Bournda a white waxy mineral, which comes very near "Bog Butter" in appearance and chemical composition. Probably this was a peaty product, and, as such, is in correspondence with the Bournda deposit, to which latter it is difficult to assign either the name of peat or lignite. I have called it "bog stuff."

The following results of distillation assign its actual character:

| Clay and sand | Water |
| 15.60         | 48.00 |
| Residue       | Tar-oil |
| 0.68          | 8.00  |
| Other inorganic matter | Gaseous |
| 8.75          | 19.00 |
| Carbon        | 100.03 |

The tar-oil is butter-like and viscous, but it contains a proportion of what is called solar oil, lubricating oil, and paraffin, to the amount of 35 per cent.

The gas was at first bluish at low temperatures, but became afterwards white, and very offensive from sulphuretted and phosphuretted hydrogen.

It may be suggested that, mixed with the better-class coal of New South Wales, it is likely to be valuable for the production of gas. It has been ascertained by actual experiment that three tons of this Bournda deposit are equal, in the manufacture of sulphuric acid, to two tons of coke.

12. Conclusions.—The chief conclusions arrived at are:

1. That, with the exception of the Stony Creek Cannel, all the oil-producing deposits occur in the Upper Coal-measures; and that the Cannel of Stony Creek, on the river Hunter, occurs in the Lower Coal-measures, which are above the Lower Marine beds with Trilobites, below which, again, are numerous fossiliferous beds before the porphyry is reached.

2. That the Cannel belongs to beds in which Glossopteris occurs, and therefore may be a slight additional evidence of their antiquity, as it is an analogue of the "Bog Head" Cannel of Scotland.
opened up some new features which have not as yet received any notice, and may be of interest to the Society.

The copper-mining district of Michigan is situated in the upper peninsula, or north-western portion of that State, forming a narrow belt of country about 140 miles in length, extending in a north-easterly and easterly direction, from the boundary of the State of Wisconsin to the end of Keweenau Point, the promontory of which projects into Lake Superior on the southern shore, about midway between Fond du Lac and the outlet of the lake at Sault S. Marie.

2. Structure of the District.—The rocks of the district consist of coarse sandstones and conglomerates, occupying either shore, with a central mass of trappean rocks, which forms the mineral range proper. The sandstones on the eastern side have a south-easterly dip, while the traps, which are well stratified, and include several conformable beds of conglomerate, together with the overlying sandstones and conglomerates of the western and northern shores of Keweenau Point, dip towards the north and north-west, or generally at right angles to the trend of the land.

The surface of the country is for the most part covered with a dense forest, interspersed with small lakes and swamps. In the drier ground maple is the prevailing timber, with spruce, pine, and oak, in less quantity. Cedar is common in the swamps, which are also remarkable for their profuse growth of enormous plants of Osuunda cinnamomea and other large ferns characteristic of wet ground.

In the northern district, and as far west as Eagle River, the rocks are free from cover, the sandstones and conglomerates on the north shore forming a steeply-scarped cliff, surmounted by gently sloping inclines on the upper surface of the beds. At Copper Harbour the face of the escarpment of one of the conglomerates is so very regular that, owing to the wood having been burnt off, it may be traced, forming a perfect wall without break, for several miles. Further to the westward, however, the geology becomes very obscure on account of the drift, which extends from near Eagle River to the extreme point of the district beyond the Ontonagon, and, in greater or less thickness, effectively covers up the rocks below. This drift is composed of a stiff blue or reddish clay, passing up into sands or gravels, and in places is full of angular or scratched stones. It is of great thickness in some places—as, for instance, at the Naumkey mine, on the south side of Portage Lake, where a shaft was abandoned from excessive influx of water, after 100 feet of sand had been sunk through without reaching the rock. Sections of contorted drift are seen in considerable numbers in the drift plateau which forms the belt of country below the Minnesota hills and the lake-shore near Ontonagon. The surfaces of the rocks immediately below the drift are often scored and striated by ice, the furrows being sometimes of extraordinary size—for instance; at the Concord mine, on Portage Lake, where they are nearly semicircular and about 1½ inch deep. The general direction of
the glacial striations is about north and south; and the drift occasionally contains Upper Silurian fossils, which have been derived from the country between the north shore of Lake Superior and Hudson's Bay.

