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# GEOLOGIC SUMMARY OF THE ASHLAND 2-DEGREE QUADRANGLE

by

M.G. Mudrey, Jr.

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# GEOLOGIC SUMMARY OF THE ASHLAND 2° QUADRANGLE



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# INTRODUCTION

The Ashland Quadrangle occupies the central part of the largest area of exposed Precambrian rock in the United States, the Lake Superior region. Many of the critical geologic relationships of the district occur within the Quadrangle. In terms of surface exposures, the region lies at the southern extremity of the North American Shield, but if the subsurface geology is considered, it is located near the center of the known Precambrian basement of the North American craton.

Traditionally, geologic studies in the Lake Superior region have focused on the economically important iron- and copper-mining districts. Although these studies have yielded a considerable amount of detailed data, the geologic history of the region as an entity is poorly understood mainly because of a wide diversity of superposed rock types and metamorphic and structural events ranging in age from about 3,800 million years to less than 1,100 million years before present.

Recent excellent summaries of the region have been prepared by Dutton and Bradley (1970) for Wisconsin, Morey (1978) for the metamorphic history, Sims (1976) for the metallogeny, Van Schmus (1976) for the Middle Precambrian record, Morey and Sims (1976) for the structural evolution, and White (1978) for the evolution of the Late Precambrian and its relationships to copper mineralization. Particular recent records that deal more directly with uranium geology include Kalliokoski (1976, 1977) for Wisconsin and the Upper Peninsula of Michigan, Ojakangas (1976) for Wisconsin and Minnesota, Geometrix (1978) for the aeroradioactivity survey as part of NURE, and Kalliokoski, Langford, and Ojakangas (1978) for identification of a newly recognized uranium occurrence related to unconformities. All of the reports listed above have a direct relationship to the economic geology of the Ashland Quadrangle.

## Physiographic Setting

The Ashland Quadrangle is divided into two major physiographic provinces, the Superior Lowland, and the Northern Highland, by two main ridges that generally trend southwest to northeast through the middle of the Quadrangle. The Superior Lowland is generally a few hundred feet in elevation higher than Lake Superior (602 feet mean level) and is underlain predominantly by Pleistocene lacustrine deposits overlying Upper Precambrian sedimentary rocks. The Northern Highland is generally about 1000 feet higher in elevation than Lake Superior, and is comprised of Pleistocene glacial deposits overlying Precambrian metamorphic and crystalline formations.

The two provinces are divided by a major ridge, or range; the Penokee-Gogebic Range of Wisconsin and Michigan. It is about 80 miles long and half a mile to a mile wide. The Gogebic Range is a monoclinal ridge, with a steep dip to the north. Its crest is formed in some places by the harder parts of the Middle Precambrian Iron Formation, in other places by resistant quartzite, or other metamorphic rocks. North of the Gogebic Range is a lesser ridge that is held up by extrusives and intrusives of the Upper Precambrian Keweenawan Series. Between this trap range and the Gogebic Range is a valley. This is a subsequent lowland, on the site of relatively weak slate of the Tyler Formation. The highest point on the crest of the Range is Mt. Whittlesey, 1,872 feet above sea level.

The Range is breached in several places by streams and rivers that form water-gaps, some of which are fault controlled. The streams generally flow to the north into Lake Superior. Drainage in the southern part of the quadrangle is to the south, and ultimately empties into the Mississippi through major rivers in western Wisconsin, such as the Flambeau and the Chippewa.

## Geologic Setting

The Lake Superior region has been divided into a series of terrane units by Morey (1978) from which the following section is taken. The concept of terrane units in the Lake Superior region was first used by Morey and Sims (1976) who recognized two fundamentally different basement terranes -- an older gneiss terrane (3,000 million years or older) and a younger greenstone-granite terrane (2,750 million years in age). Sims (1976) later expanded on this idea and emphasized the contrasting roles that these terranes had on the tectonic evolution of the Middle and Upper Precambrian strata in the Lake Superior region. Morey (1976) recognized that Precambrian rocks in Minnesota could be divided into five basic terrane units, three of which are fundamental blocks or plates separated by major crustal sutures or rifts. The remaining two terranes are essentially supracratonal features formed on the more fundamental blocks. Morey (1978, p. 285) suggests that these same terrane units, with slight modification, can be recognized throughout the Lake Superior region.

