

AD-780 285

BEDROCK GEOLOGIC DATA OF THE UPPER
MICHIGAN REGION: PROJECT SANGUINE

EDAW, Incorporated

Prepared for:

Naval Facilities Engineering Command

February 1974

DISTRIBUTED BY:

NTIS

**National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151**

AD780285

DDC
RECEIVED
JUN 17 1974
RECEIVED
C

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

Sanguine is an extremely low frequency communications project in the Research and Development phase which is intended, if implemented, to provide assured command and control of U. S. strategic forces, particularly ballistic missile submarines, deployed worldwide, despite enemy attack or jamming.

The Sanguine concept envisions buried hardened transmitter capsules located at the intersections of a widely dispersed north/south and east/west grid of buried antenna cables to provide the desired survivability.

The purpose of this site study is to assist in determining the most appropriate location of the system within a specified geographical area considering both the optimum cost of system installation and the maximum environmental compatibility.

The specific area studied is approximately 7300 square miles in area and encompasses most of the western portion of Michigan's Upper Peninsula. The area includes all or portions of the following Michigan counties: Alger, Baraga, Delta, Dickinson, Gogebic, Houghton, Iron, Marquette, Menominee, and Ontonagon.

relat

AD-780 285

BEDROCK GEOLOGIC DATA
of the
UPPER MICHIGAN REGION
PROJECT SANGUINE



for
Northern Division
Naval Facilities, Engineering Command

by

EDAW, Inc., 145 Mission Street, San Francisco, California 94105
ESA, 701 Welch Road, Palo Alto, California 94304

February 1974

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151



CONTENTS

<u>Subject</u>	Page
Summary	1
Evolution	3
Distinctive Units and Characteristics	6
Relationship to Other Data.	22
Validity.	24
Bibliography.	29
 <u>Figures</u>	
Figure 1. Key to Map Interpretation.	7
Figure 2. Bedrock Map Index.	26
Bedrock Geologic Data Map	back pocket

SUMMARY

Bedrock geology refers to the areal distribution, thickness, sequence, and types of indurated rocks that make up the earth's crust. Within the Upper Michigan study area, most of the rocks are of Precambrian age (more than 600 million years old). These ancient rocks have been divided into the Archean Series, the Huronian Series, and the Keweenawan Series. The Archean rocks are the oldest group, and they consist principally of altered lava flows intruded by granite, with associated masses of granitic gneiss. The next younger rock series, the Huronian, is largely a thick section of sedimentary rocks that overlaps the Archean Series. These sedimentary units, mainly graywackes and dolomites, have been intruded by basic igneous rocks. Metamorphic rocks, mainly slates and quartzites, occur elsewhere in the Huronian section. The Huronian sedimentary section also contains several iron-rich units known as "iron formations." The youngest Precambrian rocks, the Keweenawan Series, are principally lava flows and conglomerates, although minor units of shale and sandstone exist.

Shallow-dipping Paleozoic sedimentary rocks overlie the Precambrian sequence and crop out in the eastern part of the study area. Here Cambrian and Ordovician sedimentary formations dip gently in a southeasterly direction to form the northwesterly rim of the Michigan Basin. These rocks are mainly sandstones, dolomites, shales, and limestones. Younger (Mesozoic and Cenozoic) rocks have been almost entirely removed from the area by glaciation. The areal distribution of bedrock in the study area is shown on the bedrock Geologic Data Map.

The Lower and Middle Precambrian rocks were affected by major episodes of mountain building during Precambrian time involving folding, thrust faulting, and metamorphic alteration. Since at least the mid-Paleozoic (about 350 million years ago), however, the Upper Michigan region has been tectonically stable, with Pleistocene glaciation being the major factor in modification of the landscape. Hard bare rock is exposed at the surface in many relatively small areas, but a soil and glacial mantle ranging from a few to a few hundred feet thick overlies the bedrock throughout most of the study area.

The Bedrock Geologic Data Map that accompanies this narrative was prepared by compiling available published and unpublished geologic data and maps adjusted to a common scale. The relationship of this map to the Surficial Geologic Data Map and the Soils Data Map should be kept in mind during its use. The Bedrock Geologic Data Map provides useful data on the type of rock underlying a specific area, and descriptions of the various rock units are contained in this narrative. It gives only an indication of the rock types present at depth, however, and does not consider the thickness of the overlying deposits.

Therefore, the Surficial Geologic Data Map and the Bedrock Geologic Data Map should be used in conjunction with each other to determine the maximum amount of information about geologic conditions in a given area. For instance, by overlaying and comparing these maps and utilizing the data on rock descriptions contained in this narrative, it is possible to determine where rock outcrops occur and the type of rock present.

EVOLUTION

Processes and Time Leading to the Existing State

The geologic history of the Upper Peninsula of Michigan has been reconstructed from the record contained in the various rocks exposed in the area. The record represents a long period in the earth's history, stretching over billions of years from early in the Precambrian Era to the present, and documents many episodes of shallow water deposition, mountain building, and erosion of the land surface. Because many of the rocks which once covered the area have been removed by erosion or complexly deformed, it is an incomplete record.

The Precambrian Era (which lasted from about 4.7 billion years ago to 600 millions years ago) is especially difficult to reconstruct because of the highly deformed rocks which represent this extremely long and ancient period in the earth's history, during which several cycles of deposition, metamorphism and igneous intrusion took place. However, a generalized history has been developed which gives the highlights of the area's geologic evolution.

The oldest known Early Precambrian (Archean) rocks in the study area are schists, greenstone, and quartzite (the metamorphosed equivalents of basaltic lavas and sandstone). The presence of these rocks indicates a history of sedimentation and volcanic activity (in part subaqueous) followed by episodes of metamorphism.

An early episode of crustal disturbance was the Laurentian Orogeny, during which time the previously formed layered rocks were folded, altered and locally intruded by granitic magmas. These granitic bodies were later metamorphosed to become gneisses and gneissic granite. This relatively minor orogenic episode took place about 2.6 billion years ago, and culminated in local uplift and erosion.

A period of crustal subsidence followed, during which conglomerates, sands, and explosively ejected volcanic materials were deposited in shallow seas. The Algoman Orogeny, a period of high-grade regional metamorphism caused by widespread and intense crustal deformation, followed the formation of these layered rocks. Folding, faulting, granitic intrusion, altering of pre-existing rocks, uplift, and mountain building marked the Algoman and the end of the Early Precambrian in Upper Michigan at about 2.4 billion years ago.

Over the eroded surface of the Archean rocks, Middle Precambrian (Huronian) seas repeatedly transgressed and regressed to form a sequence of conglomerates, sandstones, algal

dolomites, iron formations (iron mineral-rich cherts), and shales. Felsitic and basaltic volcanic rocks were introduced into the sequence by near surface volcanic activity. These rocks have since been metamorphosed in part to slate, quartzite, and graywacke. Evidence has also been found in the Menominee region of glaciation during the early part of the Huronian. The Huronian Period ended about 1.7 billion years ago with renewed major crustal deformation (termed the Penokean Orogeny). Although not as intense as the Algomian, it was also characterized by folding, faulting, igneous intrusion of dikes and sills, regional metamorphism, uplift, and mountain building.

The latest period in the Precambrian Era was the Keweenawan, which lasted from about 1.7 billion years ago until about 600 million years ago. During this time, great extrusions of basaltic lava poured out of fissures in the earth and flowed over an eroded surface developed on the pre-existing sedimentary, metamorphic, and intrusive rocks. Apparently, the lava entered the ancient Lake Superior Syncline, which sagged to accept the deposits. The many thousands of feet of volcanic flows which accumulated became the host for almost all of the native copper deposits of the Northern Peninsula. In addition, gabbro and small amounts of granite were emplaced into the flows. Interbedded with some of the lavas are coarse sediments, primarily conglomerate and sandstone, which were probably deposited by streams flowing down from highland areas and across the flows. The subsiding Lake Superior Syncline was the site for the subsequent deposition of many thousands of feet of sediments. A period of gentle uplift and erosion of some of these sedimentary rocks ended the Precambrian Era.

During the early Paleozoic Era between about 600 and 400 million years ago, the Upper Michigan area was again submerged, and the present sequence of gently dipping sedimentary rocks which overlie the Precambrian rocks were deposited. Renewed deposition began early in the Cambrian Period, as streams flowed from highland areas to what may have been a freshwater basin. Tilting of these Early Cambrian sediments preceded the advance of Upper Cambrian and Ordovician seas, in which were deposited sandstone, conglomerate, shale, and dolomite. The gently dipping sedimentary rocks which resulted from these periods of deposition vary in thickness, since they were laid down on an irregular erosional surface.

