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STATUS REPORT

STRATIGRAPHIC FRAMEWORK OF THE WISCONSIN MIDDLE PRECAMBRIAN

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STATUS REPORT --STRATIGRAPHIC FRAMEWORK OF THE WISCONSIN MIDDLE PRECAMBRIAN

by

Gene L. LaBerge[1,2] and M. G. Mudrey, Jr.[2]

INTRODUCTION

Northern Wisconsin is underlain mainly by Middle Precambrian rocks, most of which are covered by a variable, but considerable thickness of glacial deposits. Recent bedrock information includes Sims, Cannon, and Mudrey (1978) with a preliminary geological map of the area based on the Bouger Anomaly Gravity Map of Ervin and Hammer (1974), an aeromagnetic map by Zietz, Karl, and Ostrom (1978), and data on the bedrock geology from Dutton and Bradley (1970), and LaBerge and Myers (1977), geochronological data from Van Schmus (1976), Sims and Peterman (in press), and some field checking. Figure 1 synthesizes the geology of the Precambrian of northern Wisconsin (Table 1). The rocks represent an east-west trending basin containing a wide range of sedimentary, volcanic, and plutonic rocks and their metamorphosed equivalents. Deformation of these rocks constitutes the Penokean orogeny, and therefore a knowledge and understanding of the rocks is essential to establishing the duration and tectonic setting of the basin and orogeny.

Within this basin, four massive sulfide deposits containing zinc, copper, and substantially lesser amounts of lead, silver and gold, have been identified in the last ten years. The relations of these deposits to the volcanic country rock are only now beginning to be understood. Inasmuch as detailed information on the deposits is not readily available in the literature, extensive summaries of the primary reports are given below.

Physiographic Setting

Northern Wisconsin is divided into two major physiographic provinces, namely the Superior Lowland and the Northern Highland. The Superior Lowland is 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 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, which trends southwest to northeast through the Mellen-Hurley area (Martin, 1965). 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

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Table 1. Time-Stratigraphic Framework of Precambrian Rocks in Wisconsin

Era	System	Stratigraphic Units	Lithology and Depositional Environment	Intrusive Rocks	Approximate Age
Paleozoic					
Late Precambrian	Upper Keweenawan	Bayfield Group	semimature at base grading upward to mature clastic rocks deposited mainly in shallow water		600-1,100 m.y.

		Oronto Group	immature clastic rocks deposited mainly in shallow water		600-1,100 m.y.
		--disconformity--			
	Middle Keweenawan	Portage Lake and Powder Mill volcanics south of Lake Superior and Chengwatana volcanics in northwest and along St. Croix River	mafic and intermediate lavas and interbedded sedimentary rocks	gabbroic and granophyric complexes near Mellen and Mineral Lake south of Lake Superior	1,120 m.y.
		--disconformity--	immature clastic rocks deposited mainly in shallow water		1,200 m.y.
	Lower Keweenawan	Bessemer Quartzite along Gogebic Range			
				rapakivi massif and associated granite, syenite and anorthosite in northeast (Wolf River area)	1,500 m.y.
		--unconformity?--			
		Quartzite at Baraboo, Barron and as isolated outliers in north	clastic rocks deposited mainly in shallow water		1,765 m.y.
		--unconformity--			
		rhyolite inliers in south	subaerial tuffs and breccias	epizonal, post-tectonic granite in south and isolated plugs in north	1,765 m.y.
		--regional unconformity--			
1,800 m.y.					
				epizonal to mesozonal, syntectonic granites	1,880-1,820 m.y.

	positions uncertain			
Middle Precambrian	basaltic to felsic volcanic and volcaniclastic rocks in north	submarine flows, tuffs, and volcanic sediments	*model lead ages from massive sulfide deposits are 1,830 m.y. Physical correlation with other units is difficult at best May correlate with Tyler Formation in north.*	
	kyanite-staurolite-garnet bearing schists and associated quartzo-feldspathic gneiss near Park Falls to Mercer (including Powell kyanite locality)		*metamorphic studies suggest 685° C at 7.5 Kbars. This area has been correlated with the Gogebic Range.*	
	basaltic to felsic volcanic and volcaniclastic rocks in extreme northeast (Florence area)	submarine flows, tuffs, and volcanic sediments	*uranium-lead ages on zircon from gneisses are around 1,850-1,900 m.y. Some volcanic rocks (Quinnesec) have been correlated with the Lower Precambrian and with the Middle Precambrian. Stratigraphic relations in this area are not clear.*	
	Tyler Formation on Gogebic Range	clastic rocks deposited mainly in deep water	(=Baraga Group of Michigan)	(=Animikie Group of Minnesota) age uncertain probably 2,050-1,850 m.y.
	--local unconformity?--			
	Ironwood Iron-formation on Gogebic Range	iron formation		
	Palms Formation on Gogebic Range	immature clastic rocks deposited in shallow water	(=Menominee Group of Michigan)	
	--regional unconformity?--			
	Bad River Dolomite on Gogebic Range	stromatolitic dolomite	(=Chocolay Group of Michigan)	
	--regional unconformity--			
2,600 m.y.				
Early Precambrian	volcanics and associated sediments south of Gogebic Range	submarine flows, tuffs and agglomerates	epizonal granite south of Hurley	2,710 m.y.
	--unconformity?--			
	gneiss, migmatite and amphibolite in south and western end of Gogebic Range	high-grade migmatites		2,800 m.y.+

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. A subsequent lowland, developed on the site of relatively weak slate of the Tyler Formation, is between this trap range and the iron range in a valley. The highest point on the crest of the Gogebic Range is Mt. Whittlesey, 1,872 feet above sea level.

The Gogebic Range is breached in several places by streams and rivers that form watergaps, some of which are fault controlled. The streams flow generally to the north into Lake Superior. Drainage in the Northern Highlands area is to the south, and ultimately empties into the Mississippi through major rivers in western, central and eastern Wisconsin, such as the Flambeau, the Chippewa, the Wisconsin, and the Wolf.

Geologic Framework

Table 1 summarizes our present understanding of the Precambrian stratigraphy of Wisconsin. Morey and Sims (1976), Sims (1976) and Sims (in press) developed a two-terrane conceptual framework for the Precambrian geology in

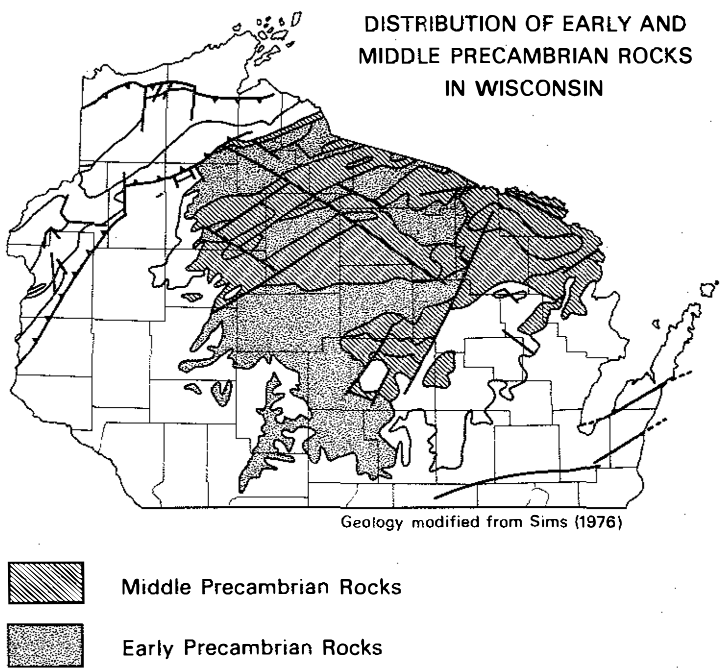

Figure 1. Map of northern Wisconsin showing distribution of Early and Middle Precambrian rocks as outlined by Sims (1976). Since 1976, reconnaissance geologic mapping and availability of detailed aeromagnetic maps by Zietz, Karl and Ostrom (1978) have permitted revisions in the map by Sims, Cannon and Mudrey (1978). Major changes have been to increase the extent of Middle Precambrian units while decreasing the extent of Early Precambrian units, and to refine the location and extent of bedrock faults.

the Lake Superior region. Essentially, the northern parts of Minnesota, Wisconsin, and Michigan are underlain by a granite-greenstone terrane about 2,700 million years old, the Archean terrane of Canadian terminology. The southern parts of those states are underlain by gneissic terrane dated at over 3.5 billion years in Minnesota, and are at least 3.2 million years in Wisconsin and Michigan (Van Schmus and Anderson, 1977; Sims and Peterman, 1976; Sims, in press; and Peterman, Zartman and Sims, 1978). The gneissic terrane has behaved as a mobile belt that was reactivated many times. The most recent significant reactivation was during the Middle Precambrian giving rise to the Penokean period of metamorphism and deformation. Based on geophysics, outcrop data, and sparse geochronology, Figure 1 illustrates a conceptual framework for Wisconsin. In Wisconsin an Early Precambrian terrane has been divided by a younger Middle Precambrian zone of volcanic rocks, sedimentary rocks, and granites.

