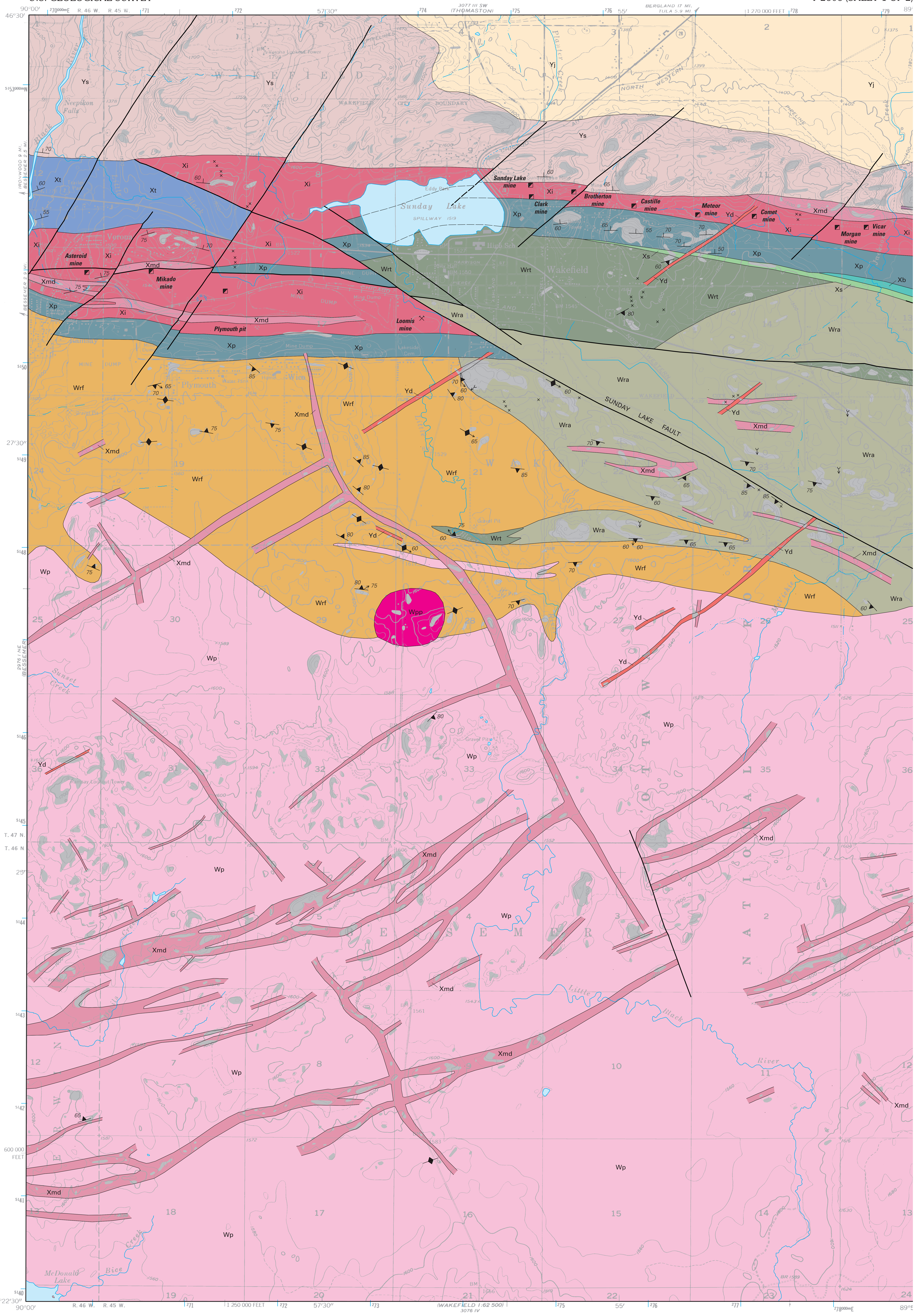
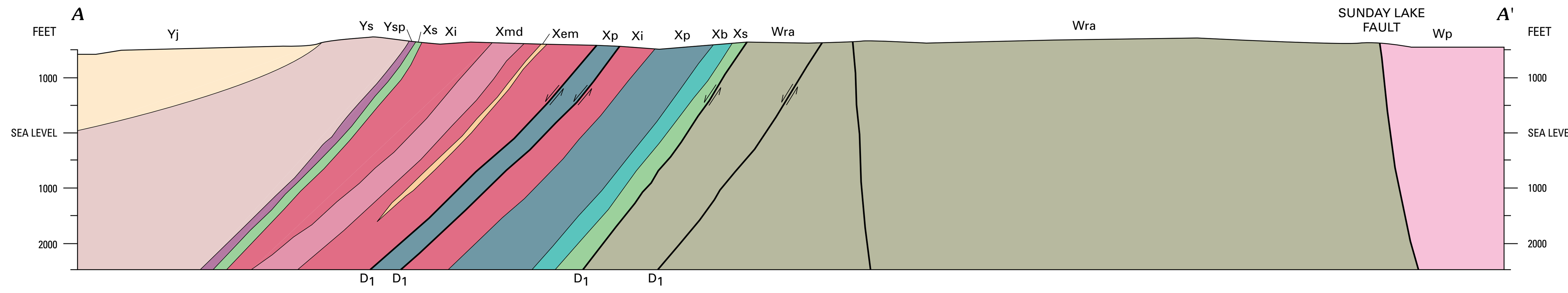
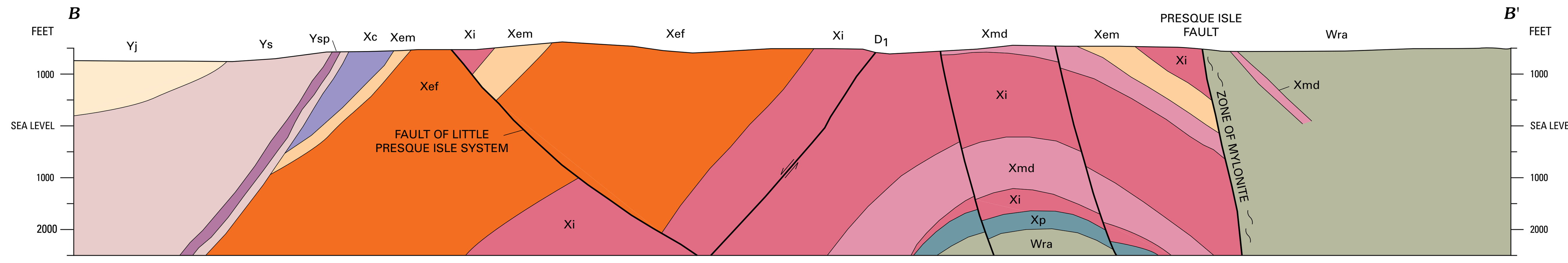


