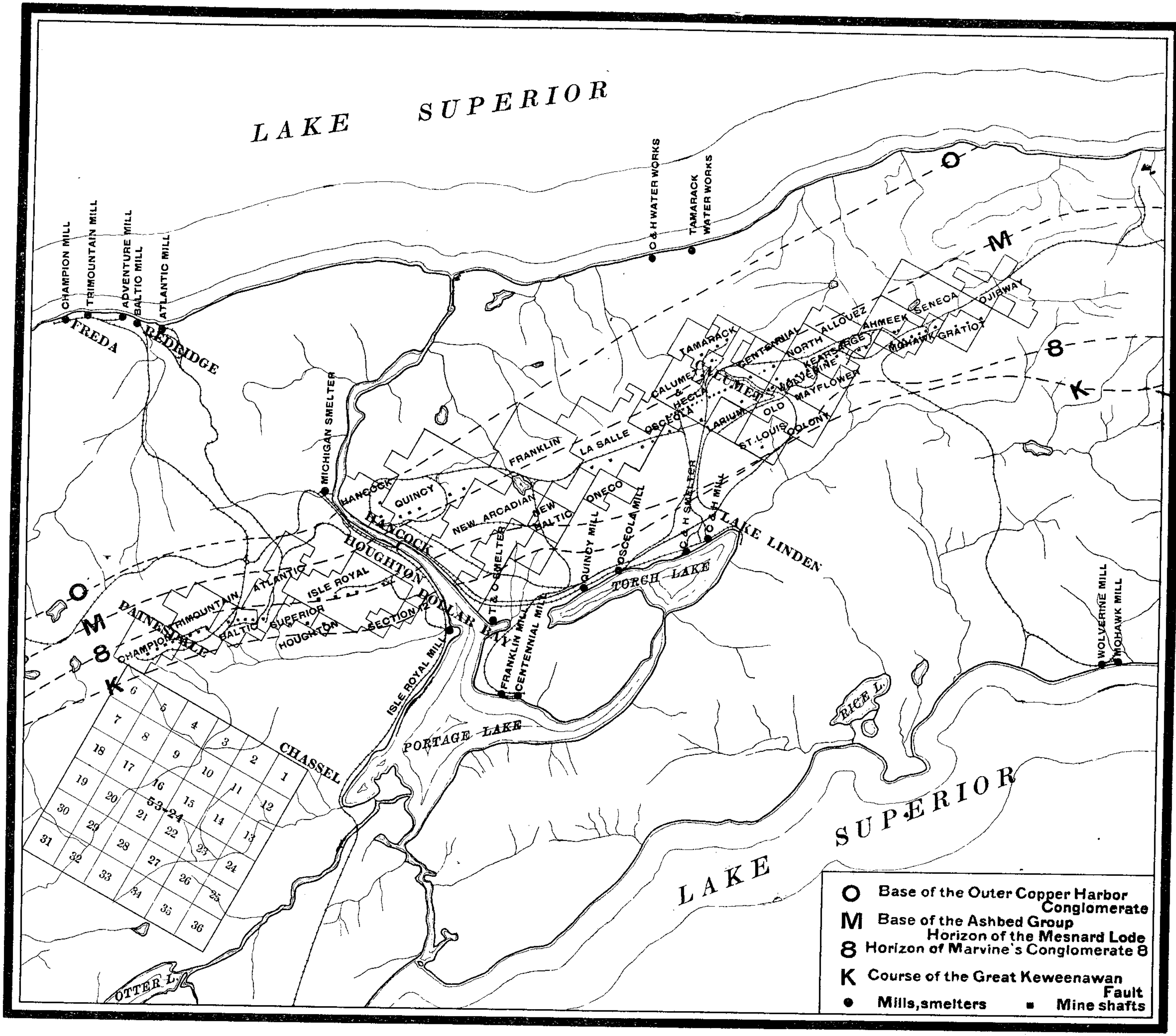

FIG. 2. CHIEF COPPER PRODUCING SECTION OF KEWEENAW POINT.

ing down on the dip of a bed, there is found in all deep mines a lower angle of dip. At the Quincy Mine the dip of the lode near surface is about 54°, while a mile down the inclined shaft the dip is only 37°. At the Calumet and Hecla, the change in the same distance is very little, the inclination being 38° to 39° at surface and 36° to 37° at a depth of over one mile. At the Central Mine in Keweenaw county the dip decreases from 27° at surface to 21° in the lower levels. On the main copper range there are few marked divergences from the general structure as above outlined. The structure is illustrated by the accompanying section taken from Dr. Lane's monograph.

Changes in strike and dip and thickness of beds occur in the neighborhood of some intrusive masses. Recent work at the Lake and South Lake mines in Ontonagon county has shown the beds there to be sharply folded, so that a part of the formation is dipping south instead of northwest. Further west in the Porcupine Mountains, folding and faulting has made the structure locally complex.

FAULTING.

Faults are very numerous in the Keweenawan formation. The most important fault has brought the Keweenawan formation up against the Potsdam sandstone. In the northern part of Houghton County according to drilling records at the Mayflower property this fault dips to the west at a much smaller angle than do the beds of the Keweenawan formation. Beds at low horizons in the latter are probably cut off at no great depth; but none of the very productive lodes are very close to the sandstone here. Further south the dip of the fault is steeper.

There are instances where upper beds have slipped on lower beds great distances; but only in a few cases has the displacement been measured. Dr. Hubbard has estimated that one part may have moved on the lower part of the series about 2.7 miles north from its original position. In other cases a similar slide fault or "slide" has displaced upper beds downwards on lower beds for considerable, but unmeasured, distances.

Throughout the series there are frequently found thin beds of soft clay-like material or fluccan, which have probably been formed by beds sliding on one another in this way.

Besides these "slides" there are numerous faults where the fault plane cuts across the bedding. Where the amount of throw has been measured it is usually less than 100 feet, and most frequently it is so much less that displaced beds are picked up in the mines by a little widening of the drifts or by driving short cross cuts. Faults are especially numerous in the parts of the series near the eastern sandstone. In some of the mines on the Baltic lode, which is at a low horizon, the rocks show innumerable small faults.

CHAPTER III.

THE COPPER BEARING ROCKS.

THE KEWEENAWAN ROCKS.[1]

The Keweenawan formation in Michigan is commonly divided into two series[2], lower and upper. The lower is largely igneous, with occasional interbedded beds of sediment, and the upper largely sedimentary with some interbedded layers of igneous rocks. The division line between the two series is the base of the Outer Copper Harbor conglomerate. The copper bearing lodes are, with one exception, in the lower Keweenawan. The exception is a deposit in sandstone in the upper series.

The Lower Keweenawan of the Copper Range is chiefly made up of dark grey and brownish volcanic rocks. These occur in beds many of which are between 10 feet and 200 feet in thickness. Many others are thinner or thicker. With the dark colored volcanic rocks are imbedded reddish conglomerates and sandstones, ranging from mere seams up to beds of several hundred feet in thickness. In the horizon of the chief productive lodes, the sediments form only about seven per cent of the total thickness of the formation. In addition to the dark colored volcanic rocks, there are much smaller areas of light colored felsitic and porphyritic types, and more basic coarse grained intrusive masses. The felsites do not occur in the immediate vicinity of the chief copper lodes; but are common at both lower and higher horizons. Distinctly grained intrusive rocks, such as gabbros, occur in the Keweenaw series but are not found in the copper mines.

While the volcanic rocks of the Keweenawan are of many varieties, it is for most purposes unnecessary and often inconvenient to use different names for all the types. A simple classification such as that used by Dr. L. L. Hubbard, in Vol. VI of the Survey's publications has proven very satisfactory for many purposes.

[1]An exhaustive monograph on the Keweenawan rocks has been recently written by Dr. A. C. Lane and published by the Michigan Geological Survey. Dr. Lane describes the rocks in detail and his report is accompanied by a large number of maps and geological sections. In the following pages will be found some earlier descriptions of the copper-bearing rocks taken from publications that are not readily obtained. Dr. Lane's report can be obtained on application to the Director of the Michigan Geological Survey at Lansing.

[2]A third division is sometimes, and notably in a recently published monography by C. R. Van Hise and C. K. Leith of the U. S. G. S. made to include only the sediments found in some localities at the bottom of what is more commonly called the Lower Keweenawan. The rest of the Lower is then called Middle Keweenawan.

L. L. HUBBARD'S CLASSIFICATION.

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

The doleritic, ophitic and diabasic melaphyres are called dolerites, ophites, and diabases respectively. This terminology is not altogether in accord with that of other districts, but it has been long in use in the copper country and has proven very useful. The rocks called ophites† are very common and easily distinguished from other traps. These rocks have been carefully described by Dr. Pumpelly, and are of special interest as almost all the amyydaloid lodes are parts of flows which in the less vesicular portions are ophites.

A. C. LANE'S CLASSIFICATION.

A. C. Lane, in the introductory chapter of his recently published monograph on the Keweenaw series says‡ regarding nomenclature:

"The commonest copper bearing rocks are mainly old lava flows, and the usual type is much the same as any ordinary trap or basalt. * * * We might call these flows *traps,* but time-honored usage discriminates the main massive part as *trap* from the originally porous upper part as *amygdaloid.* * * * The term *gabbro* is kept for the deeper-seated intrusions. * * * Most of those rocks which are generally fairly uniformly coarse in grain are *gabbro.* All the effusives are wholly or partly of the melaphyre type. So we continue to use the term *melaphyre* for the dark colored lavas generally and call the coarser streaks *doleritic melaphyre.*"

*Geological Survey of Michigan, Vol. VI, Pt. II, p. 11.
†For illustrations showing weathered surfaces, drill cores and thin sections, see Publication 6, Mich. Geol. Sur. A. C. Lane.
‡Publication 6 Michigan Geological Survey, 1909, p. 27.

Dr. Lane uses the term *ophite* for the rocks which Pumpelly called *lustre mottled melaphyres,* and restricts the term *diabase* to intrusive dikes and sills. The feldspathic porphyritic beds of the Ashbed group he calls *porphyrites* and their texture he calls glomerporphyritic.

R. PUMPELLY'S DESCRIPTIONS AND CLASSIFICATION.

R. Pumpelly gave a detailed description of the copper-bearing rocks as he knew them in 1873.* His description is a remarkably good one and a large portion is here quoted as the original publication has been long out of print:

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

"The series consists of beds of melaphyre, varying in thickness from 20 feet to more than 100 feet, the demarkation being frequently defined by the amygdaloidal or epidotic character of the upper portion of each bed.

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

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

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

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

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

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

*Geological Survey, Michigan, Vol. I, Pt. II, pp. 7-8, 1873.

"The fracture is generally uneven, or hackly, to imperfectly conchoidal. They have an earthy odor often even without having been breathed upon.

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

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

"A brick-red foliaceous mineral resembling rubellan, [iddingsite?] occurring as very minute specks in some fine-grained varieties; it lends a soft rusty-brown appearance to the weathered surface and speckles the interior with red. Specular-iron in minute flakes, seemingly more frequent in the coarser-grained varieties. Calcite in seams and, more frequently, in grains and amygdules, especially in the amygdaloidal portion of the beds. Epidote rarely crystallized; most common in the amygdaloidal varieties, but frequently in seams and impregnations, and nearly always associated with quartz. Quartz which occurs in amygdules and seams and also as an indurating medium near the hanging-wall of many beds. Prehnite in amygdules and seams, mostly confined to the amygdaloidal portion of the beds. A chlorite-like mineral (delessite) soft, compact, amorphous, greenish black, sometimes altered to brick red, occurring in grains from pin-head to walnut size. A yellowish green soft earthy mineral, probably a green earth. Laumontite and leonhardite in seams and amygdules. Analcite in amygdules. Orthoclase in small crystals and massive, in amygdaloidal cavities. Native copper sometimes in fine impregnations in the fine-grained rock, also in the sheets in joining cracks, but chiefly in the amygdules, masses, sheets and impregnations which form the metalliferous deposits in the amygdaloids, where it is occasionally associated with native silver. Native silver. Datolite massive in the amygdaloidal portion of some beds, and also in small aggregations of microscopical crystals in the same positions.*

Essential Constituents of Melaphyres.—"Everything goes to show

*In addition to the minerals mentioned by R. Pumpelly, the following have been noted by Prof. A. E. Seaman in the Keweenawan rocks. Adularia, agate, anhydrite, algodonite, azurite, aragonite, argentite, amethyst, annabergite, amphibole, ankerite, garite, biotite, bornite, cerargyrite, chalcocite, chloanthite, crysocolla, chalcopyrite, chlorastrolite, cuprite, covellite, clinochlore (?), dolomite, domeykite, fluorite, gypsum, hematite, iddingsite, jasper, koalinite, keweenawite, limonite, magnetite, martite, marcasite, malachite, melaconite, muscovite mohawkite, niccolite, para-melaconite, pyrite, pyrrhotite, phillipsite, powellite, saponite, selenite, semiwhitneyite, serpentine, siderite, talc, thompsonite, wood, whitneyite and wollastonite.

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

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

"But I do not doubt that any one who will carefully study the melaphyres of Portage Lake, and compare them with their equivalents in Keweenaw County, will feel convinced that the melaphyre owes its distinctive character to a process of metamorphism, in which the chlorite resulted, largely or wholly, from the alteration of hornblende or pyroxene. In the more distinctly crystallized traps of Keweenaw County, the pseudomorphic occurrence of chlorite after the hornblende or pyroxene constituent of the trap, may be traced through all the stages to a complete replacement of the latter by chlorite.

"*The principal varieties of melaphyre on Portage Lake are:*

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

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

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

Amygdaloids.

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

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

Amygdaloidal Melaphyre.

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

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

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

Amygdaloids Proper.

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

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

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

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

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

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

Texture of amygdaloids.—In a later article Dr. Pumpelly says* of the amygdaloids: "The uppermost zone—the amygdaloid—in many beds is, in several respects, essentially different from the rest of the rock. In these instances, the matrix has a much finer texture, often quite aphanitic, even where the lower and pseudo-amygdaloid zones of the same bed are quite coarse grained and distinctly crystalline. The amygdules have generally a spherical or ovoidal forms, filling cavities with sharply defined walls. In some rare instances, the amygdules are long and cylindrical, and arranged perpendicular to the plane of bedding.

"In thin sections, the difference between the texture of the matrix and the texture of the lower zone of the same bed is very apparent. While the primary constituents, when preserved, do not differ apparently in quality, they are of much smaller size, and sometimes show an arrested development and microfluidal structure. Here, too, the amygdules have sharply defined, evenly curved contours, differing wholly in this respect from the pseudo-amygdules of the lower zones of the same bed. Often also the primary minerals of the matrix are much more minute in the immediate neighborhood of the amygdules than away from them, and their disposition seems also to have been influenced by the presence of the amygdaloidal cavity. The color of the amygdaloid matrix varies between different shades of dark greenish brown, chocolate-brown, dull light green, and brilliant light green. All these colors often occur in the same bed, or even in the same specimen, and, like the difference in hardness—from 3 to 7—are due to metasomatic changes.

Scoriaceous amygdaloids.—"There is one variety, the scoriaceous amygdaloid, which occurs less often than the others, but is always strongly characterized. It consists of true amygdaloid and sandstone curiously associated. The amygdaloid is in contorted forms, from an inch or less to several feet in size, with a sharply defined, often wrinkled surface, and wholly enveloped with sandstone. The glaciated surface of the outcrops of this rock often present at the first glance the appearance of a conglomerate, in which here the amygdaloid, there the sandstone, appears to form the cement. Thin sections show that we

*Proc. Amer. Acad. Arts and Sci., Vol. XIII, 1878, p. 282.

have to do with a true sandstone of quartz and feldspar derived from quartz porphyry, and identical with that which forms the great sandstone beds of the copper series; and that the other constituent is a true amygdaloid.

"The conditions, as studied on the ground, indicate that these beds are volcanic scoriae, buried in the littoral sand. To this variety belong the famous 'Ash-bed' of the Copper-falls and Phoenix mines, and the beds worked in the Hancock and South Pewabic mines."

R. D. IRVING'S DESCRIPTION OF THE AMYGDALOIDS.

R. D. Irving says* of the amygdaloids: "The flows of the finer-grained rocks are all commonly provided with upper vesicular portions, by the subsequent filling of whose vesicles, and the various degrees of alteration of whose matrices have been produced the manifold types of amygdaloid known in the Lake Superior region.† The coarse rocks—olivinitic and orthoclastic gabbros—are not furnished with amygdaloids save when tending to a distinctly finer grain than usual.

"Externally, the matrix of the amygdaloid is commonly quite different from that of the rest of the bed. This difference consists principally in greater denseness of grain, from solidification while much of the matter was not developed into distinct minerals. The difference is least, then, in the case of those beds whose lower portions are composed of some phase of the diabase-porphyrites, in which there is also a greater or less proportion of unindividualized matter. In some of these beds, especially when the rock is of the dense brownish kind with highly conchoidal fracture, above described, there is no perceptible difference between the matrices of the vesicular and non-vesicular portions of the bed; but more usually there is a great difference in this respect between the lower and vesicular portions of a flow. The internal changes to which an open vesicular substance, composed largely of a molecularly unstable material like glass, must always be liable, have greatly increased the difference, and have given rise, by the variation in the decomposition products, to a great variety of amygdaloids, which it would seem at first sight hard to place together.

"*Under the microscope* the matrix of the unaltered, or relatively little altered, amygdaloid shows nearly always much non-polarizing matter, commonly deeply stained with red ferrite. In this are developed needles of plagioclase to a greater or less extent, and often these needles

*Mono. V., U. S. G. S.

†Pumpelly has spoken of the olivinitic fine-grained kinds, his melaphyres, as less commonly provided with amygdaloids than are the olivine-free diabases of the ordinary type, but in my observations this is only true when the melaphyres have a distinct tendency to become coarse-grained, as in "The Greenstone" of Keweenaw Point. When they are fine-grained they appear to have amygdaloids quite as frequently as the olivine-free kinds.

seem to be but microliths arrested in the process of aggregation into crystals.*

"Augite particles occur, but are usually relatively sparse, and frequently fail entirely. Very often there is a fluidal structure brought out in the arrangement of the plagioclase microliths and the other particles, and in many cases the flowage direction is found to coincide with the longer axes of the elongated vesicles. The vesicles themselves, filled or empty, as the case may be, are always sharply outlined in the thin section, and there is immediately about them a crowding of the plagioclases and ferrite particles, as if by pressure in the cavity. Moreover, the individualized minerals, as Pumpelly has shown†, are often more minute in the vicinity of the vesicles than away from them. Porphyritic feldspars, macroscopically visible, are frequently developed in the matrix of the amygdaloids—so far as my observation has gone they are at least as often present as not—and in this respect we have yet another affinity between the amygdaloids and the non-vesicular diabase-poryphrites.