The dated Early Precambrian rocks occur as gneisses at Morse in Ashland County, Fifield in Price County, and Pittsville in Wood County, and as a late granite (the Puritan Quartz Monzonite) south of Hurley in Iron County (Sims, Peterman and Prinz, 1977). A thin sliver of Early Precambrian volcanic rocks is found to the west of the Puritan Quartz Monzonite area, and is best exposed immediately south of Gile near Hurley in Iron County (Figure 1). Based on geochronology, petrography, and field relations, we interpret most of the remaining area of high-grade banded gneiss and migmatite in northern Wisconsin as Early Precambrian in age.

Middle Precambrian rocks include three main types: volcanic rocks, sedimentary rocks, and intrusive granitic rocks (Figure 2). Where exposed, the volcanic rocks appear to be intermediate to felsic in composition, and submarine in origin. Pillows are evident in the greenschist-grade rocks, along with agglomerates and interbedded iron formation and slates. This belt of volcanic rocks extends from the Ladysmith area in Rusk County to Pembine in Marinette County. In both directions the metavolcanic belt is lost under younger cover, Late Precambrian and Paleozoic rocks to the west, and Paleozoic rocks to the east in Michigan. Model lead ages on galena from the Ladysmith and Pelican River massive sulfide deposits are 1,820 and 1,835 m.y. respectively (Stacey and others, 1976). This belt varies in metamorphic grade from greenschist, for example, in the Monico area (Wiggins and Brett, 1977), to andalusite grade in the Ladysmith area located further to the west. Because of poor exposures, the true extent and petrography are very poorly known. The known massive sulfide occurrences, and the bulk of exploration interest has been concentrated in these units.

The northern part of this Middle Precambrian terrane is characterized by slates and iron formations; some of the iron formations are pyritic. Best exposures are on the Gogebic Iron Range which rest on Lower Precambrian basement. Units in the Gogebic Range are lithologically correlated with the Animikie Group in Minnesota and the Chocolay Group in Michigan. Billions of tons of iron ore are present on the Gogebic Iron Range. Small areas of hundreds of millions of tons of iron ore occur in smaller areas in Iron County near Butternut, Agenda, and Pine Lake (Marsden, 1978).

Younger granitic intrusions, including syn-orogengic granites about 1,850 m.y. old to post-orogenic granites about 1,750 m.y. old intrude the volcanic-sedimentary sequences (Van Schmus, 1976; and, in press).

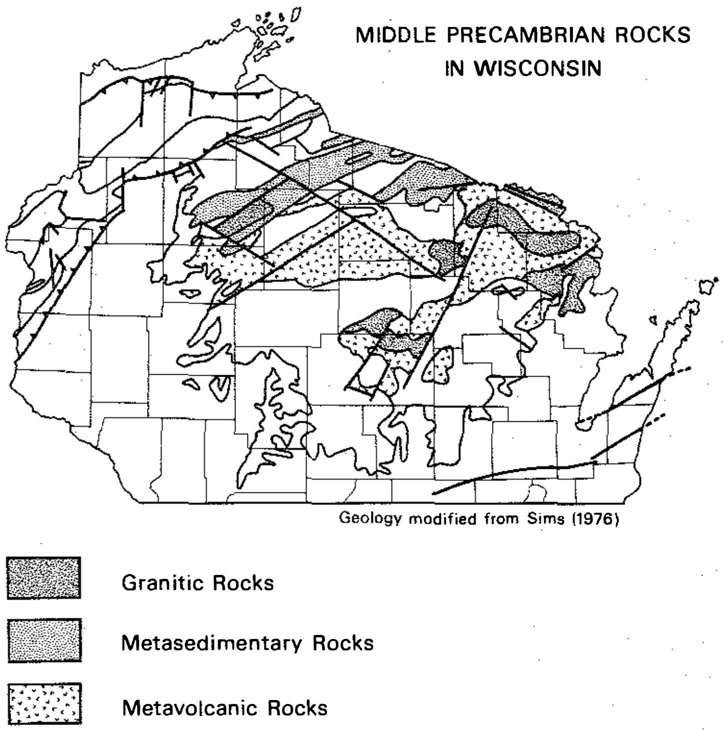

Figure 2. Map of northern Wisconsin showing distribution of various lithologies in the Middle Precambrian as outlined by Sims (1976). Since 1976, reconnaissance geologic mapping and availability of detailed aeromagnetic maps by Zietz, Karl and Ostrom (1978) have permitted revisions to the map by Sims, Cannon and Mudrey (1978). Major changes have been to increase the extent of volcanic rocks in the southwestern part of the map, and to redefine Early Precambrian gneissic areas as foliated Middle Precambrian granites.

The Upper Precambrian succession includes intracratonic volcanics, sedimentary rocks, and dominantly gabbroic intrusives about 1,100 m.y. old. Chase and Gilmer (1973) proposed that an aborted continental rift occurred during the Late Precambrian along the Mid-Continent Gravity High. 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, and Ordovician in the Upper Peninsula.

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 the final retreat of the ice.

MIDDLE PRECAMBRIAN ROCKS

The Middle Precambrian Basin in the Lake Superior region contains fairly well-defined areas with distinct tectonic and sedimentary environments shown in a general way by Sims (1976) and Morey (1978) (Figure 3). The northern part of the basin consists primarily of sedimentary rocks, including iron-formation which are correlated with Chocolay and Menominee Groups of Michigan