Base from U.S. Geological Survey,
Marenisco, Wakefield, Wakefield NE,
1955, photorevised 1975.
Polyconic projection. 1927 North American datum.
10,000-foot grid based on Michigan coordinate system,
north zone.
1,000-meter Universal Transverse Mercator grid ticks,
zone 16, shown in blue.

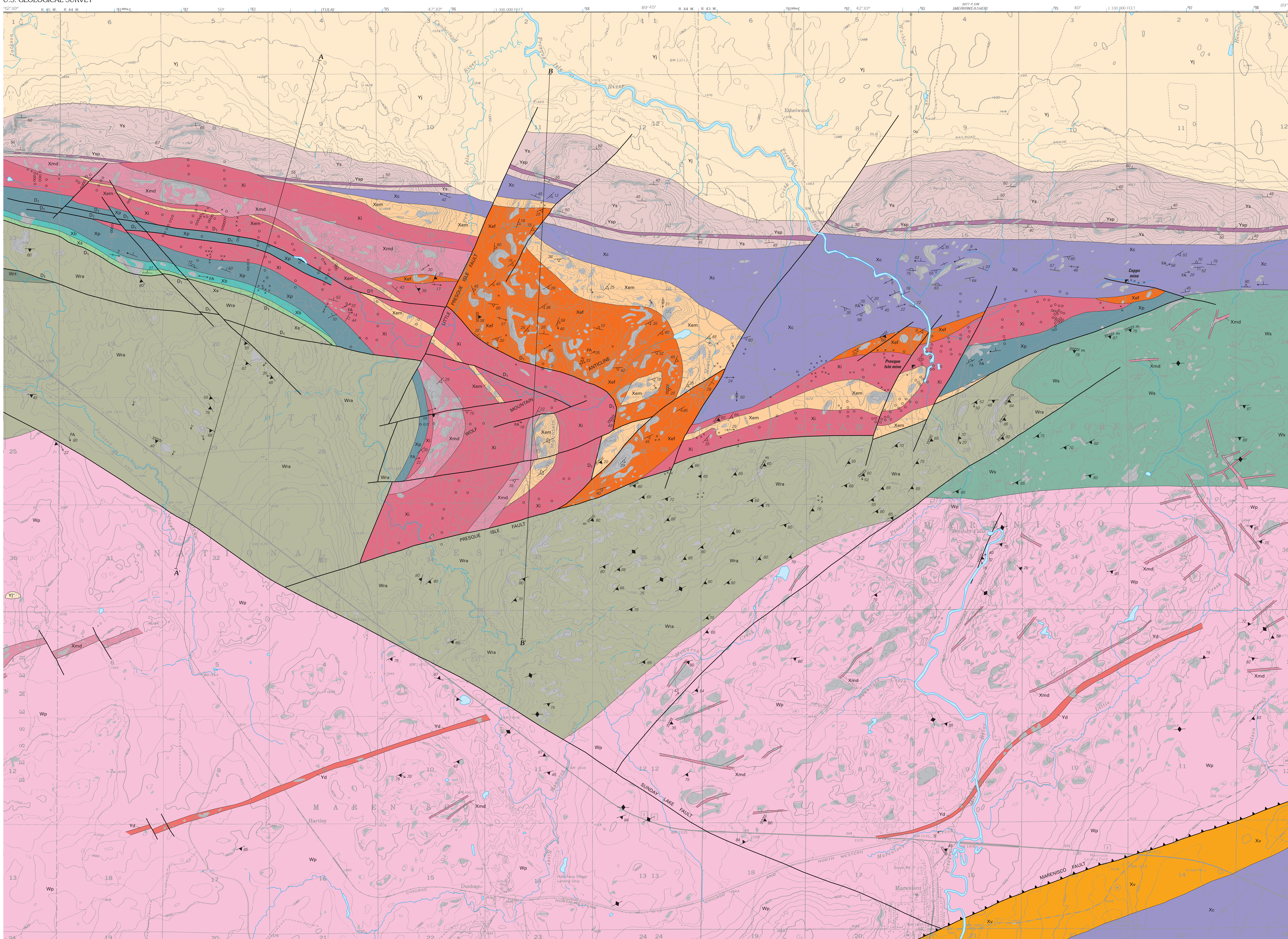




GEOLOGIC MAP OF THE EASTERN GOGEBIC IRON RANGE, GOGEBIC COUNTY, MICHIGAN

By
J.S. Klasner, G.L. LaBerge, and W.F. Cannon

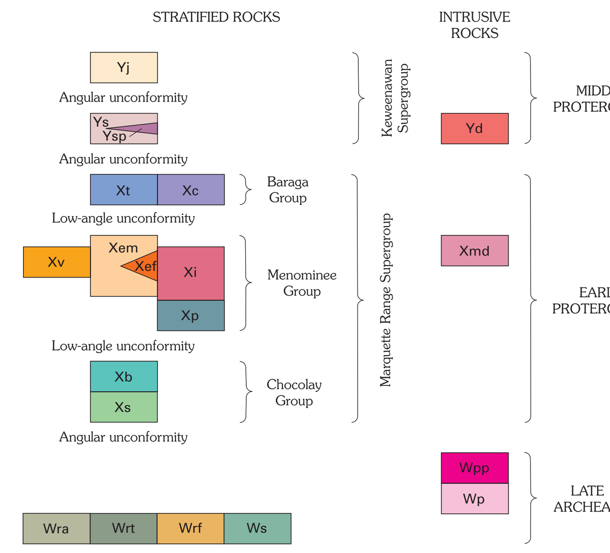
1998

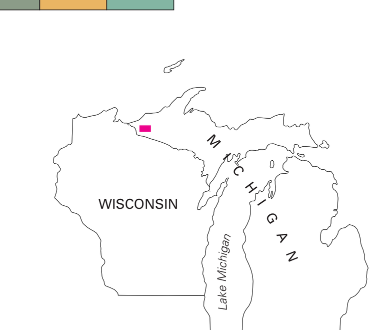


Geology mapped by authors 1993–1994
Edited by Katharine S. Schindler and Alessandro J. Donatich
Digital cartography by Alessandro J. Donatich
Manuscript approved for publication June 27, 1997

SCALE 1:24 000
1 MILE
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

CORRELATION OF MAP UNITS





LOCATION OF MAPPED AREA

DESCRIPTION OF MAP UNITS

STRATIFIED ROCKS

Keweenawan Supergroup (Middle Proterozoic)

Yj — **Jacobsville Sandstone**—Brown and red conglomerate and interbedded arkosic sandstone. Conglomerate clasts are mostly iron-formation and vein quartz. Commonly poorly cemented. Known only from drill core

Ys — **Siemens Creek Volcanics**—Olive-gray to dark-greenish-gray flood basalt and andesite. Commonly strongly chloritized. Flows generally 3–14 m thick. Basal flows are thicker and generally pillowed. Flow tops are sparsely vesicular. Vesicles are filled with chlorite, epidote, quartz, and calcite

Ysp — **Distinctive flow rich in plagioclase phenocrysts**

Marquette Range Supergroup (Early Proterozoic)

