ANNUAL FIELD TRIP

MICHIGAN ACADEMY OF SCIENCE, ARTS AND LETTERS
AND
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MICHIGAN COPPER COUNTRY

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FORWARD

When Cartier and his voyageurs sailed up the St. Lawrence they were told by the tribes of Algonquin Indians of the copper to be found to the west, copper boulders which the Indians revered as Manitous, - copper pebbles which they wrapped in birchbark and beavers' skins and wore as amulets or kept as little Manitous, - household gods – in their tepees and hogans. Indian legends are replete with evidences that copper is sacred to Nanabozo. Reports of the copper sent to France were first published in Paris in 1636. The Jesuits followed and penetrated to the lake country and there, like the Indians, found "float copper" and heard of the Great Manitou at the fork of the river – the Ontonagon boulder? They sent copper to Quebec and France and stated that they would search for the copper mines but nowhere in their writings did they report that copper was mined by the Indians. The Plains Indians had copper utensils and weapons – but no records of mines or mining. But some mysterious race had come into the copper country and had mined copper, for under the duff and litter of the great hemlock forest which grew over them, were found pits and nearby mounds containing hammers, chisels and wedges of trap rock, stone and copper tools, and fragments of wooden bowls. The debris gives evidence that these mysterious miners used fire as a mining tool and later fashioned hammers and knives of copper for which they discarded their stone implements. In one pit they left a 6-ton mass of copper raised on timbers five feet above the bed. In 1847 a hemlock felled on the nearby mound was found to have 395 annular rings. Many locations made in the boom copper days were on or near so-called "Indian diggings" of these vanished miners.

In 1770 Alexander Henry with the backing of the Duke of Gloucester and the Empress of Russia attempted unsuccessfully to mine copper at the Ontonagon boulder. The boulder is a glacial erratic described by Bela Hubbard in original notes now in the office of the Michigan Geological Survey. He wrote of the difficulty in breaking off a 25-pound mass. The boulder, much reduced in size from the original Manitou and having a romantic history of ownership and travel, is now in the Smithsonian Museum.

Henry Rowe Schoolcraft after the 1820 expedition to the source of the Mississippi and exploration of the mineral lands of the Superior Basin, wrote the first scientific account of the geology and mineral value of the Upper Lake Region, (published in American Journal of Science).

In 1830 Douglass Houghton made his first visit to this copper region and during the 1832 Schoolcraft expedition and later excursions along the coast and up the stream valleys, found the true location of the copper bearing rocks which he described in a paper read in Philadelphia in 1840. Mining operations started in 1844 near Copper Harbor and at the Cliff Mine. The work at Copper Harbor did not prosper but the Cliff Mine paid its first dividend - $60,000 - in 1849 and continued dividends to 1857. Over 38 million pounds of copper were produced from the Cliff Mine.

The copper in the Michigan mines is found in three types of deposits associated with the thick series of Keweenawan lava flows. The first type to be worked were the fissure deposits in which the copper is found in tension cracks and faults that cut across the flows approximately normal to their strike. The principal fissures were not single breaks but rather zone of parallel or interbranching factures. The width of the fissures range from a fraction of an inch up to 10 feet. The second type of copper deposit is in the porous and broken tops of the lava flows. Because the cavities in the top of these flows are almond shaped, the deposits were called amygdaloids. The third type of deposit, intermingled with the flows, is a series of conglomerate sediments. In some places these porous beds became channels for solutions which brought in large amounts of copper.

Encouraged by the success of the Cliff which produced copper from a fissure vein, the early miners looked for copper in fissures which cut across the flows, and were quite readily located by the gaps in the hills which are valleys or gaps eroded along fissures. Masses of virgin copper were often found in these fissure mines – some of them reported to weigh as much as 500 tons. However, less than three per cent of the total production is reported to have come from fissure deposits. The

Phoenix and Central were two early mines which produced copper from fissures.

The presence of copper in the amygdaloidal tops of the flows was recognized around 1856, the date of discovery of the Pewabic load. The Quincy and the Pewabic mines were the first of this type. The Quincy, known as the “Old Faithful”, has had a long and successful record and has paid dividends every year for over half a century.

The most famous of the conglomerate mines was the Calumet & Hecla Conglomerate which was opened in 1864. It is reported that this property was found by Hulbert in 1858 while surveying the state road from Copper Harbor to Houghton. He stumbled across a pit in which some copper was buried, perhaps by the early mysterious miners or by Indians. Hulbert mistook this copper for “Indian diggings” and in looking around for additional pits found the Calumet Conglomerate.

The Calumet & Hecla Conglomerate is one of the famous mines of the world. Of the 18 shafts on the property, five were carried to or below the 81st level, a distance of 8100 feet on the incline of the lode or 4900 feet vertically from surface. Six vertical shafts were sunk, three of which were below the 81st level. The cost and difficulties of hoisting directly from 5000 foot vertical depths, forced a change in methods. Underground hoists were installed on the 81st level and the ore from lower levels was transferred to the shafts which reached surface from this level. One of the sub-shafts started from the 81st level reached the 96th level – a depth of 9600 feet on the dip of the lode from surface or 5684.3 feet below the collar of the Red Jacket shaft.

Temperature increases with depth in these mines. Measurements by the U.S. Geological Survey show the following temperature changes:

From	60	to	1,080	feet	1°	F.	to	every	99.1	feet
"	"	"	1,915	"	"	"	"	"	105.6	"
"	"	"	3,090	"	"	"	"	"	119.3	"
"	"	"	5,367	"	"	"	"	"	117.4	"

The rock temperatures on the 81st level of the Conglomerate mine – depth vertically 4900 feet – is reported at 86.2° F.

Mining operations in the Calumet & Hecla Conglomerate were over an area of more than four square miles on the lode. Over 150 miles of drifts were used to extract the ore. This one property produced approximately three and one-half billion pounds of copper and paid over 150 million dollars in dividends. With this record it is no wonder that there is a continuous search for similar deposits and that this property is mentioned in all the discussions of fabulously rich mineral deposits.

Records from 1845 to 1946 show that 9,423,173,101 pounds of copper have been produced from Michigan copper deposits, an amount which would make a cube over 250 feet square. The copper bearing rock hoisted is estimated to be more than 600 million tons which would fill a pit 1000 feet wide, 500 feet deep and over three miles long. When it is realized that all of this rock was hard and tough, the figures give some idea of the amount of work done in this district since the first mines started. Some idea of the rock removed can be gained by looking at the large rock piles. However, most of the rock carrying the copper was crushed and ground to particles finer than sand and dumped into Torch and Portage lakes, after the metal was extracted. The rock waste was also used to build highways and street pavements, therefore, most of the waste is now out of sight.

In the early days the machinery and methods used for removing the copper were crude and the results inefficient as judged by modern practice. The loss of copper from the early mills treating conglomerate ran over 10 pounds per ton. The rejected crushed rock or tailings of the old conglomerate piles have been recovered, reground and treated with a resultant saving of many millions of pounds of copper. Today reclamation plants are working on amygdaloidal tailings which carry less copper than the conglomerate tailings and are more difficult to treat.

The concentrates produced by the mills and the mass copper picked out at the mine and at the mills have rock and other impurities that can be removed only by smelting. The process is essentially the melting of the concentrates and mass copper in reverberatory furnaces and the gangue is removed as slag. The copper is further refined by oxidation and slagging followed by the reduction of the excess oxide by poling (putting sticks of green timber into the molten copper). The last step is the casting of the copper into the various shapes used by the trade.

Michigan copper is unique in that it occurs practically pure in the rocks and not as an ore in the form of copper sulphide minerals as in the western mines, although some sulphides are present.

