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Detailed geologic maps of recently active copper mines,

Houghton and Keweenaw Counties, Michigan

By

H. R. Cornwall, J. J. Runner, A. A. Stromquist,
R. W. Swanson, and W. A. White.

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Introduction

Study of the accessible mine workings of the Michigan copper district was undertaken by the Geological Survey in November 1942, as part of its contribution to the search for minerals needed in the war effort. The immediate purpose of the Michigan study was to test the usefulness of detailed geologic mapping as an aid to underground development in this district. Although such studies had been carried out previously in individual mines without notable success, it was felt that very detailed mapping of a large number of workings might be more productive of useful information. A little more than 50 miles of mine drifts were mapped in considerable detail, and much of the information is recorded on the accompanying maps. Mineralogic and petrographic study of several thousand specimens was also carried out. The results of this work, while revealing many facts of interest and of possible future usefulness, were not particularly successful in producing clues to the location of ore shoots beyond the limits of mine workings. Several geologic features may be said to be favorable to the occurrence of copper, but the presence of these features is no easier to predict, at present, than the location of the copper itself.

The work was more successful in its less urgent, but equally important objectives. These were (1) the preservation of a geologic record of the accessible mine workings of the district for its potential usefulness to geologists at a time when the present openings are no longer accessible; (2) laying a foundation of information, ideas for future study, and trained personnel to be used in a broader program of study of the geology of the district as a whole. The primary objective of this district study will be to gain a better understanding of the origin of the copper deposits so that areas favorable for the presence of undiscovered deposits may be predicted.

This report consists primarily of the detailed geologic maps made during the period 1942-46. These form a valuable part of the geologic record of the district, and their preservation is desirable regardless of their immediate usefulness. Because of the time and additional drafting that would be required, unfortunately it has been necessary to omit notes recorded on the original field maps. These notes describe, for example, the width and prominent minerals of all the fissures.

The text of this report presents a summary description of the geology of the district and of the mines studied. Only such information as is necessary for an understanding of the maps has been included. The interpretation of this information will be presented in a more formal publication as soon as possible. The descriptions that follow are based, insofar as possible, on the observations of the writers. They do not claim originality for any of the ideas or types of observation made, however, and their indebtedness, in this respect, to other workers in the district will be readily apparent to all those familiar with the literature of the region.

The literature on the Michigan copper district is voluminous. For a discussion of the fundamental problems of the geology of the district and the ore deposits, the reader is referred to the following sources, listed in order of date of publication:

(1) Lane, A. C., The Keweenaw Series of Michigan (2 vols.): Michigan Geol. and Biol. Survey, Publ. 6, Geol. Ser. 4, 1911. The first truly detailed study of the ore deposits of the district.

(2) Butler, B. S., Burbank, W. S., and others, The copper deposits of Michigan: U. S. Geol. Survey, Prof. Paper 144, 1929. Based largely on geologic work undertaken for the Calumet and Hecla Consolidated Copper Company in 1920-24, with additions by Butler and Burbank in 1925. This report contains the most complete geologic description of the district and the mines. Its large bibliography includes references up to 1928.

(3) Broderick, T. M., Hohl, C. D., and Eidemiller, H. N., Recent contributions to the geology of the Michigan copper district: Econ. Geology, vol. 41, pp. 675-725, 1946. Contains a detailed discussion of factors influencing the location of ore deposits and of the problems of ore finding, based on the experience of the Calumet and Hecla Geological Department in the last 20 years.

Recent publications of members of the Geological Survey of Michigan have been omitted from the above list as they deal primarily with the surface geology of parts of the district, rather than the geology of the ore deposits.

The writers are deeply indebted to the management of the mining companies of the district for their cooperation in this study. The officials of the Calumet and Hecla Consolidated Copper Co., the Copper Range Co., and the Isle Royale Copper Co. have permitted detailed geologic examination of mine workings, and provided many services that facilitated these examinations. All the companies have been most helpful in making their records and mine maps available for study.

The Michigan College of Mining and Technology generously donated office space for the use of the field party throughout the war years, and in addition gave members of the party free use of such equipment and services as were needed for their work.

Particular thanks are due to Drs. R. S. Cannon, G. H. Espenshade, B. S. Butler, and M. H. Krieger of the Geological Survey for their continuing interest in the study and the many ideas and suggestions they have contributed to it. The writers are most appreciative of the active support of Dr. Broderick and his colleagues in the Geological Department of the Calumet and Hecla Consolidated Copper Co. This group, by its willingness to share an intimate knowledge of and experience with the problems of the geology of the copper deposits, has made the present study far more profitable than it would otherwise have been.

Regional geology

General Statement.-- The dominant rocks of the Michigan copper district are a thick series of interbedded basaltic lavas and clastic sedimentary rocks of the Keweenawan series of pre-Cambrian age. Most of the copper deposits occur in a part of the series that contains less than 2 percent clastic sedimentary rocks. There are a few small bodies of intrusive gabbro and felsite.

The rocks dip northwestward or northward; the angle of dip is generally steeper in the southernmost, lower beds of the series. The southern boundary of the outcrop of the Keweenawan series is a large thrust fault, the Keweenaw fault, south of which younger rocks of possible Cambrian age are exposed.

A few broad and gentle folds are revealed by changes in the average strike of the series from place to place. These folds pitch steeply down the dip of the beds. The prominent faults in the district belong, for the most part, to two major sets. Those of one set are dominantly reverse faults that strike at a low angle to the bedding and dip more steeply northward than the bedding. Faults of the second set strike nearly at right angles to the flows and sedimentary rocks, and generally have very steep to vertical dips. Fissures along which there has been no measurable displacement are common to both sets.

The ore deposits occur locally in conglomerate beds between lava flows, in the amygdaloidal tops of a few of the lava flows, and in some of the fissures cutting across the stratified rocks.

Conglomerate.-- Conglomerate is the principal sedimentary rock in the copper district. This type of rock forms less than 2 percent of the lower part of the series, in which most of the copper deposits have been found, and a large proportion of the upper part. The conglomerate beds range in thickness from a few inches to 3,500 feet. Some have been traced for many tens of miles along the strike.

The typical conglomerates are siliceous in general composition, and the most abundant rock fragments in them are felsite, feldspar porphyry, and quartz porphyry. There are relatively few pebbles of amygdaloid, and trap pebbles are even less common. The conglomerates are reddish in color, and owe this color to the clastic fragments of red volcanic rock rather than to ferric iron formed by weathering and surface oxidation. Most of the pebbles are fairly well rounded but some, especially those of amygdaloid and trap, are subangular.

The conglomerate beds are lenticular, and thin or thicken abruptly along the strike. In general the lenses thicken down the dip. Where thin, the beds normally consist of sandstone or grit; the thicker portions are medium-grained to coarse conglomerates. Lenses of sandstone are present in much of the conglomerate.