From the preceding remarks on the nature of the surface, it may be understood that the order of sequence of the rocks is not as yet quite conclusively determined, and that therefore there may be some doubt as to the proper age to be assigned to them, fossils being absent on Keweenau Point. Where the rocks are bare, the section has been well made from shore to shore by Mr. W. H. Stevens; and they are shown to be in conformable sequence from east to west. At Portage Lake the lower boundary of the trap is hidden; and, indeed, researches subsequent to those of Messrs. Foster and Whitney have shown that more ground is included within the trappean range than is laid down on their map. In the original survey of Messrs. Foster and Whitney, these beds were assigned to the Potsdam or Lowest Silurian group; but subsequent investigations have led Prof. Hall and Sir W. E. Logan to refer them to a somewhat higher level, or in the Quebec group—the former geologist having determined that the mass of the sandstones of the Sault S. Marie and the south-eastern shore of the lake are equivalent to the Saint Peter's sandstones of Minnesota, forming probably part of the Chazy formation*. On the Canadian side of the lake, the traps are penetrated by intrusive dykes which do not affect the overlying sandstones; but there is no good evidence of a similar unconformity in the upper beds of Keweenau Point, as no transverse dykes are seen. I have examined the junction of the traps and sandstones at three different points—namely, at Portage Lake, Copper Harbour, and Eagle River. In the latter case the junction-surface was perfectly smooth, without any indication of intrusion; while in the two former a few small irregular veins, filled with a red jaspery substance, are given off from the traps, and penetrate the sandstones and conglomerates to the depth of a few inches; but this evidence is too inconsiderable to have much weight, in view of the abundant proofs of conformable stratification derived from the regular alternation of the conglomerates with the igneous rocks.

The central trappean belt, forming the mineral range proper, varies in width from 2 to 3 miles, and extends throughout the whole length of 140 miles, passing into the neighbouring State of Wisconsin. The prevailing rock is mineralogically a dolerite, or mixture of felspar (labradorite), hornblende, and augite, with chlorite, epidote, calcite, and magnetite as occasional constituents. It is usually of a dark-brownish-red or chocolate colour, mottled with green or black by the chloritic material, but occasionally becomes bright green, or even sulphur-yellow when epidote prevails, as is the case in the Ontonagon district.

More important, however, than the mineralogical constitution of the traps is their physical structure, which varies considerably, the commonest condition being compact, with finely granular fracture,
with only a few small empty vesicles, the joints being irregularly disposed, giving fragments of no defined forms. Near Eagle Harbour a well-marked columnar bed is seen, which has been traced for several miles. Another more important bed of a crystalline character occurs a little lower down. This is the so-called “greenstone,” a finely crystalline rock without vesicles, which appears to be nearly homogeneous, and of a dark green colour on a freshly fractured surface; but a concretionary structure is brought out by weathering, the exposed surface presenting a finely mammillated appearance. The thickness of this bed is from 500 to 800 feet, according to Whitney; and where present in force it forms a well-marked feature in the scenery, the escarpment being in fact the “cliff” after which the oldest and most successful of Lake Superior mines is named. It has been traced from the Point eastward for about 40 miles, and is used to divide the mass of the trap into the northern and southern ranges—a distinction that cannot be established in the Portage Lake district, where the greenstone is absent, or covered up with drift.

Scattered through the massive trap are beds of amygdaloidal character, containing cavities that have been subsequently filled, by infiltration, with foreign minerals, usually zeolite and calc spar, with chlorite, epidote, and native copper in the mineral range; whereas chaledonic amygdules, agates, and similar siliceous substances characterize the amygdaloids of the higher or Lake-shore traps at Eagle Harbour, Copper Harbour, and Agate Harbour, &c.

3. Metallic Minerals of the District.—In addition to the native metal, other copper-bearing minerals have been observed, but only in small quantity: these include a rare substance called Whitneyite (which is the most basic of the known components of copper and arsenic, its composition being represented by the formula, Cu₁₈, As, with 88.36 per cent. of copper, and 11.64 per cent. of arsenic), copper glance, and the various oxidized ores, such as chrysocolla, malachite, azurite, cuprite, and melaconite. The latter mineral, although not of present importance, is of interest as having laid the foundation of mining industry in the country, the first operations of the Cliff Company in 1847 having been upon a vein in the upper conglomerates of Copper Harbour, which produced about 25 tons of mixed silicates and black oxide of copper, being the only instance in which a deposit of any extent has been found in the top beds. Copper glance has been found in small quantities in a vein at the Huron mine on Portage Lake, and more abundantly at the Mendola mine near Lac la Belle, in the lower or southern portion of the mineral range, which is now being explored in a regular manner. The arsenide occurs in a quartz vein at the Shelden Columbian mine, and in an unworked deposit on the Lexington location south of Portage Lake, where it has been got in masses of several hundredweights. This mineral, although rare, is of interest, as it also occurs in the copper-mines of Chili.

