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HYDROLOGY OF SOME DEEP MINES IN PRECAMBRIAN ROCKS

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Hydrology of Some Deep Mines

In

Precambrian Rocks

D. H. Yardley, Oct. 1975

Introduction

A number of underground mines were investigated during the summer of 1975. All of them are in Precambrian rocks of the Lake Superior region. They represent a variety of geologic settings.

The purpose of the investigations was to make a preliminary study of the dryness, or lack of dryness of these rocks at depth. In other words, to see if water was entering the deeper workings through the unmined rock by some means such as fracture or fault zones, joints or permeable zones. Water entering through old mine workings extending to, or very near to the surface, or from the drilling equipment, was of interest only insofar as it might mask any water whose source was through the hanging or footwall rocks.

It soon became apparent that mine pumping records were of little value except to indicate a relationship to surface rainfall entering via old mine openings.

It also became clear that in the regular geologic mine mapping, water-seeps are generally not recorded unless they are of many gallons per minute or were noted as evidence of a fracture zone being mapped. A major reason is that the amount of water encountered in the deep mine workings is so minute, or non-existent, that trying to note it on plans and sections serves no purpose for the mine operators.

While at the mines, access was provided to the engineering and geology offices where various maps and sections were made available for inspection and discussion. A number of the geologists and mining engineers have worked at other mines in Precambrian rocks. Their general concensus is that deep mines are dry.

A number of phone and personal conversations with various geologists and engineers about other deep mines confirm, that, at depth they are dry.

The courtesy and hospitality extended by the staffs at the various mines should be acknowledged. Without exception, geologists and mining engineers guided us through the deep workings, showed us the appropriate maps and freely discussed the hydrology of their operations.

Each mine property visited is reported upon individually and the general conclusions are based upon those mining properties.

General Conclusions

No evidence of running, seeping or moving water was seen or reported to us at depths exceeding 3,000 feet.

At depths of 3,000 feet or less, water seepages do occur in some of the mines, usually in minor quantities but increased amounts occur as depth becomes less. Others are dry at 2,000 feet of depth.

Rock movements associated with extensive mining should increase the local secondary permeability of the rocks adjoining the mined out zones. Also most ore bodies are located where there has been a more than average amount of faulting, fracturing, and folding during the geologic past. They tend to cluster along crustal flows.

In general, Precambrian rocks of similar geology, to those seen, well away from zones that have been disturbed by extensive deep mining, and well away from the zones of more intense geologic activity ought to be even less permeable than their equivalents in a mining district.

Homestake Copper, Centennial Mine

Location

The operations of Homestake copper are located in the Upper Peninsula of Michigan about twelve miles north of Hancock Michigan. (Fig. 1)

General Statement

The ore zone is in the relatively thin Calumet conglomerate that contains native copper. The conglomerate overlies a basalt flow and is overlain by a younger basalt flow. The general geology is outlined in the attached excerpts. (1)

Homestake is deepening the old Centennial No. 6 inclined shaft and is mining about 500 tons per day to supply a new 550 ton per day pilot mill. In September the shaft bottom was at the 6,400 level (inclined at - 38°), a vertical depth of 3,940 feet.

There is no water entering the shaft at that depth. The rocks are dry. The shaft miners stated that no water occurs and this was corroborated by the resident geologist.

A tunnel has been driven north on the 3,600 level, a vertical depth of 2,216 feet, for over 1,000 feet along the strike of the conglomerate. Part way along it a cross-cut extends west for about 1,000 feet through the volcanic flows of the hanging wall zone.

There is a minor water seep entering at one place in the unventilated hanging wall cross-cut. This was measured at one drop per second. There are some damp places along the tunnel in the conglomerate ore zone. The dust on the conglomerate is damp and so has a different shade of color than the dry dust on the basalt flow rocks above and below it. In some instances

(1) Recent developments in the Native-Copper district of Michigan. R. J. Weege, J. P. Pollock and the Calumet Division Geological Staff.

this color difference clearly defines the conglomerate layer. This indicates that there is some permeability in the conglomerate.

At the intersection of the strike-tunnel and the shaft, some water drips into the shaft. It amounted to ten drops ($\frac{1}{2}$ milliliter) per second. This represents the drainage from more than 2500 feet of tunnel. No doubt some evaporation had occurred.

At one point on the 3,600 level, old mine workings exist about 200 feet from one of Homestake Copper's tunnels. It was reported that a hole was drilled to it, and the water pressure in the old workings measured. This pressure exceeded 1,000 psi and was equal to the pressure calculated from the known water depth. The old mine workings extend to surface (Fig. 6). There is no evidence of any water permeating along the conglomerate lode from the old mining area to the now Homestake tunnel.

U. S. G. S. Prof. paper No. 144, 1929 (2) briefly refers to water in the mines in this region. "There is, moreover, good reason to believe that in the deep levels, where the rocks are essentially dry, both calcium and sodium chlorides are present as solids.", p. 123.

"Specimens from deep levels, essentially dry when collected,--", p. 123.

"Gravity circulation of solution is regarded as the transporting agent in the theory of descending origin. Doubt is thrown on the sufficiency of that method by the very slow rate of gravity circulation as indicated by the dryness of the deep levels of the mines." , p. 141.

"Moreover, the deeper levels of all the mines are essentially dry. Pockets of water encountered on these levels quickly drain off and remain dry. Some deep drill holes, however, maintain a small flow of water for considerable periods at least, and in the Baltic and other mines the water is under some pressure. The region is one of moderate precipitation, and

(2) The Copper Deposits of Michigan.

the upper levels of the mines contain abundant water. The failure of the surface water to sink through the lodes to the deep openings indicates that the ordinary gravity circulation to great depth is very slight. This conclusion of course, corresponds with the general experience of other districts.", p. 121.

It should be noted that the ore bearing zones are in conglomerate, fragmental and coalescing amygdaloids, and in sandstone which however carries ore only near fissures (2, p.119). Hence the rocks that were mineralized are considered to have been relatively permeable, originally.

"- - - bore the same relation to the surface then existing that the present deep "dry" zone bears to the surface of to-day.", p. 123.

Perhaps the most noteworthy quote is "Except in the upper levels, where water is plentiful, the mines are strikingly dry." - - - "Away from the shafts the workings are dusty, and water has to be piped from the surface for use in the Leyner drills; otherwise the air of the stopes would be filled with dust. Occasional drops accumulate on the roofs of drifts, but rarely is there enough water to drip. Even in newly opened ground only a little water is encountered, and that quickly drains out", p. 100.

A rock temperature reported at 4,900 feet is 86.2°F. (Kearserge Lode) Temperature gradients are 1°F to every 117.4 feet from 60 to 5,637 feet.

Keweenawan lava flows underlie many hundreds of square miles extending from Michigan down through Wisconsin into Pine County in Minnesota. Known economic copper deposits occur only in the upper Peninsula area of Michigan. They appear to have good potential for dry underground storage areas.

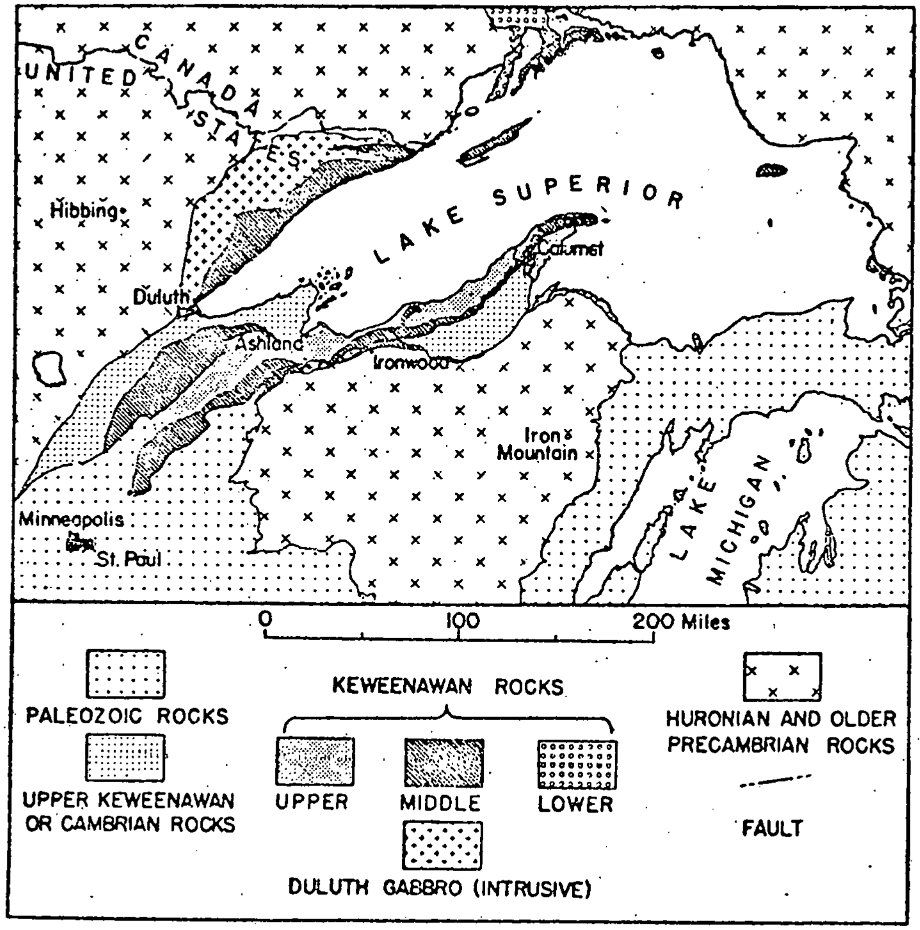

Fig. I - Generalized geologic map of the Lake Superior region. Modified after Leith, Lund, and Leith (1935, pl. I)

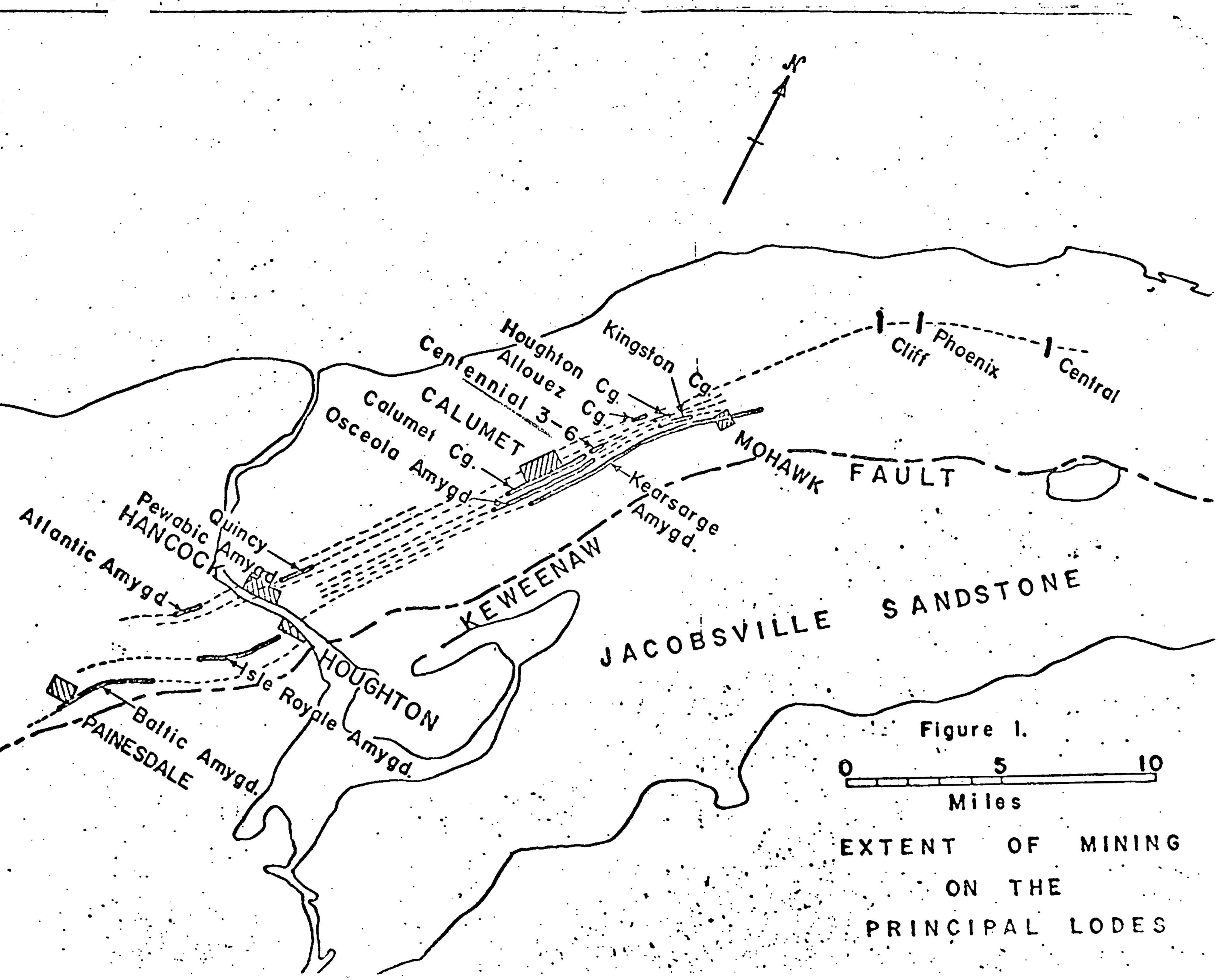

Figure I.

EXTENT OF MINING ON THE PRINCIPAL LODES

District Production

The first mine to produce significant quantities of copper was the Cliff mine, which started operations on the Cliff fissure in 1845. This led to the development of several other fissure mines in Keweenaw County, and eventually to the first mine in a stratiform deposit, the Isle Royale Amygdaloid, in 1852. Mining operations on the Calumet and Hecla Conglomerate started in 1865, and by the latter part of the 19th century, most of the major ore deposits in the district were producing.

Total production from the district amounts to 11.0 billion pounds, which gives the district a high rank among the world's copper producers. Table 1 shows the district production by lode.

The Ore Deposits

Host Rocks.--The native-copper district lies wholly within the band of rocks referred to as the Portage Lake Lava Series, on the south limb of the Lake Superior syncline. The beds strike parallel to the Keweenaw Peninsula and dip between 20 and 75 degrees toward Lake Superior. The base of the lava series is not exposed; within the native-copper district, its minimum thickness ranges from 9,000 to 15,000 feet.

The Portage Lake Lava Series consists of interbedded lava flows and subordinate sediments. The flows range in composition from mafic to felsic, but basalts are by far the most common, andesitic types second in abundance, and rhyolites the least common. The thickness of individual flows or flow units varies from less than a foot to a maximum of 1,600 feet for the Greenstone Flow in Keweenaw County. Laterally, many of the flows are known to extend for tens of miles. The Kearsarge Flow, for example, can be traced with certainty for 40 miles, and Lane (1911) has convincingly correlated some of the flows in Isle Royale with those on the Keweenaw Peninsula, a distance of more than 50 miles.

Most of the sedimentary layers in the series are conglomeratic, although shales and sandstones are common in parts of the section. In composition, the conglomerates and sandstones are rhyolitic, with quartz and feldspar phenocrysts common in the pebbles. There are over 200 flows and 20-odd conglomerates in the series.

The predominant ore deposits are manto or blanket types found both in the amygdaloidal tops of lava flows and in conglomerate beds; both types of occurrence are locally referred to as "lodes." The economically less important fissure deposits commonly crosscut the bedding nearly at right angles, and may have as wall rock any type of rock that occurs in the lava series. The lode deposits in amygdaloids account for 58.5 percent, the conglomerates for 39.5 percent, and fissures for 2 percent of the total district production.

Three general varieties of flow top are recognized in the district, and one is much more likely to contain ore deposits than the others. The commonest type is known locally as a "cellular" top; it has a relatively smooth upper surface, and the degree of original vesicularity decreases downward from this surface. Although cellular amygdaloid may commonly have traces of copper, no ore deposits are found in flow tops that are persistently of this type. A few smooth-topped flows were apparently more gassy than average, and in these there is a tendency for the amygdules to be laterally interconnected, forming what is locally called a "coalescing cellular amygdaloid." This latter type of amygdaloid is an important host rock for ore only at the Quincy mine.

About 20 percent of the flow tops consist of a rubble of fragments of more or less amygdaloidal lava, apparently formed when flow continued after a crust had begun to form. The interstices between fragments are commonly filled with secondary minerals. Five of the six major amygdaloidal ore bodies are in amygdaloid of the fragmental type, as are parts of the sixth (Quincy mine).

The term "scoriaceous" amygdaloid is used locally for fragmental amygdaloids in which the interstices between fragments ("scoria") are filled with sandy or silty detritus. The Ashbed Amygdaloid, mined both at the Atlantic mine and at various places on the Keweenaw Peninsula, is the only significant example of a cupriferous "scoriaceous" amygdaloid.

Stratigraphic Range of the Ore Deposits.--Figures 4 and 5 of the introductory chapter of this guidebook show the relative positions of the major producing horizons, as well as some of the more important marker beds. Major ore bodies occur in the Baltic, Isle Royale, Kearsarge, Kingston, Osceola, Calumet and Hecla, Houghton, and Pewabic (Quincy mine) lodes, while low-grade deposits are found in the Ashbed (a scoriaceous amygdaloid a little below Hancock (No. 17) Conglomerate), Iroquois, Allouez, and several other minor lodes. It can be readily seen that mineralization occurs throughout the series. It is important to point out, however, that almost 75 percent of the total district production has come from the middle portion (the interval between the Pewabic and Kearsarge Amygdaloids) of the series. There is, therefore, a tendency for the ore to occur near the center of the Portage Lake Lava Series, although major ore bodies occur both very high (White Pine) and very low (Baltic lode mines) in the Michigan copper district as a whole.

Lateral Extent of the District.--The Portage Lake Lava Series crops out in a belt that is at least 160 miles long, yet most of the commercial ore deposits are restricted to a relatively small portion of the belt. Figure 1 shows the extent of mining on the principal lodes in the central part of the area. Over 96 percent of the total district production of 11 billion pounds came from a 28-mile stretch between Painesdale and a few miles northeast of Mohawk. Many of the layers that contain copper deposits within this stretch have been explored without success for miles both north and south of the central mineralized area. There appears to be little or no change, however, in the physical or chemical characteristics of these layers or of the lava series as a whole at the boundaries of the Painesdale-Mohawk area. Outside this area, most of the amygdaloids carry the same gangue minerals and minor amounts of native copper. If mineralogical differences exist, they have yet to be detected. Most of the conglomerates without copper likewise appear to be identical to those that are mineralized except for copper content. While it is true that minor amounts of native copper can almost always be found wherever the Portage Lake Lava Series crops out, it is also evident that most of the commercial-grade mineralization is concentrated in a relatively small area. In this respect, the Michigan native-copper district is similar to districts all over the world and the writers do not believe, as do some others (White, 1968; Stoiber and Davidson, 1959), that the regional occurrence of minor amounts of native copper necessarily rules out the possibility of local rather than regional sources for the copper.

Factors Controlling the Localization of the Ore

All contemporary workers in the district agree that the ore deposits are epigenetic and that the ore-bearing solutions were hydrothermal. Whether the solutions were derived from a crystallizing magma (Butler and Burbank, 1929) or whether they were sweated out in depth during metamorphism (Stoiber and Davidson, 1959; White, 1968) is debatable, but, in either case, they were hot-water solutions.

It can therefore be assumed that the ore bodies in both amygdaloids and conglomerate beds were formed by hot-ascending solutions that were somehow concentrated in certain select areas. Since the lithologic characteristics of the amygdaloids and conglomerates away from the ore bodies are similar to those within the ore bodies, structural, rather than chemical, controls appear to be the main cause for localization of the ore.

The most reasonable explanation for the form of many deposits lies in the barrier hypothesis, originally advanced by Graton, Broderick, and Butler in special reports to the Calumet & Hecla Mining Co. This theory visualizes the ore solutions as traveling up dip along certain amygdaloids and conglomerates with throughgoing permeability (Butler and Burbank, 1929). Inasmuch as the thickness and permeability of a given amygdaloid or conglomerate bed may vary enormously from place to place, flow tended to be concentrated along those pathways that afforded the least resistance to flow from depth to the surface, and tended to avoid relatively impermeable areas, which would thus act as barriers. Solutions were funneled by barriers of various types into the areas that are now mineralized. Figure 2 illustrates two types of barrier causing such funneling, concentration of solutions, and formation of oreshoots. The first type is exemplified by the southwest end of the deposit on the Osceola Amygdaloid lode, where a number of parallel streaks of thin and relatively impermeable amygdaloid, raking westward, appear to have concentrated the flow of copper-bearing solutions in the rocks just down dip from the barrier. The second type is exemplified by the oreshoots of the old Calumet and Hecla Conglomerate mine. In that area, the conglomerate bed thins in each direction along strike, and both the strike length and thickness of the lens increase with depth. The funneling caused by this upward decrease in the horizontal cross section of permeable rock led to the formation of very high grade oreshoots in the upper levels.

Where no major barrier or constriction was present in a thick layer acting as a major channelway, the flow would not be concentrated, and as a result, small amounts of copper could be dispersed through a large volume of rock that would not be rich enough to mine (Broderick, 1931).

