# THE COPPER RESOURCES OF NORTHERN MICHIGAN

Prepared for

**UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF MINES**

by

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The copper resources of northern Michigan are in the Precambrian X rocks of the Marquette Supergroup, and in the Precambrian Y Keweenawan volcanics (native copper) and Nonesuch Shale (mostly sulfides). The available reserves in the volcanics are ≈1 billion pounds of copper. Approximately 80% of the volcanic outcrop belt which includes the Portage Lake Lava Series and the overlying unnamed formation has not been explored by drilling. This area, which extends from Keweenaw Point to the Wisconsin border, could contain one or even two orders of magnitude of the native copper now available.

Metal reserves in the Nonesuch Shale are estimated to be ≈12 billion pounds of copper and 90 million ounces of silver. The Marquette region is estimated to contain approximately 6.6 billion pounds of copper. The only producing mine is at White Pine. The native copper and Marquette resources will require new technology or a large increase in copper price before economic exploitation of the deposits is feasible.

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## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES



## FOREWORD

This report was prepared by John T. Wilband, Department of Geology, Michigan State University under USBM Contract number J0366067. The contract was Initiated under the Minerals Availability System (MAS) Program. It was administered under the technical direction of the Eastern Field Operations Center in Pittsburgh, Pennsylvania with Ted Drescher acting as Technical Project Officer. David Williams was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period August, 1976, to April 30, 1978. This report was submitted by the author on May 1, 1978.

## ACKNOWLEDGEMENTS


Access to much of the data summarized herein was granted to the Principal Investigator by Mr. Robert Seasor, Chief Geologist of White Pine Copper Company; Mr. James T. Schaefer, President, Universal Oil Products Company; and Mr. Robert Reed of the Michigan Geological Survey. Insofar as some data generously supplied to me were considered proprietary, they have been omitted from this report.

The courtesies shown me during this investigation by Mr. Ross Grunwald and staff of Homestake Copper Company, and by Mr. Robert Seasor and staff of the White Pine Copper Company are acknowledged with gratitude. Without the close liaison with the staff of the Michigan Geological Survey through virtually all phases of the data compilation this investigation could not have been successfully concluded.

Finally, the services of several students, especially Michael Price, William Morris, Susan Crissman, Mary Jane Klesney, Kris Roberts, and Sherry Kreger are acknowledged with thanks.

Gerald Anderson of the Cleveland-Cliffs Iron Company kindly granted permission to use Plate 1.


## INTRODUCTION

The native copper deposits of northern Michigan have been mined continuously from 1844 to 1968 arid constituted the principal source of domestic copper for 40 years. Unfavorable economic conditions and labor difficulties resulted in a cessation of mining in 1968. The only significant copper production from Michigan now comes from the White Pine mine. There does not appear to be any chance of reopening the native copper mines of Houghton or Keweenaw Counties in the near future, particularly since the underground exploration and mining feasibility program at the Centennial No. 3-6 site as well as surface exploration programs were abandoned in 1977.

Available reserves of the native copper district are estimated to be ≈1.0 billion pounds of copper in mineralized zones which range from 6 to 30 pounds of copper per ton. The total reserves of the district are probably in excess of 10 billion pounds of recoverable copper. This copper resource cannot be economically exploited at the present level of technology.

Total copper reserves, largely In the form of sulfides at the White Pine and Presque Isle (Western syncline) deposits in the Nonesuch Shale, are estimated to be approximately 12 billion pounds of copper. Of this total, the extractable reserves as of January, 1977 at White Pine are approximately 4.8 billion pounds of copper based on a cut-off grade of 20 pound copper per ton (in-place). The reserves potential at the Presque Isle deposit await an economically feasible mining method before further development. The mineralization in part underlies the Porcupine Mountain State Park and would, no doubt, be expected to satisfy rigorous environmental legislation and withstand public opposition to open a mine at the site.

Other potential sources of copper in the State of Michigan are the Kona Dolomite and the Michigamme Slate within the Marquette trough near Marquette, Michigan. Although these occurrences are of low grade, exploration work continues within the Marquette region.

# HISTORICAL INFORMATION

## Prehistoric Mining

It has been estimated that there are approximately 5,000 known pits (Drier, 1961) up to 30 feet deep, from which native copper was mined prehistorically. Drier (1961) estimates that 500 million pounds to perhaps more than one billion pounds were recovered.

The miners built fires on top of the copper bearing veins, then brushed the fires away and poured water on the surface to fracture it. Charcoal at the bottom of some of the pits has been dated as 4,000 years before present. The pits have been found the length of the copper bearing region, extending 100 miles from Keweenaw Point to the Porcupine Mountains.

So far little is known about the miners. No burial grounds have been found. No carvings, writings, paintings, or art work, except copper tools were left behind to provide clues of their culture or place of origin. The fact remains, however, the centuries of labor were represented by the area. It is assumed that such effort was probably not simply to obtain copper for trinkets and ornaments, but for tools, armament, and for trade.

The significance of this prehistorical mining became apparent in the 19th century copper rush when the extensive pits led prospectors to most of the known deposits.

## Early History

The first known account of the Copper Country of Michigan was published at Paris, in 1639 by Lagarde (Drier, 1961). This report was followed by references to copper in reports by Jesuit missionaries. No serious mining was attempted until 1844, after Douglas Houghton's report (1841) was published three years earlier.

This early copper rush, with the attendant boom towns and mushrooming population lasted for little more than a year. At this time the first successful mine, the Cliff mine, was opened in 1845. This and other early producers of copper, such as the Minesota, and Central mines became known as "mass" or "fissure" copper mines, in which the copper was contained in "masses" in steeply dipping veins. The copper produced in the first six years of mining was exclusively from this type of deposit.

The Isle Royale Mining Company began mining the amygdaloidal flow top of what became known as the Isle Royale Amygdaloid or lode. Thereafter, the "fissure" type ore bodies increasingly diminished in Importance relative to the other types of copper occurrences.

A third type of host rock was discovered by Edwin Hulbert in 1864 in what became known as the Calumet and Hecla Conglomerate. This became the bonanza lode, which produced approximately forty percent of the native copper in the district.

Hulbert proposed the formation of the Calumet Mining Company of Michigan and the name Hecla for another company to hold lands in the vicinity. In 1866, Alexander Agassiz became treasurer both of Calumet and of Hecla, and in 1867, he became resident superintendent of both mines, after Hulbert was dismissed.

His initial problems of "stamping" the extremely hard conglomerate ore were overcome by ordering the existing milling equipment to be replaced by the steam stamp developed by Thomas Ball. By the end of 1867 the Hecla Mine was the largest producer in the district. It topped Calumet and the best amygdaloid producer, the Pewabic, by more than 50 percent (Benedict, 1952).

The principle producing flow tops and associated mines with the dates of first and last production of the mines are listed in Table 1.

All the principal ore deposits were discovered and being exploited before 1900. The only significant discoveries which were not discovered in, or close to, exposure were the Iroquois Amygdaloid, and the Kingston Conglomerate. Each of these deposits was discovered by drilling.

The copper sulfide deposits in the Nonesuch formation were discovered in outcrop in the 1850's, but not mined until 1865. Only the native copper was recovered; the chalcocite was left in tailings. The old White Pine mine, which originally operated from 1879 to 1881 was purchased by the Calumet and Hecla Mining Company In 1904. Exploration and drilling revealed copper in the vicinity of the present mine site. Three shafts were sunk in 1914, and mining of the native copper continued until 1921. The mine was purchased by Copper Range Company in 1929. Interest in the deposit revived since developments in metallurgy had made the economic recovery of copper from chalcocite feasible in the 1930's and, coupled with the copper shortage created by the outbreak of the Korean War, a development of the ore body was initiated at the request of the Federal Government. The mine was put into a regular production basis In 1953, and by 1965 the one-billionth pound of copper was poured in the smelter.

## Post 1950 Developments

The Calumet and Hecla Division drilled the property around the Old Caledonia adit in the Evergreen Series of lava flows in Ontonogan County. This project outlined approximately 11.5 million tons of ore in the Butler and Knowlton lodes. Some underground development was done , and 223,145 tons of hoist were removed through the adit between 1952 and 1958.

In 1965 a major agreement between Copper Range and the Calumet and Hecla Company took place whereby a territorial zone was established. Most of Copper Range's holding northeast of Portage Lake were turned over to C and H, and C and H holdings southwest of Portage Lake were tranferred to Copper Range.

In May 1968, the Calumet and Hecla Mining Company merged with and became the Calumet Division of Universal Oil Products (UOP). The new operator continued to run the mines and took control of all mineral and land holdings. Virtually all copper production from the native copper mines operated by the Calumet Division of Universal Oil Products (UOP) ceased in August 1968 after a labor dispute. Several mines were already operating at a loss and so the decision was made to close down the mines. Most of the surface equipment was liquidated; the smelter and mill at Torch Lake, Michigan, were dismantled; and several of the shafts were sealed. Most mines are filled with water.

TABLE 1

SIGNIFICANT FLOW TOP LODES

| Lode | Principle Mines | Production (all mines) |
|---|---|---|
| Isle Royale | Isle Royale | 1852-1948 |
| Pewabic | Pewabic<br>Franklin<br>Quincy | 1856-1945 |
| Ashbed | Atlantic Mine | 1872-1906 |
| Kearsarge | North Kearsarge<br>South Kearsarge<br>Ahmeek<br>Mohawk<br>Seneca<br>Peninsula<br>(Allouez)<br>(Calumet and Hecla)<br>(Osceola) | 1882-1968 |
| Osceola | Osceola | 1891-1968 |
| Baltic | Baltic<br>Champion<br>Trimountain | 1898-1968 |
| Evergreen | Adventure<br>Caledonia<br>Mass | 1899-1958 |
| | SIGNIFICANT CONGLOMERATE LODES | |
| Allouez | Allouez | 1869-1968 |
| Calumet and Hecla | Calumet and Hecla | 1865-1968 |
| Houghton | Douglass | 1929-1968 |
| Kingston | Kingston | 1965-1968 |
| | SULFIDE PRODUCERS | |
| Nonesuch Shale | White Pine | 1945-present |

*Mines in parentheses have crosscuts into the Kearsarge Lode.*

[TABLE 1: Significant Producers (Lodes and Mines)]

In July 1972, Homestake Copper Company, a subsidiary of Homestake Mining Company, leased the mineral holdings from UOP. Homestake was joined by INCO's subsidiary the American Copper and Nickel Company in 1973 in a joint effort to explore the Centennial property and to investigate new methods of mining and milling. Homestake retained 60% of the venture and acted as manager of the exploration and development program.

The company started dewatering the mine during April 1973, as part of an initial $5 million program which also included renovation of the No. 3 and No. 6 shafts and surface equipment. Once the initial project was completed, $4.3 million more was spent on the building of a pilot plant. This plant included a concentrator to mill ore along with other new equipment the company wanted to try out. Information gathered at the pilot plant would be used to establish ore processing costs in addition to serving as a design model for a larger plant.

As of December 1975, the No. 6 shaft was being deepened at a rate of 100 to 130 feet per month. At that time the shaft was nearing 2,042 meters (approximately 1,265 vertical meters), and the goal was to reach the 55th level (2,347 meters) by September 1976.

In November 1976, mine exploration development and production was halted due, in part, to depressed copper prices and to disappointing exploration results. The pumps were pulled in 1977 and the mine is filling with water. Hopefully, this is not the epitaph of Copper Country.

## PREVIOUS WORK

Several investigations have been undertaken in an attempt to evaluate the copper resources in Michigan. Because of the "boom" atmosphere and fiercely competitive nature of the large and small companies which operated the mines in Copper Country in the latter part of the nineteenth century, data concerning regional and even local production are somewhat obscure.

The first regional investigation of "Copper Country" took place in the summer of 1840 in an expedition led by Douglas Houghton, newly appointed state geologist by Steven T. Mason, the first governor of Michigan. His report, filed in December of that same year, touched off a copper rush to the Keweenaw Peninsula.

Two papers by More (1912, 1915) are particularly useful for purposes of obtaining an historical account of the then active mines of the various copper lodes. The first exhaustive compilation of the district by Butler and Burbank (1929) became, and still is, one of the most informative references on Copper Country.

Much of the post 1929 data have not been summarized and remain in company files or annual reports of the Michigan Geological Survey. A renewed interest in non-operating mines was generated by the 1965 land exchange between Calumet and Hecla Copper Company and Copper Range. Copper Range acquired several old properties, specifically the Indiana and Champion, which were re-evaluated by Joseph Patrick of Copper Range. These reports are in White Pine Copper Company's files for the investigations which were completed in 1968. Feasibility studies on properties acquired by C and H from Copper Range are on file at Universal Oil Product's Calumet office.

Geologists of the United States Geological Survey mapped several quadrangles in Copper Country arid reported on their economic potential (Cornwall and Wright, 1956; White, et al., 1953; Cornwall, 1954a, 1954b; Davidson, et al., 1955; White, 1956). A particularly useful summary by Cornwall, et al. (1949) reported on the active copper mines in Houghton and Keweenaw Counties at the time of writing.

