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SUMMARY OF FIELD MAPPING IN THE SUPERIOR MAP SHEET

by

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ABSTRACT

Reconnaissance mapping, examination of newly acquired drill core, and preliminary reanalysis of geophysical data in northwestern Wisconsin is in progress in cooperation with the U.S. Geological Survey as part of the COGEOMAP program. Initial work has resulted in a new preliminary 1:250,000 bedrock geologic map. The broad lithologic units on the new map do not differ significantly from those on previous maps; however, the relationship and significance of the various units has changed. Archean metavolcanic rock, granite, and gneiss occupy a southwest trending belt south of the Gogebic Range. The southeast corner of the map sheet is underlain by Early Proterozoic metasedimentary rock, mafic to intermediate volcanic rock, and iron formation. The Early Proterozoic succession on the Gogebic Range which is probably contemporaneous in age with the rock to the southeast in the Mercer Butternut area is in turn unconformably overlain by Middle Proterozoic Keweenawan volcanic rock.

The regional unconformity between the Chocolay Group (represented on the west Gogebic Range by the Bad River Dolomite) and the Menominee Group (represented by the Palms, Ironwood and Tyler Formations) is confirmed, suggesting regional folding, uplift and erosion during the Early Proterozoic; the regional unconformity between the basal Keweenawan Bessemer Quartzite and the Tyler Formation indicates deformation, uplift and erosion prior to deposition of the Bessemer. Subsequently, the units were tilted to the north into the Lake Superior syncline.

GEOLOGIC SUMMARY

The geology of the Superior Sheet encompasses a wide range of rock types which represent a long and complex history. The earliest recognized rocks are Archean gneisses which are exposed around Morse in the center of the quadrangle. The culmination of the Archean is dated by a quartz monzonite batholith that intrudes a greenstone complex along the east edge of the quadrangle. This rock has been dated at 2,750 Ma. (Sims and Peterman, 1976). The overlying Early Proterozoic succession includes platform sediments in the north (Gogebic Range), and intermixed sedimentary and volcanic rocks in the south. These units were emplaced and deformed prior to the culmination of the Penokean orogeny around 1,850 Ma (Van Schmus, 1976). The Middle Proterozoic (Keweenawan) succession includes 1,100 Ma intracratonic volcanic rocks, associated sedimentary rocks, and dominantly gabbroic intrusives of the Midcontinent Rift system. Since that time, the geologic history has been one of deposition of clastic rocks with increasing maturity upward through at least the Upper Cambrian. The geologic record is generally absent from the Late Cambrian to the Pleistocene. The Pleistocene record is one of glacial advance and retreat, and the formation of ancestral Lake Superior prior to final retreat of the ice.

ARCHEAN

Rocks of Archean age underlie the southeastern part of the Superior Sheet the area south and east of the Gogebic Range. A typical greenstone assemblage crops out in the Gile Flowage area to the southwest of Hurley. Peterman and Sims (1978) report ages of 2,600-2,700 Ma for equivalent rocks to the east in

Michigan. The greenstones are intruded on the south and east by the Puritan Quartz Monzonite batholith described by Sims, Peterman, and Prinz (1977), who reported a Rb/Sr age of 2,740 Ma for this large complex pluton. In the extreme south central part of the area Sheet, a gneissic terrane has been identified and tentatively correlated with the 3,400 Ma old gneisses of the Marenisco-Watersmeet area of Michigan described by Peterman and Sims (1978).

The greenstones exposed in the Gile Flowage area south of Hurley were studied by Greathead (1975), who described the principle lithologies as massive basaltic and andesitic lava flows with minor interlayered pyroclastic beds. The tuffaceous and coarser fragmental units are typically andesitic in composition and are associated with the andesitic flows. Argillaceous sedimentary beds and felsic volcanic rocks are rare within the outcrop area. To the west of the outcrop area, south of Upson, several hundred feet of dacitic and rhyolitic rocks, largely fragmental and tuffaceous, have been encountered in exploratory drilling. This drilling was done in search of massive sulfide mineralization, and is described in an open file report by Erdosh (1973). A small granitic stock, the Pence Adamellite of Greathead (1975), intrudes the volcanic section and is truncated by the unconformity with the Early Proterozoic near the town of Pence.

The Puritan Quartz Monzonite intruded the volcanic section in the southeastern part of the Gile Flowage area. The volcanics are metamorphosed at the contact. Greathead described the Puritan in this area as predominantly foliated granodiorite, probably a border phase of the Puritan Batholith complex which extends eastward into Michigan.

To the south and west of the Gile Flowage Area, granitic gneisses crop out near the town of Morse. These rocks are pink to gray biotitic granite gneiss. Little work has been done in this area, and nothing is known of the relationship of these rocks to the greenstone terrane to the northeast.

