Map I–2739

USGS
science for a changing world

Geology and tectonic significance of Early Proterozoic rocks in the Monico area, northern Wisconsin

By Gene L. LaBerge and John S. Klasner

Geologic Investigations Series Map I–2739

LaBerge and Klasner—Geology and tectonic significance of Early Proterozoic rocks in the Monico area, northern Wisconsin   Scale 1:24,000   Map I–2739

2001

U.S. Department of the Interior
U.S. Geological Survey

ISBN 0-607-98330-2

Printed on recycled paper

GEOLOGY AND TECTONIC SIGNIFICANCE OF EARLY PROTEROZOIC ROCKS IN THE MONICO AREA, NORTHERN WISCONSIN

By
Gene L. LaBerge[1] and John S. Klasner[2]

ABSTRACT

The Wisconsin magmatic terranes constitute a major east-trending belt of mainly subduction-related Early Proterozoic volcanic and plutonic rocks and associated volcanogenic sedimentary rocks in northern Wisconsin. Magmatic rocks within the terranes have been subdivided, on the basis of lithology and structure, into two subterranes: the Pembine-Wausau terrane on the north and the Marshfield terrane on the south. Rocks in the Monico area are part of an island arc suite of the Pembine-Wausau terrane that developed and was tectonically deformed during convergence and docking with Archean rocks of a continental margin to the north.

In most areas the magmatic terranes are covered by a thick blanket of Pleistocene deposits. As a result, volcanic stratigraphy and structure within the volcanic belt are poorly known. However, outcrops are relatively abundant locally in the Monico area, which is one of the few places where stratigraphic and structural relations can be studied in the field.

Rocks exposed in the Monico area consist of banded gneisses, greenschist-grade metavolcanic rocks with well-preserved primary features, synvolcanic mafic and felsic intrusions, post-tectonic granitic rocks, and a Middle Proterozoic diabase dike that is probably related to volcanic rocks of the Keweenawan Supergroup. The northern part of the map area consists of banded gneisses of uncertain age. The gneisses are overlain to the south by a bimodal suite of mafic pillow lavas and pillow breccias intercalated with dacitic to rhyolitic flows, breccias, tuffs, and welded tuffs. Numerous pillows consistently indicate that the volcanic sequence faces stratigraphically south. Mafic and felsic volcanic units are interbedded on both a small and large scale with the felsic component generally increasing southward. The volcanic sequence is tectonically repeated by major shear zones that are approximately parallel to bedding.

A large subvolcanic pluton in the northern part of the map area was emplaced approximately along the contact between the older gneisses and the overlying volcanic sequence. The pluton is a quartz (and feldspar) porphyry with a gray aphanitic matrix. Tuffaceous layers and subtle layering suggest the porphyry is, at least in part, extrusive in eastern exposures, but abundant xenoliths in the western part suggest that in this area it is intrusive. Chemically, the quartz porphyry is almost identical to volcanic rocks associated with the Pelican River massive sulfide deposit that occurs within the map area.

A post-tectonic pink to red granite, dated at 1,739 Ma, is exposed in the southern part of the map area. The granite body is bulbous in shape and cuts the general volcanic stratigraphy. An unmetamorphosed Middle Proterozoic (Keweenawan) dike with an associated significant low magnetic anomaly transects the entire map area in a N. 70° E. direction. The dike appears to be part of a regional swarm emplaced near the beginning of the Midcontinent Rift.

Structurally the area is characterized by polyphase deformation resulting from the series of events related to docking of the island arc with a continental margin of mostly Archean rocks to the north. Among the oldest structural fabrics recognized is a north-trending gneissic foliation (SA_1) in the northwestern part of the map area. North-trending foliation was not observed elsewhere in the map area, nor has it been reported elsewhere in the Wisconsin magmatic terranes. A widespread east-trending foliation (S_1) is well developed in the volcanic rocks to the south of the gneissic rocks. S_1 is, in turn, cut by a northeast-trending foliation (S_2) consisting of discrete, isolated shear zones. The S_2 fabric is cut by well-defined, east-trending, north-side-up shear zones (S_3) that are responsible for the repetition of the volcanic succession. A conspicuous, N.88° E.-trending foliation, along the southern margin of the gneiss, is tentatively interpreted to be an S_3 structure that overprints the north-trending structure in the gneiss. D_1, D_2, and D_3 structures are truncated by the red granite in the southern part of the map area, and are crosscut by the N. 70° E.-trending undeformed diabase dike.

INTRODUCTION

The Wisconsin magmatic terranes (fig. 1) constitute an east-trending belt of Early Proterozoic volcanic and plutonic rocks in the Penokean orogen of the Lake Superior region. Sims and others (1989) subdivided the magmatic terranes into a northern Pembine-Wausau terrane and a southern Marshfield terrane, based on lithology and structure. The Wisconsin magmatic terranes are composed primarily of tholeiitic and calc-alkaline rocks probably generated between 1,890 and 1,840 Ma by subduction-related convergent tectonism during the Penokean orogeny. Also present are minor post-tectonic granitoids and rhyolites emplaced at 1,760 Ma (Sims and others, 1989). Local tholeiitic basalts and associated gabbroic dikes and ultramafic rocks in the Pembine area, Wisconsin, have been interpreted as remnants of a dismembered ophiolite (Schulz, 1987; Sims and others, 1989).

The Monico area (fig. 1) affords one of the few places where stratigraphic and structural relations can be studied within the Pembine-Wausau terrane, which is mostly covered by a thick blanket of Pleistocene deposits. Previous reports on the geology of the area include those by Dutton and Bradley (1970), Schriver (1973), Venditti (1973), Bowden (1978), and LaBerge (1991).

[1]U.S. Geological Survey and University of Wisconsin–Oshkosh, Oshkosh, WI 54901, emeritus

[2]U.S. Geological Survey and Western Illinois University, Macomb, IL 61455, emeritus

The Pembine-Wausau terrane contains a number of massive sulfide deposits, several of which, the Pelican River deposit (Bowden, 1978; DeMatties, 1994) and the Wolf River deposit (DeMatties, 1994), occur within the map area (fig. 2). The Crandon deposit (May and Schmidt, 1982; Lambe and Rowe, 1987) is approximately 28 km to the east, and the Lynne deposit (Adams, 1996) is about 50 km to the west. There are no outcrops in the vicinity of these latter two deposits. Outcrops in the Monico area provide a basis for discussing the setting of the Pelican River deposit within the volcanic succession.

