

time to save it, and finally it was hidden in the woods just east of where the Mining School now stands. Mr. Mabbs and his brother had in each case handled the oil themselves. They finally loaded it into a yawl boat and started with it for Marquette, which place they reached in safety after a narrow escape from being lost in a storm on the lake. They got permission to try it on some of the hard heads in the iron mines, and were so successful that they had no trouble in closing out their stock and the use of this material was continued there to a limited extent until the present method of making it was adopted, when its use became immediately general." (Pope.)

Early in the fall of 1864 a discovery was made in the woods thirteen miles north of Portage Lake. At that time there were no mines near there and no settlement to induce any search. It was here on Sept. 17, 1864, that Edwin J. Hulbert first located the famous Calumet conglomerate. Hulbert was a surveyor, and during the summer of 1858 he noted a violent deflection of the needle on Section 23, Township 56 North, Range 32 West. This put him on the alert and he carefully noticed signs for mineral discovery. He soon found pieces of conglomerate containing copper but different from any other conglomerate by being brecciated. Later he discovered a big block of it that was covered with moss and a depression which he took to be an ancient pit. With these for aids he after careful and diligent exploration discovered the famous belt. At his suggestion Section 13 was bought and the Calumet Mining Company formed. Later the Hecla Mining Company was formed and Section 23 bought.

One peculiar fact is that the only place where the Calumet conglomerate held a paying amount of copper was bought by Hulbert's advice. Companies were formed to work the extensions of it both to the north and south but were unsuccessful. Another peculiarity is that this conglomerate is the only one that can be considered of value. It is true that the Allouez and Albany and Boston have worked on the Allouez conglomerate but their success is not very noteworthy. The Tamarack is now working the Calumet and Hecla but cannot be considered as working another part of this belt.

As most people know the Calumet and Hecla soon established itself as the largest and richest of any mine in the world. In 1872 it produced 8747 tons of refined copper and during that time paid \$2,800,000 in cash dividends. Is it a wonder, when a mine in its seventh year pays dividends greater than its capital, that the

copper country should become famous and draw largely on Eastern capital? As one writer says: "First in the history of the copper country of Lake Superior, fissure veins, charged with enormous masses of metallic copper, had to gain favor; next stamp lodes had to fight their way into popular estimation, and lastly, the conglomerate belts astonished the scientific world."

The year of 1875 can be considered the close of a second epoch in the history of the copper country. During the first period we have the growth of the mines of Keweenaw and Ontonagon Counties. Then the mining industry began to fill in the intervening space forming the Portage Lake district. During our second period we have the growth of this intervening country until it is on a solid footing. In our third period the amygdaloid mines of Houghton County become the chief source of copper while the mines of its neighbors begin their decline. At our present day the amygdaloidal deposits are being found farther north and farther south and following closely upon it are the Portage Lake mining methods. With these changes, Keweenaw and Ontonagon counties once more become the undeveloped regions of the copper country.

By this time the explorer was a man of many accomplishments. He was well versed in woodcraft, knew something of the geology of the country, has studied the working mines and if necessary could do some surveying. Usually his attention was first called to float copper. This float had been torn from the lode and carried along by the glaciers. Upon finding this he would turn in the direction from which the glaciers came attempting to discover if the float became more frequent. If such were the case he kept on until he came to a line beyond which there was no float. At this point he directed his men to trench across the formation or rather at right angles to the strike of the lode. After the lode was found, pits were sunk on the longitudinal course of the lode to sufficiently prove its value. At this time it was believed that lodes which did not show at surface sufficient percentage for regular mining, would not pay farther down. During the last few years, however, this idea has been abandoned. In many mines paying shoots of copper are not found until a depth of a thousand feet or more is reached.

If, however the pits did prove encouraging one or two shafts were sunk to a depth of about one hundred feet. This depth, however, was not fixed, the deciding point being whether the ground were solid enough to allow drifting on the lode. This drift was then run in a horizontal direction along the lode and if two shafts were sunk the one from the other shaft meeting this one connected these

shafts. As these shafts are usually from three to fifteen hundred feet apart a good-sized block of copper ground was thus exposed on four sides and if sufficiently rich a permanent plant for mining operations was erected.

Besides this method of exploring the diamond drill was beginning to come into favor. This helped not only in locating copper deposits when hidden by the drift but when found were of some importance in proving the value of the lode. This proof is used only for deciding whether it will pay to further explore by sinking and drifting on the lode. The Quincy was beginning to use the drill for underground exploration in their mine. Here the copper occurred in scattered paying sheets but which would not pay to work if it were necessary to break down all the rock in order to find them.

The compass and dip needle were and are not as a rule used, though it can be seen by referring to the discovery of the Calumet conglomerate that it is of some use. There is certainly a deflection in the vicinity of the richer copper belts.

In the conglomerate and amygdaloidal mines the shafts were sunk in the copper bearing rock. The number of shafts depended upon the size of the mine and the length of the lode which lies on their property. They varied in size, but 10x14 feet was an average size. They were cribbed from surface to solid rock with square timbers and planks and were divided into two or more compartments. One compartment was used for hoisting, another for a ladder way and a third for pipes and pumps. These shafts were continued down on the lode to any depth which might show copper values in paying quantities.

Levels were laid off from the shafts at convenient distances, ranging from sixty to one hundred and twenty-five feet. These levels were usually six feet high and four feet wide and ran in almost horizontally connecting all the shafts. A slight grade was made rising away from the shaft so that all the water could be conveyed to sumps near the shafts. These mines, however, were not wet and a small pump working but part of the time would take care of all the water.

Between the shafts, for the purpose of ventilation and convenience in stoping, minor shafts or winzes were opened up. Thus a longitudinal map of the main workings of a copper mine could be compared to a map of a city plat, the shafts and drifts being the streets while the winzes would represent the alleys. These solid blocks of veinstone thus laid off were, if the whole lode were work-

able, taken out except for pillars of rock left to support the hanging wall and keep the mines from caving. Heavy shaft pillars had to be left and companies who did remove these were always confronted with a constant and increasing expense.

The method of working was overhand stoping, being done either by hand or by compressed air drills. At this time, however, the air drills were not in great favor as they were very heavy and much time was lost in setting them up and moving them. "No attempt is usually made to fill up the space left by what is taken out of the mine, unless the material is close at hand. In the bed called the 'Ashbed,' at the Copper Falls mine, immense chambers, seventy-five feet square have been left without any support of any kind. The roof is very firm and has stood for many years, but there is no excuse for such methods, for eventually the roof must yield.

There must come a time when wooden props will crush, and then the future of the mine will be compromised, even supposing the shaft or level is kept in order. If a timber be replaced, it must be every time shorter, as the roof descends the surface water is let in, and constant expense of repairs necessary, as witness some of the first levels of the Calumet & Hecla. After a certain time the openings will be either too low to work in, or the roof must be taken out, a hazardous and expensive operation in yielding ground. If the proper pillars had been left, the workings would have remained good for years.

Each company is obliged to own woodland and to select the best of their wood for supports or, as is the case of the Calumet, go long distances, and raft their wood. The method is otherwise bad, as when the ground begins to crack, the superficial waters must come in.

In looking at the vast chambers in many of the mines without any support of any kind, one has an involuntary feeling of dread lest the roof should cave. The solidity of the ground is remarkable, but it must one day give way. The immense amount of rock which has been thrown on the burrows suggests the advisability of filling the old workings of the mine with it and this has sometimes been done in a limited way. If it had been adopted as the policy at the commencement of mining operations, much would have been saved by it." (Eggleston in 1877.)

The rock was picked as much as possible in the mines, the poor rock being left there, and the rest sent to surface. In dumping the rock into the skip, the skip was usually supported upon a beam of wood thrown across the track. Thus the strain of "dumping on

the rope" is eliminated. When filled a signal would be given for hoisting and as soon as the skip reached surface another man would give signals informing the engineer when the skip had approached the dump and when dumped. Some skill was required at this position as any failure on his part might cause the skip to be pulled to the top where it would be caught while the rope was pulled in two.

Skips were made of half inch rolled iron and would hold from one to two tons but these small skips are now used only for exploration work. Many of the present mines use skips holding as much as eight tons of rocks.

The cables which were used for hoisting the skips were of iron or steel. In order to lessen friction and to prevent corroding they were greased with coal tar. "As this substance is always acid from the process of refining the petroleum, this greasing often does more harm than good, as it corrodes the strands and weakens the rope. It would be very easy to saturate the acid, by adding lime and boiling before using as is done in Pennsylvania, but it is not generally done." (Eggleston.)

The drum of the hoisting engine was so arranged by means of marks on it and by a tell-tale dial that the engineer could tell the position of the skip. The velocity was regulated by a strap brake passing around the revolving drum. It was attached to a very long lever of wood upon which the engineer would sit, bearing more or less of his weight.

The present dumping arrangement is the same as was then used. The front wheels were allowed to drop in between the rails while the back ones being wider were carried up the incline. The contents were in this manner dumped onto the grizzlies, the finer pieces falling through while the larger pieces slid into the rock house. These large pieces were usually broken by large sledges but the Calumet and Hecla had installed a steam hammer. This broken rock was then loaded into a tram car and sent to the rock house. One rock house had to answer for a number of shafts, being connected to them by means of an elevated tramway known as the Frue Automatic tramway. The product was then crushed by Blake rock crushers, just as large in size as is in use at present, and stored in bins.

At regular intervals this rock was sent to the stamp mill usually located on the nearest lake. The abundance of water is of great importance. The mass mines were no longer the paying ones and were it not for the fact that the finer particles were readily re-

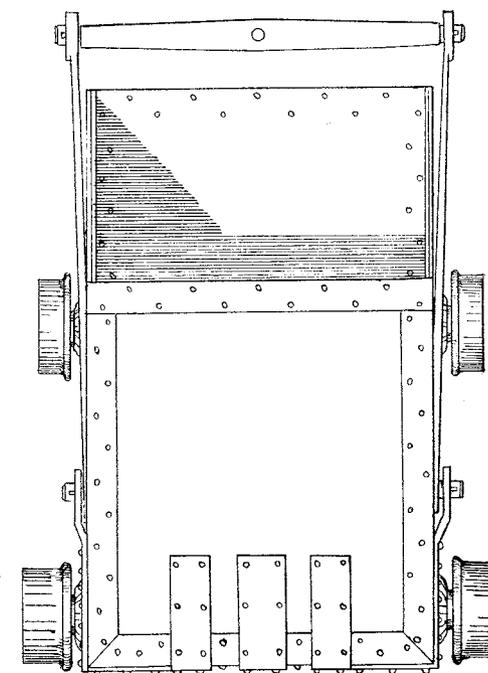
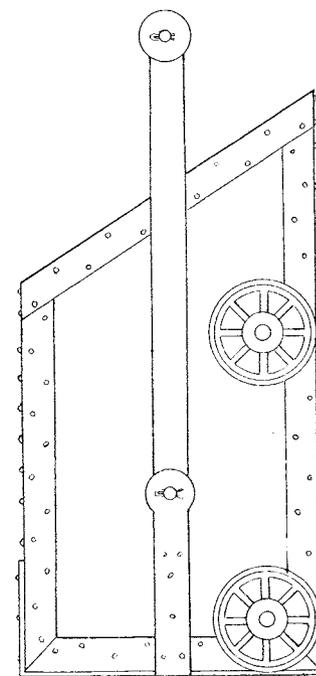
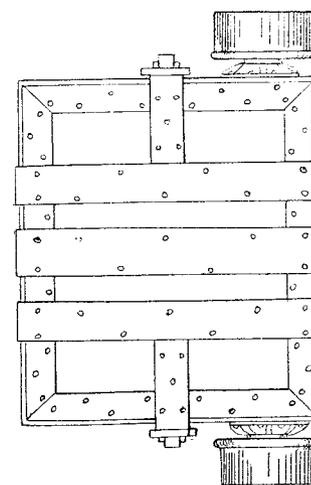


Fig. 65. Atlantic skip.

covered. Keweenaw peninsula would not long have remained a mining region.

At these mills the rock was thrown into the hoppers of the steam stamps. Unlike the present steam stamp these were on spring timbers and a foundation of wood. These stamps were nothing more than steam hammers but the stroke was made regular by having the valves to the steam cylinder operated by an independent engine. This engine was also used to run the washing machines, lathes, etc. A stamp with a twelve inch cylinder making 80 strokes per minute could stamp 120 tons of rock per day with a boiler pressure of 87 pounds.

The next machine to interest us is the Collum Jig. Here the crushed rock is separated from the copper. The crushed rock mixed with a large amount of water spreads itself evenly upon a wire screen, through which a pulsating stream of water flows. The object of the pulsations is to keep the particles in motion thus allowing the heavier particles to settle to the bottom and the lighter ones to collect on top. Those pieces heavy enough to overcome the upward current of water and small enough to pass through the screen fall into a catch box below. The lighter particles are gradually worked off as fresh ore is being constantly added. This machine makes three products; hutch, ore that which falls through the screen, being largely copper, those heavy pieces, mainly copper, that stay on the screen and the tails, which pass over the end of the screen and go to the waste launder.

The slimes which are made by crushing the rock are treated on the Evans Slime tables. This consists of a flat cone having a slope of one in twenty-five, upon which the slimes are deposited. This table revolves and the slimes being deposited upon the table, the water runs down and off the table going to waste. The heavy particles which remain on the table are washed off into a box. These heads are later keeved and a certain percentage of copper removed from them.

In some of the mills the heads, instead of being keeved are treated upon a precussion table. This table was the forerunner of the Wilfley table and operates very similarly.

At this time the tailings from the mill were run to a tail house where the No. 5 copper was recovered. These tail houses hardly paid for their maintenance. While some copper was recovered it took over fifty operations, most of which were manual, to get it. Their main use was to act to some degree as a check on the working of the mills. They were soon abandoned.

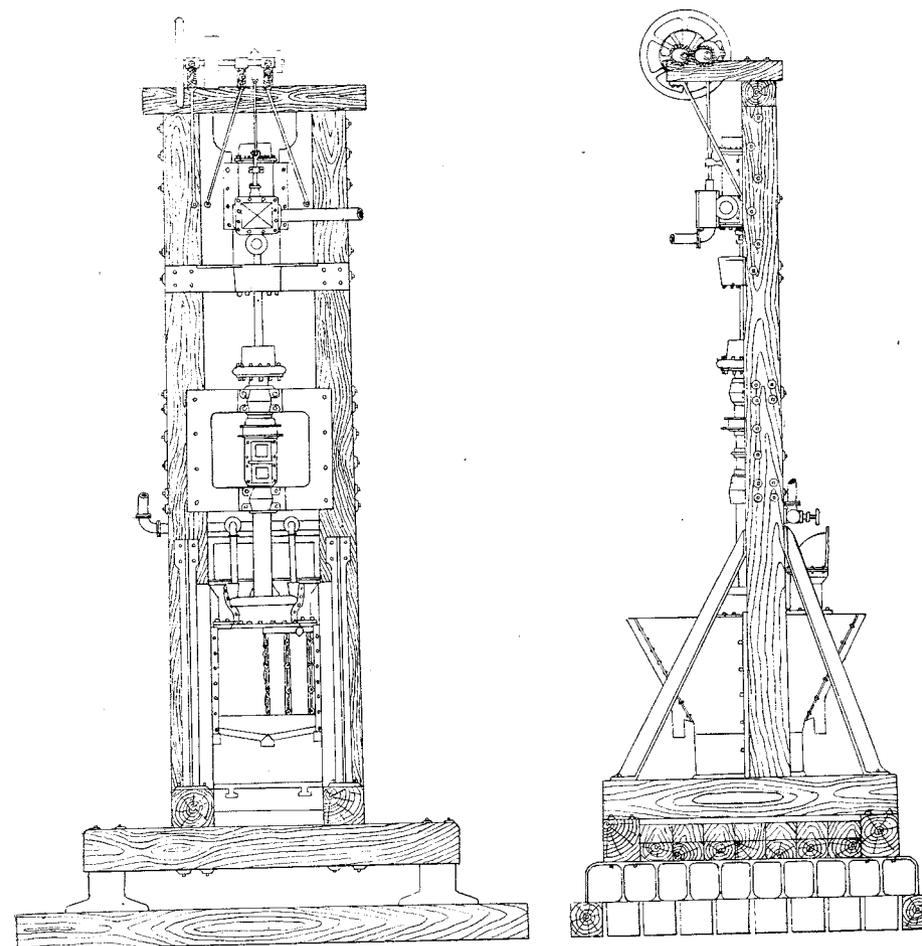


Fig. 66. Ball Stamp of 1875.

"The difficulty of the region does not lie in the want of copper for there is an abundance of it, nor in mining, for, in general it is skillfully done, but in dressing. The following assays of tailings from washers yielding the different grades of copper, I made in the winter of 1875-6. The samples were taken from a mill whose ore yielded less than two per cent.

Tails from Nos. 2 and 3, copper.....	1.325 per cent.
Tails from Nos. 2, 3 and 4 copper....	1.210 "
Tails from Nos. 3 and 4 copper.....	1.030 "
Tails from Nos. 5 copper.....	1.360 "

Much of this copper is attached to small pieces of rock and is carried off with it. This has led to re-stamping the tails, as is done in the Calumet and Hecla; this produces other rich tails, and a large loss in float copper." (Eggleston.)

During this time of gradual development in the mines and stamp mills an equal development was taking place in the smelting of the mineral. The first attempt to smelt copper in the copper country ended in failure. Up to 1850 all the copper was smelted in Boston and Baltimore. The masses were a new proposition to the smelter. All refining furnaces had small side door openings for the charging of the copper ore. At the Baltimore works a large side door was made and masses were dragged into the furnace by chains passing through a door opposite and fastened to a windlass. The result of such a method of charging was serious damage to the furnaces.

The famous "Lake Brand" of copper was originated in 1850. A Mr. Grout together with some brass companies in Waterbury, Conn., organized the Waterbury and Detroit Copper Co. Their object was to get a brand of copper on which they could depend. Before this other brands of copper were not even in quality and equal to their requirements. With this in view the Detroit works were built in 1850 and Mr. James R. Cooper was put in charge.

In 1860 the Portage Lake Smelting works were built in Ripley and they began refining copper in 1861. The Calumet and Hecla sent their product here. In 1867 these works were consolidated with the Detroit works as the Detroit and Lake Superior Copper Company. Thus the position of Lake Copper has been maintained,—not so much to the superior character of the copper but to the purity due to the care in refining.

A few years later than this the various mines erected their own smelters. The initiative was taken by the Calumet and Hecla in

1886. Rolling mills had been erected by 1877 and copper wire and sheets were manufactured in the copper country. This manufacturing has been kept up to some extent ever since.

We might consider that the year of 1894 closes another chapter in this history. At this time all the mines in Ontonagon County were closed and but one mine, the Central, was in operation in Keweenaw County. Copper at this time was selling at ten cents a pound and the country was demoralized. People in Ontonagon County were devoting their time to farming while Keweenaw was practically deserted.

Thus mining was concentrated to Houghton County. The Marquette, Houghton and Ontonagon R. R. had laid an extension from L'Anse to Houghton. Thus the copper country was no longer isolated during the close of navigation. The Mineral Range had connected Calumet with Houghton before this. At the time of writing this article the Copper Range Railroad follows the trap range very closely and runs from Calumet through Lake Linden and Houghton to Mass City where it connects with the Chicago, Milwaukee & St. Paul Railroad. A railroad, the Keweenaw Central, runs from Calumet, along the range to Lac La Belle. Thus Houghton County is connected with both Ontonagon and Keweenaw. Houghton and Hancock are the harbors for the county. All supplies are distributed from here and most all products of the two counties are shipped here. With these two roads as feeders the copper producing district is once more extending into the two counties. This time, however, the mass veins are no longer looked for. The amygdaloidal lodes now attract the attention of the explorers.

Two lodes of great value have been found. These are the Kearsarge and Baltic lodes. While the Kearsarge lode dates back to 1880 it produced in a poor manner and only two mines operated on it. These were the Kearsarge and Wolverine. In 1898 the value of the lode was recognized and it now has more producing mines operating on it than any other. Including prospects there are the Gratiot, Mohawk, Ahmeek, Allouez, North Kearsarge, Wolverine, South Kearsarge, Centennial, Calumet & Hecla, La Salle and Caldwell.

