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MICHIGAN IRON MINES

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and has replaced charcoal as a reducing agent.

Up to the close of 1902, Michigan had produced 4,178,218 tons of charcoal pig iron. Of this 1,882,274 tons were produced in the Northern Peninsula and 2,295,944 tons in the Southern Peninsula. Complete statistics are not available for total production of charcoal pig iron. It is interesting to note that 51 forges and furnaces have operated in Michigan since 1849 – 30 in the Northern Peninsula and 21 in the Southern Peninsula.

Today, all of Michigan's iron and steel is produced in the vicinity of Detroit. Three companies operate 8 blast furnaces, having a total rated capacity of 3,769,480 tons of pig iron per year. Michigan's steel capacity is 6th in the nation, rated at 6,769,480 tons per year.

Michigan iron ore averages about 51 per cent iron natural. Its parent rock, the iron formation, averages 20 per cent to 25 per cent iron. The ore is a product of a natural concentration of the iron by removal of its associated silica Ore is not found everywhere in the parent material. It represents less than one per cent of the total volume of the iron rich strata.

Geographically, Michigan iron ore is found widely scattered throughout the western half of the Northern Peninsula of Michigan. Geologically, it is a part of the exposed southern part of a triangular shaped area of bedrock known as the Canadian Precambrian Shield (fig. 1). This shield of ancient rocks (500 to 3,550 million years old) covers an area of approximately 2,800,000 square miles in Canada, Greenland, and the United States. The southern terminus of the shield is exposed in the northern parts of Michigan, Wisconsin, and Minnesota (fig. 1). The Canadian Precambrian shield is overlapped on all sides by younger strata that dip gently away from the older core. Within the Precambrian Shield lies a large part of the mineral wealth of Canada. It contains all the iron ore of the Lake Superior region and the copper deposits of Michigan's Keweenaw Peninsula.

The rock units that record the story of Michigan iron are the Precambrian rocks in the immediate vicinity of Lake Superior. They conform somewhat to a structural basin with Lake Superior at the center, (fig. 2), especially in the area surrounding the southwestern part of Lake Superior. The rocks are divided into three great series — the Archean, Huronian, and Keweenawan (fig. 3). Each series contains many smaller units, which represent three different stages of sedimentary rock deposition, igneous intrusion, mountain building, and erosion.

The Archean are the oldest rocks known in Michigan and consist of altered lava flows (greenstones) that have been intruded by granite. Overlying and lapping onto the Archean rocks of the Canadian shield are the next younger, the Huronian formation. The Huronian are a thick series of sedimentary rocks consisting of quartzites, dolomites, slates, and iron formations intruded by basic igneous rocks. Four separate zones of iron formation are in the Huronian but only two have furnished commercial ore. Huronian rocks are geologically very complex and in the interest of simplification only their trends have been indicated on Figure 2 by the trace of the iron formations. Like the overlying Keweenawan rocks, the iron formation of the Mesabi and Gunflint iron ranges in Minnesota, dip to the southeast but the Gogebic iron range formation dips to the northwest. East of the Gogebic range, rock formations assume a more nearly east-west trend, somewhat parallel to the trend of Lake Superior and of the Keweenawan basin. Locally this trend has been disturbed by granite intrusion and by cross folding.

Figure 1. Lake Superior Region; showing principal iron ranges

The youngest rocks of the Precambrian, the Keweenawan, are principally lava flows and conglomerates with minor slates and sandstones. Figure 2 shows their location. They contain Michigan's native copper. The Keweenawan formations have suffered less folding and erosion, thus their record is more complete and their geology better known. The structure of the Keweenawan rocks is a downfolded basin, enclosing Lake Superior. The axis, or center of the downfolded part, is in Lake Superior and its rock units dip toward the center of the basin.

Michigan iron ore is found as isolated masses in a Huronian rock called iron formation. Iron formation is a banded sedimentary rock commonly composed of layers of silica (the mineral of sand and glass), alternating with layers of iron minerals. Such rock is found only in very old rocks, the Precambrian (fig. 3). Conditions for banded iron formation have not been repeated in later geologic time. Precambrian banded iron formations are found in a few other places on the earth's surface, principally Labrador, Quebec, Manchuria, India, Brazil and the Krivoy Rog area of Russia, but until recently such deposits have been little utilized for iron ore production excepting the United States.

The iron formation and associated rocks of Michigan were complexly folded during Precambrian stages of mountain building. In the interval of time since mountain building, the higher parts of the mountains were eroded, leaving iron formation and associated strata as remnants in the down folded parts of the old mountains. These down folded remnants are all that remain of these ancient rocks and the trace of their outcrop with the earth's surface produces a highly complicated and contorted pattern (fig. 4).