Since the mid-Paleozoic, the Northern Peninsula of Michigan has been an extremely stable portion of the earth's crust. Until the Pleistocene Epoch and the invasion of glaciers from the north, the only major geologic processes which affected the area were wind and water erosion. While neighboring areas were sites of sedimentation during most of the Paleozoic, the

land surface of the study area apparently was mainly above sea level, although generally topographically low.

The action of glacial ice, especially during the latest Ice Age (the Wisconsin stage), profoundly altered the landscape of the study area. Deposition of the glacial cover of end and ground moraines, outwash plains, and lake sediments (which presently mantle most of the study area and are up to 300' thick in some areas) has probably been the most important factor in determining the present topography (see Evolution in Surface Geologic Data for a discussion of the glacial history of the area).

Anticipated Future States

The Upper Peninsula of Michigan is presently geologically stable, with no significant tectonic, volcanic, or seismic activity occurring. Although the geologic processes of weathering, erosion, and stream deposition continue, these processes are occurring at such a slow rate that it is unlikely they will alter the present landscape significantly within the next several centuries. Man's activities appear to be the only significant factor that could alter the landscape within the foreseeable future. Each of these activities must be evaluated separately to determine its impact on the landscape.

DISTINCTIVE UNITS AND CHARACTERISTICS

Introduction

The oldest rocks exposed in the study area are the Lower Precambrian (Archean) metamorphic rocks, which consist mainly of schist, greenstone, and quartzite with associated intrusive granite and gneiss. The Middle Precambrian (Huronian) rocks include a thick sequence of sedimentary and volcanic rocks which have been metamorphosed to schists, slates, quartzites, iron formations, and greenstone. Both the Lower and Middle Precambrian rocks have been subjected to several episodes of folding, faulting, igneous intrusion, metamorphism and erosion.

The Upper Precambrian (Keweenaw) sequence was deposited after these episodes of intense deformation. These rocks consist of unmetamorphosed basaltic lavas and sedimentary rocks, including shales, sandstones, and conglomerates. Another period of deformation followed, which resulted in tilting and erosion of the Upper Precambrian rocks.

In places, the Precambrian rocks are overlain by gently dipping sandstones and dolomites of Cambrian and Ordovician Age. These Paleozoic rocks are the youngest bedrock units in the study area. All rocks younger than these were removed by glacial erosion during the Pleistocene Ice Ages, and thick deposits of unconsolidated glacial debris cover the bedrock throughout much of the area (see Surficial Geologic Data narrative).

Within the Upper Michigan study area, several episodes of folding, metamorphism, and erosion have considerably altered the older Precambrian rocks, and definite correlations cannot be made, in most cases, between similar rock types exposed in different parts of the study area. Consequently, the Lower and Middle Precambrian rock units are described under four separate headings relating to their geographic locations: the Marquette Range; the Iron River - Crystal Falls - Menominee Area; the Gogebic Range - Watersmeet Area; and Widespread Areas of Uncertain Correlation (see Key to Map Interpretation, Figure 1, page 7).

The Upper Precambrian (Keweenaw) and Paleozoic rocks are generally continuous and readily traceable units, however, and correlations between exposures from one area to another can be made. Consequently, similar rock types in different areas have been identified and mapped as the same formation, and descriptions of these rock units apply to all portions of the study area.

There are 91 formations and units shown on the Bedrock Geologic Data Map, of which 85 are assigned to the Precambrian Era. Each has been mapped according to its predominant lithology, and other rock types may be included. Since the precise ages of Precambrian rocks are very difficult to determine, relative ages have been assigned only to units designated with a formal name (such as Michigamme Graywacke). They are described in a chronological order, beginning with the oldest. Rock units which carry only a lithologic designation (such as granodiorite) are placed in the chronologic sequence where it is believed they belong, but their relative ages have not been determined.

The mapping units were combined into five groups (each of which is represented by a separate color on the enclosed copy of the Bedrock Geologic Data Map) on the basis of rock type and age. The older, harder, Middle and Lower Precambrian rocks are divided into highly metamorphosed types and relatively unmetamorphosed igneous types. The steeply dipping and mainly unaltered Upper Precambrian rocks are divided into a volcanic unit and a sedimentary unit, while the gently dipping, relatively softer Paleozoic sedimentary rocks make up the remaining map unit.

Geologic Units

1. Older Metamorphic Rocks

a. Marquette Range

(1) Lower Precambrian (Archean)

gm, mtn,
ftm, fm--

Mona Schist. The Mona Schist is the oldest formation in the area, and contains four separate units, all of which are found primarily in the Marquette area. The units are greenish in color, massive to schistose, and volcanic in origin. The estimated minimum total thickness of the formation ranges from 13,000 to 21,000 feet. (Gair and Thaden, 1968, pp. 6-18).

gm - Basaltic Greenstone. The Basaltic Greenstone Unit of the Mona Schist Formation consists of very fine grained, dull green to brownish green, massive to schistose metamorphosed basalt. Many ellipsoidal structures may indicate deposition, at least in part, under water. This greenstone is in some places interlayered with amphibole schist of the overlying Mafic Tuff Unit.

mtm - Mafic Tuff. The Mafic Tuff Unit is generally fine grained, dark green to deep brown to pale gray-green amphibole schist. It is chemically similar to basalt, and probably resulted from the metamorphism of mafic volcanic ash beds. Typical of the unit are lensoid shaped layers, usually several inches thick and 10 to 30' long, which weather and break away in slabs.

ftm - Felsic Tuff. The Felsic Tuff Unit consists primarily of chloritic schist and slate, which are dull shades of green or brownish green, and which vary in fissility from schistose to slaty. The rock varies in composition, but is generally chlorite and quartz-rich and probably has a mixed volcanic and sedimentary origin. Small hematite-rich shear zones in the slaty part of the unit have been prospected.

fm - Felsic Porphyry. The Felsic Porphyry Unit is composed of a variety of gray to brownish gray quartz-rich felsitic slates and schists. The main types include fissile to flinty, fine grained. Commonly porphyritic, quartz and sericite-rich rocks, and massive to schistose, medium grained, quartz-feldspar rocks. The rocks occur as thin, conformable, intrusive or volcanic bodies, as well as tabular, crosscutting, intrusive dikes.

fak-- Felsic Agglomerate of Kitchi Schist. This felsic unit of the otherwise dominantly mafic Kitchi Schist is a gray-green to brown, fragmental sericite schist, which in places resembles conglomerate. It probably formed from shallow water deposited volcanic ash and fragments. The unit occurs in a broad east-west trending band located south of Marquette (Van Hise and Bayley, 1897, p. 130).

u-- ultramafic rocks. This unit consists mainly of serpentinitized peridotite. Exposures are generally dark green to reddish brown, massive except for blocky jointing, and locally cut by carbonate veins. At the Ropes Gold Mine northwest of Ishpeming, peridotite flanks the main ore body, and has been prospected for its own economic potential as verde antique. At Presque Isle, north of Marquette, the Archean age of the intrusive body is in doubt, and it may be as young as Early Keweenawan. (Broderick, 1945, pp. 115-128; Gair and Thaden, 1968, pp. 56-57.)

- db-- diabase. This is a medium-grained, dark green, metamorphosed mafic rock rich in chlorite which occurs as dikes in the area east of Marquette. (Gair and Thaden, 1968, pp. 51-52).
- gb-- gabbro. The gabbro found in the "Northern Complex" Area is a coarse-grained, mottled green, massive, metamorphosed igneous rock, which occurs as small intrusive bodies. (Gair and Thaden, 1968, pp. 51-53.)
- h-- hornblende schist and amphibolite. These coarsely crystalline, foliated rocks, in which amphibole and feldspar are the dominant minerals, are exposed in several areas in the Huron Mountains and in the central portion of the study area.
- di-- diorite. Diorite is a dark gray, coarse-grained, plutonic igneous rock composed mainly of feldspar with little or no quartz. A small body of this rock occurs on the Marquette-Baraga County line.
- gd-- granodiorite. Granodiorite is similar to granite except for mineralogical differences (mainly the type of feldspar present). An elongate area of this rock type is present in the "Northern Complex."
- sy-- syenite. Syenite is a dark red, massive to foliated plutonic igneous rock consisting principally of potash feldspar, hornblende, and little quartz. Small areas underlain by this rock type exist northwest of Marquette. (Gair and Thaden, 1968, p. 54.)
- gn-- granitic to dioritic gneiss. Granitic gneisses underlie a large portion of the study area and are especially abundant in the Northern and Southern Complexes of the Marquette Range. These plutonic rocks are foliated, generally pinkish rock with a composition generally ranging from tonalite to granodiorite with small amounts of monzonite and granite. There are, in addition, included layers up to several feet thick of amphibolite and biotite-rich tonalite. Remnants of Mona-like schist found in the gneiss indicate its possible intrusive origin. The thickness of the gneissic unit is unknown. (Gair and Thaden, 1968, pp. 18-27).
- gr-- granite. Large bodies of granite are mapped in the Huron Mountains and the central portion of the "Northern Complex."