The Baltic lode was first discovered in 1883 and a ninety-foot shaft started on the lode. The lode had a dip of 72° being steeper than any known. This original shaft was sunk on an inclination of 55° and soon ran out of the lode. Disheartened by this, work was dropped and not opened until 1898. With the boom of copper then

on the interest was revived and work was started. Within a short time its value was recognized and many other mines commenced work on it. Among these were the Champion and Tri-Mountain. The Globe south of the Champion has located it but it is 250 feet under the glacial drift. In order to get to it a drop shaft has been started. Up to date this has not been completed. (1906.)

Mining in the copper country is no longer looked upon as a venture but is considered more as a business. Changes have taken place and new factors now enter into mining. There is a constant attempt to cheapen the cost of the product. The cost of production has dropped from fifteen and sixteen cents a pound in 1875 to six and seven cents at the present writing. If a person who has not been in any of these copper mines for the last thirty years, were to go underground in them now he would see great changes and vast improvements. New factors are now to be considered. One no longer thinks of discovering huge masses. The compressed air drill has almost entirely replaced "single" or "double jacking." The drill is no longer so heavy as to cause trouble in removing. Two men can easily handle a drill and a hole can be punched into the rock very rapidly. Lately a hand drill has been devised so that all "block holing" is done by machines. Powder has been replaced by dynamite. Much of this is made in the copper country. Various strengths are used. Thirty-five and forty per cent "powder" is used for stoping, while fifty to sixty-five per cent "powder" is used in drifts, shafts, and for blowing loose small pieces of mass. No large masses are found—two or three tons being the limit.

The next change is in the depth of the mines. A shaft 2,000 feet long is not unusual but a very common occurrence. No. 4 Calumet occupies the position of being the deepest inclined shaft in the world. Measured from its collar to its lowest level it is 8,100 feet. From this level a winze is driven 190 feet farther to the extreme end of the Calumet and Hecla property. They have also sunk one vertical shaft, the Red Jacket, which is down to a depth of 4,920 feet.

At this point the story of the Tamarack will be of interest. They owned land to the west of the Calumet and Hecla. The apex law does not apply to Michigan. In buying land or mineral rights you are entitled to all the mineral directly beneath the surface enclosed by the boundaries set forth in the deed. They realized that on their property were the Allouez conglomerate, the Calumet conglomerate and the Osceola amygdaloid. The last two had proven paying lodes and the former had given promises of being rich at

some point. None of these lodes outcropped on their property, so in order to work them it was necessary to intersect them by vertical shafts.

They hit upon this plan and started No. 1 shaft as far to the east as was possible in order to strike these lodes the least distance from surface. They expected to cut the Allouez at 500 feet and the Calumet conglomerate at a depth of 2,000 feet from surface. That they were successful in putting it mildly. The Calumet conglomerate proved of high quality. Now they have five vertical shafts, one of which is the deepest in the world—No. 3 being bottomed at 5,229 feet, only 51 feet short of being a mile, below surface.

It was necessary for the Tamarack to use the vertical shaft. Other companies having copper bearing lodes on their property but not having the outcrop have adopted similar or different schemes, depending upon the circumstances. The Allouez does not carry any portion of the outcrop of the Kearsarge lode. Going as near as convenient to their eastern boundary they proceeded to sink a shaft at an angle of eighty degrees from the horizontal until the lode was encountered at a depth of 1390 feet. At this point, by using a curve seventy-five feet long the shaft was flattened to the plane of the lode which is $38\frac{1}{2}$ degrees. The steeper portion of the shaft is provided with back runners to prevent the skip from jumping the track. So smoothly does the skip travel that these runners are rarely called into use.

Still another scheme was adopted at the Centennial. They owned the N. W. $\frac{1}{4}$ of N. W. $\frac{1}{4}$ of Section 18, T. 56 N., R. 32 W., and Section 12, T. 56 N., R. 33 W. The Kearsarge lode outcropped on their forty of Section 18 but being but 860 feet from the corner was not enough to make a mine. At this corner their part of the lode was squeezed to a point since the Calumet and Hecla owned the property to the south and the South Kearsarge to the north. They, however, bought a small strip of land from the South Kearsarge Mine and thus managed to get a width of 260 feet along the lode at this point. Two shafts were sunk from the outcrop through this narrow point. No. 1 shaft is straight and was sunk along the dip of the lode. No. 2 shaft, after passing the narrow point turned a little to the north and runs away from No. 1 shaft. This twist has caused the shaft to be likened to a cork screw.

Other factors for consideration are the disadvantages of using timber to support excavations and lining shafts. The copper country today is almost barren of big timbers. They have been used underground and in building construction. With this scarcity

comes the increase in price. Another objection is that it will not support an excavation for any length of time. The pressure in the deep mines is enormous. Assuming rock to weigh one hundred and fifty pounds per cubic foot we find that at a depth of 4000 feet there is a pressure of 600,000 pounds per square foot. Placing timbers far enough apart to allow room for working, what chance have they with such pressures? A common sight underground is to see timbers as much as two feet in diameter broken in two as one would break a twig. Another fault, and not by any means the least, is that wood is not fireproof. Some of our mines have been closed for long periods on this account. A fire broke out in the Tamarack on January 11, 1906, and burned in No. 1 shaft until August 1907. No. 2 shaft resumed operations a little over a year after the fire began.

Not only is the timber incapable of holding open the enormous workings of these mines but so is everything else. Pillars of rock left standing in the mines crushed within a certain time. Today the Atlantic is a wreck because the pillars would not support it. Thus the methods of mining have had to change. No longer do they expect large excavations to remain open. Neither can they allow a stope to remain idle any length of time. The mine must be worked steadily and the rock taken out while there is time. Typical methods of mining are to be described so as to illustrate these principles.

Unique in its conservative and economical methods stands the Wolverine. Here the dip is flat—being about 40° —so that the miners stand and set their machines on the foot wall. When the rock is broken, most of it rolls down the slope to the level. The roof is strong and no timber is used in the mine. Some pillars are left while men are working, but they are eventually taken out. Thus everything is removed except shaft pillars, leaving a large open stope. Without any support the roof in time falls and the opening becomes closed.

Next in order comes the method in use at the Calumet and Hecla mines. Here the slope is not much steeper than at the Wolverine, but the rock scales off and large slabs are liable to fall at any time from the hanging wall. This means that timbering must be used. The lode here averages a width greater than in most amygdaloid mines. To reach from foot to hanging would require long timbers of the finest kind. This being too expensive the square set timbering has been adopted.

In opening up the ground preparatory to working, a drift is run

in from the shaft half way to the other shaft. This distance in one case was six hundred and seventy-five feet. At the end of the drift a raise was started to run up to the next level. Two blocks three hundred feet long are then marked off and a pillar seventy-five feet thick is left to support the shaft. The block farthest from the shaft is then removed. As the work advances the timbermen follow them up so as to make the place safe for the workmen. When the first block is removed, the second block is attacked and the space left by the first block is allowed to fill by the crushing of the roof. These workings hold open but a short time. All the expensive timber simply serves for a short time. The two blocks are hardly removed before the whole stope begins to settle. The shaft pillar will only be removed when the shaft has reached the end of its usefulness. Then they will begin from the bottom to withdraw these pillars.

Great care is taken to prevent fires. Fire doors are erected in the drifts in the shaft pillar which can be readily closed. The timbers are all treated with a coating of chloride of zinc and then whitewashed.

In the Tamarack heavy stull timbers are used to support the hanging. Here also the timberman must follow closely upon the miners. "The copper bearing rock of the vein is all mined out as they go for the reason that the life of the timber is little more than a year, and it will not do to leave ground untouched too long after it is opened. They clean out the levels as they go downward letting the hanging come in as it will. The timbermen do much of the barring of loose ground in the hanging and act a very important part in the underground work."

The Atlantic was opened on an amygdaloid having a dip of 54° and an average thickness of fifteen feet. The copper is very evenly distributed. There is no selection of rock and almost all can be considered good stoping ground. In this mine work is entirely done by contract. The plan of working is as follows: Leaving a suitable shaft pillar, the ground is divided in 100 foot blocks and is let for those lengths. These contracts include drifting and stoping. First they cut out the drift, putting in heavy stulls, about twenty inches in diameter, to support the hanging and give a safe tramway. Lagging is then put on these stulls and the broken rock allowed to pile back of these. The miners getting on top of these timbers break away the rock. It accumulates on this lagging and the men stand on the broken product. This stoping is continued to within ten or fifteen feet of the level above. When a level on

one side of a shaft has been cut out, they begin to draw off the ore from the farthest end and work back towards the shaft. In this way they get out all the rock.

One of the latest methods adopted and hence one of the most interesting is the "Baltic Method" now in use at the Baltic, the Tri-Mountain and at the Champion mines. Here the lode averages thirty feet in width and in some places is wider. The dip of the lode is 72'. Thus it can be seen that no ordinary method of timbering could be employed. If overhand stoping is used something must be had for the miners to stand on in order to keep close to the back of the ore.

The copper is in pockets, being very rich in some places and lean in others. Some large masses have been taken from this lode. This fact has led to underground sorting and to filling the old stopes with the waste rock. The stoping starts right with the level itself and is cut out the full width of the lode. With the waste rock dry pack walls are built so as to keep open a place for tramping. This is covered over with heavy timbers and lagging and the waste rock is thrown around the walls and on top of the lagging. Thus the old stopes are kept filled with the waste rock. In order to dispose of the copper rock a mill is carried up at regular intervals from the drift and down this the copper rock is thrown. It is noteworthy that even these chutes or mills are built of pack walls. Owing to the inclination of the lode it is necessary to have both the drift and the mill built on the foot wall side of the lode.

The sorting is done by the sense of feeling rather than by sight. Copper in the rock very often cannot be seen but if the hand is rubbed gently over the surface of the rock the presence of copper is readily detected by the prickliness of the sharp particles of copper.

In this method they even take out the pillar between the levels. When the level above has been worked out and abandoned, the miners, starting at some one point blast out the pillar until they break through to the level above. This allows the loose rock to run through and spread itself as a cone on the broken rock below the pillar. The men then work on the sides of the cone and keep cutting back the pillar. The waste from the level above pushes the newly blasted rock to the base of the cone or wedge where it is sorted. Having mills at various points it is not necessary to commence this method of drawing pillars at the farthest end of the stope. Thus everything is cleaned out of the mine. The only pillars left in the mine are the shaft pillars but if the shafts were driven

far enough in the foot wall even these would not have to be left.

The advantages claimed by this method are the small amount of timber used, hence the lessened dangers of fire, the great safety to the men, no waste rock having to be hoisted to surface, and not having to leave pillars in the ground which may contain a large amount of copper.

To return to the general changes of mining it will be seen that as the mines grow deeper there is a marked tendency to have fewer shafts. This is particularly true of mines such as the Tamarack, which do not expect to work the ore body until they get quite a distance below surface. Having fewer shafts they naturally would be placed farther apart. This has led to the use of mechanical tramping underground. The Quincy has electric locomotives on some of the levels. In the Tamarack an endless rope system has been devised. This was first adopted in the long cross-cuts but within the last few years has been extended to use in the drifts themselves.

There has been another tendency which has largely counteracted the use of fewer shafts. This is an increased output. In 1875 the Calumet and Hecla produced about 21,000,000 pounds of copper while in 1906 the product was over 82,000,000 pounds of refined copper. The two tendencies have forced each shaft to do more work and consequently has led to the improvement of them. All shafts in producing mines have been enlarged to have a double skip compartment. Skips, instead of holding say one ton of rock are made for two or three in some of the mines, while those of the Quincy hold eight tons of rock.

Some of the mines hoist only from certain levels. This is true at the Quincy. Here the shafts are in the footwall. A pocket is cut in the footwall of the lode, or the hanging wall of the shaft. This pocket is filled from two or three levels above. At the level where the skip is to be loaded a chute is built directly above the track so that the skip is brought to this point, the lip of the chute is lowered and the rock runs into the skip.

The travelling of the skips at high speed is also causing its changes in the shafts. The road has had to be improved. If the rails were held loosely and were not smooth the skips would jump the track. These skip roads are constructed with the greatest care and are carefully watched. In two instances the use of wooden ties has been abandoned and the rails are laid on concrete stringers. These two mines are the Allouez and Baltic.

These concrete stringers are laid directly on the foot wall of the

shaft to which they are held by means of steel pins fastened into the foot wall and projecting into the concrete moulds. The concrete being laid around them, thus binds itself to the solid rock. They are usually one foot wide and the rail is bolted directly on its face.

The use of vertical shafts is another change. So far the only mine that has used a vertical shaft when not absolutely necessary is the Calumet and Hecla. The advantages of a vertical shaft are obvious. It gives a shorter way of getting to the ore body and allows of greater hoisting speed than does an inclined shaft (4,000 feet per minute at the Whiting shaft).

The No. 5 shaft of the Tamarack is a five compartment shaft, four of which are used for hoisting, the other being used for ladders and pipes. The Red Jacket shaft of the Calumet and Hecla is a six compartment shaft, the two easterly being used for ore, the westerly for hoisting and lowering men and materials, while the middle compartments are used for hoisting water.

The methods of hoisting ore at these vertical shafts are interesting. At the Tamarack, the tram cars themselves are hoisted in cages, which are used for all purposes, including the hoisting of men. The cages are double deck, thus two tram cars are hoisted at once. Each tram car holds three tons of rock, making a total of six tons hoisted at one time. At No. 3 Tamarack the capacity is about 1,000 tons daily. At the Whiting shaft, this method has been abandoned, owing to the time required in removing the cars, dumping and replacing them on the cage. Here the Kimberly skip has been adopted. This is a form of self dumping cage used in a vertical shaft. These have a capacity of nine tons each, thus allowing 4,000 tons to be hoisted from the one shaft during a period of 24 hours.

Vertical shafts are now being sunk by the Globe and Challenge mines. The reason for adopting them here is on account of the overburden. This is 125 feet thick at the Challenge and about twice that thickness at the Globe. In both cases drop shafts were used in order to get to the ledge and these being vertical the shafts through the rock were continued vertically downward.

To allow the shafts to be run to their capacity, new methods have had to be adopted in getting the men in and out of the mines quickly and without tiring them. While ladders are placed in every mine, being required by law, they are used only by men working on the upper levels or for going from one level to another. It would take too long and prove too tiresome for a man on the

lower levels of the Calumet and Hecla to climb say 8,100 feet of ladders. Another of the pet schemes of a decade ago has also been abandoned. This is the man-engine.

A brief description of this machine might be introduced to show the ingenuity of the device and also to show its defects. Primarily it consists of two reciprocating rods A and B (Fig. 6) extending into the mine. Each rod has platforms a, c, e, g and b, d, f, h placed at equal intervals apart—generally twelve feet—but always twice the length of the stroke. On each platform there is an upright rod by which the men can steady themselves in ascending or descending. The action can best be described from the diagram. A man wishing to descend is standing on platform a. He steps on platform b when it is opposite him. The rod B then descends until platform b is at b'. In the meantime rod A has ascended so that platform c is in position of c' or opposite b'. The man steps over to the platform c which then descends and allows him to step to platform d. In this way he is carried into the mine. By reversing the operation he is carried up. The engine operating the two rods is usually governed by a fly wheel so that the speed of the strokes is most rapid in the center of the stroke, slowing down to a stop when the two platforms are together.

Such a machine may be adopted in either a vertical shaft or in an inclined one. It is, however, clumsy and costly in the first place, in operation, and in repairs. It is not safe as men have often become dizzy and confused. Besides this it does not save much more time, if any, than does the old fashioned ladders.

The universal practice now is to hoist and lower men in either cages, skips or man-cars.

In the vertical shafts and in the more steeply inclined shafts, as the Baltic and Champion cages are used. These are generally double deck affairs, so that from 20 to 30 men can be hoisted at

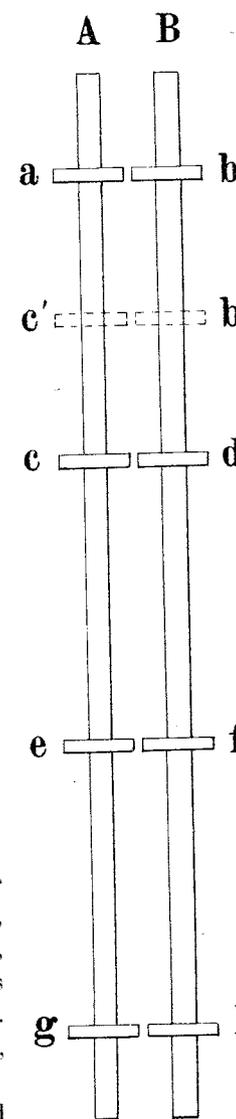


Fig. 67. Sketch of man-engine.

once. The older practice in the inclined shafts was to allow the men to ride up and down in the skips. They would pile into these until one would wonder how so many human beings could get into such a small space. When they get to surface they are very often jammed in so tight that one man has to be pulled out before the others can be loosened so that they may help themselves.

The man-cats can be likened to a set of steps set on wheels. These are wide enough to accommodate three men to a step and being ten steps long hold 30 men when full. It is an interesting operation to watch them remove the skip from the track and place the man-car there. At the Quincy there are four cranes to the shaft, two for each hoisting compartment. One of these removes the skip from the track. The other holds the man-car. This is then swung to the track, the rope fastened to it and the man-car is then lowered into the mine. The time required to make the change is less than one minute.

Some of the mines have special shafts, as the Wolverine, or special compartments of the shaft for hoisting and lowering men. In these cases this operation does not interfere with the hoisting of ore. It is noteworthy that the Calumet and Hecla have special ropes and special engines for hoisting and lowering the men.

These extensive improvements underground have led to improvements on surface. Separate shaft and rock houses connected by the Frue Automatic tramway are very seldom seen. Now that one shaft has a capacity equal to that of an entire mine in 1875 it has been found necessary to combine the two and have one rock house for each shaft. The sorting and crushing have changed but little. For the same reasons that wood is being abandoned underground it is being replaced by steel in surface construction. Gradually steel shaft houses are replacing the old wooden ones. With the use of steel comes a change in shape. The bins to the rock houses are being made circular. This is due to the greater ease of spreading the ore and entirely filling bins of this shape.

The hoisting engine has risen from one of forty horsepower with a six or eight-foot drum as a maximum to one of eight thousand horsepower with a twenty-four foot drum at a few of the mines. These first engines simply operated one skip, hoisting them to surface and by releasing the break, allow them to run back into the mine. Now each hoist controls two skips with their ropes so wound on the drum as to allow one skip to descend while the other ascends. This is known as hoisting in balance since the weight of the skips are equalized, thus giving less work for the

engine to perform. At the Red Jacket shaft of the Calumet and Hecla the weight of the rope is also equalized by hanging the ends of a rope to each cage and allowing it to pass to the bottom of the shaft. The hoist here is peculiar being the only one of its kind in the copper country. The large drum has been discarded and instead two drums of a narrow face have been used. Only one hoisting rope is used. This is connected at one end to one cage. It passes around the two drums three or four times, then back into a tail house where the proper tension is kept and at last connected to the other cage. To these two cages is hung the tail rope. The whole system may be likened to a cable car system.

Where the large drum is still used we often see, instead of a flat faced drum, a double conical drum with the rope so wound on it that when the skip is hoisted and the weight becomes less the rope is wound on a constantly increasing diameter, thus increasing the speed of the skip and keeping the strain on the engine more constant. These conical drums have their friends and enemies and much can be said for and against them.

The engineer no longer sits on the brake lever in order to stop his engine. Steam cylinders now control the brake so that an engineer merely operates a lever. By means of floating levers and oil cylinders the pressure of the break is very closely regulated.

The floating lever is used to regulate the oil and steam cylinders, operating the break and receives its name because the fulcrum is not a fixed point. This lever is held by three rods at points A, B, and C of the diagram. The rod attached at B is connected to and operated by the engineer's lever. The rod connected at C is connected to and operated by the piston rod of the steam cylinder operating the brake. The rod A operates the valves to the oil and steam cylinders.

If the engineer wishes to lift the piston rod he lifts, by his lever, the point B to the position of B'. C now acts as the fulcrum, AC as the lever arm, and the lever assumes the position A' B' C'. The rod at A, being lifted, allows the steam to enter below the piston and it rises, pushing the rod connected at C with it. Now B acts as the fulcrum and the lever assumes the position AB' C'. Thus the rod A is pushed back to its original position closing off the steam from the steam cylinder. In order, however, that the expansion of the steam in the cylinder will not carry the point C too far the piston rod of the steam cylinder is made to operate through an oil cylinder and when the rod at A shuts off the steam it also closes the valves for the oil cylinder and thus locks the

piston. The distance which the point C moves is in direct proportion to the distance which B moves. As the brake moves proportionately to C and B moves proportionately to the engineers lever it is possible for him to regulate the pressure of the brake very readily. To reverse, the point A must be pushed down to point A''.