It is impossible to determine the original area of iron deposition in Michigan. Tight folding, plus planation by erosion of the iron rich rocks created several individual iron ranges (fig. 4). Whether or not these ranges were once continuous will probably remain unknown, since erosion destroyed the evidence. Three of the ranges are of primary importance commercially — the Marquette, the Iron River-Crystal Falls, and the Gogebic. The East Menominee Range and Gwinn district were important producers in the past and the Amasa Oval and Felch Districts had only limited production. Other areas of iron formation in the Northern Peninsula are not commercially important. Each of the ranges are discussed separately with emphasis placed upon the ranges that are at present the largest producers.

Figure 2. Generalized geology of the Lake Superior Region

PROSPECTING, EXPLORATION, AND DEVELOPMENT

The host rock for the iron ore is the iron formation, which during its long complicated geological history has been partially concentrated into isolated segments of ore of different shapes, sizes and attitudes. The first step in prospecting for an ore body is to determine the continuity of the iron formation where it is at or near the surface by mapping the rock outcrops, and in areas where bedrock is covered with overburden such as glacial drift, by plotting on a map the magnetic properties of the iron formation. To measure the magnetism of the rocks an inverted compass called a dip needle is used. The magnetic pull on the needle is measured in degrees of deflection from the horizontal. Thus, in traversing an area, the iron formation is revealed by its greater magnetic properties. Refinements of the dip needle have developed instruments which are very sensitive to magnetic variation — the super-dip and the magnetometer.

Figure 3. Generalized geologic column of Michigan showing relative stratigraphic positions of iron and copper.

Figure 4. Michigan iron ranges; showing outcrop of iron formation

When the iron formation has been located it must be explored to locate areas of ore enrichment. In Michigan„ exploration is by diamond drilling - cutting out a core of rock by diamond studded bit. The cores are samples of the rock penetrated by the drill hole and are studied to determine the grade of the ore. They are split, crushed„ and chemically analyzed for iron, manganese, silica, phosphorous, and sulphur. Once an ore body has been located additional holes are drilled to determine its general outline and volume.

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*A compass needle is attracted by the mineral magnetite sometimes referred to as lodestone. Magnetite is a minor constituent in most of the iron formation and in a few places it is the major iron mineral.

After an ore body has been located and its size determined to be satisfactory, the next step is to develop it for mining. Development consists of preparing access to the ore for its extraction. Most of the iron mines in Michigan are underground mines, and, because of the shape and depth of the ore body, the ore must be removed through a shaft. A shaft is a vertical or highly inclined excavation through the rock that provides access to the ore body for mining and is used for removal of ore to the surface (figs. 7, 14, and 18). The method of preparing an underground ore body for mining is similar for all iron mines. The shaft is sunk adjacent to the ore body to a depth below the ore to be mined. At predetermined intervals along the shaft, normally every 200 feet, tunnels called drifts and crosscuts are driven from the shaft to the ore body. From these, other drifts and crosscuts pass through the ore body at regular intervals dividing it into separate parcels to be mined later. These drifts and crosscuts are the main haulage levels that undercut the ore and serve as passageways for ore, men, and supplies from the shaft to the ore body. They also serve as main ventilation passages.

The ore is divided vertically by main level drifts and crosscuts; the levels are connected by vertical tunnels called raises, then the ore body is considered developed and ready for mining. Raises are used for ventilation and ore removal and are access passages to the working places between levels for men and supplies. The main problem of mining, now, is to break the ore and transfer it to the level below for haulage to the shaft. The ore is broken by drilling holes into it with drills powered by compressed air, filling these holes with dynamite and blasting the ore into small pieces. The ore falls by gravity through the raises to the level below.

The procedure employed in breaking and transferring the ore to the main haulage level below is known as the mining method. Mining methods vary considerably in the three main iron ranges and may vary somewhat in the mines of one range but one general method seems to be predominant for each range. Different methods are used because of the difference in shape and attitude (position) of the ore body and the structure of the ore. The ore bodies are found in many shapes and sizes, from long and narrow to almost spherical. Their attitude may be vertical, horizontal, or any position between. The ore may be hard to soft; wet or dry; compact or badly fractured. The ore may cave (fall naturally) when a void is created beneath it or every ton may have to be blasted to the level below.

Ore transferred to the main level is hauled to the shaft and hoisted to the surface. Here it is either put into open railway cars or stored in stockpile. All ore mined during the winter months is stored in stockpile and transferred to railway cars during the shipping season, April to December. A small amount of Michigan iron ore is hauled by rail directly to the blast furnace but most of the ore goes to the ore docks at Marquette, Escanaba and Ashland, Wisconsin. There it is transferred to ore boats and shipped to the lower lake ports. Most of the ore from the Marquette range goes to the docks at Marquette. Iron River-Crystal Falls range ore goes to the docks at Escanaba and ore from the Gogebic range is railed to the docks at Ashland, Wisconsin.