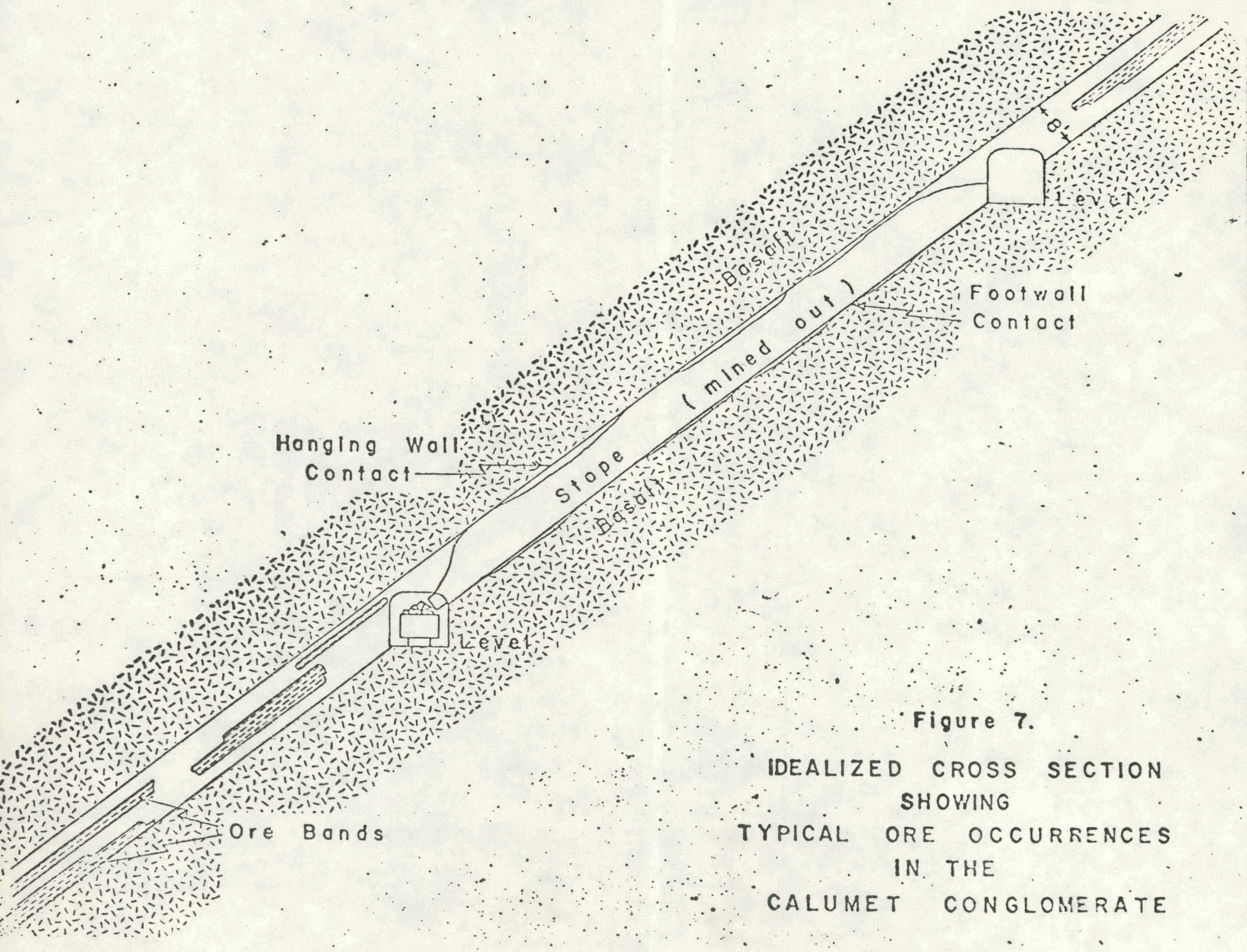

Figure 7.

IDEALIZED CROSS SECTION
SHOWING
TYPICAL ORE OCCURRENCES
IN THE
CALUMET CONGLOMERATE

consequence of the correlation of fine detritus with basins and lack of fine detritus with ridges.

As might be expected from the foregoing, there is also a correlation between grade and stratigraphic distribution of ore and thickness of the Kingston Conglomerate bed. In the northeastern part of the mine, thick, high-grade intermediate ore occurs where the bed is 45 or more feet thick, hanging-wall ore where it is 40 to 50 feet thick, footwall ore where it is 30 to 40 feet thick, and little or no ore where it is less than 30 feet thick.

Localization of the Ore Body.--As was previously mentioned, the Kingston Conglomerate averages about 40 feet thick in the vicinity of the ore deposit. At the southwest end, however, it thins very rapidly to less than 10 feet (fig. 3). Northeast of the pinch-down, the lower portion of the conglomerate consists of pebbles with little interstitial material, while to the southwest, the bed is essentially a siltstone with quartz porphyry pebbles making up only an estimated 25 to 30 percent of the rock. Some of the best ore in the mine is found adjacent to the pinch-down. The ore ends abruptly at the pinch-down (fig. 3), while the eastern edge of the ore body is gradational over several hundred feet.

It is believed that the abrupt thinning of the bed formed an ideal barrier, which being less permeable than ore-bearing lode, effectively deflected and concentrated the ore-bearing solutions east of the pinch-out and is responsible for localizing the ore body and for the streak of high-grade ore near the pinch-out.

Centennial No. 3-6 Ore Body

The Centennial #3-#6 oreshoot is located within the Calumet and Hecla Conglomerate bed approximately 1 mile northeast of the village of Calumet. It lies up dip and northeast of the old Calumet & Hecla mine workings, and represents a lateral extension of that deposit (fig. 5).

The mine was originally explored and test stoped on the upper levels by the Centennial Mining Co. prior to the turn of the century. This original work was disappointing and, while the Centennial #3 shaft was sunk 3,100 feet, no ore was found. Weak mineralization was found on the upper levels, but test stoping proved the ore to be below commercial grade.

In 1956, it was decided to rehabilitate the Centennial #3 shaft as an exploration project. The exploration was based on the hypothesis that the lower-grade mineralization near the surface represented leakages from below and that the deposit would increase in grade with depth and ultimately connect with the higher grade ore that was known to occur in the old workings.

Accordingly, the shaft was unwatered and drifts were driven on the 9th, 11th, 17th, and 31st levels. An oreshoot was intersected on all these levels that progressively increased in grade from 17 pounds per ton on the 9th level to 28 pounds per ton on the 31st level. The strike length of the mineralization also increased with depth (fig. 6, oreshoot "A"). At this point, the company decided to develop the mine for a production operation. Striking increases in grade continued with depth, and the present bottom level (36 level) is the richest and most continuously mineralized level in the mine.

Production from the mine since it was rehabilitated in 1956 totals 752,480 tons, from which 19,300,446 pounds of copper were recovered at an average yield of 25.65 pounds per ton.

Detailed geologic mapping has revealed some previously unsuspected relationships between the Calumet Conglomerate in the Centennial #3-#6 area and in the main ore body that have controlled the localization of the ore, and these relationships, described below, permit reasonably accurate projections into unexplored areas.

Main-Channel Conglomerate Versus Conglomerate of Centennial #3-#6 Mine.--The Calumet and Hecla Conglomerate can be traced for over 40 miles. For most of this length, it is very thin, ranging from an inch or less to a few feet in thickness, but in the Calumet area it abruptly thickens and averages over 10 feet in thickness. As figure 5 makes clear, the bed tends to consist of a group of subparallel thicker and thinner lenticular streaks that trend generally north. The bed as a whole also tends to thicken with depth. The lenses explored at Centennial #3-#6 mine appear to be tributary to those of the main Calumet and Hecla ore deposit, and differ from them in lithology. The boundary between what may be termed the "main-channel conglomerate" and the "tributary stream-channel conglomerate" of the Centennial #3-#6 mine is shown by the heavy dashed line on figures 5 and 6.

The pebbles of the conglomerate of Centennial #3-#6 are almost exclusively quartz-feldspar porphyry, like those at the Kingston mine. In contrast, the main-channel conglomerate contains a variety of felsite and granophyre pebbles; quartz-feldspar porphyry pebbles are common, but are generally smaller than average. The pebbles as a whole are larger and better rounded than those of the Centennial #3-#6 mine. These differences suggest that the pebbles at the Centennial #3-#6 were derived from a relatively small source area of quartz-feldspar porphyry that was close to the site of deposition, and that pebbles of the main-channel conglomerate were, on the average, transported for a greater distance from a geologically more diverse source terrane.

In both main and tributary channels, there is a tendency for the conglomerate to be coarser and to contain less fine material where it is thick than where it is thin.

Figures 5 and 6 show the 5-foot-thickness contour. Both types of conglomerate pinch out very rapidly and, for all practical purposes, the conglomerate bed outside of the 5-foot-thickness contours can be ignored. If any sedimentary material is present at all, it is usually shaly or sandy and is only a few inches thick. The reader will note that the Centennial #3-#6 conglomerate lenses trend almost directly down dip, but then turn abruptly to a northerly direction near the bottom of the mine where they approach the main channel.

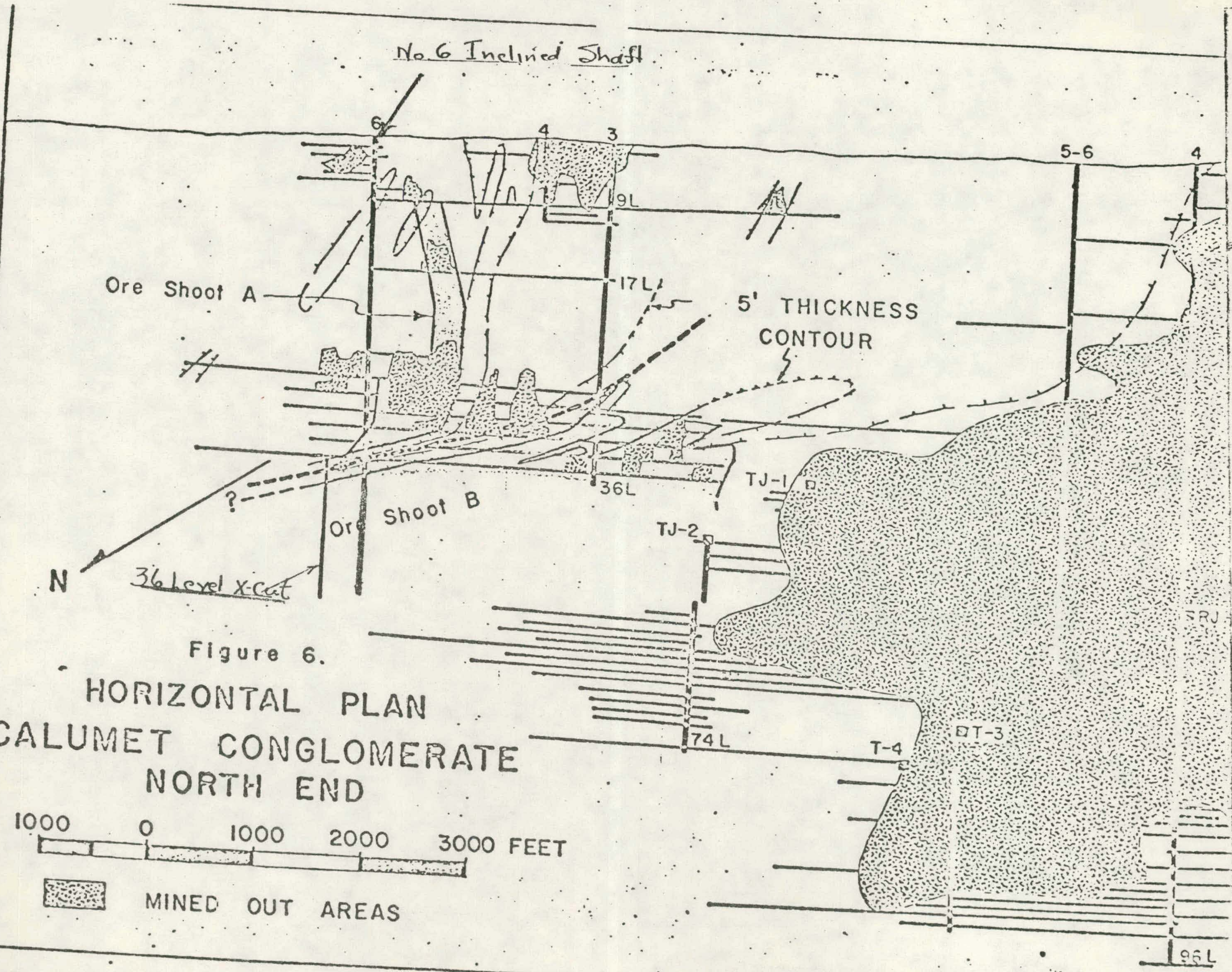

Figure 6.

HORIZONTAL PLAN
CALUMET CONGLOMERATE
NORTH END

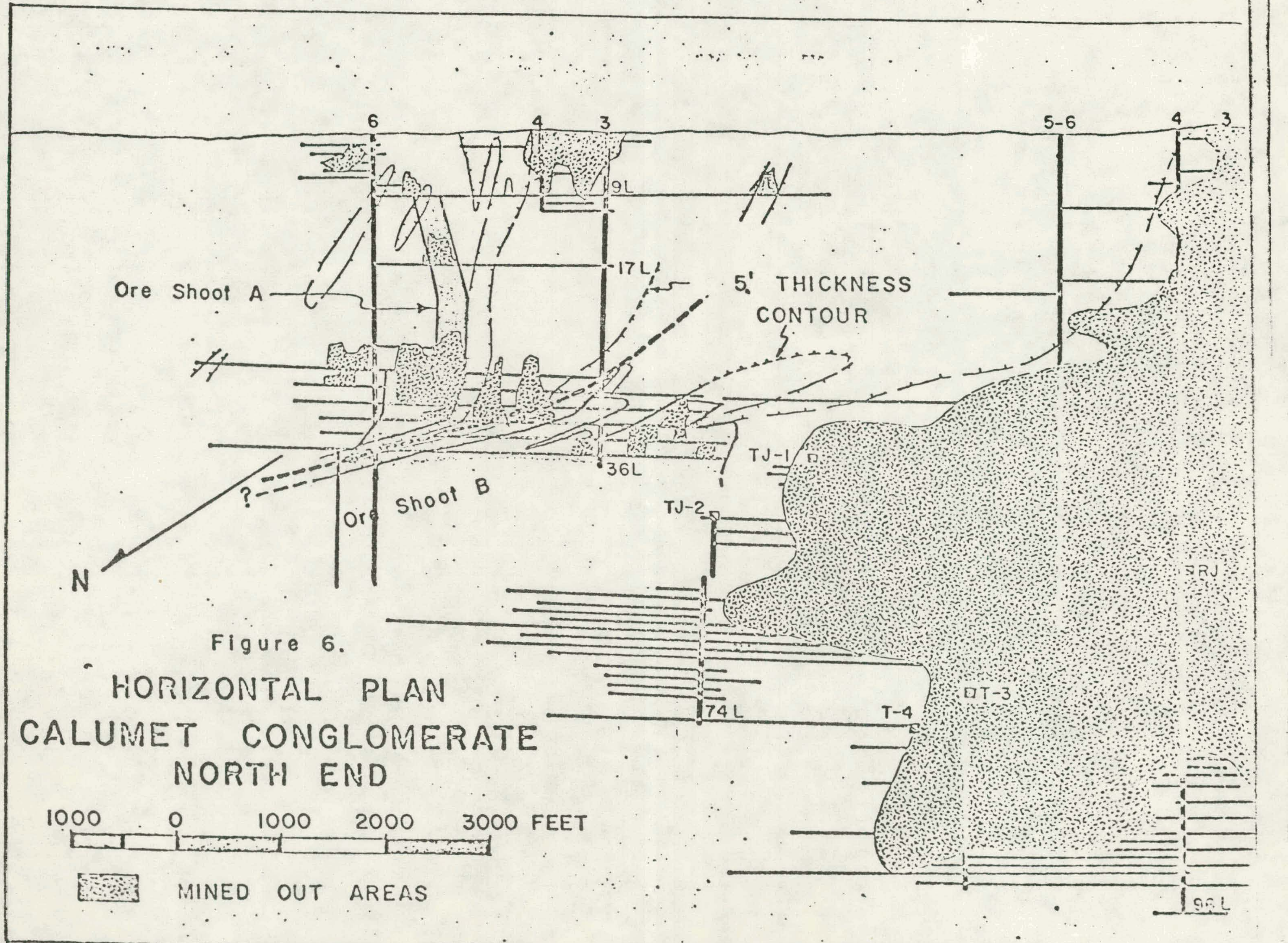

Figure 6.

HORIZONTAL PLAN
CALUMET CONGLOMERATE
NORTH END

1000 0 1000 2000 3000 FEET

MINED OUT AREAS

Copper Occurrences.--The copper tends to occur in bands within the bed as it does at the Kingston mine. However, because the conglomerate is much thinner (8-foot average) in the Centennial #3-#6 workings, the entire bed is usually mined and the segregation of the ore into zones is not as obvious. Scattered observations show that the copper tends to jump from one stratigraphic position to another, as it does in the thicker conglomerates (fig. 7).

The intensity of mineralization again appears to be controlled by several factors, particularly the type and amount of interstitial material and the location of "pinch-outs" or barriers.

The conglomerate in the higher grade areas tends to be either relatively free of fine interstitial material or carried fairly coarse sand or small pebbles in the interstitial spaces. Those areas containing abundant fine shale or silt in the interstices tend to be low grade or barren. The composition of the interstitial material also seems to exert an influence on the amount of copper present; conglomerate in which the interstitial material consists of quartz-feldspar porphyry sand or small pebbles tends to be the best mineralized. While quartz-feldspar prophyry pebbles and sand are frequently completely bleached and altered throughout the entire pebble or grain, it is rare to find pebbles representing other types of felsite or granophyre that have a bleached rim more than a small fraction of an inch thick. As previously pointed out, since bleaching is intimately associated with the copper, it has been postulated that bleached rock resulted from the chemical activity of the ore-bearing solutions. Whether this bleaching and associated copper is due primarily to the chemical composition of the rock or some physical characteristic, such as size or shape, is unknown, but there is a tendency for the highest grade copper to occur where quartz-feldspar porphyry is abundant.

Localization of Oreshoot.--The copper mineralization at Centennial #3-#6 occurs in two major oreshoots (fig. 6). Mineable ore is present in scattered areas outside of these two shoots, but is low grade and erratic and probably was formed by stray solutions that leaked out of the major oreshoots. Both oreshoots occur immediately adjacent to the 5-foot-thickness contour line. These are areas where the conglomerate bed abruptly increases in thickness from a foot or less to 5 or more feet within 10 or 20 feet along the strike of the bed. As has been previously pointed out, such conditions form ideal barriers and, in the writers' opinion, control the position of the oreshoots. Perhaps the most convincing evidence for this is the fact that the highest grade ore occurs next to these "pinch-outs" and the ore then gradually decreases in grade away from these areas until it becomes marginal.

Oreshoot "A" as shown in figure 6 lies completely within the tributary channel. The direction of mineralization follows the direction of the stream on the upper levels where the shoot trends almost directly down dip. On the 34th level, however, it turns sharply and parallels the axis of the main channel near the point where the tributary also turns and flows into the main channel. Quartz-feldspar porphyry pebbles predominate in the host rock.

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White Pine Copper Mine

Location

The White Pine operations are in T50N, R42W, Ontonagon County, Michigan. Lake Superior and the town of Ontonagon are about six miles to the north, the Porcupine mountains are situated a few miles to the west. The mine is 45 to 70 miles west - southwest of the principal native copper mines near Houghton and Hancock. The surface is flat with an elevation at the mine about 200 feet above Lake Superior elevation.

General Geology

The ore layer and therefore the mining areas are in the lower 20 to 25 feet of the Nonesuch shale, of late Keweenawan age. The shale is about 600 feet thick and is composed mostly of silt stone. It overlies 2300 to 5500 feet of sandstone and conglomerates. These latter, in turn overlie the Portage Lake Lava series in which the native copper ore occurs.