EARLY PROTEROZOIC

The Gogebic Range contains 10,000 feet of Early Proterozoic metasedimentary rock. The oldest formation is the Palms Formation. Overlying the Palms Formation in the Hurley area are the Ironwood Iron Formation and the Tyler Formation, an argillite graywacke unit. This is a succession of platform and submarine fan sedimentary rock. Regional unconformities are known within this succession. Major deformation of the Early Proterozoic succession did not occur until Middle Proterozoic time. A carbonate unit, the Bad River Dolomite is known beneath the Palms Formation in the Western part of the Gogebic Range, west of Ballou Creek, and to the east in Michigan.

South of the outcrop belt of the Archean rock which underlies the Gogebic range is a deformed, metasedimentary and metavolcanic sequence, including iron formation, that has been correlated with the little deformed Gogebic Range sequence. Although similar in lithology and probable age, the relationship of these units to the Gogebic range is uncertain. Metamorphism in this southern area reaches kyanite grade.

Bad River Dolomite

The lowest unit recognized on the Gogebic range is the Bad River Dolomite, a gray to buff dolomite and cherty dolomite up to 100 feet thick (Aldrich 1929). Stromatolitic structures are common. This unit is found in both the east and west parts of the Gogebic Range but is absent in the central areas from Ballou Creek to the east (T. 44 N., R. 2 W.). Komatar (1972, p. 11) describes the western exposures of this unit in some detail. The base of the formation is not exposed in the area covered by this report. It is obvious from cross-cutting relationships, that the Bad River Dolomite lies with angular unconformity upon the Archean basement. In the eastern third of the Gogebic Range in Michigan, the Sunday Quartzite of Early Proterozoic age lies unconformably upon the Archean basement, and unconformably beneath the Bad River Dolomite, however, the Sunday Quartzite is not known in the west. The Bad River Dolomite is a siliceous tremolitic dolomite except locally where it has been contact metamorphosed by Upper Keweenawan intrusives. Sandy quartzose beds are common, which are one to two inches thick. The thicker sandy beds, six to twelve inches, commonly show cross-bedding.

Palms Formation

The Palms Formation unconformably overlies the Bad River Dolomite (Aldrich, 1929, p. 81; Montgomery, 1977, p. 61). It is approximately 450 feet thick in Wisconsin, and thickens to the east, reaching 750 feet east of Wakefield, Michigan. Aldrich (1929) divided the Palms into three mappable units. The lowest unit is a conglomerate 3-10 feet thick which rests unconformably upon Archean volcanic and granite rock in the east. Fragments average 2 inches in diameter, although larger ones are not unusual. Granite, volcanic rock, quartz, chert and graywacke are some of the lithologies represented in these pebbles and cobbles and are set in matrix composed of chlorite, feldspar, quartz and lithic fragments. The middle unit of the Palms, which constitutes 90 percent of the formational thickness, is thin to medium bedded. Typically, the thicker beds are medium-grained, buff to pink quartzite, while the thinner beds are fine-grained, green to black argillite or graywacke. The upper unit is approximately 60 feet thick in Wisconsin, but thickens to 100 feet in Michigan. The dominant lithology in this unit is medium to thick bedded, buff to pink quartzite.

Ironwood Iron Formation

The Palms is overlain by the Ironwood Iron Formation. The formation is composed of quartz and iron minerals of 65 percent quartz and 35 percent iron minerals. The iron minerals may be carbonate, oxide, or locally silicates. The beds are marked by variation in the proportions of quartz and iron minerals. The beds, thus, can be divided into carbonate-rich with an admixture of fine quartz, and those dominated by chert with an admixture of iron minerals. Another distinction can be made on the bedding characteristics. The cherty iron carbonates are characterized by smooth, straight, regular bedding planes. The ferruginous cherts are bounded by extremely irregular or wavy bedding planes and are thick bedded on the order of one inch to several feet. The two types of rock alternate in correlations across large areas.

Hotchkiss (1919) divided the formation into five members. These formations are most easily recognized on the east end of the Range, and are less distinct to the west.

