Mineral Resource Assessment of the Iron River $1^o \times 2^o$ Quadrangle, Michigan and Wisconsin

Prepared in cooperation with Geological Survey Division, Michigan Department of Natural Resources, and Wisconsin Geological and Natural History Survey
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By W. F. Cannon

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ABSTRACT

The Iron River 1° × 2° quadrangle contains identified resources of copper and iron. Copper-rich shale beds in the north part of the quadrangle contain 12.2 billion pounds (5.5 billion kilograms) of copper in well-studied deposits including 9.2 billion pounds (4.2 billion kilograms) that are economically minable by 1980 standards. At least several billion pounds of copper probably exist in other parts of the same shale beds, but not enough data are available to measure the amount.

A small amount, about 250 million pounds (113 million kilograms), of native copper is known to remain in one abandoned mine, and additional but unknown amounts remain in other abandoned mines.

About 13.25 billion tons (12.02 billion metric tons) of banded iron-formation averaging roughly 30 percent iron are known within 500 feet (152.4 meters) of the surface in the Gogebic, Marquette, and Iron River–Crystal Falls districts. A small percentage of that might someday be minable as taconite, but none is now believed to be economic. Some higher grade iron concentrations exist in the same iron-formations. Such material was the basis of former mining of iron in the region, but a poor market for such ore and depletion of many deposits have led to the decline of iron mining in the quadrangle. Iron mines of the quadrangle were not being worked in 1980.

Many parts of the quadrangle contain belts of favorable host rocks for mineral deposits. Although deposits are not known in these belts, undiscovered deposits of copper, zinc, lead, silver, uranium, phosphate, nickel, chromium, platinum, gold, and diamonds could exist.

INTRODUCTION

The Iron River 1° × 2° quadrangle is bounded by lats 46° and 47° N. and longs 88° and 90° W. and includes several major mining districts that have produced large amounts of copper and iron. At present, only the White Pine mine, where copper is recovered from an extensive unit of copper-rich shale, remains active. In the past, a large number of mines, which are now abandoned, produced native copper. Parts of three major iron-mining districts—the Marquette Range, the Gogebic Range, and the Iron River–Crystal Falls district—are in the quadrangle. All have produced large amounts of iron ore but are now inactive. (Mining is still being done in the Marquette Range east of the Iron River quadrangle.) Large quantities of mineralized rock remain in the ground, mostly in subeconomic form, but changes in price, mining and processing technology, or demand could revitalize mining.

In addition, many parts of the quadrangle are judged to be favorable ground for undiscovered mineral deposits. Much exploration by the mining industry was carried out during the 1970's, and a high level of exploration activity is likely to continue into the 1980's. Such exploration could expectably lead to the discovery of additional deposits or districts.

Although present mineral production is relatively small, about 150 million pounds (68 million kilograms) or less of copper per year, the potential for future mineral production is great. The mineral potential of the quadrangle should enter into economic and land-use planning for the region and into considerations of future mineral supplies for the United States.

This report summarizes a mineral resource appraisal of the quadrangle carried out between 1977 and 1980 by a team of geoscientists from the U.S. Geological Survey (USGS) as part of the Conterminous United States Mineral Assessment Program (CUSMAP). During that period, much new information was gathered, and older data were compiled and evaluated. All data were then considered to estimate the known mineral resources of the quadrangle and the potential for the existence of undiscovered resources.
The report summarizes the subactivities within the project, discusses the philosophy and techniques of resource assessment, and summarizes findings and conclusions about the mineral resources of the quadrangle. More detailed technical information is presented in the Iron River CUSMAP folio (USGS Maps I-1360-A to N).

ACKNOWLEDGMENTS

This resource assessment was made possible by the acquisition of a wealth of data and by the contributions from the Iron River project participants. These contributors are Henry Alminas, Maurice Brock, David Frishman, J. A. Kalliokoski, Elizabeth King, John Klasner, Richard Ojakangas, Warren Peterson, Bruce Smith, and Karen Wier. Anita Fenichel assisted in compiling much of the data and in drafting maps. Most of the annotated bibliographic entries were compiled by Alice Weis and Martina Johnson.

THE IRON RIVER CUSMAP PROJECT

Between 1977 and 1980, a team of geoscientists from the USGS constructed the detailed data base from which the mineral resource assessment of the Iron River quadrangle has been made. This team of experts in a number of scientific fields has made possible the acquisition and evaluation of a wide variety of data. A folio of maps presents this information in technical detail. Each component of the project is described briefly below.

MINERAL RESOURCE MAP

Map I-1360-A (Cannon, 1983a) shows the distribution of identified resources and areas of potential for undiscovered resources. The resource map was constructed by compiling information on known mineral deposits and by interpreting geologic, geochemical, and geophysical data to predict areas where resources are likely to occur.