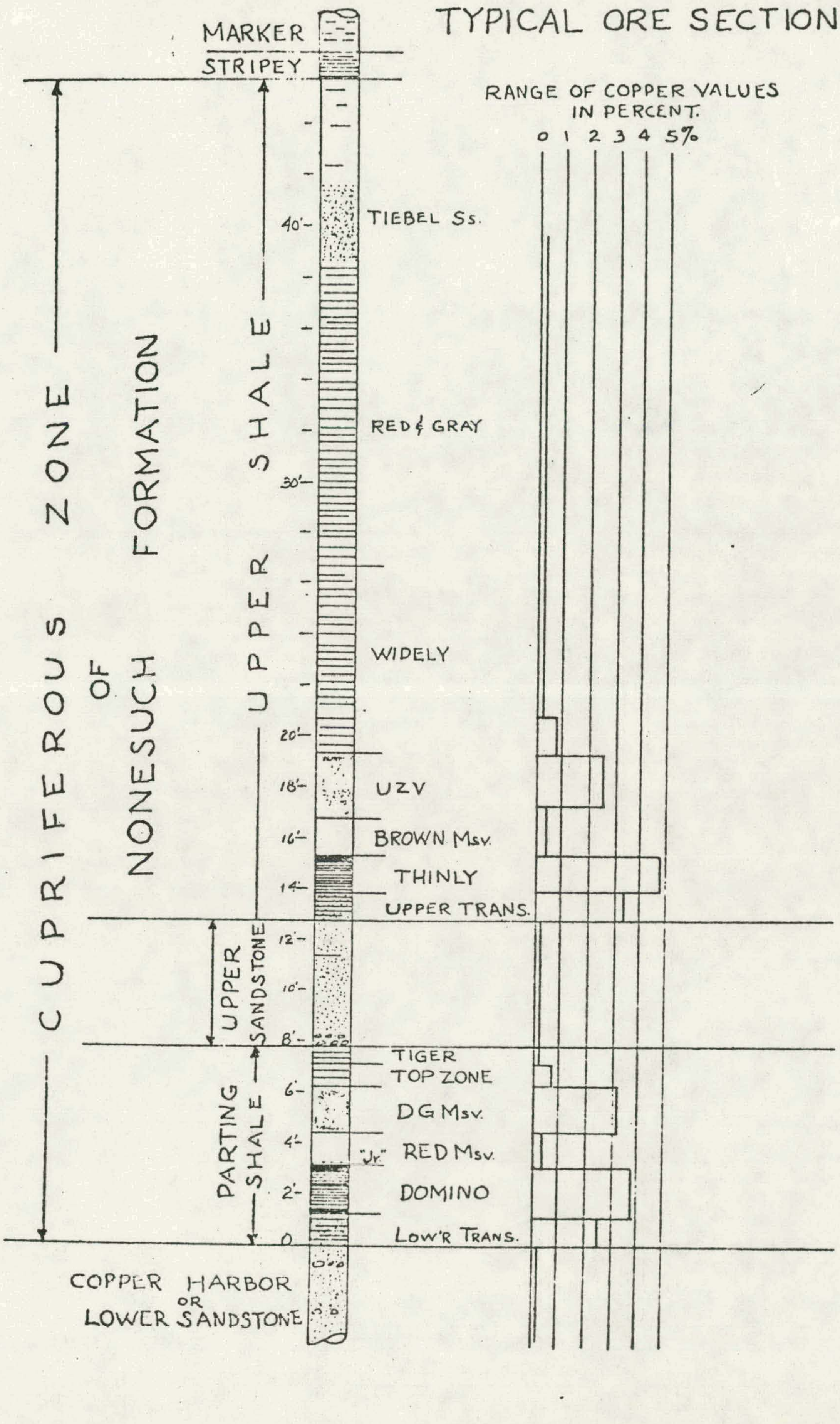
The thickness of the middle Keweenawan lavas in the copper district is probably 20,000 feet (White 1963). Overlying these are at least 15,000 feet of sedimentary rocks of late Keweenawan age.

Mining is done by the room and pillar system because of the rather gentle dip of the Nonesuch shale. The mine is reported to be the largest room and pillar mine in North America.

The major structural feature is the White Pine Fault. This fault was intersected by mine workings many years ago at 1600 feet of depth. Water was present and a flow of several hundred gallons per minute occurred. This flow has decreased to a flow of only a few gallons per minute.

The deepest mine workings are slightly below 2000 feet of depth and are dry. The mine geologists were not able to identify or recall any areas of seepage or wetness in the deeper zones. Hence hydrologic information available here is meager. It should be noted however that water flows occurred in a fault here at 1600 feet and that water flows of 100 G. P. M. or so also occur in a 150 foot wide shear zone at the Geco Mine, also at about 1600 feet of depth.

TYPICAL ORE SECTION



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White Pine Mine

Soudan Mine - Minnesota

Location

The Soudan mine is now part of Soudan State Park, some two miles east of Tower Minnesota, at the western end of the Vermillion iron range.

Geology

The geology of the mine and vicinity is given on the attached copies of excerpts from a paper by F. Klinger*.

General Statement

The Soudan mine operated for 75 years and produced about 15 million tons of hard hematite ore. The deepest openings are at 2800 feet depth. The ore bodies dipped at 75 to 85° and old workings extend to the surface. All the ore and mine workings are within the Ely, Greenstone belt. The rocks are of early Precambrian age (> 2500 M.Y.).

The mine is maintained by the Parks Department and tours are conducted on the 2500 foot level and into a main stope. Visitors wear ordinary shoes and clothes as the level and the large stope above it is dry.

One horizontal drill hole to the north on the 2500 level was moist around the collar. Some water was observed in an old drainage ditch. This water was 2" wide, less than 1/3 inch deep and barely moving. I was informed by the guide (an ex-Soudan miner) that pumping was done at the 23rd and 25th levels because water came down through the old workings during

---

* Klinger F. L. Geology of the Soudan Mine and Vicinity. Guidebook for Field Trips, 1956 - G. M. Schwartz, Editor.

rainstorms on in the Spring melt.

In reply to a letter, the resident park manager informs me that there is some water, 4 to 5 G.P.M. from one drill hole on the 25 level stope and also water entering from 3 diamond drill holes in the old workings on the 27 level. Because of lack of safety maintenance in these areas, I did not see the 27th level. The main stope on the 2500 levels is completely dry except for the drill hole noted above.

A large member of drill holes have been drilled north and south of the workings in the search for parallel zones of iron formation. These are nearly always dry with a few exceptions as noted earlier. The exact source is not known but I expect that some opening of fractures in the brittle jasper bands have developed due to the extensive past mining activities.

The greenstone belts, away from old mining areas have potential, but this potential probably is below depths of 3000 feet.

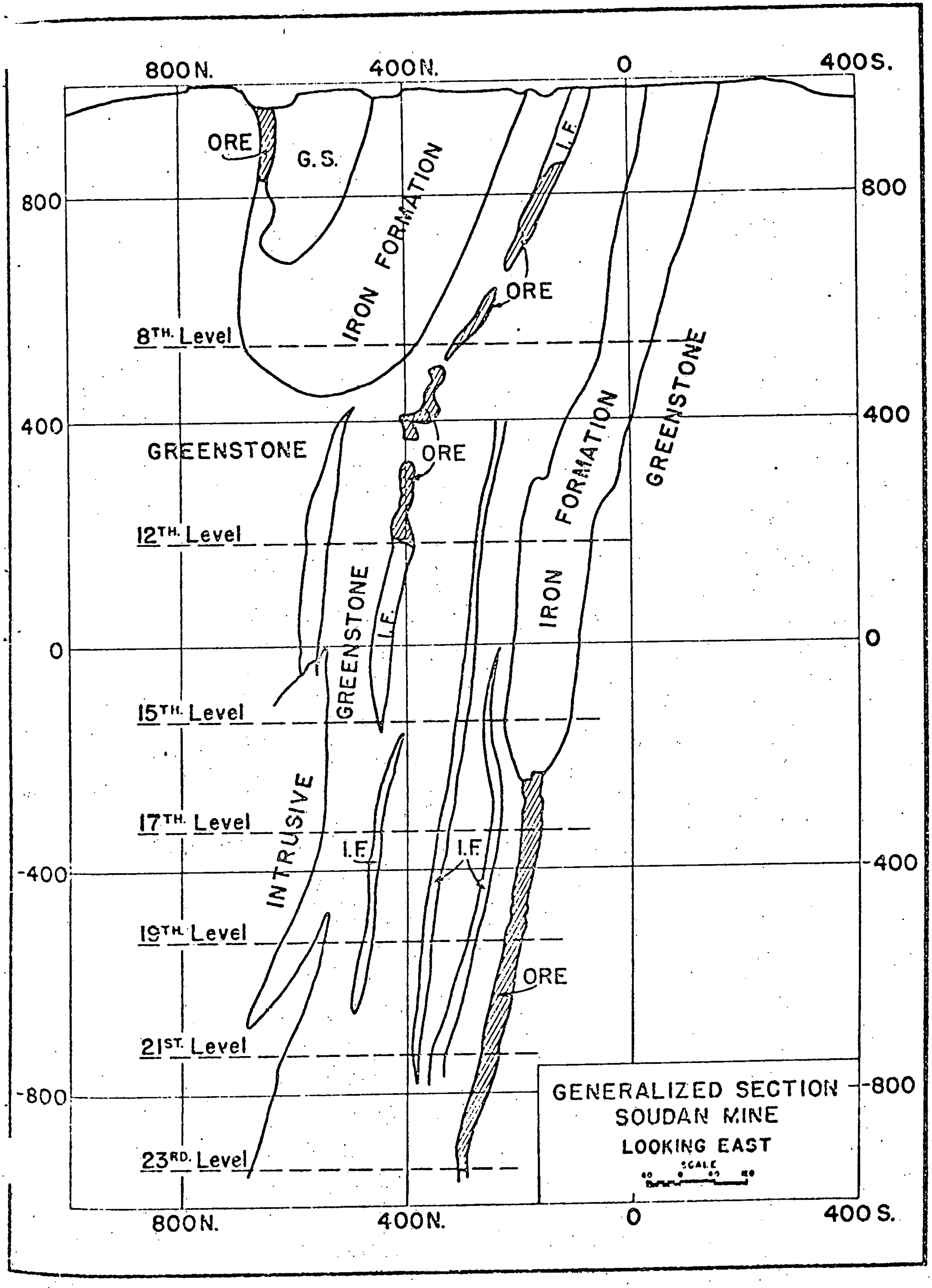


FIGURE 18.- GENERALIZED SECTION OF SOUDAN MINE

GEOLOGY OF THE SOUDAN MINE AND VICINITY

By Fred L. Klinger

ABSTRACT

The rocks of the Soudan area are composed of the Ely greenstone, containing lenses of siliceous iron formation, and the Knife Lake group which includes slate, conglomerate, graywacke, and possibly tuffs. The general strike of the rocks is E-W to N. 80° E. and the dip, 75-85° N. Mine openings do not penetrate the Knife Lake rocks.

The greenstone and included iron formation are flanked on the north and south by slate and coarse clastics previously correlated with the Knife Lake group. Certain relations between the greenstone and the southern belt of sediments suggest that this belt may stratigraphically underlie the greenstone.

The greenstone consists of schistose flows, tuffs, and sediments, cut by intrusions of basic to acidic composition. The proportion of tuffaceous and sedimentary material appears to be greater than in other parts of the Vermilion range, and may be 40 per cent of the greenstone. Zones of fragmental rocks appear to be marginal to belts of iron formation. Rounded pebbles of a granitic rock are found in some greenstone and suggest the presence of an older granite not previously recognized in the Vermilion district. Distinctive and persistent lithologic units are uncommon, and there is much intercalation of rock types. Lithologic sequences may change greatly within a few hundred feet. The greenstone shows a general lack of folds, and although it is greatly altered, many primary structures are preserved in minute detail.

The iron formation occurs as lenticular bodies within the greenstone. Its main constituents are quartz, hematite, magnetite or martite, pyrite, siderite, and chlorite. Much of the hematite is secondary. Three general types have been mapped; greenish-white chert, lean jasper, and jaspilite. The jaspilite is distinguished by its higher iron content, a prominent banded structure, and its tendency to form thicker, more persistent beds. The chert and lean jasper are marginal to the bodies of jaspilite, and the three types may represent both horizontal and vertical changes in the iron formation. Average analyses of different types are given. Strong deformation of the jasper is in contrast to the lack of folded structures in the greenstone.

material associated with the belts of iron formation. These sedimentary zones separate the iron formation from greenstone which appears to have been derived largely from igneous material. Whether the sequence--greenstone, chloritized tuffs and sediments, and iron formation--represents successively younger rocks is not known, because information as to tops and bottoms of beds is lacking.

The relationship of the southern belt of "Knife Lake" sediments to the greenstones and iron formation is a special problem. There is some structural and lithologic evidence that these sediments may stratigraphically underlie the Keewatin rocks. This problem is presented later.

ELY GREENSTONE

General Description

The Ely greenstone is a complex series of clastic sediments, intrusive rocks, volcanic flows, and tuffs. The proportion of tuffaceous and sedimentary material may exceed 40 per cent. The greenstone in the Soudan area appears to be considerably different from that in other parts of the Vermilion range. With the exception of some intrusions, lithologic units of the greenstone are parallel to each other and also to the units of iron formation. A well-developed schistosity is normally present, striking E-W to N 80° E and dipping 80-85° N. This direction is usually maintained regardless of folded structures. Although the schistosity usually parallels the strike and dip of lithic units, it sometimes cuts primary planar structures at a very low angle, usually less than 15°.

The greenstones are usually fine grained, and almost always consist of a mixture of chlorite, sericite, and quartz. Depending on the amount of chlorite or sericite present, they range in color from dark green to gray or yellowish gray. The rock types apparently represent hydrothermally altered igneous and sedimentary rocks whose primary textures and structures are partially retained. In spite of the often pronounced schistosity, shearing has not been extensive. Primary textural and structural features, such as amygdules, phenocrysts, spherulites (?), granules, bedding, fragmental texture, etc. are in many cases well preserved. Some zones are strongly sheared, especially in the vicinity of faults.

The rocks at Soudan show a wide range in chemical composition, and they differ in several respects from the typical Ely greenstone. Analyses from other parts of the Vermilion range (Schwartz and Reid, 1955) consistently indicate a basaltic composition. Although basaltic types are fairly common in the Soudan area, these are equalled if not exceeded in volume by rocks which contain relatively high silica and/or alkalies, moderate to low titania, and very low lime. The magnesia content ranges from 1 to 12 per cent, and the ferrous iron content of some types is abnormally high.

The greenstones appear to be made up largely of volcanic rocks, such as flows and tuffs. The amount of sedimentary material is probably less than 20 per cent but may be greater. The proportion of intrusive material is unknown, largely because of the difficulty in distinguishing flows from sills. An accurate estimate of genetic types is hindered by textural and compositional similarities, differing degrees of rock alteration, and limited exposures. There is considerable intercalation of the lithologic units. Discontinuities and rapid variations in thickness are common, and a lithologic sequence found in one drill hole may be greatly changed in a parallel hole 200 feet away.

Flows

Amygdaloidal phases of the greenstone are fairly abundant. The amygdules usually consist of finely granular quartz, sometimes with calcite or ferruginous carbonate. They occur in narrow zones, or may be concentrated in irregular, isolated patches. Some zones of amygdaloidal material, only a few inches thick, resemble thin sedimentary beds rather than flow tops. It is possible that in some cases, "amygdules" may be granulated phenocrysts or detrital grains of quartz. Except in rare cases, amygdaloidal zones offer little or no information of stratigraphic value. In addition to the amygdaloidal material, some spherulitic structures are occasionally found. Ellipsoidal, or pillow structure is rarely seen. The thickness of single flows appears to range from a few feet up to several hundred feet. Flow structures have not been definitely recognized, but are suggested by some banded structures.

Fragmental Rocks and Sediments

Fragmental textures are rather common in the greenstones. Although there are some good exposures of fragmental material in outcrops and in underground openings, much of the greenstone is fine grained and the fragmental texture is visible only on drill core. Such rocks usually have only a crude bedding. Rock and mineral fragments commonly show orientation parallel to schistosity; this could be due to original bedding or to later deformation. The fragmental rocks probably include both pyroclastic and water-transported material. Such beds are usually less than 20 feet thick but may be more than 100 feet thick in some places.

An interesting fragmental and/or conglomeratic rock occurs on the lower

TABLE 1. - CHEMICAL ANALYSES OF GREENSTONE AND OF PAINT ROCK

	(A) Greenstone	(B) Paint Rock (Dried at 212° F.)
SiO_2	51.7	20.9
Al_2O_3	15.3	16.8
Fe_2O_3	3.4	52.0
FeO	7.3	.4
MgO	6.7	.1
CaO	9.4	.2
Na_2O	3.8	.1
K_2O	.8	.04
H_2O+	2.9	n.d.
TiO_2	.8	n.d.
MnO	.2	n.d.

A. Average of three analyses of greenstone (Schwartz, 1924).

B. Oliver Iron Mining Division chemical laboratory.

Geco Mine

Location

The Geco mine is at Manitouwadge Ontario Canada.

Geology

The general geology is outlined in attached excerpt from Pye*.

General Statement

The Cu Zn Ag ores at the Geco mine occur in a highly sericitized quartz - feldspar - biotite gneiss horizon. North of this horizon there are garnitiferous, amphibole - biotite gneiss and biotite granite, and to the south quartzite.

A major fault, the Fox Creek fault, cuts the ore zone at the west end of the mine. Water moves along this fault structure at a depth of 700 feet. There is no deeper, mining near the fault and the ore zone rakes down to the east as shown on the longitudinal section.

---

* Pye E. G. 1957, "Geological Exploration" , Inst. on Lake Superior Geology. Mich. Tech Press

before the results of further drilling indicated a deposit of such importance that the biggest staking rush in the history of Ontario, and one of the biggest in the history of Canada, was precipitated.

Location of Area, Means of Access

The Manitouwadge Lake area forms a small but very important part of the Heron Bay - White Lake region along the north shore of Lake Superior. As shown in Fig. 1, it lies about midway between two transcontinental railways, the Canadian National Railways line on the north and the Canadian Pacific line on the south; it is 170 miles east-northeast of the Canadian Lakehead, and 200 miles northeast of Houghton, Michigan.

The area is accessible by an Ontario Department of Mines access road connecting Manitouwadge Lake with the Trans-Canada highway along the north shore of Lake Superior; by a spur railway line built south from Hillsport by the Canadian National Railways; and by a second railway line, built north from Hemlo by the Canadian Pacific Railway.

General Geology

All the consolidated rocks exposed in the Manitouwadge Lake area are of Precambrian age. They have been divided into three main groups:

(1) A system of closely folded and intensely metamorphosed volcanics and sediments, which, together with horizons of amphibole - biotite gneiss and banded iron formation, are believed to be of Early Archaean age;
(2) An assemblage of igneous rocks, of post-Early Archaean and possibly of Algoman age; and
(3) Diabase dikes, which have been correlated tentatively with basic intrusives of Keweenawan age exposed around Lake Nipigon and along the northwest shore of Lake Superior.

Early Archaean

Volcanics: A prominent series made up largely of hornblende schist is exposed south and east of Wowun Lake. It forms a well-defined belt, up to and possibly, exceeding two miles in width, which extends from this locality southwest to Manitouwadge Lake, and thence westward across the southwest corner of the map area. Two varieties of hornblende schist are present. One shows little evidence of banding; the other is characteristically finely laminated and resembles a thin bedded sediment in structure.

Excellent exposures of the non-laminated hornblende schist are found in the west part of the belt. In places where shearing has not been too intense, vestiges of original pillow structures can be seen. The pillows are somewhat irregular in shape and do not permit satisfactory top determinations. But their presence is significant, for they indicate that the hornblende schist is of volcanic origin. In consideration of the mineralogical composition - the typical schist consists of about 50 percent hornblende with lesser amounts of andesine and a little quartz, sphene, and magnetite - it is probable that the rock is the metamorphosed equivalent of original basic lava.

Thin horizons of laminated hornblende schist separate the lava flows. They are particularly well-developed in the vicinity of Manitouwadge and Mose lakes. The rock itself is similar mineralogically to the variety just described except that, at the expense of plagioclase, quartz is an essential rather than an accessory constituent. A further and more striking difference, of course, is the thin bedded structure - black layers of material rich in hornblende alternate with grey layers rich in plagioclase and quartz. These layers range from a small fraction of an inch to several inches in thickness. The laminated hornblende schist is found in places to contain lenticular fragments of greenstone, from less than an inch to six inches and up to about three inches in thickness. The two characteristics - stratification and fragmental structure - indicate that the original rock was a tuffaceous sediment deposited subaqueously during the period of volcanism.

Sedimentary Gneisses: As the north margin of the volcanic series is approached, well-developed horizons of sedimentary gneisses are found to alternate with bands of hornblende schist. These increase in both number and thickness to the north so that, within a short distance, the series gives way to one in which the principal ferromagnesian mineral is biotite. Four principal varieties of sedimentary gneisses have been recognized. They are biotite gneiss, quarts-oligoclase-biotite gneiss, quartzite, and quartz-microcline gneiss.

In view of the evidence presented by petrologists to the effect that clay minerals combine to form chlorite and sericite, and that these in turn combine to form biotite during metamorphism[2], it is thought that the biotite gneiss, the quartz-oligoclase-biotite gneiss, the quartzite, and the quartz-microcline gneiss are the altered equivalents of shale, argillaceous sandstone, quartz sandstone, and arkose, respectively.

Amphibole-Biotite Gneiss: In many places throughout the series the sedimentary gneisses are found to be interrupted by lenticular masses of amphibole-biotite gneiss of dark colour, coarse to very coarse granularity, and striking appearance. This rock is made up largely of anthophyllite, hornblende, and biotite, with small amounts of quartz, oligoclase, and magnetite. Red garnets are also commonly present. They occur as large porphyroblasts, ranging from about one-half inch to two inches or more in diameter, and in places make up 25 percent of the rock mass. The amphibole-biotite gneiss is frequently found to grade, by disappearance of amphibole and, when present, also of garnet, into typical biotite gneiss. Because of this it is considered to be sedimentary origin - it may represent the highly metamorphosed equivalent of a calcareous, chloritic grit or basic tuffaceous sediment that was developed at the same time as the enclosing rocks. It is included with the sedimentary gneiss on the generalized geological map.