One of the features of the Michigan copper deposits is the association of native silver with the copper. The amount of silver is not high and the separation other than by handpicking is difficult. A great deal of silver was recovered by hand picking in the early days but at the present time little or no attempt is made to separate the silver form the copper and the two are melted down together. (Specimens carrying both silver and copper are called “half breeds”. They are now scarce and highly prized). The silver is not an impurity and for some uses is an asset which brings a small premium in price. Before the electrolitic process was developed, most copper refined from sulphide copper minerals carried impurities which detracted from its value for certain uses. High-grade Michigan, or “Lake Copper” came on the market in the infancy of the electrical industry and accounts for the rapid development of electrical technology. In turn, the increasing need for “Lake” quality copper is a reason for the importance of the district. Until the Montana and Arizona copper mines were found, Michigan was the great source of copper for the United States. In the hundred years from 1845-

1945, Michigan produced nearly 15 per cent of all the copper smelted in the United States.

As can be seen from the map, the series of copper flows extend from northcentral Wisconsin to the tip of the Keweenaw Peninsula. In general the direction of the strike of the flows is NE/SW with the dip to the NW. On Isle Royale and the north shore of Lake Superior are similar flows which dip in the opposite direction and some geologists believe that the Isle Royale formations and those on the mainland in Michigan were deposited at the same time from a volcanic vent located somewhere near the middle of Lake Superior. The dips of the flows at the north end of the Peninsula are rather flat. At the Central Mine in Keweenaw County the dip of the flows is 27° at surface and around 21° on the lower levels. In Calumet at the Conglomerate property the beds incline around 38° at the surface and are about 36° at a depth of a mile. At the Quincy Mine the lode dips about 54° at the surface and a mile down the incline shaft the dip is only about 37°. At the Champion Mine at the south end of the district, the dip is about 73°.

It is the custom among the miners in this district, in talking about directions, to assume that the flows run north and south and dip to the west, and to speak of the north or south end of the range. This is a little confusing to the strangers who come onto the district who note that the outcrop strike is NE-SW in Houghton County and almost E-W in Keweenaw County, but it is a very natural way of designating directions and makes it easier when describing work both on surface and underground.

In this connection there are a number of expressions which are used in connection with mining that may be of interest to laymen. The miner speaks of the “footwall” or “foot” as the flow or flows which lies beneath the lode which is being mined. In the copper country the footwall is always to the SE speaking accurately but speaking locally is to the “east”. Conversely the “hanging wall” or “hanging” represents the top of the vein or the rocks which lie above the vein.

No open pit mines are in the Michigan copper district. All properties are mined from shafts. Most of the shafts are inclined and are either in the lode itself or a short distance into the footwall. From these shafts, if they are in the footwall, “crosscuts” which cross the lodes are driven to the lode that is to be mined and “drifts” running parallel to the lode are extended in both north and south directions to the property lines or to the limit of mineralization. From the drifts, which are from 100 to 200 feet apart on the incline, the miners start mining the copper bearing rock by taking out as much of the lode as can be safely extracted. In some mines practically all the lode can be recovered and in others some of the lode must be left as pillars to hold up the rock and keep it from squeezing together before the miners can finish their work. When timber was cheaper and the lode was rich, timber supports were very often used instead of leaving rock in place to hold the area open. Waste rock was sometimes used to support the walls of the lode. Mining areas above the drifts are called stopes.

Many of the miners who came to this copper country got their early experience from the mines of Cornwall and brought many of their expressions with them into this district and to the mining industry in general. For example, an opening through which ore is dumped that has crossbars to screen out the large chunks is called a “grizzly”. A shaft sunk from underground is called a “winze”. The suction end of a pump is a “clack”. A piece of timber between two other timber supports is a “studdle”. An opening for catching water for a pump is a “sump”. A post used to support the rock is a “prop” or “stull”. These are just a few of the general mining expressions used that may be of use to us on this trip.

PART I

COPPER COUNTRY ITINERARY

FIRST DAY

All cars will line up on the north side of College Avenue, facing west (toward the Douglass House) ready for departure at 8:45 A.M. Stop #1, although optional, is highly desirable since the A. E. Seaman Museum is one of the best of its kind in existence and, further, the mine models will give one an understanding of mining methods used in the local mines. (See maps #1 and #2).

Guides	Kiril Spiroff through Stop #6 T. M. Broderick Stop #7 and evening

Stop Number		Time	Approx. Mileage
1	Michigan College of Mines Museum and mine models, diameter shot drill core. Group leaves College Ave., 8:45 A.M.	7:30-8:45	
	From Stop #1 we will travel westward through the business district of Houghton following M-26 southwestward to Stop #2.		6.5
2	New South Range Quarry (on west side of road ½ mile north of South Range). Here a typical section of the flows of the Keweenawan can be observed. The section consists of a felsite conglomerate at the foot (south side of cut) overlain by two small flows, followed by a larger one. The base of still a later flow can be seen near the opposite end of the cut. Note porous tops and dense interior of flows.	9:05-9:30	1.0

3	Baltic Shaft #2 Dump (sulphide minerals) (southeast of South Range - near southwesternmost shaft house - turning right at Baltic School) The copper sulphide, chalcocite - a dark, lead gray, metallic mineral; bornite, copper red to brown, possessing an iridescent, peacock-alike luster, occasionally chalcopyrite - brassy-yellow and soft, may be found; Ankerite, a carbonate of calcium, magnesium, iron and manganese, - a white, cleavable material, is common here. The pink mineral is probably either rhodochrosite (manganese carbonate) or a pink-colored calcite. Traveling from Stop #3 to Stop #4 we are climbing stratigraphically in the series and after turning right off M-26 pass the abandoned #6 Isle Royale Shaft on the right and the active shafts #5 and #4 on the left, we proceed by them to the site of #1 Shaft from which the head frame has been removed (near triangulation tower)	9:40-10:10	5.0
4	Isle Royale #1 Shaft locality – typical section of flow, east-west glacial grooves, Isle Royale lode, and mass copper. From Stop #4 we proceed stratigraphically down across the series to the Keweenawan Fault Zone.	10:25-11:00	1.5
5	Keweenaw Fault Zone – amygdaloidal flow top, breccia, and basal Cambrian conglomerate and sandstone. From Stop #5 we will proceed back to the Isle Royale Mine area, thence through Hurontown down the hill, through Houghton, and across the bridge to Hancock. At Hancock we turn left on U.S.-41, travel through the business district of Hancock to Geno's, which is located at the extreme west end of town, for a spaghetti or fish dinner.	11:10-11:20	2.5
	LUNCH AT GENO'S IN HANCOCK At 12:30 we leave Geno's and travel up Quincy Hill via U.S.-41 to the observation turnout.	11:30-12:30	1.5
6	Quincy Hill Observation Turnout – general view of geology of the district and stratigraphic orientation by Spiroff. Good spot for camera fans. Leaving the Turnout we will travel up Quincy Hill, passing the Quincy Shaft Houses and rock piles on the right. The rather new-appearing engine house at the rear of #2 Quincy Shaft House is one of the largest, if not the largest, steam hoist in the world, having a drum of approximately 33 feet in diameter. This shaft is bottomed at a vertical depth of over 6,300 feet, or approximately 10,000 feet on the incline along the dip of the Pewabic Lodes. Beyond the third shaft we turn right and proceed again stratigraphically down the section, crossing the Keweenaw Fault which again has its usual topographic expression. We turn to the left on M-26 and stop at an outcrop of Lake Superior sandstone in the road cut on the left.		6.0
7	Lake Superior sandstone on left in road cut. Observe cross laminations, ripple marks, and concretionary structures. Leaving this sandstone outcrop we travel up the west side of Torch Lake, sometimes termed "The Red Sea" because of the red wash waters flowing from the conglomerate mills further to the north. En route to Stop #8 we will pass the Quincy Reclamation Plant on the right where they are reworking the amygdaloidal sands stamped many years ago, the Quincy Mill on the left and the flume form it over the road to the sand pile on the right, the Tamarack dredge on the	1:05-1:15	3.8