Safety devices now form a part of all hoists. By means of a worm screw the steam is thrown off and the brake set when the skip reaches a certain place, thus preventing overwinding. There are two dials on each engine marking the position of the skips in the shafts. This of course is merely approximate. On the drum itself are marked in chalk the exact positions at which it should be stopped so that the skip can be exactly stopped at any desired level.

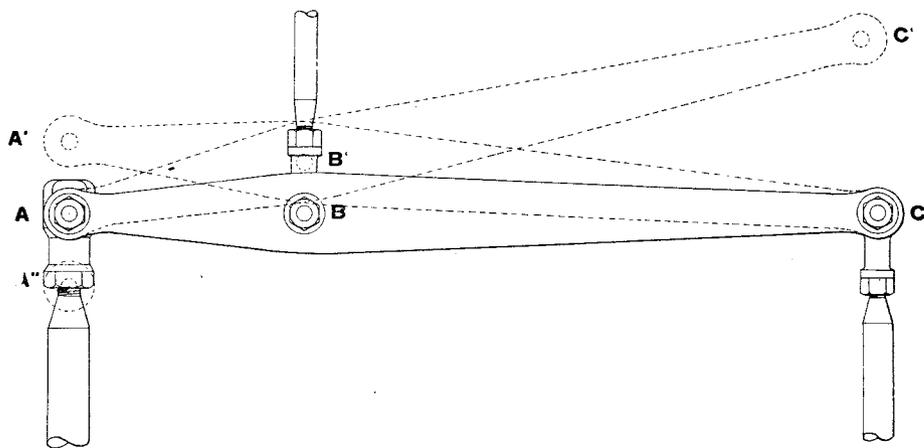


Fig. 68. Floating levers. Sketch by A. H. Meuche.

Before closing, a few remarks on drainage may not be out of place. Fortunately this is not much of a problem for the copper mines. One or two of the mines have their upper levels drained by adits. Most of the water in the mines is surface water and flows in on the first thousand feet of workings. Below this the water is very acrid in character, so much so that pumps and pipes are readily coated with rust. The amount of water is very small and does not pay for the installation of pumps on these lower levels. Most of the deeper mines, such as the Tamarack, Calumet and Hecla, and Quincy, allow this "mine water" to collect in sumps at the bottom of the shafts and bail it out in large bailers.

The stamp mill practice has changed but little during the past

thirty years. The greatest change has been in decreasing the cost of production by increasing the capacities of the various units. The steam stamp of today, with the aid of rolls have a crushing capacity of over 700 tons. This stamp is fed from a hopper by gravity into this stamp. A man with an iron hook stands here to regulate the feed or hold it back when necessary. He also watches for pieces of mass which he casts aside. The total crushing or falling weight is three to four tons and the actual stroke is from 20 to 24 inches.

In the mortar (at the Isle Royale mill) the rock is crushed to pass a five-eighths inch screen. Large lumps of copper, the size of small potatoes which are contained in the rock will not pass this screen. They are removed by a hydraulic arrangement. A four inch opening is left in the mortar just below the lip. This is connected to a pipe through which water is forced into the mortar at such a speed that only these lumps of copper can force themselves through it. They fall into a receptacle outside of the mortar. These are termed headings and make up about one-fourth of the product of the mill. Another and almost equal amount is extracted between the stamps and the trommels.

The annexed flow sheet will serve the purpose of tracing the product through the mill. The rock after leaving the stamp goes to a trommel with a 5/16" hole. The oversize passes to a set of rolls and is crushed to a smaller size. The ore then passes to a hydraulic classifier. In each section of the mill there are three such classifiers with three sets of roughing jigs, each doing the same work. The rock from the trommel is divided into three equal parts, each of which goes to a classifier. In these classifiers the rock is classified into five parts, the heaviest settling first and so on until the fifth or slimes is washed over the end and taken to settling tanks. The other products are jigged on two separate jigs, the hutch of which goes to the finishing jigs and the tails are waste. A certain amount of copper collects on the screens of the jigs and is scraped off at regular intervals. The hutch product of the finishing jigs runs to settling boxes and is ready for the smelter or subsequent treatment. The slimes are first allowed to settle. The settlings are treated on Evans tables the heads of which are treated on Wilfley or Overstrom tables and the tails go to waste.

In the operation of the stamp mill copper is taken off at every point. It is picked from the feeding hopper, discharged in big lumps from the stamps. It comes from the roughing jigs as red gravel, as fine sand from the finishing jigs and as red mud from

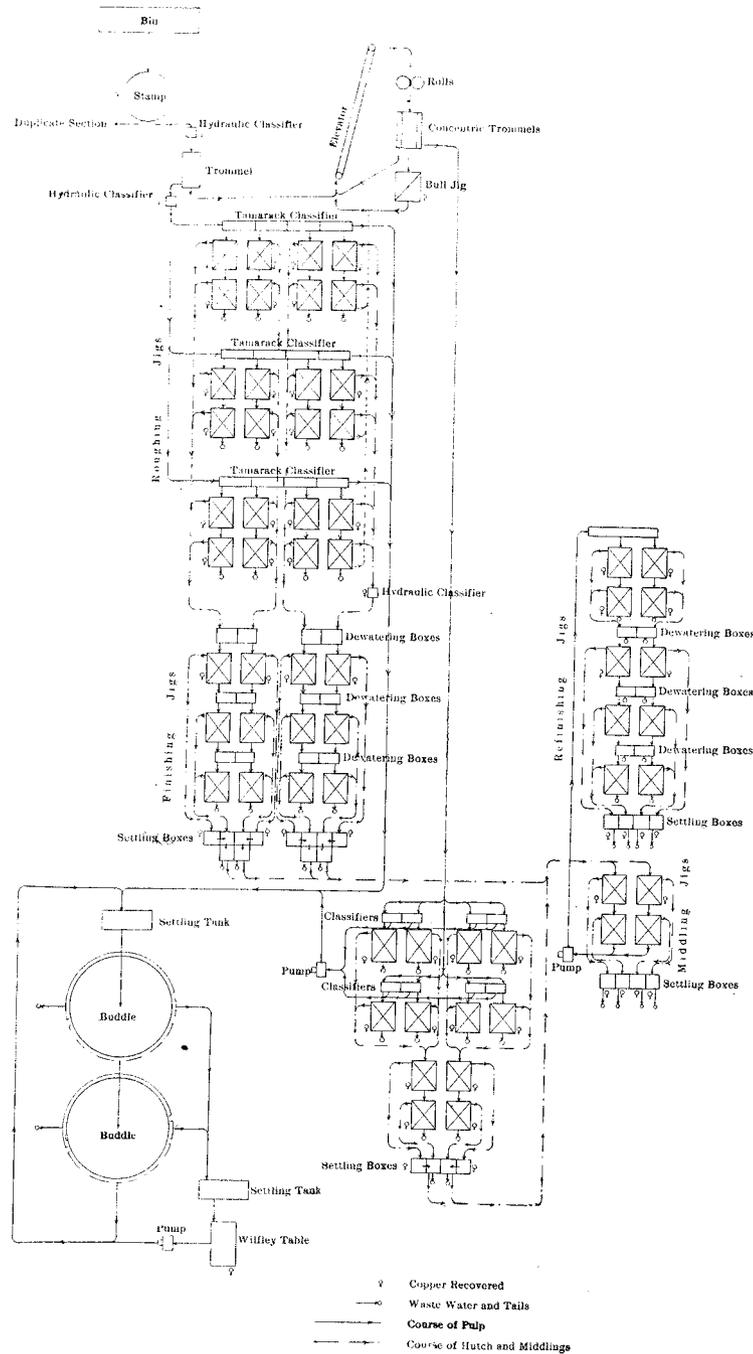


Fig. 69. Flow sheet of Stamp mill. Sketch by Meuche.

the concentrating tables. Some native silver is found with the copper. At some stamp mills a boy is employed to pick silver out of the mineral but if the pieces are very small but of rather high percentage (2%) the mineral is refined at the smelter and cast into anodes. These are then shipped to an electrical refinery where the silver and copper are separated. No reliable estimate can be made of the amount of silver in these mines as it is stolen by the employees underground, in the mills, and smelters.

The amount of water used is something enormous, being something like thirty tons of water to one of ore or three and one-half million gallons per day for each stamp. The cost of stamping has been reduced from two dollars a ton in 1854 to as low as twenty-eight cents. (Tamarack report for 1907.)

It must not be supposed that all the copper is recovered. The criticism of Prof. Egleston still holds and as stated by a more recent writer: "This will emphasize the observation that during late years the endeavor to lessen costs has been pushed at the expense of any improvement in extraction; that is, it has not realized that while the expenditure entailed by the treatment of copper ore has decreased, there has been no commensurate diminution in the amount of copper lost. Five cents worth of copper, per ton, lost in the tailing is worth just as much as a five cent decrease in milling cost."

APPENDIX.

BY A. C. LANE.

1. *Introduction.*

Between the writing of so voluminous a report as this and its actual issue, some time must elapse. This report is part of my report for the year 1909. I had to make a hard and fast rule, in order to ever get through, in reading proof, to make no changes, except where actual errors or failures to clearly convey my meaning were involved. The temptation was strong to try to include more recent drilling, but as dozens of drills had been and are continuously at work, I should never have known where to stop. The wisdom of this rule is shown by one of the few exceptions made to it. In a few cases, where I thought the reader should be forewarned of a change of views or different use of names due to it, more recent work has been mentioned. One of these references, that to the "Mayflower lode" in the foot-note of page 371, called attention to the fact that the lode recently so named is not the one so named in Figure 39 and in earlier explorations. But, misled by press accounts of recent drilling, I misstated the horizon of the new "Mayflower lode," which, according to G. S. Goodale, in the annual report of the Company for 1911, is several hundred feet below the St. Louis conglomerate.

A few reports have, however, appeared since the transmission of my manuscript and a few explorations of such importance made that I have inserted this appendix, so that, although I may not give them all the attention they merit, I may not seem to ignore them.

2. *Bibliography.*

I have not given a complete bibliography of titles pertaining to the Keweenaw series. Work thereon is so covered by the reports of the Canada, Ontario, Minnesota, Wisconsin and Michigan Geological Surveys, and especially the bibliographies of Monographs 5 and 52 of the United States Geological Survey, and its annual bibliographies, that it would be what R. S. Woodward has called "a platitude of research." I have, however, listed a few

papers overlooked in the bibliographies and some of the more recent works to which I would call attention.

The Proceedings of the Lake Superior Mining Institute, the Canadian Mining Institute, the American Institute of Mining Engineers and the Michigan Academy of Science will naturally not be overlooked by the thorough enquirer. The Michigan Engineering Society and Michigan Miner mainly concern themselves with Lower Michigan.

The losses in copper dressing at Lake Superior, by Adjunct Professor H. S. Monroe. Transactions of the American Institute of Mining Engineers, September, 1879.

The copper-bearing rocks of Lake Superior, by R. D. Irving. U. S. G. S. Monograph V; also 3rd annual report U. S. G. S., 1883, pp. 93-188.

Geologic maps of Michigan, by Jules Marcou and John Belknap Marcou. U. S. G. S. Bulletin No. 7, 1884, pp. 77, 78, 79, 80, 81, 82, 83, 85, 87, 88.

On the classification of the early Cambrian formation, by R. D. Irving. U. S. G. S. 7th Annual Report, 1888, pp. 365-454.

Notes on some diabase dykes of the Rainy Lake region, by Andrew C. Lawson. Proceedings Canadian Institute, 1887.

Las aguas minerales de Chile, by Dr. L. Darapsky. Valparaiso, 1890.

The copper region of Michigan, by Frank B. Phelps. Engineering Magazine, Vol. IV, 1892, pp. 47-63.

Building stone from Michigan, at World's Columbian Exposition. M. R., 1893, p. 567.

Excursion to Lake Superior—Pre-Cambrian geology of the Lake Superior district, by C. R. VanHise. Int. Cong. Géol. Compte Rendu, 5th session, 1893, pp. 110-50.

Basic massive rocks, by W. S. Bayley. Journal of Geology, Vol. I, 1893, pp. 433-56, 587-96.

On powellite from a new locality, by George A. Koenig and L. L. Hubbard. American Journal of Science, 3rd ser., Vol. XLVI, 1893, pp. 356-8.

The copper resources of the United States, by James Douglas. Sci. Am. Suppl., Vol. XXXV, 1893, pp. 14183-6.

A reconnaissance of the abandoned shore lines of the south coast of Lake Superior, by F. B. Taylor. American Geologist, Vol. XIII, 1894, pp. 365-83.

Ueber powellit von einem neuen Fundorte, by Georg A. König

and Lucius L. Hubbard. *Zeitschrift für Krystallographie, etc.*, XXII 5/6 1894, pp. 463-6.

Changes of level in the region of the Great Lakes in recent geological time, by F. B. Taylor. *American Journal of Science*, 3rd ser., Vol. XLIX, 1895, pp. 69-71.

On underground temperatures at great depth, by A. Agassiz. *American Journal of Science*, 3rd ser., Vol. I, 1895, pp. 593-4.

A northern Michigan base-level, by C. R. Van Hise. *Science*, new ser., Vol. IV, 1896, pp. 217-20.

A central Wisconsin base-level, by C. R. Van Hise. *Science*, New ser., Vol. IV, 1896, pp. 57-9.

The crystallization of the calcite from the copper mines of Lake Superior, by Charles Palache. *Michigan Geological Survey*, Vol. VI, Pt. II, Appendix, 1898, pp. 161-84.

The origin and mode of occurrence of the Lake Superior copper deposits, by M. E. Wadsworth. *Transactions American Institute of Mining Engineers*, Vol. 27, 1898, pp. 669-96.

Some dike features of the Gogebic iron range, by C. M. Boss. *Idem.* pp. 556-63.

On the thermal conductivities of certain poor conductors, by B. O. Peirce and R. W. Willson. *Proc. Am. Acad. Arts and Sciences*, Vol. XXXIV, No. 1, 1898, pp. 3-56.

Powellite crystals from Michigan, by Charles Palache. *American Journal of Science*, Vol. VII, May 1899, pp. 367-9.

Altitudes in Michigan. U. S. G. S. 21st Annual Report, Pt. I, 1899-1900, p. 465.

Note on a method of stream capture, by A. C. Lane. *G. S. A. Bulletin*, Vol. X, 1899, pp. 12-15.

The development of the copper industry of Northern Michigan, by James Ney Wright. *Michigan Pol. Sci. Ass. Pub.*, Vol. 3, No. 5, Ann Arbor, 1899.

On the thermal diffusivities of different kinds of marble, by B. O. Peirce and R. W. Willson. *Proc. Am. Acad. Arts and Sciences*, Vol. XXXVI, No. 2, 1900, pp. 13-16.

On mohawkite, stibiodomeykite, algodinite and some artificial copper-arsenides, by George A. Koenig. *American Journal of Science*, Vol. X, December 1900, pp. 439-48.

Note sur la région cuprifère de l'extrémité nord-est de la péninsule de Keweenaw (Lac Supérieur), by Louis Duparc. *Archives sci., phys. et Nat.*, Vol. X, 1900, p. 21.

The geothermal gradient in Michigan, by A. C. Lane. *American Journal of Science*, 4th ser., Vol. IX, 1900, pp. 434-8.

The origin of the native copper in the Michigan deposits, by J. F. Blandy. *Engineering and Mining Journal*, Vol. XX, 1900, pp. 278-9.

Suggestion from the State Geologist, by A. C. Lane. *Michigan Miner*, Vol. 3, No. 10, 1901, p. 9.

Annual report of the State Geologist (Michigan), by A. C. Lane. *Michigan Miner*, Vol. 3, 1901, pp. 13-22.

Work of the Geological Survey in the Upper Peninsula, by L. L. Hubbard. *Michigan Miner*, Vol. 3, No. 3, 1901, p. 9.

Geological Survey of Michigan. Report of field work for 1900, by W. V. Savicki. *Idem.* pp. 9-11.

On artificial production of crystallized domeykite, algodinite, argentodomeykite and stibiodomeykite, by George A. Koenig. *Proceedings Am. Philosophical Society*, Vol. XLII, No. 173, pp. 219-37.

Crystallographic properties, by F. E. Wright. *Idem.* pp. 237-49.

On the thermal conductivities of certain pieces of rock from the Calumet and Hecla mine, by B. O. Peirce. *Proceedings American Academy of Arts and Sciences*, Vol. XXXVIII, No. 23, 1903, pp. 651-60.

Copper mining in Upper Michigan, a description of the region, mines and some of the methods and machinery used, by J. F. Jackson. *Mines and Minerals*, Vol. 23, 1903, pp. 535-40.

The theory of copper deposition, by A. C. Lane. *Michigan Miner* Vol. 6, No. 2, 1904, pp. 9-11, No. 3, pp. 9-11; *American Geologist*, Vol. 34, 1904, pp. 297-309.

Copper mines of Lake Superior, by T. A. Rickard. *Engineering and Mining Journal*, Vol. 78, 1904, pp. 585-7, 625-7, 665-7, 705-6, 745-7, 785-7, 825-7, 865-7, 905-7, 945-50, 985-7.

The geology of some of the lands in the Upper Peninsula (Michigan) by R. S. Rose. *Mining World*, Vol. 21, 1904, pp. 205-7; *Engineering and Mining Journal*, Vol. 78, 1904, pp. 343-4; *Proc. Lake Superior Mining Institute*, pp. 88-102. See Monograph LII.

Historical review of the geology of Michigan, by A. C. Lane. *Michigan Academy of Science*, 5th Annual report, 1904, pp. 184-95.

Comment on the "Report of the special committee on the Lake Superior region," by A. C. Lane. *Journal of Geology*, Vol. 13, 1905, pp. 457-61.

The Tamarack Mine cross-section and the Keweenaw lodes, pp. 271-94; also—

Waters of the Upper Peninsula of Michigan, pp. 111-67; also—
Report of progress in the Porcupine, by F. E. Wright. *Michi-*

gan Geological Survey, Annual Report for 1903, 1905, pp. 33-44. Also preliminary geological map of the Porcupine Mts. and vicinity, by F. E. Wright and A. C. Lane. Michigan Geological Survey, Annual Report for 1908, 1909, Plate I.

Notes on the rocks and minerals in Michigan. To accompany the loan collection issued by the Michigan College of Mines, by F. E. Wright, Houghton, 1905.

Mines of the Lake Superior copper district, by Horace J. Stevens. Program for 12th Annual meeting Lake Superior Mining Institute, 1906, pp. 9-27; also Proc. Lake Superior Mining Institute, Vol. 12, 1907, pp. 8-24.

An ecological survey in the Porcupine Mts. and Isle Royale, Michigan, by A. G. Ruthven. Michigan Geological Survey, Annual Report for 1905, 1906, pp. 17-47.

The copper mines of the United States in 1905, by W. H. Weed. U. S. G. S. Bulletin No. 285, 1906, pp. 93-124.

The Nonesuch sandstone, by G. W. Corey. Engineering and Mining Journal, Vol. 82, 1906, p. 778.

Material for geography of Michigan, by M. S. W. Jefferson, Ypsilanti, Michigan, 1906.

Peat, essay on its origin, uses and distribution in Michigan, by C. A. Davis. Michigan Geological Survey, Report of State Geologist for 1906, 1907, pp. 93-395.

The Newark (Triassic) copper ores of New Jersey, by J. Volney Lewis. Annual report of New Jersey State Geologist, 1906, pp. 131-64.

Die Entstehung der Kupfererzlagertstätte von Corocoro und verwandter Vorkommnisse in Bolivia, by G. Steinmann. Festschrift Harry Rosenbusch, Stuttgart, 1906, pp. 335-69.

Copper deposits of the New Jersey Triassic, by J. Volney Lewis. Economic Geology, Vol. II, No. 3, 1907, pp. 242-57.

Structure and correlation of Newark trap rocks of New Jersey, by J. Volney Lewis. G. S. A. Bulletin, Vol. 18, No. 4, 1907, pp. 195-210.

