

| | No. 20 |
|---------------------------------|------------------------|
| Cl | 3.4564 grams per liter |
| Ca | 1.5523 |
| Na (computed) | .45 |
| Sum | 5.46 |
| Total solids ¹ | 7.850 |
| Whence | |
| Ca : Cl = | 0.45 |
| Na : Cl = | 0.13 |

On the 13th level we had tests of a sample of wet mud (No. 21) and of a (No. 22) water from a pool 50 feet on under drops from the roof that showed a refraction equivalent to Sp. Gr. 1.10 which is about what the analysis calls for

| | No. 21 | No. 22 |
|---------------------------------|------------------|------------------------|
| Cl | .1879 milligrams | 59.556 grams per liter |
| Ca | .0933 | 28.560 |
| Na (computed) ... | | 93.8 |
| Sum | | 126.25 |
| Total solids ¹ | | 153.9 |
| Whence | | |
| Ca : Cl = | 0.496 | |
| Na : Cl = | 0.08 | |

It is quite clear that whereas No. 21 is pretty nearly the pure type of lowest water, the others are mixed.

GLOBE EXPLORATION.

The Copper Range Company took an option on this land the next mile south of the Champion. The overburden was heavy (356 feet). While the diamond drill is said to have shown encouraging copper values, exploration to a depth of 1000 feet showed so little that the option was surrendered. Three small samples were sent by Agent F. W. Denton, April, 1908.

¹At 110°C, including crystal water.

| No. | 1 | 2 | 3 |
|-----------------------|-----------|-----------|------|
| Location | 6th level | | |
| Depth | 855 | only 4 cc | |
| | 625 | | |
| Cl | 3.55 | 6.0 | |
| Ca | 2.? | 2.26? | 1.8? |
| Ca : Cl | 0.56? | | |
| Sp. Gr. by J. W. Holm | 1.004 | | |
| Sp. Gr. by urinometer | 1.008 | | |
| Index of refraction | 1.56 | 1.59 | |

Challenge exploration of St. Mary's Mineral Land Co. (Fig. 59.) The Challenge mine at the 3rd level at about 700 feet from the surface is distinctly saline.

The index of refraction is also distinctly greater than that of pure water, and corresponds to a specific gravity somewhere about 1.015. The sample was not, however, so taken as to be free from possibility of urine contamination.

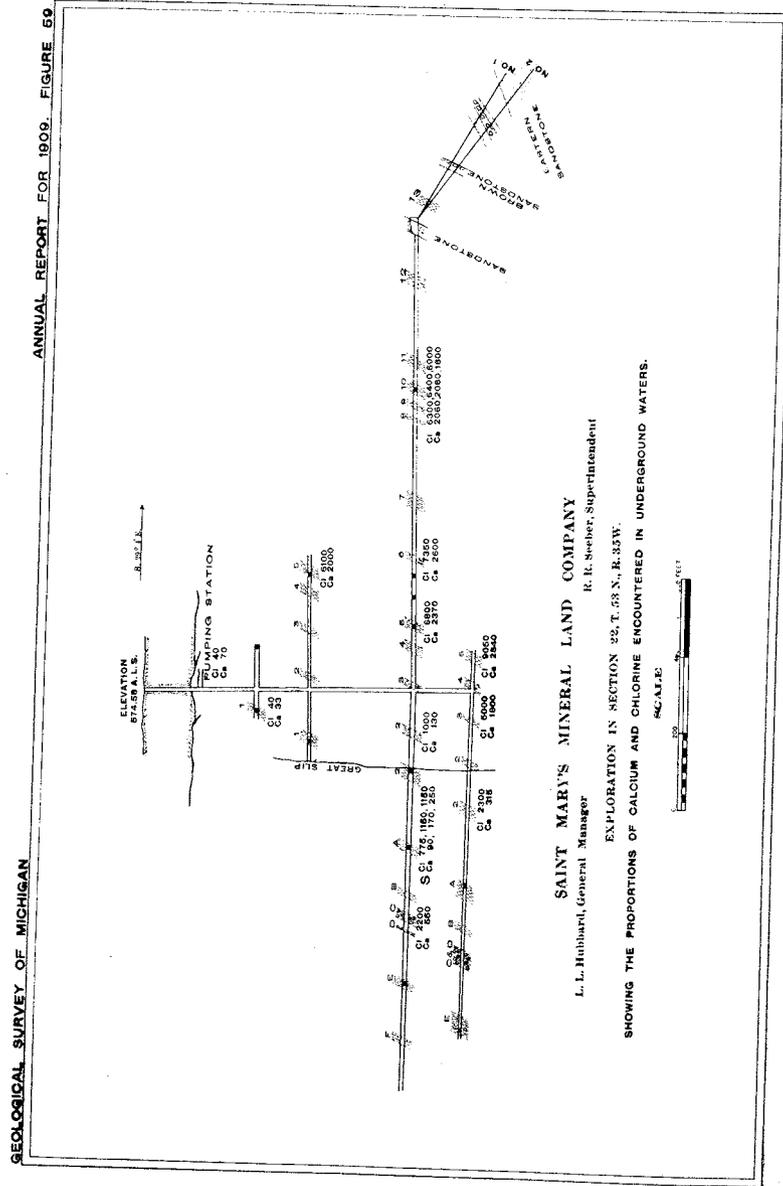


Fig. 59. Challenge exploration of St. Marys Company with the concentration of the mine waters plotted thereon.

A sample, very salt, from No. 9 vein east cross-cut had Sp. Gr. 1.009 to 1.012

| | | | |
|--|--------|--------------------------|--------|
| Cl..... | 6.600 | | |
| Ca..... | 2.882 | Ca Cl ₂ | 7.881 |
| Alkalinity as Ca CO ₃ | .004 | Ca CO ₃ | .004 |
| SO ₄ | .080 | Ca SO ₄ | .120 |
| Na (computed)..... | 1.010 | Na Cl..... | 2.569 |
| | | | <hr/> |
| | 10.576 | | 10.574 |

Total solids (ignited)... 10.362

Ca : Cl = 0.437

Na : Cl = 0.149

No. 7 vein in the east cross-cut gave poor field tests Cl 3.48+?

F. B. Wilson found Ca .232+ (?2.32)

refraction equivalent to Sp. Gr. 1.015

This agrees well with a later test, but is not on the Baltic lode perhaps. (See Fig. 59.)

Dr. M. L. Holm, State Bacteriologist, kindly made additional tests of the Challenge explorations. His report follows.

Lansing, August 31, 1908.

Laboratory Dept.

Dr. Alfred C. Lane, State Geologist, Lansing, Michigan:

Dear Doctor—In submitting this report on the series of mine waters received August 28th, it will be necessary to outline briefly the methods employed in the analysis, in order to make these results intelligible for your interpretation.

These samples, consisting of from 10 to 25 cc. each, would not permit the use of any of the standard methods of analysis, as we have no standard methods adaptable to so small a quantity. It therefore became necessary to devise special methods for this particular series in order to get the greatest possible accuracy with the least possible quantity of water, since only such very limited quantities were at hand.

The chlorides, reported in terms of Cl., were determined as follows,—50 cc. of distilled water was placed in a 200 cc. flask and carefully sensitized, K₂CrO₄ indicator was added and 2 cc. of the mine water was run in from a carefully graduated pipette. This was then titrated with a standard solution of AgNO₃. If the 2 cc. did not require sufficient quantity of standard solution to permit of accurate reading, more mine water was added in 2 cc. quantities until sufficient was used to allow for a fairly accurate reading.

In cases where the limited quantity of water was not sufficient to require an amount of standard solution for reasonably accurate reading, the quantity of chlorine was reported as "trace."

The H_2S was next determined by placing a drop of the mine water on a filter paper prepared by moistening in a 10% solution of lead acetate and dried. Where sufficient H_2S was present to produce a distinct brown color of PbS , the H_2S was designated as plus (+), and as the color deepened, more plus signs were used to indicate the increased quantity. Where no coloration of the PbS paper occurred, the H_2S was designated as minus (-). Several of these waters contained an appreciable quantity of precipitated sulphur and yet no H_2S . It is probable in these cases that the sulphides had decomposed.

The water samples were next acidified with HNO_3 to dissolve all calcium present as carbonates, and filtered. A carefully measured quantity, ranging from 5 to 20 cc. in each case, or as much as the size of the sample would permit, was then taken, made alkaline with NH_3 and precipitated with $NH_4C_2O_4$. This precipitate, of course, would bring down, together with the calcium, any quantity present of iron and aluminum. The last two named elements would, of course, not appreciably affect the results where the quantity of lime was large, but where the quantity of lime was found to be very low, the interference of these elements, iron and aluminum, must be considered in interpreting the results. The precipitate was next carefully washed with distilled water and titrated with $\frac{N}{10}$ $KMnO_4$. After the titration, 10 cc. of 5% $KSCN$ was added, and where sufficient quantity of iron was present to give a distinct coloration, the same was determined colorimetrically, as shown in the report. Where sufficient quantity of iron to give distinct coloration was not present, iron was designated as minus (-).

The following is the report on the various samples of water submitted with their findings:

| | Chlorine. | Calcium. | Hydrogen Sulphide. | Iron. |
|---|------------|-----------|--------------------|--------|
| | parts per | million | | |
| Challenge mine. | | | | |
| No. 406, Pump Station..... | 40.000 | 70.000 | — | — |
| Depth No. 407, 1st level, 1st vein..... | 40.000 | 33.000 | + + | — |
| No. 408, 2nd level, 5th vein..... | 6,100.000 | 2,000.000 | + | — |
| No. 409, 3rd level, veins C & D..... | 2,200.000 | 550.000 | — | — |
| No. 410, 3rd level, 1st vein. Drift S. No. 3 x cut..... | 775.000 | 90.000 | + + + | — |
| No. 411, 3rd level, 1st vein, No. 1 x cut South..... | 1,150.000 | 170.000 | + + | — |
| No. 412, 3rd level, 1st vein..... | 1,150.000 | 250.000 | + | — |
| No. 413, 3rd level, 2nd vein..... | 1,000.000 | 130.000 | + + + | — |
| No. 414, 3rd level, 5th vein..... | 6,800.000 | 2,370.000 | — | — |
| No. 415, 3rd level, 6th vein..... | 7,350.000 | 2,600.000 | — | — |
| No. 416, 3rd level, 9th vein..... | 6,300.000 | 2,060.000 | — | — |
| No. 417, 3rd level, 10th vein..... | 6,400.000 | 2,080.000 | — | — |
| No. 418, 3rd level, 11th vein..... | 6,000.000 | 1,800.000 | — | — |
| No. 419, 4th level, 2nd vein..... | 2,300.000 | 315.000 | — | — |
| No. 420, 4th level, 3rd vein..... | 5,000.000 | 1,800.000 | — | — |
| No. 421, 4th level, 4th vein..... | 9,050.000 | 2,840.000 | — | — |
| Winona mine. | | | | |
| No. 422, 4th level, No. 3 shaft..... | Trace | 160.000 | — | 5.000 |
| No. 423, 5th level, 3 Shaft S..... | 2,050.000 | 260.000 | + | 3.000 |
| No. 424, 6th level, 3 Shaft N..... | 100.000 | 120.000 | — | 10.000 |
| No. 425, 7th level South..... | 225.000 | 106.000 | — | — |
| No. 426, 8th level S. 3 Shaft..... | 125.000 | 320.000 | + | 6.000 |
| No. 427, 9th level S. 3 Shaft..... | 250.000 | 106.000 | + + + + | — |
| No. 428, 10th level S. 3 Shaft..... | 300.000 | 120.000 | + | 10.000 |
| No. 429, 3rd level N., 3 Shaft..... | Trace | 53.000 | — | 1.000 |
| King Philip Mine. | | | | |
| No. 430, 5th level, No. 1 Shaft..... | 406.000 | 120.000 | + + | 5.600 |
| No. 431, 6th level, No. 1 Shaft..... | 900.000 | 260.000 | — | — |
| No. 432, 7th level..... | 2,850.000 | 853.000 | — | 1.300 |
| No. 433, 8th level, No. 1 Shaft..... | 15,250.000 | 6,820.000 | — | — |

Respectfully,

M. L. HOLM, M. D., Bacteriologist.

F. W. SHUMWAY, M. D., Director.

Very noticeable here is the fresh water found near the great fault, nearly a strike fault, shown in Figure 59, which is thought to have displaced lodes A and 1, while the other veins 3 to 11 have about 6 per thousand of chlorine and perhaps show the normal salinity. Evidently, however, even at this moderate depth we have the middle and not the upper waters. The lodes 3, 4, 5 and 7 all showed some copper, almost an encouraging amount.

The following are some additional field tests (not reliable). The Nonesuch mine water in September, 1908, has about .016 Cl., .043 (Ca Mg), .065 CO_2 when Iron River just above, not leaking in had .029 Cl., .030 (Ca Mg), .045 CO_2 .

SURFACE WATER.

These above are mine waters proper. In my annual report for 1903 and in Volume XIII, Proc. L. S. M. I., will be found many analyses of surface waters which have an interest in discussing the

problem of circulation. We need not repeat them all here. From them I derived as a normal surface water analysis in the copper country, in grams per liter.

| | |
|---|--------|
| Cl | 0.0035 |
| Ca | 0.019 |
| Mg | 0.004 |
| Na | 0.0023 |
| Si O ₂ | 0.010 |
| CO ₃ | 0.040 |
| SO ₄ | 0.006 |
| (Fe Al) ₂ O ₃ | 0.0015 |
| | 0.0863 |

WATER FROM DRILL HOLES AND WELLS.

In a few cases (more of late) samples been obtained from flowing and other drill holes. They are, of course, free from mine contamination.

Freda. Dr. Koenig also made some tests of the water of a deep well put down in the Freda sandstone at Freda by the Copper Range Co., which, with the record of the well, are given in the 1903 annual report, page 165. It is worth remembering that this is by the side of Lake Superior, five or six miles from the traps of the main copper range in the formation which I have concluded to call the Freda sandstone, the western sandstones of some writers, the Upper Keweenawan of Irving. The well all the way down was in red sandstones, red clays, and fine grained conglomerates, with a good proportion not only of felsites but of grains of more basic rocks. Computing the figures in ions we have:

| | |
|----------|-------------------------|
| Cl | 40.42 |
| Na | 7.60 |
| Ca | 16.04 |
| Mn | .57 |
| Mg | .03 |
| K | .30 |
| Br | .21 to .35 ¹ |
| | 65.17 |

Na : Cl = 0.173

Ca : Cl = 0.396

Sp. Gr. 1.051 or 1.049

¹Midland Chemical Co.

It is worth noting that the much deeper wells at Lake Linden in the Jacobsville sandstone are not reported to have struck any salt water and the analyses (1903 report, pp. 163-164), show only a few. 52.69 parts per million of salt (sodium chloride). It is said, however, that the 1200' well at Grand Marais struck salt water and calcium chloride springs at Whitefish Lake are described in the report for 1908, page 18.

A well at Pickford put down in 1907, which reaches down into the Potsdam sandstone and has a heavy flow of water below 1,000 feet, probably at about 1,400 feet, gave Prof. F. S. Kedzie

| | |
|----------------------------------|--------|
| Na Cl | 0.5148 |
| Ca CO ₃ | 0.2029 |
| Ca SO ₄ | 0.075 |
| Mg CO ₃ | 0.0038 |
| Si O ₂ | 0.0072 |
| Difference | 0.061 |
| Total mineral constituents | 0.9647 |

| | | |
|-------------------------|-------|------------------|
| This would give us | 1 | 2 |
| Cl | 0.320 | .304 |
| SO ₄ | 0.053 | .120 to 50 |
| | | .167 |
| Ca | 0.103 | |
| Mg | 0.030 | .072 |
| CO ₃ | 0.196 | Hardness .115 to |
| Si O ₂ | 0.007 | .321 |
| Na | 0.195 | |

Field assay tests on a nearly similar sample gave the results of column 2.

A drill hole (No. 10) put down by the Calumet and Hecla (Fig. 36) was very soft. Tests gave

| | | | | |
|-----------------------|--------|-------------|-------|---------------------------------|
| Cl..... | 0.016 | say | .0257 | Na Cl |
| Ca..... | 0.0126 | say | .0334 | Ca CO ₃ |
| Na..... | 0.014 | requiring | .0009 | Na CO ₂ or silicate? |
| SO ₃ | tr | trace | | Na ₂ SO ₄ |
| | Ca | : Cl = 0.79 | | |
| | Na | : Cl = 0.87 | | |

This is a characteristic upper water as there is not enough chlorine to combine with the sodium, to say nothing of the calcium, yet after all it is so weak that we can not suppose the middle waters made by a mixture of it and the lower water. It is notable

that in presence of sodium in excess the amount of calcium carbonate is just above that of saturation when no bicarbonate is present.

On the other hand a salt water has just been struck in South Lake drill hole No. 2, Section 31, T. 51, R. 37, which is said to have deposited copper on the rods. It came from shortly above 2348 feet depth. It gave Dr. Koenig the following results:

| | |
|--------------------------------------|--------|
| Ca Cl ₂ | 11.66% |
| Na Cl | 1.24 |
| Fe ₂ O ₃ | tr |
| SO ₄ | tr |
| Mg | 0 |
| Sp. Gr. | 1.1097 |

Whence

- Cl = 84 per thousand
- Ca = 42
- Na = 5
- Na : Cl = 0.084
- Ca : Cl = 0.50

This is a pure lower water in ratio, diluted perhaps by some remnant of the water used in drilling.

Near by, Belt mine drill hole No. 5 flowed freely nearly one cubic foot a minute (T. 45° F.) and the flow is probably below 127 feet, between 112 and 180 feet vertically. There was found

| | |
|-------------------------------------|-------|
| Cl | 0.264 |
| SO ₄ | 0.082 |
| Hardness as Ca | 0.024 |
| Alkalinity as Ca | 0.010 |
| With CO ₂ | 0.015 |
| Alkalinity as Na ₂ | 0.014 |
| With CO ₂ | 0.018 |
| Ca : Cl = 0.01— | |

Its softness relative to the chlorine is characteristic of the top of the middle water which is evidently high.

A well in the Freda sandstone, I believe, put down by the Greenwood Lumber Company at Green, west of Ontonagon, only 1000 feet from the shore of Lake Superior and 100 feet above it yielded it is reported

| | |
|--------------------------|-----|
| Na Cl | .06 |
| Ca Cl ₂ | .04 |

This like the Freda well is so related to the main range that one might expect artesian conditions which might force (in case fissures were present) salt water up from the underlying Keweenawan. Mr. Weidman also informs me that the salt water reported by A. R. Schultz from the "Potsdam" at Osceola¹ is really from the underlying Keweenawan. Whether the salt licks such as are listed in my report for 1908 derive their salt always from cross-fissures and are thus a sign of faults remains to be seen. They indicate something abnormal. For instance, Union Springs in the Porcupine Mountains has only 3 milligrams per liter chlorine and about 45 of CO₂ but not far off on Section 22, T. 51 N., R. 42 W. is a salt lick.

§ 6. WIDE SPREAD CHARACTER OF THE CALCIUM CHLORIDE WATERS.