BEDROCK GEOLOGIC MAP

The bedrock geology of the quadrangle is presented in map I-1360-B (Cannon, 1983b). The map was made largely from data gathered during detailed mapping by many geologists during the past 40 years. Two years were devoted to mapping areas that had not been mapped previously and to resolving the structure and correlation of some rock units. Interpretation of geophysical data also played a major role in understanding the bedrock geology in many parts of the quadrangle that are covered by sand, gravel, and other surficial deposits.

SURFICIAL GEOLOGIC MAP

The distribution of various types of unconsolidated deposits, mostly glacial deposits, is presented in map I-1360-C (Peterson, 1983). At the start of the project, little information was available on a regional scale, therefore, 3 years of field studies combined with an analysis of landforms as revealed by aerial photographs and topographic maps were needed to produce an adequately detailed map. The surficial geologic map is of great use in determining whether geochemical data and some types of geophysical data are related to surficial deposits only or possibly are caused by mineralization in underlying bedrock.

STRUCTURAL AND TECTONIC MAP

Additional information on the bedrock of the quadrangle is given in map I-1360-D (Cannon, 1983c). The structural and tectonic map provides information on the age, mode of origin, and subsequent history of rock units. Such information is useful in predicting rock units in which mineral deposits might have formed. As with the bedrock geologic map, much information was compiled from previous studies, but some new information was gathered during the CUSMAP study.

BOUGUER GRAVITY MAP

Map I-1360-E (Klasner and Jones, 1983) shows variations in Bouguer gravity values, identifies gravity anomalies, and includes interpretations of many of them. The CUSMAP project involved compiling data from previous surveys and performing additional surveys to provide a uniform coverage of the quadrangle and to adjust various older surveys to a common base value. The gravity map is useful in recognizing and tracing some broad tectonic features, in providing information on the density of rocks in the
subsurface, and in placing constraints on estimates of the depth of geologic features.

**AEROMAGNETIC MAP**

A map showing variations in magnetic attraction in the quadrangle (map I-1360-F) was compiled by King (1983). Data were from previous airborne surveys by the USGS in Michigan (Zietz and Kirby, 1971) and from John Karl of the University of Wisconsin at Oshkosh for Wisconsin. The Wisconsin data were compiled and published by Zietz and others (1977). For the current map, the Wisconsin data were recontoured by computer to add detail not shown in previous maps and were adjusted to match the Michigan data. Aeromagnetic data are invaluable in the Iron River quadrangle because they enable the tracing of numerous iron-rich magnetic units through areas where bedrock is not exposed and are an important source of information in making geologic maps. In addition, magnetic data can directly indicate some resources, such as iron-formations of possible economic value.

**METAMORPHIC MAP**

A map showing zones of metamorphic intensity of various ages was published as map I-1360-G (Wier, 1983). Information was obtained by previous studies and by the microscopic examination of many new rock samples to determine their mineralogic makeup. The metamorphic pattern is believed to control the distribution of some types of ore deposits, and the refinements and detail added by this study to the understanding of the metamorphic pattern of the quadrangle have resulted in the definition of some belts of resource potential.

**GEOCHEMICAL MAPS**

Maps I-1360-H to N (Alminas and others, 1983a, b, c; Hoffman and others, 1983a, b; Hopkins and others, 1983a, b) present the results of an extensive survey of the trace-element content of soils. A total of 3,156 B-horizon soil samples (about 1 sample per 2 mi²) were collected and analyzed spectrographically. The distribution and amounts of several important metals are shown on the maps along with interpretations of the distribution patterns of these elements. The variations of metal content in the soils reflect both regional trends in bedrock composition and more local variations, possibly related to mineralized areas in the underlying bedrock. An interpretation of the geochemical data has led to the identification of several areas where undiscovered mineral deposits might exist.

**ELECTROMAGNETIC STUDIES**

Airborne electromagnetic surveys were performed in parts of the quadrangle where such data are essential to a mineral resource appraisal. Results have been published in USGS Open-File Report 80-297 (Heran and Smith, 1980). Electromagnetic surveys identify units of rock that are electrically conductive. Information from the surveys is useful for mapping such conductive units in areas where bedrock is not exposed and also for more directly indicating the presence of some types of mineral deposits that are electrically conductive.

**URANIUM RESOURCE STUDIES**

Uranium resources were not a direct concern of the CUSMAP program. Concurrent studies were carried out, however, by Maurice Brock, J. A. Kalliokoski, Richard Ojakangas, and David Frishman of the USGS, funded in part by the National Uranium Resource Evaluation program of the Department of Energy. Information and advice provided by these geologists have been incorporated into the overall resource evaluation of the Iron River quadrangle.