"*Macroscopically,* the vesicles are seen to be commonly filled with secondary minerals—one or more of 'calcite, chlorite, epidote, quartz, prehnite, laumontite, copper, orthoclase, or their products of alteration.'‡ Often, however, I have observed the vesicles empty, either from the removal of the amygdules or from their having always remained empty. The walls of these empty cavities are commonly found to be smooth and dense, apparently from the pressure of the confined vapor.

Alteration —"Although a large number of sections of amygdaloids were cut with this object in view, I have not been able to find the time to extend the studies, so ably begun by Professor Pumpelly, of the changes which have brought about the fillings of the vesicles and the various stages of alteration of the matrix. He sums up the results of his studies on the alterations of both pseud-amygdaloids and the true vesicular amygdaloids in the following table, which is designed to show the course and final results of the most common process of alteration:

Pseud-amygdaloid stage..........	I. Hydration of chrysolite, when present.
	II. Change of augite, loss of lime, and partial loss of iron and magnesia.
	III. Change of feldspar to prehnite, and formation of prehnite pseud-amygdaloids.
	IV. Change of prehnite to chlorite.
	IVa. Change of prehnite to orthoclase.

*R. Pumpelly, "Metasomatic Development," p. 282, U. S. Geol. Sur., Monograph V.
†Ibid., p. 283. U. S. Geol. Sur., Monograph V.
‡R. Pumpelly, Geology of Wisconsin, U. S. Geol. Sur., Vol. III, p. 31.

Amygdaloid stage.	I. Filling gas vesicles with prehnite, or other minerals. Change of matrix to ferruginous prehnite.
	II. Change of the prehnite, in places, to Chlorite; in others, to calcite and green-earth; in others, to epidote and calcite.
	III. Entrance of quartz, filling all the interstices and replacing the calcite.

The following are Pumpelly's comments on this table: "This is the broader history. Orthoclase is here, as in pseudo-amygdaloid, of sporadic occurrence and a product of the prehnite.

"The changes under II may affect only the amygdules, or, if the matrix was prehnitized, it applies to the whole mass of the amygdaloid. It does this in such a manner that, where carried to its extremes, considerable portions of the bed have lost every semblance of an amygdaloid and consists now of chlorite, epidote, calcite, and quartz, more or less intimately associated, or forming larger masses of the most indefinite shapes and merging into each other. Sometimes portions of partially altered prehnite occur. In places considerable masses of rich brown and green fresh prehnite filled with copper occur; but as a rule this mineral has given way to its products.

"To this process the copper-bearing beds of Portage Lake owe their origin. Considerable portions of these beds are but partially altered amygdaloids, containing amygdules of prehnite, chlorite, calcite, or quartz, with more or less copper; other portions are in the condition described above.

"This, too, (II. and II.), appears to have been the principal period of concentration of the copper. In the still amygdaloidal portions, this metal was deposited in the cavities and in cleavage-planes of some minerals, and replaced calcite amygdules, etc. But in the confused and highly altered parts of the bed it crystallized free, where it had a chance; more generally it replaced other minerals on a considerable scale. It formed, in calcite bodies, those irregular, solid, branching forms, that are locally known as horn-copper, often many hundred pounds in weight; in the epidote, quartz, and prehnite bodies, it occurs as thread and flake-like impregnations; in the foliaceous lenticular chloritic bodies, it formed flakes between the cleavage-planes and oblique joints, or in places—and this is more particularly true of the fissure-veins, which we are not now considering—it replaces the chloritic, selvage-like substance till it forms literally pseudomorphs, sometimes several hundred tons in weight.

"When the amygdaloid has arrived at the condition we have been describing, it assumes some of the characters of a vein, in that although it presents no open fissure it contains greater or smaller masses of calcite and other minerals that are easily replaced by an intruder. To this period, probably belongs the replacement of calcite by datolite; and here, also, the rather rare occurrence of analcite crystals and the pseudomorphs of orthoclase after these.

"As I have already remarked, the pseudo-amygdaloids are merely altered forms of the same rock as the lower zone. There seems to be a definite limit at which this progressive change stops, and that is when all augite is changed to its green pseudomorph and a large percentage of the rest of the rock consists of pseudo-amygdules of delessite, and partial pseudomorphs of this after plagioclase. The occurrence of epidote and quartz is not general, and is confined to scattering pseudo-amygdules, in which these minerals have succeeded prehnite, perhaps in the local absence of the conditions necessary to produce the usual delessite.

"Thus I conceive that the extent of the change to the pseudo-amygdaloidal form is conditioned essentially by the amount of augite present, to supply first the lime necessary to aid in changing the plagioclase to prehnite, and next the iron and magnesia to form the delessite, whether by acting directly on the feldspar substance or on the prehnite.

"The amygdaloids proper were, probably, both structurally and chemically, somewhat different from the lower zone, in that it is reasonable to suppose that, in addition to being more or less porous, they contained a greater or less amount of amorphous base, which is more easily altered than a crystalline aggregate. But, from whatever cause, the amygdaloids have, as we have seen, been capable of much greater changes than the lower zone. In them the tendency is undoubtedly towards the formation of quartz, chlorite and epidote rocks, as a more stable limit, through the mediation of prehnite and calcite."

A. C. LANE ON AMYGDALOIDS.

A. C. Lane says* of the amygdaloids: "The top of each flow is naturally more likely to be open in texture, full of bubbles, and thus more porous and easily crushed. Such tops are known as amygdaloids, and they are sought by the explorer, for in the filling of their pores the copper may be concentrated. A real amygdaloid top to an independent lava flow is likely to be fairly persistent and has numerous round walled cavities often filled with some white mineral. Its top is commonly pretty well marked while its base fades out gradually into the underlying not bubbly compact part of the flow which is distinguished as 'trap.'

*Pub. 6, Keweenaw Series of Michigan, Mich. Geol. Sur., 1909, p. 28.

"But just as modern lavas or streams of slag are liable to gush over and envelop cooled crusts or crystallize and leave cavities like those lined with melilite crystals in the pots of slag from the copper cupola furnaces, so was it with those old lavas. Amygdaloidal streaks often run down into the trap, and amygdaloid spots, bombs or inclusions, characteristic under the Wolverine sandstone, are often found in the solid trap, and coarsely and openly crystallized 'doleritic'* streaks are also found especially in very thick flows, and between the crystals, calcite, etc., may form giving these streaks also a spotted and amygdaloidal appearance.

"The trap under the amygdaloid, the foot wall trap, is liable to be relatively lighter and more feldspathic, feldspar being the lighter mineral. The feldspar is generally oligoclase of labradorite, and appears as rice-like grains if the rock is coarse enough. The darker interstitial matter is mainly augite or its alteration product, chlorite. The olivine is easiest recognized when it is more or less changed to a reddish micaceous mineral. The magnetite is not conspicuous in the hand specimen, but is easily attracted from the powder by a magnet."

R. PUMPELLY'S DESCRIPTION OF A TYPICAL OPHITE.†

Dr. Pumpelly describes a typical ophite, the "Greenstone," as follows: "The rock, commonly known in the copper district as 'the Greenstone,' is the best type of this subdivision. Forming a bed 400-500 feet thick, dipping northerly, its outcrop consists of a continuous series of ridges and nearly vertical escarpments, often several hundred feet high. These extend from the Allouez mine to Point Keweenaw and form both the most salient topographical feature of the peninsula and a well-defined horizon to which the geologists and the miner refer their measurements. The rock has suffered only to the extent of a partial alteration of one of its constituents—the olivine.

"It is dark-green, greenish-black, finely crystalline, very compact, hard, and brittle, and breaks with an uneven to semi-conchoidal fracture. Porphyritic crystals, apparently of orthoclase, from 1-3 inch in length down, occur here and there—one or two on the surface of a specimen. They are generally single individuals; but sometimes twinned after the Carlsbad law, as is shown by the oppositely inclined basal cleavage. The powder of the rock yields to the magnet a beard of magnetite. The specific gravity is 2.92-2.95. It is an important characteristic of this rock, that its freshly fractured surface is mainly occupied by spots 1-3 to 3-4 inch in diameter, each of which reflects the light with a satin-like sheen. The reflection is not carried to the

*Vol. VI, Part 1, Pl. 6, Fig. 3 and p. 167. I think the feldspar crystallizes better in the presence of steam, and that these doleritic streaks are where the lava had more water vapor.
†Proc. Amer. Acad. Arts and Sci., Vol. XIII, 1878, p. 260.

eye from all the spots at once; it is generally necessary to change the position of the specimen many times to observe the different reflections. Aside from this sheen, there is nothing, either in difference of color or texture, visible to the naked eye, to betray the presence of these spots, which might be called lustre-mottlings.

"To the naked eye, this phenomenon suggests, at once, interrupted cleavage of large individuals of one of the constituents, as the cause; but under a strong hand-glass, these reflecting surfaces show the same granular texture and character as the rest of the rock; and it is only when examined under the microscope, with an objective of the low power and in polarized light, that the appearance to the unaided eye is corroborated. We here find the cause in the fact that each spot is the cross-fracture or cleavage of a crystal of pyroxene, which in crystalizing has enclosed hundreds of feldspar crystals.

"The weathered surface is rusty gray, scarcely 1-50 inch thick; but it is covered with knobs which are due to the more rapid destruction of the materials between the pyroxene individuals.

"Examining thin sections under the microscope, we find the constituents to be plagioclase, pyroxene, olivine, and its alteration product, as well as magnetite, and an unindividualized substance, both fresh and altered, occupying interstices.

"In thin sections, the plagioclase is seen to exist in very sharply defined and fresh, thin, tabular crystals .001 to .002 inch thick and .01 inch, and less, long. It contains scattering interpositions of an opaque black substance, and minute brown particles, which may be, or have been, glass.

"The crystals of plagioclase have predetermined the contours of all the other constituents, except the olivine, which crystallized first.

"The predominating feldspar is anorthite, as determined by the angle between the principal sections in adjoining bands in the zone 0.1.i Scattering large crystals, which happen in the sections to be cut parallel to i.i, have their principal sections at an angle of 23° with the edge 0.ii, which would indicate albite or labradorite.

"The augite is very fresh and transparent, almost colorless in the thin section, but with a tendency to purple-gray. An imperfect cleavage is indicated by somewhat irregular parallel fractures. It fills the interstices between the closely packed individuals of feldspar in such a manner that a single pyroxenic crystal encloses many hundreds of these, while its crystalline integrity is shown by the uniform color in polarized light, and by the arrangement of the cleavage cracks throughout the area of the augite individual.

"It is a remarkable fact that, while these large individuals of pyroxene contain thousands of feldspar crystals, they enclose only very few of olivine or of magnetite. These minerals, together with the unindividualized substances, are crowded into the spaces between the pyroxenes. In this intermediate space, which surrounds the pyroxene individuals with a continuous network, we find also a few small pyroxenes, just as isolated grains of olivine occur in the pyroxene areas.

"A careful examination of this occurrence will, I think, convince the observer that at the time the pyroxene crystallized both the olivine and the feldspar crystals, and apparently the magnetite, were already individualized; for, where we find any of these in contact with the pyroxene, we see that the latter has adapted itself to the already defined contours of the others. While the pyroxene enclosed the feldspar crystals with ease, it crowded the other constituents almost wholly into the surrounding spaces; a process which was facilitated by the presence of the then fluid, unindividualized substance.

"The pyroxene contains also brown interpositions similar to those in the feldspar, and some opacite. Where it occurs with olivine it often surrounds the grains of this mineral.

"The magnetite bodies are of irregular shape, moulding themselves sharply around the contours of the feldspar and olivine. Their sharply defined outlines are black and fresh.

"The olivine is abundant in integral and aggregated grains, and, very rarely, in crystals with recognizable though rounded contours. The individuals are .0008 to .005 inch in diameter, and are readily distinguishable from the augite, between crossed nicols, by the difference of colors, and in the crystals, by the parallelism of the principal section with the longer sides. Where pains have been taken to give a tolerably good polish to the surfaces of the thin section, the characteristic finely pitted surface of the olivine distinguishes it, even in ordinary light, from the augite, which takes a more perfect surface.

"There are few grains of olivine in this rock that are not more or less altered to a very pale green substance, sometimes tinged with brown. Under a high power, the olivine is seen to be traversed by intercommunicating canals .0002 to .00005 inch thick, filled with clear faint yellowish green to greenish-blue substance. From the sides of these channels, jagged points of the same substance penetrate the fresh olivine. In this manner larger or smaller parts of the grains have been changed to a feebly double-refracting substance which gives an aggregate polarization due to the arrangement of the minute individuals of the alteration product, which are sometimes felted, at others, parallel fibrous. This product is dichroitic; the pale green when the fibrous structure is parallel to the shorter diagonal of the polarizer, and pale orange when parallel to the longer diagonal. On the uncovered sections, this alteration product was found to be very soft under the needle

"Apparently, not more than twenty to thirty per cent of the olivine is altered, which is very remarkable in a rock of such great age, considering the fact, which is emphasized by Zirkel,* that the olivine is subject to complete alteration, even when its neighbors remain wholly intact.

"Where the interstices between the constituent crystalline minerals are not occupied by augite, they are filled with a transparent substance, in places colorless, in others of faintest green, almost colorless, only just distinguishable from the colorless feldspar in ordinary transmitted light. It often penetrates the feldspar crystals in cross fractures. Between crossed nicols it is black, sprinkled with minute blue-gray clouds—an aggregate polarization due, probably, to either an exceedingly minute radiating fibrous, or a granular, structure. Under a 1-16 inch objective (Hartnack's No. 10), portions of the black seem to remain dark on revolving between crossed nicols. The substance is at the most only very feebly double refracting. Unfortunately I was able to find with a low power, and to try with the needle on an uncovered section, only those portions which were faintly green, and these were soft. Still, I am forced to believe that we have here to do with remnants of glass base, which is altered in the faint green portions to a chloritic or serpentine substance. Its whole mode of occurrence in this very fresh rock shows conclusively that it is not an alteration product of any of the constituent crystalline minerals.

"The relative ages of the constituents of this rock appear to be well defined as follows:

(1) Original Magma.

(II) 1. Olivine. 2. Plagioclase. (Anorthite.) 3. Magnetite. 4. Augite. 5. Residuary Magma.

1 (a) Dichroitic alter. product. 5 (a) Alteration product.

"The residuary magma (5) must have been the last to solidify; to its presence was due the internal mobility of the mass, which rendered it possible for the augite to crystallize in larger individuals, and, in doing so, to crowd from its centers the olivine and magnetite individuals.

"This residuary base, probably, differs in chemical constitution from the original magma, since it is only the residue of this after the removal of the ingredients forming the crystalline constituents."

*Mikrosc. Besch. d. Mineralien u. Gesteine, p. 217.

R. PUMPELLY'S DESCRIPTION OF THE CONGLOMERATES.

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

"The pebbles, in most of the beds on Portage Lake, consist almost exclusively of varieties of non-quartziferous felsitic porphyry. Two kinds predominate. One of these has a chocolate-brown to liver-brown subcrystalline to compact almost vitreous matrix containing very scattered minute crystals of triclinic feldspar of the same color as the base. The other and rarer variety, also non-quartziferous, has a chocolate-brown, compact to minutely crystalline matrix in which lie crystals 1-8 to 1-2 inch long, of a flesh-colored trinclinic feldspar.

"In some beds there appear pebbles of a flesh-red rock, composed almost entirely of granular feldspar, containing small specks of a black undetermined mineral. In some instances the feldspar is wholly triclinic, in others the twin-striation is frequently absent. This variety of pebble is altogether absent in some beds, at least where they are opened, while in others they predominate, as in the Albany and Boston Conglomerate. Pebbles of compact melaphyre and of melaphyre amygdaloid also occur, but are quite subordinate in number to those already enumerated.

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

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

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

*Michigan Geological Survey, Vol. I, Part II, pp. 16-17.

A. C. LANE ON DECOMPOSITION OF THE KEWEENAWAN ROCKS.

Dr. A. C. Lane has summarized* the changes as follows:

"I. 1. Primary reactions, glass decomposes, chloritic filling to cavities, ferric minerals (olivine, etc.) attacked. Chalcedony, agate, quartz, delessite and serpentine, and epidote formed; laumontite, thomsonite, and chlorastrolite in amygdules?, iron bearing red calcite, orthoclase? and ankerite? Some of these reactions may not be all primary.

II. Secondary reactions.

"2. Prehnite, other kinds of chlorite, also epidote and quartz formed; lime-bearing minerals dominant.

"3. Iceland spar (calcite) and copper formed.

"4. Selenite, barite, datolite, orthoclase, natrolite, apophyllite, analcite, and the sodium bearing minerals, fluccan.

"In the four groups above it must not be understood that the order is absolute but that on the whole the copper is most intimately associated with calcite, but at times occurs sprinkled through the prehnite and epidote as the contemporary.

"It is, however, true that the minerals of the last group are rarely if ever formed before those of the earlier ones and the first group are often replaced by the later ones. Chloritic replacements are common.

"It is understood of course that primary orthoclase of the original felsites may be and often is replaced by the others, and calcite occurs of all ages. An older calcite is often bright red.

"These studies are adapted from Pumpelly's thorough studies of the order of crystallization, Volume I, Part II, p. 32 of these reports, with additions."

*Pub. 6, Mich. Geol. Sur., p. 858.

CHAPTER IV.

NATURE OF THE COPPER DEPOSITS.

MODE OF OCCURRENCE OF THE COPPER.

The Copper Minerals.—Practically all of the copper mined occurs as the native metal. A very minor production is made from other copper minerals, chiefly arsenides. The deposits are remarkable for their very meagre content of sulphides. Chalcocite is the most common sulphide, but it is seldom found in large quantity. Oxide, carbonate and silicate minerals containing copper have been found frequently, but not in economic amounts.

The native copper occurs chiefly in bedded deposits. It has filled cavities in and replaced mineral and rock constituents of conglomerates and amygdaloids. If we except the fissure veins, the richest lode is a conglomerate; but all the other lodes now being worked are amygdaloids. Large amounts of native copper have also been mined from fissure veins which cut across the formation, and from epidotic veins or beds which lie nearly parallel with the formation. One deposit which promises to be profitable is a sandstone containing native copper and chalcocite. Native copper has also been found in a much fissured and altered mass of felsite.

The bedded deposits are long and continue to great depths. The most important ones are being worked for a distance of two to five miles along the strike. Two of the lodes are still being worked at over a mile down on the slope of the beds, and it is probable that others will be worked at a like depth. Most of the lodes average at least eight, and some over twenty-five feet in thickness.