We have already called attention to the fact that calcium chloride water occurs not only throughout the Copper Country, in the iron country, in all the ranges and at Whitefish Lake and Pickford which is at the eastern end of the Upper Peninsula, but they are world wide. Numerous analyses of such waters will be found cited in my previous papers. I give as examples here one or two which came to my attention in the current year (1909). Dr. M. L. Holm made for me an analysis of the Fischer well, Mt. Clemens as follows, in grams per liter.

| | |
|------------------------------------|---------|
| Fe | .002 |
| Al | .182 |
| Mg | 4.481 |
| Na ² | 34.338 |
| NH ₄ | .103 |
| Cl ³ | 94.785 |
| SO ₃ | .585 |
| S | .304 |
| CO ₂ ⁴ | .126 |
| Ca ⁵ | 16.4 |
| Sp. Gr. at 15.5° C. | 1.11 |
| <hr/> | |
| Ignited solids | 148.380 |
| Ca : Cl = .174 | |

This may be combined for geological purposes as follows:

¹U. S. G. S. Water-Supply Paper 114, p. 240.
²Including potassium, but this was very low.
³Bromine 0 by comparison of gravimetric and volumetric tests.
⁴Directly determined, being precipitated as lime water.
⁵Strontia 0.

| | | Molecular proportion. | |
|--|--------|-----------------------|--|
| Fe H ₂ (CO ₃) ₂ .. | .006 | .000035 | |
| Al ₂ Cl ₆ | .893 | .00335 | |
| Mg Cl ₂ | 19.052 | .200 | |
| Na Cl | 87.263 | 1.493 | |
| NH ₄ Cl | .305 | .057 | |
| Ca Cl ₂ | 39.981 | .3515 | |
| Ca SO ₄ | .809 | .0061 | |
| Ca S | .684 | .0095 | |
| Ca H ₂ (CO ₃) ₂ .. | .162 | .0010 | |
| Ca O ₂ H ₂ | 3.100 | .0419 | |
| | | 151.275 | |
| Substract Volatile solids | | | |
| H ₂ S | .323 | | |
| NH ₄ Cl | .305 | | |
| CO ₂ | .092 | | |
| H ₂ O of Ca O ₂ H ₂ | .755 | 1.509 | |
| | | 149.766 | |
| Result | | | non volatile |
| with | | 148.38 | solids? to be compared actual residue |

It is possible that a little Na Cl goes over on ignition, but there is also oxidation of the iron and alumina and transfer of any chlorine supposed to be combined with them to the calcium and probably other changes to be allowed for. It seems to me probable that a perfectly fresh deep-seated water of this type would contain enough S to convert all the calcium hydrate shown to calcium sulphide. The H₂S escapes in bubbles as the water rises in the well, leaving an alkaline water. While this water contains calcium chloride, however, it differs widely from the Copper Country waters, and notably in the greater amount of magnesia and sulphur contained. In Chapter IX will be found references to analyses of calcium chloride from Chili, from New Jersey and from Germany.

§ 7. GASES IN ROCK AND WATER.

The only scientific investigation of the gases in the rocks and mine water is that of R. T. Chamberlin¹ who found that on heating the core at 524 feet, Franklin Junior drill hole No. 3 there was driven off

¹Gases in Rocks (1908) pp. 20, 33-34.

| | H ₂ S | CO ₂ | CO | CH ₄ | H ₂ | N ₂ | O | Ratio volume of gas to volume of rock. |
|------------------------------|------------------|-----------------|------|-----------------|----------------|----------------|---|---|
| First heat..... | 0.00 | 1.31 | .09 | .09 | 2.34 | .05 | 0 | 3.88 |
| Second heat six months later | 0.00 | 1.33 | 0.08 | 0.03 | 0.43 | 0.05 | | 1.92 |
| Third heat one week later... | 1 | 0.53 | 0.12 | 0.00 | 0.12 | 0.02 | | 0.79 |

These gases Chamberlin thinks are partly due to reactions in heating, of ferrous minerals and those containing water, partly to occlusion or possibly decomposition of carbides, very little to inclusion in actual cavities. But it is worth noting that inflammable gas was found in the Silver Islet vug and in the Tamarack Junior mine water, and that on unwatering the Old Delaware mine a gas explosion took place.

Moreover, Capt. W. Wearne told me that on unwatering the old National mine in Ontonagon county at about the 40th level he was burned from a pocket of gas in the roof of a stope and that there was some gas in the old St. Clair when the Phoenix opened it up, but he had never seen gas in a new mine, and that in unwatering an old mine there was always a water line marked on old stopes and drifts showing where gas had been confined above the water. My general impression would be that the gas was produced from the reaction of water on the rock, most likely on the ferrous salts therein.

§ 8. DISCUSSION.

No one can be more painfully conscious than I of the uncertainties of all the mine water work. Uncertainties that arise from human contamination seem not to be as serious a source of error as I feared but account for certain discrepancies. Uncertainties, also, arise from defects in analyses and evaporation of the small samples which alone it was practical to take. But the greatest source of error may be the circulation which is consequent on the mining operations themselves. We can never be sure that we are dealing with the water that belongs at a given level and lode and not water that may have followed down recently from above on the one hand or come in from the wall rock on the other hand. In fact as we go through a copper mine the damp places where there is real dripping are the exception. Had I but realized sooner that by soaking the rock one can get a solution strong enough to analyze we could have had better systematized results. As it is, I place very little reliance on any particular sample of water being characteristic of the bed in which it is supposed to occur or the exact

depth at which it is supposed to come. While the summary of results given in § 2 above will be found, I think, firmly established by the mass of evidence, yet there are interesting points that need farther investigation.

In these copper mine waters, beginning at the top, we see a prompt and practically complete elimination of the magnesia which we found in other regions in the chloride and in the surface waters. This may be associated with the occurrence of secondary chlorite, replacing even felsite in the Calumet and Hecla boulder and other secondary minerals like prehnite.

Near the surface and in the zone of vadose, that is circulating, waters, the ratio of lime to chlorine is very irregular, sometimes high and sometimes low. See, for instance, the upper analyses at the Winona, etc., by Dr. Holm. This is, however, only where the chlorine itself is very low and we presumably have a mixture of hard surface water. As we get to the bottom of the circulating waters, however, the ratio gets low, not merely because the chlorine is greater but because the lime is less. See, for instance, the analyses from the Tecumseh and South Kearsarge. This may be due to the fact that we are free from the influence of water percolating through calcareous drift, or it may be due simply to the less solubility of carbonates than bicarbonates, the extra carbonate molecule being lost in presence of sodium silicate, precipitating calcite and silica, leaving sodium carbonate in solution. The alkaline reaction of some of the waters suggests this.

But then, rather suddenly as we strike the middle water, sometimes as in the Baltic lode close to the rock surface, again as in the Franklin Junior, as deep as the 17th level, we find the concentration and calcium to chlorine ratio both rising suddenly. Within a few hundred feet the ratio Ca : Cl becomes over 0.4, but thereafter it rises but little and I doubt if it ever exceeds 0.49, the few analyses which go more than that being perhaps inaccurate. The ratio 0.483 which is just the ratio which would indicate a salt Ca_2NaCl_7 is approached within the limit of accuracy (when we consider that Br is often included with chlorine and is often over one per cent of the latter) in a great many cases. But I can find no reference to any such salt or any solution of this constant composition, either in Van Hoff or Hahn, nor any known chemical reason why the calcium chloride water might not be stronger. Indeed Hahn's tests on evaporation brines point to a practically complete elimination of the sodium where the calcium magnesium chloride solution reaches a concentration of about 370 per thousand. So we

are thrown back upon the supposition that this ratio was that of the connate water that pervaded the formation. But is this proportion inherited from an early ocean? I once thought so, but this could not be if the Keweenaw was a land formation.

Is it due simply to a tendency to equilibrium in presence of the containing rock?

Then should it not vary more than it does in soda and lime melaphyres, and sandstone and conglomerate? There is, to be sure, some sign of difference here and perhaps a slow ionic migration tending to bring all the water to the composition which is in equilibrium, will account for the facts. Or are we to look to some Keweenaw "Great Salt Lake" which determined the ratio?

As to circulation producing these waters (1) the surface waters pick carbon dioxide near the surface and after they have dissolved enough to satisfy these acid radicals, they are soon saturated, and have relatively little solvent power further. It increases, of course, slowly as they warm up, and they might attack silico-chlorides in glass. But analyses of hot springs of circulating water show no such percentage of salt as we have here.

Against the idea that downward working surface waters pick up sodium chloride to become salt, and then later add calcium chloride we have independent of chemical arguments two lines of facts. The order of attack of the traps, as microscopic thin sections show, is that lime and magnesia minerals are earlier attacked than those containing sodium and moreover, the hydrous lime secondary minerals, like prehnite, epidote, and laumontite precede the sodium minerals, which are confined to the upper levels.

(2) No simple upward circulation of the calcium chloride water can explain the facts, for water cannot dilute itself. Suppose, however, we assume that there are two types of water concerned, one buried with the strata and that there has also been water circulating or sucked in from the surface, we still have a number of different possibilities to consider.

(3) How far have the waters been concentrated by hydration, absorbing part of the water and leaving the rest stronger? This is certainly a factor, as the computations of Chapter II, pp. 84-87, show quite plainly.

(4) How far can the excess of sodium in the middle waters be accounted for by supposing that the upper circulating waters toward the lower range of their action not only dissolved more, but lost more by hydration thus producing a stronger water, which mixed with the lower waters might account for the middle waters?

A study of the analyses even at several hundred feet depth of waters like those at the Medora shaft Kearsarge No. 21, etc., shows that so long as there is really active circulation, absorption of the water by the rock does not tend to increase the strength half so much as actual solution of rock material. The waters change in composition, bicarbonates becoming less, chlorides more important, sulphates going in and out but remaining very fresh compared with the deeper type. Even in much reddened and hydrated rocks the waters are fresher rather than stronger. Compare those of Isle Royale, Section 12 with those of the Superior mine nearby.

(5) How far are the middle waters to be explained by ionic migration, the sodium silicate or carbonates of the upper circulating water zone being caught by the calcium chloride and precipitated as calcium silicate or carbonate while the sodium chloride remains in solution?

This is certainly a factor of importance. Yet it seems to me that if this were all, the border line between the fresh circulating, and the deeper waters would be sharper than it is. We should have calcium silicate common instead of rare. For the calcium aluminum hydrous silicates actually formed we must look to reaction with the rocks as shown in § 2.

The theory that explains all the facts seems to me more complex. It assumes original (connate) water and circulating (vadose) water, and it assumes that both are sucked in and react with the rock and with each other. As one of the products of these reactions is copper, further discussion may be put off to the next chapter.

CHAPTER VIII.

THE FORMATION OF COPPER.

§ 1. THE ARTIFICIAL PRODUCTION OF COPPER.

It will be convenient to repeat here a brief account of some experiments by Dr. G. Fernekes then of the Michigan College of Mines, now of Pittsburg, in which he succeeded in forming copper from chloride solutions such as the mine waters.

DR. FERNEKES' EXPERIMENTS IN ARTIFICIAL PRODUCTION OF COPPER.

These he has already described.¹ We may sum up his work, modelled after Stokes,² in a diagram as follows:

| | | |
|--|---|--|
| | | To water in sealed tube were added |
| Cold water jacket around upper end. | 18-inch tube of glass filled with water and sealed. | Solution of ferrous chloride FeCl_2 nearly neutral with sodium carbonate. Few crystals potassium bromide K Br. .2 gram cuprous chloride Cu_2Cl_2 5 grams calcium hydrate CaO_2H_2 or " carbonate CaCO_3 or " silicate Ca SiO_3 or prehnite $\text{H}_2\text{O}, 2\text{CaO}, 2\text{Al}_2\text{O}_3, 3\text{SiO}_2$. or datolite " " , $\text{B}_2\text{O}_3, 2\text{SiO}_2$. in fine powder. |
| Lower end in sand both at 200° C. to 280° C. | | |

Dr. Fernekes then describes the following reactions as taking place.

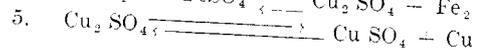
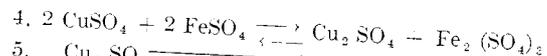
| | | |
|-------------|---|-------------|
| hotter end. | $1. 2 \text{FeCl}_2 + 2 \text{CuCl}_2 = \text{Cu}_2\text{Cl}_2 + 2 \text{FeCl}_3$ $2. 2 \text{FeCl}_2 + \text{Cu}_2\text{Cl}_2 = 2 \text{Cu} + 2 \text{FeCl}_3$ $3. \text{FeCl}_3 + 2 \text{H}_2\text{O} = \text{Fe}(\text{OH})_2 \text{Cl} + 2 \text{HCl}$ | cooler end. |
|-------------|---|-------------|

Now in Stokes' experiments in unequally heated solutions like this sulphate instead of chlorides were used,³ so that his equations were:

¹Economic Geology, 1907, pp. 580 ff (II, No. 6, Sept.-Oct).

²Economic Geology, 1906, pp. 644 (I, No. 7, July-August).

³Economic Geology, 1906, p. 644 (I, No. 7, July-August).

hotter
end.cooler
end.hotter
endcooler
end.

There is another experiment by Stokes¹ of interest to us, to-wit:

hotter
end.cooler
end.

We may apply this to the silver which we find most in the upper levels on, and later than, the copper. While silver chloride is quite insoluble it is soluble enough in these strong chloride solutions for the following reaction slowly to go on.

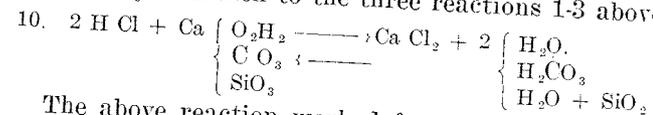
hotter
end.cooler
end.

Now, as Dr. Fernekes remarked, the copper shown in equation 2 did not appear as such (because it would be attacked and re-dissolved by the HCl set free by reaction 3) until a neutralizing agent was added (eq. 10).

Possibly in nature electric currents or very great length of tube and slow action might take the place of such an agent, but there was one obvious reaction suggested by the geological conditions we were trying to imitate. (In nature the copper is persistently associated with calcium carbonates or silicates and often deposited on corroded surfaces of calcite.) This was the neutralization of the acid (HCl). This was successful, first with calcium hydroxide CaO_2H_2 , then with CaCO_3 , then with calcium silicate in the form of powdered wollastonite. Copper was deposited within 10 to 15 minutes heating at 200°C . Complete precipitation took a longer time.

Sodium carbonate was also used.

We may add then to the three reactions 1-3 above one more.

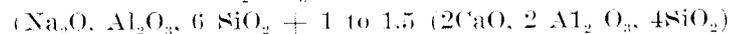


The above reaction worked freely and rapidly; the copper came down in a fluffy mass.

¹Loc. cit., p. 650.

To obtain it crystallized it seemed natural to use a less soluble neutralizing agent. The following minerals occurred to me from the geological conditions as especially worth trying:

Labradorite $\text{Ab}^1 \text{An}^1$ to $\text{Ab}_2 \text{An}_2$



Prehnite, $\text{H}_2\text{O}, \text{Al}_2\text{O}_3, \text{SiO}_2 + 2 (\text{CaO}, \text{Al}_2\text{O}_3, \text{SiO}_2)$

Laumontite $4 \text{H}_2\text{O} (\text{CaO}, \text{Al}_2\text{O}_3, 4 \text{SiO}_2)$

Datolite $\text{H}_2\text{O}, 2 \text{CaO}, \text{B}_2 \text{O}_3, 2 \text{SiO}_2$

Pectolite $(\text{Ca}, \text{Na}_2\text{H}_2) \text{SiO}_3$

Analcite $2 \text{H}_2\text{O} (\text{Na}_2, \text{Ca})\text{O}, \text{Al}_2\text{O}_3, 4 \text{SiO}_2$

Labradorite and laumontite gave no results. As a matter of fact neither are intimately associated with copper, the labradorite occurring in the fresh unaltered trap, and the laumontite, though a secondary zeolite, being notoriously a bad sign for copper, though at times pseudomorphs of copper after laumontite do occur.

On the other hand prehnite and datolite both gave positive results, and both frequently occur in nature colored pink with finely divided copper. Capt. J. Vivian had a wonderful collection of flesh colored datolites. Datolite nodules are often coated with copper.

The tubes were heated intermittently, for 10 hours a day, the heat removed in the evening, and again applied the next morning.

After heating the solution and prehnite in this manner five days an explosion took place at about 250°C . A portion of the side of the tube about 5 cm from the bottom that is *at the hotter end*, was blown off, leaving a cake of mineral underneath, which could be seen under a hand lens to be interspersed with shiny particles of crystalline copper. That they were such was proved by tests.

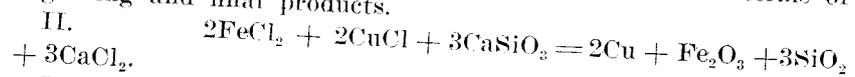
The prehnite had become much darkened, and the particles of the mineral were *stained red with iron oxide*.

Datolite was acted on in a similar manner for six days at the end of which time minute crystals of copper could be detected throughout the mass of the mineral.

It is profitable to consider the reactions from the point of view of electro-chemistry and ionic dissociation. There is this extra justification for this that experiments by J. M. Longyear and W. W. Stockly have shown measurable differences of electric potential near lodes, and abnormal magnetic variations are not uncommon. In fact from the almost northerly direction of the main shoot of the Calumet and Hecla deposit and the great sensitiveness of copper to electricity it has been suggested that certain electric currents were the determining factors in its deposition. There is

some indication not only that the copper in the Calumet and Hecla shoot pitches north, but that other beds beneath are enriched in a band or zone across the formation, whose borders run north and south. The general course of the Calumet and Hecla conglomerate shoot is shown on Plate IX. The west line is nearly north and south as shown, though a rich spot or two has been found outside,—one at 7000 feet in South Hecla. To the south in less than nine miles it changes its character becoming a basic amygdaloid conglomerate, and in one of the Tamarack Junior shafts which mark the other side of the shoot it was only six inches thick and black.

Schematically we may express the reactions above in terms of beginning and final products.



That this reaction, which is only a slight modification of that suggested 30 years ago by Pumpelly is really *schematically* one by which native copper has been formed seems to me almost conclusively proved by the facts:

1. Dr. Fernekes has shown that it actually takes place.
2. The end products are actually the common products of the veins, and the most abundant constituent of the mine water.

It is understood that the calcium or sodium silicate is really in more complete molecules and goes into more complex molecules, and that similarly the ferric iron and silica may go into other molecules like epidote. Finally instead of ferrous chloride there may be some ferrous silicate, for it is important to remember that we combine as end products what are really probably extremes in a chain of reactions that we have to consider, which end products may be a good deal separated in space.

Another interesting series of experiments are those of E. C. Sullivan in Bulletin 312 of the U. S. Geological Survey on the interaction between mineral and water solutions. The points which seem to me of importance are that the feldspars tend to produce alkaline solutions and that orthoclase and a whole string of silicates tend to take copper from its (sulphate) solution. But native copper was not formed nor involved in the reaction, which (and this is of especial importance) goes on only in an alkaline solution.