Field work for this project consisted of 4 weeks of mapping in 1990 by LaBerge and John Franklin, and 2 weeks of mapping by LaBerge and Klasner and structural studies by Klasner in 1991. The geologic map and structural data (fig. 3) were derived primarily from outcrops, but the aeromagnetic map of the area (also fig. 3) was invaluable in delineating most of the map units and in deciphering regional structures in the area as shown in figures 2 and 3. The aeromagnetic map was prepared in 1976 by Geoterrex, Ltd., for Noranda Exploration, Inc., Rhinelander, Wis., from a flight-line spacing of approximately 1,000 ft (300 m) with a terrain clearance of 400 ft (120 m). Horizontal control was based on photomosaics. In addition to outcrops and the aeromagnetic map, numerous drill holes provided data on bedrock where there are few outcrops. Drill hole locations are shown in figure 3.

The main purposes of this report are to describe the stratigraphic and structural relations of rock units in the Monico area and to discuss their kinematic evolution. We also discuss the significance of these data relative to the tectonic evolution of the Penokean orogen in Wisconsin and northern Michigan.

ACKNOWLEDGMENTS

A number of agencies and individuals aided in this project. Noranda Exploration, Inc., Rhinelander, Wis., provided maps of outcrop locations as well as a detailed aeromagnetic map of the area. Discussion of the geology with company geologists was also very helpful. University of Wisconsin–Oshkosh faculty development grants FDR–943 and FDR–073 to Gene LaBerge provided support for field work in 1990 and 1991. The Wisconsin Geological and Natural History Survey provided a 4-wheel-drive vehicle for field work. Timothy Flood provided a canoe that afforded access to a number of areas. Michael Slaughter and Marsha Hilmes worked as field assistants, and Matt Benson assisted in the preparation and analysis of thin sections for kinematic studies. This report was greatly improved through careful editing by James Estabrook and cartography by Paul Mathieux of the U.S. Geological Survey. We acknowledge all these contributions with thanks.

MAJOR ROCK UNITS

The Monico area contains a bimodal suite of mafic metavolcanic rocks (Xmv) (high-alumina basalt to low-silica andesite) intercalated with felsic volcanic rocks (Xfv) (dacite to rhyolite) (Sims and others, 1989), and a minor occurrence of metadiabase (Xmd) in the southwestern part of the map area (figs. 2 and 3). An extensive area of quartz porphyry (Xqp) is present in the northern part of the map area, and a post-tectonic granite (Xg) underlies the southern part of the map area. In addition, compositionally banded gneiss (XAgn) and metagabbro (XAmg) are present in the northernmost part of the map area, and a diabase dike (Yd) transects the entire map area.

Gneissic Rocks (XAgn)—Compositionally banded gneisses, composed of a variety of layered biotitic and amphibolitic rocks, intricately veined and segmented by foliated granitoid rocks, are exposed in widely scattered, small outcrops near the northern margin of the map area. The largest outcrop area of gneiss is in the W1/2 SE1/4 sec. 17, T. 36 N., R.10 E., but the general distribution of gneissic rocks is inferred from scattered exposures and their distinctive aeromagnetic signature of high-amplitude, variably oriented anomalies. Gneissic rocks also occur extensively as xenoliths, which range in size from a few centimeters to many meters in the quartz porphyry in the northern part of the map area. Field relations indicate that the gneissic rocks are the oldest rocks in the map area.

Volcanic Succession (Xmv and Xfv)—Mafic and felsic metavolcanic rocks are present in about equal proportions in the volcanic succession in the Monico area. The northern (lower) part of the volcanic pile, roughly along U.S. Route 8, consists mainly of massive to weakly foliated basalt containing few pillows or other primary features. The basalt is extensively epidotized and contains quartz and quartz-feldspar grains. South of U.S. Route 8 most exposures are pillow basalt or pillow breccias. Pillows typically have highly amygdaloidal selvages 2 to 5 cm wide. They are generally flattened, measuring 0.5 to 1.5 m long and 0.25 to 0.5 m high, and they consistently face stratigraphically south (fig. 2). Pillow breccias are monolithologic, with angular to subrounded clasts that range to about 30 cm in length, in a fine matrix of chloritic material (fig. 4). The pillow breccias are typically less than 20 m thick and probably represent debris flows. Some debris flows also contain clasts of felsic volcanic rocks.

Our mapping indicates that felsic and mafic volcanic rocks are interbedded with units ranging from a few centimeters to hundreds of meters in thickness. Felsic rocks include tuffs, welded tuffs, debris flows, flow-banded lava flows, and related subvolcanic plutons. The most common rock type is lithic tuff breccia having flattened felsic clasts as long as 10 cm in a greenish chloritic matrix (fig. 5). Some units are crystal-rich tuffs. Pyrrhotite is widespread as small veinlets and finely disseminated in the matrix of the tuffs. Well-preserved fiamme and flattened shards are present in the NW1/4 sec.4, T. 35 N., R.10 E. (fig. 6), and flow-banding is present in the SW1/4 sec. 2, T. 35 N., R.10 E. (fig. 7). Although outcrops and hand specimens clearly exhibit primary volcanic textures, recrystallization during regional metamorphism has obscured many primary features on a microscopic scale, especially where the rocks consist of quartz, feldspar, and muscovite with a granoblastic texture.

At least four 200- to 500-meter-thick units of felsic volcanic rocks alternate with mafic units of comparable thickness. Small-scale interlayering of mafic and felsic rocks, along with the presence of clasts of mafic rocks in felsic units and clasts of felsic rocks in mafic units, indicates that some of the interlayering of volcanic units is primary. However, some repetitions in the succession appear to be structural, as discussed below. Widely scattered outcrops, drill core data, and the aeromagnetic map suggest that the intercalation of mafic and felsic units is characteristic of this part of the Pembine-Wausau terrane.