Baraga Group

Xc — **Copps Formation**—Mostly metagraywacke with graded bedded units ranging from 10 to 50 cm thick. Carbonate concretions present locally. Basal member is brown, conglomeratic, ferruginous quartzite with clasts of chert, jasper, quartz, volcanic rocks, and gneiss

Xt — **Tyler Formation**—Ferruginous black chert and black pyritic slate with minor argillite and arkose interbeds

Menominee Group

Emperor Volcanic Complex

Xef — **Felsic volcanic rocks**—Gray- to buff-weathering volcanic breccia. Angular, 1- to 20-cm clasts of gray microcrystalline felsite, some with flow banding and (or) quartz phenocrysts, commonly in a finer matrix of hyaloclastite

Xem — **Mafic volcanic rocks**—Lower units are massive, aphanitic, sparsely porphyritic basalt and associated medium- to coarse-grained metadiabase sills. Upper units are massive basalt, pillowed basalt, pillow breccia, and basaltic hyaloclastite

Xv — **Metavolcanic rocks**—Metavolcanic rocks of poorly known character. Not exposed in map area but projected from area to the south of the area of aeromagnetic data

Xi — **Ironwood Iron-Formation**—Mostly wavy-bedded granular iron-formation with irregular, 2- to 10-cm-thick cherty layers containing granules (0.5–2 mm in diameter) of iron silicates, magnetite, or jasper in a chert matrix, separated by 0.5- to 3-cm-thick layers of magnetite or siderite. Also present are units of laminated iron-formation with 1-mm- to 1-cm-thick layers of chert alternating with comparable layers of iron carbonates, iron silicates, or iron oxides. The iron-formation is locally interbedded with volcanic rocks of the Emperor Volcanic Complex where it occurs as lenses of jasper-magnetite iron-formation within the volcanic rocks

Xp — **Palms Formation**—Upper part is thick-bedded and commonly crossbedded, white to light-gray vitreous quartzite. Lower part is green to brown, laminated argillite and siltstone with lesser quartzite interbeds

Chocolay Group

Xb — **Bad River Dolomite**—Dolomite and silicified dolomite; gray on fresh surfaces but tan to brown on weathered surfaces. Abundant layers and irregular patches of white, gray, or black chert. Stromatolitic layers composed of individual mounds ranging in diameter from 5 to 20 cm are common but are most abundant near top of formation. Stromatolitic layers tend to be more silicified than the evenly bedded dolomite and locally are nearly completely silicified

Xs — **Sunday Quartzite**—Mostly crossbedded, reddish vitreous quartzite with several quartz-pebble conglomerate layers. Mud-chip conglomerates and mud-cracked horizons are also present. Several bedding-parallel mylonitic zones are present within the quartzite

Ws — **Biotite schist (Late Archean)**—Quartz-plagioclase-biotite schist and gneiss, probably derived from intermediate volcanic rocks of Ramsay Formation where intruded by Puritan Quartz Monzonite. Locally cut by irregular masses of granitic rocks

Ramsay Formation (Late Archean)

Wra — **Mafic to intermediate flow member**—Andesite to dacite flows, commonly pillowed and amygdaloidal. Varies from massive to schistose. Metamorphosed to chloritic and amphibolitic rocks, which also contain sericitized plagioclase, epidote, and calcite

Wrt — **Mafic to intermediate pyroclastic member**—Metamorphosed pyroclastic rocks ranging from fine-grained tuff to lapilli tuff to volcanic conglomerate and breccia containing boulders as much as 1.5 m across; also includes some graywacke. Tuff varies from thin bedded to thick bedded or massive. Mineralogy is similar to that of mafic to intermediate flow member (Wra)

Wrf — **Felsic schist and pyroclastic member**—Variably metamorphosed rhyolite and rhyodacite. Original textures are poorly preserved, but fragmental textures in some outcrops indicate unit is at least partly pyroclastic. Where least metamorphosed consists of quartz, plagioclase, and potassium feldspar with minor biotite, chlorite, epidote, and calcite. Pyrite is locally abundant. Most of unit is quartz-feldspar-biotite-garnet schist

INTRUSIVE ROCKS

Yd — **Diabase (Middle Proterozoic)**—Dark-gray, medium-grained, massive olivine diabase. Mostly in dikes that produce distinctive negative aeromagnetic anomalies

Xmd — **Metadiabase (Early Proterozoic)**—Massive, medium- to coarse-grained metamorphosed diabase and gabbro, generally with well-preserved igneous textures. Most pyroxenes are converted to actinolite, hornblende, or biotite. Occurs mostly as sills and subconcordant sheets in Early Proterozoic strata and as numerous dikes cutting Archean rocks

