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International geological correlation project 426: Granite systems and Proterozoic lithospheric processes

1998 International Field Conference: Proterozoic granite systems of the Penokean terrane in Wisconsin

Editors and organizers:
W. Randall Van Schmus
University of Kansas, Department of Geology

Bruce A. Brown
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Cover Photo

Penokean Athelstane pink granite (ca. 1840 Ma) cut by dike of 1760 Ma Amberg gray granite, which is in turn cut by a pegmatite dike (Wolf River age?).

Photo taken of outcrop at Stop 2-07

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Part I

Overview: Proterozoic Geology of Wisconsin

OVERVIEW OF THE PROTEROZOIC GEOLOGY OF WISCONSIN

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Introduction

The Proterozoic geology of Wisconsin can be subdivided into ten major lithotectonic assemblages or tectonic episodes with distinctly different tectonic styles or petrologic genesis. These are: (1) Paleoproterozoic cratonic sedimentary and volcanic rocks overlying Archean basement in northwestern Wisconsin; (2) the Wisconsin magmatic terrane of the Penokean orogen, (3) the Marshfield terrane of Archean basement and Penokean plutons in west-central Wisconsin, (4) the 1760 Ma plutonic rocks of northern Wisconsin; (5) the 1760 Ma granite-rhyolite suite of southern Wisconsin; (6) cratonic quartzites of the "Baraboo interval"; (7) a cryptic ca. 1650 Ma deformational and metamorphic event; (8) the ca. 1500 Ma syenite complexes of the Wausau area; (9) the ca. 1480 Ma Wolf River batholith of east-central Wisconsin; and (10) ca. 1100 Ma igneous activity (e.g., Keweenawan volcanic and associated plutonic rocks) associated with the Midcontinent Rift System. During this field trip we will be able to examine representatives of (2) through (9). (1) and (10) are best observed during a field trip in northern Michigan. A more comprehensive overview of the Lake Superior region can be obtained in the review by Sims et al. (1993). This overview highlights key aspects of the regional geology and cites literature that can serve as an entry for more detailed reading.

1. Superior Craton

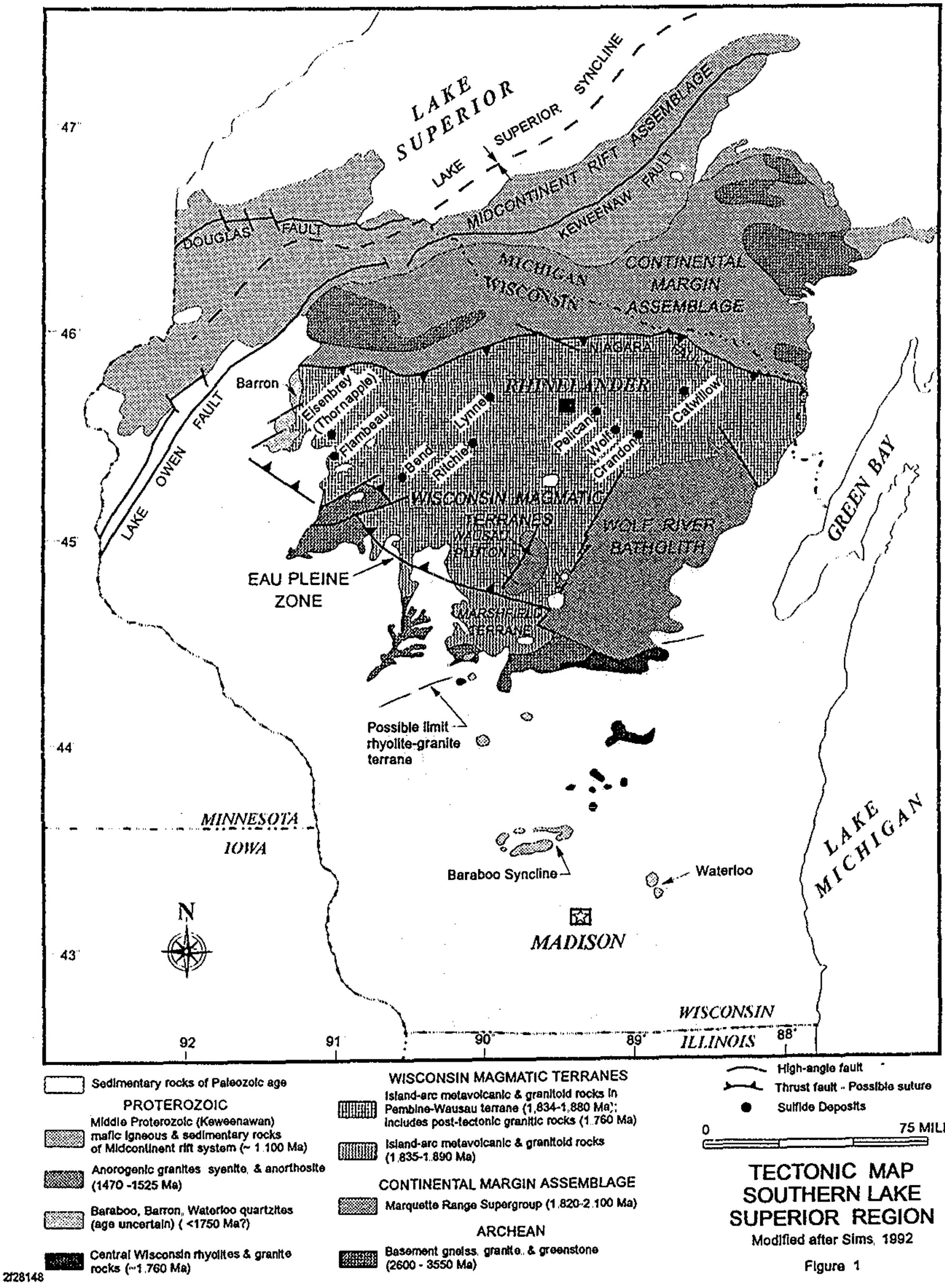
The Archean basement in northwestern Wisconsin is connected to the more extensive Archean terranes of northern Michigan and of Minnesota, which in turn represent the southern margin of the Superior Province of the Canadian Shield. Paleoproterozoic rocks overlying the Archean basement of the shield are represented primarily by metasedimentary rocks (including banded iron formations) and metavolcanic rocks of the Marquette Range Supergroup of Michigan and the Animikie Group of Minnesota, and their equivalents in NW Wisconsin. Mesoproterozoic rocks are primarily represented by Keweenawan volcanic, plutonic, and metasedimentary rocks associated with the Midcontinent rift system. See Sims et al. (1993) for further information.

2. Wisconsin Magmatic Terrane

The 1880 to 1830 Ma Penokean orogen in Wisconsin is represented primarily by the Wisconsin magmatic terrane (also sometimes referred to as the Pembine-Wausau magmatic terrane), which underlies most of the northern part of the state and extends south into the Wausau region of central Wisconsin. This terrane is bounded on the north by the Niagara Fault Zone, which is a major crustal boundary that juxtaposes rocks of the Wisconsin magmatic terrane against Archean (2.6 to 3.6 Ga) basement rocks and overlying Paleoproterozoic cratonic rocks of the Superior Province to the north. This margin probably developed as a result of pre-1900 Ma separation of the Superior Province from other parts of a middle Paleoproterozoic supercontinent.

Figure 1 (DeMatties, 1996) summarizes the major features of Precambrian geology in Wisconsin, including identification of several of the known sulfide deposits. Figure 2 (Sims et al., 1989) shows the Proterozoic geology of northern Wisconsin in more detail, and Table 1 (Sims et al., 1989) summarizes much of the Precambrian geological history. Van Wyck (1995) has reported several new U-Pb zircon analyses for the Precambrian of Wisconsin, and these are cited as appropriate in this guidebook.

(from Erickson and Côté, 1996)



TECTONIC MAP SOUTHERN LAKE SUPERIOR REGION
Modified after Sims, 1992
Figure 1

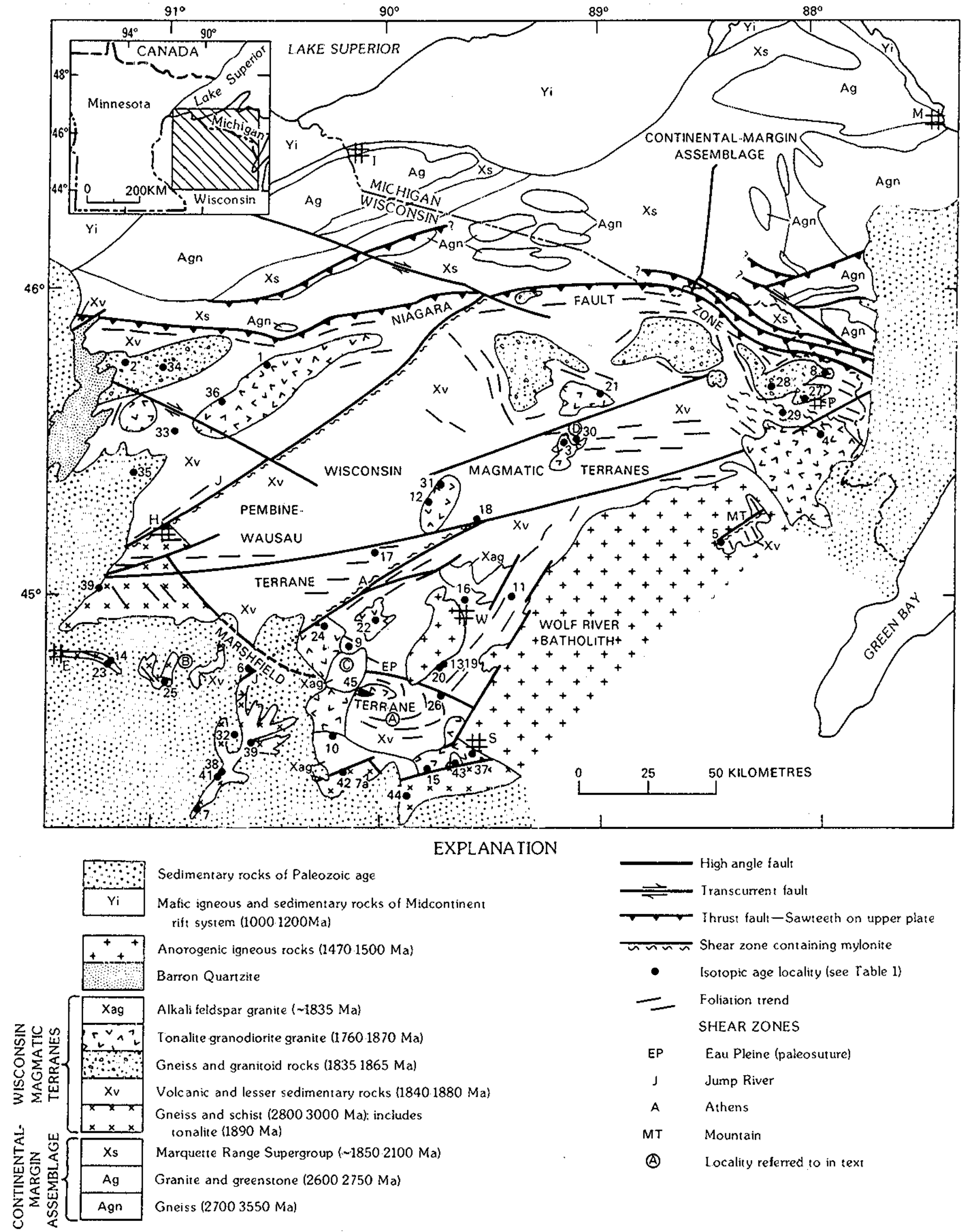


FIG. 2. Geologic map of eastern part of Lake Superior region showing relationships of rocks within Penokean Orogen. E, Eau Claire; H, Holcombe; I, Ironwood; M, Marquette; P, Pembine; S, Stevens Point; W, Wausau. Yi, Precambrian Y = Middle Proterozoic (900–1600 Ma); Xag etc., Precambrian X = Early Proterozoic (1600–2500 Ma); Ag etc., Archean (2500–3800 Ma). Compiled by P. K. Sims

from Sims et al., 1989

TABLE 2. Major Early Proterozoic magmatic and tectonic events, Wisconsin magmatic terranes

Approximate age (Ma)	Event			Age constraints	Comments
	Magmatism or sedimentation	Deformation	Metamorphism		
1128±20		Differential uplift marginal to Mid-continental rift system	Thermal event	Peterman *et al.* (1985), Peterman and Sims (1988)	Reset Rb–Sr biotite ages
1630		Mild folding of 1760 Ma rhyolite in southern Wisconsin on northeast axes	Regional thermal event	Peterman *et al.* (1985)	Reset Rb–Sr whole-rock and mineral ages
1760	Anorogenic rhyolite and granite in southern Wisconsin			1760±10 Ma; Van Schmus (1978)	See Smith (1978) for description of rocks
~1815		Discrete, spaced shear zones	Low amphibolite and upper greenschist facies	Hines Quartz Diorite (locality 5, Table 1) intruded Mountain shear zone, Octonto County (localities 7, 10, and 22, Table 1)	Includes Mountain, Athens, and Jump River shear zones
1835	Post-tectonic alkali-feldspar granite and rhyolite				Possibly related to calderas; transects Eau Pleine shear zone
1835–1845	Felsic calc-alkaline volcanic rocks and granophyric granite in Wausau area, preceded by subvolcanic tonalite–granodiorite			(Localities 13, 16, 19, and 20, Table 1)	Younger volcanic sequence; tonalite is older than rhyolite and granophyre
1840		Eau Pleine shear zone	Greenschist facies	Truncates rocks in Wausau area and is cut by ~1835 Ma alkali-feldspar granite	Amalgamation of Pembine–Wausau and Marshfield terranes; interpreted as paleosuture zone
~1860		Niagara fault zone; regional deformation	Low amphibolite to greenschist facies	Preceded ~1835 Ma plutonism (Spikehorn Creek Granite, locality 8, Table 1)	Paleosuture resulting from collision of Pembine–Wausau terrane with south-facing passive continental margin
1860–1889	Felsic to mafic calc-alkaline and tholeiitic volcanic rocks; calc-alkaline granitoid rocks, Pembine–Wausau and Marshfield terranes			(Localities 25, 26, 29, 30, and 33, Table 1)	The two terranes were separate entities
1870–1892	Tonalite in Stevens Point area and granite in Neillsville area, Marshfield terrane			(Localities 37 and 32, Table 1)	Intruding Archean basement rocks; possible associated volcanic rocks not known

from Sims et al., 1989

The Wisconsin magmatic terrane is dominated by volcanic and plutonic rocks; metasedimentary sequences are rare. Pelitic schists and paragneisses such as found in the 1.8 to 1.7 Ga Proterozoic terranes of the southwest United States (Karlstrom and Bowring, 1993; Reed et al., 1993; Robertson et al., 1993) are notably lacking in Wisconsin. Volcanic rocks range from mafic pillow basalts to ignimbritic rhyolites, with a tendency toward a bimodal relationship (Schulz, 1984). Plutonic rocks range from ultramafic units to silicic granites. Chemical compositions of the igneous rocks generally suggest calc-alkaline, arc-related affinities (Sims et al., 1985, 1989, 1992). Isotopic data suggest that most of the magmatic material came from juvenile sources (ca. 1900 to 1800 Ma depleted mantle), although it is clear that older crustal material was locally significant (Barovich et al., 1989; Van Wyck and Johnson, 1997; Schulz and Ayuso, 1998). The Wisconsin magmatic terrane is generally interpreted as accretion of island arcs to the southern margin of the Superior province during the late Paleoproterozoic Penokean orogeny (Sims et al., 1989), with the main polarity being southward dipping subduction under the converging arc(s), although the Nd isotopic data of Barovich et al. (1989), Van Wyck and Johnson (1997), and Schulz and Ayuso (1998) show that the picture is not simple.

Massive sulfide deposits have been found in numerous locations throughout northern Wisconsin (Figure 1; LaBerge, 1996), although only the deposit at Ladysmith has been developed.

Penokean volcanic and plutonic rocks are also abundant throughout central Wisconsin, particularly in Marathon County (LaBerge and Myers, 1983). The rocks of this area are commonly referred to as the Wausau terrane, whereas those in northeastern Wisconsin have been called the Pembine terrane; the combined Penokean complex of central and northern Wisconsin is thus designated the Pembine-Wausau terrane. Isotopic ages (Sims et al., 1989; Van Wyck, 1995) suggest that parts of the Wausau terrane may be younger (ca. 1820 to 1840 Ma) than those to the north, indicating that the northern terranes are generally older, and that younger phases of the Penokean orogen are more common to the south. However, the existing geochronology is not sufficiently precise to make more detailed chronostratigraphic interpretations within the overall Penokean orogen. We will see Penokean rocks of northern Wisconain on Days 1 and 2; we will see parts of the Wausau terrane on Day 4.

3. Marshfield Terrane

To the south, plutonic and volcanic rocks of the Penokean orogen intrude and overlie Archean gneisses and migmatites of the Marshfield terrane (Figs. 1 and 2), which appears to be a large block of 2.8 to 3.2 Ga Archean basement that was detached from the Superior Province about 1900 Ma and subsequently acted as a microcontinent during the Penokean orogeny (Van Schmus and Anderson, 1977). The Marshfield terrane probably formed during latter stages of the Penokean orogeny as the previously detached Archean microcontinent drifted back toward the Superior craton. The abundant granitoids in the Marshfield terrane require subduction-generated magmatism. Only the northern margin of this terrane is exposed, and it is not clear if such subduction was southward dipping along the northern margin, northward dipping along the (now buried) southern margin, or both. We will examine some of the rocks of this terrane on Day 4.

4. 1760 Ma Plutonic Rocks of Northern Wisconsin

There are several small granitic plutons in the northern part of the Wisconsin magmatic terrane that have been dated by U-Pb on zircon at ca. 1760 ma (Van Schmus, 1980; Sims et al., 1989). These plutons are otherwise petrologically similar to granites of the Wisconsin magmatic terrane, but they are clearly post-tectonic. They are coeval with epizonal granites and rhyolites of southern Wisconsin (next section) and are presumably genetically associated with them. We will see examples of these rocks during Days 1, 2, and 4.

5. 1760 Ma Granite-Rhyolite Suite of Southern Wisconsin

Smith (1978a, 1978b) has documented in detail a suite of felsic igneous rocks that occurs throughout south-central Wisconsin (Fig. 3). These rocks are typically epizonal, granophyric granites and ignimbritic, rhyolitic volcanic rocks, with the plutonic rocks exposed to the north and the volcanic rocks to the south. This relationship suggests the region is tilted toward the south, with deeper erosion levels in the north. The occurrence of more deeper seated plutons farther north is consistent with this picture. These rocks yield U-Pb ages of ca. 1760 Ma (Van Schmus, 1978, 1980). However, the Rb-Sr systems in these same rocks yield a nearly colinear array of data with an apparent age of 1630 Ma, presenting a problem for interpretation of the regional tectonic history (see Section 7). We will visit these rocks during Day 5.

6. Quartzites of the Baraboo Interval

Cratonic quartzites and associated pelites are common in the Wisconsin, SW Minnesota, and SE South Dakota region. These quartzites have local names such as Sioux, Barron, Baraboo, and Waterloo quartzites, and may all be parts of a major post-1760 Ma suite of mature clastic sediments deposited on eroded cratonic basement during the "Baraboo Interval" (Dott, 1983; Greenberg and Brown, 1983, 1984; Brown and Greenberg, 1986). These rocks probably represent alternating marine and continental sedimentation during several trangressions and regressions in the late Paleoproterozoic. We will examine rocks of this association in the Baraboo area on Day 5.

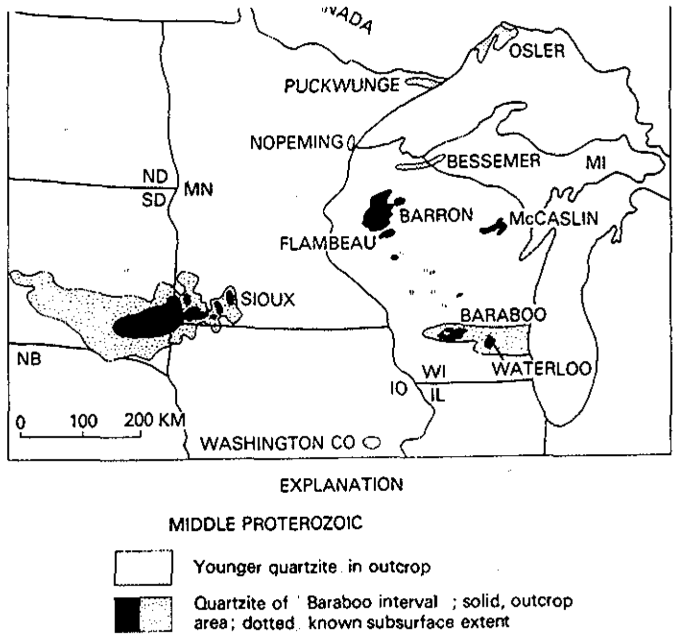


Figure 4. Map showing locations of Proterozoic quartzite units in the Lake Superior region. (from Sims et al., 1993).

7. 1650 Ma Deformation and Metamorphism

The ca. 1630-1650 Ma apparent age mentioned for the 1760 Ma rhyolites and granites has been recorded from other Penokean and older suites of rocks throughout the southern Lake Superior region (Van Schmus and Woolsey, 1975; Van Schmus, 1980; Peterman et al., 1985). This is a cryptic age, since no igneous rocks of this age have been found (e.g., ages confirmed with U-Pb on zircon) in the entire region. Recent Ar-Ar studies on muscovite from Baraboo Interval rocks in Wisconsin (Holm et al., 1998) also yield ages of ca. 1650 Ma for deformed rocks of the suite (e.g., Baraboo area), whereas undeformed rocks of the Barron quartzite yield older ages. These data confirm earlier speculations (Van Schmus, 1980) that the 1650 ages are probably due to deformation and low-grade (wet) metamorphism throughout the region. This deformation is most likely a foreland manifestation of tectonism associated with a Mazatzal-age (e.g., 1650 Ma; Karlstrom and Bowring, 1983) tectonic belt along the southern margin of Laurentia (see also Van Schmus, Bickford, and Condie, 1983).