Distribution of the native copper.—The copper is by no means evenly distributed throughout the lodes. Very large stretches are mined out in continuous stopes, but the regularity indicated by the stope maps gives an erroneous impression of the occurrence of the metal. Large quantities of barren rock are broken with the ore, and the copper-bearing portion has a content varying from a few pounds to several hundred pounds per ton. The rich ore forms a comparatively small portion of the output. The amount of waste rock included with the ore shipped varies not only with the deposits, but also according to the amount of hand sorting that is done in the mine. In some mines the ore is rather carefully picked and much of the rock broken is left underground. In other cases nearly all becomes mixed with the ore. It should be evident from these remarks that the proper interpretation of reports on yield per ton of different lodes or parts of the same lode requires a knowledge of the method of mining and handling the ore. Further information is to be found on the stope-maps which show ground supposed to be barren or very low grade. It is common practice to record daily the character of ground opened in drifts, but most of the mine maps fail to show in any other way the grade of ore mined from individual stopes. The output from most shafts shows considerable uniformity in grade of ore produced from day to day, but this is largely due to the common practice of mining simultaneously in many widely separated stopes.

Productive portions of beds.—The irregular distribution of the metal is frequently commented on by the miners. Assays are seldom necessary and are not very satisfactory. Where there is any considerable quantity of copper, the mineral is readily detected by the naked eye or by feeling the rough jagged projections, and rich and poor ground are thus readily distinguished. It is known that the ore-bearing portions of a bed are of all shapes and sizes. It is common experience in a single stope to have a whole face in good ore followed for a few cuts by practically barren ground and then by good ore again. Within the limits of a stope the ore occurs in several bodies which are perhaps best referred to as *patches*. Sometimes the patches are larger and a whole stope may then be continuously in ore. These patches, small and large, form parts of still larger areas of the lode which are referred to as the *productive areas* and which are of very great size.

Shoots.—While the ore does not occur in shoots, in the sense in which this term is most commonly used, the productive areas bear a somewhat similar relation to the bed of which they are a part, as do shoots to veins. The difference is, at least partly, one of magnitude. The great size of the productive areas is a feature which distinguishes these from most other ore deposits and the use here of the term oreshoot is thus made after some hesitation and because there is no similar term available for deposits of such magnitude.

Some of these socalled shoots show a marked pitch along the strike. The Calumet shoot pitches almost due north and others in Houghton County pitch in a northerly direction. The pitch of the ore bodies at the Quincy mine is shown by the old stope plan, Fig. 21. At Victoria mine, the pitch is toward the west. No very accurate record is kept of the output of individual stopes. Hence there are no figures available from which to construct diagrams showing how the copper was distributed in the ore mined. In some mines it is the practice to make daily notes on the character of new openings. This is commonly done by the captain or shift boss who notes simply whether the showing is good, fair or poor. From these notes maps have been constructed showing approximately the distribution of copper for large areas of a lode. These however are not available for publication. Not infrequently the necessary information has never been recorded, but entrusted to the captain's memory and ultimately lost entirely. Some idea of the distribution of the metal may be obtained from the description of individual lodes given in this report.

Change in value with depth.—The deposits show no very regular change in copper contents with depth. The deepest workings in the district are in comparatively lean ore. The best ore in the Calumet conglomerate was taken at depths from surface which increased as the workings were extended to the north. The statements of several who have commented on the change with depth agree to the extent that below 2,000 feet the ore does not average as rich as above 2,000 feet. It is probable however that the average for depths of 1,000 to 2,000 feet is above that of the portion above 1,000 feet. Mr. Jas. MacNaughton, general manager of the Calumet and Hecla Mining Co. states that "the copper contents lessen with depth and the falling off in richness begins to be noticed at 2,000 feet." This statement is a general one for large areas of a lode. It should not be interpreted to mean that there is a gradual falling off in values. The lodes are patchy.

CONGLOMERATE LODES.

Characteristics of the Conglomerate Lodes.—The conglomerate lodes are portions of sedimentary beds which are interstratified with the volcanic rocks. They are commonly reddish rocks with very numerous large pebbles. The pebbles are mostly quartz-porphyry and felsite, but there are occasional pebbles of many different types of trap and amygdaloid. The cement is a rather coarse sand made up of small rock grains and a few minerals of which the most common are calcite, quartz, native copper, and magnetite, hematite (var. martite) or other oxide. Epidote and chlorite are of frequent occurrence as constituents of the sand and as alteration products of the pebbles. In places these sedimentary beds contain few or no large pebbles, but in the copper-bearing zone such sandstone portions are usually subordinate to the coarse conglomeratic phase. At the Franklin Jr. mine, the lower part of the Allouez conglomerate bed is a sandstone.

Considering their character, the conglomerate beds are remarkably persistent, for it might be expected that they would vary much more in thickness than they do and frequently pinch out. On the lode which has been most extensively worked, the Calumet lode, variations in thickness from a few feet up to 40 feet have been found, but as the workings extend two miles along the strike and over a mile down on the dip, it is remarkable that the thin bed of coarse conglomerate was spread out so evenly. That some other conglomerate beds in the district are much less regular in thickness has been shown by Dr. Hubbard.*

Copper is in both pebbles and matrix.—In the conglomerate lodes the copper occurs chiefly in the matrix, where it has apparently filled spaces between and also replaced grains of mineral and rock. While part of it occurs in fine particles which may have been deposited between the sand grains, much of it is in particles of size and shape not in accord with such origin and it seems likely that most of the copper has replaced other constituents. Native copper also occurs in the pebbles and frequently these are quite heavy with the metal. Examination of these pebbles shows conclusively that the deposition of the copper has been made at the expense of the rock. It does not occur simply as a filling in fractures in the pebbles, but has rather the character of a pseudomorph after the pebble. Frequently the copper is in the form of a shell, but in other cases it occurs in irregular masses throughout the pebble, sometimes almost completely replacing it. At some rockhouses very large numbers of these heavy pebbles have been picked out from the ore and sent directly to the smelter. The present workings do not afford so many as were encountered a few years ago.

Copper is in small particles.—The copper in conglomerate lodes is commonly in smaller particles than that in the amygdaloids. Large masses have occasionally been found, but they are comparatively rare. Small masses or "barrel work" are also infrequently met with. With the exception of the copper pebbles, pratically all the conglomerate ore is stamped and concentrated before smelting, while a very considerable portion of the copper from some amygdaloid lodes occurs in large and small masses which are sent directly to the smelter.

The replacement of pebbles by copper has been described by Dr. Raphael Pumpelly and Dr. A. C. Lane, and will be referred to later in this report in the discussion of origin of the ore.

AMYGDALOID LODES.

Characteristics of amygdaloid lodes.—The term amygdaloid lode is applied to those deposits which occur in much altered portions of the

*L. L. Hubbard, Geol. Sur. Mich., Vol. VI.

volcanic beds. Usually they are the upper part of the bed and decidedly amygdaloidal in character. Some, however, are not markedly amygdaloidal, and a large part of the ore in some mines occurs as replacement deposits and fracture fillings in fissured traps.

As a rule the rock carrying high values in copper is largely made up of secondary minerals, and the metal is usually enclosed in masses of these, especially in calcite, epidote, prehnite, chlorite and quartz. Copper occurs as a filling in amygdaloidal cavities, but it is by no means confined to them. In some lodes there is considerable copper with calcite, prehnite and quartz in minor fissures, but other lodes show little ore of this character. In some cases native copper occurs in a network of seams. These seamed masses show characteristics of mineralized shattered zones, but as the mineralization is confined largely to single beds the deposits are tabular masses similar in shape to the beds which are not so much fractured.

The amygdaloid lodes seldom occur singly, the chief producing lodes being closely accompanied by others carrying a subordinate amount of copper. In some cases, and this is notably so of the Kearsarge amygdaloid, the quantity of ore mined from the "east" and "west" lodes is almost negligible, but in other cases, of which the Pewabic is a notable example, there are two or three lodes of importance. The main lode at one shaft at the Quincy mine is not the lode which was regarded as the main lode at another shaft.

The Pewabic is thus a series of lodes which vary in relative importance from place to place. They are commonly spaced a short distance apart and occasionally come together, then often forming unusually large bodies of good ore. A somewhat similar feature is characteristic of the several lodes at the Mass Mine. On the Osceola amygdaloid the ore occurs partly in a fairly regular hanging portion and partly in a less regular but much thicker foot portion. At the Superior Mine there has been opened up a rich lode which lies a short and variable distance above the Superior lode. At the Isle Royale Mine, there are two somewhat similar lodes—the Isle Royale and the Grand Portage—spaced a short distance apart. At the Copper Range mines crosscuts into foot and hanging from the Baltic lode often disclose additional ore.

Hard portions.—Throughout the amygdaloid lodes there occur irregular masses, frequently somewhat lenticular in shape, that are much harder than the surrounding rock. Such masses are commonly greenish in color and consist largely of a dense aggregate of epidote and other green minerals with quartz. The frequent occurrence of this material is called to the attention of the miners by the comparatively great difficulty encountered in drilling it.

Soft portions.—Occasionally also there occur very soft portions, in which much of the rock is friable and readily breaks away from irregularly branching copper masses which it contains. It has been noticed in some mines that these soft streaks commonly run across the lode, while the hard epidotic masses extend in the direction of the lode. There is often much copper in the epidotic rock and many masses occur in it.

Wet and dry portions.—It is often noticed that rich parts of the lode are wetter than the dry and in some mines the encountering of a little water in the openings is considered a sign of better ore ahead.

Crushed portions.—It is often found in following the lodes, that portions which are fractured and crushed very extensively are comparatively poor in copper contents. Dr. Lane says* regarding this phenomenon: "So far as my experience goes, where there is a great deal of disturbance and the rock is thoroughly decomposed, it is not likely to contain copper. The copper seems to be driven from it into a zone between the thoroughly disturbed and the less disturbed rock."

Shear zones.—As Dr. Hubbard has pointed out, some of the amygdaloid beds are seats of shear zones, the copper and other secondary minerals occur in cavities caused primarily by shearing. He says:†

"Observation has already shown us that the copper in the amygdaloids is generally found not in the amygdaloidal cavities, but in brecciated material—in fissures. The thick footwall bed rendered possible a widespread and bubble-studded capping, in other words, a marked and extensive plane of weakness which would be particularly susceptible to shearing. The more circumscribed the amygdaloidal capping, by comparison with the more compact rocks in the extension of its plane, the less it would be subject to shearing, and consequently the less it would offer cavities of mechanical origin for the deposition of secondary minerals. At the Champion Mine, I remember to have seen in six years only one piece of rock that contained shot copper. In the Winona Mine a similar condition exists. Moreover in the latter mine a well defined slip marks the course of the lode on the hanging-wall side, and other evidences of shearing are seen in the adjacent rock material. At the Ojibway near the shaft that has uncovered the more copper, a fissure vein in the hanging of the east lode is in evidence from near the surface to the bottom of the mine. I say fissure vein because I believe that specimens of crystallized copper occur more often in what we are accustomed to call fissure veins than in accidental cavities of more irregular occurrence."

He states further‡ "We may expect to find shearing either (1) limited approximately by the area of any one of these beds; (2) extending

*L. S. M. I., 1912, p. 135-136.
†L. S. M. I., 1912, p. 231.
‡Loc. Cit. page 230.

into or through an adjoining trap bed; (3) deflected into a transverse fault, or from the latter (4) transmitted into another amygdaloid.

"Of the first of these cases, we can probably collect little material evidence in this area, because we do not often mine in the traps beyond the limits of the copper. As to the second, I have sometimes thought that the Mabbs vein may possibly be the extension of the Baltic-Superior shear zone system, through the more compact trap; that the temporary disappearance of the Baltic zone of enrichment north of the Baltic Mine is due to the cross fissuring and disturbance in Section 16; and that the Arcadian-Isle Royale and Grand Portage lodes come under the fourth class of a shear transmitted from one plane of weakness to another."

Spliced structure.—Dr. Hubbard describes the development of a spliced structure in a bed and compares it with similar structure found in veins. He says:*

"The spliced structure above referred to was applied by Pumpelly to the ordinary fissure vein. The causes that produced it must be the same or closely allied to those that bring about shearing in the tilted beds of volcanic origin. In our amygdaloids we see these on a comparatively small scale. Near the extremity of Keweenaw Point 'accomodation' appears to have been made so far as evidence is at hand, largely in the cracks that run across the formation, some of them copper-bearing, and in the Ontonagon district the drag of the overlying beds has resulted in at least two cases in fissure veins that strike nearly parallel with, but dip more steeply than, the beds of the series. It is largely between these two areas that our productive bedded deposits have been found. May they or some of them not be due to mechanical movements very similar to those that produced the so-called fissure deposits at each end of the district."

The copper bearing beds are thick.—The amygdaloid lodes now being worked are parts of thick beds. According to Dr. Hubbard† the footwall trap at Winona Mine is 40 to 50 feet thick; at the Baltic and Champion from 100 to 150 feet thick for a length of four miles; and at Ojibway and Mohawk it (Kearsarge Foot) will probably average more than 100 feet and maintains a much greater thickness for several miles. It has been pointed out by Dr. Hubbard that the upper part of thick beds formed more or less continuous horizons of weakness through which shearing might easily take place, more easily than in beds of smaller area.

Dr. A. C. Lane remarks‡ that the most favorable place for copper is

*Loc. Cit., p. 234.
†L. S. M. I., p. 230, 1912. "In the Lake Superior area what influence, if any, did the thickness and contour of foot-wall beds have upon the subsequent disposition and distribution of copper in overlying beds."
‡L. S. M. I., 1912, p. 128. Unexplored parts of the copper Range of Keweenaw Point.

"A belt near a heavy impervious belt, and in a somewhat pervious one, in which a certain amount of shattering has taken place." He elsewhere* calls attention to the fact that copper is commonly found under heavy impervious beds.

Dr. R. D. Irving, in Mono. V, U. S. G. S. says of the amygdaloids, "The copper in these deposits is not restricted to that portion of the bed which was originally vesicular, but runs from it downward irregularly into the originally compact portions, following always a great alteration of the rock. The copper, however, tends always to be very irregular in distribution, and, even in the longest worked and most reliable amygdaloids, has frequently to be searched for through many feet of barren rock. In this search the diamond drill is now extensively used, the miners being guided in its use by the occurrence of seams of calcite and epidote, and other alteration forms, which, when followed up with the drill, are often found to lead to pockets containing much copper.

"In one class of amygdaloids, those of the ashbed-type—which I agree with Wadsworth in regarding as merely very highly scoriaceous and open lava flows, into whose interstices the intermingled detrital material has subsequently been washed—the distribution of the copper is sometimes more uniform than in the ordinary cupriferous amygdaloids, so that the whole of the bed may be broken down and taken to the stamps, as is done for instance at the Atlantic mine."

SANDSTONE LODES.

Nonesuch and White Pine.—In some deposits in the Porcupine Mountain District, Ontonagon County, copper occurs in sediments of the upper Keweenawan. At the Nonesuch and White-Pine mines the cupriferous beds are gray sandstones which are in places conglomeratic. Copper occurs as the native metal and as a sulphide, chalcocite, distributed in the form of small grains and flakes. Some of the copper is in mere films which are readily carried away by water and hence not easily saved, but much of it is in grains that can be concentrated economically. The sandstones are largely made up of quartz grains with some darker colored rock particles and minerals. Among these grains the copper occurs partly in forms which suggest simple filling of spaces, but partly at least is probably a replacement. According to some authorities† copper frequently occurs as a coating on grain of magnetite.

*Pub. 6, Michigan Geological Survey, 1912, p. 44.
†Steidtman. U. S. G. S. Monograph No. 52, Geology of Lake Superior District.

Dr. Irving notes* that at the Nonesuch Mine most of the copper is clustered around magnetite particles.

EPIDOTIC BEDS.

Ontonagon "veins."—Epidotic beds, yellowish green in color, and composed largely of epidote and quartz, are of common occurrence, and several contain native copper. Such deposits are not commonly very productive; but in Ontonagon County a very profitable mine, the Minesota, had most of its copper in such an ore body.

The beds, or veins as they are sometimes called, strike with the bedded volcanic rocks, but dip somewhat more steeply and are hence not confined to one horizon. Many exceptionally large masses were found in the Minesota deposit.

Irregular distribution of the copper.—Chas. E. Wright describes the irregular distribution of the copper in these deposits. He says:†

"In Ontonagon County the copper occurs in veins and in belts, which run with the formation. The copper-bearing veins, while conforming in direction with the strike of the inclosing rock, frequently dip at a greater angle, but always in the same direction. The beds which have been mined for copper are frequently distinguished by their irregularity, rendering it extremely difficult or impossible to define them. The product, which has been mainly in the form of masses, is in some portions of the range found scattered in the trap rock in a manner that sets at defiance any method of determining their location other than mere chance; blind, persistent work may lead to the discovery of an isolated mass or of a collection or a succession of masses, but it is frequently blind luck, and not the result of following any well defined clues."

Irving on Ontonagon Veins.—R. D. Irving in Mono. V, U. S. G. S. says of the bedded veins of Ontonagon County: "The copper deposits of the Ontonagon region have not had the study given them that has of late years been devoted to those of the Keweenaw Point and Portage Lake districts; so that it is not possible to be quite so positive in our statements in regard to them. The copper of this region never occurs in transverse fissures, but either lies in irregular accumulations—often solid masses many tons in weight—associated with much epidote and calcite, distributed along the course of diabase beds, or else occurs with more persistent and vein-like aggregations of epidote and calcite. The latter coincide always with the bearing of the formation, and commonly also with its dip, but in some cases, as for instance in the once famous Minesota mine, dip at a higher angle than that

*Vol. V, U. S. G. S. Copper Bearing Rocks of Lake Superior, R. D. Irving, 1883, p. 221.
†Report of Com. of Min. Statistics, Michigan, 1880, p. 68.

of the formation, which they consequently slowly traverse in depth. According to Foster and Whitney, deposits like that of the Minesota mine show another indication of a vein-like character in the shape of slickensided and generally sharply defined walls. The 'vein' at the National mine is also peculiar in lying at the base of one of the great lava flows, and immediately above a conglomerate bed, while coinciding with them in both bearing and dip.

"It is evident, even with our present knowledge of the deposits of the Ontonagon district, that their history has been essentially the same as that of the Portage Lake deposits. In the case of that copper which occurs irregularly distributed, along with epidote and calcite, throughout certain of the trappean beds, the process of replacement has gone on irregularly, because of some irregularity of texture in the original rock. Deposits like that of the Minesota mine may have resulted from the deflection of the altering waters along the course of a pre-existing but not open fissure; the 'vein' being in this case, as before, a replacement, at least in large measure, of original rock substance."

CUPRIFEROUS FELSITE.

Indiana deposit.—Native copper and some malachite and chrysocolla have been found in recent years in masses of felsite at the Indiana and adjoining properties in Ontonagon County. While no deposits of this type have yet been extensively opened up, the management of the Indiana Copper Company considered that the showings obtained in drill cores are promising and a shaft has been sunk to permit of the testing of such deposits at a depth of over 1,400 feet.