Wpp — **Pegmatite (Late Archean)**—Massive pegmatite consisting of pink microcline crystals as long as 50 cm, quartz, and muscovite. Contains irregular masses of aplite

Wp — **Puritan Quartz Monzonite (Late Archean)**—Medium- to coarse-grained, pink granitic rocks. Massive to weakly foliated and in part porphyritic with potassium feldspar phenocrysts. Border phase is rich in inclusions of quartz-feldspar-biotite schist, probably derived from the adjacent Ramsay Formation

EXPLANATION OF MAP SYMBOLS

Contact—Mostly concealed. Accuracy can be judged by locations of outcrops, drillholes, and test pits

Fault—Penokean thrust faults are labeled D_1

Thrust fault (Middle Proterozoic)

Primary planar structures

Strike and dip of bedding and volcanic layering—Ball indicates top known from sedimentary structures

- 83 **Inclined**
- **Vertical**
- 74 **Overturned**

Stratigraphic top determined by volcanic pillow

Planar structures developed during the Penokean orogeny—Symbols may be combined

Strike and dip of ductile first-generation foliation (S_1)

- 60 **Inclined**
- **Vertical**

Strike and dip of ductile second generation (S_2)

- 52 **Inclined**

33 **Strike and dip of zone of brittle deformation (S_4)**

20 **Strike and dip of foliation in strongly sheared rock**

Linear structures developed during the Penokean orogeny

- FA 22 **Bearing and plunge of minor fold axis**
- FA **Bearing of horizontal fold axis**
- 33 **Bearing and plunge of axis of recumbent minor fold**
- 25 **Bearing and plunge of lineation from intersection of cleavage and bedding**—Some are determined from stereoplot
- 31 **Bearing and plunge of elongation of volcanic fragments, clasts, and mineral grains**

Structures in Archean rocks—Mostly from Archean deformation, some from Penokean deformation. Symbols may be combined

Strike and dip of foliation and schistosity

- 85 **Inclined**
- **Vertical**

5 **Bearing and plunge of lineation**

45 **Strike and dip of foliation in strongly sheared rock**—m, mylonite

Shaft

Mine pit

Prospect pit

Diamond drillhole

Areas of bedrock outcrop

INTRODUCTION

The map area encompasses the eastern end of the Gogebic iron range, which includes the Early Proterozoic Ironwood Iron-Formation and related strata of the Marquette Range Supergroup. These rocks lie unconformably on a basement of Archean metavolcanic and metasedimentary rocks, derived schists and gneisses, and intrusive granitoid rocks that are some of the southernmost exposures of rocks of the Superior province. The youngest rocks in the area, flood basalt and sandstone of the Middle Proterozoic Keweenawan Supergroup, were deposited in the Midcontinent rift and lie with a low-angle unconformity on Early Proterozoic strata.

Geologic interest in the region stemmed mostly from the iron-rich strata of the Gogebic iron range, whose eastern terminus is within the map area. The productive iron ore region is mostly west of the map area, but several important mines are in the western third of the map area. The first published map of the area was that of Irving and Van Hise (1892). It showed the distribution of rock units but little structural data. Subsequent work included that of S.A. Tyler, who produced an unpublished map for the Jones and Laughlin Steel Company in 1935. Hendrix (1960) and Trent (1973) made some stratigraphic and structural refinements based on additional field work, unpublished data of Tyler, and mapping by Allen and Barrett (1915). Detailed mapping by Prinz and Hubbard (1975) was carried out in the Wakefield quadrangle. Schmidt (1980) described the rocks of the Marquette Range Supergroup on most of the Gogebic range.

Our work was undertaken to clarify the stratigraphic and structural relations of Early Proterozoic rocks of the eastern Gogebic range, an area where a number of critical features of the Marquette Range Supergroup and the Penokean orogen are exposed. The map presented here is based largely on detailed maps by Trent (1973) for the Wakefield NE and Marenisco quadrangles and by Prinz and Hubbard (1975) for the Wakefield quadrangle. We have made some changes to their map pattern and have further documented and clarified details of the stratigraphy and structure.

Our work was greatly aided by the precise locations of outcrops mapped by Trent (1973) and Prinz and Hubbard (1975) and by maps and field notes of S.A. Tyler, provided to us by Thomas Hendrix. Milton Gere of the Geological Survey Division of the Michigan Department of Natural Resources provided lithologic data from drillholes available through their core facilities at Marquette, Mich. Marsha Hilmes and Toni Ealy served as field assistants, and Mitch Anderson assisted in the preparation of petrographic thin sections.