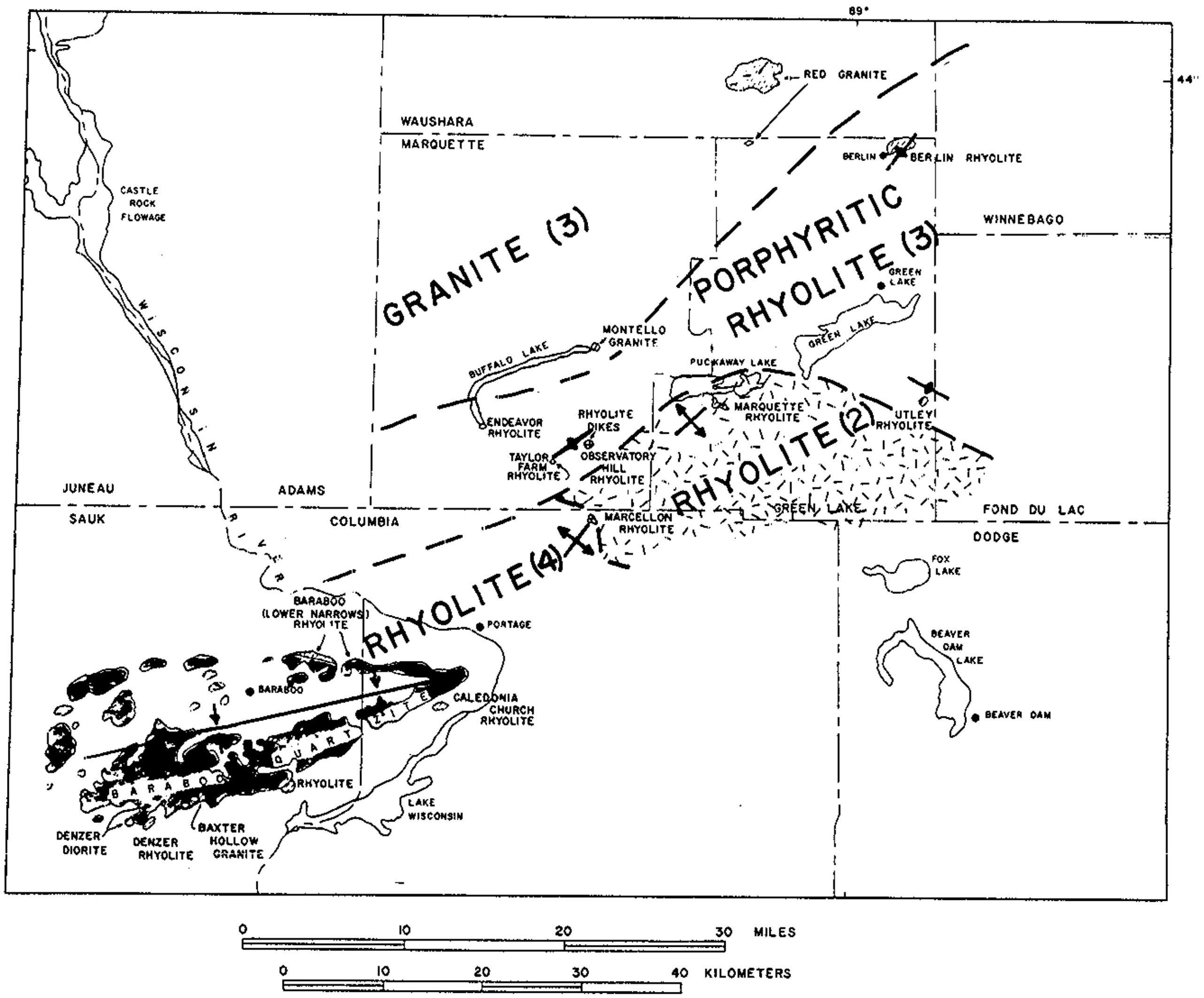


Figure 4. Map of the Fox River Valley-Baraboo area showing the geographic distribution of the chemical groups. Dashed lines are inferred contacts between chemical groups. Since these contacts parallel structures in exposures, patterns on this map probably reflect the geology of the buried Precambrian basement in this area. Foliation symbol indicates trend of banding in rhyolites, fold symbols indicate mean direction of axial plane traces, and shaded areas are outcrops of Baraboo Quartzite (from Smith, 1978a).

8. Wausau Syenite Complexes

Some interesting suites of rock in the Wausau area are known as the Stettin and Wausau syenite complexs (the latter may consist of several plutonic centers). These occur to the west of Wausau and are relatively small plutonic complexes with rock types ranging from nepheline syenite through granite. Their reason for being is still somewhat uncertain. The Wausau complex has yielded U-Pb ages of 1500 to 1520 Ma (Van Schmus, unpublished data), but rocks from the Stettin complex have yielded ages as old as 1565 Ma (Van Wyck, 1995). It does not seem reasonable that these two complexes are 60 Ma different in age, although it is possible. Furthermore, although the age of the Wausau complex is only slightly older than that of the Wolf River batholith (1485 Ma), there is no clear genetic association between the two plutonic complexes. We shall see some parts of the Wausau complex on Day 4.

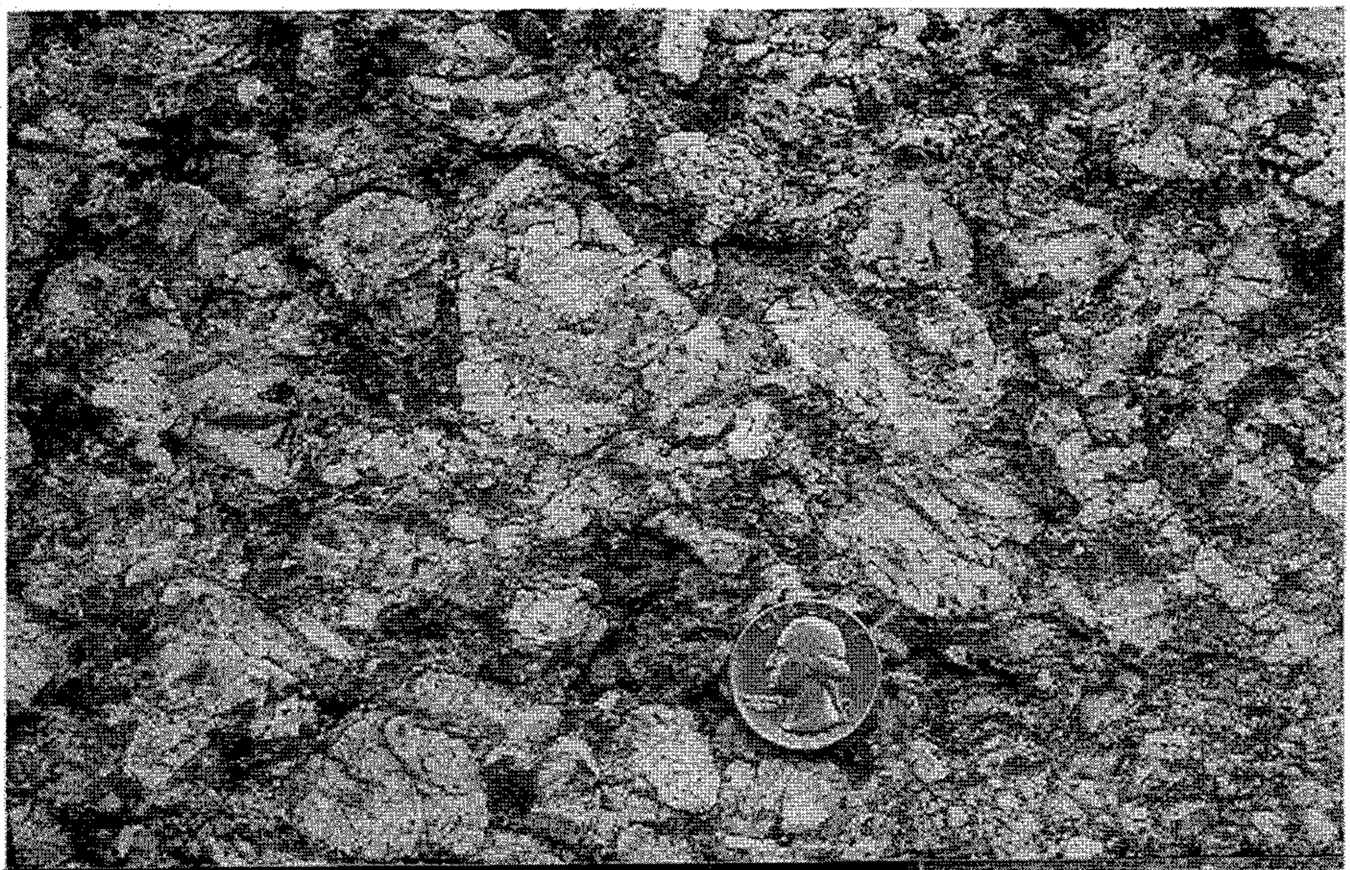
9. Wolf River Batholith

The Wolf River batholith is a large 1485 Ma plutonic complex in east-central Wisconsin. It is particularly noteworthy because is has anorthosite-mangerite-rapakivi granite associations and it is coeval with a large suite of A-type ("anorogenic") plutons that occur throughout the 1850 to 1650 Ma Paleoproterozoic basement of southern and eastern Laurentia. Most of these plutons in the central and western United States are somewhat smaller than the Wolf River batholith , and most are magnetite series granites, showing up as pronounced anomalies on aeromagnetic maps (a feature which has made them easy to document in the subsurface of the midcontinent region; Van Schmus et al, 1987). The Wolf River batholith has a relatively weak magnetic signature, except around anorthosite blocks, and it is mainly an ilmenite-series granite. The origin of this batholith in particular and the anorogenic suite in general will be the focus of stops on Day 2 and Day 3.

The two photos on the facing page show aspects of the wiborgite phase of the Wolf River batholith at Tigerton, Wisconsin (Stop 3-07).

The top photo shows a characteristic mantled alkali feldspar on the east face of the outcrop north of the road.

The lower photo shows a large, round alkali feldspar megacryst on the top face of the outcrop north of the road.



GUIDEBOOK REFERENCES The following abbreviations are used in this guidebook for matrial duplicated from previous guidebooks in Wisconsin that cover the material of this trip. ILSPG = Annual Meeting of the Institute on Lake Superior Geology; TRI-STATE = Annual geological field conferences held by a an informal Tri-State (Wisconsin, Michigan, Minnesota) association of college and university geoscience departments.

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International Geological Correlation Project 426: Granite Systems and Proterozoic Lithospheric Processes

Wisconsin
1998

1998 International Field Conference: Proterozoic Granite Systems of the Penokean Terrane in Wisconsin

September 13-19, 1998

Field Guide and Proceedings Volume

Part II

Field Trip Guide

Field Trip Day 1
Madison to Rhinelander

Objectives:

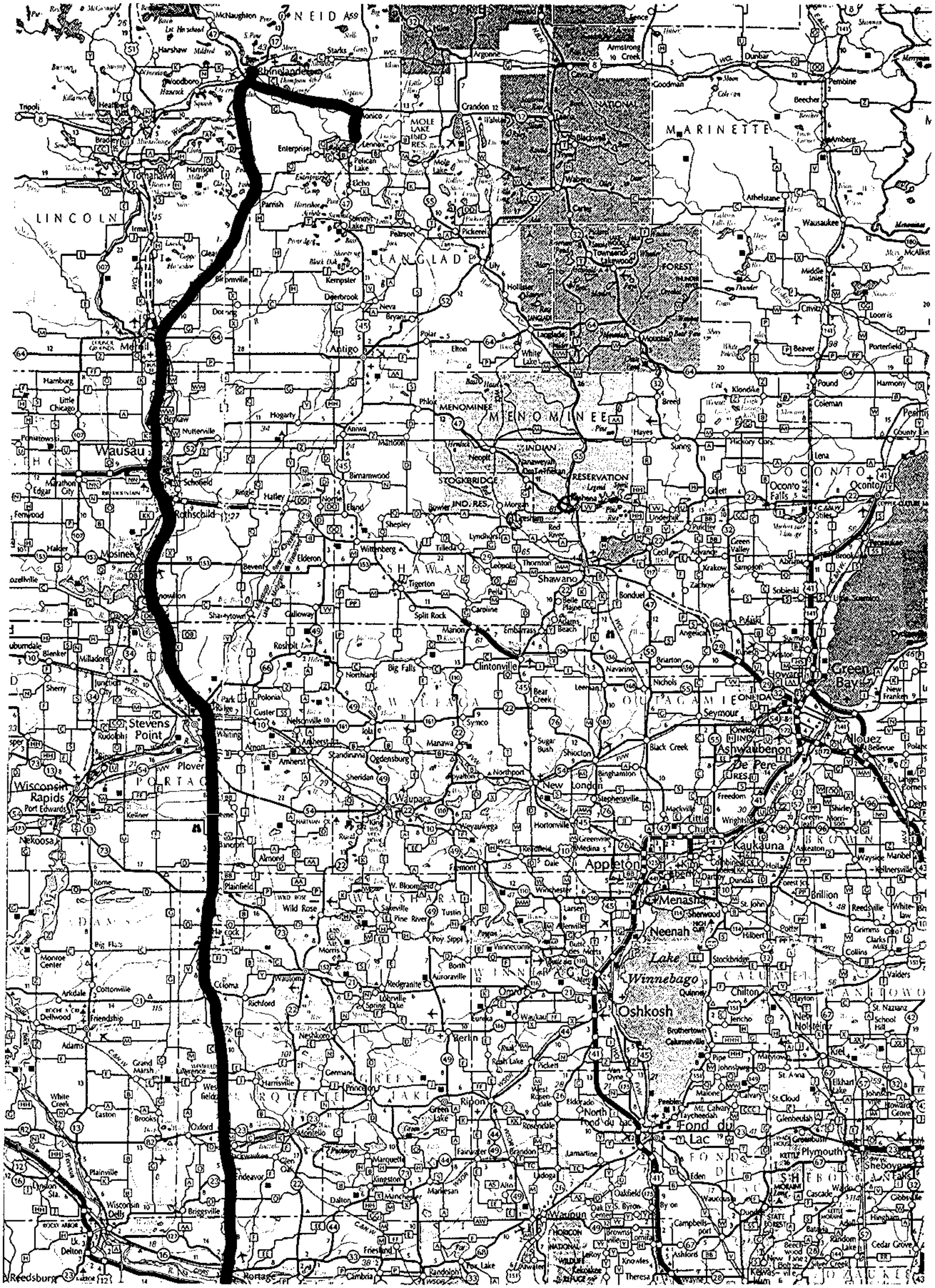
The main objective of the day is to travel to northern Wisconsin. We will begin with a brief review of the Precambrian geology of Wisconsin before we leave. We will break our trip in Wausau at Rib Mountain State Park for a picnic lunch and a brief overview of the Wausau region (focus of Day 4 stops).

We will have time in the afternoon for a few stops in the Monico region east of Rhinelander In particular, we can examine some good examples of Penokean mafic and felsic volcanic rocks plus an example of 1760 Ma (post-Penokean) granitic plutonism in northern Wisconsin

In the evening we will have a presentation by Mike Mudrey and Bruce Brown on past, present, and potential development of mineral resources in the Penokean terrane of northern Wisconsin, including the political and environmental aspects of trying to develop a major mine in the Crandon massive sulfide deposit.

Itinerary:

0800	Orientation Presentations
0900	Depart Madison
1200	Stop 1-01: Lunch in Wausau (Rib Mountain Park)
1430	Arrive Monico area
	Stop 1-02: Penokean pillow basalt
	Stop 1-03: Penokean rhyolite porphyry
	Stop 1-04: Silicified Penokean pillow basalt
	Stop 1-05: Fragmental Penokean felsic volcanics
	Stop 1-05: 1760 Ma Granite at Pelican Lake
1800	Arrive Rhinelander (Claridge House Best Western)



Rhinelander
Tomahawk
LINCOLN
LANGLADE
Antigo
Merrill
MARINETTE
MENOMINEE
Wausau
Schofield
Rothschild
Mosinee
SHAWANO
Shawano
OCONTO
Stevens Point
Plover
PORTAGE
Wisconsin Rapids
WAUPACA
Waupaca
OUTAGAMIE
Green Bay
Appleton
Menasha
Neenah
Lake Winnebago
Oshkosh
WAUSHARA
WINNEBAGO
GREEN LAKE
CALUMET
MANITOWOC
Fond du Lac
FOND DU LAC
Sheboygan
Portage
Wisconsin Dells

Stop 1-01: Rib Mountain State Park

Location: Picnic area and overlook at Rib Mountain State Park, Wausau; SE 1/4 Sec. 8, T.28N., R.7E., Marathon County, Wisconsin.

Stop Description: Rib Mountain is a roof pendant of quarzite within the ring structure of the Wausau syenite complex. It is the highest point in the region and provides a good overview of the Wausau area

Prior Guidebook Reference: Myers (1984a); LaBerge et al. (1986a)

Stop 1-02: Penokean pillow basalt

Location: Outcrop south of U.S. Highway 45, just west of intersection with old highway pavement (now County Highway V), east end of Monico. NE cor. SE 1/4 Sec. 29, T 36N., R 11E., Oneida County, Wisconsin

Stop Description: Pillow basalts are common in the mafic Penokean volcanics throughout Wisconsin, but the outcrops are often in out-of-the-way or poorly accessible places. At this locality we can observe well preserved pillow structures in the Monico portion of the Penokean succession of northern Wisconsin. The two-foot (60 cm) x three-foot (90 cm) long pillows are slightly stretched and have tops to the south. Original pyroxene has altered to hornblende and chlorite; plagioclase is extensively altered.

Prior Guidebook Reference: Mudrey (1979), Stop 6, p. 30-31; Schulz and Ojakangas (1989), Stop 6-2.

Stop 1-03: Penokean rhyolite porphyry

Location: Outcrop along small ridge 100 ft. north of maintanance building, north side of Lake Street, north of Monico. SE 1/4 SW 1/4 Sec. 20, T 36N., R 11E., Oneida County, Wisconsin.

Stop Description: An example of quartz-porphyry felsic volcanics of the Penokean belt in northern Wisconsin. This particular outcrop is a rare example where zircons do not accompany quartz phenocrysts! Consequently, this part of the succession has not been dated. A U-Pb zircon age of 1869 ± 6 Ma was obtained from another unit a few miles to the south (Sims et al., 1989; Van Schmus, unpublished data).

Prior Guidebook Reference: None

STOP #1

TITLE: RIB MOUNTAIN SUMMIT - GENERAL GEOLOGY

LOCATION: Rib Mountain State Park observation platform: SE/4 Sec. 8, T28N, R7E; Wausau 15' Quadrangle, Wausau West 7.5' Quadrangle

DATE: March, 1984

DESCRIPTION:

From this vantage point, one can get a general perspective of the major elements of the geology and geography of the Wausau region. This observation tower and all of Rib Mountain are on the upturned edge of nearly vertical beds of very coarse-grained metaquartzite with tops facing southward. Facing direction is indicated by sparsely exposed cross-bedding and occasional ripple forms. The Rib Mountain quartzite is an arcuate, keel-shaped xenolith embedded in quartz syenite: it is situated on the northern edge of the Rib Mountain syenite-quartz syenite pluton, whose core (just south of here) is occupied by granite and quartz monzonite of the northern lobe of the Ninemile pluton. Mosinee Hill southeast of here (the knob with the radio antenna on it) and Hardwood hill southwest of here are similar, but smaller quartzite xenolith remanents that are located in analogous positions in the cylindrical Rib Mountain pluton. The quartzite xenoliths form about three-quarters of a circle with a diameter of about 5 miles. Relict bedding in the quartzites at Mosinee Hill (STOP #2) and Hardwood Hill is parallel to elongation direction of the lenticular xenoliths.

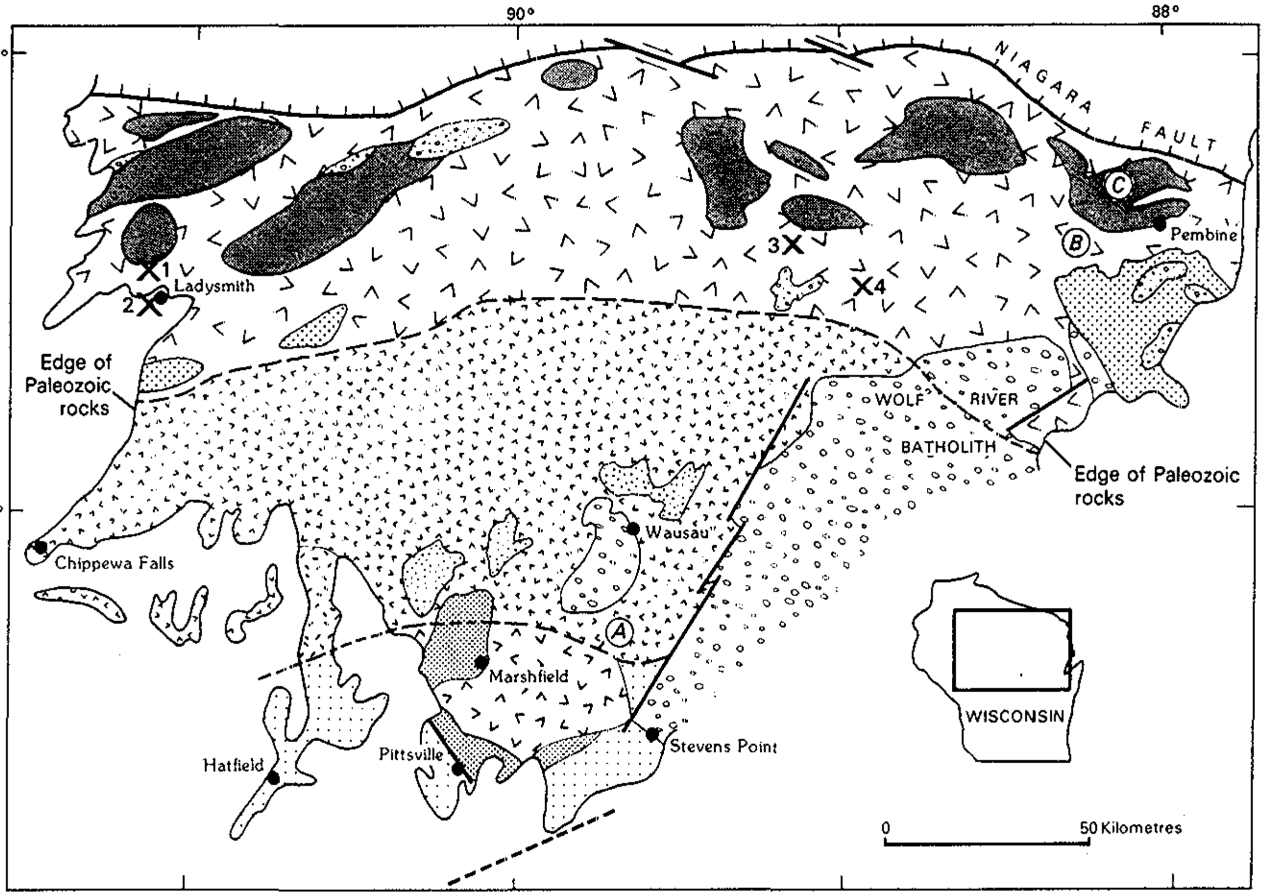
A large, abandoned quarry, operated by 3M Corporation as a source of roofing granules, affords an excellent exposure of the quartzites. A porphyritic diabase dike cuts through quartzites on the south wall of the quarry, and is traceable in float for about 2 miles to the west-southwest. The quarry is located on the west end of Rib Mountain about one-half mile west of here.

The east end of the Rib Mountain quartzite body is offset by a small northeast-trending fault. This fault is parallel with larger faults of similar trend that cut the edges of the Rib Mountain pluton.

The Wausau pluton and the Rib Mountain pluton show an uncanny resemblance: their contact is covered by Rib River alluvium just north of Rib Mountain. Each of the plutons is cored by granite, and each contains a large mass of metaquartzite in its northern edge. One is tempted to suggest that the apparent "duplication" was produced by low-angle faulting. However, the two plutons are significantly different in mineral composition and in the types of xenoliths making up their intermediate zones. The Wausau syenite has a broad intermediate zone of amphibole syenite containing mainly metavolcanic xenoliths, while the Rib Mountain pluton intermediate zone is composed dominantly of quartz syenite (with a texture strongly resembling arkose) and xenoliths mainly of metaquartzite, biotite schist, and amphibolite.

Interesting questions arise as to the origin and mode of emplacement of these xenoliths. The schists, amphibolite, and possibly at least some of the metaquartzite xenoliths show higher grades of regional metamorphism than is displayed in the rocks surrounding the Wausau complex at its present level of exposure. It is therefore inferred that these xenoliths were brought up from a more highly metamorphosed basement. Volcanic xenoliths, like those seen in the Wausau syenite at Stop 3 may represent material collapsed into the pluton during caldera subsidence.