Felsitic conglomerate is commonly underlain by soft red or brownish basic _/ sandstone or shale that contains rounded and angular fragments of amygdaloid. These fragments become increasingly abundant downward, and

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_/ Authors note: "Basic refers to the basaltic and andesitic composition of the rock constituents.

were evidently derived from the underlying amygdaloid. These beds are called scoriaceous amygdaloids or amygdaloidal conglomerates. Many of the scoriaceous amygdaloids, however, are not overlain by felsitic conglomerate.

Lava flows.--The lava flows of the copper district are typically composed of two major parts that grade into one another, namely, an amygdaloidal top, commonly 5 to 15 feet thick, and an underlying massive trap layer, which may be a few feet to several hundred feet thick. The amygdaloids are generally classified as cellular, cellular coalescing, fragmental, and scoriaceous.

Cellular amygdaloid contains vesicles of different sizes scattered through it that are now filled with secondary minerals. In cellular coalescing amygdaloid, the vesicles coalesed to form openings that extended, before being filled, for a few inches to scores of feet in the plane of the flow. Fragmental amygdaloid consists of fragments of cellular amygdaloid a fraction of an inch to several feet in diameter in a matrix of clastic grains, trap, and secondary minerals. The secondary minerals generally replaced the interfragmental matrix, but locally, especially in the footwall trap just below the fragmental zone, they are found in a stockwork of cracks that were independent of the original fragmental outlines. Thus the original fragmental amygdaloid is typically somewhat modified, particularly along its basal contact, by a secondary replacement breccia. Scoriaceous amygdaloid, as described above, is a fragmental amygdaloid whose interfragmental matrix consists chiefly of basic sand and finer material.

The contact between fragmental amygdaloid and the underlying foot-wall trap is commonly rather abrupt, but the trap for a few feet under the fragmental layer of many flows may contain fragments of amygdular rock. These fragments are generally very rounded, as if partly resorbed, and the amygdules are typically filled with chlorite. The zone containing these inclusions is called the "foot-inclusion" or "amygdaloid-inclusion" zone.

Large tabular bodies of trap, similar in appearance to the foot-inclusion trap, locally occur in the midst of a fragmental amygdaloid. These tabular bodies of trap are called "vein trap." They are commonly, though not everywhere, nearly parallel to the plane of the flow.

The adjective "trappy" is applied to poorly fragmental or cellular amygdaloids that contain relatively sparse amygdules.

The traps underlying the amygdaloids have been classified according to their texture as melaphyre, ophite, porphyrite, and glomeroporphyrite. Melaphyre is fine-grained trap. Porphyrite is fine-grained trap containing well-defined feldspar crystals. In glomeroporphyrite, the plagioclase crystals are more abundant and bunched. Ophite is the name given to a spotted rock whose roughly circular spots are large pyroxene crystals with poikilitically included plagioclase crystals.

Structure.--Structural features described in the following sections include only the results of deformation after consolidation of the lavas. These features are folds, fissures, and faults.

The folds of the district are very gentle, and are, for the most part, made apparent only by slight differences in the attitude of a given horizon from place to place. Most of these folds plunge steeply down the dip of the horizons, and are revealed only by differences in strike. In a few places, like the Quincy mine, there are notable differences in the dip of a horizon between the top and bottom levels of a mine.

The term fissure, as used in the district, refers to cracks or veins in the rock that contain secondary minerals or gouge and breccia. Most of the fissures are transverse to the stratigraphic horizons, although concordant fissures are not uncommon. The fissure, as a unit, includes all the material between the boundary planes of country rock on either side. Along some fissures there is a measurable displacement of the stratigraphic units, and these fissures are more properly called faults. In general usage, the term "fissure" is used where the filling is to be emphasized, or where only a few of all the fissures in a set are actually faults. "Fault" is used where the emphasis is on the displacement.

Mineralogy.--The minerals found in the rocks belong in two groups, namely, (1) the primary minerals formed by direct crystallization from the original lava, or laid down as sedimentary fragments, and (2) the secondary minerals (a) that have filled amygdules and interfragmental spaces, or have irregularly replaced the rock adjacent to such openings; and (b) that are found in the fissures. The primary rock minerals of the lavas are largely pyroxene and plagioclase, with subordinate magnetite, hematite, olivine, and accessory minerals. Quartz and feldspar are the dominant minerals of the felsite conglomerates.

The secondary minerals include native copper, calcite, epidote, chlorite, prehnite, quartz, orthoclase pumpellyite, laumontite, and minor amounts of copper sulfides and arsenides, native silver, barite, sulfates, datolite, saponite, sericite, and ankerite. These minerals are concentrated in the amygdaloidal flow tops in variable amounts, and make up a very small part of the massive trap underlying the amygdaloids. Secondary minerals, other than copper, calcite, epidote, and chlorite, are not notably abundant in the conglomerates. In general, the minerals of the fissures are the same as the secondary minerals of the flow tops, although the relative abundance of the different minerals may not be the same in both fissures and flow tops.

In the mine descriptions that follow, only the secondary minerals are considered, because these minerals show the greatest differences from mine to mine. From a metallurgical point of view, however, a large part of the gangue is actually made up of the primary rock-forming minerals.

Ore bodies.--Of the 9-1/2 billion pounds of copper produced from the Michigan copper district, 53 percent has come from amygdaloids, 45 percent from conglomerates, and 2 percent from fissures. Within this district the term "lode" is applied to an ore-bearing conglomerate or amygdaloid. Within the limits of a mine the ore-bearing horizon is called a lode even at points where it is locally barren. The fissure deposits are not called lodes.

Practically all of the conglomerate copper has come from the Calumet and Hecla conglomerate. The ore body occupied a lens of conglomerate which fingered out both up the dip and laterally. The newly developed Houghton conglomerate ore body is similar to that of the Calumet and Hecla conglomerate in this respect.

The two largest amygdaloid producers, the Kearsarge and Baltic lodes, as well as the less productive Isle Royale and Osceola lodes, are characteristically fragmental amygdaloids. The ore body in the Quincy mine, that is also one of the largest in the district, occurs in the Pewabic lodes which are typically coalescing, although in part fragmental, amygdaloid.

The stratigraphic and areal distribution of copper is considered in the descriptions of the individual ore deposits in this folio. The term "areal distribution" refers to the distribution of copper in the plane of the lode.

In the fissure deposits, the copper occurs as large masses and disseminated grains on or adjacent to fissures that cut across the stratigraphic horizons.

In considering the copper deposits of Michigan, one should keep in mind the fact that there are many amygdaloids, conglomerates, and fissures, both adjacent to and far removed from the known ore bodies, which appear identical to the productive lodes and fissures in their physical and chemical characteristics and yet are barren.