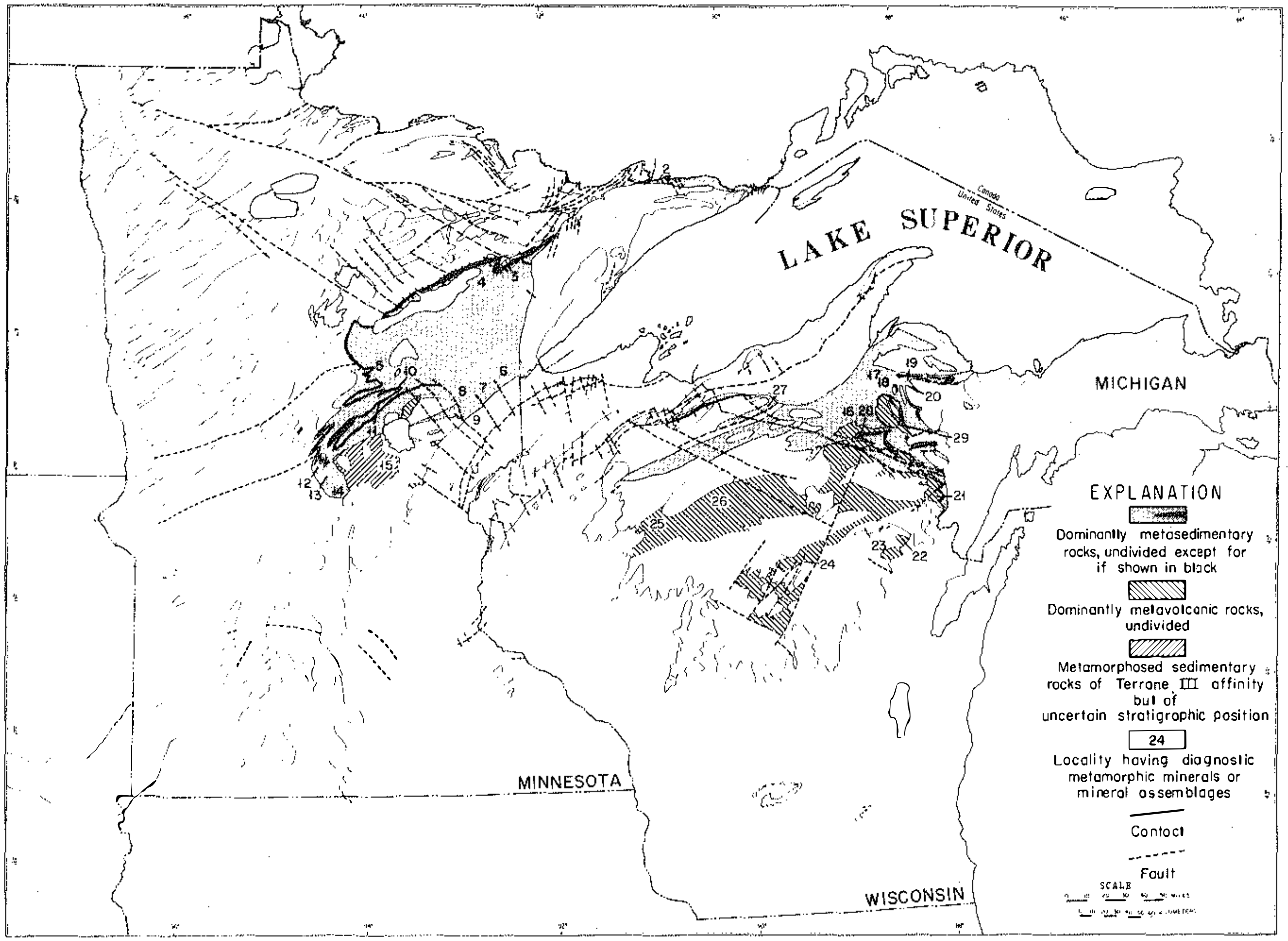

Figure 3. Bedrock geologic map of the Lake Superior region showing the known or inferred distribution of rocks assigned to Terrane II-Intracratonal Supracrustal Rocks (Middle Precambrian sedimentary and volcanic rocks). This map was developed by G. B. Morey of the Minnesota Geological Survey to show the spatial association of diagnostic metamorphic minerals and assemblages in the Lake Superior region. Taken from Morey (1978, Fig. 6) and reproduced from Geological Survey of Canada Paper 78-10.

(Table 1). The impetus from iron mining and better exposure has resulted in numerous studies of these rocks over the past 100 years. The southern part of the basin consists mainly of igneous rocks, both volcanic and plutonic which are correlated with the Baraga Group in Michigan. These rocks are poorly exposed, and until recently, have received little geological study. The discovery of at least four massive sulfide orebodies in the volcanic rocks, coupled with geophysical and geochemical studies, has stimulated study of rocks in the igneous southern part of the basin. While correlation of the volcanic rocks with sedimentary rocks to the north is still tentative, it appears that they represent parts of the same basin.

The Sedimentary Environment

Numerous discussions of the stratigraphy of the northern part of the basin are in the literature and, therefore, only a brief summary will be presented here. Figure 4 from Schmidt and Hubbard (1972) provides an excellent reference for the trip.

At least 10,000 feet of Middle Precambrian metasedimentary rocks are present in the Gogebic district in the sedimentary part of the basin. The oldest formation is the Sunday Lake Quartzite which lies unconformably on Lower Precambrian greenstones and granites in the eastern part of the district. The Sunday Lake Quartzite does not crop out in Wisconsin. The Bad River Dolomite unconformably overlies the quartzite, and is present in both the eastern and western ends, but is absent in the central part of the district. Conglomerate and quartzite of the Palms Formation unconformably overlies the Bad River Dolomite at the east and west ends of the district, and overlies Lower Precambrian greenstones and granites in the central part of the Gogebic Range. The Ironwood Iron-Formation conformably overlies the Palms Formation and is in turn overlain by the Tyler Formation of argillite and graywacke. In places the Tyler is unconformable on the Ironwood, but it appears to be conformable at others. The uppermost Tyler was removed by erosion prior to deposition of the Upper Precambrian Bessemer Quartzite of early Keweenawan age. All the Middle Precambrian formations were tilted about 65° north during the Keweenawan, but are otherwise little deformed.

South of the Gogebic Range for about 20 miles is an area of Lower Precambrian greenstones and granite. Farther south is a deformed metasedimentary and metavolcanic sequence, including iron-formation that is generally correlated with the little deformed sequence on the Gogebic Range. Metamorphism in this southern area reaches sillimanite grade.

Bad River Dolomite

The Bad River Dolomite is the oldest Middle Precambrian unit exposed in Wisconsin. It is the only formation of the Chocolay Group (James, 1958) of the Marquette Range Supergroup (Cannon and Gair, 1970) represented in the State and crops out along the western third of the Gogebic Range. It consists of a gray to buff dolomite and cherty dolomite up to 450 feet thick (Komatar, 1972). Stromatolitic structures are common at some horizons. Quartzose beds are common in the upper part of the formation; the thicker beds commonly show cross-bedding (Komatar, 1972). At most exposures the Bad River Dolomite has been metamorphosed to a tremolitic siliceous marble. In the eastern third of the Gogebic range the Sunday Lake Quartzite unconformably underlies the Bad River Dolomite.

The regional distribution of the Chocolay Group is important as regards the development of the Middle Precambrian basin. The group is best preserved at the eastern end of the Marquette Range (James, 1958), but it was removed by erosion west of Ishpeming prior to deposition of the Ajibik Quartzite. The correlative Randville Dolomite and Saunders Formation (James, 1958) are present to the west in the Amasa area. The Bad River Dolomite and Sunday Lake Quartzite are present in the eastern Gogebic, and the Bad River Dolomite is present in the western Gogebic, but both were removed by erosion in the central part of the range prior to deposition of the Animikean Palms Formation (Aldrich, 1929). Marsden (1972) reports a similar dolomite in the Cuyuna District in east central Minnesota. This suggests a regional flexuring and erosion in the northern part of the basin in pre-Animikie time (Figure 4). The extent and effect of this deformation on the southern part of the basin (if, in fact, the southern part of the basin existed during Chocolay time) is not known.

Palms Formation

Deposition of the Palms Formation (and its correlatives in the other iron districts) marks the submergence of the eroded Chocolay Group and the beginning of the Animikie Basin in the Lake Superior region. The Palms formation is approximately 450 feet thick in Wisconsin and thickens to about 750 feet east of Wakefield, Michigan (Montgomery, 1977). Aldrich (1929) divided the Palms into three mappable units. A 3- to 10-foot thick basal conglomerate rests unconformably upon Bad River Dolomite or Lower Precambrian greenstone or granite. The major part of the Palms is a "quartz-slate" unit composed of thin- to medium-bedded, buff to pink quartzite layers interbedded with thin layers of green to black argillite or graywacke. The upper Palms is a buff to pink, medium- or thick-bedded quartzite about 60 feet thick in Wisconsin and 100 feet thick in Michigan.

The Palms and its correlatives constitute the basal detrital unit of the Animikie Group. This detrital unit varies considerably in thickness from district to district in the Lake Superior region, in general, increasing from north to south. The Kakabeka Formation is only a few feet thick in the Gunflint district (Goodwin, 1954). The Pokegamma Formation ranges up to 250 feet in the Mesabi district (Morey, 1972). The Ajibik Quartzite-Siamo Slate sequence in the Marquette district is several thousand feet (Boyum, 1964). This suggests that the basin was deeper to the south, or, alternatively, subsided more rapidly to the south. The 450 to 750 foot thickness and lithology of the Palms Formation suggests that the Gogebic district was transitional between the shelf and deeper basin.