STRATIGRAPHY

LATE ARCHEAN ROCKS

Archean strata are mildly to moderately metamorphosed volcanic and lesser sedimentary rocks of the Ramsay Formation. These rocks are an intertongued assemblage of pillowed to massive basalt flows (Wra), felsic pyroclastic rocks (Wrf), and mafic tuff (Wrt). Schist and gneiss (Ws) of volcanic parentage is the likely equivalent of the Ramsay Formation. Uniformly south-facing pillow structures in the basalts suggest a lack of repetition by folding. The Ramsay Formation is estimated to be at least 3 km thick. Massive to weakly foliated granitic rocks of the Puritan batholith (Wp) intruded the Ramsay Formation at about 2.75 Ga based on age determinations southeast of the map area (Sims and others, 1984).

EARLY PROTEROZOIC ROCKS

Early Proterozoic strata of the Marquette Range Supergroup consist of three groups, each separated by an unconformity. The oldest strata, the Chocolay Group, are a basal orthoquartzite of the Sunday Quartzite (Xs) and an overlying cherty dolomite of the Bad River Dolomite (Xb). These rocks lie with profound angular unconformity on Archean rocks. The Chocolay Group is incompletely preserved because of erosion prior to deposition of overlying strata and is present only in the central part of the map area, where as much as a few hundred meters of the strata are preserved.

The Menominee Group consists of argillite and quartzite of the Palms Formation (Xp), which grades upward into the Ironwood Iron-Formation (Xi), one of the major iron-bearing units of the Lake Superior region. The base of the Menominee Group is a low-angle unconformity where it lies on the Chocolay Group and a profound angular unconformity where it lies on Archean rocks.

Volcanic rocks of the Emperor Volcanic Complex (Xem, Xef) intertongue with the Ironwood Iron-Formation and provide documentation of the contemporaneity of iron-formation deposition and volcanism in this region. The Little Presque Isle fault marks a prominent change in both the lithology of the Ironwood and in the thickness of the Emperor Volcanic Complex. To the west of the fault, the Ironwood is predominantly granular, irregularly bedded iron-formation typical of shallow-water deposition. East of the fault it is predominantly evenly laminated, typical of deeper water deposition. The Little Presque Isle fault also marks a prominent change in the distribution and thickness of the Emperor Volcanic Complex. West of the fault the Emperor consists of two thin units of basalt interlayered with the Ironwood. East of the fault the Emperor is a thick sequence of basalt, felsic volcanic rocks, and hyaloclastite. The abrupt change in lithology recorded at the Little Presque Isle fault indicates that the fault bounded the western side of a graben into which the Ironwood and Emperor were deposited. Farther east, the Emperor thins near the Presque Isle fault, suggesting that that fault bounds the southeastern side of the graben. A poorly exposed unit of volcanic rocks (Xv) near the southeastern corner of the area may be equivalent to the Emperor Volcanic Complex.

The youngest Early Proterozoic rocks are graywacke and slate of the Copps Formation (Xc) in the east and the equivalent Tyler Formation (Xt) in the west, which compose the Baraga Group. The Copps lies with angular unconformity on older rocks as indicated by the truncation of pre-Copps units evident in the map pattern and by the basal conglomerate that contains clasts of older units, including abundant iron-formation clasts and clasts of felsic volcanic rocks similar to the Emperor Volcanic Complex.

MIDDLE PROTEROZOIC ROCKS

The Middle Proterozoic rocks in the area are part of the Keweenawan Supergroup, which was deposited within the Midcontinent rift. The lower part of the succession consists of flood basalts of the Siemens Creek Volcanics (Ys). Typically the one or two earliest flows are pillowed subaqueous basalt; the remainder are massive subaerial flows. Assuming approximate equivalence with basal Keweenawan flows on the northern shore of Lake Superior, eruption began at about 1,109 Ma (Davis and Sutcliffe, 1985). Flows slightly younger than the Siemens Creek Volcanics were erupted at about 1,106 Ma (Cannon and others, 1993a).

The youngest unit in the area is the Jacobsville Sandstone (Yj), a thick sequence of fluvial conglomerate and sandstone, which lies with angular unconformity on the Siemens Creek Volcanics. The unit is not precisely dated, but sedimentologic and structural data indicate that it was deposited, at least in part, during movement on the Marenisco fault (Hedgman, 1992). That fault movement has been dated at approximately 1,060 Ma (Cannon and others, 1993b).