THE MARQUETTE IRON RANGE

The iron bearing rock unit of the Marquette Iron Range was discovered in 1844 southwest of the present City of Negaunee by a Government linear surveying party. Ore was first mined in 1848 by the Jackson Mining Company and reduced in a Catalan forge on the Carp River, three miles east of Negaunee. Mines opened and forges and blast furnaces were built using charcoal as a reducing agent, but up to 1855 consumed only about 25,000 tons of iron ore. In 1855, a canal was opened along the St. Mary River connecting Lake Superior with Lake Huron and in 1856 regular shipments began from the Marquette range to the lower lake ports.

Through 1955, shipments from this range totaled 270,895,347 tons, 244,268,577 tons from the main basin, 8,731,092 tons from the Republic district, and 17,895,678 tons from the Palmer district. During 1955 - 5,364,808 tons of ore were mined and 6,639,966 tons were shipped from eleven mines, three siliceous open pits, and two concentration plants. Three of the mines, Cliffs Shaft, Greenwood, and Champion, produce a very hard hematite, much of which is of the "lump" variety. The lump ore is desirable because it can be used directly as feed into the open hearth furnace, thus bypassing reduction in the blast furnace. The Republic, Humboldt, and Ohio mines are associated with concentration plants where the lower grade iron formation is made into a salable product by separating the iron from the undesirable silica. A siliceous iron ore is produced from the Tilden, Volunteer, and Richmond open pits. A small amount of this ore is required in blast furnace operation. A direct shipping soft red hematite is produced from the other operating mines. Most of the soft hematite ore comes from the northeastern part of the main iron range in the vicinity of Ishpeming and Negaunee.

The Marquette iron range is a tightly folded basin of iron formations and associated rocks approximately 33 miles in length and 3 to 6 miles in width. The basin trends almost east-west and slopes gently to the west. In the vicinity of Palmer a faulted segment from the main range is called the Palmer district. To the south of Lake Michigamme and extending southeast to Republic, a tightly folded trough of iron formation, and its southern extension is called the Republic district. The outline of the Marquette basin and associated districts shown on Figure 5 gives a good indication of the structural geology of the range.

A generalized geologic column of the strata of the Marquette iron range is shown on Figure 6. Below the principal iron formation, the Negaunee, are a series of quartzites, dolomites, and slates that lie outside and surround the iron formation basin (fig. 5). The strata above the Negaunee iron formation lie within the basin and consist of quartzites, slates, volcanics, and a thinner less valuable iron formation, the Bijiki. This whole rock series, originally deposited as horizontal strata, has been compressed into the tightly folded basin that exists today. The strata everywhere dip toward the center of the basin but in places assume an almost vertical attitude.

Most of the iron ore produced is from the Negaunee iron formation at the east end of the range. A north-south cross section through the north limb of the basin is shown in Figure 7. This section shows the relation of the ore deposits to the other rock units. The Negaunee member has been intruded along the bedding planes (horizontal cracks) by thick basic igneous rocks called diorite. In some places where iron formation lies above the diorite, part of it has been converted to one of the types of ore deposits of the Marquette range. Basic igneous rocks also penetrate fractures (vertical or inclined cracks) through the iron formation and form dikes. Ore, locally known as "ore pipes", found between or at the Intersection of two or more vertical dikes is a second type of Marquette Range ore. The third, the most common type of ore deposit, is a concentration along the base of the iron formation just above the underlying or footwall slates. These ore bodies are commonly terminated down the dip by faults as illustrated in Figure 7. A fourth type of ore deposit is not shown on the cross section. These deposits are in the hard ore zone at the top of the iron formation immediately below the overlying quartzite and conglomerate. They contain a very hard hematite and magnetite ore and from them premium grade "lump" ore is produced.

With the exception of ore from three mines, all direct shipping ore produced on the Marquette iron range is soft hematite. This ore is not competent, that is, it cannot support itself, thus will not remain in place or stand when a void is created beneath or beside it. For this type ore, a caving method of mining is used. In early mining, a method called top slicing was used but more recently the sublevel caving method is employed. In the past few years, because of the high cost of labor and of timber, the block caving method has been used successfully and is gradually replacing other methods of mining on this range. Block caving is one of the simplest methods of mining. The procedure: — A block of ore is developed, undercut, and caved to the level below.

Ore blocks are laid out on either side of a crosscut. Their size is determined by the size of the ore body but generally does not exceed 250 feet because the scrapers cannot work efficiently on larger blocks. Figure 8 shows four very generalized sets of diagrams of a typical ore block in Plan, Side, and Front Views of the block. The Plan View is horizontal, Side and Front Views are vertical views of the front and side of the ore block. In block caving the whole ore block is undercut, creating a void into which the overhanging ore may fall and be transferred to the ore cars in the crosscut. This is accomplished in the following manner:

1. The size of the ore block is determined and the crosscuts are driven at right angles to the drift through the ore body. Directly above and at right angles to the crosscut, longitudinal drifts (A of fig. 8B) are driven 25-30 feet apart to the end of the block. These are called transfer drifts or scraping drifts and are used to transfer the broken ore to the ore cars in the crosscut. These drifts are well protected as they are used for transferring all the ore in the block.