4. Mode of Occurrence of the Copper.—In addition to its presence in the amygdaloids, copper is found in one of the conglomerates associated with the trap rocks, finely interspersed in the more epi-
dotic portions of the latter, and in two classes of true lodes,—one of which crosses the strata at right angles to their strike, forming the so-called fissure-veins of the Keweenau Point and Eagle River districts; while the other includes such veins as run with the formation, and are found in the Ontonagon district. These are very irregular in character; and the fact of their being veins can only be made out by their relations to the containing rocks as developed in deep working, the surface appearance being that of irregular masses of epidote-breccia, continually varying in thickness, although capable of being traced for considerable distances. In the fissure-veins the metal occurs in comparatively smooth platy masses, of all sizes, and comparatively free from intermixed rock; while in the Ontonagon lodes the masses are rough and on a very large scale, arborescent in form, and usually contain large adherent and included fragments of the vein-stone—a breccia of epidote rock and quartz; but in either case they may attain a great size, and at times a weight of several hundred tons. In the cupriferous amygdaloids of Portage Lake, masses of great size are not found, the largest being that discovered about two years since in the Mesnard location, which weighed about 18 tons, and lay loose on the drift covering the rock. In addition to the masses, thin sheets of metal are common wherever narrow transverse cracks occur in the rock, either forming masses of tangled crystals with a serrated edge, or, when of large size, being more compact and not unlike worn-out copper sheathing. The metallic kernels of the amygdaloids are rarely solid, but form thin shells moulded to the wall of the cavity, or to the crystals of some mineral previously deposited, usually carbonate of lime. In the conglomerates, in like manner, the metal usually incrusts the pebbles, sometimes completely investing, but never entirely replacing them. When crystallized in its own form, the copper has also a great tendency to appear in hollow crystals, the simplest solid forms being formed in the hollows of the larger masses. A fine example of this has been recently furnished by the great mass of the central mine, which on one of the cuts disclosed a druse full of nearly perfect crystals of tetrahedral form, without any se-
condary planes. The finest crystallized varieties are, as a rule, obtained from the Ontonagon district, and generally are more abundant in newly opened mines than in those which are worked at greater depths.

In the Porcupine Mountains, to the west of the Ontonagon River, a compact epidote rock is found containing copper in such a very finely divided state, that it has hitherto been impossible to work it advantageously. Native silver is found to a small extent, either crystallized in arborescent forms, or irregularly spotted through the copper, the line of separation between the two metals being well marked in polished specimens. The Cliff and Minnesota mines have produced the largest amount of the precious metal, the absolute production, however, being but small; and scarcely any portion of what is found comes into the hands of the mining adventurers, except a few pounds which are annually got by hard picking from the coarser sizes of the dressed mineral. The larger pieces find their way into the hands of dealers and collectors, the earlier miners having appropriated them to their own use, and the precedent has been persistently followed ever since.

5. Distribution and Association of the Copper.—Among the three classes of deposits in which the mines are worked, the most important are the stratified amygdaloids, which will therefore be first considered. They are confined to the district of which Portage Lake (an inlet which nearly cuts the Peninsula into two parts) is the centre. The oldest mines are on the southern or Houghton side of the lake, so called from the town or village named after the geologist who examined the country; while the newer and more important ones are on the northern side, above the village of Hancock. The banks of the lake on either side rise steeply from the water to a height of from 400 to 600 feet; the dressing-flows, being placed close to the water, receive the ores from the mines (which are located on the high tablelands above) by means of railways and inclined planes. Taking the extreme north and south mines as limits, the district has a length, measured along the strike of the trappean belt, of about 9 miles, and a breadth of from 3 to 5 miles. The general section, showing the position of the copper-bearing beds, is as shown in Fig. 1. The series of beds indicated are amygdalous traps, which contain more or less copper in the cavities, and are regularly mined under the name of "lodes." In the uppermost or Hancock series, only one mine is opened, bearing the same name. The ground is more
irregular than is usual in the lower beds, three different belts of metalliferous rock being known. The principal one is 24 feet thick, without any defined walls; and about one-half of it is workable: the drivage is done on the upper or hanging wall, which often presents a laminated appearance from the occurrence of strings of calcspar, testing cross-cuts being driven into the vein below at intervals; the copper mass is chiefly on the lower or foot-wall side, the upper part being a hard compact trap. The yield of the rock sent to the stamps in 1864 was about 272 lbs. per cubic fathom, equal to 15 lbs. per ton, or about \( \frac{3}{4} \) per cent.

The second or Pewabic group is more important than the preceding, and includes several belts or lodes, whose thicknesses and positions are given in Fig. 2, which represents the section obtained in a cross cut made at the 70 fathom-level of the Pewabic mine.