Iron Formation: Commonly intimately associated with the amphibole-biotite gneiss is a peculiar banded rock. This banded rock consists of layers of coarse-grained quartz, from a fraction of an inch to a foot or more in thickness, alternating with equally thin or thinner layers of one or more of amphibole schist, garnetiferous amphibole-biotite schist, and a very coarse amphibolite. In the field it has been variously termed quartz-chlorite rock, quartz-amphibole rock, quartz-amphibole-pyroxene rock, and iron formation. Since the rock is distinctly banded, since the schist or amphibolite layers contain disseminated crystals and thin seams of fine granular magnetite, since individual horizons can be traced by dip needle and magnetometer, and since these horizons are very persistent and follow the folded pattern of the sedimentary gneisses, it is thought that "iron formation" is the most appropriate term.

Post-Early Archaean (Algoman ?)

Basic Metaintrusives: Small lenticular bodies of metagabbro are found in a number of places within or close to the belt of volcanic rocks.

2. Harker, Alfred, "Metamorphism, A study of the Transformations of Rock Masses," Methuen & Co. Ltd., London, 11, 45-61, 1950.

These bodies have intrusive relations with the Early Archaean formations, but are themselves cut by granite and pegmatite. For the most part they consist of a medium- to coarse-grained rock made up of about equal amounts of dark-green hornblende and plagioclase, with small amounts of biotite, quartz, and magnetite. This rock is generally quite massive in the outcrop.

Granitic Rocks: The most abundant igneous rock found in the Manitouwadge Lake area is biotite granite gneiss. Together with massive granite, migmatite, and pegmatite, it occurs in three principal localities: (1) the extreme southeast corner of the area; (2) the extreme northwest corner; and (3) the whole of the northeast quarter. The granitic rocks to the northwest and southeast are believed to represent a single large mass, in which the Early-Archaean rocks form a deeply infolded inclusion; those in the northeast quarter of the area are believed to represent a satellite of the main mass, which has been localized along the major synclinal axis (see Structural Geology).

Associated with the granite gneiss, migmatite, and the medium-grained, massive, intrusive biotite granite, and cutting the Early-Archaean formations, are dikes and sills of pegmatite and aplite. The pegmatite is of three ages. It occurs as: (1) dikes which cut metagabbro inclusions in, and which are themselves truncated by, the massive biotite granite; (2) irregular bodies which grade into, and hence represent a phase of, the massive biotite granite; and (3) dikes, which cut the massive biotite granite. Some of the pegmatites are pre-ore in age, and on the properties of Geco Mines, Limited, and Willroy Mines, Limited, they were instrumental in the localization of the ore deposits.

Algonkian

The youngest rock exposed is diabase. The diabase forms a number of narrow, but fairly persistent north-south dikes, some of which are localized along transverse faults (see Fig. 2). In that these dikes cut sharply across all the other consolidated rocks, including the various granitic rocks, it is thought that they are of Algonkian or Late Precambrian age. It is possible that they could be correlated with similar rocks, of Keweenawan age, that crop out to the west of the area in the vicinity of Lake Nipigon.

Structural Geology

Folding: The rock type described as iron formation is the only one that occurs in sufficiently distinct and persistent horizons to be useful in outlining the structural geology. Examination of the generalized geological map of the area shows that, in the vicinity of Wowun lake on the east, the iron formation and the gneisses strike southwest and dip vertically to steeply north. Proceeding westward to Fox creek and the Geco mine, however, the formations assume an east-west strike; and still farther west, midway between Fox and Nama creeks, they strike northwest and dip 50° N. Finally, at the west side of the map area, the formations assume first a northerly strike and then double back on themselves to strike northeast again. They delineate a large trough or synclinal fold, which dip measurements indicate to be assymetrical and overturned to the north. Other dip measurements, at the nose of the fold, indicate a plunge to the northeast of from 15 to 25 degrees. In the eastern part of the area, lineation and drag folds indicate a steeper plunge of about 40 degrees.

Faulting: After the major folding, the Manitouwadge Lake area suffered a series of disturbances that resulted in the development of a large number of faults. These faults are of three types: (1) Longitudinal or strike faults, which more or less parallel the formations along the south limb of the syncline; (2) transverse faults, which strike in a general north-south direction; and (3) diagonal faults, which strike northwest, obliquely to the other faults. All are represented in the field by deep linear depressions in the topography.

An example of a major strike fault is the Agam Lake fault, which strikes due west, from north of Manitouwadge lake to almost the west boundary of the map area, just north of and roughly parallel to the belt of volcanic rocks. This fault is pre-ore in age, and is represented by a wide zone of graphitic schist, in places mineralized with pyrite and pyrrhotite. The magnitude and direction of movement along this break have not been determined. However, the fault appears to truncate a number of pre-ore, right-hand transverse faults, and at the same time, appears to be terminated by the north-south, post-ore, left-hand Fox Creek fault.

At least three periods of movement are thus indicated. A possible fourth period of disturbance may be responsible for the fault that extends diagonally across the area from northwest to southeast. In regard to this fault, the offsets shown by the rock formations are of interest. In the northwest section of the area, the formations dip rather flatly to the southeast. Here the displacement was lefthand, or east side to the north.

In the southeast section of the area, the formations dip about 65° to the northwest. Here the displacement was right-hand,, or east side to the south. To the east of the Geco mine, the formations dip vertically. Here the formations have been traced across the fault to Wowun lake without any apparent offset. Such anomalous conditions can be explained satisfactorily by assuming that the displacement along the fault was mainly vertical, and that the relative movement was up on the west side. South of Mose lake, a diabase dike was localized along this diagonal fault. But the diabase has been brecciated. Further, north of the Geco mine, the fault cuts and offsets two diabase dikes. In view of these facts and the simple vertical displacement indicated, it is thought that the two ore more movements represented occurred in Late Precambrian time.

Mineral Deposits

All the important mineral deposits discovered to date are sulphide replacement bodies. Their locations are shown in Fig. 3. They strike and dip parallel to the formations that contain them, and have been found in or closely associated with either iron formation or a variety of sedimentary rock. A determination of the lead isotope ratios of a sample of galena, from one of the occurrences, by mass spectrometer is reported by J. T. Wilson of the University of Toronto to indicate an age of 2,600± 120 million years[3]. According to Wilson, the indicated age is close to that of leads found in the Golden Manitou and Barvue deposits in Quebec and the gold ores of Timmins in Ontario. The lead from Manitouwadge lake, and those from the other deposits, are all much older than the Sudbury nickel-copper ores, which are believed to have been formed in Late Precambrian time. In view of this, it is reasonable to assume that the ore minerals were deposited during the period of granitic intrusion, and that they are of Late Archaean or Algoman age.

Deposits in Iron Formation: Sulphide replacement deposits in iron formation have been found on the properties of Lun-Echo Gold Mines, Limited, about the nose of the Manitouwadge syncline, and Willroy Mines, Limited, on the south limb of the syncline.

As mentioned previously, the iron formation is a banded rock, in which layers of quartz alternate with layers of amphibole schist, garnetiferous amphibole schist, or coarse-grained amphibolite. In the replace-

3. Wilson, J. T., personal correspondence.

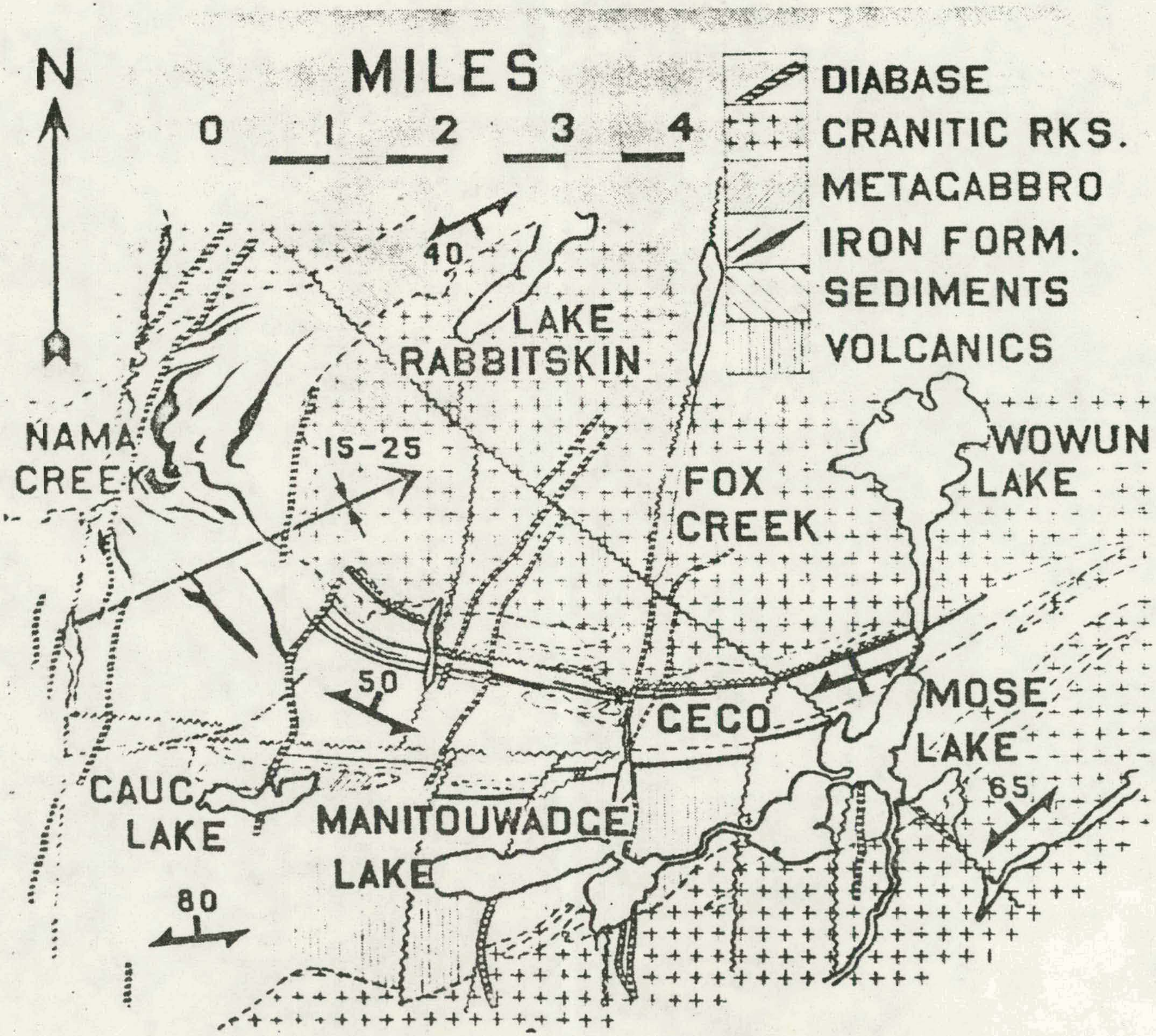


Fig. 2. Generalized geological map of the Manitouwadge Lake area.

NORANDA MINES LIMITED
(Geco Division)

POLLUTION CONTROLS

The following measures are employed at Geco to minimize the pollution of the Manitouwadge area water systems.

(a) Ten locations relating to the tailings area, Fox Creek and the water discharged from the mine are sampled and assayed on a weekly basis. Assays are made for copper, zinc, iron, suspended solids, dissolved solids, sulphate, ammonia and the acidity measured as pH.

In addition, Fox Creek upstream and Kaginu Creek at the Ontario Paper Company bridge are sampled on a monthly basis.

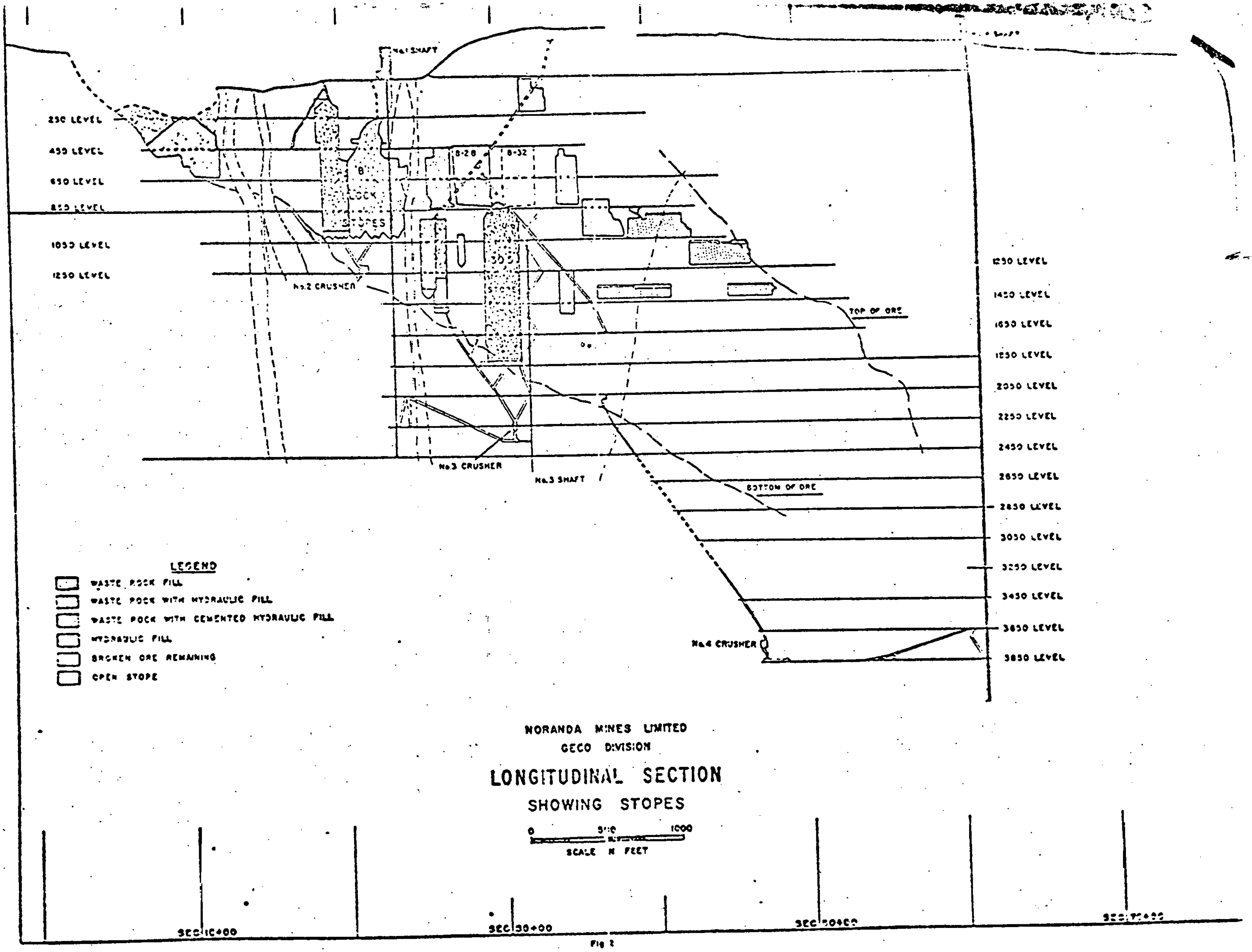
(b) A system to recycle the decant water from the tailings pond back to the mill was installed in 1972 at a cost of $275,000. The water discharged from underground is pumped to the tailings pond as well as the seepages through the tailings embankments. Thus almost all the water used is collected in the tailings pond, is neutralized in the pond and is recycled back to the mill. During the spring run-off and periods of heavy rainfall it is, however, necessary to decant the excess water to the lake system.

(c) About $100,000 is spent annually on power, labor and supplies for pollution control purposes. One major item is 1,300 tons of lime required to neutralize acidity.

(d) An initial experiment on the growth of vegetative cover on passive sulphide tailings has been made at a cost of $10,000.

(e) A further proposal has been made to install a waste water treatment plant at a cost of $300,000. This plant will neutralize the mine and seepage waters. The clarified effluent will flow to the lake system and the heavy metal contents will be precipitated as hydroxides and pumped as a sludge into the tailings area.

This plant has been designed so that tailings effluents, mine water seepages will be treated even after mining operations have ceased due to depletion of the ore bodies.



NORANDA MINES LIMITED
GECO DIVISION

LONGITUDINAL SECTION
SHOWING STOPES

0 500 1000
SCALE IN FEET

Fig 2

George MacLeod Mine, Algoma Steel Corporation

Location

The MacLeod mine is 140 miles north of Sault Ste. Marie Ontario.

Geology

A report on the geology of the MacLeod mine is attached. As pointed out in that report faulting is rather extensive with five major types recognized. To quote from page 10, "---a complicated fault pattern has developed probably during late stages of folding. Faulting is more intense in the upper levels of the mine than at depth. Faulting may be developed in one or more stratigraphic units and missing in an adjoining unit. A great difference in relative competency of stratigraphic units with each reacting differently to stress is suggested as the logical explanation."

A point not noted in the report is the presence of occassional open "vugs" in the siderite ore zone. On the 2800 level there are several up to 20 feet long. Some are partly filled with stagnant water. The mine staff has tried to trace the connection between some of them without success. Below the 3200 level the few vugs reported are 2 or 3 inches in size. The implication is that the "vugs" formed as solution cavities at some point in the mine history and that the zones along which the solutions moved have long since been sealed by pressure and/or deposition. Also, that movement of water did not extend below about 3200 feet.

Near - surface, there has been a good deal of solution and oxidation to form goethite and some hematite ore from the siderite and pyrite. These ores bottomed at about 700 feet but some large sand and water bearing zones developed for a short distance further. A report is attached, on a run of water and sands when a large solution cavity was encountered.

The inspection of the lower workings consisted of walking along the levels and haulage ramps to depths a bit below 3200 feet. The siderite is rather blocky, but does have fractures which are tight and dry. No water was seen or reported entering the mine workings through the wall or roof rocks. At this depth these rocks are not permeable.

Two inclined haulage tunnels are being driven from surface to the 3400 level, a distance of 16,000 feet. From surface to 1600 feet depth (vertical) water seepage was rather common. This disappeared before a depth of 2000 feet was reached and the rocks of the haulage tunnel are completely dry. This haulage drive is not yet completed.

In spite of the folding faulting and fracturing, the rocks are dry below 3000 feet of depth. This may be a result of mineral deposition in part (though none was seen on any fractures) but more likely is a result of long-term creep of the rocks at these depths.

ALGOMA ORE DIVISION

THE ALGOMA STEEL CORPORATION, LIMITED

GEO. W. MACLEOD MINE

MARCH 1970

REGIONAL GEOLOGY

Introduction

The Michipicoten area is situated 150 miles north of Sault Ste. Marie. It extends approximately from Lake Superior on the south to the C.P.R. tracks on the north, a distance of 30 miles, and from Lochalsh on the east to Pucaswa River on the west, a distance of 90 miles. The portion herein described lies in the southern part of the area, extending from Wawa Lake northeastward for 14 miles to Hawk Junction on the Algoma Central Railway. The purpose of this section of the report is to briefly describe the regional geological setting in which mining operations of the company are located.

Brown iron ore was discovered north of Wawa Lake in 1898. Within the next two years most segments of the iron formation extending northeastward to the Algoma Central Railway had been discovered and prospected in a preliminary manner. The segments which have since attracted most attention are from west to east, the Helen, MacLeod Mine, Sir James Mine, Lucy, Ruth, Josephine and Britannia. At the Helen, brown ore was first mined. It was realized that the brown ore represented an oxidized portion of a much larger body of siderite which was explored and tested in detail. Active mining of the siderite was initiated in 1939 and has continued to the present. Much surface work was performed on the Ruth and Lucy properties were examined in detail by Jones and Laughlin Steel Corporation during the years 1947 to 1952. The Josephine-Britannia range was discovered in 1899. A hematite deposit at the Josephine was drilled in 1900 and 1906 and again in 1913 to 1914. In 1941, Michipicoten Iron Mines sank a shaft on the property. The mine was put into production by Sheritt Gordon Mines Limited in 1945 but closed one year later because of caving. The Britannia siderite property was first drilled in 1912 by Algoma Steel Corporation and again in 1946 by Algoma Ore Properties Ltd. A sizeable body of siderite was discovered beneath drift cover at the Sir James Mine in 1948. This was mined as an open pit unitl 1967, when the ore was depleted.

Lucy Mine: Following the depletion of the Sir James Ore Body, development work was completed and pit production started at the Lucy Ore Body. This Ore Body is approximately two miles north of the Sir James Mine.

GENERAL GEOLOGY

The iron formation, which contains all known ore bodies, lies within a complex assemblage of Precambrian volcanic and sedimentary rocks which are collectively termed the Michipicoten series. The larger part of the series consists of volcanic rocks varying in composition from basalt to rhyolite and in structure from flow to fragmental. Two principal horizons of sedimentary rocks - iron formation and assorted clastics - occupy stratigraphic positions within this volcanic pile. Both sedimentary horizons are structurally concordant for the most part with enclosing volcanics. Iron formation appears to have formed during a period of relative volcanic quiescence in which chemical activity prevailed, and the clastics during a period of moderate structural uplift with attendant erosion and sedimentation. The Michipicoten series, thus, represents in essence a single structural and stratigraphic unit, the sedimentary horizons reflecting relatively brief sedimentary interludes in a dominantly volcanic process.

Intrusive into the volcanic-sedimentary rocks are stocks and larger masses of granite and granite gneiss, sill and dyke-like masses of diorite and numerous diabase dykes.