Tyler Formation

The youngest and by far the thickest formation of the Early Proterozoic sedimentary sequence is the Tyler Formation. The nature of the contact between the Tyler and the Ironwood has been debated for some time. In Wisconsin the two formations look conformable except for the presence of a fragmental zone at the base of the Tyler, which, according to some, represents an erosional unconformity. Hotchkiss (1919) cites erosion as the sole cause of thickness variation in the Anvil Member (youngest) of the Ironwood Iron Formation. The Anvil varies from 0 to 375 feet thick. The presence of an unconformity marked by a conglomerate resting on Middle Precambrian volcanics at the base of the Copps Formation (which occupies the same stratigraphic position as the Tyler to the east of this area) is uncontested, although the lateral extent of this conglomerate is debatable. Atwater (1938) concludes that the Tyler and Copps Formations are correlative and suggests the presence of an unconformity between the Ironwood and Tyler on the basis of that found between the Ironwood (and interfingered volcanics) and the Copps. A strong case for a gradational contact was made by Aldrich (1929). A conglomeratic zone like that in the Copps does not crop out in the Tyler area, and in fact, all references to the Pabst Conglomerate (the Basal fragmental member of the Tyler) are either to drill core or to underground exposures in iron mines which are no longer accessible. However, because of a post-Ironwood/pre-Tyler period of tectonism by Felmlee (1970, p. 82) and Cannon (1973), the Tyler is tentatively considered to rest unconformably on the Ironwood Iron Formation.

Alwin (1976, p. 69) reports a maximum thickness of the Tyler in the Hurley area of 9,500 feet. It is overlain unconformably by the basal quartzite of the Keweenawan. Greater amounts of Tyler were eroded prior to deposition of the Middle Proterozoic units in the western areas, and it is essentially absent in the western area of the Gogebic Range. Alwin (1976, p. 70) describes the Tyler Formation in detail. He determined that the Tyler consists of 41 percent argillites or slate, 24 percent graywackes or siltstones which exhibit sedimentary structures indicative of turbidity current deposition, and 35 percent graywackes and siltstones which lack significant primary sedimentary structures. There seem to be no significant trends in the numerical importance of the lithologic subdivisions going up section. Argillaceous beds seem to make up progressively less of the total volume of each outcrop up section.

Intermixed Metasedimentary and Metavolcanic Rocks

In the southeastern part of the sheet, particularly around Mercer, a sequence of intermixed metasedimentary and metavolcanic rocks are exposed. Black (1977) has recently described these units. The northern parts of this area consist of metamorphosed pillow basalts, basic volcaniclastic rocks, massive diabase sills and dikes, and iron formation and slate. The southern part of this area is underlain by biotite gneiss, amphibolite, staurolite and kyanite-bearing metapelitic schist and sulfide-bearing graphitic schist. The areal extent of this terrane is unknown because of thick and extensive glacial cover.

MIDDLE PROTEROZOIC

Middle Proterozoic rock in the Superior Sheet consists of four main sequences, namely a basal quartzite sequence, a sequence of volcanic rock of various compositions and associated interflow sedimentary rock, an intrusive sequence of gabbro and related differentiates, and an upper sequence of sedimentary rock. These are generally referred to as Keweenawan. Because the Keweenawan has been studied in some detail for over 130 years, the discussion that follows is necessarily abbreviated. The reader is referred to more comprehensive reports cited in the text.

Various methods have been used to divide the Middle Proterozoic. The classical division, and the one used in this report, is that the Lower Keweenawan rocks are sedimentary, Middle Keweenawan are both extrusive and intrusive igneous, and the Upper Keweenawan are immature to mature sedimentary. Other divisions can be made on presence or absence of reversely polarized remnant paleomagnetic properties; however as there is some doubt as to the reliability of using paleomagnetics for stratigraphic correlation, the classical method is used.

Lower Keweenawan Rock

Unconformably overlying the Early Proterozoic sedimentary sequence is Upper Precambrian sedimentary rock. The unconformity between Early and Middle Proterozoic rock of the Lake Superior region is recognizable on the Gogebic Range (Montgomery, 1977, p. 69). An exposure northwest of Upson Lake is the only known outcrop that clearly shows truncation of Tyler bedding and substantial (one foot) relief on the upper surface on the Tyler. The basal Upper Precambrian sequence is the Bessemer Quartzite, which varies in thickness, but is generally about 400 feet thick. The basal 10 feet of the Bessemer is a distinctive conglomerate consisting of well-rounded and moderately sorted pebbles and cobbles of quartzite, iron formation, graywacke and igneous rock. The framework grains of the matrix are predominantly monocrystalline quartz, rock fragments, and polycrystalline quartz and chert. Overlying this basal unit is a thin- to thick-bedded, buff to pink cross-bedded quartzite. This unit is texturally immature in that the grains are angular to subangular, and sorting is poor.