	right and the Tamarack Mill on the left.		
8	Ahmeek Mill (trip through after explanation of flow sheet)	1:25-1:55	1.0
9	Calumet & Hecla Smelter	2:00-2:30	
	From the smelter we proceed through the village of Lake Linden and along the Trap Rock Road northeasterly to the Trap Rock School where we turn north. After going 3/4 mile, we take the gravel road left up the hill. En route along this road note where possible, the change in dip of the Lake Superior sandstone from nearly horizontal to vertical at Rock Wall Ravine.		6.4
10	Rock Wall Ravine This vertical wall consists of Lake Superior sandstone which has been upthrust by the Keweenaw Fault. Several other sandstone beds apparently less resistant, can be found up-stream from the rock wall, and the Keweenawan traps, can be observed near the head of the ravine.	2:45-3:05	
	From here we proced on up the hill and pass through the villages of Laurium and Calumet to Stop #11		2.5
11	Calumet & Hecla Engine House-glacial grooves striking approximately east-west.	3:20-3:30	
	Drive, about along the strike, to Stop #12 noting en route WPE "memorial #95" the "SS Kearsarge", 4.3 miles to Allouez #3 Shaft on Houghton conglomerate lode. We turn left off the highway at the village of Allouez.		3.6
12	Allouez #3 Shaft and conglomerate dump: shaft equipment and native copper in rock pile.	3:40-4:00	
	Drive to Copper via U.S.-41 passing near the village of Ahmeek, (a) the Ahmeek mine on right and left (b) the Mohawk mine dumps on right just beyond the town of Mohawk, (c) Cliffs & Phoenix mines on left near Phoenix – the cliff on the left is the Greenstone flow, (d) Central mine location, (e) Delaware mine location, (f) Lake Medora on left. Here the road swings northeasterly cutting through younger beds, passing the Park and Golf course.		
	(g) At M-26 turn left to entrance at Brockway Mt. Drive, (h) turn left and note, in addition to scenery, conglomerate sandstones and some traps en route to peak. Observe the steep southern (left) escarpment and gentle dip slope to the north.		33.0
13	Peak – Brockway Mt. Drive (elev. 1337' and 735' above level of Lake Superior)	Arrive 5:00	
	Turn around and descent mountain and go directly to Keweenaw Park – register at Lodge	Arrive 5:45	5.5
	SUPPER AT 6:30		
	Informal talk by Dr. T. M. Broderick, Chief Geologist Calumet & Hecla Consolidated Copper Co., or his assistant Dr. C. D. Hohl, on geology of the district.		

SECOND DAY

The morning of the second day will be spent in the upper part of the Keweenawan section which includes, in descending order, the Outer Conglomerate, the Lake Shore traps, the Great Conglomerate, the Ash Bed lode, The Greenstone, and the fissure deposits. (Broderick in charge, assisted by Messrs. Cornwall, White and Swanson of the U.S.G.S.)

Stop Number		Time	Approx. Mileage
Leave Park and drive to Eagle Harbor		8.00-9:20	
	The outcrops observed along the shore line are a part of the Outer Conglomerate, a thick sediment near the top of the middle Keweenawan section; striking erosional and depositional features will be observed between the Park and Eagle Harbor.		4.3
14	Evil's Wash Tub (wave cut cavern in Outer Conglomerate)	8:10-8:20	

	Observe at least two tombolas – land-tied islands – en route to Eagle Harbor. Just north and east of Silver Creek we will pass the east entrance to Brockway Mt. Drive. Here a contact between the middle conglomerate and sandstone may be observed, and those interested in making a further study can walk back a short distance from Stop #15		7.5
15	Silver Creek – middle conglomerate and sandstone. Some excellent photographs of the small gorge may be taken here.	8:40-9:10	4.6
16	Lake Breeze Hotel (coffee, doughnuts and rest stop) Lake Shore trap – amygdaloidal flow top; pipe amygdules, and ropey lava structures are reported. En route from #16 to #17 we will cross a high bridge over Jacobs Falls and if too much water is not going over the dam, some striking pot holes can be observed in the trap near the base of the Falls. A stop on or near the bridge will be made if stream conditions are favorable.		8.5
17	Douglass Houghton Monument (cross high bridge over Jacobs Falls.) Leaving the monument we will proceed southeasterly, descending stratigraphically until we reach the Ash Bed lode. The Ash Bed is one of the explosive types of lava flows and the copper here may be found in the fragmental, pervious, and cellular part of the flow.	10:10-10:20	0.9
18	Ash Bed Mine and columnar basalt – native copper in lode – walk on lode to river and see basaltic columns in hanging trap on outside of stream meander. Between Stops #18 and #19 we pass through a valley cut in the Greenstone and pass the Phoenix Mine on the right at the junction. We turn right on M-26 and U.S.-41 and go about ¼ mile to a dump and adit on the right.	10:25-10:55	1.4
19	So. Phoenix dump and adit between Phoenix and Cliff mines. See adit and find copper, chlorite, prehnite, apophyllite. This will be the last stop before lunch. The group will travel from here to Stop #20 at which time "Cousin Jack" pasties, saffron cake, and all the trimmings will be served at the old Cliff Mine.	11:00-11:40	1.6
20	Cliff Mine – Pasty lunch (at mine if weather suitable – at Vansville Hotel if inclement). Brief history of Cliff Mine and geology by Cornwall. Rugged 400' ±. (!) climb to top of Greenstone flow. Those going underground will leave immediately after lunch. A maximum of 25 men can be accommodated. They will be selected by lot or some other equitable means.		6.5
21	Ahmeek #3 and #4 combined shaft house. Large steam hoist, air compressor, rock house. Copper specimens from railroad cars.	1:45-2:15	1.2
22	Mohawk dumps, north of village of Mohawk. Best locality for copper-arsenide minerals. The copper and arsenic form complex mixtures and the various minerals are difficult to distinguish in hand specimens. Spiroff refers to all varieties as the "domeykite group". Three minerals which he states may be roughly identified in the field are (a) domeykite, - a metallic mineral, silvery-white on the fresh fracture, and brittle, chemical composition Cu_3As; (b) algodonite,-pinkish, chemical composition Cu_3AS; (c) whitneyite, copper red in color; malleable but breaks with a hackley fracture which thus distinguishes it from the	2:20-3:00	

native copper. Chemical composition Cu_9AS.

This is the last stop. Those with friends, husbands, etc. underground will drive to mine and pick them up and return to Keweenaw Park. Remainder of party will drive directly to Park, via U.S.-41 to Junction with M-26. Take M-26 to left to Eagle Harbor and turn right on Brockway Mt. Drive. 32.0

BANQUET AT 6:30

Reminscenses of the Copper Country by Professor James Fisher of Michigan College of Mining and Technology.

PART II

GENERAL GEOLOGY

Introduction

The geology Of the Michigan Copper Country has been discussed many times in technical publications on the areas and these papers are available to those wishing to make a detailed study of the district. The purpose, therefore, of this part of the trip outline is to bring to the attention of the group the essentials of the historical geology, the structural features and their topographic expression, and the theories on the origin and genesis of the copper deposits.

Guide Book No. 27, pp 29-49, of the International Geological Congress, which was prepared by Dr. T. M. Broderick for the excursion of that Society in 1933, contains as concise a summary and condensation of the geology of the region as could be prepared by the committee in the time available the following discussion, therefore, consists of excerpts from this excellent field guide:

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"GEOGRAPHY

The mines in the copper district of Michigan lie within a narrow belt from 2 to 4 miles wide and more than 100 miles long. The central part of this belt, about 26 miles in length, has furnished more than 95 per cent of the total production of the district. By far the greater part of this has come from mines in Houghton County. Keweenaw County, to the north, ranks second, but the production from Ontonagon County, to the south, has been very small.

The most prominent topographic feature of the district is a narrow flat-topped plateau rising to a general level of 500 to 600 feet above Lake Superior and cut through by several low transverse valleys. This plateau extends in a northeasterly direction and projects into Lake Superior as Keweenaw Point.

GEOMORPHOLOGY

The area underlain by the Keweenawan traps forms a long, narrow plateau with small monadnocks rising above the general level and, especially toward the northern, and southern parts of the district, with long monoclinal ridges and longitudinal valleys between them, which were formed by the erosion of the alternate inclined beds of varying hardness. The sandstone and conglomerate areas that lie on both sides of the basalt plateau have been eroded to for the present lowlands near the lake shores.