(2) Middle Precambrian (Huronian)

- ce-- Enchanted Lake Formation. This formation consists of metamorphosed conglomerate, graywacke, arkose, sericitic slate and quartzite. It is discontinuous and lenticular, with a maximum thickness of 500'. (Gair and Thaden, 1968, p. 27.)
- qm-- Mesnard Quartzite. The Mesnard is a hard, thick, massive, vitreous quartzite, generally light gray to pink, with thin interbeds of gray slate and conglomerate. The quartzite generally contains more than 90% quartz, is strongly jointed, ranges from 200-500' thick, and is thought to be correlative with the Sturgeon Quartzite of Dickinson County. (Gair and Thaden, 1968, pp. 34-37.)
- dk-- Kona Dolomite. The Kona consists mainly of tan, pinkish or gray dolomite and interlaminated chert-dolomite, red quartzite, and, in the lower part of the formation, maroon, gray, and green sericitic slate. The dolomite is fine to medium grained, generally massive, and may be up to 1200' thick. Laminated structures apparently formed by Precambrian algae are an indication of the shallow water origin of the dolomite. The Kona Dolomite is considered to be correlative with the Randville Dolomite of Dickinson and Iron Counties. (Gair and Thaden, 1968, pp. 37-45.)
- sw-- Wewe Slate. In addition to slate, this formation contains sericitic quartzite and meta-conglomerate. Where fresh the slate is gray to greenish, and it weathers to brown or gray. It is massive to laminated, and is probably up to 900' thick in the synclinal structure south of Marquette. (Gair and Thaden, 1968, pp. 45-46.)
- qa-- Ajibik Quartzite. The Ajibik Quartzite consists mainly of massive quartzite with minor amounts of thin bedded quartzite, slate, and conglomerate. In most places, the Ajibik is lithologically indistinguishable from the Mesnard Quartzite. One of the few visual differences is the presence of small yellowish or reddish brown iron oxide stains, which are rare in the Mesnard. The formation is approximately 650' thick, and is considered to be an equivalent of the Palms Quartzite of the Gogebic area and the lower part of the Felch Formation in Dickinson County. (Gair and Thaden, 1968, pp. 47-48.)

- ss-- Siamo Slate. The Siamo Slate is mainly laminated to massive, dark argillaceous slate with minor interbeds of dark coarse-grained quartz-rich rocks. The formation is tightly folded in areas of outcrop near Marquette, and estimates of its thickness vary from 600-1250'. (Gair and Thaden, 1968, pp. 48-49.)
- in-- Negaunee Iron Formation. The Negaunee is a hard, mostly cherty, silicate iron formation with upper ore horizons of banded cherty or jaspery iron oxides (magnetite and hematite). It lies southwest of Marquette in an east-west trending synclinal trough, and may be up to 2000' thick. Ore production from the Negaunee, the principal source of iron ore in the Marquette Range, has been continuous for more than 100 years, with the earlier production coming from the high grade ore, and the more recent production from lower grade ore which requires concentration. (Meshref and Hinze, 1970, p. 7; Cannon and Klasner, 1972, p. B7.)
- qg-- Goodrich Quartzite. The Goodrich Quartzite is a relatively clean, dense, quartzose rock with discontinuous (but in some places thick--up to 300') interbeds of conglomerate and minor graywacke. The Goodrich is thought to unconformably overlie the Negaunee Iron Formation, and in the conglomeratic zone which separates them, iron minerals have been concentrated in sufficient quantity to produce low grade ore. (Cannon and Klasner, 1972, p. B19.)
- sm-- Michigamme Slate. The Michigamme Slate is composed of units of interbedded slate and metagraywacke which crop out in a synclinal trough west of Ishpeming. (James, 1958, p. 37.)
- ig-- Greenwood Iron Formation. The Greenwood is a hard, cherty silicate iron formation. It is a relatively thin unit which has been mapped in contact with the Michigamme slate approximately 10 miles west of Ishpeming, and may possibly be correlative with the Bijiki Iron Formation. (James, 1958, p. 36; Cannon and Klasner, 1972, p. B5.)
- pc-- Clarksburg Mafic Pyroclastics. These are a group of metamorphosed mafic pyroclastic rocks (ejected volcanic ash fragments) with interbedded meta-argillite and iron formation. (Cannon and Klasner, 1972, p. B5.)
- ib-- Bijiki Iron Formation. The Bijiki is mostly hard, cherty, silicate iron formation which, although

of lesser importance than the Negaunee, has yielded quantities of high grade limonitic ore. (Cannon and Klasner, 1972, pp. B5 and B7.)

gkm-- Michigamme Graywacke. The Michigamme Graywacke is part of a widespread formation of gray slate and dark gray, massive, fine to medium grained metagraywacke which is probably on the order of 5000' thick. This rock is the result of metamorphism of shaly sediments and volcanic debris. Several iron-rich beds are present in the formation. (Gair and Weir, 1956, p. 59; Cannon and Klasner, 1972, p. B5; Meshref and Hinze, 1970, p. 7.)

b. Iron River - Crystal Falls - Menominee Area

1. Lower Precambrian (Archean)

gq-- Quinnesec Greenstone. The term Quinnesec Greenstone is applied to metavolcanic greenstones, amphibolites, and schists that form a belt in the southernmost part of Dickinson County. (James, 1958, p. 33.)

ake-- East Branch Arkose. The East Branch Arkose consists of poorly sorted, coarse grained arkose, arkosic conglomerate, and interbedded metamorphosed basalt and basic tuffs. In some areas, the arkosic beds appear gneissic, and the conglomerate pebbles are deformed and elongated. The formation is believed to be at least 1000' thick. (James, 1958, p. 31.)

hs-- Metasediments of Solberg Schist and Six Mile Lake Amphibolite. These are principally biotite-hornblende schist, thin-bedded metachert and magnetic rock (iron formation), massive, gray quartz-mica schist, micaceous quartzite, and massive dark amphibolite. Most of the rocks appear to be metamorphosed sediments, with the exception of amphibolite, which is basaltic in composition and may represent altered volcanic flows and tuffs. The Solberg Schist unit, including a 100' thick section of iron formation, reaches a thickness of about 3000', and the Six Mile Lake Amphibolite probably reaches a thickness of greater than 3000'. (James, 1958, p. 32.)

gn-- granitic to dioritic gneiss. Most of this unit, which is mapped in the Felch Area, is reddish, porphyritic granitic gneiss, with sparse inclusions of schist and quartzite. There are also dark,

medium-grained dioritic gneisses, and other light-colored gneiss. The rocks are generally well foliated, with layers trending east-west. The thickness of this unit is unknown. (James, 1958, pp. 31-33.)

gr-- granite. Gneissic granite occurs in portions of the area, and is probably younger than the meta-sediments of the East Branch, Solberg and Six Mile Lake Formations.

(2) Middle Precambrian (Huronian)

cf-- Fern Creek Formation. This is a sequence of coarse-grained, clastic sedimentary beds which rest directly on granitic gneiss in southern Dickinson County. The formation occurs in isolated patches and includes some tillite (lithified glacial till). (James, et al., 1961, p. 31.)

qs-- Sturgeon Quartzite. This massive vitreous quartzite is lithologically and stratigraphically almost identical to the Mesnard Quartzite of the Marquette Range. Although variable, the thickness of this formation is nearly 2000' in southern Dickinson County. (James, et al., 1961, pp. 31-33.)

dr-- Randville Dolomite. This locally metamorphosed formation of dolomite and slate is considered to be correlative to the Kona Dolomite of the Marquette Range, and is up to 1600' thick. (James, et al., 1961, pp. 33-36.)

qt-- Felch Formation. The Felch Formation is a heterogeneous group of rocks that includes mostly quartz-mica schist and quartzite, with magnetite-bearing quartzite and schists, and magnetic rocks. The Felch Formation is separated from the underlying Randville by an unconformity, and varies in thickness from 5 to several hundred feet. (James, et al., 1961, pp. 36-39.)

iv-- Vulcan Iron Formation. The economically important Vulcan Iron Formation consists mainly of gray-banded, oolitic, metachert and hematite, and varies in thickness from approximately 250' near Felch to almost 600' in southern Dickinson County. (James, et al., 1961, pp. 39-46.)

qg-- Goodrich Quartzite. The dense, deep red, ferruginous, cherty Goodrich Quartzite, which reaches a thickness of about 500' near Michigamme Mountain, is apparently correlative with the Goodrich of the Marquette Range. (Gair and Wier, 1956, pp. 35-40.)