Middle Keweenawan Rock

Conformably overlying the Bessemer Quartzite is a sequence of extrusive flows of varying composition, the majority of them basalt. The flows lying directly upon the Bessemer are pillowed, indicating that the initial outpouring of lava was subaqueous. Above this initial basalt flow is an interval of extrusives up to 40,000 feet thick that have been divided into formations and members. The upper parts of this sequence appear to be subaerial. The lowermost flows have been termed the Powder Mill by Schmidt and Hubbard (1972) who consider that this unit is Lower Keweenawan. These volcanics are overlain conformably by the Portage Lake Lava Series that forms the bulk of the Middle Keweenawan succession. Overlying the Portage Lake lavas is an unnamed Keweenawan volcanic formation that differs from the Portage Lake lavas by a great abundance of interbedded sedimentary rock. This unit is 10,000 feet thick along the eastern edge of the quadrangle and thin to disappearance before entering Wisconsin. The Portage Lake volcanics accumulated in a basin which was part of the midcontinent rift. Termination of this basin at the pinchout of the Portage Lake Volcanics near Mellen implies that lavas of the younger volcanic formation (or formations) farther west in Wisconsin were poured out of a separate basin, and may or may not be contemporaneous with the Portage Lake lavas.

Exposures of Keweenawan volcanics are known in Douglas County (Grant, 1900), and areas to the south. These have been termed the Chengwatana series, and is here used informally. The Chengwatana group consists mainly of mafic lava flows, but at least five conglomerate beds are present at the type locality. The group is at least 4,000 feet thick in Minnesota, and is nearly 20,000 feet thick along the western edge of the Superior sheet (Morey and Mudrey, 1972; Craddock, 1972).

Two major intrusive sequences have been mapped intruding the volcanic rocks, namely the Mellen intrusive complex (Olmsted, 1969), and the Mineral Lake intrusive complex (Tabet and Mangham, 1978). Both are still-like bodies of olivine gabbro and related mafic rock, about eight percent of ferrodiorite and eight percent of granophyre and granite.

The Round Lake intrusion underlies an area of thick glacial drift about ten miles east of Hayward (Stuhr, 1976). It is a diabasic gabbro and associated units about one mile wide and at least five miles long emplaced within Archean gneiss. In the core of the intrusions, olivine and plagioclase crystallized early and the iron-titanium oxides crystallized late. At the base of the narrow intrusion a thick zone of magnetite-troctolite formed. A -40,000 gamma magnetic anomaly and a 10 milligal gravity anomaly are associated with the body.

Dikes of Keweenawan diabase up to 50 feet wide intrude both Archean and Proterozoic rock.

Upper Keweenawan Rock

The boundary between the uppermost volcanic rock of the Middle Keweenawan and the Upper Keweenawan is not resolved. The volcanic rock grades upward with increasing abundance of interbedded immature volcanic sediment, until no more flows are found. The classical boundary is drawn at the top of the uppermost lava flow, whereas many modern studies suggest that the boundary should be drawn at a lower level (Hubbard, 1975). Inasmuch as the Wisconsin Survey uses the generally accepted classical boundary, and the alternate boundary is only accepted in Michigan, the classical boundary will be used in this report.

In Wisconsin, the Upper Keweenawan sedimentary rocks are divided into two groups with an apparent unconformity between them. This division, with changes in formational names, is generally accepted for Minnesota. In Michigan, however, correlation of the upper group is more difficult.

Oronto Group

The basal unit of the Oronto Group within Wisconsin is the Copper Harbor Conglomerate which is gradational and interbedded with the upper part of the Portage Lake Lava Series. The Copper Harbor Conglomerate is 450 to 6,000 feet thick and is a reddish-brown, lithic conglomerate and sandstone (Hite, 1968).

The conglomerate varies considerably, but consists dominantly of subangular to rounded fragments of Middle Keweenawan volcanic and intrusive rock, and lesser amounts of Lower Proterozoic rock. The Nonesuch formation immediately overlies the conglomerate and appears in places to interfinger with it. The Nonesuch is composed of shale, siltstone and sandstone, but conglomeritic horizons occur locally. In Wisconsin the maximum thickness on the east is 350 feet, but it thins rapidly westward to 120 feet near Mellen (Aldrich, 1929, p. 111).

The Freda Formation is the major unit of the Oronto Crop. It has an estimated thickness of 12,000 feet. It is noted for its red color, which is present throughout except for local leaching or bleaching along fractures or within the more porous and permeable coarse units of the upper part of the section. Hite (1968, p. 60) provides details of the stratigraphy and sedimentology. The Freda Formation is immature, both compositionally and texturally. The sedimentary structures of the Freda have long been interpreted as evidence of a fluvial depositional environment.

Bayfield Group

The basal unit of the Bayfield Group is the Orienta Formation, a feldspathic arenite up to 2,700 feet thick (Myers, 1971). It thins rapidly to the west and pinches out west of Washburn, Wisconsin. The critical lower contact with the underlying Freda Formation is not exposed. The best interpretation is that the Orienta lies with slight angular discordance upon the underlying Freda, and elsewhere is known to be in fault contact with Middle Keweenawan volcanics.