(from Sims et al., 1993)



EXPLANATION

LADYSMITH—PEMBINE BELT

EARLY PROTEROZOIC

- Granite (1760 Ma)
- Granodiorite granite (~1835 Ma)
- Dominantly metavolcanic rocks (1865 1880 Ma)
- Gneiss and amphibolite (~1865 Ma) and tonalite granite (1835 1860 Ma)

CHIPPEWA—WAUSAU BELT

MIDDLE PROTEROZOIC

- Anorogenic granite (1485 Ma) and syenite (1518 Ma)

EARLY PROTEROZOIC

- Granitic gneiss (~1835 Ma)
- Granodiorite granite (~1840 1860 Ma)
- Dominantly metavolcanic rocks (~1840 1860 Ma)

MARSHFIELD—STEVENS POINT BELT

EARLY PROTEROZOIC

- Granite (~1835 Ma)
- Dominantly metavolcanic rocks

LATE ARCHEAN

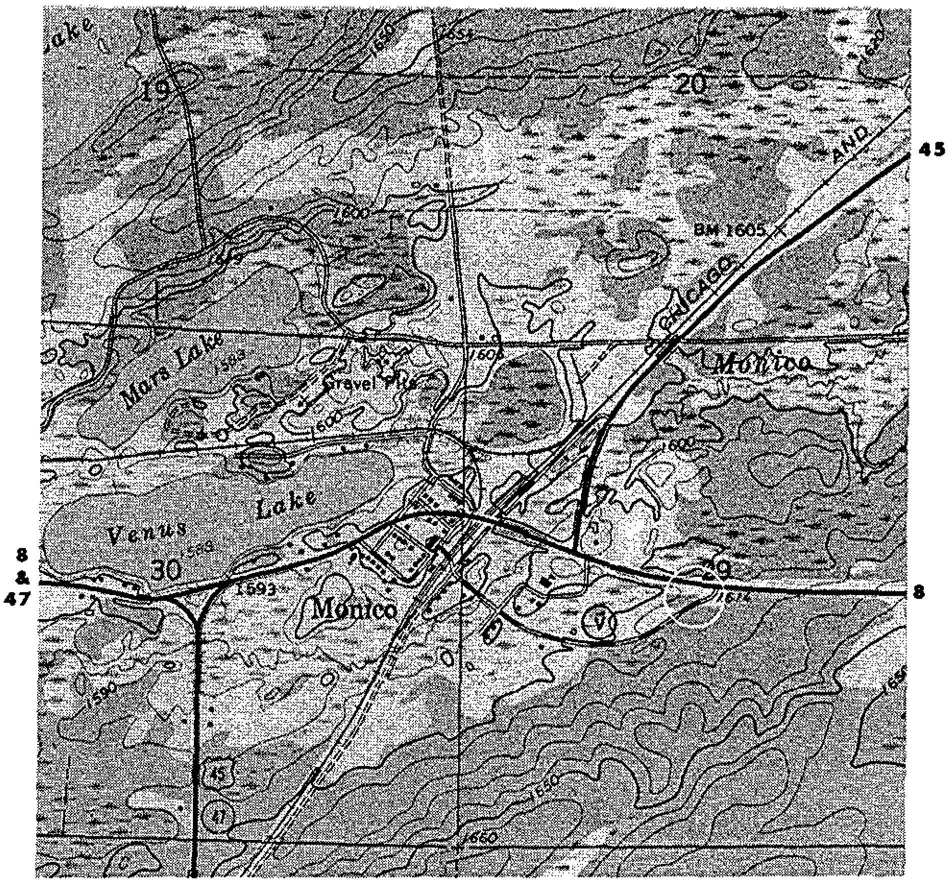
- Gneiss and amphibolite (~2500 2800 Ma) cut by foliated tonalite in Stevens Point area (1830 1890 Ma) and foliated granite in Black River valley north of Hatfield (1870 Ma)

- Inferred boundary of belt short dashed where concealed
- High angle reverse fault — hachures on downthrown side
- Fault showing apparent relative movement
- High angle fault
- Concealed fault — possible southern limit of Archean rocks
- X1 Massive sulfide deposit. 1 Thornapple 2 Flambeau 3 Pelican River 4 Crandon
- (A) Localities referred to in text

Figure 29. Map showing volcanic belts in Wisconsin magmatic terrane (after Sims, 1987)

Title: Monico East - Mafic Pillow Basalt

Location: Intersection of U.S. 8 and County V, center of Sec. 29, T.36N., R.11E., Oneida County (Monico 7½-minute topographic quadrangle, 1965).



Author: M.G. Mudrey, Jr. (1978)

Description: A large outcrop is in the southwest corner of the intersection. The rock consists predominantly of sulfide-bearing, gray-green, chloritic pillow basalt trending N. 85° E., and dipping 80° SE. The two-foot thick by three-foot long pillows are slightly stretched and top to the south. Original pyroxene has altered to hornblende and chlorite. Plagioclase is extensively altered. The southeast edge of the outcrop is a ten-foot thick massive flow or sill. Diabasic texture in this unit is well developed.

Discussion: Two supracrustal sequences characterize the Middle Precambrian succession in northern Wisconsin and Michigan, a dominantly sedimentary unit including iron formations to the north, and a dominantly volcanic sequence including massive sulfide deposits to the south. Inasmuch as bedrock exposures are poor south of the Gogebic Range area, geologic maps of northern Wisconsin are based dominantly on geophysical interpretation. Units defined in the few areas of outcrop are extrapolated into the poorly exposed areas. The belt of rocks from Ladysmith on the west to Pembine on the east appears to be dominantly volcanic, with few intrusives. The volcanics in the Monico area are among the least deformed and better exposed in this belt. Pillows and other indicators of subaqueous deposition are evident in the volcanic rocks exposed in the Monico area. These features are well preserved because of the low metamorphic grade. The sequence around Monico appears to young to the south, and the sequence is known to be repeated by faulting that trends east-northeast. This particular outcrop appears to lie stratigraphically above the massive sulfide deposit at Pelican River to the west, and possibly above the Crandon deposit to the east. It is representative of the basaltic rocks in the Monico area.

Stop 1-04: Silicified Penokean pillow basalt

Location: Boulders and loose bedrock in north part of a gravel pit, south side of Lake Street, NW of Monico NE 1/4 NE 1/4 Sec. 30, T 36N., R 11E., Oneida County, Wisconsin. Unit is also exposed behind houses at the top of the hill to the east

Stop Description: The volcanic rocks at this stop also show good pillow structures, but chemical analyses indicate SiO_2 contents on the order of 53-54%, suggesting these rocks have an andesitic composition One point for discussions is whether the higheer silica content is primary or secondary.

Prior Guidebook Reference: Mudrey (1979), Stop 7, p 32-33; Schulz and Ojakangas (1989), Stop 6-3.

Stop 1-05: Fragmental Penokean felsic volcanics

Location: *Outcrop in low ridges 100 yards northeast of abandoned dwelling, east side of U S. Highway 45, about 1 mile NE of Monico. SE 1/4 NW 1/4 Sec. 21, T.36N., R.11E., Oneida County, Wisconsin*

Stop Description: Felsic volcanic breccia of local Penokean volcanic section. The rocks exposed here include a coarse felsic agglomerate that includes dacitic clasts ranging in size from a few cm to a few meters; the clasts are hosted in amphibole-bearing tuff or graywacke. Individual clasts show good primary flow banding and phenocrysts, suggesting the original eruptive unit was pyroclastic This type of rock has been interpreted as closely associated with massive sulfide ores, and this unit is part of the succession that includes the Crandon deposit.

Prior Guidebook Reference: Mudrey (1979), Stop 8, p. 34-35; Schulz and Ojakangas (1989), Stop 6-4

Stop 1-06: 1760 Ma Jennings Granite

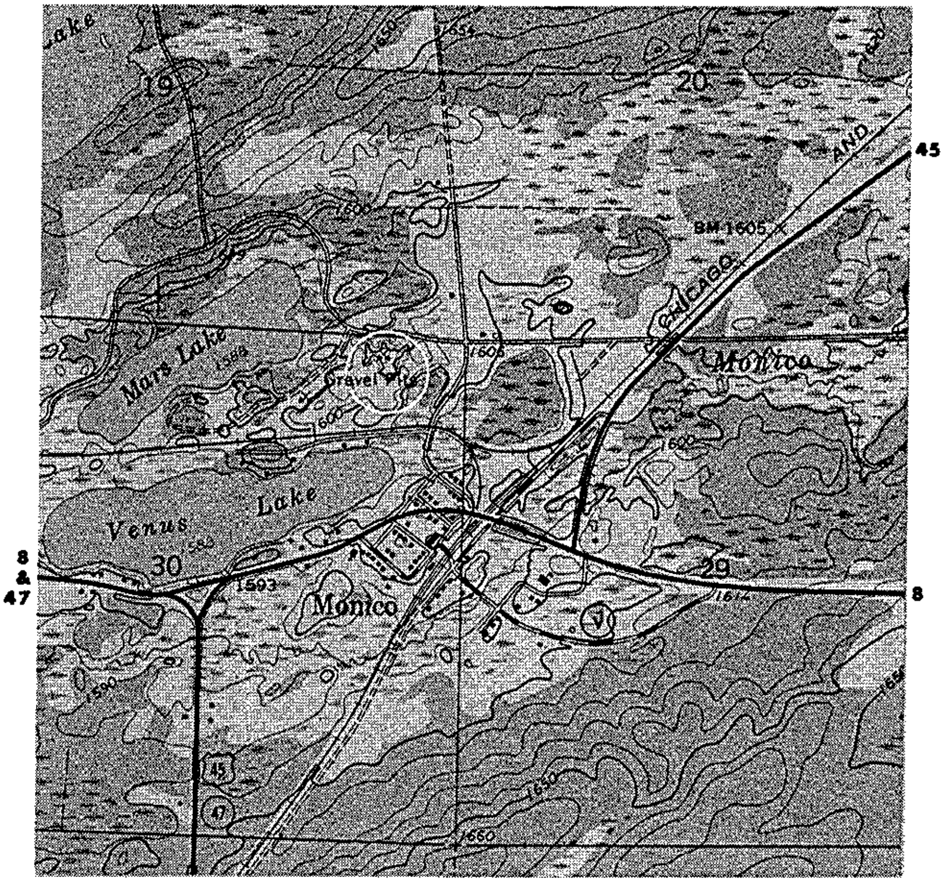
Location: Former roadside park on west side of U S. Highway 45, about 2.3 miles south of Monico, Wisconsin *SE cor., SW 1/4, Sec 6, T.35N., R.11E., Oneida County, Wisconsin.*

Stop Description: Numerous large boulders and a glaciated bedrock pavement of the Jennings granite are exposed at the site of a former roadside park. Two zircon fractions from this locality yield U-Pb data that fall on a 1760 ± 10 Ma discordia defined by data from here and several other localities throughout Wisconsin (Van Schmus, 1980). The origin and significance of this suite of rocks will be the focus of discussions on Day 5

Prior Guidebook Reference: Mudrey (1979), Stop 10, p. 38-39; Schulz and Ojakangas (1989), Stop 6-1.

Title: Monico Gravel Pits - Andesite Pillow Lava

Location: Exposures are at the top of the hill behind houses on Baade and Lake Roads, and on the north side of the gravel pit to the west, NE¼, NE¼, Sec. 30, T.36N., R.11E., Oneida County (Monico 7½-minute topographic quadrangle, 1965).



Author: M.G. Mudrey, Jr. (1978)

Description: The outcrops consist of pillowed, fine grained, light gray andesite with sparse to abundant quartz and plagioclase phenocrysts. The pillows appear to top south. Schriver (1973, p. 25) describes the rocks as amygdaliodal basalt. In the gravel pit, the amygdule fillings have weathered out, leaving a pock-marked vesicle texture. Amygdules constitute up to three percent of the rock, range in size up to three mm, and have a globular shape, but are generally undeformed. A chlorite rim encloses the amygdule filling of epidote or epidote and quartz. The groundmass consists predominantly of epidote and actinolite less than 0.05 mm in size. Plagioclase phenocrysts are largely altered to epidote and calcite and appear to be around An_{25-30}.

Schriver (1973, p. 80, no. 16) reports the following chemical data:

		Molecular Norm (Irvine-Baragar)	
SiO_2	53.5	Q	20.5
TiO_2	0.7	Or	0.3
Al_2O_3	14.0	Ab	10.1
FeO_T	9.3	An	15.3
MnO	0.1	Wo	12.9

MgO	6.9	En	25.5
CaO	10.6	Fs	12.0
Na_2O	2.1	Mt	2.1
K_2O	0.1	Il	1.3
Total	97.3		

Other analyses of this unit several miles to the southwest contain more silica and potassium, and might more properly be termed dacite.

Other outcrops of this unit may be found on the hills to the southwest and to the northeast. Mapping in 1978 by Mudrey suggests that this unit can be traced along an east-northeast strike about 3/4 mile. Mapping also suggests that this unit overlies the tuffaceous agglomerate unit to the east and south.

Discussion: Intermediate to felsic Middle Precambrian volcanism characterizes the northern Wisconsin volcanic belt. May (1977) describes the host rocks associated with the Flambeau deposit near Ladysmith, and Schmidt and others (1978) describe similar rocks associated with the Crandon deposit. Recently, Bowden (1978) described a similar sequence of rocks at the Pelican River deposit. Present mapping and geophysics suggest that the sequence of volcanic rocks immediately around Monico are close to the same stratigraphic position as the rocks at Pelican River. This exposure probably lies stratigraphically beneath the Pelican ore body, although definitive mapping has not been completed.

References Cited:

Bowden, D.R., 1978, Volcanic rocks of the Pelican River massive sulfide deposit, Rhinelander, Wisconsin: A study in wallrock alteration: Unpub. M.S. Thesis, Michigan Technological University, 62 p.

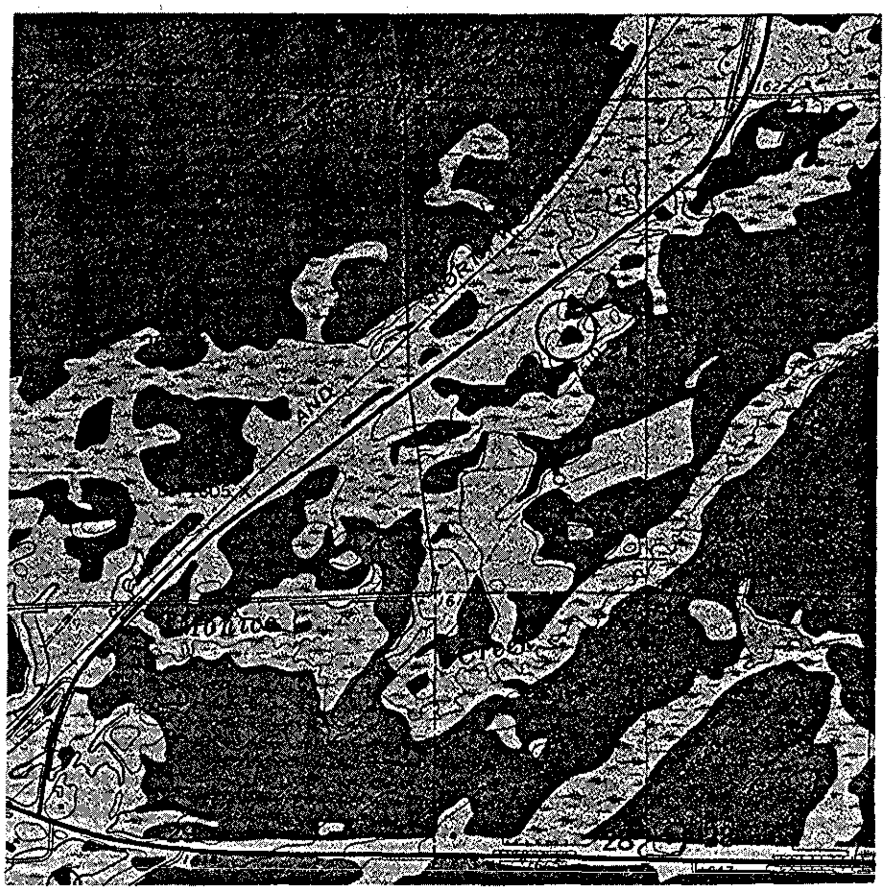
May, E.R., 1977, Flambeau - A Precambrian supergene enriched massive sulfide deposit: Geoscience Wisconsin Vol. 1, p. 1-26.

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

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

Title: Witte Farm - Coarse Felsic Agglomerate

Location: 1.4 miles north of intersection of U.S. 8 and U.S. 45. Outcrop located 400 feet east of highway behind abandoned house. SE¼, NW¼, Sec. 21, T.36N., R.11E., Oneida County (Monico 7½-minute topographic quadrangle, 1965).



Author: M.G. Mudrey, Jr. (1979)

Description: Three-foot long, angular, dacite clasts range in size from inches to several feet are set in an amphibole-bearing tuff or graywacke. Within the clasts, sparse euhedral plagioclase phenocrysts (An_{20}) up to 1.8 mm in maximum dimension are set in a flow banded matrix which wraps around the crystals. The rock is intensively altered, and sericite extensively replaces plagioclase. The groundmass consists predominantly of quartz, muscovite, and calcite. Blood red hematite is present, along with local concentrations of epidote and chlorite.

The matrix for the clasts consists of altered mineral grains 0.3 to 0.4 mm in size. A few relict (? pyroxene (?) and amphibole crystals remain, but the grains in the matrix consist predominantly of epidote-chlorite-muscovite-quartz granules. Calcite occurs abundantly as granules and in veins. Blood red hematite is sparse, and reflict glass shards can be seen in thin sections.

The trend of bedding is N. 70°-75° W. and dips 85° SW. About 700 feet to the northeast, intermediate pillow lavas appear to top south, however the bedding trend at this locality is N. 60° W. This is the only area of the quadrangle in which folding has been suggested.

A small body of intrusive granodiorite can be found about one thousand feet north.

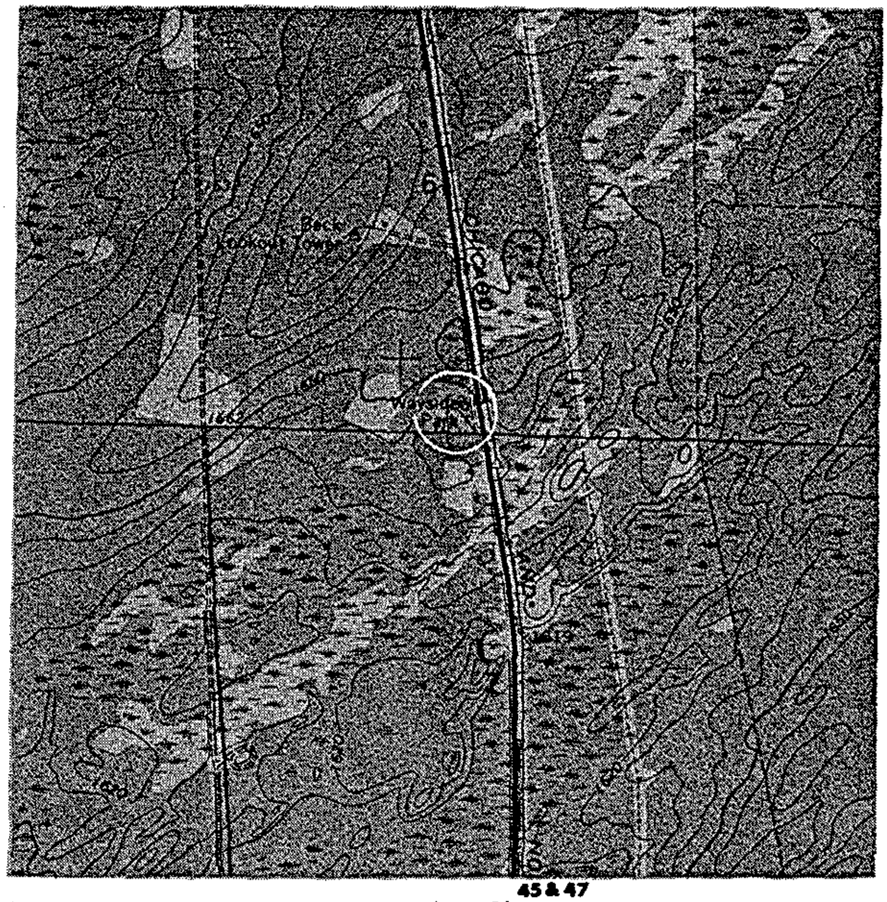
Discussion: Sangster (1972) noted the close spatial association between felsic agglomerates (or coarse pyroclastics) and massive sulfide ores, and that these agglomerates were a characteristic feature of many mining regions. Sangster (1972, p. 3) remarks that "the author [Sangster] once remarked to his colleagues that whenever he stood on the outcrop containing the largest fragments of acid pyroclastic in any given mining camp, he could invariably hear the mine mill nearby. His colleagues immediately dubbed this distinctive lithology 'millrock' and since then, 'millrock' has been observed close by most massive sulfide deposits in Precambrian volcanic rocks." The interpretation of this distinctive lithology is still open. Millrock is generally found in, or close to volcanic units in which the massive sulfides occur. The belt of rocks from the Pelican deposit, about 7 miles west, to several miles east of this locality has been extensively explored since the early 1970's. Although only the Pelican deposit has been announced as a possible massive sulfide deposit, the intensity of exploration attests to the favorable terrane.

References Cited:

Sangster, D.F., 1972, Precambrian volcanogenic massive sulfide deposits in Canada: A review: Geological Survey of Canada Paper 72-22, 44 p.

Title: Beck Tower Wayside Park - Jennings Granite

Location: 2½ miles south of Monico on U.S. 45 and State 47, SW¼, SE¼, Sec. 6, T.35N., R.11E., Oneida County (Monico 7½-minute topographic quadrangle, 1965).



Author: M.G. Mudrey, Jr. (1978)

Description: This outcrop is a coarse, red, biotite granite and exhibits spheroidal weathering. Another outcrop is present 500 feet to the northeast in a railroad cut. Fresher outcrops of the same granite are found near Jennings, about 6 miles east. According to Venditti (1973, p. 46), the rock contains euhedral orthoclase, microcline and microperthite (40 percent), subhedral to euhedral oligoclase (An_{27}, 23 percent), anhedral quartz (31 percent), and minor amounts of interstitial biotite (3 percent). The biotite is pleochroic and light brown to dark brown, is sagenitic, and altered to chlorite. The grain size is 4-5 mm and shows no cataclastic textures at this outcrop, although outcrops near Jennings show narrow, well developed mylonitic zones.

Venditti (1973, p. 90, no. 24) reports the following analysis:

SiO_2	73.1
TiO_2	tr
Al_2O_3	15.5
FeO_T	1.5
MnO	tr
MgO	tr

CaO	1.5
Na_2O	3.0
K_2O	4.3
Total	98.9

Van Schmus and others (1975, p. 1259, no. D1356) report a Rb-Sr age of 1,580 m.y. from this locality. Van Schmus (in press) reports a U-Pb zircon age of 1,765$\pm$ 10 m.y. from this locality.

Discussion: The potassic granitic intrusives in the Middle Precambrian of northern Wisconsin are all post-tectonic, and their ages cluster around 1,765 m.y. The younger 1,600 m.y. Rb-Sr age represents a wide-spread alteration of Rb-Sr ages that is not fully understood.