- gh-- Hemlock Greenstone. The Hemlock consists of a thick series of altered basic volcanic flow rocks, tuffs and agglomerates, which now consist of massive to schistose and slaty greenstone. Narrow belts of slate and some graywacke have also been found. The formation completely surrounds an ellipsoidal gneissic intrusive body ("dome") near Amasa, termed the "Amasa Oval." The thickness of the Hemlock Greenstone is thought to be greater than 2300'. (Gair and Wier, 1956, pp. 41-42.)
- fh-- Hemlock Felsic Volcanics. The Hemlock Felsic Volcanics consist of small exposures of well-bedded grayish-green to reddish rhyolitic tuff or felsite. (James, et al., 1961, pp. 46-48.)
- gkm-- Michigamme Graywacke. Rock types within the Michigamme Graywacke are characterized by a range of metamorphic grade. A large part of the formation consists of moderately to intensely metamorphosed massive graywacke granulite and gray lustrous garnet-mica schists. There are also less metamorphosed beds of red or gray graphitic slate, friable sandy graywacke, and slaty iron-rich rocks. Estimates of thickness range from 5000' to a possible maximum of 11,000'. (James, et al., 1961, pp. 48-51.)
- gba-- Badwater Greenstone. The Badwater Greenstone consists principally of chloritized basaltic flows, some of which show structures which indicate underwater deposition. Near Iron River, these massive, fine grained, greenish rocks attain a maximum thickness of several miles. (James, 1958, p. 37; James, et al., 1961, p. 53.)
- sd-- Dunn Creek Slates. The Dunn Creek is a sequence of siltstones, graywacke, and slates which is exposed near Crystal Falls and is probably 400-800' thick. The upper units contain slaty sideritic iron formation and a black pyritic graphitic slate. (James, 1958, pp. 37-38.)
- ir-- Riverton Iron Formation. The Riverton is the productive Iron Formation for the Iron River - Crystal Falls district, and consists mainly of 100-600' of interbedded chert and siderite. (James, 1958, p. 38.)
- gkh-- Hiawatha Graywacke. Overlying the Riverton Iron Formation (locally with minor unconformity) is the clastic Hiawatha Graywacke. It includes slate interbeds and a breccia unit, but is dominantly 50-400' of metamorphosed graywacke. (James, 1958, p. 38.)

sfs-- Stambaugh and Fortune Lake Slates. Included as one mapping unit are the Stambaugh Formation siderite-magnetite slates, and the slates with minor gray-wacke of the Fortune Lakes Slates. The total thickness of the two formations is at least 4000'. (James, 1958, pp. 38-39.)

c. Gogebic Range - Watersmeet Area

(1) Lower Precambrian (Archean)

gs-- greenstone. Areas of fine grained, basaltic greenstone occur near Wakefield in the Gogebic Range.

gn-- granitic and dioritic gneiss. This unit consists of medium- to coarse-grained pinkish rocks of granitic composition, which contain alternating gneissic bands of feldspar and hornblende.

gr-- granite. Large areas of massive, medium-grained, gray to pink, porphyritic granite are present near the western border of the study area. (Dutton and Bradley, 1970, Sheet 4.)

(2) Middle Precambrian (Huronian)

gsd-- Sunday Quartzite. The Sunday Quartzite is mapped as a narrow band of coarse-grained vitreous quartzite in contact with the overlying Bad River Dolomite. At the base of the formation is conglomerate which unconformably overlies greenstone. (Meshref and Hinze, 1970, p. 6.)

dbr-- Bad River Dolomite. This gray to buff, cherty dolomite, in part recrystallized, is probably correlative with the Kona and Randville Dolomites of the Marquette and Iron Mountain areas, respectively. (Dutton and Bradley, 1970, Sheet 4; Meshref and Hinze, 1970, p. 6.)

qp-- Palms Quartzite. The Palms Quartzite, consisting of basal conglomerate, graywacke-slates, and massive vitreous quartzite, is considered to be equivalent to the Ajibik Quartzite of the Marquette Range. (Gair and Thaden, 1968, p. 48; Dutton and Bradley, 1970, Sheet 4.)

ii-- Ironwood Iron Formation. The Ironwood Iron Formation consists of well bedded, iron-bearing chert and metachert beds separated by slate members. Predominant minerals are siderite, hematite, iron silicates, quartz, and magnetite. The formation

rarely exceeds 800' in thickness. (Meshref and Hinze, 1970, pp. 6-7.)

- cgk-- Copps Graywacke. This dark gray, massive, fine to medium-grained graywacke formation is found in an arcuate band near Marenisco.
- st-- Tyler Slate. The Tyler Slate is a very thick sequence of black and gray argillite, slate, and graywacke of variable texture and composition. Quartzite, phyllite and arkose are present locally. This formation is probably the age equivalent of the Michigamme Slate of the Marquette Range. (Dutton and Bradley, 1970, Sheets 3 and 4.)

d. Widespread Areas of Uncertain Correlation

Twenty-one other Middle and Lower Precambrian rock units have been identified and mapped in the Upper Michigan region. Because these units have only limited exposure or because their relationship with other rocks is uncertain, they have not been correlated with other known formations in the region. The units are listed under the column entitled "Correlation with other Precambrian units uncertain" in the Key to Map Interpretation (Figure 1). These generally metamorphosed units include metavolcanic rocks such as greenstone, mafic tuffs and thuyolite; plutonic rocks such as granite and migmatite; metasedimentary rocks such as tillite, conglomerate, arkose, graywacke-slate, quartzite, dolomite, and siltstone; dike rocks (mainly diabase); and iron formation. There are also magnetic units, probably iron formations, which are under a thick glacial cover and have been mapped mainly on the basis of magnetic surveys of the area.

- gr₂-- Granite
- db₂-- Diabase
- stn-- Siltstone
- ms-- Magnetic strata, mostly concealed by overburden
- i₂-- Iron formation
- s₂-- Slate
- gk₂-- Graywacke
- d₂-- Dolomite
- q₂-- Quartzite
- ak₂-- Arkose

c ₂ --	Conglomerate
tr--	Tillite
r--	Rhyolite
mtf ₂ --	Mafic tuff
mag ₂	Mafic agglomerate
g ₂ --	Greenstone
mig--	Migmatite
i ₁ --	Iron formation
mtf ₁ --	Mafic tuff
g ₁ --	Basaltic greenstone
g ₁ /mtf ₁ --	Undifferentiated basaltic greenstone and mafic tuff

2. Upper Precambrian (Keweenawan)

Keweenawan rocks make up a northwest-dipping sequence of sedimentary and igneous rocks in the western part of the study area. The age of these rocks generally decreases to the northwest.

qk--	<u>Keweenawan quartzite.</u> A few small, isolated bodies of Keweenawan quartzite underlie the South Range Lava Series. These units are about 500' thick and represent the base of the Upper Precambrian sequence. (Meshref and Hinze, 1970, p. 4.)
bss--	<u>South Range Lava Series.</u> About 8000' of basaltic, andesitic, and rhyolitic volcanic rocks make up the South Range Lava Series. Although older, these rocks are similar to the Portage Lake Lava Series. (Meshref and Hinze, 1970, p. 4.)
bspl--	<u>Portage Lake Lava Series.</u> The Portage Lake Lava Series consists of about 15,000' of basalt and andesite flows, with interbedded rhyolitic conglomerates and with local rhyolites and ash beds. These rocks cover a large part of the extreme western portion of the study area. (Meshref and Hinze, 1970, p. 4.)
bsk--	<u>basalt.</u> Two small areas of columnar jointed, amygdaloidal basalt represent the western tip of a large basaltic lava flow sequence, most of which

is exposed outside the northern boundary of the study area. These basalts may be part of the Portage Lake Lava Series.

- ak-- andesite. Andesite is a light-colored volcanic rock composed essentially of feldspar and one or more mafic minerals. It forms a thick sequence between the Portage Lake Series and the Copper Harbor Conglomerate.
- fk-- felsite; felsite porphyry. A small body of felsite and felsite porphyry is located along Black River in the Portage Lake Lava Series. It is composed mostly of fine grained quartz and feldspar, with scattered larger feldspar crystals.
- cch-- Copper Harbor Conglomerate. Light red to brown, nonporous, boulder conglomerates with small lenses of interfingering pebble conglomerates and sandstones make up the 5000' thick Copper Harbor Conglomerate. Within this extensive formation is a 300-400' thick series of basic lava flows. (Doonan, et al., 1970, p. 3; Meshref and Hinze, 1970, p. 5.)
- sn-- Nonesuch Shale. The Nonesuch Shale consists of about 800' of gray to reddish gray siltstone with interbedded gray to greenish gray silty shales. This formation grades upward into the Freda Sandstone. (Meshref and Hinze, 1970, p. 5.)
- ssf-- Freda Sandstone. The Freda Sandstone is composed of 3-4' thick beds of fine to medium-grained, red to greenish-gray sandstone interlayered with red to greenish gray shale and siltstone. Because it borders Lake Superior, only the lower part of this 14,000' formation is exposed in the study area. This sandstone is the youngest of the Upper Precambrian rocks. (Meshref and Hinze, 1970, p. 5.)

