New Observations on the Age and Structure of Proterozoic Quartzites in Wisconsin

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Chapter B

New Observations on the Age and Structure of Proterozoic Quartzites in Wisconsin

By GENE L. LABERGE, J.S. KLASNER, and PAUL E. MYERS

U.S. GEOLOGICAL SURVEY BULLETIN 1904

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New Observations on the Age and Structure of Proterozoic Quartzites in Wisconsin

By Gene L. LaBerge,[1] J.S. Klasner,[2] *and* Paul E. Myers[3]

Abstract

Proterozoic quartzite is exposed at several isolated localities within an area of nearly 13,000 square kilometers in Wisconsin. Although early workers proposed that the quartzite is of two different ages, more recent workers have suggested that the various quartzite bodies are correlative, and that their protoliths were deposited between 1,760 and 1,630 Ma.

Structural and stratigraphic studies of the quartzite deposits together with new age data indicate that the quartzite is at least of two distinct ages. Quartzite at McCaslin and Thunder Mountains, in northeastern Wisconsin, is older than 1,812 Ma, as indicated indirectly by a dated intrusion, and quartzite boulders in conglomerates in central Wisconsin are at least as old as the rhyolite country rock (≈1,840 Ma). Deformed quartzite at Hamilton Mounds, in south-central Wisconsin, is intruded by undeformed granite that is 1,764 Ma. The ages of many other quartzite bodies, however, cannot be tightly constrained at present.

Quartzite exposed in central and southern Wisconsin, south of the Eau Pleine shear zone, is interpreted as remnants of a passive margin sequence that was deposited on an Archean microcontinent (Marshfield terrane) and subsequently deformed in a major south-verging fold-thrust system during collision between the microcontinent and oceanic-arc rocks of the Pembine-Wausau terrane. The occurrence of quartzite-bearing conglomerates in the 1,860 Ma volcanic rocks of the Marshfield terrane suggests that the allochthonous quartzite bodies are 1,860 Ma or older. Collision occurred at about 1,840 Ma, and marked the end of the Penokean orogeny.

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INTRODUCTION

Proterozoic quartzite occurs in a variety of geologic settings at several widely separated localities in Wisconsin (fig. 1). In some areas it is possible to determine the age relationships between the quartzite and adjacent Precambrian rocks. In other areas few or no data are available to constrain the age because of an extensive cover of Paleozoic rocks and Pleistocene deposits. As a result, stratigraphic and structural relationships of the quartzite bodies to one another are not well established.

Numerous workers have studied the quartzite occurrences in Wisconsin, and a number of different ages, names, and possible correlations have been suggested. In this report we have followed the terminology used in table 1 for the quartzites in Wisconsin. Van Hise and Leith (1911) summarized earlier interpretations on the age of Precambrian quartzites in the Lake Superior region, and suggested correlation of strata based on (1) relations to series or groups of known age, (2) unconformities, (3) lithologic likeness of formations, (4) like sequence of formations, (5) subaerial or subaqueous origin, (6) relations with intrusive rocks, (7) deformation, and (8) degree of metamorphism (1911, p. 598). Based on these criteria, they suggested that the various quartzite deposits are "Huronian" in age. Thus, a general correlation of many of the quartzite occurrences based on field relations has a longstanding tradition. They suggested that the Barron Quartzite may be Keweenawan in age. Thus, they concluded that at least two distinctly different ages of quartzite probably are present in Wisconsin.

Numerous subsequent studies have contributed additional data on the nature, origin, and possible correlation of the quartzite bodies. For example, Dalziel and Dott (1970) concluded from sedimentological studies of the quartzite and isotopic studies of the slate member of the Baraboo Quartzite that this quartzite is about 1,500 Ma. Van Schmus (1978) concluded from U-Pb zircon ages of

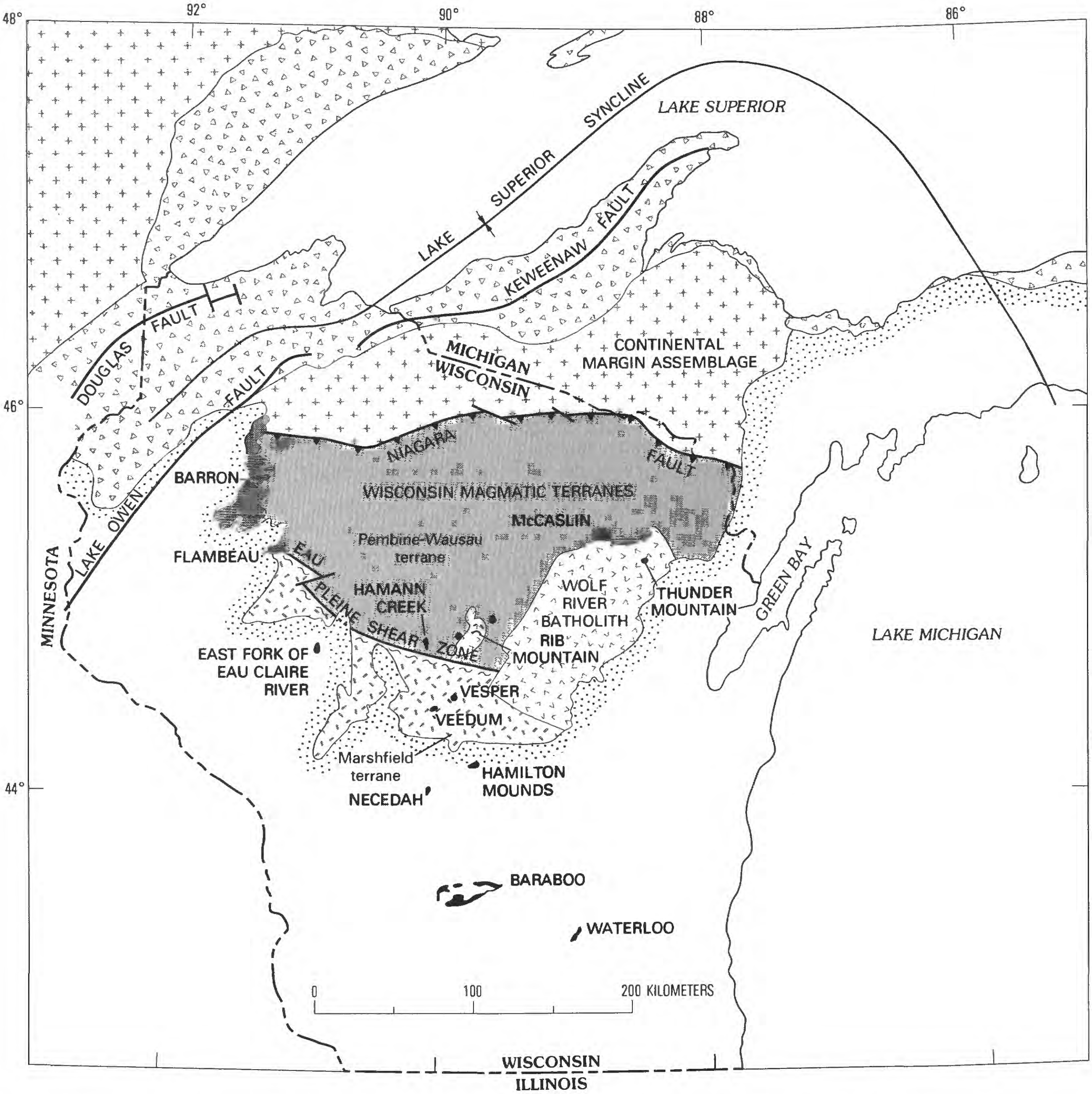

Figure 1 (above and facing page). Map showing location of quartzite occurrences in Wisconsin relative to major tectonic provinces of the region. Modified from Sims (in press).

southern Wisconsin rhyolites that the Baraboo Quartzite is younger than 1,760 Ma. Smith (1978a,b) inferred from field and chemical studies of southern Wisconsin rhyolites, as well as Rb-Sr age determinations by Van Schmus, that the Baraboo Quartzite was deformed about 1,630 Ma. An important aspect of these interpretations is that the rhyolites in the Baraboo area itself have not been dated; instead, the rhyolites at Baraboo are correlated on the basis of chemistry with dated rhyolites some 25–50 km away. Based on sedimentological studies, Dott (1983) suggested that the various quartzites in Wisconsin, namely the Baraboo, Waterloo, McCaslin, Flambeau, and Barron, as well as the Sioux Quartzite of southwestern Minnesota and adjacent South Dakota, are correlative. He suggested that the parent materials were deposited, consolidated, and deformed between 1,760 Ma and 1,450 Ma, and proposed the term "Baraboo interval" for this interval of time. He suggested that rocks of the Baraboo syncline serve as the type section for Baraboo interval rocks. Greenberg and Brown (1983, 1984) and Greenberg and others (1986) redefined Baraboo interval to include all anorogenic igneous and sedimentary activity between the end of the Penokean orogeny, which

EXPLANATION

Sedimentary rocks of Paleozoic age

Middle Proterozoic (Keweenawan) mafic igneous and sedimentary rocks of Midcontinent rift system (1,200–1,000 Ma)

Anorogenic igneous rocks (1,510–1,470 Ma)

Quartzite in central and southern Wisconsin

WISCONSIN MAGMATIC TERRANES

Quartzite in Wisconsin magmatic terranes

Island-arc metavolcanic and granitoid rocks in Pembine-Wausau terrane (1,880–1,835 Ma); includes post tectonic granitic rocks (1,760 Ma)

Island-arc metavolcanic and granitoid rocks (1,890–1,835 Ma) and gneiss (≈2,800 Ma) in Marshfield terrane

CONTINENTAL MARGIN ASSEMBLAGE

Marquette Range Supergroup (2,100–1,820 Ma) and gneiss, granite, and greenstone (3,550–2,600 Ma)

Contact

High-angle fault

Thrust fault—Sawteeth on upthrust block

Shear zone

they placed at 1,760 Ma, and the emplacement of the Wolf River batholith at approximately 1,500 Ma. They also concluded that all the Wisconsin quartzites are essentially the same age, that is, post-1,760 Ma.