Van Schmus (in press) has divided the Middle Precambrian igneous activity into two pulses. The older one began with mafic to felsic volcanism 1,850$\pm$ 20 m.y. ago, and was followed immediately by tonalitic to granitic plutonism 1,840 - 1,820 m.y. ago. Structural studies by Maas (1977) indicate that these rocks were emplaced during the main phase of the Middle Precambrian thermotectonic event. The second pulse consisted predominantly of phyolitic and granophyric granite and occurred about 1,765$\pm$ 10 m.y. ago. No plutonic units have been found so far with zircon ages in excess of 1,850, nor have any been found with ages on the order of 1,615 - 1,630 m.y., the time of widespread alteration of the Rb-Sr isotopic systems in the region.

After emplacement of the late granites, major faulting occurred (LaBerge and Myers, 1976 and LaBerge, 1977), and has been recently studied to the south in Marathon County. Late faulting is recognized in north-central Wisconsin as seen in the mylonitic samples from Jennings. Extent and magnitude of the faulting in north-central Wisconsin is not known.

References Cited:

LaBerge, G.L., 1977, Major structural features in central Wisconsin and their implications to the Animikie Basin (abs.): 23rd Annual Institute on Lake Superior Geology (Thunder Bay, Ontario).

LaBerge, G.L., and Myers, P.E., 1976, The Central Wisconsin Batholith (abs.): 22nd Annual Institute on Lake Superior Geology (St. Paul, Minnesota).

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

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

Van Schmus, W.R., Thurman, E.M., and Peterman, Z.E., 1975, Geology and Rb-Sr chronology of Middle Precambrian rocks in eastern and central Wisconsin: Geological Society of America Bulletin, V. 86, p. 1255-1265.

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

(For Presentation Monday Evening)

EARLY PROTEROZOIC SETTINGS OF WISCONSIN VOLCANOGENIC MASSIVE SULFIDE DEPOSITS

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The Early Proterozoic Penokean terrane of northern Wisconsin is host to at least 13 volcanogenic massive sulfide (VMS) deposits and occurrences. The VMS deposits formed within the Rhinelander/Ladysmith volcanic belt. This is a volcanic-arc and back-arc basin accreted along with several other terranes to the southern margin of the Archean Superior Craton during the Penokean Orogeny (1880-1830 Ma). Although no economic deposits have been identified to the south in the Proterozoic and Archean volcanic rocks of the Central Wisconsin Terrane, base and precious metal potential are considered good.

All major deposits of the Rhinelander/Ladysmith belt (Flambeau mine, Crandon deposit) and the smaller Lynne and Bend deposits are associated with felsic volcanic centers. Other occurrences are known to be associated with cherty magnetic iron formation and with mafic rock. Major deposits can be classified by metal content as Cu-type (Flambeau, Bend), Zn-Cu type (Crandon) or Zn-Pb-Cu type (Lynne). The distribution and size of known deposits along with favorable geology suggest high potential for further discoveries. Exploration in northern Wisconsin is difficult because of thick glacial deposits (up to 100 m); as a result, geophysics and extensive drilling of anomalies are the preferred exploration techniques.

The Flambeau orebody is the only VMS deposit that has actually been mined in this terrane The permit process to develop the Crandon deposit is ongoing. Northern Wisconsin is a region with significant mineral potential, but competing land use priorities and local environmental concerns lead to development conflicts.

from DeMatties, 1996

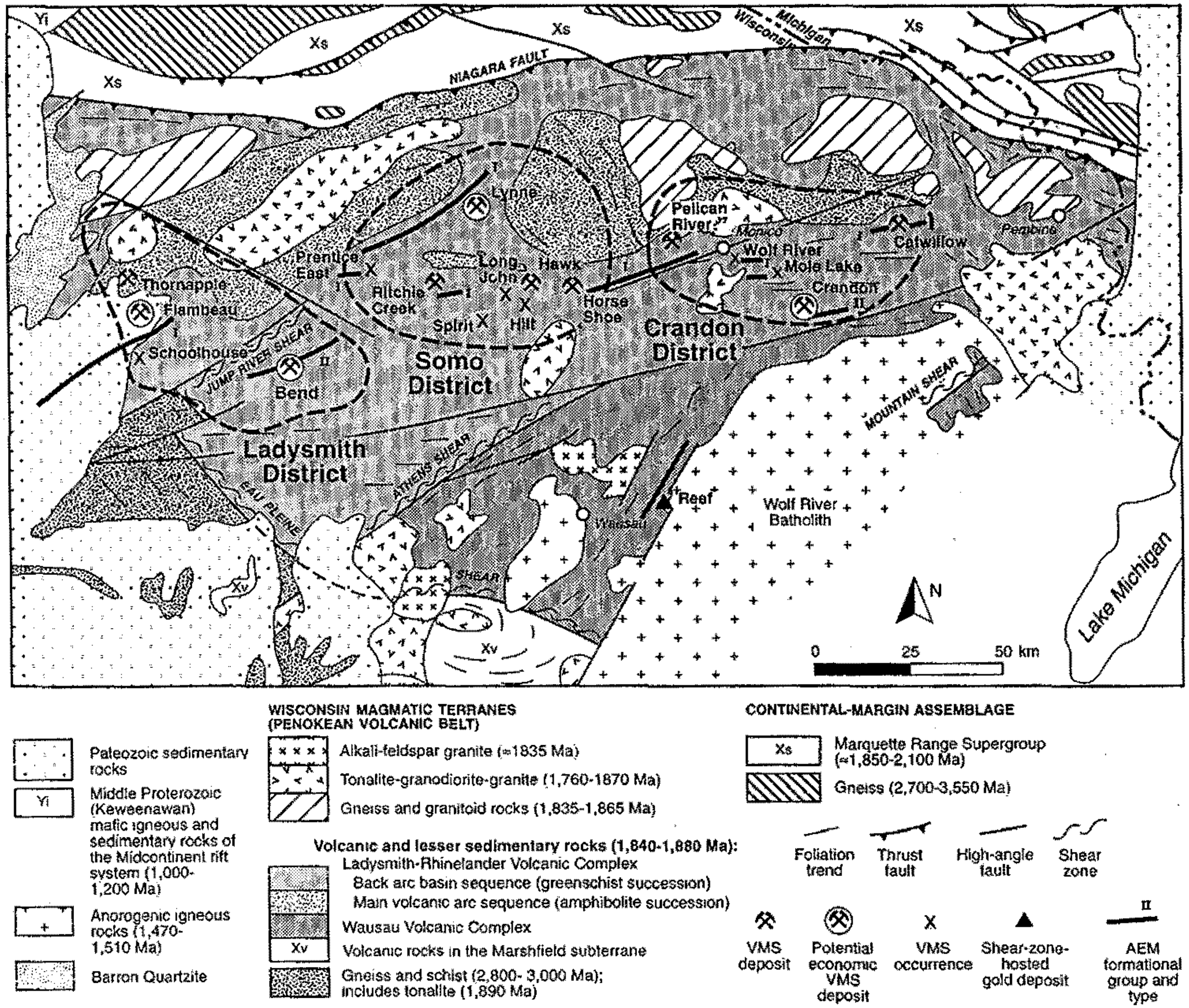


Figure 3. Geologic map of northern Wisconsin showing major volcanic complexes, distribution of VMS deposits and occurrences, and major ore-related meta-argillite formational groups (modified from Sims, 1989).

Field Trip Day 2
Rhinelander to Keshena

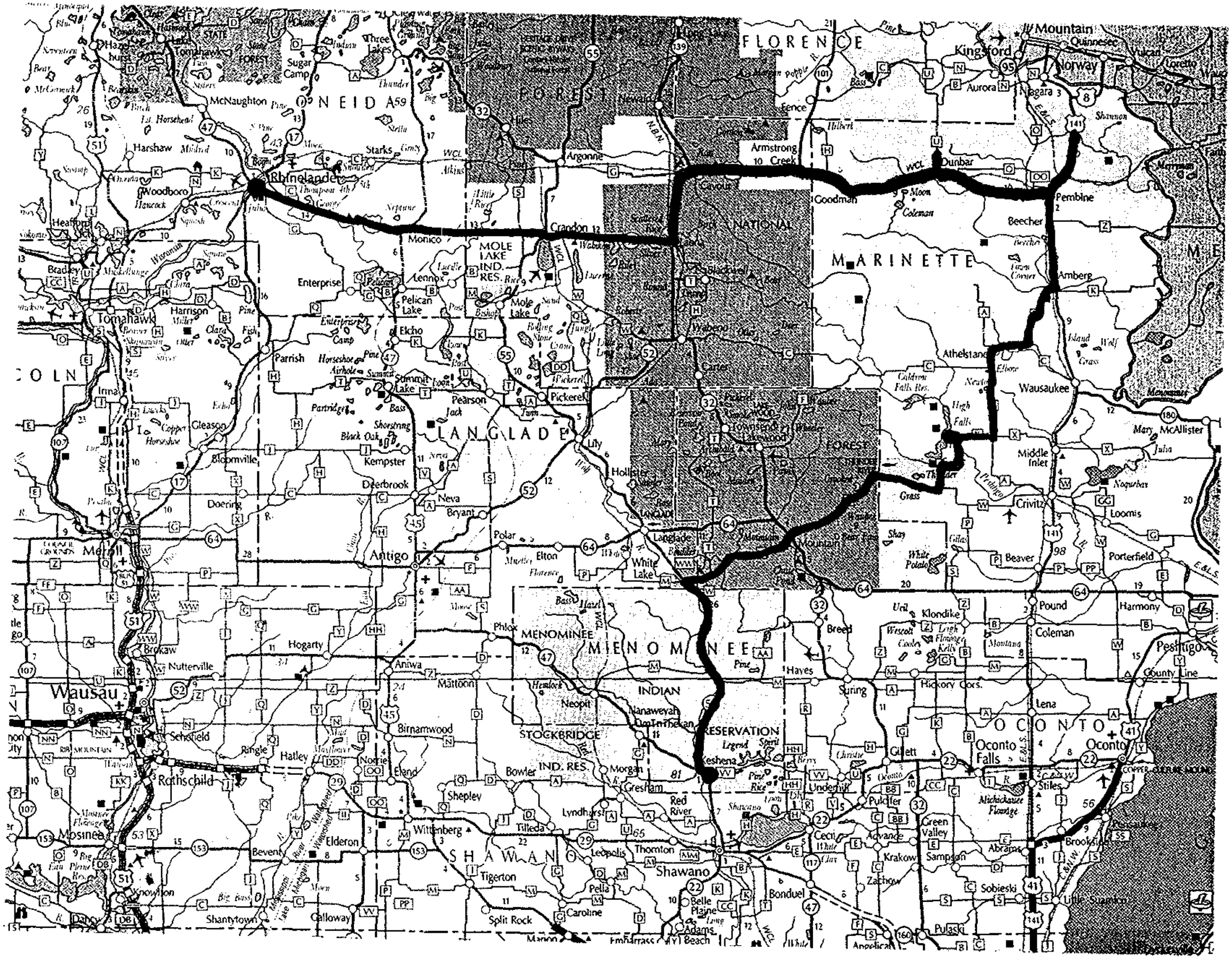
Objectives:

The main objectives of the day are (1) to examine rocks of the Penokean magmatic terrane in northeastern Wisconsin and (2) to examine rocks of the northeastern part of the Wolf River batholith The Wolf River Batholith was presumably derived from partial melting of a large portion of the Penokean terrane, so we have a good chance to observe both the starting material and the end producst over the next couple days.

In the evening we can have R&R (rest and relaxation) at the Menominee Hotel and Casino This is an example of economic development on many tribal lands throughout the United States due to recent court rulings that uphold the sovereignty of Indian nations

Itinerary:

0800	Depart Rhinelander
	Stop 2-01: Dunbar gneiss
	Stop 2-02: Newingham granodiorite
	Stop 2-03: Niagara, Wisconsin (Niagara Fault, edge of Archean craton)
	Stop 2-04: Spikehorn (Hoskin Lake) Granite
	Stop 2-05: Spikehorn Granite intrusive into Penokean Basalt
	Stop 2-06: Amberg quartz monzonite
	Stop 2-07: Athelstane q.m with dikes of Amberg q m. and pegmatite
1200	Lunch
	Stop 2-08: Athelstane q m. with dikes of Amberg q.m and pegmatite
	Stop 2-09: Athelstane quartz monzonite @ Athelstane
	Stop 2-10: Peshtigo monzonite at High Falls Reservoir
	Stop 2-11: Hager Porphyry phase of WRB NE of Mountain
	Stop 2-12: Coarse-grained Belongia granite phase of WRB
	Stop 2-13: Fine-grained Belongia granite phase of WRB
	Stop 2-14: Wolf River granite at Wolf River Dells
	Stop 2-15: Wolf River granite at Keshena Falls
1800	Arrive Keshena
	Dinner
	Evening activities



FLORENCE
ONEIDA
FOREST
NATIONAL
FOREST
MARINETTE
LANGLADE
MENOMINEE
MENOMINEE INDIAN RESERVATION
STOCKBRIDGE IND. RES.
MOLE LAKE IND. RES.
SHAWANO
OCONTO
Rhinelander
McNaughton
Harshaw
Woodboro
Tomahawk
Harrison
Irma
Gleason
Bloomville
Merrill
Brokaw
Wausau
Schofield
Rothschild
Mosinee
Knowlton
Sugar Camp
Three Lakes
Starks
Monico
Crandon
Argonne
Hiles
Armstrong Creek
Fence
Goodman
Dunbar
Kingsford
Mountain
Quinnesec
Norway
Niagara
Aurora
Pembine
Beecher
Amberg
Athelstane
Wausaukee
Middle Inlet
Crivitz
Loomis
Porterfield
Beaver
Pound
Coleman
Harmony
Peshtigo
County Line
Lena
Oconto Falls
Oconto
Stiles
Brookside
Abrams
Little Suamico
Pulaski
Enterprise
Pelican Lake
Lennox
Elcho
Parrish
Summit Lake
Pearson
Pickerel
Lily
Kempster
Deerbrook
Neva
Bryant
Antigo
Polar
Elton
Hollister
Langlade
White Lake
Mountain
Doering
Hogarty
Aniwa
Mattoon
Phlox
Neopit
Keshena
Gresham
Morgan
Red River
Birnamwood
Hatley
Ringle
Norrie
Eland
Wittenberg
Elderon
Bevent
Tigerton
Split Rock
Caroline
Pella
Leopolis
Thornton
Shawano
Belle Plaine
Bonduel
Cecil
Underhill
Gillett
Pulcifer
Green Valley
Sampson
Krakow
Zachow
Sobieski
Angelica
Hayes
Breed
Suring
Klondike
Hickory Cors.
McAllister
Shantytown
Galloway
Nutterville
Heafford Jct.
Bradley
Lyndhurst
Tilleda
Sheplev
Bowler
Carter
Townsend
Lakewood
Wabeno
Laona
Cavour

Stop 2-01: Dunbar gneiss

Location: Outcrops along County Highway U, center of west side SW 1/4 Sec. 13 and east side SE 1/4 Sec 14, T 37N , R 18E., Marinette County, Wisconsin.

Stop Description: The Dunbar gneiss is a typical example of Penokean tonalitic gneiss within the Wisconsin magmatic terrane. This locality also shows some cross-cutting aplite and pegmatite dikes Banks and Cain (1969) reported a U-Pb age of 1847 ± 15 Ma (age recalculated) from this locality, whereas Peterman et al. (1985) reported a more precise age of 1862 ± 4 Ma, also from this locality Rb-Sr data summarized by Peterman et al (1985) indicate open system behavior in these rocks, with suggestions of resetting at ca. 1760 Ma and much stronger evidence for reginal resetting ca 1650 Ma. The regional tectonic significance of the younger ages will be discussed in detail on Day 5.

Prior Guidebook Reference: Sims et al.(1984), Dunbar Dome Stop 3, p. 47

Stop 2-02: Newingham granodiorite

Location: Outcrop on north side of U.S Highway 8, about 2+ miles west of Pembine; SE corner, NE 1/4, NE 1/4 Sec. 6, T.36N., R 20E , Marinette County, Wisconsin.

Stop Description: The Newingham granodiorite (Banks and Cain, 1969) or Newingham tonalite (Peterman et al., 1985) in another good example of calk-alkaline Penokean plutons in NE Wisconsin Banks and Cain (1969) reported an age of 1827 ± 15 Ma (age recalculated) for zircons from this locality and from an occurrence of Athelstane quartz monzonite ("Amberg pink granite") to the south

Prior Guidebook Reference: None

Stop 2-03: Niagara, Wisconsin (Niagara Fault, edge of Archean craton)

Location: U. S. Highway 141, about 1 mile north from downtown Niagara, Wisconsin; Center, S side Sec 4, T.38N., R 20E., Marinette County, Wisconsin

Stop Description: The Niagara Fault, which separates the Archean craton to the north from Wisconsin magmatic province, crosses the highway here. Bluffs north of the Menominee river in the town of Niagara are gabbro sills emplaced in the Penokean volcanic terrane; the Niagara fault is just north of these gabbros. The Niagara Fault is a major crustal boundary that runs through northern Wisconsin and separates the Archean provinces to the north from the basically juvenile Penokean provinces to the south Nd isotopic data suggest that the Penokean volcanics are largely juvenile (Barovich et al., 1989; Van Wyck and Johnson, 1997), although recent studies (Van Wyck and Johnson, 1997) indicate there may be one or more Archean crustal fragments within the Penokean terrane of northern Wisconsin.

Prior Guidebook Reference: None

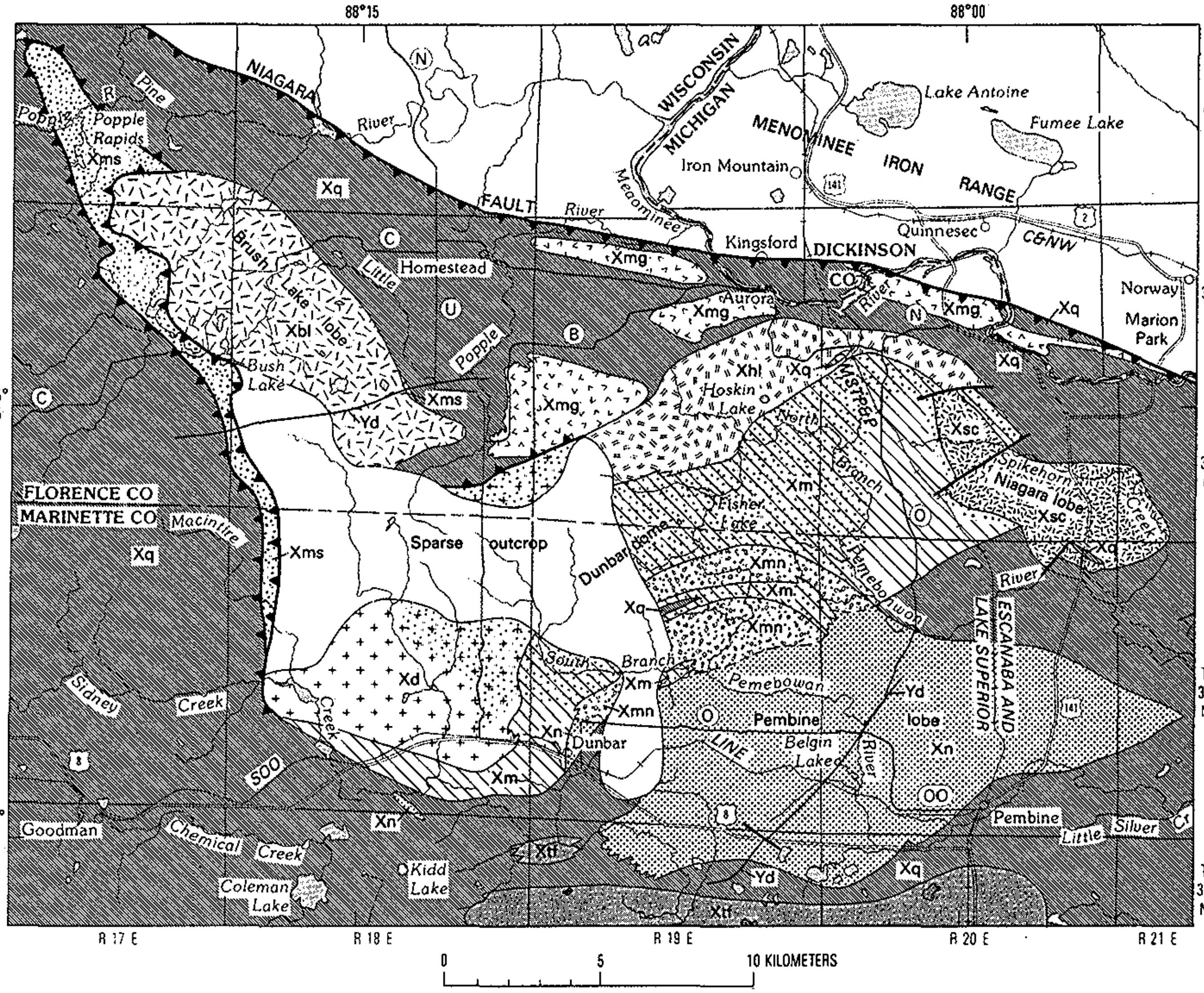


FIGURE 2 (above and facing page).—Geologic map of Dunbar area, northeastern Wisconsin. Compiled by P.K. Sims, 1988. Base from Iron Mountain, Mich.-Wis. 1:100,000 quadrangle

EXPLANATION

MIDDLE PROTEROZOIC (1,600–900 Ma)

- Yd — **Diabase**

EARLY PROTEROZOIC (2,500–1,600 Ma)

- Xsc — **Spikehorn Creek Granite**
- Xbl — **Bush Lake Granite**
- Xhl — **Hoskin Lake Granite**
- Xm — **Marinette Quartz Diorite**
- Xd — **Dunbar Gneiss**
- Xmn — **Megacrystic facies of Newingham Tonalite**
- Xn — **Newingham Tonalite**
- Xtf — **Twelve Foot Falls Quartz Diorite**
- Xmg — **Metagabbro sills**
- Xq — **Quinnesec Formation**
- Xms — **Metasedimentary rocks**
- **Area of strong to moderate potassium metasomatism**

- **Approximate contact**
- **Gradational contact**
- **Fault—Relative movement not known**
- **Thrust fault—Teeth on upper plate**

(from Sims et al., 1992)

Stop 2-04: Spikehorn Creek (Hoskin Lake) Granite

Location: Outcrop along east side of section of old U.S. Highway 8-141, about 5.5 miles north of Pembine and east of modern highway. Center, Sec. 1, T.37N., R.30W., Marinette County, Wisconsin.

Stop Description: Porphyritic phase of Spikehorn Creek granite (formerly the Niagara lobe of the Hoskin Lake Granite). This is outcrop of "Hoskin Lake granite" was sampled by Banks and Cain (1969) in their study on U-Pb ages of Penokean igneous rocks in NE Wisconsin. Their data, from two outcrops, yield an age of 1858 ± 3 Ma (recalculated); Peterman et al. (1985) recently reported a newer determination of 1836 ± 6 Ma from a sample located about 1.5 miles (2 km) farther north.

Some of the K-feldspar phenocrysts have thin rims of plagioclase. Discussion point: what is the significance of plagioclase rims on K-feldspar in a granite of this type?

Prior Guidebook Reference: None

Stop 2-05: Spikehorn Granite intrusive into Penokean Basalt

Location: Outcrop on east side of U.S. Highway 8-141, about 5 miles north of Pembine, just north of bridge over the North Branch, Pemebonwon River; SW 1/4 Sec. 1, T.37N., R.20E., Marinette County, Wisconsin.