Several of the terranes are lithostratigraphic entities whose boundaries correspond to temporal boundaries as defined or assumed in conventional time-stratigraphic classification schemes. However, other terranes are not simple litho- or time-stratigraphic entities. Rather they are the end products of a number of separate geologic events, which did not operate everywhere in the region with equal intensity. Thus, each terrane is a geologic entity characterized by distinctly different rock assemblages, tectonic styles, and metamorphic grades.

Within the Ashland Quadrangle, three and possibly four of the terranes can be identified (Figure 1). Immediately south of the eastern half of the Gogebic Range a sequence of Terrane II (Greenstone-Granite of Early Precambrian age) is known. This generally served as the depositional basement for Terrane III (Middle Precambrian sedimentary, volcanic and plutonic rocks) rocks. The north half, and the

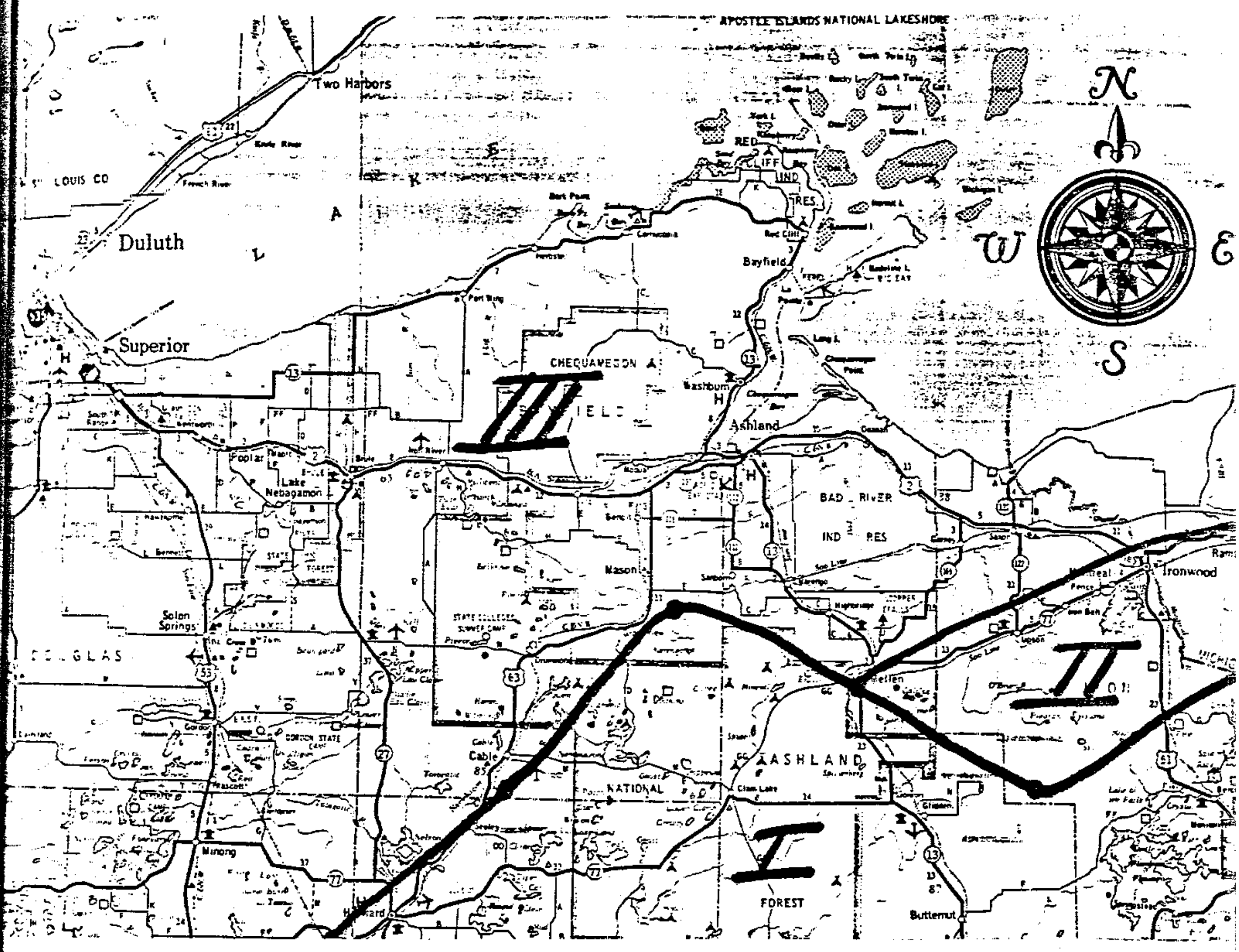


Figure 1. Reference map of the Ashland Quadrangle. Terrane I - Gneiss terrane probably older than 3.0 billion years consists of upper amphibolite facies quartzo-feldspathic gneiss; Terrane II - Greenstone-granite terrane around 2.6 billion years consists of low to medium grade granite and metavolcanic rocks; Terrane V - Mid-continent rift system terrane around 1.1 billion years consists of volcanics and associated intrusives and overlying sedimentary rocks related to the Mid-continent rift system. Terrane III rock (intracratonal stratified rocks including iron formation) were deposited on Terranes I and II.

west parts of the quadrangle are parts of Terrane V (Late Precambrian Mid-continent Rift System). Terrane I (Early Precambrian Gneiss Terrane) may be the basement in the southwestern part of the Quadrangle, although definitive data to adequately classify this terrane are lacking.

## Geologic Summary

The geology of the Ashland Quadrangle encompasses a wide range of geologic ages and processes. The earliest recognized event is the formation of Lower Precambrian gneisses which are particularly well exposed around Morse in the center of the quadrangle. The culmination of the Early Precambrian is dated by a quartz monzonite pluton that intrudes a greenstone complex along the east edge of the quadrangle. This has been dated at 2,750 million years before present (Sims and Peterman, 1976). The overlying Middle Precambrian succession includes platform sediments in