Ironwood Iron-Formation

The deposition of the Ironwood Iron-Formation, and its correlatives, signals a major change in the basin from detrital to chemical sedimentation. The iron-formation consists of roughly equal proportions of silica and iron-bearing minerals (averaging about 35 percent Fe), occurring as alternating chert-rich and iron-rich beds. Detrital material is scarce. Aldrich (1929)

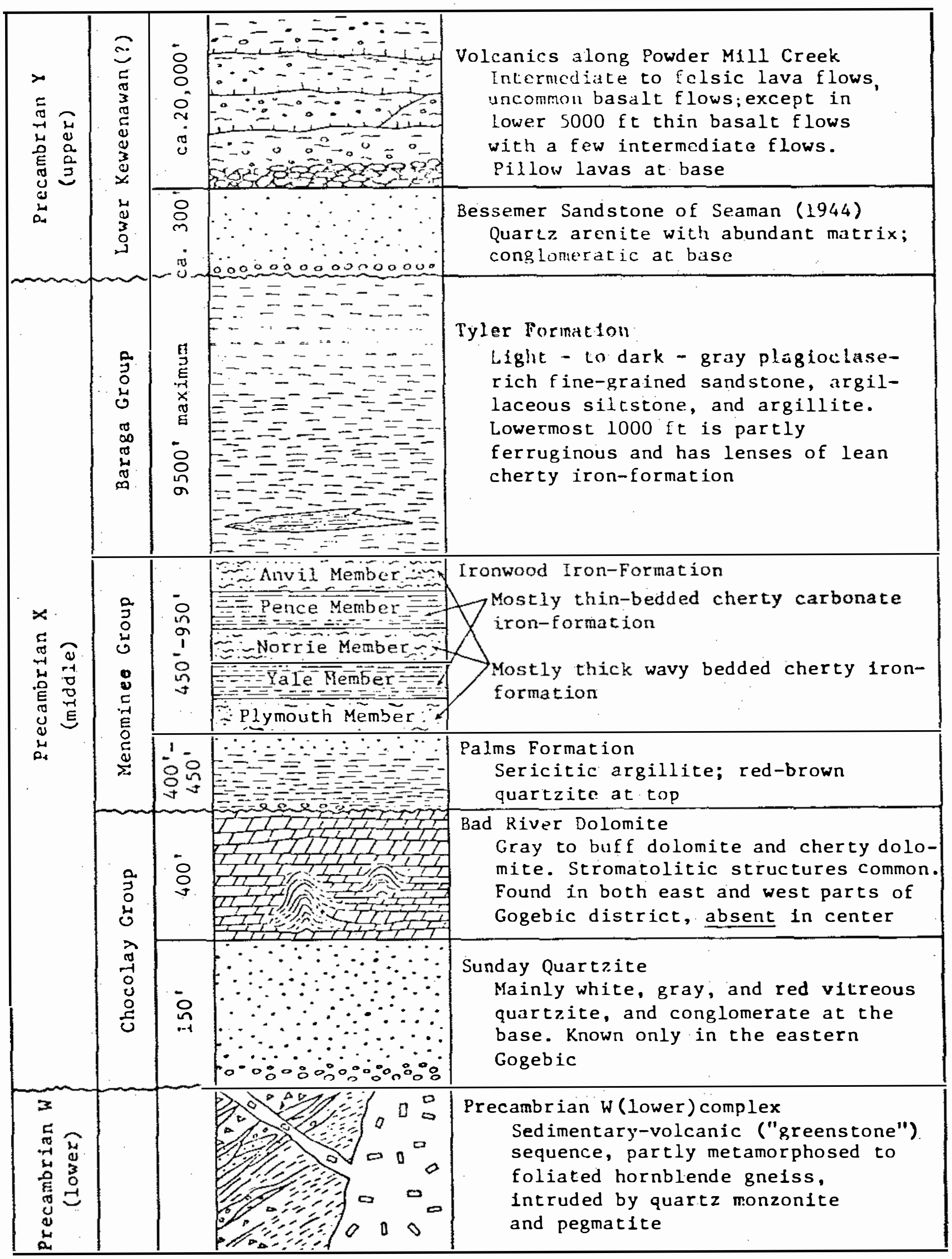

Figure 4. Generalized stratigraphic section in central and western Gogebic Iron Range area. Taken from Schmidt and Hubbard (1972), 18th Institute on Lake Superior Geology (Houghton, Michigan).

reports that the Ironwood is 600 to 900 feet thick, and Hotchkiss (1919) subdivided the formation into five members based on the dominant texture and bedding characteristics (Figure 4). The Plymouth (basal unit), Norrie, and Anvil (top unit) members are characterized by granular cherts and irregular bedding. They are interbedded with the Yale and Pence members which are dominantly laminated (slaty) units. The granular members formed in shallow, agitated water whereas the laminated members formed in deeper water (Hotchkiss, 1919). The members are similar to the cherty (granular) and slaty members of the Biwabic Iron-Formation in the Mesabi district in Minnesota. The five-fold subdivision holds remarkably well on the eastern two thirds of the Gogebic, but is less obvious toward the western end of the range. Morey (1972) shows a similar relationship for the Mesabi range, where a four-fold subdivision of slaty and cherty units is difficult to apply on the western end of the range. These lateral changes, the much thicker section, and interbedded clastic and volcanic rocks within the iron-formation in the Cuyuna district (Marsden, 1972) suggest a transition southward from a stable platform to a more unstable basin. Volcanic rocks make their first (?) appearance in the Animikie Group during iron-formation deposition in the Gogebic district (Trent, 1973), the Cuyuna district (Marsden, 1972), the Gunflint district (Goodwin, 1954), and the Mesabi district (Morey, 1972).

Tyler Formation

Throughout the Lake Superior region the major Animikean iron-formations are overlain by a thick graywacke-slate sequence that is conformable on the iron-formation in the Gunflint (Goodwin, 1954) and Mesabi (Morey, 1972) districts, and unconformable in the Marquette (Van Hise and Bayley, 1892) and Menominee (Van Hise and Leith, 1911) districts. This signals a change back to detrital sedimentation along with volcanic activity, although iron-formations (such as the Bijiki in the Marquette district) are locally present in the sequence.

The youngest sedimentary formation, and by far the thickest of the Animikie Group, is the Tyler Formation. It consists of about 9,500 feet of interbedded graywackes and argillites or slates (Alwin, 1976). At a number of places the Tyler rests unconformably on the Ironwood; in fact, Felmlee (1970) documents a post-Ironwood/pre-Tyler period of tectonism. Hotchkiss (1919) sites evidence from drill cores and mine workings that demonstrate an unconformable relationship between the Ironwood and the Tyler. However, Aldrich (1929) and Schmidt (1972) site evidence for a gradational contact. Thus, there appears to be good evidence for an unconformity at some places, and a gradational contact at others, suggesting local uplift or folding or both.

Alwin (1976) concludes that the Tyler Formation formed mainly from turbidity currents moving to the north down the basinal slope, and that the material was derived primarily from a granitic source area to the south. This suggests that the southern margin of the basin was a granitic highland rapidly shedding sediments into the Animikie Basin in the Gogebic area. The source of these sediments is difficult to identify because the Lower Precambrian granites and greenstones south of the Gogebic must have been buried with 1000 feet or more of Middle Precambrian rocks (the Palms and Ironwood) at the time the Tyler was deposited. Furthermore, about 20 miles south of the Gogebic range is a sequence of interbedded volcanic and sedimentary rocks generally believed to be correlative with the rocks in the Gogebic range (Allen and Barrett, 1915). Thus, the "granitic source area" to the south must have been very narrow and, if so, must have been rising rapidly, and undergoing erosion to provide the great volume of sediments for the Tyler.