The Devils Island Formation overlies the Orienta Sandstone is a fine to medium grained quartz arenite and is thin bedded and laminated. Although not exposed, the lower contact of the Devils Island with the Orienta appears to be conformable. This formation is estimated to be 300 feet thick.

The Chequamegon Formation is the youngest formation of the Bayfield Group. The Chequamegon formation is predominantly a medium grained grayish red to pale red feldspathic arenite. The lower contact of the Chequamegon appears to be gradational with the Devils Island Formation. This sandstone appears to be about 1,000 feet thick. There is some data suggesting that the Chequamegon may be Late Cambrian in age (Ostrom, 1967).

Alternate interpretations of the Upper Keweenawan sedimentary rock are possible. Ostrom (verbal communication, 1979) has recognized some stratigraphic relationships in the Lake Superior region that suggest to him that the Chequamegon and the Orienta might be correlative, and that the overlying Devils Island might be equivalent to the Galesville Formation of Late Cambrian age. This would necessitate an unconformity at the base of the Devils Island.

CAMBRIAN

A small area of upper Cambrian sandstone is known in the Hayward area of Wisconsin. A few water wells penetrate the sandstone. No surface exposures are known in the Superior Sheet. As discussed above, the Upper Keweenawan Devils Island Formation may be Cambrian.

PLEISTOCENE

All of the Ashland Quadrangle was covered by the most recent glaciation (Wisconsinan). The Pleistocene deposits can be divided into ice related, and lacustrine (Clayton, 1984). Generally south of the Gogebic Range ground moraine and local outwash predominate. North of the Gogebic Range, lacustrine deposits accumulated in Glacial Lake Duluth, formed by a temporary lull in the retreat of ice. Extensive red clay and fine silt accumulated in this area, and thicknesses can reach 600 feet, particularly in the western parts of the quadrangle. Wherever glacial deposits directly overlie Keweenawan sandstones, drainage is good, whereas in the more southerly areas where the glacial deposits are thin and overlie volcanics and older units, drainage is poor.

STRUCTURAL GEOLOGY

The structural geology of the Superior Sheet can be described in terms of events affecting respectively Archean, Early Proterozoic and Middle Proterozoic rocks.

Archean

The Archean rock is poorly exposed, and not well studied. Based on work in Minnesota (Morey and Sims, 1976) and Michigan (Peterman and Sims, 1976) the following structural sequence can be inferred. Prior to 2,700 Ma, the Archean volcanic and associated sedimentary rock were deformed and metamorphosed to greenschist grade. About 2,750 Ma, the late syntectonic Puritan batholith and associated granitic plutons were emplaced. Evidence in Michigan and central

Wisconsin suggest an earlier event, at least 3,000 Ma (Van Schmus and Anderson, 1977; Sims and Peterman, 1976) however such age data are absent in so far as known in the Superior Sheet. The gneissic rock in the south central part of the quadrangle now appears to be deformed and higher grade gneiss similar to other Superior province gneiss terranes rather than equivalents of the Puritan Quartz Monzonite to the east.

A diabase dike swarm is known in the Morse area. Examination of the diabase dikes disclose that half of the dikes are fresh and presumably of Keweenawan age. The remaining dikes, on the other hand, are metamorphosed to amphibolite grade, and have been folded along with the enclosing gneissic rocks. The age of these dikes have not been determined, but their orientation attest to a pre-keweenawan tensional setting that could be as early as Archean. Such deformed dikes are not known in the better studied parts of the Gogebic Range Early Proterozoic succession.

Early Proterozoic

Reference to the Early Proterozoic stratigraphic succession discloses numerous unconformities within the sequence. Elsewhere, notably in Michigan and north central Wisconsin, major folding is documented. This Early Proterozoic event has been termed the Penokean Orogeny. However, as contrasted with those two areas, major deformation is generally absent in the Superior Sheet except for the intermixed metavolcanic and metasedimentary rock in the southeast corner of the map.

Uplift and erosion must have preceded the deposition of the Bad River Dolomite (the Sunday Quartzite of Michigan is absent beneath the Bad River in Wisconsin). Inasmuch as the Bad River is absent throughout the central parts of the Gogebic Range, uplift and erosion must have followed deposition of the Bad River and preceded deposition of the Palms Formation. Uplift and erosion are of unknown magnitude and duration, and generally cannot be correlated to structural sequence observed in the better studied areas of Michigan such as the Marquette Trough. Similar minor erosional intervals are problematically documented higher in the Early Proterozoic succession. Inasmuch as there is still controversy as to their presence or absence, their role in the structural history of the region is probably minor.