Stop Description: This outcrop shows the contact of the Spikehorn Creek granite with volcanic rocks of the Quinnessec Formation. The Quinnessec Formation unit is the oldest of four volcanic successions recognized in the Pembine area of northeastern Wisconsin and includes quartz-porphyry rhyolites in addition to mafic units. Banks and Rebello (1969) reported an age of 1871 +30/-10 Ma (age recalculated; Simms et al., 1985, recalculated the age to 1866 ± 39 Ma). The younger volcanic succession have not been dated (no zircons), and some could be post-Penokean.

Several more outcrops of the Quinnessec Formation occur along the highway for the next 1-2 miles (2-3 km) to the south.

Prior Guidebook Reference: Sims et al.(1984), Stop 8, p. 49; Schulz and Ojakangas (1989), Stop 5-1

Stop 2-06: Amberg gray granite (quartz monzonite?)

Location: Outcrop on east side of U.S. Highway 8-141, about 1.7 miles north of Amberg; West side, SW 1/4, Sec. 3, T.35N., R.20E., Marinette County, Wisconsin.

Stop Description: Typical example of Amberg gray granite, the easternmost occurrence of 1760 Ma granite in northern Wisconsin. This unit was called "quartz monzonite" by Medaris, Van Schmus, Lahr, Myles, and Anderson (1973), but quartz is locally abundant. The petrology of this granite should be noted for comparison with the Jennings granite (Stop 1-6) and coeval granites that will be seen during Day 4 and Day 5. We will probably not stop here, but rely on seeing this granite at Stop 8.

Prior Guidebook Reference: None

Stop 2-07: Athelstane pink granite with dikes of Amberg gray granite.

Location: Exhumed glaciated bedrock surface in SE corner of intersection of U.S Highway 141 and Black Sam Road, about 1 mile north of Amberg. NW Cor SW 1/4 Sec 10, T 35N., R 20E., Marinette County, Wisconsin.

Stop Description: Coarse-grained Athelstane granite ("Amberg pink") is cut by dikes of "Amberg gray" granite and younger pegmatite dikes Banks and Cain (1969) reported an age of 1827 ± 15 Ma (age recalculated) for zircons from the Newingham granodiorite (Stop 2-02) and from an occurrence of Athelstane granite to the south Two zircon fractions of the Amberg gray granite from a nearby quarry yield U-Pb data that fall on a 1760 ± 10 Ma discordia defined by data from here and several other localities throughout Wisconsin (Van Schmus, 1980). The age of the pegmatite dikes is unknown; some of them may be offshoots from the Wolf River Batholith. This unit was also called "quartz monzonite" by Medaris, Van Schmus, Lahr, Myles, and Anderson (1973), but quartz is locally abundant and "granite" is probably a more correct general designation.

Prior Guidebook Reference: Medaris, Van Schmus, Lahr, Myles, and Anderson (1973, Locality 2); Schulz and Ojakangas (1989), Stop 5-8

Stop 2-08: Amberg gray granite and Athelstane pink granite north of Athelstane

Location: AB&J Granite Co. quarry, west end of Nutt Rd., 2.5 miles west of County Highway V; NW 1/4 SE 1/4 Sec. 24, T 35N., R 19E., Marinette County, Wisconsin.

Stop Description: This quarry contains both gray (Amberg) and pink (Athelstane) "granite", but "gray granite" is the quarry stone The exposures in this quarry have not been examined prior to compilation of the guidebook, but it should offer us a good three-dimensional view of the inter-relationships between these two units

Prior Guidebook Reference: None.

Stop 2-09: Athelstane granite @ Athelstane

Location: Outcrop on south side of County Highway A, 1/2 mile west of Athelstane. Center of north edge, Sec. 15, T 34N., R 19E., Marinette County, Wisconsin

Stop Description: This is an outcrop of typical Athelstane granite, a nice Penokean calc-alkaline pluton. Assuming that we get good looks at this unit during the two previous stops, we will probably not stop here, but continue on to examine other units

Prior Guidebook Reference: None

Field Trip Locality 2

TITLE:

Athelstane pink quartz monzonite and Amberg grey quartz monzonite

LOCATION:

NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 10, T.35N., R.20E., Marinette County

AUTHORS:

L.G. Medaris, Jr., UW-Madison; W.R. Van Schmus, Univ. of Kansas; M.M. Lahr, Cotter Corp., Colorado; J.R. Myles, Univ. of California-Santa Barbara; and J.L. Anderson, UW-Madison

DATE:

Summer, 1972 to March, 1973

SUMMARY OF FEATURES:

Dikes of Amberg grey quartz monzonite are intrusive into Athelstane pink quartz monzonite.

DESCRIPTION:

Granitic rocks in the Athelstane-Amberg area originally were given the name Amberg granite by Cain (1963), and pink and grey varieties subsequently were recognized by Cain and Beckman (1964). Banks and Cain (1969) reported an age of 1860 ± 15 m.y. (U-Pb, zircon) for a sample of pink Amberg granite and presented a map on which Amberg granite (pink) and a separate Amberg granodiorite (grey?) were distinguished.

Field mapping has established that the grey variety is predominant in the vicinity of Amberg, occurring in four distinct plutons, and that the pink variety has a wide distribution, being particularly abundant in the Athelstane area (Plates 1 and 2). Because of the geographic distribution of the two lithologies, we propose that the pink variety be called the Athelstane pink quartz monzonite and the grey variety, the Amberg grey quartz monzonite.

An age of 1810 ± 50 m.y. (Rb-Sr, whole rock isochron) has been obtained for the Athelstane pink quartz monzonite, in good agreement with the age of 1860 m.y. given by Banks and Cain (1969). Preliminary isotopic data suggest that the Amberg grey quartz monzonite is younger possibly being 1640 to 1670 m.y. in age.

At this locality Athelstane pink quartz monzonite is intruded by dikes of Amberg grey quartz monzonite, thus confirming the relative age of these rock types indicated by isotopic dates. About $\frac{1}{2}$ mile to the east, extensive areas of Amberg quartz monzonite are exposed in quarries.

The Athelstane quartz monzonite has a medium- to coarse-grained, allotriomorphic granular texture, contains both biotite and hornblende, and has a distinctive appearance due to the presence of pink perthitic microcline and white plagioclase (An 23-28). Biotite from five specimens yielded values of 100xFe/Fe+Mg from 71 to 78, but two other samples gave values of 85 and 91. Amphibole is hastingsitic hornblende or magnesian hastingsitic hornblende. Foliation is common in this unit, as are recrystallization textures, such as aggregates of quartz grains with mosaic outlines. Saussuritization of plagioclase is widespread, and epidote is usually associated with biotite and hornblende.

The Amberg grey quartz monzonite has a medium- to fine-grained, hypidiomorphic granular texture. Although hornblende occurs in a few samples, biotite is by far the most abundant mafic mineral. Values of 100xFe/Fe+Mg of 67 and 69 have been obtained for biotite from two specimens. As in the Athelstane quartz monzonite, foliation and recrystallization textures are common in the Amberg. Plagioclase (An 22-39) is extensively saussuritized, biotite is partially altered to chlorite, and epidote is present in plagioclase and associated with biotite.

REFERENCES

Banks, P.O., and Cain, J.A., 1969, Zircon ages of Precambrian granitic rocks, northeastern Wisconsin: Jour. Geol., v. 77, p. 208-220.

Cain, J.A., 1963, Some problems of the Precambrian geology of northeastern Wisconsin: a review: Ohio Jour. Sci., v. 63, p. 7-14.

Cain, J.A., and Beckman, W.A., 1964, Preliminary report on the Precambrian geology of the Athelstane area, northeastern Wisconsin: Ohio Jour. Sci., v. 64, p. 57-60.

Stop 2-10: Peshtigo monzonite (mangerite) at High Falls Reservoir

Location: Outcrop on west side of road, at bend; just north of corner, west of County Highway X bridge over High Falls Reservoir (park carefully; dangerous corner) Center, NW 1/4, Sec 25, T 33N , R18E., Marinette County, Wisconsin.

Stop Description: The Peshtigo monzonite is a medium-grained, slightly porphyritic rock that is a marginal phase of the Wolf River batholith (Van Schmus et al , 1975a). This unit is distinguished by its dark gray to brown color, paucity of quartz, and relative abundance of mafic minerals In spite of its black color, the dominant coarse-grained mineral is K-feldspar. The rock contains plagioclase and alkali feldspar in subequal amounts, with fayalitic olivine, Fe+2-rich orthopyroxene, clinopyroxene, amphibole, and biotite; trace minerals include opaques and quartz. Some localities also show olivine phenocrysts We will visit this stop if the bridge repair on County Highway X is completed.

Prior Guidebook Reference: None. Nearby related stop (and alternate): Medaris, Myles, and Anderson (1973)

Stop 2-11: Hager Porphyry phase of WRB NE of Mountain

Location: Large hill south of local bar, SE corner of intersection of County Highway W with Crooked Lake Road SE 1/4 NW 1/4 SE 1/4, Sec. 22, T 32N., R 17E , Oconto County, Wisconsin.

Stop Description: The suite of Hager feldspar porphyry, Hager quartz porphyry, Hager granite, and the Hager syenite are hypabyssal phases of the Wolf River batholith which intrude Penokean volcanic and plutonic rocks and a quartzite of probable post-Penokean age (Van Wyck, 1995).

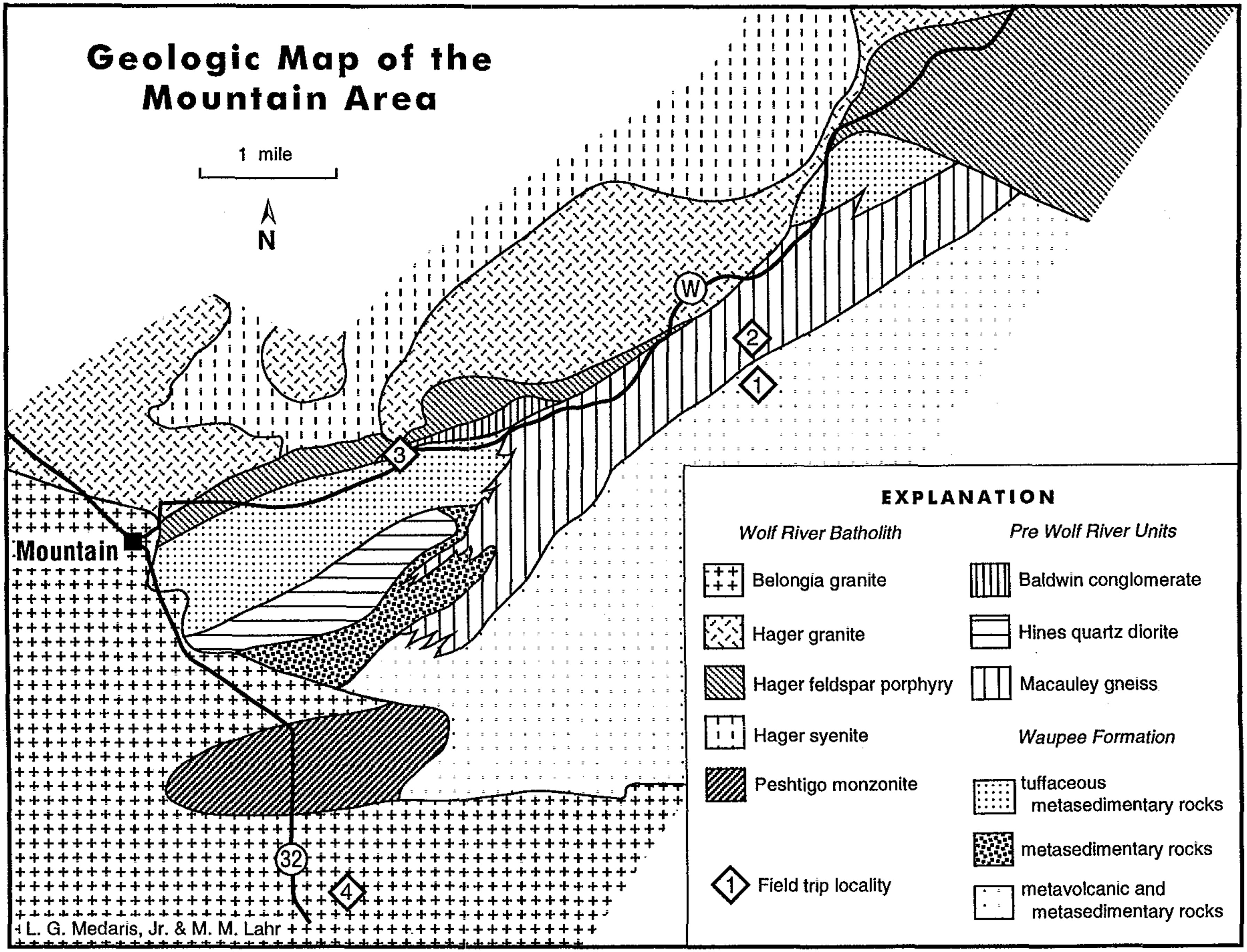
Prior Guidebook Reference: Related stop: Medaris, Van Schmus, and Lahr (1973)

Stop 2-12: Coarse-grained Belongia granite phase of WRB

Location: Outcrop on the east side of Wisconsin Highway 32-64, 1.0 miles south of Mountain, Center, NE 1/4, Sec 14, T 31N., R 16E., Oconto County, Wisconsin

Stop Description: Typical example of Belongia granite phase of Wolf River Batholith. The WRB was dated at 1485 ± 15 Ma by U-Pb on zircon (Van Schmus et al., 1975a) using a sample from this outcrop, from an outcrop 1.8 miles to the west on County W, and from an outcrop of Red River Granite to the southwest. The Belongia Granite is the only phase of the Wolf River Batholith that shows any tendencies toward being a "tin granite". The trace element abundances of Sn and W are slightly elevated in this unit with respect to abundances in the main phases of the batholith. The Belongia coarse granite has been interpreted as a differentiation product from the Wolf River granite, which is the oldest major phase of the batholith (Anderson and Cullers, 1978). The Belongia granite is inferred to intrude the Peshtigo monzonite (Medaris, Myles, and Anderson, 1973).

Prior Guidebook Reference: None. Related stop: Medaris, Myles, and Anderson (1973)


Geologic Map of the Mountain Area
1 mile
N
Mountain
W
1
2
3
4
32
EXPLANATION
Wolf River Batholith
Belongia granite
Hager granite
Hager feldspar porphyry
Hager syenite
Peshtigo monzonite
Field trip locality
Pre Wolf River Units
Baldwin conglomerate
Hines quartz diorite
Macauley gneiss
Waupee Formation
tuffaceous metasedimentary rocks
metasedimentary rocks
metavolcanic and metasedimentary rocks
L. G. Medaris, Jr. & M. M. Lahr

Stop 2-13: Fine-grained Belongia granite phase of WRB

Location: Outcrop on the east side of Wisconsin Highway 32-64, 0.5 miles south of Mountain, Center, SW 1/4, Sec. 11, T 31N., R.16E., Oconto County, Wisconsin.

Stop Description: Fine-grained portion of Belongia granite. This phase of the Belongia granite has been interpreted by Anderson and Cullers (1978) as a more differentiated phase of the Belongia granite than the coarse-grained part (previous stop)

Prior Guidebook Reference: None

Stop 2-14: Wolf River granite at Wolf River Dells

Location: Outcrops of Wolf River Batholith along the east side of the Wolf River at a public access park (Wolf River Dells) in the Menominee Indian Nation Reservation (at end of road westward from Wisconsin Highway 55). Center, NW 1/4, Sec. 3, T.29N., R.15E., Menominee County, Wisconsin

Stop Description: The Wolf River granite in this area is intruded by dikes of Red River granite and late pegmatites. The relative age relationships of the Wolf River granite, Red River granite, and pegmatites are well displayed here. Cursory examination of this outcrop prior to setting up this field trip did not reveal any major dikes of the Wiborgite porphyry, which is intermediate in intrusive relationships between the Wolf River granite and the Red River granite. A 1/4 mile long footpath southward from the parking area leads to a good variety of excellent glacially-polished and recently exhumed outcrops.

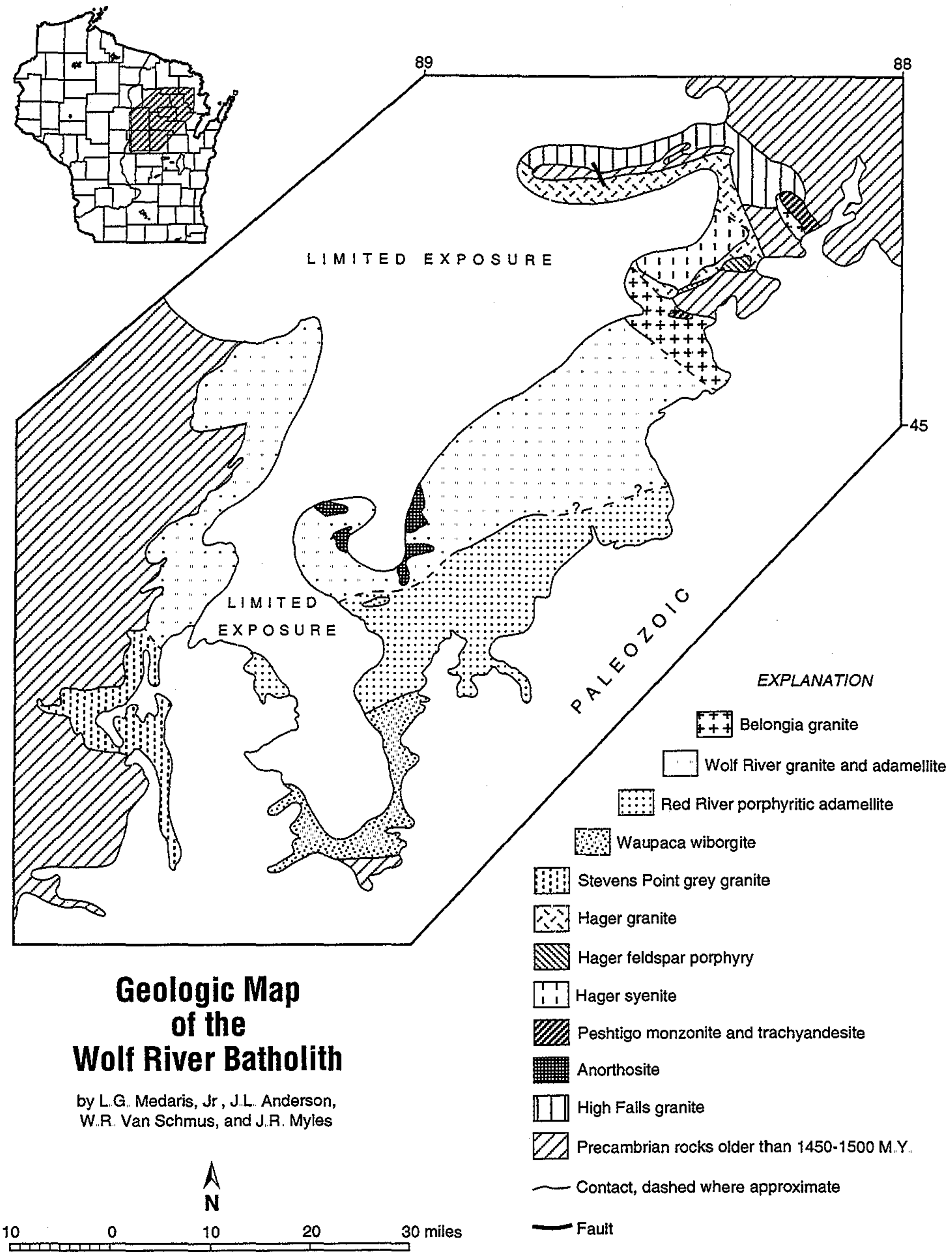
Prior Guidebook Reference: None.

Stop 2-15: Wolf River granite at Keshena Falls

Location: Outcrops of Wolf River Batholith along the west side of the Wolf River at Keshena Falls in the Menominee Indian Nation. SE 1/4, NE 1/4, Sec 22, T.28N., R.15E., Menominee County, Wisconsin

Stop Description: The Wolf River granite in this area is intruded by fine-grained dikes of Red River granite. The relative age relationships of the Wolf River granite and Red River granite are well displayed here also. The Wolf River granite is the most extensive rock type in the batholith, accounting for about half of the exposed area.

Prior Guidebook Reference: Medaris et al. (1973b)


89
88
45
LIMITED EXPOSURE
LIMITED EXPOSURE
PALEOZOIC
Geologic Map of the Wolf River Batholith
by L.G. Medaris, Jr., J.L. Anderson, W.R. Van Schmus, and J.R. Myles
N
10 0 10 20 30 miles
EXPLANATION
Belongia granite
Wolf River granite and adamellite
Red River porphyritic adamellite
Waupaca wiborgite
Stevens Point grey granite
Hager granite
Hager feldspar porphyry
Hager syenite
Peshtigo monzonite and trachyandesite
Anorthosite
High Falls granite
Precambrian rocks older than 1450-1500 M.Y.
Contact, dashed where approximate
Fault

Field Trip Day 3
Keshena to Wausau

Objectives:

The main objective of the day is to examine several representative phases of the Wolf River Batholith.