Central Exploration fissure mine (pls. 2 and 3)

Introduction.-- The Central Exploration fissure mine of the Calumet and Hecla Consolidated Copper Co. is located in sec. 25, T. 58 N., R. 31 W., Keweenaw County, 1 mile east of the famous and productive Central fissure. The copper ore occurs along a steeply dipping fault that strikes almost at right angles to the strike of bedding. The fissure has been explored on 3 main levels, the lowest 458 feet below the surface. The mine had produced over 2,500,000 pounds of copper when it was shut down at the end of 1945.

Stratigraphy.--The rocks cut by the Central Exploration fissure at the mine are lava flows that lie stratigraphically above and below the Kearsarge conglomerate. The conglomerate adjacent to the fissure ranges from 0 to 6 feet in thickness, and provides a trustworthy datum for stratigraphic measurements. The flows in the mine area are irregular in thickness, and the number of flow tops within 300 feet vertically above and below the conglomerate ranges from 7 to 12.

Structure.--The conglomerate and flow tops strike N. 70° -80° E., and dip 25° -30°NW. Drag on the fault has locally produced northwesterly strikes. The fissure (fault) strikes about N. 25°W and dips 83°NE. It has been traced, by diamond drilling and on aerial photographs, for over 2 miles to the south and to the north of the mine. It appears to be continuous, on the north, with the Owl Creek fissure, which produced over 7,000,000 pounds of copper.

The fault has a horizontal stratigraphic displacement of 500 feet and a vertical stratigraphic displacement of about 230 feet (pl. 3). The apparent displacement is of the normal-fault type. The fault probably has a very large horizontal component of movement, however, and should be classified as a tear fault. The best evidence, which includes both structural and stratigraphic data, suggests that the east, or hanging-wall, has moved southward and upward with respect to the footwall. The horizontal component of the net slip is probably of the order of 3,000 feet.

The main fissure is a gouge breccia zone 3 inches to 5 feet thick. The rocks adjacent to the fissure, particularly those on the hanging-wall side, are highly fractured, and contain numerous steeply dipping fissures that typically make a low angle with the main fissure. The average plunge of the intersection of these fissures with the main fissure is steep and southward.

There is one major flexure or roll in the main fissure, exposed at the intersection of the 200-level drift and the shaft crosscut. The plunge of this flexure as shown on plate 3 is the maximum plunge consistent with the position of the fissure in a drill hole intersection below the 200-level, and the actual plunge may be about 22° N.

<u>The Ore</u>.--The native copper of the Central Exploration ore body occurs as finely disseminated grains, as thin sheets along cracks and in small and large masses (largest 5 tons). A small amount of native silver occurs intimately intergrown with the copper.

Most of the minable copper in the ore zone above the 257-foot sublevel is finely disseminated in prehnite immediately adjacent to the fault, for the most part on the east or hanging-wall side. This copper-bearing prehnite zone is 3 to 15 feet wide and has been stoped for approximately 240 feet horizontally along the fault. The average tenor of the ore was about 30 pounds per ton of ore. The prehnitic material apparently replaced country rock and rock breccia, for the most part, and fault gouge to a lesser extent. A small Amount of calcite occurs with the prehnite. The prehnite is quite commonly brecciated, and the fragments are surrounded by fine ground-up prehnite and small amounts of epidote and chlorite. Fine copper occurs abundantly scattered through the prehnite fragments. It does not appear to be associated with the epidote and chlorite in the breccia matrix. These facts indicate that the copper was deposited contemporaneously with prehnite and before the epidote and chlorite, which were formed after recurrent movement on the fault had brecciated the prehnite.

Downward from the 358-foot sublevel the amount of copper-bearing prehnite along the fault decreases, and the amount of mass copper in small fissures nearly parallel to the main fault on its hanging-wall side increases. The richest mass copper zone is 10-15 feet wide and is separated from the main fault by 10-35 feet of barren, fractured country rock. The ore shoot of mass copper plunges steeply southward. The mass copper fissures in this mass zone range in width from 1/4 to 5 inches and locally contain calcite, prehnite, chlorite, and small amounts of datolite. About 32 percent of all the copper recovered from the mine was in masses large enough to be extracted separately.

Two amygdaloids on the east or hanging-wall side of the fault, between the 358 and 458 levels, were found to contain enough copper to warrant stoping. Nowhere, however, has this type of ore been found to extend for more than 50 feet away from the fault.

Iroquois Exploration (pl. 4)

Introduction.--The Iroquois Exploration shaft of the Calumet and Hecla Consolidated Copper Co. is located in Keweenaw County 2-1/2 miles north of the Houghton County line and 1-1/4 mile NW. of Mohawk village. The Iroquois lode, which is stratigraphically about midway between the Calumet and Hecla conglomerate and the Houghton conglomerate, was found to contain significant amounts of copper in 1926 in a crosscut from the Allouez No. 2 shaft near the Kearsarge lode, and over 1,000 feet of drifting on it was done at that time. Subsequent exploration by diamond drilling was followed by shaft sinking and drifting in 1942 at the present mine location. Production through 1945 was 3,883,297 pounds from ore whose average yield has been 16.12 pounds per ton. At the mine the lode dips about 33° N.47°W.

Stratigraphy.--The Iroquois flow _/ is about 110 feet thick at the mine; the lower part of the flow is a massive ophite. The flow top ranges in thickness from 1 to nearly 50 feet and averages about 25 feet. Thick and thin places are locally very close to one another. The character of the flow top is also non-uniform. Moderately red fragmental amygdaloid is most abundant, but nonfragmental amygdaloid is common, particularly in the lower part of the flow top. Masses and layers of vein trap are distributed irregularly throughout the top. Thicker

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_/ Broderick, T. M., Hohl, C. D., and Eidemiller, H. N., op. cit., p. 720.

portions of the lode are generally more prominently fragmental, and at the outer limits of the mine area the lode is thinner and less fragmental. At the base of the lode a foot-inclusion zone of amygdaloidal fragments immersed in trap is generally present. Scoriaceous material has been found at several places in the mine, but the areas are mostly of small extent. On the 20th level, northeast of the shaft, however, an area of scoriaceous material several hundred feet across in strike length was encountered. Scoriaceous material occurs in areas of both thin and thick amygdaloid, but is more common in thin amygdaloid.

Structure.--There is very little variation of either dip or strike within the Iroquois workings, though the regional bending of the lodes in this general area is gently synclinal. Two reverse faults striking a little more easterly and dipping a little more steeply than the lode show significant, though not large, displacement. Numerous fissures and prominent joint planes strike nearly at right angles to the lode and dip steeply southwest. Small displacements were noted on several of these. Other fissures are parallel to the reverse faults.

Mineralogy.-- Native copper is the principal ore mineral, though small amounts of chalcocite and native silver are present. The chief gangue minerals are prehnite, calcite, chlorite, and an unidentified mineral near prehnite in optical properties. Quartz, epidote, pumpellyite, and laumontite are locally abundant; the last named is characteristic of scoriaceous amygdaloid. Hematite is widespread, but is conspicuous only as the source of the red color of the amygdaloid.