2. At the far end of the transfer drifts two mills which are short raises 3 to 4 feet in diameter are cut up about 25 feet on opposite ends of the block.

3. A drift (C of fig. 8B) is driven to connect the two mills.

4. A slot (D of fig. 8B) is opened along and above the entire length of drift to a height of 40 + feet above the floor of the drift.

5. Two drilling drifts (E of fig. 8B) are driven parallel to the transfer drifts A and at opposite ends of the block at the same level as the bottom of the slot, D.

6. Next, the rest of the mills (F of fig. 80) are cut up along the transfer drifts. They also go up 25 feet. Usually 10 mills are on each side of the transfer drift. They serve as the passage for the broken ore to fall into the transfer drift where it is scraped into the ore cars.

7. From the drilling drift, a series of holes (G of fig. 8C) are drilled toward the center of the block from each drilling drift. These series of holes are drilled at about five-foot intervals, starting five feet from the slot D9 and are drilled to the center of the block to a height equal to the top of the slot. After a series has been drilled the holes are filled with dynamite and the ore is blasted into the open slot. The broken ore falls down the mills and is scraped into the ore cars in the crosscut.

8. Retreating toward the crosscut the entire block is undercut to a height of 40 feet. The ore is then expected to fall by gravity and to be carried out through the mills and transfer drifts.

9. Ore is drawn from the mills until too much non-ore rock falls, then each mill is plugged. When all the mills in a scraping drift, A, are plugged, the scraping drift is abandoned and allowed to cave.

Figure 5. Marquette Iron Range, Marquette County

GWINN IRON DISTRICT

South of the Marquette Range and due south of the city of Marquette is a spoon-shaped basin containing iron formation called the Gwinn Iron District. Figure 2 shows its position in relation to other iron areas.

The Gwinn area was first explored in 1869. The first mine was opened in 1871 and the first shipment was made in 1872. From 1872 to 1947, 12,785,258 tons of iron ore were shipped from eight mines. No mines are operating at the present time.

The Gwinn Iron District is an isolated elongated basin about six miles long arid one to two miles wide. It trends approximately N 45° W, almost parallel to the Republic trough. Its structure is well illustrated by the outline of the iron formation shown on Figure 9. The basin is an isolated downfolded remnant of sedimentary rocks completely surrounded by granite. The original sediments probably covered a much larger area, but have been removed by erosion.

Outside and surrounding the iron formation is a granite and a granite arkose, (a partially decomposed granite). In some places a thin black and gray slate separates the arkose from the iron bearing member. Within the iron formation basin and stratigraphically above the iron formation is a thick slate series. Note that Figure 9 shows all the mines thus far are on the northeast limb of the basin.

The future of the Gwinn Iron District is problematical. The iron-rich stratum is very thin compared with iron formations of the major ranges. The phosphorus content of the ore is quite high, so that the ore is less desirable for blast furnace use.

Figure 6. Generalized geologic column, Marquette Iron Range.

Figure 7. Generalized geologic cross section of the Marquette Iron Range.

Figure 8. Mining by block caving, Marquette Iron Range.

Figure 9. Gwinn Iron District, Marquette County, T45N, R25W

EAST MENOMINEE IRON RANGE

The earliest reports of Iron ore discovery on the East Menominee range were made in 1848 when specular iron ore was reported in Section 30, Township 40 North, Range 30 West. Iron discoveries were reported in 1851 and 1858 but no exploration work was done until 1866.

In 1874 the first shipment of 55 tons of ore was hauled to Menominee and smelted. In 1877 the railroad was extended to Quinnesec and the first ore from this range was shipped from Michigan. By 1956 this range produced 81,555,154 tons of ore from 23 mines. At the present time, no direct shipping ore is being produced. Two open pit mines are producing siliceous ore. During 1955, they mined and shipped 87,117 tons.

The East Menominee Iron Range consists of two belts of iron formation stretching twenty five miles between Iron Mountain and Waucedah. The belts are parallel, striking in an east-southeast direction and dipping steeply to the south (fig. 10). The Northern belt is not continuous, but is separated in the center by a five mile interval. A generalized geologic column of the range is shown on Figure 11. The oldest rock, a granite gneiss, is at the bottom of the geologic column. It lies ½ to 4 miles to the northeast of the northern belt of iron formation. Above the granite gneiss and wrapped around and south of it in outcrop is a quartzite. Above the quartzite is the dolomite, iron formation, and slate series that is repeated on the surface by faulting. The two iron formation belts that contribute the ore from this range are the result of faulting.