the north, and intermixed sedimentary rock and volcanic rocks in the south. These units were emplaced and deformed prior to the culmination of the Penokean orogeny around 1,850 million years ago (Van Schmus, 1976). The Upper Precambrian succession includes intracratonic volcanics, associated sedimentary rocks, and associated dominantly gabbroic intrusives about 1,100 million years old. Chase and Gilmer (1973) determined that during the Late Precambrian an aborted continental rift occurred. Since that time, the geologic history has been one of deposition of clastic rocks with increasing maturity upward through at least the Upper Cambrian in the Hayward area. The geologic record is generally absent from the Late Cambrian to the Pleistocene. The most recent record is one of glacial advance and retreat, and the formation of ancestral Lake Superior prior to final retreat of the ice.

Mineral deposits are known within all of the main geologic periods. The major mineral deposits include iron in the Middle Precambrian, and copper and copper-nickel in the Upper Precambrian. No uranium occurrences are known, although the general

Table 1. Time-stratigraphic framework of Precambrian rocks in the Ashland Quadrangle, Wisconsin.

| a | Lithology and depositional environment | Approximate age | Intrusive Rocks | Areas of occurrence |
|---|---|---|---|---|
| leozoic | | | | |
| | ----Unconformity---- | | | |
| 0 m.y. | Clastic rocks deposited mainly in shallow water | (600-1000 m.y.) | | Sandstones with minor conglomerate and shale in area south of Lake Superior |
| | ----disconformity---- | | | |
| te ecambrian | Lava flows and interbedded sedimentary rocks | (1100 m.y.) | Intrusions of basic composition | Lavas interbedded with sandstones and conglomerates, gabbroic intrusions near Mellen |
| 00 m.y. | | | | |
| | -----unconformity----- | | | |
| ddle ecambrian | Lava flows and clastic rocks and iron formation deposited mainly in deep water | (1850-2400 m.y.) | Wide-spread granite emplacement | Iron-formation and associated strata in Pine Lake, Butternut, Conover, and Gogebic areas; dominantly volcanic rocks in southeast; granite intrusion southeast |
| | -----unconformity----- | | | |
| 00 m.y. | Gneisses, migmatites and amphibolites of igneous and sedimentary derivation | (2600 m.y.) | Granite emplacement | Granite, metavolcanic and metasedimentary rocks south of Gogebic Range. Also locally within Butternut-Conove area. |
| ly ecambrian | | | | |