Ninth annual report of the State Geologist of Michigan for the year 1907, by A. C. Lane. State Board Geological Survey report, for 1907, 1908, pp. 1-31.

A reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin, by J. W. Goldthwaite. Abstract: Science, new ser., Vol. 27, May 8, 1908, pp. 724-5; Journal of Geology, Vol. 16, No. 5, 1908, pp. 459-76.

The altitude of the Algonquin beach and its significance, by J.

W. Goldthwaite. Abstract: Science, new ser., Vol. 28, Sept. 18, 1908, pp. 382-3.

Features indicative of physiographic conditions prevailing at the time of the trap extrusions in New Jersey, by C. N. Fenner. Journal of Geology, May-June, 1908, pp. 299-327.

Use of "ophitic" and related terms in petrography, by A. N. Winchell. G. S. A. Bulletin, Vol. 20, 1908, pp. 661-67.

In the Michigan copper country, by R. E. Hore. Canadian Mining Journal, Vol. 30, July 15, 1909, pp. 421-2.

Michigan iron mines and their mine waters, by A. C. Lane. Mining World, Vol. 31, August 21, 1909, pp. 413-16.

Geology of the Porcupine Mts., Michigan, by A. C. Lane. Mining World, Vol. 30, June 12, 1909, pp. 1115-17.

The decomposition of a boulder in the Calumet and Hecla conglomerate and its bearing on the distribution of copper in the Lake Superior copper lodes as indicating the trend and characters of the waters forming the chute, by A. C. Lane. Economic Geology, Vol. 4, No. 2, 1909, pp. 158-73.

Mines waters and their field assay, by A. C. Lane. Geol. Soc. Am. Bulletin, Vol. 19, 1909, pp. 501-12.

Tenth annual report of the State Geologist of Michigan to the Board of Geological Survey for the year 1908, by A. C. Lane. Michigan Miner, Vol. 11, No. 2, Jan. 1909, pp. 9-17.

Salt water in the Lake mines, by A. C. Lane. Michigan Miner, Vol. 11, No. 4, March, 1909, pp. 24-26.

The Watchung basalt and the paragenesis of its zeolites and other secondary minerals, by Clarence N. Fenner. Annals of the New York Academy of Science, Vol. XX, No. 2, Pt. II, Aug. 4, 1910, pp. 93-187.

The crystallization of a basaltic magma from the standpoint of physical chemistry, by Clarence N. Fenner. American Journal of Science, Vol. XXIX, March, 1910, pp. 217-34.

Copper-bearing amygdaloids of the White River region, Alaska, by Adolph Knopf. Economic Geology, Vol. V, No. 3, April 1910, p. 247. See also U. S. G. S. Bulletin No. 417, Moffit and Knopf.

Copper, a weekly review of the Lake Superior Mines, (published by Gay and Sturgis, A. L. Carnahan, Editor), Vol. 3, No. 23, September 3, 1910.

Copper in the red beds of Oklahoma, by William Arthur Tarr. Economic Geology, Vol. V, No. 3, April, 1910, p. 221.

Ein Beispiel der "Zeolith-Kupfer-Formation" in Andesit-Massiv

Osterbeins, by Stud. M. Lazarevic Leoben. *Zeitschrift für Praktische Geologie*, February, 1910, p. 81.

Das Vorkommen und die Gewinnung des Kupfers, by Prof. Dr. Krusch. *Naturwissenschaftliche Wochenschrift*, Nos. 51 and 52, December, 1910.

The effect of leakage at the edges upon the temperatures within a homogeneous lamina through which heat is being conducted, by B. Osgood Peirce. *Proc. American Academy of Arts and Sciences*, Vol. XLV, No. 13, April, 1910, pp. 355-60.

The geology of the Lake Superior region, by Charles R. Van Hise and Charles K. Leith. U. S. G. S. Monograph LII, 1911. Chapter IV (Physical Geography) by Lawrence Martin; W. J. Mead, R. C. Allen, A. N. Winchell and Edward Steidtmann also mentioned in the table of contents as co-authors.

Some modes of deposition of copper ores in basic rocks, by Waldemar Lindgren. *Economic Geology*, Oct.-Nov., 1911, Vol. VI, No. 7, pp. 687-700.

The Copper Handbook, by Horace J. Stevens, 1900-1911 inc.

Some practical suggestions for diamond drill explorations, by A. H. Meuche. *Lake Superior Mining Institute*, Vol. XVI, 1911, pp. 77-81.

Genesis of copper with zeolites in basic rocks, by Waldemar Lindgren. *Mining and Engineering World*, Vol. 35, No. 27, Dec. 30, 1911, p. 1311.

Appraisal of mining properties of Michigan by the State Board of Tax Commissioners, 1911, by J. R. Finlay.

Native copper in basalt, by R. Brauns in *Bonn. Zeitschrift für Krystallographie*, 1911, p. 493; *Central Blatt*, 1908, pp. 705-9.

The copper-mining industry of Michigan, by R. E. Hore. *Mining World*, Vol. XXXVI, No. 11, 1912, pp. 601-3, No. 12, pp. 656-58, No. 13, pp. 707-10, No. 14, 763-67.

Notes on the paragenesis of the zeolites, by J. Volney Lewis. Preliminary list of papers for 24th meeting of G. S. A., Dec. 27-30, 1911, p. 5; also *Science*, February 23, 1912, Vol. XXXV, p. 313.

Diamond drilling at Point Mamainse, Province of Ottawa, by A. C. Lane. *Bulletin 6*, Department of Mines, Canada, 1912.

Divergences.

It would be pleasant and not profitless to point out in detail where the observations herein recorded confirm, agree with and strengthen the conclusions of Fenner and Lewis in New Jersey and of Van Hise, Leith, Steidtmann, Martin and Thwaites on the

Keweenawan. I shall do this to some extent by seeing that not merely their names are thoroughly indexed, but also certain headings under which are grouped references to observations on subjects of especial interest to them, such as: prehnite and other zeolites, paragenesis of; Keweenawan, signs of origin of; Upper distribution and relations; water, effect of; copper, formation of.

Although less pleasant, it may be of more use to point out wherein there are divergences, so that the reader of this report may be duly warned thereof.

With Monograph LII, there are three main points of divergence; (1) as to the intrusive character of the Greenstone¹; (2) as to the age of the Keweenawan; (3) as to the age and connate character of the salty mine waters.

As to the Greenstone, the authors of Monograph LII, on page 381, cautiously suggest that it may be, at least in part, intrusive. The coarseness of the grain of this, perhaps the coarsest single lava flow that is known, and the cliffs above the Cliff Mine, like those of the intrusive Palisades of the Hudson, make the suggestion natural. But, on the other hand, we have the following facts:

(a) So far as it is always at one horizon, just above the Allouez conglomerate, and never seems to cut across strata we have a very strong argument for its being a flow. How far this is true can only be judged by a detailed study of Chapter V. The authors of Monograph LII are hardly inclined to accept my correlations of exact beds of the section on Isle Royale with beds on Keweenaw Point; (b) it has not the contact effect of the igneous rocks, neither producing tourmaline as under the Palisades nor changing augite to such hornblende as produced in the ophites by the gabbro of Mt. Bohemia; (c) the occasional induration, and especially the occasional production of steam bubbles in the originally muddy upper layers of the bed below, which are now filled with calcite, are quite characteristic of an effusive contact; (d) the coarseness of the grain clear to the center is much more likely to occur in a thick flow than in a thick sill, as shown in Chapter IV; (e) even the lighter streaks, the diorite streaks of Marvine, or doleritic streaks, in which the feldspar is coarser than in many gabbros, show by the fact that the nearer they are to the center of the Greenstone as a whole the coarser they are, while they show no change in coarseness in their contact with the darker, poikilitic part, that they are an essential part of the original flow. They do, indeed, look very much like some gabbro pegmatites, and are,

¹Note the capital. The term is used on Keweenaw Point as a proper name applied to the bed above the Allouez Conglomerate.

I believe, due to a similar segregation of mineralizers, which tended to produce a greater power of crystallization and more perfect crystals, and possibly delayed, also, the crystallization. For details regarding this, see the references indexed under Greenstone, doleritic texture, Allouez conglomerate.

(2) As to the age of the Keweenaw, owing to the work of Thwaites, we are now happily agreed as to almost all the facts summarized on pages 416 to 426 of Monograph LII. I still adhere to the conclusion of my report for 1908, drawn from these facts, that the Cambrian age of the Keweenaw is probable. That the Keweenaw is "largely subaerial" and (naturally therefore) "not fossiliferous," I find no argument against its Cambrian age, but quite the reverse. That the Cambrian contrasts with the Keweenaw in lacking volcanism, is certainly not true of the Upper Keweenaw, which is later than any volcanism in the Lake Superior region, unless, indeed, Wilson's suggestion that there are Cretaceous lavas near Nipigon Bay should prove to be correct. (Monograph LII, p. 369.) On the other hand, the early Cambrian of eastern Canada and New England, as well as the typical Welsh Cambrian, contains coeval volcanics. This does not show anything as to Lake Superior of course. I only wish to point out that the statement of Monograph LII must be qualified until it, too, does not prove anything. Though the "Upper Cambrian is flat lying," so is the Lake Superior sandstone of the Apostle Islands, which Thwaites recognizes as conformably above and part of the Upper Keweenaw. That the upper marine Cambrian rests unconformably upon Middle Keweenaw beds is quite to be expected, when the latter are land volcanics.

"The similarity of lithology and accordance of structure between Upper Keweenaw and Cambrian" might, indeed, be the result, as the authors say, of a very much later transgression of the sea over flat lying sediments, but since the Lake Superior basin began to form before the Keweenaw, and seems to have never ceased to be a basin, there should have been continuous deposition in the center. This would be true whether it were a marine or a desert basin, a bolson or a playa, and this, indeed, seems to be accepted by the authors of Monograph LII, in their resumé (on page 416) of the course of events, but in that case, the whole Cambrian must be represented in the series of red sediments between the Jacobsville sandstone and the Freda sandstone, which can hardly be more than a few thousand feet, while Walcott gives for the Cambrian section of the Rocky Mountains (National Geographic Magazine,

Vol. 22, No. 6, p. 514) 3,590 feet Upper Cambrian, 4,963 feet Middle Cambrian, 4,524 feet Lower Cambrian, largely limestones and shales, which are generally supposed to be very much more slowly accumulated than the sandstones. Under any hypothesis, the Keweenaw beds "constitute a marked local variation" from general conditions, but to me they seem lithologically far more allied with the Upper Cambrian than with the Pre-Cambrian. This is shown by the fact that for a long while almost everyone supposed that the Bayfield or Western sandstone of the Apostle Islands was of the same age as the Jacobsville or Eastern sandstone, which the Limestone Mt. section seems to show to be Cambrian.

Again, not only the Porcupine Mt. monadnocks referred to by Van Hise, which, as he says, were (Science, new ser., Vol. IV, 1896, pp. 57-9) more nearly reduced to base-level during a time extending down to the Cretaceous, but numerous contacts of the Jacobsville sandstone that show relations of contact against cliffs of the Lower Keweenaw beds, while they indicate, indeed, much erosion during intervening time, also seem to me to indicate that the Lower Keweenaw was by no means base-leveled at the time of the Upper Cambrian transgression nor lay beneath the Pre-Cambrian peneplain. But the profound discordance of the Keweenaw and Huronian on the Gogebic Range and not merely that, the whole relation of distribution and attitude of the Keweenaw to the Huronian folds and formation, as A. E. Seaman has suggested, seems to show almost at a glance relations like those of the Triassic sandstones and traps (which the Keweenaw so much resembles) to the Palaeozoic. The main movement, much folding, many synclinal axes, much iron ore concentration, much erosion, took place before the Keweenaw. In other words, the master gap, at the beginning of the Palaeozoic, comparable to that at the end of the Palaeozoic, occurred prior to the Keweenaw, rather than after. The problem thus seems to be analagous to that of the "Red Beds" of Pennsylvania-Permian-Triassic age. Final conclusions must come from a valid correlation of volcanic outbursts, continental uplifts, and world-wide changes of strand line. The nearer we can get marine Cambrian, in which there are signs of contemporaneous volcanic action, the surer we shall be that the Keweenaw volcanics are Cambrian in age.

Seaman's map of the Keweenaw Point district (Plate XXVIII, Mono. LII) seems to draw the line between Upper and Lower Keweenaw at the base of the Great Conglomerate,—a suggestion

stratigraphically worthy of consideration, though it does not accord with Irving's original division, nor with the text.

M. Colten in *Economic Geology*, 1907, page 572, (Vol. II, No. 6) describes a series of copper deposits in the Belt formation of Montana. This is unconformably overlaid by the Middle Cambrian. Flat head sandstone, and is said to be separated by great unconformities both from it and the "Archean" beneath. It is divided into two series by an unconformity. The upper and lower series contain black fetid limestones, and certain beds of this are impregnated with chalcopyrite and chalcocite. There is also a great thickness of red shale,—the Spokane shale. These red beds carry copper ores sometimes in veins and sometimes in bedded deposits associated with "intrusion" of diabase. The copper is most abundant when the diabase is thoroughly altered. He believes it has been leached by circulating ground water from the diabases. These diabases should correspond very closely to the Keweenaw. It is notable that the sulphides are mentioned, not native copper, and intrusives not effusives.

(3) The third question is as to the "explanation for the characteristics" of the deep waters high in chlorides. The authors of Monograph LII are not inclined to accept my suggestion that these characteristics are connate, that is original, "for all the essential kinds of conditions which produce the salt water of the ocean are present." (p. 544) "Chlorine is present," as they say, "in minute quantities in original igneous rocks and in nearly all surface waters. Its salts tend to remain in solution, while the salts of other acids are more largely precipitated. With a given amount of water, there seems likely to be, therefore, a progressive relative accumulation of chlorine salts. Such is the case in salt waters at the earth's surface, where a large factor in the accumulation is the lack of sufficient circulation to carry off and dilute the salt waters that are developing by evaporation. In deep underground waters there is essentially the same condition of stagnancy, and therefore we suggest progressive accumulation of soluble chlorine salts."

Is not evaporation an "essential kind of condition" for surface salt waters? The only thing that can replace it underground is rock hydration and the absorption of water into solid minerals. This may be a factor, but one would not expect it to be of much weight, especially when these salt waters occur in limestones and pure sandstones.

It is gratifying to notice that Van Hise realizes the importance of stagnant water. The more stagnant the water, the more largely

must it be connate. That the chemical composition of connate waters may be changed after burial, one can not deny, but the only way that one can suppose such stagnant connate waters could acquire the large percent of salts they often contain is to suppose that a small percentage of interstitial waters in the pores has leached a good part of a very small amount of chlorine from the fresh rock. A rock with a half percent pore space filled with water or say five ounces of water in a cubic foot would have about a sixth of a percent, of the weight of a cubic foot of rock. The segregation of enough chlorine to make this a strong solution of chlorides would be less than a tenth of a percent,—so small a quantity that no chemical work yet done, to be sure, is enough to prove that it may not have happened. Neither is there chemical or petrographic evidence, such as corroded apatite adduced to show that it has taken place. Stagnant waters would certainly retain strong traces of their original character, and I see no reason why my assumption that the chlorine is almost wholly connate does not better agree with the facts.

For in the first place, the term "progressive," as above used, must be understood as referring to time, not to space or distance from surface. If anything stands out from my mine water studies, it is the rather sharp change from fresh to salt. The fact that the salt water at the top has much more sodium in proportion to the strength than the stronger, deeper water, seems to show most surely that it is not by the increase of chlorine, first taking up sodium, then "when the sodium is taken care of by the chlorine," the calcium, but by a direct reaction of the calcium chloride waters, either with rocks that contain soda or surface waters containing sodium silicate or carbonate that these waters, intermediate in position, but not in composition, have been formed. I wish I had printed as a figure some diagrammatic tabulations of the composition of the waters in which this clearly comes out. The suggestion of Van Hise and Leith is, however, very interesting and important, if true,—that the percent of chlorine can be taken as an index of the degree of stagnation. In this, I should be inclined to agree myself.

With regard to the formation of copper (see especially page 558 of Monograph LII) we are agreed that the formation of the copper was but shortly after the formation of the beds in which it is found, and that the copper-bearing solutions were hot. I am inclined to dwell on the fact that they were unequally hot and think that they tended to throw down the copper in the hotter parts;

that the turning of calcium chloride into sodium chloride helps to throw out copper I do not doubt, but am inclined to emphasize the presence of trap rocks that help to make an alkaline solution. We agree that the water was "both juvenile and meteoric." I think the chlorine was also, and suggest that there may have been some concentration in desert pools, which lava streams may have helped to evaporate. We both are inclined to consider the effusive rather than the intrusive rocks as the source of copper. In that, we differ from the explanation of Volney Lewis of the New Jersey zeolites and the copper associated with them.

In 1911, I went down the Somerville mine, one of the deepest of the New Jersey mines, to the bottom. I saw no reason to believe that the formation of the copper was there different from that at Lake Superior. The occurrence is directly under and in the joints of an effusive lava sheet and seems to be where the water impregnating the sandstones and shales below (in which shales steam bubbles were formed by the lava) was hotter and more alkaline, being near the alkaline trap. The native copper appears to be an original ore as it is in Lake Superior and oxide and sulphide largely secondary. Fenner and Lewis have recently gathered numerous facts as to the paragenesis of the zeolites and the flow of lava on land and in lakes that entirely fit with what I have seen in Lake Superior. I wish I had read their works twenty years ago. But it must not be forgotten that the mineralizers or magmatic waters of a magma do not cease to exist, if, instead of being intruded, the molten lava reaches the surface, and there is no reason why the boron, found so often in borax lakes in volcanic arid regions, should not be efficient as a mineralizer, if buried under hot lava flows, even though it had seen day-light. The difficulties as to the source of boron raised by Lewis may thus be removed.

The "circulation" seems to me rather an imbibition or absorption with an ionic migration toward points where precipitation is going on. Long ago, de Lapparent called attention to the fact that the traps are alkaline and have a reducing action.

It would be foolish to deny that intrusives in many places have a large part in ore deposition. Intrusive traps occur at many places and at many ages, but the primary ore associated with them is generally chalcopyrite. Only in the formation of native copper does it seem as though it were needful for them to reach the surface so as to give the sulphur a chance to oxidize to sulphate and be carried in one direction, while the more readily re-

duced silver and copper, which have less affinity for oxygen than the sulphur, are reduced without it.

Native copper deposits, as I have pointed out, appear to be associated with certain former physiographic surface conditions.

The report of J. R. Finlay was made for purposes of taxation and this report is pretty closely confined to geology, but there is one sentence (p. 33) that I would challenge geologically, viz.: that "the copper district has been pretty thoroughly explored." According to the authors of Monograph LII and myself, the occurrence of copper has but little to do with the present surface, though there may have been some mainly pre-glacial, perhaps pre-Ordovician impoverishment connected with a surface not unlike the present. If, as I have suggested, certain lava flows evaporating certain pools in the desert tended to produce some concentration of copper, certain horizons must be regarded as more favorable than others. This might apply to the Kearsarge or Pewabic lodes. The Nonesuch horizon also shows heavy decomposition of basic rocks and there may have been copper dissolved in that connection, and while it shows signs of copper almost everywhere, it has been closely tested for copper but for a very few miles. The horizons of very few lodes have been explored for more than a small fraction of their distance.

Again, if I am right in thinking that the mineral crests or richest parts of the lodes are in the belt of middle waters, it is obvious that only explorations of lodes of something over 1,000 feet, on the average, is a fair test of their worthlessness.

Finally, when we remember that the surface of the range is largely covered by thirty to three hundred feet of drift, and that there is not the slightest reason, so far as I know, to suppose that there is any such connection between drift and the copper that the copper should be found mainly where the drift was thin; that the only way of testing drift covered regions at all is by diamond drills or shafts and that diamond drilling has been used not much over twenty years and is, at best, like probing for a needle in a haystack, with a long steel rod, it seems very unlikely that we have already pretty thoroughly explored and developed the best copper mines. It is quite likely that the cost of preliminary exploration may grow, but that, as fast as more copper is needed, more exploration will be done to find it and more will be found. I may say that I have some times, by request, refrained, in this report from reporting visible copper, so that the references to copper in the drill core, sections given in this report are not on

a uniform basis and cannot be used to determine the relative value of lodes.

Recent Explorations.