STRUCTURE

MIDDLE PROTEROZOIC

Middle Proterozoic strata compose a north-facing monocline with dips as steep as 70° but more typically 40° to 50°. Underlying Early Proterozoic strata, which have only mild structural discordance with Middle Proterozoic rocks, also were tilted northward in the monocline, so the present generally northward dip of rocks on the Gogebic range is mostly a result of post-Keweenawan tilting. Archean rocks also were tilted and uplifted in this same structure as shown by southerly dips of once-vertical diabase dikes that cut these rocks (Cannon and others, 1993b). The Marenisco fault has been shown to be a crustal scale listric thrust, active at about 1,060 Ma, which resulted in the northward tilting of all rocks to the north of the fault trace (Cannon and others, 1993b; Sims, 1992).

A set of north-northeast-trending faults, the Little Presque Isle system, offsets all units and therefore has had movement as young as 1,060 Ma. At least some of the faults may be reactivated structures that were important in the Early Proterozoic history as well. The Middle Proterozoic movement on these faults probably compensated for changes in the shape of the upper plate of the Marenisco fault as it was thrust over a curviplanar fault surface.

EARLY PROTEROZOIC

All Early Proterozoic supracrustal rocks were multiply deformed during the Penokean orogeny at about 1.85 Ga. Deformational phases are defined mostly by fault systems of various orientations and by crosscutting relations. Many of these faults can be seen as shear zones in outcrops but the strong prominent gradients or discontinuities on the aeromagnetic map of the area (U.S. Geological Survey, 1972). The oldest deformation (D_1) is expressed as north-verging, thin-skinned folding and thrusting. A thrust fault near the base of the section is the Sunday Quartzite detached the Early Proterozoic strata from underlying Archean rocks. This fault is best exposed in the SE¼, sec. 18, T. 47 N., R. 44 W. Other thrust faults are nearly parallel to bedding higher in the Early Proterozoic section. These faults become less prominent to the west, and the basal detachment is not known west of the Sunday Lake fault. Most of the D_1 thrusts now dip steeply northward because of Middle Proterozoic tilting and present a geometry of down-to-the-north normal faults (see cross sections A–A′, B–B′).

A second phase of thin-skinned deformation (D_2) folded Early Proterozoic strata and thrust faults into the gently east-plunging Wolf Mountain anticline. Thin-skinned structures generally are not recognized in underlying Archean rocks where neither the Archean foliation nor a dense network of Early Proterozoic diabase dikes was folded during the Penokean orogeny. One possible exception is the west-trending fault immediately south of the base of the Proterozoic section between Wakefield and sec. 22, T. 47 N., R. 43 W., which appears to be a thin-skinned feature that incorporates as much as 1 km of Archean rocks in the thrust sheet.

The third phase of deformation (D_3) involved block faulting on a set of north-northwest-trending faults that included reactivation of the Little Presque Isle fault. Down-on-the-east movement on the Little Presque Isle fault juxtaposed the Wolf Mountain anticline, a Penokean structure mostly within Early Proterozoic strata, and the Archean Ramsay Formation, which is apparently devoid of Penokean structures. The fourth phase of deformation (D_4) reactivated the Presque Isle fault and brought Archean gneiss up against Early Proterozoic strata. Several faults within Archean rocks have orientations similar to the Presque Isle fault and are probably also D_4 structures.

The Sunday Lake fault and parallel faults cut faults of each of the other sets and thus appear to be the youngest Early Proterozoic structures. The Sunday Lake fault produces about 1.5 km of offset of Early Proterozoic units near Wakefield, but does not offset the base of the Middle Proterozoic Siemens Creek Volcanics north of Wakefield.

The steep northwest tilting of the region produced by Middle Proterozoic deformation must be taken into account and compensated for to determine the original geometry and kinematics of structures developed during the Early Proterozoic. The compensation is most striking in the structural relation between the Little Presque Isle and Presque Isle faults. Archean and Early Proterozoic strata and their contained structures were tilted northward (counterclockwise as viewed from the west) as a single block during regional compression shortly following development of the Midcontinent rift. Removal of this Middle Proterozoic rotation is accomplished by clockwise rotation of about 50° around an east-trending axis. When thus rotated, the Little Presque Isle fault assumes an easterly strike, nearly parallel with the Presque Isle fault, and has a steep southerly dip. The strike of the moderately south-dipping Presque Isle fault is nearly east-west so it does not change substantially upon rotation, but its dip becomes steep to the north.

Thus, the Little Presque Isle and Presque Isle faults, which diverge at a large angle in the present map view, had nearly parallel easterly strikes during the Early Proterozoic. They appear to have been growth faults that bounded an east-northeast-trending and gently east-northeast-plunging graben in which the Ironwood Iron-Formation and Emperor Volcanic Complex were deposited. As a result of Middle Proterozoic tilting this graben now plunges steeply to the northeast.