Miska and Fris (1971) give a very general summary, up to 1968, of all commodities including copper for the Lake Superior East planning subarea of the Great Lakes Basin. More specifically, Bennet, et al. (1973) reported on Michigan reserves as part of an appraisal of copper supply from domestic sources.

An excellent compilation of nonferrous metal potential in northern Michigan by Bodwell (1972) includes a section on the copper deposits.

# GEOLOGY

## General

The Michigan copper reserves are found in 3 geologically distinct environments. Two of the three environments, the Nonesuch lode and the lodes within the Portage Lake Lava Series, are of middle to upper Keweenawan age (Precambrian Y[1]) and underlie the Keweenaw Peninsula of Northern Michigan. The remaining environment is in the Marquette "trough", particularly within the Kona Dolomite of Precambrian X age. The Kona Dolomite is part of the Marquette Supergroup whose younger members are presently mined for their iron ore.

[1]*Scheme for the subdivision of Precamrian time, adopted by the U. S. Geological Survey:*
*Precambrian Y = 800 m.y. to 1,600 m.y.*
*Precambrian X = 1,600 m.y. to 2,500 m.y.*
*Precambrian W = older than 2,500 m.y.*

## Marquette Area

The Precambrian W rocks of Michigan are exposed in an east-west trending belt which extends from Marquette west into Wisconsin. The rocks consist predominantly of granitic intrusives (now mostly gneissic) and greenstone volcanic flows. The greenstone belt has intercalations of metasedimentary and felsic pyroclastic rocks. The flows are mostly of mafic composition and the development of pillow structures which can be found in several exposures indicate subaqueous solidification of the basalt. These greenstones, typified by the Mona Schists in the Marquette region (Plate 1) have a suggested age of 2.77 billion years before present (Goldich, 1972).

The Precambrian X rocks of Michigan in the Marquette region have been collectively referred to as the Marquette Supergroup (Cannon and Gair, 1970). The Supergroup appears to have been deposited and deformed in a similar tectonic setting to the Animikie of Northern Minnesota and S.W. Ontario. The rocks of the Supergroup have been subdivided into four groups: the Chocolay, Menominee, Baraga and Paint River Groups (see Plate 1).

The lowermost Chocolay Group has characteristics in common with a modern miogeosyclinal or shelf sea fades association. The Kona Formation (maximum thickness 800 m) is a mixture of carbonates, slates and quartzites and contains algal structures similar to those found in present day intertidal zones. The overlying Menominee Group has been suggested to be a transgressive sequence (Tyler and Twenhofel, 1952). The Negaunee Iron Formation is the uppermost unit in this Group. Extensive erosion of this formation serves as a break between the Menominee and overlying rocks of the Baraga Group.

The youngest unit within the Group, the Michigamme Formation, covers a large area of the Upper Peninsula. The formation has been thought of as a deep water sequence containing some turbidites and mafic volcanics. Cannon (1973) has called the formation eugeosynclinal.

The Paint River Group is exposed in the Iron River - Crystal Falls district of Michigan. It is a series of slates, graywackes, an iron formation.

## The Michigan Copper District

The native-copper deposits in the middle Keweenawan Portage Lake Lava Series occur in flow tops and Interflow conglomerate beds (Figure 1). More than 96 percent of the copper produced from this formation has come from a area 28 miles long (White, 1968) which extends just southwest of Painesdale to just east of Mohawk (Figure 2, Plates 2, 3, 4&5). Minor production has come from the Mass-Victoria area and from small mines northeast of Mohawk.

Copper sulfides with minor amounts of native copper occur at the base of the Nonesuch Shale, and within the upper few feet of the underlying Copper Harbor Conglomerate. Although traces of copper can be found at this contact over an area at least 125 miles long (White, 1971), only two deposits of significant copper concentration have been found so far. These are the White Pine orebody and the synclinal area west of the Porcupine Mountains known as the Western Syncline or Presque Isle Syncline.

The stratigraphy in the copper district is as follows:

Top: Not exposed
- Freda Sandstone, >12,000'
- Nonesuch Shale, 250-750'
- Copper Harbor Conglomerate, 200-7,000'
- Unnamed Formation, 0-8,000'
- Portage Lake Lava Series, >15,000

Base: Not exposed

The base of the Nonesuch Shale has been selected as the boundary between upper and middle Keweenawan rocks (White, 1972). The stratigraphic section below the base of the Nonesuch Shale is given in Figure 3.

## Copper Deposition in the Marquette Supergroup

Taylor (1972) suggests that the Kona sediments were deposited in a stable shelf, lagoonal environment. The sulfides, mainly chalcocite, chalcopyrite, bornite and pyrite are found disseminated within three beds with a total thickness of 56 feet. The beds are approximately 200 feet above the base of the formation. The three beds, an upper argillite, middle quartzite, and lower argillite are not mineralized in equal amounts; mineralization Is most Intense at the argillite contacts.

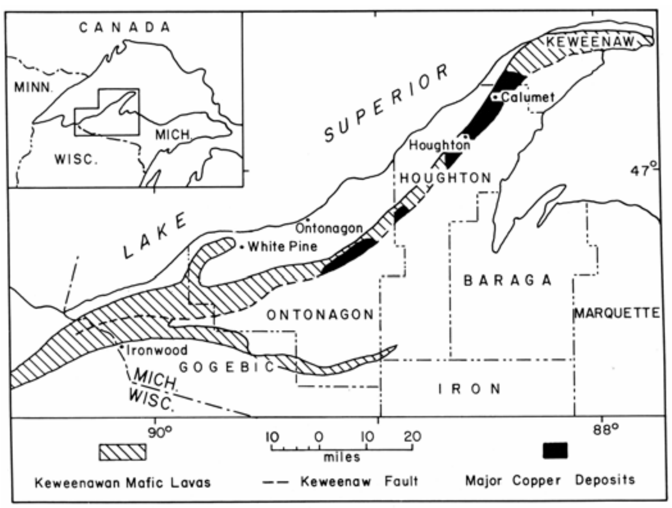


Figure 1

[FIGURE 1: Distribution of Keweenaw Lavas with Major Native Copper Deposits]

The genesis of the sulfides has been summarized by Taylor (1972) and Clark (1974). Clark (p. 31) suggests that copper solutions moved through the middle quartzite bed and into the enclosing argillite and replaced preexisting (syngenetic?) pyrite. Although the source of the solution has not been defined, Clark suggests they may have migrated updip from offshore pelagic sediments.

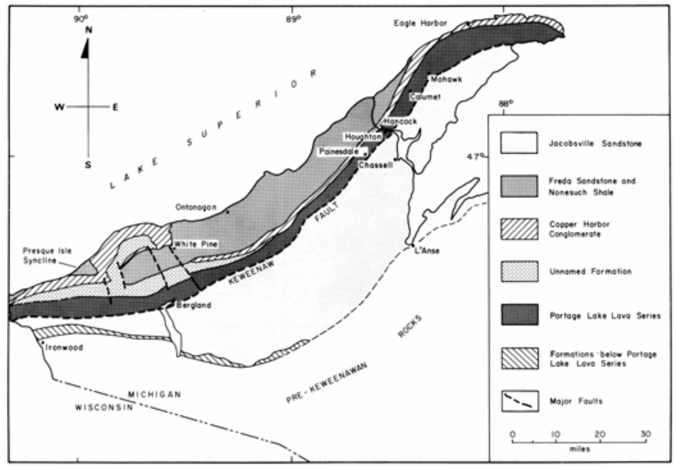


Figure 2

[FIGURE 2: Keweenawan Rocks of Michigan]

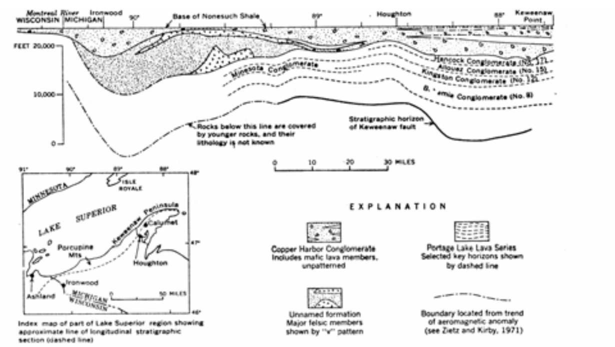


FIGURE 3.—Longitudinal stratigraphic section of Keweenawan rocks below the base of the Nonesuch Shale from Keweenaw Point to the Montreal River. All data projected to an east-west line. Dashed lines within the Portage Lake Lava Series represent individual horizons that can be traced with confidence between the indicated points, largely by correlation of drill-hole sections. Thickness east of long. 89°15′ from sources listed in figure 1 and from Butler, Burbank, and others (1929, pl. 15); thickness west of long. 89°15′ calculated from unpublished maps by E. R. Brooks, H. A. Hubbard, R. F. Johnson, W. S. White, J. T. Wilband, and J. C. Wright.

From White, 1972.

[FIGURE 3: Stratigraphic Section of Keweenawan Rocks Below the Base of the Nonesuch Shale]

## Distribution and Genesis of Native Copper Ores

The copper mineralization within the Portage Lake Lava Series was contemporaneous with, or later than, much or most of the deformation (White, 1968). This deformation is represented by minor folding, tilting, and high-angle faulting. Where mineralized, these last features formed the so-called fissure or vein lodes. White (1968, op. cit.) notes that the dips in individual horizons of the Lava Series tend to steepen 20 to 30° along strike from Mohawk to Painesdale (Figure 1). This variation, he states, creates a gentle twist in each horizon which may be a significant factor since most of the copper production has come from this area.

The forms of the orebodies have been described in detail by White (1968), Butler and Burbank (1929), Cornwall, et al. (1949), Broderick, et al. (1946), and Weege, et al. (1972). The following summary draws heavily upon their investigations.

The amygdaloidal lodes have irregular copper distributions since several flows stratigraphically above one another can be mineralized up to depths of 40 feet in fragmental portions. The flow tops are not continuously fragmental so that lateral pinchouts in the ore are very common. This erratic distribution causes great difficulty in assigning a meaningful average thickness to many ore deposits. Stope heights vary from mine to mine; ten to fifteen feet are common.

Conglomerate orebodies often defy the most comprehensive development plans to best follow the ore. In the Kingston ore-body, for example, native copper may occur at any place within the 40-foot-thick conglomerate. In general, it occurs within roughly restricted zones designated as hanging wall, footwall, and intermediate ore (Weege, et al., 1972). The segragation of the ore zones is not as obvious at the Centennial No. 3-6 orebody; however, because the conglomerate averages approximately 8 feet, the entire bed Is usually mined. Considerable time and effort have been expended by Homestake geologists to ascertain the controls of copper distribution at the Centennial No. 3-6 mine. The variation of copper between channel sand and conglomerates, tributaries, and silt lenses provide empirical ore guides which appear to be related to permeability of the members and perhaps to differential compaction during burial and deformation.

The ultimate source of the copper and the paucity of sulfur is still not fully explained. Most investigators agree, however, that the native copper is epigenetic. The ore has been attributed to downward percolating meteoric waters, magmatic hydrothermal solutions, and to upward migrating copper solutions, probably as brines, which derived their copper by a dehydrating metamorphism from the lavas themselves. This last hypothesis appears to be the most favored, particularly in the light of recent geochemical investigations by Jolly (1974). The low amount of sulfur is more easily explained by this hypothesis since normal magmatic hydrothermal solutions would be expected to form copper sulfides.

## Genesis of the White Pine Orebody

The origin of the copper mineralization at White Pine and the Presque Isle syncline is not fully known. At White Pine the geologists recognize that the characteristics of the orebody can be fitted into several models. In fact, Robert Seasor, Chief Geologist at the mine, asks visiting geologists whether they wish to take the "syngenetic or the epigenetic mine tour".

Ensign, et al. (1968) have summarized the problems of both genetic hypotheses. More recently, Brown (1974) has experimentally duplicated the trace element pattern of Cd, Pb, and Zn which is found at the White Pine orebody. These elements are found in a narrow blanket-like zone which directly overlies the cupriferous zone and transects the bedding at gentle to moderate angles. They are also found in a second zone which is strictly stratabound associated with a pyritic bed some 60 feet above the Nonesuch base. Brown (1971) attributes this first zone to copper chloride brines which ascended through the Nonesuch strata replacing preexisting pyrite, and sweeping the more soluble Cd, Pb, and Zn before the copper front. The transition between the cupriferous zone below and the unreplaced pyritic zone above Is thought to represent the position where the copper solutions were finally spent.

The overlying trace concentrations have been interpreted as syngenetic, however, Brown (1974) interprets this as a temporary but sudden pulsation of the ore solution, perhaps due to some tectonic readjustment. Brown, under laboratory conditions, demonstrated that the Cd, Pb, and Zn could be swept much higher than the defined zone set by the observed "fringe" or "transition" zone.