The geological and diamond drill exploration in the years 1909-1912 has been mainly in two districts. The one is from the Adventure and Lake Mines northeast. To some extent, drilling later than 1909 has been incorporated in Plates XIII and XIV. The formation is, no doubt, broken by many faults, but I know of no serious changes required in these or in Plate VIII, except (according to a theory I can not yet accept) in the neighborhood of the Lake lode.

The question as to the relation and direction of the Lake lode is still an open one. One theory is that it curves around, forming a synclinal and so continues with certain copper bearing belts of the South Lake. This would naturally imply a belt of at least some distance in Section 31, T. 51, R. 37 and 36, T. 51, R. 38, where the dips, instead of those everywhere else universally present through the Copper Range toward Lake Superior, would become southeastward. This is the theory which has been naturally attractive to the South Lake Mining Company and which is illustrated in the map accompanying their annual report for 1910. It is also favored in the Lake Mining Company report for 1911. One objection to it seems to be the apparent dip of the beds in Adventure drill hole 1, shown especially in the sandstone at 779. It will be remembered that that hole dips about 65° to the southeast, so that the bedding of the sandstone makes an angle of something from 40° to 70° against the direction of the hole. These observations would seem to agree with a northward dip such as we found at the Algomah and Lake properties, and would make it rather difficult, though not impossible to suppose that the dips were so suddenly reversed. The Algomah drilling shows northerly dips, I believe.

Another way to account for the apparent southward dips in Holes 4 and 6 of the South Lake is shown by studying the section of the Mass in Figure 52¹, these South Lake holes occupy a position relative to the formation between Mass d 5 and 1 of Figure 52. If there is a series of faults as therein indicated, throwing the southeastward side downward, it is quite easy to see that if one correlated horizons directly across, from one hole to the other, one could infer southward dips.

¹In Fig. 52 the number to Hole 1 is carelessly omitted. It is the vertical hole just north of No. 2.

Which of the theories illustrated is the correct one, only further drilling, probably, can determine, and I may have been too much influenced in my feeling that there is no such fold, by the fact that no similar folds have heretofore been noticed.

The Contact, formerly Elm River Company, give in their report for 1912 an account of drilling in a heavy drift covered region, confirming, on the whole, the lines of Plate VIII, where it was a good deal guess work.

The second district is in the neighborhood of Calumet (Plate IX) where the Mayflower, Old Colony, Oneco, New Baltic and New Arcadian have been drilling. Many of the holes are not far from the lines of Conglomerate 8 of Plate IX, or, as it is often called, the St. Louis conglomerate. Its flat dip in the Torch Lake section (Fig. 38) becomes (according to the report of the mining company) steeper to 43° on the Old Colony and 50° on the Mayflower. The course of Conglomerate 8 may be rectified slightly.

The structure of the Torch Lake section, like the structure along the Keweenaw fault at the Lake and a number of other places, may be easily accounted for by the explanation given on the figure, i. e., by supposing that there was an uplift of the Lower Keweenaw accompanied by more or less normal faulting and that upon the uplifted and eroded edges of this Lower Keweenaw the Jacobsville sandstone was laid down, and that after this, disturbances still continued along the same line which here, and not infrequently elsewhere, took the shape of over-thrust faulting.

In Plate IX, there is an error whereby the base of the Eagle River group is placed at Conglomerate 17, just covering Marvine's groups b and c. Both Seaman and I agree that the more important change in the character of the trap is not at Conglomerate 17 but at Conglomerate 18 which in the Tamarack Mine is (394) feet above. Conglomerate 17, as the horizon of mining work at the Copper Falls, Arnold, Phoenix and Atlantic Mines, is, however, an economically important horizon. The boundary of the Eagle River group, as I have defined it, is at the top of Conglomerate 18 and should, therefore, be about 500 feet farther northwest in Plate IX.

With regard to Plate X, also, it should be noted that not only has the culture been revised, but the geology also, for which I, therefore, must now bear the responsibility rather than Dr. L. L. Hubbard. With regard to the densities of the rocks (pp. 66-97), it may be worth noting that the Calumet and Hecla Mining Company assume 12 cubic feet to a ton or 18 feet to a fathom

(6x6x6 = 216 feet) of ground of their conglomerate broken, and usually the same for the amygdaloid, which they say runs but little more—18.07.

To correct § 12 of Chapter I. (pp. 48 and 51), Leverett sent me the following interesting notes of his work.

In 1909, he found a well-defined beach on Centennial Hill in north part of Calumet which reaches 1303 feet A. T., and a lower one at 1,245 feet. Northwest of the Tamarack mine, are beaches at about 1,240, 1,220, 1,200, 1,170 and 1,135-40 feet. These beaches are all tilted in a north-northeast to south-southwest direction, the fall between these and the Quincy mine being about 3 feet per mile. The beach which is 1,135 feet at the Tamarack mine falls to about 1,080 feet west of the Quincy mine. The fall keeps about the same rate clear to the south shore of the old lake. The beach which is 1,303 feet A. T. on Centennial Hill falls to only 554 feet above Lake Superior on the north side of the Porcupine Mts., and 1,134 feet A. T. at Bruce's Crossings or 169 feet in about 60 miles. It is doubtful if any beaches except the ones at 1,303 and 1,245 on Centennial Hill can be carried into the St. Croix outlet of Lake Duluth. It is also doubtful if any between 1,245 and 1,100 feet A. T. in the vicinity of Calumet belong to Lake Algonquin. The beaches at 1,220, 1,200, 1,170 and 1,135 feet are suspected to pertain to a lake stage with outlet northwest into the basin of the Red River of the north which, at one time, held a large glacial lake—Lake Agassiz.

Regarding the mine waters, I should like to add an analysis of a salt water on the Baltic lode, where it was explored by the Atlantic mine, close to a fault. This was from a diamond drill on the 25th level, at a depth of 2,240 feet. The composition according to G. A. Koenig is

CaCl ₂	11.58 per cent
NaCl ₂	1.07
MgCl ₂	0.06
SO ₃	0.00
that is: Ca	41.7 per thousand
Mg2
Na	4.2
Cl	81.0
Sum	127.1
Na : Cl =	.052
Ca : Cl =	.515

The sodium is abnormally low.

Sp. Gr. at (20° C.) 68° F., 1.1043. Temperature of the flow in the mine 62.6° F.

Absorbed gas 33.5 cc. per liter of which there was oxygen 6.27 present; nitrogen 93.73.

It is noteworthy, if this is correct, that while the gas is not the reducing inflammable gas which I had supposed associated with the rocks and the lower water, the oxygen is much less than in normal air, showing that if this gas is derived from air, it has been exposed to reducing action. Occasionally, probably through some artesian circulation, the water is quite salt at a shallow depth. The dip of the rocks toward Lake Superior is such that one would expect such salt wells along the shore, if the strata were broken by fissures or joints, to give effect to the artesian pressure. An example seems to be met at Green, a hamlet west of Ontonagon, on the Lake shore. The Greenwood Lumber Company, in a well 100 feet deep, struck a water which was not a strong brine but in which the ratio of NaCl:CaCl₂ was, according to Dr. G. A. Koenig, as 0.06: 0.04. Another well, about 1,000 feet farther along the shore, was not quite so salt. This seems to indicate a mixture of a surface water with a little of a strong brine, like that of the Freda well, uprising from a depth or a fault (?)

The identification of the various zeolites is probably somewhat uncertain, especially as regards thomsonite. Inasmuch as I did not have the advantage of so thorough a treatment of the same, as is given in Winchell's "Optical Mineralogy," (pp. 394-410) very probably some of the minerals called thomsonite are other zeolites.

INDEX.

INDEX.

	Page
A.	
A a type of lava (See also amygdaloid conglomerate).....	69
Abeel, G. H., Jr., On Gogebic Range mine waters.....	784, 785
Adamellose, defined.....	72
Adams, F. D., cited.....	79
Adventure Mine drill holes and section	
described.....	574-587, 592
referred to.....	569, 570, 588, 594, 595, 598, 599, 946
Adventure lodes.....	885
Agassiz, A., reference.....	762, 763, 934
Agate	
Carnelian.....	716
occurrence in conglomerates.....	630
paragenesis of.....	858, 860
Agate Harbor, reference.....	200
Air drills, use of.....	911
Akerose, defined.....	72
Albany and Boston conglomerate.....	409
position of (See Allouez conglomerate).....	35
Albany and Boston Mine or section (See Franklin Junior).....	906
Albite twins of feldspar, extinctions of.....	123, 630-754 passim
Algodonite, paragenesis of.....	869
Algomah.....	566, 865, 946
Allen, R. C., acknowledgment and reference.....	13, 938
Allouez conglomerate 175-750 passim,—especially 436, 489, 490, 491, 493, 694, 714, 797, 799, 800, 802, 889	
correlations of.....	175-750 passim
position of.....	35, 409
termination of.....	26
See also Marvine's conglomerate.	
Allouez, Father C. J., reference.....	890, 891
Allouez Mine.....	919, 923
Alteration (by water).....	94, 96
of amygdaloids.....	175-750 passim,—especially 791, 854
of Calumet boulder.....	87, 91
of Keweenaw dikes.....	91
Alumina	
in alteration.....	89, 91, 94
rock analyses.....	99-119
water analyses.....	781-842
Amphibole.....	62, 312, 662, 939
Amygdulites.....	175-750 passim
agate.....	628
grain around.....	149
paragenesis of minerals in.....	867
pipe.....	628, 650, 690, 713, 879
Amygdaloid	
alteration zones in.....	854
better defined in depths.....	791
favorable to copper.....	829
occurrence.....	175-750 passim
usage of term.....	27, 51, 64
See pumiceous amygdaloid	

	Page
Amygdaloid conglomerate	
defined	31
occurrence of	175-750 passim,—especially 363, 469
usage of term	34, 68, 89, 190
Amygdaloidal texture, usage of term	139
Analcite, analyses of	104, 549
occurrence of	252, 262, 684, 859
paragenesis of	859, 861, 862, 871
Analyses illustrating derivation of sedimentary from igneous rocks	115
Analyses illustrating kaolinitic alteration	117
Analyses of chloritic materials	114
Analyses of Calumet and Heda boulder	89, 115, 116
Analyses of Duluth gabbro	101, 102
Analyses of feldspar	104, 658
Analyses of gabbro aplite	108
Analyses of greenstone	112
Analyses of Keweenaw rocks of Minnesota	100, 101
Analyses of Keweenaw sediments	118
Analyses of Lake Superior sandstones	118
Analyses of Lighthouse Point dike	99, 160
Analyses of lime melaphyre	113
Analyses of melaphyres	111
Analyses of minerals in Keweenaw basic rocks	103, 104
Analyses of Mt. Bohemia ophite	109
Analyses of Mt. Houghton quartz porphyry	106
Analyses of Nonesuch Shale by Dr. Gysander	30, 118
Analyses of Oligoclase gabbro	109
Analyses of olivine	104, 113
Analyses of ophites	516
Analyses of porphyrite flows	107
Analyses of pyroxenes	104
Analyses of sandstone	118, 629
Analyses of sodic melaphyres	110
Analyses of water	523, 570, 781-846 passim
Analyses, miscellaneous minerals, table of	105
Analyses, table of (See composition)	86
Analysis, methods of water	778, 835
Anamesite, usage of term	52
Ancient miners work of	889, 890, 899
Andose defined	72
Anhydrite, paragenesis of	861
Ankerite, paragenesis of	465, 467, 858, 861, 864
Anorthite	693
Anorthosite defined	71
Apatite	631, 638, 721
petrographic description	128
Aplite (See gabbro aplite)	
Apophyllite	
analysis of	104, 105
occurrence of	303, 858, 862
Apostle Islands sandstones	41, 940
Arcadian drill holes and section	
described	430-456
referred to	200, 274, 275, 298, 301, 304, 320, 323, 324, 325, 379, 381, 407, 419, 420, 421, 422, 431, 437, 461, 463, 467, 563, 669
Arcadian lode, reference	371, 448, 464, 467, 486, 561, 905
Arlington (Schuyler) Mine, New Jersey, copper at	876
Arnold Mine section described	239, 262
Arsenic in copper (See Mohawkite)	830, 868-871
Arsenides in Bolivia	879
Artesian flows	570, 759, 838-847, 949
Ash, volcanic, occurrence of	668, 690, 691, 694, 739, 755
Ashbed	34, 175-750 passim,—especially, 670
definition of	31
(See Ashbed group and Mesnard lode.)	

	Page
Ashbed (conglomerate), description of	33, 68
occurrence (See Marvine's conglomerate 17)	17, 262
Ashbed group, characteristics of	29, 35, 138
composition of traps of	110, 111, 114
exploration on, amount of	172, 173
occurrence of	261, 409, 436, 548, 551, 559, 565, 605, 624-625, 629, 652 and passim to 692
specimens from	142
thickness of	37, 310
Ashbed mine, location of	35, 911
Atlantic mine section 16 crosscut of	459, 494, 563
Atlantic Mine, methods of mining	920, 921
section at	491-494
temperature in	760, 949
water in	829, 948, 949
Auzigite	
composition of	76, 103, 104,
decomposition to chlorite	123, 229
decomposition to hornblende	123, 230
grain of	146, 175-750 passim
porphyrite hiatus	732, 733
petrographic description of	122
prismatic form of	123, 393, 702
sheaf like	639
Auzigite porphyrite	56, 392
Aurora Mine, water of	782, 783
Auvergnase, occurrence of	518
Auvergnose, defined	72-73, 79, 518
Aztec Mine (South Lake), reference	566, 574
Azurite, occurrence of	861
B.	
Backbone greenstone	739
Ball steam stamps, use of	906
Bad River gabbro, appearance of	60, 627
grain of	129
Baltic conglomerate	34, 225, 474, 483, 498, 499, 522, 527, 544, 564
See also Marvine's conglomerate 3.	
Baltic lode	
dip of beds on	23
location of	48
mining operations on	917
occurrence of	473, 497, 498, 499, 505, 522, 523, 544, 564
paragenesis of minerals in	826, 828, 831
salt water in	828, 829, 948
Baltic Mine, methods in	922, 923
Baltic Mine section	498
Baltic sandstone	495, 499
See Marvine's conglomerate 5	
Bare Hill, felsite at	755
Barite, paragenesis of	803, 858, 860, 861, 868, 879, 880
Barrell, J., reference	32
Barrel work (copper)	902
Basalt, usage of term	27, 52
Basalt porphyry, usage of term	64
Bastite, see Olivine alteration products of.	
Batholite, a possible cause of faults	21
Baveno plagioclase twins	679, 683
Bay City, geothermal gradient at	768
Bayley, W. S., reference	56, 59, 71, 781, 933
Beaches, altitudes of	49, 948
Becke, F., reference	76, 120
B. Shaft of Minnesota Mine	610, 611, 825

	Page
Beerbachose, defined	72
Bell, J. M., reference	850
Belt Mine (See Lake Mining).	
Belt formation, copper in	942
Bismuth, characteristic of "Western copper"	863
Black Hills, part of Calumet Mine	
copper and silver in	810, 863
Black River, section	
abstract of	624-627
reference to	35, 37, 39, 40
Blake Point, Isle Royale, formerly "Greenstone"	692
Blandy, J. F., reference	935
Bohemia conglomerate	33, 34, 175-750 passim,—especially 189, 190, 243
See Marvine's conglomerate 8.	
Bohemian Range group,	
distribution of	172, 173, 450, 456, 459, 463, 485, 614, 625, 627, 628, 748, 756
thickness of	33, 310
Boiling point of salt mine water	795
Bolivia, native copper in	874, 879
Bolson, Keweenaw rocks formed in a	585, 940
Bornite, occurrence of	629
Boss, C. M., reference	934
Boston Creek	487
Bowen, N. L., acknowledgment	79
Bowlingite, see Olivine, alteration products of	
Brady, S., reference	604, 609
Branch vein, see Rockland	
Brauns, R., reference	938
Breakfast Lake, section north from.	
See Clark Montreal section.	
Breccia, definition of	31, 32
fault	175-750 passim
Brick clay	526, 567, 597
Britannare, defined	71
Brogger, W. C., reference	76
Bromine,	
occurrence of	788, 793-796, 805, 807-808, 813-815, 817, 818, 823, 830, 831, 838
Brooks, T. B., reference	894
Brotocrystals	80, 668, 681, 685, 691, 716, 739, 748, 755
Broughton, S. H., reference	610
Brucite, occurrence of	379
Brun, A., reference	45
Bunsen,	
normal basaltic magma,	
composition of	65, 75, 76, 81, 102
grain of	146
normal trachytic magma,	
composition of	75, 76
Burrage, A. C., acknowledgment	15
reference	430
Burrall, F. P., analyses by	106, 107
reference	658, 659, 660
Burt, W. A., reference	51, 52, 893
Buthiatrephis	525
Butler lode, occurrence of	567, 611, 612
Byerly, W. E., reference	156, 158, 768, 769, 771
Bytownite, porphyritic	644

C.

Cables, use of in mines	912
Calcite,	
occurrence of	175-750 passim,—especially 552, 607, 641, 723, 754, 767, 826, 831, 855, 877
paragenesis of	295, 615, 617, 858, 859, 860
petrographic description of	126

	Page
Calcium,	
in alterations	94, 776
in rock analyses	99-119
in water analyses	781-891
Calcium chloride in rock	805, 806
wide spread occurrence of in waters	841
See analyses.	
Caldwell drill holes, described	320-324
drill holes referred to	325, 326, 327
Caledonia Bluff	604
Caledonia conglomerate	567, 576, 580, 588, 593, 612
See Marvine's conglomerate 8.	
Calico lodes	493, 556, 557, 565, 569, 590, 610
See Houghton conglomerate.	
Calumet,	23, 947
subdivisions at	39
thickness of Keweenawan at	37
Calumet amygdaloid,	
occurrence of	175-750 passim,—especially 252, 411, 423, 705
Calumet conglomerate, composition of	68, 89, 93, 118, 361, 362
composition of water in	802-804, 807-811
decomposed boulders in	87-91, 353, 361, 364, 365, 864
discovery of	908
occurrence of	181, 196, 208, 251, 252, 258, 264, 267, 314, 361, 365, 367, 411, 423, 440, 444, 558, 703, 715
richness of	43, 48, 810, 811, 850, 889
Calumet and Hecla Mine,	
methods in	908, 918, 920, 923, 924, 926, 927
Calumet and Hecla Mine, temperature observations at	762
Calumet and Hecla Mining Company,	
drill holes referred to	298, 419, 442, 444, 839
drill holes on section 18 described	328-333
near Kearsarge lode described	366-370
water of shaft 21 (Kearsarge) referred to	171
Cambrian age of Keweenawan	940, 941
Cameron, F. K., reference	850
Camptonose, defined	73
Canadare, defined	71
Canadian Geological Survey	756
Canadian Mining Institute, proceedings cited	784
Cape d'Or, copper at	878
Capen vein, horizon of	464, 465
Card Point, Isle Royale, greenstone at	692
Carnahan, A. L., reference	937
Carp Lake.	
See also Little Carp Lake.	
Cascade River, porphyry near	624
Cass, Lewis, reference	892
Castile Mine, base of Keweenawan at	628
Celestite, occurrence of	803
Centennial Mine,	
natrolite	859
section at	365
shafts at	919
water at	817, 818-820
Central Mine,	
Mohawkite in	869
temperature in	760, 761
vein	855
Central Mine cross section,	
described	264-309
specimens from	142
Central Mine, drill holes referred to	188, 193, 196, 198, 200, 210, 217, 219, 220, 236, 237, 238, 239, 240, 249, 256, 275, 324, 386, 419, 442, 444, 715, 729, 732, 756