The copper so far obtained occurs in portions of the felsite that are much altered and crushed and is usually accompanied by secondary quartz, calcite and epidote. In one case the copper occurs chiefly at the bottom of a mass of felsite, but in other cases it is well within the felsites traversed by the drills. The shape of these rock masses and their relation to the amygdaloids and sedimentary beds are as yet unknown. It is probable that the felsite occurs as irregular masses intruding the amygdaloids. Concerning the extent and shape of the copper deposits in the felsite there is as yet very little knowledge. Some of the information thus far obtained will be given in describing the Indiana deposit.

FISSURE VEINS.

Occurrence of copper in veins.—In fissure veins the copper occurs in masses, very irregularly distributed. The veins which have been extensively worked are all in Keweenaw County and most of them at nearly the same horizon—just below the thick bed known as "the Greenstone." They cut across the amygdaloid and trap beds and commonly are more productive and wider in the amygdaloids. In the dense traps and in sandstones the veins contain but little copper. At present no fissure vein deposits are being worked independently but considerable quantities of ore are taken from veins traversing the Kearsarge lode at the Ahmeek and Mohawk mines. Years ago large production was made from veins at the Central and Cliff mines.

In the deposits mined at the Cliff, Central and several other properties, the copper occurred almost entirely as the native metal. At the Mohawk mine similar deposits yield arsenides which carry some cobalt and nickel in addition to copper. At the Ahmeek mine there is a very rich vein carrying native copper in a calcite gangue, and some mohawkite veins which have quartz as the chief gangue mineral.

Central and Cliff Veins.—According to those who examined these deposits when they were being worked, the copper commonly occurs with epidote, prehnite and chlorite. Calcite is abundant in most of the veins, but is stated to be not specially characteristic as there are many barren calcite veins. Numerous masses of country rock are enclosed in the vein matter. The veins are nearly vertical and the mine maps show that the ore bodies pitched with the dip of the beds traversed.

Ahmeek Vein.—The Ahmeek fissure vein crosses the Kearsarge amygdaloid close to No. 2 shaft and has therefore been frequently cut in drifting on the Kearsarge lode. It shows good ore on several of the upper levels, but has not been extensively opened up there. At the tenth level there is a drift on the vein for 245 feet into the hanging which has opened up remarkably rich ore. The copper occurs in thick slabs in masses of several tons. A short drift at the thirteenth level uncovered a slab twenty-eight feet long which was with difficulty broken into several pieces each weighing a few tons.

The vein varies in thickness from a mere ribbon to three feet and in places breaks into two parts separated by rock. It strikes across the Kearsarge lode and dips at about 70° northeast.

Production of fissure veins.—As compared with the amygdaloid and conglomerate lodes, the output from fissure veins has been very small and with the one conspicuous exception, the Ahmeek, it is at present almost negligible. Special interest is attached to them however, by the fact that the richest part of such veins is commonly found to be at the intersection with one of the cupriferous beds and hence they are encountered while mining the beds.

The most productive of the known vein deposits were worked out many years ago at the Cliff and Central mines. I can give no description of these deposits from personal observation, but may do some service by quoting from works not now readily available.

C. E. Wright's description of Central Mine Vein.—In the report of the first Commissioner of Mineral Statistics* Mr. Chas. E. Wright says of the Central Mine deposits:

"The vein, which has nearly a north and south course, dips to the east. The principal product is mass copper of 65% purity; the deposits of this metal are found in talcspar, sugar spar, laumontite, chlorite and other minerals, often occurring in the form of beautiful crystals. The masses are often enormous, irregular slabs—isolated bodies of copper—and weigh in gross from 400 to 800 tons. They are mined by working on each side and removing the vein rock, and are blasted down so as to expose one face, by sand blasts in which several kegs of powder are used. They are cut, by means of chisels, into convenient blocks for handling, of from four to eight tons each. Some of these blocks are of great purity; when hoisted from the mine they are sent to the smelting works without further dressing."

The copper in the Ahmeek vein is also exposed by drifting in the rock on either side; but it is broken into pieces by heavy charges of 90% nitroglycerin and not cut, if cutting can be avoided.

R. D. Irving's description of fissure veins.—R. D. Irving says† of the productive veins.

"The transverse veins have been mined for copper on Keweenaw Point only, where they are found varying in width from mere seams to ten and even twenty and thirty feet. For the most part, however, they do not exceed one to three feet in width, the expanded portions being met where they traverse the amygdaloidal or otherwise open textured portions of the flows. The same veins which, in the amygdaloid and looser textured diabases, are expanded and often rich in copper, will, when in the more compact and massive beds, such as the well known Greenstone, contract to mere seams without metallic content; and the same is in large measure true of their intersections with the sandstone belts. The veins lie always very nearly at right angles to the trend of the beds which they traverse, standing always very near the perpendicular quartz, calcite and prehnite make up the common veinstone, but they are mingled with more or less of the wall rock of the vein, which frequently predominates greatly over any true veinstone. The veins are in fact for the most part not sharply defined from the surrounding rock, but consist in each case of a network of smaller seams traversing the shattered wall rock. Veins composed almost wholly of calcite are not unknown, but they are never productive

*Lake Superior Copper Mining Industry, p. 178, 1877-78. Report Commissioner of Mineral Statistics State of Michigan, 1897.
†Copper-Bearing Rocks of Lake Superior, Mono. V., U. S. G. S., p. 423.

of copper. The copper in these veins occurs both in smaller fragments and minute particles intimately mixed with veinstone, and again in masses many tons in weight. The larger masses frequently are found to contain within them portions of the wall rock.

"Nearly all the productive mines based on these transverse veins are working directly beneath the Greenstone, the layer which is described in a previous chapter as constituting as prominent a feature in the geology and topography of Keweenaw Point. This position of the mines is one not due to the non-occurrence of copper elsewhere in the course of these veins, but results from the fact that further south they become buried beneath a heavy coating of drift, while to the northward they pinch out and become barren in the broad Greenstone belt.

"These veins, on account of their transverse position to the bedding of the formation, of their often slickensided walls, and from their carrying often a true veinstone, have commonly been regarded as 'true fissures.' That they are on the lines of pre-existing fissures or transverse cracks in the formation there can, I think, be no doubt, but they are not true fissure veins in the sense that the veinstone and metallic matter occupy, along with wall-rock fragments, original fissure space. I see in them simply the results of rock alteration entirely analagous to that which has brought about the deposition of copper and its associated veinstone minerals within the cupriferous amygdaloids. They are alteration zones which traverse, instead of following, the bedding, simply because the drainage of the altering waters has been given this direction by the pre-existing fissures. All of the phenomena of these veins coincide completely with the vein; the common occurrence of wall rock within the vein, or rather the embracing of the wall rock masses by the vein; the replacement of wall rock by copper masses; the occurrence of wall rock within these masses; the expansion of the veins and their greater richness where traversing the more readily alterable amygdaloids and looser textured diabases; their contraction and barrenness within the compact and less readily changeable Greenstone; and the coincidence of the paragenesis of the vein minerals with that of the cupriferous amygdaloids, are all facts better explicable on this theory than on any other."

Wadsworth on veins.—Dr. M. E. Wadsworth says* of the vein deposits:

"In the veins the copper is found intimately mixed with the gangue, or in sheets or irregular masses. In sheet-form the copper extends downward or has its sides approximately parallel with the vein. Often the sheet is divided, and holds between its parts some of the gangue or melaphyre. It is also not uncommon to find, entirely enclosed in

*Origin and Mode of Occurrence of the Lake Superior Copper Deposits. Trans. A. I. M. E., Vol. XXVII, 1897, p. 694.

the copper, masses of melaphyre, quartz, calcite or other vein-minerals. The melaphyres themselves are often impregnated with copper adjacent to the veins."

C. E. Wright's description of Keweenaw County Veins.—Chas. E. Wright describes* the copper-bearing fissure veins of Keweenaw County in his 1882 report.

"The fissure veins in this portion of the range cross the formation, usually at an inclination approaching a right angle and dipping nearly or quite vertically; they vary in width from a few inches to several feet, sometimes, in very productive portions, widening out to even twelve feet or more. It is in these wide pockets that the greater portion of the copper is found; the extreme narrow portions of the vein serve only as leaders to guide in the work of excavating; the gangue of these veins is made up of quartz, calcite, prehnite, epidote, laumontite, datolite; quartz and calcareous spar are usually the predominating minerals. The rock in the richest metalliferous portions is a rather soft amygdaloid trap of a fine texture.

"These veins can be traced through the greenstone and have been found to be productive on both sides of it, but never in it.

"The product obtained from the veins is very largely in masses of native copper, or in pieces of a size termed barrel work. These veins sometimes contain more or less of the trap rock, in small pieces, to fragments of considerable size cemented together with the vein matter."

PARAGENESIS OF COPPER AND CALCITE.

R. Pumpelly has discussed[1] the relations of copper and calcite in several cases. He says:

"In many of the instances in which calcite crystals are found enclosing copper, it is difficult and often impossible to distinguish as to the relative ages of the two. But specimens in my collection offer conclusive proof that each of the following cases occurs:

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

"In this way calcite crystals, formed in a cavernous mass of copper,

*Rep. Com. Min. Stat. Mich., 1882, p. 55-56.
[1]Michigan Geological Survey, Vol. I, Part II, pp. 32-35.

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

II. *The crystal of calcite was partly formed, then became incrusted with copper, and was finished by a new growth of calcite over the metallic film.*[2]

"A most remarkable instance of this case is that of a crystal about two inches long—a steep scalenohedron—with a basal termination of about one square inch surface. At this stage of its growth it was covered, over nearly the whole surface, with a thin coating of copper. The basal termination on scalenohedrons of calcite is as rare on Lake Superior as elsewhere, and in the few instances where I have seen it, it lacks the polish which indicates perfect growth. The tendency to complete the point of the scalenohedron is well shown on this specimen; over the partially copper-coated basal plane there are scattered a large number of perfectly pointed scalenohedrons—two or three of these are 1-3 to 1-2 inch high—and others are scattered over the side-faces. All of these younger crystals are arranged in perfect uniformity with the plan of the underlying, older individual.

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

"The copper is not confined absolutely to the surface of the crystal on which it lies; it penetrates to a slight distance along the cleavage-planes, and the result is an exceedingly delicate reticulation on its upper surface. The calcites which are planted on the copper contain brilliant particles of the metals swimming, if one may use the word, in the interior of the crystals; and these are so disposed as to lead to the idea that, throughout the growth of the younger crystals, they had to contend with the continued deposition of the metal. Thus one of the new scalenohedrons, after growing to the height of 1-4 inch, was, like the underlying one, also ended with a basal termination, on which again smaller new and well-pointed individuals were built up.

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

"A specimen, in my collection, illustrates this remarkably well. It is a cleavage-rhombohedron of opaque calcite, traversed by intersecting sheets of copper, which are wholly independent of the cleavage planes. On detaching the copper from the calcite, the surface of the latter appears rough; it is a fracture oblique to the cleavage, and the face of the fracture is formed by countless corners, or solid angles,

[2]Commenting on this Dr. L. L. Hubbard says: "In many cases the outer or later crystal is in twin position to the earlier. The earlier is generally milky and the later clear. These are distinctly two generations of calcite."

of minute cleavage-rhombohedrons, as is fully proved by the reflection of the light. The copper-sheets, which are about 1-40 inch thick, reproduce this very completely.

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

Dr. L. L. Hubbard has observed that in the trappy portion of the Kearsarge bed there are some feldspar crystals having copper along their cleavage planes.

SULPHIDE VEINS.

Sulphides are found in veins similar to those containing arsenides, but are of even less commercial importance. At some mines, notably those of the Copper Range Consolidated Company, very narrow veins are frequently encountered in working the amygdaloid lodes and the sulphide is thus mined with the native copper ore; but never in very large quantity. Many of the veins cut across the formation but others strike with it. Chalcocite ($Cu_2 S$) is the sulphide most frequently found. Covellite ($Cu S$), Bornite ($Cu_3 FeS_3$) and chalcopyrite ($Cu FeS_2$) also occur. Chalcopyrite is more common in the intrusive rocks of the Keweenawan than in the extrusives and is very rarely met with in the latter.

It was noted by Dr. L. L. Hubbard that some of the sulphide veins first observed seemed to pinch out at a comparatively short distance from the surface. However, deeper workings show quite numerous

sulphide veins. Many of these if traced can be found to pinch out upwards as well as downwards. They have apparently no dependence, as far as origin is concerned, on the present surface.

ARSENIDES AND SULPHIDES OF COPPER.

While seldom of economic importance, several arsenides of copper occur in veins traversing the amygdaloid lodes. The best known ones are keweenawite $(Cu, Ni, Co)_2 As$; mohawkite $(Cu, Ni, Co)_3 As$; whitneyite $Cu_9 As$; domeykite $Cu_3 As$; algodonite, $Cu_6 As$; and stibiodomeykite, a variety of domeykite. At the Champion mine a large quantity of algodonite was found.

G. A. Koenig's Studies.—These minerals were carefully studied and analyzed by Dr. George A. Koenig, who says* regarding their occurrence:

"The knowledge of the existence of copper arsenides in the Keweenaw copper formation is nearly as old as the mining operations in this region themselves. In the matter of occurrence there are two points to be noted; (1) The arsenides are not found in the bedded deposits of native copper, but always in fissures, intersecting the beds. (2) These veins have thus far only been observed in the lower beds, near the foot of the formation to the southeast.* Arsenic, however, is found in the smelted and refined copper of all the mines. This element is a minimal amount in the copper from the Great Conglomerate of the Calumet and Hecla mine and becomes a maximum in the copper from the amygdaloid beds of the lower measures, on which the Mohawk, Wolverine, Arcadian, Sheldon-Columbia, Isle Royale, Atlantic, Baltic, Champion, etc. are located. The Shelden-Columbia location near the shore of Portage Lake in the village of Houghton was the first mine which furnished copper arsenides, notably domeykite. The larger parts of the specimens in collections come probably from this mine. Whitneyite was found in a quartz vein† in dark melaphyre, not far from the present Mohawk, but the existence of any copper rock was not suspected at that time at that point. Several masses of domeykite have been found in the drift on the Hancock shore of Portage Lake, very much decomposed, cuprite and arsenates being the chief products. In the spring of 1898, the opening of a new street in East Houghton on the old Shelden-Columbia location, disclosed a quartz vein containing some foliated domeykite. Many good specimens were gathered and have come into collections. A similar vein has been known for years on the old Huron location, now the southern end of the Isle Royale property. Algodonite was found in the Pewabic mine, located on the Quincy amygdaloid bed and which lies about 5,000 feet higher

*Amer. Jour. Sci., Vol. X, 1900, p. 439.
†A vein of Whitneyite was long known on the Greenstone bluff near the Cliff mine.

than the Isle Royal amydaloid. In developing the Mohawk property a cross vein at right angles to the copper-bearing amygdaloid was met in December, 1899. This cross vein was from 12 to 15 inches wide when struck, but has since shown very varying dimensions. In a gangue of quartz and calcite the copper arsenides have been found in this vein more abundantly than in any of the locations mentioned above. Early in January Mr. Fred Smith, Superintendent of the Mohawk mine, sent me a solid piece weighing from four to five pounds, with the request to make a thorough investigation and report. On January 18th I reported to Mr. Smith that the mineral substance which he had sent me was a new mineral species which I would call Mohawkite. Later on I received other material from Mr. Smith in which I identified an antimonial domeykite for which I propose the name Stibio-domeykite, and also some very peculiar intimate mixture of Mohawkite with Whitneyite. It appears that the Stibio-domeykite is the more prevalent of the arsenides, and not the Mohawkite as was thought at the start. The vein has since been traced to the outcrop where it was found to form a ridge owing to the quartz in the gangue."

Dr. Koenig gives the following analyses of type specimens:
Mohawkite Cu 61.67, Ni-7.02, Co 0-2.20 Fe-trace, As 28.85
Stibio-domeykite Cu 72.48, (Fe. Ni. Co) 0.24, As-26.45, Sb-0.78.
Algodonite Cu 83.72, (Fe. Ni. Co) 0.08, As 16.08.

A. C. Lane on sulphides and arsenides.—Dr. A. C. Lane says* of the occurrences: "Sulphides and arsenides occur but there is no sign of replacement of native copper with sulphides in depth. The contrary, if anything, is true. It is characteristic that the abundant sulphides are basic with excess of copper. Chalcopyrite is rare. Chalcocite is commoner and occurs in the Baltic and Champion mines in long 'seams' nearly parallel to the strike, not in 'fissures' across the lode. On the other hand the mohawkite occurs in cross-fissures. The algodonite at the Champion mine, according to Dr. Hubbard, is in a seam nearly parallel with the lode.

"*Whitneyite* $Cu_9 As_2$ occurs on the third level of the Champion as well as in Mohawk.† On the whole, however, the sulphides and arsenides are thought to be superficial.

"*Domeykite* Cu_3 As (or stibiodomeykite with 1.29 to 0.7856% Sb) Sp. Gr. 7.906 at 21° C, occurs like the mohawkite, which is really only a nickeliferous variety, in the Grand Portage vein.

"*Ledouxite* $(Cu\ Ni\ Co)_4$. As may be an eutectic mixture‡.

"*Algondonite* Cu_6 As, Sp. Gr. 8.383 at 21_6 C.

*Keweenaw Series of Michigan, p. 868-869.
†Am. Jour. Sci. (1900) X, p. 446 and (1902) XIV, pp. 404-416.
‡Koenig, G. A. Am. Jour. Sci. (1900) X, pp. 440-446; Richards, J. W. A. M. Sci. (1901), XI, p. 457; Ledoux, Eng. M. J., April 7, 1900.

"*Mohawkite* $(Cu\ Ni\ Co)_3$ As, a nickeliferous domeykite, Sp. Gr. 8.07 at 21° C. carrying about 63-69% copper, 3 to 7% nickel and 0.5 to 3% cobalt occurs in the Mohawk mine on the Kearsarge lode, and at least as far south as the North Kearsarge lode. A speck perhaps was seen in the Central mine section and Rhode Island four at 529 feet.

"It occurs in cross-fissures tightly welded to apparently fresh country rock, and H. V. Winchell thinks it is not a segregation.

"According to some indications the amygdaloids are leaner, harder and cold grey epidotic near these fissures.

"The occurrence of so-called mohawk-whitneyite with more copper, a mixture of whitneyite with a little mohawkite shows the tendency to native copper.

"*Keweenawite* $(Cu\ Ni)_2$ As (39-54% Cu 9.7 to 20% Ni) is pale red and occurs with Mohawkite in the Kearsarge lode."

ARSENIC IN THE COPPER.