Itinerary:

0800 Depart Keshena

Stop 3-01: Red River phase of WRB east of Gresham

Stop 3-02: Red River phase of WRB NE of Gresham (gravel quarry)

Stop 3-03: Red River phase of WRB in Gresham

Stop 3-04: Anorthosite at Bowler High School

Stop 3-05: Anorthosite north of Wittenberg

Stop 3-06: Anorthosite and WRB granite along County Highway J

1200 Lunch

Stop 3-07: Wiborgite in Tigerton

Stop 3-08: WRB phases at Big Falls

Stop 3-09: WRB phases at Little Falls Resort

Stop 3-10: Wiborgite at quarry NE of Waupaca

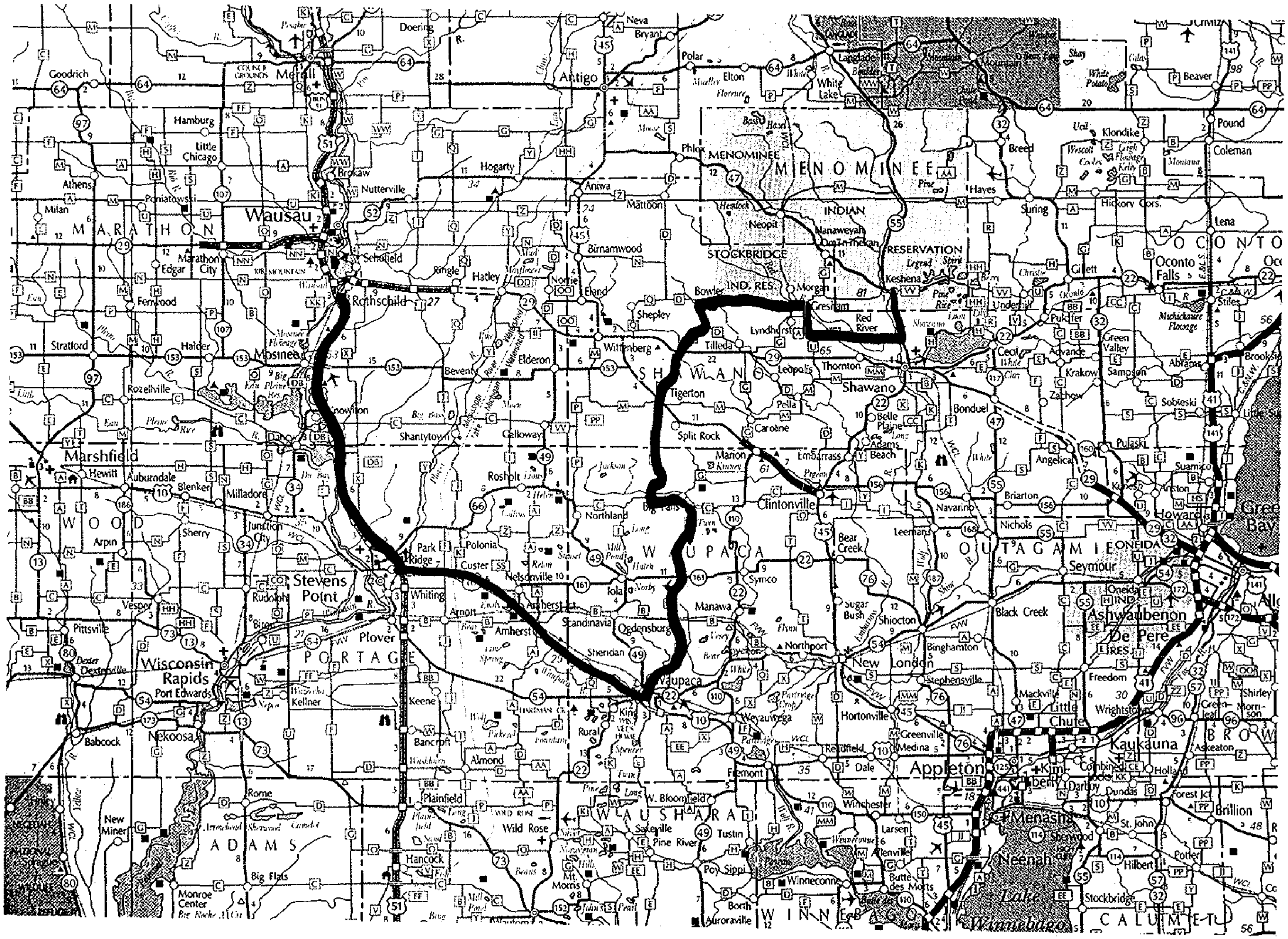
Stop 3-11: Wiborgite east of Waupaca

Stop 3-12: Red River granite northeast of Stevens Point

1800 Arrive Wausau/Mosinee Holiday Inn

Dinner

Evening activities



Goodrich
Merrill
Antigo
Neva
Bryant
Polar
Elton
White Lake
Langlade
Doering
Hamburg
Little Chicago
Athens
Milan
Poniatowski
Brokaw
Nutterville
Hogarty
Aniwa
Mattoon
Phlox
MENOMINEE
MENOMINEE
INDIAN
RESERVATION
STOCKBRIDGE
IND. RES.
Neopit
Keshena
Hayes
Suring
Breed
Klondike
Pound
Coleman
Hickory Cors.
Lena
Wausau
Schofield
Rothschild
Ringle
Hatley
Norrie
Birnamwood
Eland
Bowler
Morgan
Gresham
Red River
Gillett
Oconto Falls
Stiles
MARATHON
Marathon City
Edgar
Fenwood
Stratford
Halder
Mosinee
Knowlton
Shepley
Wittenberg
Tilleda
Lyndhurst
Leopolis
Thornton
Shawano
SHAWANO
Tigerton
Bonduel
Pulcifer
Cecil
Krakow
Zachow
Green Valley
Sampson
Abrams
Sobieski
Pulaski
Rozellville
Marshfield
Hewitt
Auburndale
Blenker
Milladore
Shantytown
Galloway
Bevent
Elderon
Split Rock
Caroline
Marion
Embarrass
Pella
Belle Plaine
Angelica
Suamico
Howard
Green Bay
WOOD
Arpin
Sherry
Junction City
Rosholt
Northland
Big Falls
Clintonville
Navarino
Nichols
Briarton
Park Ridge
Polonia
Custer
Nelsonville
WAUPACA
Iola
Bear Creek
Leeman
OUTAGAMIE
Seymour
ONEIDA
Stevens Point
Rudolph
Whiting
Plover
Amherst
Amherst Jct.
Scandinavia
Ogdensburg
Manawa
Symco
Sugar Bush
Shiocton
Black Creek
Ashwaubenon
De Pere
Vesper
Pittsville
Wisconsin Rapids
Port Edwards
Nekoosa
Babcock
Biron
Kellner
PORTAGE
Sheridan
Waupaca
King
Northport
New London
Binghamton
Stephensville
Freedom
Mackville
Little Chute
Wrightstown
Kaukauna
Keene
Bancroft
Almond
Rural
Weyauwega
Hortonville
Greenville
Medina
Appleton
Kimberly
Combined Locks
Darboy
Dundas
Holland
Askeaton
Shirley
Morrison
Brillion
Forest Jct.
Rome
New Miner
ADAMS
Plainfield
Hancock
Wild Rose
WAUSHARA
W. Bloomfield
Fremont
Dale
Readfield
Winchester
Larsen
Menasha
Neenah
Sherwood
St. John
Hilbert
Potter
Saxeville
Pine River
Tustin
Poy Sippi
Winneconne
Butte des Morts
Allenville
Stockbridge
CALUMET
Big Flats
Monroe Center
Mt. Morris
Borth
Auroraville
Lake Winnebago

PART I - THE WOLF RIVER BATHOLITH

(J. K. Greenberg, B. A. Brown, L. G. Medaris, and J. L. Anderson)

For information on the Wolf River batholith there is no better source than the work of J. L. Anderson and colleagues (see reference list) upon which most of the background information here is based. Additional pertinent data and interpretations for the Tigerton anorthosite are available from Weis (1965) and Gnat (1984), for the 1760 Ma anorogenic magmatism and comparisons with the Wolf River batholith from Anderson and others (1980) and for tectonism associated with 1500 Ma anorogenic magmatism in Wisconsin from Greenberg and Brown (1986b).

The one day of the field trip which is devoted to the Wolf River is far from a comprehensive survey. The diversity of rock types and the quality of outcrops which will be examined should compensate for the limited time available. The field trip will begin near the southern contact of the batholith at Waupaca and travel north to near its center at Bowler (see the back-cover map). Stops enroute include several enigmatic outcrops in and around Waupaca, a quarry in Waupaca adamellite, a variety of Wolf River lithologies at Little Falls (lunch stop), and the Tigerton anorthosite at Bowler. From Bowler the trip proceeds west to the last two stops, near the batholith margin, where foliated Red River adamellite is featured at the first stop (in eastern Marathon County), and several textural variants of the Red River adamellite, are exhibited at the second, just north of Stevens Point.

General Characteristics of the Batholith

The Wolf River batholith is a large, anorogenic rapakivi massif, which in present-day terminology would be classified as an A-type granite. The batholith has an age of 1485 Ma and is related to a major anorogenic magmatic event (1410 to 1490 Ma) extending from Labrador to southern California. The batholith is composed predominantly of granitic rocks and smaller quantities of monzonite (mangerite) and anorthosite (fig. 1). Such an association of granite, monzonite, and anorthosite is common in anorogenic massifs of rapakivi affinity and represents a cogenetic, but not necessarily comagmatic, suite of rocks.

Rapakivi texture, that is mantling of alkali feldspar by plagioclase, is a conspicuous textural feature which occurs variably, but extensively, in the batholith. In addition, the Wolf River batholith is distinguished by a number of features which it shares in common with other rapakivi massifs, including

1) relatively high contents of alkalis (particularly K), Si, and F and low contents of Ca, Mg, and Al;
2) a predominance of alkali feldspar over plagioclase;
3) the common occurrence of porphyritic texture with phenocrysts of ovoidal to subhedral alkali feldspar and, to a lesser extent, plagioclase and euhedral quartz;
4) relatively high Fe/Mg, which is expressed mineralogically in the form of Fe-rich ferromagnesian silicates, including annitic biotite, ferroedenitic to hastingsitic hornblende, and locally ferroaugite, ferrohypersthene, and fayalite;
5) occurrence of fluorite, allanite, and zircon as accessory minerals; and
6) field characteristics which are typical of epizonal plutons.

Distribution of Plutonic Rocks

The Wolf River batholith underlies an area of approximately 9300 km² in the southeastern part of the exposed Precambrian shield in Wisconsin. The slightly younger (1456 Ma) and probably cogenetic Wausau and Stettin syenite complexes are located three to ten miles west of the batholith. In addition to the exposed plutons, other 1500 Ma granitic rocks in the subsurface of Wisconsin and adjoining northern Illinois are either known from drilling or inferred from geophysical measurements.

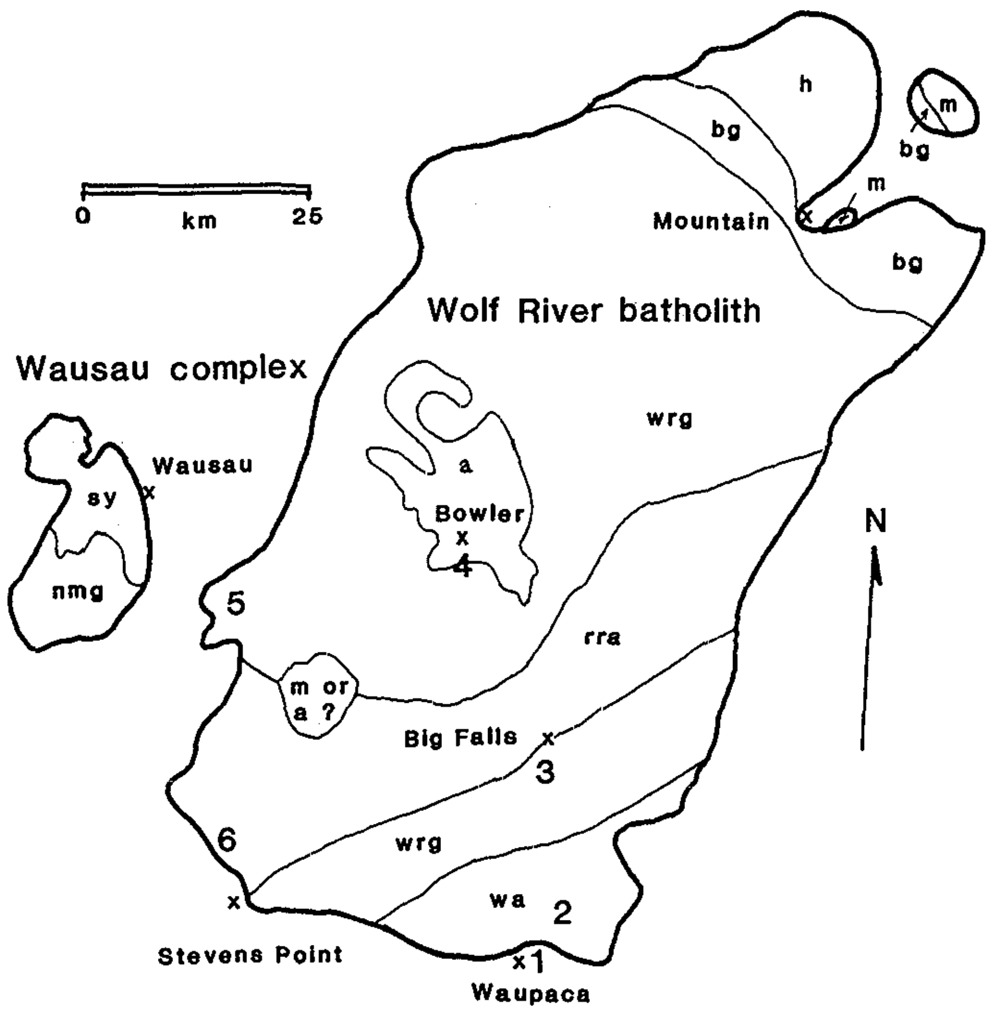


Figure 1. Geologic map of the 1500 Ma Wolf River batholith and Wausau plutonic complex. Small x's indicate the location of towns; numbers 1 to 6 represent the location of field trip stops. Letter symbols for plutons are as follows: m-monzonite, h-Hager granite/porphyry/felsite, bg-Belongia granites, wrg-Wolf River granite, a-anorthosite, rra-Red River adamellite, wa-Waupaca adamellite, sy-syenites, nmg-Nine Mile granite.

Within the Wolf River batholith, eleven distinctive lithologic units are recognized (fig. 1) which, with the exception of volumetrically subordinate syenite, monzonite, and anorthosite, are mostly granite and adamellite (fig. 2). The granitic plutons have intruded older Proterozoic plutonic and volcanic rocks along the western margin of the batholith and on the east are overlain noncomformably by Paleozoic sedimentary rocks. Hypabyssal syenite, granite, and porphyry (Hager units) are distributed in a roughly concentric band at the northeastern end of the batholith, where Proterozoic plutonic, volcanic, and sedimentary rocks have been intruded. The only other rocks recognized as possibly equivalent to the Hager units are those exposed in Waupaca. As discussed later in the guidebook, geologic relationships at Waupaca are not well understood.

Petrogenesis

Relationships among the different plutons of the batholith and their petrogenesis have been discussed in detail by Anderson (1975, 1980) and Anderson and Cullers (1978). It is sufficient for the purpose of this guidebook to

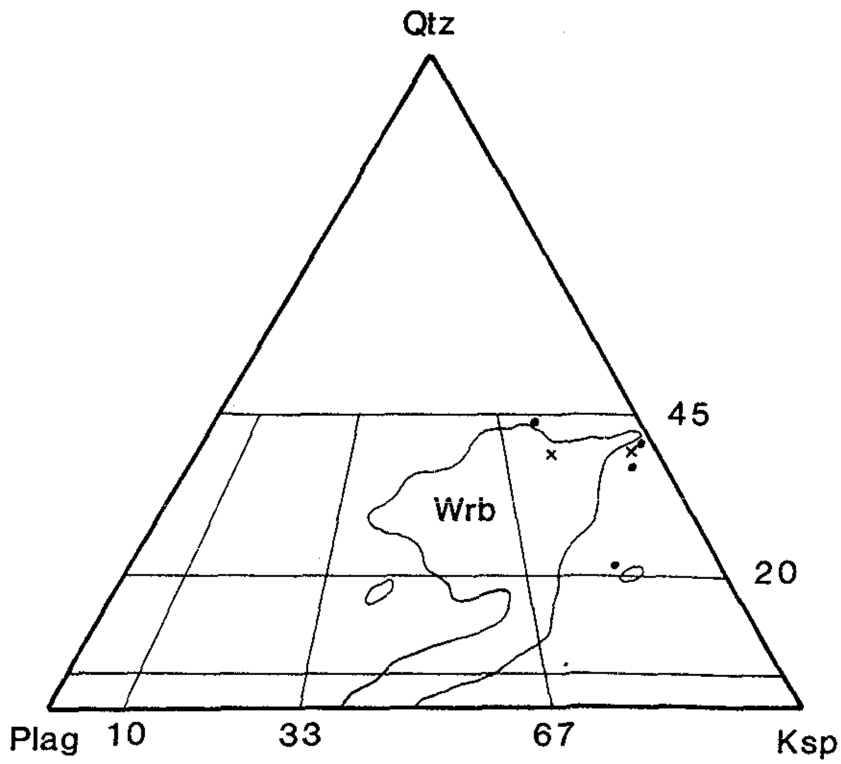


Figure 2. Modal quartz-plagioclase-potassium feldspar ternary diagram (modified from Anderson and Cullers, 1978). Small x's represent the two samples of Waupaca quarry granite reported in Anderson and others (1980). Dots represent two samples from the Waupaca city park (a dark gray and a pink variety), a sample of foliated rock from the river-bank outcrop (lowest quartz of the four from Waupaca), and a sample from the Waupaca quarry (plots with one of the Anderson and others samples). The enclosed fields represent Wolf River batholith granitic units and monzonite.

Table 1.
Major and Trace-Element Compositions of Waupaca Area and Comparison Samples

	1	2	3	4	5	6	A	B	C	D	E
in Wt. %											
SiO_2	69.20	63.50	64.90	65.00	71.60	64.30	73.05	72.82	63.44	70.59	77.32
TiO_2	0.33	0.62	0.48	0.47	0.17	0.20	0.19	0.19	0.85	0.37	0.21
Al_2O_3	13.90	15.00	15.60	16.00	12.50	16.60	13.17	13.56	15.40	13.61	1.32
Fe_2O_3*	2.49	4.78	3.65	3.76	2.14	2.24	1.61	1.68	6.69	3.22	1.83
MnO	0.06	0.10	0.07	0.08	0.06	0.05	--	--	0.15	0.07	0.05
MgO	0.57	1.70	0.98	0.95	0.24	0.53	0.25	0.24	0.29	0.17	0.10
Na_2O	3.23	3.14	3.99	4.15	3.64	3.73	3.05	3.14	4.21	3.57	2.21
K_2O	5.15	4.09	4.67	3.96	5.56	8.26	5.19	5.80	5.19	5.49	5.07
CaO	1.54	3.08	2.69	2.89	0.69	0.61	0.91	0.75	2.66	1.29	0.88
P_2O_5	0.33	0.33	<0.01	0.01	0.05	0.04	--	--	--	--	--
LOI	0.40	1.25	0.50	0.90	0.35	0.85	--	--	--	--	--
TOT	97.20	97.59	97.53	98.17	97.00	97.41	97.46	98.23	98.88	98.38	99.99
in ppm											
Rb	245	174	171	128	211	218	160	176	136	141	207
Sr	229	381	344	409	106	150	120	100	160	93	54
Y	36	29	32	20	41	88	--	--	--	--	--
Zr	236	245	296	257	244	399	--	--	--	--	--
Nb	34	30	29	23	28	53	--	--	--	--	--
Ba	810	936	994	904	632	707	739	778	2110	1353	--
Be	<1	1	<1	8	<1	<1	--	--	--	--	--
Li	33	34	20	22	30	15	25	20	16	22	18
Sc	11.1	3.6	4.6	10.8	7.4	7.0	--	--	--	--	--
La	19.4	66.0	56.7	50.2	55.8	41.9	--	63	90.3	--	-
Ce	45	124	109	99	112	86	--	134	193	--	--
Nd	19	44	40	41	37	32	--	--	--	--	--
Sm	4.3	7.4	6.7	7.1	6.9	5.8	--	10.3	18.3	--	--
Eu	0.9	0.9	0.8	1.2	1.3	1.2	--	0.78	5.8	--	--
Tb	0.8	0.9	0.7	0.7	0.5	0.6	--	2.10	2.4	--	--
Ho	1.0	1.4	1.1	1.4	1.2	1.0	--	--	3.4	--	--
Yb	2.1	3.7	3.8	3.1	3.3	2.8	--	4.8	7.0	--	--
Tm	0.3	0.6	0.7	0.6	0.5	0.5	--	--	--	--	--
Lu	0.3	0.6	0.6	0.5	0.5	0.4	--	0.76	1.1	--	--
Th	2.3	21.6	22.6	12.5	14.2	12.0	--	23.9	--	--	--

1. Sample WP-85-1 granite from Granite Street, Waupaca
2. Sample WP-85-2 light gray porphyry from Waupaca City Park
3. Sample WP-85-3 dark gray syenite porphyry from Waupaca City Park
4. Sample WP-85-4 foliated adamellite from Highway K
5. Sample WP-85-5 granite from Waupaca City quarry
6. Sample WP-85-6 foliated "syenite" from Waupaca City Park river bank

A Sample 70-12 granite from Waupaca City quarry (Anderson and others, 1980)
B Sample 70-13 granite from Waupaca city quarry (Anderson and others, 1980)
C Sample GR17B monzonite, northeastern WI (Anderson and Cullers, 1978)
D Sample 72M Hager granite, northeastern WI (Anderson and Cullers, 1978)
E Sample 50M Hager porphyry, northeastern WI (Anderson and Cullers, 1978)

outline briefly some important chemical and physical characteristics of the Wolf River batholith and its member units. Most of the plutons in the batholith are undifferentiated, although the Belongia granite has formed by differentiation from the Wolf River granite. The undifferentiated plutons probably originated by partial melting of lower crustal material at pressures of about 7 to 10 kb (depths of 25 to 36 km), and the more evolved felsic granitic plutons crystallized at emplacement depths of less than 4 km. With respect to a

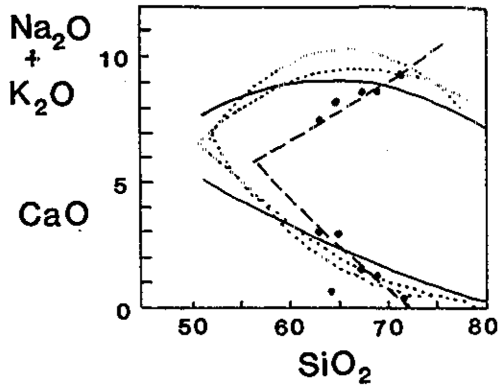


Figure 3. Peacock diagram (modified from Anderson and Cullers, 1978) comparing the trend of six Waupaca samples (dots and corresponding dashed lines) with the more alkaline trends of the Wolf River batholith (solid lines) and the Nigerian younger granites and White Mountain magma series (two pairs of dotted curves).

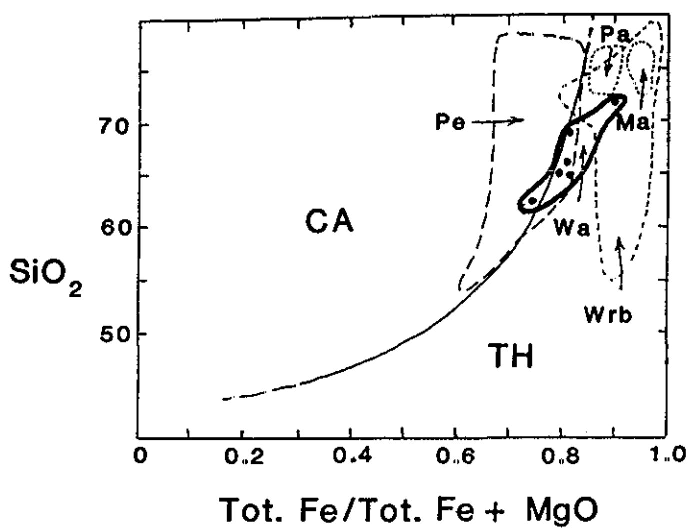


Figure 4. Plot of silica versus an iron/magnesium ratio (modified from Anderson and others, 1980). The solid curved line divides the CA-Calcalkaline field from the TH-tholeiitic field. Labeled fields are as follows: Pe-Penokean granitic rocks, Pa-peraluminous 1760 Ma granites, Ma-metaluminous 1760 Ma granites, Wa-Waupaca sample field (heavy line) from this study, Wrb-Wolf River batholith granitic rocks.