The Iron rich rocks are in two strata separated by a thin slate. The formation has been highly faulted and somewhat folded, so that segments have been offset along the strike. The faults are somewhat systematically oriented northwest-southeast, north-south, and approximately east-west. Most of the ore mined came from the lower member of the iron formation. Ore is normally found at the base of the iron formation where it is intersected by a fault.

FELCH IRON DISTRICT

The Felch Iron District (fig. 10) is an east-west trending, tightly folded syncline of sedimentary rocks that include iron formation. It extends from west of Randville to east of Felch and is about 1 mile wide and 15 miles long. The iron formation of this district has yielded 482,075 tons of siliceous grade ore from four mines. In 1951 a pilot plant for concentrating the iron formation into ore was constructed at the old Groveland mine, four miles east of Randville. In 1952, 7,289 tons of concentrates were shipped. The pilot plant has since been removed.

The stratigraphy of this district is somewhat similar to the stratigraphy of the East Menominee range (fig. 11). The oldest rock member is a granite gneiss upon which rests a quartzite and dolomite. Above the dolomite is a slate highly metamorphosed to schist. Upon the schist lies the iron formation of this district. No known Precambrian strata are above the iron formation. All of this rock strata has been tightly folded into a very narrow east-west basin. Subsequent erosion planed off the top, leaving only the sediments in the bottom of the trough.

Figure 10. East Menominee Iron Range and Felch Iron District

Figure 11. Generalized geologic column, East Menominee Iron Range

IRON RIVER - CRYSTAL FALLS IRON RANGE

The first discovery of iron ore on the Iron River-Crystal Falls range (figs. 12A, B) is credited to a United States land survey in 1851 near the southwest corner of Section 36, T 43 N, T 35 W. Mining did not begin until 31 years later when a Mr. Miller's discovery became the site of the Iron River Mine south of the city of Iron River. The district was opened to shipping in 1882 when the Chicago and

Northwestern railroad reached Iron River. Through 1955, 162,621,749 tons of iron ore were shipped from the Michigan part of this range. This tonnage includes 110,384,940 tons from the vicinity of Iron River and 52,263,809 tons from the vicinity of Crystal Falls, Amasa, and the formation limb south of Crystal Falls. Most of the ore produced is soft red hematite and yellow limonite with a subordinate amount of hard blue hematite. All the presently operating mines are underground, accessible only through a shaft. The Fortune Lake open pit mine near Crystal Falls has recently been closed. In 1954 the Book mine, south of Crystal Falls, converted to a low grade mine by utilizing a concentrating plant to upgrade low grade ores mined from underground.

The iron bearing rock unit of the Iron River-Crystal Falls range is in a triangular shaped basin between Iron River and Crystal Falls, Michigan, and Florence, Wisconsin. Figure 12A, B shows the surface outcrop of the iron formation along the borders of the basin. Iron formation is believed to underlie the entire 70 square miles of the basin but the area has not been explored beyond the limits of the outcrop because of the great depth of the basin.

The sedimentary rocks of the basin rest on a very thick volcanic greenstone. Figure 12 shows the outcrop of the iron formation, the eastern leg extends to Florence, Wisconsin. Part of the limb between Iron River, Michigan and Florence, Wisconsin is not shown on the map. It is believed the iron formation is in this area although it has not been found by exploration. Thick glacial drift makes exploration difficult. North of Crystal Falls, a relatively thin iron formation intersects the surface in a large oval shown on Figure 4. Some ore has been produced in the vicinity of Amasa and on the two southern north-south legs east of Crystal Falls (fig. 12).

The oldest rocks in the main basin area are huge volcanic greenstones that are as much as 5 miles thick. The greenstones outcrop on the north and southwest sides and on most of the east end almost surrounding the basin. They are very old lava flows, in which the original minerals have been partially altered to secondary minerals that have a greenish color. Altered rocks of this type are called greenstones as the original minerals are difficult or impossible to identify. Between the greenstone and the iron formation are a series of mudstones or slates. The upper 50 feet of the series are very black due to a high carbon content, and contain 30-40 per cent of finely disseminated pyrite. Above the iron formation, and completely surrounded by it, is another thick series of slates and a coarser rock called graywacke (fig. 13).

Figure 12 shows the intricate folding and faulting of the iron formation. The folds are very tight and some faults are present, with displacements of over 2,000 feet. The sedimentary rocks, the slates and the iron formation, were deposited horizontally on top of the greenstone. During mountain building, these sediments were squeezed into a tight folded basin. The folding was so intense that the limbs of iron formation are in a vertical or near vertical attitude. After folding, planation or levelling by erosion left the sedimentary basin, as it now exists.

Figure 12 A, B, shows the areal distribution of the mines on this range. Most of the mining in the Michigan part of the range has been in the immediate vicinity of Iron River and Crystal Falls at the apices of the basin, and on the limb extending south from Crystal Falls. Figure 1 is a generalized cross section through the iron formation on this range. It illustrates the intense folding that is common in the mine area. Ore is normally found concentrated upon the structural footwall of the iron formation in the lower part of a synclinal fold. In some places ore concentration is at some height above the fold and some ore is across the full width of the iron formation (fig. 14).