Another of these Bulletins (49) by Frank K. Cameron and James M. Bell on the action of water and aqueous solutions on soil carbonates is of interest especially in showing the solubility of calcium carbonate in sodium chloride and gypsum, being a maxi-

imum at about 40 grams per liter of Na Cl, being less for greater and less concentrations. This will explain ready migration and solution and precipitation of calcite in the zone of middle waters. Lime is more soluble in sodium chloride than in pure water (Table XL¹) and also it is relatively soluble in hot strong solutions of calcium chloride (Table XLIII, loc. cit.) so that it may readily be precipitated from cooling solutions of the deep waters.

§ 2. REACTIONS OF ROCK AND WATER IN THE KEWEENAWAN.

We have then only slight modifications to make to adapt the results of Fernekes to the conditions under which copper occurs in the Keweenawan rocks, this great series of ancient lavas separated either by originally porous scoriaceous lava tops or agglomerates or ordinary sediments.

Whether deposited beneath the sea or on land is not really essential to the argument. The pores would be filled with water or gas. Chlorides are associated with lavas and enclosed in them is glass.

It seems safe then to assume that some of the conglomerates and some of the amygdaloids were filled with water—and it also seems safe to assume that this water contained some chlorides, even though not so great a ratio as at present. When the next lava flow would come over it it would be heated. But the amount of heat given off at once would be but a small proportion of that which existed in the lava flow, as lava is a poor conductor and quickly chills at the surface while the interior remains hot. In fact one can walk on the surface while yet the interior is so hot that a walking stick thrust into a crack bursts into flames and the cracks produced by contraction and cooling show a dull red heat.

As I have elsewhere pointed out² in case of lava flows 240 feet thick there is some reason to think that it may be 20 or 30 years before consolidation at the center was finished and that it was nearly 10 times as long before the temperature at the center would drop to say 100° C.

In the meantime no doubt many other lava flows might have come. Much of the heat of the lava would probably escape upward, and since the specific heat and heat of evaporation of water is very great, and the diffusivity of lava small, the water in the underlying beds might or might not be turned to steam.

We had then at the close of the Lower Keweenawan period a

¹Of Bulletin 49 above cited. See also Bull. No. 92; The Effect of Water on Rock Powder by A. S. Cushman.

²Annual report for 1903, p. 248. See also Chapter VI § 6.

series of many thousand feet of lavas containing here and there streaks of hot water or vapor. These hot waters attacked the lavas and produced the chlorite and zeolites so characteristic of the melaphyres. The first products of these reactions may take up more room than the original minerals. Olivine changing to serpentine and magnetite Van Hise¹ cites as giving an expansion of 30 per cent. And for a change of augite to chlorite, epidote, quartz, and hematite² an expansion of 8.58 percent is estimated, and most of the changes of the albite and anorthite molecules to minerals of the zeolite group are also changes which produce expansion, though few of them are directly applicable to our problems. But I have given above a change producing copper in which there is no expansion (pp. 84-87).

The net result of this first work must also have been that much of the water was absorbed. The deepest and freshest specimens of the traps are hydrated and chloritic, so that what water remained was relatively stronger in chlorides. There may also have been some exchange of bases, but the older and deeper seated secondary minerals produced by alteration do not contain sodium and in sections of trap from diamond drill cores the feldspar is often quite fresh. The olivine and then the augite alter first. What sodium was absorbed, if any, most likely came from the glass. The chlorine does not come in any of the secondary minerals formed and so must have accumulated and was³ either originally present in the water or in the silico-chloride glasses. But calcium carbonate which is insoluble in hot water, is found everywhere and to all depths and chlorite and epidote are equally wide spread among secondary minerals. Thus since calcium occurs also in the glasses it would not be safe to venture any guess as to the original amount of lime in the connate water from that in the present mine waters except for the curious fact that Ca : Cl does not go much above 0.49.

With regard to the iron and magnesia dissolved at this stage, the iron may have been partly precipitated and may have partly remained in solution as ferrous chloride, since it is ferrous iron that mainly occurs in olivine and augite. If epidote formed, copper might form also, as I have elsewhere shown.

But the magnesium according to T. S. Hunt's reactions⁴ would in the presence of calcium carbonate and silicate be thoroughly reprecipitated as hydrous magnesium and ferrous, more or less

¹Treatise on Metamorphism, p. 388.

²Loc. cit., p. 378.

³Apatite is not recognized in the lavas generally.

⁴Chemical and geological essays, pp. 122, 138.

aluminous silicate. This is so characteristic of melaphyres that green earth (chlorite, diabantite, delessite) has been taken to be an essential constituent. The mine waters, though nearly free from magnesium, may once have contained more in proportion.

The absence of Mg in the mine waters and its tendency to replace all other minerals, even porphyrite pebbles, is one of the well settled factors in the problem. The ratio of calcium to chlorine in the waters may originally have been more or less than that now, since calcium has been taken up from the augite and thrown down again in epidote, etc., except that in the deeper waters it is closely dependent on the ratio of sodium to chlorine and in the waters of the deep mines the ratio of sodium to chlorine was probably about the same since there are no secondary minerals in which sodium or chlorine have been precipitated and little or no sign of any change by which chlorine could be leached. The present ratio must be greater, if anything. So far as hydration has gone on the concentration is likely to have increased unless affected by circulation of fresh water taken in at the outcrop.

The native copper specks found isolated in doleritic streaks or in the center of a heavy trap bed¹ may be accounted for by this primary local decomposition.

But to have valuable accumulation of copper there must be not merely the decomposition of the rock and the concentration of the copper near by but a considerable migration, since the rocks on the average run only something like 0.02% of copper. Unless, therefore, there was a migration of the water it could only take a little from the rocks or add a little to them until equilibrium was established.

It is probably true that in nature the chlorine waters act not merely locally but on a large scale, that there is not only a migration of ions as in a battery fluid but a migration of the fluids which tend to sort and collect the different ingredients, the arrangement being similar laterally and vertically, but differing somewhat according to the temperature and pressure in exact composition. For instance, epidote might be formed in depth where in the presence of a water of corresponding concentration near the surface the oxidation of the iron oxide would lead directly to hematite and red clays. Nearer the surface too there might be more CO₂ and the lime go into carbonates.

Thus surface alterations laterally from the main channel of porosity and the downward succession might be not exactly the same and yet have points of resemblance.

¹e. g. Tecumseh at 164 feet (Box 16).

In Franklin Junior Holes 3 and 4 the various zones are well developed, the highly altered red amygdaloid with calcite amygdules, often brecciated, grading down into hard grey or yellowish green, with quartz and epidote. The feldspathic trap underneath toward the base becomes darker and more chloritic. Clark Bed 13 illustrates the occurrence of copper adjacent to the pervious bed proper. Again in Adventure d 5 at 710 feet the last two inches of the trap just above the conglomerate is heavily charged with copper, and the Nonesuch shales carry copper for some distance above the pervious underlying sandstone which is the lode proper. A shattered zone characterized by irregularity in comparing different sections is just the place along the margins of which copper seems to accumulate, e. g. the Baltic, the Calumet conglomerate and two beds below, the Osceola, the horizon of the Montreal lode, the Pewabic lode.

CONCENTRATION AND MIGRATION.

Cooling after the first stage of immediate reactions must still have gone on and the water enclosed must have shrunk, and if the rocks had already been so much cemented, that as they cooled they no longer settled so as to squeeze the water out, then—since for water the cubical expansion and contraction by change of temperature is greater than for rocks¹—there would have been a tendency to contract within the rock and draw in fresh water at the outcrop.

A drop in temperature of water from 100° C. (212° F.) to 28° C. (82° F.) would mean a shrinking of volume of something like 4 percent while the contraction of rock for the same change would probably be less than 0.4 percent.

If now we assume some porous bed of the Lake Superior basin extending from Keweenaw Point to Isle Royale (say the Allouez conglomerate) to have a length of 60 miles across and the water therein to have contracted equally from both sides as it cooled then the early waters might have shrunk (.04 x 30 x 5280) about 6300 feet on each side. This would not be equal of course all along the outcrop. The relatively fresh water sucked in by this shrinkage would penetrate farther where topographic conditions and greater porosity favored it and then spread laterally. If any part of the formation was filled when buried not with water but with gas the

¹Which is natural as the amount of heat given off in lowering a given volume 1 degree in temperature is about twice as much. Data are given in the Chemiker Kalender.

shrinkage in cooling and condensation would be very much greater.¹

Thus so far as the amygdaloids were buried with the bubbles filled with gas only, and occasional bubbles occur scattered all through quite massive beds of trap, there are tremendous possibilities of absorption. The regularity of this shrinkage and absorption circulation must have been interfered with in various ways. Let us enumerate some of the factors, each of which will be effective only so far as other factors do not interfere.

1. It must have been more extensive in the most porous and pervious beds.
2. But slide faults, seams or slips or pinches or anything that tends to check the continuity of the pervious beds might have checked this circulation.

Some examples are the following. The Central mine vein was good down to the Kearsarge conglomerate, and was stoped up on it. It was barren below. (Figs. 30 to 33) The Victoria mine found barren rock below a fissure which dipped about 45° to S. 10° E. and cut the shaft at the 14th level plat and the 14th level about 200 feet west, dropping the hanging ten feet (Fig. 60). The Nonesuch lode is rich on the upthrow side of a fissure only. The mining men generally report the character of the rock likely to change in crossing a fissure.

There seems to be one factor worthy of special mention. When a bed thickens away from the outcrop, and has but relatively small or thin porous areas at which it reaches the surface the tendency to suction of the upper waters along them will be exceptionally strong if the connections to the surface are kept open.

We have then as our second stage the imbibition of the cooler waters from the surface *which may average several thousand feet* and may be more or less than this according to circumstances. This process must have been very slow as we know from hot springs that heat lingers around such enormous masses of volcanic materials for ages.

Now the coarseness of the crystallization accompanying much of the copper formation points to the action which formed it having been very slow. The large crystals of calcite with copper in them and of copper itself (for instance, the two and one-half inch crystal of copper which Dr. Hubbard has from the Ojibway) are illustrations. Mr. J. B. Cooper tells me that a tooled surface of one of

¹From 200 degrees to 100 degrees for instance it would be something like $\frac{100+273}{200+273} = .71$, something like 30 percent. of its volume. To this must be added its condensation or absorption.

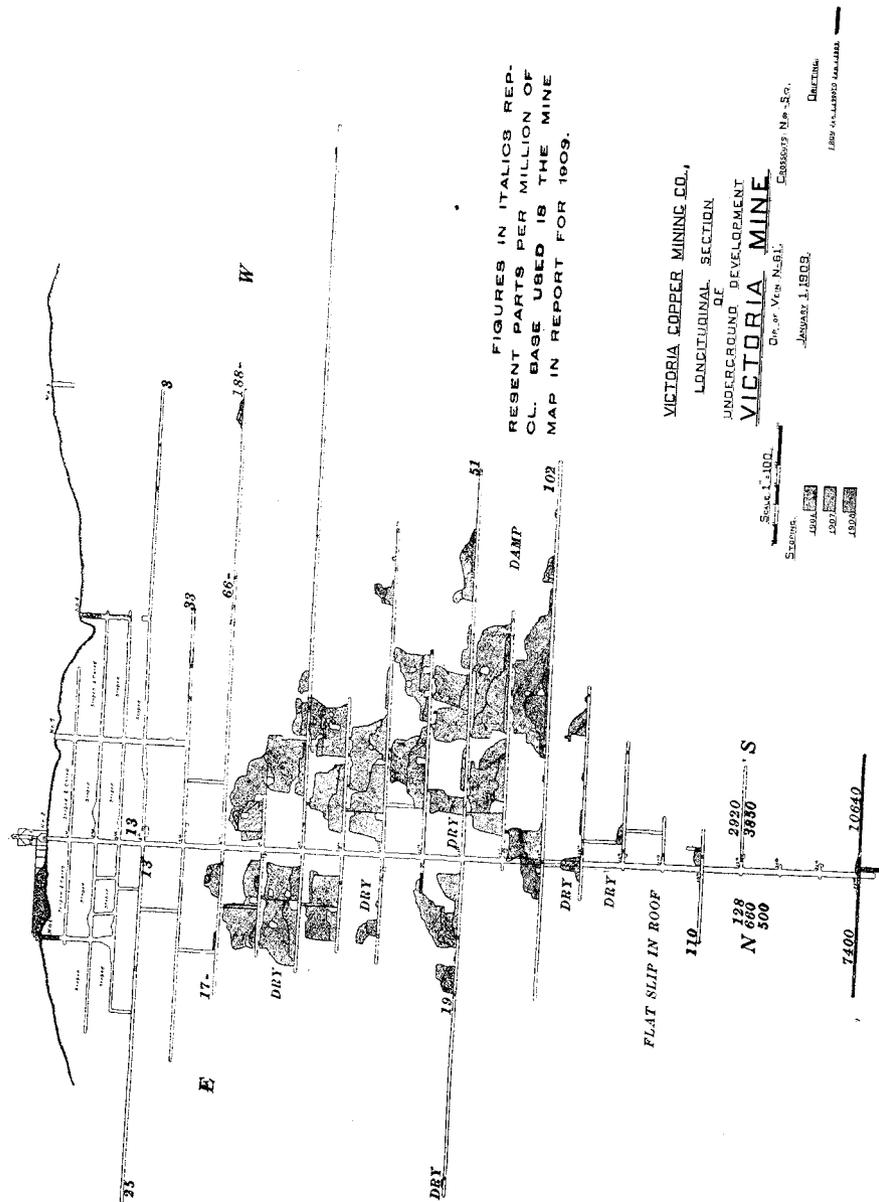


Fig. 60. Geological cross-section of Victoria mine with concentration of mine waters thereon.

the large masses of copper shows the coarse crystallization beautifully, that W. J. Uren once had a surface twenty by thirty inches tooled, and it showed a finer crystallization toward the margin, coarser at the center. This coarse crystallization gives native copper a peculiar density, toughness and hardness to which may be due the notion that the Indians who fashioned instruments of it had some way of tempering copper,—a notion in which Mr. J. T. Reeder, who has a very fine collection of such implements, takes no stock.

One reason why electrolytic copper is not so strong as Lake is that it is usually rapidly formed in minute crystals. If formed in a week it is fine, short and can not be rolled. Were a month used it could be and a year might give the toughness of Lake.¹

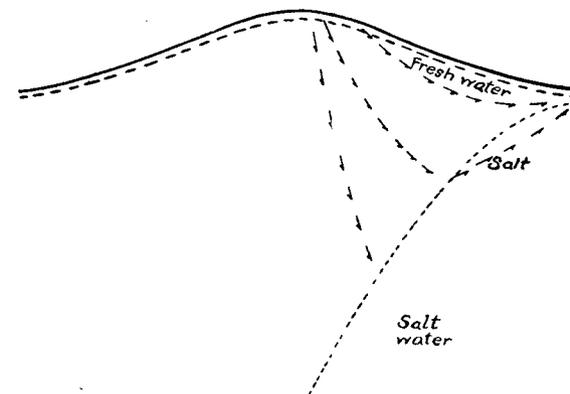


Fig. 61. Theoretical circulation of water from beneath high ground.

And this second stage brings an alteration by descending waters, either (a) the original connate chlorine waters migrating nearer the center of the basin, or (b) the same more or less mixed with waters drawn in from the surface. The pressure will increase. The temperature will increase decidedly when they travel in much faster than the formation is cooling and as underground temperatures always increase slightly, will increase anyway somewhat. Moreover, we must remember that these upper waters will be pulled in in streaks and sandwiched between quarry moisture of the deeper type in the less porous layers, so that we shall have a tendency to lateral reaction and ionic migration between the cooler upper waters in the porous beds, and the hotter, less pervious traps. The tendency for the lode water to be somewhat fresher

¹J. B. C.

than the country rock water (shown by the analyses) is, if not an effect of mine operations, one of the strongest arguments for this theory.

Thus along every pervious channel on its foot and hanging will be contact zones of the upper water against the lower water, and this is precisely what we really find.¹

This slow secular sucking of water on a larger scale may take the place of Fernekes' repeated action of the same sort described above.

In the Keweenawan *igneous* rocks we make out two stages of decomposition as follows:

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

II. Secondary reactions.

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

3. Iceland spar (calcite) and copper formed.

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

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

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

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

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

¹The Osceola lode, an amygdaloid, has always a little copper at the top, then perhaps 30 feet off in the foot again copper, more massive and more irregular.

| Early. | | Late. |
|-------------|--------------|-----------------|
| Laumontite | | |
| Quartz | | |
| Delessite | and chlorite | |
| Epidote | | |
| Prehnite | | |
| Calcite | red | white colorless |
| Copper | | |
| Silver | | |
| Datolite | | |
| Analcite | | |
| Orthoclase | | |
| Apophyllite | | |

Among other minerals whose occurrence is interesting we may note that *powellite* occurred not only in the 14th level of No. 8 shaft South Hecla¹ but in a vein of calcite in the Calumet and Hecla conglomerate five feet from the foot, in the 40th level between Shafts 6 and 7. It came in nests in the calcite in the boulders as well as the matrix. It has been noted also in the rock hoisted from the Tamarack mine with epidote and copper, and President McNair has picked up one crystal of different habit that presumably came from the re-opened Isle Royale, though prolonged search has yielded no more. It seems thus to be,—as one might expect since it is a calcium-tungstate and molybdate (Ca (MoW) O₄—a mineral of the calcium chloride zone. Pumpelly noticed that the secondary sodium minerals were confined to the upper levels, those in which the mine waters are also high in sodium. As farther illustrations may be noted the following occurrences.

Analcite occurs in first vein under the drift in Tamarack 5, and at the surface on Isle Royale, in Osceola 15th level, copper older than analcite, later than natrolite, in Centennial, natrolite, coarse square prisms with copper moulded about it.

Salt crystals (J. Pollard) were found on the 9th level of South Hecla and were quite likely due to evaporation and the product of mining operations. They are interesting, though, as the shallowest indication of salt water at the Calumet that I have.

Capt. J. Chynoweth presented the Survey with a fine specimen

¹Koenig and Hubbard, "Über Powellit, von einem neuen Fundorte." Palache, C. Am. Jour. Sci., (1899) VII, p. 367.

of polished quartz, copper, silver and calcite from the Old Colony lode, showing their mutual relations.

A convenient place to see the minerals is the dumps of the Isle Royale Consolidated mine (Pl. XI), not only near the mine but on a siding of the track to the mill. A fine collection will be found in the College of Mines, largely due to the collecting of Professor Seaman and his students. Here have been found:

Primary

Labradorite

Augite, (the ophitic mottles show well at the Mabb vein dumps).

Magnetite

Hematite, also secondary

Olivine (? wholly altered to bowlingite, rubellan, Iddingsite, serpentine, chlorite, etc.)

Secondary early

Quartz associated with calcite and copper in crystals at times with 2P2 and trapezohedra as described by Lincio.¹ One piece is dusted over with iron oxide, then laumontite formed on it, then later calcite and last barite.