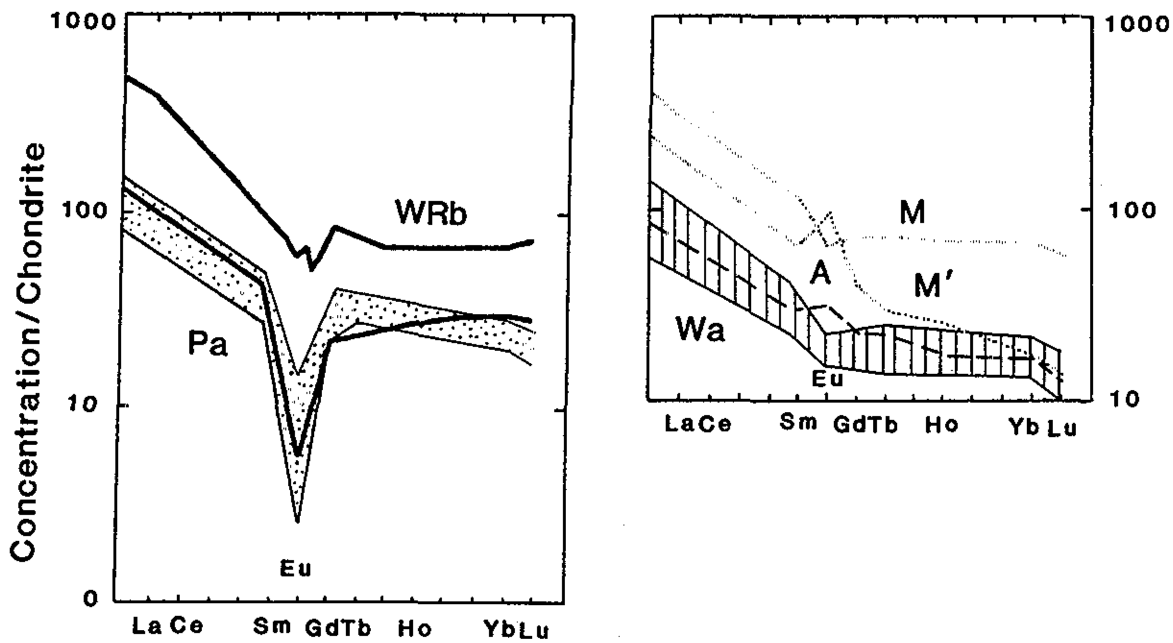


Figure 5. Plots of chondrite normalized rare-earth data (modified from Anderson and Cullers, 1978 and Anderson and others, 1980). Field within solid lines on left diagram represents combined patterns of Wolf River batholith granitic rocks. Dotted field on the left diagram represents Pa-peraluminous 1760 Ma granites. Dotted-line patterns on the right diagram represent two monzonite samples (M and M'). Dashed-line pattern on right diagram represents A-Tigerton anorthosite. The vertical-lined field on the right diagram represents the combined patterns of six Waupaca samples from this study.

generally alkaline, though not peralkaline, character and high Fe/Mg, the Wolf River batholith is similar to other continental anorogenic plutonic series (figs. 3, 4). Trace element contents and rare earth element patterns (fig. 5, Table 1) preclude derivation of the granitic units from either the associated anorthosite or monzonite. The anorthosite-granite suite may have been generated by ponding of tholeiitic magma at the base of continental crust; anorthosite was derived by crystallization from the tholeiitic magma and granite originated by partial melting of the lower crust, which was induced by the addition of heat from the ponded magma.

Associated Tectonism

The Wolf River batholith and other associated 1500 Ma intrusions were generated at a time when the region was relatively stable. Magmatism at 1500 Ma was both preceded and followed by other periods of anorogenic magma- tism, each of which was indicative of a particular stage in the progressive evolution of the crust (Greenberg and Brown, 1984). The Wolf River batholith was not syntectonic in the sense of having been contemporaneous with regional metamorphism and deformation, although its intrusion may have had a substantial effect on the surrounding country rocks. Metamorphic effects in the country rocks which may be associated with intrusion of the batholith include the development of staurolite, sillimanite, garnet, and andalusite in aluminous rocks and hornblende, cummingtonite, garnet, and pyroxene in mafic rocks. In addition, certain distinctive structural features, such as overprinting of foliations and cataclasis occur in country rocks in the vicinity of the batholith. Possible explanations for tectonic features associated with 1500 Ma magmatism in Wisconsin are discussed in Greenberg and Brown (1986b).

Outcrops of all rock types within the Wolf River batholith are typically massive and fractured along sets of widely-spaced joints. A planar fabric due to alignment of crystals, usually feldspar phenocrysts, occurs at various locations, commonly near the margins of plutons, and has probably resulted from igneous flow. Only in a few exposures near contacts with country rocks or interplutonic contacts have the granitic plutons obviously been modified by subsolidus deformation. This type of deformation is evidenced by cataclasis and attenuation of grains within foliation planes which are roughly parallel to the aforementioned contacts. Such relationships indicate that the subsolidus deformation occurred during emplacement of the batholith and probably was not related to later tectonism.

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Stop 3-01: Red River granite east of Gresham

Location: Outcrop below dam on Red River, on N-S side road just north of Cherry Road; SE 1/4, SW 1/4, SE 1/4, Sec 2, T.27N., R 14E., Shawano County, Wisconsin.

Stop Description: The Red River granite constitutes about 20 percent of the exposed area of the Wolf River batholith and is located in an east-northeast trending belt between the Wolf River granite to the north and the Waupaca granite (wiborgite) to the south. The Red River granite is younger than the Wolf River granite, as shown by intrusive relationships. The Red River porphyritic granite in the Gresham area shows a pronounced flow foliation defined by K-feldspar phenocrysts. Previous descriptions of this unit have referred to it as the "Red River adamellite", but modal analyses generally place it in the granite field using modern classification.

Prior Guidebook Reference: Medaris, Van Schmus, and Anderson (1973)

Stop 3-02: Red River phase of WRB NE of Gresham (gravel quarry)

Location: Several "whale backs" of granite in the floor of unused gravel quarry; NW corner, SW 1/4 Sec. 1, T 27N., R 14E., Shawano County, Wisconsin

Stop Description: Red River granite and younger aplite and pegmatite dikes are well exposed in the bedrock and boulders within this quarry.

Prior Guidebook Reference: None

Stop 3-03: Red River phase of WRB in Gresham

Location: Outcrops on north bank of Red River in Riverside Park, Gresham, under road bridge west of park, and in river bed below dam west of road; North 1/2 Sec. 3, T.27N., R.14E., Shawano County, Wisconsin

Stop Description: Foliation defined by K-feldspar phenocrysts is well defined by boulders and outcrop along the south bank of the Red River in Riverside Garden Park. There is also good bedrock outcrop under the highway bridge to the west and below the dam on the west side of the road where various pegmatitic dikes can be seen. Quartz and K-feldspar in some of the pegmatites show excellent myrmekitic texture.

Prior Guidebook Reference: None

Field Trip Locality 6

TITLE:

The Red River porphyritic quartz monzonite

LOCATION:

SW$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 2, T.27N., R.14E., Shawano County, on the Red River

AUTHORS:

L.G. Medaris, Jr., UW-Madison; W.R. Van Schmus, Univ. of Kansas; and J.L. Anderson, UW-Madison

DATES:

Summer, 1972

SUMMARY OF FEATURES:

Exposure of typical Red River porphyritic quartz monzonite

DESCRIPTION:

The Red River porphyritic quartz monzonite constitutes 20.6% of the exposed area of the Wolf River batholith and is located in an ENE-trending belt between the Wolf River quartz monzonite and the Waupaca quartz monzonite (see Fig. 1, page 10, this guidebook).

At this locality the quartz monzonite consists of 10 to 20% subhedral alkali feldspar phenocrysts (0.5 to 2.0 cm in length) in a medium-grained matrix (1 to 2 mm) of idiomorphic to subhedral quartz, two feldspars, and biotite. The quartz monzonite displays a prominent foliation due to alignment of feldspar phenocrysts.

Stop 3-04: Anorthosite in Bowler

Location: Outcrop near west edge of practice field, northwest of Bowler High School building, west of County Highway D, 0.4 miles south of Bowler; SE 1/4 SE 1/4 Sec. 36, T. 28 N., R. 12 E., Shawano County, Wisconsin.

Stop Description: Anorthosite occurs as a central large mass and as smaller inclusions in the Wolf River granite. The rock varies from anorthosite to gabbroic anorthosite and consists predominantly of coarse-grained blue-gray plagioclase (An_{38} to An_{64}). Augite is common in the matrix and may be replaced by hornblende, with or without a reaction rim of various minerals. At this locality the anorthosite is also cut by a pegmatite.

Prior Guidebook Reference: Anderson and Medaris (1986c).

Stop 3-05: Anorthosite north of Wittenberg

Location: Outcrop on west side of road at south end of curve, U.S. Highway 45, 2.75 miles north of Wisconsin Highway 29 and the town of Wittenberg; NE corner, SW 1/4, NE 1/4 Sec. 33, T.28N., R.12E., Shawano County, Wisconsin. (Careful: busy highway)

Stop Description: This outcrop displays typical coarse-grained anorthosite with altered mafic minerals. It is included here because it may be somewhat easier to sample than at other stops. Watch for traffic!

Prior Guidebook Reference: None

Stop 3-06: Anorthosite and Wolf River granite north of Tigerton

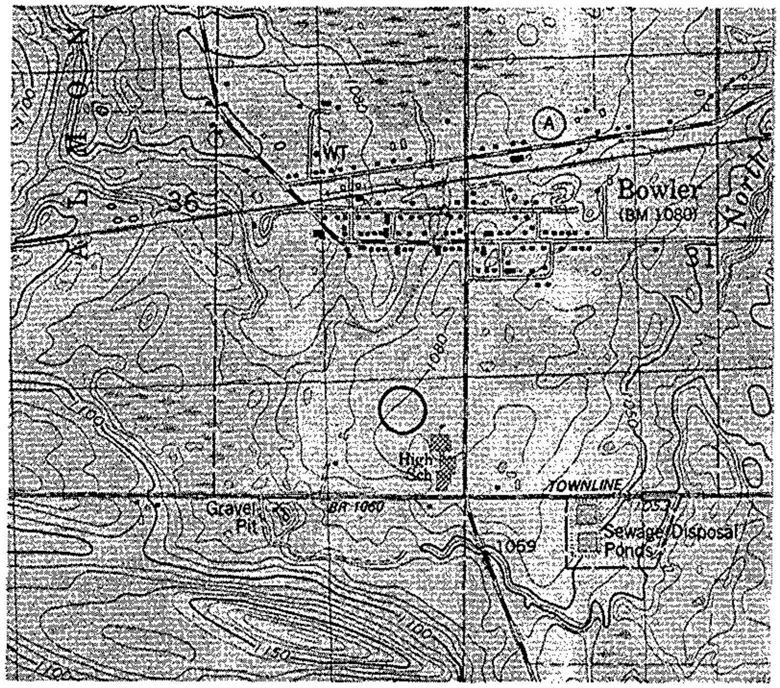
Location: Outcrop on east slope of ridge to west of County Highway J (at Thoma Farm), about 1/4 mile south of Wisconsin Highway 29; East edge, SE 1/4 Sec. 22, T.27N., R.12E., Shawano County, Wisconsin.

Stop Description: This locality displays the xenolithic nature of the anorthosite within the Wolf River batholith. Along this ridge several blocks of foliated anorthosite are hosted by Wolf River granite. In some instances the contacts are sharp, whereas in others the contacts show evidence of partial assimilation of the anorthosite.

Prior Guidebook Reference: Stop 1 of Read and Weis (1962)

Title: Anorthosite near Bowler

Location: Outcrop in schoolyard on west side of County Trunk Highway J, approximately ½ mile south of Bowler, SE¼, SE¼, Sec. 36, T. 28 N., R. 12 E., Shawano County (Bowler 7½-minute topographic quadrangle).



Authors: J. L. Anderson and L. G. Medaris, Jr. (1986)

Description: Anorthosite occurs as a centrally located large mass and as smaller inclusions in the Wolf River granite. The rock varies from anorthosite to gabbroic anorthosite and consists predominantly of coarse-grained (1-20 cm) blue-gray plagioclase, which ranges in composition from $An_{37.5-63.5}$ (Gnat, 1984). The texture is porphyritic granoblastic, or cataclastic; coarse-grained plagioclase is set in a medium-grained matrix of plagioclase and interstitial clinopyroxene (salite to augite), orthopyroxine (hypersthene to bronzite), hornblende, magnetite, and ilmenite. Pyroxenes are typically surrounded or replaced by hornblende.

Anorthosite at the Bowler locality varies from anorthosite to gabbroic anorthosite and is intruded locally by pegmatite. The anorthosite tends to be porphyritic, with coarse-grained plagioclase phenocrysts situated in a medium-grained matrix, in which plagioclase displays well developed 120° grain boundaries. Augite is either surrounded by hornblende or replaced by an assemblage of hornblende, cummingtonite, and iron-titanium oxides, and biotite occurs on hornblende and iron-titanium oxides (fig. 10).

Figure 10. Photomicrograph of porphyritic anorthosite. Interstitial pyroxene is rimmed by hornblende, biotite occurs on opaque oxides, and the groundmass texture is a mosaic of plagioclase. Long dimension is 6 mm.

<u>Discussion</u>: As discussed in the introduction to this guidebook, it has been demonstrated that the three main rock types in the Wolf River batholith (granite, monzonite, and anorthosite) are not all comagmatic, although they may be cogenetic. Gnat (1984) has suggested that the anorthosite has evolved from a high-alumina tholeiite parent by means of open-system fractionation and plagioclase accumulation in a periodically replenished and tapped magma chamber. In addition, geochemical data are consistent with monzonite having been derived from anorthosite through fractional crystallization of plagioclase, hypersthene, augite, and apatite (Anderson and Cullers, 1978).

Stop 3-07: Wiborgite in Tigerton

Location: Outcrop on west side of Embarass River, both sides of U. S Highway 45, just west of bridge in Tigerton; Center, SW 1/4 Sec 9, T 26N., R 12E., Shawano County, Wisconsin

Stop Description: This is an excellent example of Wiborgite textures (mantled feldspars, spherical phenocrysts) in Wolf River batholith The best viewing is at an outcrop on the north side of the highway at the west end of the bridge (no hammers please - someone has already removed a large, round phenocryst); outcrop along the west river bank is also good, but it has more lichen cover. Samples can be collected from scattered small outcrops on the south side of the road.

Prior Guidebook Reference: None

Stop 3-08: Wolf River batholith phases at Big Falls

Location: Outcrop slong south side of Little Wolf River, roadside park at "T" intersection 1/4 mile north of village of Big Falls; also exposed in roadcut on both sides of County Highway C-G just south of intersection. South side, SW 1/4 Sec. 23, T 25N., R 12E., Waupaca County, Wisconsin

Stop Description: See description for Little Falls, below (Stop 3-09)

Prior Guidebook Reference: See Anderson and Medaris (1986b).

Stop 3-09: Wolf River batholith phases at Little Falls Resort

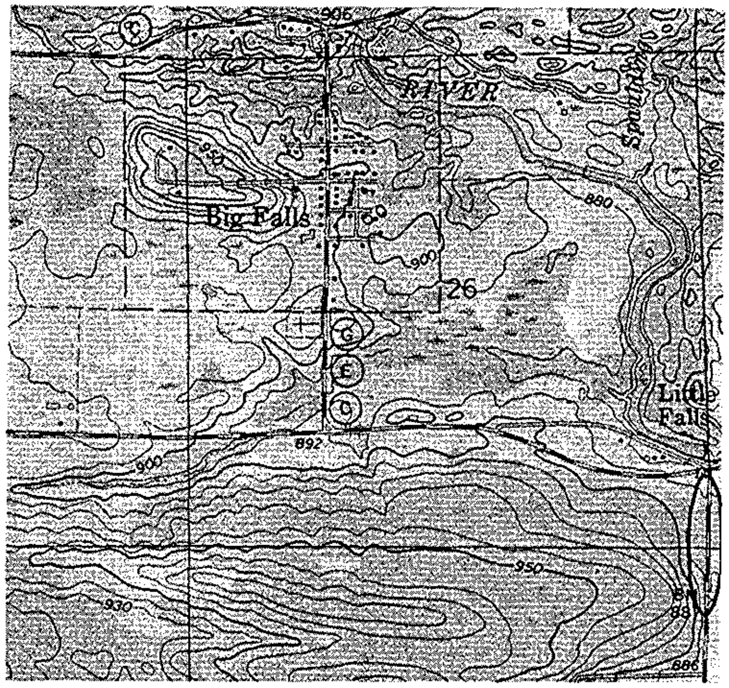
Location: Outcrops along south side of Little Wolf River at Little Falls Resort, north of "T" intersection of County Highways C-E-G SE 1/4 SE 1/4 Sec. 26, T 25N., R 12E., Waupaca County, Wisconsin

Stop Description: Three lithologic units of the Wolf River batholith (Wolf River granite, Wiborgite porphyry, and Red River granite) may be examined in excellent outcrops along the Little Wolf River (Anderson and Medaris, 1986b). The Wolf River granite is the oldest and largest granitic phase of the batholith, accounting for about 50% of the exposed area. The red, coarse-grained granite consists of large (1-3 cm) ovoidal to subhedral alkali feldspar with interstitial plagioclase (An_{15-20}), quartz, biotite, hornblende, and accessory minerals that include apatite, zircon, allanite, ilmenite, magnetite, titanite, and fluorite. Only 3 to 10 % of the alkali feldspar are mantled by plagioclase. Texturally, the Wolf River granite resembles the pyterlite variety of the Finnish rapakivi granites The Wiborgite porphyry contains extensive rapakivi mantling of feldspars. It occurs as large, massive dikes up to 5 km long and 1 km wide within the Wolf River granite. The Red River granite is the youngest of the undifferentiated plutons It occurs as dikes in the Wolf River granite and as a large ENE trending body to the south.

Prior Guidebook Reference: Anderson and Medaris (1986b)

Title: Outcrops at Little Falls (1986)

Location: Southwest of Big Falls on the south bank of the Little Wolf River at the intersection of County Trunk Highways C and E, SE¼, SE¼, Sec. 26, T. 25 N., R. 12 E., Waupaca County (Big Falls 7½-minute topographic quadrangle).



Authors: J. L. Anderson and L. G. Medaris, Jr. (1986)

Description: Three lithologic units of the Wolf River batholith (Wolf River granite, Wiborgite porphyry, and Red River adamellite) may be examined in excellent outcrops along the Little Wolf River.

The Wolf River granite is the oldest granitic pluton in the batholith and the largest, accounting for approximately 50% of the exposed area. The red, coarse-grained granite consists of large (1-3 cm) ovoidal to subhedral alkali feldspar with interstitial plagioclase (An_{15-20}), quartz, biotite, hornblende, and accessory minerals, including apatite, zircon, allanite, ilmenite, magnetite, sphene, and fluorite. Only 3 to 10 percent of the alkali feldspar grains are mantled by plagioclase. Texturally, the Wolf River granite resembles the pyterlite variety of the Finnish rapakivi granites.

Field, petrologic, and geochemical data indicate that in the northeastern part of the batholith a differentiated granitic suite (Belongia coarse and Belongia fine granite) has been produced by fractional crystallization of the Wolf River granite. The Wolf River granite crystallized at a temperature of approximately 700 °C and an oxygen fugacity of $10^{-17.9}$ bars, based on the compositions of coexisting ilmenite, magnetite, and biotite.

The <u>Wiborgite porphyry</u> is a granite porphyry which contains extensive rapakivi and less abundant anti-rapakivi mantling of feldspars. The porphyry contains 45 to 70 percent phenocrysts of mantled alkali feldspar and lesser amounts of plagioclase (An_{17-24}), quartz, biotite, and hornblende in a medium- to coarse-grained matrix of the same minerals and accessory phases. The porphyry occurs as large, massive dikes up to 5 km long and 1 km wide within the Wolf River granite.

The <u>Red River adamellite</u> is the youngest of the undifferentiated plutons in the batholith. The adamellite is porphyritic and contains coarse-grained phenocrysts (1-20 percent) of subhedral to rectangular alkali feldspar and lesser amounts of euhedral plagioclase (An_{17-27}), euhedral quartz, and clusters of biotite ± hornblende. The medium-grained matrix consists of anhedral quartz, two feldspars, biotite, ± hornblende, ilmenite, ± magnetite, sphene, allanite, apatite, zircon, and fluorite. Texturally, the Red River adamellite is similar to the porphyritic varieties of the Finnish rapakivi granites.

The compositions of coexisting ilmenite, magnetite, and biotite yield a temperature of approximately 760 °C and an oxygen fugacity of $10^{-16.3}$ bars for crystallization of the Red River adamellite.

Stop 3-10: Wiborgite at quarry NE of Waupaca

Location: Exposures in abandoned (and overgrown) quarry on north side of Granite Quarry Road, about 1/4 mile east of West Waupaca Road; NE corner, Sec 5, T.22N , R.12E , Waupaca County, Wisconsin.

Stop Description: The Waupaca granite forms the southernmost pluton in the Wolf River batholith On its southern margin it intrudes gneissic rocks (probably Penokean). This granite is characterized by rapakivi texture and is equivalent to the wiborgite in the massifs of Finland. Approximately 70 to 80 percent of the coarse ovoid alkali feldspar grains are mantled by plagioclase.

Prior Guidebook Reference: Anderson and Medaris (1986a).

Stop 3-11: Wiborgite east of Waupaca

Location: Exposures in abandoned (and overgrown) small quarry on north side of hill, south side of road; Center, north edge, NW 1/4 Sec. 14, T 22N., R.12E., Waupaca County, Wisconsin

Stop Description: Waupaca granite with rapakivi texture (Wiborgite), similar to that at Stop 3-10.

Prior Guidebook Reference: None (see Anderson and Medaris, 1986a)

Stop 3-12: Red River porphyry northeast of Stevens Point

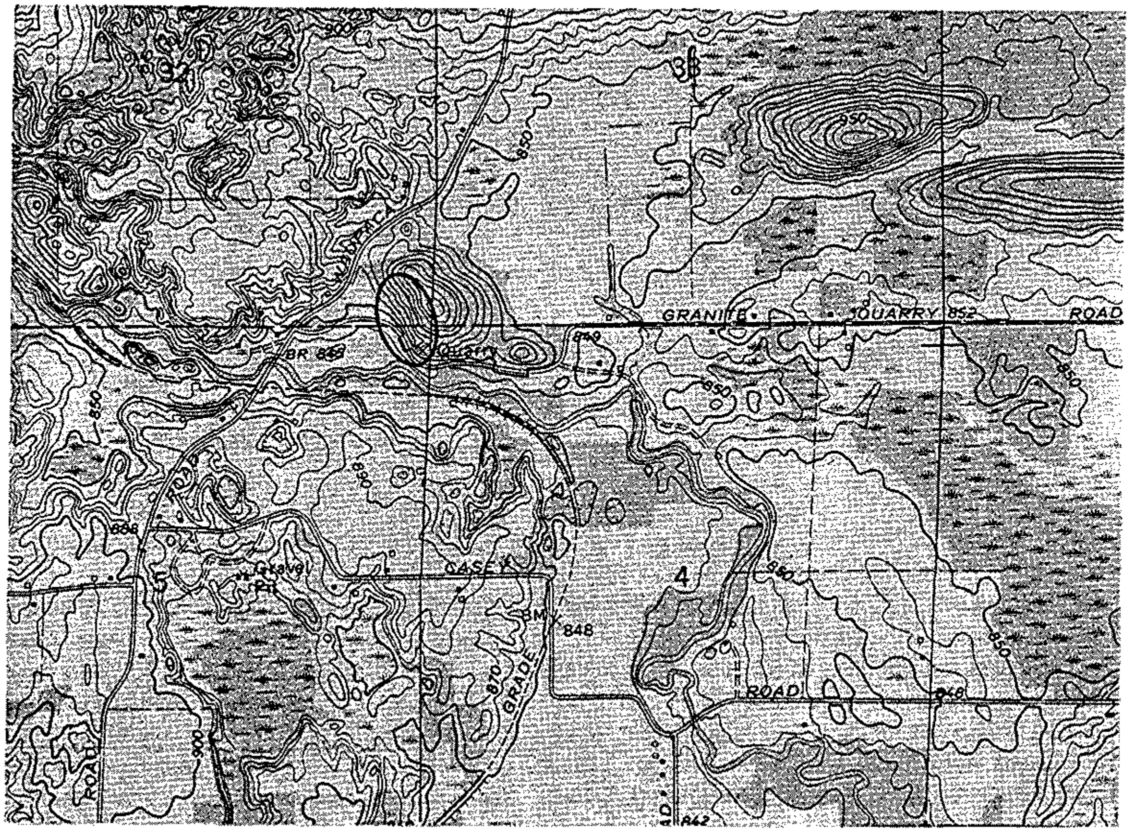
Location: Western part of the Red River granite is exposed below the dam at Jordan Pond, south side of Wisconsin Highway 66; NE 1/4 SW 1/4 Sec. 12, T.24N., R.8E., Portage County, Wisconsin.