3. Paleozoic

a. Cambrian

- Els-- undifferentiated. This unit includes white to yellow dolomitic and glauconitic sandstones, locally quartzitic, which have not been assigned to a specific formation, but which can be placed in the Cambrian Period by relative age determinations or stratigraphic position.
- Ej-- Jacobsville Sandstone. The Jacobsville Sandstone is exposed in a broad arc along the entire northern

boundary of the study area. It is a fine to medium-grained, red to white, quartz sandstone containing minor coarse sand and conglomerate lenses. The formation is probably up to 2000' thick in some areas, but pinches out locally. (Hamblin, 1958, pp. 15-25.) It is assumed to be Cambrian in age, although some researchers (Thwaites, 1943; Oetking, 1951; Meshref and Hinze, 1970) believe it to be Upper Precambrian.

Em-- Munising Formation. The Munising Formation is a thin (about 200' thick) and easily identified sequence of medium grained, white to grayish-blue, cross-bedded sandstone containing some blue shale layers and a pebble conglomerate at the base. It occurs in the eastern part of the study area. (Hamblin, 1958, pp. 71-109.)

b. Ordovician

Oesd-- undifferentiated. This map unit includes sandstones and dolomites which have not been assigned to a specific formation but are probably in the Cambrian to Ordovician age range.

Oat-- Au Train Formation. The Au Train is a resistant, brown to green dolomitic sandstone which is present throughout relatively extensive areas in the eastern part of the study area. Lenses of dolomite and sandstone are scattered throughout the 300' thick formation, and concentrations of glauconitic sands occur near the base. (Hamblin, 1958, pp. 115-120.)

Obr-- Black River Formation. The Black River Formation is composed of gray to bluish gray to pink, fine grained to conglomeratic, well bedded, argillaceous limestone, and is located along the extreme eastern margin of the study area (Hussey, 1952, p. 17.)

Structure

The Upper Michigan region is part of an ancient and geologically stable portion of the earth's crust known as the Canadian Shield. Geologic structures in the area were formed hundreds of millions of years ago during Precambrian and early Paleozoic time, and the region is presently tectonically quiescent.

Two regional structural features which have dimensions of hundreds of miles border the study area on the northwest and

the southeast. The Lake Superior basin is a northeast-trending synclinal trough formed in the rocks beneath Lake Superior. The upper Precambrian rocks northwest of the Keweenaw fault (see below) dip gently toward the axis of this fold, which is located about 40 miles northwest of the study area boundary. Along the southeast edge of the study area, the Paleozoic rocks dip gently toward the Michigan basin, a dish-shaped feature with its center about 200 miles to the southeast.

The major fault in the region is the Keweenaw fault, a northwest-dipping reverse, or thrust fault that lies principally outside the study area to the northwest. This northeast-trending fault traverses the entire length of the Keweenaw peninsula, crosses the westernmost tip of the study area, and continues on a westerly trend across Wisconsin. On the Keweenaw peninsula, it separates Cambrian Jacobsville Sandstone on the southeast from Precambrian rock on the northwest, and may have a total offset of as much as 3 miles, with the northwest side up. Because of this sense of movement, the generally steeply northwest-dipping strata along the southeast side of the fault have been bent upward along the fault by drag-folding so that they dip to the southeast in some areas. Numerous smaller faults which moved during Paleozoic time have resulted in lateral offsets of the Keweenaw fault, and other, generally east/west-trending, faults cross portions of the area (see Bedrock Geologic Data Map). These east/west-trending faults have been located primarily on the basis of geophysical data, and appear to have resulted from tension produced by regional subsidence during the Paleozoic Era. There is no evidence for post-Paleozoic faulting anywhere in the study area.

In addition to the regional folds which border the study area, several smaller synclines and anticlines with dimensions of hundreds of feet to tens of miles exist within the study area. These general east/west-trending zones of tightly folded rock are of economic significance because iron formation crops out along the margins of the folds (see Mineral Extraction Data narrative). The largest and most important of these folds is a gently westward-plunging syncline 3 to 6 miles wide which extends 35 miles westward from the vicinity of Marquette. This major fold, along which the strata generally dip at 30° to 70° toward the axis, lies between and separates the two major granitic gneiss areas of the Upper Peninsula. Other major folds in the study area exist in the vicinity of Felch, Iron Mountain, Iron River, and Ironwood (see Bedrock Geologic Data Map).

Structures known as "gneiss domes," which consist of a central core of gneiss protruding up through the surrounding metasedimentary and metavolcanic rock, are also present in the area. They have dimensions of a few miles and are of importance because iron formations are exposed around their margins.

RELATIONSHIP TO OTHER DATA

The distribution and character of mineral deposits are governed by bedrock geologic conditions, or by surficial geologic conditions in the case of sand and gravel deposits, placer gold, etc. The concentration of valuable minerals in specific locations within the earth's crust is the result of certain types of geologic processes, such as the intrusion of igneous rocks, unique sedimentological conditions, regional metamorphism, etc. Consequently, a definite relationship exists between various types of minerals and the host rock (or environment) in which they are likely to be found. For example, in the Upper Peninsula, copper, molybdenum, lead, zinc, gold and silver deposits are generally associated with greenstone belts, while the iron formations occur within the Middle Precambrian sedimentary rocks.

In many nonglaciaded regions soils are formed in place as a result of the weathering and decomposition of the underlying bedrock. In these areas distinctive residual soils may be the key to mapping the underlying bedrock. These relationships do not prevail in Michigan, since the bedrock formations of the Michigan site area are generally covered by up to 300' of loose glacial material. Only in areas of very thin glacial cover does the bedrock in Michigan affect soil types, and then only to a minor degree. The limited exposures of consolidated rock have little or no soil, which is primarily the result of the slow weathering and breakup of the rocks. The presence of glacial striations, or "scratches," on the surface of some of the in-place crystalline rocks, indicates that very little rock has been removed by weathering during the last 10,000 years, and this explains the lack of soil.

Bedrock geology in the study area is, to a small degree, related to topography. For example, topographically steep or rugged areas such as knobs, ridges, etc., are mainly underlain by hard rock with little or no surficial cover.

Bedrock geology has limited effects on vegetation and land use. Rough, knobby areas tend to have thin or no glacial deposits, and, consequently, little or no soil formation that would support a healthy growth of vegetation. These areas of knobby terrain and thin surficial cover tend to be areas of mining activities and related mineral production. The lake plains and hilly glacial moraine areas, where surficial cover is thicker, are locally cultivated and used for crops and pasture.

Bedrock geology is related to the occurrence of ground water. The hard, crystalline Precambrian rocks are extremely poor water aquifers, and almost total dependence is placed on

glacial deposits for supplying ground water in areas where bedrock is of this type. If glacial deposits are thin over these crystalline rock areas, only small yields of water can be expected. The younger Precambrian and Paleozoic sedimentary rocks on the northern and eastern borders of the study area generally yield considerably more water to wells, and are important sources of ground water in some areas.

VALIDITY

General Procedures and Data Sources

The Bedrock Geologic Data Map represents an unchecked compilation of all pertinent existing bedrock geologic mapping available for the study area. As in the case with most traditional geologic mapping, surficial deposits have been largely ignored, and the map shows the types of rock present at depth throughout the area. Little information is presented that pertains to the condition of the rock at or near the surface, or to the presence or absence of soil deposits in a given area.

Geologic maps providing complete coverage of the study area were available at scale ranging from 1:24,000 to 1:500,000. Since these varying scales were used in the compilation, the information presented is more accurate in some portions of the study area than it is in others, although an attempt was made to attain a uniform level of detail. The Index to Available Geologic Mapping in the Study Area, Figure 2, shows the locations of maps used in the compilation of the Bedrock Geologic Data Map. The geology of the rocks of Precambrian age (which encompasses the majority of the study area) was obtained from Willard A. Bodwell's 1972 map, "Precambrian Geology of Upper Peninsula, Michigan," which is itself a compilation of all mapping that was available for the area at that time. In some areas, contacts were modified to conform with those shown on a revised copy of Bodwell's map prepared and made available by Kalliokowski in September 1973. Geologic data for Paleozoic rock formations were obtained from State and Federal maps varying in detail and scale. At present, little work has been done in detail on the Paleozoic bedrock of the Northern Peninsula of Michigan. A general indication of the status of mapping throughout the study area is presented on Figure 3 of the Mineral Extraction Data narrative.