Recent geologic studies (LaBerge and Myers, 1983, 1984; LaBerge and others, 1984a, 1984b; LaBerge and Klasner, 1986, 1988, 1989; Van Schmus, 1976, 1980; Sims and others, 1989; Greenberg and Brown, 1983), have led to the interpretation that the Early Proterozoic rocks and structures in Wisconsin are primarily the result of plate tectonic processes. Several major crustal domains have been identified, including the Early Proterozoic Wisconsin magmatic terranes, which are flanked on the north by Archean rocks of the Superior craton, and on the south by Archean and Proterozoic rocks of the Marshfield terrane (Sims and others, 1989) (fig. 1). The Niagara fault zone marks the boundary between Early Proterozoic igneous rocks of the magmatic terrane and the Archean Superior craton, and the Eau Pleine shear zone marks the boundary between the Pembine-Wausau terrane and the Marshfield terrane in central Wisconsin. The quartzite bodies in central and southern Wisconsin (fig. 1) appear to overlie Archean rocks of the Marshfield terrane, although some occur as isolated inliers within the Paleozoic cover in southern Wisconsin, and their relationship to basement rocks is problematical.

The purpose of this study was to determine the structural and stratigraphic relationships among the various quartzite exposures and their country rocks in an attempt to further our knowledge of these enigmatic rocks in central and southern Wisconsin. Our approach was to map structures within the various quartzite bodies and to compare the structure within individual quartzite deposits with that in associated, or nearby, igneous rocks, some of which have been dated. In this report, we present the results of our field observations for the quartzite localities shown in figure 1. We also comment on the implications of the data concerning the age and structural setting of the quartzite, and we present an interpretation of these data in terms of the Early Proterozoic plate tectonic history of the Lake Superior region.

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Several key localities discussed in this paper were brought to our attention by B.A. Brown and J.K. Greenberg, and we acknowledge their contributions with thanks. Faculty Development Grant R837 at the University of Wisconsin Oshkosh (to GLL) helped fund the study and is gratefully acknowledged. Critical reviews by K.J. Schulz, W.F. Cannon, R.W. Ojakangas, P.K. Sims, and B.A. Brown improved the manuscript.

DESCRIPTION AND INTERPRETATION OF INDIVIDUAL QUARTZITE OCCURRENCES

Hamilton Mounds

Hamilton Mounds (fig. 1) consists of several unnamed quartzite outcrops (table 1) that occur as inliers in Paleozoic sandstone in southern Wisconsin. The mounds are about 75 km north of the Baraboo syncline and have special significance regarding the age and structure of the southern Wisconsin quartzites. The locality was first mapped by Ostrander (1931), who interpreted the structure as a series of N. 75° W.-trending folds with gently plunging axes (fig. 2*A*). He also reported a 25-m-thick zone of brecciated quartzite cemented by white vein quartz from most of the hills that compose Hamilton Mounds. Ostrander also recognized that quartz grains in the quartzite are highly strained and that associated sericite is aligned (foliated). He proposed that these features were developed by dynamic metamorphism. In addition, Ostrander noted that pegmatitic granite intrudes the quartzite and has some accompanying hydrothermal alteration. Ostrander assumed that the quartzite was correlative with the Baraboo Quartzite. Later, Greenberg and Brown (1983), and Greenberg and others (1986) recognized structures at Hamilton Mounds similar to those described by Ostrander (1931). They also interpreted the quartzite to be correlative with the Baraboo, and assigned it to the Baraboo interval.

We recognize several distinct structural units in the main quarry at Hamilton Mounds (fig. 2*B*). The lower part of the quarry exposes steeply north dipping quartzite beds with a prominent, gently north dipping spaced cleavage (fig. 3*A*). Crossbedding indicates that the beds top toward the southwest and are overturned in that direction. A shallow north-dipping fault zone with slickensides on the shear

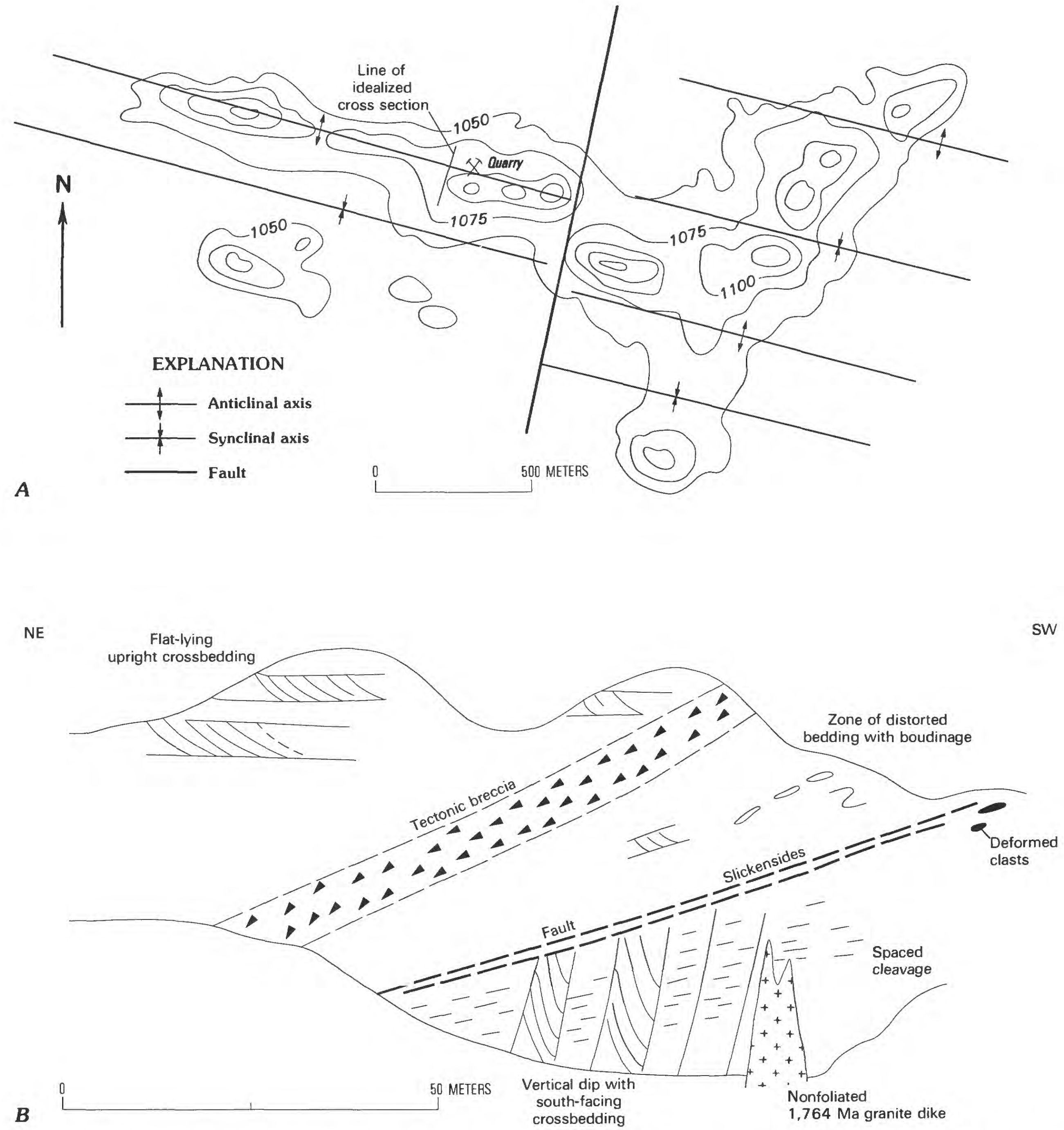


Figure 2. Map and cross section of Hamilton Mounds area. *A*, Topographic hills (contoured in feet) and N. 75° W.-trending anticline and syncline axes (modified from Ostrander, 1931). *B*, Diagrammatic cross section showing major lithologic and structural features at the main quarry in the Hamilton Mounds area. Location of cross section is shown in *A*. Vertical scale exaggerated.

Table 1. Index of Proterozoic quartzite localities and previously used historic names

Locality	Historic name
Baraboo syncline, Sauk and Columbia Counties	Baraboo Quartzite (Irving, 1877).
Barron, Rusk, Sawyer, and Washburn Counties	Barron Quartzite (Chamberlin, 1882).
Flambeau Ridge, Chippewa County	Flambeau Quartzite (Hotchkiss and others, 1915).
Hamann Creek, Marathon County	Marathon Conglomerate (Weidman, 1907).
Hamilton Mounds, Adams County	"Hamilton Mounds Quartzite" (Ostrander, 1931).
McCaslin Mountain, Forest, Oconto, and Langlade Counties.	McCaslin Quartzite (Mancuso, 1960).
Necedah, Juneau County	"Necedah quartzite" (Van Hise and Leith, 1911).
Rib Mountain, Marathon County	Rib Hill Quartzite (Weidman, 1907).
Thunder Mountain, Marinette County	"Thunder Mountain Quartzite" (Mancuso, 1960).
Vesper quarry, Wood County	Powers Bluff Quartzite (Weidman, 1907).
Waterloo area, Jefferson and Dodge Counties	Waterloo Quartzite (Buell, 1892).

surfaces truncates the overturned quartzite layers. S_1 foliation strikes about N. 88° W. and dips 22° N. (fig. 3*A*). Poles to bedding (fig. 3*A*) lie along a great circle and define a beta fold axis (β) that plunges gently toward the east. Slickensides on the foliation surface plunge toward the north-northeast (fig 3*B*).

A 12-m-thick zone of quartzite with highly contorted bedding and boudinage structures (fig. 2*B*) overlies the slickensided fault zone. The presence of a Z-shaped fold (looking southeast) and a boudinaged quartzite layer (fig. 2*B*) suggests that movement was from northeast to southwest.

The breccia zone (figs. 2*B*, 3*C*) described by Ostrander (1931) overlies this contorted zone. It contains common tabular quartzite clasts, some with strong internal foliation, and rare exotic granitoid clasts. Although not obvious on first examination, poles to the strike and dip of the flat surfaces of 12 sample quartzite clasts tentatively indicate that they have a preferred orientation. The clasts have about the same strike as the breccia zone, but dip toward the northeast slightly steeper than the breccia zone itself, suggesting that they have an imbricate orientation relative to the tectonic zone (sketch within stereoplot of fig. 3*C* shows the nature of the oriented clasts). This configuration also provides kinematic data suggesting tectonic transport from northeast to southwest. Above the breccia zone, the bedding in the quartzite is subhorizontal with upright crossbedding.

The presence of boudinaged beds, ductile folds, and contorted bedding indicates that the rocks at Hamilton Mounds were subjected to ductile deformation. Spaced cleavage and the brecciated zone of quartzite, however, indicate brittle deformation. A southward sense of tectonic transport is indicated for both the ductile and brittle deformation. Interestingly, the main zone of ductile deformation lies between zones of brittle deformation with a fault zone at the base and the breccia zone at the top. These structural relations are similar to those shown by the Hinesburg thrust in the northern Appalachians near Burlington, Vt.: the Cheshire Quartzite (Lower Cambrian), containing prominent ductile deformation features, has been thrust over relatively undeformed carbonates of the Lower Ordovician Bascom Formation (Stanley and others, 1987). As concluded for the Vermont structures by Stanley and others (1987), so at Hamilton Mounds the superposition of brittle deformational features on ductile deformational features likely reflects multiple periods of deformation.