**MINERAL RESOURCE TERMINOLOGY**

Mineral resources are naturally occurring concentrations of materials that are useful to man and that can be economically extracted now or potentially in the future. Resources, in their broadest sense, include all such existing concentrations, whether or not they have yet been discovered. Mineral resources can be broadly classified, therefore, into identified resources (those that have been discovered) and undiscovered resources (those that reasonably may exist but that have not yet been found). Identified resources are further subdivided into reserves (material that is presently profitable to mine) and subeconomic resources (material that requires either some increase in price or
improved mining or processing technology to become economically minable).

Undiscovered resources are subdivided into hypothetical resources (material yet to be found in known mining or mineralized districts) and speculative resources (deposits in yet unrecognized districts or yet unrecognized types of deposits). The classification of mineral resources is discussed in detail in USGS Circular 831 (U.S. Bureau of Mines and U.S. Geological Survey, 1980). A simplified version of that classification system is used here (fig. 1), and the definition of categories as they apply to the Iron River quadrangle is given below.

**IDENTIFIED RESOURCES**

Identified resources are concentrations of elements known to exist in specific locations. Information on their existence and nature is derived from direct observations of mineralized rock at the Earth’s surface, in drill holes, or in mine workings. In general, enough information exists to make at least semiquantitative estimates of the tonnage and grade of mineralized rock.

**RESERVES**

A reserve is an identified resource that has been thoroughly measured and tested and that is known with reasonable certainty to be economically exploitable by current technology and under current economic conditions. The copper-rich shale at the White Pine orebody is the only material in the Iron River quadrangle classed as a reserve in this report.

**SUBECONOMIC RESOURCES**

A subeconomic resource is that portion of identified resources that is not economically exploitable at present. Future increases in price or cost savings from improved mining or processing technology may convert subeconomic material to the reserve category.

**HYPOTHETICAL RESOURCES**

Hypothetical resources are concentrations of elements that can reasonably be inferred to exist in known mining or mineralized districts or extensions of those districts but that have not yet been found. In the Iron River quadrangle, for instance, hypothetical resources include deposits of native copper that might exist but have not yet been discovered in or near the abandoned mining district near Greenland and Winona. Future exploration may find some of these deposits and convert them to the identified-resource category.

**SPECULATIVE RESOURCES**

Speculative resources are undiscovered concentrations of elements whose existence is believed possible on the basis of broad geologic reasoning but for which there is no direct indication of their existence. No deposits of the elements are known in the immediate vicinity. Exploration of belts deemed likely to contain speculative resources may discover deposits of such materials and thereby convert them to identified or hypothetical resources. In the Iron River quadrangle, speculative resources include massive sulfide deposits of copper, zinc, and lead that are not yet known to exist but that are considered possible because the geology of parts of the quadrangle is very similar to the geology of other areas that contain massive sulfide deposits.

**MINERAL RESOURCE ASSESSMENT TECHNIQUES**

Mineral resource assessment is the quantification and estimation of the amount and nature of potentially useful minerals and the identification of areas where resources exist or may exist. Assessment is based on data from many sources, including geologic mapping, geochemical and geophysical surveys, studies of ore-forming processes, and the distribution patterns of ore deposits and their size and grade in well-explored mining districts.

The objective of the Iron River CUSMAP project has been to assemble the best possible and the most up-to-date data base on which to make a resource assessment. Such data, however, are never complete and commonly are not totally diagnostic of the presence or lack of mineralization. Any resource appraisal is a state-of-the-art estimate and is subject to revision and reevaluation as more data are obtained and as a better understanding of ore-forming geologic processes is achieved. The assessment presented here is based on our knowledge in 1980.
Judgment is an important factor, especially in estimating undiscovered resources, and somewhat different assessments probably would be made by different individuals using the same data.

In short, a mineral resource assessment must be viewed as an estimate. The accuracy of the estimate reflects the quality and amount of data available and the degree of understanding of the geologic occurrence of ore deposits and the processes that formed them. Future exploration and research probably will provide new data and insights that will allow improved estimates to be made.

In the Iron River quadrangle, identified resources include the copper-bearing shale in and around the White Pine orebody, native copper in and near the Greenland and Winona mining districts, and iron in banded iron-formation in the Gogebic, Marquette, and Iron River-Crystal Falls districts. All areas of identified resources either have had past mining or have been thoroughly tested by mining company drilling programs. Those companies generally have made much information available for use in evaluation of the resources.