White (1971) has suggested the Copper Harbor Conglomerate as a potential source of the copper. He presents calculations that show the conglomerate could have contained a sufficient amount of water released by compaction to account for the White Pine ore-body, assuming a copper concentration of 50 ppm. This model requires a load of 3,000 to 5,000 meters of Freda Sandstone above the Nonesuch to compact the Copper Harbor. White alternatively suggests that surface waters could have entered an exposed portion of the Copper Harbor on the northern limb of the syncline and migrated to the White Pine area, so long as a suitable hydraulic gradient existed between the recharge area and the water table at the orebody during the mineralization event.

# PRODUCTION

With the closing of the joint experimental mining and milling venture by the American Nickel Company and Homestake Copper Co-pany at the Centennial 3-6 Mine in 1976 there has been no copper producation from "Copper Country" since. The price of copper reached all time highs in 1974 just before the rehabilitated mine went into production. When the mine went into production in 1975 the price of copper plummeted, and the grade, which was expected to increase at depth, remained disappointingly low as the shaft was deepened from the old 38th to beyond the 50th level. The financially unsuccessful project was closed, the pumps removed, and the mine is flooding.

The refined copper production from the native copper mines (Figure 4) spans a period of 130 years in which the amount of copper produced rose almost exponentially with time from 1845 to World War I as new mines were brought on line. The "boom and bust" production of two World Wars and the effects of the depression, with a spurt during World War II reflect the economic turmoil of the times. The gradual overall decay in production from the peak production years of 1915 to 1918 reflects the fact that no new native copper lodes were developed that could match or even sustain the production of the older lodes which were slowly being mined out.

The White Pine orebody was brought into production in 1953 (see Figure 5) and has produced over 2.5 billion pounds of copper (including 1978 production). The copper produced at White Pine is already 23 percent of the total amount produced for all the native copper mines. Although the White Pine Company mines copper sulphide and native copper, the production figures (Table 4) for this orebody are listed under "Pounds Sulphide Copper" to differentiate this ore from "Copper Country" native copper ores.

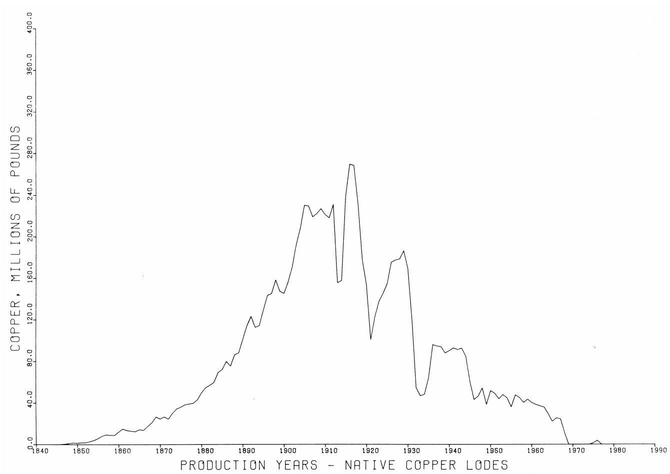


Figure 4

[FIGURE 4: Copper Production - Native Copper Lodes]

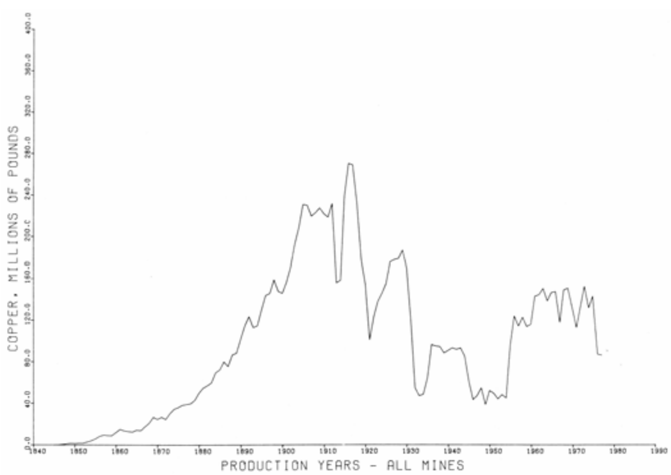


Figure 5

[FIGURE 5: Copper Production - All Mines]

TABLE 2

REFINED COPPER PRODUCTION (POUNDS) FROM ALL LODES

| | 1845-1925 | 1926-1977 | LODE TOTAL | % of NATIVE COPPER LODES |
|---|---|---|---|---|
| Algomah amygdaloid | 12,467 | 112,368 | 124,835 | |
| Allouez conglomerate | 69,521,253 | 4,454,284[b] | 73,975,537 | |
| Arcadian amygdaloid | 4,783,711 | 22,430 | 4,806,141 | |
| New Arcadian amygdaloid | 164,794 | 0 | 164,794 | |
| Ashbed +Atlantic) amygdaloid | 142,840,804 | 6,219,555[b] | 149,060,359 | 1.42 |
| Baltic (+Superior) amygdaloid | 873,525,912 | 427,942,546 | 1,301,468,458 | 12.37 |
| Calico amygdaloid | 8,006,420 | 0 | 8,006,420 | |
| Calumet and Hecla conglomerate | 3,375,361,468[b] | 843,173,416[b] | 4,218,534,884 | 40.08 |
| Evergreen series | 66,508,152 | 5,565,470 | 72,073,672 | |
| Houghton cgl. & Iroquois amyg. | 0 | 86,022,420 | 86,022,420 | |
| Isle Royale amygdaloid | 210,839,585 | 130,550,073 | 341,389,658 | 3.24 |
| Kearsarge amygdaloid | 1,176,948,378 | 1,094,869,382[b] | 2,271,817,760 | 21.58 |
| Kingston conglomerate | 0 | 19,959,554 | 19,959,554 | |
| Lake amygdaloid | 7,326,227 | 0 | 7,326,227 | |
| "Mesnard" epidote | 84,095 | 0 | 84,095 | |
| Nonesuch | 18,622,725 | 2,455,666,905[b] | 2,474,289,630 | |
| Osceola amygdaloid | 416,398,662 | 179,713,337[b] | 596,111,999 | 5.66 |
| Pewabic amygdaloid | 873,712,184 | 206,916,809[b] | 1,080,628,993 | 10.27 |
| Fissures[a] | 199,853,050 | 3,487,180 | 203,340,230 | 1.93 |
| Not designated | 71,015,685 | 24,858 | 71,040,543 | |
| Mines on Isle Royale | 978,625 | 0 | 978,625 | |
| TOTALS | 7,516,504,197 | 5,464,700,587 | 12,981,204,784 | |
| | | Native Cu | 10,525,378,879 | 96.50 |

*a: includes 230,897 pounds mohawkite from Mohawk Mine.*
*b: includes reclamation of sands and slimes.*

[TABLE 2: Refined Copper Production from all Lodes]

[TABLE 3: Production of Refined Copper by Lode and Mine]

PRODUCTION OF REFINED COPPER BY LODE AND MINE

TABLE 3A

ALLOUEZ CONGLOMERATE

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Albany and Boston (1865-1878) | 865,057 | 0 | 865,057 |
| Allouez (1969-1892) | 25,786,651 | 2,788,411 | 28,575,062 |
| Delaware (1882-1885) | 1,770,570 | 0 | 1,770,570 |
| Franklin Jr. (1901-1919) | 34,473,984 | 0 | 34,473,984 |
| Peninsula (1883-1892) | 6,624,991 | 0 | 6,624,991 |
| SUBTOTAL | 69,521,253 | 2,788,411 | 72,309,664 |
| Miscellaneous | | | |
| Allouez (rock pile & sands) | 0 | 1,665,873 | |
| TOTAL | 69,521,253 | 4,454,284 | |
| GRAND TOTAL | 73,975,537 | | |

[A: Allouez Conglomerate]

TABLE 3B

BALTIC AMYGDALOID

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Baltic (1898-1916; 1917-1925) | 236,523,711 | 20,004,300 | 283,528,011 |
| Champion (1902-1925) | 438,403,286 | 384,176,397 | 822,579,683 |
| Trimountain (1902-1925) | 141,040,592 | 7,759,077 | 148,799,669 |
| Superior (1908-1920) | 30,018,271 | 0 | 30,018,271 |
| Houghton (1915-1917) | 540,052 | 0 | 540,052 |
| SUBTOTAL | 873,525,912 | 411,939,774 | 1,285,465,686 |
| Miscellaneous | | | |
| Reclamations (sands) | 0 | 16,002,772 | |
| TOTAL | 873,525,912 | 427,942,546 | |
| GRAND TOTAL | 1,301,468,458 | | |

[B: Baltic Amygdaloid]

TABLE 3C

CALUMET AND HECLA CONGLOMERATE

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Calumet and Hecla (1865-1925) | 2,831,092,153 | 449,336,193 | 3,280,428,346 |
| Centennial (1882; 1897-1898) | 202,744 | 24,524,556 | 24,727,294 |
| Osceola (1874-1880; 1897-1903) | 25,056,028 | 0 | 25,056,028 |
| Schoolcraft (1869-1874) | 1,882,529 | 0 | 1,882,529 |
| Tamarack (1882-1883; 1885-1917) | 379,978,899 | 0 | 379,978,899 |
| Tamarack Jr. (1892-1896) | 9,462,191 | 0 | 9,462,191 |
| SUBTOTALS | 3,247,674,544 | 473,860,749 | 3,721,535,287 |
| Miscellaneous | | | |
| Centennial #6 ventilation raise | | 240,642 | |
| Centennial #2 rockpile | | 39,795 | |
| Reclamation (1915-1925) | 127,686,924 | 368,981,540 | |
| Tamarack Jr. rockpile | | 40,814 | |
| Laurium rockpile | | 9,882 | |
| TOTAL | 3,375,361,468 | 843,173,416 | |
| GRAND TOTAL | 4,218,534,884 | | |

[C: Calumet and Hecla Conglomerate]

TABLE 3D

KEARSARGE AMYGDALOID

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Ahmeek (1904-1923) | 258,287,424 | 433,234,213 | 691,521,637 |
| Allouez (1905-1923) | 82,222,989 | 0 | 82,222,989 |
| Calumet and Hecla (1904-1925) | 67,351,569 | 0 | 67,351,569 |
| Centennial (1900-1923) | 33,033,675 | 127,546,619 | 160,580,294 |
| Douglass | 0 | 52,393,311 | 52,393,311 |
| Gratiot (1910-1920) | 313,848 | 0 | 313,848 |
| Kearsarge (1888-1896) | 14,512,073 | 0 | 14,512,073 |
| LaSalle (1910-1920) | 7,814,730 | 0 | 7,814,730 |
| Mohawk (1902-1925) | 259,114,348 | 116,802,708 | 375,917,056 |
| Ojibway (1911) | 49,662 | 201,203 | 250,865 |
| Osceola (1897-1920) | 261,527,694 | 0 | 261,527,694 |
| Seneca (1872-1925) | 3,863,385 | 143,149,578 | 147,012,963 |
| Tecumseh (1906) | 59,874 | 0 | 59,874 |
| Wolverine (1882-1925) | 188,797,107 | 0 | 188,797,107 |
| North Kearsarge | Osceola | 71,294,085 | 71,294,085 |
| South Kearsarge | Osceola | 1,015,963 | 1,015,963 |
| Peninsula | 0 | 120,050,222 | 120,050,222 |
| SUBTOTAL | 1,176,948,378 | 1,065,687,902 | 2,242,636,280 |
| Miscellaneous | | | |
| Seneca rockpiles | 0 | 152,416 | |
| Ahmeek rockpiles | 0 | 2,397,540 | |
| Calumet crosscut | 0 | 129,400 | |
| Kearsarge rockbin | 0 | 4,257 | |
| Reclamation | 0 | 26,497,867 | |
| | 0 | 29,181,480 | |
| TOTAL | 1,176,948,378 | 1,094,869,382 | |
| GRAND TOTAL | 2,271,817,760 | | |

[D: Kearsarge Amygdaloid]

TABLE 3E

ISLE ROYALE AMYGDALOID

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Grand Portage (1863-1884) | 3,529,822 | 0 | 3,529,822 |
| Huron (1855-1893) | 25,309,270 | 0 | 25,309,270 |
| Isle Royale (1853-1885; (1901-1925) | 180,537,926 | 130,550,073 | 311,087,999 |
| Shelden & Columbia (1864-1884) | 1,463,336 | 0 | 1,463,336 |
| SUBTOTAL | 210,839,585 | 130,550,073 | 341,389,658 |
| GRAND TOTAL | 341,389,658 | | |

[E: Isle Royale Amygdaloid]

TABLE 3F

IROQUOIS AND HOUGHTON LODES

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Allouez #3 | 0 | 42,960,653 | 42,960,653 |
| Iroquois | 0 | 43,061,767 | 43,061,767 |
| TOTAL | | 86,022,420 | 86,022,420 |
| GRAND TOTAL | 86,022,420 | | |

[F: Iroquois and Houghton Lodes]