Chalcedony and agate banded

Chlorite occasionally in hexagonal light green barrels, well crystallized but universally diffused. There are several minerals included probably.

Delessite is the name commonly used for the dark green variety that often lines the amygdules and is early.

Saponite is reported

Kaolinite

Serpentine after olivine

Laumontite, reddish, mainly in seams, readily crumbling, sometimes after quartz and before calcite

Powellite, one crystal only, found by F. W. McNair.

Prehnite is generally in light greenish barrel shaped crystals and radiating fibres like thomsonite. Palache found some yellow at the Phoenix.

Epidote, yellow and yellow-green, often in crystals.

Calcite is both early and late but largely later than some of the quartz chlorite and epidote.

Dolomite seems to occur more in veins.

Siderite and the red calcite seems early in formation.

¹Neues Jahrbuch für Min. B. B. XVIII, p. 155, 156. (-4, -3 74), (-3, -2 53) (-12, -7, 19, 12), (-9, -5 14 9), (-15, 8, 23, 15), (-2 -1 32) on No. 1; (7 2, -9 9), (3 1 -4 4), (-11, -8, 19, 12), (8 19 8) on No. 2; (90, -97), (40, -41), (11, 0, -11, 1), (8 1, -9 8), (11, 10, -21, 11) on No. 3.

Ankerite occurs as a vein filling.

Thomsonite occurs in thin radiating fibres on the sides of a seam.

Copper occurs in amygdules and veins, but the copper compounds only in veins or secondary after the copper, and are all much rarer than it, must indeed be hunted for and are hard to find.

In veins are:—

Bornite, rare.

Chalcocite, not so uncommon.

Chalcopyrite. I have seen it in one small speck imbedded in a piece of chalcocite that Seaman has.

Whitneyite

Pyrrhotite? reported

Domeykite

Due to weathering and surface carbonation are

Azurite

Malachite

Chrysocolla

Cuprite. Capt. J. Vivian had a fine specimen showing a core of native copper changing to cuprite and chrysocolla.

Silver with native copper.

Characteristically late are

Limonite

Natrolite

Orthoclase as a secondary mineral

Analcite (also found at Champion mine by Palache)

Later than the calcite are the sulphates such as:

Anhydrite (a calcite vug has a gypsum filling with anhydrite center).

Gypsum, after anhydrite.

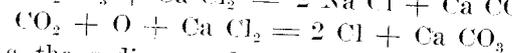
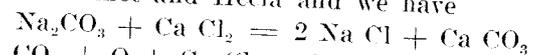
Barite, not very uncommon, the last mineral formed so far as I remember.

Datolite is generally the porcelain variety forming the center of nodules of decomposition, often surrounded by a coating of copper. This form often occurs at the Franklin Junior mine also.

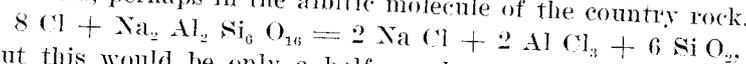
Summing up we may say that the later minerals that form mainly after the copper, the zeolites with soda, the sulphates, etc., are the minerals whose bases occur mainly in the upper and middle waters while those minerals which distinctly and always precede the form-

ation of the copper, to-wit, the lime zeolites, are those whose base is characteristic of the lower water and that up to the stage of the copper formation whatever solution of country rock might have been, or reaction therewith by the water and precipitation, they could not have been such as to lower the ratio of sodium but presumably such as to increase it.

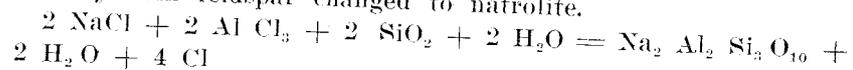
Now how do these facts check with the chemical reactions that would be likely? Coming back to the sucking in of surface waters and picking out from the numerous ions existing in the waters only those most necessary to understand the reactions (but not forgetting that the presence of other ions may be necessary in order that these reactions may go on) the middle belt of waters rich in sodium chloride is thus accounted for, and the salt crystals in the Calumet and Hecla and we have



As the sodium and chlorine accumulate they tend to find new partners, perhaps in the albitic molecule of the country rock. Thus

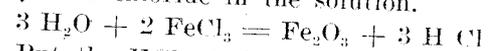


but this would be only a half-way house. Perhaps the real step would be the formation of natrolite, leaving 4 Cl and 2 Si O₄ ions to wander farther for partners, the fluid being less acid, and the country rock feldspar changed to natrolite.



This is merely a theoretical reaction that may go on momentarily in the zones where the natrolite, analcite, orthoclase and apophyllite are formed. By slight changes the same type of reaction may be made to apply to orthoclase and datolite. It is noteworthy that this leaves Cl in the downward working water.

In the presence of salt (sodium chloride) iron tends strongly to rust, and salt and red rocks are everywhere associated with the circulating waters. So with a reaction that produces sodium chloride it is natural to add one that produces ferric oxide if there is any iron chloride in the solution.

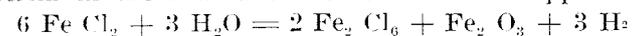


Put the HCl of this reaction in the place of NaCl above and combine the two equations and we have a reaction that will produce the red fluccan clays. It is noteworthy that the secondary orthoclase is generally reddish and brick red orthoclase and analcites are not unknown.

R. T. Chamberlin¹ cites from Precht a reaction a little different

¹Loc. cit., p. 77.

from this but of especial interest to us as it might account for the combustible gas actually found in the mines and by Chamberlin in the rock and the reduction of copper, to-wit,



The hydrogen of this reaction will tend to form HCl with chlorine if the latter is weakly bound, or would be available as a reducing agent for copper.

Now we know that ferric iron is formed, that we have red amygdaloids and we know that the country rock, even the felsite, is attacked and replaced. These reactions above tend to produce an excess of chlorine and therefore just where the oxidation takes place copper will not be deposited, but rather that already deposited will be dissolved and moved down to where the neutralizing agent, the country rock is in excess,—that is, copper will tend to replace this latter. But silver chloride is less soluble than copper chloride and would lag behind, and when moved be deposited on it. It must be remembered that silver chloride is quite perceptibly soluble in strong chloride solutions.

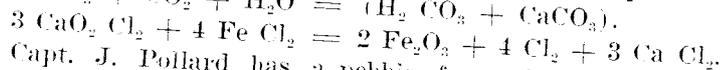
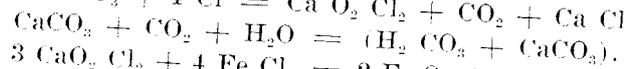
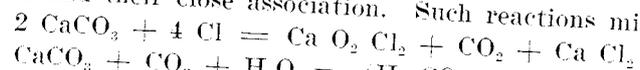
1000 cc. of a 41.26% Ca Cl₂ solution contains 6.28 grams

1000 cc. of a 25.96% Na Cl₂ solution contains 0.96 grams

so that it would be soluble in the strong mine waters and tend to precipitate as they were diluted or the calcium base replaced by sodium, that is in the upper waters and as these migrated downward. We see that the distribution of silver and the mine waters match beautifully, for silver is most abundant in the upper levels and the south corner of the Calumet and Hecla shoot (see Pl. VIII) was said to be fairly "lousy" with silver, the percentage of which was 5 up to 54 ounces but decreased to 4¾ ounces per ton in the Tamarack mine. Silver is characteristic of Lake copper, for electrolytic has less silver while the "Western" copper, if it has silver, has also tellurium and bismuth.

The chlorine which dissolves the copper would also attack calcium carbonate if already present. Thus we may account for the migration of copper and calcite at the same time in this way. But we also have to consider variation in the concentration of the salt solutions. Lime is more soluble in a hot calcium chloride solution than in a cold and lime and calcium bicarbonate both have a maximum solubility for a certain percentage of sodium chloride. Of calcium bicarbonate there may exist as much as 0.225 grams per liter if there are 50.62 grams of NaCl also in solution. It would seem possible, therefore, that a simple migration of the middle water zone downward would slowly dissolve and then slowly reprecipitate the copper.

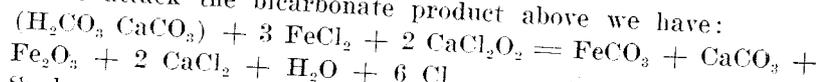
We may thus account for the migration of the copper and calcite and their close association. Such reactions might be written



Capt. J. Pollard has a pebble from the Calumet Mine dissolved out so as to leave a vug lined with beautifully crystallized orthoclase and hematite.

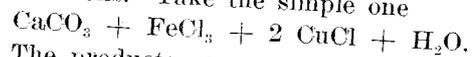
This reaction very probably does not take place except in the presence of other ions, but it went on as Fernekes' test with prehnite showed to some extent under those conditions, as red oxides were formed.

If we attack the bicarbonate product above we have:



Such reactions may suggest the method of formation of the red calcite and red ankerite, which are as we know relatively early products of alteration, and also show how acid ions are continually shoved ahead to find new affinities.

By such migration presumably the copper pseudomorphs after chlorite, epidote, laumontite and even sometimes quartz are formed,—and in fact *almost any rock*, for great masses of trap and solid pebbles of conglomerate may be changed to copper. The reactions are ones of replacement and equilibrium with a large number of ions. Take the simple one



The products are:

in solution + ions Ca (comes in), Fe, Cu (goes out), H;
— ions CO_3 , Cl? OH, FeO_3

Besides this there are at various temperatures and concentrations, various amounts of undissociated salts, and possibilities of ions like OCl and Fe O_3 . The general effect of dissolving CaCO_3 is to add a strong + ion and a weak negative ion. One way to keep balance in the solution is to eliminate some other + ions, which may be and is accomplished by precipitating the copper, and also by converting the + ions Fe into negative FeO_3 . If it were not for the possibility of using the O of the — ions CO_3 and OH in converting the + ions Fe into a — ion Fe O_3 which is the kind of change needed to restore equilibrium, the copper ion might take CO_3 or the O of the OH with it. This is what presumably happened in the Allouez conglomerate at the Allouez mine where cores of native copper are surrounded with oxides and

carbonates of copper and chrysocolla for quite a depth.¹ This is exceptional, however. The zone of carbonates is extremely shallow generally and native copper often occurs "at the grass roots".

The same principles apply if for CO_3 we write SiO_3 ², and so the attack on prehnite

$\text{H}_2\text{Ca}_2 \text{Si}_3\text{O}_{12} + \text{Ca Cl}_2 + \text{Fe Cl}_2 + \text{CuCl} + \text{H}^2$
will result in a solution of

+ ions Ca, Fe Cu, H, (AlO_3 ?) (Si ?)

— ions SiO_3 , (FeO_3 ?) (AlO_3 ?) Cl OH

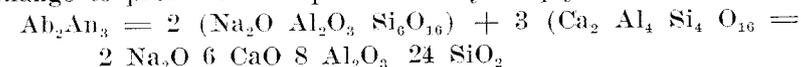
As the Ca comes in the Cu drops out. The reason why the laumontite does not precipitate the copper so readily as the prehnite, (the fact is clear both naturally and artificially) is probably that the latter contains a basic calcium hydrate group, while the laumontite having simply hydration water has less of the stronger bases + ions like Ca and H and more of the — ions (even though weak) like SiO_3 and AlO_3 . The formulae are:

Prehnite $\text{H}_2\text{Ca}_2 \text{Al}_2 \text{Si}_3 \text{O}_{12}$

Laumontite $\text{Ca Al}_2 \text{Si}_4 \text{O}_{12} + 4 \text{Aq}$

The solutions obtained in dissolving laumontite would be much richer in alumina and silica and in oxygen in proportion to lime. This might tend to favor the direct oxidation of the iron. Red colors are associated with laumontite.

With the very common feldspar (Ab_2An_3) or labradorite the change to prehnite and epidote is very simply written.



add 8 $\text{H}_2\text{O} + 10 \text{Ca}$ and subtract 2 Na_2 and we have prehnite: 8 $\text{H}_2\text{O} 16 \text{CaO} 8 \text{Al}_2\text{O}_3 24 \text{SiO}_2$. So that this would mean simply the replacement of Ca by Na in the mine water, and its concentration.

The formation of the *epidote* is of considerable importance. Its formula is:

Epidote $\text{H Ca}_2 (\text{Al Fe}_{1.6 \text{ to } 2.3}) \text{Si}_3\text{O}_{12}$

Prehnite $\text{H}_2\text{Ca}_2 \text{Al}_2 \text{Si}_3\text{O}_{12}$

As compared with prehnite the difference is that there is less hydrogen, considerable ferric iron (about 10%). There is no reason why it might not act as a precipitant of the copper just as we know prehnite does, but less readily, as there are fewer + ions.

There are two kinds of epidote, — a pale colored zoisitic kind

¹Cf. also the Algoma mine near the middle of Section 3, T. 50 N., R. 38 W.

²Though there is the possibility of the formation of compounds like SiCl_4 and SiFe_4 which account for the solution of pure quartz, though rarely, with difficulty, and as a last resort. There must be a relatively large amount of cuprous chloride and little silica in solution in order to favor this reaction.

which is formed in the decomposition of the feldspar and a deeper colored epidote¹ which is the commoner variety and no doubt is richer in iron. The epidote is very commonly associated with chlorite in sharp crystals. The chlorite takes in magnesia and ferrous iron, but not willingly or to any great extent lime and ferric iron. Therefore in the hydrous decomposition of the augite, the lime, alumina and ferric iron of the same are precipitated in epidote as the solution gets over loaded with lime. This early epidote is formed before the copper and is very wide spread where there is no copper, and is almost as wide spread if not quite as abundant as the chlorite.²

Epidote also, however, occurs replacing the whole mass of the rock. In this case the feldspar and glass of the amygdaloid are also decomposed. If we compare the formula of epidote with that of feldspar we see at once that there will be silica left over in its formation. And if we take the trap as being roughly CaO , MgO $(\text{Na}_2\text{O FeO})$ $(\text{FeAl})_2 \text{O}_3$ 4SiO_2 and suppose it decomposed into chlorite = (2FeSiO_3) , Al_2O_3 , 3SiO_2 , $3 \text{Mg}(\text{OH})_2$, $\text{Fe}(\text{OH})_2$ and epidote = $(\text{AlFe})_2\text{O}_3$, 3SiO_2 , CaO , CaOH we have shown in chapter II that there must also be, as in the Calumet and Hecla pebbles, silica (quartz) SiO_2 and soda Na_2O to be accounted for. We do as a matter of fact find quartz commonly associated with epidote and chlorite, but often later, the sodium silicate being quite soluble, but precipitated by calcium chloride, giving calcium silicate for epidote.

In the lower part of the lava flows, the hanging of the lodes, there is an accumulation of the lime and iron, while at the top, which is the foot of the amygdaloid lodes there is more sodium (feldspar). Nevertheless, generally speaking, the hanging is chloritic, the foot and the amygdaloid itself more epidotic.

The lime and silica are always abundantly present and the more important conditioning factors seem to be the presence of alumina, and the accumulation of oxygen to oxidize the iron.

This might very well go hand in hand with the formation of copper, and indeed it does, if only the physical conditions were such (as in Fernek's tubes) that the oxygen derived from the decomposition of silicates by chlorides was preferably employed in building epidote or hematite. On the whole, however, epidote is vastly more wide spread than copper, that is in the attack of silicates the oxygen was in most cases provided for change from the

¹Thallite or pistazite, yellow in thin section, deep yellow-green. Vol. VI, Pt. I, p. 166.
²Capt. J. Pollard says that in the Calumet conglomerate the cement was calcitic, the epidote more confined to boulders.

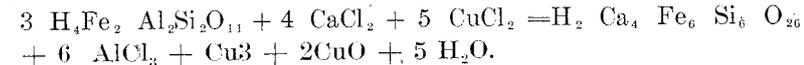
ferrous iron of traps and chlorites to the ferric iron of the red amygdaloids and epidote without reducing the copper.

Of especial importance is the role of the chlorite family for they are so widespread and often replaced by copper. They have had a great many formulae assigned¹ but the essential thing to remember is that they are a hydrous alumomagnesian silicate with the magnesia always largely replaced by ferrous iron.

The chlorite naturally forms first in the hydration of ferrous minerals like olivine and augite. But that is only the beginning of the story. Chlorite is attacked by chlorine and HCl , and as soon as corrosive chloride solutions reach a delessite, that bears ferrous iron, they will readily attack it. It is not uncommon to find amygdules that look like solid copper but are a fraud. They were coated with delessite and then this has been attacked and replaced by a thin film of copper that coats around the outside of the amygdule as though it were the first formed.

So the early chlorite is very apt to be attacked by the migrating mine waters. But the mineral brought into solution can not remain in solution. Hunt has remarked that magnesium chloride is precipitated by calcium silicate and carbonate quite completely, and there is very little magnesium chloride in the mine water—barely a trace. It seems, therefore, that the magnesium chloride is thrown out again as chlorite as fast as it is brought into solution, but with this difference, that if there is copper chloride present a proportionate amount of ferrous iron remains permanently in the form of ferric iron, either as hematite or epidote, while the copper takes the place of that much of the chlorite.

This may be written (remembering that all the magnesian part of the chlorite and most of ferrous remains chlorite), for the fraction of the chlorite that reduces the copper, and the fraction of the epidote which has ferric iron.



Compare also the reaction of Chapter II, p. 85.

The aluminum chloride shown in this transformation from chlorite to epidote seems to be used in making more chlorite out of relatively not aluminous minerals like augite and olivine.

The latter seems to be the reaction at lower levels, and may be the source of much of the chlorite on veins, joints and fissures.

We have now, it seems to me, reactions enough to account in principle for all the phenomena of the copper lodes, without sup-

¹See Chapter II.

posing anything unlikely in the course of circulation, the elements previously dissolved, the character of the country rocks or the temperatures, while there is yet very much to be learned with regard to the relative solubility of the ions concerned.

Pumpelly's theories seem to be altogether confirmed except that chlorine rather than sulphuric anhydride was the acid radical.

Since we are laying little or no stress on sulphates or sulphides it may be well to say why and note a few facts that may be raised in opposition. The reason why we do not consider sulphates or sulphides or arsenides of primary importance is that; first, in many of the mines there is very little sulphur associated with the copper, barely a trace.¹ Secondly, there is very little sulphate in the lower mine water, more in proportion in the upper waters. In the Quincy mine, 55th level analysis, for instance, there is 0.110 SO₄ as against 176.027 Cl. less than a thousandth part as much.

Thirdly, these sulphate minerals are few and rare. Those which do occur are, I think, later in formation than the copper. Beside occurrences already noted are the following:

Barite from 36th level, No. 6 Hecla shaft, very rare.

Phoenix Mine (Palache).

Gypsum (selenite) was in fine pieces in the Mass mine. A specimen three inches long and ten wide came in a vein on the 13th level, Shaft E, of Champion mine on the Baltic lode. The order of formation was, chlorite, epidote, calcite in sharp half inch dog-tooth spar crystals and the gypsum last.

Sulphides and arsenides occur but there is no sign of replacement of native copper with sulphides in depth. The contrary, if anything, is true. It is characteristic that the abundant sulphides are basic with excess of copper. Chalcopyrite is rare. Chalcocite is commoner and occurs in the Baltic and Champion mines in long "seams" nearly parallel to the strike, not in "fissures" across the lode. On the other hand the mohawkite occurs in cross-fissures.