The Tyler Formation was extensively eroded prior to deposition of the basal Upper Precambrian sediments and volcanic rock. Montgomery (1977, p. 93) infers that the Tyler was gently warped (folded) about a northeast- to east-trending axis during the Penokean orogeny because locally the Tyler was dipping both north and south after the Penokean orogeny. This is based on reconstructed dip directions of the Tyler prior to deposition of the Bessemer Quartzite.

Middle Proterozoic

Middle Proterozoic structural events have received the greatest attention because of their controls on emplacement of copper deposits in Michigan and Wisconsin, and as controls on flow of meteoric waters in the formation of the soft iron ores along the Gogebic Range.

Sandberg (1938) was one of the first to note that the Keweenawan succession was deposited in a continually subsiding basin as evidenced by steeper dips of the older parts of the succession compared to the younger parts. White (1966a) proposed a poly-structural history for Keweenawan rocks that is generally accepted for the Lake Superior district, but locally his model has been modified to account for slight differences from one area to another. The three main stages in the tectonic evolution are (1) accumulation during Middle Keweenawan time of a thick series of lava flows and mafic intrusives in two or more troughs separated by a positive area trending almost north-south that generally lies west of Mellen; (2) evolution of the present Lake Superior Basin, having an axis trending northeast, during late Keweenawan time, and (3) evolution of the Ashland Syncline (the depocenter for the Middle Proterozoic sedimentary rocks) and the major faults (Douglas, Keweenaw and Lake Owen) of the region still later in Keweenawan time.

The Douglas Fault is exposed at Amnicon Falls east of Superior, the Keweenaw Fault enters the Ashland Quadrangle from the east several miles south of Lake Superior, and the Lake Owen Fault from the southwest and passes through Lake Owen within the quadrangle. These faults generally define a major horst (the St. Croix horst) that formed a highland that shed detritus into the Oronto and Bayfield depositional basins. It should be noted that Hubbard (1968) among others feels that all of the major faults are not necessary to explain the juxtaposition of various units, and that facies changes and pinch outs, and intrusive events may explain the data. Morey (1977) on the other hand, clearly documents such a horst to explain Middle Proterozoic sedimentation.

In addition to these major northeast trending faults, other northeast trending faults have been documented by Sims, Cannon, and Mudrey (1978) in interpreting aeromagnetic data for Wisconsin and Michigan. These faults are presumably of late Keweenawan age, but do not involve Middle Proterozoic rocks, but rather appear to affect only earlier units. Major northwest trending faults, such as the Mineral Lake fault were also active at this time, and may have controlled the emplacement of the various Middle Keweenawan intrusive bodies such as the Mineral Lake Intrusion and the Round Lake Intrusion.

Many minor northwest to north faults have been documented along the Gogebic Range and are probably more extensive than shown on the map. These generally serve to control leaching and formation of the soft iron ores.

ECONOMIC GEOLOGY

Numerous mineral commodities are known to occur within the Superior Sheet.

Kyanite

Kyanite occurs in a belt of rock that extends for 15 miles along part of the Flambeau River in Ashland and Iron Counties south and southwest of Mercer, Wisconsin. Outcrops of kyanite-bearing schist have been reported in T. 41 N., R. 1 and 2 E., and T. 42 N., R. 1, 4, and 5 E. The kyanite forms 6 to 7 percent of some layers of the schists, and occurs in crystals as much as several inches long associated with quartz, feldspar, biotite and garnet and staurolite. The kyanite is not considered economic at this time, because of unknown tonnages, and admixtures of other minerals.

Dimension Stone

The Mellen Intrusive has supplied a quality dimension stone called "black granite," a gabbro quarried extensively north of Mellen. Quarries ceased production in the late 1960s and early 1970s.

The only product of economic value derived from the Bayfield Group is building stone (Thwaites, 1912, p. 45). This was formerly obtained from the most ferruginous phase of the sandstone which is commonly known as brownstone. It will be noted that the quarries, especially those in the Apostle Islands, are arranged in a nearly straight line along the strike of the Chequamegon Formation, although good stone was seen at many scattered points. By 1900, quarrying had ceased.

Iron

Iron ore shipments from the Gogebic Range from the start of mining in 1884 through 1967 totalled 320 million long tons, of which about 65 million long tons was from the Wisconsin part of the district. Major production from the Ironwood Iron Formation was from Wakefield west to Iron Belt. Most of the production was what is called soft iron ores.

The soft oxidized ore probably formed through deep weathering and this suggests that supergene processes have been active in the region. This meteoric theory proposed by Van Hise and Leith (1911) is consistent with the mineral assemblages, the occurrence of ores in upward facing structures, and the decrease in oxidized iron formation with depth. Alternate theories involving hydrothermal alteration have been proposed by some, however, dominant thought prefers the meteoric model.