The most important members of this series are the highest, or Pewabic lode, and the lowest, or Albany and Boston conglomerate. The former has been systematically mined by the Quincy, Pewabic and Franklin Companies for a length of about 1½ mile in a north-easterly direction from the Hancock shore of the lake. North of the Franklin it has been traced, but not worked, for a further length of about 3½ miles, up to the Albany and Boston mine. It is a dark brownish-red amygdaloid, filled with small vesicles containing chlorite and native copper; the thickness varies from 6 to 30 feet, the average being 9 feet in the Pewabic, and 10 feet in the Quincy mine; the hanging wall is a compact greenstone-like trap; while the foot-wall is a dark-coloured amygdaloid, with very small kernels of chlorite. Fig. 3 shows the character of the lode at the 130-fathom level of the Pewabic mine. Copper is well sprinkled through the whole mass, with a few small masses near the foot-wall, and with irregular calcspar strings in the upper side. Although not producing any very large masses, the yield is tolerably uniform, the produce being at the rate of 1.5 per cent. in the Pewabic, and 1.6 per cent. in the Quincy mine: the latter is sunk below the 100-fathom level. The concentration of the copper towards the foot-wall is characteristic of the whole of the amygdaloids.

The other members of the group, below the Pewabic lode, although not of any great importance as regards produce of copper, are of interest as establishing the regular succession of the amygdaloids over areas of a certain extent, the section being substantially the same in the Pewabic cross cut as it is in the Albany and Boston line about 3½ miles further north. It is not necessary to go further into the characteristics of these belts or lodes; but it may be incidentally remarked that the epidote lode is filled with a purplish rock, containing a great deal of bright-green epidote, and that the Albany and
Boston lode is also very epidote, and in the hollows carries large quartz crystals and masses of prehnite.

The Albany and Boston conglomerate is a deposit of considerable interest, as it forms a well-marked horizon in the rocks of the Portage district, and carries in places a very considerable amount of copper. It is about 30 or 32 feet in thickness, and is included between a soft argillaceous sandstone floor, 4 feet thick, and a clay roof of 9 inches in thickness. The latter contains at times parallel sheets of copper, and is locally known as the "fluean lode." The pebbles are chiefly of red jaspisous porphyry, and are for the most part well-rounded, varying in size from about half an inch up to six or eight inches in greatest diameter. The cementing material varies considerably, being mainly calcareous at the Pewabic, and a compact epidote at Rhode Island mine. The more usual character, however, is a granular mixture of epidote, quartz, and finely divided rock-matter with small specks of copper.

More remarkable conditions, however, have been observed in some portions of this rock at the Albany and Boston mine, where the cement is in places entirely metallic, the copper forming closely-fitting shells over the pebbles, and at times permeating them to such an extent as to form, with the siliceous mass, a kind of copper-concrete, which of course is extraordinarily tough, such pebbles being capable of passing almost unaltered in form through the jaws of the powerful rock-breakers employed in the dressing-floors. In places, however, the copper in the cement of the coarse conglomerate has been changed to chrysocolla and red copper ore, both of the octahedral and fibrous forms, associated with which are calc spar, prehnite, and, probably, cuprous allophane. Out of the total thickness of 32 feet, only the lower portion of the bed, from 10 to 15 feet thick, is cupriferous; so that in this respect the conglomerate resembles the amygdaloids.

The lower metalliferous, or Isle Royale series, is a belt of amygdaloids similar in general particulars to those of the Pewabic group. It includes two great lodes:—the grand Portage, worked in the mine of the same name on the south shore of Portage Lake; and the Isle Royale, which is opened on the Huron mine, also on the south side, but has also been traced for several miles on the north shore. It is a pale-green amygdaloid containing quartz, steatite, chlorite, epidote, and copper in small quantity, from 24 to 33 feet in thickness, yielding about 1 per cent. of copper when dressed. Below the Isle Royale is another lode called Mabb's lode, which has recently been discovered; and it is not quite certain whether it be a parallel belt or an actual fissure-vein, as its dip is much steeper, being 75° instead of from 52° to 60°, which is the amount of inclination of the higher belts.

6. Mines of the Northern District.—In the district of Keweenau Point the cupriferous amygdaloids occupy but a subordinate position, the whole of the produce being derived, with a very few exceptions, from true lodes, or, as they are called in the district, fissure-veins, which, as a rule, are nearly vertical, and cross the trappean formation.
atright angles to its strike, the greater number being included between the directions N.W. & S.E., and N. & S. The relation of the rocks is shown in the sketch-section, Fig. 4, from which it will be seen that the trappean series is divided into two parts by the great greenstone bed, the upper portion being known as the northern, and the lower as the southern mineral range. Now although lodes in many cases pass through both ranges, yet, as a rule, up to the present time they have rarely proved to be of value for copper in both, the most important deposits being confined to the southern side, and at no great distance from the greenstone, the principal mines being the Cliff near Eagle River, the Amygdaloid, Delaware, and Pennsylvania near Eagle Harbour*.