ASSESSMENT OF IDENTIFIED RESOURCES

The assessment of identified resources is relatively straightforward. It is based on data directly indicating the tonnage, grade, and location of mineralized rock. Calculations and estimates of tonnage and grade can be made from available data, and the degree of certainty of the assessment commonly can be expressed in quantitative or qualitative terms.
near enough to the Earth's surface in areas that contain deposits that are likely to be discovered are shown. Hence, zones having a potential for undiscovered resources might be viewed as areas where mineral exploration is most likely to occur and where discoveries might be made. As such, the assessment is a prediction of future events—mineral exploration and possible discovery of deposits that might occur. As a prediction, it is subject to uncertainty and error but should be considered in planning.

Mineral deposits can be grouped into genetic types by placing together all deposits that have formed as a result of similar processes, regardless of their location. For each type of deposit, a genetic model can be developed to describe the process or set of processes that operated in the geologic past to form the deposit. A set of features recognizable in rocks and deposits caused by those processes can be defined. Such processes commonly operated over an area larger than that within the ore deposit and therefore have recognizable features that provide a larger target for mineral exploration than the deposit itself. Recognition of the features indicative of ore-forming processes may lead to the supposition that an orebody could exist nearby, even though it may not be observable at the surface.

Furthermore, ore-forming processes commonly take place in a broader geologic framework. For instance, processes that may form one genetic type of ore deposit may occur only in volcanic regions; whereas processes that form a second type may occur only along marine shorelines. The presence and recognition of rocks formed in such widespread environments provide a regional framework for resource assessment.

As an example of how such reasoning leads to a resource assessment, let us examine a specific case. Massive sulfide deposits are ores of copper, zinc, lead, and various byproducts. Such ores are common in many parts of the world; thorough study of them on a worldwide basis reveals striking similarities in the way that they formed and in the types of rocks that commonly surround them.

It is generally agreed that many massive sulfide deposits form on the sea floor when material crystallizes from fluids emitted by submarine hot springs in areas of volcanic activity. Such deposits commonly are interlayered with submarine volcanic and sedimentary rocks near ancient volcanic vents. The vent areas are recognized by characteristic textures preserved in the rocks.

No massive sulfide deposits are known in the Iron River quadrangle, but some have recently been discovered as little as 20 miles (32 kilometers) south of the quadrangle. To determine if undiscovered massive sulfide deposits might exist in the Iron River quadrangle, one first looks for areas that contain submarine volcanic rocks because massive sulfides might have formed in the general environment where such rocks formed. Submarine volcanic rocks are found in several belts in the south half of the quadrangle, and these belts are judged to have at least broad favorability for the occurrence of massive sulfides.

Each volcanic belt is then examined in more detail to determine if areas within it can be identified as having been near volcanic vents. If such vent areas can be identified, their potential is considered to be even higher than that of the volcanic belts in general, because rocks within these areas have formed not only in a generally favorable setting but also in the specific part of that setting where massive sulfides typically have formed elsewhere in the world. Within identified vent areas, further examination might reveal features directly indicative of ore-forming processes, or geochemical or geophysical measurements may suggest that ore is buried beneath the surface. In some cases, mineralized rock might be directly observed, but such is not likely to be the case in the Iron River quadrangle because most bedrock is covered by a veneer of glacially transported sand and gravel.

By using such evidence and reasoning, various parts of the quadrangle can be classified as being broadly favorable for mineral occurrence (class C areas of this report). Parts of some class C areas are given additional importance because rocks within them are known to have formed in specific environments where ore might have formed (class B areas). Parts of some class B areas are further identified as having experienced potentially ore-forming processes (class A areas). (See section on "Undiscovered Resources.")

The ability to classify areas in this manner is limited by the amount of geologic information on the area and by the detail known and the assurance about the mode of origin of a genetic type of deposit.

In many parts of the Iron River quadrangle, knowledge of the bedrock is not detailed because of the cover of sand and gravel. Hence, the information required to define class A and class B areas commonly is lacking, and most areas of undiscovered resources can be identified only as class C. Likewise, incomplete understanding of the mode of origin of some genetic types of deposits does not allow a definition of criteria specific enough to differentiate class A or class B areas from the general belts of class C favorability. As a result, many favorable belts in the Iron River quadrangle are classified only as class C. Within these belts, the lack of class A or class B zones in the present
assessment may reflect the lack of information more than the absence of mineralization.

CLASSIFICATION OF RESOURCES IN THE IRON RIVER QUADRANGLE

The Iron River quadrangle has been zoned into seven categories of resource potential, as shown in figure 2.