Distribution of copper.--Copper occurs (1) in amygdules or other primary openings, (2) with secondary minerals which have replaced trap, (3) directly replacing trap, (4) as thin sheets in joints, and (5) in fissures. Most copper is fine or in small masses whose surfaces are notably jagged. Prehnite is the most consistent associate of copper.

Copper is most widespread in the lower part of the fragmental amygdaloid, but in the area where the lode is thick, the copper may extend to the top contact. The average minable thickness is generally 10-12 feet. Insasmuch as the drifts follow the base of the lode, information about the upper part is very incomplete, even with the many diamond drill-hole sections available.

The principal area of copper-bearing rock at the Iroquois Exploration lies mostly north of the shaft, has a strike length of about 1/2 mile, and plunges a little more westerly than the dip. Within this area the copper is of rather erratic distribution; there are alternating lean and fair areas and some spots of fairly rich copper. Information available from the openings made to date is inadequate to define or prove the existence of any clear-cut ore shoots.

Kearsarge lode (pls. 5 to 10)

Introduction.--The large mines on the Kearsarge lode lie in southern Keweenaw County and northern Houghton County; their names and locations are shown in plate 5. The average strike and dip of the lode in this area are, respectively, N. 40°E. and 37°NW. The lode has been mined continuously for a distance of 6 miles along the strike and locally for over a mile down the dip. None of the mines and explorations on the Kearsarge lode north or south of this continuously stoped area has been profitable. Only the lower workings of some of the mines are now accessible for study (pls. 6 to 10). A total of 1,780,139,070 pounds of copper had been recovered from the Kearsarge lode at the end of 1945.

Stratigraphy.--The sequence of stratigraphic units in the vicinity of the Kearsarge mines is as follows, from top to bottom:

Overlying flow -	Ophite, slightly porphyritic
"West" flows -	Thin discontinuous flows of porphyritic trap, with fragmental and cellular tops.
Kersarge flow -	(Amygdaloidal top - Kearsarge lode
--------	(Porphyritic melaphyre grading down (into porphyritic ophite.
Wolverine sandstone	

The Kearsarge flow has been traced, on the basis of its lithology and relation to the Wolverine sandstone, for over 35 miles along its strike. In general the flow is thickest in the mine area, where it is 170 to 200 feet thick.

The porphyritic trap above the main ophitic portion of the flow contains plagioclase phenocrysts that are typically less than a half-inch long but locally exceed 2-1/2 inches.

In the mine area the amygdaloidal top of the Kearsarge flow is characteristically fragmental, but locally it is poorly fragmental or nonfragmental. In a few places it is only sparsely cellular. The average thickness of fragmental amygdaloid is 6 to 7 feet, but it ranges from 0 to over 30 feet. The rock is red in color, and the redness decreases downward from the top of the flow. A bright red zone locally encountered at the hanging-wall contact is called "red cab." In general, where the amygdaloid is poorly fragmental or non-fragmental it has a dull-brown color.

Cellular or banded cellular amygdaloid, brown to red in color, is found in many places in the flow top. It may constitute the whole top, or be associated with fragmental amygdaloid. Where both banded cellular and fragmental types occur together, the banded cellular type commonly underlies the fragmental amygdaloid. The banded cellular layer, where present, has an average thickness of 2 or 3 feet, but may be as much as 6 feet thick.

At the base of the amygdaloidal top there is, in many places, a layer up to 6 feet thick known as the "foot lode." The rock of this layer is slightly coarser textured trap with scattered large amygdules.

Immediately overlying the Kearsarge amygdaloid in a few places are one or more thin flows whose tops are known as West lodes. Many of these flows are only a few feet thick, and their tops are generally 1 to 3 feet thick. The tops are commonly cellular, locally fragmental. The trap of these "West" flows is slightly porphyritic, and is locally connected to the trap of the Kearsarge flow by dikes that cut the

Kearsarge amygdaloid (33 and 38 levels, Centennial mine, pl. 10). This relationship suggests that the "West" flows are thin gushes from the main Kearsarge flow. Where these flows are absent, there is a thick ophitic flow immediately above the Kearsarge.

Structure.--Very broad and gentle folds are reflected by changes in the attitude of the Kearsarge lode as it is traced through the mine area. The Allouez anticline, which centers in the Allouez mine, plunges essentially down the dip, and the Ahmeek syncline, farther northeast, plunges somewhat northward. In these folds the average change in strike is about 1° per thousand feet horizontally along the lode. The maximum curvature in strike is about 16°. The dip of the lode flattens slightly in depth, but the amount of flattening is generally less than 2°.

Faults and fissures are closely related to the broad folds in the lode. On the fold limb between the axes of the Allouez anticline and Ahmeek syncline, fissures are very abundant and many are large and persistent. Northeast of the curved portion of the Ahmeek syncline and southwest of the curved portion of the Allouez anticline fissures are less abundant and less conspicuous. There are comparatively few fissures in the Centennial mine, where the strike of the lode is essentially constant.

The average strikes and dips of the prominent sets of fissures at each mine studied are tabulated below:

Ahmeek	N. 15°W., 85°NE.	N. 43°W., 88° SW.
North Kearsarge	N. 70°W., 70°SW.	N. 51°W., 87°SW.
Centennial	N. - S., 78°E.	N. 54°W., 82°SW.

Fissures belonging to the set tabulated in the first column are generally more persistent than those in the second. The fissures in and near the prominent shatter zones (fault zones) of the Ahmeek mine belong to this set. Fissures of the set tabulated in the second column strike almost at right angles to the lode at each mine.

The larger faults of the Kearsarge mines all belong to the set of fissures tabulated in the first column, but faults with a displacement of less than 10 feet are found with either orientation.

The two prominent shatter zones of the Ahmeek mine (pls. 6 and 8) are accompanied by marked offset of the lode in some areas, little offset in others. This offset is not uniform from level to level, and demonstrates the rotational character of the apparent movement. The block between the two fault zones dips more steeply than the block on either side.

Mineralogy.--Native copper occurs as disseminated grains and small masses in the amygdaloidal top of the Kearsarge flow. Locally there are small amounts of native silver.

The common gangue minerals of the Kearsarge lode are quartz, calcite, epidote, chlorite, red feldspar, and pumpellyite. Laumontite, prehnite, saponite, and barite are less abundant. Hematite is widespread, but is generally too fine grained to be recognized megascopically except by the color of the earthy variety.

The minerals in the fissures, including copper and a little silver, are much the same as those of the lode. In addition copper arsenides and sulfides are characteristically found in fissures in the north half of the mine area.