TABLE 3G

OSCEOLA AMYGDALOID

| Mine | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Calumet and Hecla (1904-1924) | 213,817,584 | 0 | 213,817,584 |
| Centennial (1891-1900) | 2,556,685 | 0 | 2,556,685 |
| Osceola (1879-1920) | 190,787,393 | 114,507,974 | 305,295,367 |
| Tamarack (1885-1917) | 9,237,000 | 0 | 9,237,000 |
| SUBTOTAL | 416,398,662 | 114,507,974 | 530,906,636 |
| Miscellaneous | | | |
| Allouez #3 exploration | 0 | 7,862 | |
| Smelter slag | 0 | 3,063 | |
| Reclamation | 0 | 65,194,438 | |
| TOTAL | 416,398,662 | 179,713,337 | |
| GRAND TOTAL | 596,111,999 | | |

[G: Osceola Amygdaloid]

TABLE 3H

PEWABIC AMYGDALOID

| Mines | Pre 1926 | Post 1926 | Total Pounds |
|---|---|---|---|
| Albany and Boston (1862-1864) | 14,982 | 0 | 14,982 |
| Franklin (1857-1919) | 119,842,467 | 0 | 119,842,467 |
| Pewabic (1855-1884) | 27,823,416 | 0 | 27,823,416 |
| Quincy (1856-1925) | 726,000,319 | 109,790,547 | 835,790,866 |
| Rhode Island (1903;1906) | 31,000 | 0 | 31,000 |
| SUBTOTAL | 873,712,184 | 109,790,547 | 983,502,731 |
| Miscellaneous | | | |
| Quincy reclamation | 0 | 96,635,312 | |
| Franklin sands | 0 | 490,950 | |
| TOTAL | 873,712,184 | 206,916,809 | |
| GRAND TOTAL | 1,080,628,993 | | |

[H: Pewabic Amygdaloid]

TABLE 4

MICHIGAN COPPER PRODUCTION

| Year | Pounds Native Copper | Pounds Sulphide Copper | Pounds Total Copper | Average Value Per Pound | Value Of Copper |
|---|---|---|---|---|---|
| 1845 | 26,880 | | | $.20096 | $5,400 |
| 1846 | 58,240 | | | .17170 | 10,000 |
| 1847 | 477,120 | | | .18511 | 88,320 |
| 1848 | 1,032,640 | | | .19455 | 200,900 |
| 1849 | 1,505,280 | | | .22321 | 336,000 |
| 1850 | 1,281,280 | | | .22321 | 286,000 |
| 1851 | 1,744,960 | | | .16591 | 289,500 |
| 1852 | 1,774,080 | | | .22321 | 396,000 |
| 1853 | 2,905,280 | | | .22321 | 648,500 |
| 1854 | 4,074,560 | | | .22321 | 909,500 |
| 1855 | 5,808,320 | | | .27304 | 1,585,904 |
| 1856 | 8,211,840 | | | .26995 | 2,216,786 |
| 1857 | 9,531,200 | | | .24998 | 2,382,609 |
| 1858 | 9,157,120 | | | .23245 | 2,128,573 |
| 1859 | 8,926,400 | | | .21821 | 1,947,830 |
| 1860 | 12,069,120 | | | .21999 | 2,655,086 |
| 1861 | 15,037,120 | | | .22973 | 3,454,478 |
| 1862 | 13,585,600 | | | .26749 | 3,634,012 |
| 1863 | 12,985,280 | | | .34004 | 4,415,515 |
| 1864 | 12,490,240 | | | .46993 | 5,869,538 |
| 1865 | 14,358,400 | | | .39248 | 5,635,385 |
| 1866 | 13,749,120 | | | .33668 | 4,629,054 |
| 1867 | 17,525,760 | | | .25365 | 4,445,409 |
| 1868 | 20,935,040 | | | .23600 | 4,940,669 |
| 1869 | 26,624,640 | | | .23399 | 6,229,900 |
| 1870 | 24,622,080 | | | .20699 | 5,096,524 |
| 1871 | 26,750,080 | | | .22250 | 5,951,893 |
| 1872 | 24,552,640 | | | .32498 | 7,979,117 |
| 1873 | 30,089,920 | | | .28807 | 8,668,003 |
| 1874 | 34,332,480 | | | .23328 | 8,009,081 |
| 1875 | 36,039,360 | | | .22699 | 8,180,574 |
| 1876 | 38,270,400 | | | .20899 | 7,998,131 |
| 1877 | 39,025,280 | | | .18777 | 7,327,777 |
| 1878 | 39,690,560 | | | .16601 | 6,589,030 |
| 1879 | 42,848,960 | | | .17172 | 7,358,023 |
| 1880 | 49,736,960 | | | .20008 | 9,951,371 |
| 1881 | 54,573,120 | | | .18280 | 9,975,966 |
| 1882 | 56,982,765 | | | .18410 | 10,490,527 |
| 1883 | 59,702,404 | | | .15842 | 9,458,055 |
| 1884 | 69,353,202 | | | .13690 | 9,494,453 |
| 1885 | 72,148,172 | | | .11009 | 7,942,792 |
| 1886 | 79,890,798 | | | .10861 | 8,676,940 |
| 1887 | 75,471,890 | | | .11220 | 8,467,946 |
| 1888 | 86,472,034 | | | .16780 | 14,510,007 |
| 1889 | 88,175,675 | | | .13490 | 11,894,899 |

Michigan Copper Production Contd.

| Year | Pounds Native Copper | Pounds Sulphide Copper | Pounds Total Copper | Average Value Per Pound | Value Of Copper |
|---|---|---|---|---|---|
| 1890 | 101,410,277 | | | $.15600 | $15,820,003 |
| 1891 | 114,222,709 | | | .12760 | 14,574,818 |
| 1892 | 123,198,460 | | | .10091 | 12,431,957 |
| 1893 | 112,605,078 | | | .10750 | 12,105,046 |
| 1894 | 114,308,870 | | | .09494 | 10,852,484 |
| 1895 | 129,330,749 | | | .10730 | 13,877,189 |
| 1896 | 143,524,069 | | | .11093 | 15,921,125 |
| 1897 | 145,282,059 | | | .11584 | 16,829,474 |
| 1898 | 158,491,703 | | | .12050 | 19,098,250 |
| 1899 | 147,400,338 | | | .17760 | 26,178,300 |
| 1900 | 145,461,498 | | | .16667 | 24,244,068 |
| 1901 | 156,289,481 | | | .16722 | 26,134,727 |
| 1902 | 170,609,228 | | | .12160 | 20,746,082 |
| 1903 | 192,400,577 | | | .13720 | 26,397,359 |
| 1904 | 208,309,130 | | | .13010 | 27,101,018 |
| 1905 | 230,287,992 | | | .15890 | 36,592,762 |
| 1906 | 229,695,730 | | | .18745 | 43,056,465 |
| 1907 | 219,131,503 | | | .20045 | 43,924,910 |
| 1908 | 222,289,584 | | | .13580 | 30,186,926 |
| 1909 | 227,005,923 | | | .13480 | 30,600,398 |
| 1910 | 221,462,984 | | | .13125 | 29,067,017 |
| 1911 | 218,185,236 | | | .12376 | 27,002,605 |
| 1912 | 231,112,228 | | | .16341 | 37,766,049 |
| 1913 | 155,715,286 | | | .15269 | 23,776,167 |
| 1914 | 158,009,748 | | | .13602 | 21,492,486 |
| 1915 | 238,956,411 | | | .17275 | 41,279,720 |
| 1916 | 269,794,531 | | | .27202 | 73,389,508 |
| 1917 | 268,508,098 | | | .27180 | 72,980,501 |
| 1918 | 231,096,150 | | | .24628 | 56,914,360 |
| 1919 | 177,594,135 | | | .18691 | 33,194,120 |
| 1920 | 153,483,952 | | | .17456 | 26,792,159 |
| 1921 | 100,918,001 | | | .12502 | 12,616,768 |
| 1922 | 122,545,126 | | | .13382 | 16,398,989 |
| 1923 | 137,691,306 | | | .14421 | 19,856,463 |
| 1924 | 145,333,227 | | | .13024 | 18,928,199 |
| 1925 | 154,799,247 | (TOTAL 7,521,064,924) | | .14042 | 21,736,910 |
| 1926 | 175,441,565 | | | .13795 | 24,202,164 |
| 1927 | 177,537,775 | | | .12920 | 22,937,881 |
| 1928 | 178,442,704 | | | .14570 | 25,999,102 |
| 1929 | 186,393,974 | | | .18107 | 33,750,357 |
| 1930 | 169,297,775 | | | .12982 | 21,978,237 |
| 1931 | 118,495,055 | | | .08116 | 9,617,059 |
| 1932 | 54,396,108 | | | .05555 | 3,021,704 |
| 1933 | 46,853,130 | | | .07025 | 3,291,432 |
| 1934 | 48,215,859 | | | .08428 | 4,063,633 |
| 1935 | 64,107,889 | | | .08649 | 5,544,691 |
| 1936 | 95,968,019 | | | .09474 | 9,092,010 |
| 1937 | 94,649,805 | | | .13167 | 12,462,540 |
| 1938 | 94,075,588 | | | .10000 | 9,407,559 |
| 1939 | *87,969,153* | | | .10965 | 9,639,897 |

Michigan Copper Production Contd.

| Year | Pounds Native Copper | Pounds Sulphide Copper | Pounds Total Copper | Average Value Per Pound | Value Of Copper |
|---|---|---|---|---|---|
| 1940 | 90,402,594 | -- | -- | $.11296 | $10,211,877 |
| 1941 | *92,864,678* | -- | -- | .11797 | 10,886,823 |
| 1942 | 91,365,660 | -- | -- | .11775 | 10,758,306 |
| 1943 | *92,736,686* | -- | -- | .11775 | 10,833,000 |
| 1944 | *84,843,078* | -- | -- | .11775 | 9,104,913 |
| 1945 | 60,801,716 | -- | -- | .11775 | 7,159,402 |
| 1946 | 43,203,563 | 2,741 | 43,206,304 | .13820 | 5,971,111 |
| 1947 | 46,581,000 | 473,473 | 47,054,473 | .20958 | 9,861,676 |
| 1948 | 54,309,661 | 124,381 | 54,434,042 | .22038 | 11,996,174 |
| 1949 | 38,498,167 | -- | 38,498,167 | .19202 | 7,392,418 |
| 1950 | 51,788,017 | -- | 51,788,017 | .21235 | 10,997,185 |
| 1951 | 49,297,405 | 459 | 49,297,864 | .24200 | 11,930,083 |
| 1952 | 43,939,304 | -- | 43,939,304 | .24200 | 10,633,312 |
| 1953 | 47,999,690 | -- | 47,999,690 | .28798 | 13,822,951 |
| 1954 | *44,796,824* | -- | *44,796,824* | .29694 | 13,298,993 |
| 1955 | *36,265,073* | 58,943,499 | *95,208,572* | .37491 | 35,690,374 |
| 1956 | *47,649,651* | 75,699,096 | *123,348,747* | .41818 | 51,553,329 |
| 1957 | *45,118,291* | 68,562,019 | *113,680,310* | .29576 | 33,612,279 |
| 1958 | 40,402,115 | 81,656,908 | 122,059,023 | .25764 | 31,447,287 |
| 1959 | 43,434,301 | 69,647,232 | 113,081,533 | .31182 | 35,261,084 |
| 1960 | *40,314,264* | 75,120,243 | *115,434,507* | .32053 | 37,001,514 |
| 1961 | *38,517,943* | 103,756,178 | *142,274,121* | .29921 | 42,572,436 |
| 1962 | 37,147,227 | 106,613,451 | 143,760,678 | .30600 | 43,990,767 |
| 1963 | 35,880,333 | 113,900,191 | 149,780,524 | .30600 | 45,832,840 |
| 1964 | 29,326,043 | 108,458,751 | 137,784,794 | .31960 | 44,036,020 |
| 1965 | 22,174,047 | 123,743,392 | 145,917,439 | .35017 | 51,095,910 |
| 1966 | 25,562,323 | 121,181,717 | 146,744,040 | .36170 | 53,077,319 |
| 1967 | 24,458,983 | 92,731,257 | 117,190,240 | .38226 | 44,797,141 |
| 1968 | 11,288,306 | 137,092,516 | 148,380,822 | .42247 | 62,686,446 |
| 1969 | -- | 149,952,283 | 149,952,283 | .47534 | 71,278,318 |
| 1970 | -- | 131,373,570 | 131,373,570 | .57700 | 75,802,550 |
| 1971 | -- | 112,155,147 | 112,155,147 | .52000 | 58,320,676 |
| 1972 | -- | 131,937,378 | 131,937,378 | .50617 | 66,782,743 |
| 1973 | -- | 151,678,939 | 151,678,939 | .62100 | 94,192,621 |
| 1974 | -- | 131,037,602 | 131,037,602 | .83170 | 108,983,973 |
| 1975 | 1,455,651 | 140,819,850 | 142,275,501 | .58000 | 82,519,791 |
| 1976 | 3,866,218 | 83,044,081 | 86,910,299 | .68624 | 59,641,323 |
| 1977 | -- | 85,960,551 | 85,960,551 | .68770 | 59,115,071 |
| TOTAL | 10,529,198,135 | 2,455,666,905 | 12,984,865,040 | | |

*Data in italics are corrections from original file reported in unpublished updates by Hardenburg (see text).*

[TABLE 4: Annual Copper Production]

## Copper

This section presents copper production data by lode (Table 2), lodes and mine (Table 3), and by year (Table 4). Annual production by mines and reclamations are presented only for those which operated from 1926 to 1977 (see Tables In Appendix A) to avoid redundancy since Butler and Burbank (1929) have presented a detailed account of Michigan copper district production up to and including 1925. Post 1925 data are drawn heavily from unpublished files (tax files, at the Michigan Geological Survey annual production sheets, etc.) and especially from the unpublished files of Harold Hardenburg (geologist - retired, Michigan Geological Survey). Production data for 1844 to 1925 are largely drawn from Butler and Burbank (1929).