IDENTIFIED RESOURCES

Identified resources are known deposits whose location can be shown on a map and for which some information on size and grade exists. Three categories of identified resources are used in this report:

1. Reserves.—Known concentrations of materials economically exploitable in 1980.
2. Outcrop belts of mineralized strata.—Areas in which continuously or discontinuously mineralized rock is exposed or exists in the shallow subsurface.
3. Subsurface mineralized rock.—Areas in which mineralized rock is known to exist underground but is overlain by unmineralized rock. These areas are, in general, the subsurface extensions of outcrop belts of mineralized rocks.

UNFAVORABLE AREAS

Unfavorable areas are those for which no strong indications of economic minerals occur either directly or by an analogy with known deposits elsewhere. Unfavorable areas contain types of rocks in which few, if any, important ore deposits occur anywhere in the world. No area, however, can be considered totally unfavorable. Additional knowledge, discovery of new classes of deposits, or future needs for minerals not currently in demand could cause areas now considered unfavorable to be reclassified eventually as favorable.

FAVORABLE AREAS

Favorable areas are those where some indication, either direct or indirect, of undiscovered mineral deposits is known. Favorable areas are here subdivided into three categories.

Class C areas are those areas for which geologic evidence indicates a general environmental setting where mineral deposits could occur, but no direct evidence of mineralization is known.

Class B areas are those areas where the contained rocks represent the specific parts of the generally favorable environment where mineral deposits could have formed and, hence, have a higher favorability than class C areas.

Class A areas, the most favorable areas, are areas where actual mineralizing processes are known to have occurred. Whether those processes formed ore anyplace is not necessarily known.

UNDISCOVERED RESOURCES

Undiscovered resources are deposits likely to exist but not yet discovered. They, of course, cannot be shown on a map. Rather, areas can be shown for which varying degrees of favorability for the discovery of such deposits can be inferred. The zones shown in figure 2 are belts in which potentially mineralized rock is at or very near the surface and in which contained deposits could be found by standard exploration techniques. Such potentially mineralized rocks generally extend into the subsurface away from their outcrop belts, but these subsurface extensions are not shown in figure 2. Although the rocks in the subsurface may be as likely to be mineralized as those at the surface, deposits that might exist at deep levels are not likely to be discovered in the near future. Areas are broadly classified as favorable and unfavorable.

MINERAL RESOURCES OF THE IRON RIVER QUADRANGLE

Figure 2 shows areas of the Iron River quadrangle where resources are known to exist or thought likely to exist, and table 1 summarizes the resources of the quadrangle. The resources are discussed separately in identified, hypothetical, and speculative categories.

IDENTIFIED RESOURCES

COPPER

Zones Cu₁ through Cu₃ contain identified copper resources. Zone Cu₁ is the area underlain by the reserves of the White Pine mine. The reserves, for the most part, are in the deep subsurface. The material
The copper content of the Presque Isle deposit, including belts Cu_2 and Cu_3, is conservatively estimated to contain at least several billion pounds of copper. The remaining areas peripheral to the White Pine reserve are probably mineralized, but it is not economic because of low grade, thin beds, or more difficult to mine than the material that constitutes the White Pine reserve.

Zone Cu_4 contains volcanic rocks (basalt) that are mineralized with native copper. Many inactive mines are in the area. An unknown amount of mineralized rock of subeconomic grades is still in the ground at some mines, and additional mineralized rock may yet be found in the belt. At the Caledonia mine, about 11.5 million tons (10.4 million tonnes) of rock having an average grade of 1.1 percent copper is known to remain in the ground (Wilband, 1978). The discontinuously mineralized rock of Cu_4 forms a thick slab inclined northward so that it continues in the subsurface north of the outcrop belt.

Zone Cu_5 is the extension of known mineralized rock at depth from Cu_4. Its northern limit is defined approximately by the limit of data from mine workings and drilling, but mineralization may extend downward and northward beyond the deepest data points.

Very large quantities of iron-rich rocks exist in the quadrangle. All those of potential resource importance are banded iron-formations. Production of ore between 1872 and 1978 totaled about 210 million tons (191 million tonnes), mostly from the Iron River-Crystal Falls district. All of that production was of relatively high grade ore (generally 50-60 percent iron), which occurred as irregular bodies within lower grade iron-formation having about 30 percent iron. Since the 1950's, the production of iron in the United States has shifted away from the use of natural high-grade ores to pelletized iron concentrates produced from iron-formations containing about 30 percent iron, commonly called taconite. As a consequence, the market for high-grade ores has greatly diminished, and exploration for new deposits has virtually ceased in the area.