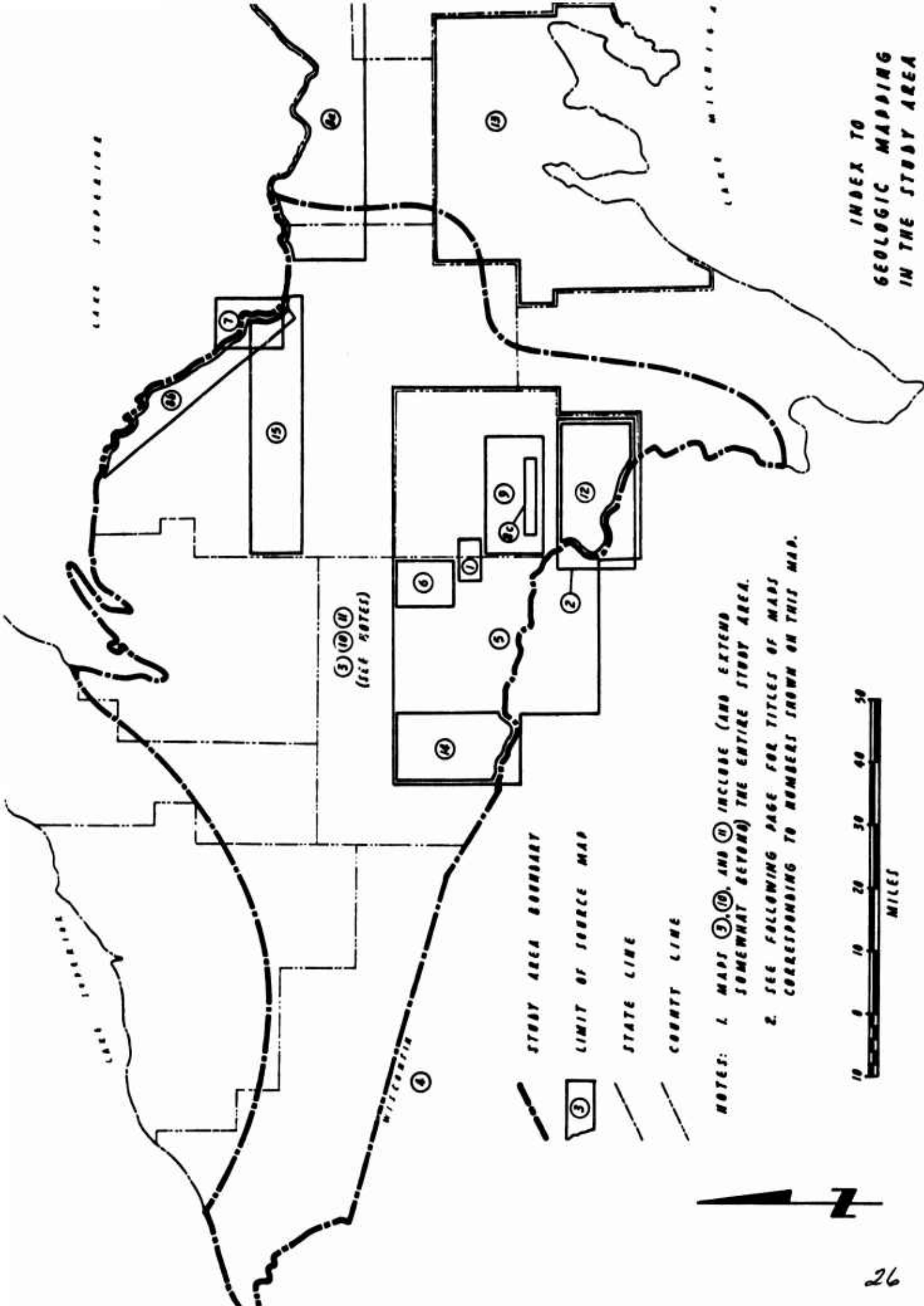
The intended use of this map is to provide a basis for determination of the rock type present at depth within any general section of the study area. Rock quality is now shown.

Data Reliability/Specific Procedures/Limitations

The Bedrock Geologic Data Map provides information on the distribution of rock types at depth below soil and glacial cover. Because the data were compiled from pre-existing maps which ranged in scale from 1:24,000 to 1:500,000, and in publication date from 1911 to 1973, the accuracy of mapping varies. Additionally, some adjustments had to be made where maps of differing scales adjoin. Contacts were also adjusted somewhat to

conform with the topography shown on the base map where it was obvious that this was necessary.

Since glacial deposits blanket most of the study area and little detailed field work has been done in large areas of Upper Michigan, locations of some formational contacts and geological features should be considered as reliable estimates rather than precise determinations. In particular, there are large areas where little or no information on bedrock conditions is available north of the Marquette Range (see Bedrock Geologic Data Map), and many Keweenaw dikes in the central portions of the study area are only approximately located.



INDEX TO
GEOLOGIC MAPPING
IN THE STUDY AREA
FIGURE 2

- NOTES: 1. MAPS ③, ⑩, AND ⑪ INCLUDE (AND EXTEND SOMEWHAT BEYOND) THE ENTIRE STUDY AREA.
2. SEE FOLLOWING PAGE FOR TITLES OF MAPS CORRESPONDING TO NUMBERS SHOWN ON THIS MAP.

TITLES OF MAPS SHOWN ON FIGURE 2

1. Bayley, R. W., 1959. Geology of the Lake Mary Quadrangle, Iron County, Michigan, USGS Bull. 1077, p. 64.
2. Bayley, R. W., Dutton, C. E., and Lamey, C. A., 1966. Geology of the Menominee iron-bearing district, Dickinson County, Michigan, and Florence and Marinette Counties, Wisconsin. USGS Prof. Paper 513, Plates 1, 2, and 3.
3. Bodwell, W. A., 1972. Precambrian geology of Upper Peninsula, Michigan, a compilation, part of Master's thesis, Geol. Map Series, Map 2, Michigan Technological University Press.
4. Dutton, C. E., and Bradley, R. E., 1970. Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin: USGS Misc. Geol. Inv. Map I-631, Sheets 3 and 4.
5. Dutton, C. E., and Linebaugh, R. E., 1967. Map showing Precambrian Geology of the Menominee Iron-bearing District and Vicinity, Michigan and Wisconsin, USGS Misc. Geol. Investigations, Map I-466.
6. Gair, J. E., and Thaden, R. E., 1968. Geology of the Marquette and Sands Quadrangles, Marquette County, Michigan; USGS Prof. Paper 397, Plate 1.
7. Gair, J. E., and Wier, K. L., 1956. Geology of the Kiernan Quadrangle Iron County, Michigan, Geol. Survey Bull. 1044, Plate 1.
8. Hamblin, W. K., 1958. The Cambrian sandstones of northern Michigan: Michigan Dept. of Conservation, Geol. Survey Div. Pub. 51, 146 pp. (8a is Plate 2 of this report; 8b is Plate 3, and 8c is Plate 4.)
9. James, H. L., Clark, L. D., Lamey, C. A., Pettijohn, F. J., 1961. Geology of Central Dickinson County, USGS Prof. Paper 310, Figure 2, p. 11.
10. Kalliokowski, J., 1973. Revision to Bodwell, W. A., 1972. Geol. Map Series, Map 2, Michigan Technological University Press.
11. Martin, H. M., 1936. Bedrock map of the Upper Peninsula of Michigan, a compilation, Mich. Geol. Survey, Pub. 39, Geol. Series 33.

12. Michigan Academy of Science, Arts and Letters, Section of Geology and Mineralogy, 1939. Ninth Annual Field Excursion, May 27-30, Route Map.
13. Michigan Geological Society, 1950. The Ordovician rocks of the Escanaba Stonington area, annual field trip, June 1950, led by R. C. Hussey. Map: West half Delta County.
- 14 and 15. Van Hise, C. R., and Leith, C. K., 1911. The geology of the Lake Superior region, USGS Monograph Vol. 52. (9 is Plate 24 of this report, 10 is Plate 17.)