A special characteristic of the Kearsarge lode is the peculiar type of alteration product known as "Kearsarge bleach." Small masses or finely disseminated grains of copper are commonly surrounded by irregular zones of bleached rock, light greenish gray in color, in which the rock is altered to a mixture of epidote, altered feldspar, quartz, and calcite. The bleached rock is distributed in irregular patches a few inches to a few feet across, with very sharp boundaries.

Distribution of copper.--Most of the copper in the Kearsarge lode is finely disseminated, or occurs as small masses. Large masses of copper are not common in the lode, but are characteristic of the fissures. In the lode the copper has filled amygdules and other primary openings and has replaced the rock in the vicinity of these openings. Replacement copper is most common in rock with Kearsarge bleach.

In areas of better than average grade, copper is generally fairly well distributed throughout the lode. The lower part of the fragmental amygdaloid is consistently copper bearing. The top of the fragmental horizon locally contains a lot of copper, and in rich shoots the higher values are generally due in large part to copper in the upper part of the lode. The middle part of the fragmental lode is least consistently copper bearing. The upper part of the banded amygdaloid is frequently mined with the fragmental lode; in some areas both the banded amygdaloid and the foot lode have been extensively mined, particularly in the Wolverine and South Kearsarge mines, though the grade in these horizons is generally not very high.

Areas of thin and cellular lode tend to be poor in copper, and conversely thick lode tends to be richer than average. The areas (1) near the outcrop between Mohawk and South Kearsarge, extending locally to considerable depth, (2) just north of Ahmeek shafts 3 and 4, lower levels, and (3) between levels 21 and 24 at the south side of No. 4 shaft, North Kearsarge, have thin lode and are poor in copper. Richer than average lode was found in the vicinity of South Kearsarge and Wolverine and in the southern part of the Ahmeek and Mohawk mines; the lode in these areas had a greater than average thickness. Other smaller areas of thick lode have also been found to contain fairly rich copper.

The West lode has been observed over a considerable area in the Centennial mine and was also seen in the North Kearsarge mine. Occasinally a little copper is found in it, but seldom enough to encourage stoping. More striking is the fact that the main Kearsarge lode is typically very poor in areas where West lodes overlie the main flow. In some such places, as in the Centennial, the Kearsarge lode is so trappy that it is difficult to follow in drifting.

Copper in fissures does not typically make up a significant part of the total production. Many of the large fissures are not only barren, but the adjacent lode as well may be low in copper. A few fissures, however, contain spectacularly large masses of copper. The Mass fissure in Ahmeek was followed into the hanging wall and extensively mined in the upper levels; more than 11,000,000 pounds of copper were taken from this fissure.

The Houghton conglomerate ore body, Allouez No. 3 shaft (plates 11 and 12)

Introduction.--The Allouez No. 3 shaft on the Houghton conglomerate is located in the NW$\frac{1}{4}$ sec. 32, T. 57 N., R. 32 W., Keweenaw County, about 4 miles northeast of Calumet. The conglomerate bed strikes N. 45°E., and dips 36°NW. The ore body was discovered and explored by diamond drilling, and the shaft was started in 1943. The workings and the drill holes that outline the ore body are shown in plate 11. The mine workings extend for about 1,300 feet along the strike and for 1,400 feet down the dip. Total production through 1945 was 2,415,705 pounds of copper, of which 78 percent came from the conglomerate and the remainder from the overlying amygdaloids.

Stratigraphy.--The principal lode at the mine is in the conglomerate bed. The pebbles and boulders in the conglomerate are predominantly felsite and quartz porphyry; a few are trap and amygdaloid. The matrix consists of finer grains of the same materials. The rock is typically more fine-grained near the top than along the bottom of the bed. Scattered lenses of sand and silt, a few inches to 3 feet in thickness, are interbedded with the conglomerate. The conglomerate ranges in thickness from 0 to 22 feet, and averages between 8 and 10 feet in the mine area. The conglomerate bed is, for the most part, underlain by scoriaceous amygdaloid.

The lava flows above the conglomerate are very irregular in thickness and extent. Their irregularity is apparent from the distribution of amygdaloid and trap on the 4th and 6th levels (pl. 12). Cellular amygdaloid predominates, but partly fragmental and partly coalescing types are also present.

Structure.--The Houghton conglomerate ore body is located at the crest of the gentle Allouez anticline. This anticline is represented by a marked change in strike on the Kearsarge lode (pl. 5), about 2,700 feet stratigraphically below the Houghton conglomerate.

Fissures and faults are only locally prominent. A persistent gouge zone 3 to 12 inches thick lies along the hanging wall of the conglomerate; this zone was probably formed by differential movement parallel to bedding during the tilting of the beds. A prominent zone of fissures and small faults cuts the amygdaloids above the conglomerate at a distance of 150 to 400 feet southwest of the shaft on the 4th and 6th levels. The average strike of these fissures is nearly east-west, and most of them dip steeply south. The largest of them terminates, on the 4th level, against the hanging-wall slip at the top of the congolmerate. A less prominent set of fissures strikes nearly north-south and dips steeply east.

Mineralogy.--The ore mineral is native copper. It is disseminated in the conglomerate in minute grains that have replaced the interstitial material. Locally small masses of copper have replaced chloritized felsite porphyry pebbles. Copper in small grains and masses is locally abundant in the amygdaloids above the conglomerate. Copper is present in parts of the hanging-wall slip over the conglomerate, and is a common mineral in many of the fissures, particularly those in the fissure zone just southwest of the shaft.

The typical secondary gangue minerals of the conglomerate are calcite, epidote, and chlorite. Where the conglomerate is highly epidotized, it generally contains abundant finely disseminated copper.

Most of the chlorite occurs in isolated spots where it has replaced the felsite groundmass of quartz-porphyry pebbles. The common gangue minerals of the amygdaloids are prehnite, calcite, chlorite, and datolite; quartz, epidote, adularia, and laumontite are less abundant. The same minerals are found in the fissures; quartz and epidote are the most prominent in the gouge zone on the hanging wall of the conglomerate.

Distribution of copper.--Copper is more abundant within 2 to 5 feet of the upper or lower contact of the conglomerate than in the central portion of the bed. Near the fine-grained rock at the top, the copper is generally very fine grained, and occurs in intensely epidotized rock. The copper that occurs in the coarser conglomerate near the bottom of the bed is notably coarser and the rock is slightly to moderately epidotized.

The areal distribution of copper in the conglomerate bed (pl. 11) is closely related to persistent thick streaks in the bed. In the upper levels of the mine the copper is concentrated in the constricted portions of these thick streaks.

Minable copper was found in the amygdaloids in only one small area that lies (1) in a zone of fracturing and (2) almost vertically above an apex of a conglomerate lens.