Although most of the iron-formation in the Iron River quadrangle does contain 30 percent iron or more, none now is commercially workable as taconite. Various problems, including thinness of iron-formation layers, steep dips, and large amounts of waste rock above and interlayered with the taconite, make it difficult to mine profitably large tonnages of ore from open pits, as taconite must now be mined. In addition, the mineralogic complexity of much of the iron-formation makes most of it untreatable by current metallurgical concentrating processes.

Zones Fe_1 through Fe_7 contain identified resources of iron. The iron-resource potential of these zones is shown in figure 2 and described briefly below.
Areas in which iron-formation exists in the subsurface are of little short-term resource importance. Although they could contain undiscovered deposits of high-grade ore, the present poor market for such ores makes it unlikely that subsurface iron deposits will be explored for and found in the foreseeable future. Some of the material could be used as taconite but would not be commercially minable unless mining technology were improved so that underground mining became economically competitive with open-pit mining.

Such areas could have some resource importance sometime in the 21st century if near-surface iron deposits now being exploited elsewhere become depleted and if improved mining and metallurgical technology permit their mining and processing.

The two areas having the best potential for taconite are probably zones Fe₁ and Fe₂ in the western part of the Marquette Range. Both areas contain substantial amounts of iron-formation very similar to that now being mined at the Republic mine, which is only about 1 mile (1.6 kilometers) east of the quadrangle.

Zone Fe₁ is the outcrop belt of iron-formation in the western Marquette Range. Some high-grade ore has been produced in the past. Parts of the formation may be amenable to treatment as taconite. About 0.75 billion tons (0.68 billion tonnes) of iron-formation are within 500 feet (152.4 meters) of the surface. About 250,000 tons (227,000 tonnes) of that contain a mineralogic makeup that may be treatable by existing concentration processes. The deposits of the western Marquette Range are probably not economic now because of the thinness of iron-formation layers and the relatively large amounts of waste rock that would have to be moved to recover the iron-formation.

Zone Fe₂ is a second outcrop belt of iron-formation having some taconite potential in the western Marquette Range. The tonnages of available rocks are about the same as those for zone Fe₁, and development of the area faces the same problems.

Zone Fe₃ is the outcrop belt of iron-formation in the Gogebic Range. The area has had some past production of high-grade ore. Some high-grade ore may remain to be found. The area contains about 10 billion tons (9 billion tonnes) of iron-formation within 500 feet (152.4 meters) of the surface. Some of that material might be useful as taconite in the future if metallurgical improvements allow treatment of the mineralogically complex iron-formation.

Zone Fe₄ is the outcrop belt of iron-formation in the Iron River-Crystal Falls district. The area has had a large production, about 210 million tons (191 million tonnes), of high-grade ore. James and others (1968) estimated that about 50 million tons (45 million tonnes) of identified ore remain in the ground and that about 90 million tons (82 million tonnes) of undiscovered ore exist. About 1.75 billion tons (1.59 billion tonnes) of iron-formation are within 500 feet (152.4 meters) of the surface (James and others, 1968), but this material has very little taconite potential because of mining problems and unsuitable mineralogy.

Zone Fe₅ is the subsurface extension of the iron-formation of the Gogebic Range projected to about a 1-mile (1.6-kilometer) depth. The iron-formation has some potential for high-grade ores and very limited short-term potential as taconite.

Zone Fe₆ is the subsurface extension of the iron-formation of the Marquette Range to a depth of about 1 mile (1.6 kilometers). The iron-formation contains some potential resources of high-grade ore and, largely because of depth, has very small potential as a resource of taconite.

Zone Fe₇ is the subsurface extension of the iron-formation of the Iron River-Crystal Falls district to a depth of about 1 mile (1.6 kilometers). The material probably contains undiscovered deposits of high-grade ore but has very limited taconite potential because of depth and unsuitable mineralogic form.

HYPOTHETICAL RESOURCES

Hypothetical resources are undiscovered deposits in known mineral districts, as shown in figure 2, that are restricted to parts of the native copper district and the iron-mining districts.

COPPER

Zone Cu₆ in figure 2 is the extension along the geologic trend of the same rocks that are mineralized in belts Cu₄ and Cu₅, but only minor (subeconomic) mineralization is known. A high potential for undiscovered native copper and perhaps sulfide copper is indicated by strong similarities in nearly all details between these rocks and the mineralized rocks in zones Cu₄ and Cu₅. Areas of subeconomic mineralization are widespread. A high copper content of soils overlying these rocks, especially in the western part of the quadrangle, is another favorable sign.