Total refined copper production by lode is presented In Table 2. The grand total for the district is subdivided into 1845-1925 and 1926-1977 production periods for each lode. The 1845-1925 sum of 7,516,504,197 pounds reported by Butler and Burbank (1929, p. 69) is used to maintain continuity with their report. This value differs from that reported in their summary table (7,504,265,411 pounds; 1929, p. 64) and from the high value (7,521,064,024 pounds) reported in the Michigan Geological Survey files (Table 4, "Pounds Native Copper" column). It is not clear why these discrepancies exist.

The original data in Table 4 have been modified for 1939, 1941, 1943, 1944, 1954-1957 inclusive, and 1960-1961. The updated figures (Italicized) were obtained from Hardenburg's data which I interpret from his notes to be more desirable than those of the compilation.

Nevertheless, total amount of copper produced during the 1926-1977 period is 900,471 pouuds higher than the corresponding summation in Table 1. The 1926-1977 production data in Table 2 represent summations of production by mines in Tables presented in Appendix A.

Assignment of copper recovered from tailings or "stamp sands" is based on Michigan Geological Survey records. These data are listed in Table 5.

TABLE 5

COPPER RECOVERED FROM TAILINGS AND SLIMES

| | | |
|---|---|---|
| Allouez | C & H (1955, 1957, 1960-1962) | 1,056,250 |
| Calumet and Hecla | | |
| Lake Linden sands | C & H (1915-1925) | 121,007,924 |
| | (1926-1930, 1935-1943) | 261,474,764 |
| Tamarack sands | (1925) | 6,679,000 |
| | (1926-1930, 1937-1943) | 17,405,497 |
| Kearsarge | | |
| Lake Linden sands | C & H (1944-1947) | 26,497,867 |
| Tamarack sands | (1947-1967) | 65,194,337 |
| Atlantic | Copper Range (1963-1967) | 6,116,719 |
| Baltic | Copper Range (1937-1947, 1956-1964) | 16,002,772 |
| Pewabic | Quincy (1944-1967) | 96,635,312 |
| | | 618,070,432 |

[TABLE 5: Copper Recovered from Tailings and Slimes]

TABLE 6

MICHIGAN SILVER PRODUCTION

| | Troy Oz. | Value |
|---|---|---|
| 1883 | | $ 173 |
| 1884 | | 2,000 |
| 1885 | | 2,879 |
| 1886 | | 4,654 |
| 1887 | | |
| 1888 | | 5,331 |
| 1889 | | 9,655 |
| 1890 | | |
| 1891 | 73,000 | 72,270 |
| 1892 | 65,600 | 57,072 |
| 1893 | 43,500 | 33,930 |
| 1894 | | |
| 1895 | | 1,373 |
| 1896-1909 | -- | -- |
| 1910 | 262,200 | 141,600 |
| 1911 | 507,700 | 274,100 |
| 1912 | 528,453 | 324,999 |
| 1913 | 295,173 | 178,284 |
| 1914 | 413,500 | 228,665 |
| 1915 | 585,933 | 297,068 |
| 1916 | -- | 247,485 |
| 1917 | 759,068 | 499,300 |
| 1918 | 473,342 | 504,480 |
| 1919 | 425,610 | 477,054 |
| 1920 | 510,601 | 518,326 |
| 1921 | 310,727 | 310,727 |
| 1922 | 361,912 | 361,912 |
| 1923 | 253,705 | 208,038 |
| 1924 | 153,201 | 102,951 |
| 1925 | 139,499 | 96,812 |
| 1926 | 107,094 | 66,827 |
| 1927 | 97,193 | 55,109 |
| 1928 | 17,152 | 10,035 |
| 1929 | 17,899 | 11,084 |
| 1930 | 7,820 | 3,011 |
| 1931 | 2,024 | 587 |
| 1932 | 71,408 | 20,137 |
| 1933 | 125,926 | 44,074 |
| 1934 | 529 | 342 |
| 1935 | 4,219 | 3,032 |
| 1936 | -- | -- |
| 1937 | 25,454 | 19,689 |
| 1938 | 93,634 | 60,531 |
| 1939 | 101,878 | 69,154 |
| 1940 | 88,657 | 63,045 |
| 1941 | 60,796 | 43,233 |
| 1942 | 61,674 | 43,857 |

TABLE 6 (continued)

| | Troy Oz. | Value |
|---|---|---|
| 1943 | 48,479 | 34,474 |
| 1944 | 54,218 | 38,555 |
| 1945 | 21,863 | 15,547 |
| 1946 | -- | -- |
| 1947 | 3,089 | 2,796 |
| 1948 | -- | -- |
| 1949 | -- | -- |
| 1950 | -- | -- |
| 1951 | -- | -- |
| 1952 | -- | -- |
| 1953 | -- | -- |
| 1954 | -- | -- |
| 1955 | -- | -- |
| 1956 | 365,960 | -- |
| 1957 | 430,114 | -- |
| 1958 | -- | -- |
| 1959 | -- | -- |
| 1960 | -- | -- |
| 1961 | -- | -- |
| 1962 | 401,491 | 435,618 |
| 1963 | 244,773 | 317,945 |
| 1964 | 349,195 | 451,509 |
| 1965 | 457,851 | 592,000 |
| 1966 | 473,266 | 611,933 |
| 1967 | 301,992 | 468,088 |
| 1968 | 472,813 | 1,013,995 |
| 1969 | 744,290 | 1,332,778 |
| 1970 | 891,579 | 1,578,826 |
| 1971 | 629,162 | 989,136 |
| 1972 | 699,160 | 1,177,770 |
| 1973 | 654,175 | 2,175,000 |
| 1974 | 642,944 | |
| 1975 | 628,270 | |
| 1976 | 461,971 | |
| 1977 | 446,808 | |

[TABLE 6: Silver Production]

## Silver Production

Silver production has not been carefully monitored for Keweenaw Copper mines because most of the silver eventually became part of the refined product. This product, known as "Lake Copper" is characteristic of the copper refined from the Nonesuch ores at White Pine and the native copper ores. Silver production data (Table 6) are from data supplied by the Michigan Geological Survey.

Present production of silver is limited lo the White Pine orebody. The silver is only partially recovered as a by-product and from 12 to 14 ounces of silver per refined ton of "Lake Copper" go to White Pine's customers.

The silver is scavanged by a special silver circuit in the White Pine mill which serves the dual purpose of: (1) removing excess silver for which White Pine is not compensated for, or which may render the copper unsuitable to a customer's specifications, and (2) providing a silver concentrate which can be added to the copper concentrate in the smelter for special orders which require a higher than normal "Lake Copper" silver content. Present policy at White Pine Copper Company is to ship the excess silver concentrate to an offsite smelter.

# RESERVE ESTIMATIONS

The reserve estimations presented in Table 7 were derived from several sources. Most useful were the files of the Calumet Division of Universal Oil Products in Calumet, and information and company reports filed with the Michigan Geological Survey. Without permission to peruse certain files from Industry and Survey personnel, the figures presented in this section would be highly speculative. The White Pine reserves, when released to the writer, were the latest figures available (December, 1976).

Reserve estimates for the strata bound Nonesuch lode are considered to be highly reliable. The reserve values and grades reported for native copper orebodies are not, however, reported with a high degree of confidence. During the course of this investigation it has become very apparant through discussions with mine geologists, mining engineers, and miners of the native copper ores that grade estimation in an operating mine is an extremely difficult task because of the erratic distribution of the copper mineralization.

Attempts to delimit the ore by drilling are frequently frustrated because the drill may sample a lean portion of the lode less than a meter from highly enriched ore. In several mines exploration was conducted, not by drilling, but by drifting through the lode. Although several experienced geologists arid mine captains could make good grade approximations, it was more common to find the grade of ore after it had been stamped. As mining progressed, the pattern of ore distribution in developing areas was then established by the bulk assays from the mined out stopes.

The tonnage and grade estimates for the deposits are rated alphabetically for convenience, rather than attempt to classify their accuracy according to methods established for rating data from other mining camps. Data rated A are considered reliable on the basis of drilling or other methods of sampling where ore has been blocked out, remains as pillar, or was left in stopes. In most cases the values are probably conservative estimates of the tonnage.

The estimates rated B are viewed with less confidence. For example, the Presque Isle deposit which was drilled by Amax cannot, be considered to be outlined in grade and tonnage with the same level of confidence as it's operational counterpart at White Pine.

TABLE 7

IN SITU COPPER RESERVES (THOUSANDS OF TONNES) AND GRADE

| NATIVE COPPER LODES | MINE | RESERVES | GRADE (%) | RATING[1] | THOUSANDS OF POUNDS COPPER |
|---|---|---|---|---|---|
| (Reserves-Grade) | | | | | |
| ALLOUEZ (1,000-1.0) | Allouez | 1,000.0 | 1.0 | C | 22,046 |
| BALTIC (1,506.5-0.80) | Baltic | 100.0 | 0.5 | B | 1,102 |
| | Champion | 1,402.6 | 0.82 | A | 25,356 |
| | Trimountain | 3.9 | 1.89 | A | 163 |
| CALUMET and HECLA (2,976.5-1.18) | C & H | 1,000.0 | 1.0 | C | 22,046 |
| | Centennial #2 | 345.1 | 0.95 | A | 7,228 |
| | Centennial #3-6 | 1,631.4 | 1.34 | A | 48,195 |
| EVERGREEN SERIES (11,421.5-1.11) | Caledonia | 11,421.5 | 1.11 | A | 279,499 |
| HOUGHTON-IROQUOIS (655.2-0.74) | Alloiez #3 | 576.2 | 0.76 | A | 9,654 |
| | Iroquois | 74.3 | 0.61 | A | 1,070 |
| ISLE ROYALE (10,000-1.0) | Isle Royale | 453.6 | 1.0 | A | 10,000 |
| KEARSARGE (8,785.5-0.69) | Seneca & Allouez & Peninsula | 6,336.7 | 0.625 | A | 87,313 |
| | Mohawk | 429.6 | 1.4 | A | 13,259 |
| | North Kearsarge | 2,019.2 | 0.76 | A | 33,832 |
| KINGSTON (4,372.1-1.25) | Kingston | 4,372.1 | 1.25 | A | 120,485 |
| PEWABIC (5,000-1.0) | Quincy | 5,000.0 | 1.0 | C | 110,231 |
| OSCEOLA (10,297.8-0.95) | Osceola #6-13 | 10,297.8 | 0.95 | A | 215,676 |
| OTHERS (1,500-0.63) | Indiana | 1,000.0 | 0.5 | C | 11,023 |
| | Winona | 500.0 | 0.9 | C | 9,921 |
| | TOTAL | 47,969.0 | | | 1,028,101 |

TABLE 7 (CONTINUED)

| SULFIDE LODES | MINE | RESERVES | GRADE (%) | RATING[1] | THOUSANDS OF POUNDS COPPER |
|---|---|---|---|---|---|
| NONESUCH (433,075.5-1.25) | White Pine | 337,821.1 | 1.24 | A | 9,235,124 |
| | Presque Isle | 95,254.4 | 1.27 | B | 2,667,000 |
| | TOTAL | 433,075.5 | | | 11,902,124 |
| KONA DOLOMITE (1,000,000-0.3) | Kona | 1,000,000.0 | 0.3 | C | 6,613,867 |
| | GRAND TOTAL | 1,481,044.5 | | | 19,544,092 |

[1] A: *Data believed to be reliable and conservative.*
B: *Speculative.*
C: *Highly speculative.*

[TABLE 7: In Situ Copper Reserves]

The C-rated deposits are those for which only minimal tonnage and/or grade data were available. In most cases the geologic setting of these deposits are well-described and it is possible to make extrapolations down and along dip using "district norms" (if, indeed, the district has a norm). Some are little more than explored prospects, such as the Indiana mine. Others, such as the Quincy mine, one of the main producers in the district have become legends without a tonnage. Virtually every person who knows "Copper Country" will attest to the fact that there was still a lot of ore left underground when the Quincy closed. How much is left? The answer, if available, has not been found in the copious amount of literature written about the mine. Therefore, the values presented for the Quincy in Table 7 are very speculative. Table 8 summarizes the reserve estimates In each category.