A hydrothermally altered granitoid dike (as described by Ostrander, 1931) intrudes the quartzite beneath the fault zone (fig. 2*B*). We interpret the numerous aligned mafic xenoliths and megacrysts in the dike to define a flow fabric that strikes N. 5° E. and dips 35° SE. This orientation differs markedly from the cleavage in the surrounding quartzite, which strikes N. 88° E. and dips 22° N. (fig. 3*A*), and indicates that the granitoid dike was not deformed with the quartzite. W.R. Van Schmus (written commun., 1989) reported a U-Pb age of 1,763±7 Ma on zircons from the dike, and a U-Pb age of 2,449±84 Ma on detrital zircon in the quartzite.

Interpretation.—Quartzite exposed at Hamilton Mounds exhibits a variety of deformational styles, which reflect a complex structural history, indicating the juxtapositioning of ductile and brittle structures. The ductile deformational features must have been imposed under very different conditions than those that produced the brittle deformation features. A southward sense of tectonic transport is indicated by both the ductile and brittle deformational features. Because the brittle and ductile structures are similarly oriented, we suggest that the superimposed structural units were tectonically emplaced by multiple coaxial south-verging thrust events. The granitoid dike that cuts the quartzite constrains the age of deformation and the

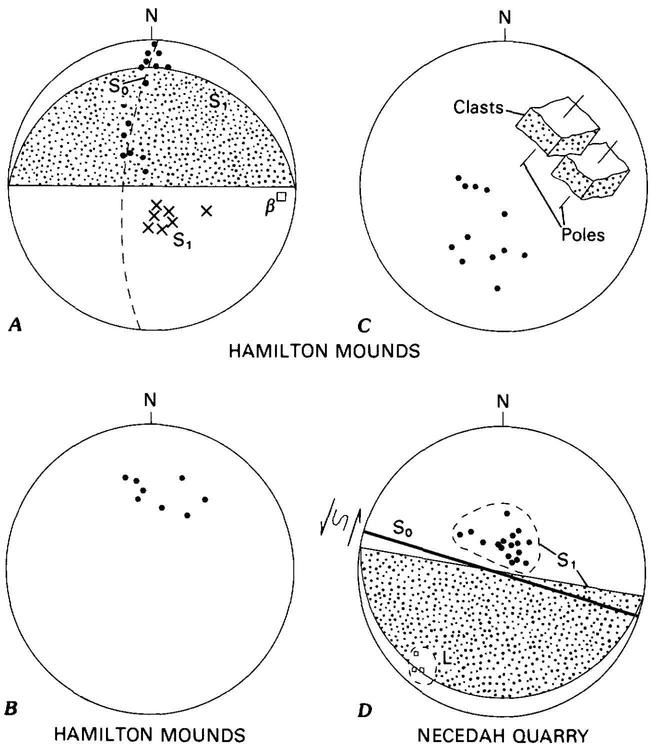


Figure 3. Lower hemisphere stereographic plots and accompanying diagrams illustrating the main structural features at Hamilton Mounds and Necedah localities. *A*, Dots represent poles to bedding (S_0) and define a great circle whose beta axis (β) plunges gently east-southeast at Hamilton Mounds. Poles to foliation (S_1, X) define an average foliation surface (stippled S_1 plane) that is axial-planar to folds in bedding (S_0). *B*, Orientation of slickenside lineations on S_1 surfaces at Hamilton Mounds. *C*, Dots represent 12 poles to strike and dip of quartzite clasts in breccia zone at Hamilton Mounds. Nature of quartzite clasts shown diagrammatically. *D*, Combined plot of field measurements from the north and south quarries at Necedah. Dots, poles, and stippled plane show orientation of spaced cleavage (S_1); heavy solid line, strike of bedding. Beds are vertical to near vertical. Square, mineral lineation on S_1 surface at north quarry; a drag fold with inferred shear couple suggests southward structural vergence—drag fold was observed at south quarry.

age of the quartzite. Deformation of the quartzite preceded emplacement of the dike (1,763±7 Ma) indicating that both the quartzite and the deformation are older than 1,763±7 Ma. The 2,449±84 Ma U-Pb age on detrital zircon in the quartzite at Hamilton Mounds suggests a probable Archean, rather than Proterozoic, provenance for the quartzite.

Necedah Area

Two inliers of Necedah quartzite (table 1) were examined in quarries near the village of Necedah (fig. 1), 30 km west-southwest of Hamilton Mounds. Red-shaded to pink brecciated quartzite is exposed in a quarry just northwest of Necedah. The quartzite dips steeply and has a fracture cleavage that strikes northwest and dips gently southwest (fig. 3*D*). Mineral lineations on the cleavage surfaces are generally perpendicular to the strike of the foliation and possibly indicate a stretch direction. Thin-bedded, weakly foliated quartzite is exposed in an east-trending ridge of outcrops at the south edge of Necedah. Bedding is vertical and crossbedding indicates that the beds face southward. The south-facing crossbeds indicate that bedding was rotated toward the south, and a small drag fold also indicates a southward sense of structural vergence.

Van Hise and Leith (1911, p. 358) reported that "Drilling at Necedah has disclosed the presence of granite, probably intrusive into quartzite," and B.A. Brown and J.K. Greenberg (Greenberg and others, 1986) reported a quartzite breccia at Necedah with a granitic matrix (an intrusion breccia). The granite appears to be undeformed, and must, therefore, postdate the deformation. The age of the granitoid rock at Necedah is not known.

Interpretation.—Although data at the Necedah locality are meager relative to Hamilton Mounds, the major structure is consistent with a south-verging fold/thrust and the igneous rock appears to postdate the structural event. The major relationships are thus the same at both localities. However, the lack of isotopic age on the granitoid at Necedah precludes establishing the timing of the events.

Baraboo Area

The general geology of the Baraboo area (fig. 1) has been known since the early studies of Irving (1877), Weidman (1904), Van Hise and Leith (1911), and Leith and others (1935). More recent studies include those of Dalziel and Dott (1970), Dott (1983), Smith (1978a,b), Van Schmus (1978), Jenk and Cambray (1986), Kean and Mercer (1986), and Hempton and others (1986). Proterozoic rocks at Baraboo, which structurally define a northeast-trending doubly plunging syncline (figs. 4, 5), consist of massive Baraboo Quartzite (table 1) overlain by the Seeley Slate and the Freedom Formation, which consists of dolomite, slate, and cherty zones, some of which are ferruginous. The ferruginous chert of the Freedom Formation is similar to iron-formations of the main Lake Superior region to the north (Schmidt, 1951). The Dake Quartzite and Rowley Creek Slate are interpreted to overlie the Freedom Formation (Leith and others, 1935). Morey and Van Schmus (1988) implied that the Freedom Formation/Dake Quartzite contact is erosional. These units are similar to underlying units, and Schmidt (1951) suggested that they may be segments of the Baraboo Quartzite and Seeley Slate that are repeated by faulting. Volcanic rocks (mainly rhyolite) and granitoid rocks are exposed at several localities surrounding the quartzite of the Baraboo syncline (fig. 5).

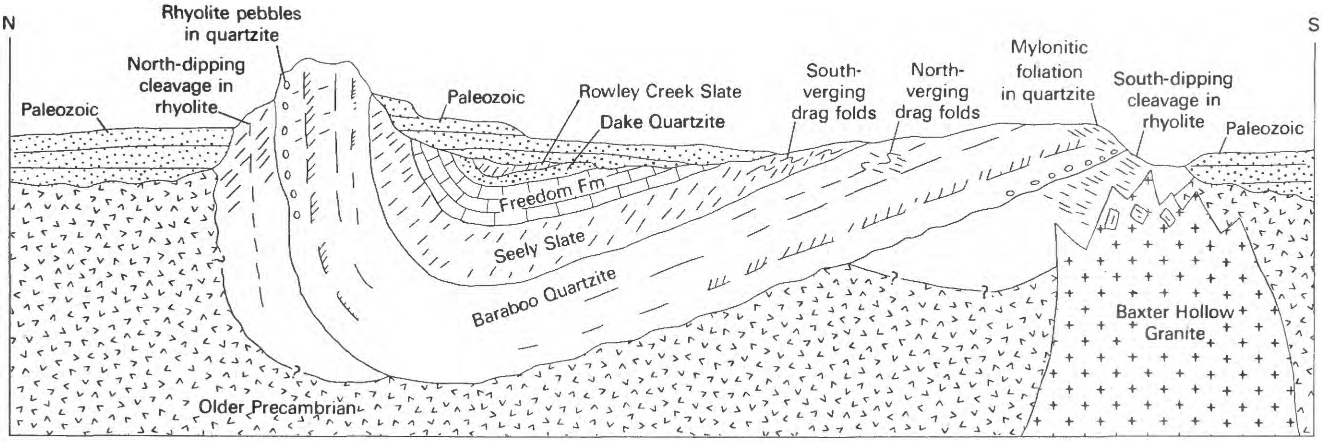


Figure 4. Generalized cross section of the Baraboo syncline. Rhyolite underlies the quartzite on both north and south limbs; rhyolite pebbles occur in the basal conglomerate. Bedding and cleavage in the rhyolite are parallel to that in the quartzite on north limb, suggesting that the units were deformed together. Rhyolite on the south limb has south-dipping cleavage that is similar to mylonitic foliation in the quartzite and parallel to axial planes of "reverse" drag folds on the south limb. The undeformed Baxter Hollow Granite on south limb intrudes foliated rhyolite, suggesting that the intrusion postdated the deformation. Length of section ≈ 20 km. Vertical, not to scale.

The structural and stratigraphic relationship of the quartzite to the adjacent volcanic and plutonic rocks is of major importance in resolving the age and origin of the rocks in the Baraboo area. However, the nature of the relationship has been debated for nearly a century. Weidman (1904) discussed the schistose nature of the rhyolite near the contact with the quartzite and suggested that the rhyolite was part of the sedimentary sequence. He also reported the presence of rhyolite pebbles in conglomerates in the basal quartzite. Van Hise and Leith (1911, p. 360) stated that granitic rocks on the south side of the Baraboo syncline are intrusive into the quartzite. Stark (1930, 1932) concluded that the rhyolites are tuffs and flow breccias and that they are older than the Baraboo Quartzite, and further, he questioned whether the "Otter Creek granite" was intrusive into the quartzite. Gates (1942), however, concluded that the Baxter Hollow Granite ("Otter Creek granite" of Stark, 1932) intrudes the quartzite. Dalziel and Dott (1970) interpreted the quartzite to unconformably overlie the rhyolite and the granite surrounding the Baraboo syncline. Smith (1978b) suggested that an angular unconformity exists between the rhyolite and quartzite in the Baraboo area, where he reported that the rhyolite strikes at an angle to the quartzite. However, he did not report dip directions or the presence of foliation in the rhyolite.