geologic favorability for various kinds of uranium occurrences is considered good. Extensive weathering and erosion in the past 500 million years may well have removed the easily accessible surface occurrences that are usually used in mineral exploration. Glacial drift adds another compliation and locally over 500 feet of glacial and lacustrine deposits are known in the Bayfield area of the Ashland Quadrangle.

## LOWER PRECAMBRIAN

Rocks of Early Precambrian age underlie the southeastern part of the Ashland Quadrangle. 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 m.y. 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 m.y. for this large complex Pluton. In the extreme south central part of the Ashland Quadrangle, a gneissic terrane has been identified and tentatively correlated with the 3,400 m.y. 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 are rare, and felsic volcanic rocks are not known within the outcrop area. To the west of the outcrop area, south of Upson, several hundred feet of dacitic and rhyolitic rocks, largely fgramental 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 Middle Precambrian 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. With further study, these rocks may prove to correlate with the older (3,400 m.y.) gneisses of the Marenisco-Watersmeet area of Michigan, reported by Peterman and Sims (1978) to contain 1.4 to 14 ppm U and 9 to 35 ppm Th.

## MIDDLE PRECAMBRIAN

In the Gogebic Range area, 10,000 feet of Middle Precambrian metasedimentary rocks are present. The oldest formation in the Ironwood area at the east edge of the Ashland Quadrangle is the Palms Formation. Overlying the Palms Formation in the Ironwood area are the Ironwood Iron Formation and the Tyler Formation, an argillite graywacke unit. This is a succession of platform and submarine fan sedimentary rocks. Regional unconformities are known within this succession. Major deformation of the Middle Precambrian succession did not occur until Late Precambrian time. A carbonate unit is known beneath the Palms Formation in the western part of the Gogebic Range.

South of the Gogebic Range is a deformed, metasedimentary and metavolcanic sequence, including iron formation, that is generally correlated with the little deformed Gogebic Range sequence. 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 <u>absent</u> 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 Lower Precambrian basement. In the eastern third of the Gogebic Range, the Sunday Quartzite of Middle Precambrian age lies unconformably upon the Lower Precambrian basement, and unconformably beneath the Bad River Dolomite, however, the Sunday Quartzite is not exposed in the area covered by this report. 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, 197~~2~~7, p. 61). It is approximately 450 feet thick in Wisconsin, and thickens to the east. East of Wakefield, Michigan, the Palms thickens to 750 feet. Aldrich (1929) divided the Palms into three mappable units. The lowest unit is a conglomerate 3-10 feet thick which rests unconformably upon Lower Precambrian volcanic and granite rocks. Fragments average 2 inches in diameter, although larger ones are not unusual. Granite, volcanics, 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. In 1978, R.J. Ojakangas (University of Minnesota - Duluth) identified phosphatic clasts at Pence where the conglomerate rests directly on Lower Precambrian granite. The middle unit of the Palms constitutes 90 percent of the formational thickness, and is thin to medium bedded. Typically, the thicker beds are medium-granied, 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 succeeded 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 sedimentary formation and by far the thickest of the Middle Precambrian 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 documentation 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 quartzites of Upper Precambrian rocks. Greater amounts of Tyler were eroded prior to deposition of the Upper Precambrian 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 litholigic 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 quadrangle, 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 gneisses, amphibolites, staurolite and kyanite-bearing metapelitic schists and sulfide-bearing graphitic schists. The sequences appear to be separated by a major northeast-trending fault zone (Sternberg and Clay, 1977). The areal extent of this terrane is unknown because of thick and extensive glacial cover.