Dr. A. C. Lane says* of the distribution of arsenic in the copper lodes.

"On the Kearsarge lode Mr. J. B. Cooper's tests indicate that there is more arsenic on the whole steadily to the north. Mohawkite occurs in the Ahmeek and North Kearsarge mine as well as in the Mohawk. The conductivity is 77½ to 81 at the Mohawk, 89-91½ at the Wolverine, 91 at the Kearsarge. In the Calumet Tamarack shoot the arsenic increases going north and down. But the copper from the Osceola amygdaloid under (southeast of) the Calumet has but .0006%. As (conductivity 101) while the Calumet has .004 (conductivity 99.5). The Tamarack copper conductivity is 92 to 96, the per cent of copper in the rock melted being lower. The more coarsely crystallized copper is naturally the purest, but coarse copper from the Wolverine contained 0.12 to 0.003% As. However, the arsenic in the 'matrix' (the country rock) is generally more than in the copper. The Mass and Quincy have an extra low amount of arsenic. In the geologically higher lodes the arsenic is less. If the conductivity is more than 90 the As is less than 0.04. The Calumet No. 2 mineral has 0.015% As relative to the copper contained. Arranged according to conductivity (arsenic) we have—

Franklin Junior 100 and Quincy 101 on Pewabic lode.
Atlantic mine (near Ashbed) 100.
Adventure 101, Mass 100 and Michigan 101.
Victoria 93 to 94.5.

*Loc. Cit., p. 869-870.

Kearsarge 91.
Wolverine 89 to $91\frac{1}{2}$.
Mohawk $77\frac{1}{2}$ to 81.
Isle Royale 50 to 55.
Copper Range mines, Baltic, Champion, etc. 65 to 45.
Baltic 45 (with 0.19% As).

This is close to the Shelden and Columbia property and Grand Portage vein from which the arsenides were early described (algodonite, whitneyite, domeykite, etc.).

"It seems to me there are two or three factors involved which need disentangling, and I have not the data yet. The geologically younger lodes often have less As or S. But some of it I think comes from the country rock, for the mineral sent to the smelter may run from one-tenth to one-third rock, and some from arsenides and sulphides of the fissures."

COPPER OXIDE, SILICATE AND CARBONATE MINERALS.

These minerals are only occasionally encountered and do not occur, so far as known, in commercial quantity. One deposit at the Algomah property shows black melaconite (CuO), green chrysocolla ($Cu\ SiO_3 + 2\ H_2O$) and green malachite ($Cu\ CO_3.\ Cu\ (OH_2)$ in irregular masses, and also a veinlet in a brown melaphyre. The deposit follows the bedding of the rocks, making bodies of varying thickness along the strike.

In several cases the green copper minerals have been found in drill cores, especially in the felsites in Ontonagon county. In one opening, on the Indiana property, carbonate and silicate with some native copper have been encountered at a depth of 1,140 feet in felsite.

ACCESSORY MINERALS CONTAINING FLUORINE, BORON OR TUNGSTEN (APOPHYLLITE, FLUORITE, DATOLITE AND POWELLITE.)

Apophyllite (hydrous silicate of calcium and potassium with some fluorine).

The occurrence of apophyllite has been noted by several writers who discuss the significance of its fluorine content in regard to origin of the deposits. The mineral is comparatively rare and the specimens collected are nearly, if not all, from a few fissure veins. Prof. A. E. Seaman has found numerous specimens at the Phoenix, St. Clair and Clark mines in Keweenaw County, but states that he has seldom seen it in Houghton county.

An analysis by L. J. Smith of one specimen, shows 0.96% fluorine.

Flourite (Calcium flouride $Ca\ F_2$).

According to Prof. A. E. Seaman flourite occurs in some veins in the Eagle River district. Recently it has been found in small quantity in the shaft at the Indiana Mine, Houghton County.

Datolite (A basic orthosilicate of boron and calcium, $H\ Ca\ B\ Si\ O_5$).

Is a fairly common mineral in the copper deposits, occurring both in the fissure veins and also in considerable quantity as rounded masses in the amygdaloid lodes. An analysis of the common white compact variety by Chandler shows SO_2-37.41, $B_2\ O_3$ 21.40, Ca O 35.11, H_2O 5.73, (Al_2O_3, $Fe_2\ O_3$) 0.35.

Powellite.—Dr. G. A. Koenig and Dr. L. L. Hubbard have described* specimens of powellite found in the 21st level of No. 8 shaft, South Hecla, Calumet conglomerate lode.

They describe it as a pale bluish green tetragonal mineral with vitreous lustre having one distinct and one imperfect cleavage. Analyses showed it to be essentially calcium molybdate containing tungsten. Two analyses made by independent methods showed:

	$Mo\ O_3$	WO_3	CaO	MnO	Fe_2O_3	$Si\ O_2$	Sum.
I	65.74	4.50	27.41	....	Undet.	....	97.65
II	67.84	1.65	27.30	0.16	0.96	1.52	99.43

The methods for estimation of tungsten give the percentage only approximately, one figure being probably too high and the other too low.

SILVER IN MICHIGAN COPPER DEPOSITS.

Silver occurs in many, and probably all, of the copper lodes. It is present only in very minor quantity compared with the copper, but it is by no means negligible. The ore is not all treated for its silver and the actual amount mined is therefore not definitely known. The ores known to contain appreciable amounts of silver are treated separately from the others at the smelters and the copper is cast in anodes in order that the silver may be recovered electrolytically. Some silver is also recovered by hand-picking metallics at the mills. The total production of silver for the past four years is reported by B. S. Butler, in the U. S. G. S. reports on Mineral Resources, as follows:

*Am. Jour. Science, Vol. XLVI, Nov., 1893, pp. 356-358.

PRODUCTION OF SILVER FROM MICHIGAN COPPER MINES.

Year.	Ounces silver obtained by picking.	Tons ore yielding copper treated for silver.	Pounds copper treated electrolytically for silver.	Ounces silver recovered electrolytically.	Ounces silver per ton of ore treated for silver.	Total ounces silver recovered.	Value of the silver.
1908....	3,595	1,494,339	26,786,485	237,460	0.1589	241,055	$127,759
1909....	1,364	1,500,000	31,500,113	285,066	0.19	286,430	148,944
1910....	....	1,518,000	34,189,526	330,500	0.2176	330,500	178,470
1911....	513	2,300,000	43,755,777	496,768	0.216	497,281	263,559
1912....	....	2,500,000	45,570,130	528,453	0.211	528,453	324,999

The silver, like the copper, occurs as the native metal. Frequently small masses of copper and silver are found intergrown—forming so-called half-breeds. It has frequently been pointed out that the metals are not alloyed; but are simply grown together and can be easily separated by mechanical means. According to several writers, silver was more abundant nearer the surface than it is at great depths. The descriptions also indicate that it was more abundant in the fissure-vein mines of Keweenaw County, than it is in the bedded deposits now being worked.

CHAPTER V.

THE COPPER DEPOSITS OR LODES.

The numerous lodes which have been worked more or less successfully will be described in alphabetical order. The chief producing lodes are the Calumet conglomerate and the Kearsarge, Baltic, Quincy, Osceola and Isle Royale amygdaloids.

ADVENTURE NO. 4 LODE.

The chief production at the Adventure mine, which was unprofitably operated for some years, was from lodes in the horizon of the Mass mine lodes described later. The recent work has been of an exploratory nature. The following remarks apply to the unusual type of deposit encountered in the recent openings.

In the cross at 1,500 feet level south from No. 3 shaft, there is exposed a fine grained greenish rock which carries in places some native copper. The rock resembles some epidotic felsites, but microscopic examination shows it to be distinctly fragmental. It is composed largely of quartz, epidote and rock grains. The latter are very dense and largely composed of feldspar and quartz. Many of them are probably felsites, but they are red stained and the texture is obscured. One section shows numerous copper particles with quartz and epidote between the sand grains. Some copper occurs in and has probably partly replaced the grains themselves. Some copper extends in a continuous mass from the quartz-epidote cement through the sand grains. It seems likely that the copper was not deposited with the sand but was brought in later and replaced constituents of sand grains and cement.

Below this light colored sandstone there is a dark brown sandstone containing much quartz and epidote, with some feldspar and calcite and numerous rounded grains of black oxide, probably magnetite, and red patches, probably hematite.

Above the sandstones is a brown mottled much fractured trap containing masses of green epidotic rock which frequently carries copper. The trap is largely made up of altered feldspar and dark green chlorite with numerous black grains and irregular red patches. One specimen of trap shows numerous minute grains of copper in a feldspar crystal.

ALGOMAH LODE.

The Algomah lode is the upper portion of a brown colored amygdaloid. It differs from the other lodes in carrying black oxide, green silicate and green carbonate of copper instead of the native metal. Along the strike it shows great masses of green colored ore, more or less separated by stretches of brown amygdaloid. Sixty tons of selected ore was sampled and said to yield assays of 24% copper. Development has not proved a large body of good ore however.

The copper oxide in the Algomah lode occurs chiefly as dull black massive melaconite, but Prof. A. E. Seaman has found specimens showing black tetragonal crystals of paramelaconite in green malachite.

The lode strikes nearly north and dips to the west at an angle of about 70° at the shaft. It is close to the eastern sandstone and the northern drift on the lode intersected the great Keweenaw fault and the sandstone.

ALLOUEZ CONGLOMERATE.

This lode is not now being worked;* but it contains considerable copper in places and may be opened up again at an early date.

At Allouez Mine.—Some characteristics of this lode are given in Chas. E. Wright's account of operations at the Allouez mine in 1882. He says:†

"The center of the main 'shoot' of copper crosses No. 2 shaft at about the eighth level and makes with the vertical an angle of 30°, opening upward to the south.

"A remarkable 'slide' extends down through the mine from the surface 200 feet south of No. 1 shaft, and pitching to the north at an angle of 60°, crossing No. 2 at the thirteenth level. This slide is soft clay loam, crossing the formation. The tenth level is extending south to intercept a good shoot of copper that has been found to follow the slide. During the past year the eighth, ninth and tenth levels have been driven north to nearly No. 3 shaft, and the main copper shoot of the mine is found to continue to these levels.

"The lode bears north 39° east, and dips 38° northwesterly; it is a very wide, coarse, conglomerate belt, corresponding with that which further north immediately underlies the greenstone. It is the same belt which is now being opened at the Delaware—Conglomerate Mining Company—though, at the latter mine it is claimed that the belt is richer in copper than it is at the Allouez. They find richer specimens at the Conglomerate than are found to occur at the Allouez, and likewise limited portions of the lode that carry more copper, but to what

*Since this report was written the lode has again been opened up at the Franklin Jr. mine.
†Report Com. Min. Stat. Mich., 1882, p. 82.

extent this will affect the average yield to the advantage of the former company remains to be seen. Here, as at the Conglomerate, the belt is very wide—twenty to thirty feet in width—much too wide to work to advantage.

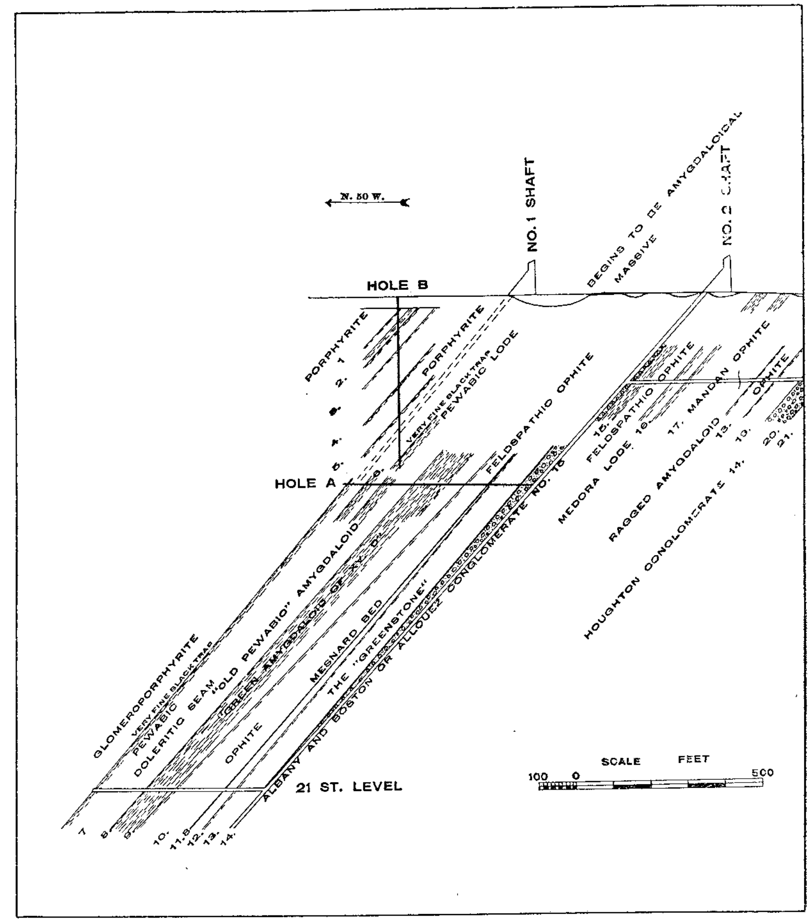

Figure 4. Section at Franklin Junior mine showing Pewabic and Allouez lodes (after Lane).

"The drifts are carried along the foot wall, and four feet or five feet of the conglomerate are left next to the hanging to help support it. The hanging wall is exceedingly poor, and requires frequent pillars to be left, together with considerable thickness to the bottoms of the drifts and a portion of the lode in contact with the wall, to support it.

"The lode is not uniform in richness. The copper appears to be in seams, where it occurs, alternating, in streaks. It is exceedingly lean in copper, but requires to be all taken down and subsequently sorted, and even then very much of it is stamped that is really worthless."

"They have stamped during the year (1881), 74,538 tons of rock, which yielded 969 tons, 860 pounds of mineral, which, smelted, gave 710 tons, 1,403 pounds ingot copper. Number of tons rejected was 12,837, 1-7 of whole number of tons hoisted."

The yield per ton from the ore mined in 1881 was 19 pounds copper.

At Franklin Jr. Mine.—Thomas Macfarlane says* of the conglomerate mined by the Albany and Boston Mining Company (now Franklin Junior):

"The boulders and pebbles consist of various species of porphyry. One of them has a dark brown matrix with small white crystals of feldspar; another has a matrix of the same color, but with larger crystals of orthoclase, while a third variety consists principally of a fine grained mass of orthoclase, with which a small quantity of a dark colored mineral occurs in particles too small for determination. The matrix consists of a course grained sand of porphyritic material, impregnated with calcareous matter. In many places the interstices are not at all filled up, in other calcspar is the matrix, and very often, in the lower part of the bed, the matrix is almost all pure metallic copper. Sometimes the metal completely fills the whole space between the pebbles, sometimes it is accompanied by calcspar, but much nore frequently is is disseminated in fine particles through the coarse grained matrix. Sometimes a pebble is found quite saturated with copper, but it seems to have been of a more porous nature than the others, and an amygdaloidal structure may be detected in it.

"As above mentioned, a bed of sandstone underlies the conglomerate. It shows traces of stratification, is of a dark-red color and evidently of the same material as the conglomerate pebbles but in finer particles."

At the thirty-second level of the Franklin Junior mine a cross cut has been run from the workings or the Pewabic lode to test the Allouez conglomerate which had not been previously opened up at so great a depth. Where cut at the thirty-second level the conglomerate is thick and shows considerable copper.

ASHBED LODE.

The Ashbed lode is an amygdaloidal porphyrite which has been worked at several mines in Keweenaw county. It was frequently first opened incidentally in working fissure veins and commonly was then found richest where traversed by the veins. It has for some years not been

*Report Geological Survey of Canada, 1866, pp. 156-157.

worked, but the Keweenaw Copper Company has begun a thorough investigation of its possibilities.

The bed lies comparatively flat, being commonly inclined at an angle of less than 30°. This flat dip does not permit the broken ore to run freely down the stopes, and thus increases the cost of handling the ore. This difficulty is partially offset by the fact that the lode is rather easy to drill and break.

The Ashbed derives its name from the character of the upper part of the lava flow. This has a conglomeratic character due to mixture of large volcanic fragments with ash and mud.

Chas. L. Lawton says* of the lode at Copper Falls Mine:

"The rock yields about 0.7% copper. The lode is but seven feet in width and lies at an angle to the north of about 27°. * * * The Ashbed is faulted at three different points in this mine, west of the main adit. The main faults are 65 feet and cause a good deal of dead work in the drifts in each level. The Ashbed mines very cheaply. The main drawback is in the matter of getting the rock down from the stopes."

ATLANTIC LODE.

General character.—The Atlantic Lode is comparatively low grade bed but was for several years worked profitably by the Atlantic Mining Company. In its best part it yielded only from 13 to 14 pounds copper per ton and as the workings were extended north and south and deeper the yield fell to 11 and 12 pounds. That the lode was profitable at all is due to the fact that this yield was obtained by continuous stoping. The copper was not very regularly scattered through the lode, but neither was it confined to portions which could be readily selected from waste rock. The whole lode was broken and an unusually low cost per ton thus obtained.

The rock in which the copper occurs is, according to Dr. Hubbard, a melaphyre conglomerate. The fragments of melaphyre, commonly amygdaloidal, are cemented by dark reddish sandy material which is in places greenish with epidote. This conglomeratic character is more noticeable in the upper part of the lode, while the lower portion is a dark brown amygdaloid. The Atlantic mine has been idle for several years, having caved in 1906.

Dr. L. L. Hubbard's description.—Dr. L. L. Hubbard's description† follows:

"The bed worked by the Altantic Mining Co. is in part a melaphyre conglomerate,‡ being made up of fragments of amygdaloidal melaphyre in a matrix of fine but more or less angular basic sandy material, in

*Rep. Com. Min. Sta. Mich., 1885, p. 224.
†Geol. Sur. of Mich., Vol. VI, Pt. II, p. 137.
‡Pumpelly's description tallies with this designation. Ibid 1, Pt. II, p. 77.

places altered to epidote. The copper-bearing belt extends down into the unbroken amygdaloid. This and the underlying trap belong to the more basic lavas and have no immediate resemblance to the typical Ashbed rock as we find it on Keweenaw Point as far south as the Tamarack mine, other than in the fine dissemination of the copper which it carries. The Ashbed rock shows abundant greenish to reddish crystals of feldspar."

C. Rominger's description.—C. Rominger says* of the Atlantic lode: "The Atlantic Mine, situated about one mile south of its stamp works, is opened in a large dark brown colored amygdaloid belt, overlain by a conglomerate belt fifty feet wide. This amygdaloid belt has in part the character of a breccia composed of irregular larger and smaller blocks and rounded masses of a brown colored amygdaloid full of cavities, filled principally with calcspar and laumonite, but also quartz, prehnite, delessite, epidote and copper take part as filling-materials, either one alone or several of them associated, and of a cementing groundmass of the same brownish color as the inclosed amygdaloid masses, which exhibits distinct sedimentary lamination. The surface of the inclosed rounded masses of the amygdaloid is sometimes coated with a polished crust, streaky like slickensides; other times their pitted surface is shining as if glazed by exposure to fire.