	Page
Central (Mine) group.....	829
beginning of.....	34, 409, 456
end of.....	34, 456, 463
per cent of sediment in.....	455
specimens from.....	142
thickness of.....	35, 310, 455, 456
Chalcedony, occurrence of.....	378, 720, 731, 753, 858, 859, 860
Chalcoite, occurrence of.....	629, 756, 831, 861
Chalcopyrite, occurrence of.....	228, 629, 756, 876
paragenesis of.....	861, 868, 879
Challenge exploration cross section,	
described.....	505-524
referred to.....	170, 527, 538
salt water at.....	833-7
Chamberlin, R. T., on gases.....	45, 418, 842, 862-3
Chamberlin, T. C., reference.....	27, 762, 763, 768
Chambers in mining.....	911
Champion Copper Mine, geological conditions at.....	505, 522
minerals in.....	860, 870
mining methods at.....	918, 922
salt water in.....	829, 831, 832
temperatures in.....	760, 761
Champion Iron Mine,	
temperature in.....	760, 761
water in.....	787
Champion Lode in Evergreen Bluff.....	567
Chemical classification of rocks.....	73
Chili, copper in.....	776
Chippewa felsite,	
occurrence of.....	33, 409, 565, 606, 622, 625, 626, 689
Chippewa lobe.....	526
Chlorastrolite,	
analyses of.....	104
paragenesis of.....	93, 94, 125, 858
Chlorine,	
See mine water analyses of.	
Also endothermic reactions.	
Chlorite.....	175-750 passim,—especially 275, 294, 295, 297, 363, 451, 684, 708, 725, 844, 853
analyses of.....	83, 114
occurrence of.....	63, 83, 94-96
paragenesis.....	93, 615, 860, 866, 867
tufted.....	684
Chloritoid.....	788
Chrysocolla, paragenesis of.....	861, 865
Chutes, see shoots.	
Chynoweth, Jas. S., acknowledgment and reference.....	15, 371, 527, 859
Chynoweth, S., acknowledgment.....	527, 533
Clark, Wesley, reference.....	262
Clark-Montreal section, described.....	174-190
referred to.....	193, 194-199, 251, 254, 886
Clasolite, occurrence.....	175-750 passim
definition of.....	31, 47
Classification, of rocks quantitative.....	71
Clay and kaolin.....	710
petrographic descriptions.....	128
See also fluccan and brick clay.	
Cliff Mine,	
salt water in.....	774
section.....	314
work at.....	896, 899
Clinker bed, definition of.....	31
Cobb, M. A., analysis by.....	787
Cobrizos.....	880

	Page
Colby Mine, water in.....	784
Cole's Creek, sandstone on.....	487
Collen, M., on belt formation.....	942
Compositions (chemical).....	57-119
of Nonesuch shale.....	36
of traps.....	26, 27
See analyses.	
Compass, variation of, near lodes.....	910
Conductivity,	
of copper.....	870
of rocks.....	765, 766
of snow.....	772
Conglomerate Bay.....	651
Conglomerate Mine, temperature in.....	760
Conglomerates, position of various.....	35, 37, 39, 482, 753
See also list under Marvin's numbers and synonyms there given.	
Connate waters,	
See waters, mine.	
Connecticut Mining Property, location of.....	259
Consanguinity of rocks, defined.....	77, 78
Contact effects.....	72, 109, 229, 416, 939
Contact Copper Company, reference.....	527, 530, 947
See Elm River.	
Cook, Newell, analyses by.....	108, 109, 110
Cookose, defined.....	73
Cooling, effect on grain.....	145-169
earth temperature gradient.....	766-770
Cooper, J. B., acknowledgment.....	15, 93
reference.....	869
Cooper, J. R., reference.....	916
Cooper, W. F., reference.....	524
Copper,	
cost of.....	918
crystallization of.....	811, 855, 857
slow.....	767
formation of.....	43, 83-90, 777, 847, 872, 873, 880, 885
distribution of.....	41, 487, 497, 799, 813, 850, 873 and passim
mass.....	888, 892, 899, 900
no.....	790
occurrence of.....	42, 175-750 passim,—especially 398, 418, 444, 461, 473, 552, 577, 607, 616, 639, 658, 684, 687, 700, 706, 711, 712, 723, 724, 735, 738, 767
occurrence.....	810, 813, 824, 831, 851, 852, 853, 857, 874, 875, 876, 888, 922
in drift.....	48, 904
in mine waters.....	42, 778, 792-795, 803, 807, 814, 815, 818, 819, 823
in shale.....	421, 581
origin of.....	872, 873, 944
epigenetic.....	880, 885
syngenetic.....	880, 885
paragenesis of.....	175-750 passim, 561, 617, 858, 860, 861
See also prehnite, datolite and calcite.	
percentage in lava or lodes.....	175, 778, 813
in mine waters.....	793-796
petrographic description of.....	127
production of.....	923
replacement by.....	42
residual nuggets of.....	474, 828
sulphide derivation.....	870
tempering.....	857
water associated with.....	809, 822
Copper Crown Mine, work at.....	622
Copper cutters.....	900
Copper Falls adit.....	259, 652
"Copper Handbook," cited.....	469

	Page
Copper Harbor conglomerate	605, 625, 627
base of	332
use of term	37-39
See also Great and Outer Conglomerate.	
Copper Harbor, vein at	896
"Copper Mines of Lake Superior," cited	409
Copper Point, Mamainse, porphyritic bed at	738
Corey, G. W., reference	337-348, 936
Cornish Stamp, use of	902, 903
Corocoro, Bolivia, copper mines at	879, 884
Courtis, W. M., on Silver islet mine water	774, 788
Credner, H., reference	53, 68
Cretaceous peneplain, referred to	48, 940
Crustification, absence of	884
Crystallinity of rocks	129
Crystallization, power of, defined	149
Cumberland Point	652
Cypricardites at Limestone Mt.	525
Cyrtodonta at Limestone Mt.	525
Cuneamya at Limestone Mt.	525
Cuprite, paragenesis of	861
Curtis, H. L., reference	771
D.	
Dacotah Heights Company, drilling by	486, 488
Daly, R. A., reference	77, 78
Darapsky, L., on Chilean mine waters	882, 933
Datolite	42
occurrence of	214, 237, 239, 262, 301, 304, 306, 309, 376, 379, 405, 471, 556, 561, 591, 628, 667, 675, 712, 720
paragenesis of	858, 861, 862
petrographic description of	127, 561
precipitating copper	849
Davis, C. A., reference	936
Delaware Mine, cross section at	257
temperature in	760
water in	802
Delessite	175-750 passim,—especially 688
paragenesis of	858, 860
See chlorite.	
Dengler, T., reference	492, 494
Dennis, M., acknowledgment	15
Density, see specific gravity.	
Denton, F. W., acknowledgment	15
referred to	407, 546, 625, 832
Deposition, dips of	680
Devon conglomerate	622
Diabase, usage of term	52, 61, 63
analyses	99, 100, 116, 117
decomposition	91
occurrence	627, 628, 756
Diamond drill exploration	910, 945
Differentiation,	
magmatic	658, 659, 739
wet and dry	81, 82, 79-83
See mineralizers.	
Diffusivity, effect of varying on grain	155, 167
in Keweenaw rocks	Ch. VI, 765, 766
of snow	772
Dikes,	
occurrence of	784, 785
Dip of beds	23, 175-750 passim, 790, 799
at Medora shaft	802

	Page
Dip needle, deflection of	910
Doelter, C., reference	150, 154
Dolerite, usage of term	27, 52, 66
Dolerite porphyry, usage of term	64
Doleritic melaphyre, definition of	27
occurrence of (See doleritic texture).	
Doleritic ophite	175-750 passim,—especially 446
Doleritic texture,	
cause of	83, 134-6, 183, 445
copper in	86, 221, 222, 234, 419, 452, 510
grain in	136-7, 185, 201, 214, 216, 246, 253, 303, 306, 307, 310, 356, 360, 368, 420, 424, 530
Doleritic texture,	
occurrence of	183, 199, 228, 240, 244, 254, 305-6, 368, 444, 466, 592, 645, 655, 708, 721, 723, 750, 853, 939
parallel to bedding	570
rhyocrystals in	246
usage of term	28, 66, 134, 135
See also chlorite.	
See also druses.	
Dolomite, paragenesis of	860
Domeykite, paragenesis of	861, 868, 879
Doney, J., reference	799
Dorchester Mining Company	906
Douglas, E. Fenner, acknowledgment	15
Douglas, James, reference	933
Douglas Houghton Falls, occurrence of	22
Drainage, Pre-glacial	527, 564, 588, 604
Drift, thickness of.	
See drainage pre-glacial and overburden.	
Drill holes,	
crookedness of	520, 534, 586
observations	175-750
temperature in	762, 763
Drum, types of, in mining	912, 927
Druses	277-279, 291-297, 371, 690, 708, 725
See doleritic textures.	
Duluth gabbro, analyses of	101, 102
Duparc, Louis, reference	934
Durkee, F. W., analysis by	798
E.	
Eagle River, thickness of Great Copper Harbor Conglomerate at	39
Eagle River group	629, 630
occurrence of	37, 548, 573, 605, etc.
thickness of	310
Eagle River section,	
described	311-313
referred to	261, 262, 311, 332, 640, 645, 647, 657, 658, 661, 664, 678, 681, 691
Eastern Sandstone,	
See Jacobsville sandstone.	
Edwards, R. M., acknowledgment	15
reference	762
Effusive and intrusive rocks distinguished	60, 62, 63, 129, 135, 168, 939
Egleston, T., reference	887, 931
Ellipsoidal greenstones	399
Elm River Company, see contact.	
Elm River drill holes, described	530-535
Elm River drill holes, referred to	538, 561, 563
Elm River section, abstract of	528
Emerson, L. E., reference	260, 262, 593
on salt water	774
Empire drill hole, described	192-200

	Page
Empire drill holes, referred to.....	170, 183, 208, 210, 250, 252, 253, 254, 255, 256
Empire section.....	191-200
Endothermic reactions.....	764, 765, 770
Eocrysts.....	133, 678
See hiatal texture.	
Epidote.....	
copper in.....	530, 584
crystals in.....	280-291, 669
distribution of.....	188-750 passim,—especially 227, 270, 293, 296, 379, 465, 467, 552, 826
paragenesis of.....	85-86, 513, 552, 615, 617, 858, 860, 864, 866
petrographic description of.....	127
zoisititic.....	457
Eutectic.....	72-75, 79-81, 102, 103
dry.....	73
Evans tables.....	929
Evergreen Bluffs.....	565
Evergreen Shaft.....	567, 568, 593, 594, 611
Exner, Sigm., reference.....	120
Explosives.....	907
F.	
Faulting near Portage Lake.....	486
Faults.....	21, 22, 23, 24, 173, 175-750 passim,—especially 260, 262, 437, 469, 475, 566, 613, 623, 629, 646, 670, 688, 707, 725, 740, 756, 791
strike.....	595, 626
upheaval.....	573
See slides.	
See fractures.	
See grain, crack effect on grain.	
Fay, H. B., acknowledgment to.....	527
Feldspars.....	
analysis of.....	104, 658
in altered boulders.....	87, 90, 353
petrographic description of.....	123, 175-750 passim
pink secondary.....	308, 361
primary.....	175-750 passim
seriate porphyritic.....	643
zonal extinctions of.....	724
Feldspathic melaphyre.....	175-750 passim
See also plagioclase.	
Felsite.....	
distribution of.....	172, 173, 565, 573, 755
usage of term.....	55, 71
Felsite breccia, defined.....	68
origin of.....	68
Felsite tuff.....	399, 401
See Mesnard epidote, and Ashbed.	
Fenner, C. N., reference.....	32, 878, 937, 944
Fernekes, G., reference.....	42, 43, 757, 766, 778, 780, 781, 786, 790, 792, 793, 797, 816, 847, 848, 866
Finlay, J. R., reference.....	938, 945
First Adventure lode.....	583
First Mountain.....	885
Fischer well.....	841
Fisher, J., Jr., reference.....	98, 790, 804
Fissure veins.....	909
Flemington Mine.....	876
Float copper, distribution of.....	48
Floating lever.....	927, 928
Flow sheet.....	930
Fluccan, described.....	21, 47, 556
occurrence of.....	175-750 passim,—especially 270, 449, 455, 552, 554, 555, 556, 560, 616, 619, 646
paragenesis of.....	858

	Page
Flooding.....	
bluish.....	754, 755
petrographic description.....	128
with calcite.....	754
Fontainebleau calcite pseudomorphs.....	604
Forbes, D. C., reference.....	880
Ford, Wm. E., letter of.....	126
Forest Conglomerate.....	614, 825, 826
Formis, A., acknowledgment.....	15
reference.....	782
Fort Wilkins, temperature at.....	896
Foster & Whitney, reference.....	29, 52, 53, 96, 629, 758, 894, 897, 909
Foster Mass Amygdaloid.....	464
Fractures, see faults.	
Franklin, B., reference.....	891
Franklin Junior drill hole, described.....	407-422
referred to.....	200, 218, 219, 273, 298, 324, 366, 413, 414, 420, 435, 440, 441, 444, 445
Franklin Jr. Mine.....	406, 407, 437, 688, 691, 789, 797, 801, 802, 844
Frapwell, A. P., reference.....	800, 825
Freda.....	838
Freda sandstones, described.....	40
referred to.....	406, 456, 485, 487, 604, 622, 625, 627, 630, 840
Frontenac drill hole.....	253
described.....	253-256
See Manitou.	
Frue automatic tramway.....	926
Fuller, M. L., reference.....	565
G.	
Gabbro (Bad River).....	627
character of occurrence of.....	33, 129
of Mt. Bohemia.....	108, 109, 229
of Porcupine Mts.....	624
Gabbro aplite.....	
analyses of.....	108
definition of.....	40, 56, 59, 60
occurrence of.....	60, 82, 231
texture of.....	141
Gabbro, definition of.....	27, 134, 135
Gabbro, usage of term.....	60, 63, 135
Gabbro intrusion.....	72, 624, 627
pegmatites.....	939
sill.....	627
See Mt. Bohemia, Porcupine Mt., Bad River.	
Gases.....	843
effect of.....	146, 231, 949
in mine waters.....	788, 842
in rock.....	842, 855
Germania Mine.....	783
Giraffe vein, usage of term.....	201
Glacial action, described.....	48, 824
deposits.....	569, 888, 918
phenomena.....	525, 540
Glass, brown.....	718, 719, 726, 753
conchoidal, fragments of.....	739
Glen Ridge Mine.....	876
Globe.....	505, 832, 918, 924
Glomeroporphyrite.....	175-750 passim,—especially 303, 306, 307, 377-379, 391, 422, 424, 473, 488, 612, 729
definition of.....	27, 137
texture of.....	35, 64
marginal.....	240
Glomeroporphyritic texture.....	
occurrence.....	549, 559, 587
usage of term.....	137

	Page
Goldthwaite, J. W., reference.....	936
Goodale, S. G., acknowledgment.....	527, 932
Gordon, W. C., reference.....	39, 565, 625
Gouge.....	291, 372
See fluccan.	
Grain of rocks, effect of crack on.....	149
inaccuracy in observing.....	154, 201
indicating faults.....	709
irregular, explanation of.....	634
observations on.....	176-760 passim
variations in.....	576
See also ophitic and doleritic texture.	
Grand Portage amygdaloid.....	448, 905
Granophytic texture.	
See graphic texture.	
Grant, U. S., reference.....	56, 59
Graphic texture, described.....	140
See micropegmatite and granophytic.	
Grayling.....	768
Great (Copper Harbor) Conglomerate.....	548, 565, 573, 624
composition of.....	67
described.....	39
position of.....	37, 174, 328, 605, 625, 627
thickness.....	39, 310
Green.....	840
Greenland.....	574
Greenstone bluff.....	896
Greenstone.	
analyses of.....	112
contact.	
upper.....	245
lower.....	247
see "slide" under and Allouez Conglomerate.	
differentiation in.....	135, 246
doleritic texture in.....	135, 201, 246
effusive character of textures in.....	135, 939
extent of.....	22, 456, 490, 491
grain of.....	137, 170
occurrence of.....	262, 409, 436, 552, 559, 561, 629, 652, 678, 688, 689, 691, 692, 693, 739
ophitic texture in.....	133
petrography of.....	312, 692-694
porphyritic heatal plagioclase in.....	201, 246, 692-694
thickness of.....	32, 174, 245, 263
usage of term as proper name.....	52-54, 939
Greenstone, "slide" under.	
See Allouez conglomerate.	
specific gravity of.....	99, 112
Greenwood Lumber Company.....	840, 949
Grierson, E. S., acknowledgment.....	15
reference.....	810, 819, 820
Grout, F. F., reference.....	78, 104
Grunerite.....	788
Gypsum.....	831
paragenesis of.....	858, 861, 868, 879, 880
with copper.....	884
Gysander, C. R., analysis by.....	118
H.	
Hahn, H. C., reference.....	844
Hahn, C. Otto, reference.....	883
Haight, C. M., reference.....	604, 612
Haire, Norman W., acknowledgment.....	15
Hall, J., reference.....	762

	Page
Hancock, dip of beds at.....	23
quarry near.....	456
Hancock lode.....	491
Hancock Mine.....	486, 487
Hancock West Conglomerate.....	546, 550, 551, 661, 669
See Marvine's conglomerate 17.	
Harker, A., reference.....	63, 77, 154
Hannony Iron Company.....	783
Hartman, W. F., acknowledgment.....	15
reference.....	883
Hauy, R., reference.....	94
Hawes, G. W., reference.....	896
Hays Point.....	15, 89, 802, 863
Heath, G. L., analyses by.....	600
Hematite.....	175-750 passim
Hematite plates.....	863, 864
paragenesis of.....	891
Henry, Alexander, reference.....	525
Heron Lakes, geology near.....	55
Herrick, C. L., reference.....	72
Hessose, defined.....	
See melaphyre.....	138
Hiatal texture.....	241, 434, 678, 733
occurrence of.....	
See also Huginnin.	
porphyrite, Kearsarge amygdaloid, eocrystals and rhyocrystals.....	574
Hilton.....	22, 59, 76
Hobbs, W. H., reference.....	820
Hohl, C. D., reference.....	926
Hoisting.....	824, 833, 835, 837, 841, 844
Holm, M. L., reference.....	485, 524
Honnold, W. L., reference.....	15
Hooper, Geo., acknowledgment.....	621, 810, 937, 938
Hore, R. E., reference.....	901
Horse whim.....	15
Hotchkiss, W. O., acknowledgment.....	917
Houghton.....	23
Houghton, dip of beds at.....	37, 51, 53, 892, 893
Houghton, Douglass, reference.....	889
Houghton, Jacob, reference.....	175-750 passim,—especially 188; 192, 193, 249, 257, 258, 264, 363,
Houghton Conglomerate.....	410, 437, 493, 554, 558, 559, 698, 715
position of.....	35
Hubbard, B., reference.....	51, 52, 53
Hubbard, L. L., acknowledgment.....	15
reference.....	31, 33, 56, 107, 174, 229, 261, 262, 263, 265, 268, 297, 407, 444, 451, 464, 486, 491, 505, 546, 565, 691, 767, 825, 855, 859, 933, 934, 935, 738
Huginnin Cove.....	738
Huginnin Creek.....	56, 729, 738, 739, 748, 753
Huginnin porphyrite.....	787
Hulst, H. R., reference.....	73
Hungarare, defined.....	84, 852, 867
Hunt, T. Sterry, experiments by.....	32
Huntington, E., reference.....	487, 908
Hurlbert, E. J., reference.....	783
Hurley Mine.....	824
Huron Mine.....	905
Huron Mining Company.....	18
Huronian rocks.....	139
Hyalopilitic texture, usage of term.....	84, 852
Hydration.....	59

I.

Ice-land spar.	
See calcite.	
Iddings, J. P., reference	76, 77, 78
Iddingsite, see Olivine, alteration products of.	
Illinois (steamer)	906
Indiana	565
Indians	890
Intrusives, composition of	109, 101, 108
contact effects of	229-231, 939
occurrence of	374, 393, 400, 565, 583, 624, 628, 740, 756, 774, 788
textures characteristic of	61, 62, 63, 171, 646, 939
See also gabbro, aplite, diabase, porphyry.	
Ions migration in copper formation	43, 864
Iron country mine waters	780
Iron oxide,	
in alterations	94
in rock analyses	99-119
in water analyses	781-841
Iron oxide, as rock constituents	175-750 passim
See Olivine, alteration product of.	
extra abundant in certain melaphyres	601, 742, 749, 750
Ironwood, salt water at	628
Irving, J. D., reference	39
Irving, R. D.,	39, 41, 54, 55, 173, 624, 625, 686, 933
Ishpeming Mine water	782
Island Mine Conglomerate	651, 652, 653, 661
Isle Royale, section on,	
described	629-755
referred to	29, 35, 548, 939
Isle Royale Consolidated Mining Company section,	
described	459-485
referred to	381, 382
specimens from	142
Isle Royale Consolidated Mine, mine water	822
Isle Royale lode.	
See Arcadian.	
Isle Royale Mill	929
Isle Royale Mine	458, 524, 859, 907
Isle Royale—Arcadian	371

J.