Interbedded Sediments and Volcanics Near Mercer

Approximately 20 miles south of the Gogebic Range, particularly around Mercer, a sequence of interbedded metasedimentary and metavolcanic rocks are exposed. The northern parts of this area consist of metamorphosed pillow basalts, mafic volcaniclastic rocks, massive diabase sills and dikes, and iron formation and slate (Black, 1977). The southern part of this area is underlain by biotite gneisses, amphibolites, staurolite and kyanite- and sillimanite-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 these sequences is unknown because of thick and extensive glacial cover.

The Volcanic Environment

The Middle Precambrian volcanic rocks in northern Wisconsin have only recently been studied in detail. Several theses have included large-scale geologic maps, petrography and geochemistry. The more recent investigations in the area of the field trip include Venditti (1972) and Schriver (1972) for the Monico area, Bowden (1978) for the petrography and petrochemistry of the Pelican massive sulfide deposit, and Cudzillo (1978) for a comprehensive overview of the petrochemistry of the Middle Precambrian and presumed Middle Precambrian volcanic rocks in northeastern Wisconsin and adjacent Michigan. In addition, May (1977) and Schwenk (1977) have presented preliminary geologic and geophysical observations on the Flambeau massive sulfide deposit, and Schmidt and others (1978) for the Crandon massive sulfide deposit.

These preliminary observations, although meager in areal extent, do provide tantalizing information and preliminary interpretation of the nature and significance of this volcanic belt. Cudzillo (1978) has recently documented geochemical differences in Middle Precambrian volcanic rocks from Michigan and northeastern Wisconsin (Figure 5). He sampled the volcanic rocks along a transect from 46° 30' north latitude in Michigan to 45° 10' in Wisconsin so that any regional gradient in chemical composition would be evident. Regional gradients in total iron, TiO_2 and Zr concentrations were detected, but other more diagnostic chemical gradients were not. Two explanations for the iron gradient are readily apparent. The iron may be locally enriched at depths of magma formation for the Hemlock, Badwater, and Clarksburg basalts in Michigan compared to Wisconsin, or alternately, the lower iron in the Waupee and Quinnesec basalts in Wisconsin can be the result of higher oxygen fugacity in the magma compared to Michigan (Cudzillo, 1978).

The iron enrichments are also seen in TiO_2 data. Miyashiro (1974) and Nicholls and Ringwood (1973) concluded that TiO_2 concentrations would be low in magmas generated at deep levels of a subduction zone, and would thereby be low in the rocks extruded from those magmas as a result of relatively high oxygen fugacity or total pressure. Using this criteria developed from Cenozoic island arcs, the Middle Precambrian volcanic rocks in Michigan (high in Fe and

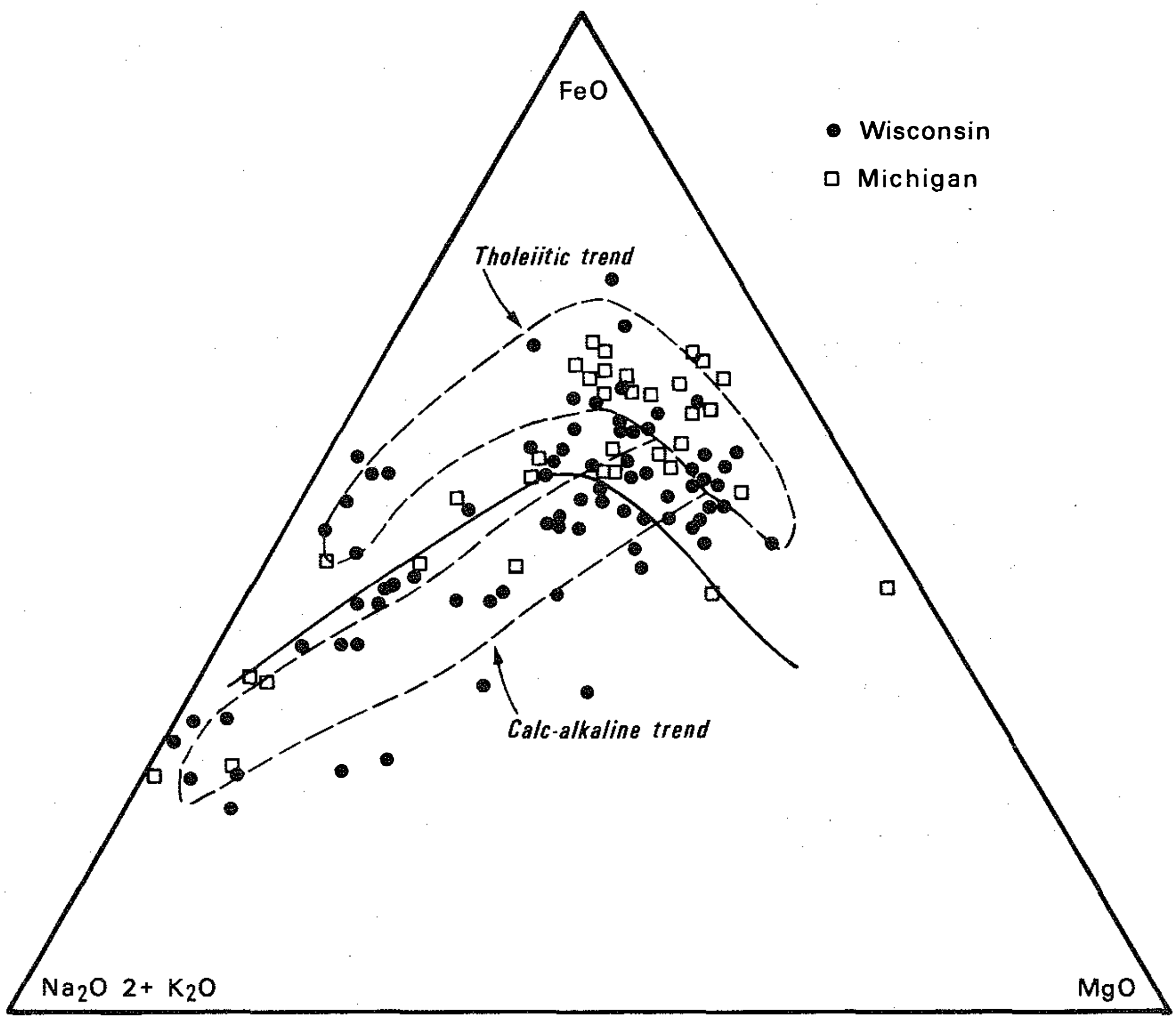

Figure 5. AFM($Na_2O + K_2O$, FeO_T, MgO) diagram of volcanic rock analyses from northeastern Wisconsin (●) and Michigan (□). Wisconsin analyses plot more to a calc-alkaline trend, and the Michigan analyses to a tholeiitic trend. Data from Cudzillo (1978) and Bowden (1978).

Ti) should have been extruded above the shallowest part of a magma generating zone, whereas the relatively impoverished Wisconsin volcanic rock were extruded over the deeper parts. Cudzillo (1978, p. 90) also notes the increase in Zr with Fe and Ti, ambiguous K/Rb ratios, and absolute K and Rb concentrations. He concluded that the Middle Precambrian volcanic rocks do not indicate regional geochemical gradients that would be diagnostic of petrogenesis along subduction zones in the Middle Precambrian.

Although the volcanic suites sampled in the Middle Precambrian do not fit Phanerozic petrogenetic models, nether do they conclusively fit Early Precambrian geochemical patterns. These observations led Cudzillo (1978, p. 91) to suggest the following possibilities:

(1) Subduction zones had not yet developed anywhere in the Middle Precambrian and any similarity between Middle Precambrian and Mesozoic-Cenozoic tectonic belts is not the result of subduction; or

(2) The magmas for the volcanic rocks were formed in a primitive subduction environment that developed with high geothermal gradients under Early Precambrian granitic crust; or

(3) Volcanic rocks represent volcanic activity that began in the Early Precambrian and continued sporadically into the Middle Precambrian and more than one tectonic and magma generation style is present; or

(4) The rocks studied may represent an incomplete sampling due to lack of exposure across the tectonic belt, and may, in fact, form only a small part of a more extensive and more complex orogenic zone.