These major preglacial topographic features were not materially changed during the glacial period. The old weathered rock surfaces were scoured off by the ice, and the topography was smoothed and rounded somewhat. The minor details of the surface are determined by the irregularities of a deposit of drift 200 feet or more in maximum thickness, which was laid down by the ice and glacial streams. This deposit seriously affects the ease of exploration and development of the copper deposits. In addition to the moraines and glacial-stream deposits are those formed by the lakes along the south margin of the ice. Several old beach lines formed by the glacial predecessors of Lake Superior are presents and the highest in the copper country is about 700 feet above the present lake level.

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GENERAL GEOLOGIC FEATURES

In Keweenawan time some hundreds of basaltic flows were extravasated, forming a series thousands of feet in thickness. Interbedded with the flows are felsite conglomerates, subordinate to the flows in number and thickness in the middle of the series but abundant and thick in the lower and upper parts. Interbedded with the traps in a few places are felsite and quartz porphyry flows, and the whole series is intruded by bodies of gabbro and associated acidic differentiates ranging in size from small masses, such as Mount Bohemia in Michigan to the great Duluth gabbro of Minnesota. These intrusives are especially abundant toward the base of the series on both limbs of the Lake Superior syncline. The largest one, the Duluth gabbro, lying along the plane of unconformity a the base of the Keweenawan, is about 10 miles in thickness and forms a tabular body dipping with the overlying lavas toward the center of the syncline. Thus the series has a large intrusive mass at its base, of which the smaller intrusives in the Michigan copper district are probably offshoots. The sediments are all thought to be land deposits derived from a source down to the present dip, toward the center of Lake Superior. The intrusives are thought to have been derived from the same magmatic chamber as the flows.

Each lava flow, as it cooled, gave off great quantities of gas, which collected into bubbles and rose to the top of the flow, where most of it escaped. But as the flow became cooler it also became more viscous, and finally the gas bubbles were entrapped near the tope forming a cellular capping. Some of the entrapped bubbles flattened out horizontally and coalesced with other flattened vesicles. In many of the flows the vesicular crust was broken up into fragments by subsequent movement or by further explosive outbursts of gas from the still liquid interior of the flow. These fragments of shattered vesicular rook tended to pile up in irregular heaps on the tops of the flows. Later filling of the vesicles produced the amygdaloids, which are classified as cellular, coalescing, or fragmental, according to their physical condition. These amygdaloidal tops are distinctly red, and examination of polished sections, supported by chemical analyses, shows that there is a steady increase in hematite toward the tops of the flows. This hematite was formed by oxidation of the original iron-bearing minerals of the traps; it evidently took place at high temperatures, probably while the flows were solidifying, and was accomplished largely by the escaping gases, although atmospheric oxygen may have played a part.

Most of the flows followed one another so closely that there is no evidence of any erosion or normal weathering between them. Occasionally, however, there was an interval long enough to allow the surface to become broken up and to permit the finer sand thus produced to sift in between the larger fragments, forming what is known as the scoriaceous amygdaloid. If the interval was long enough and other conditions were favorable, felsitic debris was carried in and deposited on the weathered surface, forming a felsite conglomerates. Thus many (but not all) scoriaceous amygdaloids underlie conglomerates.

The structure of the district is rather simple. The large ore bodies so far found have all been on the Keweenaw Peninsula, which is on the south limb of the Lake Superior syncline. The beds dip to the northwest at increasingly flatter angles toward the axis of the syncline. They are cut off on the southeast by the Keweenaw fault, which is a thrust fault dipping nearly parallel with the beds and bringing the Keweenawan lavas and conglomerates on the northwest side against Cambrian sandstone on the southeast side. (The usage of the United States Geological Survey is followed in classifying these formations as Keweenawan and Cambrian.) There are numerous branches of this fault in the lower part of the series, and where the beds have transverse folds there are associated transverse fissures. Although there was probably considerable movement on the Keweenaw fault in late Keweenawan and Paleozoic time, the main structural features (such as the big syncline, and minor transverse folds, and numerous faults and fissures, including the Keweenaw fault) were well developed when copper deposition occurred.

ORE DEPOSITS

The six ore bodies that have yielded more than 90 per cent of the copper produced in the district lie within the central portion of the series, which consists chiefly of lava flows. The ore mineral is native copper. Although native silver occurs in minor amounts, it is not usually separated from the copper in treatment. Both copper sulphide and arsenide also occur, but not in commercial amounts.

The Calumet conglomerate ore body occurs in a felsite conglomerate: although known for many miles as a sedimentary stratum, for most of its known extent it is simply a thin sandstone or shale, in many places but a few inches in thickness. At Calumet, however, it opens out into a body from 5 feet to more than 20 feet in thickness and becomes much coarser, with many pebbles and boulders 6 or 8 inches in diameter and some much larger. This conglomerate lens lengthens and thickens down the dip, and the copper is confined to this body, the depositing solutions apparently having been unable to penetrate the sandy or shaly margins that close in on the conglomerate lens like on the sides of an inverted funnel. The copper, with adularia, epidote, calcite, and quartz was deposited chiefly through replacement of the finer material between the pebbles. The richest mineralization occurred rather near the surface, where the solutions flowed through the more constricted portions of the lens. Zeolites or zeolitic minerals, such as datolite and prehnite, are not found in the Calumet conglomerate. The rock immediately associated with the copper is bleached as a result of the removal of the primary hematite of the felsite pebbles and of the detrital hematite grains in the finer cementing material by the ore-depositing solutions.

The amygdaloid lodes are of a permeable type, because of their fragmental character, although the Pewabic amygdaloids are permeable in part because of the coalescing of the vesicles. None of the numerous cellular amygdaloids have been found to be copper bearing commercially. Minerals found in the amygdaloid lodes comprise a greater variety then those in the conglomerate lode, including quartz, epidote, chlorite, calcite, pumpellyite, adularia, sericite, ankerite, datolite, prehnite, and some zeolites. In most of these deposits there has been a rock alteration immediately associated with the deposition of the copper, which has resulted either in the total removal of the iron originally in the primary hematite of the lode or in its reduction to the ferrous state and incorporation in ferrous silicates.

The deposits differ in gangue minerals and character or rock alteration, and these differences have been regarded as peculiarities of the individual lodes. Zoning had been looked for, but the mineralogic changes in depth in even the deepest mines are inconspicuous. However, all the deposits carry minute amounts of arsenic. The ratio of arsenic to copper ranges in the different deposits from a few ten thousandths of 1 per cent up to 0.5 per cent. There is a corresponding variation in the small quantities of sulphur present, but

there are more quantitative data on the arsenic. Deposits with similar arsenic ratios are found to have similar types of gangue minerals and rock alteration. The deposits with highest arsenic and sulphur ratios are characterized by a gangue of sericite and ankerite. Those with less arsenic and sulphur are characterized by an adularia-prehnite gangue. Those with the least arsenic are practically sulphur free and have increasing quantities of zeolites. These types of deposits are regarded as having been formed at successively lower temperatures in the order named and therefore represent different temperature zones. The three zones grade into one another, and commercial copper occurs in all of them. Calculations bases upon the rate of increase in the ratio of arsenic to copper in depth indicate that commercial copper was deposited over a distance of more than 20,000 feet down the dip of the lodes. This estimate seems not unreasonable, inasmuch as mines like the Calumet & Hecla and Quincy already have followed copper about 10,000 feet down the dip and are still in ore.

Apparently among the conditions that an amygdaloid or conglomerate should have had in order to make an ore body were the following: (1) It should have had access to the sources of the copper-bearing solutions in depth, either directly or indirectly, perhaps being fed by fissures that in turn made connections with the sources; (2) it should have offered a through-going solution channel-that is. It should have been a continuously permeable body as compared with the adjacent rocks and (3) there should have been suitable restrictions to the permeable portion. All the ore bodies are in relatively permeable rocks, but apparently some sort of a barrier was necessary to prevent the solutions from spreading out and dissipating their copper content in great bodies of noncommercial grade. Solutions ascending the Calumet conglomerate, for instance, were confined by the gradually converging shale margins. Those ascending the Osceola amygdaloid were deflected under long, raking bars of tight, cellular amygdaloid.