Whitneyite Cu₅As² occurs on the 3rd level of the Champion as well as in Mohawk.² On the whole, however, the sulphides and arsenides are thought to be superficial.

Domeykite Cu₃As (or stibiodomeykite³ with 1.29 to 0.7856% Sb) Sp. Gr. 7.906 at 21° C occurs like the mohawkite, which is really only a nickeliferous variety, in the Grand Portage vein.

¹In fact it seems as though there were more in the country rock as the percent of S or As increases sometimes in the lower grades of mineral.

²Am. Jour. Sci., (1900) X, p. 446 and (1902) XIV, pp. 404-416.

Ledouxite (Cu Ni Co)₄ As may be a eutectic mixture¹ and is found with the Mohawkite.

Algodonite Cu₆As, Sp. Gr. 8.383 at 21° C.

Mohawkite² (Cu Ni Co)₃As, a nickeliferous domeykite, Sp. Gr. 8.07 at 21° C, carrying about 63-69% copper, 3 to 7% nickel and 0.5 to 3% cobalt occurs in the Mohawk mine on the Kearsarge lode, and at least as far south as the North Kearsarge lode. A speck perhaps was seen in the Central mine section and Rhode Island d 4 at 529 feet.

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

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

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

Keweenawite³ (Cu Ni)₂As (39-54% Cu 9.7 to 20% Ni) is pale red and occurs with Mohawkite in the Kearsarge lode.

Some notes largely derived from the testimony of J. B. Cooper on the distribution of the arsenic and sulphur in the molten copper are suggestive.

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

¹Koenig, G. A., Am. Jour. Sci., (1900) X, pp. 440-446; Richards, J. W. Am. Jour. Sci., (1901) XI, p. 457; Ledoux, Eng., M. J., Apr. 7, 1900.

²Koenig, G. A., "On Mohawkite, Stibiodomeykite, Domeykite, Algodonite and some artificial copper-arsenides;" Am. Jour. Sci., (1900) X, p. 439, also L. S. M. I., VII, p. 62, also Koenig and Wright (F. E.), Proc. Am. Ph. Soc., 43 (1903) p. 219.

³Am. Jour. Sci., (1902) XIV, p. 410.

the copper contained. Arranged according to conductivity (arsenic) we have

Franklin Junior 100 and Quincy 101 on Pewabic lode.

Atlantic mine (near Ashbed) 100.

Adventure 101, Mass 100, and Michigan 101.

Victoria 93 to 94.5.

Kearsarge 91.

Wolverine 89 to 91½.

Mohawk 77½ to 81.

Isle Royale 50 to 55.

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

Copper Range mines, Baltic, Champion, etc., 65 to 45.

Baltic 45 (with 0.19% As).

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

In connection with what I have written, since I have minimized the role of sulphur it is only fair to insert the following interesting letter which suggests the possibility that the native copper was derived from sulphides by reaction with the salt mine water.

Houghton, Mich., U. S. A., May 15, 1909.

Dr. Alfred C. Lane, Lansing, Mich.

My dear Dr. Lane—* * * * In reply to your inquiry regarding the New Zealand mine in which the sulphide ores of a mine abandoned for 40 years were found partly transformed to native copper by the action of the sea, which had broken into the workings, would say that the property in question, on Kawau Island, was known generally as the Kawau Island Copper Mine, and was worked around the middle 60's, and some work, of a rather desultory nature, was done circa 1901 or 1902, in the way of reopening, and it was then that the native copper was found in the bottom of a comparatively shallow shaft, obviously due to transformation of copper sulphides into native copper through reactions caused by chlorides in the sea-water. The ore, according to my understanding, was exclusively or almost exclusively chalcopyrite, and this mine, which is on Kawau Island, Hauraki Gulf, Auckland, N. Z.,

was worked probably more extensively than any other New Zealand copper mine, until the recent efforts at copper mining of the Ferguson and Maoriland companies, but, of course, the scale of operations are small, compared with any of the important mines of this country. * * * *

Very truly,

HORACE J. STEVENS.

While I give these interesting facts for what they are worth, I am unable to see in them any indication that the copper as a whole is derived from deep-seated rising waters, though one might imagine the arsenic and sulphur to be so. The amount of As or S found in the copper generally is so small that it hardly needs any explanation. Such quantities generally occur in rocks. The thing to explain really is that they are so low. But if we adopt the explanation above outlined that copper replaces minerals that tend to keep a chloride solution alkaline in spite of a tendency toward ferric oxide and chlorine, yielding at the same time its oxygen or an equivalent to the iron, I know no reason why S or arsenic should ordinarily be precipitated or sulphates reduced at the same time. On the other hand sulphur and arsenic seem at times to have accumulated so as to be precipitated, and I would not deny that in this case the depositing waters were ascending. Such sulphide veins have never been followed deep or investigated so as to show their relation to the different types of water. It will be noticed that (whether in the decomposition of the Calumet and Hecla boulders or the turning of an ophite into chlorite and epidote, or any other of the reactions we have cited) in all reactions that lead to the deposition of copper there is a tendency to the same accumulation of sodium in the mine waters, which we actually find at the top of the lower waters, and though after the copper formed the sodium accumulation continued to such an extent that sodium minerals like natrolite and analcite formed, yet these are confined to the upper levels and on the whole the formation of the lime zeolites and decomposition of olivine and augite preceded and the formation of soda zeolites and decomposition of feldspar was later than the formation of copper. The following diagram may sum up our results.

Schematic diagram of bedded lode.

| Footwall | Pervious lode | Hanging wall |
|--|---|---|
| <p>Generally feldspathic. <i>Ferric zone.</i> Surface decomposed zone, full of fractures, and of water coming from the surface only a few feet deep. Red colors—amygdaloids, hematite formed. Soda zeolites may be formed.</p> <p><i>Ferrous zone.</i> Copper is formed or accumulated in a zone of equilibrium laterally and downward where the tendency of the copper to be attacked is neutralized by the supply of decomposable silicates, chlorite, prehnite, etc. ferric iron present built into epidote. Early alterations, water absorbed, feldspar and augite and olivine changing into epidote, chlorite, and serpentine. Glass decomposed, partial amygdaloid filling, original CO₂ gives carbonate.</p> | <p>(a) <i>Upper.</i> Water largely circulating fresh, Na:Cl more than .65 at first; chlorine less than 200 per million. Carbon dioxide from surface forms carbonate. Chlorine increases, sodium both by solution of feldspars and diffusion. Copper dissolved and carried by the chlorine released in the formation of hematite and soda zeolites to be deposited below or in foot and hanging.</p> <p>(b) <i>Middle.</i> accumulates sodium chloride and copper. When above a certain strength of copper chloride the mine water attacks a ferrous chlorite, precipitates iron in ferric form at one end of an unequally heated solution, copper at the hotter lower, positive, alkaline end.</p> <p>(c) <i>Lower.</i> Water, almost stagnant, works slowly down and in, as the rocks cooled and hydrated, gets stronger by loss of water absorbed in hydration and gain of soluble solids. The proportion of sodium falls with depth down to Na:Cl=0.08. Chlorine soon measured in percents, maximum 17.6%.</p> | <p>Much like the foot but more chlorite and augite, less epidote and feldspar. Generally more impervious and so the copper more in thin sheets on the chloritic joints at right angles or parallel to lode on columnar joints at right angles to dip.</p> |

It will be seen that my studies have led to no radical change in the views as to the origin of copper expressed by me in the annual report for 1903, and by Wadsworth in the Transactions of the American Institute of Mining Engineers (xxvii p. 669), and by Pumpelly earlier.

Copper should then be looked for not merely along pervious lines but *near* pervious lines,¹ with a strong tendency to appear in hanging and foot and the mineral crest or richest part of a lode will be in the salt water belt, adjacent either to right, left or below where the downward absorption has gone deeply. (Fig. 60.)

¹Cf. the figure on p. 127 of Marvin's report, Vol. I., Mich. Geol. Sur.

CHAPTER IX.

COMPARISON OF MICHIGAN COPPER DEPOSITS WITH OTHER SIMILAR DEPOSITS.

§ 1. COMPARABLE DEPOSITS.

It is not my purpose to pad this report with an extensive account of other copper deposits, though such comparison of formations is often very instructive. Many of the deposits of copper ores, especially those of chalcopyrite out west are probably or certainly quite different in origin and mode of occurrence. There are, however, two or three deposits which are so similar that a brief comparison seems to be demanded, for the light thereby to be thrown on our own conditions and this is the more the case because two recent writers have given good accounts of them and have discussed their origin. I refer to the "Copper Deposits of the New Jersey Triassic" discussed by J. Volney Lewis¹, and the deposits of Bolivia described by G. Steinmann.² The three deposits all agree in certain striking points, as to which they differ also from most of the western deposits: (1) In all of them native copper is a characteristic ore. (2) In all three the associated sedimentaries are characteristically red. (3) in all three there are associated basic rock, (4) in all three there is a lack of well-defined crustified veins, but the copper occurs disseminated or in irregular large masses in the more pervious beds, not, however, by any means confined in any zone of contact igneous metamorphism. (5) In two and probably three there are saline waters. (6) The silver is more abundant in the upper levels. On the other hand the deposits differ in certain marked respects. They are of widely different geologic age and have not the same associated minerals.

It might be well also to mention the fact that in the red rocks of the Permian, or that general time, copper is known to occur both out west and in the famous Mansfield district. Copper and nickel have also been found in small quantities in the old and new red sandstone of Scotland.³

¹Economic Geology, Vol. II, No. 3, pp. 242-257. Other papers by Lewis, Weed and Kummel are referred to in this paper, and will be found listed in the bibliographic bulletins of the U. S. Geological Survey. See also Fenner's paper in the Journal of Geology, 1908.

²Die Entstehung der Kupfererzlagertätte von Corocoro und verwandter Vorkommnisse in Bolivia, Festschrift Harry Rosenbusch, pp. 335-368.

³Mackie, Wm., Transactions Edinburgh Geol. Soc. 1903 (VIII, Art. XXVII) p. 258.

§ 2. NEW JERSEY.

The copper deposits of New Jersey occur in the Triassic area. This area consists of a series whose most characteristic sediments are red shales, but there are also sandstones and coarse conglomerates, and black argillites and grey and green flags, which may correspond to the Nonesuch group. In general the sediments are so much like those of the Keweenaw, that on this ground early visitors to Lake Superior were inclined to assume that they were of the same age. There are also igneous rocks, both extrusive and intrusive, whose chemical composition is not far from that of the melaphyres of the Keweenaw series. The over flows occurring in various places, but especially west of Newark, Orange, Plainfield, Bound Brook and Paterson, rise in ridges easily recognized and like those of Keweenaw Point. They contain amygdules and zeolites very similar to many of those found in Michigan. The main intrusive sheet is that which forms the great Palisades of the Hudson over against New York City, and probably extends thence south to the neighborhood of Princeton and Trenton. The dips are rather gentle like those of Isle Royale or the end of Keweenaw Point, 10° or 20° to the northwest. Like the Keweenaw district, too, there are great faults each of which displaced the strata many thousand feet, which would correspond to the Keweenaw and Porcupine Mountain faults. Besides these there are numerous smaller faults corresponding to the smaller fissures of Keweenaw Point, and they run mainly north and south or northeast and southwest. These faults have a down throw on the east toward the Atlantic Ocean. The copper has been shown to exist to the extent of 1/40 of 1% in the extrusive trap of First Mountain and 1/50 of 1% in the pyroxene of the intrusive trap.¹ The commonest occurrence of the copper is as chalcopyrite in the traps and as native copper or chalcocite in the sedimentary rocks. Green and blue silicates, and more rarely carbonates, and small quantities of cuprite and azurite occur. According to Lewis the ores occur in four types of association. In two cases with and in two cases without known intrusive trap.

THE ORE DEPOSITS NEAR INTRUSIVE TRAP.

The Rocky Hill (Griggstown) mine. Essential ores, chalcocite and chalcopyrite in fissures and brecciated zones in flinty black hornstone in which are specks, to inch masses, of chlorite. Tourmaline, magnetite, hematite, epidote and feldspar also occur. The color is sometimes bleached near the ore and the thrust-plane parallel to the bedding carries 3 inches to a foot of fluccan.

¹Cf. the results of the sludge tests of the Clark cross-section on Keweenaw Point.

The Arlington (Schuyler) mine. Eight miles west of New York City. Similar ores in gray arkosic sandstone near intrusive trap sheets and dikes, and in occasional fault breccias of sandstone and trap.

The Flemington mine. Ores again chalcocite and chalcopyrite with similar associated secondary minerals and geologic conditions. Note the dominance of sulphide ores. The few times I have seen chalcopyrite in Michigan has generally been not far from intrusions.

ORE DEPOSITS NEAR EFFUSIVES.

The Somerville (American) mine. Three miles north of Somerville, lying just under the big outflow of First Mountain, the copper mainly in the upper 2½ feet of shale below, and sometimes running up into the hanging for ½ foot. The metal is in grains, strings, sheets, and ragged masses up to over 100 pounds. Beds of native silver also occur. Immediately about the copper and shale is bleached, just as some of the Calumet and Hecla pebbles are bleached probably. It is intimately associated with calcite which seems to have been replaced in some cases by copper. Prehnite and chalcopyrite also occur. Exactly similar conditions which anyone will recognize who is familiar with our Michigan deposits, have similarly occurred clear way around to Plainfield.

The Hoffman mine. Two miles northwest of Somerville on top of the trap. Some chalcocite in the sandstone and brecciated trap near the fault.

ORE DEPOSITS APART FROM KNOWN IGNEOUS ROCKS.

The New Brunswick mine. Close to Rutgers College. Sheets of copper have been found in the joints of red shales and small grains disseminated through the rock. No trap is known to occur, or has been struck by wells over 400 feet deep, which are all in the red shales.

Menlo Park Mine. One-half mile north from the station. Native copper in the dark grey shale which is the wall rock and makes up the breccia of a fault. The shales elsewhere have the usual bright red color. There is also some chalcopyrite and magnetite in the shale. Copper in thin sheets and films in the joint cracks like our Michigan leaf copper. There are also minute grains and streaks in the shale, especially around the occasional bituminous plant remains.

Glen Ridge. Four miles northwest of Newark. Grey sandstone with disseminated chalcocite and green with chrysocolla. The minerals especially gather around bituminous plant remains.

Newton. Four miles northeast of New Brunswick. Native silver in scales and particles in the grey sandstone, stained green.

§ 3. ORIGIN OF NEW JERSEY COPPER.

Weed suggested, in 1904, that the ores were due to surface percolating waters, partly changing the trap as follows: The melaphyre chloritized and the iron changed from silicate to ferrous salt.

The calcite amygdules formed in the basalt and pores of the altered shale. The copper was dissolved out from the trap by percolating waters and carried downward. Copper and calcite were deposited in the pores of the ore, the chalcocite being reduced at the same time as the ferric oxide about it. He supposes solutions carrying the copper contained alkaline carbonates and precipitated copper and chalcocite with calcite, and that the reduction of the chalcocite to native copper was due to organic acids. Weed argues that if as Pumpelly suggests for Michigan it were ferrous solutions that caused the reduction we should have ferric oxide associated with the native copper instead of the bleached spots, which we as a matter of fact find.¹ Lewis objects to Weed's hypothesis that the trap rock of First Mountain is not enough altered to account for the underlying ores. Of the 1/40 of 1% of the copper originally contained, ¼ would have to be transferred without loss over a sheet 600 feet thick to give 2½% in 2 feet of underlying shale.

To this objection it may be replied that in the first place it is by no means sure that the analysis represents the amount of copper which may have existed in the original trap moisture, and in the second place it is very unlikely that the underlying shale runs 2¼%, save in exceptional spots.

(2) Lewis' second objection is that ores are found above as well as below the First Mountain trap and above the intrusive traps of Rocky Hill and Arlington, and that the system of circulation which would at the same time deposit ores below their source and above is inconsistent.

I can not see that this is necessarily so, any more than it is impossible for a pebble to be coated with iron ore all around, by diffusion from the interior.

(3) The ore at Arlington besides lying above the trap, is out of all proportion in quantity to sheets of this rock.

(4) The thin tabular crystals of calcite are found in unaltered red shales far from the mine and have not, therefore, been supplied from the trap, though, of course, the calcite and amygdules in the grains in the trap have come from that rock itself.

(5) Organic matter would doubtless aid to reduce the copper as is shown by some specimens but the prevailing barrenness of the red shales in organic matter is one of the best established facts in geology.

Weed's theory fails to account in any manner for the ore deposits not associated with the traps.

Accordingly Lewis suggests the following hypotheses.

¹We can get round this by assuming ionic migration as in battery fluid or in Stokes' tubes.

Beginning with the ores associated with intrusive traps he suggests that heated copper bearing solutions and possible vapors arose from great underlying masses of intrusive along the dikes and deposited their chalcocite in the immediate neighborhood while still heated. The chief effect then would be ascribed to the solutions coming directly from the magma. The relatively impervious shales overlying the Rocky Hill intrusive retarded the escape of these waters to the surface. Dikes and accompanying fissures were confined to the immediate neighborhood of the sill in this locality. And he also thinks likely that reaction of the solutions with calcite of the shale contributed to the origin of the shale. As to the origin of the ores, apart from intrusives, he refers to Stokes' experiment where a solution of cuprous sulphate saturated will deposit metallic copper on cooling, and to such acid sulphate solutions he would attribute the deposition of the copper and the leaching out of the ferric coloring matter to the red shales. In other words he attributes all the copper to hot copper bearing solutions, probably magmatic, coming out from the great underlying Palisades trap sill. It will be noticed that he finds the source of the copper in the formation itself and that it is carried in solution, and in these two points we shall agree with him. He does not investigate the extent to which chlorides may have been present nor does he show any definite reason why heat and solutions from effusives might not have produced the remarkable concentration of copper near the effusive trap. We may remark, moreover, that wherever these Triassic traps occur along the Atlantic coast in Connecticut, Massachusetts and clear up to Nova Scotia where they are well developed about the Bay of Funday, where (as at Cape d'Or) there is no sign of intrusives other than the faults and fissures everywhere present we find the same zeolites as in New Jersey and we also find native copper. The occurrence at Cape d'Or which I have examined is strikingly like that of Lake Superior. Here too though the zeolites are different, the lime zeolites are older than the copper or the soda zeolites, which two latter are more nearly coeval. The trap has about 56% SiO₂. It has been described in some detail by Sir Wm. Dawson in his *Arcadian Geology*. Beside the papers on the New Jersey traps by Darton, Russell, Lewis and Weed, there has recently appeared an excellent description of "Features indicative of Physiographic conditions in New Jersey," by C. N. Fenner.¹

His account of what I (following Wadsworth) have called clasolitic material, and the amygdaloidal conglomerates is perfectly

¹Journal of Geology, May-June, 1908, pp. 299-327.

applicable. His conclusions that some of the traps flowed on the land (such for instance, as the smooth coiled ropy topped flows north of Bessemer with their regular pipe amygdule base) while others flowed into lake (some of the inclusion beds and ashbeds) entirely agree with mine. His paragenetic series (p. 315) differs mainly in the absence of epidote, and in his noting chalcopyrite, but not native copper, which, however, as we know occurs.