Quincy mine (pls. 13 and 14)

Introduction.--The Quincy mine of the Quincy Mining Co. is in secs. 23, 24, 25, and 26, T. 55 N., R. 34 W., 1 mile northeast of Hancock, Mich. A large number of closely spaced amygdaloidal flow tops, the Pewabic lodes, have been mined. Their average strike and dip are N. 33°E., 55°NW. in the upper levels, and N. 38°E., 35°NW. in the lower levels. The mine workings extend for 12,500 feet along the strike of the lodes and 8,800 feet down the dip. The mine was shut down in 1945. The total production up to that time was almost exactly one billion pounds of copper.

The accessible workings of the Quincy mine were not mapped in detail by the writers. Underground inspection of the mine was limited to a few days, which were spent mostly in the lower levels. The following description of the mine was prepared from a detailed study of the company records, including geologic maps and sections of parts of the mine by W. A. Seaman; from published descriptions of the mine, principally U. S. Geological Survey Professional Paper 144; and from the brief observations that were made underground.

The lodes.--The Pewabic amygdaloid lodes at the Quincy mine occur in a group of relatively thin, glomeroporphyritic flows which overlap one another. Where a flow terminates, its amygdaloidal top is in contact with the amygdaloid of the underlying flow, but no sharp boundary can be drawn between these two amygdaloids. The Pewabic amygdaloids are all characteristically coalescing. A typical lode averages 3 to 5 feet in thickness and contains 2 to 10 coalesing amygdular layers which are now mostly filled with secondary minerals and copper.

Locally, however, there are large areas of amygdaloid that is fragmental and somewhat thicker, especially on the stratigraphically lowermost lode that has been mined, the Pewabic. The average thickness of the trap layers between amygdaloids is of the order of 20 feet, but locally a single flow may attain a thickness of 100 feet or more.

The correlation of individual tops through the mine is uncertain in many places. Records of crosscuts or drill holes on some levels reveal more flow tops in a given stratigraphic interval than are shown on the level above or below (pl. 14). The tops are not plane surfaces, and correlation at such points must be rather arbitrary. Considerable uncertainty is a result of the incompleteness of the geologic record in many parts of the mine. Correlation is most certain on those lodes that have been fairly continuously stoped, such as the East, Main, and First West lodes.

Structure.—The variation in strike of the lodes in the mine is small, but the dip varies from 55° at the surface to 35° in the lower levels. The dip flattens more abruptly at the south than at the north end of the mine, forming a gentle flexure which pitches at a low angle to the north.

One particularly prominent and persistent fissure, the "Spar Crossing," extends through the mine; it strikes nearly at right angles to the lodes and dips steeply northward. Less persistent fissures with a similar trend are shown on the company maps (see pl. 13). The only fault of note that affects the Pewabic lodes is the Hancock fault, which cuts the lodes in the upper levels at the south end of the Quincy mine as shown on plates 13 and 14. The fault strikes northeast and dips rather steeply to the northwest; it causes a repetition of the beds and has a horizontal stratigraphic displacement of about 500 feet.

Mineralogy.--Native copper is the chief ore mineral, and occurs in minute grains and in masses up to 100 tons or more. There is enough native silver with much of the copper to warrant its separation.

The secondary minerals that occur in the lodes with the copper are quartz, calcite, epidote, pumpellyite, and chlorite. These minerals have filled cavities and have replaced the original rock-forming minerals. The Spar Crossing, described above, contains these minerals and, in addition, laumontite.

Distribution of copper.--In the coalesing amygdaloids the copper occurs in and near the coalescing layers; it has filled the coalescing vesicles and replaced some of the adjacent trap. The copper is fairly uniformly distributed from top to bottom of the fragmental amygdaloids in areas where they are mineralized.

The distribution of stopes (pl. 13) suggests that most of the copper in the upper levels was mined from lodes that are stratigraphically higher than the lodes principally mined in the lower levels. Too great reliance cannot be placed on stopes as indicators of the distribution of copper at this mine, because many of the lodes have been explored only by an occasional crosscut or drill hole. This is particularly true of the Pewabic, the Far West, and the Far Far West lodes. In some places the lodes are too closely spaced to permit safe mining of two adjacent lodes, yet not closely enough spaced to permit taking both together; in other places stopes started on one lode have cut across the intervening trap and continued on another. There is no reason to believe that all, or even most, of the copper has been recovered from the Pewabic lode within the mine area, particularly in the upper levels.

The stoping pattern in the bottom of the mine reflects the fact that about 50 percent of the ground has been left in pillars because of the depth of these workings. The grade of the ore on the bottom levels is as good as that on the upper levels.

Ripley adit (plate 15)

The Ripley adit is located on the north side of Portage Lake about 1 mile east of Hancock. It was started into the hillside 116 feet above the lake in 1939. Exploration continued until the latter part of 1943, at which time four amygdaloids had been explored by 2,700 feet of drift. Approximately 23,800 pounds of copper were recovered from small stopes in the richest spots in the adit, but most of the rock from the drifts was discarded as waste.

The average dip of the seven amygdaloids exposed in the accessible drifts and crosscuts of the adit is 56° N. 53° W. As shown on plate 15, exploration was confined, for the most part, to the No. 1 and No. 3 amygdaloids, which vary in thickness from 10 to 20 feet and are underlain by 35 to 70 feet of trap. Moderately red fragmental amygdaloid is characteristic of the No. 1 and No. 3 amygdaloids. The others are little explored but are less fragmental where seen. Amygdaloids 4 and 5 have been correlated with the hanging and foot branches of the Arcadian lode (pl. 1) by Professor W. A. Seaman of the Michigan College of Mining and Technology_/. The amygdaloids have also been tentatively correlated with those in the vicinity of the Isle Royale mine south of Portage Lake.

Numerous small fissures cross the amygdaloids at fairly high angles; most of them dip southwestward at moderate to steep angles. A few of

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_/ Oral communication

them show small displacements. Other fissures strike nearly parallel to the amygdaloids and dip either parallel or normal to them. These fissures are mostly confined to the traps. At the top contact of No. 4 lode there is a prominent gouge slip along which there may have been appreciable displacement.

Native copper is the only important ore mineral, but small amounts of chalcocite and native silver have been found. The copper occurs as small masses, small crystals in cavities, and fine grains. The gangue minerals are prehnite, quartz, calcite, chlorite, epidote, pumpellyite, and, in a few places, datolite, laumontite, and adularia. The gangue and ore minerals have both filled cavities and replaced the original rock. The prehnite is intimately associated with copper. Where copper has replaced the rock, it occurs with pumpellyite, epidote, and chlorite.

Considering the workings of the Ripley adit as a whole, most of the copper occurs where the amygdaloids are locally thicker than normal due to bulges in the hanging wall and sags in the footwall contacts. Mineralization was most intense near the boundaries of these areas.