"The copper is quite unequally distributed in this rock belt; the richer portions of it are copiously interspersed with larger shotlike grains and also with branching hackly masses of the metal which have moulded themselves after the shape of pre-existing fissures and cavities in the rock; much of copper is also contained in the amygdules in association with the other mentioned minerals.

"Other portions of the belt are poor and the copper contained in them occurs in smaller molecules. Practically no selection is attempted of the poorer rock from the richer, the entire width of the rock seam is taken out and the material run through the stamp mill."

Production.—Chas. L. Lawton says† of this lode:

"It is a comparatively soft amygdaloid, not so soft but what it breaks well under the action of blasts. It averages 10 feet in width and is uniform enough to permit its all being stoped."

Mr. Lawton gives the figures on yield per fathom for years 1875-1888. The figures for following years are from the annual reports.

*Geol. Sur. of Mich., Vol. V, Keweenaw Group, p. 97.
†Report, 1888, p. 28.

PRODUCTION OF ATLANTIC MINE, 1875-1902.

Year.	Tons ore stamped.	Ground broken, fathoms.	Yield of copper per fathom broken.	Yield of copper per ton (in pounds).	Remarks.
1875	80,000	....	278	19.58	
1876	96,696	....	280	18.99	
1877	105,780	....	290	19.42	
1878	121,709	....	243	18.50	
1879	112,668	....	266	19.00	
1880	169,825	....	244	14.27	
1881	176,555	....	2,735	14.36	
1882	189,800	....	259	13.866	
1883	195,669	....	240	13.708	
1884	209,510	....	259	15.1	
1885	241,010	....	267	14.86	
1886	247;035	....	238	14.18	
1887	255,750	....	234	14.24	
1888	298,055	....	228	13.34	
1889	278,680	16,155.9	228.9	13.272	
1890	278,300	18,819.8	192.3	13.0	
1891	297,030	20,591	177.4	12.3	"Falling off in 1891 probably due to extension of openings north and south of the central portion of the mine where the best ground is located."
1892	300,900	17,811	207.9	12.31	
1893	315,670	18,398	229	13.375	
1894	315,626	20,243	219	14.06	
1895	331,058	20,037	241	14.6	
1896	371,128	20,629	237	13.19	
1897	394,296	24,429	209	12.96	
1898	370,767	20,438	214	11.8	"Lower grade ore from new 'A' shaft, falling off due largely to increased production north and south."
1899	380,781	22,101	211	12.28	
1900	410,674	23,071.5	213	12	
1901	409,124	24,883	187	11.4	
1902	446,098	25,764	192	11.095	

BALTIC LODE.

General character.—The Baltic lode is the cupriferous upper portion of a thick bed of melaphyre. It is in part amygdaloidal, but in part also dense brown trap which is more or less shattered and seamed with secondary minerals, especially calcite. The amygdaloid portions have commonly a gray or brown ground mass and amygdules of white calcite. The trap is a brown melaphyre spotted with dark green chlorite—a pseud-amygdaloid. Very little of the copper occurs as a filling in amygdaloidal cavities, and much of it is not in amygdaloid at all. The lode differs therefore from the regular portions of typical amygdaloid lodes and fracturing has been largely responsible for the formation of cavities in which the copper was deposited. This character has been noted by several writers and is expressed by Dr. Lane in the statement that "the Baltic lode is not one well defined amygdaloid top to a flow, but rather an impregnated shear zone or stockwerk, copper being found over a belt more than 40 feet wide." The footwall trap is, according to Dr. Hubbard, from 100 to 150 feet thick for a length, at the Baltic and Champion mines, of four miles. In the hanging wall of the main lode there is a second smaller deposit, known as the "West lode," which has been opened in several places by crosscuts or 45° raises. It has yielded good ore in some parts of the Champion and Baltic mines.

The Baltic lode is a wide one, being commonly from 15 to 60 feet and in some places 80 or 90 feet. The thickness at the mines averages about 24 feet. At the Baltic mine the lode strikes N. 60° E. and dips 73° N. W. This dip is much steeper than that of any of the other lodes being mined. At the Champion mine the Baltic lode strikes N. 26° E.

Fissures are numerous in the lode and at some of the mines faults and soft seams cut across it at short intervals. Many of the fissures are filled with calcite, making conspicuous, though usually very narrow white veins running across the dark colored rock. Many others are filled with soft greenish and reddish material, chloritic, talcose or clayey. These soft seams have apparently resulted from crushing and slipping. Often in such ground the lode is displaced many times

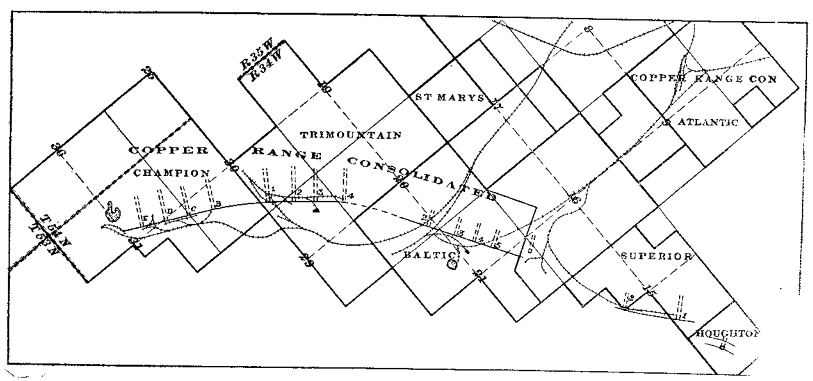

Figure 5. Map showing mines on Baltic, Superior and Atlantic lodes.

in a short distance. Numerous narrow veins of calcite run parallel to the bedding and some contain chalcocite.

Distribution of the copper.—In parts of the lode, the copper is distributed rather evenly through the rock and little selection is then possible. In other places however, the copper is in bunches separated by very low grade or barren rock and the good ore is readily sorted out and the waste is used for filling the stope. As a rule the rich portions of the lode show copper very conspicuously and often include numerous masses. In places the copper, while all in small particles and not showy, is very evenly distributed through the rock giving an ore which is comparatively low grade, but not mixed with barren rock.

The main production of the Baltic lode is from a three mile stretch worked at the Champion, Baltic and Trimountain mines. Further

northeast, operations on the Baltic lode have disclosed ore at the Superior and Houghton mines. Here a lode known as the "Superior lode" is about at the horizon of the Baltic lode and is thought to be a continuation of it. On the intervening properties no important ore body has been found. At the Atlantic section 16 shaft, the lode was found to be very badly fractured, faulted and crushed, and there was great difficulty in identifying horizons. The ore bodies were repeatedly cut off by faults and the workings were seldom in ore for any considerable distance. At the Superior mine the lode is also much fractured, but a large body of good ore has been blocked out at one shaft. Similar ground has been found also further north at the Houghton mine shaft.

At the Champion, Trimountain and Baltic mines the lode is comparatively firm. There are numerous fissures, but the ground has not been so severely disturbed as further northeast. In some places at the Baltic and Trimountain mines the lode is more broken up and between the Trimountain and Baltic mines there is a disturbed area accompanying a marked change in strike of the lode. It is generally supposed that there has been considerable faulting here.

At the Copper Range mines, Champion, Trimountain and Baltic, the ore is commonly sorted and the waste rock is used for fill. The sorted ore from the different mines in 1912 yielded 19 to 22.5 pounds copper per ton. At the superior mine the ore is of quite different character, much of the copper being in very fine particles, and sorting is not practiced. The ore mined from this lode at the Superior in 1910 averaged 22.64 pounds per ton. At present much of the ore from the Superior mine is coming from a second deposit known as the West lode, which is described elsewhere in this report.

Future production.—None of the mines on the Baltic lode have yet reached very great depth and its future yield can only be roughly guessed at. In 1911 Mr. J. R. Finlay estimated that the lode should produce 15,000,000 tons of ore containing 311,000,000 pounds of copper. This estimate is based on a lesser depth than that of the other great lodes and will be much exceeded if the ore persists with depth.

L. L. Hubbard on Baltic lode.—Dr. L. L. Hubbard in Vol. VI, of the publications of the Survey says* of the Baltic lode:

"The Baltic mine is in an amygdaloid bed, whose strike according to Mr. Theodore Dengler, Mining Engineer of the Atlantic and Baltic mines, is N. 60° 30' E. (Magn.). This bed crosses the line between sections 20 and 21, T. 54, R. 34, about 200 feet north of the quarter-post. It shows some slight evidence of disturbance, in the nature of shearing or slide-faulting, in the presence of several small fissures that strike with the bed and are nearly vertical; they are filled with a

*Page 135, Vol. VI, Keweenaw Point.

carbonate of lime and carry some chalcocite. These fissures appear to wedge out at a short depth from the surface. Other irregular seams cross the rock, filled with calcite, this being also the usual filling of the amygdules. The latter are irregular in shape, and in places almost look as if they were secondary, i. e., pseudoamygdules, due to the filling of irregular cavities or pores induced by chemical or by mechanical changes, or by both. The calcite is of earlier origin than the copper found associated with it, the latter showing the mould of the cleavage and twin-planes in the former. On being exposed to weathering the clacite becomes yellow from a small percentage of iron in it. The dip of this bed is about 73° to the northwest."

CALUMET CONGLOMERATE LODE.

General character.—The Calumet lode is the cupriferious portion of one of the conglomerate beds interstratified with the volcanic rocks of the lower Keweenawan. The conglomerate is a thin bed which has been traced more or less continuously for several miles. The ore bearing portion is almost entirely confined to that part, about two miles long, which outcrops on the property of the Calumet and Hecla Mining Company and which at depth crosses into the property of the Tamarack Mining Company. On other properties north and south it has been extensively worked but with the exception of a small area at the Tamarack Junior Mine, proven unprofitable. The conglomerate is overlain and underlain by thick beds of trap, chiefly coarse ophites.

The conglomerate rock mined is made up largely of pebbles of felsite and quartz-porphyry cemented together with small particles of rock, calcite and native copper. The cementing material commonly contains also iron oxides, quartz, epidote and chlorite. Much of the iron oxide is martite, a pseudomorph of hematite after magnetite. While most of the pebbles are silicious rocks, some are melaphyres or porphyrites.

The conglomerate is characteristically red, both pebbles and cement being commonly of that color. Near the surface it is somewhat redder than at depth. Most of the constituents are of light tones, but parts of the lode are largely made up of dark reddish brown pebbles. Most of the lighter colored pebbles, light red or flesh colored, are dense felsite or quartz porphyry. The darker colored ones have usually a finely felsitic ground mass and phenocrysts of brown red feldspar. Other dark brown ones have a very dense ground mass enclosing phenocrysts of quartz. Some are dark colored felsitic rocks with no phenocrysts. Many pebbles show an outer rim of lighter color than the interior. This results from alteration.

The small rock particles in the matrix are similar in character to the pebbles, but have been more extensively altered.

Occurrence of the copper.—The copper occurs chiefly as part of the cement, filling spaces between sand grains and pebbles, but some has replaced the rock constituents. It is a common occurrence to find large pebbles partially replaced by native copper. Mr. Chas. L. Lawton says in one of his reports that of the 47,247,990 pounds of copper recovered in 1885 about two per cent was from the "nigger heads" or small copper boulders. While most of the copper is coarse, much of it is in very minute particles and the ore has to be finely ground to avoid heavy losses in sand tailings.

Light and dark portions.—Where a large section across the lode is exposed, as in the drifts and stopes, there are usually to be seen rather distinct light and darker colored portions. The copper is chiefly in the light colored rock. The darker colored portions are noticeably more compact and less altered than the lighter. They have evidently not been much affected by the solutions which in more porous parts altered the rock and deposited native copper.

Sandy portions.—In places the conglomerate grades into a sandstone made up of particles similar to the cement of the conglomerate. The sandstone sometimes is locally heavy with copper, giving the so-called "brick" copper, but more commonly the sandstone portions are comparatively lean and often barren.

Thickness.—The thickness of the lode, as determined by mining operations, is from 10 feet to 20 feet. Near the surface at the Calumet mine the lode is said to have averaged about 13 feet, at some levels at great depth at the Tamarack mine about 22 feet and at similar depth further south in the Hecla mine about 10 feet. In the upper levels the lode was much thicker at the south Hecla shafts than at the Calumet shafts, but not so rich. According to Capt. Daniell, the thin portions "seem to occur in spots rather than in regular courses." The average thickness of the ore still to be mined by the Calumet and Hecla Company is said to be about 15 feet.

Distribution of copper.—As a rule the values are irregularly distributed from wall to wall. In places the poorest part of the lode is near the hanging wall, and in other places the upper portion is the richest. In extensive workings tributary to one deep shaft the portion next the foot wall was always the least productive.

The Calumet shoot.—The richest part of the lode was that opened at the Calumet shafts and which forms a very large shoot pitching north at about 70°. While production was largely from this shoot the ore averaged over five per cent copper and yielded over four per cent refined copper. The available records do not show definitely

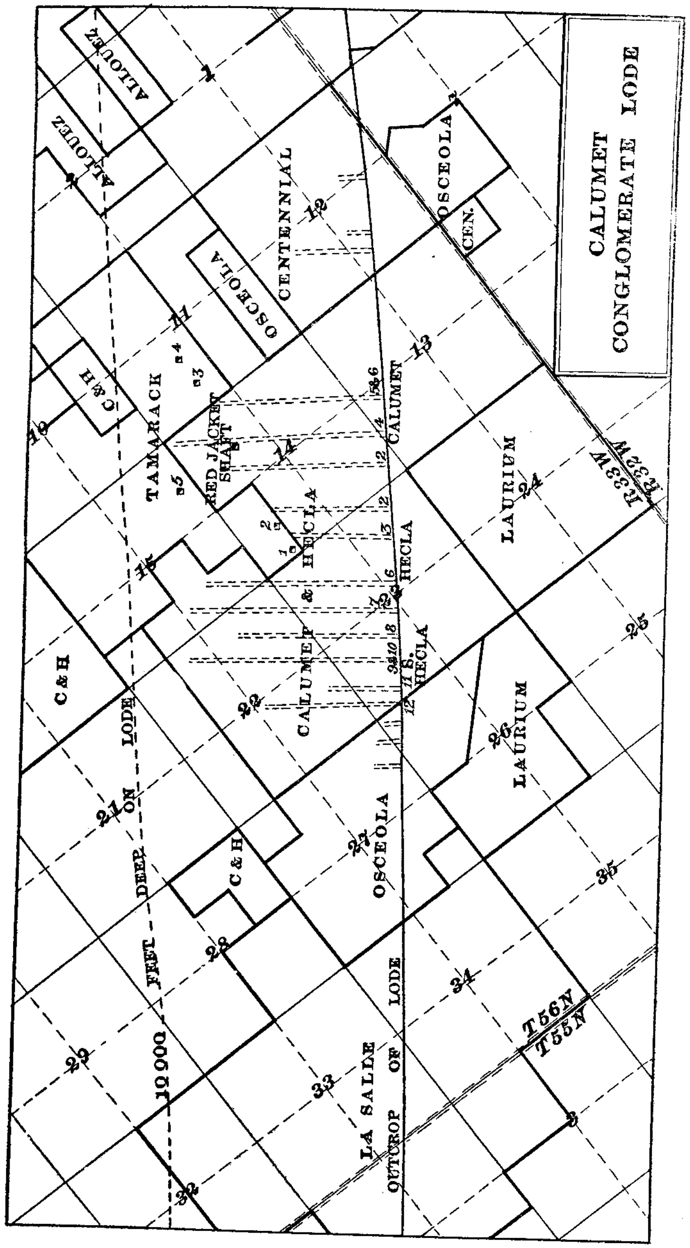

Figure 6.

how the values held with depth, as the production from other leaner parts of the lode became larger in 1887 and the product is not distinguished. It is known, however, that the values at the fortieth level were still practically as high as in any of the levels above. As near as can be judged from the available records, the Calumet ore shoot for over a mile downwards on its pitch of 70°, continued with

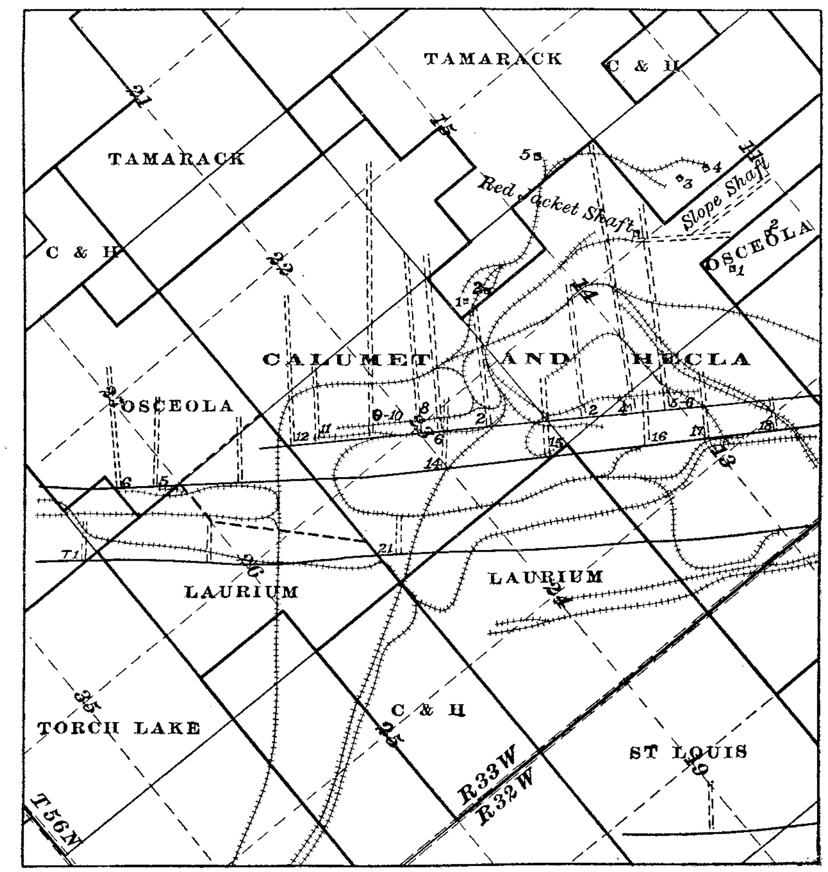

Figure 7. Map showing Calumet and Hecla and Tamarack mine locations.

fair regularity to yield over four per cent copper and then, below the 57th level, yielded ore of much lower grade.