Most of the ore mined on this range is at a depth shallower than the ore bodies of the Marquette and Gogebic ranges, but some ore is being removed from depths in excess of 2,000 feet below the surface.

Unlike the soft ores of the Marquette and Gogebic ranges, the ores of the Iron River-Crystal Falls range are comparatively hard and competent, and in general, the attitude of the ore bearing formation is nearly vertical. The combination of these factors produce ore bodies that can not be mined by regulated caving. It is necessary to mine this type ore by what is known as an open stoping method or excavating the ore above and/or below levels. Since access to the ore between levels is made through intermediate levels it is further defined as sublevel stoping. If in stope mining all the ore were removed, large openings dangerous to future mining would be made, therefore, horizontal and vertical pillars of ore are normally left between each stope or excavation. If the void of the mined out stope can be filled with sand and gravel, thus supplying support, some of the pillar can be removed at a later date.

As illustrated in Figure 14, an ore body is developed for mining by sinking a shaft adjacent to the ore and connecting it at regular vertical intervals to the ore by crosscuts. Drifts from the crosscut are driven parallel to the ore body in the ore near the footwall (rock unit below ore) side (fig. 15A). The ore body is divided into stopes and pillars. The ore from the stopes is mined and the pillars left for support. Sublevel stoping of the ore is performed in the following manner:

1. The main haulage level drift (A) is driven in the ore close to the footwall side.

2. Above the drift and perpendicular to it, one or more scraping subs (B) are driven from the hanging wall to the footwall sides of the ore body.

3. Two raises are driven to the level above. A man-raise (C) 9 is cut up through the ore pillar. Near the hanging wall (rock unit above ore) side an ore raise (D) is driven through the ore. The man raise serves as a passageway to the sublevels for men and supplies. The ore raise is the opening through which the ore falls from the sublevels to the scraping drift below.

4. Along the scraping drift (B) and at regular horizontal

intervals, short raises (E), called mills, are opened to a height of about 25 feet above the main haulage level. They are put at an angle diverging from the scraping sub.

5. From the man-raise, small working drifts are driven at regular vertical intervals from the pillar through the area to be stoped and connected to the ore raise (F). Development of the stope is now complete and ready for mining.

6. The plan maps of Figure 15B, C represents the first sublevel in the stope. The drift from the man-raise to the ore-raise is shown and the round openings (E) represent the top of the mills from the scraping drift up to the bottom of the first sublevel. Mining commences by belling out the top of the ore-raise (G fig. 15B). This opening is further enlarged above and below the sublevel, (H), until it intersects the tops of the mills from the scraping sub. The mills intersected are belled out to the edge of the stope area (I). As illustrated on cross-section 15B, drilling and blasting created an opening half way up to the next sub. Mining the remainder of the ore from the first sub is merely a matter of belling out the tops of the mills from the scraping drift until they intersect each other like rows of funnel tops, and drilling and blasting the ore halfway to the sub above.

Figure 12A. Iron River – Crystal Falls Iron Range, western part

7. The ore around the ore raise on the second sub is mined as it is on the first sub. The ore just above the sublevel drift is removed and a bench (J) left from which to work along the width of the stope, (fig. 15C). Mining now consists of an orderly retreat on the various sublevels. First the back is drilled and blasted, (K) and then the jutting edge of the floor, (L). The broken ore falls to the floor of the stope and into one of the funneled mills, (M) that lead to the scraping drift. Then it is scraped to the main haulage level, (A) and falls through an opening into an ore car below. Retreat on the sublevels is arranged so the face of the stope slopes downward toward the footwall side to allow a free fall of the ore through the stope. Only one crew of miners work in a stope per shift. No one works above or below any one else.

GOGEBIC IRON RANGE

The iron formation of the Gogebic range was first noted in Wisconsin in 1849. But not until 1883 was the first ore found in Michigan, at the location that became the Colby mine. The first production of 1,022 tons was shipped in 1884. The largest yearly shipment of 7,956,459 tons was in 1920. In 1955, 3,182,532 tons were shipped from 7 mines.

Through 1955 the Michigan part of Gogebic range has shipped 238,460,488 tons of iron ore. All present operating properties are underground mines but ore was once produced from three open pit mines. The ore produced is a soft red hematite that is mined by a caving method. The ore has a higher than average grade, containing about 52.50 per cent natural iron.

The iron formation of the Gogebic Iron Range extends almost 80 miles between Atkins Lake in Wisconsin and Lake Gogebic in Michigan. In Michigan, its length is approximately 25 miles from the state boundary at Ironwood to a point west of Gogebic Lake (fig. 4). The trace of the outcrop at the surface is slightly S shaped and trends just north of east sub-parallel to the Mesabi, Cuyuna, and Gunflint iron ranges of Minnesota (fig. 1).