Isle Royale mine (pls. 16, 17, and 18)

Introduction.--The Isle Royale copper mine is located in secs. 1, 2, and 11, T. 54 N., R. 34 W., Houghton County, Mich., 2 miles south of the village of Houghton. Mining has been confined to the Isle Royale amygdaloid, which dips 53-58° NW. The lode has been mined for 16,000 feet along the strike, and the deepest workings are almost 5,000 feet down the dip. Except for two shutdowns of about 6 years each, production has been continuous from 1852 to the present. The total amount of copper recovered by the end of 1945 was 322,076,246 pounds. For the period 1940-1945, a total of 38,438,161 pounds of refined copper were recovered from ore which yielded an average of 19.84 pounds of copper per ton.

Stratigraphy.--The Isle Royale amygdaloid is a fragmental layer, 20 to 45 feet thick, that forms the top of the Isle Royale flow. The amygdaloid is red or brown, and is locally nonfragmental. In places large tabular bodies of "vein trap" are included in the fragmental zone. These bodies range in thickness from 1 to 5 feet and in length from a few feet to more than 50 feet.

A well-developed foot-inclusion zone lies at the base of the fragmental amygdaloid; it caries in thickness from 0 to 20 feet. The underlying trap portion of the Isle Royale flow is 50 to 65 feet thick. It is an ophite in which the augite grains attain a maximum size of 3 millimeters near the center of the flow.

The trap overlying the Isle Royale amygdaloid is a greenish ophite whose thickness exceeds 200 feet.

Structure.--The rocks at the Isle Royale mine lie in an open syncline. The strike of the rocks on the southwest limb is N. 58° E., and on the northeast limb is N. 28° E. The dip ranges from 53° to 58° NW. The axis of the syncline plunges about 51° N. 25° W. and lies about 300 feet northeast of the No. 4 shaft at the surface (pl. 16).

The Isle Royale lode is cut by one large fault and a number of smaller faults. The principal fault (shown on pls. 16, 17, and 18) strikes about N. 59° E. and dips 65-75° NW. in the northeastern part of the mine; in the southwestern part it strikes N. 40°E. and dips 80° NW. The net slip is approximately 550 feet along a line that plunges about 28° N. 37° E. There is a slight increase southwestward in the amount of the net slip. Smaller faults strike parallel to the main fault and dip steeply. Four sets of fissures are recognizable: (1) nearly vertical fissures, striking at right angles to the lode; (2) fissures that strike parallel to the lode and dip steeply southeast; (3) fissures that strike essentially parallel to the lode and dip, on the average, slightly steeper in the same direction as the lode (these fissures are most abundant at the top of the foot-inclusion zone); (4) fissures dipping less than 40° to the southeast and southwest.

Mineralogy.--Native copper is the principal ore mineral. It occurs in minute grains and in masses up to several tons in weight. About 5 percent of the copper is in masses large enough to be shipped directly to the smelter. Small amounts of chalcocite, bornite, chalcopyrite, copper arsenides, and silver (0.2 to 0.3 oz. per ton of ore) are present.

Where copper is abundant, the surrounding rock has been moderately to intensely altered to material composed largely of pumpellyite, chlorite, epidote, quartz, calcite, and sericite. This altered rock, like the copper, is confined, for the most part, to the lower part of the fragmental and upper part of the foot-inclusion zones. Several large areas of intensely altered rock, however, contain little copper.

Calcite, quartz, prehnite, chlorite, and sericite, and small amounts of laumontite, specularite, anhydrite, and gypsum occur as secondary fillings in or replacing the original materials of the fragmental amygdaloid and fissures. The set of fissures that dips steeply southeast and strikes nearly parallel to the lode contains, in addition to the above-named minerals, some copper sulfides and arsenides, and ferruginous carbonate.

Distribution of copper.--

(1) Stratigraphic distribution: The greatest concentration of copper is in the lower part of the fragmental zone and the upper part of the foot-inclusion zone of the Isle Royale amygdaloid. Lesser amounts occur higher in the fragmental zone, particularly at and near the top. At many places joints in the basal part of the hanging-wall trap contain conspicuous amounts of leaf copper.

(2) Lateral distribution: Commercial copper is scattered throughout the mine area in irregular patches whose lateral dimensions vary from a few to several hundred feet. A roughly oval area extending from 1,000 feet northeast of No. 4 shaft almost to No. 6 shaft and lying between the 7th and 31st levels contained most of the best ore in the mine. Outside of this area the proportion of stoped to unstoped ground is less and the rich patches are smaller and more widely scattered.

Champion mine (plates 19 to 24)

Introduction.--The Champion mine of the Copper Range Co., located at Painesdale, is the southernmost of the three large mines on the Baltic lode (pl. 19). This lode has an average strike of N. 29° E., and dip of 69° NW. at the mine. The principal workings have a strike length of 7,500 feet near the surface, and extend 5,600 feet down the dip. Three lodes, in addition to the main Baltic lode, have been mined, but only 3 percent of the total copper mined at the Champion mine has come from these other lodes. The mine, opened in 1899, had produced 760,819,473 pounds of refined copper at the end of 1945.

Stratigraphy.--The sequence of stratigraphic units at the Champion mine is as follows, from top to bottom:

		Approximate thickness
"First West" flow	Amygdaloid 1/	10-50 ft., av. 20 ft.
	Trap	35-70 ft., av. 60 ft.
Baltic flow	Amygdaloid 2/	10-65 ft., av. stoping width 26 ft., upper levels; 15 ft., lower levels
	Trap	135-210 ft., av. 175 ft.
No. 3 conglomerate 3/		0-25 ft.
"First East" flow	Amygdaloid 3/	0-40 ft., av. 18 ft.
	Trap	20-80 ft., av. 60 ft.
"Second East" flow	Amygdaloid	10-60 ft., av. 15 ft.
	Trap	

1/ The "First West" amygdaloid is called the West lode.

2/ There are 2 Baltic amygdaloids above the main body of trap of the Baltic flow at many places. The lower of the two, stratigraphically, is called the Baltic Back lode, and may lie as much as 80 feet stratigraphically below the top of the flow. The upper and lower amygdaloids are separated by trap in such places.

3/ The No. 3 conglomerate and the "First East" amygdaloid are collectively referred to as the First East lode (average stoping widtth 19 feet).

The "First West" amygdaloid is typically red and fragmental. Cellular amygdaloid without fragments is not abundant within the mine area as a whole, but predominates locally, as on the 30th level (pl. 22). Thin layers and irregular masses of nonamygdular or slightly amygdular vein trap are characteristic of the "First West" amygdaloid; locally they make up 20 to 40 percent of the rock mapped as amygdaloid.

The trap underlying the "First West" amygdaloid is a fine-grained ophite.

The Baltic amygdaloid is partly red and fragmental and partly dull brown and cellular. Some nonfragmental areas are very poorly amygdular. In general the flow top is much thicker where it is fragmental than where it is cellular.