The leaner portions.—Aside from this main ore shoot and other smaller and less rich shoots in the southern portion of the property, the conglomerate usually contains enough copper to pay for mining. Some very large blocks have been left as unprofitable ground and numerous smaller blocks are left in different parts of the mine. It is not customary to do much sorting of broken ore in the mine and the poor ground is as far as possible left unbroken. The broken rock is practically all hoisted and a little, chiefly hanging wall trap, is discarded at surface. The trap is in places very weak and a little of the lode is commonly left on the hanging to provide a better roof for the openings. Not infrequently however, some of the trap breaks and becomes mixed with the ore.

Strike and dip.—At the Calumet mine the conglomerate lode strikes N. 33° E. and near surface dips to the N. W. at an angle of about 38°. At the South Hecla mine the dip at surface is about 39°. At depth the angle of inclination is slightly less than at surface. One shaft, following the lode closely is inclined at 38° down to the 36th level and below that at 37° 30′. Dr. A. C. Lane in a section across the lode lode at one shaft gives the dip as 37° 10′.

"Brick" copper.—At the Calumet mine the conglomerate contains numerous sandstone streaks. These as a rule are thin and pinch out quickly, being of lenticular form; but in some places the sandstone layer is of considerable extent. There is frequently a good parting along the bedding of the sandstone and it is stated that such surfaces often show distinct ripple marks. Generally the sandstone contains very little copper, but on the other hand there are some thin bands two to three inches thick which are very rich. The copper is in a fine red sandstone made up of rock and mineral fragments of the same kinds as is the coarse conglomerate. Much of the sandstone is of a greenish gray color made up largely of quartz and epidote and commonly barren of copper.

In some places the thin red sandstone seams contain enough copper to pay the whole cost of mining and treating 12 feet of conglomerate. It is stated that some of these seams contain as high as 80 per cent copper.

The hanging wall.—The hanging wall of the conglomerate is a dense trap which has a good fracture plane at a distance of about one to two feet from the contact. In places there is vein material along this face and it appears to be a fissure along which some movement has taken place and which has been subsequently filled, chiefly with calcite. When exposed to the air the calcite crumbles and the roof breaks off easily thus necessitating care to prevent the fall of the "cab" as it is called by the miners. It is common practice to leave a little of the conglomerate on the hanging wall, to avoid disturbing the cab. Except where the lode is rich, the saving in cost of mining more than compensates for the loss of copper left in the conglomerate.

In the upper levels at the south end of the property there is a mud seam about four inches thick at the contact between the lode and the overlying trap.

Early openings at Tamarack mine.—Chas. L. Lawton describes the portion of the conglomerate first opened at the Tamarack mine. He says:*

"The lode averages about 12 feet wide, and so far as opened is all good ground, that is, all the vein carries copper; not in equal amount, however; some of it is very rich, but the rich rock and the poor are everywhere, in all parts of the lode. If a light is thrown upon a smooth, vertical section of the deposit, it shows the rich and poor rock nicely; the dark, barren portions are strongly contrasted with the segregations of light colored rock richly impregnated with mineral—a small amount of rock—five per cent—is rejected; this comes in part from the hanging, but also, mainly, from a deposit of sandstone that occurs in the vein south of the shaft. It is of variable width, but at no place takes more than five feet of the vein; sometimes against the hanging and again leaving a few feet of rich conglomerate between it and the hanging; in places it is simply a thin seam and wedges out entirely. So far they have no rich shoots of copper, as are found in the Calumet and Hecla, to bring up the average percentage."

At Tamarack mine in 1896.—Supt. W. E. Parnall said in his 1896 report on the Tamarack mine:

"The mine from the 12th to the 21st level (No. 1 shaft) opened lean, except in patches, compared with the ground above. Being confined to comparatively narrow limits, considering the output of rock, there was no chance for special selection, nor would it have been good mining to leave behind and expose to absolute loss ground on which a small profit could be made. This, I am pleased to state, has been struggled through."

South of No. 1 shaft there was a "crossing" or fault and near this the lode was poor. Supt. Daniell refers to it several times in his reports. He says in his report for 1889: "The 6th level has in all been opened for a length exceeding 800 feet and, excepting 50 feet in length of lean ground in the vicinity of the 'crossing,' has been of excellent quality. The lode in 8th level south narrows from crosscut, and near the crossing is not much in excess of nine feet wide. We drifted through lean ground here; 100 feet in length we scarcely regard as good enough to stope. Beyond or south of the crossing the conglomerate affords fairly good stoping ground, but the lode does not run in excess of 10 feet wide." Speaking generally of the parts of the lode near the crossing, he says: "We consider that the crossing affects this ground unfavorably." Regarding the distribution of the copper in the lode he says:

*Report Com. Min. Stat. Mich., 1885, pp. 243-244.

"I cannot say that the copper courses in the (Tamarack) mine have any particular direction. Ordinarily, when the conglomerate is less than average width it is off in productiveness, but the narrow parts seem to occur in spots rather than in a regular course."

Supt. W. E. Parnall in his report for 1895 says of the portion of the lode first opened up at No. 3 shaft. "It will average 21 feet wide and is made up of very rich and very lean streaks." No. 3 shaft reached the lode at a depth of 4,185 feet where it was 19 feet thick.

The "crossing."—Reference to the "crossing" is also made by Supt. Daniell in the 1886 report of the Tamarack Mining Co. He says: "In the workings of the Hecla mine a 'crossing' or fault running nearly at right angles to the lode and enclosing strata has been noted. It heaves or dislocates the beds of rock, the displacement being generally equal to, or greater than the thickness of the conglomerate, say from eight to ten feet. This, for a long time was regarded as the southern limit of the copper ground, and in its vicinity the lode has not been of average quality. As we pushed south at the second and third levels (Tamarack No. 1) we encountered several small fractures running across the conglomerate, and recently found, at 210 feet from the shaft the 'crossing.' At this point the throw is fully eight feet, the southern extension of the lode being towards the west or hanging wall."

Tamarack ore.—At Tamarack No. 3 according to Dr. Lane, the main good shoot of copper ground coming in from the Hecla (or "Black Hills") end of the Calumet comes in according to Capt. Rosevear, in the 15th level at 1,300 feet; and on the 18th level at 600 feet. Dr. Lane remarks that the damp ground is said to be better copper bearing.

Mine water.—Dr. Lane states* that "The Calumet conglomerate water is relatively fresher than that in the amydaloid rocks around it on either side; but this difference seems to disappear somewhat at great depth or at least that the ratio of Ca:Cl becomes about the same. The copper is richest in the middle water and becomes very slowly less rich as the lower water is reached, but continues good long after the lower water is well established and the Ca:Cl ratio has become 0.485."

At Osceola mine.—Chas. L. Lawton says† of the Calumet conglomerate as opened up at the Osceola mine.

"The conglomerate (C. and H.), which underlies this west amygdaloid has in places a remarkably good hanging wall. Where it was worked out ten years ago in large chambers the roof remains perfect. At other points it was broken up. Where the hanging is broken and poor the conglomerate is said to have carried copper, but in the portion having a firm hanging, the conglomerate was proportionally barren,

*Keweenawan Series, Pub. 6, Mich. Geol. Sur., p. 811, 1909.
†Report Com. Min. Statistics, 1885, p. 248.

and the amygdaloid was good—giving rise to the theory that the broken rock between the lodes allowed the copper to pass from the amydgaloid into the conglomerate."

Production of Calumet conglomerate lode.—The conglomerate has yielded more copper than any other lode on Keweenaw Point, and the metal has been won at a cost which has made the Calumet and Hecla the leading dividend producer among the mines of the world. Mr. J. R. Finlay estimated, in 1911, that the Calumet and Hecla had still on the conglomerate lode about 27,000,000 tons of ore which should yield 26 pounds per ton—a total of 702,000,000 pounds of copper. Another estimate in the same year was 30,000,000 tons yielding 30 pounds per ton, a total of 900,000,000 pounds. On account of great depth and lower values, the Tamarack yield for the future is very problematical.

The following table from "The Mineral Industry" shows the output for Calumet and Hecla for several years. It will be noted that for the period from 1875 to 1886 the yield was remarkably uniform. During this period the Calumet mine was deepened to the 30th level, and the output was largely from the main Calumet ore shoot. Subsequently a much increased tonnage came from other shafts. Beginning in 1887, there was a large production from the Black Hills or South Hecla shafts. After 1891 for several years the yield was not made public. For the past few years it has been about 1.5 per cent.

PRODUCTION OF CALUMET AND HECLA MINE, 1767-1891.

Year.	Ore milled, short tons.	Pounds refined copper produced.	Yield, per cent.
1867	...	1,351,173	...
1868	...	5,098,375	...
1869	...	c12,315,771	...
1870	...	14,061,584	...
1871	...	16,222,590	...
1872	...	16,183,836	...
1873	...	18,848,265	...
1874	...	20,125,225	...
1875	249,704	21,473,954	4.30
1876	259,935	d21,690,737	4.17
1877	247,935	22,568,468	4.55
1878	271,000	25,251,128	4.66
1879	284,715	26,271,243	4.61
1880	334,343	31,675,239	4.75
1881	340,080	31,360,781	4.61
1882	344,132	32,053,540	4.59
1883	372,570	33,125,045	4.45
1884	435,352	40,473,585	4.63
1885	535,820	47,247,990	4.40
1886	598,522	50,518,220	4.22
1887	654,055	46,016,123	3.52
1888	763,728	50,295,720	3.29
1889	807,918	46,668,296	3.01
1890	i947,700	59,868,106	3.16
1891	h960,309	63,586,620	3.31

cFor 12 months ending December 31, 1869.

dFrom 1867 to 1872, inclusive, the respective reports are for the year ending July 1. From 1873 to 1875, inclusive, the reports are given up to the first of May. In accordance with an act of the Legislature, the form of the report, as well as its date, was changed, the latter being the 31st of December of each year instead of the company's fiscal year. Owing to this change the year 1876 is carried to December 31 and covers 20 months.

hThis figure represents the tons transported from mine to mill over the Torch Lake Railroad.

iEstimated from best available data.

For a number of years no public statement of production was made. The yield fell off with depth and with lateral extension of the openings. The southern Calumet shafts passed on through the rich ground which pitches to the north. The northern Calumet shaft after being for many hundred feet in lean ore entered the rich shoot and continued in it to below the 57th level. Below this lean ore was again encountered. No separate record for the rich shoot is available. The average yield became lower until it is now less than 1.5 per cent. The company has during the past few years published figures showing the quantity and copper yield of ore mined.

PRODUCTION AND YIELD OF CALUMET AND HECLA CONGLOMERATE DURING PAST FEW YEARS.

Year.	Tons of ore stamped.	Pounds refined copper produced.	Yield in pounds per ton treated.	Yield, per cent.
1908	1,958,200	70,427,877	35.96	1.798
1909	1,999,880	66,285,684	33.14	1.657
1910	1,950,040	58,739,509	30.12	1.506
1911	1,924,480	58,469,399	30.38	1.519
1912	1,746,960	51,935,245	29.73	1.486

The rich portion.—The richness of the ore mined when the shafts were less than 2,000 feet is shown by the fact that the average yield of refined copper per ton of ore treated in 1874 was 4.28% and in 1875, 4.30%. Probably about one per cent was lost in milling, so the actual content of copper in the ore was over five per cent. Some years later the product was still richer, the output for 1880 yielding 4.75 pounds refined copper per ton from 334,343 tons. The figures indicate that the decrease in contents with increasing depth was by no means a gradual one. For the 12 years 1875-1886 the yield varied from 4.17 to 4.75 per cent. If records for production from the main ore body for subsequent years were available it could be shown that the rich ore continued to much greater depth than the lowest openings which existed in 1886. The yearly record beginning in 1887 shows a much lower average in grade of ore produced; but this was due largely to the fact that in that year began the large production from the lower grade ore opened by the South Hecla shafts.

The rich portion pitches to the north and continues down to the 57th level. Below that level there is said to be comparatively little rich ore in the lode. Long before the 57th level had been reached the increasing output of lower grade ore from outside the rich shoot had brought down the average yield very considerably. Now that the rich portion has been almost completely mined out the average yield is still lower, being in 1912 only 29.3 pounds copper per ton of ore. There is still a little rich ore standing, mostly as pillars, of which a considerable portion will be recovered before the mine is abandoned.

Rich ore at depth.—That the lode was in places rich at considerable depth is shown also by the following table of results obtained at the Tamarack mine in years 1886-1893. The stope maps show that there was remarkable continuity of pay ore.

Supt. John Daniell says in his 1886 report on the Tamarack mine. "The extensive development of the conglomerate in the neighboring (Calumet and Hecla) mine had shown its unimpaired productiveness, down to a depth corresponding to our first level." (This was at a point fully 1,000 feet north of the Tamarack No. 1 shaft).

PRODUCTION OF TAMARACK MINE, 1886-1893.

Fiscal year.	Tons ore stamped.	Refined copper produced.	Yield, per cent.	Remarks.
1886	36,129	1,979,400	2.7	
1887	90,587	4,636,521	2.6	
1888	144,412	10,389,861	3.6	
1889	169,250	11,036,469	3.3	
1890	155,250	8,928,249	3.9	
1891	282,987	14,076,957	2.5	
1892	338,700	16,805,360	2.5	
1893	345,925	16,061,106	2.32	All ore from below 9th level.

Chemical composition of the conglomerate.—Dr. Lane has published, from information furnished by Mr. J. B. Cooper, the following anaylsis of slime overflows from trough classifiers between stamp-heads and jigs taken at the Calumet mill, September, 1906. It cannot fairly be taken as a sample of the conglomerate but nevertheless gives some idea of its composition.

Analysis of Calumet Conglomorate Slime.

Loss of ignition	5.03%
$Si\ O_2$	55.08
$Fe_2\ O_3$	9.04
$Al_2\ O_3$ (+ traces of $Ti\ O_2$)	15.41
Ca O	7.02
Mg O	2.49
Cl	0.18
SO_3	0.04
Cu (perhaps with some oxide)	1.70
K_2 O and Na_2O	Not determined.
	95.99

C. Rominger's description of the conglomerate.—C. Rominger describes* the Calumet lode in his report on the Keweenaw Group, 1885.

"The conglomerate belt of the Calumet and Hecla mine averages a width from 12 to 25 feet; its dip varies from 36 to 39 degrees to the northwest. Fully two miles of the length of the belt are on this mining property; the deepest shafts following the inclination of the belt are 2,700 feet long, which makes a vertical depth of about 2,068 feet below the surface. On the entire extension of the property, the conglomerate belt has very few barren spots, and the rock is, without selection, sent to the stamp mills where it yields about five per cent of washed

*Vol. V, pp. 114-117, Geol. Surv. Mich., 1885.

metal; portions of the rock are much richer, as high as thirty per cent in metal. The product of the mines during the last three or four years was about 16,000 tons of ingot copper annually.

"The conglomerate of this belt is reddish brown colored, hard and compact; locally composed of rather large, rounded pebbles, but the main mass consists of smaller pebbles with many little-worn angular rock fragments among them. The interstitial material consists of smaller arenaceous particles held together by siliceous and calcareous cement; the copper in the rock occupies mainly these interstitial spaces between the pebbles, and is sometimes replacing the cement altogether.

"The union of these fragmental masses is very firm, a stroke of a hammer does not sever their connection, but breaks the mass straight across the pebbles, which, with the exception of a small proportion of diabasic and amygdaloidal boulders are all of porphyritic nature but quite variable in molecular structure. A large portion of them consists of a reddish brown, compact, homogeneous, silico-feldspathic substance, with smooth, conchoidal fracture. Others inclose within the same aphanitic ground mass well formed, large crystals of feldspar, of red or whitish color; in still others, which are often more abundant than the others, the dark reddish colored, compact groundmass incloses, besides feldspar crystals, a great number of rounded transparent, colorless grains of quartz which, on fractures, gives a blackish reflex. Other pebbles have none of the amorphous ground mass; they consist of a granite-like agglomeration of interwoven red feldspar crysta's, with scarcely any other component, or else this same crystalline, feldspathic rock mass contains copiously interspersed quartz grains, besides scattered blackish colored molecules which sometimes are recognizable as altered hornblende crystals or as biotite scales, but often are a shapeless, earthy-looking remnant of a decomposed mineral, not to be determined. These rocks could, with propriety, be classed with granite, but they are allied with the before mentioned prophyries by transitory forms which are not completely crystalline, but have a scanty interstitial ground mass analogous to the ground mass of the porphyritic kind.

"I have stated above that the copper occupies, in the conglomerate, the interstitial spaces between the pebbles and often takes the place of the previously existing arenaceous cement. Rarely the copper had a chance to enter the substance of the pebbles through capillary fissures imperceptible to the eyes before the pebble is fractured, but sometimes the same altering influences which remove the interstitial arenaceous material, replacing it by calcspar, epidote and copper, affected also the larger pebbles; they made them first porous and discolored and finally changed them into an epidotic mass permeated with a spongeous skeleton of copper in association with more or less calcspar. Such altered pebbles some of them as large as a man's head, quite frequently occur at the Calumet mine, and also sometimes in the conglomerate of the Albany and Boston mine. In some instances the copper has almost entirely replaced the material of such pebbles and forms solid, ponderous masses in the shape of the pebble, other times the change was not perfect, and the spongeous copper skeleton inclosed within its cavities yet unaltered crystals of orthoclase and quartz grains enveloped by a mealy chloritic and epidotic crust.

"Prof. Pumpelly first gave notice of the occurrence of such copper masses in pebble form and suggested their paramorphic origin by replacement of the material of the decomposing porphyry pebbles.

"The conglomerate of the Calumet mines frequently incloses seams of a fine-grained, well laminated sandrock, exhibiting ripple marks on the surface of its layers, and locally such beds are richly impregnated with copper. Like in all the sandrocks of the Keweenaw group, the feldspar grains overbalance the quartzose grains in the rock mass. The hanging of the Calumet conglomerate is a dark colored, fine-grained diabase, which, like the above mentioned diabase belt in the Tamarack shaft, 500 feet below the surface, has a jointed structure, with the cleavage seams coated over with a soft, chlorite-like mineral in slickenside fashion, holding between themselves sheets of copper from the thickness of tissue paper to that of a knife blade and sometimes six or eight inches square; likewise are cloudy patches in the solid mass of the diabase disseminated with an abundance of scaly molecules of copper, but the miner considers the amount of metal too small to pay any attention to its collection. In association with the compact diabase in the hanging, amygdaloidal rock masses occur, whose amygdules formed of calcspar, laumonite, quartz and delessite, often contain a considerable amount of copper.