All the known ore shoots come to the rock surface somewhere with good copper content. There is no evidence of a leaching of copper at the surface with a redeposition at depth. As explained below, however, there is reason to believe that there may be undiscovered deposits in the district that do not reach the present surface, and the attempt to locate them is the object of exploratory work now in progress.

GENESIS OF THE DEPOSITS

There are two strongly contrasting theories to account for the native copper deposits. One is that cold, oxidising chloride waters descended from the surface for many thousands of feet by gravity or by atmospheric pressure0 first percolating through hot traps and gathering up disseminated copper, then carrying it laterally and downward into amygdaloids and conglomerates, where the solutions reacted with the ferrous silicates forming native copper and ferric compounds. According to this theory, the traps are essential as sources of copper, the chloride waters are essential as carriers, and the deposits should be found on the upper sides of impermeable barriers.

The theory favored by the Calumet & Hecla geologists is that underlying the intrusives known to exist in the Lake Superior Keweenawan, on crystallizing, gave off solutions rich in copper, arsenic, and sulphur; expelled under enormous pressures, they followed permeable amygdaloid and conglomerate channels upward, cooling and entering regions of lower pressure as they ascended; reacting with the highly oxidizing wall rock, they had their arsenic and sulphur oxidized by the ferric iron of the lodes and their copper deposited as native metal. According to this theory, the traps were not essential to the formation of the ore bodies. The copper did not come from them, and any other oxidizing environment would have served to precipitate native copper, just as Coro Coro, Bolivia, where there are no lava flows, and native copper was deposited in commercial quantities in red sandstones. The chloride waters now found in the Michigan mines are not regarded as being necessary to explain the native copper. The copper deposits should be found underlying impermeable barriers.

EXPLORATION

Most of the known amygdaloid and fissure deposits were found with copper showing in the outcrops. In some places a prehistoric race had mined the rock at the surface, and the white men later “rediscovered” the deposits by cleaning out the old pits. These prehistoric miners sometimes dug pits at convenient places to cache their coppers and by a strange coincidence, as the story goes, after one of these random caches containing amygdaloid copper had bean cleaned out and deepened a few feet, it was found to lie directly over a part of the rich Calumet conglomerate ore body. There is some reason to believe that this pit was not simply a cache for the amygdaloid copper found in it, but that it actually encountered mineralized bedrock, because early accounts mention the fact that an amygdaloid in the immediate hanging wall of the conglomerate was found to be mineralized at this point. Thus by examination of the small percentage of the bedrock that is not thickly covered with glacial sand and gravel and by opening up the ancient miners’ pits, the major ore bodies of the district have been found. The latest commercial ore body to be discovered was the one on the Baltic lode. Since that discovery, about 50 years ago, millions of dollars has been spent in diamond drilling, trenching, and underground work without discovering a new ore body. In the face of this long period of expensive exploration with negative results, what encouragement is there for further search for new ore bodies? Some of the considerations involved in exploration may be briefly reviewed.

Only a small percentage of the copper-bearing formation is not covered with drift, yet the examination of this small

percentage led to the discovery of most of the amygdaloid and fissure ore bodies. Although, the drift covering hampers exploration, the very fact that it is so widely present leads to the conviction that there must be undiscovered ore bodies beneath it. If the rock cropped out everywhere there would be little chance of finding new deposits exposed at the surface after 85 years of search.

Copper deposits are known to occur over an area of some hundreds of square miles. This is to be contrasted with other districts, such as Butte, where a similar production has come from but a few square miles. Thus in this district the explorer is handicapped by the enormous areas of barren ground in the midst of which commercial deposits must be sought. On the other hand, it means just so many more square miles in which deposits may possibly occur.

There seems to be a generally accepted notion that enormous tonnages of rock exist with a copper content just below that required for a profit. The Ashbed and Allouez conglomerates are often mentioned as beds that are appreciably mineralized over large areas, because they are known to have some copper at widely spaced localities. Although the idea that higher prices for copper would increase the reserves of commercial ore is true to some extent, such an increase would by no means be as great as is generally believed. Experience in this district indicates that the rich deposits are large and the leaner deposits are smaller.

Although mineralogic studies have been a feature of all the geologic surveys of the district, nothing very positive of a mineralogic nature has been developed to serve as a guide in exploration. It is recognized, however, that the commercial lodes have a greatest variety of minerals than the average amygdaloid. The recognition of the approximate position of a prospect in the zonal range by means of the arsenic ratio and characteristic gangue minerals is, of course, an advantage.

A study of surface geology is an inexpensive and necessary first step in exploration. It has resulted in the discovery of most of the deposits in the district and has furnished a fund of information on the general geology. The chances that any new deposits can be found by inspection of surface outcrops are exceedingly remote. Where the overburden is thin enough trenching and test pitting may be used to advantage.

Diamond drilling is the most satisfactory method of determining the general geologic conditions, such as kinds of rocks mid character and position of lodes, where any considerable depth of overburden exists. But it is not a reliable method of determining copper content because of the very erratic distribution of the metal. The drill may encounter local bunches of copper in a worthless lode; and on the other hand, in going through ordinary amygdaloid lodes of commercial grade, it is more than likely to miss the copper. Where the copper content is more uniformly distributed, as in a sandstoae or conglomerate ore body, the drill has a better chance to obtain a good sample of it.

It was hoped that geophysical methods would be useful in the search for new deposits, but after a variety of electrical and magnetic methods had been tried out the results were found to be disappointing. The copper is so small in amount and so widely disseminated that its effect on electrical methods is little or no greater than the effects caused by differences in thickness and character of overburden and in character of bedrock. There are no known magnetic effects connected in any way with the ore bodies. Various geophysical methods, however, are somewhat useful in preliminary geologic work, such as laying out diamond-drill locations. For such work the dip needle has so far been found to be satisfactory, as it affords a rapid method of determining the main features of the geologic structure. It could have been used to considerable advantage in earlier years in some places where the local strike was not so well known as it is at present, in recent years the Michigan Geological Survey has taken dip-needle readings over large areas of the copper-bearing formation for the purpose of studying the reliability of this method in mapping the details of stratigraphy and structure in the district.

After diamond drilling or any other method has done all that it can in determining the general geologic features of an area, actual underground openings must be made to locate ore and to determine its grade. For every major lode deposit there are scores of erratic and local patches of mineralized rock scattered throughout the Keweenawan series, not only in Michigan but in the satire Lake Superior district. Only by opening up the lodes for hundreds or thousands of feet can it be determined whether or not the mineralisation has produced ore of commercial importance; and large-scale mill-runs are necessary to determine the grade, ordinary sampling methods being useless because of the erratic nature of the mineralization.

It is apparent that the ore bodies are determined by favorable conditions of a purely local, character, such as access to the source of solutions in depth, through-going permeability, and suitable restrictions by barriers. Even though the beds at a given horizon fulfill ail the necessary conditions and include an ore body at one place. It would be purely a coincidence if beds at that same horizon in another place should be found to have the necessary conditions. Nevertheless, much of the exploratory work hitherto done in the district has been based upon the idea that if an ore body occurs at a certain horizon in one place it is likely that other ore bodies may be found at the same horizon elsewhere.

In recent years the method of exploration adopted by the Calumet & Hecla Consolidated Copper Co. has been to crosscut those parts of the series that, by diamond drilling or other means, are known, to have exceptionally numerous “beds of a favorable physical character, these crosscuts are driven from conveniently located places in the mines or from shallow shafts sunk for the purpose. This method has an advantage over the old one in that

numerous favorable beds are crosscut instead of one bed only-any individual bed, although having an ore deposit perhaps many miles away because of local favorable conditions, may be of a most unfavorable character at the place being explored. Even this improved method is unsatisfactory, however, it lacks definiteness in that it dose not indicate specific places of outstanding attractiveness; furthermore, some of the known ore bodies are at the only favorable horizon for hundreds of feet in either direction. Therefore, the policy of exploring in belts of dominantly favorable amygdaloids would fail to find such ore bodies as occur in isolated favorable lodes.