The Baltic trap is an ophite. The largest augite crystals are about 10 millimeters in diameter and occur approximately 80 feet above the bottom of the flow. The rock is fine-grained toward the top and bottom

The No. 3 conglomerate where observed has very erratic distribution and lithology. In many places the bed is absent; where present, it may consist of felsite conglomerate, dark red sandstone, or red shale. All three types of sediment may be represented in a single section, but the stratigraphic relations of one to the other are not constant. This stratigraphic unit has not been cut in enough places to permit generalizations on the distribution of the various rock types. The only thick felsite conglomerate encountered is at the north end of the 9th level. At a number of places a thin layer of amygdaloid lies stratigraphically above the sediment.

The "First East" amygdaloid, which is mined with the No. 3 conglomerate as the First East lode, is typically cellular or scoriaceous. The scoriaceous amygdaloid consists of amygdaloidal fragments with sedimentary material in some of the interstices. Where the amount of such sedimentary material is prominent the rock is more properly termed an amygdaloidal conglomerate, but such rocks are included with the amygdaloid in plates 21 and 22. Cellular amygdaloid is locally well banded. The amygdaloid is missing in a few places, and the No. 3 conglomerate lies directly on trap; this relationship suggests erosion of the amygdaloid prior to deposition of the conglomerate.

The "First East" trap is a fine-grained ophite.

The "Second East" amygdaloid is typically thick and cellular. It may be prominently banded, near the top, into alternate layers of more and less amygdular rock. Fragmental amygdaloid, in the few exposures seen, appears to be less common than cellular, though it contains most of the copper. The base of the "Second East" amygdaloid must be very arbitrarily drawn, as the fine-grained trap for many tens of feet below the top contains scattered patches, and possibly layers, of amygdular rock.

<u>Structure</u>.--The most prominent structural feature of the Champion mine is the abundance of small faults and fissures; they are more abundant here than in any other lode in the district. Out of 1,290 measured fissures there are very few that do not correspond within 20° in strike or dip to the average of one of the sets described below. The average strike and dip of the principal fissure systems is as follows:

N. 32 E.	76° NW.	- "longitudinal" set, most prominent
N. 45 W.	55° NE.	- intermediate prominence
N. 65 W.	80° SW.	- minor set

The average longitudinal fissure strikes a little more east and dips a little steeper than the lodes. A few of the faults of this set are accompanied by measurable displacement of the lodes; displacement is typically such as to indicate reverse movement. The actual direction of movement is generally not known, but may have a large component parallel to the strike of the faults. The largest fault in the mine, the "48" fault, belongs to the longitudinal set. In the lower levels of the mine, the apparent vertical displacement on this fault is locally over 400 feet (pl. 19). The displacement decreases northward, and at No. 1 shaft there seems to be no displacement.

The next most prominent set of faults and fissures in the mine dips northeast, and shows a wider range in both strike and dip than the longitudinal set. Throughout most of the mine area, none of these faults displaces the flow tops more than a few feet. The relative displacement may suggest either reverse- or normal-fault movement. A large fault belonging to this set forms the southern boundary of the mine in most of the upper levels. This fault, called the First fault, forms the northern boundary of an extensive area of highly fractured ground. Most of the fissures and faults in this fractured area, as observed in the lower levels, belong to the same general set as the First fault, but in the upper levels longitudinal faults with large displacement have been recognized by company geologists in the vicinity of the First fault and farther south in the Globe area. The First fault appears to be a normal fault in the upper levels and a reverse fault in the lower. It apparently does not cross the "48" fault, as it cannot be identified on the northwest side of the later, even with a reasonable allowance for horizontal offset by the latter. This suggests that it is contemporaneous with the "48" fault.

The minor set of fissures dipping southwestward is important only for its content of epidote.

Mineralogy.--The only ore mineral of quantitative importance is native copper. Most of it occurs as masses or smaller particles in the fragmental amygdaloids, but locally masses or sheets are found in fissures. Chalcocite occurs in many of the longitudinal fissures, but was not found in any nonlongitudinal fissures. At a few places chalcocite is prominent in amygdaloid. Copper arsenides are neither common nor abundant. Gouge is common to fissures of all orientations, but none was found in fissures containing chalcocite.

The principal gangue minerals of the amygdaloids, in order of the frequency with which they are encountered, are quartz, calcite, epidote, chlorite, sericite, prehnite, ankerite, and pumpellyite. Ankerite is more abundant in the West lode than in the Baltic, and red feldspar, found in the West lode, is uncommon in the Baltic. Albite, laumontite, and saponite are present in small amounts.

Distribution of gangue minerals in most of the fissures does not differ greatly from the distribution in lodes; except that laumontite is prominent and abundant in fissures. The longitudinal chalcocite fissures are different, however, and typically contain quartz, ankerite, calcite, and chlorite; some contain sericite and specularite. The fissures that strike about N. 65° W. and dip 80° SW. commonly contain epidote, or are bordered by highly epidotized rock.

Distribution of copper.—Copper distribution is considered in terms of (1) the relative amounts of copper in the various lodes, (2) the stratigraphic distribution within individual flow tops, and (3) the areal or lateral distribution within individual tops.

(1) All but 3 percent of the copper from the Champion mine has come from the Baltic lode. The West lode has produced 1.4 percent, the First East 1.2 percent, and the Second East 0.3 percent. The average grade of ore, after hand sorting underground, has been 36.5 pounds per ton from the Baltic lode, 49.6 from the West, 21.3 from the First East, and 62.9 from the Second East. Because the mining has been highly selective, particularly in recent years, and because much waste rock is discarded in sorting, these figures tell little of the relative values of these lodes in terms of their total explored area. The average copper content of the whole Baltic lode, including unstoped ground, within the areas explored by fairly closely spaced drifts, probably lies between 9 and 12 pounds per ton. The First and Second East lodes, on the same basis, are only a little more than half as rich as the Baltic, and the West is the poorest.

(2) Copper may be concentrated near the stratigraphic top, middle or bottom of the amygdaloidal lodes in the Champion mine. In rich shoots, the copper may be fairly uniformly distributed from top to bottom. On the average, there is probably slightly more copper near the hanging wall than near the footwall. The thick felsite congolmerate of the First East lode at the north end of 9-level is almost barren. Sandstone facies of the No. 3 conglomerate are locally richer than the underlying amygdaloid.

(3) The areal distribution of copper in the Baltic lode of the Champion mine is typically irregular. Particularly in the lower levels, the distribution of good and poor ground (see stope pattern, pl. 19) locally suggests shoots pitching steeply westward, although most of these shoots are neither continuous nor regular. A few shoots seem to pitch steeply northward. Most of these shoots are not coincident in position or orientation with zones of prominent fissures. Where observed in the bottom levels the poor ground between shoots typically coincides with areas of thin, rather cellular amygdaloid.

The lodes other than the Baltic are too little explored to permit valid generalizations on the areal distribution of copper.

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