Numerous structural studies of the quartzite and associated metasedimentary rocks have been carried out (Riley, 1947; Hendrix and Schaiowitz, 1964; Dalziel and Dott, 1970; Hempton and others, 1986). Although points of disagreement remain, the major aspects of the structure appear well established. The major structure in the Baraboo area is an east-northeast-trending doubly plunging syncline overturned toward the south (fig. 4). The axial plane of the syncline strikes N. 75° E. and dips 60° N., with the north limb vertical, or locally overturned toward the south, and the south limb dipping gently toward the north.

The overall structural configuration of the Baraboo syncline as shown in Dalziel and Dott (1970) indicates that it was formed by south-verging tectonic transport. Dalziel and Stirewalt (1975) suggested that major and minor structures formed in a single progressive deformational event, whereas Hendrix and Schiaowitz (1964), Riley (1947), and Hempton and others (1986) suggested at least two tectonic events, the first being a south-verging event that formed the syncline and its major deformational fabric. Cambray (1987) suggested that the syncline is a sheath fold caused by southerly directed shearing.

We have focused on resolving the controversy regarding the stratigraphic relationships of the Baraboo Quartzite and the adjacent igneous rocks, because of the longstanding nature of the problem and the importance of determining these relationships.

At the lower narrows on the north limb of the syncline (fig. 5), the rhyolite is brick red near the contact with the quartzite, but it turns to black within a few hundred meters of the contact. Conglomeratic layers near the base of the quartzite (outcrops in SW¼SW¼NE¼ sec. 22, T. 12 N., R. 7 E.) contain clasts of rhyolite, vein quartz, jasper, and minor granitoid rocks. Primary layering in the rhyolite is expressed locally as layers of volcanic clasts as much as several centimeters in diameter. Orientation of this layering (fig. 6*A*) is approximately the same as the orientation of bedding in the adjacent quartzite on the north limb (compare with stereoplot 1A, pl. V of Dalziel and Dott, 1970). A prominent N. 72° E., 46° NW. foliation that is developed locally in the rhyolite near the quartzite is compatible with the foliation in the quartzite of the north limb (see stereoplot 3A, pl. V, of Dalziel and Dott, 1970). Bedding/cleavage

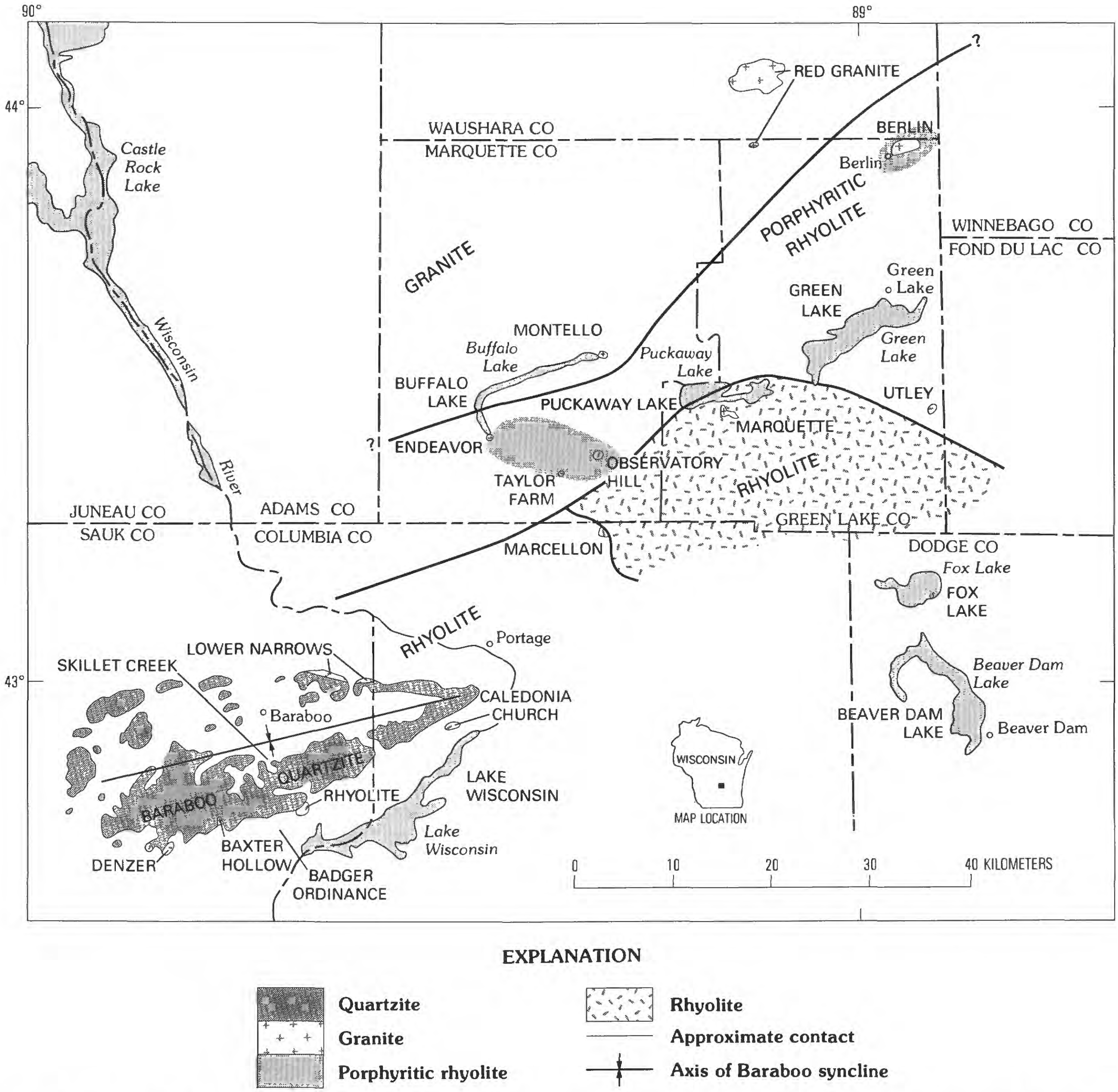


Figure 5. Generalized geologic map of the Baraboo syncline and associated rhyolite. Locations of areas discussed in text are also shown. Heavy solid lines, boundaries between belts of igneous rocks. Dated igneous rocks are at Montello, Observatory Hill, Marquette, and Utley. Modified from Smith (1978a).

intersection lineations in the rhyolite define a gently west-southwest plunging fold axis (fig. 6*B*), roughly parallel to the fold axis of the Baraboo syncline, and similar to the bedding/cleavage intersection lineations of Dalziel and Dott (stereoplot 4A, pl. V, 1970). Therefore, the rhyolite and quartzite on the north limb of the syncline appear to have been deformed together. Furthermore, the presence of red rhyolite clasts as much as 3 cm in diameter in conglomerates near the base of the quartzite suggests that the quartzite may stratigraphically overlie the rhyolite on the north limb. It should be noted, however, that the rhyolite within approximately 30 m of the contact has a strong foliation parallel to the contact with the quartzite.

Structural relationships between the quartzite and adjacent igneous rocks on the south side of the Baraboo syncline are more complex than those on the north limb. Rhyolite in the southernmost outcrops at Caledonia Church (fig. 5) is a gray to black plagioclase phyric rock with well-preserved primary features suggesting densely welded tuff and flow-breccia; it has no visible tectonic foliation.

However, rhyolite closer to the quartzite has a prominent south-dipping foliation (fig. 6*C*); the northwest-dipping foliation, which is well developed in the rhyolite on the north limb, is absent in the rhyolite on the south limb. The nearby Baraboo Quartzite has a steeply northwest dipping cleavage (Dalziel and Dott, 1970), and locally, near the foliated rhyolite, a south-dipping foliation expressed by highly recrystallized (mylonitized) quartzite—a fine mosaic of quartz that largely obscures the original detrital grains (figs. 4, 5, locations).

LaBerge's studies of engineering drill cores from the Badger Ordnance area just south of the south limb of the Baraboo syncline (fig. 5) show that Baraboo Quartzite overlies dark-reddish-brown to greenish-gray volcanic rock, which in turn is intruded by a granitoid breccia (Baxter Hollow Granite?). The basal quartzite in most of the drill cores is a breccia consisting of clasts of various size. In some cores, the quartzite forms lensoidal slabs surrounded by branching and recombining fractures, and in still other cores the quartz in the quartzite is highly polygonized and has a prominent mylonitic foliation. White clay (kaolinite?) forms the matrix between the clasts and coats fracture surfaces, and drusy quartz lines some fractures and cavities. In several cores, the base of the quartzite is several meters of clay that may be a fault gouge.

The volcanic rock in the engineering drill cores at Badger Ordnance is highly chloritic andesitic to basaltic rock with highly foliated, slickensided zones as well as relatively nonfoliated zones. Thus, it contrasts with the felsic volcanic rocks in the Caledonia Church area. However, near Denzer, approximately 13 km west of Badger Ordnance, black undeformed rhyolite is exposed just south of the Baraboo Quartzite (fig. 5). Therefore, a variety of volcanic and intrusive rocks with varying degrees of deformation are present on the south side of the Baraboo syncline, whereas only red to gray rhyolite is exposed on the north limb.

The granitoid rock (Baxter Hollow Granite?) encountered in the drill cores is an intrusion breccia that is highly variable in texture and color, contains numerous greenish-gray volcanic xenoliths, and is undeformed. Quartzite xenoliths are absent. Some intervals of the quartzite in the core are highly bleached and (or) epidotized, suggesting hydrothermal activity.