The ores are restricted to zones of low-grade regional metamorphism (chlorite zone) and extend to depth exceeding 6,000 in some places. The mineral assemblage includes goethite, hematite, illite, kaolinite, gypsum, and apatite(?). The ore bodies were formed in their present structural positions. Extensively folded and contorted relict bedding is often present but it is impossible for these very soft and porous ores to have been so deformed after oxidation. Minor folding, faulting, and intrusion may have occurred since formation of the ores. The formation of the oxidized ores post-dates the Penokean (1900 Ma) deformation and metamorphism. Gair (1975) notes the presence of an extensively altered Keweenawan dike in soft iron ore in the Tracy Mine near Negaunee in the Iron River Quadrangle. This leads him to conclude that most of the alteration of the iron formation took place after the intrusion of the Keweenawan diabase or post 1,000 Ma. A similar age (450-650 Ma) for the soft iron ores is given by set of discordant U/Pb and Pb/Pb ages from pitchblende in a vein of soft iron ore found at the Sherwood Mine in Iron River (Vickers, 1956).

The deep extent of the ores is explained by their formation during a prolonged period involving a deep artesian circulation system. If Gair's (1975) observation is correct, that the weathering is of post-Keweenawan age, then the arid period may be coincident with the time of formation of the Jacobsville Sandstone. These redbeds show evidence of extensive chemical weathering in the source area. West of Lake Gogebic they are seen to contain abundant pebbles of well rounded chert, quartz, and iron formation, and rarer angular fragments of feldspar. A period of pre-Jacobsville weathering is indicated by the paleo-regolith at Presque Isle near Marquette in the Iron River Quadrangle (Kalliokoski, 1975).

Marsden (1978) has reviewed the reserve data for the iron deposits in Wisconsin. The study of the iron ore reserves for the U.S. Bureau of Mines is an estimate of reserve tonnages for potentially mineable iron ore materials to an estimated no-profit, no-loss economic cutoff. His report provides the necessary technical and cost factors in arriving at the reserve estimates.

Marsden (1978) provides a comprehensive reserve estimate for iron ore in Wisconsin and estimates 3.7 billion long tons of reserve on the Gogebic Range. The Agenda magnetic taconite deposit is located in T. 42 N., R. 1 E. about 10 miles northeast of Butternut, Wisconsin. This rather typical garnet grade Middle Precambrian iron deposit has estimated reserves of 160,000,000 long tons. The Butternut taconite deposit is located in T. 49 N., R. 1 W. This rather typical chlorite grade Middle Precambrian iron deposit has estimated reserves of 48,000,000 long tons. The Pine Lake or Magnetic Center deposit is located about 12 miles south of Hurley in T. 44 N., R. 3 E. This chlorite-grade iron deposit has estimated reserves of 206,000,000 long tons. Other iron-bearing rocks can be determined from aeromagnetic maps (Zietz, Karl, and Ostrom, 1978) and its interpretation (Sims, Cannon, and Mudrey, 1978).

Copper

Two kinds of copper occurrences are known within the Ashland Quadrangle: copper-nickel associated with Middle Keweenawan gabbroic intrusives, and native copper and chalcocite associated with Middle Keweenawan extrusives and sediments.

Inasmuch as the detailed petrography of the gabbroic rocks of the Mellen and Mineral Lake intrusives are similar to the Duluth Complex in Minnesota, the description of the mineral occurrences will probably be similar (Bonnichsen, 1972). The Mineral Lake intrusion has surface occurrences of chalcopyrite and pyrohotite (Olmsted, 1969). No further information is available.

White (1978) summarized his observations on where in the Keweenawan succession native copper might occur in Wisconsin. These have been generally known since the 1800s, but his evaluation of stratigraphy, metamorphic grade and other factors, suggest reevaluation of the St. Croix and Minong copper ranges, with lesser emphasis on the Douglas Copper range.

Titanium-Vanadium

The Round Lake intrusion has been estimated to contain approximately 53 million tons of 0.56% V in a magnetite segregation (Stuhr, 1976). Commercial potential at this time is not favorable.

RECOMMENDATIONS FOR ADDITIONAL WORK

The geological reconnaissance mapping identified eleven topics requiring more detailed mapping, acquisition of geophysical data, and petrographic and chemical study.

1. Stratigraphic relationship of the Upper Keweenawan sandstone units

The reversal of maturing upward clastic units in the Bayfield Group from the Devils Island to the Chequamegon is unparalleled in the Lake Superior region. Field data suggest alternatives to continuous deposition: section repeated by a major northeast trending fault or repetition by local folding. Gravity and magnetic data may help to resolve the alternatives.