The Plutonic Rocks

The granitic rocks in northern Wisconsin occupy an area of at least 1,200 square miles (Sims and Peterman, in press). Outlines of individual plutons can be approximately delineated from exposures along major rivers and interpretation of the regional aeromagnetic and gravity data (Sims, Cannon, and Mudrey, 1978).

The granitic rocks range in composition from granite to tonalite. Biotite, hornblende, or both are conspicuous, particularly in the more mafic phases, and often impart a weak to moderately strong foliation to the rocks. In general, the tonalitic phases have a more prominent foliation. All of the rocks contain concentrically zoned plagioclase and have other characteristics indicative of crystallization at moderate depths. Inclusions of schist comparable in lithology to observed country rocks and the gross map patterns (Sims, Cannon and Mudrey, 1978) also indicate that the granitic rocks intrude the adjacent metasedimentary and metavolcanic rocks.

The Middle Precambrian plutonic rocks range in age from about 1,850 to 1,765 m.y. (Van Schmus, 1976 and in press). The older plutons are mainly syntectonic, and many show a pervasive cataclastic foliation (LaBerge and Myers, 1976; LaBerge, 1977). The younger plutons are post-tectonic and generally are little deformed. The plutonic rocks are minor and related to gneiss domes in the north, and form large, syntectonic mesozonal to epizonal batholiths in the central and southern part of the basin. Later, a widespread group of post-tectonic plutons and associated extrusive rhyolites were emplaced.

Van Schmus (in press) interprets two main suites of Middle Precambrian plutonic rocks. The main suite is dated around 1,850 m.y. consisting of granites and tonalites, and the younger suite consists of rhyolitic volcanic rocks and associated potassic granites which are exposed principally as inliers in southern Wisconsin, but also as discrete plutons within the tonalitic to granitic suite in the north. At present there are few published data on the chemical compositions of these rocks, and it is not clear whether they represent a distinct late phase of the main orogeny, or whether they are due to some tectonically distinct later event.

The older pulse of plutonic activity is dated by Van Schmus (in press) at 1,840 - 1,820 m.y. ago. Structural studies by Maass(1977) indicate that these rocks were emplaced during the main phase of the orogeny in the southern part of the area. The second pulse of predominantly rhyolite and granophyric granite occurred about 1,765 m.y. ago. No igneous units have been found so far with zircon ages in excess of 1,850 million years (Van Schmus, in press).

The Tectonic Setting--Speculation

Not enough is known of Wisconsin's Middle Precambrian rocks to characterize the tectonic setting with any precision. However, studies to date have led to speculation some of which is presented here for purposes of discussion.

The Middle Precambrian basin in the Lake Superior region consists of several distinct tectonic and plutonic environments, which have resulted in different features in different parts of the basin. Morey and Sims (1976) divided the Lake Superior region into two fundamental terrains - and older gneiss terrane (3,000 m.y. or older) and a younger greenstone-granite terrane (2,750 m.y. old). Sims (1976) expanded on this idea and emphasized the contrasting roles that these terranes had on the tectonic evolution of the Middle Precambrian rocks in the Lake Superior region. Morey and Sims (1976) pointed out that Middle Precambrian strata overlying the greenstone-granite terrane are largely undeformed whereas those overlying the gneiss terrane are intensely deformed, and at least locally intensely metamorphosed. Sims (1976) attributes this to remobilization of the gneisses forming gneiss domes in the Middle Precambrian basin. The upwelling of the older gneisses deform the supracrustal rocks into a dome, with bedding in the supracrustals remaining approximately parallel to the contact with the gneisses. According to Sims (1976), remobilization may involve partial melting of the gneisses, producing local anatectic granites, and metamorphism of the overlying and surrounding Middle Precambrian. Sims (1976) identifies a number of probable gneiss domes from northern Michigan to east-central Minnesota that have involved Middle Precambrian rocks. These gneiss domes occur in an east-west zone across the Middle Precambrian basin south of, but near the boundary between the greenstone-granite terrane and gneiss terrane (Figure 3).

South of the gneiss domes the tectonic and plutonic style is distinctly different. In Marathon County, in central Wisconsin, and evidently in much of the volcanic portion of the basin (between the Gogebic Range and Central Wisconsin) the granitic intrusions are of batholithic proportions and discordant upper mesozonal to epizonal plutons showing classic examples of magmatic stoping. Aside from relatively narrow contact effects around the plutons, metamorphic grade is generally greenschist to lower amphibolite facies. Plutons of this type appear to have formed in an environment very different from those in the gneiss domes.

The plutonic rocks range in age from about 1,850 - 1,765 m.y. (Van Schmus, 1976; and in press). The older plutons are mainly syntectonic, and many show a pervasive cataclastic foliation (LaBerge and Myers, 1976; LaBerge, 1977). The younger plutons are post-tectonic and generally are little deformed (Van Schmus, 1976). Thus, the plutonic rocks are minor and related to gneiss domes in the north forming large syntectonic mesozonal to epizonal batholiths in the central and southern part of the basin. There is also a widespread group of post-tectonic plutons. Clearly, all these granitic rocks cannot be closely related.

The tectonic environment in which the Animikie Basin developed is problematical. The basin contains some rock types typical of Lower Precambrian greenstone belts, such as tholeiitic and calc-alkaline basalt-rhyolite piles with associated graywacke-slate sequences. The volcanogenic massive sulfide deposits are typical of those in Lower Precambrian rocks throughout the shield.

The presence of extensive platform sediments, including pure quartzites, dolomites and iron-formations, and the general size of the basin is considerably different from most (or all) greenstone belts. Furthermore, the iron-formations are characteristically in the sedimentary sequence rather than in the volcanics. The widespread occurrence of granitic batholiths, regional metamorphism and general distribution of rock sequences is more like Phanerozoic "geosynclines", which many geologists relate to convergent plate boundaries. However, the preponderence of vertical tectonics within the basin, breaking it into a number of sub-basins (Cannon, 1973; Bayley and James, 1973; Sims, 1976; LaBerge, 1977) during the filling suggest that this basin was different from both Archean greenstone belts and from Phanerozoic "geosynclines".

Many geologists believe that Lower Precambrian greenstone belts formed in an early version of an island arc environment (see Windley, 1975, 1976; Sims, 1976), but that greenstone belts are not directly comparable to a Cenozoic arc system. The differences in tectonic style between the Animikie Basin and Phanerozoic "geosynclines" similarly indicates that the two are not directly comparable.

Tectonically the southern part of the basin is characterized by large-scale faults (LaBerge, 1972, 1977). These broad, long zones of cataclasis suggest that, in those areas, the crust was behaving in a more brittle manner than Sims (1976) describes in the gneiss domes. These large faults have broken the southern part of the basin into a number of horsts and grabens (LaBerge, 1977). Thus, the gneissic basement has behaved differently in different parts of the basin, with a zone of gneiss domes in the north and block faulting in the south (Figure 6). This shows that the gneissic basement was remobilized only locally -- along the contact with the greenstone-granite terrane. This feature may have considerable significance in interpreting the major tectonic environment in which the basin developed.