## UPPER PRECAMBRIAN

Upper Precambrian rocks in the Ashland Quadrangle consists of four main sequences, namely a basal quartzite sequence, a sequence of volcanic rocks of various compositions and associated interflow sedimentary rock, an intrusive sequence of gabbros and related differentiates, and an upper sequence of sedimentary rocks. These are generally referred to as Keweenawan rocks. 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 Upper Precambrian. The classical division, and the one used in this report, is that the Lower Keweenanwan 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 Rocks

Unconformably overlying the Middle Precambrian sedimentary sequence are Upper Precambrian sedimentary rocks. The unconformity between Upper and Middle Precambrian rocks 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 rocks. 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 Rocks

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 rocks. This unit is 10,000 feet thick along the eastern edge of the quadrangle and thins 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 Ashland quadrangle (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 rocks, 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 lower Precambrian 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 Lower and Middle Precambrian rocks. Locally these can be divided into an ilmenite-pyroxene series and an olivine series (Weiblen and Morey, 1975).

## Upper Keweenawan

The boundary between the uppermost volcanic rocks of the Middle Keweenawan and the Upper Keweenawan is not resolved. The volcanic rocks grade upward with increasing abundance of interbedded immature volcanic sediments, 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 volcanics and intrusives, and lesser amounts of Middle Precambrian rocks. The Nonesuch Formation immediately overlies the conglomerate and appears in places to interfinger with it. The Nonesuch is composed of shales, siltstones and sandstones, 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 coloration, 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 (1970, 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 fluivial 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 Devil's 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 rocks 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 Devil's Island might be equivalent to the Galesville Formation of Late Cambrian age. This would necessitate an unconformity at the base of the Devil's Island.

## Jacobsville Sandstone

A small area of Jacobsville Sandstone is known within the Ashland Quadrangle along the eastern edge north of Bessemer, Michigan. It is a thick red bed sequence on the order of 10,000 feet thick and consists of sandstone with some conglomerate and siltstone. The Jacobsville is generally assigned to the Upper Keweenawan, although others such as Dorr and Eschman (1973) assign the sandstone to the Cambrian. The Sandstone is known to overlie Middle Keweenawan volcanics, and in the eastern parts of the Iron River Quadrangle the sandstone can be shown to rest on a paleosol (Kalliokoski, 1975). The sandstone formation is significant in that it represents a period of subareal erosion and intense chemical weathering in the source area. A distinctive sequence of reddish-brown to brownish-gray or light gray quartz pebble conglomerate and quartz rich sandstone comprise the entire Jacobsville Sandstone sequence in the area west of Lake Gogebic and includes the Ashland Quadrangle part of the formation.

## 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 Ashland Quadrangle. As discussed above, the Upper Keweenawan Devil's 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. 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 overprint in the Ashland Quadrangle can be divided into events affecting respectively Early Precambrian, Middle Precambrian and Late Precambrian rocks. Reference will be made to definitive studies outside of the quadrangle area where such studies are pertinent to understanding the structural evolution of the Ashland Quadrangle.

### Early Precambrian

As discussed above, Lower Precambrian rocks are 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 determined. Prior to 2,700 million years ago, the lower Precambrian succession of volcanics and associated sediments were deformed and metamorphosed to greenschist grade. About 2,750 million years ago, the late syntectonic Puritan Quartz Monzonite and associated granitic plutons were emplaced at the culmination of the Early Precambrian thermotectonic cycle. Evidence in Michigan and central Wisconsin argue for another and earlier event, at least 3,000 million years old (Van Schmus and Anderson, 1977; Sims and Peterman, 1976) however such age data are absent in so far as known in the Ashland Quadrangle. The gneissic rocks in the south central part of the quadrangle now appear to be structurally deformed and higher grade equivalents of the Puritan Quartz Monzonite to the east. Work is continuing on dating these gneissic rocks in U.S. Geological Survey laboratories.