Zone Cu₇ contains volcanic rocks that are in many ways similar to those in zones Cu₄ and Cu₅, but that differ in some important details relating principally to
FIGURE 2.—Generalized mineral-resource map of the Iron River 1° × 2° quadrangle, Michigan ar
EXPLANATION

IDENTIFIED RESOURCES

- Areas underlain by reserves
- Areas where iron-formations are at or near the surface
- Areas where copper-mineralized rocks are at or near the surface
- Subsurface extensions of mineralized rocks. For iron-formations a 1-mile (2.6-km) depth cutoff was chosen although units can be inferred confidently to continue to greater depth

UNDISCOVERED RESOURCES

- Areas with class A favorability
- Areas with class B favorability
- Areas with class C favorability
- Unconformity near which unconformity-type uranium deposits might occur. Tick-marks are on side of unconformity where older rocks are found
- Unconformity near which uraniferous phosphate deposits might be found. Tick-marks are on side of unconformity where deposits are probable
- Identifying symbols for specific resource-potential areas. See text for details

composition of the rocks. No substantial copper mineralization is known. The existence of undiscovered native copper deposits is possible but seems less likely here than it is in zone Cu6.

IRON

Undiscovered deposits of iron ore could exist in any of zones Fe1 through Fe7, which are all within or are extensions of past mining districts. Such ores are of limited importance in the short term and are not likely to be explored for in the foreseeable future.

SPECULATIVE RESOURCES

Speculative resources are those that possibly exist but that, if found, would be a new type of deposit for the region. Several genetic types of speculative resources are discussed here. They are the ones judged most likely to occur. Other types, not discussed, could also occur but, at present, are judged either to have insufficient potential to enter into near-term resource considerations or to have not yet been recognized as possible resources.

VOLCANOGENIC MASSIVE SULFIDE DEPOSITS

Volcanogenic massive sulfide deposits occur in submarine volcanic rocks and generally near centers of volcanic activity. Massive sulfides are generally polymetallic ores that may be mined for copper, lead, zinc, silver, and gold. Areas designated Ms, in figure 2 are zones where ancient submarine volcanic rocks are at the bedrock surface and are considered favorable for massive sulfides. In most areas, however, the bedrock is so poorly exposed that few details of the volcanic rocks are known; the belts are defined as class C areas and cannot be further subdivided.

Zone Ms1 is a thick unit of submarine volcanic rocks that is considered to be a class B area because it appears to have formed near a volcanic center and, in addition, because it causes several distinctive geophysical anomalies (electromagnetic conductors) that could result from massive sulfide deposits in the subsurface.

Zone Ms2 is a belt of submarine volcanic rocks about which few details are known, but that is ranked class B because geophysical anomalies there could be caused by massive sulfide deposits in the subsurface.

Zone Ms3 is a small belt west of Lake Gogebic that is ranked class A because it shows geophysical anomalies and contains favorable rock types and also subeconomic copper and zinc mineralization.

SEDIMENT-HOSTED SULFIDE DEPOSITS

Several types of sediment-hosted sulfide deposits are possible in the quadrangle and could contain ores of copper, zinc, lead, silver, or gold.

CARBONATE-SHALE HOSTED DEPOSITS

About 30 miles (48 kilometers) east of the quadrangle, near Marquette, Mich., a large subeconomic copper sulfide deposit, estimated to contain 1 billion tons (0.9 billion tonnes) of mineralized rock (Wilband, 1978), occurs in shale beds in a generally dolomitic rock unit. Extensions of the dolomite unit are known in several parts of the quadrangle. Areas containing the dolomite are ranked class C and shown as zones Ss, on the map. Zone Ss1 is ranked class B because geophysical anomalies indicate that subsurface rocks contain either extensive shale beds within the dolomite or possibly sulfide-rich beds. Zone Ss2 is a small area ranked class A because it contains an outcrop of mineralized bedrock. Copper sulfide minerals occur in quartzite beds that are interlayered with dolomite. Grades are locally as high as 1 percent copper (Cannon, 1980).

SHALE AND IRON-FORMATION HOSTED DEPOSITS

Several areas contain shale and interbeds of iron-formation, zones Ss4, in figure 2. Many of these areas are poorly known because of the scarcity of bedrock exposures but are judged to be potential hosts for sulfide deposits of copper, zinc, and lead. Some low-grade mineralization (generally less than 0.1 percent copper plus zinc) is known locally, and undocumented verbal reports from mining companies indicate discoveries of subeconomic sulfide deposits. Some carbonate-hosted deposits such as those of zones Ss1 are also possible within the Ss4 zones.

VOLCANIC-SEDIMENT ASSOCIATION

Massive and disseminated sulfide deposits sometimes occur at the fringes of submarine volcanic
zones where the volcanic rocks are interlayered with submarine sedimentary rocks. Zone Ss, is assigned class C favorability because it contains interlayered volcanic rocks, shale, graywacke, and iron-formation. No direct signs of mineralization are known. Zone Ss, is given class A favorability. It contains rocks similar to those in zone Ss, but, in addition, is known to contain sulfide-rich rock units that have subeconomic concentrations of copper and zinc.