"I have previously mentioned that the Calumet conglomerate thins out and is almost destitute of copper in its extension south of the Osceola mine, and soon after entirely disappears. The same is the case in its extension northeast of the Calumet mine, on the Schoolcraft mining property, where extensive work has been done in this belt, but the large burrows of waste rock, in which no copper can be detected, show that the Calumet mine struck an extraordinary rich spot and that locally this belt is almost barren of the metal. The work in this conglomerate on the Schoolcraft mine was long since suspended, but on the Osceola amydgaloid belt, which likewise intersects the property, mining has been continued until late. Farther to the northeast the continuation of the Calumet conglomerate belt has been traced only for a short distance; it was found to be much narrower and poor in copper."

Replacement of pebbles by copper.—Dr. Pumpelly thus describes* the replacement of conglomerate pebbles by chlorite and copper.

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

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

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

*Geological Survey, Michigan, Vol. I, Part II, pp. 37-38.

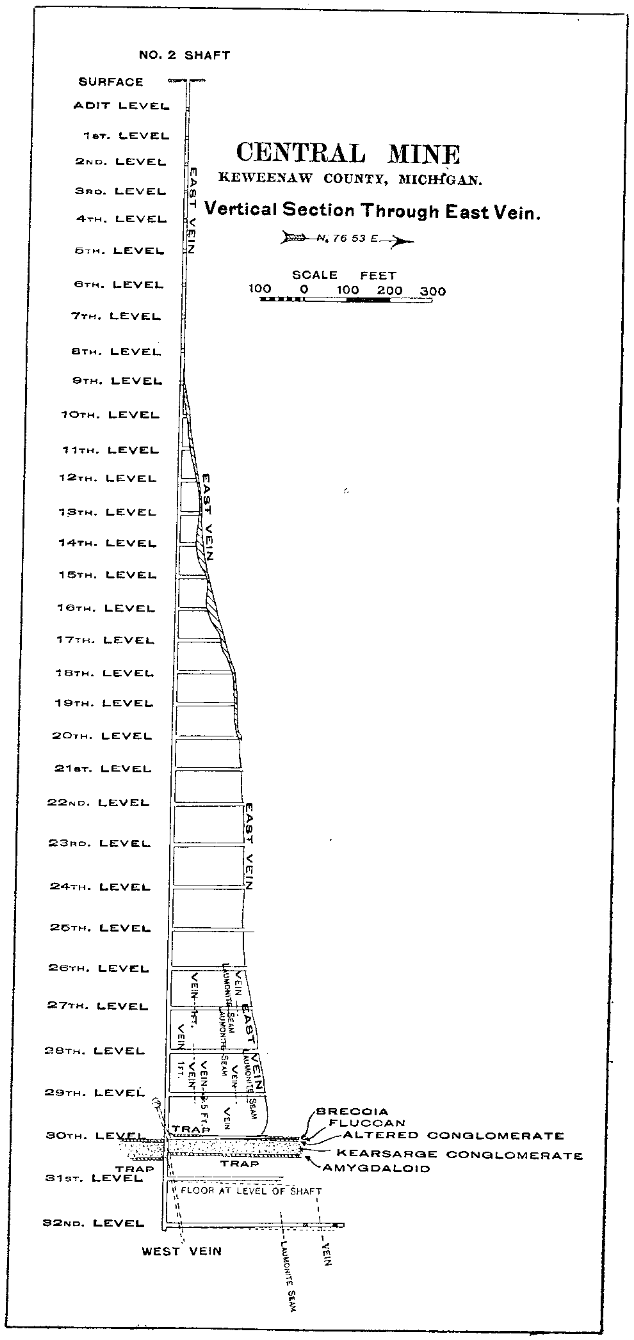

Figure 8.

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

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

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

CENTRAL MINE VEIN.

C. L. Lawton's description.—Chas. L. Lawton says* of the copper deposits at the Central mine, the mine being at the time, 1885, over 2,000 feet deep.

"It is in a fissure vein, crossing the formation south of the greenstone and extends vertically down, the bottom being 2,160 feet below the surface. It is a small mine, there is only one hoisting shaft—No. 2, and the copper bearing ground, which has a gradual pitch to the south, is now all south of the shaft—No. 2. The mine looks about the same as it has heretofore; there is no change whatever. The small conglomerate belt, which has been worked downward north of No. 4, has been abandoned, the belt no longer proving productive. The mining work is all confined to the copper shoot, which has, practically, afforded all the mineral that the mine has produced. The vein is continuous, sometimes only a ribbon of vein matter, which widens to eight feet to ten feet in width and contains the masses of copper; the most copper is found in the widest portions of the vein. When the vein matter is soft and spongy it is found to lack productiveness; a firm, hard vein yields the most copper.

*Report Com. Min. Statistics, 1885, p. 221.

"The man engine is down to the 22d level. They open very little in advance of the stoping. In 1885 the total cubic fathoms of ground broken in the mine was 2,800, yielding 770 pounds of refined copper to the cubic fathom. Pretty rich ground, certainly."

Production and variation in values with depth.—Following are the statistics of copper production for each year of operation. In a general way the yield for successive years shows character of change in values with depths. The "slide" at the top of the Kearsarge conglomerate was encountered in sinking below the 29th level. Below the "slide" the vein was found to be 240 feet west and to be lean though well defined and carrying some copper.

PRODUCTION OF CENTRAL MINE VEIN.

	Tons ore stamped.	Pounds refined copper produced.	Yield, per cent refined copper.
1859	....	241,622	....
1860	....	114,197	....
1861	....	248,742	....
1862	7,514	484,764	....
1863	9,946	619,268	....
1864	....	901,292	....
1865	17,552	1,099,242	3.13
1866	19,702	1,333,036	3.39
1867	17,064	1,244,441	3.64
1868	15,232	1,800,943	5.88
1869	17,688	1,807,801	5.11
1870	18,380	1,327,156	3.62
1871	21,646	1,432,662	3.30
1872	18,942	1,244,349	3.02
1873	15,903	1,503,117	4.72
1874	15,668	1,740,603	5.54
1875	17,118	1,466,952	4.28
1876	12,658	2,161,400	8.54
1877	14,119	1,995,609	7.06
1878	13,858	1,891,013	6.82
1879	12,478	1,799,495	7.21
1880	14,520	2,026,078	6.97
1881	20,549	1,418,465	3.45
1882	18,639	1,353,597	3.63
1883	18,146	1,268,556	3.49
1884	18,146	1,446,747	3.98
1885	17,812	2,157,408	6.05
1886	....	2,512,886	....
1887	....	1,923,277	....
1888	....	1,817,023	....
1889	....	1,270,592	....
1890	....	1,413,391	....
1891	....	1,321,417	....
1892	....	1,562,887	....
1893	....	1,177,500	....
1894	....	584,950	....
1895	....	370,381	....
1896	....	469,243	....
1897	....	614,891	....
1898	....	291,339	....

FOREST LODE.

The Forest lode is the productive amygdaloid of the Victoria mine in Ontonagon County. The ore occurs in a thick shattered bed of ophite, the copper being partly in amygdaloid and partly in dull altered trap. On some levels the lode is in three parts, referred to by Mr. Schacht, formerly engineer at the mine, as main, hanging and foot parts.

The hanging wall is characterized by remarkable "cups" or shallow circular depressions. These depressions are numerous and make the

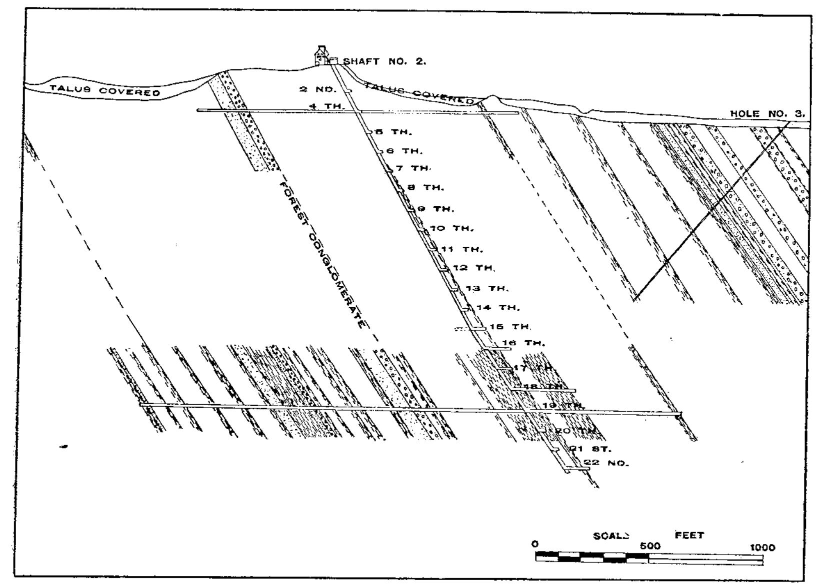

Figure 9. Geological section at Victoria mine, Forest lode (by George Hooper).

horizon an easily recognizable one. The depressions are not deep but the term "cup" is commonly used for them. In drifting, this "cup"-marked hanging has often served as a good guide in following the lode, though occasionally there is ore above instead of below it. The ore does not commonly extend to the cup-marked hanging, but is separated from it by one or two feet of dense trap known as the "cab." This "cab" has thin leaf copper in its numerous fractures, but seldom contains good values. It breaks off readily with the lode and thus adds a lot of waste which must be sorted out.

As a rule the ore bodies are small and separated by much poor ground. The most productive ground shows a pitch to the west. The bed dips northwest at an angle varying from 61° at surface to 55° at the 15th level.

The ore mined in the past two years yielded between nine and ten pounds refined copper per ton. That this low grade material could be treated is due to the ownership of power rights on the Ontonagon River. Air is compressed by the fall of water, and mine and mill are operated at low cost.

HANCOCK LODES.

Several lodes have been opened up at the Hancock mine and others are now being tested. At No. 1 shaft there are three lodes known as No. 1, No. 2 and No. 3. At the new or No. 2 shaft there are three lodes which have been numbered No. 4, No. 5 and No. 6. Another lode has been found recently east of, that is below, No. 3.

The No. 3 lode is a chocolate brown amygdaloid spotted with numerous amygdules, many of which are chlorite. The rock is much altered, has a dull earthy appearance and is rather soft. The lode as mined averages about eight feet in thickness. It dips at about 45° to the northwest. The stopes are remarkably regular, the hanging wall being easily followed though frequently displaced for a few feet by faulting. Much of the copper in the ore is in the amygdules, and often enclosed in chlorite. During 1911 there was mined and treated from this lode 41,449 tons ore which yielded 18.21 pounds copper per ton. The quantity blocked out however, is not large.

The No. 4 lode, where cut in No. 2 shaft at a depth of 3,105 feet is a brownish gray amygdaliod. There are very numerous amygdules and many of them are quartz. Most of the other amygdules are calcite. Both quartz and calcite are often greenish in appearance owing to the presence of chlorite scales and occasional epidote grains. Many of the fracture faces of the rock are coated with quartz and calcite. On some there are fine scales of copper. Most of the copper is in the amygdules with the calcite and quartz; but some is in grains scattered through the matrix of the rock and some in seams of calcite and quartz. The lode where cut showed a thickness of seven or eight feet of good ore.

The No. 4 lode where opened by crosscut at the 34th level has quite a different appearance from that in the shaft. In the crosscut there ia a thick bed of coarsely grained red colored trap which at some distance from the top shows an altered zone, of greenish color, containing much copper. This altered zone shows numerous light colored veins, many of which run about parallel to the bedding. The veins show some calcite and quartz; but much of the vein material is prehnite. The rock enclosing the veins has evidently been much altered and is impregnated with secondary quartz. In the veins and in the altered

rock native copper occurs in numerous forms, part coarse and heavy, part fine and part mere scales coating fracture surfaces.

Footwall trap.—Microscopic examination of specimens taken from the red trap below the lode show feldspar particles which are much altered, dull and red stained. The secondary aggregate is partly sericite and shows occasional grains of epidote. In some cases grains of native copper occur in the altered feldspar. The green chloritic mineral is partly ordinary chlorite showing pale green absorption

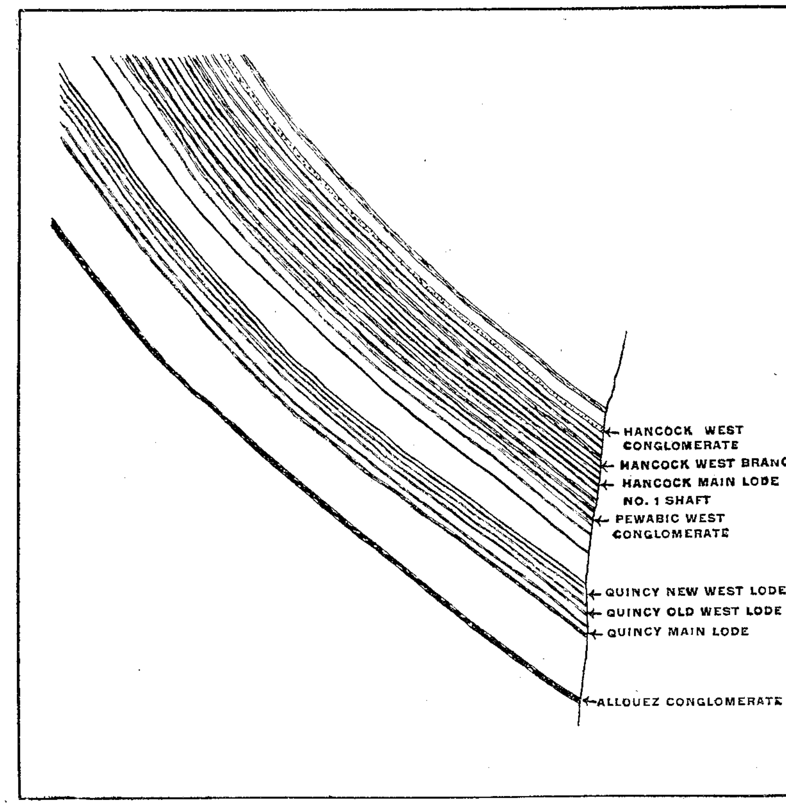

Figure 10. Section across Pewabic and Hancock lodes (by J. L. Harris).

colors and very low interference colors, but part of it is better crystallized and shows bright interference colors like delessite. Epidote occurs in distinctly colored and pleochroic yellowish grains. Magnetite occurs partly in large grains and partly as aggregates of very small grains. Some of the black iron ore has skeletal form of ilmenite and is surrounded by white opaque substance like leucoxene. Quartz occurs with the patches of green minerals and also in several crooked veinlets.

Some copper occurs in the quartz but more of it in the other minerals on either side of the quartz veinlets. Throughout the rock there is much red semi-opaque material that is probably iron oxide. It occurs abundantly around the black grains and more finely disseminated through the feldspars, giving them their red color.

The lode.—The lode is a decidedly green colored chloritic altered portion of the red trap, containing numerous thin light colored veins which are largely prehnite and calcite. In places there are numerous large grains of quartz and calcite scattered irregularly. Copper occurs as jagged grains scattered through the rock, as a constituent of the veins and as thin films in minor services in the rock.

Microscopic examination shows the rock to be composed largely of chlorite, delessite, epidote, rust stained altered feldspar, prehnite and iron oxides. Several black grains show a white alteration product and are probably titaniferous. Red oxide also occurs abundantly with the black oxide and as finely disseminated powder in the feldspar. Coarse clear quartz occurs in scattered particles, often with delessite crystals. In some specimens quartz encloses numerous delessite crystals; in others quartz is surrounded by delessite. A calcite veinlet runs through a broken plagioclase crystal.

Occurrence of the copper.—Copper occurs chiefly in the prehnite, being finely disseminated in threads and grains in fine granular aggregates of radiating crystals of that mineral. In a vein in the rock, copper occurs chiefly in prehnite, but also in or with a blue-black metallic mineral or with epidote. The mode of intergrowth seems to indicate that the copper has grown between grains of these minerals, penetrating cracks in and partly enclosing them. Between the rock and vein proper is a very thin zone that is a dull semi-opaque aggregate containing numerous very small grains of copper. Between crossed nicols the aggregate shows low gray interference colors with a few bright spots and some almost isotropic brownish areas. This zone probably has originated by replacement by vein material while the vein proper is a simple fissure filling.

One specimen shows very abundant quartz, part of which seems to have taken the place of large feldspar crystals. The quartz includes grains of epidote and copper and crystals of delessite. Some small copper grains are wholly enclosed by an epidote grain. Some quartz is peculiarly intergrown with a brownish pyroxene. Much copper is intergrown with a black metallic mineral (magnetite?) which occurs in long rods penetrating the other minerals.

Prehnite veins.—In the red trap there occur several prehnite veins carrying copper. The veins exposed in the crosscut are roughly parallel to the lode. A specimen of one of these veins examined microscopically, shows the wall rock to change suddenly from the coarsely crystalline trap described above to a finely granular semi-opaque aggregate of greenish gray particles spotted with small grains of black and red iron oxides. A vein one-half inch thick shows clear colorless prehnite enclosing large and small, ragged and regular grains of copper. Part of the prehnite is a very fine granular aggregate from which radiate large crystals. The granular aggregate contains much fine copper while the clear coarsely crystalline prehnite contains few but much larger grains of copper. While microscopic examination shows that there has been some change in the wall rock at the immediate contact, the vein is in reality very distinctly marked off from the rock and to the naked eye appears as a simple filling in a fissure in the coarse trap. The reaction with the wall rock has been comparatively slight.

One section showing a prehnite vein enclosed by wall rock has the prehnite crystallized in large plates and grown out at right angles to the walls. The prehnite, encloses numerous coarse grains of copper in the middle portion and fine grains at the edge. Between rock and clear prehnite is a zone of semi-opaque granular prehnite containing numerous grains and strings of copper. In the midst of this semi-opaque aggregate are several clear grains of calcite.

INDIANA LODE.

This is a deposit located by diamond drilling on the Indiana property in Ontonagon County. Little is yet known of the extent of the deposit, but as several rich cores were obtained a shaft has been sunk 1,500 feet to permit of its investigation.

The lode is peculiar in that the copper occurs in felsite. Previously these light colored siliceous rocks had not been known to contain copper and the developments here are consequently of more than ordinary interest. The felsite from which the richest copper bearing cores were obtained is a very dense rock of light color. Generally it shows reddish tones, but in places it is pale yellowish-green from abundance of epidote. Much of it has a pale flesh color. In places the felsite is fairly fresh looking, but frequently it shows signs of much alteration. Calcite and epidote are abundant in the copper bearing portions. In places the rock is finely brecciated, the fragments being cemented with calcite. In practically all the drill cores there are very numerous joints and fractures and the mine openings thus far made show the same character. The rock is hard to drill and breaks up into very small pieces when blasted.

In a short drift at the 600 foot level at the Indiana mine copper was found at the bottom of a felsite mass at the contact with a soft, dull