Metagabbro (XAmg) and Metadiabase (Xmd)—There appears to be more than one age of metagabbro in the Monico area; some bodies within the volcanic succession may be genetically related to the mafic volcanic rocks. Metagabbro (XAmg) constitutes a considerable part of the gneissic rocks in the northeastern part of the map area. The metagabbro bodies in the gneisses are probably an older generation of mafic rocks than metadiabase in the volcanic succession to the south. Medium- to coarse-grained metadiabase (Xmd) is exposed in several areas within the volcanic succession. Exposures at the west end of the hill in the SE1/4 NE1/4 sec. 10, T. 35 N., R.10 E., consist of metadiabase that contains somewhat altered feldspar and hornblende crystals as long as 3 mm, but the rock retains the original diabasic texture. Along the southern margin of the outcrop area in sec. 10, T. 35 N., R.10 E., the metadiabase is strongly foliated and is converted to an amphibolite; however, the presence of actinolite and chlorite indicates that metamorphism is low grade (greenschist facies). A similar area of amphibolite is exposed about 0.5 mi to the east, in the SW1/4 NE1/4 sec. 11, T. 35 N., R.10 E., where it is cut by small undeformed dikes of the same granite occurring at Jennings.

A metagabbro body in the W1/2 sec. 15, T. 36 N., R.11 E. produces a conspicuous aeromagnetic anomaly. Pyroxenes are converted to hornblende; however, most of the body contains little or no foliation. The metagabbro is cut by numerous granitoid dikes up to 1 m wide.

Quartz Porphyry (Xqp)—A distinctive quartz porphyry underlies approximately 36 km^2 in the northern part of the map area. The rock is characterized by a felsic gray aphanitic matrix containing abundant euhedral to subhedral, somewhat embayed, commonly blue-quartz phenocrysts (fig. 8) up to 1 cm in diameter. Variable amounts of saussuritized feldspar phenocrysts are also present. Locally north and east of Neptune Lake the rock is mainly a massive quartz porphyry; however, variations in concentrations of phenocrysts produce a subtle layering, and local, 1- to 3-meter-thick tuffaceous layers with clasts as long as 10 cm suggest that the rocks are mainly volcanic. Lens-shaped mafic pods and basaltic dikes are relatively common in the quartz porphyry. West of Neptune Lake the exposures are massive quartz porphyry with scattered basaltic dikes and xenoliths of metabasalt and gneissic rocks. The northern and western margins of the body (in R.10 E. near the North Branch of the Pelican River) are primarily an intrusion breccia (fig. 9) containing abundant blocks of gneiss, metabasalt, and segmented diabase dikes in a foliated blue-quartz porphyry matrix. This suggests that the northern and western margins of the body are intrusive into a gneissic country rock, in contrast to the extrusive relations farther east. Quartz porphyry dikes in massive metabasalt near U.S. Route 8 in the W1/2 sec. 29, T. 36 N., R.10 E., suggest that the quartz porphyry postdates and intrudes basalts along its southern margin.

Post-Tectonic Granite (Xg)—Relatively undeformed, pink granitoid intrusions cut the highly deformed volcanic and gneissic rocks in the Monico area. Approximately 46 km^2 at the southern margin of the map area (figs. 2 and 3) near Pelican Lake is underlain by massive pink to red granite that yields a uranium/lead zircon age of 1,739 ± 8 Ma (Sims and others, 1989). The granite is a medium-grained rock composed of quartz, microcline, and plagioclase.

Outcrops of undeformed to weakly foliated granite in the N1/2 SE1/4 sec. 14, T. 35 N., R.11 E., north of the small community of Jennings (fig. 3) are apparently an apophysis of the larger granitic body to the west.

A similar undeformed, locally porphyritic granite of unknown extent intrudes gneissic rocks in the NW1/4, SE1/4, and NE1/4, sec. 17, T.36 N., R.10 E., near the North Branch of the Pelican River in the northwest corner of the map area, but the outcrops are too small to show at the scale of the map (fig. 3). This granite also occurs just outside the map area.

Diabase (Yd)—Unmetamorphosed diabase, containing plagioclase laths about 5 mm long in a pyroxene matrix, is exposed in several places, such as the southwest corner of the intersection of U.S. Routes 8 and 45. The diabase dike forms a prominent aeromagnetic anomaly that transects the entire map area. It is one of a swarm of diabase dikes that were emplaced during formation of the Midcontinent Rift (Wold and Hinze, 1982).

STRUCTURE

The Monico area has been subjected to at least five deformational events: DA_1, D_1, D_2, D_3, and D_4 (table 1). Evidence for D_2, D_3, and D_4 is found or is inferred to exist in all of the rock units except the granite at Jennings and the diabase dike, which postdate Early Proterozoic deformation. D_1 does not occur in the gneiss along the northern edge of the map area, nor does it

Table 1.—Summary of structural events and features in the Monico area

Event	Structural features	Remarks
DA_1	SA_1	Vertical north-striking banding with a right-lateral sense of horizontal movement. Found only in the gneiss unit in the northern part of the map area.
D_1	S_1, flattened clasts	Prominent, vertical east-striking foliation, with flattened, pancake-shaped clasts in S_1, and some minor folds. Occurs mainly in the volcanic succession and in the quartz porphyry. Does not occur in the gneiss to the north.
D_2	S_2	Direct N. 35° to 60° E.-striking, vertically dipping shear zones that crosscut S_1. Sense of movement is right lateral, up on the southeast. Shear zones occur mainly in the volcanic succession but are also present in the gneiss to the north. Seen as northeast trends on the aeromagnetic map (fig. 3).
D_3	S_3, L_3	Prominent, nearly vertical, east-striking mylonitic shear zones that overprint S_2 foliation. Deformation was constrictional with L_3 stretch axes and mineral lineations plunging west to steeply south. Sense of movement is right lateral, north side up.
D_4	S_4	North-trending spaced fractures filled with quartz and felsic veins. Marks late east-west extension and brittle deformation.

occur in the diabase dike or in the granite at Jennings, and DA_1 exists only in the gneiss along the northern edge of the map area.

Orientation of foliations (SA_1, S_1, S_2, and S_3) and lineations (L_3) of deformational events DA_1, D_1, D_2, and D_3 are shown in figure 10*A–G*. SA_1 is expressed as a vertical, north-oriented, spaced foliation in the gneiss along the northern edge of the map area (fig. 10*A*). S_1 is a vertical, east-oriented, penetrative foliation that occurs in much of the volcanic strata (fig. 10*B*) and in the quartz porphyry (fig. 10*C*). Vertical, northeast-oriented S_2 foliation occurs in isolated zones in the volcanic strata (fig. 10*D*) and in the gneiss along the northern edge of the map area (fig. 10*E*). S_3 is a penetrative, east-oriented, vertical foliation that occurs in discrete zones several meters wide in the volcanic strata (fig. 10*F*) and possibly near the southern margin of the gneiss in the SE1/4 sec. 17, T. 36 N., R.10 E., in the northern part of the map area (fig. 10*G*). L_3 lineations (fig. 10*F*) are found as stretched clasts in the volcanic strata (orientation shown by solid dot).