A major fault zone, the Mineral Lake Fault, cuts through the entire Precambrian section (Sims, Cannon and Mudrey, 1978). Because ages of the gneissic rocks close to the fault zone still reflect and Early Precambrian age, and because of analogies to the better studied areas of Minnesota, the Mineral Lake Fault may well have been active during the Early Precambrian, and most of the motion may have been taken up at that time. North of the fault, the Lower Precambrian succession is greenschist grade, and south is amphibolite grade.

A diabase dike swarm is known in the Morse area. Cursory examination of the diabases 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 Early Precambrian. Such deformed dikes are not known in the better studied parts of the Gogebic Range Middle Precambrian succession.

## Middle Precambrian

Reference to the Middle Precambrian stratigraphic succession discloses numerous unconformities within the sequence. Elsewhere, notably in Michigan and northcentral Wisconsin, major folding is documented. This Middle Precambrian event has been termed the Penokean Orogeny. However, as contrasted with those two areas, major structural modification is generally absent in the Ashland Quadrangle except for the intermixed metavolcanic and metasedimentary rocks in the southeast corner of the quadrangle.

Uplift and erosion must have preceeded 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 preceeded deposition of the Palms Formation. These uplifts and erosions are of unknown magnitude and duration, and generally cannot be correlated to the better studied areas of Michigan such as the Marquette Trough. Similar minor erosional intervals are problematically documented higher in the Middle Precambrian succession. Inasmuch as there is still controversy as to their presence of absence, their role in the structural history of the regional is probably minor.

The Tyler Formation was extensively eroded prior to deposition of the basal Upper Precambrian sediments and volcanics. 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. A more comprehensive description of this style of deformation is given by Mudrey (1976) for similar rocks along the North Shore of Lake Superior in Minnesota.

## Late Precambrian

Late Precambrian 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 succesion 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 Upper Precambrian 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 Late Precambrian 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 Precambrian age, but do not involve Upper Precambrian 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 within the Ashland Quadrangle. Although the major emphasis of this report is uranium, discussion of other minerals is pertinent as many of the ore controls may well be applicable to various classes of uranium deposits.

### 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. Aeroradioactivity anomaly 39 is spatially associated with this belt.

## 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 1960's and early 1970's.

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.

A review of the origin of soft iron ores is important to our understanding of the geological history of the area, and origin of supergene uranium deposits. The following section is taken mainly from Kalliokoski (1976, p. 69).

There are two reasons for considering soft iron ores in connection with the study of uranium deposits: (1) several of the known radioactive occurrences in Michigan are found within oxidized iron formation. There are no radioactive occurrences with hard oxidized ores, or within the banded nonoxidized iron formation; (2) The soft oxidized ore probably formed though 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 formaton 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 m.y.) 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 m.y. A similar age (450-650 m.y.) for the origin of 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 (the Ashland Quadrangle) 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 estimate 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 37,111,000,000 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. No significant uranium occurrences are known associated with either of these units.

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 (Bonnichseu, 1972). The Mineral Lake intrusion has surface occurrences of chalcopyrite and pyrohotite (Olmsted, 1969). No further information is available.

White (1978) has recently summarized his observations on where in the Keweenawan succession native copper might occur in Wisconsin. These have been generally known since the 1800's, 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. No uranium occurrences are known, but this body might locally give vanadium and titanium anomalies in its immediate vicinity.

## Uranium

### Possible Sites for Uranium Occurrences

Kalliokoski (1976) and Kalliokoski and others (1978) identify the following types of uranium occurrences that might exist in this area:

1. Precambrian Uraniferous Quartz-Pebble Conglomerate
2. Uranium in Granite and Pegmatite
3. Uranium Associated with Diabase Dikes
4. Uranium in Iron Formation (Supergene Lake Superior Type)
5. Proterozoic Unconformity-Type Pitchblende Deposits
6. Epigenetic Sandstone Deposits
7. Shale, phosphorite, asphaltite deposits

(1) Precambrian Uraniferous Quartz-Pebble Conglomerate

Three formational units offer the possiblity for uraniferous quartz-pebble conglomerates, although none of these have been found to contain greater than background uranium concentrations: The basal part of the Palms Formation, the basal part of the Bessemer Quartzite; and the conglomeritic phase of the Jacobsville Sandstone.