Interpretation.—The data presented raise some questions regarding the relationship of the rhyolites to the quartzite in the Baraboo area. Although the quartzite may be stratigraphically younger than the rhyolite on the north limb, where both quartzite and rhyolite were affected by the deformational event that formed the Baraboo syncline, the relationship of the quartzite to the rhyolite on the south limb of the syncline is ambiguous. The rhyolite near Caledonia Church and at Denzer lacks the S_1 fabric related to formation of the Baraboo syncline, but near the contact with the quartzite in the Caledonia Church area the rhyolite has

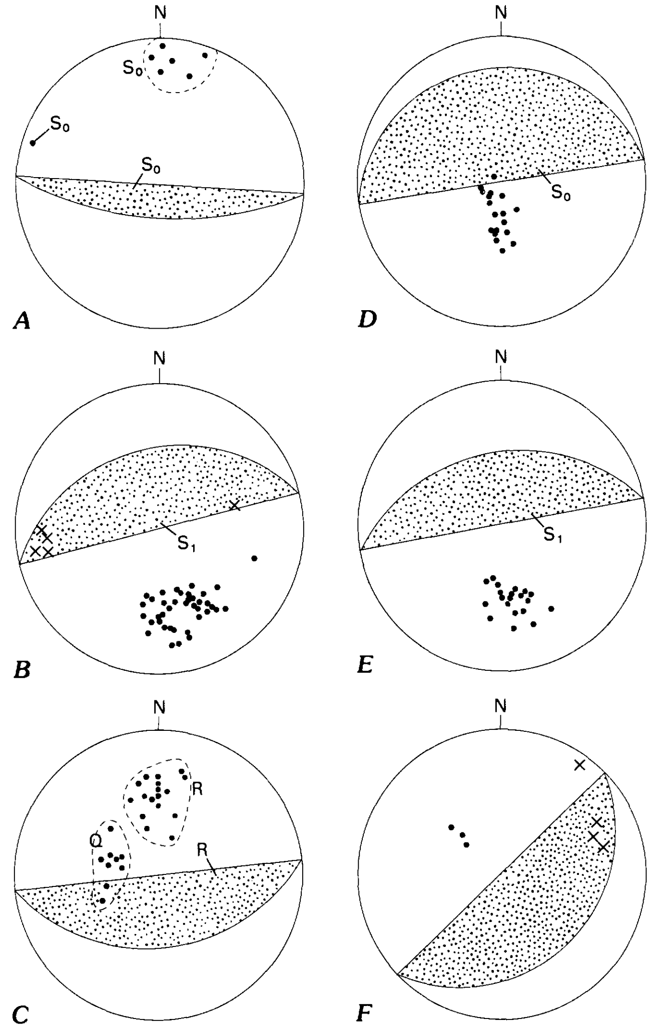


Figure 6. Lower hemisphere plots of structural features in the Baraboo syncline. *A*, Seven poles to layering (S_0, dots) in rhyolite near the Lower Narrows, north limb. Stippled area, approximate orientation of bedding plane. *B*, Thirty-nine poles (dots) to S_1 foliation in rhyolite at the Lower Narrows and five measured lineations (x) resulting from intersection of cleavage (S_1) and bedding (S_0). Stippled area, approximate orientation of S_1 plane. *C*, Seventeen poles to foliation in rhyolite (R), Caledonia Church area, and nine poles to foliation in quartzite (Q) near the rhyolite. Stippled area, approximate plane of orientation of foliation in rhyolite in this area. Difference in orientation of foliation between rhyolite (R) and quartzite (Q) is interpreted to be caused by refraction resulting from different lithologies. *D*, Eighteen poles to bedding on south limb of Baraboo syncline; stippled area, plane of approximate orientation of bedding. *E*, Twenty poles to S_1 on south limb of the Baraboo syncline; stippled area, plane of approximate orientation of bedding. *F*, Three poles to spaced axial plane foliation of chevron folds in S_1 foliation at Skillet Creek (see fig. 5), and orientation of four fold axes (x). Stippled plane, approximation of the axial plane foliation.

a post-S_1 fabric. This suggests that deformation in the rhyolite on the south limb may be younger than the structural event that formed the Baraboo syncline, and that the igneous rocks may be younger than the quartzite. Alternatively, the rhyolite and other igneous rocks on the south limb lie stratigraphically below the quartzite, but an S_1 fabric simply did not form in this area during formation of the Baraboo syncline. (It should be noted that quartzite within 100 m of the rhyolite does have an S_1 fabric.) The structural differences between the volcanic rocks on opposite limbs of the syncline suggest the possibility of more than one age of rhyolite in the Baraboo area. If more than one rhyolite is present, then the proposed post-1,760 Ma age of the Baraboo Quartzite, based on dating of rhyolite some 25–50 km northeast of the Baraboo area, is uncertain.

A post-1,760 Ma age for the Baraboo Quartzite is based on the following assumptions: (1) the quartzite stratigraphically overlies the adjacent rhyolite (Dalziel and Dott, 1970), and (2) the rhyolite in the Baraboo area is the same age as the rhyolite from 25–50 km northeast of it (dated igneous rocks noted in fig. 5 are samples dated by Van Schmus, 1978; Smith, 1978a). Smith (1978a, 1983) used major- and trace-element geochemistry to suggest the existence of a series of northeast-trending belts of igneous rocks in south-central Wisconsin, and based on Van Schmus' (1978, 1980) U-Pb zircon age of 1,760 Ma, he concluded that the rhyolite at Baraboo can be inferred by chemical similarity to correlate with the dated rocks. However, new compositional data (K.J. Schulz, written commun., 1988), on granite and rhyolite at Cary Mound, 10 km north of Veedum in central Wisconsin, are similar to those described by Smith (1978a,b, 1983), yet they yield a U-Pb zircon age of 1,833±4 Ma (W.R. Van Schmus, written commun., 1989). This suggests that chemical similarity alone may not be a valid basis for inferring the age of the rhyolite in the Baraboo area; we suggest that the age of the rhyolite in the Baraboo area is still in question.

Waterloo Area

In the Waterloo area, approximately 50 km east-southeast of the Baraboo syncline (fig. 1), occur two distinctly different quartzites, which historically were named the Waterloo Quartzite (table 1) in Jefferson and Dodge Counties. One exposure, in a farmyard in the NE¼SE¼ sec. 35, T. 9 N., R. 13 E., is a thin-bedded, red-brown, prominently crossbedded quartzite. The other is a gray quartzite exposed at Portland quarry (E½SE¼ sec. 33, T. 9 N., R. 13 E.) and near Reeseville (NW¼SE¼ sec. 3, T. 9 N., R. 14 E.). Our studies indicate that the red and gray quartzites have had different deformational histories and could be of different ages.

The red quartzite consists of thin (≈1 cm) layers of buff to red quartzite with ≈1-cm-thick pelitic layers. Bedding in the quartzite is oriented N. 4° E., 30° SE. (fig. 7*A*). The quartzite lacks a distinct deformational fabric, but the pelitic layers have a penetrative cleavage that strikes N. 19° W. and dips 20° NE. Bedding/cleavage intersection lineations plunge 12° N. 28° E. (fig. 7*A*).

The gray quartzite at Portland quarry is conglomeratic, containing pebbles of maroon to red quartzite, vein quartz, chert, and volcanic rocks. Bedding is oriented approximately N. 20° E., 54° SE. and cleavage is oriented N. 59° W., 60° SW. (fig. 7*B*); bedding/cleavage intersection lineations plunge 53° S. 42° E. Pebbles within some layers in the gray quartzite are stretched and have long:short axial ratios of as much as 4:1, suggesting constrictive strain. Stretch lineations defined by the long axis of the pebbles plunge about 70° WSW.

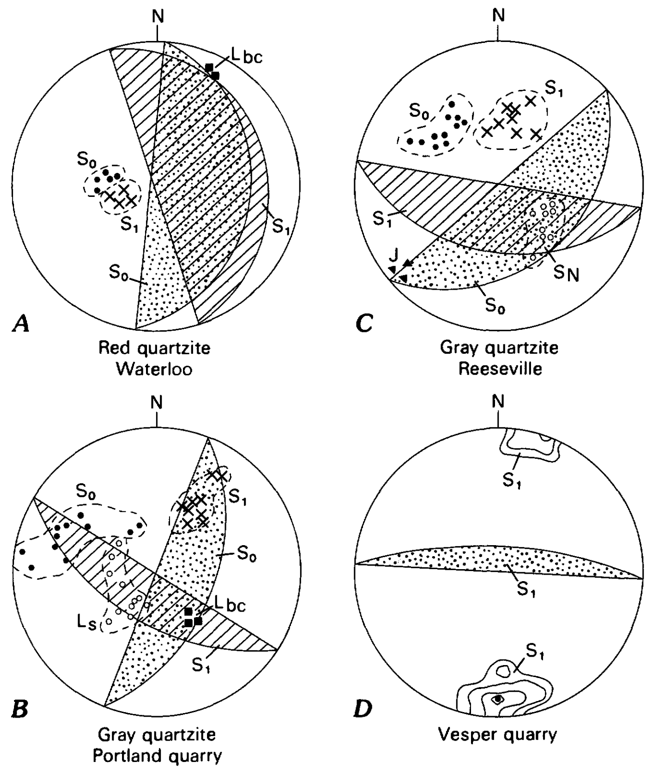


Figure 7. Lower hemisphere plots of structural data from Waterloo and Vesper areas. *A*, Red quartzite at Waterloo. Solid dots and stippled plane indicate orientation of bedding (S_0); x and lined plane indicate orientation of cleavage (S_1) in thin pelitic layers. Solid squares are measured lineations formed by intersection of cleavage and bedding (L_{bc}). *B*, Gray quartzite at Portland quarry. Solid dot, pole to bedding (S_0); stippled plane, approximate orientation of bedding; x, pole to spaced cleavage (S_1); lined plane, approximate orientation of spaced cleavage (S_1) in quartzite. Solid square, orientation of lineation (intersection of bedding and cleavage, L_{bc}). Open circle, orientation of long axis of stretched clast (L_S). *C*, Gray quartzite near Reeseville. Solid dot, pole to bedding; stippled plane, approximate orientation of bedding (S_0); x, pole to S_1 foliation; lined plane, approximate orientation of foliation (S_1). Solid triangle, pole showing orientation of joints (J); open circle, pole to a spaced cleavage/joint system (S_N). *D*, Stereoplot of spaced cleavage in quartzite at Vesper quarry. Contours 5, 10, 20 percent are on 21 poles to cleavage (S_1). Solid dot, area of highest concentration. Stippled plane, orientation of S_1 cleavage.

The quartzite at Reeseville is dark gray (like that at Portland quarry), thin bedded with abundant dark- and light-gray bands, crossbedded, and locally conglomeratic; it contains minor pelitic layers. Crossbedding indicates that the beds are upright. Northwest-trending joints abound, and some are in closely spaced zones. An irregular, northwest-trending, 10-m-wide zone of brecciated quartzite cemented with white vein quartz cuts the quartzite. Bedding is oriented N. 50° E., 42° SE., and a spaced cleavage is oriented N. 78° W., 50° SW. (fig. 7*C*). Joints are near vertical and strike about N. 40° W. The breccia zone is roughly parallel with the joints. A vague, spaced fracture (joint?) system S_N oriented approximately N. 50° W., 36° NW. is also present; however, its relative age and significance are not known.