Abundant kinematic data (see Simpson and Schmidt, 1983) for deformational events (DA_1, D_1, D_2, and D_3) were found in the field and in oriented thin-sections. Selected examples of these kinematic data are shown in figure 11 from field measurements and in figure 12 from thin-section analyses. The locations where the kinematic analyses were done are shown by the location numbers in figure 2 and corresponding location numbers in figures 11 and 12.

DA_1 deformation

The earliest deformation in the Monico area is preserved as a variously oriented foliation in mafic clasts within the gneissic intrusion breccia found along the northern edge of the map area (fig. 2). DA_1 is the next event, in which the gneissic intrusion breccia is overprinted by a north-striking vertical fabric (SA_1). Mafic clasts in the granitoid matrix of the gneiss tend to be aligned with their long dimension parallel to SA_1 foliation. Some clasts are broken with right-lateral horizontal offset. SA_1 foliation is cut by most other deformational fabrics; for example, S_2, S_3, and S_4.

D_1 deformation

D_1 was a ductile deformational event. It is expressed as a nearly vertical, N. 85° E.- to N. 80° W.-oriented foliation (S_1) in nearly all the volcanic units and possibly in the quartz porphyry north of U.S. Route 8. Stratigraphically south-facing pillows are flattened parallel to S_1, and primary volcanic layering lies parallel to S_1 foliation.

Although large-scale folding was not observed, certain data suggest isoclinal folding at all scales. For example, the parallelism of primary layering to S_1 foliation, and the tight to isoclinal folding of bedding and flow-banding with S_1 axial planar foliations (figs. 11*A* and *B*) suggest tight to isoclinal folding at all scales. Opposite sense of movement on folds in flow banding in figures 11*A* and *B*, for example, suggests that these may be parasitic folds on opposite limbs of a larger fold. This interpretation is supported by studies of drill core from the Pelican River massive sulfide deposit (Bowden, 1978), which indicates that the ore zone is a tight anticlinal structure.

Several kinematic indicators for D_1 deformation were found. A sigmoidally deformed phyllosilicate pod (fig. 11*C*) yields a left-lateral sense of movement, and kinematic data from photomicrographs (figs. 12*A* and *B*) indicate north-side-up movement. Thus, the D_1 kinematic indicators suggest left-lateral, north-side-up movement during D_1 deformation.

D_1 kinematic indicators, however, are not as conspicuous or abundant as D_2 or D_3 kinematic indicators. This may reflect the fact that measured principal strain axes of volcanic clasts that lie within S_1, but away from S_2 and S_3 deformational fabrics, plot mainly in the field of flattening on a Flinn (1962) diagram (fig. 13). Clasts are equidimensional on the S_1 surface, but are flattened perpendicular to S_1.

The quartz porphyry near Neptune Lake in sec. 19, T. 36 N., R.11 E., has a prominent east-striking, nearly vertical foliation (fig. 10*C*) which we interpret either as S_1, or S_3 as explained below in the Interpretation section. Xenoliths of basalt in the porphyry also possess an east-striking foliation, and 25-cm-wide veins of granite and quartz are folded about the S_1 axial planar foliation.

A nearly east-trending foliation labelled S_3 in figure 10*G* occurs in the NW1/4 SE1/4 sec. 17, T. 36 N., R.10 E., near the southern edge of the gneiss in the northern part of the map area. Although it is nearly parallel to S_1, we interpret this foliation as a D_3 fabric, rather than D_1 as explained below.

D_2 deformation

D_2 deformation was also ductile. It is represented by isolated, vertical, N. 35–60° E. S_2 shear zones up to several meters wide. The S_2 shear fabric crosscuts S_1 foliation as shown in figure 11*A*.

Kinematic data, as shown by minor z-folds in quartz veins (fig. 11*D*) indicate right-lateral movement during D_2. Likewise, S_1 is crosscut in a steeply southeast-dipping D_2 shear zone (fig. 11*E*), indicating up-on-the-southeast movement. Furthermore, right-lateral, southeast-side-up movement is illustrated by deformed quartz grains (figs. 12 *C* and *D*) in S_2 foliation.

In the gneissic rocks along the northern edge of the map area, north-oriented foliation is overprinted by widely spaced zones of S_2 fracture foliation and associated anastomosing quartz-felsite veins that strike N. 35° E. and dip steeply northwest (fig. 10*E*). This northeast-trending fabric in the gneiss is roughly parallel to N. 40° E.-trending lineaments on the aeromagnetic map which extend into the volcanic rocks. We interpret the northeast-trending foliation in the gneiss and the northeast-trending aeromagnetic lineaments to be D_2 features. The difference in orientation of S_2 in the volcanic rocks and the gneiss is problematic (compare stereoplots in figs. 10*D* and *E*). Possibly S_2 is refracted across the gneiss-volcanic boundary and reflects differences in rheologic properties of the rocks. Alternatively, S_2 foliation in the gneiss may be an older fabric. However, we believe that the northeast-trending aeromagnetic lineaments are expressions of D_2 shear zones, and their continuation from the gneiss into the volcanic rocks suggests a common origin for the fabric in both rocks.

D_3 deformation

D_3 deformation produced distinctive, nearly vertical N. 88° E.-trending (fig. 10*F*) zones of ultramylonite as wide as 35 to 40 m, especially in the SW1/4 sec. 34, T. 36 N., R.10 E., and the NW1/4 NW1/4 sec. 3, T. 35 N., R.10 E. Mylonitic shear zones formed by this event grade inward from protomylonite to ultramylonite (see Wise and others, 1981) within the shear zones. Collectively, kinematic field data (figs. 11*F* and *G*) and photomicrographic data (figs. 12*E* and *F*) indicate right-lateral, north-side-up sense of shearing. Sigmoidally shaped volcanic clasts with S_2 foliation (fig. 11*F*; full length of clasts not seen here) form a sigmoidal S-C pattern in the alternating quartz-rich phyllosilicate bands (stippled) (see Lister and Snoke, 1984), indicating that the north side is up. Likewise, figure 11*G* shows volcanic clasts that are oriented with their long (stretch) axes slightly inclined to S_3, indicating right-lateral movement. A deformed quartz grain shown in figure 12*E* indicates north-side-up D_3 deformation. The orientation of the tension veins and slight inclination of the volcanic clast to S_3 foliation in figure 12*F* suggest right-lateral D_3 deformation.