Figure 12B. Iron River – Crystal Falls Iron Range, eastern part

In Michigan the iron formation of the Gogebic range intersects the surface as a broad arc with the concave side toward the south (fig. 16). From the Montreal River, east to the City of Wakefield, the most productive part of the range, the formation dips steeply north at an angle of 60-70 degrees. The thickness of the iron formation varies from 600 to 1,000 feet so its width at the surface is not great. In the City of Wakefield the formation has been displaced by faulting. The formation has been flattened by this structural complexity and therefore covers a greater area at the surface. The southern edge of the flattened section was the location of the largest open pit mine In Michigan. From it was taken more than 31,000,000 tons of high grade ore. The pit is now abandoned and water filled. The flattened area is terminated to the east by a large northwest southeast trending fault shown on the map of Figure 16. East of the fault, the formation assumes its more natural attitude, dipping steeply to the north. East of the fault only one mine is operating. A few small prospects there have been abandoned. East of Range 45 W, the formation has been intermittently offset by northeast trending faults. Its width has been increased by intrusion of dark colored basic igneous rocks between layers of iron bearing strata.

Figure 13. Generalized geologic column, Iron River – Crystal Falls Iron Range

Figure 17 shows the sequence in columnar section of rock units on the Gogebic range. The oldest rocks at the base of the column are igneous and form a base for younger sediments. Most of the oldest rocks are granites, the others are altered lava flows, the greenstone. The basal sediment is a quartzite, found only in a few places because most of it has been eroded away. Above the quartzite is a dolomite and above that a quartz slate. Next is the series of iron rich rocks. The series consists of five units described as three units of ferruginous chert, alternating with two units of ferruginous slate. All five members have a high iron content. The cherty members are more like the iron formation of other ranges and contain most of the ore, although in some places the slaty members have been concentrated to ore grade. The iron formation on this range has an aggregate thickness of 600 to 1,000 feet. Above the iron formation is a huge thickness of slate and graywacke that ranges in thickness from a feather edge to more than 10,000 feet.

A generalized geologic cross-section of the Gogebic range is shown in Figure 18. The iron formation dips about 70° and is cut in many places by dikes perpendicular to the bedding and plunging to the east. In many of the mines a large fault in the iron formation slopes toward the footwall side and is parallel to the bedding. It is obvious from Figure 19 that faulting occurred after the intrusion of the dikes as the dikes are displaced by the fault. In places this fault is responsible for the footwall termination of ore concentration.

Ores are normally found concentrated in a structural trough. One side of the trough may be the quartz slates, the slaty member of the iron formation, or the fault that parallels the bedding. The other side of the trough is formed by a crosscutting dike. Almost without exception ores are found above the dikes. Rarely is ore concentration found across the slaty member. Most ore is found toward the footwall side.

Figure 14. Generalized geologic cross section, Iron River – Crystal Falls Iron Range

Figure 15. Mining by sub-level stoping, Iron River – Crystal Falls Iron Range

Throughout most of the Gogebic iron range the iron formation dips to the north at a fairly uniform angle. In mining a shaft is sunk on the foot-wall side of the formation and drifts are driven to the ore zone at regular intervals, usually every 200 feet as illustrated in Figure 18.

On the Gogebic range the sublevel caving type mining method is used. The ore is mined from sublevels between the main levels and transferred by gravity to the main level below for haulage to the shaft. Most of the sublevels have a vertical separation of 25 feet but the present trend is to increase this interval to 50 feet. The mining method is illustrated in a set of four diagrams in Figure 19. Figure 19 shows a horizontal plan and a vertical cross section view of the operations. Mining is accomplished as follows.

1. A crosscut from the shaft is driven in the granite or greenstone to a point just short of the contact with the quartz slates. From the crosscut a drift, (A) is continued parallel to the quartz-slate contact for the length of the ore body to be mined from that particular level. At regular intervals from this drift, usually every 400 feet, crosscuts, (B) are opened across the quartz slates into the iron formation or ore. One or more manway raises, (C) from the crosscut goes up in the footwall to the main level above. This is used to transfer men and supplies to the sublevels for mining the ore. In the iron formation above the crosscut a scraping sub, (D) is installed and from that an ore raise, (E) is cut up to the main level above. The ore-raise is used to transfer ore mined from the sublevel down to the scraping sub. The ore transferred to the scraping sub is scraped into ore cars in the crosscut for haulage to the shaft.

2. The next step is to divide the ore body into sublevels for mining. At intervals, sublevel crosscuts, (F) connect the ore and man raises and are driven through the ore body to the contact with the iron formation or dike intersection to a distance that would undercut all overlying ore.

3. From the crosscuts, mining drifts, (G of fig. 19B) are driven into the ore body. The pattern of the drifts depends on the ore outline on a particular sublevel. Drifts are so spaced that their centers are within 25 feet of each other so that all the ore between the drifts can be extracted.