Stratigraphy of the Michipicoten Series

The stratigraphic sequence of the Michipicoten series in the Helen - Britannia area is as follows in descending order

Doré Sediments
Basic Volcanics
Iron Formation
Acid Volcanics
Basic Volcanics

The distribution of rock types is illustrated in Diagram 1. A principal stratigraphic feature is that the iron formation is located at or near the contact between acid volcanics below and basic volcanics above.

Volcanics

Basic volcanics occur in two parallel zones, one lying south of the acid volcanics and the other north of the iron formation. The common variety is a greyish green, fine grained, schistose rock approaching andesite in composition. Pillow structures, amygdules and flow tops are common, particularly in the north zone.

Acid volcanics immediately underlie iron formation throughout the length of the range and, in the vicinity of the Britannia property, overlie it. The band varies considerably in width, ranging from 2000 feet at the Britannia to more than 6000 feet at the MacLeod. It is composed mainly of grey to yellow schistose felsite flows and pyroclastics. Pyroclastic phases range from fine grained tuff to unusually coarse agglomerate. Fragments in the latter range up to 18 inches in diameter and are composed of massive and porphyritic felsite together with minor basic lava. Acid volcanics have been extensively carbonatized south of the iron formation. The degree of carbonatization increases northward and is a maximum at the contact with iron formation.

Iron Formation

Iron formation normally consists of the following ternary succession in descending order:

Banded chert member
Pyrite member
Siderite member

The banded chert member is a thick and persistent unit. The two iron-bearing members, on the other hand, are in the form of lenticular, irregular masses basal to banded chert. The relative positions of the members are consistent and are used to indicate original stratigraphic tops.

The characteristic phase of the banded chert member consists of thin bands of nearly pure chert alternating with equally thin bands of chert intermixed with one or more of siderite, pyrite and magnetite. The member thickens and thins considerably along strike; it ranges from a few feet to 1000 feet and averages approximately 350 feet. Zones of carbonaceous material ranging up to 25 feet are present.

The lowermost or siderite member attains a maximum thickness of 300 feet at the MacLeod property. Elsewhere it ranges up to 200 feet thick. It is distinctly variable in distribution and thickness. The siderite ranges from light grey to pale buff in color. It is of massive uniform structure for the most part although locally finely laminated. It contains variable siliceous impurities which are present either as disseminated grains and patches of chert or as thick, persistent chert zones. The siderite contains variable chloritic and micaceous impurities. Adjacent to diabase dykes in particular, siderite has been partly converted to magnetite.

Doré Sediments

Sedimentary rocks of the Doré series extend as a parallel band north of the iron formation and separated from it by a thickness of volcanics. The Doré band varies greatly in thickness, ranging from approximately 3000 feet at the west end to less than 300 feet at the east end. It consists of conglomerate, greywacke, shale, arkose and quartzite, the first three predominating. Coarser phases are more common to the southwest. Pebbles and boulders of granite, iron formation and basic and acid volcanics compose most of the conglomerate.

Intrusive Series

Intrusive into the volcanic sedimentary rocks is a series of granites, granodiorites, diorites and related rocks, and diabase dykes. A main mass of granite and granite gneiss is situated southeast of the Helen-Britannia area. Smaller masses of granite, feldspar porphyry and splite occur. Diorite intrusives ranging from thin dykes to large sill-like masses several hundred feet thick are present in the volcanics, particularly south of the iron formation. All older rocks are intersected by two sets of diabase dykes. Older, quartz-bearing diabases occupy northwest-trending fractures and younger relatively unaltered diabases occupy northeast-trending fractures.

Structure

The main structural features of the Helen-Britannia area are relatively simple. The volcanic-sedimentary sequence forms the south limb of an east-west trending syncline which has been slightly overturned to the north. Thus, the rocks dip steeply southward in monoclinal succession and have their tops to the north. The syncline plunges eastward at 40 to 60 degrees in the vicinity of the MacLeod Mine.

Thus, rock units at the mine pass eastward at depth.

The iron formation has been segmented by a group of northwesterly trending, left-hand cross faults i.e relative movement east side north. Horizontal movement ranges up to two miles as in the case of the fault separating Sir James Mine and Lucy segments. Low angle, east-west striking thrust faults are present in the Helen range and are probably present elsewhere. Other smaller fault groups are also present. The entire assemblage of volcanic-sedimentary rocks has been rendered more or less schistose by strong shearing; the prevailing schistosity strikes north 65 degrees east and dips steeply southward.

MINE GEOLOGY

Stratigraphy

Lower Volcanics

A mixed assemblage of acid tuffs, agglomerates and rhyolites form the base of the iron deposit at a slight angular unconformity.

Individual beds and flows show little continunity and are often sharply truncated. They are thus not useful as horizon markers. One large bed of agglomerate at the west end of the line is the main exception being 4000 feet long and 700 feet wide. It also is sharply truncated.

The tuffs range from fine to coarse grained and grade into agglomerates. They are composed of quartz and feldspar grains with scales of sericite.

The agglomerates usually contain rhyolite fragments up to six feet in diameter in a pale coloured acidic ground mass. One bed with a length of 2300 feet and a thickness of 300 feet contains rhyolite fragments in a ground mass of chlorite schist.

Bodies of porphyritic rhyolite occur with quartz phenocrysts forming a large proportion of the rock. They conform to the surrounding volcanics but may be intrusive into them. They do not intrude the siderite or iron formation. If they are intrusive, they are probably genetically related to the lower volcanics and therefore confined to them.

The above rocks have been sheared with large volumes being altered to sericite-carbonate schists often containing large amounts of ottrelite. Ottrelite is not limited to the schists and is known to occur in siderite, metadiorite and quartz-carbonate veins.

Lower Banded Iron Formation

Between the lower volcanics and the siderite a band of banded silica type iron formation usually occurs from a few inches to 15 feet in width. This band is indistinguishable from the upper banded iron formation. Where the iron formation is absent the underlying tuffs are commonly sideritized to some depth.

Siderite-Pyrite And Secondary Oxides

The siderite is dense and felsitic in appearance. It is usually massive although some siderite is distinctly banded. Colours range through buff, brown, grey and black. The fracture is blocky.

The siderite resembles fine-grained acid rocks in fresh specimens and it is difficult for the inexperienced to distinguish between them. Siderite oxidizes to a chocolate brown colour whereas the volcanics remain relatively unoxidized. A specific gravity of 3.5 is another distinguishing feature.

Pyrite is present in the siderite from lows of less than one per cent to highs of 60 per cent by volume. It is found in small grains and clusters of grains throughout the siderite. The pyrite is concentrated near the top of the ore-body and commonly occurs in a "honey-comb"-like structure enclosing small masses of siderite. It has a banded structure with increase and decrease in pyrite content.

Ore widths in the MacLeod Mine reach a maximum of 300 feet. In the last section of the mine a 40 to 60 foot band of central granular silica divides the ore body.

A typical siderite assay is as follows:

	Per cent
Fe	35.62
SiO_2	7.14
S	2.93
Mn	1.98
CaO	2.38
MgO	5.82
Al_2O_3	1.41

Magnetite has formed from the alteration of siderite in the vicinity of intrusives, particularly diabase dykes. A width of 5 to 25 feet is commonly altered alongside these dykes.

A body of oxide ore, mainly geothite with some hematite was formed as a result of oxidation of siderite and pyrite by surface waters, beneath the waters of Boyer Lake. The oxide ore extended to a depth of 700 feet. This oxide ore body was the basis of the original Helen Mine. The ore was reported as porous and cavernous, containing large pockets of silica sand and pyrite sand.

Argillite

Within the siderite a band of argillaceous rock, with a thickness up to 5 feet, occurs usually at a distance of 40 feet above the lower banded iron formation. One band has been traced for 800 feet in this position. A similar band occurs immediately above the lower banded iron formation.

The rock is grey coloured and finely bedded with bands of pyrite and pyrrhotite. It usually grades into siliceous siderite.

Central Granular Silica

A bed of granular silica occurs centrally within the siderite. It is a relatively coarse granular silica with a coarse banded structure. Colour is usually white or buff from the addition of siderite. Bands and patches of siderite occur most commonly on the lower side.

This bed is thin to absent in the west end of the mine but gradually thickens to the east where it reaches a maximum thickness of 60 ft.

Occasionally small bands of silica are found above this central band mainly in the west end of the mine.

Upper Granular Silica

This band is similar to the central silica band and lies immediately above the siderite-pyrite. The silica is commonly interbanded with siderite and pyrite. Some sections are brecciated producing a silica-siderite-pyrite braccia.

This band grades imperceptibly upwards into the upper banded iron formation as the beds become thinner and darker coloured. Maximum widths of 100 feet are obtained in the upper mine levels in the vicinity of the 5000 E. co-ordinate thinning rapidly to the east and west.

Upper Banded Iron Formation

Above the upper granular silica and siderite-pyrite is a band of banded silica type iron formation. The band ranges from 600 feet thick at the west end of the mining area to 300 feet at the east end. West of the mining area a thickness of 1400 feet is obtained but this increase is attributed to folding.

The beds are composed of granular silica laminae 1/16 inch to several inches in thickness varying from white to black in colour and producing a pronounced banded structure. Individual laminae tend to lens out within a few feet and the whole represents a series of overlapping lenses.

Siderite bands often alternate with silica and fill fractures in the silica. The iron formation is more sideritic at the base where typical assays range from 24 per cent iron and 42 per cent silica to 11 per cent iron and 74 per cent silica at the top.

Beds of graphitic slate are found within the banded iron formation and one commonly marks the contact between the upper granular silica and the upper banded iron formation.

A few bands of silica and coarse magnetite are known but magnetite is a minor constituent of the iron formation.

Some beds have been intensely brecciated. They vary from one foot to tens of feet in width. Fragments up to a foot long, lying in chaotic arrangement and cemented by granular silica is the common type. Bands of unbrecciated iron formation above and below are conformable suggesting the brecciation is contemporaneous with deformation and is possibly due to slumping of bess.

A large area of brecciated iron formation lies to the west of the mine. This breccia is largely cemented with siderite but may be a breccia resulting from dynamic metamorphism.

Upper Volcanics

A thickness of 1600 feet of basic lava, basalt and andesite, overlies the banded iron formation. Amydaloidal lava is common and pillow lavas are numerous with their tops facing north. Basic lavas give way to more acid phases with interbedded pyroclastics above this.

Intrusives

Gabbro, Metadiorite and Related
Acidic Intrusives

Large sill-like masses of coarse gabbro lie to the south of the mine area. From these sills numerous irregular off shoots occur which intrude the volcanics the siderite and iron formation. Locally these intrusives are called metadiorite.

The rock is largely composed of clusters of dark green chlorite in a paler coloured chloritic and carbonatized matrix giving a mottled texture. Irregular quartz-carbonate stringers are common. These intrusives grade into more acid phases with a great variety of compositions and textures. Differentiation of metadiorite is the probable origin of these intrusives which intrude along fault zones.

Where the siderite has been intruded by metadiorite a magnetite aureole n the siderite sometimes occurs.

Diabase-Lamprophyre Dykes

Five steeply dipping diabase dykes intrude the mine area. Two of these dykes cut through the center of the mining area on a northwesterly strike. They are called the east and the west dykes. The west dyke is normal diabase with occasional large phenocrysts of olivine. The east dyke is a highly altered saussuritized diabase. A strong fault zone along this dyke displaces the ore between west and east sections of the mine.

The east end of the mining area is terminated by a dyke and similar fault movements. The dyke, referred to as the Wallbank Lake dyke, is olivine diabase.

A fresh quartz diabase dyke with a north-east strike cuts through the centre of Boyer Lake and is called the Boyer Lake dyke. This dyke is the youngest diabase in the area.

A normal diabase dyke at the west end of the mine cuts through Talbot Lake with a northwesterly strike and is known as the Talbot Lake dyke.

Lamprophyre dykes parallel the east and west diabase dykes. The most notable of these is one 2 to 10 feet wide which closely parallels the west diabase dyke. This dyke splits into two and reconverges along its strike. Numerous small lamprophyre dykes parallel the east dyke closely on its east side.

All of the above dykes are known to exist to the greatest depths reached in mining.

Some dykes intrude fault zones entirely while others partially follow both fault zones and tension fractures with no apparent displacement of the ore horizon across the dyke.

STRUCTURAL GEOLOGY

Folding

The foregoing stratigraphic sequence has been overturned by folding and now represents a monoclinal structure dipping south at 80 degrees to vertical with displacements down the dip producing average dips of 60 to 70 degrees. The strike is a few degrees north of east. Due to this overturning the geological footwall becomes the mining hanging wall and is referred to as such.

Metadiorite intrusions probably occurred during the late stages of folding as intrusives of this type are found in faults related to folding. Diabase dykes of the Keweenawan type are the youngest rocks and were emplaced after folding.

A major fold occurs in the banded iron formation west of the mining area at surface and plunges easterly at 50 to 60 degrees. The ore zone terminates on surface in this area but is much confused by intense brecciation and faulting.

Underground mining and diamond drilling have proven that the ore rakes east in a similar attitude. This is also indicated by an easterly rake to the pyrite zone and the central granular silica.

Minor folds of a similar nature occur in the banded iron formation particularly in the east and west diabase dyke area. The ore zone is not folded similarly but is displaced by major faults.

Folded thrusts with dips 15 to 30 degrees south have displaced the ore zones above relatively northward and up. This feature, while partly due to faulting, is largely due to folding as the wall rocks have been folded to these flat attitudes. The actual contact between the upper banded iron formation and siderite in these zones is always a flat thrust fault.

This folding was more pronounced in the Victoria ore-body and has resulted in much greater displacement of ore blocks than in the Helen. In the Helen ore-body the thrust is marked in places by a fault only.

Two major thrust zones are now known to exist. The number one thrust zone lies between the second level Helen Mine and first level in the MacLeod ore-body and is displaced relatively upwards to the east by faulting at the east and west diabase dyke area. The thrust lies just above the first level in the old Victoria ore-body and reaches surface between the 6800 and 7000 east co-ordinate.

A second flat thrust zone has been located at the sixth level horizon and has displaced the ore-body similarly to the number one zone. A repeating imbricate structure is thus inferred.

Faulting

Five major fault types occur within the mining area.

Flat Thrust Faults - as mentioned under folding these faults dip 15 to 30 degrees south and due to their flat nature are sinuous in plan but have a general east-west strike.

East Type Faults - strike north 60 degrees east and dip 60 degrees south easterly to 60 degrees north-westerly. They have left hand movement and have thinned the ore zone due to their large displacements at small angles to the ore-body.

These faults are confined to the Victoria ore-body, and at the tops of the ore blocks flatten and merge with the flat thrust faults.

Valley Type Faults - strike due east to south 60 degrees east and dip steeply south. Relative movement is right handed and is mostly horizontal. This type of faulting commonly has a thick breccia whereas all other fault types are tight.

They are confined to the Victoria ore-body. Above the first level they have caused a rough hanging wall as they have produced a series of small overlaps of the contact. Below the first level immediately east of the east dyke, a large ore area was faulted out in part by faulting of this type. However, this may be in part due also to a steepening of the flat thrust zone below first level.

Transverse Type Faults - strike north 35 degrees east across the ore-body with steep dips east and west. They have left hand movement with a maximum of 250 feet of horizontal displacement, and are sometimes quite discontinuous. A strong displacement on the footwall may not be apparent on the hanging wall, or the opposite may occur.

Displacement along the faults decreases as the flat thrust zones are approached. They are not known to displace flat thrust zones and are probably confined to blocks of ore between such zones. Above number one thrust zone in the MacLeod ore-body these faults were numerous. Below the thrust zone they are scarce and have only minor displacement.

Victoria Type Faults - strike north westerly and dip deeply southwest to northeast. Relative movement is left handed.

Most of the diabase dykes follow these faults or tension fractures on the same strike.

They predominate in the east and west dyke area and apparently displace the flat thrust zones relatively upwards on the east side. One large fault paralleling the east diabase dyke is known as the Victoria fault. It has several branches to the west.

The second main Victoria type fault is known as the Helen fault. It lies between the east and west diabase dykes and displaces the ore 200 feet. The strike is more northerly than the Victoria fault. The dip is steeply west at surface but changes to steeply east. Between the first and second level, drilling indicates it joins the Victoria fault above the fourth level of the MacLeod Mine.

A third main fault of this type lies along the east side of the west diabase dyke and is named the west Helen fault. This fault begins to show some displacement just below the first level of the Helen. At the second level Helen displacement has increased to 100 feet and at the 2nd level MacLeod 180 feet.

The mining zone terminates to the east of the Wallbank diabase dyke.

As can be observed from the above, a complicated fault pattern has developed probably during late stages of folding. Faulting is more intense in the upper levels of the mine than at depth. Faulting may be developed in one or more stratigraphic units and missing in an adjoining unit. A great difference in relative competency of stratigraphic units with each reacting differently to stress is suggested as the logical explanation.

SYMBOLS:

- GEOLOGICAL CONTACT
- FAULT
- ATTITUDE OF FORMATION (80)
- ATTITUDE OF SCHISTOSITY (75)
- TOP OF LAVA FLOW – PILLOW

LEGEND:

- DIABASE
- ANDESITE FLOWS
- QUARTZ PORPHYRY
- METADIORITE
- BANDED IRON FORMATION
- SIDERITE, PYRITE
- MAINLY DACITE TUFF BRECCIA
- MAINLY RHYOLITE TUFF BRECCIA

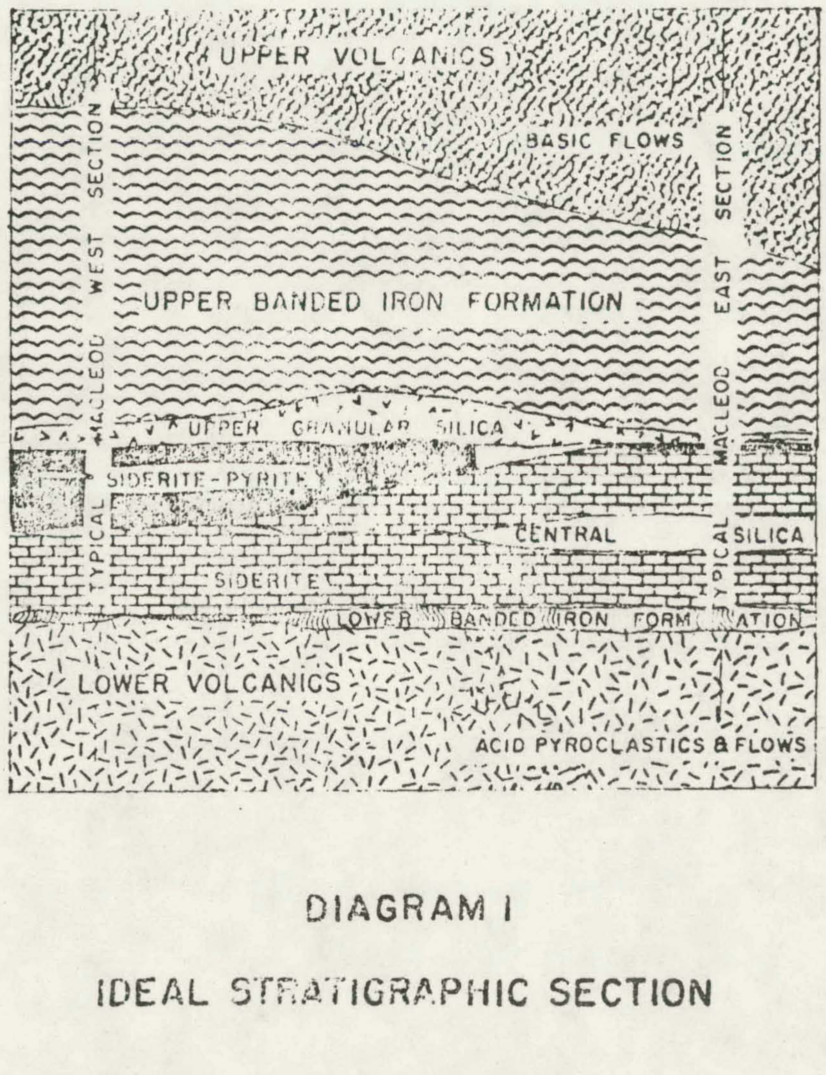


DIAGRAM I

IDEAL STRATIGRAPHIC SECTION

MACLEOD MINE

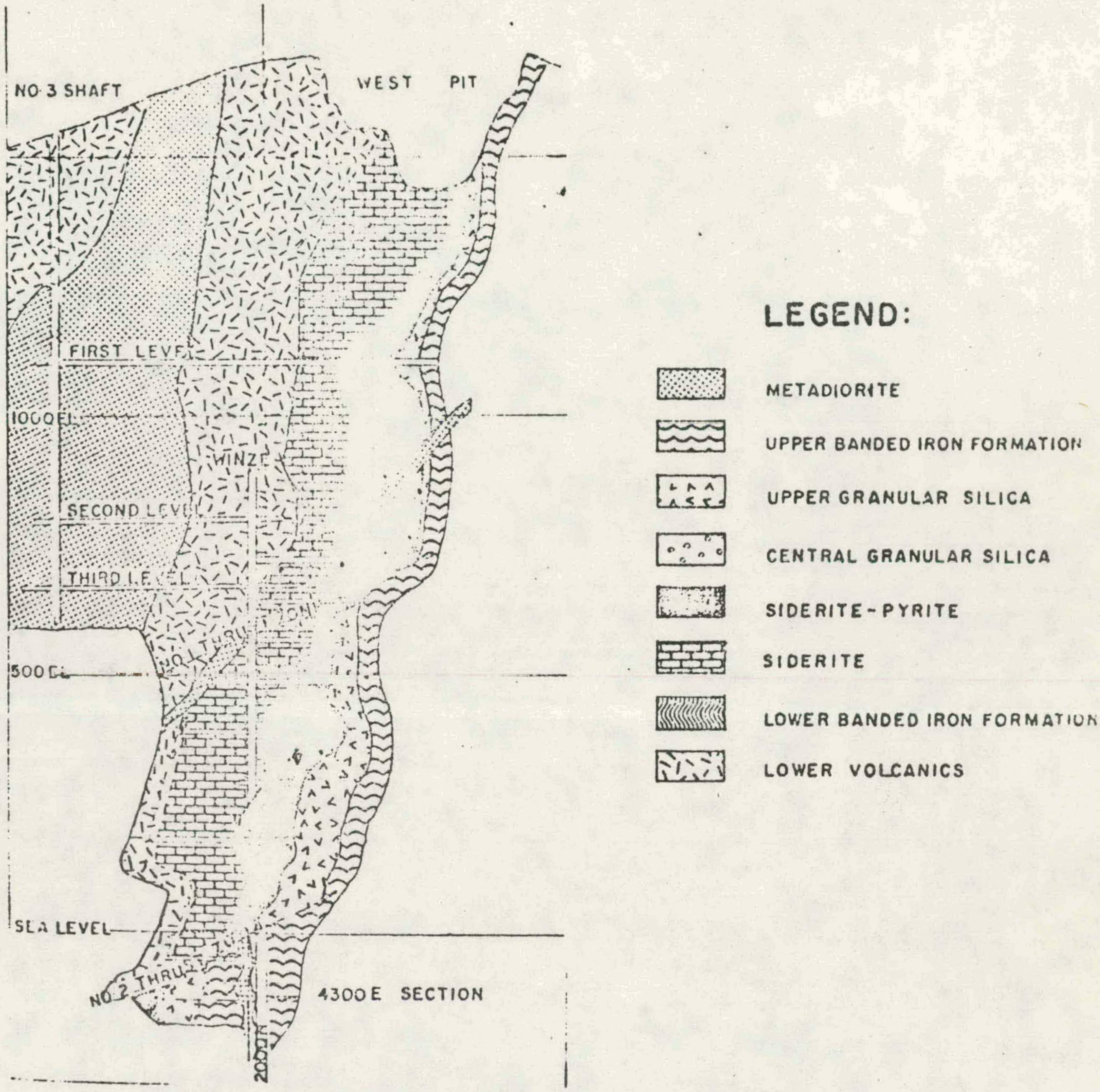


DIAGRAM 2.