Geologic studies during the last few years indicate more specific places to explore. A study of the relationships of lode mineralisation and fissure mineralisation has developed the idea that some of the fissures were mineralised by solutions that leaked away from the major amygdaloid or conglomerate channels. Especially would this have occurred if the lode were partly blocked off by the barriers closing in more or less completely, a condition in which the solutions might be able to make their way upward above such places only by escaping through the fissures intersecting the lode. In the few known examples where such a relationship between fissure and lode seems to exist, the copper does not continue on the fissure right down to the feeding lode but there is a gap of hundreds of feet of fissure vein in which there is not much copper. This situation leads to the speculation as to whether or not the old fissure veins that were so prominent in the early history of the district as producers of mass copper may not have been merely the vents for the solutions that escaped from some amygdaloid or conglomerate ore body at greater depth. These fissure deposits were worked to comparatively shallow depths, where they became too lean to mines yet they continue downward as strong fissure veins filled with gangue minerals of a type which indicates that they are still high in the zonal range over which copper was deposited in this district. In order to test this idea, two of the old fissure-vein mines, the Cliff and the Phoenix, have been unwatered, and an attempt is being made to find a major amygdaloid or conglomerate deposit that may have acted as a feeder for the fissures. The chief elements of uncertainty, of course, are whether these particular fissures have such a relationship to a lode solution channel-way, and, if so, whether that lode has been commercially mineralized and whether the gap between the bottom of the ore in the fissures and the ore in the lode is short enough to be bridged by a reasonable expenditure.

The following list of typical minerals found in the rocks of the Copper Country and their descriptions are taken from “Rocks and Minerals”, Vol. 13, No. 5, for May 1938 by Kiril Spiroff, General Superintendent of Isle Royale Copper Company:

Agates - cryptocrystalline quarts having various colored rings. They are cemented to the matrix very tightly, and it is almost impossible to free them. Agates can be gathered on some of the Lake Superior beaches on Keweenaw Points where they have been worn away from the matrix by wave action.

Anhydrite - lilac-colored mineral having three different cleavages at right angles, an arrangement which gives it a brick-like pattern. Its hardness is about that of a penny. It occurs mixed with variously colored calcite. However, the pattern, of the calcite cleavages is diamond-shaped. Chemical composition, $CaSO_4$, calcium sulphate.

Ankerite - white cleavable material showing three perfect cleavages at 75°, in veins cutting various colored lava fragments. It usually shows a slight rust on the weathered surface, which readily distinguishes it from similar appearing calcite. Chemical composition variable, Ca, Mg, Fe, Mn) CO_3, --- calcium, magnesium, iron, manganese carbonate.

Barite - small, white, tabular crystal associated with calcite and quartz in cavities. By its crystal form it can be readily distinguished from the associated minerals. Chemical composition $BaSO_4$---barium sulphate.

Bornite - Copper red to brownhis, iridescent metallic mineral, occurring with chalcocite. The brilliant peacock-like colors that bornite assumes in tarnishing distinguish it from the dark lead-gray chalcocite. Chemical composition Cu_5FeS_4 – copper, iron sulfide. Copper 63.3%.

Calcite appears in many hues, white, red, pink, green, etc., but the white variety predominates. Calcite shows three cleavages of 75°, and most of the cleavage fragments have striations parallel to the long diagonal of the diamond faces. Various-shaped calcite crystals are to be found in cavities. Chemical composition, $CaCO_3$ --- calcium carbonate.

Chalcocite – a dark lead-gray metallic mineral slightly sectile, (polishes when cut with a knife), appearing in white veins cutting chocolate-colored lava fragments. Chemical composition, Cu_2S, Cuprous sulfide. Copper 79.8%.

Chalcopyrite. At times along with chalcocite-bornite a brass-yellow metallic mineral is found. It is soft (only slightly harder than a penny) and makes a greenish-black mark on an unglazed porcelain plate. Chemical composition, $CuFeS_2$ – copper, iron sulfide. Copper 34.5%; iron 30.5%.

Chlorite – a soft dark-green mineral which occurs as fillings in amygdules, crevices and seams. It has a white streak which is easily obtained by rubbing any sharp object over the specimen. Its chemical composition is variable, but usually chlorite is considered to be an aluminum silicate, with ferrous iron, magnesium, and chemically combined water.

Chrysocolla – greenish, or bluish, stony-appearing mineral, which adheres to the tongue. Chemical composition variable; $CuSiO_3 2H_2O$, - a copper silicate with water.

Cuprite - a soft, brilliant red mineral with a red streak. Most of it is massive, but occasionally cube crystals with truncated corners (cubes modified by octahedrons) are found in cavities. Chemical composition, Cu_2O - cuprous oxide.

Datolite – grayish-white to green, quite hard crystals with very complex crystal form. The lack of symmetry distinguishes this mineral from similar-colored analcite, and prehnite.

Most of the datolite occurs as botryoidal material, which on breaking appears porcelanic. The white variety predominates, but occasionally delicate tins of pink and yellow copper and silver inclusions are found. Datolite has a conchoidal fracture, and is quite hard (51/2). It takes a beautiful polish; consequently, cut and polished, it is found in jewelry stores. Chemical composition $HCaBSiO_5$-, a hydrous calcium boron silicate.

Epidote – various shades of green, tabular crystals occurring in amygdules. Its hardness is that of quartz. Much of the pistachio – (yellowish-green) colored massive material found throughout the district is due to alteration and partial replacement of the country rock by epidote. This process is called epidotization, and the term is used as an adjective, e. g. epidotized sandstone. Chemical composition variable, $HCa_2(AlFe)3Si_{3-}O_{13-}$ a hydrous calcium silicate containing some iron. The massive variety predominates at the Isle Royale Mine. Crystals can be collected at the Wolverine Mine.

Gypsum – white and soft, showing one perfect cleavage. It can be pried into sheets with the finger nail. It appears in cavities only, and consequently one must break open the rocks to find it. Chemical composition, $CaCO_4H_2O$, - a hydrous calcium sulphate. Lake Mine and other mines in Ontonagon County have produced the selenite variety. This beautiful transparent mineral often has native copper inclusions.

Iddingsite - most abundant at the south edge of the triangulation tower where red flashes can be seen in the rock. This is not copper, although, it looks very much like it. It is an alteration product of olivine. Chemical composition, $MgFe_2Si_3O_{10},4H_2O$ - a magnesium, iron silicate with water.

Laumontite – radiated salmon pink mineral which crumbles when handled. It breaks into small rectangular blocks, showing two perfect cleavages at right angles. Chemical composition, (Ca,Na_2) $Al_2Si_4O_{12}4H_2O$, - calcium sodium aluminum silicate containing water.

Microcline – a reddish, platy mineral, usually lining cavities, with white calcite filling in the center. At times this feldspar can be found crystallized in vugs, where it closely resembles rhombohedrons. Close observations show that the angles are different (mm=60°) and that only one of the faces has a perfect cleavage (face c.) Chemical composition, $KAlSi_3O_8$, - potash aluminum, silicate with variable amounts of soda.

Natrolite – long, slender reddish, four-sided crystals (square in cross-section) with pyramidal terminations, found with the red-colored analcite in cavities. Chemical composition, $Na_2Al_2Si_3O_{10}$, 2H) – a sodium aluminum silicate with water.

Prehnite – a greenish (light-apple to oil-green) radiating mineral in veins cutting lava fragments. It is nearly as hard as quartz and closely resembles it. In geodes it builds up into reniform aggregates or circular blocks having rectangular tops. Both the crystalline and the massive varieties should be obtained. Chemical Composition, $HCa_2Al_2Si_3O_{12}{}^{1}$ –a complex silicate of calcium and aluminum. Prehnite is sometimes classed with the zeolites, with which it is often associated. The small gray specks appearing in the prehnite should be carefully scraped with a knife blade. They are likely to be either silver or native copper.