Interpretation.—Our data indicate that the structural features in the red quartzite are distinctly different from those in the gray quartzite. The red quartzite lacks a strong deformational fabric, but cleavage in pelitic layers dips gently east-northeast, and fold axes (determined from bedding/cleavage intersection lineations) plunge gently north-northeast. In contrast, foliation in the gray quartzite strikes northeast and dips moderately to the southeast; fold axes plunge steeply southeast. Not only do these attitudes suggest that the structural history of the quartzites is different, but also the presence of pebbles of red quartzite in the gray quartzite at Portland quarry suggests in particular that the gray quartzite may be younger than the red, even though the gray quartzite is more deformed.

The gray quartzite at Waterloo, the rhyolite and adjacent quartzite near Caledonia Church, and the reverse drag folds (chevron folds) at the Skillet Creek locality on the south limb of the Baraboo syncline (Adair, 1956; Dalziel and Dott, 1970; Hendrix and Schaiowitz, 1964) have a south-dipping deformational fabric. The south-dipping fabric may thus be of regional significance, and it could represent a structural event that postdates formation of the major structure of the Baraboo syncline. However, this fabric apparently is absent in rocks on the north limb of the Baraboo syncline, and does not occur in the red quartzite at Waterloo. Consequently, the event that produced the south-dipping fabric apparently did not affect all of the rocks in the region.

Geiger and others (1981) concluded that the pelitic rocks intercalated with the quartzite in the Waterloo area underwent a static metamorphism that postdates the deformation. Inasmuch as undeformed granitic dikes cut the quartzite on Rocky Island in the Crawfish River northeast of Waterloo (Brown, 1986), we suggest that the metamorphism is related to the igneous activity in the area, and that both postdate the deformation. Unfortunately, the age on the igneous rocks in the Waterloo area is poorly constrained.

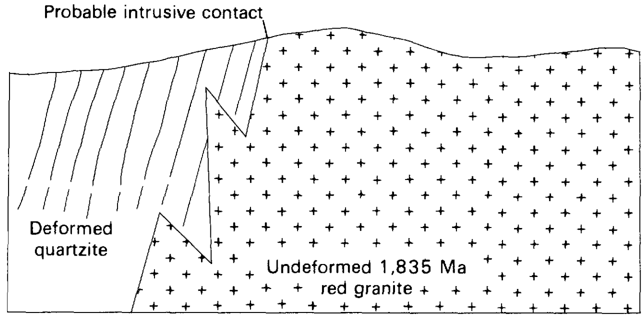


Figure 8. Interpretation of geologic relationships between undeformed granite and deformed quartzite at Vesper quarry. Length of section ≈50 m. Vertical, not to scale.

Vesper Quarry

The Vesper quarry in Wood County (fig. 1) contains exposures of pink quartzite historically named the Powers Bluff Quartzite (table 1), containing minor pelitic zones and massive red granite (fig. 8). The quartzite has a pervasive, steeply dipping, spaced cleavage; pelitic zones in the quartzite have a penetrative cleavage subparallel with that in the quartzite. A stereoplot of poles to fracture cleavage and penetrative cleavage at Vesper quarry shows that the cleavage is oriented N. 85° E., 80° NW. (fig. 7*D*). The red granite, which crops out within several meters of the quartzite, has no discernible deformational fabric. Although the contact between the granite and quartzite is not exposed, a highly altered, iron oxide-rich zone of quartzite lies within the contact zone. Inasmuch as the granite lacks any penetrative fabric, we suggest that it was emplaced after deformation of the quartzite.

The red granite at Vesper is typical of the widespread alkali-feldspar granites in central Wisconsin (LaBerge and Myers, 1984; Sims and others, 1989). They are undeformed and posttectonic. The granite at Vesper is mineralogically, texturally, and chemically similar to the red alkali-feldspar granite at Cary Mound about 15 km to the southwest (K.J. Schulz, written commun., 1989), which has a U-Pb zircon age of 1,833±4 Ma (Sims and others, 1989).

Interpretation.—Assuming that the red granites at Vesper and Cary Mound are coeval, then the deformed quartzite at Vesper quarry must be older than 1,833±4 Ma. This interpretation is supported by the occurrence of large blocks of quartzite at a red granite quarry on Cary Mound (Greenberg and Brown, 1983, p. 27).

Veedum Area

Exposures in quarries at Veedum in Wood County (fig. 1), about 10 km south of Cary Mound, consist of highly sheared unnamed quartzite that contains a green chrome-rich mica (probably fuchsite) on nearly horizontal slickensided fault surfaces. Foliation appears to be nearly horizontal in the northernmost pit, but the outcrop is badly broken and structural observations are difficult to obtain. B.A. Brown (Greenberg and others, 1986, p. 46) reported that Archean gneiss is exposed in Turner Creek just east of the Veedum quarries, and that drilling encountered Archean gneiss 3 to 4 m below the floor of the southernmost quarry. Structures in Archean gneiss in nearby quarries are steep to vertical, markedly different from those in the overlying quartzite.

Interpretation.—The slickensides and near-horizontal foliation suggest that the quartzite was emplaced on the gneiss by low-dipping (possibly thrust) faults. Alternatively, the quartzite could have been deposited directly on the Archean rocks.

Conglomerate at Hamann Creek

Four occurrences of conglomerate interbedded with volcanic rocks of the Wisconsin magmatic terranes have been mapped in central Wisconsin, and several other occurrences were recorded and named the Marathon Conglomerate (table 1) by Weidman (1907). The largest exposure is along Hamann Creek in southwestern Marathon County (SE¼ sec. 35, T. 28 N., R. 3 E.). Other exposures are in the western margin of Marathon City, along the Wisconsin River just west of Brokaw, and along the East Fork of the Eau Claire River in eastern Eau Claire County about 100 km west of Wausau (fig. 1). The conglomerate along Hamann Creek contains boulders as much as 1 m long of both red and gray quartzite, jaspilitic iron-formation, volcanic rocks, and granitoid rocks; it is interbedded with graywacke and intermediate and felsic volcanic rocks. The boulders are matrix supported, and the conglomerate has been intensely deformed (fig. 9) in local zones that are as much as 20 m wide (LaBerge and Myers, 1984). Deformation in the conglomerate is similar to that in the surrounding graywacke and volcanic rocks. The volcanic rocks are part of a succession (Pembine-Wausau terrane) that has been dated at ≈1,840 Ma (Sims and others, 1989). About 3 km south of the Hamann Creek exposures the major zone of deformation is cut by a posttectonic granite (LaBerge and Myers, 1983).

Relatively undeformed conglomerate containing quartzite and granitoid boulders as much as 25 cm in diameter in a volcanic sandstone matrix is exposed along the Wisconsin River at Brokaw, just north of Wausau. Both red and gray quartzite clasts are present. A deformed conglomerate with boulders of quartzite and volcanic rocks was exposed in excavations in Marathon City, west of the syenite plutons at Wausau. These conglomerates are enclosed in volcanic and plutonic rocks of the Pembine-Wausau terrane. A similar deformed conglomerate containing gray quartzite cobbles and boulders is also exposed along the East Fork of the Eau Claire River (Myers, 1980). This conglomerate is associated with deformed volcanic rocks of the Marshfield terrane, which has been dated at 1,858±5 Ma (Sims and others, 1989).

Interpretation.—These quartzite occurrences define an easterly trending belt of conglomeratic rocks in central Wisconsin that roughly parallels the trend of the Eau Pleine shear zone to the south (fig. 1). The east-trending zone of quartzite-bearing conglomerate indicates that an older quartzite and iron-formation unit was being eroded during deposition of the ≈1,860–1,840 Ma volcanic rocks. Thus, quartzite with a minimum age of ≈1,840 Ma existed in central Wisconsin during deposition of the conglomerate.

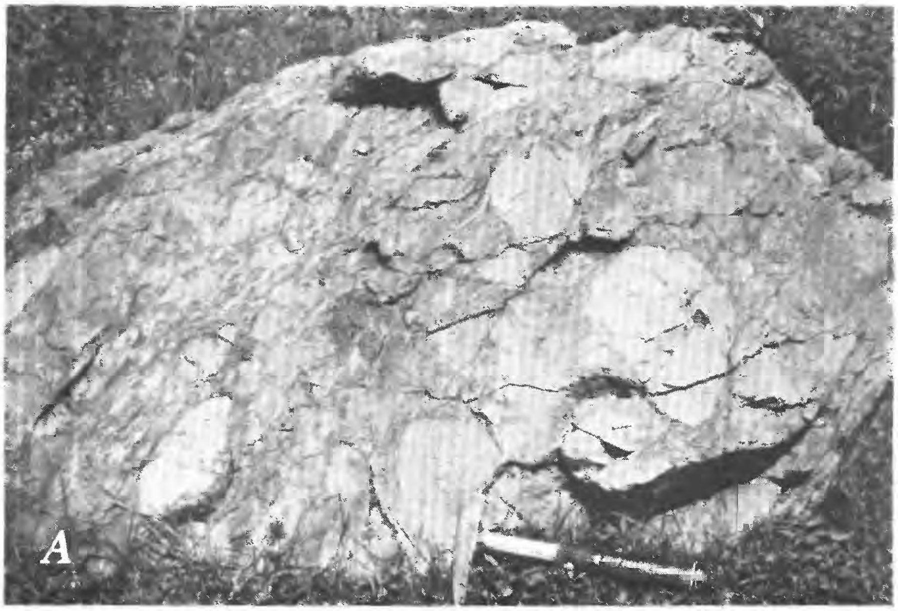
Rib Mountain

Quartzite xenoliths are common in the ring-shaped 1,470 Ma alkalic plutons near Wausau. Most of these xenoliths are white quartzite; some, however, are red quartzite. The largest of the white quartzite xenoliths forms the crest of Rib Mountain, historically named the Rib Hill Quartzite (table 1) by Weidman (1907) (this report, fig. 1). The alkalic plutons intrude calc-alkaline volcanic and plutonic rocks of the Pembine-Wausau terrane (LaBerge and Myers, 1983). Although the volcanic rocks surrounding the plutons at the present erosion level are metamorphosed only to greenschist facies, several of the quartzite xenoliths contain highly flattened quartz grains and strongly lineated sillimanite.