We suggest that the Animikie Basin formed in an environment transitional between that of Lower Precambrian greenstone belts and that of Phanerozoic fold mountain ranges. The location of the basin along a major crustal boundary between a greenstone-granite terrane and a gneiss terrane <u>may</u> indicate a form of plate tectonics was involved, but a simple comparison with modern systems is not warranted. We believe that studies of the tectonic setting of this

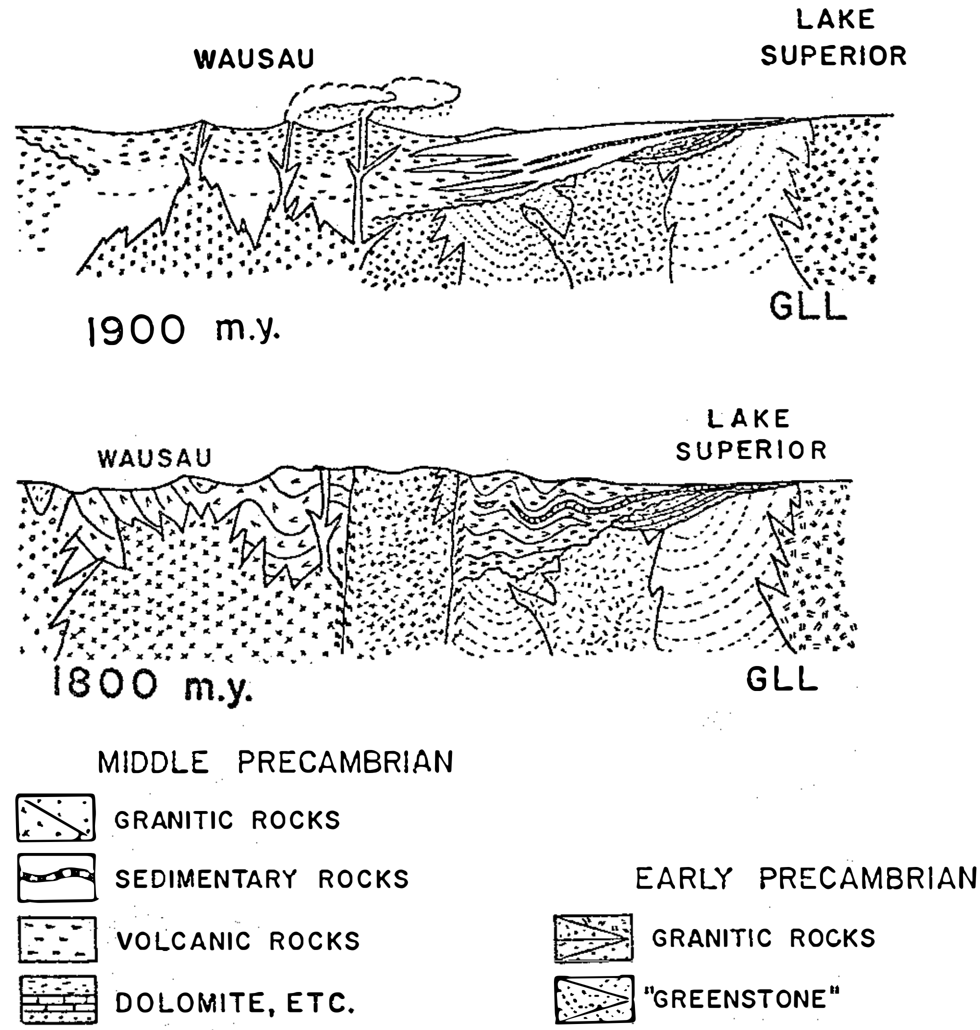

Figure 6. Schematic cross sections showing inferred lithologic-structural relations during the "Penokean" event of Middle Precambrian age. Upper diagram illustrates the depositional framework around 1,900 m.y. ago. In the north (right side of diagram) platform and stable shelf sediments were deposited, whereas to the south an island arc and adjacent deep basins were accumulating volcanic and volcaniclastic materials, during emplacement of syntectonic granitic plutons. The diagram illustrates the structural framework around 1,800 m.y. ago after the cessation of the main thermo-tectonic processes. Low-grade metasedimentary rocks were exposed in the north (right side of diagram), and higher-grade metavolcanic rocks and granitic plutons were brought close to the surface along deep-seated faults forming local grabens and horsts.

basin are important to understanding the evolution of (plate?) tectonic environments through time.

An alternative considered by LaBerge is that there is no compelling evidence that the Middle Precambrian basin was intracratonic. He believes it may well have formed as a result of continental collision; the boundary between the greenstone-granite and gneiss terranes, with the associated gneiss domes, may mark the present location of collision of the Lower Precambrian continental blocks. The Middle Precambrian volcanic and plutonic rocks in the central and southern part of the basin may represent products of subduction of the converging plates. The present occurrence of Early Precambrian crust at various locations within the basin may be a consequence of underthrusting of the older continental crust during subduction, with later block faulting bringing the older crust up to the level of Middle Precambrian rocks.

Whatever the tectonic environment, it is evident that the Middle Precambrian basin in Wisconsin developed in an environment different from Lower Precambrian greenstone belts and different from Phanerozoic mountain ranges. We propose that the tectonic environment is transitional between the two, and represents a stage in the evolution of tectonic style through time. Further studies in the basin should help to reveal the true character of Middle Precambrian tectonism in the Lake Superior region.

REFERENCES CITED

Aldrich, H. R., 1929, The geology of the Gogebic Iron Range of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 71, 279 p.

Allen, R. C., and Barrett, L. P., 1915, Contribution to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geological Survey Publication 18, Geologic Series 15, p. 13-164.

Alwin, B. W., 1976, Sedimentation of the Middle Precambrian Tyler Formation of northcentral Wisconsin and northwestern Michigan: Unpub. M.S. thesis, University of Minnesota-Duluth, 175 p.

Bayley, R. W., and James, H. L., 1973, Precambrian iron-formations of the United States: Economic Geology v. 68, p. 934-959.

Black, F. M., 1977, The geology of the Turtle-Flambeau area: Iron and Ashland Counties, Wisconsin: Unpub. M.S. thesis, University of Wisconsin-Madison, 150 p.

Bowden, D. R., 1978, Volcanic rocks of the Pelican River Massive Sulfide Deposit, Rhinelander, Wisconsin: A Study in Wallrock Alteration: Unpub. M.S. thesis, Michigan Technological University, 62 p.

Boyum, B. H., 1964, The Marquette Mineral Range, Michigan: Geological Society of America Field Trip to Marquette Iron Range, Michigan, 21 p.

Cannon, W. R., 1973, The Penokean Orogeny in Northern Michigan: Geological Association of Canada Special Paper 12, p. 251-271.

Cannon, W. F., and Gair, J. E., 1970, A revision of stratigraphic nomenclature for Middle Precambrian rocks in northern Michigan: Geological Society of America Bulletin, v. 81, p. 2843-2846.

Chase, C. G., and Gilmer, T. H., 1973, Precambrian plate tectonics: The Mid-continent Gravity High: Earth and Planetary Science Letters, v. 21, p. 70-78.

Cudzilo, T. F., 1978, Geochemistry of Early Proterozoic igneous rocks north-eastern Wisconsin and Upper Michigan: Unpub. Ph.D. Diss., University of Kansas, 194 p.

Dutton, C. E. and Bradley, R. E., 1970, Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-631.

Ervin, C. P., and Hammer, S. H., 1974, Bouguer anomaly gravity map of Wisconsin: Wisconsin Geological and Natural History Survey Map.

Felmlee, J. K., 1970, Geologic structure along the Huronian-Keweenawan contact near Mellen, Wisconsin: Unpub. M.A. thesis, University of Wisconsin-Madison, 91 p.

Goodwin, A. M., 1954, Facies relations in the Gunflint Iron-Formation: Economic Geology, v. 51, p. 565-595.

Hotchkiss, W. O., 1919, Geology of the Gogebic Range and its relation to recent mining developments: Engineering/Mining Journal, v. 108, p. 443-452, 501-507, 537-541, 577-582.

James, H. L., 1958, Stratigraphy of Pre-Keweenawan rocks in parts of northern Michigan: U. S. Geological Survey Professional Paper 314-C, p. 27-44.

Komatar, F. D., 1972, Geology of the Animikian metasedimentary rocks, Mellen Granite, and Mineral Lake Gabbro West of Mellen, Wisconsin: Unpub. M.S. thesis, University of Wisconsin-Madison, 70 p.

LaBerge, G. L., 1972, Lineaments and mylonite zones in the Precambrian of northern Wisconsin(abs.): Geological Society of America, Abstracts with Programs, v. 4, no. 5, p. 332 (North-Central Section, DeKalb, Illinois).

LaBerge, G. L., 1977, Major structural features in central Wisconsin and their implications on the Animikie Basin (abs.): Institute on Lake Superior Geology, Abstracts and Field Guides no. 23, p. 23.