2. Nature and distribution of sulfide minerals in Keweenawan gabbroic bodies

Copper-nickel sulfide mineralization is known in the Mellen and Mineral Lake gabbro units, which were explored in the late 1950s. Platinum group elements have recently been identified in the equivalent the Duluth Complex of Minnesota. Refined analysis of footwall specimens and trace and isotopic element analysis could detect or identify possible mineral resource potential.

3. Geology of Douglas County, with particular reference to gabbroic bodies and vein copper mineralization

Turn of the century copper prospects are abundant in Douglas County, although no serious copper production occurred. White (1978) identified additional areas for possible economic mineralization. These areas can only be evaluated by drilling.

Several gabbroic bodies are known, unfortunately most are based on only one outcrop per body. Magnetic and gravity work, with possible drilling should be undertaken to define the character, extent and metallogenic significance of these bodies.

4. Nature and extent of the Douglas Fault

The Douglas Fault can be followed in outcrop from Minnesota to the eastern county Line of Douglas County. Recently, Mudrey and Dickas (1988) have proposed that the fault does not continue further to the east, a model that contradicts prevailing interpretations. Gravity and magnetic would augment reflection seismology and help to resolve the continuity and extent of the basin bounding faults.

5. Nature of the Ashland Syncline

The Ashland Syncline is defined by dips in volcanic units, although the eastern limit of the syncline may be fault in the Grandview area. Drill core data from the 1950s suggest significant structural modification of the basin based on contours of the Nonesuch Formation. Reflection seismic work is needed to define the structures and extrapolate them into areas where drilling data is absent.

6. Deposition, cementation, and age of Keweenawan sandstone units

The age of the Oronto Group, and the entire Bayfield Group is not known. Recent interest in petroleum in the Nonesuch Formation emphasizes the need for better chronologic control in order to correlate elsewhere along the Midcontinent trend. Paleomagnetic analysis and isotopic dating are badly needed to resolve the age of these units.

7. Distribution and significance of contact metamorphic isograds along the Gogebic Range

Four billion tons of taconite reserve are estimate in the western Gogebic Range. Extraction potential requires abundant magnetite. Analysis of metamorphic assemblages and distribution of isograds are necessary to refine the reserve estimates.

8. Structural history of the Tyler Formation and relation to Penokean deformation

The slaty cleavage in the Tyler Formation at Hurley has been interpreted as a Keweenawan fracture cleavage, or as evidence of horizontal tectonism during the Penokean. Detailed geologic mapping could resolve these two extreme conclusions.

9. Extension of the Keweenaw Fault into Wisconsin

There is no evidence requiring the extension of the Keweenaw Fault from Michigan into Wisconsin. Detailed mapping and gravity studies in the Wisconsin-Michigan boundary region would define the western limit of the Keweenaw Fault.

10. Nature of the southern contact of the Archean north of Mercer/Pine Lake

The contact of the Archean rock south of Hurley with the Proterozoic(?) rock north of Mercer/Pine Lake is not exposed. Work in Michigan suggests a fault contact, whereas work in Minnesota suggests an unconformity. Geophysical analysis and drilling would help to resolve the nature of the contact.

11. Thrust development at Mount Whittlesey

Proprietary data based on drilling at Mount Whittlesey suggest a thickening of the iron formation by thrusting. Exposures near the base of Mount Whittlesey suggest possible thrust faulting. Detailed mapping, thin section analysis, evaluation of available drill core are needed to evaluate this and other interesting structural problems in the Mellen area.

Several areas of sufficient exposure were identified to warrant more detailed, 1:24,000 quadrangle geologic mapping.

South Range 7-1/2 Minute Quadrangle

The Douglas Fault is exposed in this quadrangle. Abundant exposures of volcanic rock and associated copper deposits warrant more detailed examination.

Grandview, Marengo Lake, Mineral Lake, Mellen, Mt Whittlesey and Morse 7-1/2 Minutes Quadrangles

This area includes the Mineral Lake Gabbro and the west end of the Gogebic Range. Detailed mapping would resolve the structural relations of the Middle Keweenawan and the Upper Keweewan, relations of the Keweenawan to the older Archean and Proterozoic rocks, and determine the extent, if any, of thrust faults.

Iron Belt, and Ironwood 7-1/2 Minute Quadrangles

Possible continuation of the Keweenaw fault into Wisconsin, relations among the various Keweenawan volcanic units, and the nature of the tilting of the Proterozoic succession northward towards Lake Superior could be resolved.

Pine Lake, Lake of the Falls, Mercer, Butternut, Haycreek Flowage, Turtle Flambeau Flowage and Wilson Lake 7-1/2 Minute Quadrangles

This area includes the contact between the Archean on the north and the Proterozoic metasedimentary and volcanic rocks on the south. The southern quadrangles include the various kyanite localities.

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