§ 4. BOLIVIA.

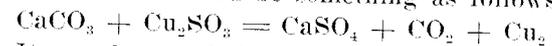
The copper mines of Bolivia lie in more or less of a line running nearly north and south, through the Atacama desert. Of these the one at Corocoro is most fully described by Steinmann,¹ and will suffice for purposes of comparison. The copper occurs in a series of red sandstones, known as the Puca sandstone, very much like the new red sandstone of the New Jersey deposits, but really somewhat younger, belonging to the Cretaceous. Here again the dominant form of the copper is the native metal, and native silver is also associated with it. But sulphides and arsenides like domeykite also occur. The ore occurs in the neighborhood of a large fault and a vertical displacement not less than 350 meters. The copper does not occur at any one particular level in these beds, but in small grains scattered through the sandstone which now and then blend to almost continuous veins running across the formation or sheets in the joints. Especially is this thin sheet and leaf copper liable to occur in the red clays, and sometimes the copper occurs in most fanciful and grotesque forms. In the higher levels (exactly as in Michigan) they used to find silver ore, and beside native silver and copper, chalcocite and domeykite. The ordinary vein minerals are absent. Barite comes occasionally, and celestite, but is very likely primary in these red sandstones. Calcite is even rarer than barite. In this respect there is a striking contrast with the Michigan district. When it does occur it is intergrown with copper as in Michigan. On the other hand gypsum (which is rare, or at least not very abundant in Michigan), is said almost never to fail. It often thrusts itself in between the thicker copper pieces and the surrounding sandstones and may envelope the copper completely. Such minerals as secondary quartz and tourmaline seem to fail absolutely.

Associated Igneous Rocks. No igneous rocks are known nearer than about 15 miles from Corocoro. At the same time Steinmann points out that the occurrence of copper ores in the Andes is generally associated with a certain type of rock known as Andes

¹Rosenbusch, Festschrift, (1906) p. 335.

diorite, and that this occurs about 15 miles north and not far south. And he assumes that it occurs also not far beneath and that from it have come the solutions which have deposited the copper. In this respect then his theory agrees decidedly with that of Lewis for New Jersey.

Origin of the Copper. The three writers who have discussed with the most personal knowledge and intelligence the origin of the copper are perhaps Forbes¹, Sundt² and Steinmann³. Sundt thinks that the copper was contained in the form of oxide or carbonate originally in the Puca sandstone and that later sulphurous acids and arsenic compounds which came up with the diorite injection beneath reduced the metal, while the sulphuric acid thus formed combined with the carbonate of lime to make gypsum, which all observers agree usually accompanies the native copper. The form of reaction then would be something as follows:



It may be noted that carbon dioxide gas is very abundant and a serious difficulty in some of the mines, especially the Cobrizos. According to this theory the copper would be "syngenetic," belonging to the formation itself, and yet in the process of alteration by these waters it would naturally suffer concentration and migration and would not belong in the same place in which it was found in the same way that particles of gold would be found in the placer. Mossbach also considered the copper syngenetic but in a stricter sense, in that he thought that the copper sulphate reacted with the carbonate of lime as the sediments were deposited. Sundt, however, decided in favor of the idea that the copper was introduced (epigenetic). He appeals to the following arguments.

The copper in its native form is doubtless younger than the sediments because it fills secondary jointing and other clefts and makes pseudomorphs after aragonite. It coats over pebbles of quartzite and conglomerate, and then penetrates into the interior, (just as the Calumet and Hecla pebbles are altered) along the fault line. It is found on both sides both in the older beds of the sandstone as main veins or "vetas," and in the younger, more clayey beds as branches or "ramos." Also the copper is closely associated with secondary gypsum and barite. Also wherever the copper is present the red sandstones are blanched, as in New Jersey and Michigan. Also the water of the copper bearing beds is strongly

¹D. Forbes, 1861. Report on the Geology of South America. Part I. Bolivia and Southern Peru (Qu. Jour. Geol. Soc. 17, 1861; 38-48); 1866, Domeykit von Corocoro (Phil. Mag. (4) 32, 135).
²L. Sundt, 1892. Estudios geologicos en Corocoro y en la altiplanicie de Bolivia (Bolet. Soc. Nacion. Min. Santiago. 1892. ser. 2a, 4, No. 44, 104-108; No. 45, 131-133; No. 46, 164-167).
³Loc. cit.

charged with sulphates and chlorides of the alkalis and alkaline earths. This is a striking point of resemblance of our Keweenaw mine waters, except that we do not have sulphates to an important degree. With this may be associated the fact that with our deposits the sulphates, such as selenite, barite and celestite, are rarities. He also appeals to the presence of copper on both sides of the fault as showing connection between that dislocation and the introduction of copper solutions. He supposes that copper was introduced as follows.

Long after the deposition of the sandstones and clays, either at the time they were folded and faulted, or later, solutions of cuprous or cupric chloride and sulphate were pressed into certain of the strata, more especially the pervious sandstones, in which certain beds proved favorable for the deposition of the copper. He also assumed that carbonate of lime was derived from the shells of sea animals and that the organic products of decomposition of the same reduced the copper and the iron oxide at the same time. Then the carbonate of iron and lime were removed in the waters containing carbon dioxide, while the sandstone was bleached, as it so often is around organic matter, and in place of the original carbonate of lime, copper and gypsum remained.

The main change by Steinmann in this theory, which it will be seen very strongly resembles that of Weed, is entirely analogous to that suggested by Lewis. Steinmann points out that fossils and organic matter are rare in red beds here and elsewhere, while aragonite crystals and small masses of carbonate of lime and magnesia are found in small quantities of sandstone in many layers. They do not appear to be associated with fossils, but are possibly chemical precipitates. He doubts altogether the introduction of copper as sulphate or chloride, but believes that the oxygen must have been relatively low in the solutions,—in other words that they were either sulphides, sulphites or thiosulphates. Any such solutions would act strongly deoxidizing. (I may remark in passing that I have made some special iodine tests for such salts in our deeper Michigan mine waters, but without showing any trace of them.) Such solutions if not exposed to an oxidizing agent might deposit the copper in the form of sulphides but in the presence of an oxidizing agent, such as ferric oxide and hydrate so abundant in the Puca sandstone, we could have the oxidization of the sulphide at the expense of oxygen of the ferric oxide and the consequent bleaching of the sandstone, which is as a matter of fact observed regularly around every particle, even the smallest. Such bleaching around pyrite is very well known.

Unfortunately, I have not been able to find out as much about South American geology as I could wish, and we have no analyses of the water directly associated with the native copper which occurs there. We do find, however, in Darapsky¹ analyses of waters which suggest at least that similar waters to those found in our copper mines may be the saline waters found in connection with the copper there. For instance, the analysis of Los Banitos is as follows:

Taste: saline

Reaction: neutral

Sp. Gr. 1.0076 at 15° C

Residue dried at 16° C: 9.545 grams per liter

Residue on ignition 8.996

Composed as follows:

| | |
|---|-------|
| Si O ₂ | 0.273 |
| SO ₃ | 0.150 |
| CO ₂ | 0.086 |
| Cl | 4.515 |
| Al ₂ O ₃ + Fe ₂ O ₃ | 0.088 |
| Ca O | 0.768 |
| Mg O | 0.017 |
| Na ₂ O | 2.726 |
| K ₂ O | 0.384 |
| Li ₂ O | 0.135 |

Sum

Minus oxygen equivalent to chlorine.....

Grams per liter.....

The sum of the alkaline chlorides is.....

This he supposes probably combined in the form of the following salts.

| | |
|---|-------|
| Si O ₂ | 0.273 |
| Al ₂ O ₃ + Fe ₂ O ₃ | 0.088 |
| CO ₃ Ca | 0.196 |
| SO ₄ Ca | 0.254 |
| Cl ₂ Ca | 1.097 |
| Cl ₂ Mg | 0.035 |
| Cl Na | 5.144 |
| Cl K | 0.732 |
| Cl Li | 0.382 |

¹Las Aguas Minerales de Chile, Valparaiso, 1890.

The geology of the occurrence is not given but so far as I can judge by comparing with Plate 8, Sec. A of the Atlas of the Physical Geography of the Republic of Chili by A. Pirssis, 1875, it comes from a region in which lavas and red sandstone also occur. Other analyses also are given in this book which contain earthly chlorides, such as Petrohue (p. 108) and San Lorenzo (p. 104). We are, therefore, so far as we at present know, justified in assuming that the native copper formation of Bolivia and Chili may have the same history as that of Michigan, except that calcium sulphate was largely present.

§ 5. OBERSTEIN, GERMANY.

Another district which strikingly resembles the Keweenaw is that around Oberstein in Germany (Lat. 49° 40' N., Long. 7° W.) where many "Lake Superior" agates are polished. The following factors meet once again.

(1) Tholeytic, i. e., ophitic traps, as cited by Rosenbusch, Laspeyres¹ and others, of similar chemical composition (see the analyses of the Norheim tunnel rock), containing a small amount of copper.

(2) Red rocks of the time of the Permian and Triassic or "New Red" epoch.

(3) Agates, for the polishing of which Oberstein is famous.

(4) Other zeolites and amygdaloids very much as in the Keweenawan.

(5) Felsites, e. g. those near Kreuznach.

(6) Salt water in depth (?) as suggested by the Durkheim (Lat. 49° 30', Long. 8° 12') water cited by Laspeyres¹ which has calcium chloride.

(7) Native copper in depth, carbonates at the surface as C. Otto Hahn informs me.

(8) The Hancock quartz described by Lincio² has a peculiar habit in which it resembles a quartz crystal from Oberstein described by Haüy.

§ 6. COMMENTS.

There are some general comments which may be made with regard to the theories here outlined. All of them work with only one solution and assume that its reaction upon solids or its change in physical condition have led to precipitation. None consider the possible mingling or ionic migration in two solutions. It is to my mind a rather serious objection to any theory which attributes the de-

¹Z. D. G. S., in Vols. XIX and XX, 1868, p. 191.

²N. J., B. B. XVIII, p. 155.

position of the copper to rising solutions, which must of necessity be losing heat and pressure that there are no signs, (and this is emphasized by Steinmann especially for Bolivian occurrences), of vein quartz and crustification. From what we know of the solubility of silica in hot and cold water, and from what we know of true fissure veins generally, it would be a fact hard to explain. Copper replaces silica and silica goes into solution. One solution was gaining in solvent power for silica. The occurrence of the salt water as spoken of by Suidt is very suggestive. The occurrence and distribution of these waters is to my mind one of the strongest arguments against the copper having been formed by upward circulation of deeper seated magmatic waters carrying the copper. I can imagine these waters might in the first place not have contained calcium chloride, but how, working upward and cooling, they would form sodium chloride, and then become fresh, I have not been able to understand. A careful examination of the Corocoro mines from this point of view should either relieve the difficulty or make it greater. There is another difficulty which on the ground might perhaps disappear. The veins or bedded lodes in which the copper occurs dip away from the fault, and if the water that deposited the copper came up this fault, it must have gone down backwards and sideways like the splash of a fountain. This seems strange but is conceivable, if we imagine the hydrostatic head very low in the adjacent strata. It must be remembered too that the igneous intrusions at Corocoro, at some of the New Jersey locations and at many of those in Michigan must be hypothetically put in to fill the demands of the theory that the copper comes from them. This does not really add to the strength of it. We also lack in the theory outlined by Lewis and by Steinmann anything which shows why such similar deposits so different from others occur in such similar relations. I would not say, however, that the three deposits were all formed in the same way. It might be falling into a very common and easy mistake to make that assumption, for indeed there are points of striking difference.

The regular association of gypsum with the copper in Bolivia and not in Michigan is one. This may well be accounted for by assuming that in one case a water containing a good deal more of sulphate or sulphide was involved which was lacking in the other. But why should it be in one and not in the other? One answer to this might be that in one case there were sulphides derived from intrusions and the other not, and it is true that even in Michigan, where we find intrusions, we are more liable to find sulphides, such as chal-

copyrite, pyrite and chalcocite. It may also be suggested that the one set of deposits are very old and others very young, and there had probably been an accumulation of sulphates in the ocean which at the early time of the Keweenaw formation may have been nearly free from sulphates. This would, however, be a mere suggestion, because the question also arises whether these red rocks in all three cases do not indicate terrestrial, perhaps desert conditions, and whether in such cases there might not be an accumulation of minute quantities of copper chloride such as are found in the exhalations of Santorin and Stromboli¹, which under proper conditions might work down and be precipitated, according to the reactions suggested by Steinmann, or those which seem to be more applicable to the Keweenaw formation.

This question as to whether certain deposits are syngenetic or epigenetic is not a matter of mere scientific curiosity. If the copper is introduced along certain fissures, then search should be made along these fissures for the porous beds impregnated with it. The vein of the Central mine, for instance, seemed to enrich the various amygdaloids through which it passed. If, on the other hand, the copper was in some sense or other syngenetic, that is to say (I wish to use the term in a broad sense) in the water which came out with eruptions of a certain date, or in the rocks thereof, then it is along such lines that one should look for a continuation of copper bearing lodes.

The wise man will not decide too hastily or lay down too arbitrary a rule, but if anyone will look at Lewis' map of the New Jersey Triassic it will be pretty clear that the base and top of First Mountain are definite stratigraphic lines along which search for copper has proven relatively promising, just as it has along the Kearsarge lode of Keweenaw Point.

It seems to me that in all cases where native copper is the dominant ore it may be well to see how far its accumulation can be explained as a replacement of some substance which going into solution keeps the solution neutral or alkaline, while the acid element (O or Cl) with which it was combined is used either in oxidizing iron or in attack on other elements and perhaps at the other end or pole of the perhaps unequally heated solution. The repeated occurrence of traps, salt water, and red rocks associated with native copper would seem to be more than accidental, and to favor a theory of lateral secretion, using the term in a broad way, so as not to exclude intra-formational circulation.

¹Lincoln, Economic Geology 1907, p. 260 (II, No. 3, April-May) cited from Janssen.

In coming to this conclusion I do not wish to have it taken too broadly,—it applies to the Lake Superior native copper deposits primarily with some probable application to similar native copper deposits elsewhere. The universal distribution of the copper in the Keweenaw must not be overlooked. The Clark-Montreal figures are elsewhere given. Hole No. 1 at Mamainse gave in 530 feet an average of .0146%. Another feature is the fact that copper occurs at times with no other lode minerals, in the Nonesuch sandstone, for instance.

CHAPTER X.

THE DEVELOPMENT OF THE COPPER MINES OF LAKE SUPERIOR AND THEIR GEOLOGICAL RELATIONS.

BY A. H. MEUCHE.

A large percentage of the people living in states bordering the Great Lakes have, at one time or the other enjoyed a trip on the palatial steamers plying these waters. Those who have been fortunate enough to have gone along the southern shore of Lake Superior and passed through Portage Lake will probably remember Keweenaw Peninsula by its deep copper mines and the ponderous machinery there in use.

Some probably wonder about the beginning of this district and think about the first discoveries and explorations, but few take the trouble to follow the development of this district and determine how the mines have gradually come to be worked on so grand a scale that it takes from half a million to a million dollars to equip one. In order to explain these facts it is necessary to go into the history of the development of these mines. This report, written largely for that purpose, will quote from articles written at various times by different authors. I defend myself for doing so mainly because these original articles give us the view point of the country at that time and contain prophecies, some of which have been fulfilled, and criticisms, some of which have and are being acted upon now and others which I prefer not to hold as my own. This is especially true of Professor T. Egleston's paper of 1877.

While copper has been found along the north shore and on Isle Royale and some mining has been done there, the only locality where mines are worked to any profit is on Keweenaw Peninsula, and to this I shall confine myself. This peninsula which juts into Lake Superior is about seventy miles long and at its base thirty-five miles wide. The trap or Keweenawan formation is the central ridge. In Keweenaw county it extends to the shores of the lake as far west as Bete Grise on the southeast side and to Gratiot River on the northwest side. Here it takes a more southerly trend than does the shore and departs rapidly from it so that when it reaches the Ontonagon River it lies back about ten miles from the lake, being separated from it by the Western or Freda sandstone. The

eastern limit of the trap is marked by a great fault which can be traced from Bete Grise to some distance past Lake Gogebic. This fault does not follow the strike exactly but cuts across it somewhat irregularly so that while we have a horizontal thickness of almost seven miles in Keweenaw county it does not average more than four between Portage Lake and the Ontonagon River. On the east of the copper bearing traps lies the Eastern Sandstone.

In Keweenaw county, owing to the tilting at an angle with the horizon the range is made up of a series of sharp ridges lying parallel with the outer coast line. These cliffs, rising to a height of from one to two hundred feet, face the southeast with cliffy southern and flat northern faces. After leaving Keweenaw County the ridges disappear, due to the higher dip of the strata, and we have a plateau some six hundred feet above the lake, marking the trap range, and sloping gently to the lake toward the west but abruptly dropping off on the east.

In this plateau there are some noticeable breaks, such as Portage Lake and the Ontonagon River, both of which cut across the trap in deep vales. As a rule the country is covered by glacial deposits. The average thickness is six or eight feet, but there are some heavy moraines, a notable example being Wheal Kate. At other places the rocks lie bare inviting the scrutiny of any prospector.

There are two distinct methods of the occurrence of copper. In Keweenaw and Ontonagon counties most of the copper has been extracted from veins while in Houghton county it is the amygdaloids and conglomerates that are workable. In Keweenaw county veins run across the strata at nearly right angles to the formation. They are within ten or twelve degrees of being vertical and expand and contract at short intervals. Among the most prominent of the mines worked on these veins were the Cliff, Phoenix, and Central.

An entirely different set of veins is found in Ontonagon County. Here they strike parallel with the formation, but generally dip at a higher angle than the country. Among the mines located upon such veins, we have the Minesota, National, and the Rockland. Veins are principally famous for the masses, all of the above named mines having produced them weighing as much as four or five hundred tons.

The mines in Houghton County are worked on deposits where little mass but a large amount of stamp rock is found. These deposits have proven more persistent and more reliable than those of

either of the other two counties. The beds are really a part and parcel of the country having the same dip and strike. The amygdaloids are merely the upper vesicular portions of the lava flows which, owing to their porosity, have become a depository for the copper or copper solutions. This is also true of the conglomerates. While there are about twenty distinct conglomerates traversing the Point, still there are but two which have yielded enough copper to work. These are the Calumet and Allouez Conglomerates.

The copper mines were worked before the advent of the white men. Just how long before is a question. Mr. Jacob Houghton thinks these ancient miners lived during the stone age of the race and another writer that copper used in brazen images during the bronze age was imported from America.

"The high antiquity of this mining is inferred from these facts: That the trenches and pits were filled even with the surrounding surface, so that their existence was not suspected until many years after the region had been thrown open to active exploration: that upon the piles of rubbish were found growing trees which differ in no degree as to size and character from those of the adjacent forest, and that the nature of the materials with which the pits were filled, such as a fine washed clay enveloping half decayed leaves, and the bones of such quadrupeds as the bear, deer, and caribou, indicated the slow accumulation of years, rather than a deposit resulting from a torrent of water."