Dimensions of measured clasts in S_3 plot within the fields of constriction and plane strain as shown on the Flinn (1962) plot (fig. 13). This is supported by data from the NE1/4 sec. 1, T. 35 N., R.10 E., where stretched volcanic clasts and quartz amygdules plunge steeply west (L_3 in figure 10*F* shows average orientation of long axes of clasts) within S_3 foliation. Quartz-filled gashes in a stretched volcanic clast (fig. 12*F*) are oriented perpendicular to the L_3 axis of stretching. These stretch axes are uncharacteristic of D_1 deformation, which was primarily a flattening event. Thus, we interpret these outcrops (location 6 in figure 2) as part of the D_3 deformational event and extend the D_3 shear zone eastward to this region.

In general, there is no penetrative east-trending foliation in the gneiss along the northern edge of the map area. Thus, we interpret prominent, but localized, east-trending foliation (fig. 10*G*) that lies near the southern margin of the gneiss unit to be S_3. This suggests that the contact between the gneiss and volcanic rocks may be a shear zone, but such a shear zone has not been identified in the field, perhaps due to lack of adequate outcrop. It cannot be ruled out that the east-trending foliation in the gneiss was caused by D_1 deformation.

Most metadiabase-metagabbro bodies are not foliated; however, they contain local zones of deformation, producing foliated and lineated amphibolite (for example, SE1/4 NE1/4 sec. 10, T. 35 N., R.10 E.). These zones may represent either S_1 or S_3. The amphibolite is cut locally by undeformed veins of post-orogenic granite.

The marked parallelism between S_3 and S_1 foliation suggests that S_1 surfaces may have controlled subsequent D_3 deformation, with D_3 slip occurring along pre-existing S_1 foliation surfaces.

D_4 deformation

This deformation is expressed as a late, vertical, north-striking spaced fracture fabric, with most fractures filled with quartz or quartz-feldspar veins. The D_4 features were not studied in detail, but they indicate a late east-west extensional event in this region. The same fracture system is found in the gneissic rocks to the north. The S_4 fractures in the gneiss are also spaced, north-striking fractures, some filled with quartz and (or) quartz-feldspar veins that cut the gneiss and earlier deformational fabrics.

Structural features and the aeromagnetic map

There is a close correlation between trends on the aeromagnetic map (fig. 3) and the structural features discussed above. For example, a prominent aeromagnetic gradient generally coincides with an east-trending mylonitic shear zone just south of and parallel to the boundary between T. 35 N. and T. 36 N. This shear zone roughly marks a boundary between felsic and mafic volcanic rock units.

The northeast-trending lineaments on the aeromagnetic map are more or less parallel to S_2 shear zones in both the gneiss and volcanic rocks. Thus, as noted above, because the aeromagnetic lineaments extend from the gneiss into the volcanic succession, the northeast-trending features in the gneiss and volcanic succession are assumed to be coeval.

Summary of structural features

Rocks in the Monico area have undergone at least five deformational events: DA_1, D_1, D_2, D_3, and D_4 (table 1). Besides the randomly oriented gneissic foliation, the DA_1 event is older than all other structural features and occurs only in the gneiss along the northern edge of the map area. D_1 was a regional flattening event that affected the volcanic succession and possibly the quartz porphyry but not the gneisses to the north, suggesting either thin-skinned deformation or lack of development of S_1 in the gneiss. It formed a penetrative S_1 foliation, flattened the volcanic clasts, and formed small, tight to isoclinal folds suggesting that the volcanic succession may be repeated by folding, but firm evidence in the Monico area for such large-scale folding is lacking. D_2 formed discrete northeast-trending, right-lateral, up-on-the-south shear zones (S_2). Parallel northeast trends on the aeromagnetic map indicate that the shear zones are regional, extending into the gneissic rocks to the north. D_3 formed conspicuous east-trending, vertical, right-lateral, up-on-the-north mylonitic shear zones (S_3). Also, isolated zones of foliation occur near the southern edge of the gneiss. One possibility, discussed further below, is that these zones of foliation are expressions of a D_3 shear zone that separates the gneiss from the volcanic strata to the south. D_4 was a late, brittle deformation that formed north-trending vertical fractures (S_4), which were filled with quartz and quartz-feldspar veins in both the volcanic rocks and the gneiss.

ECONOMIC GEOLOGY

Pelican River massive sulfide deposit

The Pelican River massive sulfide deposit is located in the NE1/4 SW1/4 sec. 29, T. 36 N., R.10 E., in the western part of the map area (figs. 2 and 3). There are no exposures of mineralized rocks. Therefore, the description of the mineralized zone is taken from Bowden (1978), who studied drill cores of the deposit, and DeMatties (1994). An Early Proterozoic age for the deposit was established by Afifi and others (1984).

DeMatties (1994) described the Pelican River deposit as a stacked-lens zinc-copper deposit within a bimodal volcanic sequence. The mineralized zone consists of a number of stacked massive sulfide lenses within a felsic volcanic unit. The lower, copper-rich lenses contain pyrite-chalcopyrite-(sphalerite), and are overlain by zinc-rich lenses composed of banded pyrite-sphalerite, and both of these massive sulfide zones stratigraphically overlie a stockwork zone with chalcopyrite, pyrite, and magnetite (Bowden, 1978, p. 12). Chalcopyrite-pyrrhotite-stringer mineralization overprints the massive sulfide lenses in the lower parts of the mineralized zone (DeMatties, 1994, p. 1143). Mineralization is confined mainly to dacitic to rhyolitic tuffaceous rocks, interbedded with and bounded by mafic volcanic units (Bowden, 1978). Mineralization has a strike length of 1,000 ft (305 m), a downdip length of 650 ft (198 m), and an average thickness of 50 ft (15 m). For a more detailed description of the deposit, the reader is referred to Bowden's (1978) report.

Timber-cutting operations in the W1/2 sec. 29, T. 36 N., R.10 E. resulted in relatively abundant rock exposures at about the stratigraphic level of the deposit, which aids in interpreting the geologic setting in which the deposit formed. In contrast, exposures are largely lacking in the vicinity of the Crandon deposit, some 28 km to the east, and the Lynne deposit, 50 km to the west. Rocks in the Monico area consistently face stratigraphically south. Lambe and Rowe (1987) report that the volcanic succession at Crandon faces north, and Adams (1996) reports that the volcanic succession that hosts the Lynne deposit also faces north. This suggests that the Monico area may be on a limb of a large fold within the Pembine-Wausau terrane.