Jackson, C. T.,	
analyses by	103, 105
reference	52, 96, 758, 894
temperature observations	759
Jackson, J. F., reference	935
Jacksonite, referred to	126
Jacobsville sandstone	41, 401, 406, 476, 485, 524, 544, 572, 603, 628
Jasper	52, 558
Jefferson, M. S. W., reference	936
Jigs, use of	914
Johnson Creek Conglomerate	527, 546, 554
Johnston, W. H., reference	787
Julien, A. A., reference	53

K.

Kaolinite, paragenesis of	860
Kaolinitic alteration	91, 117, 785
Karlsbad twins, occurrence	89, 90, 123, 630-754, passim
Kawau Island Copper Mine	870
Kearsarge amygdaloid and conglomerate,	
occurrence	175-750 passim, especially 184, 199, 215, 235, 255, 257, 259, 340, 367, 414, 415, 416, 418, 429, 431, 443, 917

Kearsarge conglomerate,	
occurrence of	26, 35, 264, 269, 297, 412, 439, 441, 442, 556, 558, 714, 715, 719, 728
Kearsarge lode	810
copper and water in	810-822, 885
correlation with	557, 565, 726, 727
extent of	25, 493, 945
Kearsarge lode (amygdaloid)	
hiatal crystals in foot wall of	138, 257
mining upon	919
origin of	315
phenocrysts in	224, 225, 273, 274, 427, 428
Keweenaw fault, The	21, 406, 485, 573, 888
Keweenaw lobe	526
Keweenaw Point, thickness of beds at end of	39
thickness of Outer Conglomerate	39
Keweenawan rocks,	
age of	940
analyses of minerals in	103, 104
consanguineous relationships of	78
occurrence of	45
quantitative classification of	70
specific gravity of	97, 98, 99
thickness of	174, 310, 558, 559
Keweenawan rocks of Minnesota, analyses of	100, 101
Keweenawan sediments	
amount of in Central Group	34
composition of	32, 40, 67, 118
signs of subaerial origin	42, 67, 479, 541, 646, 721, 753, 845
of lake origin	32, 578, 585, 620, 879
of marine origin	879
Keweenawan series, Lower,	
age of	939
base of	630
Upper relation of	173, 623, 625, 630, 756, 940, 941
Keweenaw type of rocks, Osann's	518
Keeweenawite	813
paragenesis of	869
Kedzie, F. S., analysis by	839
Kelly, W., on Vulcan Mine waters	780
Kemp, J. F., reference	57, 775
Keratophyre, defined	71
Keewatin center	526
Keweenaw Copper Company, water from Medora shaft of	802
See Mandan cross section.	
Keyes, C. R., reference	775
Kilauose, defined	73
King Philip Mine,	
geology near	564
waters in	824, 837
Kingston conglomerate (same as Kearsarge)	270
Kirschbraun, L., analyses by	108, 109, 110
Knopf, Adolph, reference	937
Knowlton vein, occurrence of	567, 574, 576, 588, 591, 593
Koch, A. A., reference	52, 53, 810, 821
Koenig, G. A., reference	790, 792, 838, 859, 933, 934, 935
Königsberger, J.	764

L.

Labrador center	526
Labradorite	312, 515, 630-750 passim, especially 849, 860
paragenesis of	849, 860
Labradorite porphyry, usage of term	64
occurrence of	28
Labradorose, defined	71

	Page
Lac la belle conglomerate	225
See conglomerate 3, Baltic conglomerate	
Lake Agassiz, connection with post glacial beaches	948
Lake Algonquin, reference to beaches of	59, 948
Lake Brand of copper	767, 916
silver in	860, 863
Lake Duluth, reference to beaches	49, 948
Lake Linden	839
Lake Mining Company section,	
described	566-574
referred to	48, 573, 588, 593, 594, 595, 840, 946
Lake Nipissing, reference to beaches	50
Lake Richie	692
Lake Shore traps, distribution of	39, 173, 695, 625, 627
thickness of	174, 310, 623, 625
Lake Superior, size of	18
Lake Superior, a basin	15
Lake Superior sandstones	630
analyses of	118
See also Jacobsville and Freda sandstones.	
Lane, A. C., work of	56, 762, 935, 937, 938
de Lapparent, A., reference	944
Larsen, E. S.	767
La Salle Mining Co.,	
mine water of	821, 822
sections on	319
Laumontite	849
occurrence of	175-759 passim, especially 599, 677, 706, 811
paragenesis of	849, 858, 860, 864, 865
petrographic description of	125
unfavorable to copper	849
Laspeyres, H., reference	883
Lawson, A. C., reference	23, 933
Lawton, C. B., acknowledgment	15
Lawton, C. D., reference, Com. of Min. Stats.	257, 261, 267, 487
Lebachose, defined	71
Ledouxite, paragenesis of	869
Leith, C. K., reference	13, 32, 938
Leoben, M. Lazarevic, reference	938
Leopard sandstones	456
Leucoxene	662
Levels, distance apart in mining	910
Leverett, F., on glacial geology	760, 948
Lévy, Michel A., reference	76, 130
Lewis, J. Volney, reference	737, 874, 877, 884, 885, 936, 938, 944
Lighthouse Point dike, analysis of	99, 100
Lime, effect of alteration on.	
See also composition.	
Lime melaphyre, analyses of	113
See ophite.	
Limestone Mountain, palaeozoic strata at	22, 485, 521, 524, 824
Limonite, paragenesis of	861
Linceo, G.	767, 860
Lindgren, Waldemar, reference	938
Liparase, defined	71
Little Carp Lake, elevation of	624
Little Montreal River, felsites of	190, 755
Locke Point, Minong trap at	716
Lone rock,	
no dike in Upper Keweenawan near	39, 173, 623
Longyear, J. M., reference	624, 849
Loring, Thacher, reference	374
Los Banitos, salt waters of	882

	Page
Mabbs, John, reference	907
Mackie, William, reference	874
Magleburgose, defined	71
Magnesia	816
in alterations	84-94
in rock analyses	99-119
in water analyses	781-841, 844, 853
See also chlorite, delessite.	
Magnetite, paragenesis of	860
Malachite, paragenesis of	861
Mamainse,	
Keweenawan rocks at,	
described	172, 173, 756
red rocks intrusive at	229
referred to	67, 229, 755, 886
Mamainse conglomerates at	67
copper at	175
geological position of section at	172, 173
Mamainse felsites	755
Man-engine, working of	925
Mandan ophite	175-759 passim, especially 205, 206, 248, 409, 490, 491
Mandan section, described	200-224
Mandan (i. e. Medora) section (in drill holes),	
referred to	170, 180, 181, 193, 195, 197, 198, 199, 202, 236, 246, 248, 249, 250, 252, 253, 254, 255, 267, 275
Manebach twins	632, 634, 654
Manitou Mining Co.,	
lode	233, 234
section described	231-257
Mabb ophite, distribution of	34, 190, 225, 229, 460, 471, 472, 476, 477, 484, 496, 498, 499, 523, 524, 828
grain of	170
Manitou,	
section referred to	177, 183, 184, 185, 187, 188, 189, 193, 199, 200, 201, 206, 208, 210, 213, 216, 217, 218, 219, 220, 222, 223, 245, 254, 273, 275, 419, 653, 729
Mansfeld, Germany, copper at	874
Marcou, John B., reference	933
Marcou, Jules, reference	933
Marquette, Father J., reference	890
Marquette, Houghton and Ontonagon R. R.	917
Martin, Lawrence, reference	938
Marvine, A. R., reference	30, 32, 34, 35, 53, 55, 148, 257, 258, 261, 266, 435, 437, 464, 465, 657, 664, 721, 873
See Eagle River section.	
Marvine's conglomerates	No. 1
No. 3	225, 474, 483, 498, 499, 527, 544, 564, 828
See Baltic and Lac la belle conglomerates.	
No. 4	454, 460, 467, 470, 495, 563, 598
No. 5	432, 453, 459, 467, 495, 563, 580, 596
No. 6	432, 453, 460, 466, 498, 509, 528, 557, 565, 569, 574, 577, 583, 587, 591, 594, 595
No. 7	464, 465, 598, 528, 532, 613
No. 8	310, 394, 395, 432, 459, 459, 463, 505, 507, 527, 528, 529, 557, 565, 569, 574, 576, 594, 617, 736, 749
kinds of	69
occurrence of	34
pebbles of	175-759 passim
pebbles, alteration of	62
See Mt. Bohemia, St. Louis and Winona conglomerate.	
See also Wolverine.	
No. 9	527, 558, 736
No. 10	882

Marvine's conglomerates—Continued:	
See also Wolverine.	Page
No. 11	715
No. 12	
See also Kearsarge conglomerate.	
No. 13	439
See also Calumet conglomerate.	
No. 14	698
See also Houghton conglomerate.	
No. 15	435, 439, 574, 694
See also Allouez and Albany and Boston conglomerates.	
No. 16	262, 550
See also Pewabic West conglomerate.	
No. 17	488, 635
See also Hancock West conglomerate and Ashbed.	
No. 18	661
No. 21	640
Mason, R. T., reference	546, 548, 559, 563
Mass copper	902
Mass lode, referred	576, 588, 593, 611
section at, described	588-604
Mass Mine, reference	900
section at	569, 588, 825, 946
water in	825
Mayflower lode	371, 375, 932, 947
Mayflower Mine	947
McFarlane, Thos., reference	53
McCargoe Cove	738
McCulloch's Mine	716
McNair, F. W., acknowledgment	98
reference	96, 804, 820, 859
specific gravity tests.	
notes on samples used in	348-366
McNaughton, Jas., acknowledgment	15
Medora lode	233, 248, 265, 409, 490
See Mandan.	
Melaphyrporphyry, usage of term	64
Melaphyre	541, 653, 670
alteration of	92
analyses of	111
definition of	27, 53, 62, 63
sodic	110
Melaphyre, doleritic	
occurrence (see Doleritic texture)	175-750 passim
usage of term	66
Melaphyre, pegmatitic, usage of term	66
Melaphyre porphyrite	110, 433
pumiceous	578
Melilite in slags	77
Menlo Park Mine	876
Mendota,	
described	226-228
drill holes referred to	190
Mendota vein, occurrence of	201
Merchant's lode	576
Mesnard (epidote, jasper or sandstone) lode	31, 310, 400, 409, 431, 433, 436, 490, 552, 558, 565, 626, 691
correlation of	37
Mesnard, Father, reference	890
Metapoikilitic texture, described	141
Meuche, A. H., acknowledgment	13, 488
Meuche, A. H., reference	573, 586, 587, 614, 621, 622, 887, 938
Meuche, Karl S., reference	621, 810
Meuche, Leon, reference	621
Mica, petrographic description of	127

	Page
Michigan Agricultural College	771
Michigan Geological Survey	894
Cooperation with U. S. G. S.	893
Michigan Mine,	
dip at	610
section at	604-613
See also Minnesota Mine.	
South or contact vein	611
referred to	590
Microfelsitic texture, described	140
Micropegmatite, usage of term	63
Middle (Copper Harbor) Conglomerate, position of	37
Mine water, see water	788
Mineral land, appraisal of	896
Mineral Range R. R.	917
Mineralizers,	
effect of	30, 134, 135, 145, 149, 151
laws of loss of	152-169
Mines,	
cost of equipment	887
depth of	919
timbering of	911, 919
Minnesota Mine	899
See Michigan Mine.	
Mining methods	920, 923
Minong conglomerate	728
Minong porphyrite	57
described	714
referred to	755
Minong trap,	
described	716
reference	391, 392, 549, 695, 606, 607, 630, 724, 729
Minnesota conglomerate,	
correlation of	557, 565, 569, 574, 590, 593, 610, 611
Minnesotare, defined	73
Mississippi Valley, salt water in	776
Modialopsis at Limestone Mt.	525
Mohawk Mine, water of	811, 812, 820
Mohawkite,	
occurrence	23, 426, 813
paragenesis	868, 869
Monadnocks	525
Montana, Belt copper formation in	942
Montreal lode	194, 209, 231, 250, 251, 364, 493, 555
Monument Rock, occurrence of greenstone there	29
Monzonase, defined	72
Moraines	888
Mosaic texture, described	141
Mosler, Chr., reference	54
Mottles, like Castile soap	206, 301, 303
See ophite, pockilitic texture.	
Mottling, irregular or banded.	
See ophitic texture.	
Mt. Bohemia Conglomerate,	
horizon of	33
Mt. Bohemia, gabbro aplite.	
analyses	108
petrographic descriptions	229
Mt. Bohemia oligoclase gabbro,	
analyses of	109
Mt. Bohemia ophite, analyses of	109
Mt. Houghton felsite	83, 106, 175-750 passim, especially 565
Mud rock, cement, etc.	583, 598, 591, 595, 599, 602
See clasolite and amygdaloid conglomerate.	

	Page
Mügge, O., reference	767
Munroe, H. S., reference	933
Myers, Jesse, photography by	134
N.	
Nankervis, J. L., acknowledgment	89
National Mine	900
National sandstone, referred to	557, 565, 573, 574, 590, 610
Natrolite, paragenesis of	858, 859, 861, 862, 871
Navitic texture, usage of term	137
Nebraska Conglomerate, see Caledonia.	
Nests,	
of olivine	740
New Arcadian Mine	947
New Baltic Mine	947
New Brunswick Mine	876
New Jersey Copper	776, 874, 875, 944
New Zealand Copper Mine	870
Newton Mine	876
Niagara,	
occurrence at Limestone Mountain	22, 521
Nickel, occurrence of	869, 874
Nipigon Bay, igneous rocks on	940
Nonesuch formation,	
color of	67
composition of	92, 118
described	40, 92, 456
lack of development	945
occurrence of	39, 40, 614, 622, 623, 625, 627
Nonesuch Mine	761, 837, 855
North Kearsarge Mine	814, 815, 869
North Lake Mine	570
North Star,	
See Kearsarge.	
North Tamarack, highest beaches at	49
temperatures at	762
water from	810
Norwich Mine,	
See Copper Crown.	
O.	
Oberstein, Germany, copper at	883
Ogemaw,	
See Ogima.	
Ogibway Mine, reference	314, 315, 855
Ogima Mine, reference	567, 576, 588, 593, 611
Old Colony Mine,	
drill holes referred to	375, 402, 421, 445, 947
Old Colony Mine, section described	371
Old Colony sandstone	304, 375
Old Pewabic amygdaloid	407, 435
Olivine	732, 750
altered, described	127, 368, 375, 378; 422, 461, 575, 595, 599, 600, 601, 616, 645, 654, 657, 699 and 175-750 passim
corrosion of	122
fresh	741
grain of	615
paragenesis of	860
petrographic description of	122
Olivine, alteration products of,	
Bastite	657

	Page
Olivine, alteration products of—Continued:	
Bowlingite	127, 645, 654, 657
Iddingsite	375, 381, 382, 386, 388, 395, 595, 645, 654, 736
Iron oxides	584, 631
Mica	417, 461, 705
Rubellan	461
Serpentine	378, 417, 457
Talc	634
Ontario Bureau of Mines, reference	756
Oneco Mine	947
Ontonagon River Valley,	
beaches in	49, 948
outcrops of Keweenaw in	625
Opaque minerals, petrographic description of	124
Ophitic texture,	
alternately fine and coarse	211, 235, 257, 383, 399, 403, 404, 450, 470, 575
use of term	30, 130, 133 175-750 passim, especially 247, 515
very minute	182, 450, 598
Ophite,	
composition of	109, 116-114, 515, 516
occurrence and grain in	65, 175-750 passim
usage of term	54, 65, 132
See also greenstone.	
Orthoceras at Limestone Mountain	525
Orthoclase, paragenesis of	858, 861, 862, 864
Osann, A., classification of rocks by	73, 77, 518
Osceola Mine,	
temperature in	760
water in	841
Osceola amygdaloid or lode	182, 191, 213, 253, 269, 365, 411, 423, 431, 441, 705, 706, 804
Outer (Copper Harbor) Conglomerate, position of	37, 39, 174, 328, 456, 605, 623, 625, 627, 630
Overburden, noteworthy	505, 535, 564, 567, 569, 832, 924
See pp. 175-750 passim.	
Overhand stoping in mining	911
Overstrom tables, use of	929
Ovitz, F. K., analyses by	516, 783
Owl Creek vein	260, 262
P.	
Packard, R. L., analyses by	774
Palache, Charles, reference	861, 934
Palaeozoic strata at Limestone Mountain	22, 524
See also Jacobsville sandstone.	
Palisade trap, comparison with	737, 875
Paragenesis	276-297, 373, 615, 858, 860, 861, 864, 879
See mineral names.	
Parnall, W. E., reference	762
Pascoe, P. W., reference	786
Patton, H. B., reference	56, 91
Paull, J. F., reference	805
Paull, James	893
Pectolite	672, 849
Pegmatites, connection of doleritic texture with	66
Peirce, B. O., reference	763, 765, 769, 938
Peneplain,	
Cretaceous	941
Pre-Cambrian	941
Penhallegon, W. J., acknowledgment	15, 29, 225, 233
Pentamerus at Limestone Mountain	525
Percussion table, use in mining	914
Permian, copper deposits of	874, 883
Permits, mining, issue by U. S. Government of	895
Peters, A. D., on diffusivity of snow	771
Peterson, J. O., reference	561, 563

	Page
Petrographic descriptions.....	120-144, 630-755
Petrographic, description of.....	
apatite.....	128
augite.....	122, 382
calcite.....	126, 539
clay and kaolin.....	128
copper.....	127
datolite.....	127, 561
dolerite.....	721
epidote.....	127
feldspar.....	123, 480, 515, 655-755
fluorite.....	128
laumontite.....	125
mica.....	127
Olivine.....	122
opaque minerals.....	124
plagioclase.....	312, 313, 378, 383, 393, 457, 480, 515, 630-755
quartz.....	123
sandstone.....	544
steam sediment.....	416
sulphides.....	128
thomsonite.....	125
viridite.....	124
wollastonite.....	125
Pewabic amygdaloid lode.....	262, 407, 435, 488, 489, 491, 536, 539, 685, 686, 689, 797, 799, 805, 906
Pewabic West Conglomerate.....	243, 546, 550, 551, 680, 681
See Marvine's Conglomerate 16	
Phelps, Frank B., reference.....	933
Phenocrysts.....	175-750 passim, especially 220, 678, 693
See rhyocrystals, brotocrystals, eocrysts, Kearsarge lode.	
Phoenix Mine.....	897
geology at.....	311, 312
work in.....	897
Physiography.....	
of Lake Superior region.....	17, 21, 48-51, 486, 527, 564, 588, 604, 887, 888, 909, 940, 941
Pickford, water from well at.....	839
Pigeon Point, origin of rocks at.....	77, 82
Pirsson, L. V., reference.....	27
Piscatqua lode.....	567, 593
Pistazite.....	866
Pits, exploring.....	909
Pittsburg and Boston Mining Company.....	896
Placerose, defined.....	72
Plagioclase.....	
distribution and grain of.....	175-750 passim
petrographic description of.....	123, 312, 313, 515, 630-755
See also doleritic texture.	
Plagioclase, defined.....	71
Plagiophyre.....	321, 367
See Kearsarge lode and glomeroporphyrite.	
Plate I., referred to.....	29, 629
Plate II., referred to.....	29, 69, 112, 133, 148, 245
Plate III., referred to.....	112, 133, 148, 190, 245, 247
Plate IV., referred to.....	30, 133, 134, 147, 148, 174
Plate V., referred to.....	30, 40, 67, 148
Plate VI., referred to.....	74, 133, 147, 148, 515
Plate VII., referred to.....	64, 65, 69, 134, 137, 138, 139, 148, 203, 224, 315, 418
Plate VIII., referred to.....	35, 622, 624, 946
Plate IX., error in, corrected.....	947
referred to.....	29, 315, 316, 328, 424, 427, 430, 456, 757, 850
Plate X., referred to.....	430, 458, 485, 486, 491, 493, 494, 498, 947
Plate XI., referred to.....	535, 527, 564