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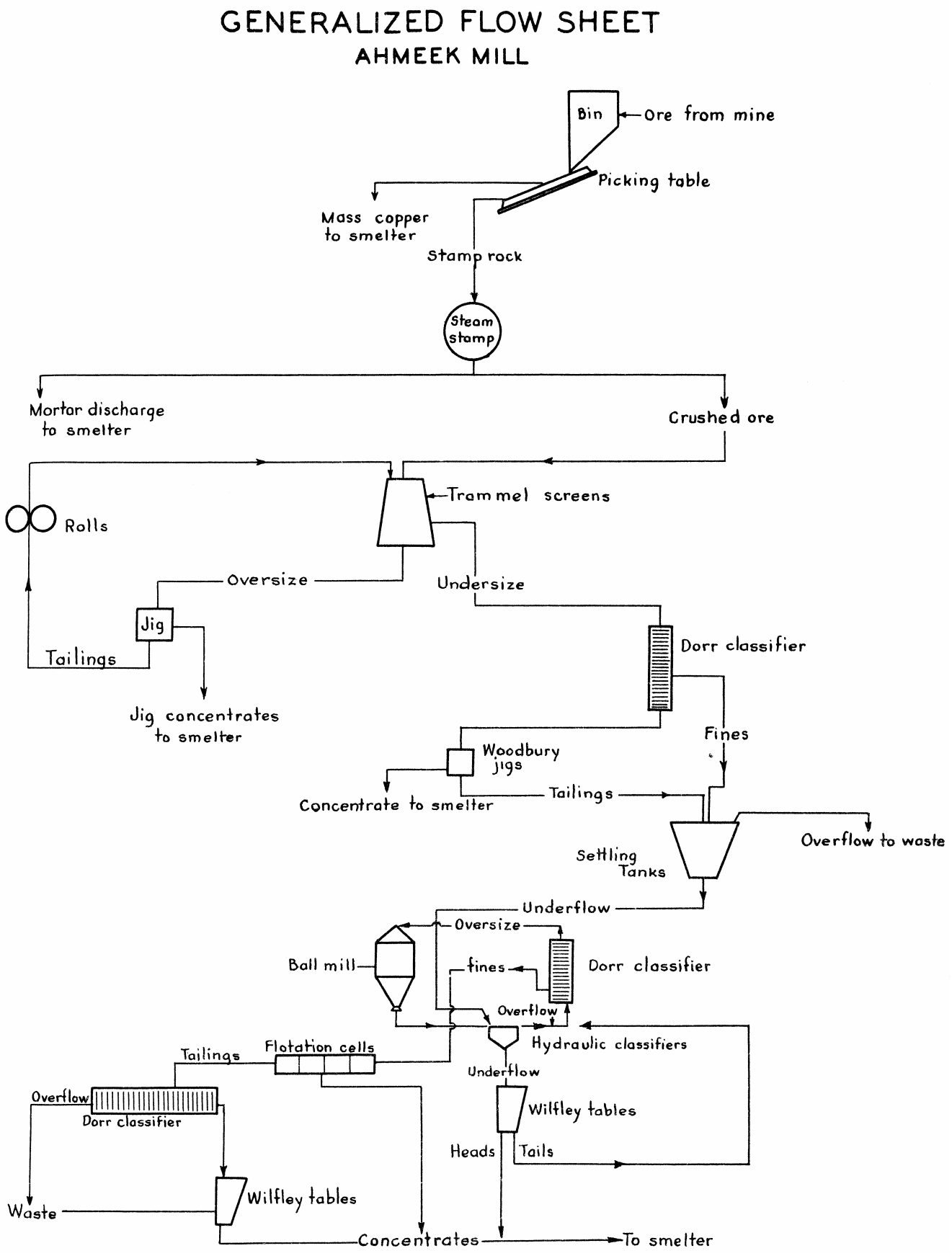
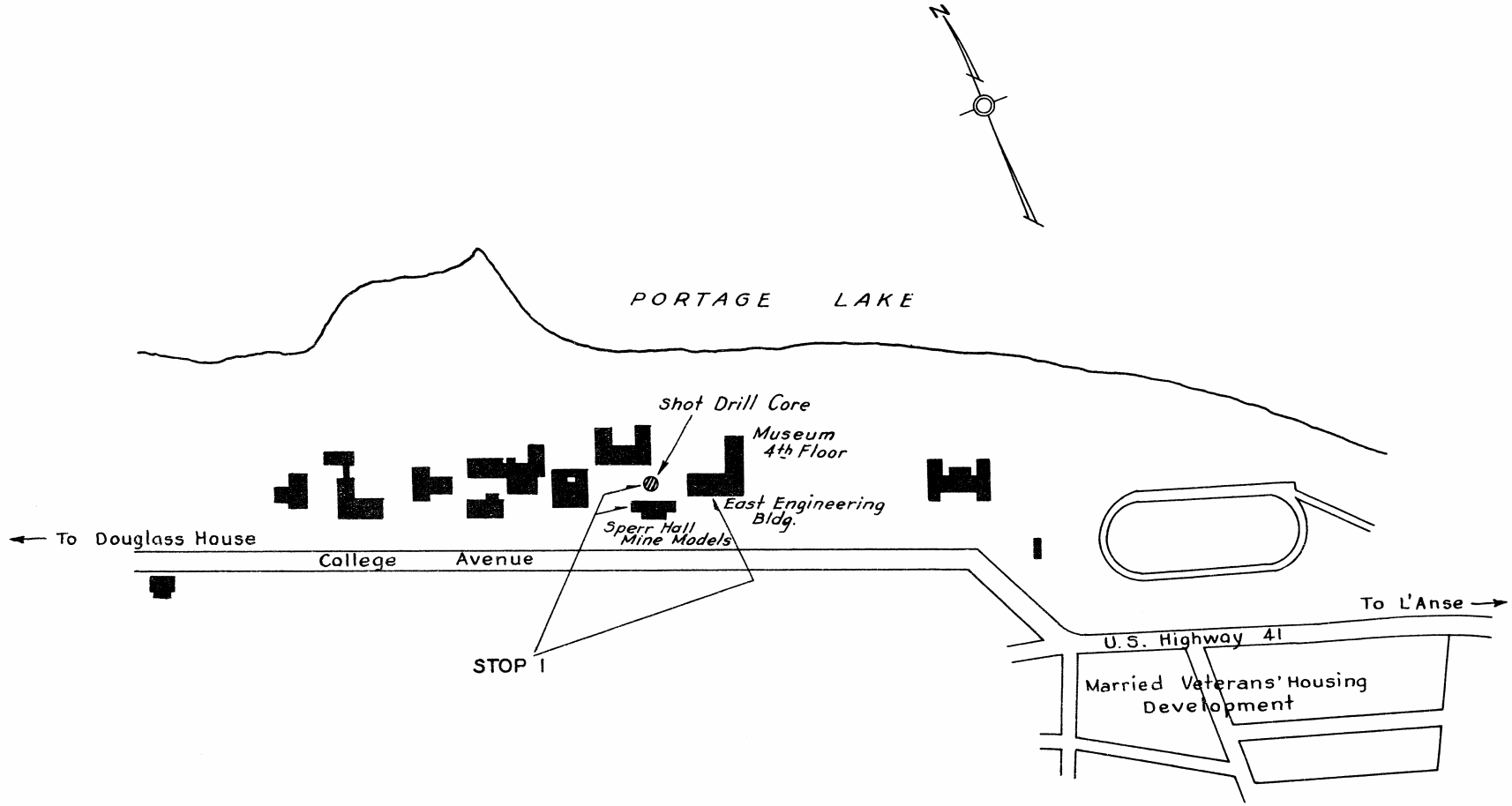
[Diagram (Ahmeek flow sheet) on Maps]