DEPOSITS ASSOCIATED WITH MAFIC INTRUSIVE ROCKS

Igneous rocks that have undergone strong chemical fractionation as they crystallized from a molten state to solid state may contain concentrations of copper, nickel, cobalt, chromium, or platinum. Such strongly fractionated mafic rocks exist in a few places in the quadrangle, but no mineralization is known in them. Zones Mi, are areas where such rocks are known. Zones Mi, contain rocks formed in that part of the mafic fractionation sequence in which mineral deposits are most likely to occur. They are assigned class B favorability.

UNCONFORMITY URANIUM DEPOSITS

During the 1970's, some very rich uranium deposits, some of which also contain nickel and gold, were discovered along ancient erosion surfaces (unconformities) in Australia and Canada. The unconformity extending across the Iron River quadrangle from near the northeast corner to Wakefield has many features in common with those uranium-bearing unconformities. In the late 1970's, many mining companies explored for uranium along the unconformity in the quadrangle. A broad belt parallel to and including the unconformity Uu, is given class C favorability because of similarities between the geology there and that of mineralized unconformities. A zone east of Lake Gogebic (Uu,) is given class B favorability because it contains some of the specific features directly associated with mineralization elsewhere (as noted in the explanation, fig. 2).

URANIUM-IRON ASSOCIATION

In the Iron River-Crystal Falls district, concentrations of uranium were discovered in several places at the fringes of iron-ore bodies in the Sherwood and James mines (James and others, 1968). These deposits are of small size and subeconomic grade. Consequently, the belts in which the iron ores of the district occur (zones Fe, and Fe,) are considered to have class C favorability for uranium.

URANIFEROUS PHOSPHATE DEPOSITS

In 1976, small deposits of phosphate-rich rock, some with small concentrations of uranium, were discovered at several localities in the northeast part of the quadrangle (Cannon and Klasner, 1976b). Since then, additional low-grade occurrences have been found in the Gogebic Range. All known deposits are very near (within a few hundred feet) the unconformity separating very ancient crystalline rocks from somewhat younger metasedimentary rocks. That unconformity is shown, wherever it is known to exist, in figure 2, and a class C favorability belt is considered to exist along it, although that belt is too narrow to show at this scale.

SILVER-BEARING SHALE

A belt of black shale and slate in the northeast part of the quadrangle (zone Ag) contains unusually high concentrations of silver, which, in places, are accompanied by molybdenum. Soil overlying these rocks commonly is also silver rich. Although these rocks are far from being economically exploitable for silver or molybdenum, they are considered to have class C favorability for silver or molybdenum deposits because, within the shale belt, some process locally might have further concentrated the widespread high silver and molybdenum values to potentially economic levels.

DIAMOND

About 15 miles (24 kilometers) northeast of Crystal Falls, a small body of kimberlite was discovered recently (Cannon and Mudrey, 1981). Kimberlite is a rare type of rock and is the only natural source of diamonds. About 1 kimberlite body in 10 contains diamonds. Only one kimberlite occurrence is known in the quadrangle, but it is likely that others exist nearby, so diamond-bearing rocks may exist in the quadrangle.
CONCLUSIONS

The Iron River quadrangle is part of a mineral-rich region that contains large identified deposits that are currently or potentially economic to mine. In addition, large areas of promising ground for exploration exist, and future discoveries of presently unknown deposits are possible. Despite the relatively low level of mining in the quadrangle in 1980, the Iron River quadrangle has the potential to produce large amounts of minerals in the future.

Within the quadrangle, about 12.2 billion pounds (5.5 billion kilograms) of copper are known to exist in well-studied deposits. Material that is presently economic includes 9.2 billion pounds (4.2 billion kilograms) of copper in the White Pine orebody. At least several billion additional pounds are likely to occur in known mineralized rocks in areas where data do not allow quantification.

About 13.25 billion tons (12.02 billion tonnes) of banded iron-formation are estimated to exist within 500 feet (152.4 meters) of the surface in three principal mining districts—the Marquette, the Gogebic, and the Iron River–Crystal Falls districts. A small percentage of that material might someday be minable as taconite if improved mining or metallurgical technology or increased iron prices permit profitable extraction of iron.

Possibly, parts of the quadrangle contain undiscovered deposits of copper, zinc, lead, silver, uranium, phosphate, nickel, chromium, cobalt, platinum, gold, and diamonds. Future exploration seems likely to find some of these and add to the known mineral wealth of the region.

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