	Page
Plate XII, referred to.....	527, 536, 546, 548, 564, 689
Plate XIII, referred to.....	564, 566, 574, 946
Plate XIV, referred to.....	574, 588, 604, 609, 611, 612, 946
Plate XV., referred to.....	614, 621, 622
Pleurotomaria at Limestone Mountain.....	525
Poikilitic texture.....	148, 631
See ophitic texture.	
Poikilophitic texture, defined.....	132
See ophitic texture.	
Point Houghton sandstone.....	40, 92, 118, 629
Pollard, J., acknowledgment.....	15, 859, 864
Pope, Graham, reference.....	762, 889, 905
Porcupine Mts.....	573, 622
Chippewa felsite of.....	560
felsite at.....	83
formations of.....	49, 941
gabbro.....	229, 624
Porcupine Mountains, highest beach at.....	49, 948
lake shore at.....	50
thickness of Nonesuch shales at.....	49, 622
thickness of Outer Conglomerate at.....	39, 623
Pore space, in amygdaloid.....	806
in conglomerate.....	809
in Marquette diabase.....	100
Porphyrite.....	
defined.....	72
occurrence.....	175-750 passim
See especially Minong trap, glomeroporphyrite, Ashbed group.	
Porphyrite below Mt. Houghton quartz porphyry.....	
analyses of.....	107
Porphyritic crystals, definition of.....	27, 81
See Kearsarge lode.	
See phenocrysts, brotocrystals, rhyocrystals, eocrystals	
Porphyritic hiatal texture, definition of term.....	138
distribution.....	175-750 passim
See especially Greenstone, Kearsarge Lode, Huginnin porphyrite.	
Porphyry.....	
occurrence of.....	especially, 263, 400, 624, 636
See also felsite.	
usage of term.....	33, 52, 58, 59, 60
Porphyry tuff.....	691, 753
See also Mesnard lode.	
Portage Lake.....	
faulting near.....	486, 487, 491
thickness of Central Group.....	35
Portage Lake Smelting works.....	916
Portage Mining Co.....	905
Portage River Improvement Co.....	906
Potassium.....	
in alterations.....	94
in rock analyses.....	99-119
water analyses.....	781-841
Powder House vein and ophite.....	573, 590, 609, 612
Powellite, paragenesis of.....	859, 860
Praysville (porphyry).....	263
Precht, J. reference.....	862
Prehistoric mining.....	488, 890
Prehnite.....	849, 876
analyses of.....	93, 104
occurrence.....	42, 93, 94, 104, 175-750 passim, — especially 375, 376, 377, 513, 571, 662, 681, 685, 726, 847
paragenesis of.....	94, 615, 858, 860
pink copper bearing.....	222, 239, 302, 303, 305, 308, 397, 462, 468, 482, 616, 617, 619

	Page
Prehnite—Continued:	
with copper.....	214, 234, 252, 266, 291, 298, 424, 425, 447, 587, 600, 607, 610, 639, 684, 687, 700, 705, 706, 711, 722, 723, 724, 733, 735, 738, 831
Presque Isle River, section.....	625
Propagation, of hot and cold waves.	
See diffusivity.	
Pryor, Reg. C., acknowledgment.....	15, 431, 432
reference.....	437, 440, 442, 443, 444, 447, 449
Pyroxene.	
See augite.	
Pyrrhotite.	
paragenesis of.....	861
Puca sandstone, copper in.....	879
Pumiceous amygdaloid conglomerate.....	69, 491-493, 406, 578, 581, 585, 620, 694
Pumpelly, Raphael, reference.....	29, 41, 45, 53, 54, 87, 94, 111, 265, 267, 774, 868

Q.

Quarry moisture.....	806
Quartz.	
crystals.....	279, 767, 860
occurrence of.....	552, 607, 639, 685, 687
paragenesis of.....	858, 860, 864
petrographic description of.....	123
Quantitative classification.	
described.....	71
referred to.....	58, 516
Quartz porphyry.....	400
Mt. Houghton, analyses of.....	106
See porphyry and felsite.	
Quaternary.	
See overburden and glacial phenomena.	
Queneau, A. L., reference.....	157
Quincy Mine, geology at.....	224, 431, 435, 487, 491, 791, 793, 799, 868, 910
mining methods in.....	905, 910
samples from.....	
temperatures in.....	760, 762
waters in.....	760, 790-796

R.

Rafinesquina at Limestone Mountain.....	525
Ragged amygdaloid.....	410, 490
Ramos at Corocoro.....	880
Randville dolomite.....	780, 781
Ravines showing faults.....	22
Raymond, Mr., reference.....	896
Red Beds.....	941
Red rock, defined.....	59
Reeder, J. T., reference.....	857
Republic Mine.....	786
Rhode Island drill hole, described.....	424-429
Rhode Island drill holes referred to.....	325, 326, 869
Rhyocrystals.....	80, 244, 246, 247, 379
Rhyolite.....	55
Richards, Jas. E., acknowledgment.....	15
Rickard, T. A., reference.....	799, 935
Ridge Mine.....	900
Ridley, F. W., acknowledgment.....	15
Rivot, M. L. E., reference.....	52
Roberts, J. F.....	761
Rockland Creek.....	606
Rockland, geology near.....	40, 565, 573, 574, 610
Rockland sandstone.	
See National Sandstone.	

	Page
Rockland vein.....	573, 610
Rocky Hill (Griggstown, N. J.) Mine.....	875
Rolling Mills.....	917
Rominger, C., reference.....	54, 257, 593, 624
Rose, R. S., reference.....	935
Rosenbusch, H., reference.....	53, 54, 57, 59
Roughing jigs.....	929
Rubellan, see Olivine, alteration products of.	
Ruthven, A. G., reference.....	936

S.

Salt crystals, paragenesis of.....	859
St. Croix sandstone.....	630
St. John's Creek, sandstone on.....	487
St. Louis conglomerate.....	33, 400, 932
See Bohemia Conglomerate.	
St. Louis property, geology on.....	365, 371
St. Mary's epidote	
See Mesnard lode.	
St. Mary's Mineral Land Co. (Challenge exploration).....	506, 833, 906
Salfemone, defined.....	72, 518
Sandstone (generally red or chocolate) 175-750 passim,—especially.....	680, 753, 601
See sediment and mudrock.	
analyses of.....	629
basic.....	519, 578, 581
blanched red.....	880
epidotic or green.....	235, 275, 301, 369, 370, 386, 426, 445, 451, 510, 520, 542, 577
indurated.....	510, 520, 535, 536, 564
Wolverine, Marvine's No. 9.....	369, 370
Santorin.....	885
Saponite, paragenesis of.....	860
Savicki, W. V., reference.....	371, 624, 606, 621, 935
Sawyer, A. H., acknowledgment.....	15
Schneider, C. F., reference.....	757
Schultz, A. R., reference.....	841
Schultz, R. S., acknowledgment.....	15
reference.....	614
Schoolcraft, H. R., reference.....	892
Scoriaceous conglomerate, defined.....	31, 69
Scotland, copper in Old Red Sandstone of.....	874
Scott, D. D., acknowledgment.....	15
Scovill Point.....	692
Seaman, A. E., reference.....	860, 941, 947
Sediment.....	115, 175-750 passim,—especially 703
analyses of	
coating in amygdaloid.....	641
composition of.....	91-93
concentration of	
elements in.....	91
contact effects on (epidotized sandstone).....	228, 238, 239, 255
copper bearing.....	237, 431, 445
amount in Central group.....	34
occurrence between Kearsarge and Wolverine.....	256, 273, 298
per cent of.....	34, 455
See conglomerate, sandstone, clausolite.	
Seeber, R. R., acknowledgment.....	15
reference.....	505
Selenite, paragenesis of.....	858
See gypsum.	
Separk, E. A., reference.....	782
Seriate porphyritic texture.....	138, 723
See also glomeroporphyritic.	

Serpentine, see Olivine, alteration products of	Page
paragenesis of	858, 860
Shaft pillars	921
Shafts of mines	910
Shale, red	640
See sediment and mud	
Shattered zone	828
See Shear zone and Breccia	
Shawmut conglomerate	527, 536, 546, 554
Shear zones	25, 47, 475, 476, 513, 535, 539, 583, 828
Shelden amygdaloid	448
Sheldon, C. D., reference	761, 905
Shields, E., acknowledgment	432
Shields, R. H., acknowledgment	15, 432
Shoots, described	47
occurrence of	610, 803, 810, 850
Shumway, F. W., reference	837
Siderite,	
occurrence of	389
paragenesis of	860
See ankerite	
Siebenthal, W. A.	786
Sienite (Syenite)	52
See gabbro aplite	
Silica	
in alterations	94
in rock analyses	99-119
water analyses	781-841
Silver mountain, exposure of Keweenawan rocks at	18, 625
Silver Islet Mine, saltwater and gas at	774, 788
Silver, occurrence of	43, 262, 616, 931
paragenesis of	860, 861, 863
Siskowit Point	92, 651, 692
See Point Houghton	
Skips	902, 913, 923
size of	912
Slaughter, W. F.	786
Slicken-siding,	
defined	25
occurrence of	175-759 passim,—especially 268, 294, 363
Slides,	
defined	25
in Central Mine	264
occurrence of	175-759 passim,—especially 261, 263, 539, 543, 555, 560
Slime table, use of	914
Slip, see Shear zone	
Smillie, S., reference	760, 762, 790, 791
Smith, Fred, acknowledgment	15
Smith, P. S., reference	260, 263, 271, 276, 371, 606, 624
Smyth, H. L., reference	783, 837, 808
Snow,	
Propagation of hot and cold waves into	771
Sodium,	
in alterations	94, 777
in melaphyres	82, 110
See glomeroporphyritic	
in rock analyses	99-119
in water analyses	781-841
Somerville (American) Mine,	
origin of copper in	876, 944
South Brother Hill, near Rockland	612
South Hecla part of Calumet Mine, salt and powellite in	859
South Kearsarge branch of Osceola Mine	820, 844, 919
South Lake Mining Co.	566, 570, 574, 946

HENRY A. BUEHLER
 CHIEF
 MEMORIAL LIBRARY
 U.S. GEOLOGICAL SURVEY

South Quincy	Page
See Dacotah Heights	
South Range	625
South Range Mining Company, drill holes	493
Specific gravity	96-99
changes affecting	765
of rocks	96-99, 920, 947
of water	519, 777, 779, 797-799, 814-818, 826, 949
Spherulitic texture	140, 754
Stamps	914, 929
cost of	931
water used by	931
Stamp mill	912, 927, 930
Stamp rock	888, 902
Steidtmann, Edward, reference	938
Steiger, G., reference	790
Steinmann, G., reference	874, 880, 881, 884, 936
Stevens, H. J., reference	871, 936, 938
Stillbite, occurrence of	303
Stockly, W. W., acknowledgment	15, 263
reference	260, 374, 391, 392, 400, 486, 689, 716, 774, 849
Stockwerk	
See Shear zones	
Stokes, H. N.	757, 766, 847, 848
Stonington	525
Geology near	
Strikes abnormal	566
(See faults)	
Stromboli, copper in exhalations of	885
Strontium, occurrence of	803
Sulitelma type, of rock	518
Sullivan, E. C., reference	850
Sulphide,	
description of, petrographic	128
occurrence only near intrusives	228, 756, 942
Sulphur	830
in copper	869, 871
in water	835-837
role of, in copper formation	944
Summit mining property	259
Sundt, L., reference	880
Superfusion, effect of	146, 165
Superior shafts	829
Superior and Ottawa Mine, Wisconsin	783
Swedetown Creek, geological section on	456
Sweet, E. T., reference	92
T.	
Tailings, copper in	916
Tamarack cross-section, notes on 30th level	337-348
Tamarack Junior Mine, water and conglomerate in	803
Tamarack Mine	656
geological section in	333-365
references to	142, 408, 434, 435, 548, 652, 656, 662, 691
sinking, timbering, etc. in	918-924
temperature in	760, 762
water in	802-806, 808-810
Tammann, G., reference	139, 149, 150, 675
Tarr, W. A., reference	937
Taylor, F. B., reference	933, 934
Tecumseh shafts of La Salle property,	
salt water at	821, 844
section	327, 374
Tehamose, defined	71

	Page
Tellurium, characteristic of Western copper	863
Temperature.	
causes of low	764, 770
effect of ice age on	763, 767, 768
of downward working waters	766
explanation of	763
increase of	768
Temperatures	
of air	757, 758
of mines	758, 759, 761, 761, 762, 786, 797
of soils	757, 760
of water	759, 761, 780, 840, 949
Texture.	
petrographic	27, 128-141
variation of, near amygdale	711
Thallite (epidote)	866
Thermal waters, see waters hot	
Third Brother hill, geology of	612
Thomas shaft, of Arnold Mine	261, 262
Thomsonite	175-759 passim,—especially 376, 949
occurrence of	208
paragenesis of	858, 861
petrographic description of	125
Thunder Bay, dolomites and dolomitic marls at	67
Thwaites, F. T., reference	628, 938, 940
Tight, W. G., reference	55
Tobin porphyrite, defined	56, 65
referred to	431, 661, 700
Todd Harbor	714
Toledo claimed by Michigan	892
Toltec Mine	574
Tonalose Dacose, defined	72
Torch Lake Mining Company,	
geological section of	374, 404
referred to	422, 486, 524, 620, 715, 729
Tourmaline, occurrence at Champion Iron Mine	788
Town 44 North, Range 34 W.	505
T. 46 N., R. 2 E. (Wisconsin)	628
T. 46 N., R. 41 W.	628
T. 47 N., R. 46 W.	628, 784
T. 47 N., R. 47 W.	628
T. 48 N., R. 37 W.	629
T. 49 N., R. 35 W.	629
T. 49 N., R. 36 W.	629
T. 49 N., R. 40 W.	621
T. 49 N., R. 41 W.	622
T. 49 N., R. 42 W.	624
T. 50 N., R. 30 W.	243, 246
T. 50 N., R. 33 W.	402
T. 50 N., R. 38 W.	865
T. 50 N., R. 39 W.	588
T. 50 N., R. 39 W.	565, 604, 610
T. 50 N., R. 44 W.	624
T. 51 N., R. 33 W.	380
T. 51 N., R. 35 W.	22, 524, 525
T. 51 N., R. 37 W.	564, 565, 567, 569, 570
T. 51 N., R. 38 W.	573, 574, 586, 589, 591
T. 51 N., R. 42 W.	624
T. 52 N., R. 35 W.	506, 531
T. 52 N., R. 36 W.	531, 532, 534, 535, 536, 538, 539, 549, 541, 542, 543, 544, 545, 548, 549
T. 52 N., R. 37 W.	548
T. 53 N., R. 35 W.	515
T. 54 N., R. 34 W.	479, 481, 491, 492, 494
T. 55 N., R. 33 W.	406, 419, 424, 427, 429, 430

	Page
T. 55 N., R. 34 W.	40, 143
T. 55 N., R. 35 W.	595, 598, 514
T. 56 N., R. 31 W.	229
T. 56 N., R. 32 W.	33, 365, 373, 400, 919
T. 56 N., R. 33 W.	25, 319, 327, 367, 374, 375, 376, 382, 383
T. 56 N., R. 33 W.	387, 391, 394, 400, 404, 919
T. 57 N., R. 27 W.	174
T. 57 N., R. 31 W.	229, 314
T. 57 N., R. 32 W.	25, 33, 128, 315
T. 57 N., R. 33 W.	328
T. 58 N., R. 28 W.	142, 175, 176, 178, 179, 189, 192, 755
T. 58 N., R. 29 W.	200, 226, 229, 231, 459
T. 58 N., R. 30 W.	205, 250, 252, 259, 459
T. 58 N., R. 31 W.	263, 270, 272
T. 58 N., R. 31 W.	35, 142
T. 58 N., R. 32 W.	142
T. 58 N., R. 37 W.	142
T. 58 N., R. 38 W.	172
T. 64 N., R. 37 W.	651
T. 65 N., R. 36 W.	651
T. 66 N., R. 35 W.	738
Trap, definition of	27, 51, 64
Trachyte	55
Trap rock, composition of	26
Tretheway, M., reference	267, 271, 829
Triassic	883, 885, 936
Copper of New Jersey	
Trichites (marginal) texture	175-759 passim,—especially 643, 696, 700, 726
Trimountain Mine,	
methods in	918, 922
salt water in	830, 831
Trochonema, at Limestone Mt.	525
Troctolite, facies like	750
Tufaceous texture, described	141
See also amygdaloid conglomerate and pages	175-759 passim
Tuff, defined	59
U.	
U. S. Geological Survey Bulletin	418
analyses from	103
Umptekase, defined	72
Umptekose, defined	72
Union Springs, water of	841
Upper Peninsula, history of	892
Uren, W. J., acknowledgment	15
references	532, 857
Urinometer, use in water testing	778, 786, 895
V.	
Vaalose, defined	72
Van Hise, C. R., reference	13, 91, 775, 852, 933, 934, 938, 941, 943
Van Orden, F., reference	536, 537, 540, 544
Van't Hoff, J. H., reference	844
Varioloid greenstone, occurrence of	29
Vetas, at Corocoro copper mine	880
Victoria lode	616
Victoria Mine geological section	576, 578, 579, 614, 825, 855, 856
Viridite, petrographic description of	124
Viscosity, effect of	129
Vitrophyric texture, described	140
Vivian, Johnson, reference	774, 789, 849, 861
Vogt, J. H. L., reference	79, 155

Volcanic focus,	Page
at Mt. Bohemia	627
at Porcupines	624, 625, 627
Vulcan Mine,	
waters of	780, 781
W.	
Walcott, C. D., reference	940
Wall ravine, occurrence of	22
Ware, E. E., analyses by	99, 781
Washington harbor	707
Washington Island	678, 692
Washington River	707
Water,	
alteration by	45-47, 87-96, 399
analyses of	522, 523, 570
corrosive effect of	808
effect on crystallization	28
(See doleritic and granophyric texture)	
hot, effect of	42, 83, 84, 140
See mineralizers.	
magmatic	
circulation of	884, 885
migration of	857
of mine	372, 409, 774, 775, 778, 780, 809
analyses of	780, 785, 787-846, 948
amount of	780, 786, 787
character of	928
concentration of	834, 856
contraction of, in cooling	854
importance in copper deposition	44
middle	846
origin of	43, 845, 846, 942, 943
salty	43, 271, 522, 614, 618, 784, 787
of ocean	777
of surface	837
Waterbury and Detroit Copper Co.	916
Waterbury Mining property	259
Weed, W. H., reference	936
Weidman, S., reference	841
Wendigo property	716
Wheal Kate	505, 904
altitude	49
Wheeler, H. A., reference	760, 763, 764
White, C. P., reference	155
White Pine Mine	623
Whitneyite, paragenesis of	831, 861, 868
Wichmann, C. A., reference	53
Wifley table	914, 929
Wilcox, J. M., acknowledgment to	15
Wilson, F. B., reference	804, 816, 834
Wearne, W., reference	569, 843
Wilson, J. G., reference	940
Winchell, A.	52
Winchell, A. N.,	
analyses by	100, 103
reference	27, 51, 58, 71, 81, 120, 122, 654, 660, 670, 937, 938, 949
on ophitic texture	130-132
Winchell, H. V., reference	813, 869
Winchell, N. H., reference	58, 122
Winona conglomerate	547, 563, 566
See Marvines conglomerate 8	
Winona drill holes, described	549-564
referred to	461, 507, 537, 538, 544

	Page
Winona lode	524, 536, 558, 564
dip of	547
hanging of	530
Winona Mine	546, 561, 824, 837
trench I	561
J	561
K	561
Winzes, use in mining	910
Wollastonite, petrographic description of	125
Wolverine Mine,	
geology of described	317-318
reference to	413, 414
salt water in	816-818
shafts of	926
Wolverine sandstone	35, 218-750 passim,—especially 218, 257, 274, 428, 443, 556, 626, 721, 727
character of beds near	298, 431
occurrence of	183-750 passim,—especially 558
reduction by slide	26
See also Marvine's conglomerate, 9.	
Wood, A. B., acknowledgment	464
Woodward, R. S., reference	158, 932
Wright, C. A., acknowledgment	15
Wright, F. E., reference	57, 59, 108, 122, 153, 201, 225, 229, 767, 935, 936
Wright, J. N., reference	934
Wright Island	630
"Wyoming" property	192
Wyandotte drill holes, described	536-545
Wyandotte Mining Co.	536
referred to	507, 531
Y.	
Yale Mine	784
Z.	
Zonar extinctions	724
Zeolites,	
in amygdules	175-750 passim,—especially 654
paragenesis of	42, 43, 97, 672, 681, 685, 696, 765, 811, 944
See prehnite, apophyllite, analcite, thomsonite, chlorastrolite.	