Fig. 4.—Section from Copper Harbour to Lac la Belle (after Foster & Whitney).

![Fig. 4](image)

The lode worked at the Cliff mine has been traced for about 2½ miles, but the main workings are below the greenstone, and extend southward for about 1400 yards. It is a nearly vertical fissure, varying in breadth from a mere line to six feet, filled with broken rock and zeolitic minerals, with native copper, both in fine particles and large masses, the latter being common in the wider portions, which alternate with barren strings made up of laumonite and decomposed trap. The containing rock is a hard trap, with interstratified beds or “flows” of amygdaloid, which have been laid down in the plans to the number of 12 or 13. These are occasionally

* The total yield of copper from the mines of Lake Superior in 1864 was as follows:—

From 13 mines in Portage Lake district, 4293 tons of 70 per cent. mineral.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keweenau</td>
<td>2548</td>
</tr>
<tr>
<td>Ontonagon</td>
<td>1722</td>
</tr>
</tbody>
</table>

8663 tons.

These quantities are in American customary tons of 2000 lbs. The above total is equal to about 5609 statute tons of fine copper.

The largest individual production was, in dressed mineral (70 per cent):—

1485 tons 13 cwt., American weight, from Quincy Mine.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cliff Mine</td>
<td>1133</td>
</tr>
<tr>
<td>Pewabic</td>
<td>932</td>
</tr>
<tr>
<td>Central</td>
<td>608</td>
</tr>
<tr>
<td>National</td>
<td>525</td>
</tr>
</tbody>
</table>


1866.] BAUERMAN—COPPER-MINES OF MICHIGAN. 457

impregnated with copper to a depth of about 20 feet from the lodes. The mine is 156 fathoms deep, and produces from 35 to 65 masses weighing about a ton each per month, and about an equal weight from stamp-rock, containing about 1·9 per cent. The copper-ground, as a rule, appears to follow the greenstone in depth, dipping about 27° north-westerly. The North and South Cliff mines, opened on the prolongations of the same lode, are not now at work.

The Central mine, about 14 miles east of the Cliff, is opened upon a similar lode, consisting of a series of alternations of red laumontite strings, with large lenticular expansions containing copper. The original discovery of this lode was made in an old Indian working at the No. 2 shaft, out of which a mass of copper, weighing 50 tons, was taken. Only a small amount of metal has been found immediately below this point in sinking; but further north, below the greenstone, under similar conditions to those observed in the Cliff mine, a very rich run of ground has been discovered. There is a good deal of calcite in the vein, and the finer copper appears rather in sheets than in shots. At the 50-fathom level, on the No. 4 shaft, the largest mass that has as yet been discovered on the lake was struck; it measured 50 feet in length, 30 in height, and about 4½ feet in greatest thickness, and yielded somewhat over 500 tons of copper.

Fig. 5.—Longitudinal Section of the Central Mine.

![Longitudinal Section of the Central Mine](image)

The mines in the range north of the greenstone are the Petherick, Copper Falls, and Phoenix, which derive their produce almost entirely from a remarkable bed of very much decomposed finely vesicular trap, filled with small shots of copper, known locally as the "ash-bed." Associated with this is a compact trap, containing elongated cavities at its contact with the more vesicular portions. These cavities are usually filled with copper in ramifying forms resembling eagles' claws. The ash-bed, according to its discoverer, Mr. Hill, has been traced for about 8 miles, and by its position probably represents some of the upper beds of Portage Lake. Although extensively worked, it is too poor to yield any great profit, the produce at Copper Falls being 1 per cent., and at the Phoenix only ¾ per cent., of the rock treated.
7. Ontonagon District.—The mines of this district are all opened in the same class of deposits—namely, very irregularly defined lodes which follow the strike of the trappean belt, commencing on the Minnesota Hills, at the southern end of the district, which rise abruptly from a drift-covered plateau, about 12 miles in length, lying to the south of the town of Ontonagon. They extend in a north-easterly direction for about 16 miles to the Wynona mine, the last explorations in the direction of Portage Lake. The Minnesota mine has been worked to a depth of about 200 fathoms, on a lode dipping about 46° northerly, and included between a roof of compact grey trap and a floor of conglomerate. A northern branch, dipping at a higher angle, falls into it at the fifth level below the adit; between these is another branch, more nearly parallel with the main lode, in which the great mass of 400 tons was found in the year 1856, about 20 fathoms below the surface. This mine has shown a decided decrease of richness in depth, the produce having diminished from 2058 tons in 1857, derived from ground yielding 1267 lbs. per fathom, to 387 1/3 tons in 1864, the amount per fathom being reduced in the latter year to 186 lbs. The lower workings are now completely abandoned, and an attempt is being made to develop the northern lodes. As seen in the adjoining National mine, the Minnesota lode is filled with a mass of epidote and quartz, apparently of a brecciform structure, with rough particles of copper scattered irregularly through it. The hanging wall is full of small slipped pieces of rock and clay, and is covered with longitudinal striations.