Interpretation.—LaBerge and Myers (1984) interpreted the relations at Rib Mountain to indicate that the quartzite was subjected to amphibolite-grade regional metamorphism, and that the quartzite xenoliths were carried up through the 1,840 Ma greenschist facies metavolcanic rocks during intrusion of the syenitic magma (fig. 10). This interpretation requires that the quartzite be older than 1,840 Ma.

Quartzite at McCaslin and Thunder Mountains

The quartzite at McCaslin Mountain and adjacent areas, historically named the McCaslin Quartzite (table 1) by Mancuso (1960), is exposed in hills along the northern margin of the Wolf River batholith in northeastern Wisconsin (fig. 1) (Sims, 1990). Olson (1984) reported that the quartzite at McCaslin Mountain is at least 1,220 m thick. It contains lenticular conglomerates in the lower 300 m, but consists mainly of a mature quartz arenite. Although the base is not exposed, the quartzite is interpreted to unconformably overlie mafic to felsic volcanic rocks, which are assumed to be part of the older (1,889–1,860 Ma) volcanic succession of the Pembine-Wausau terrane (Sims and others, 1989). The quartzite was folded into a southwest-



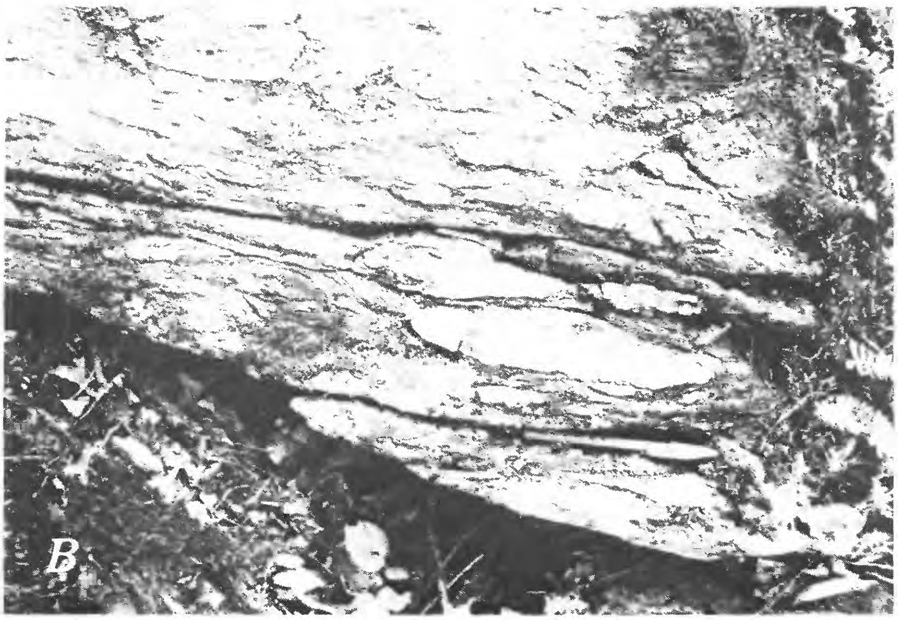


Figure 9. Quartzite boulders in deformed conglomerate along Hamann Creek. *A*, Relatively undeformed conglomerate with abundant volcanic clasts in the matrix. *B*, Flattened quartzite boulders in conglomerate about 30 m from locality of *A*.

plunging syncline (Olson, 1984) after regional deformation of the underlying volcanic rocks (Sims and others, 1989). Olson reported an increase in metamorphic grade from epidote-albite hornfels to hornblende hornfels facies from west to east in the quartzite, and she attributed the metamorphism to intrusion of phases of the Wolf River batholith. Sims and others (1988) suggested that quartzite clasts in the nearby Baldwin Conglomerate were derived from this quartzite, and that the Baldwin Conglomerate was deformed in the Mountain shear zone prior to intrusion of the Hines Quartz Diorite, which has been dated at 1,812.7±3.6 Ma (Sims and others, 1990).

Interpretation.—If the quartzite clasts in the Baldwin Conglomerate were derived from nearby sources at McCaslin and Thunder Mountains, as seems almost certain, these quartzites are definitely older than 1,812 Ma. The Mountain shear zone is a post-Penokean discrete ductile deformation zone (Sims and others, 1990) that was intruded by the 1,812.7±3.6 Ma Hines Quartz Diorite (Sims and others, 1988).

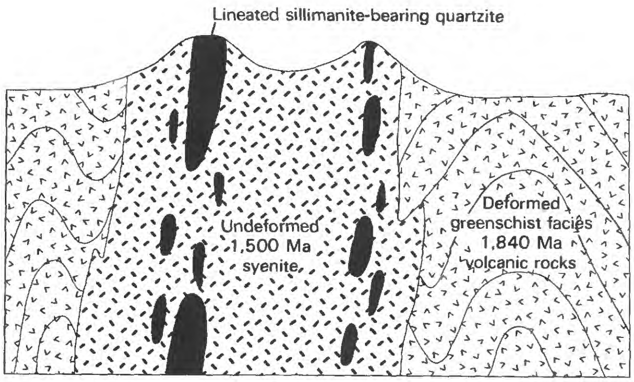


Figure 10. Interpretation of geologic relationships of quartzite at Rib Mountain, Wausau area. Lineated sillimanite-bearing (amphibolite facies) quartzite is at the same present topographic level as greenschist facies volcanic rocks, suggesting that the quartzite has been transported upward to its present position. Length of section ≈25 km. Vertical, not to scale.

Barron Quartzite and Quartzite at Flambeau Ridge

The Barron Quartzite (table 1) crops out in an area of about 480 km^2 in parts of Barron, Rusk, Sawyer, and Washburn Counties in northwestern Wisconsin (fig. 1). According to Hotchkiss and others (1915) and Rozacky (1987), the major lithology is pink to red quartz-cemented quartz arenite, with interbedded red argillite and a thin basal conglomerate. Pebbles in the conglomerate are mainly white quartz, but include volcanic rocks, granitoid rocks, and iron-formation. Drill cores show that the formation is at least 198 m thick, and may be as much as 400 m thick, although the upper contact is not exposed (Rozacky, 1987). Rozacky suggested that crossbedding indicates deposition on a braided alluvial plain succeeded upward by a marine shelf environment; the postulated source area is to the north and comprises mainly sedimentary rocks. The Barron Quartzite is almost undeformed, with dips averaging 5°–10°; it is unmetamorphosed (Hotchkiss and others, 1915; Rozacky, 1987). It uncomformably overlies a regolith developed on igneous and metamorphic rocks of the Pembine-Wausau terrane.

The quartzite at Flambeau Ridge forms a much smaller area than the Barron Quartzite. It is located in northern Chippewa County (fig. 1) and lithologically resembles the Barron Quartzite (Campbell, 1986). Exposures comprise approximately 700 m of conglomeratic quartzite, divisible into three major units: (1) A 50-m-thick basal conglomeratic unit with abundant subangular clasts (5 cm) of iron-stained slate (probably derived locally from an underlying regolith), overlain by approximately 100 m of crossbedded maroon quartzite containing scattered slate clasts. The slate clasts are embedded in a matrix of subrounded iron-stained quartz. (2) A 450-m-thick middle conglomeratic unit that contains subrounded clasts (5 cm) of vein quartz, granular iron-formation (jasper), pale-yellow metachert, and minor pale-green metavolcanic rocks. (3) An upper 100-m-thick well-cemented pale-orange crossbedded quartzite. Campbell (1986) reported that the matrix in the quartzite is dominantly sericite and kaolinite; therefore, the rocks are virtually unmetamorphosed. The contact between the quartzite and underlying rocks is not exposed; however, drill holes in the surrounding area (Campbell, 1986; LaBerge, 1988) encountered volcanic and plutonic rocks typical of the Pembine-Wausau terrane. The penetration of these rocks suggests that the quartzite unconformably overlies rocks of Early Proterozoic age, as does the Barron Quartzite.

The quartzite at Flambeau Ridge, historically named the Flambeau Quartzite (table 1) by Hotchkiss and others (1915), differs from the Barron Quartzite in several ways. It is thicker, contains far more conglomeratic zones than the Barron, and lacks interbedded argillite (Campbell, 1986). Additionally, the quartzite has been tightly folded into an asymmetric syncline with a nearly vertical south limb and a more gently dipping north limb; the fold axis plunges 55°–65° WNW. The north limb is truncated by a branch of the Jump River fault zone, a major N. 60° E. lineament in the Wisconsin magmatic terranes (Myers, 1974). Sheared, unmetamorphosed (Keweenawan?) diabase intersected in drill cores along the Jump River fault zone near Jump River (LaBerge, 1988) suggests reactivation of this major fault during Keweenawan (or later) time.

Interpretation.—Similarity in lithology, bedding features, relationship to underlying Early Proterozoic igneous rocks, and lack of metamorphism all suggest that the Barron Quartzite and the quartzite at Flambeau Ridge are correlative, and that they are younger than the volcanic rocks of the Pembine-Wausau terrane (1,889–1,860 Ma). One of the distinctive features of the Barron Quartzite and the quartzite at Flambeau Ridge is the presence of clasts of *granular* iron-formation in the conglomerates. Granular iron-formations are mainly restricted to Early Proterozoic sedimentary sequences (Gross, 1965), and the presence of such clasts suggests a source area of Early Proterozoic sedimentary rocks such as those in the Gogebic iron range to the north. We suggest that these quartzite formations are demonstrably younger than the Penokean orogeny. Similar granular iron-formation clasts are present in the Sioux Quartzite in southwestern Minnesota, and their presence, along with that of kaolinitic argillite ("pipestone") layers, suggests a correlation between the Barron, the Flambeau unit, and the Sioux Quartzite.