The Kona Dolomite in Marquette County has been vigorously explored. The low grade and poor grindability has made it somewhat less attractive at present copper prices and marketability. The tonnage reported was derived by planimetric analysis of maps of the mineralized zones in theses by Taylor (1972) and Clark (1974), and from other sources.

The percentage of extractable ore cannot be ascertained from the data available except for the White Pine ore body where the insitu reserves (372,384,000 tons at 24.89 lbs/ton) and extractable reserves (212,260,000 tons at 22.66 lbs/ton) are quoted. The present extractable reserve model assumes 57% of the ore remains as pillars. This value (57%) may change as the mine progressively deepens.

Approximately 12 billion pounds of copper are projected for the Nonesuch lode (Table 7). These reserves surpass the 130 year production figure for all the native copper mines. On the other hand, the native copper district reserves are a conservative 1 billion pounds of copper. Stated otherwise, this is the approximate equivalent of what was mined from the Pewabic Lode (Table 2). Most of the reserves are from the Kingston, Osceola, and Caledonia mines, and from the Kearsarge lode.

Silver reserves cannot be estimated for the native copper deposits because of lack of data. The Nonesuch reserves (Table 8) were obtained from the silver values reported by Robert Seasor (personal communication, 1977) for the White Pine orebody. These range from 0.16 to 0.2 troy oz. per short ton of ore. The extractable silver reserves for the White Pine mine are assummed to contain 0.16 oz. per short ton, or approximately 33.9 million oz. In situ reserves, estimated to contain up to 0.2 oz. per ton, would be approximately 74.5 million oz. This total could be increased by 16.8 million oz. to 91.3 million oz. If the 105 million tons of copper bearing shale at the Presque Isle syncline contained .16 oz. of silver per ton. Silver values for the Presque Isle are not available.

TABLE 8

SUMMARY OF INSITU RESERVES (ALL WEIGHTS IN THOUSANDS OF UNITS)

*Values in parentheses are exclusive of Kona*

| Rating | Tonnes | Grade (%Cu) |
|---|---|---|
| A | 377,190.1 | 1.21 |
| B | 95,345.4 | 1.27 |
| C | 1,008,500.0 | 0.30 |
| | (8,500.0) | (0.91) |
| TOTAL | 1,481,044.4 | 0.60 |

| | Tonnes | Grade | Percent | Pounds | Percent | Oz. Ag. |
|---|---|---|---|---|---|---|
| NATIVE COPPER LODES | 47,969.0 | 0.97 | 3.2 (= 10) | 1,028,099 | 5.3 (8) | unknown |
| NONESUCH | 433,075.5 | 1.25 | 29.2 (= 90) | 11,902,124 | 60.9 (92) | 76381.4 |
| KONA | 1,000,000.0 | 0.3 | 67.5 | 6,613,867 | 33.8 | unknown |
| TOTAL | 1,481,044.5 | 0.6 | | 19,544,090 | | |
| | (481,044.5) | | | | | |

[TABLE 8: Summary of Reserves by Ratings]

## COSTS

The absolute costing of an operating native copper mine can be approximated from past cost data. The figures listed in Table 9 are given as percentages of the total costs for five native copper mines (two conglomerate lode mines and three amygdaloid lodes mines). Although all mines were not operating simultaneously, the production rates were approximately similar. The low standard deviations for each unit cost average indicate a relative uniformity of cost percentages between 1959 and 1968 when the various mines were in production. The lumping together of both types of native copper producers does not introduce a significant difference in the variance for the size of the populations sampled. For simplicity the costing is considered to be the same for both types.

Approximately 50 percent of the total cost was attributable to fixed mining costs, and 25 to treatment costs. The last column in Table 9 should be considered an *order-of-magnitude estimate* as defined by Zimmerman (1968). These are ratio estimations which are based on previous cost data and have a probable error over ± 30 percent.

Direct costs for the Kingston mine, which mined the Kingston Conglomerate from 1965 to 1968, have been estimated by Karkkainen (1977). The direct mining costs are estimated to be $9-50/ton for a 1000 TPD mining rate. Direct milling cost estimates ranged from $2.216 to $3.80 per ton mined for a 1715 TPD and 1000 TPD mining rate, respectively.

If the mining cost estimated by Karkkainen is assummed to be relatively constant across the district for native copper producers, as the relatively low standard deviation from the five mines sampled would seem to indicate, then the total cost of mining can be derived from the percentages. A projected total costs would be $19.48/ton based on a calculation which assumes that the mining cost is 48.756 percent of the total cost.

Based on these estimates a breakeven operation for a mine with an extractable grade of 1% copper (20 lbs/ton) requires a return of $0.974 per pound of copper.

Mining costs at the White Pine mine are lower than those estimated for the native copper producers. Like all underground mines it is a relatively high cost operation in which expenses increase as the orebody is developed further from the shafts. It is current practice to control production so that only 9,000 TPD are hoisted rather than the 25,000 tons designed capacity so long as the price of copper is supressed. Unfortunately, this production cutback is also reflected in a cutback in the workforce.

TABLE 9

ESTIMATED COSTS FOR A 1000 TPD NATIVE COPPER MINE

| | Percentage of Cost | σ | Estimated Cost/Ton |
|---|---|---|---|
| General Overhead | | | |
| Depreciation | 5.466 | 1.931 | $ 1.06 |
| General Officers | 1.124 | 0.211 | 0.22 |
| General Supplies | 6.804 | 0.780 | 1.33 |
| General Insurance | 0.626 | 0.300 | 0.12 |
| Employee Benefits | 7.554 | 1.183 | 1.47 |
| Legal Expense | 0.090 | 0.018 | 0.02 |
| | 21.664 | | $ 4.22 |
| Taxes (except Federal) | | | |
| Property | 0.734 | 0.130 | 0.14 |
| State Corporation | 0.552 | 0.140 | 0.11 |
| Unemployment | 0.494 | 0.240 | 0.09 |
| Old Age | 0.978 | 0.144 | 0.19 |
| | 2.758 | | $ 0.54 |
| Costs of Mining (Direct) | | | |
| Labor, Superintendence | 26.156 | 0.995 | 5.10 |
| Supplies, Maintenance, materials | 22.600 | 2.687 | 4.40 |
| | 48.756 | | $ 9.50 |
| Treatment Costs | | | |
| Transportation, Mine to mill | 4.024 | 0.445 | 0.78 |
| Milling, concentration (Direct) | 14.528 | 2.656 | 2.83 |
| Transportation, mill to smelter | 0.094 | 0.012 | 0.02 |
| Smelting and Refining | 6.798 | 2.071 | 1.32 |
| | 25.444 | | $ 4.96 |
| Costs Beyond Smelter | 1.378 | 0.653 | 0.26 |
| TOTALS | 100.00 | | $19.48 |

[TABLE 9: Estimate Costs for a 1000 TPD Native Copper Mine]

The mine and mill capital costs listed by Karkkainen (1977, p. 24) for the Kingston mine are offered as a model which may be applied to the district.

Mine Capital Costs

| | |
|---|---|
| Preproduction Development | $12,245,000 |
| Underground Plant | 2,300,000 |
| Surface Plant | 1,800,000 |
| Working Capital | 850,000 |
| TOTAL | $17,195,000 |

Mill Costs - $3.80/ton mined
Milling Capital Cost - $5,000,000
Working Capital - $325,000
Net Copper Recovery - 90%

These figures are for a convential simple crusher - flotation mill and concentration plant with a throughput of 13000 TPD The cost of a larger mill can be estimated by the current “rule-of-thumb” used by industrial cost analysts which is $5,000 x daily throughput (tons).

Mining capital cost would necessarily vary with the size of the operation; no attempt is made to cost a mine with a hoist greater than 1,000 tons. Preproduction rehabilitation of existing mines would be extremely costly due to the amount of dewatering required. In many cases the shaft pillars were robbed in the final phases of mining and the shafts have collapsed.

# FUTURE POTENTIAL

## Exploration

It is unlikely that surface basic prospecting will reveal significant or mineable concentrations of copper. The area has been traversed many times and most outcrops already bear the marks of prospectors hammers. Probably the best chances of discovering more deposits will be from a combination of geochemical, geophysical, and exploration drilling.

A basic factor which thwarts geologists and prospectors is the glacial overburden which may cover up to 98 percent of a 7 1/2 minute quadrangle. The exposures of basalt which dip towards Lake Superior at angles of 70° near the base to 25° near the top of the volcanic pile weather nonuniformly. The massive, coarser-grained interiors form ridges with the Intervening flow tops and conglomerates In parallel depressions or in valleys. It is possible that several large deposits underlie these low areas.

Copper Range Company has conducted geochemical soil surveys and geobotanical surveys on the volcanic rocks over areas known to be mineralized and have confirmed the presence of copper in the underlying bedrock. Several geochemical anomalies were outlined in covered areas where no previous deposits were known except for visible traces of copper (which is almost ubiquitous) in nearby outcrops. It is difficult to evaluate the magnetitude of the anomalies in the drift covered areas because of the variable depth to bedrock and the fact that downslope movement of copper solutions would tend to collect in these areas.

Conventional geophysical methods which have proven to be successful in outlining sulfide mineralization cannot clearly delimit native copper mineralization. Recent refinements such as VLF-EM have also proven to be disappointing.

It is clear that the area still warrants considerable exploration. At present, the economic incentives to conduct a rigorous, long range exploration program have been dampened by low copper prices which resulted in closure of all the native copper producing mines, and a 60% cutback in the mining rate at White Pine. Nevertheless, the Copper Range Company has reinitiated an exploration program of its mineral holdings which could last for a period of 5 years.

Bodwell (1972) has investigated the exploration potential of the Portage Lake Lava Series by subdividing the pile into divisions based on the following marker horizons (see Figure 3):

a) Base of lower division - Keweenaw fault.
b) Base of middle division - Kearsarge amygdaloid.
c) Base of upper division - Pewabic West conglomerate to Sec. 3, T 57 N, R 32 W, four miles north of Mohawk where unit pinches out. From there to Keweenaw Point, Ashbed amygdaloid.
d) Top of upper division - lower contact of Copper Harbor conglomerate.

The data presented in Table 10 are from Bodwell (op. cit., Table 5, p. 23), and serves as a basis for his discussion of the past exploratory drilling efforts. His discussion (p. 26-27) is presented below:

> *"….. it can be seen that the highly productive middle division has received substantial exploration effort (40.7%) for the area north of Portage Lake. South of Portage Lake, the middle division has received considerably less attention, while the lower division has been more extensively explored. This reflects the empirical result of early discoveries of ore deposits in the lower division.*
>
> *Portage Lake marks a break in the predominant stratigraphic position of ore deposits within the Portage Lake Lava Series. North of Portage Lake, 99% of production from the entire Portage Lake Series came from the middle division, whereas south of Portage Lake, 95% of all production came from the lower division.*
>
> *Probably the most attractive opportunities for additional exploration lie in the lower division. It constitutes about 48% of the total section of which about 15-20% has been explored according to the above criteria. The middle division has not been extensively explored south of Portage Lake, but it thins rapidly and becomes progressibely more difficult to define westward. The upper division shows 11% explored ground from Keweenaw Point to Norwich Exploration.*
>
> *West of Norwich Exploration, no significant production has been recorded, although there are some old shafts and surface explorations. The character of the total section changes considerably westward from this point. The succession of predominantly basaltic lava flows (Portage Lake Series) continues southwesterly into Wisconsin. However, stratigraphically above these the succession changes to flows of predominantly andesitic composition with substantail sections of included felsitic flows and intrusives. In recent mapping (Johnson and White, 1969) the U.S. Geological Survey has separated this higher series as a distinct formation, tentatively referred to as "unnamed formation."*
>
> *The lavas west of Norwich resemble those of the principal district and copper occurs in similar manner. There is no obvious reason to believe that the lavas are any less favorable host rocks in this section than elsewhere. About 170 square miles of the lava series has been only superficially explored and there is recorded diamond drilling only at the Onondaga Exploration."*

The controversy of whether the native copper was concentrated in the area of the principal mining district or whether it is a regional phenomenon within the volcanic conglomerate pile has not been settled. Bodwell (1972, op. cit.) notes that approximately 80% of the ground between Keweenaw Point to the Norwich section are so far unexplored if mineralization is considered to be of regional extent. If, however, the mineralization is limited to the area which has produced 96% of native copper production, 67% of that area remains untested and the likelyhood of finding a large deposit, such as the Kearsarge Amygdaloid, are considerably reduced.

The basement rocks, the greenstone volcanic sequences which lie to the south and east of the Keweenaw Peninsula are potential hosts for massive sulfides. This area will probably be receiving more attention since the recent discovery of large amounts of sulfide mineralization near Crandon, Wisconsin.