The sandstone below the conglomerate on the underside of the lode occasionally contains a little copper, when it assumes a laminated appearance, in thin stripes of red jasper and yellow epidote grains, interspersed with bright metallic leaflets, the arrangement being similar to the cement of the Albany and Boston conglomerate and the compact epidote-rock of the Porcupine Mountains.

The lode at the Indian mine is an epidotic mass, apparently a concretion in the hornblendic trap. It is remarkable for carrying large quantities of analcime, with small masses of copper in solid crystals. A very decided concretionary structure is seen in the trap at the Bohemian and Toltec mines, which are on the same run of ground; the deposit worked is a course of trap, filled with epidote about 8 feet thick, the rock containing spheroidal masses which in section present alternately light- and dark-green rings, the former being due to epidote, and the latter to the prevalence of hornblende and chlorite, the two colours being divided by intermediate rings of calc spar; the largest of these concretions are about 15 inches in diameter. The lode is an epidotic amygdaloid, about 8 feet in thickness, with a N.W. dip of 35°. It is spotted through with small strings of calc spar and quartz; the copper occurs either in pseudomorphs or in crystallized masses of no great size, or in leaf-like plates in the bright-green epidote; similar conditions prevail in the Wisconsin mines further to the N.E.; but as yet none of these mines are distinguished by any great production. Several heavy masses have recently been taken out of the shallow workings at the Flint–Steel mine, which is opened
upon an epidote-brecia lode divided into two branches by a horse or rib of barren trap. Very extensive traces of aboriginal mining have been discovered at this place, the old miners having sunk their pits on both branches of the lode, avoiding the barren ground between them. It is very remarkable that almost all the valuable mining locations on the lake show traces of Indian or Aztec work; and recent discovery has shown that they not only worked on the mass lodes, but also—in one instance at least—on the conglomerates. If the country were less wooded, these old workings might be of considerable service in indicating the position of deposits of value; but they are, in almost all instances, filled up and covered by vegetation, the trees being as large as any of those of the surrounding forest, thus giving proof of the remote antiquity of these workings.

8. Paragenesis.—The following are a few of the chief alternations of minerals observed in the Lake Superior mines: others will be found in the works of Professor Whitney:—

1. Chlorite, calcite, copper—Pewabic lode.
2. Chlorite, quartz, copper—Isle Royale lode.
3. Chaledony, quartz, apophyllite, calcite—Bay State mine.
4. Laumonite, quartz, green-earth—Phoenix mine.
5. Prehnite, quartz, copper, laumonite—Bay State mine.
6. Natrolite, laumonite, analcime—Copper Falls mine.
7. Calcite, copper, analcime, orthoclase—Copper Falls mine.
8. Apophyllite, copper, orthoclase—Copper Falls mine.
9. Datholite, copper, calcite—Copper Falls mine.
10. Analcime, copper, orthoclase—Bohemian mine.
11. Quartz, prehnite, copper, calcite, clay—Albany and Boston lode.
12. Quartz, epidote, laumonite—Isle Royale lode.
15. Calcite, chrysocolla, malachite, cuprite, silver—Albany and Boston conglomerate.
17. Copper-glance, calcite—Mendola mine.

From the above list it will be seen that the copper is sometimes older and sometimes newer than the associated minerals. In the Ontonagon district it occurs very generally as incrusting pseudomorphs upon opaque rhombohedra of calcite, but is also itself enclosed in transparent complex scalenohedral forms of the same mineral, but of later formation. Similar encrusting pseudomorphs of quartz are also common, the original mineral having at times been removed, leaving an empty six-sided tube. The best examples of this class are to be found at the Huron and Bohemian mines. Silver occurs, both in massive lumps included in the copper and in crystallized arborescent forms. The two metals have probably been deposited simultaneously.