BIBLIOGRAPHY

- Bayley, R. W., 1959. Geology of the Lake Mary Quadrangle, Iron County, Michigan. USGS Bull. 1077, 112 pp.
- Bayley, R. W., Dutton, C. E., and Lamey, C. A., 1966. Geology of the Menominee iron-bearing district, Dickinson County, Michigan, Florence and Marinette Counties, Wisconsin, with a chapter on The Carney Lake Gneiss, by S. B. Treves: USGS Prof. Paper 513, 96 pp.
- Bodwell, W. A., 1972. Geologic compilation and nonferrous metal potential, Precambrian section, northern Michigan: unpublished Master's thesis, Michigan Technological University, Houghton, Michigan, 110 pp.
- Boyum, B. H., and Gair, J. E., 1970. Field Trip to Marquette Iron Range, Michigan: Geol. Soc. American Guidebook, Nov. 9-10, 37 pp.
- Broderick, T. M., 1945. Geology of Ropes Gold Mine, Marquette County, Michigan. Econ. Geology, Vol. 40, pp. 115-128.
- Cannon, W. F., and Klasner, J. S., 1972. Guide to Penokean deformation style and regional metamorphism of the western Marquette Range, Michigan. Institute on Lake Superior Geology, Houghton, Michigan, Field Trip B, 38 pp.
- Doonan, C. J., Hendrickson, G. E., and Byerly, J. R., 1970. Ground water and geology of Keweenaw Peninsula. State of Michigan, Dept. of Natural Resources, Geol. Survey Div., Water Inv. 10, 41 pp.
- Dorr, J. A., and Eschman, D. F., 1970. Geology of Michigan. Univ. of Michigan Press, Ann Arbor, Michigan.
- Dutton, C. E., 1971. Geology of the Florence Area, Wisconsin and Michigan. USGS Prof. Paper 633, 54 pp.
- Dutton, C. E., and Bradley, R. E., 1970. Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin. USGS Misc. Geol. Inv. Map I-631, scale 1:500,000.
- Dutton, C. E., and Linebaugh, R. E., 1967. Map showing Precambrian Geology of the Menominee iron-bearing district and vicinity, Michigan and Wisconsin. USGS Misc. Geol. Inv. Map I-466.
- Gair, J. E., and Thaden, R. E., 1968. Geology of the Marquette and Sands quadrangles, Marquette County, Michigan. USGS Prof. Paper 397, 77 pp.

- Gair, J. E., and Wier, K. L., 1956. Geology of the Kiernan quadrangle, Iron County, Michigan. USGS Bull. 1044, 88 pp.
- Hamblin, W. K., 1958. The Cambrian sandstones of northern Michigan. Mich. Dept. Conservation, Geol. Survey Div. Pub. 51, 146 pp.
- Hussey, R. C., 1952. The Middle and Upper Ordovician rocks of Michigan. State of Michigan, Dept. of Conservation, Geol. Survey Div., Pub. 46, Geol. Series 39, 89 pp.
- James, H. L., 1958. Stratigraphy of pre-Keweenawan rocks in parts of northern Michigan. USGS Prof. Paper 314-c, pp. 27-44.
- James, H. L., Clark, L. D., Lamey, C. A., and Pettijohn, F. J., 1961. Geology of central Dickinson County, Michigan. USGS Prof. Paper 310, 176 pp.
- Kalliokowski, J., 1973. Revision to Bodwell, W. A., 1972, Geological Map Series, Map 2, Michigan Technological University Press.
- Leith, C. K., Lund, R. J., and Leith, A., 1935. Precambrian rocks of the Lake Superior region; a review of newly discovered geologic features with a revised geologic map. USGS Prof. Paper 184, 34 pp.
- Martin, H. M., compiler, 1936. The centennial geological map of the Northern Peninsula of Michigan. Mich. Dept. Conservation, Geol. Survey Div. Pub. 39, Geol. Ser. 33.
- Meshref, W. M., and Hinze, W. J., 1970. Geologic interpretation of aeromagnetic data in western upper peninsula of Michigan. State of Michigan, Dept. of Natural Resources, Geol. Survey, Rept. of Inv. 12, 25 pp.
- Michigan Academy of Science, Arts and Letters, Section of Geology and Mineralogy, 1939. 9th annual field excursion, May 27-30, Route Map.
- Michigan Geological Society, 1950. The Ordovician rocks of the Escanaba Stonington area. Annual field trip led by R. C. Hussey, June 1950.
- Puffett, W. P., 1969. The Reany Creek Formation, Marquette County, Michigan. USGS Bull. 1274-F, 25 pp.
- Van Hise, C. R., and Leith, C. K., 1911. The geology of the Lake Superior region. USGS Mon. 52, 641 pp.

PROJECT SANGUINE - Site Study

UPPER MICHIGAN REGION

**ECKBO
DEAN
AUSTIN &
WILLIAMS** landscape architecture
environmental planning
urban design
san francisco, los angeles,
honolulu, minneapolis
145 mission st., san francisco, calif. 94105

**NORTHERN
DIVISION** department of the navy
naval facilities engineering command
naval base, philadelphia, pa.

1973-74

9	4	1
	3	
18		

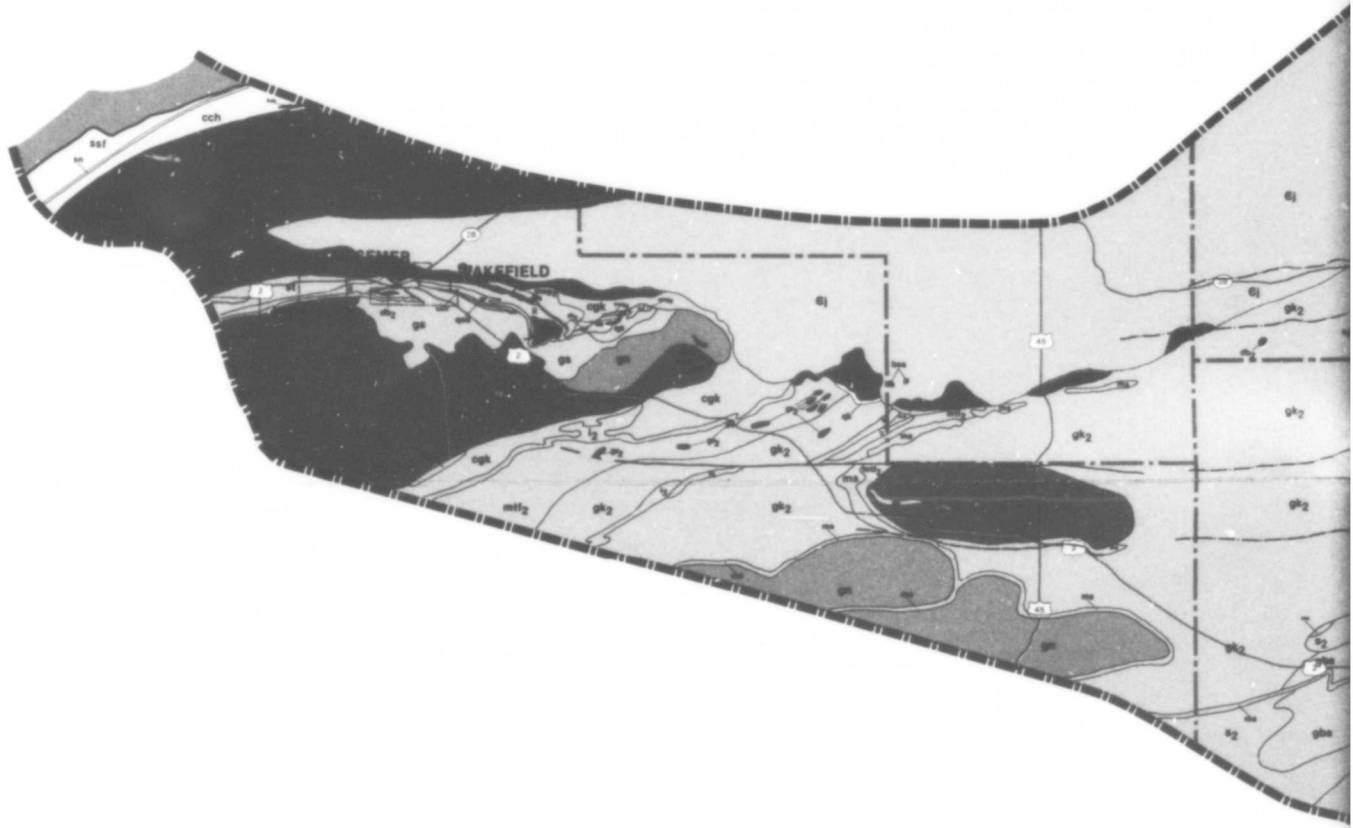
SQUARE MI.