Mr. Graham Pope, an early pioneer thinks differently. He says: "To us the explanation is simple enough if we dismiss from our minds the troublesome theory of an ancient race coming from a far distant southern land and spending only the season of navigation here. When the Europeans made their appearance on this continent, they brought with them cooking utensils made of copper, hatchets, knives and axes made of steel, and all kinds of attractive ornaments for the person. The native Indian found it easy to obtain all these things in exchange for the skins of wild animals then so plentiful.

He found them vastly superior to any he could make from copper which he could obtain only in the form of float, or of small pieces broken from the rough edges of masses. He therefore had no longer the need of hidden copper which was obtainable by means of hard labor, always distasteful to him, and so his mining operations were abandoned forever.

Two hundred and fifty years and more had passed after the red man had discontinued his work before the white man took it upon

himself. There was then ample time for these pits and trenches to assume the appearance and condition in which they were found in 1845. There was no sign of any work done in the past other than that which could have been done by our modern Indian."

The Indians in the country had no knowledge of lodes or beds containing copper and it was many years after the country was thrown open before the workings of these ancient miners were discovered. It was then learned that almost every vein or outcrop of any value had pits some as deep as sixty feet, extending into the solid rock. At the bottom of these pits were found cartloads of stone hammers, some of which weighed as much as thirty pounds. Here masses have been discovered which were too large to be removed and the marks upon them show that they contented themselves with heating the mass and pounding off chunks. The method of mining was to heat the rock by building a fire upon it, then suddenly cooling it with water, and pounding with their stone hammers to disintegrate it. There is no indication of melting or smelting. Their efforts were therefore confined to middle sized pieces, neither the large ton masses nor the minute particles in the stamp rock attracting them.

When the knowledge of these ancient workings became known to the explorer he used them to aid him in discovering his much coveted copper lode. In this respect they have been of much use.

The discovery of America brought many people to this shore. Among these were the Jesuit Fathers who labored earnestly to establish the Christian Faith among the Indians. To them the Great Lakes offered an easy path to the interior and they soon had penetrated to the head of Lake Huron. In 1641 two priests landed at the Sault Ste. Marie and from a party of Indians learned of a great lake lying farther, which they declared was larger than any other of the great lakes.

Father Mesnard in 1660 set out from Quebec and pushed his canoe along the shore to the head of Keweenaw Bay. Here he remained through the winter and in the spring accompanied by a single Indian entered Portage Lake. In 1668 Father Marquette and Father Allouez established a permanent mission at the Sault Ste. Marie and formal possession was taken in the name of the King of France.

Two years later two Jesuit Priests explored the entire coast of Lake Superior and published a map of the Lake in Paris in 1672.

These Jesuit Missionaries failed in their attempt to colonize this district and to convert the Indians, for it was two centuries after

they came that this solitary wilderness was disturbed by other than the Indians and some adventurous voyager. They, however, left records of their adventures and discoveries and these have proven of immense value not only to historians but as records of the country. The occurrence of copper was one of the objects which attracted their attention.

The first account of the occurrence of native copper on Lake Superior was published in Paris in 1636. The author says: "There are mines of copper which might be made profitable, if there were inhabitants and workmen who would labor faithfully. That would be done if colonies were established. About eighty or one hundred leagues from the Hurons is a mine of copper, from which Truchement Brusle showed me an ingot on his return from a voyage he made to the neighboring nation."

Father Allouez makes mention of pieces of copper, weighing ten to twenty pounds in possession of the Indians, which they esteemed as domestic gods. He also makes mention of a large mass rising from the water.

The first mining operations were begun by an Englishman, Alexander Henry, who in 1771 formed a company and selected a spot twenty miles from the mouth of the Ontonagon River as the seat of his operations. He was attracted to this spot by the erratic boulder found there. During the winter they drifted into the bluff some forty feet but failing in their search they abandoned the place in the spring. They obtained some copper which probably had been chipped from the boulder.

A second attempt, equally unsuccessful but more encouraging was attempted on the north shore. Here they struck a vein after drifting about thirty feet but it narrowed rapidly and soon disappeared. The work was soon abandoned as his associates refused to advance more money. Henry, who seems to have been a good historian, gives a detailed account of his operations but in closing comments "that the country must be cultivated and peopled before copper can be profitably mined."

It has been suggested and probably with some truth that the present ownership of this district by the United States is due to the reports of these early explorers. While Dr. Franklin was in Paris, during the American Revolution, representing the interests of the colonies he probably became acquainted with the records of the Jesuit Fathers and learned of the existence of copper along the southern shore of Lake Superior. Knowing this, would not his foresight tempt him to draw the boundary line as he did? This

is particularly probable when we notice how the line curves up to take in Isle Royale (Vol. VI. Pt. I page 3).

However this may be, it is certain that the upper peninsula did not appeal strongly to the People of Southern Michigan when it was given to them. Prior to admission to the Union both Michigan and Ohio claimed a strip of land bordering on Lake Erie including what is now the city of Toledo. So great was the dispute that in 1835 when a convention assembled at Detroit to define the boundaries of the new state both sides began to prepare for a conflict.

When the matter came before Congress that body agreed to admit Michigan provided the people would relinquish their claim to this most coveted territory and to mollify their feelings offered them the little known region bordering on Lake Superior. A convention called soon after indignantly refused these conditions but later it was decided to reconsider the matter and reluctantly the state accepted the Upper Peninsula in place of the Lake Erie territory and in January of 1837 Michigan was admitted to the Union.

This ends the preliminary history of the Upper Peninsula. Just two centuries after the first published report of the occurrence of copper we find the country little changed, little known and considered of no value. Hardly, however, had this territory been acquired by Michigan than people began to realize its value and ten years later we find a fairly populous country with mining companies. This change is due in good part to Dr. Douglass Houghton and the Geological survey.

The survey of Michigan was begun in 1818-19 under the Federal Government. In the latter year Gen. Lewis Cass, accompanied by Mr. H. R. Schoolcraft in capacity of geologist, proceeded on a tour of inspection which included the south shore of Lake Superior. In July the party entered the Ontonagon River for the purpose of visiting the celebrated copper rock. Mr. Schoolcraft speaks of finding copper along the banks of the river. Many of the reports of copper that they had heard referred to this river but nothing definite was known and it was for that purpose they were making the trip.

With great difficulty they accomplished the trip but the size of the boulder scarcely met their expectations. Still Mr. Schoolcraft thought it remarkable. He says the mass had evidently been moved some distance as the adhering rock was "serpentine" and foreign to the vicinity.

This mass of copper up to its removal was the largest in the

world. In 1842 it was taken to the mouth of the river by James Paull. (Paull or Ehlreds?). Preparing a truck upon which he hoisted the rock, he succeeded by means of a windlass in drawing it down below the rapids. Here he loaded it on a flat boat thence conveying it to the mouth of the river. It was soon sold to the United States Government and has since been on the grounds of the war department at Washington. Mr. Paull remained at Ontonagon and thus became the first permanent resident of the copper country.

At the time or really just before the time of the deeding of the Upper Peninsula to Michigan, Dr. Douglass Houghton, in 1834, commenced its first systematic and scientific exploration and in his first annual report, published in 1841 presented the results thus far obtained. It was this report that attracted the attention of the world and which a few years later caused the influx of people and capital to Northern Michigan. How well he knew what the future was is shown by his words: "While I am fully satisfied that the mineral district of our state will prove a source of eventual and steadily increasing wealth to our people, I cannot fail to have before me the fear that it may prove the ruin of hundreds of adventurers who will visit it with expectations never to be realized." At the same time, however, the nature of his findings were so different from what had been known anywhere else that many laughed at him and dubbed his work as "back woods mineralogy."

Smarting under the chaff he entered into a contract with the United States Government to execute the linear survey of the northern peninsula in connection with a geological survey according to a system devised by himself. The township lines were run by Mr. Burt or under his supervision while the other subdivisions were made by other deputy surveyors. All rock outcrops were examined and specimens taken and locality noted. Besides this, special information was taken for whatever geological or topographical knowledge that could be gained. The system was fairly organized and field work for one season completed when his brilliant and useful career was terminated by his drowning on the night of October 13, 1845.

"Dr. Houghton was a man of indomitable energy and perseverance, and fervently devoted to the cause of science. Had he lived to complete this great work, he would have erected an enduring monument to perpetuate his name. He died in the discharge of his duty, prematurely for the cause of science, prematurely for his own fame."

The next survey was carried on by the United States Geological Survey. In the spring of 1847, Dr. Chas. T. Jackson was appointed to execute a geological survey of the mineral regions of the Upper Peninsula, but resigned two years later and Messrs. J. W. Foster and J. D. Whitney were appointed to complete it. They made two reports, one on the copper deposits in 1850 and the other on the iron deposits in 1851. The fact that none of the essentials have changed show how carefully this work was done.

In 1869 a joint committee of the two houses of the Legislature made a report on the subject of a geological survey of the state and in urging for a geological survey of the Upper Peninsula said: "In the meanwhile these hardy pioneers have labored and waited until now, with a population of near 35,000, a capital invested in 112 companies, for developing copper, of \$16,250,500, upon which has been paid dividends of \$5,880,000 and an iron interest which, in the twelfth year of its commercial life, produced one-fifth of all the iron mined in the United States, they have rights, and the state has duties—long neglected duties—toward them, which it were wise to no longer neglect."

Acting upon this report the Legislature brought into existence the present Geological Survey. How little the needs of such a survey were realized is shown by the introduction to the first report in 1873 by Major T. B. Brooks in which he says: "The present survey was inaugurated by act of the Legislature of 1869, which appropriated \$8,000 per year for the work one-half of which went to the Upper Peninsula. This amount was again divided equally between the Iron and Copper Regions, which gave \$2,000 per year to cover all expenses, including salaries, supplies, instruments, travelling, etc. To the \$8,000 aggregate for four years from this source the Geological Board added \$1,000 for chemical work, making \$9,000 in all received by me from the State for the survey of the Iron Regions. In addition to this sum I have expended about \$2,000 of my own means, and have not received any compensation for my services. This small sum would have been inadequate to have accomplished anything worthy of the importance of the work undertaken, had not several corporations and individuals generously come to my relief."

Up to the time of Dr. Houghton's report there was little more than a vast wilderness on the shores of Lake Superior. A mission had existed at Sault Ste. Marie since 1668. There were humble missions at L'Anse and La Pointe. At Fort Williams, on the north shore, there was a trading post, but these few places made up the

entire list of settlements. But a few years later a land office was established at Copper Harbor and in 1844 a company of infantry was posted here and their stockade named Fort Wilkins. These two establishments formed a nucleus for settlement.

This became the first camp in the copper country. It was a safe and convenient harbor. Moreover it was right on the copper range and copper had been found right on its shores. There was very little glacial drift to hinder them and the geological horizon could be readily followed. During the season of 1845 and 1846 the place became a city of white tents and it teemed with life and hope. In 1846, a subland agency was established at the mouth of the Ontonagon River. This river afforded a good harbor and it soon became a lively camp. With these two starting points it is little wonder that the two counties of Keweenaw and Ontonagon should become the places of our first active mines as well as original explorations.

Usually all lands are controlled by the Land Office, but in the case of the Lake Superior District, the War Department had charge of it. To begin with they first decided to lease the land, and permits, as they were called, were issued in Washington. They at first covered nine square miles, but it was soon found that the applications were too numerous and there would be a scarcity of land, so a change was made in the permits reducing their holdings to one square mile. "These permits were authority for taking possession of any lands not otherwise claimed. The holder of the permit was allowed one year for exploration, and three years more to mine, with the privilege of two renewals of three years each, making the whole term of occupancy ten years. The department required returns to be made to the Mineral Agency giving an account of the work performed and the mineral raised, and a payment to the mineral collector at the rate of twenty per cent of the mineral value. The term of the grant, or lease, was presumed to be ample to enable the fortunate holder thereof to realize immense gain—such wealth as would enable him to leave his mine, plant and improvements without regret, free to the next comer. In the days when permits were issued they were much sought for. The holder of one of these pieces of paper considered himself a rich man. So valuable was the whole copper district considered to be that it mattered little where one plastered his permit. People were simply wild—hence after an examination, many a rich location was found to be entirely worthless, was not on the trap range, or was covered fathoms deep below Lake Superior; money was made

by the sale and transfer of these permits, but the last holder had the grim satisfaction often of knowing himself sold."

Afterwards commissions were appointed to appraise the mineral lands and they fixed upon a price of five dollars an acre. Later, however, all lands were sold at the price of one dollar and a quarter an acre. By the laws of Michigan no corporation could hold more than ten thousand acres but a later amendment allows mining and manufacturing companies who use charcoal largely to own fifty thousand acres.

The speculative craze commenced in 1843 when the cession of the land to the United States by the Chippewas was ratified. During the summer of this year a Mr. Raymond made certain locations, three of which he disposed of to the Pittsburg & Boston Mining Company, who began mining the summer of the following year. "The first location made was at Copper Harbor, where the outcrop of a cupriferous vein on what is now called Hays Point, was a conspicuous object, known to the 'voyageurs' as 'the green rock,' and had given a name to that beautiful harbor long before it became the center of the copper excitement. A little work was done here in the autumn of 1844, but on clearing away the ground on the opposite side of the harbor, where Fort Wilkins now stands, numerous boulders of black oxide of copper were found, evidently belonging to a vein near at hand, which was discovered in December, and proved to be a continuation of the one worked on Hays' Point.

Mining was commenced here immediately; two shafts were sunk, about a hundred feet apart, and considerable black oxide of copper taken out, mixed with the silicate. This was very remarkable, as it is thus far the only known instance of a vein containing this as the principal ore, or in any other form other than as an impure mass, mixed with the sulphuret of copper and oxides of iron and manganese, and resulting from the decomposition of the common ore, copper pyrites. This proved, however, unfortunately to be only a rich bunch in the vein of limited extent, and which gave out at the depth of a few feet, although the fissures continued." About thirty or forty tons of oxide were obtained.

Finding that their present location would not pay for further development the company turned its attention to its other properties, among which was the Cliff vein discovered in the summer of 1845. This vein was first discovered on top of the large greenstone bluff. Here it appeared to be but a few inches wide containing native copper and specks of silver. During the succeeding fall a

drift was carried into the greenstone a distance of about one hundred feet, but did not prove encouraging.

About this time it was examined by Dr. Jackson and Mr. Whitney who reported that the surface indications were not favorable but because it seemed to widen out and become richer in depth they advised a thorough examination at the base of the cliff. During the winter the miners discovered a small mass while clearing away the talus at the base. This stimulated their search and soon the vein was traced into the amygdaloid. From this point a drift was carried into the vein when, after having proceeded seventy feet they struck a large mass—"a fortunate circumstance, not only to the company, but to the whole mining interest on Lake Superior. It gave encouragement to those engaged in these pursuits, and induced them to persevere. It also demonstrated the true source from which the loose masses occasionally found on the lake shore had been derived. It demolished the fanciful theory advanced by at least one geologist as to the transport of the Ontonagon mass from Isle Royale, and showed that it was not necessary to resort to icebergs and changes in the relative level of land and water to account satisfactorily for its position." (Foster & Whitney.)

To this mine the Copper Country owes much. It acted, we might say, as the fly wheel which carried the country through the depression of 1847 following the wild speculation, when the country was almost deserted. It became a success from the start and in 1849 paid its first dividend, of \$60,000, over half of what had been paid in on its capital. Before this time many people had been looking for sulphurets, thinking that the conglomerates and sandstones were the original source of the copper. After much dearly bought experience the explorers began to realize that in and only in the trap range could they expect to find copper. It did, however, have one bad effect, and that was to completely turn the attention of the miners toward fissure veins. They considered it the one thing needful. This was an easy task owing to the bare escarpments facing the south all along the range. Veins crossing the formation and dividing the cliff would be detected in exposed places or the deep breaks would point out them.

A large number of mines were soon located upon these fissure veins. Among those may be mentioned the Phoenix, Central, Conglomerate, Copper Falls and many others. Many of these paid for themselves but all were started with extravagant ideas of wealth. One of the early reports of the Phoenix very readily illustrates this. "The whole known length of the vein is about eighteen hundred

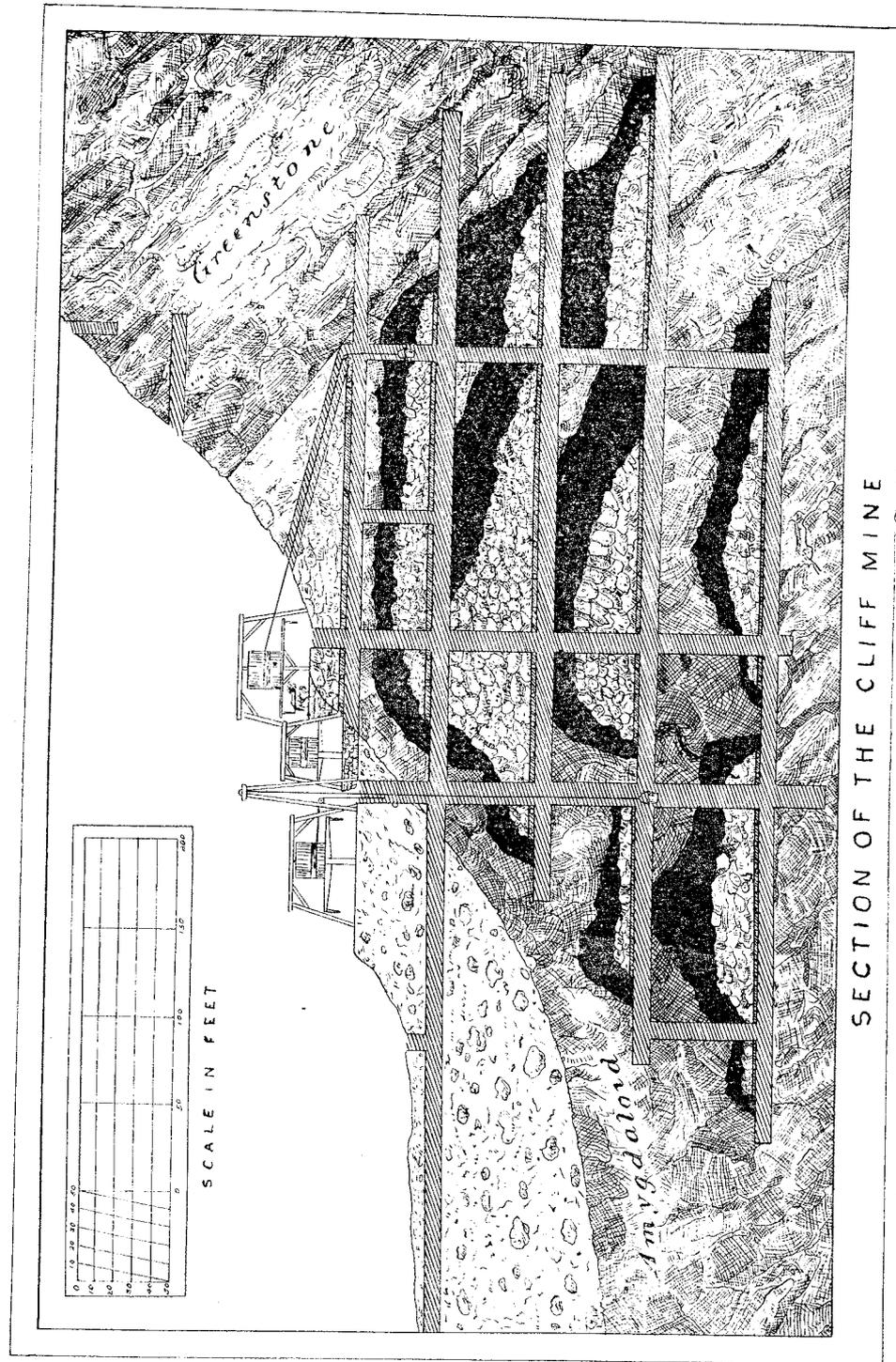


Fig. 62. Cliff mine in 1850. Sketch by A. H. Meuleke, after Foster & Whitney.

feet. Its width is satisfactorily proved to be eleven feet for a distance of two hundred feet; and it is probable that it will hold a workable width throughout the eighteen hundred feet. It is obvious that there is an adequate quantity of rich ore in this vein to render the work very profitable, and that there is no danger of exhausting the ore, even should it give out at the depth of one hundred feet, of which there is no probability. If the ore runs out at a considerable depth, say two hundred feet, it will be a matter of little importance to the present generation, though it might be to posterity."