TABLE 10

EXPLORATION DIAMOND DRILL HOLE DATA, PORTAGE LAKE LAVA SERIES

| | Segment of Portage Lake Lava Series | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Keweenaw Point to Portage Lake | | | Portage Lake to Norwich Expl. | | | Total-Keweenaw Pt. to Norwich Expl. | | | Norwich to Wisc. | Totals Portage Lake Series |
| Surface area, sq. miles | 33.6 | 89.8 | 92.3 | 24.1 | 34.4 | 72.7 | 57.7 | 124.2 | 165.0 | 170.0 | 517.0 |
| Area drilled, sq. miles | 5.3 | 36.5 | 10.6 | 1.3 | 2.8 | 17.1 | 6.6 | 39.2 | 27.7 | negli-gible | 73.4 |
| % of area drilled | 15.6 | 40.7 | 11.5 | 5.4 | 8.0 | 23.5 | 11.3 | 31.6 | 16.8 | " | 14.2 |

From Bodwell, 1972

[TABLE 10: Exploration Diamond Drill Data]

## Reopening of Existing Mines and New Deposits

The existing mining technology and beneficiation techniques cannot be used to exploit the copper resources at present copper prices unless the deposits are selectively "Highgraded". The Presque Isle deposit in the Nonesuch Formation awaits the development of a suitable mining method because of the caving problems encountered in a test mining venture. The Caledonia project has not been considered because of the suppressed copper price. The reserves in the Kearsarge amygdaloid, a six mile long interconnected network of crosscuts, drifts, and shafts, require the removal and the ecologically acceptable disposal of several billions of gallons of calcium chloride rich water before an equally expensive rehabilitation of the mines could reach the ore, proven at the time of closure, and to develop new ore. This essentially summarizes a somewhat bleak picture.

The aformentioned factors have not deterred a more or less continuous effort of research sponsored by Federal agencies or by the mining companies.

Most recently, a promising contribution to the extractive technology of native copper was reported on by Karkkainen (1977). The investigation dealt with a pilot sorting maching whereby crushed copper ore is sorted from barren rock by means of a voltage differential which activates a seperatory mechanism. Although the present design has a low throughput, and economic analysis (assuming a greater capacity) shows that sorting could greatly reduce the costs of copper production. For example, his calculations show for certain cases that sorting could reduce the break even price by approximately $0.05/lb. Furthermore, the reduction in price required to produce an acceptable 15% return on investment after taxes would be approximately $0.15/lb.

## SUMMARY

Based on data available for this investigation the Michigan copper resource is estimated to 19.5 billion pounds of copper, of this total 12.9 billion pounds are from Gogebic, Ontonagon, Houghton, and Keweenaw Counties in Michigan's Keweenaw Peninsula mining district. The remaining resource is from Marquette County. Of this total, most of the reserves are within the Nonesuch Formation. This does not necessarily reflect the true distribution of copper; it simply reflects the relative ease of estimating reserves within the Nonesuch lode as compared to the native copper lodes. The 1 billion pounds of copper estimated for these lodes is considered conservative.

It is unlikely that the native copper production would ever approach the production levels of bygone years. Nevertheless, the existing properties such as the Kingston mine, portions of the Kearsarge and Osceola amygdaloid mines, the Champion mine at Painesdale, the Caledonia property, and possibly the Quincy mine could provide a modest amount of copper to the domestic requirements with production rates of 500 to 2,000 TPD per 260 day year. Without new discoveries most of these native copper mine resources would be depleted within 5 years; some could remain in production up to 20 years.

Should the present technological and economic environment improve the existing native copper mines which are deemed re-habitable would require a common mill and smelter facility to be reconstructed. The mill should have a capacity of 10,000 TPD in the eventuality that at least five or six mines would be brought on line. At current prices, the facility would cost approximately 50 million dollars. Smelter costs may be avoided if the ore could be shipped to White Pine's smelter.

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# APPENDIX A

## [Mine Production Tables by Year]

### [Allouez Conglomerate]

ALLOUEZ CONGLOMERATE

| | Allouez |
|---|---|
| 1925-1954 | No production |
| 55 | 31,207 |
| 56 | 115,109 |
| 57 | 222,508 |
| 58 | -- |
| 59 | 137,327 |
| 1960 | 283,156 |
| 61 | 313,554 |
| 62 | 792,493 |
| 63 | 657,614 |
| 64 | 32,583 |
| 65 | -- |
| 66 | 32,166 |
| 67 | 170,694 |
| 68 | -- |

TOTAL = 2,788,411 pounds

### [Baltic Lode]

BALTIC LODE

| | Baltic | Champion | Trimountain |
|---|---|---|---|
| 1926 | 3,690,041 | 17,658,820 | 2,177,416 |
| 27 | 4,207,819 | 16,098,926 | 2,354,808 |
| 28 | 3,415,082 | 19,563,535 | 1,275,515 |
| 29 | 2,127,926 | 20,660,701 | 1,408,589 |
| 1930 | 3,251,705 | 19,999,564 | 542,649 |
| 31 | 3,311,727 | 14,409,543 | - |
| 32 | | 12,188,578 | |
| 33 | | 12,167,130 | |
| 34 | | 13,929,859 | |
| 35 | | 16,759,889 | |
| 36 | | 17,486,019 | |
| 37 | | 15,790,600 | |
| 38 | | 18,010,937 | |
| 39 | | 17,856,237 | |
| 1940 | | 18,207,973 | |
| 41 | | 15,948,202 | |
| 42 | | 17,772,116 | |
| 43 | | 16,886,013 | |
| 44 | | 13,989,318 | |
| 45 | | 6,912,669 | |
| 46 | | 60,482 | |
| 47 | | 945,264 | |
| 48 | | 1,885,603 | |
| 49 | | 2,306,993 | |
| 1950 | | 2,999,095 | |
| 51 | | 1,748,563 | |
| 52 | | 2,630,204 | |
| 53 | | 4,365,077 | |
| 54 | | 4,157,588 | |
| 55 | | 4,295,585 | |
| 56 | | 4,435,469 | |
| 57 | | 4,222,936 | |
| 58 | | 2,951,192 | |
| 59 | | 2,414,141 | |
| 1960 | | 2,369,843 | |
| 61 | | 2,573,688 | |
| 62 | | 4,917,903 | |
| 63 | | 3,700,767 | |
| 64 | | 2,078m880 | |
| 65 | | 1,950,979 | |
| 66 | | 2,005,928 | |
| 67 | | 2,919,542 | |
| 68 | | | |
| | 20,004,300 | 384,176,397 | 7,759,077 |

TOTAL = 411,939,774 pounds

## [Calumet and Hecla Conglomerate]

CALUMET AND HECLA CONGLOMERATE

| | C & H | Centennial 3-6 |
|---|---|---|
| 1926 | 26,422,924 | |
| 27 | 28,226,000 | |
| 28 | 34,933,000 | |
| 29 | 35,377,000 | |
| 1930 | 40,982,000 | |
| 31 | 40,349,000 | |
| 32 | 27,861,000 | |
| 33 | 34,686,000 | |
| 34 | 34,286,000 | |
| 35 | 38,230,000 | |
| 36 | 34,352,000 | |
| 37 | 28,724,000 | |
| 38 | 29,820,000 | |
| 39 | 8,436,000 | |
| 1956 | | 2,995 |
| 57 | | 428,289 |
| 58 | | 844,174 |
| 59 | 470,329 | 533,519 |
| 1960 | 2,393,761 | 232,366 |
| 61 | 2,008,248 | 1,114,436 |
| 62 | 1,609,577 | 2,029,074 |
| 63 | 169,354 | 1,064,709 |
| 64 | -- | 162,654 |
| 65 | | 543,801 |
| 66 | | 782,853 |
| 67 | | 6,072,936 |
| 68 | | 5,390,875 |
| 75 | | 1,455,657 |
| 76 | | 3,886,218 |
| | 449,336,193 | 24,524,556 |

TOTAL = 473,860,749 pounds

## [Houghton-Iroquois Lodes]

HOUGHTON-IROQUOIS LODES

| | Allouez #3 | Iroquois |
|---|---|---|
| 1943 | 43,167 | 596,220 |
| 44 | 672,480 | 1,387,386 |
| 45 | 1,700,058 | 1,882,375 |
| 46 | 1,593,748 | 2,074,866 |
| 47 | 2,271,963 | 3,399,829 |
| 48 | 2,762,721 | 3,989,673 |
| 49 | 1,959,516 | 2,736,241 |
| 1950 | 3,080,115 | 4,023,452 |
| 51 | 2,417,174 | 3,870,396 |
| 52 | 2,861,589 | 3,441,272 |
| 53 | 2,898,133 | 4,390,572 |
| 54 | 2,618,501 | 3,742,502 |
| 55 | 1,868,069 | 2,394,916 |
| 56 | 2,399,419 | 3,196,693 |
| 57 | 2,082,953 | 1,933,033 |
| 58 | 2,064,185 | -- |
| 59 | 1,701,499 | 2,341 |
| 1960 | 1,721,918 | -- |
| 61 | 2,093,656 | |
| 62 | 1,700,517 | |
| 63 | 1,357,024 | |
| 64 | 214,547 | |
| 65 | 176,595 | |
| 66 | 675,438 | |
| 67 | 25,668 | |
| 68 | -- | |
| | 42,960,653 | 43,061,767 |

TOTAL = 86,022,420 Pounds

## [Kearsarge Lode]

KEARSARGE LODE

| | Ahmeek | Peninsula | Centennial | Douglass |
|---|---|---|---|---|
| 1926 | 35,284,000 | | | |
| 27 | 34,065,000 | | | |
| 28 | 37,231,000 | | | |
| 29 | 35,105,000 | | | |
| 1930 | 26,538,000 | | 1,900,000 | |
| 31 | 22,656,000 | | 2,950,000 | |
| 32 | 4,493,000 | | | |
| 33 | - | | | |
| 34 | - | | | |
| 35 | - | | | |
| 36 | 24,963,000 | | | |
| 37 | 25,022,600 | | | |
| 38 | 18,680,000 | | | |
| 39 | 20,479,000 | 543,000 | | |
| 1940 | 20,728,000 | 4,342,000 | | |
| 41 | 22,624,000 | 5,466,000 | | 580,000 |
| 42 | 15,948,292 | 4,908,125 | | 3,025,041 |
| 43 | 10,423,493 | 8,971,344 | | 5,090,150 |
| 44 | 12,630,348 | 9,872,217 | 3,176,258 | 1,566,239 |
| 45 | 5,423,722 | 6,360,643 | 5,146,617 | 2,738,541 |
| 46 | 2,122,259 | 4,512,473 | 5,009,413 | 4,518,126 |
| 47 | 2,791,315 | 4,528,737 | 5,627,680 | 4,110,942 |
| 48 | 2,400,231 | 5,306,886 | 5,068,224 | 4,832,466 |
| 49 | 1,393,535 | 3,093,260 | 3,577,711 | 3,638,998 |
| 1950 | 1,860,736 | 5,136,542 | 5,064,016 | 5,636,550 |
| 51 | 2,786,045 | 5,482,068 | 5,084,991 | 5,239,702 |
| 52 | 3,040,769 | 3,354,506 | 4,146,325 | 4,385,906 |
| 53 | 3,483,122 | 4,383,893 | 5,032,781 | 3,736,428 |
| 54 | 3,644,218 | 4,121,025 | 5,359,756 | 1,928,040 |
| 55 | 3,320,933 | 3,548,250 | 3,210,369 | 220,819 |
| 56 | 7,349,964 | 4,156,327 | 5,364.729 | 209,093 |
| 57 | 6,291,661 | 3,889,457 | 5,812,445 | 276,903 |
| 58 | 7,536,106 | 4,621,008 | 7,072,543 | 659,394 |
| 59 | 7,128,893 | 4,318,680 | 8,400,947 | |
| 1960 | 3,557,018 | 3,739,851 | 8,217,138 | |
| 61 | 2,212,953 | 4,232,563 | 6,247,634 | |
| 62 | - | 3,687,697 | 6,811,340 | |
| 63 | | 3,824,980 | 5,602,033 | |
| 64 | | 2,890,409 | 5,609,982 | |
| 65 | | 859,281 | 3,466,309 | |
| 66 | | - | 2,862,298 | |
| 67 | | | 725,089 | |
| 68 | | | - | |
| | 433,234,213 | 120,050,222 | 127,546,618 | 52,393,311 |