GENERAL CROSS-SECTION

MACLEOD MINE

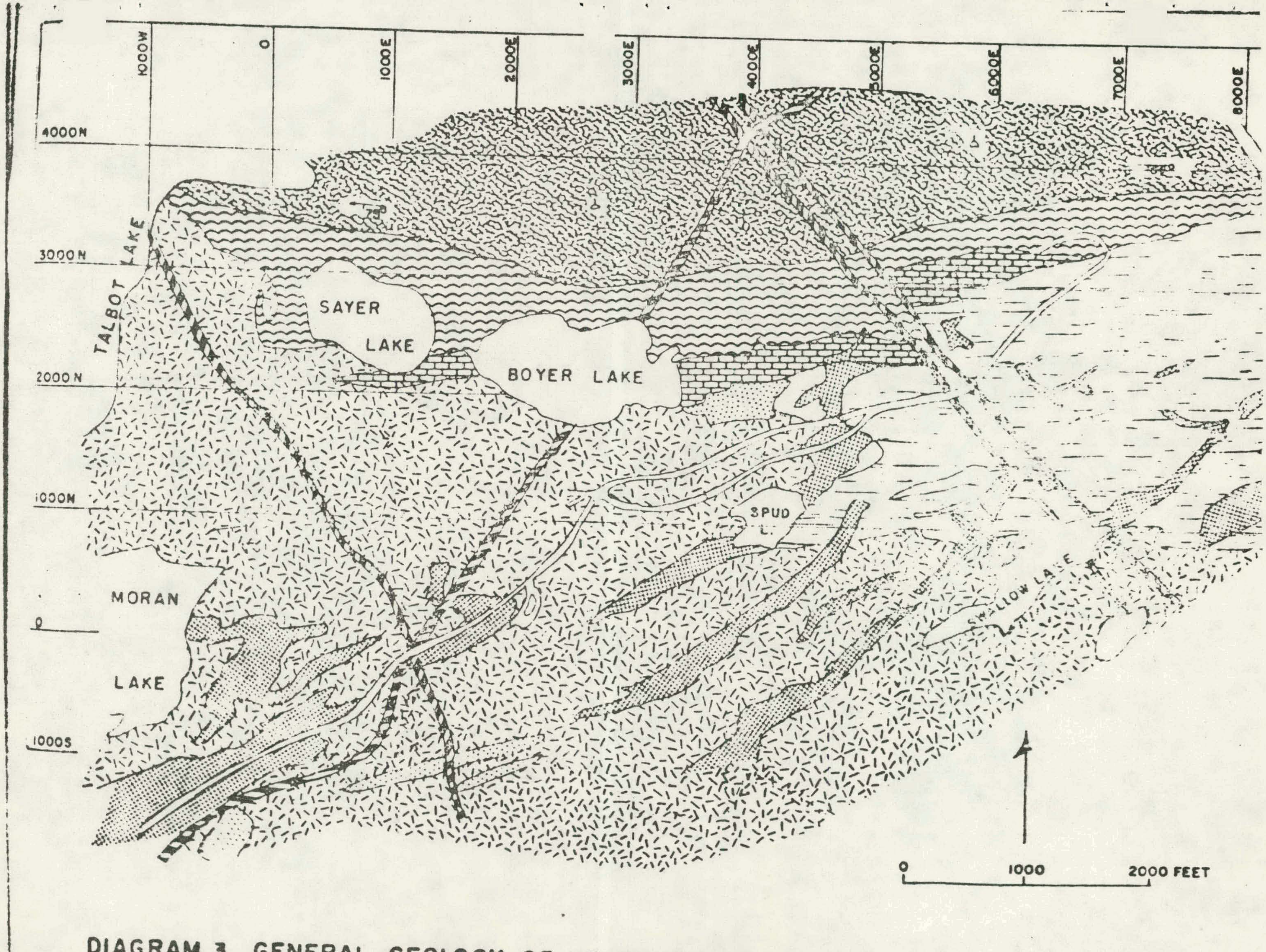


DIAGRAM 3. GENERAL GEOLOGY OF HELEN IRON RANGE - TP. 29. R. XXIV. MICHIPICOTEN

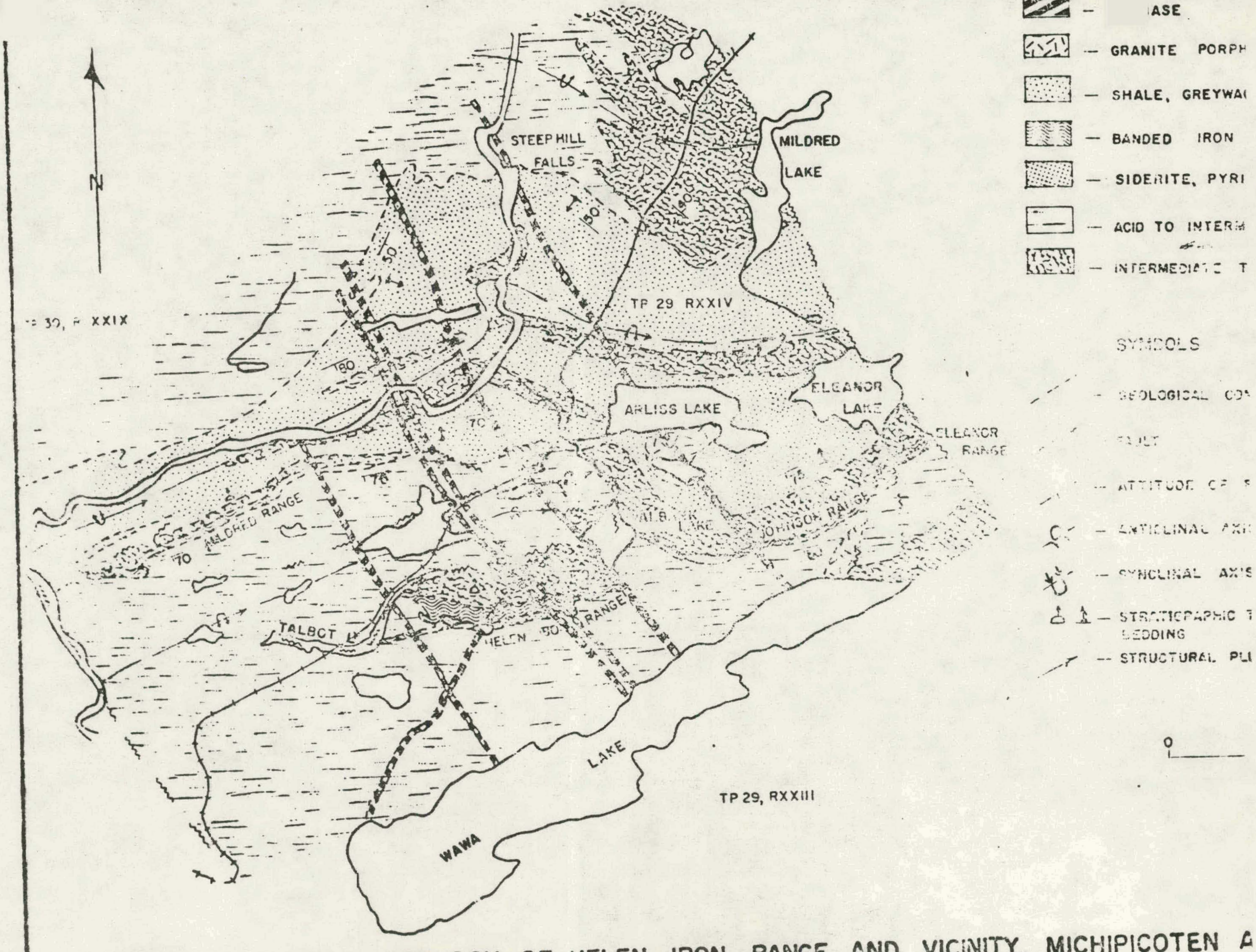


DIAGRAM 4. GENERAL GEOLOGY OF HELEN IRON RANGE AND VICINITY, MICHIPICOTEN A

December 3, 1963

REPORT OF A RUN OF WATER & SANDS ON M-1 LEVEL OF MacLEOD MINE

On November 29, 1963 dayshift a crew of two men were driving M-124 Vent. Raise. The crew completed the drilling cycle and reported heavy water flow out of five holes but no pressure. Instructions were left for the night shift crew that if water flow diminished they were to blast the round. The water flow had not diminished and the round was left to drain for the weekend.

On December 2, 1963 dayshift the crew was sent to the raise. Upon checking by a senior supervisor the water flow had diminished greatly and crew were instructed to blast the round at the end of dayshift.

The shots did not go at the regular blasting time of 3:15 p.m. due to a faulty battery and crew was sent back down with another battery to blast the round. The round was blasted at approximately 4:45 p.m. The crew phoned to surface from M-120 lunchroom and reported approximately 1 1/2 ft. of water at the bottom of M-124 Vent. Raise.

The M-1 level pumpman was notified to prepare for heavy water. When the two men returned to surface they were questioned. J. Roussain and N. Green went to M-1 level to check conditions. Water heavy with sands was noted in the ditch running to the M-1 sump. Mud was noted across the track at M-1 Clayton charging station and flow of water in ditch was approximately double normal conditions. After proceeding about 100 ft. east of M-112 Raise the mud was about 8 inches deep and a loud noise could be heard in drift ahead. Another flow of water and mud was running down the drift carrying with it fairly good size timbers. Could not proceed further east in the M-1 H. W. Dr. due to mud conditions. Returned to M-1 Clayton charging station and the floor of the charging station was covered with about 4 inches of mud. Main switch was pulled off power in charging station. Mud was also flooding track at junction of M-1 H. W. Dr. and M-1 F. W. Dr. From the above location to the shaft sump the flow was contained in the ditch.

J. Roussain and N. Green proceeded east in M-1 F. W. Dr. to try to get near raise from the east end. Upon passing M-120 lunchroom a phone call was made to surface (approximately 6:00 p.m.) to notify P. M. Nixon, Supt. - Mines and Mechanical Foreman to get a millwright out to keep a check on M-1 pumps.

Upon checking, water and mud was found at east end of M-124 Vent. Drift. Proceeded back to west end and the flow past M-112 Exhaust Raise had diminished and area was relatively quiet. Proceeded east to bottom of M-124 Vent. Raise. Approximately 1 ft. of mud was in floor of drift east to M-120 Access Drift. From M-120 Access Drift to M-124 Vent. Raise mud thickness increased gradually to approximately 5 ft. at the raise. The raise was observed from a distance of about 20 ft. Broken timber and muck could be seen in the manway and steelslide of the raise completely blocking the raise opening. There was a small flow of water from the raise. Proceeded back to surface to report conditions. Arrived on surface at approximately 6:30 p.m.

After consultation with Mine Staff personnel, it was decided to construct a temporary dam at ventilation door frame about 50 ft. east of M-1 Clayton charging station. The dam consisted of 7" x 9" timbers wall to wall and 6 ft. high. Ditch was left open and sand bags were provided to seal ditch if a rush of mud was experienced.

A watchman was left in the area on a continuous basis. The dam was complete by 3:00 a.m. December 3rd.

At approximately 5:30 a.m. another flow of mud and water was experienced. The dam contained the main force of the rush but the ditch was not plugged and allowed a heavy flow to proceed on out to shaft sump. A minor amount of the mud passed the sump to the shaft station. No difficulty was experienced on the shaft bottom due to the small flow of mud.

After examination at 7:00 a.m. by N. Green and J. Roussain, it was decided to curtail mining operations. After further examination by Mine Staff it was decided to erect three timber bulkheads; one in M-1 H.W. Dr. at west door frame east of M-1 Clayton charging station; one at west side of M-124 Ore Pass Raise and one at east end of M-124 Vent Drift.

The bulkheads were complete by 7:00 p.m. December 3rd. Normal operations resumed with the 7:30 p.m. shift on December 3, 1963.

N. E. Green,
Mine Captain.

NEG:gr

Algoma Ore Properties.

December 10, 1963.

Report of a Second Run of Water & Sands on M-1 Level of MacLeod Mine.

At 10:30 P.M. December 4th, two men working in M-127 slusher drift reported a run of sand and water into their working place to a shift boss. The shift boss notified the MacLeod Shaft hoistman who in turn notified senior supervision.

At 11:10 P.M. the senior supervisors at the mine site had the stench gas injected into the mine air to remove all personnel. Eighteen men were kept at the mine to do necessary work after investigation.

Upon investigation it was found that a timber bulkhead in the east end of M-124 By-Pass Drift that had been erected on Dec. 3rd, had failed. Sand and water had run through M-1 H.W. Dr. to M-127 Slusher Drift and north in the Slusher Drift to approximately #3 boxhole. At that point the flow was held back by a build up of muck in the slusher drift. Further investigation was made and it was noted that the mud had run east through M-1 H.W. Dr. to M-129 X-Cut E. then north through M-129 X-Cut E. The flow had been approximately 1' deep at the M-129 slot drift location. The flow had run further north in M-129 X-Cut E. and down M-130 Pillar Raise which was being used as an ore pass.

A flow of water and sands had gone down through the ore pass system to "I" crusher station and filled the jaw of the crusher. A minor amount was noted on the crusher room floor.

A heavy flow of mud was also experienced through the 6" valve in the dam erected on Dec. 3rd in M-1 H.W. Dr. just west of M-112 Raise. The flow was handled by the pumping station at M-1 station of MacLeod Shaft.

Since one of the three bulkheads erected on Dec. 3rd failed, it was decided to strengthen the remaining two immediately with further 7" x 9" timbers on 1¼" pins in the walls. A decision was also made to re-construct the timber bulkhead that had failed as soon as possible. Upon completion of the strengthened bulkheads, work would commence on installation of three, reinforced concrete bulkheads 5' thick outside of the timber bulkheads. The concrete bulkheads were designed to withstand the pressure of the head to the H-2 level.

A fourth reinforced concrete bulkhead 6'-6" in thickness was started in 220 X-Cut. The bulkhead was thought necessary because M-220 P. Rse. had been driven to within 6' of M-1 level. The break through round had been drilled and blasted but investigation at the top of break through location on Dec. 2nd indicated that in fact the raise was not broken through. The thickness of ground from break-through was unknown and the bulkhead was thought necessary.

Before re-construction the bulkhead at the east end of M-124 By-Pass Drift and strengthening the bulkhead at west side of M-124 Ore Pass Raise, it was necessary to remove the mud and water from the area. This was done by slushing the material down the millhole of M-127 Slusher Drift. Guards were posted at the M-2 level and "I" crusher room to ensure that the water and sands were passing through the ore pass system.

M-112 Area Bulkhead -

In M-1 H.W. Dr. strengthening of the timber bulkhead was complete by 7:30 A.M. Dec. 5th. Construction of the reinforced concrete bulkhead was then commenced and comple by 3:30 P.M. Dec. 7th.

M-124 By-Pass Bulkhead -

Completed timber bulkhead at 3:30 A.M. Dec. 6th and commenced work on the reinforced concrete bulkhead. The reinforced concrete bulkhead was complete at 6:00 A.M. Dec. 8th.

M-124 Ore Pass Bulkhead -

Completed reinforcing the timber bulkhead at 7:30 A.M. Dec. 6th. The reinforced concrete bulkhead was complete by 2:00 P.M. Dec. 8th.

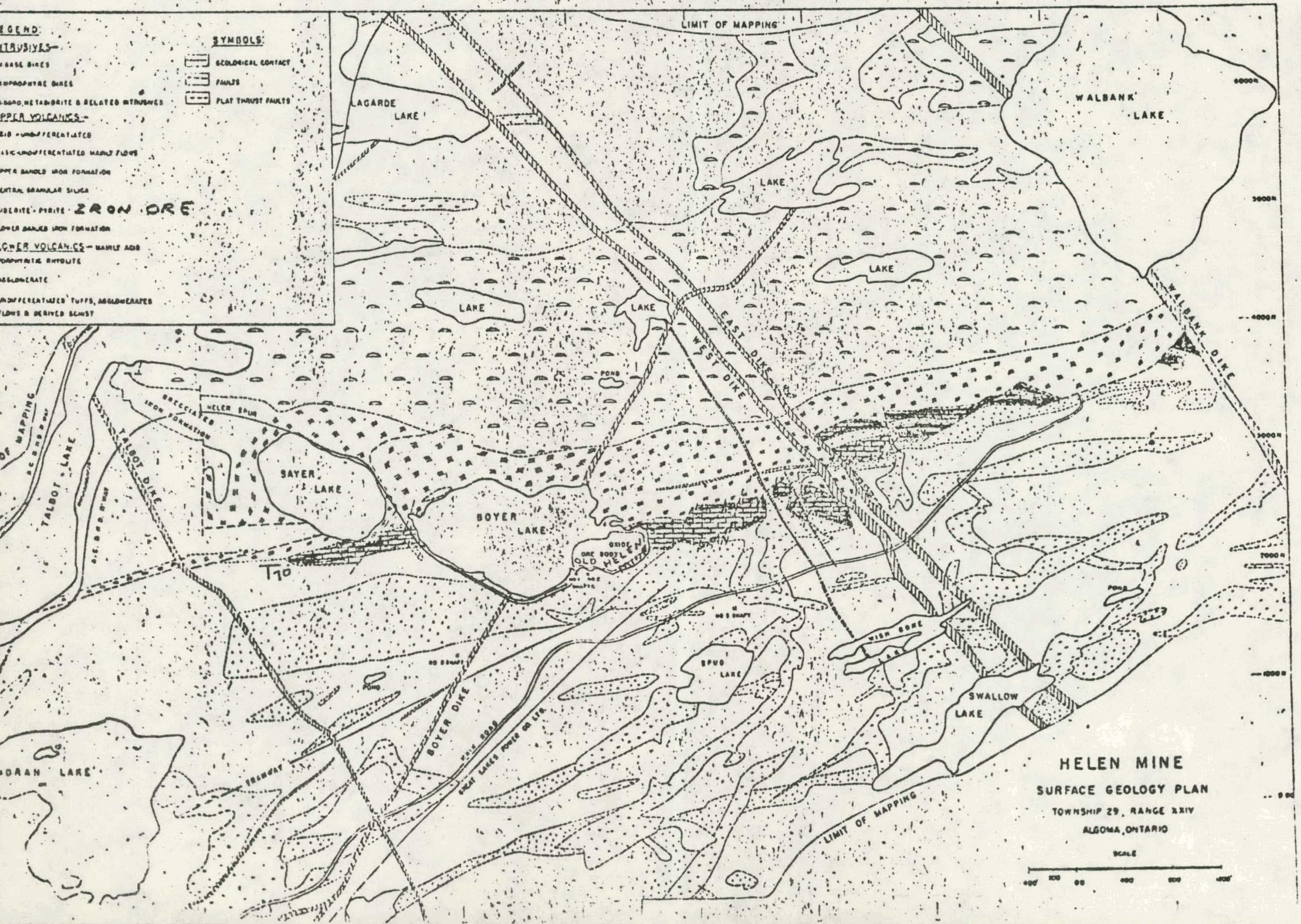
M-220 X-Cut Bulkhead -

Commenced work on reinforced concrete bulkhead on Dec. 5th at 7:30 A.M. Bulkhead was complete at 8:00 P.M. on Dec. 7th.