The Pelican River deposit occurs in a bimodal suite of volcanic rocks having dominantly tholeiitic affinity. This suggests that the deposit formed during a time of extension (rifting) during the evolution of the Pembine-Wausau terrane, perhaps in a back-arc setting. This is consistent with the bimodal nature of the volcanic rocks (DeMatties, 1994) and the extensional environment suggested for more recent massive sulfide deposits, such as the Kuroko deposits in Japan (Dudas and others, 1983).

Exposed rocks in the stratigraphic level of the Pelican River deposit are mainly altered basaltic rocks cut by innumerable felsic dikes and sills. The mafic component is massive, aphanitic and porphyritic basalt extensively veined by epidote, quartz, and quartz-feldspar (fig. 14). Some exposures are a massive gray-green altered mafic volcanic rock containing lensoidal pods of white-weathering siliceous material, irregular patches of epidote, and randomly oriented hornblende needles. Medium-grained mafic units, some highly porphyritic that are also intensely epidotized and veined with quartz, appear to be altered metadiabase sills.

An approximately 1-meter-thick zone of intensely deformed layered chloritic material containing abundant lensoidal pods of carbonate occurs within the generally volcanic sequence. Weathering has removed much of the carbonate, forming a highly pitted surface. Although it does not crop out well, the chloritic zone appears to extend for several hundred meters.

Several generations of felsic rocks, in veins, dikes and sills that range from a few millimeters to several meters wide, along with innumerable quartz and quartz-feldspar veins, cut the mafic rocks. Although much of the felsic material is aphanitic and appears volcanic in hand specimen, contact relations indicate that it is intrusive into the basaltic rocks (fig. 15). A porphyritic phase of felsic sills and dikes, containing blue quartz phenocrysts similar to the quartz porphyry intrusion to the north, cuts the basaltic rocks, and is, in turn, cut by non-porphyritic felsic dikes and sills. This system of felsic dikes and sills, widespread epidotization, and the myriad of quartz and quartz-feldspar veins presumably formed in the hydrothermal system above a felsic intrusion that generated the Pelican River deposit.

Chemically the quartz porphyry pluton in the Neptune Lake area is compositionally similar to the dacitic volcanic rocks within the Pelican River deposit that overlie it to the south (Klaus J. Schulz, U.S. Geological Survey, oral commun., 1990). The eastern part of the body, at least in part, is extrusive, whereas the western part is clearly intrusive. The porphyry probably represents a subvolcanic pluton emplaced approximately along the contact between the gneisses on the north and the volcanic rocks on the south. The contact between the gneiss and the porphyry is poorly exposed, but both units have an east-trending shear fabric in the few places where they are exposed. The volcanic rocks overlying the quartz porphyry are extensively epidotized and silicified, and they contain numerous quartz-feldspar veins indicative of hydrothermal alteration. These epidotized and silicified rocks underlie the massive sulfide deposit near the Pelican River (fig. 3).

Volcanic rocks exposed at the stratigraphic level of the Pelican River deposit have few primary features preserved, due to extensive alteration. As a result, direct evidence on the depth of water in which the deposit formed is lacking. However, the volcanic succession has been, at least in part, repeated by faulting. Therefore, data from other volcanic rocks in the region may be relevant in inferring the setting in which the sulfides formed.

Pillows in basaltic rocks in the Monico area are commonly highly amygdaloidal, suggesting a shallow-water origin. The felsic volcanic rocks contain lava flows and welded tuffs, suggesting at least local emergence. Sedimentary rocks are relatively scarce, suggesting that the Monico area was a volcanic center and a topographic high. Rocks indicative of deep water are lacking. Therefore, the available evidence suggests that the volcanic rocks in the Monico area formed in relatively shallow water.

The general setting of the Pelican River deposit appears to fit the depositional model proposed by Franklin and others (1981). The quartz porphyry pluton to the north stratigraphically underlies the massive sulfide deposit and may have provided heat for the hydrothermal system that formed the deposit and the highly altered basaltic rocks now exposed along U.S. Route 8. The Pelican River deposit appears to have formed in relatively shallow water in a volcanic setting over a subjacent (subvolcanic?) pluton in an extensional environment within the Pembine-Wausau terrane.

Massive sulfide deposits, informally referred to as the "Duckblind," "Rabbit," and "Lobo," also occur in the eastern part of the map area (figs. 2 and 3). They are collectively referred to as the Wolf River deposit by DeMatties (1994). The deposits, presumably subeconomic, occur in the NE$^{1}/_{4}$ sec. 9, T. 35 N., R.11 E., where 10 drill holes were cored, and in the N$^{1}/_{2}$ sec. 4, T. 35 N., R.11 E. (fig. 3), where 17 cores were taken. There is no description of the mineralized rocks in the public record. However, outcrops in the general mineralized area are lithic and crystal felsic tuffs interbedded with mafic volcanic rocks. Thus, the lithologies are generally similar to those at the Pelican River deposit.

INTERPRETATION

The Monico area contains several lithologic units, including (1) a sequence of gneissic rocks that have been metamorphosed to amphibolite grade; (2) a bimodal sequence (or sequences) of mafic and felsic volcanic rocks and associated subvolcanic intrusions that have been complexly deformed and metamorphosed to upper greenschist facies; (3) a synvolcanic granitoid body that intrudes the lower part of the volcanic pile as well as the older gneiss; (4) Early Proterozoic metadiabase bodies; (5) a post-tectonic granite that cuts all older rock units; and (6) an unmetamorphosed diabase dike that transects all structures in the area. These units and, in large part, the structural features within them, are consistent with comparable features that occur elsewhere in the Wisconsin magmatic terranes.

The gneiss exposed in the northern part of the map area represents the oldest rock-forming event in the Monico area. It has a structural grain and metamorphic grade distinctly different from that of other rocks in the area. The origin of the gneiss is uncertain; it may be highly metamorphosed Early Proterozoic rocks produced during early stages of subduction, and may represent some of the earliest-formed volcanic rocks. Alternatively, it may represent Archean rocks that were uplifted from a buried continental margin along which the volcanic rocks were accreted. The age of the gneiss is especially problematic because its north-trending structural grain is significantly different from the east-trending structures found in Early Proterozoic units elsewhere in northern Michigan and Wisconsin. Van Wyck (1995) obtained uranium/lead zircon ages of 1894 ± 4 Ma and 1859 ± 2.9 Ma for the gneiss, making it clearly Early Proterozoic.