(2) Uranium in Granite and Pegmatite

No uraniferous granites or pegmatites are known within the Ashland Quadrangle. Because of the Watersmeet Gneiss to the east does have higher than background concentrations of uranium, similar bodies may exist in the south central part of the Ashland Quadrangle.

(3) Uranium associated with diabase dikes

Diabase dikes of various ages are known in the Quadrangle, and only the larger, better exposed dikes have been examined or can be determined from geophysical surveys. Dikes are abundant (about 3 percent) in the iron formation (Marsden, 1978), and occur reasonably abundantly in the Morse area. In the Iron River Quadrangle (Kallokoski, 1976) and in Ontario (Noffeld, 1956) pitchblendes are mineralized in the contact zone of these dikes in granite

(4) Uranium in Iron Formation (Supergene Lake Superior Type of Kalliokoski)

As discussed above, post-Middle Precambrian leaching of the iron formations, and the known occurrence of pitchblende in soft iron ores from elsewhere in the Lake Superior District (Vickers, 1956) make this a favorable environment.

(5) Proterozoic Unconformity-Type Pitchblende Deposits (Kalliokoski, Langford, and Ojakangas)

Kalliokoski and others (1978) p. 470-474, identify the following areas as similar to their Proterozoic Unconformity Pitchblende Deposits.

High similarity:

Jacobsville resting on Keweenawan volcanic rocks (north of Bessemer, Michigan).

Medium similarity:

Bessemer resting on Middle Precambrian rocks (Gogebic Range).

Oronto resting on Keweenawan lavas (southwest to northeast trending across Quadrangle).

Low similarity:

Freda Sandstone resting on Nonesuch shale (southwest to northeast trending from middle of Quadrangle to state line and Lake Superior lake shore).

Palms resting on Lower Precambrian granite and gneiss (Gogebic Range west of Pence).

Bayfield Group resting on Oronto and on Keweenawan flows (parallel to Freda, and in the area of the Douglas Fault).

(6) Epigenetic Sandstone Deposits

Porosity and permeability of the Upper Keweenawan sandstones and the Jacobsville Sandstone are favorable, but a reducing environment is generally lacking. Perhaps the interface at a paleoground water level offered enough reducing potential.

(7) Shale, Phosphorite, Asphalitite deposits

The Tyler is an argillite-graywacke unit, and in the Hurley-Ironwood area the formation is low grade. In this area, graphite and carbonaceous material are reasonably abundant, although no uranium occurrences are known within the quadrangle. Recently, Cannon and Klasner (1976) reported the occurrence of phosphorite in Middle Precambrian rocks. Similar occurrences may be present in the slaty parts of the Middle Precambrian succession including the intermixed metasedimentary-metavolcanic rocks.

## Aeroradioactivity Surveys

Geometrix (1978) recently completed an aeroradioactivity survey that included the Ashland Quadrangle for the NURE program. Forty-one anomalies were identified by meeting the following statistical requirement (p. 46): "Two consecutive averaged U samples lying two or more standard deviations above the mean." They emphasize (p. 60) that "none are considered to be 'preferred' anomalies, rather they have been cited because they meet the minimum statistical criteria." The strongest anomaly is No. 16 at 16 cps (eU 3.6 ppm). The locations of the 41 anomalies have been transferred from the Geometrix (1978) 1:500,000 scale map to 1:250,000 quadrangle maps. The locations should be within 1 mile of their true location. The data have been plotted both to a bedrock geology map, and to the best available

Inasmuch as the thickness of glacial and lacustrine deposits exceeds several hundred feet over most of the quadrangle, and generally exceeds 50 feet, bedrock control on the aeroradioactivity anomalies will only be apparent where drift material reflects bedrock. Fifteen of the anomalies, including the major anomaly No. 16, fall within the boundaries of lacustrine glacial deposits (Unit 5 on the attached map). The remaining 25 anomalies are closely spatially related to glacial drift, both end moraines and ground moraines.