MacLeod Mine returned to normal shift operation at 11:30 P.M. Dec. 8th, 1963.

N.E. Green,
Mine Captain.

NEG/cv


SYMBOLS:
GEOLOGICAL CONTACT
FAULTS
FLAT THRUST FAULTS
IRON ORE
LIMIT OF MAPPING
LAGARDE LAKE
WALBANK LAKE
LAKE
EAST DIKE
WEST DIKE
WALBANK DIKE
TALBOT DIKE
TALBOT LAKE
BRECCIATED IRON FORMATION
HELEN SPUR
SAYER LAKE
BOYER LAKE
OLD HELEN
BOYER DIKE
SPUD LAKE
SWALLOW LAKE
POND
TRAMWAY
HELEN MINE
SURFACE GEOLOGY PLAN
TOWNSHIP 29, RANGE XXIV
ALGOMA, ONTARIO
SCALE

Denison Mine

Location

The Denison mine is located about 11 miles north of Elliot Lake, Ontario Canada.

Geology

The geology is outlined in the attachments from material supplied by Denison Mines.

General Statement

The mine visit started by entering the mine at the 2465 level. During the tour we covered about 15 miles of mine workings by truck, over an area of four square miles, with numerous stops. The deepest workings visited were at a depth of 2960 feet. The areas visited are below Quirke Lake which is 350 feet deep. The workings are dry.

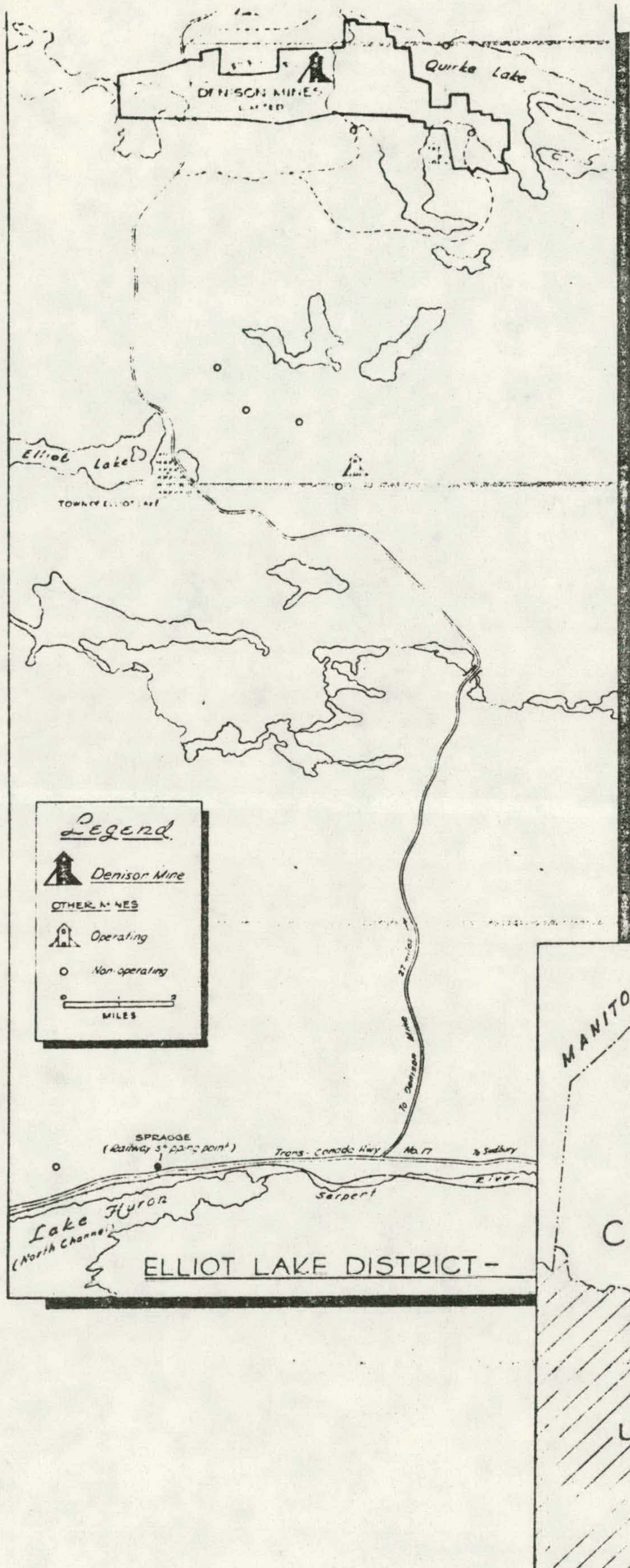
At one 20 foot face there are 5 bedding plane slips in the ore layer, but no seepage or dampness. There was some minor iron - staining that extended 100 feet or so laterally. Some minor steep strike-slip faults cut the ore, show slickensides and an apparent movement of about 2 feet. No evidence of water was seen in or near these faults.

The only water reported was in an abandoned area, no longer accessible, where 20 G.P.M. occurred. This was grouted and sealed.

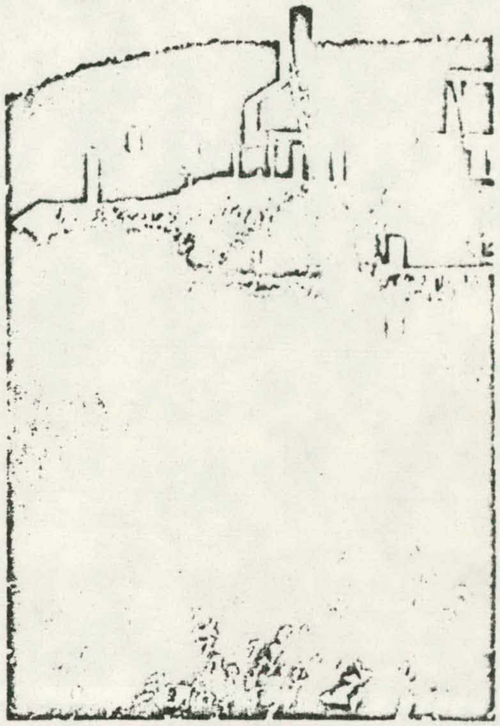
A shaft from surface encountered a thrust fault at 1200 feet that was very wet. A three month delay ensued while grouting was carried out. No water was encountered below that depth. The thrust fault is shown on the attached geologic section.

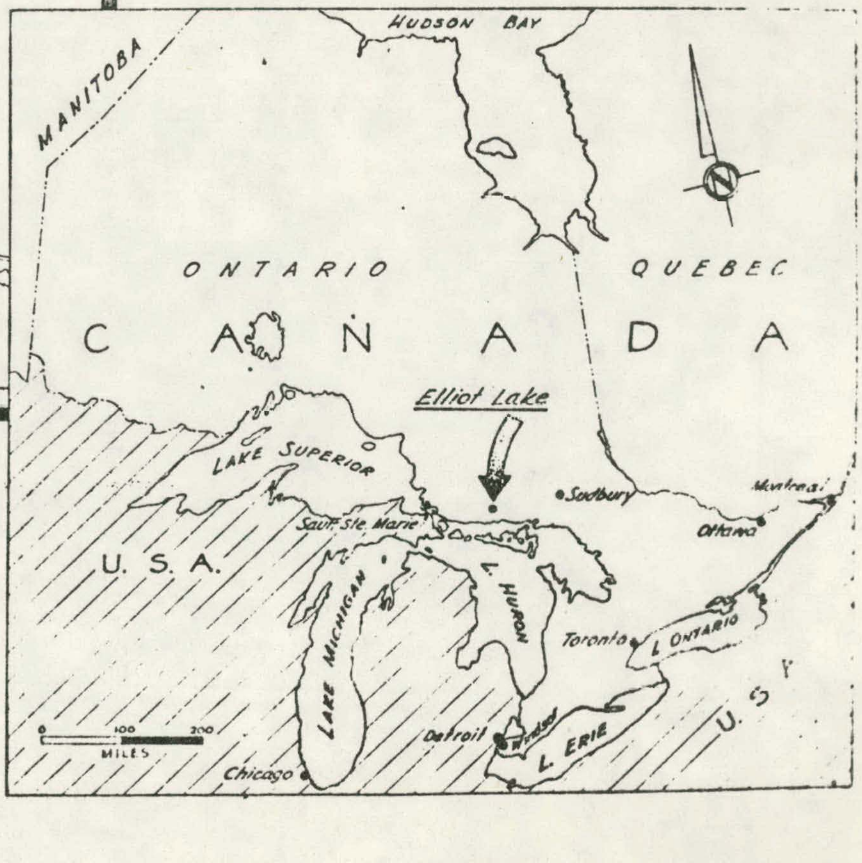
It is reported that this same thrust fault extends into the adjoining Spanish American mines and that it was quite wet. Further details on this are being sought.

It is noteworthy that despite the extensive mining there appears to be no hydrologic connection to the water - bearing thrust fault a thousand or so feet above the workings. The lack of water movement on the numerous bedding plane slips, faults, or dikes suggests that at these depths the rock pressures are sufficient to "pressure seal" the fractures in the geologic time available since the fractures developed.

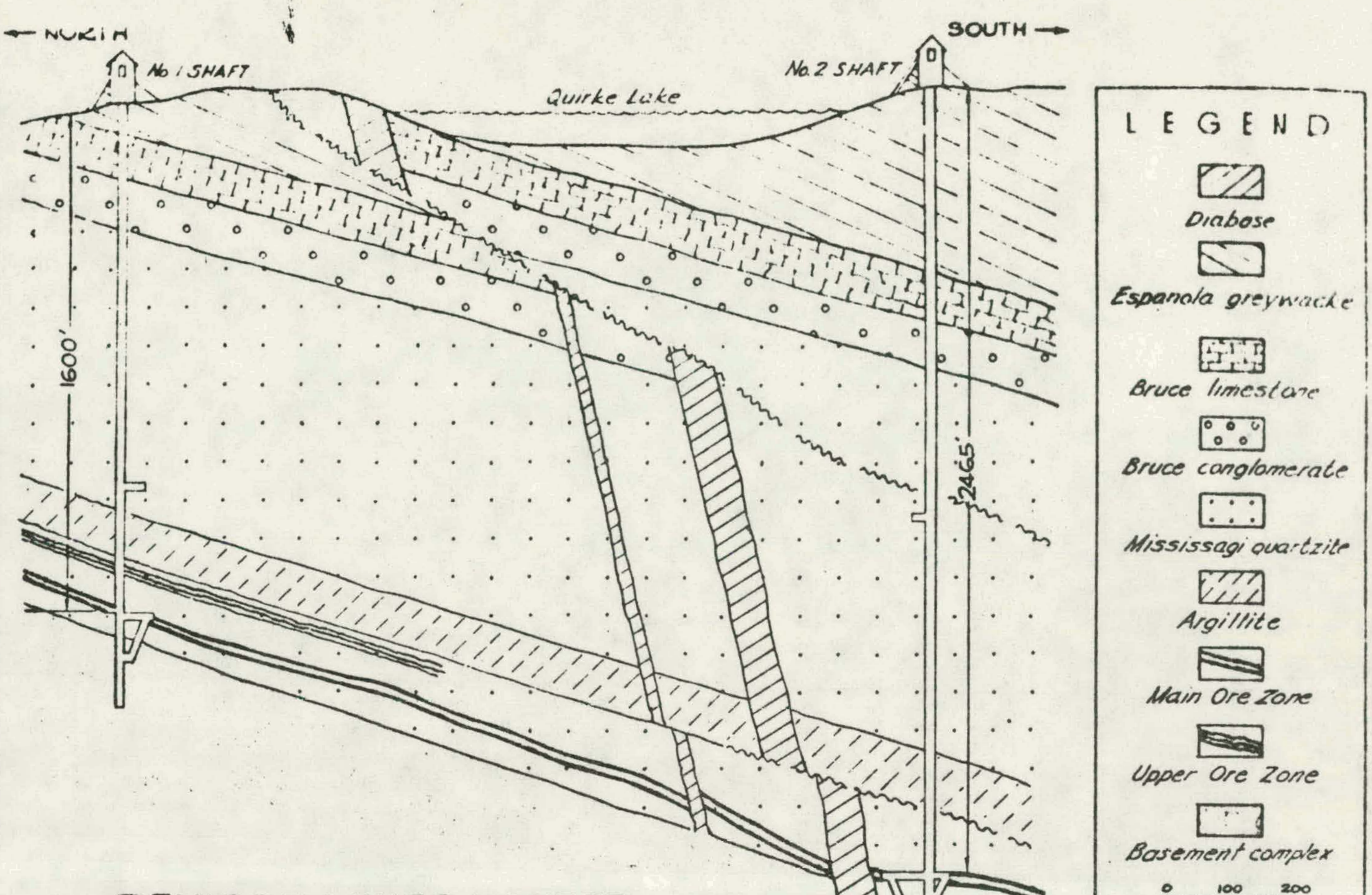


Quirke Lake
DENISON MINES
Elliot Lake
Legend
Denison Mine
OTHER MINES
Operating
Non-operating
MILES
To Denison Mine
SPRAGGE
Trans-Canada Hwy No. 17
To Sudbury
Serpent River
Lake Huron
(North Channel)
ELLIOT LAKE DISTRICT -





HUDSON BAY
MANITOBA
ONTARIO
QUEBEC
CANADA
Elliot Lake
LAKE SUPERIOR
Sudbury
Montreal
Ottawa
Sault Ste. Marie
U.S.A.
L. HURON
LAKE MICHIGAN
Toronto
L. ONTARIO
Detroit
L. ERIE
Chicago
0 100 200
MILES



DENISON MINES LIMITED
GEOLOGICAL SECTION THROUGH NO. 1 & NO. 2 SHAFTS LOOKING EAST

The Denison mine, more than 4,700 acres in surface area, is located on the north limb of the famous Quirke Lake syncline. The main ore zone, consisting of the two uranium-bearing conglomerate beds, dips from north to south at an average angle of 19 degrees. At the upper end it lies 550 feet below the surface and deepens to 3,000 feet at the south property boundary. Minor undulations occur throughout the orebody and faults, dykes and sills have been encountered in several locations.

The uranium-bearing conglomerate beds are reached by two main vertical shafts, approximately one-half mile apart. The first shaft gives access to the orebody at the 1,600 foot level and the second shaft, farther down-dip, intersects the main ore zone at the 2,454 foot horizon. The mining method requires only one main underground station at each shaft. The ore now is hoisted at No. 2 shaft.

Two other shafts at the east end of the property, formerly part of the neighboring Can-Met mine, have been connected with the Denison underground workings for ventilation purposes.

Creighton Mine

Location

The Creighton mine is located at Sudbury Ontario Canada.

Geology

A brief summary of the mine geology, supplied by the International Nickel Co., is attached. Also attached are excerpts from Field Excursion C33 International Geological Congress 1972.

General Statement

Inspection of the Creighton mine was confined to the 6400 level stope and tunnels. The rocks are dusty and dry. No water was seen. A prominent shear zone crosses two of the tunnels but there was no evidence of moisture. The mine geologists report that they do not know of any water seeps below the 3000 foot level, a contract tunnel miner confirmed that in ten years of tunnel driving, he has never seen water except at one point on or above the 3000 foot level. Mine geologic maps show the presence of a number of shears and faults. No water occurs in these at depths exceeding 3000 feet.

The various rock types exposed give the distinct impression of a giant breccia which is completely re-sealed.

Fractures and joints are quite closely spaced in some areas. A fracture frequency of 4 to 6 per foot occurs in some of the tunnel walls but no moisture or staining was seen.

It seems clear that at this depth in these Precambrian rocks, no water circulates and there is an absence of any effective permeability.

CREIGHTON MINE

History

The Creighton orebody was originally discovered by A. P. Salter in 1856 while engaging in base line survey work as a Provincial Land Surveyor. He was of the opinion that the marked deflections in his compass readings were caused by the presence of a large iron deposit nearby. This was examined by Alexander Murray who was making a geological survey of the district. Sampling indicated copper and nickel mineralization; however due to the inaccessibility of the area, the discovery was forgotten. It was rediscovered in 1886 by Henry Ranger following a flurry of exploration in the area. Three years earlier a mineral occurrence had been discovered during railway construction. In 1900 an open pit mining operation was started by the Canadian Copper Company. The first shipment of Creighton ore was made in August 1901. The mining has continued to the present, although at several times the orebody appeared to be pinching out. Diamond drilling proved the continuation of the orebody at depth and the mining has continued to the lowest present mining level of 6,600 feet. These deep workings are made accessible by a shaft from surface to just below the 7,000 foot level.

Geology

The Creighton orebody is located on the outer rim of the nickel irruptive of the southeast corner of an embayment into the footwall rocks. As a generalization the lower member of the irruptive (norite) is the hangingwall of the orebody. The footwall rocks are lower Huronian volcanics (metamorphosed basalts and andesites) and granites. These have been subjected to thermal and dynamic metamorphism. The footwall rocks are the oldest in the mine area.

The sub-layer norite contains most of the ore. It occurs between the hangingwall norite and footwall rocks and consists of basic to ultrabasic and footwall inclusions in a matrix of norite and sulphides. The emplacement of this ore-bearing zone appears to have been in several pulses; this is suggested by different ore types occurring as inclusions in other ore types. The main orebody has been subdivided on mineralogical and/or geographical location differences into a number of separate orebodies. A general sequence of ore types in the sub-layer from hangingwall to footwall is as follows:

(1) disseminated sulphide in norite
(2) interstitial sulphide in norite (INSU)
(3) ragged disseminated sulphide in inclusion packed norite (RGDI)
(4) gabbro peridotite inclusion sulphide (GPIS)
(5) contorted schist inclusion sulphide (CSIS) associated with structure zones
(6) inclusion massive sulphide (INMS) - generally large inclusions floating in massive sulphide
(7) massive sulphide (MASU)

The sequence in most of the orebodies fits into this generalized section. There are a few exceptions to this; they are as follows: (1) ore associated with a quartz diorite dyke, (2) high grade pods in the footwall and (3) ore that occurs along a low angle shear that extends into the footwall.

The most common sulphides are pyrrhotite, pentlandite and chalcopyrite. Precious metals are present in small quantities but their distribution is erratic. The average pyrrhotite - nickel and copper - nickel ratios are 9 : 1 and .8 : 1, respectively. The values for the individual orebodies can be substantially different from these figures.

The youngest rocks in the area are the trap and olivine diabase dykes.

Mining Methods

As previously stated the original mining was open pit: the ore was drawn up a ramp by horse drawn carts. From this primitive beginning in the early 1900's mining methods have developed to meet the economic and ground control requirements of the time. At present, five mining methods are being used; they are: shrinkage, blast hole, cut and fill, undercut and fill, and post pillar. The efficiency of these methods has been greatly improved by the introduction of mechanized equipment. For a detail description of the various methods used at Creighton since its beginning the reader is referred to J. R. Boldt's "The Winning of Nickel".

Structure

The location of the ore in the upper part of the mine is generally controlled by shears associated with the footwall contact of the norite embayment. The shears tail out into the footwall at a steeper dip than the contact and are ore-bearing. One of the major shears (6 Shaft) is a low angle structure dipping into the footwall along which ore has been emplaced and appears to be a channelway for the deposition of a small orebody which contains the highest grade at the mine. In the lower portion of the mine, shearing does not appear to be as significant except for the east end of the ore zone (401 O.B.). The major control is the norite - footwall contact.

References:

(1) Boldt, J. R., Jr., 1967, The winning of nickel.

(2) Hawley, J. E., 1962, The Sudbury ores, their mineralogy and origin: Canadian Mineralogist, v. 7, pt. 1.

(3) Canadian Mining Journal, v. 67, No. 5, May 1946.

(4) Souch, B. E., Podolsky, T., and Geological Staff, Inco, 1969: The sulphide ores of Sudbury: their particular relationship to a distinctive inclusion-bearing facies of the nickel irruptive; Econ. Geol., Monograph No. 4, p.252 - 261.