The next event in the Monico area was the deposition of a bimodal suite of mafic and felsic volcanic rocks. It is not known whether these volcanic rocks were deposited on Archean crust, on eroded remnants of metamorphosed and deformed older Early Proterozoic volcanic rocks, or directly on oceanic crust. Regardless of the substrate, the volcanic pile consists of intercalated mafic and felsic volcanic rocks with subordinate amounts of sedimentary rocks. This bimodal suite of volcanic rocks may have formed during an intra-arc rifting event associated with convergence in a subduction environment. Metasedimentary rocks, mainly graywackes, are common in drill cores to the south, east, and west (LaBerge, 1988), suggesting that the Monico area was an igneous center, probably a volcanic island flanked by sedimentary basins. This interpretation is supported by the fact that the basaltic pillow lavas and pillow breccias tend to be highly amygdaloidal, suggesting shallow-water deposition. Furthermore, welded tuffs in the felsic volcanic sequence suggest at least periodic emergence.

Because of the abundance of outcrop near Monico relative to other parts of the Wisconsin magmatic terranes, it is possible to generally work out the details of deformation. Our interpretation of the structure and stratigraphy is shown in figure 16. The gneissic rocks with north-trending foliation (SA_1) are overlain to the south by a volcanic succession that has a conspicuous east-trending fabric (S_1, not shown in figure 16). This east-trending fabric is also present in the quartz porphyry that intrudes both the gneiss and volcanic strata, but it is not present in the gneiss. One explanation for the lack of S_1 in the gneiss may be that the gneiss was not significantly affected by D_1 deformation, whereas the volcanic strata and quartz porphyry were. Alternatively, it is possible that the east-trending fabric in the quartz porphyry is not D_1 in age, but rather is D_3 in age. According to this explanation, the volcanic strata were detached from the underlying gneiss during D_1 along a decollement. The quartz porphyry intruded the gneiss and volcanic strata along the detachment zone. Reactivated deformation of the detachment zone during D_3 also affected the quartz porphyry, thus accounting for the D_3 age of the east-trending fabric in the quartz porphyry. The east-trending foliation near the southern part of the gneiss (see the weak, east-trending foliation in the gneiss in the northwest corner of the map area in figure 16) is an expression of this D_3 shear zone. Because of these uncertainties, the inferred detachment zone shown in figure 16 is not shown in figures 2 or 3. D_2 deformation formed northeast-trending shears (S_2) that cut both the volcanic rocks and the gneiss. The prominent D_3 mylonitic shear zones appear to have tectonically repeated the bimodal volcanic succession as shown diagrammatically in figure 16. Metagabbro bodies are probably of variable age, but some predate S_3 because they were sheared and metamorphosed to form amphibolite gneiss. Following an east-west extensional event (not shown in figure 16) which formed S_4 fractures, the area was intruded by post-tectonic granites both in the south and north and later by Keweenawan diabase.

TECTONIC SIGNIFICANCE

The Pembine-Wausau terrane lies south of the Niagara fault, a proposed suture in the Penokean orogen (Sims and others, 1989). Attoh and Klasner (1989) and Klasner and others (1985) suggested that the margin of the continental foreland, which is exposed north of the Niagara fault, actually lies in the subsurface, well south of the Niagara suture (fig. 17) along a prominent gravity gradient. This suggests that the region between the Niagara fault and the southern edge of the buried continental margin is underlain by Archean crust, implying that the Pembine-Wausau terrane is allochthonous and thrust northward onto the continental margin of the Superior province. As part of the Pembine-Wausau terrane, the Monico area also lies within part of the Penokean orogen that is marked by prominent east-trending structures with superimposed northeast-trending mylonitic ductile shear zones similar to the Athens, Jump River, and Mountain shear zones. Thus the stratigraphy and structures near Monico mimic broader-scale features observed elsewhere in the Pembine-Wausau terrane. The Monico area provides detailed information on structure and stratigraphy that is not available elsewhere in the Pembine-Wausau terrane.

The bimodal volcanic succession and sequence of deformational events in the Monico area provide new data on the tectonic evolution of the Pembine-Wausau terrane. We suggest that the volcanic succession is part of an allochthonous package of rocks thrust northward onto the now-buried continental margin. Initial docking was from the south and created a compressional (largely pure strain) stress regime that formed a regional S_1 foliation and flattened volcanic clasts. This was probably a thin-skinned event because it did not affect the underlying gneiss. Similar thin-skinned deformation is common elsewhere on the continental foreland to the north (see Klasner and others, 1991). This was followed by vergence from the east-southeast as shown by the right-lateral, up-to-the-south, northeast-trending ductile D_2 shear zones found in the Monico area. These northeast-trending shear zones have the same sense of movement as the northeast-trending Athens shear zone to the south (Klasner and LaBerge, 1985) and the well-studied Mountain shear zone to the east (Sims and others, 1990).

The gravity gradient shown in figure 17 suggests that the Monico area lies along the southern edge of the buried continental margin. If so, the region would be where there was an abrupt change in crustal thickness and strength. This condition may have produced out-of-sequence backthrusts which thickened and strengthened the north-verging thrust plate during docking of the island arc, similar to the interpretation by Morey (1988). The D_3 mylonite zones may represent such backthrusts, which, at the tectonic level exposed in the Monico area, are right-lateral, north-side-up vertical shears that have tectonically repeated the volcanic section.

As discussed above, the age of the gneissic rocks in the northern part of the area is problematic. The north-trending deformational fabric is unknown elsewhere in Early Proterozoic rocks in Wisconsin or northern Michigan, except in discrete ductile shear zones. Therefore, the structure in the gneisses may be interpreted as (1) an Archean structure, implying that the gneisses are Archean; (2) an Early Proterozoic structure in a block of rocks subsequently rotated and uplifted during collision; or (3) a heretofore unrecognized Early Proterozoic deformational event. The recent uranium/lead zircon dating of the gneisses in the Monico area by Van Wyck (1995) indicates that the gneisses are Early Proterozoic in age. This would support either alternative 2 or 3 as correct.