Table 2 of Precambrian Formations near Hurley-Ironwood.
Ashland Quadrangle.

Upper Precambrian (600 m.y. - 1,800 m.y.)

| | | | |
|---|---|---|---|
| Bayfield Group | Chequamegon Fm<br>Devil's Island Fm<br>Orienta Fm* | Jacobsville Sandstone*<br>(in east) | |
| Oronto Group | Freda Fm*<br>Nonesuch Fm<br>Outer Conglomerate* | | |
| Middle Keweenawan | Unnamed Fm<br>Portage Lake Lava Senes<br>Powder Mill Creek Volcanics | Chenqwatana Volcanics<br>(in west) | Gabbroic Intrusives<br>(Mineral Lake, Mellen)<br>and diabase dikes* |
| Lower Keweenawan | Bessemer Sandstone* | | |

Middle Precambrian (1,800 m.y. - 2,600 m.y.)

| | | |
|---|---|---|
| Tyler Formation<br>Ironwood Iron Formation*<br>Palms Formation*<br>Bad River Dolomite | Intermixed metasedimentary*<br>and metavolcanic rocks<br>(in southeast) | Possible*<br>diabase<br>dikes |

Lower Precambrian (2,600 m.y. -- ).

| | | |
|---|---|---|
| Puritan Quartz Monzonite<br>Volcanic rocks in Gile Flowage<br>Quartzo-feldspathic Gneiss*<br>(age uncertain) | | Possible<br>diabase<br>dikes |

*Favorable Uranium Environment
(See text).

Table 3 of Geometrix (1978) identified aeroradioactivity anomalies.

| Anomaly Number | Township North | Range | Section |
|---|---|---|---|
| 1 | 49 | 4W | 6 |
| 2 | 49 | 10W | 23 |
| 3 | 48 | 11W | 6 |
| 4 | 48 | 10W | 1 |
| 5 | 48 | 8-9W | 19/23-24 |
| 6 | 48 | 7W | 19-20 |
| 7 | 47 | 12W | 5 |
| 8 | 47 | 11W | 26 |
| 9 | 47 | 10W | 29 |
| 10 | 47 | 8W | 25-27 |
| 11 | 47 | 6W | 30 |
| 12 | 47 | 6W | 29-20 |
| 13 | 48 | 46W | 33 |
| 14 | 49 | 6W | 21 |
| 15 | 46 | 8W | 6 |
| 16 | 46 | 5W | 7-8 |
| 17 | 46 | 3W | 11 |
| 18 | 46 | 1E | 9 |
| 19 | 47 | 46W | 7 |
| 20 | 46 | 9W | 17 |
| 21 | 46 | 8W | 27 |
| 22 | 46 | 8W | 25 |
| 23 | 46 | 5-6W | 30/25 |
| 24 | 46 | 2W | 28-29 |
| 25 | 45 | 12W | 5 |
| 26 | 45 | 12W | 9-10 |
| 27 | 45 | 6W | 17 |
| 28 | 45 | 4W | 7,8,9 |
| 29 | 45 | 2W | 8 |
| 30 | 45 | 8W | 29 |
| 31 | 45 | 4W | 30 |
| 32 | 45 | 3W | 21 |
| 33 | 43 | 1W | 34 |
| 34 | 43 | 1E | 34 |
| 35 | 43 | 1E | 36 |
| 36 | 42 | 7W | 20-21 |
| 37 | 41 | 5W | 19 |
| 38 | 41 | 3W | 24 |
| 39 | 41 | 2E | 22 |
| 40 | 41 | 2E | 24 |
| 41 | 45 | 12W | 21-22 |

Anomalies 13 and 19 in Michigan, all others in Wisconsin

Anomaly 16 is 3.6 eU (16 cps)

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