9. Origin of the Copper.—The occurrence of native copper in the cavities of amygdaloid traps has been observed under circumstances similar to those seen on Lake Superior, in the agate-bearing melaphyre of Oberstein in Rhenish Prussia, in Nova Scotia, and in the Faroe Islands. Thin sheets encrusting the walls of cracks in similar rocks
have been found in several places near Glasgow. In the whole of the above localities, however, it is a comparatively rare phenomenon, and might be accounted for by the reduction of dichloride of copper sublimed from a volcanic vent—a process of which we have indications in the occurrence of oxychloride of copper in the lavas of Vesuvius. It is difficult, however, to consider this an adequate cause for the metallization of a mass of rocks which, from their appearance on Isle Royale, Michipecoton, and other points on the northern and eastern shores of the lake, must cover an area of many thousands of square miles. Another hypothesis, suggested by Müller, supposes the copper to have formed part of the felspathic component of the trap rock when in the unaltered state—a view that is supported by the occasional occurrence of protoxide of copper in small quantities, usually less than 1 per cent., in several anhydrous silicates, such as felspar, orthoclase from Schemnitz, and Amazon-stone from Siberia, epidote from S. Marcel in Piedmont, idocrase in the Norwegian variety called cyprine, and olivine*. This hypothesis may be modified by supposing the copper to have existed in the trap as sulphide, mechanically interspersed in minute quantities, in the same way that it is found in the coarse metal slags of copper-furnaces. On the other hand, we have the recorded statement of Whitney†, who, in an analysis of the trap from Isle Royale, found it to contain no copper, although it was specially sought for; but traces were found in the sandstones overlying the trappean series. This piece of negative evidence, however, must not be overestimated, as it would in any case be very difficult, if not impossible, to determine the original composition of the traps as they exist at present. They have undoubtedly undergone considerable change, as is shown by the presence of hydrated minerals, such as chlorite and zeolites, as well as calcspar.

Rammelsberg has found as much as 0.56 per cent. of protoxide of copper in a lava from Vesuvius from the eruption of 1811—a rock not very dissimilar in composition from the Lake Superior trap; and although we have great masses of copper concentrated at single points, it must be remembered that the percentage contents of the deposits selected as rich enough for working are included between the narrow limits of one-half and two per cent.; and supposing the contents of these deposits to be uniformly distributed through the whole mass of the traps, the state of division would be so great as to render the copper difficult of detection. The presence of copper in the sandstones suggests another origin—namely, that it may have originally been deposited with the quartz-ore sediment as a finely divided sulphide from sea-water under the influence of organic matter, and by subsequent oxidation and solution have been removed and collected in the rocks below. Cupriferous sandstones and other sedimentary rocks are comparatively common, as, for example, the Carboniferous Sandstones of Nova Scotia and the Kupfer Schiefer, which contain sulphides of copper in an unaltered form, partly on account of the state of aggregation of the deposited mineral, and partly from the texture

† Geology of Lake Superior, pt. 2. p. 87.
of the rock and the presence of organic matter, which prevents oxidation. In coarser and more easily permeable rocks, however, not containing organic matter, it is easy to see how the finely divided sulphide would be readily oxidized by infiltrated atmospheric water, giving rise to sulphates, carbonates, and other oxidized minerals—a condition which is exemplified by the cupriferosus Triassic Sandstones of Cheshire, which contain only oxidized compounds of copper.

The size of the accumulated masses of metal appears to be mainly dependent upon the size of the cavities in which they are deposited, whether in the amygdaloids or in the main fissures; and their absence in the compact traps is probably only due to the non-occurrence of such cavities. In almost all cases the introduction of the metal has been preceded by the deposit of minerals produced from the decomposition of the rock, such as quartz, calcite, chlorite, and zeolite; and in the larger cavities it is often followed by transparent crystals of calcite, which are formed over branching masses of copper, or even show signs of simultaneous deposition, being filled with fire-spangles of metal arranged parallel to the diagonal striations or lines of growth on the rhombohedra. Similar alternations in the formation of zeolites, more particularly analcime, have been described by Whitney.

Bischoff* has shown that hydrated silicates of copper, both artificially prepared and the natural mineral dioptase, are sensibly soluble in pure water, but much more readily so when carbonic acid is present, the solution in the latter case being attended with a partial decomposition and separation of silica. A reaction of this kind is suggested by the occurrence of chalcedonic and quartzose kernels in the amygdaloids of the higher portion of the trappean series, while copper is found lower down. As regards the reduction of the metal from solution, it is probable that the chief agents have been substances containing protoxide of iron derived from the decomposition of the trap itself. Professor Andrews, of Belfast†, has suggested a more potent reducing-medium in the presence of metallic iron in certain varieties of basalt in Ireland, and other crystalline rocks from other localities; but it does not appear to be very likely that such an agency can have been at work on Lake Superior, as it is difficult to suppose that an eminently oxidizable substance like finely divided iron could have remained unaltered after the changes produced by infiltration of water had once been set up; and these changes appear to have preceded the deposition of the copper.