SUDBURY DISTRICT GEOLOGY

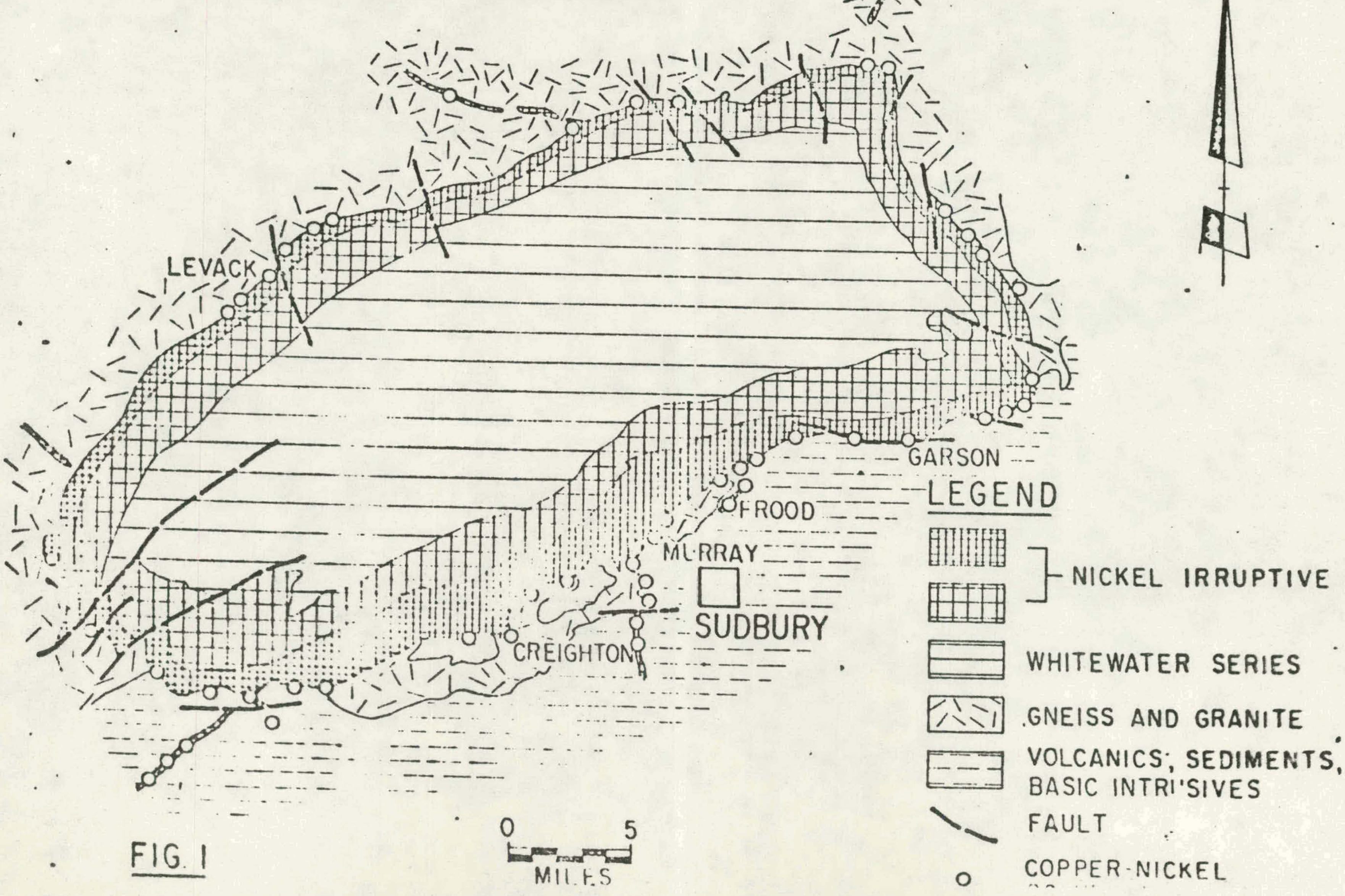


FIG. 1

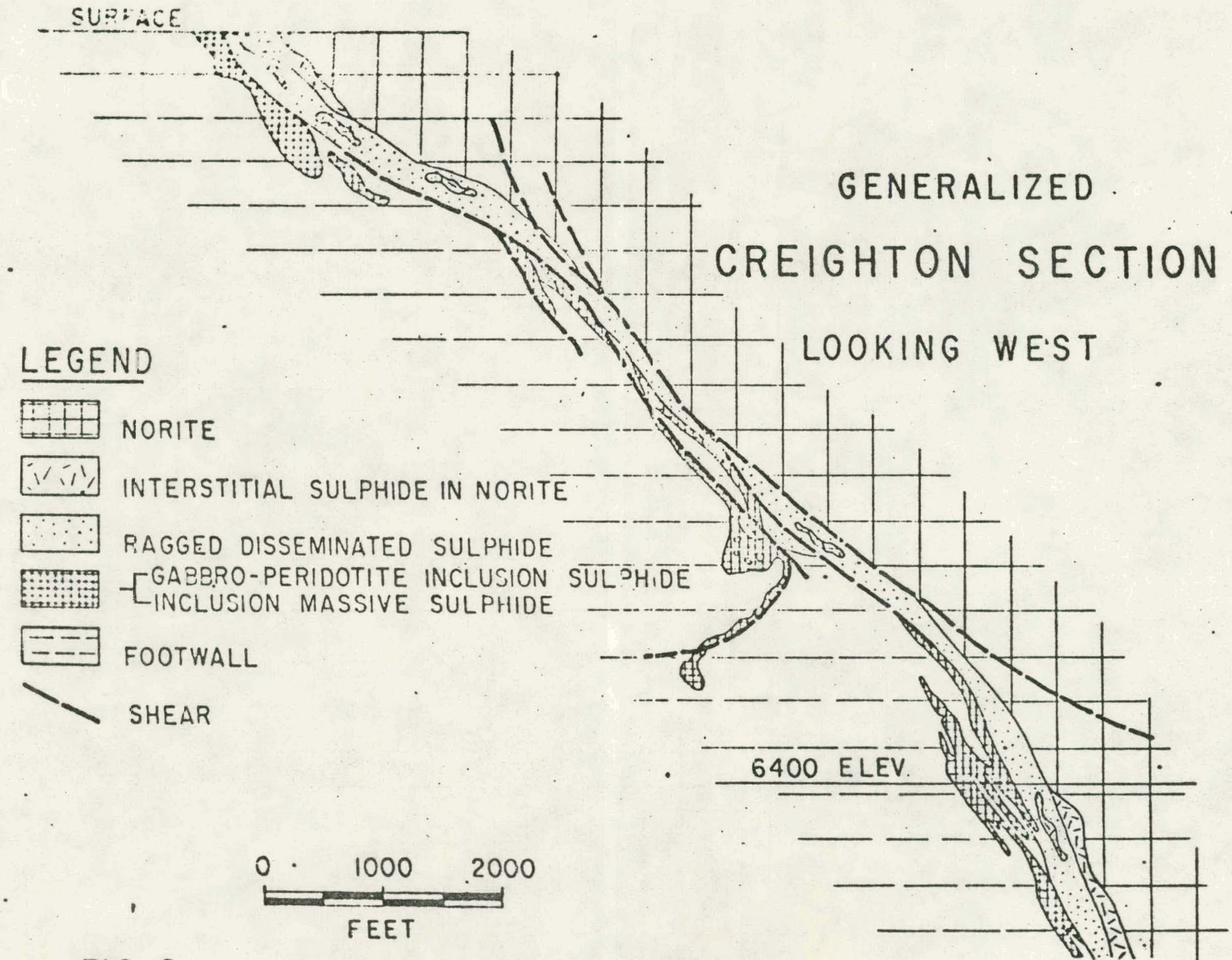

SURFACE
GENERALIZED
CREIGHTON SECTION
LOOKING WEST
LEGEND
NORITE
INTERSTITIAL SULPHIDE IN NORITE
RAGGED DISSEMINATED SULPHIDE
GABBRO-PERIDOTITE INCLUSION SULPHIDE
INCLUSION MASSIVE SULPHIDE
FOOTWALL
SHEAR
6400 ELEV.
0 1000 2000
FEET

FIG. 2

Group	Formation	Lithology	Primary Structures	Thickness (Metres)
Huronian Supergroup — Cobalt Group	Bar River	Orthoquartzite, subordinate hematitic siltstone	Ripple marks, crossbedding, laminated bedding	900
	Gordon Lake	Fine grained siltstone,	Ripples, desiccation cracks, ball and pillow structures, crossbedding	900+
	Lorrain	Arkose, aluminous and hematitic quartzite, fine grained orthoquartzite subordinate quartz jasper pebble conglomerate	Crossbedding and ripple marks	2100
	Gowganda	Polymictic paraconglomerate, orthoconglomerate, laminated argillite, protoquartzite and subarkose	Ripple marks, graded beds, ball and pillow structures, laminated bedding, rafted clasts, tilloid fabric	1500
		Conformable to Unconformable		
Quirke Lake Group	Serpent	Subarkose and protoquartzite with subordinate calcareous siltstone	Crossbedding, laminated bedding	720
	Espanola	Calcareous siltstone, limestone, and sandstone	Crossbedding, ripple marks, desiccation cracks, intraformational conglomerate, and clastic dikes	540
	Bruce	Polymictic paraconglomerate, minor siltstone and sandstone	Tilloid fabric, rafted clasts	150
		Conformable to Disconformable		
Hough Lake Group	Mississagi	Arkose, protoquartzite, siltstone and argillite	Crossbedding; coarsening upward cycles in the Sudbury area	1500+
	Pecors	Siltstone, argillite, and feldspathic protoquartzite	Ripple marks, ripple-drift cross-beds, laminated bedding, graded bedding, slump structures	600
	Ramsay Lake	Polymictic paraconglomerate with subordinate sandstone and siltstone	Massive, bedding rare, rafted clasts	180
		Conformable to Disconformable		
Elliot Lake Group	McKim	Siltstone, greywacke, laminated argillite, and protoquartzite	Graded beds, ripple marks, ripple-drift crossbeds, laminated bedding and clastic dikes	900
	Matinenda	subarkose, siltstone, argillite, polymictic conglomerate, oligomictic conglomerate	Crossbedding, laminated bedding, scour-and-fill	210+
	Metavolcanic Sequences Frood-Stobie, Copper Cliff, Pater, Thessalon etc.)	Mafic & Felsic metavolcanics, greywacke, and sulphide facies iron formation	Pillows, phenocrysts, amygdules and flow layering in the volcanics; graded bedding in the sediments. Cyclic repetitions of flows and interflow sediments	1500?
		Regolith	Unconformity	
Archean		Mainly granitic rocks with included migmatic, metavolcanic and metasedimentary rocks.		

Approximately $12,000,000,000 worth of nickel, copper, cobalt, selenium, tellurium, platinum metals, gold, silver, iron ore, and sulphur have been produced from the ore deposits of the Sudbury Nickel Irruptive over the past 85 years. At present, some 20 mines are in production. The sulphide ores are associated with the "sub-layer", a discontinuous layer of inclusion-bearing igneous intrusions which form a distinct lower unit of the Nickel Irruptive. The offset dikes, which radiate outward from the main body of the Irruptive, are part of this sub-layer.

Other types of mineral deposits in the region include copper-lead-zinc sulphides of possible exhalative origin associated with the Whitewater Group of the Sudbury Basin (Thomson, 1956), and copper-nickel sulphides and gold-bearing quartz vein deposits associated with Nipissing diabase intrusions. Copper sulphides occur in the lower Huronian volcanic sequences. Several of these deposits have been worked.

Field Trip A — Sudbury as an Astrobleme

by

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Introduction

There are two main theories or origin for the Sudbury structure: the "traditional" and the "astrobleme". The older theory has undergone various changes in detail but it rests upon broad conventional considerations of regional structure (location at the intersection of several major lineaments), petrology and metallogeny (association of Fe-Ni-Cu sulphides with layered basic intrusives; proximity to ring complexes; presence of explosive "volcanic" rocks with Cu-Zn-Pb sulphides) and geochronology (occurrence of other regional events ca. 1.7 b.y. age; apparent existence of a positive "Sudbury" element in Huronian time).

According to Speers (1957) the structure was formed by volcanic-tectonic explosion processes, somewhat as follows. A broad dome, 60 miles (95 km) across and involving Huronian and older rocks, was uplifted by the presence of magma. Successive periods of uplift followed by tensional release gave rise to the Sudbury breccia dikes and finally led to caldera collapse at the apex of the dome. Magma escap-

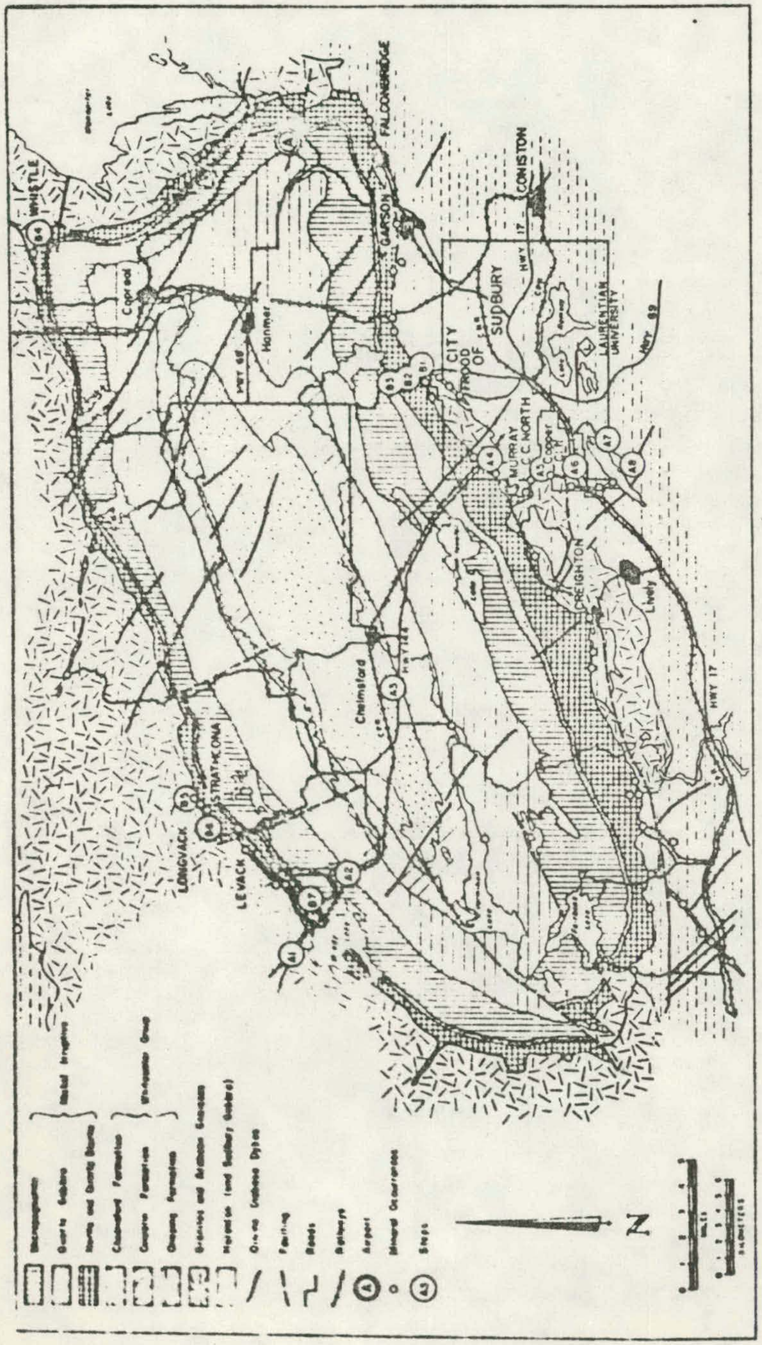

Fig. 4. General Geology of the Sudbury District.

ing around the rim of the caldera and flowing into the collapsed centre produced the Onaping Formation. The Irruptive was intruded subsequently along the base of this formation; the Nickel Irruptive is thus a later plutonic manifestation of the igneous activity which had previously formed the extrusive Onaping.

More recently Dietz (1964) suggested that the geometry of the Sudbury structure and the associated brecciation could best be explained by an explosive meteorite impact, an interpretation for which his own discovery of shatter cones gave support. This theory led French (1970) to find, in inclusions in the Onaping Formation, microscopic features characteristic of shock metamorphism. Subsequent work has shown that shock metamorphism, a normal feature of impact sites but unknown in volcanic rocks, is widespread and common in the Onaping, and is also found in footwall rocks adjacent to the Irruptive and in fragments in the Sudbury breccias.

Dietz considers the Ni-Cu ores to be cosmogenic, derived from the meteorite, but in the more accepted version of the theory, the explosion is thought to have acted as a trigger for endogenic magmatism with associated sulphide mineralization, as follows. Shock waves radiating from the point of impact produced brecciation, melting, microscopic shock features and shatter cones, and excavated a circular crater, the collapsed outer limit of which is now marked by remnants of down-faulted Huronian sediments north of the Basin. Part of the material blasted from the crater fell back as a poorly sorted breccia; the Onaping Formation. Fracturing and heating of the rocks, and reduction of pressure in the upper mantle below the crater, initiated evolution of the Nickel Irruptive. The magma, including the ores, was emplaced between the brecciated crater wall and overlying crater-filling breccias in the central zone of the structure (Figure 5).

Dence (personal communication, 1971) discovered, in glacial deposits in Maclennan Township, friable heterogeneous breccias with abundant fresh glass and shock metamorphic features. These rocks evidently derive from Lake Wanapitei which is thus identified as a separate and much younger impact site.

Road Log

From Laurentian University Campus, where Mississagi quartzite with shatter cones is exposed, we travel directly

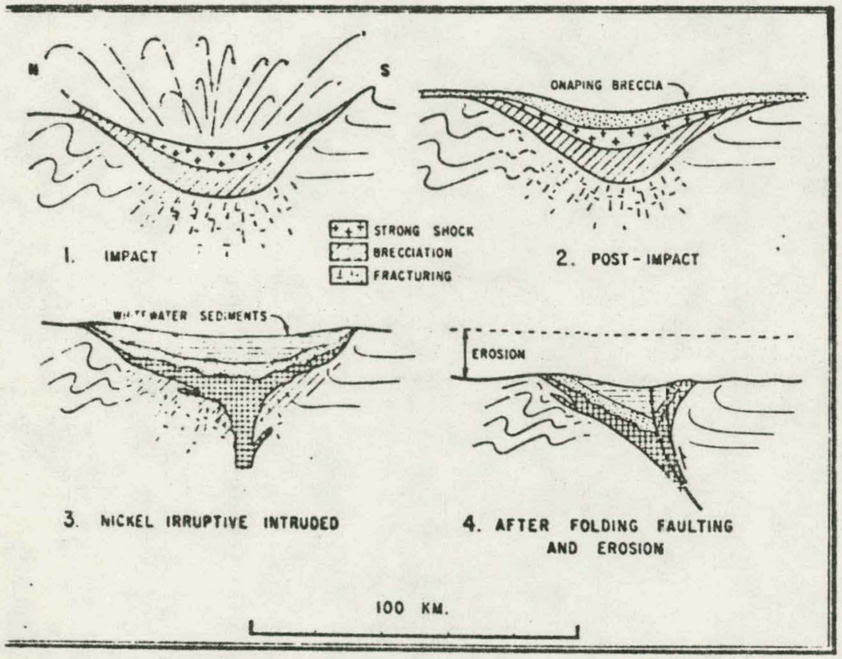

Fig. 5. Evolution of Sudbury Basin structure according to the astrobleme hypothesis.

to Stop (1), a distance of some 33 miles (55 km), crossing the Sudbury Basin from southeast to northwest (Figure 4).

The City of Sudbury is built mainly upon ridges of McKim Formation intruded by Nipissing diabase. Highway 144 (the route to Timmins) winds out of the city between bare hills of Copper Cliff rhyolite on the right or northeast side, and slag on the left. The road climbs northwestwards through basal Huronian sediments and volcanics, past the Clarabelle concentrator and the distant Copper Cliff North Mine shaft.

The lower contact of the Sudbury Nickel Irruptive (Stop 4) is marked by the gossan of the historic discovery site next to the Canadian Pacific tracks, and by the concrete of the original Murray Mine buildings. From this point we drive for more than a mile over the typically subdued plateau topography of South Range norite, then down through sheared micropegmatite into the interior lowland of the Sudbury Basin at Azilda. The hills of the North Range are visible, ten miles (16 km) to the northwest.

The Onwatin slate and the sheared southern limb of the Onaping make generally flat farmland; in the central part of the Basin low, wooded, east-northeast trending hills are formed by open folds in the Chelmsford sandstone. Beyond Dowling the highway climbs into the North Range: the massive, resistant Onaping Formation is marked by the cataract of High Falls on the Onaping River (Stop 2); above the falls the route winds through rugged hills of micropegmatite, which forms the highest ground in the district. On Highway 144 the summit is close to the quartz gabbro ("transition zone"), a mile north of Levack station; the road then drops down, across the norite, to the Archean granite and gneiss terrain north of Windy Lake (which can be seen while descending the hill).

Stop 1 is on Highway 144, 0.7 miles (1.1 km) past the C.P.R. level crossing at Windy Lake Provincial Park.

Stop Descriptions

Stop 1: Sudbury Breccia

0.00 miles/0.0 km

Exposures of migmatitic gneiss are pervaded by irregular tongues of pseudotachylitic breccia. The blocks are rounded to angular disoriented fragments of country rock, in a matrix of finely comminuted rock flour. No foreign igneous component is present: the breccia has been formed by attrition in situ, without apparent melting. In thin section the larger fragments may show weak shock features.

The Sudbury Basin is surrounded by a zone of such brecciated rocks, extending at least 15 miles (24 km) beyond the Irruptive contact. This zone is co-extensive with the zone containing shatter cones. Together with the presence of shock metamorphism in the breccia fragments and in the wall rocks, this suggests that the breccias formed as a consequence of explosive meteorite impact.

Stop 1 to Stop 2

Closer to the Nickel Irruptive contact the gneissic structure of the country rock becomes quite irregular and brecciation is pervasive. The Irruptive contact is not exposed, but as is usual on the North Range, it is marked by a topographic depression.