4. After one or more mining drifts have been installed the actual mining of the ore can be started. Mining commences at the end of the sub-level drift and retreats toward the crosscut. Figure 19D shows two cross-sections and a longitudinal section to illustrate the procedure. At the end of the mining drifts, two raises, (H) called dog-holes are opened to a height almost to the mined sub-level above. Around the dog-holes, holes are drilled and blasted making a slot, (K). A slot is merely an opening into which ore can be blasted. Retreating from the slot at predetermined intervals, a series of closely spaced holes, (J) are drilled. By discharging dynamite in these holes a large section of ore is blasted toward the slot. The broken ore falls into mills that lead into the mining drift.

5. From the mining drift the ore is scraped to the crosscut, (F, fig. 19B, D). It is then cross-scraped into the ore-raise, (E) and falls into the scraping drift, (D) above the main haulage level where it is scraped into ore cars and transferred to the shaft to be hoisted to the surface. This process is repeated until all the ore above a sublevel has been mined and then men and equipment are transferred to the sublevel below.

Figure 16. Gogebic Iron Range, Gogebic County

Figure 17. Generalized geologic column, Gogebic Iron Range.

Figure 18. Generalized geologic cross-section, Gogebic Iron Range

Figure 19. Mining by sub-level caving, Gogebic Iron Range

ORE CONCENTRATION

The demand for iron and steel products has grown almost continuously since World War II. Blast furnace and steel making capacities increased to keep up with this growth demanding an ever increasing amount of iron ore. Increased demand for ore has been partially satisfied by shipments from Canada, Venezuela, Brazil, Chile, and other foreign countries. Decline in production of high grade ore on the Mesabi iron range in Minnesota, places an ever increasing need for foreign ore imports, a precarious situation in case of national emergency.

For some time, research has been in progress to determine economical methods of separating iron minerals from associated impurities in the iron formation. Although new in the iron industry, it is not unusual in other metal industries to concentrate ore at the mine before shipment to the smelter. Iron minerals are finely intermingled with silica, and to liberate them for separation the rock must be crushed and finely ground. The method of separation depends upon the particular iron mineral present and its grain size. The greatest problem to concentration results from lack of uniformity of iron minerals and their grain size in ores. Two research laboratories have been built on the Marquette range, to study this problem on Michigan formations, one in Ishpeming and the other in Negaunee. Research has already progressed to production and it is expected that concentrated iron ores will be produced in ever increasing tonnages. A new Ores Research Laboratory has been constructed and is operated by the Michigan College of Mining and Technology at Houghton. Research is coupled with student training for further research and for plant operation.

High grade iron ore bodies occupy less than one per cent of the iron-rich rock formations which leaves a tremendous reserve of iron tied in rock of too low grade to be of economical, use for direct reduction in the blast furnace. Figure 4 shows the areal extent of the most important iron bearing formations. An estimate of the reserve of low grade iron compiled by F. G. Pardee and B. E. Kennedy, former members of the Michigan Geological Survey, shows that per one hundred feet of depth, almost as much ore remains after concentration as has been shipped from Michigan during the last one hundred years. This does not mean that all this material can or will be utilized. Physical conditions such as thickness of overlying glacial drift, and width of outcrop of iron formation at the surface may be determining factors in the location of a mine. Equally important is the ease in which and extent to which iron particles can be separated, as the physical characteristics of the iron formation vary considerably.

The two plants in operation in Michigan, that utilize fine grinding for liberation of iron particles are working with a raw material that has a comparatively large grain size, easily separated by flotation. In the grinding operation the fines are mixed with a water solution of chemicals that coat only the iron particles. The mixture goes through a battery of flotation cells that form bubbles either by agitation by moving paddles or by inducing compressed air. The coated iron particles adhere to the bubbles, float to the top and are raked off. Silica is drawn out through the bottom of the cells and pumped to large settling basins. Low grade mines of the future in Michigan will work with material more difficult to separate because of finer grain size and a more intricate intermingling of impurities.

The iron product from a concentration plant is composed of very fine particles which cannot be used directly in the blast furnace as they would be blown out the top of the furnace. The fine material must be lumped into larger size, a process called agglomeration. An agglomeration plant at Eagle Mills makes small iron pellets by mixing the fine iron particles with coal dust and clay. The pellets are rolled in a tilted drum forming small balls which are hardened by burning.

The growth in production of low grade iron concentrates is expected to increase rapidly. The concentrates will not only supplement the declining direct-shipping high grade ores but may replace them to some extent as the high-iron concentrates are very popular with blast furnace operators. In concentrated iron ore, the iron content is 60 to 65 per cent. Impurities and moisture are reduced. Use of such higher iron-content ores or concentrates will increase pig iron capacity of blast furnaces without the addition of new units.