TOTAL = 1,065,687,902 pounds

KEARSARGE LODE (continued)

| | Mohawk | North Kearsarge | Seneca |
|---|---|---|---|
| 1926 | 18,340,712 | 2,064,000 | 4,981,524 |
| 27 | 22,124,830 | 1,400,000 | 2,881,382 |
| 28 | 21,243,265 | 826,000 | - |
| 29 | 20,043,265 | 1,600,000 | 2,999,882 |
| 1930 | 13,306,762 | 2,427,000 | 4,857,895 |
| 31 | 13,100,000 | 1,260,000 | |
| 32 | 8,450,388 | | |
| 1932-1941 | NO PRODUCTION | | |
| 1942 | | 4,255,503 | |
| 43 | | 7,731,503 | |
| 44 | | 7,061,874 | |
| 45 | | 4,732,440 | |
| 46 | | 4,501,521 | |
| 47 | | 4,478,937 | |
| 48 | | 4,676,707 | 4,275,405 |
| 49 | | 3,283,163 | 4,608,597 |
| 1950 | | 4,280,069 | 7,762,538 |
| 51 | | 3,820,827 | 8,128,994 |
| 52 | | 3,035,618 | 6,437,911 |
| 53 | | 3,356,535 | 8,437,187 |
| 54 | | 3,809,179 | 7,840,330 |
| 55 | | 2,385,674 | 6,113,436 |
| 56 | | 307,535 | 7,587,311 |
| 57 | | | 8,131,404 |
| 58 | | | 9,006,237 |
| 59 | | | 9,032,436 |
| 1960 | | | 8,718,754 |
| 61 | | | 8,412,595 |
| 62 | | | 6,469,719 |
| 63 | | | 6,005,883 |
| 64 | | | 5,463,463 |
| 65 | | | 3,409,064 |
| 66 | | | 1,587,631 |
| 67 | | | - |
| 68 | | | |
| | 116,802,708 | 11,294,085 | 143,149,578 |

TOTAL = 1,065,687,902 pounds

## [Osceola Lode]

OSCEOLA LODE

| | Osceola | Osceola #13 | Osceola #6 |
|---|---|---|---|
| 1926 | 9,527,000 | | |
| 27 | 16,362,000 | | |
| 28 | 18,318,000 | | |
| 29 | 18,237,000 | | |
| 1930 | 16,051,000 | | |
| 31 | 5,152,000 | | |
| 1954 | | 45,762 | |
| 55 | | 457,593 | |
| 56 | | 2,249,247 | 14,943 |
| 57 | | 2,197,687 | 95,875 |
| 58 | | -- | 376,714 |
| 59 | | 5,379 | -- |
| 1960 | | 262,797 | -- |
| 61 | | 860,843 | -- |
| 62 | | 2,316,648 | -- |
| 63 | | 3,735,040 | -- |
| 64 | | 4,169,837 | -- |
| 65 | | 3,534,433 | 175,352 |
| 66 | | 5,135,499 | 113,336 |
| 67 | | 3,662,063 | 263,746 |
| 68 | | 1,198,180 | -- |
| | 83,637,000 | 29,831,008 | 1,039,966 |

TOTAL = 114,507,974 pounds

## [Pewabic Lode]

PEWABIC LODE

| | Quincy | Quincy Reclamation |
|---|---|---|
| 1926 | 13,290,052 | |
| 27 | 9,718,662 | |
| 28 | 1,220,536 | |
| 29 | 4,459,426 | |
| 1930 | 10,939,787 | |
| 31 | 7,575,367 | |
| 32 | -- | |
| 33 | -- | |
| 34 | -- | |
| 35 | -- | |
| 36 | -- | |
| 37 | 4,224,528 | |
| 38 | 8,426,054 | |
| 39 | 8,852,856 | |
| 1940 | 8,999,635 | |
| 41 | 8,032,175 | |
| 42 | 7,683,600 | |
| 43 | 6,544,621 | |
| 44 | 6,846,772 | 5,581,745 |
| 45 | 2,956,470 | 6,066,700 |
| 46 | CLOSED | 5,052,519 |
| 47 | | 4,750,895 |
| 48 | | 3,468,825 |
| 49 | | 4,621,896 |
| 1950 | | 5,946,545 |
| 51 | | 4,724,495 |
| 52 | | 5,549,064 |
| 53 | | 4,498,462 |
| 54 | | 4,272,144 |
| 55 | | 5,317,103 |
| 56 | | 4,760,000 |
| 57 | | 4,364,900 |
| 58 | | 780,640 |
| 59 | | 4,042,545 |
| 1960 | | 3,351,208 |
| 61 | | 3,486,265 |
| 62 | | 2,478,858 |
| 63 | | 3,840,510 |
| 64 | | 3,837,407 |
| 65 | | 2,320,273 |
| 66 | | 3,093,606 |
| 67 | | 336,707 |
| | 109,790,541 | 96,635,312 |

| | Baltic Lode Sands | Atlantic Lode Sands |
|---|---|---|
| 1937 | 340,677 | |
| 38 | 55,954 | |
| 39 | 253,172 | |
| 1940 | 661,727 | |
| 41 | 729,102 | |
| 42 | 669,491 | |
| 43 | 571,674 | |
| 44 | 554,909 | |
| 45 | 209,305 | |
| 46 | 2,741 | |
| 47 | 338,390 | |
| 48 | -- | |
| 49 | | |
| 1950 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | 571,935 | |
| 57 | 1,701,824 | |
| 58 | 1,572,392 | |
| 59 | 216,239 | |
| 1960 | 2,086,398 | |
| 61 | 1,226,081 | |
| 62 | 1,217,664 | |
| 63 | 591,680 | 1,525,454 |
| 64 | 487,158 | 941,408 |
| 65 | | 1,417,146 |
| 66 | | 1,008,215 |
| 67 | | 1,224,496 |
| | 16,002,772 | 6,116,719 |

| | Lake Linden Reclamation | Tamarack Reclamation (C & H) |
|---|---|---|
| | (121,007,924) | (6,679,000) |
| 1926 | 22,970,076 | 8,018,000 |
| 27 | 20,192,000 | 8,525,000 |
| 28 | 22,437,000 | 7,459,000 |
| 29 | 25,991,000 | 7,520,000 |
| 1930 | 11,965,000 | 5,877,000 |
| 31 | | |
| 32 | | |
| 33 | | |
| 34 | | |
| 35 | 9,118,000 | |
| 36 | 19,167,000 | |
| 37 | 15,210,000 | 5,188,000 |
| 38 | 11,175,000 | 5,444,000 |
| 39 | 16,865,000 | 6,535,000 |
| 1940 | 22,488,000 | 7,194,000 |
| 41 | 24,647,000 | 8,119,000 |
| 42 | 20,672,454 | 10,078,562 |
| 43 | 18,577,234 | 10,232,727 |
| 44 | 11,400,419 | 3,337,744 |
| 45 | 6,981,339 | 3,279,833 |
| 46 | 4,269,473 | 2,986,012 |
| 47 | 3,846,636 | 3,239,039 |
| 48 | 7,217,728 | 3,268,976 |
| 49 | 3,697,944 | 2,599,736 |
| 1950 | 2,552,998 | 3,669,372 |
| 51 | 2,479,331 | 2,921,021 |
| 52 | 1,457,486 | 2,393,936 |
| 53 | | 2,890,980 |
| 54 | | 2,280,126 |
| 55 | | 1,820,255 |
| 56 | | 3,692,993 |
| 57 | | 2,855,090 |
| 58 | | 2,819,375 |
| 59 | | 2,651,447 |
| 1960 | | 2,576,069 |
| 61 | | 2,658,215 |
| 62 | | 2,459,020 |
| 63 | | 2,432,115 |
| 64 | | 2,530,911 |
| 65 | | 1,971,964 |
| 66 | | 2,319,957 |
| 67 | | 1,451,252 |
| | 305,378,118 | 155,295,727 |

# APPENDIX B

## [Plate 2-5:  Geological Maps - Isle Royal to Seneca]

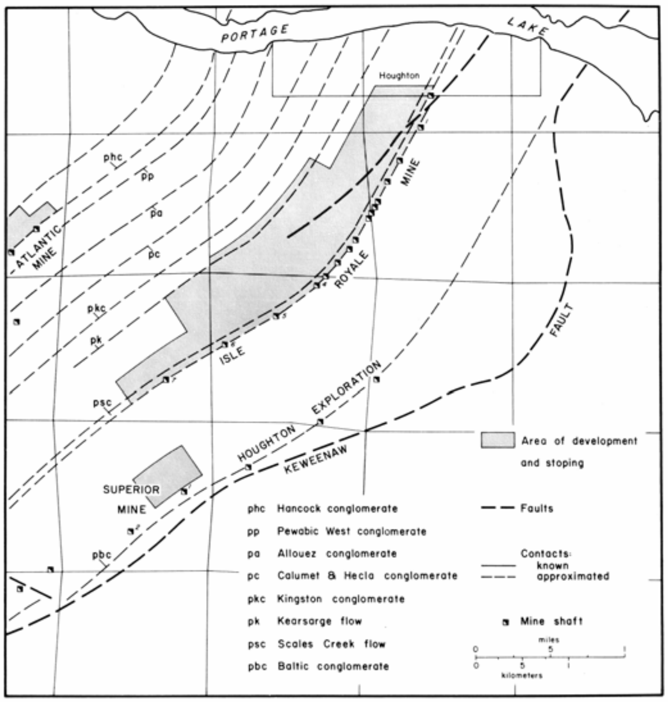


Plate 2

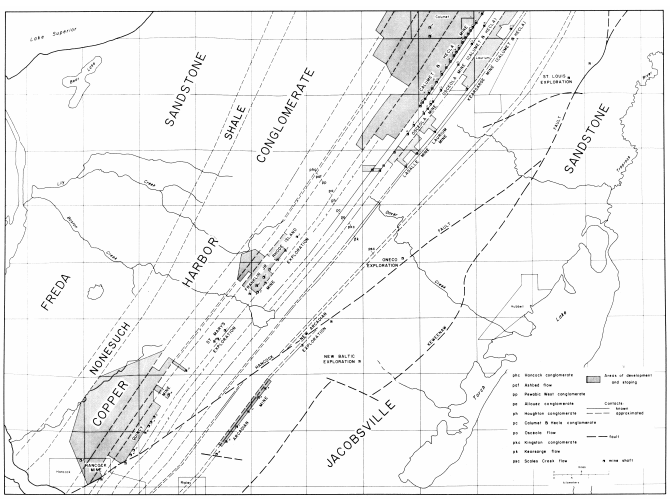


Plate 3

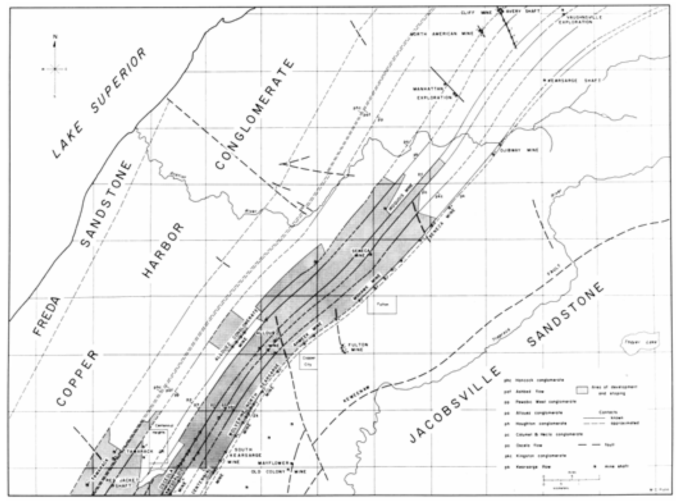


Plate 4

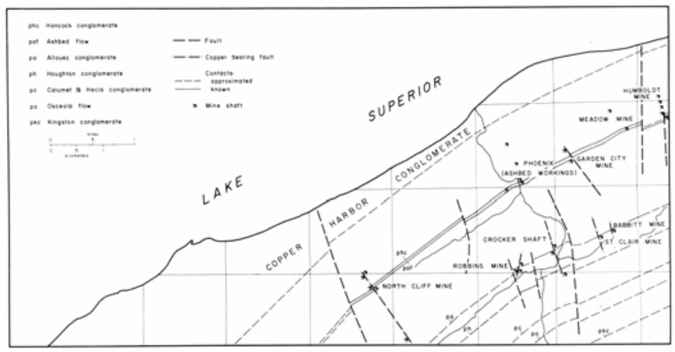


Plate 5

# APPENDIX C

## MINING METHODS

The mining method used in the native copper mines was more or less uniform throughout the district. In general, tonnages were obtained from development down the dip of the lode. The shafts usually followed the lode down dip, in some cases within the mineable horizon. Calumet and Hecla Mining Company used a retreat open-stope mining method which proved quite satisfactory.

Levels which did not connect with the shafts directly were, in some cases, connected by crosscuts which served as skip compartments. These skip loading pockets were installed at alternate levels and connected to the levels above by a storage raise. Alternatively, ore was drawn directly to the skips in areas where pocket loading was impractical.

Usually the lode was mined by stoping to the level above. As stoping proceeded a sufficient number of round pillars were left in the stope to support the hanging wall.

The room-and-pillar method is practiced almost exclusively at White Pine. This mining method would not be satisfactory at the Presque Isle (Western) Syncline deposit because of roof caving problems. Possibly a modification of a longwall mining method could be developed which would allow the economic exploitation of the deposit.