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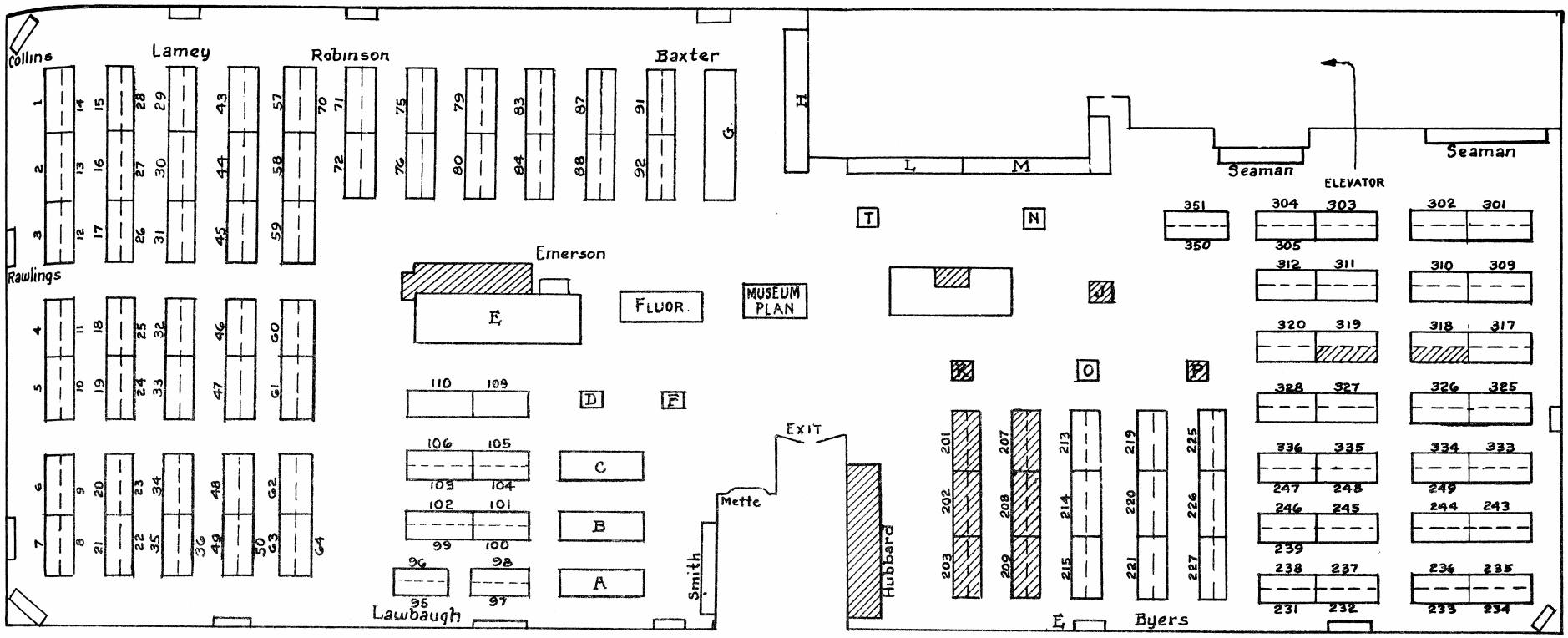
HOUGHTON - MICHIGAN

MAP NO. 1



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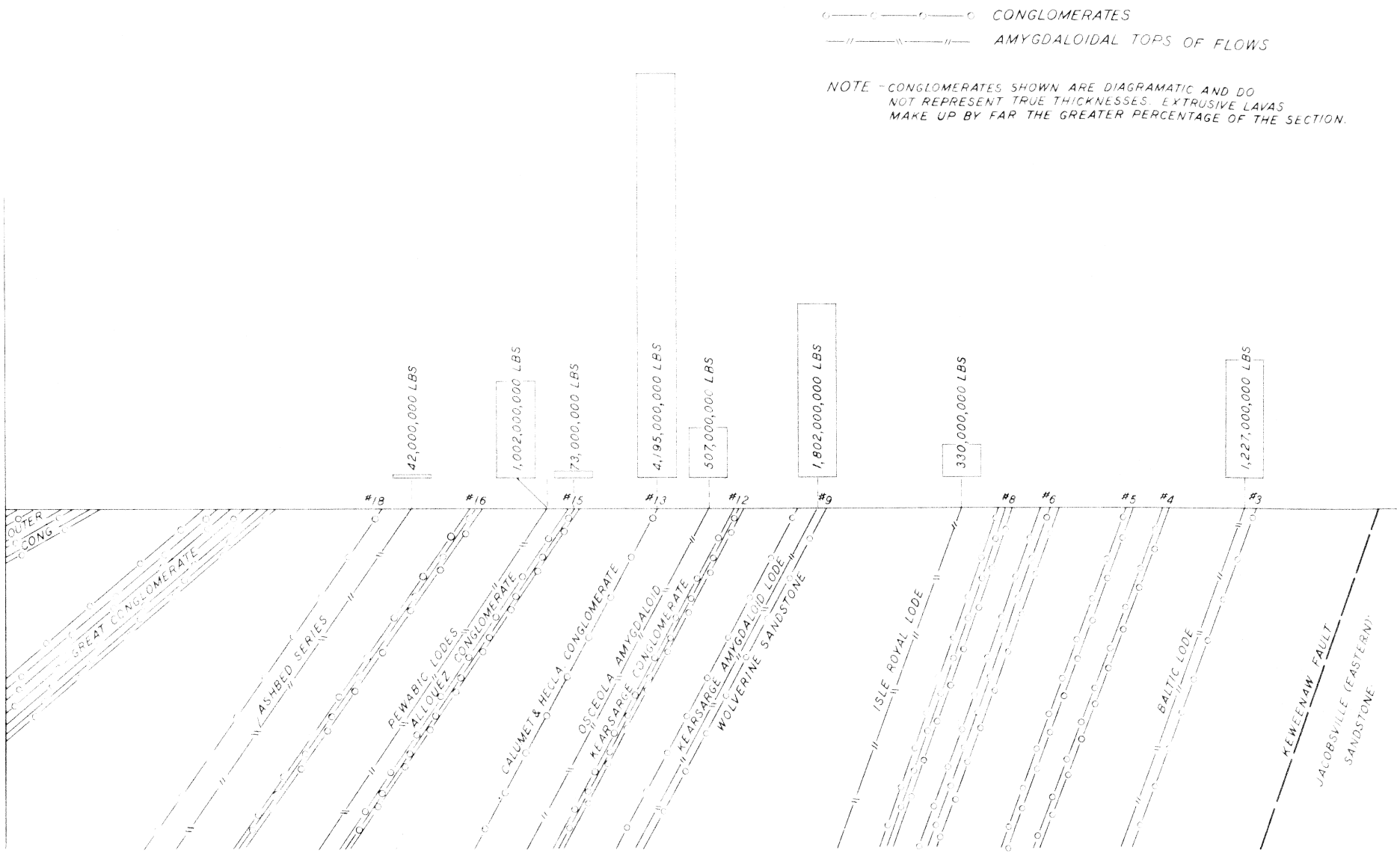
Classified Minerals Collections — Sections 1 to 94
Cases Showing Properties of Minerals — Sections 95 to 110
Classified Rock Collection — Sections 301 to 340
Economic Collection — Sections 225 to 246
Copper Country Minerals — Sections 201 to 212
Iron Country Minerals — Sections 213 to 224
Unclassified Collections — A to P

MUSEUM FLOOR PLAN

Fourth Floor East Engineering Bldg.
Michigan College of Mining and Technology
HOUGHTON. MICHIGAN.

MAP NO. 2



IDEALIZED SECTION

SHOWING STRATIGRAPHICAL POSITION OF THE PRODUCTIVE HORIZONS IN RESPECT TO KEY CONGLOMERATES
PRODUCTION FIGURES FROM MICHIGAN GEOLOGICAL SURVEY AND PROFESSIONAL PAPER 144-U.S.G.S.

MAP 4