A point of considerable interest, but which we have at present no means of determining precisely, is, whether the copper in the fissure-veins is of the same age, newer, or older than that of the amygdaloids of Portage Lake. I am inclined to think that the latter are the older class of deposits, and that they have served as feeders for the fissure-veins, for the following reasons:

1. The lodes carry more copper between amygdaloid walls than they do when encased in compact trap.

2. The transverse joints and fissures of the amygdaloids on

Portage Lake carry masses and sheets of copper analogous to, but much smaller than, the masses of the northern mines.

3. The amygdaloids adjoining the bearing portions of the veins are often found to contain considerable quantities of copper for some distance from either wall.

The last of the above reasons may no doubt be made available in support of the opposite hypothesis of the permeation of the cellular rock by materials introduced from the lodes; but in order to prove this, it would be necessary to show that the rock was barren, except within the distances explored. This is, however, by no means certain, as the miner stops at the limit of profitable working without carrying on systematic researches along the strike of the bed, as is done in the Portage district.

Bischoff* showed, as far back as the year 1825, that copper may be deposited from solution in a massive condition in a comparatively short time, by the action of organic matter upon solutions containing sulphate of copper partly in the state of a salt of the sub-oxide. This was observed at Linz, on the Rhine, where a solid malleable mass of copper, weighing \(2\frac{3}{4}\) lbs., was deposited in a wooden vat, used in the concentration of blue vitriol leys obtained from the lixiviation of poor copper ores after roasting.

Where the amygdaloids are compact, and tolerably free from cracks and joints, the metallic kernels have undergone no change, and appear as clean brilliant masses on a freshly fractured surface. It is different, however, at the outcrops, where the cavities are usually empty, and their former contents, converted into malachite, have been absorbed by the crystalline base of the rock, which is stained green for a considerable distance round. Similarly in the conglomerates atmospheric agencies have been largely at work, producing malachite, red copper ores, chrysocolla, and similar secondary products; and another instance of the same kind may be adduced in the old vein in the sandstones of Copper Harbour, which yielded melaconite and chrysoeolla in considerable quantities, but not metallic copper. The mines, as a rule, are very dry, the deepest requiring only a small amount of pumping-machinery of no great power, and that only employed at intervals, in order to keep the workings free from water. This comparative impermeability of the rock is probably the cause that has preserved its metallic contents with such a small amount of change, as it is well known that metallic copper is rapidly oxidized when exposed to ordinary atmospheric vicissitudes. This is well seen in the "floats," or small masses, that have been removed from the rock by denudation, and are found in the drift covering the backs of the lodes. These are often incrustated with a coating of earthy malachite nearly half an inch in thickness.

Perhaps the most interesting fact in connexion with the mineralogy of the Lake Superior mines is the prominent occurrence of orthoclase among the newest minerals in the lodes, and in succession to zeolites;

and as it is found deposited upon the faces of crystals of analcime and apophyllite, it is evident that it must have been formed at a very moderate temperature*.

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APRIL 25, 1866.

The following communications were read:

1. ADDITIONAL DOCUMENTS relating to the VOLCANIC Eruptions at the KAIMENI ISLANDS. By Commander BRINE, of H.M.S. 'Racer.'

[Communicated by the Lords Commissioners of the Admiralty.]

(An abstract of this communication was published in Quart. Journ. Geol. Soc. No. 87, p. 319, by order of the Council.)

2. REPORT to the EPARCH of SANTORINO on the Eruptions at the KAIMENI ISLANDS. By M. Fouqué.


(An abstract of this communication was published in Quart. Journ. Geol. Soc. No. 87, p. 320, by order of the Council.)

3. REMARKS upon the INTERVAL of TIME which has passed between the Formation of the UPPER and LOWER VALLEY-GRAVELS of part of ENGLAND and FRANCE; with Notes on the Character of the HOLES bored in ROCKS by MOLLUSCA. By A. Tylor, Esq., F.G.S.

The elaborate examination of the Quaternary deposits made by Mr. Prestwich has induced that geologist to divide the valley-gravels into upper and lower, which are supposed to be separated from each other by a considerable interval of time.

There is much similarity in these deposits, although separated for purposes of classification by Mr. Prestwich; for the organic remains are nearly identical, and the human implements found in both (made of roughly chipped flint) are of the same general character. Mr. Prestwich argues that although the upper valley-gravels are at a

* The following are the chief works on Lake Superior Mine:

- J. D. Whitney, 'The metallic weight of the United States.'