ARCHEAN

Except for the faults and shear zones described above, all structures within Archean rocks appear to have formed in Late Archean time. The Ramsay Formation has a steep south-dipping foliation generally parallel to lithologic layering and a prominent lineation that plunges steeply within foliation. Stratigraphic tops are uniformly to the south, in contrast to the north-facing Early and Middle Proterozoic strata. When the effects of Middle Proterozoic tilting are removed, the restored orientations of Archean structures are moderately north-dipping layering and foliation and downward-facing stratigraphic top directions. Thus, the Ramsay Formation appears to be the overturned limb of a recumbent Archean fold. The Puritan batholith (Wp) intruded this fold at about 2.75 Ga and is itself weakly foliated in places.

GEOLOGIC HISTORY

The rocks of the map area were formed and modified during three episodes of geologic activity ranging in age from Late Archean to Middle Proterozoic. The oldest rocks in the area are Late Archean submarine volcanic rocks of the Ramsay Formation and the schists and gneisses derived from them. These rocks were apparently folded into a large overturned fold, the overturned limb of which is presently exposed in the area. The folded rocks were intruded by a post-tectonic or late syntectonic granitic body, the Puritan batholith, at about 2.75 Ga. An extended period of uplift and erosion peneplaned these rocks prior to deposition of the Early Proterozoic sedimentary and volcanic rocks.

In the Early Proterozoic the area was part of a south-facing continental margin that subsequently was deformed along the distal margin of the foreland fold and thrust belt of the Penokean orogen. The map area straddles the boundary between a western region, where deposition was largely on a stable platform and subsequent deformation was minor, and an eastern region, where deposition was in a tectonically active belt, and deformation was moderate to intense.

The Chocolay and Menominee Groups appear to have been deposited on the subsiding passive margin of the Superior craton during continental separation and subsequent development of an ocean basin to the south. Extensional growth faults developed in the eastern part of the area during the latter stages of Menominee Group sedimentation and resulted in the lateral facies changes in the Ironwood Iron-Formation and the eruption of the Emperor Volcanic Complex in a local graben.

Younger parts of the Marquette Range Supergroup, including the Copps Formation and Tyler Formation of the Baraga Group, were deposited in a foreland basin north of accreting island arcs of the Wisconsin magmatic terranes at about 1,850 Ma (Sims and others, 1989). Continued accretion of magmatic rocks to the south led to compressional deformation, especially in the eastern part of the map area. Deformation probably occurred soon after deposition of the Baraga Group.

Finally, in Middle Proterozoic time, the area lay along the southern flank of the Midcontinent rift and was deeply buried by continental flood basalts of the Siemens Creek Volcanics and the slightly younger Jacobsville Sandstone. During development of the rift, between 1,109 and 1,095 Ma, the region was tilted northward toward the rift axis. Additional northward tilting occurred shortly after rifting during a compressional event in which the Marenisco fault developed as a crustal-scale listric thrust.

ECONOMIC GEOLOGY

IRON

Most economic interest in the area has resulted from mining of iron ores in the Ironwood Iron-Formation. These ore bodies consisted of masses of iron oxides and hydroxides that formed by secondary concentration of the iron-formation. Deeply circulating ground waters altered original minerals and removed silica and other components from the iron-formation, leaving behind residual concentrations of the ore minerals. The most productive part of the Gogebic iron range was west of the map area, but about 50 million tonnes of ore were produced from 14 mines in the western third of the area between 1885 and 1950 (Lake Superior Iron Ore Association, 1952). Additional production of this type of ore in the future is unlikely because the ore bodies are mostly depleted and other types of iron ores are more desirable in modern steelmaking.

Concentrating-grade ores have never been mined on the Gogebic range but some potential exists in the map area. In particular, the broad outcrop belt of the Ironwood Iron-Formation on the Wolf Mountain anticline and the relatively low dips of the iron-formation in that area provide a large tonnage of material that could be mined by open-pit techniques. The suitability of the iron-formation for concentrating-grade ores is not known. Substantial mineralogical and metallurgical testing is required to determine its economic potential.

LEAD AND SILVER

The area was prospected for silver (in argentiferous galena) in the late 1800's. The most significant occurrence is the Copps mine (sec. 14, T. 47 N., R. 43 W.) where an adit and shaft were developed along a fault zone in the Copps Formation. The property did not sustain production and was abandoned soon after development. Samples remaining on waste piles include strongly silicified rocks with masses of galena and lesser copper sulfide minerals. The origin and age of the mineralization is not known. Galena was also reported in two zones in the shaft of the Presque Isle iron exploration (Trent, 1973), but no details of these occurrences are known.

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GEOLOGIC MAP OF THE EASTERN GOGEBIC IRON RANGE, GOGEBIC COUNTY, MICHIGAN

By J.S. Klasner, G.L. LaBerge, and W.F. Cannon

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