NORTH

0 1 2 4 6 15 MILES

STUDY AREA





90°30' + 90°15' + 90°00' + 89°45' + 89°30' + 89°15' + 89°00' + 88°








A




B

BEDROCK GEOLOGIC DATA

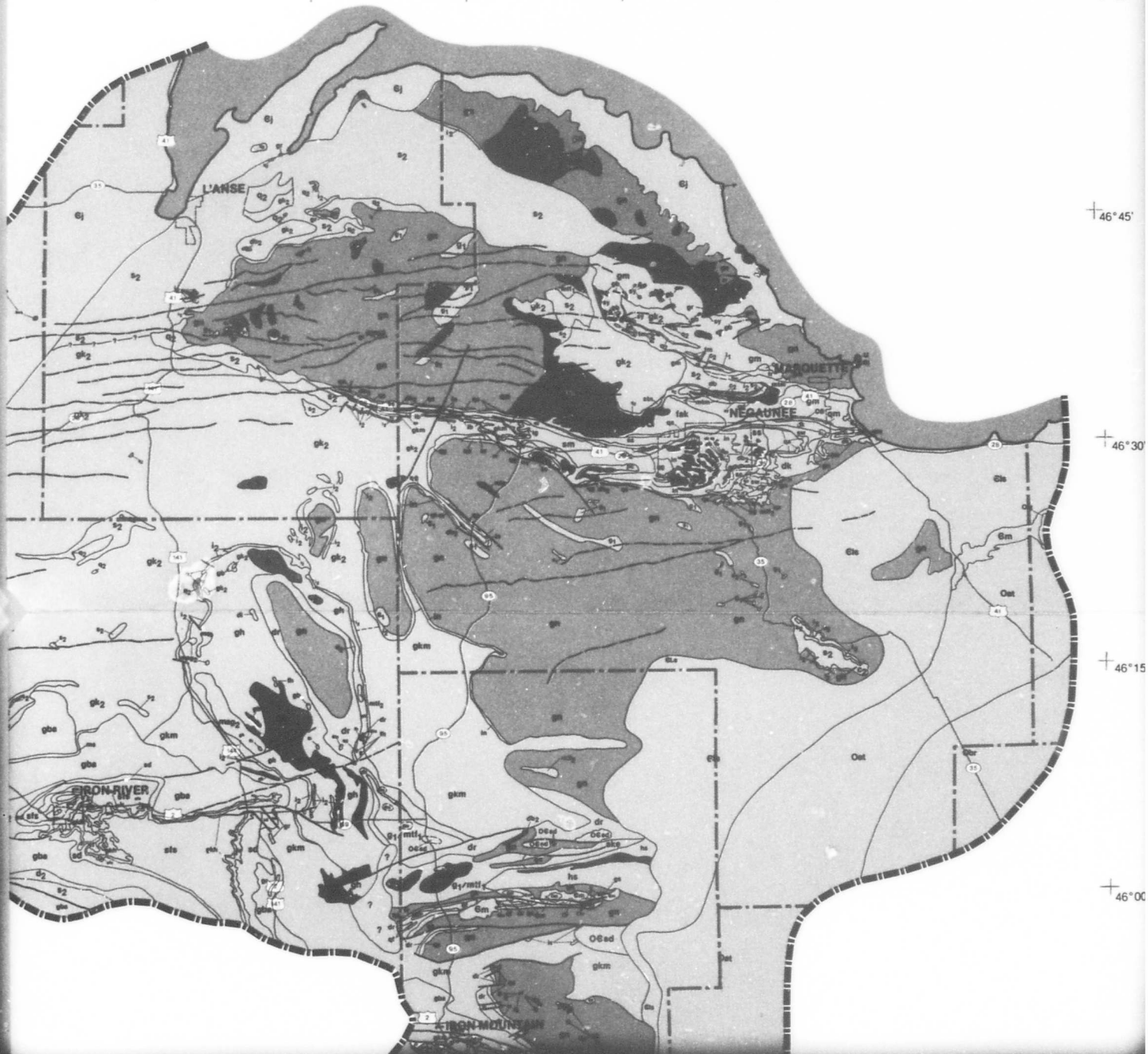
-  GEOLOGIC FORMATION
(see text for explanation)
-  GEOLOGIC CONTACT
-  APPROXIMATELY LOCATED
GEOLOGIC CONTACT
-  PALEOZOIC ERA
CAMBRIAN ORDOVICIAN SYSTEM

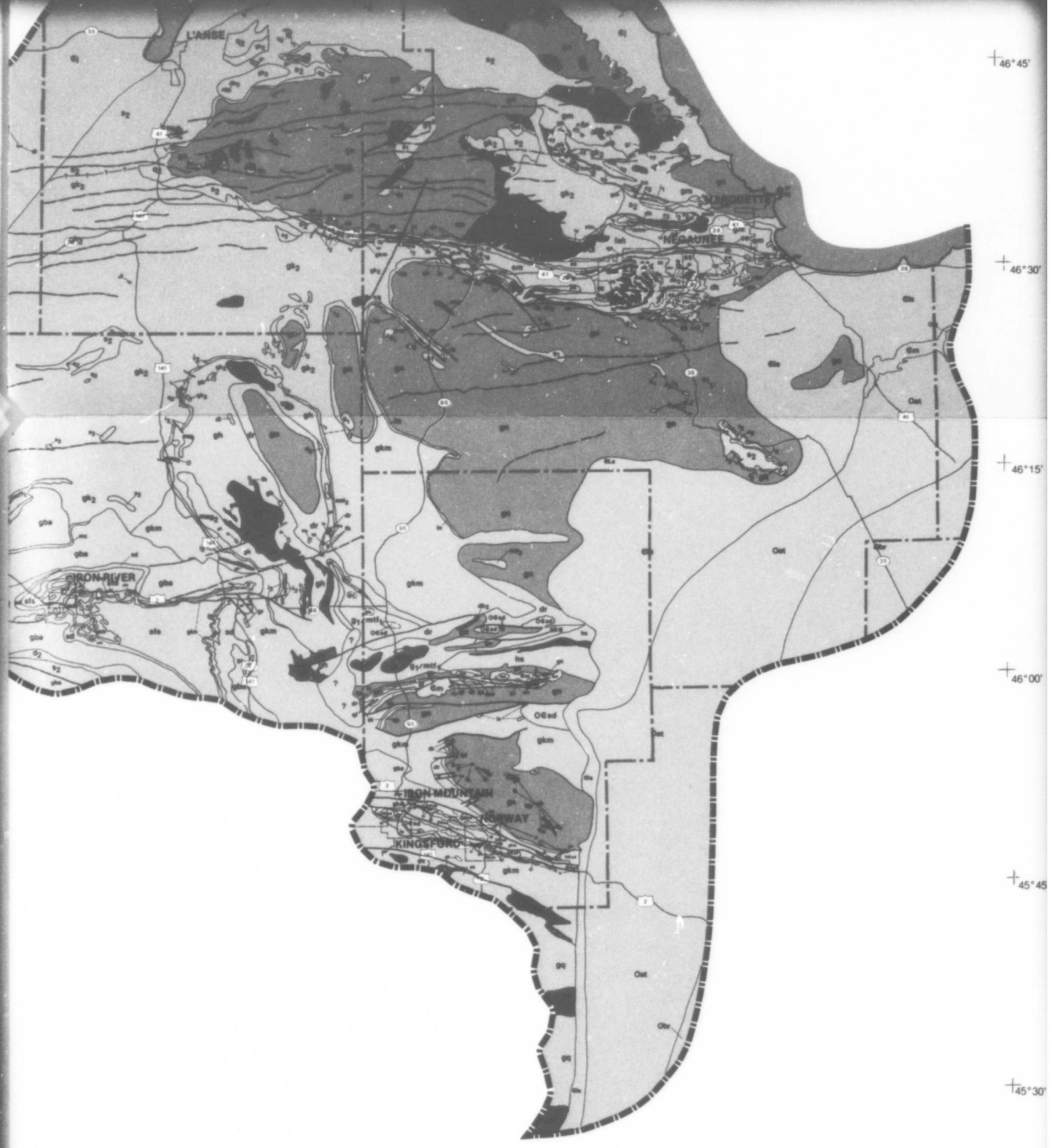
-  INFERRED GEOLOGIC CONTACT
-  INACTIVE FAULT
-  APPROXIMATELY LOCATED
INACTIVE FAULT
-  UPPER PRECAMBRIAN ERA
SEDIMENTARY ROCKS
-  IGNEOUS (volcanic) ROCKS

-  KEWEENAWAN DIKES

-  LOWER AND MIDDLE PRECAMBRIAN ERA
GNEISS
-  OTHER METAMORPHIC ROCKS
-  IGNEOUS ROCKS

88°30' + 88°15' + 88°00' + 87°45' + 87°30' + 87°15' + 87°00' + 47°00'





+ 46° 45'

+ 46° 30'

+ 46° 15'

+ 46° 00'

+ 45° 45'

+ 45° 30'