Leaving Keweenaw county with its fissure veins, the next point to be developed was Ontonagon county, where the vein parallel to the formation is the source of copper. Here the first mine of any great value, the Minnesota, was discovered by the discovering of the ancient mines. Mr. Samuel O. Knapp, during the winter of 1847-48 observed a continuous depression in the snow, then three feet thick. This snow had been so little disturbed by the wind that it followed closely the contour of the ground. "Following up these indications along the southern escarpment of the hill, where the company's works are now erected, he came to a longitudinal cavern, into which he crept, after having dispossessed several porcupines which had selected it as a place of hibernation. He saw numerous evidence to convince him that this was an artificial excavation, and at a subsequent day with the assistance of two or three men, proceeded to explore it. In clearing out the rubbish they found numerous stone hammers, showing plainly that they were mining implements of a rude race. At the bottom of the excavation they found a vein with ragged projections of copper, which the ancient miners had not detached.

"The following spring he explored some excavations to the west, where one of the shafts of the mine is now sunk. The depression was twenty-six feet deep, filled with clay and a matted mass of mouldering vegetable matter. When he had penetrated to a depth of eighteen feet he came to a mass of native copper, ten feet long, three feet wide, and two feet thick, and weighing over six tons. On digging around it the mass was found to rest on billets of oak, supported by sleepers of the same material. This wood, specimens of which we have preserved, by its long exposure to moisture, is dark colored, and has lost all its consistency. A knife blade may be thrust into it as easily as into a peat bog. The earth was so packed around the copper as to give it a firm support. The ancient miners had evidently raised it about five feet and then abandoned

the work as too laborious. They had taken off every projecting point which was accessible, so that the exposed surface was smooth. Below this the vein was subsequently filled with a sheet of copper five feet thick, and of an indetermined extent vertically and longitudinally." (Foster & Whitney.)

This mine during the early history of the country stood next to the Cliff as a producer. The remarkable results of these two established the reputation of the respective counties and generally the prospectuses of the mining enterprises referred to these as examples, though in fact they were the exceptions. To the Minesota we must give the credit of having produced the largest mass of native copper. Its greatest length was forty-six feet, the greatest breadth eighteen and one-half feet, and its greatest thickness eight and one-half feet, and had a weight of over five hundred tons. This one mass took twenty men over twenty-three months to cut up. The success of the Minesota prompted the miners to locate upon similar deposits with varying degrees of success. Among the more successful stand the National, Ridge and Mass.

These early mines were all mass mines. They cared little for the stamp rock, using crude methods of dressing it, thus obtaining a small percentage of the copper. Owing to the wonderful tenacity of the metal these masses were difficult to handle and required special methods of mining. When one of these masses was encountered a chamber was generally picked out from one side and under it. It was then loosened by levers, but if this proved impossible an excavation was commenced behind the mass, being made large enough to receive from five to thirty kegs of powder. Bags of sand were used to tamp the charge and the drift is barricaded by refuse and loose dirt. The famous Minesota mass required 110 kegs or 2,750 pounds of powder before it was dislodged. First five kegs of powder were used. This was increased until after four futile attempts thirty kegs were used. This shot tore the "immense body from its bed without exhibiting sign of breaking or bending in any place, so great was its thickness and strength. It was torn off from other masses, which still remained in the solid rocks."

These huge masses of copper were too large to be handled and had to be cut up. The copper cutters first marked off the mass into blocks or squares. The tools used were simply narrow chisels and striking hammers. The chisels were made of flat bars of half-inch steel about two inches wide and eighteen inches long. The cutting edge was a little wider than the thickness of the bar so as not to cause the chisel to jam in the cut. A slice was then

taken across the mass of the copper. This slice was flat, about one-eighth inch thick and half the length of the cut, owing to thickening while cutting. In this way a narrow cut was carried through the copper. The contract price was twelve dollars a square foot, at which rate the cutters made about two dollars a day.

These masses were taken to surface and dumped on a pile of logs. When enough masses had accumulated the logs were fired and the whole heated to redness. This disintegrated the adhering rock, which was mainly calcite, so that when cooled it could be knocked off by pounding. They were then marked and shipped to the smelting works where they were melted down in reverberatories.

This early practice of cutting masses by hand is still in use. The greatest difference is that instead of cutting a flat strip they now take out a wedge strip, being thicker on one side than on the other. This arrangement is alternated so that in the next cut the thick side will take the place of the thin one. Instead of heating to disintegrate the rock it is usually pounded off either by a trip hammer or a regular steam hammer.

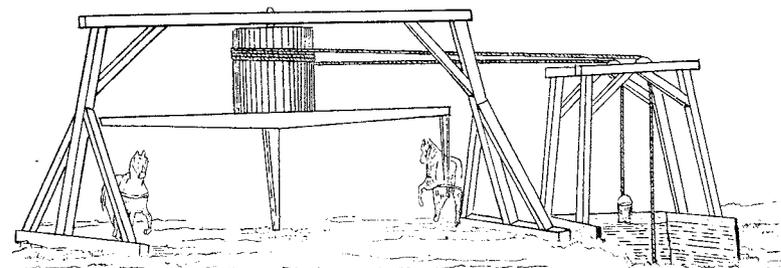


Fig. 63. Horse whim. Sketch by A. H. Meuche, after Foster & Whitney.

The machinery used before 1850 was very crude. Horse whims were then used for hoisting mineral and water. These are best illustrated by the cut in Foster & Whitney's report. The drum at the top held the rope, one end of which was unwinding while the other was being wound up. Thus one bucket, or kibble, ascended while the other descended. Water power could not be relied upon owing to the severe winters which often choked off their supply of power. "In the stamp mills, during the intensely cold weather, it becomes necessary to resort to fires to prevent steam from congealing on the engine, in long icicles, and the ice from forming on the stamp heads." (Foster & Whitney.)

At the stamp mill they had but a few batteries of Cornish Stamps. These consisted of three or four wooden pestles with iron shoes. A cylindrical wooden shaft, with cams, revolving horizontally, successively caught into the shoulders of the pestles and raised them to the required height. They then fell into the oblong cast iron trough which was fed with ore from a hopper above.

These wooden machines were well suited for the country. Wood was cheap, while transportation of better machinery was difficult and expensive. These old Cornish Mills soon became changed as transportation facilities were bettered. The wooden parts were changed to iron and the entire machine being made more adjustable until it assumed the type known as the California type.

The ore mined was divided into three classes: mass, barrel-work and stamp-work. The mass copper consisted of those enormous masses for which the country soon became famous. Masses of less than fifty pounds were dressed by a hammer and barrelled in casks holding from five to eight hundred pounds. This barrel work was estimated at fifty per cent pure copper. Stamp-work included all veinstone with sufficient copper to send to the stamp mills. With the crude arrangements very little copper was saved this way and only the richest pieces of rock were stamped. There was no defined method of washing and only the larger pieces of copper were saved.

The adoption of the skip is characteristic of the change in mining the bedded lodes instead of the vertical fissures. In the fissure mines the vertical shaft was used and the bucket answered very well. The inclined shaft was better adapted for the bedded lodes and even though, at first, they did adopt the bucket it was necessary to slide it along a set of wooden guides at a great waste of power.

Skips were first used at the Ridge mine in Ontonagon County and the report in the Mining Magazine 1856 is of interest. "Their stuff is hauled up on trams laid down the shaft on the inclination of the vein—about 45° —which seems to answer the purpose well. And it is certain that an immense amount of friction is avoided by this plan, if there proves to be no difficulties in its practical operation. Where the vein is so flat it seems to us that its advantages are obvious."

During this period of development the Portage Lake District was lying dormant. It can be seen at a glance that its natural advantages are greater than those of either Ontonagon or Keweenaw

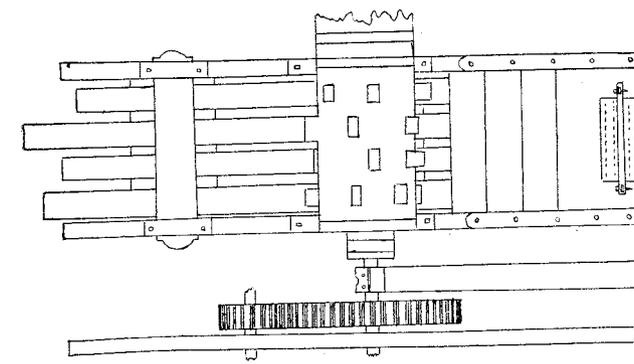
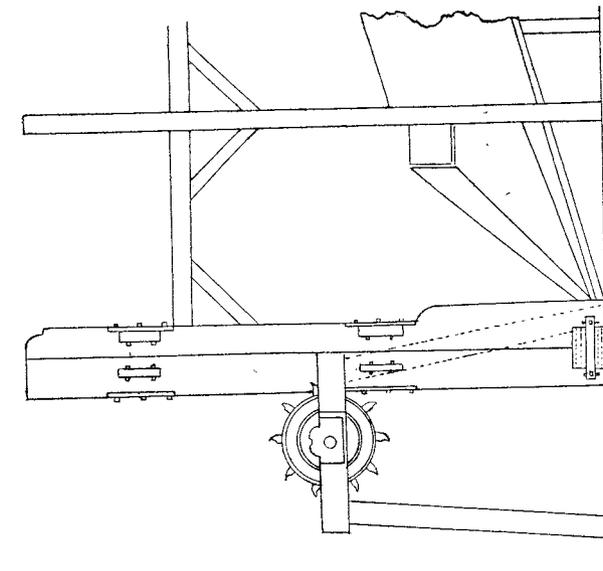


Fig. 64. Cornish Stamp mill. Sketch by A. H. Meuche, after Foster & Whitney.

counties. It lies midway between the two named counties. Portage Lake cuts across the range at the place now occupied by Houghton and Hancock. At Torch Lake some sixteen miles distant from Houghton the shores come within a mile of the range. The shores on the north side of the Lake rise abruptly and at a point half a mile back obtain a height of six hundred feet. Those on the south side are not quite so abrupt, attaining a height of four hundred and fifty feet a distance of one mile from the shore. Mines located near the shore could easily bring their mineral to the shore by means of tramways. There is plenty of water here to run any or all the stamp mills.

There were, however, two great disadvantages to the locality. The first and probably greatest disadvantage to these early miners was the fact that the copper occurred in stamp rock and not as masses. This difficulty has now been more or less overcome at the present time and even though all the copper cannot be extracted, enough can be readily extracted to make the mining of these lodes profitable.

The other disadvantage is in prospecting. The country is rather heavily drift covered so that outcrops are few. These outcrops generally consist of the traps as they are harder and more resisting than the amygdaloids. Hence the copper, which is in the amygdaloidal part of the lava flows, is generally hidden by a layer of detrital matter. This drift, in covering the trap range, hinders the explorer not only in hiding the copper from him but is of much annoyance in other ways. This drift has masses of copper scattered through it and even to this day we hear reports of copper deposits, "just like those of Keweenaw Peninsula," from points as far south as Ohio. It has also been misleading to many explorers right on the trap range. South of Wheal Kate, even into Ontonagon County, the drift is as much as four hundred feet thick. Such a heavy overburden makes diamond drilling very hard and expensive, and even though a promising bed may be located, the cost of sinking a drop shaft may be as much as one thousand dollars a foot thus making the work prohibitory. Hence explorers and mining men are very slow in doing much work in this heavily drift covered section.

During the first few years of the copper country many men came to the Portage Lake District. They came in the early spring and returned to their homes with the approach of winter. The first winter work was in 1846-47 when two parties engaged in mining at two different points. One party drifted an adit under Douglass

Houghton Falls and opened the surface of the rocks at many places in the neighborhood. The work at Wheal Kate was not any more successful although they continued with it until 1853 when the work was permanently closed. Mr. Graham Pope with his dry humor tells of the methods of paying the men at the Wheal Kate Mining Co. "In the absence of a banking system Capt. Pryor paid his men with orders on Capt. Edwards, who in turn, paid them with orders on John Senter, then engaged in business in Eagle River. When a workman wanted money he could easily get it from Mr. Senter after walking twenty-five miles through the forest with his order. Mr. Senter never told these men to come some other day."

In 1848 the Quincy Mining Company started exploratory work on the north side of the lake, but for many years had no satisfactory results. In 1852 the Isle Royale lode was discovered. This was the first amygdaloid lode discovered that contained a workable amount of copper. In 1853 the fame of the Isle Royale lode was spread abroad and many mining companies were started to work it. The Portage lode was found two hundred feet west of the Isle Royale and the Portage Mining Company was organized to work both lodes. During this year the Huron Mining Company was organized with Boston capital to work the southern continuation of the Isle Royale lode. This caused great rejoicing as it was the first large investment of Boston capital here. The first steam boiler in the Portage Lake district was installed at the Isle Royale mine with a horizontal engine of twelve horsepower. When the whistle blew at noon for the first time all men quit work for the day and indulged in a holiday for the occasion.

"In the spring of 1854 the Huron Mining Company decided to use steam power at one shaft and a purchase was made of a locomotive boiler with engine and drum attached. Capt. Bennett made up his mind that that plant should go up the hill by means of its own power. So with an equipment of rollers, blocks, and tackle, with steam up and a lad of fourteen years, C. D. Sheldon, at the throttle, a start was made with Capt. Bennett in charge of the blocks. The people assembled in great numbers to see the work, and voted it better than a circus. During one performance Bennett rushed down the hill at great speed using language carrying a high percentage of profanity. When Sheldon got block and block he found a number of Bennett's fingers on the ground, and then knew what was the matter with Bennett. They got the plant up to the mine, a mile and a half in ten days." (Pope.)

Another amusing experience in regard to the early use of steam power is told by Mr. Graham Pope when they brought in the boilers for the Albion Mining Company in 1854. At that time no canal had been cut at the Portage and the Entry was not navigable for large boats. When these boilers were brought to the Entry no lighters were to be had on which these boilers could be placed. "Finally under the charge of J. B. Lyon, all the openings being plugged the boilers were launched overboard. One of these came back at the steamer and knocked a big hole in her side, but fortunately, above the water line. The boilers were well roped together, the domes being kept upright by means of heavy planks bolted across them. A large sail was hoisted and the boiler catamaran sailed into the river. A large Mackinaw sail boat was then chartered to go ahead with a long cable and the whole outfit sailed up Portage River and Portage Lake fifteen miles to Houghton, where the boilers were pulled ashore by cattle power."

In 1856 the great Pewabic amygdaloid was uncovered by the Pewabic Mining Company organized three years previously. The lode was immediately located by the Quincy Company and from that time forth the advancement of this district has never halted. The Franklin Mining Company was organized in 1857 to work the Pewabic lode and was under the same management as the Pewabic.

These companies decided to build mills during 1858. Both the Pewabic and Franklin mills erected Ball steam stamps. These were the first to be used and they mark an epoch in the history of the copper country. These first stamps were put in under a guarantee to crush twenty-five tons per twenty-four hours. It developed, however, that they were able to do almost twice this much work.

The success of the Pewabic attracted eastern capitalists and the Mesnard, Dorchester, St. Marys, and Albany and Boston Companies were organized to work the lode to the north. The St. Marys and Albany and Boston Companies did not succeed in finding it but opened up the Albany and Boston conglomerate which, while looking good did not prove profitable.

In 1859 the producing mining companies organized the Portage River Improvement Company and dredged out the Entry so that in November, 1860, the steamer Illinois drawing ten and one-half feet of water came to Houghton with 400 tons of freight on board. The work was continued the following year so that it could accommodate any boat able to pass the "Soo" locks which had been completed in 1855. Thus the boats could be loaded at lower lake

ports and brought direct to Portage Lake docks without any portage or use of lighters.

In 1864, Mr. John Mabbs became agent of the Isle Royale mine. To him we are indebted for some of the saving methods which took place. He introduced the large drum for deep winding by installing one of 16 feet diameter at his mine. He induced Mr. Rand who had introduced a heavy drill for tunnelling to make a light and portable one for mine use. With some old engines at the mine he made a compressor and with cast iron pipe conducted his compressed air underground, thus introducing the power drill to the mining world. To him we are also indebted for introducing the diamond drill, having bought an unworkable one in Chicago.

Mr. Mabbs also introduced high explosives, the story of which is told by Mr. Pope. "In 1870, I think it was, but possibly in 1869, Mr. Mabbs bought in New York 4,000 pounds of nitroglycerine oil which was contained in one hundred tin cans. The oil was thirteen times stronger than the black powder then in use. About this time a number of terrible accidents occurred from the use of this oil, and a great outcry rose against it, but after much trouble he persuaded one of the Pennsylvania coal carrying roads to take it. Unfortunately news of its shipment was sent forward when a mob assembled and stopped its passage. It was then sent back one hundred miles, transferred to another road and finally reached Cleveland. Mr. Mabbs, fearing arrest for violating the city ordinances, was anxious enough to get away, but could get no steamboat to take it, and as few sailing vessels were bound for Portage Lake it was only after great trouble he was able to persuade a master to take it to a powder magazine above Hancock. The Hancock authorities, having heard of its presence promptly ordered it out of the place and it was removed to an old stope in the mine. A few days after this, orders came from the east to close the mine, and he had time only for a few blasts. Nothing disheartened he persuaded the Huron mine agent to allow its use there with the understanding that he was to do the blasting. He put up a little magazine back of the burrows and under cover of darkness put there one can only of oil, containing forty pounds. The miners became so excited and furious that they stopped the mine. A great mob gathered and preparations were made to ride the enterprising agent out of the place on a rail, but they did not get him. That night they blew up the magazine thinking all the stock was there. It having leaked out that there was more of it searching parties were formed to get it. It was moved half a dozen times just in