REFERENCES CITED

Adams, G.W., 1996, Geology of the Lynne base-metal deposit, north-central Wisconsin, U.S.A., *in* LaBerge, G.L., ed., Volcanogenic massive sulfide deposits of northern

Wisconsin; a commemorative volume: Proceedings and Abstracts, Institute on Lake Superior Geology, 42d Annual Meeting, v. 42, part 2, p. 161–179.

Afifi, Afifa, Doe, B.R., Sims, P.K., and Delevaux, M.H., 1984, U-Th-Pb isotope chronology of sulfide ores and rocks in the Early Proterozoic metavolcanic belt of northern Wisconsin: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 79, no. 2, p. 338–353.

Attoh, Kodjopa, and Klasner, J.S., 1989, Tectonic implications of metamorphism and gravity field in the Penokean orogen of northern Michigan: Tectonics, v. 8, no. 4, p. 911–933.

Bowden, D.R., 1978, Volcanic rocks of the Pelican River massive sulfide deposit, Rhinelander, Wisconsin; a study in wall-rock alteration: Michigan Technological University, Houghton, Mich., unpublished M.S. thesis, 62 p.

DeMatties, T.A., 1994, Early Proterozoic volcanogenic massive sulfide deposits in Wisconsin; an overview: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 89, no. 5, p. 1122–1151.

Dudas, F.O., Campbell, I.H., and Gorton, M.P., 1983, Geochemistry of igneous rocks in the Hokuroku district, northern Japan, *in* Ohmoto, H., and Skinner, B.J., eds., The Kuroko and related volcanogenic massive sulfide deposits: Economic Geology Monograph 5, p. 115–133.

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, 7 sheets.

Flinn, Derek, 1962, On folding during three-dimensional progressive deformation: Geological Society of London Quarterly Journal, v. 118, part 4, no. 472, p. 385–433.

Franklin, J.M., Sangster, D.M., and Lydon, J.W., 1981, Volcanic-associated massive sulfide deposits, *in* Skinner, B.J., ed., Economic Geology 75th Anniversary Volume, 1905–1980: The Economic Geology Publishing Co., p. 485–627.

Klasner, J.S., and LaBerge, G.L., 1985, Structural geology and kinematics of Early Proterozoic shear zones in central Wisconsin [abs.]: Proceedings and Abstracts, Institute on Lake Superior Geology, 31st Annual Meeting, p. 46.

Klasner, J.S., King, E.R., and Jones, W.J., 1985, Geologic interpretation of gravity and magnetic data for northern Michigan and Wisconsin, *in* Hinze, W.J., ed., The utility of regional gravity and magnetic anomaly maps: Tulsa, Okla., Society of Exploration Geophysicists, p. 267–286.

Klasner, J.S., Ojakangas, R.W., Schulz, K.J., and LaBerge, G.L., 1991, Nature and style of deformation in the foreland of the Early Proterozoic Penokean orogen, northern Michigan: U.S. Geological Survey Bulletin 1904–K, p. K1–K22.

LaBerge, G.L., 1988, Exploration drill cores in the Wisconsin magmatic terrane: U.S. Geological Survey Open-File Report 88–536, 72 p.

——1991, Early Proterozoic rocks in the Monico, Wisconsin area; implications on the Wisconsin magmatic terrane [abs.]: Proceedings and Abstracts, Institute on Lake Superior Geology, 37th Annual Meeting, part 1, p. 65–66.

Lambe, R.N., and Rowe, R.G., 1987, Volcanic history, mineralization, and alteration of the Crandon massive sulfide deposit, Wisconsin: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 82, no. 5, p. 1204–1238.

Lister, G.S., and Snoke, A.W., 1984, S-C mylonites: Journal of Structural Geology, v. 6, no. 6, p. 617–638.

May, E.R., and Schmidt, P.G., 1982, The discovery, geology, and mineralogy of the Crandon Precambrian massive sulfide deposit, Wisconsin, *in* Hutchinson, R.W., Spence, C.D., and Franklin, J.M., eds., Precambrian sulfide deposits: Geological Association of Canada Special Paper 25, p. 446–480.

Morey, G.K., 1988, Out-of-sequence thrusts: Tectonics, v. 7, p. 539–561.

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

Schulz, K.J., 1987, An Early Proterozoic ophiolite in the Penokean orogen: Program with Abstracts, Joint Annual Meeting of the Geological Association of Canada, Mineralogical Association of Canada, and Canadian Geophysical Union, v. 12, p. 87.

Simpson, Carol, and Schmidt, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geological Society of America Bulletin, v. 94, no. 11, p. 1281–1288.

Sims, P.K., comp., 1992, Geologic map of Precambrian rocks, southern Lake Superior region, Wisconsin and northern Michigan: U.S. Geological Survey Miscellaneous Investigations Series Map I–2185, scale 1:500,000, 2 sheets.

Sims, P.K., Klasner, J.S., and Peterman, Z.E., 1990, The Mountain shear zone, northeastern Wisconsin; a discrete ductile deformation zone within the Early Proterozoic Penokean orogen: U.S. Geological Survey Bulletin 1904–A, p. A1–A15.

Sims, P.K., Van Schmus, W.R., Schulz, K.J., and Peterman, Z.E., 1989, Tectonostratigraphic evolution of the Early Proterozoic Wisconsin magmatic terranes of the Penokean orogen: Canadian Journal of Earth Science, v. 26, no. 10, p. 2145–2158.

Van Wyck, Nicholas, 1995, Major and trace element, common Pb, Sm-Nd, and zircon geochronology constraints on petrogenesis and tectonic setting of pre- and Early Proterozoic rocks in Wisconsin: University of Wisconsin, unpublished Ph.D. thesis, 280 p.

Venditti, A.R., 1973, Petrochemistry of Precambrian rocks in southeastern Oneida County, Wisconsin: University of Wisconsin–Milwaukee, unpublished M.S. thesis, 93 p.

Wise, D.U., Dunn, D.E., Engelder, J.T., Geiser, P.A., Hatcher, R.D., Kish, S.A., Odom, A.L., and Schamel, S., 1984, Fault-related rocks; suggestions for terminology: Geology, v. 12, no. 7, p. 391–394.

Wold, R.J., and Hinze, W.F., eds., 1982, Geology and tectonics of the Lake Superior basin: Geological Society of America Memoir 156, 280 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 2001 — 673-049 / 30044 Region No. 8