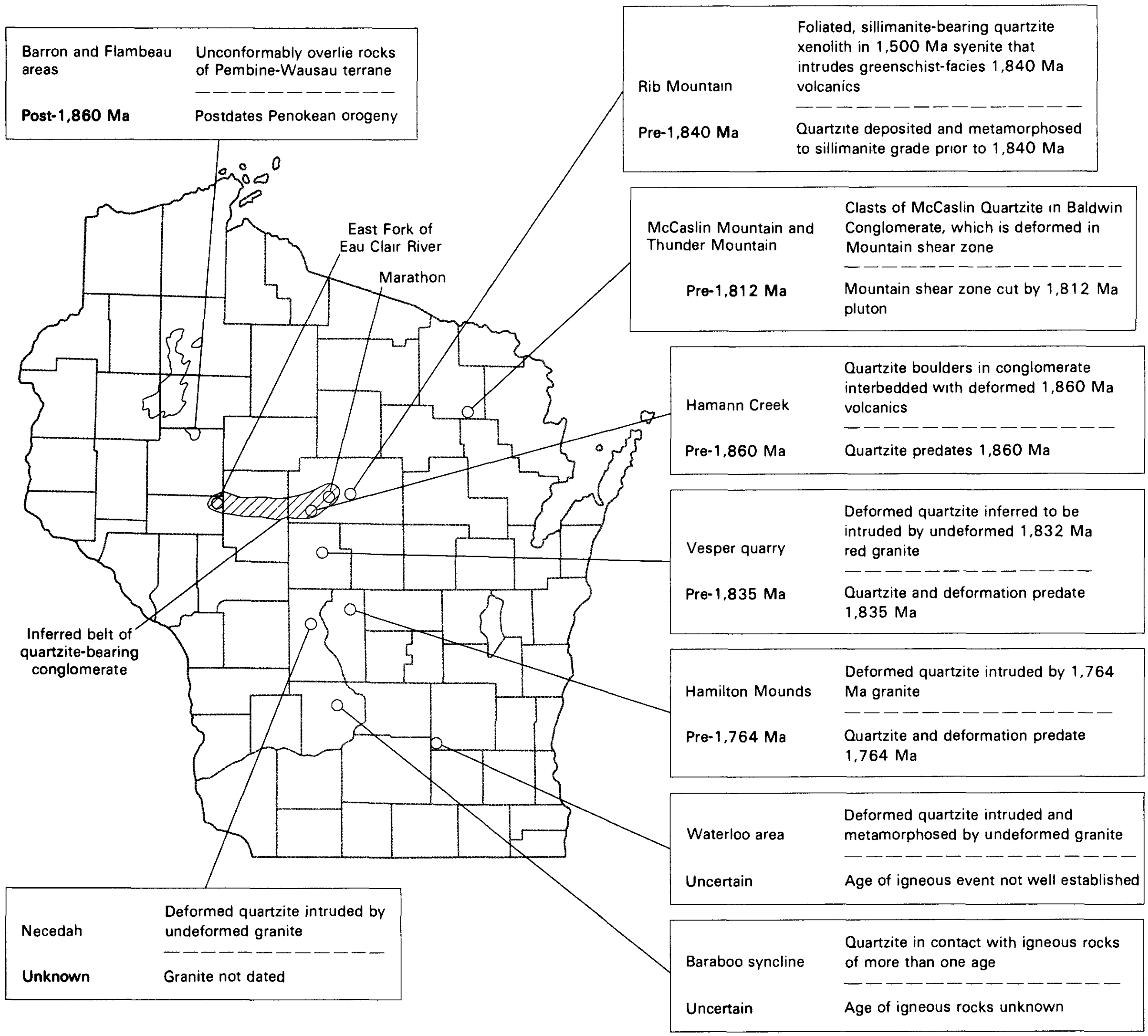


Figure 11. Summary of data on age relationships of Proterozoic quartzite at nine localities in Wisconsin.

SUMMARY OF INTERPRETATIONS

Age of Quartzites

The data presented herein clearly indicate that some quartzite bodies are older than 1,760 Ma (fig. 11), the lower age limit of the Baraboo interval, as defined by Dott (1983). The quartzite at McCaslin and Thunder Mountains is older than 1,812 Ma, as indicated by the age of undeformed Hines Quartz Diorite that cuts quartzite-bearing conglomerate, and the quartzite at Hamilton Mounds is older than 1,764 Ma, the age of undeformed granite that intrudes it. Also, the quartzite at Vesper quarry must be older than 1,760 Ma, and probably is older than 1,835 Ma, the presumed age of the undeformed red granite associated with the quartzite. The quartzite-bearing conglomerates in central Wisconsin, such as at Hamann Creek—which are interbedded with volcanic rocks in the Pembine-Wausau terrane—predate 1,860 Ma volcanic rocks. Another quartzite-bearing conglomerate in Eau Claire County (Marshfield terrane) is interbedded with 1,860 Ma volcanic rocks.

The ages of many other quartzite bodies cannot be tightly constrained, however, because of the absence of associated igneous rocks of known age. The Barron Quartzite and the quartzite at Flambeau Ridge, for example, are only known to be younger than the underlying volcanic rocks (1,889–1,860 Ma). The controversial Baraboo

Quartzite is presumed to be younger than the underlying(?) rhyolite (Dalziel and Dott, 1970), which probably is 1,760 Ma (Van Schmus, 1978), but this should be confirmed by dating rhyolite in contact with or near the quartzite.

Structural Summary

Structures present in all the quartzites in central and southern Wisconsin south of the Eau Pleine shear zone suggest that these rocks were deformed by south-verging structural processes. At Hamilton Mounds, structures indicate deformation in a south-verging fold-thrust system wherein rocks with brittle and ductile deformation features were tectonically stacked (fig. 2*B*). As at Hamilton Mounds, the quartzite at Waterloo and Vesper also has north-dipping cleavage, which suggests southward vergence. At Necedah, the quartzite is steeply dipping, has south-facing cross-bedding, and a nearly horizontal cleavage; kinematic data indicate southward transport. Along the southern margin of the exposed Precambrian in Wisconsin, the Baraboo syncline is overturned to the south and has an axial plane cleavage that dips north. Cambray (1987) suggested two episodes of deformation in the Baraboo area: (1) formation of an upright syncline; and (2) south-directed simple shear to deform the upright fold to its present symmetry. Similarity of structural features indicates that the quartzite and the rhyolite on the north limb have been deformed together.

We propose that the similarity in structural style and evidence of consistent southward vergence together suggest that the several quartzite bodies in central and southern Wisconsin, in the Marshfield terrane, were deformed by a major, complex, south-directed fold-thrust event. Available data suggest that deformation predates the 1,835 Ma post-tectonic red granite in central Wisconsin and clearly indicate that the deformation predates the 1,764 Ma granite/rhyolite event in southern Wisconsin. Structural data at Baraboo and Waterloo suggest that a north-verging structural event of unknown age and extent postdates the south-verging event. This event is expressed as south-dipping foliation in rhyolite and quartzite at Caledonia Church on the south limb of the Baraboo syncline and in the Waterloo area.

TECTONIC IMPLICATIONS

The scattered quartzite bodies in central and southern Wisconsin are interpreted as remnants of a once-extensive sequence of platform sedimentary rocks that were deposited on the passive margin of the Archean minicontinent (Marshfield terrane) that lies south of the Eau Pleine shear zone. We propose that all of them were deformed in a major south-verging fold-thrust system that extends southward from the Eau Pleine shear zone for at least 140 km to the Baraboo and Waterloo areas in southern Wisconsin. Structural and stratigraphic data presented herein indicate that these rocks were deposited before 1,860 Ma, inasmuch as clasts of quartzite (and iron-formation) are present in conglomerates interbedded with the 1,860 Ma volcanic rocks of the Marshfield terrane. This interpretation is consistent with that proposed recently by Sims and others (1989). They proposed that northward subduction moved the Archean minicontinent (Marshfield terrane) beneath the Pembine-Wausau terrane along the Eau Pleine shear zone, resulting in voluminous magmatism (≈1,850–1,840 Ma) in the southern part of the Pembine-Wausau terrane. Following collision, the platform quartzite and associated rocks were obducted southward, being deformed for distances of at least 140 km, to account for the distant Baraboo syncline (fig. 12). Deformation predates the late-stage (1,835 Ma) magmatism in central and southern Wisconsin.

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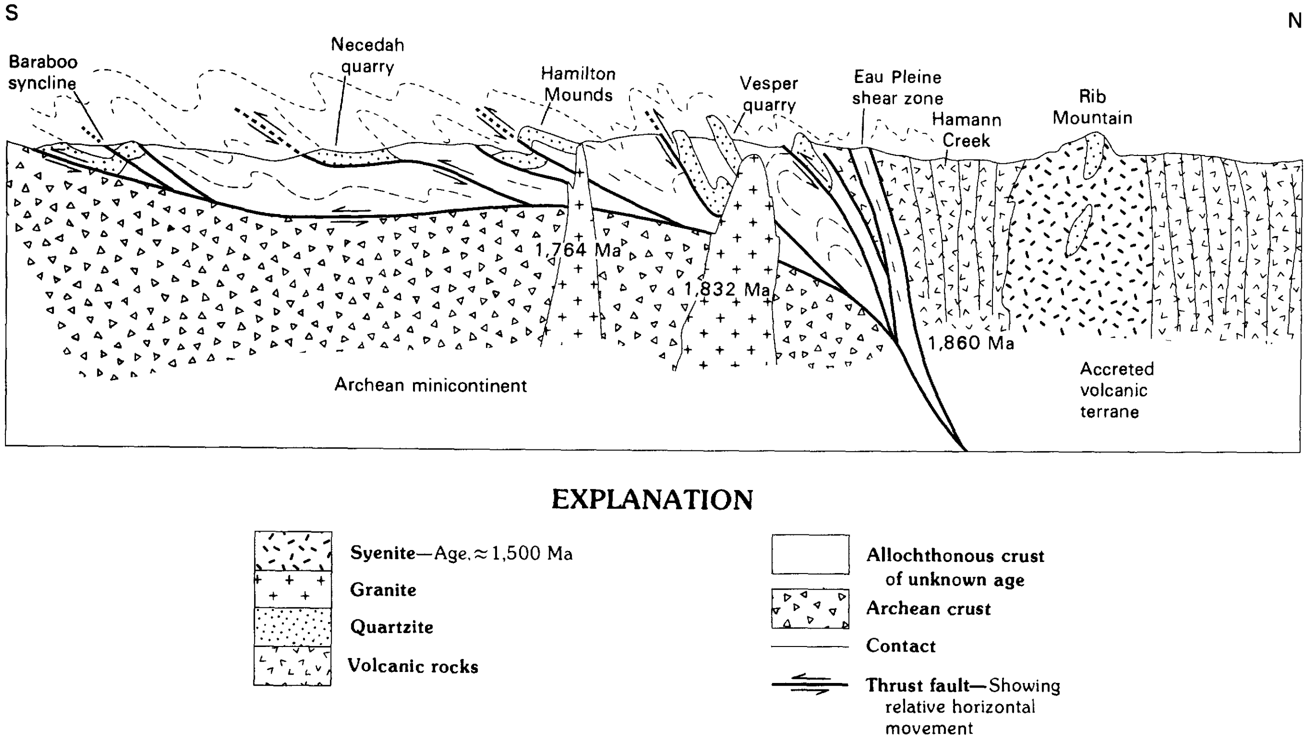

Figure 12. Interpretive sketch of tectonic relationships of the quartzites in central and southern Wisconsin, illustrating nature of proposed south-verging deformation. Length of section ≈175 km. Vertical, not to scale.

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