LaBerge, G. L., and Myers, P. E., 1976, The Central Wisconsin Batholith (abs.): Institute on Lake Superior Geology, Abstracts and Field Guides No. 22, p. 26.

LaBerge, G. L., and Myers, P. E., 1977, Preliminary geological map of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Open-file Report.

Maass, R. S., 1977, Structure and petrology of an Early and Middle Precambrian gneiss terrane between Stevens Point and Wisconsin Rapids, Wisconsin: Unpub. M.S. thesis, University of Wisconsin-Madison, 128 p.

Marsden, R. W., 1972, Cuyuna District: in P. K. Sims and G. B. Morey, editors, The Geology of Minnesota (G. M. Schwartz Volume): Minnesota Geological Survey, p. 227-239.

Marsden, R. W., 1978, Iron ore reserves of Wisconsin - A Minerals Availability System Report: Proceedings of the 51st Annual Meeting Minnesota Section AIME and 39th Annual Mining Symposium (Duluth, Minnesota) p. 24-1 -- 24-28.

Martin, L., 1965, The Physical Geography of Wisconsin: Wisconsin Geological and Natural History Survey, Bulletin 36 (third edition), 608 p.

May, E. R., 1977, Flambeau - A Precambrian supergene and enriched massive sulfide deposit: Geoscience Wisconsin Vol. 1, p. 1-26.

Miyashiro, A., 1974, Volcanic Rock series in island arcs and active continental margins: American Journal of Science, v. 274, p. 321-355.

Montgomery, W. W., 1977, Deformation of the Tyler Slate (Middle Precambrian) in northern Wisconsin and western Upper Michigan: Unpub. M.S. thesis, University of Wisconsin-Madison, 115 p.

Morey, G. B., 1972, Mesabi Range: in P. K. Sims and G. B. Morey, editors, The Geology of Minnesota (G. M. Schwartz Volume): Minnesota Geological Survey, p. 204-217.

Morey, G. B., 1978, Metamorphism in the Lake Superior region, U.S.A., and its relation to crustal evolution: in J. A. Fraser and W. W. Heywood, editors, Metamorphism in the Canadian Shield: Geological Survey of Canada, Paper 78-10, p. 283-314.

Morey, G. B., and Sims, P. K., 1976, Boundary between two Precambrian W terranes in Minnesota and its geologic significance: Geological Society of America Bulletin, v. 87, no. 1, p. 141-152.

Nicholls, I. A., and Ringwood, A. E., 1973, Effect of water on olivine stability in tholeiites and the production of silica-saturated magmas in the island-arc environment: Journal of Geology, v. 81, p. 285-300.

Peterman, Z. E., Zartman, R. E., and Sims, P. K., 1978, Gneiss of early Archean age in northern Michigan, U.S.A.: in R. E. Zartman, editor, Short Papers of the Fourth International Conference, Geochronology, Cosmochronology, Isotope Geology 1978: U. S. Geological Survey Open-file Report 78-701, p. 332-334.

Schmidt, P. G., Dolence, J. D., Lluria, M. R., and Parsons, G., III, 1978a, Geology of the Crandon Massive Sulfide Deposit in Wisconsin: Skillings' Mining Review, v. 67, no. 18, p. 1, 8-11.

Schmidt, P. G., Dolence, J. D., Lluria, M. R., and Parsons, G., III, 1978b, Geologists block out Exxon's big find of Zn-Cu at Crandon: Engineering/ Mining Journal, July 1978, p. 61-66.

Schmidt, R. G., 1972, Geology of Precambrian rocks, Ironwood-Ramsay area, Michigan: U. S. Geological Survey Open-file Report, 17 p.

Schmidt, R. G., and Hubbard, H. A., 1972, Penokean orogeny in the central and western Gogebic region, Michigan and Wisconsin: Institute on Lake Superior Geology Abstract and Field Guides No. 18, Field Trip A, p. Al-A27 (Houghton, Michigan).

Schriver, G. H., 1973, Petrochemistry of Precambrian greenstones and granociorites in southeastern Oneida County, Wisconsin: Unpub. M.S. thesis, University of Wisconsin-Milwaukee, 83 p.

Schwenk, C. G., 1977, Discovery of the Flambeau deposit, Rusk County, Wisconsin: A Geophysical Case History: Geoscience Wisconsin, Vol. 1, p. 27-42.

Sims, P. K., 1976, Presidential address - Precambrian tectonics and mineral deposits, Lake Superior Region: Economic Geology, v. 71, no. 6, p. 1092-1118.

Sims, P. K., in press, Boundary between Archean (Precambrian W) greenstone and gneiss terranes in northern Wisconsin and Michigan: Geological Society of America Special Paper.

Sims, P. K., Cannon, W. F., and Mudrey, M. G., Jr., 1978, Preliminary geologic map of Precambrian rocks in part of northern Wisconsin: U. S. Geological Survey Open-file Report 78-318.

Sims, P. K., and Peterman, Z. E., 1976, Geology and Rb-Sr ages of reactivated Precambrian gneisses and granite in the Marenisco-Watersmeet area, Northern Michigan: U. S. Geological Survey Journal of Research, v. 4, no. 4, p. 405-414.

Sims, P. K., and Peterman, Z. E., in press, Geology and Rb-Sr age of Lower Proterozoic granitic rocks, northern Wisconsin: Geological Society of America Special Paper.

Sims, P. K., Peterman, Z. E., and Prinz, W. C., 1977, Geology and Rb-Sr age of Precambrian W Puritan Quartz Monzonite, Northern Michigan: U. S. Geological Survey Journal of Research, v. 5, no. 2, p. 185-192.

Stacey, J. S., Doe, B. R., Silver, L. T., and Zartman, R. E., 1976, Plumbo tectonics IIA, Precambrian Massive Sulfide Deposits. U. S. Geological Survey Open-file Report 76-476, 26 p.

Sternberg, B. K., and Clay, C. S., 1977, Flambeau Anomaly: A high-conductivity anomaly in the southern extension of the Canadian Shield: in J. G. Heacock, ed., American Geophysical Union Monograph 20, p. 501-530.

Trent, V. A., 1973, Geologic map of the Marinesco and Wakefield NE quadrangles, Gogebic County, Michigan: U. S. Geological Survey Misc. Geological Investigation, Open-file Map, 4 fig.

Van Hise, C. R., and Bayley, W. S., 1897, The Marquette Iron-bearing District of Michigan: U. S. Geological Survey Monograph 28, 608 p.

Van Hise, C. R., and Leith, C. K., 1911, The Geology of the Lake Superior Region, U. S. Geological Survey Monograph 52, 641 p.

Van Schmus, W. R., 1976, Early and Middle Proterozoic History of the Great Lakes Area, North America, in Global Tectonics in Proterozoic Times: Royal Society (London) Philosophical Transactions, A, v. 280, p. 605-628.

Van Schmus, W. R., in press, Chronology of igneous rocks associated with the Penokean Orogeny in Wisconsin: Geological Society of America Special Paper.

Van Schmus, W. R., and Anderson, J. L., 1977, Gneiss and migmatite of Archean age in the Precambrian basement of Central Wisconsin: Geology, v. 5, p. 45-48.

Venditti, A. R., 1973, Petrochemistry of Precambrian rocks in southeastern Oneida County, Wisconsin; Unpub. M. S. thesis, University of Wisconsin-Milwaukee, 93 p.

Wiggins, L. B., and Brett, R., 1977, Pelican River Cu-Zn Deposit, Wisconsin: Metamorphic Conditions in Penokean Time: Geological Society of America Annual Meeting, Vol. 9, no. 7, p. 1226-1227.

Windley, B. F., 1975, ed. The Early History of the Earth: John Wiley and Sons, N. Y. 619 p.

Windley, B. F., 1976, The Evolving Continents: John Wiley and Sons, N. Y., 385 p.

Zietz, I., Karl, J. H., and Ostrom, M. E., 1978, Preliminary aeromagnetic map covering most of the exposed Precambrian terrane in Wisconsin: U. S. Geological Survey Miscellaneous Field Study MF-888.