Stop Description: Medium-grained biotite granite assigned to the Red River phase is exposed south of the dam. This granite is typical of that found among the western exposures of the batholith in the Stevens Point region. The granite is bordered on the west by Archean gneiss and Penokean plutonic rocks.

Prior Guidebook Reference: None

Title: Quarry in Waupaca Adamellite

Location: Quarry is on the north side of Granite Quarry Road, NW¼, NW¼, Sec. 4, T. 22 N., R. 12 E., Waupaca County (Ogdensburg 7½-minute topographic quadrangle).



Authors: J. L. Anderson and L. G. Medaris, Jr. (1986)

Description: This quarry is located in the Waupaca adamellite, which forms the southernmost pluton in the Wolf River batholith. The Waupaca adamellite intrudes gneiss (perhaps Archean), an outcrop of which occurs on the hill above the quarry wall. The northern contact of the adamellite with the Wolf River granite is not exposed, so its relative age with respect to the other lithologic units in the batholith is unknown.

The Waupaca adamellite is characterized by rapakivi texture (fig. 9) and is equivalent to wiborgite of the classical rapakivi massifs in Finland. Approximately 70 to 80 percent of the coarse ovoidal alkali feldspar grains are mantled by plagioclase. The adamellite is massive, coarse-grained, and inequigranular, with anhedral quartz, hornblende, and biotite occurring interstitially to the large ovoidal feldspar. Accessory minerals include apatite, zircon, ilmenite, magnetite, allanite, sphene, and fluorite.

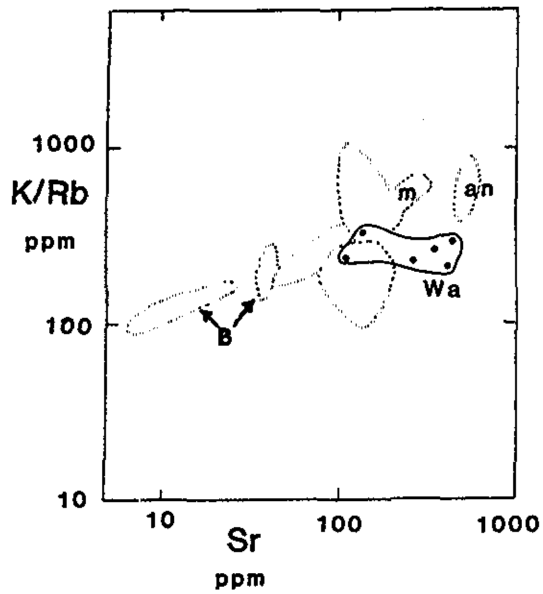


Figure 8. Plot of K/Rb versus Sr (modified from Anderson and Cullers, 1980). Black dots and solid-line field represent Wa-Waupaca area samples (this study). Dotted-line fields represent Wolf River batholith samples, including B-Belongia granites, m-monzonite, and an-Tigerton anorthosite.

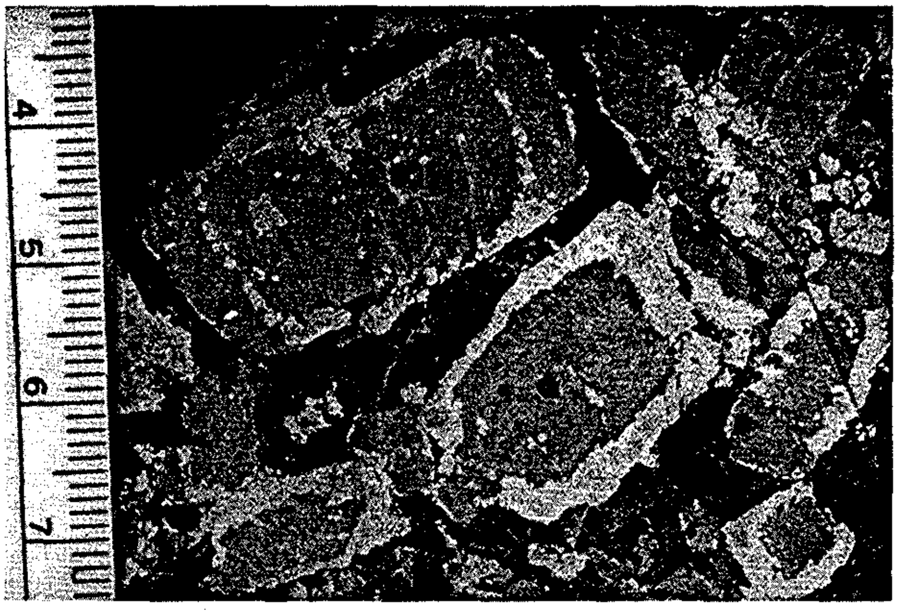


Figure 9. Rapakivi texture in Waupaca adamellite. Scale in centimetres.

The Waupaca adamellite is a member of the suite of undifferentiated granite to adamellite plutons in the batholith. Although there is some compositional overlap with the Red River adamellite, the Waupaca adamellite is one of the most aluminous plutons (13.75 to 14.70%) within the undifferentiated suite, has the highest values for $CaO/CaO + Na_2O$ (0.32 to 0.42), has the highest contents of $K_2O + Na_2O$ (8.60 to 9.23%), and has intermediate values of $FeO/FeO + MgO$ (0.86 to 0.89). The one sample (from this quarry) of Waupaca adamellite which has been analyzed for the rare earth elements contains the greatest concentration of these elements among samples from the undifferentiated plutons.

Ferromagnesian phases in the Waupaca adamellite are relatively Fe-rich, as they are elsewhere in the batholith. In a sample from this quarry, $Fe/Fe + Mg$ is 0.77 in biotite and 0.84 in amphibole, which is close to ferroedenite in composition. Individual plagioclase grains exhibit normal zoning and range in composition from An_{13-24}; plagioclase mantles on alkali feldspar also range in composition from An_{13-24}. The bulk composition of perthitic alkali feldspar is $Or_{74}\ Ab_{23}\ An_3$. The compositions of coexisting ilmenite, magnetite, and biotite indicate a crystallization temperature of approximately 745 °C and an oxygen fugacity of $10^{-16.7}$ bars.

At this quarry some portions of the adamellite have been extensively altered to epidote and chlorite, which imparts a green color to hand samples.

Field Trip Day 4
Wausau-Wisconsin Rapids Region

Objectives:

The main objectives of the day are (1) to examine the enigmatic "Wausau Red" (Granite Heights) granite, (2) to examine parts of the 1.5 Ga Wausau syenite complex, (3) to examine several representative units of the Penokean magmatic complex in the Wausau region, and (4) to examine Penokean plutonic and Archean gneissic rocks of the Marshfield terrane.

Itinerary:

0800 Depart Wausau/Mosinee Holiday Inn

Stop 4-01: Penokean (?) felsic volcanics at Brokaw

Stop 4-02: 1760 Ma (?) "Wausau Red" granite

Stop 4-03: Wausau syenite at Employers' Insurance parking lot

Stop 4-04: Rotten granite quarry in Nine-Mile granite

Stop 4-05: Penokean granite at Cherokee (optional)

Stop 4-06: Archean gneiss east of Marshfield (optional)

Stop 4-07: Penokean granite with Archean xenoliths east of Marshfield

1200 Lunch

Stop 4-08: Archean gneiss SW of Pittsville (optional)

Stop 4-09: Penokean tonalite at Biron Dam

Stop 4-10: Archean gneiss at Linwood Quarry

Stop 4-11: Archean gneiss and Penokean tonalite at Conant's Rapids

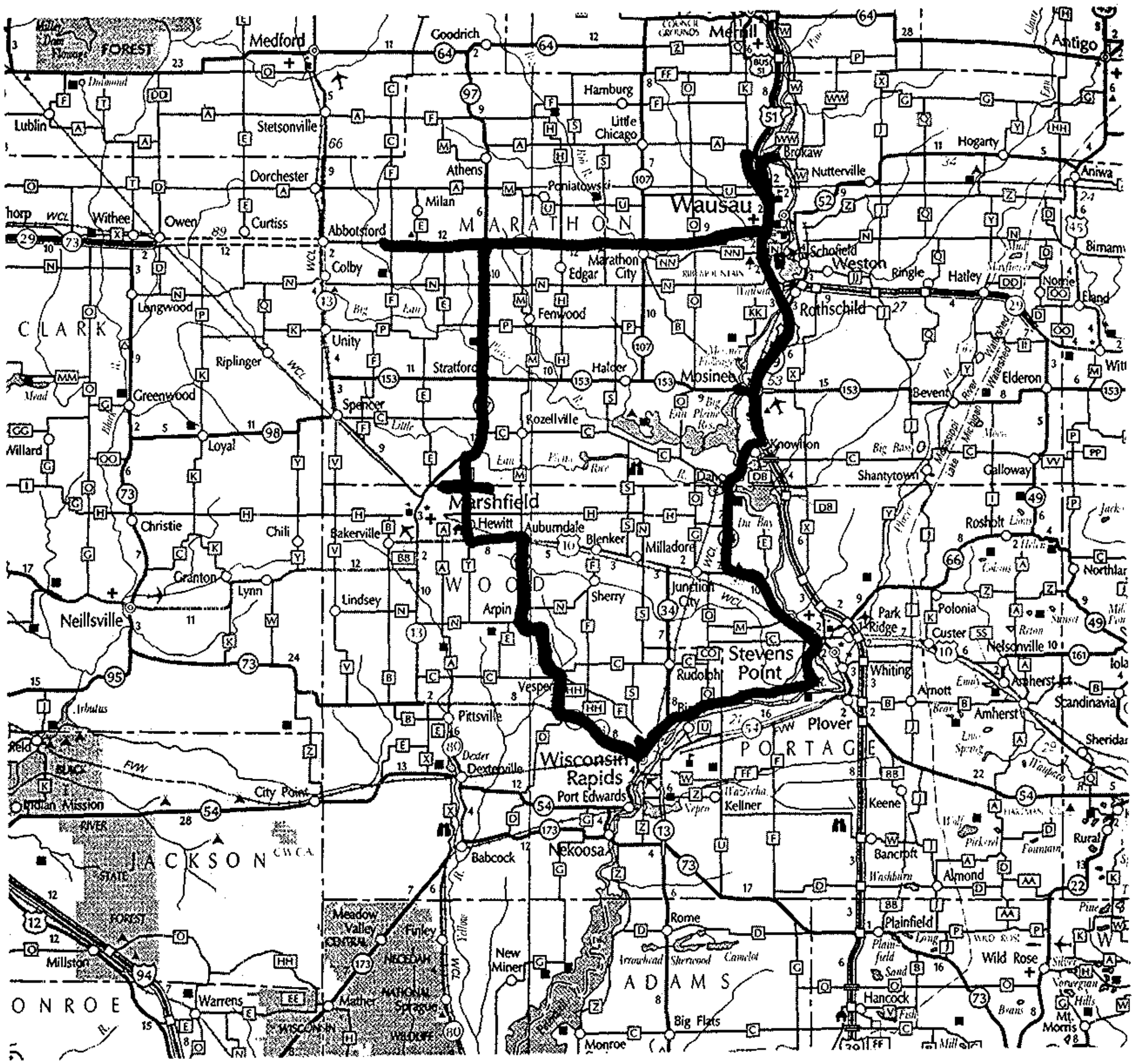
Stop 4-12: Penokean tonalite north of Dancy

Stop 4-13: Penokean tonalite near Mosinee

1800 Arrive Wausau/Mosinee Holiday Inn

Dinner

Evening activities


Medford
Goodrich
Merrill
Antigo
Stetsonville
Hamburg
Little Chicago
Hogarty
Dorchester
Athens
Brokaw
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Wausau
Withee
Owen
Curtiss
Abbotsford
MARATHON
Colby
Marathon City
Edgar
Schofield
Weston
Ringle
Hatley
Longwood
Fenwood
Rothschild
CLARK
Unity
Riplinger
Stratford
Halder
Mosinee
Elderon
Greenwood
Spencer
Rozellville
Loyal
Knowlton
Shantytown
Galloway
Willard
Marshfield
Hewitt
Auburndale
Blenker
Milladore
Christie
Chili
Bakerville
Rosholt
Granton
Lynn
WOOD
Junction City
Neillsville
Lindsey
Arpin
Sherry
Park Ridge
Polonia
Custer
Nelsonville
Stevens Point
Rudolph
Whiting
Arnott
Amherst Jct.
Amherst
Pittsville
Vesper
Plover
PORTAGE
Dexterville
Wisconsin Rapids
Port Edwards
City Point
Kellner
Keene
JACKSON
Babcock
Nekoosa
Bancroft
Almond
Rome
Millston
Plainfield
New Miner
ADAMS
Wild Rose
Warrens
Mather
Hancock
MONROE
Big Flats
Monroe

Stop 4-01: Penokean felsic volcanics at Brokaw

Location: Outcrop on south side of County Road WW, east of U S Highway 51 and west of Wisconsin River; SE 1/4 NW 1/4 Sec 3, T 29N., R 7E , Marathon County, Wisconsin

Stop Description: A large outcrop of quartz-porphyry rhyolitic to dacitic felsic volcanic rock (tuff? volcaniclastic sediment?) is exposed here This unit is presumed to be part of the Penokean bimodal volcanic succession of Marathon County (pillow basalts are exposed elsewhere in the Wausau area and mafic volcanics represent a large portion of the succession) This unit is flat-lying and undeformed; it is quarried near Brokaw by the MMM Co for use as roofing granules Three fractions of zircon from this unit define an age of 1851 ± 3 Ma (Fetter and Van Schmus, unpublished data, 1998); a fourth fraction has an older Pb-Pb age of 1859 ± 2 Ma and may represent a xenocryst.

Prior Guidebook Reference: Related stop: see Weiss and LaBerge, 1969, Stop 4

Stop 4-02: 1760 Ma (?) "Wausau Red" granite

Location: AB&J Granite Co , quarry, 0 5 mile east of County Road K (old U.S. Highway 51) on Prehn Road; Center, south edge Sec. 9 & north edge Sec. 16, T 30N., R 7E., Marathon County, Wisconsin

Stop Description: *This granite is quarried extensively in the* Wausau region It is known locally as the "Wausau Red" granite, but is shown on the geologic map of Marathon County as the Granite Heights granite This rock is used extensively for tombstones and building stone So far attempts by WRVS over the past 25 years to obtain a U-Pb age on this unit have failed due to a total absence of zircon in this granite Rb/Sr data for this granite (Van Schmus et al , 1975a) yield an age of 1580 Ma (recalculated), but this is undoubtedly a reset age due to a pervasive low-grade hydrothermal event that affected the Penokean orogen This problem will be discussed further on Day 5

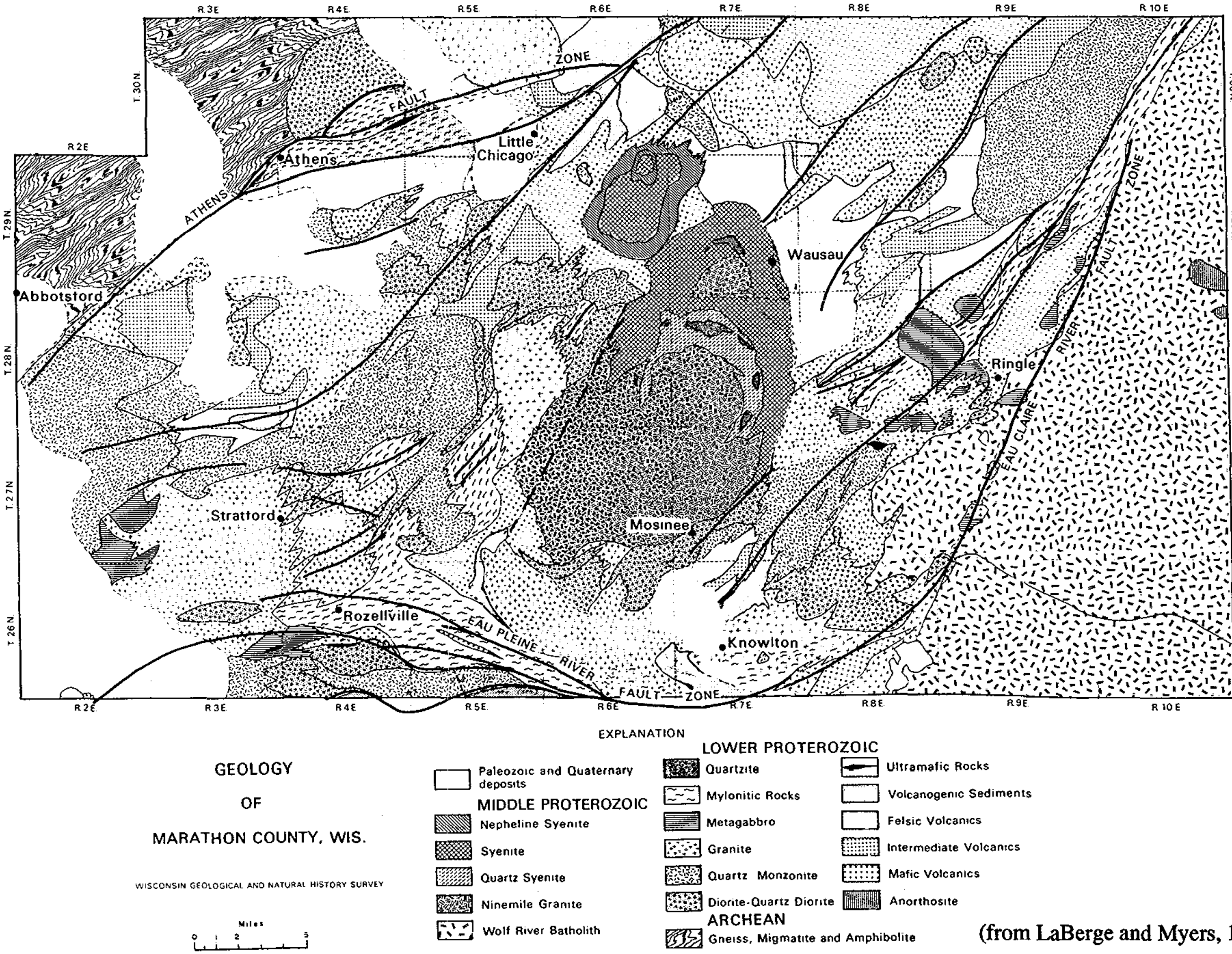
Prior Guidebook Reference: None

Stop 4-03: Wausau syenite at Employers' Insurance parking lot

Location: Large outcrop on north side of road north of parking lot, and small outcrop in triangular traffic island at NE corner of parking lot. NW 1/4 SE 1/4 Sec 27, T 29N., R 7E., Marathon County, Wisconsin

Stop Description: Coarse pink and brownish gray quartz syenite is well exposed in faces of an old quarry along the north side of the access road into the offices of Employers' Mutual Insurance Co A small trafic island to the east (NE corner of the lot) shows abundant xenoliths in the syenite. Two zircon fractions from this locality suggest an age of 1520 Ma. However, the more discordant of the two fractions falls on the chord defined by the Nine-Mile granite (Stop 4-05), suggesting that the apparently more concordant fraction could have been *contaminated by xenocrystic material.*

Prior Guidebook Reference: Myers (1984b).



(from LaBerge and Myers, 1983)

Summary geologic map of Marathon County showing major lithic units and cataclastic zones.

STOP #6

TITLE: *Contaminated Amphibole Quartz Syenite - Wausau Pluton*

LOCATION: Old quarry behind Employers' Mutual Insurance Company offices, NW/4, SE/4, Sec. 27, T 29 N, R 7 E; Wausau West 7.5' Quadrangle

AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: April, 1984

DESCRIPTION:

Coarse pink and brownish gray amphibole quartz syenite is well exposed in relatively fresh faces of an old quarry along a road leading into the offices of Employers' Mutual Insurance Company. Four facies were recognized: (1) brownish gray quartz-bearing syenite, (2) coarse, dark gray amphibole syenite, (3) pink quartz syenite with abundant volcanic xenoliths, and (4) medium-grained pinkish brown to brownish gray amphibole quartz syenite with magnetite segregations. (See Table 3). The pink syenites have a distinctly higher Fe^{3+}/Fe^{2+} ratio than the gray syenites Magnetite sheets and irregular masses occur in the medium-grained syenite along the road on the east side of the outcrop. The magnetite-bearing quartz syenite forms a large, crescentic aeromagnetic anomaly on the map by Henderson, Tyson, and Page, (1963). The anomaly is concentric and concordant with the structure of the Wausau pluton.

The concentric structure of this pluton is accentuated by the occurrence just north of here on the tree-covered hillside of numerous, large quartzite xenoliths. Unlike the Rib Mountain quartzite xenolith, this mass comprises many smaller quartzite blocks. Orientation of xenoliths here and elsewhere in the Wausau pluton is concentric and nearly vertical - a factor strongly suggesting subvolcanic emplacement with successive collapse and intrusion of magma into concentric fracture systems of the caldera rim. The xenoliths at this location are quite unlike those anywhere else in the Wausau pluton: they consist almost entirely of felsic volcanics showing virtually no pre-intrusion metamorphism. (See Figure 20).

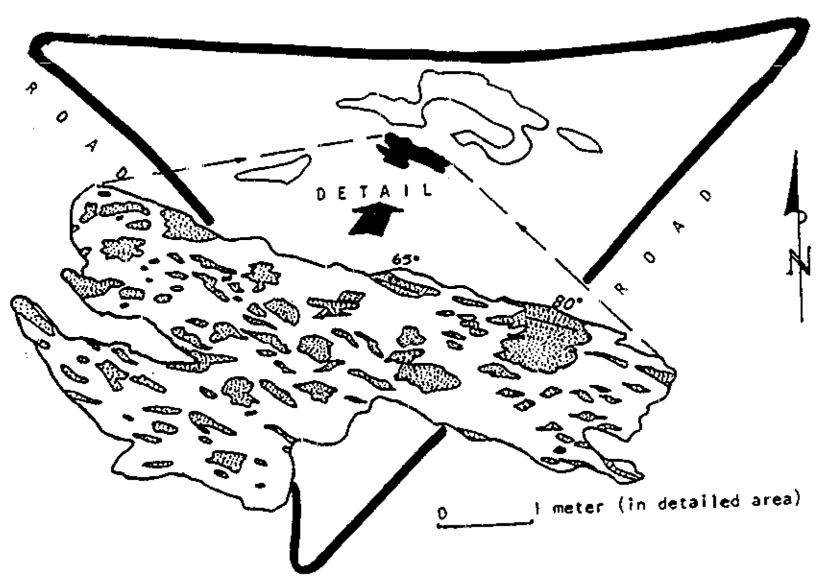


Figure 20-- Felsic volcanic xenoliths (dotted) in flow-lineated amphibole quartz syenite.

Bulk chemical compositions of the four principal quartz syenite facies from Employers' Mutual Insurance Company Quarry.

	EW-3 (WEST)	EW-5 (EAST)	NSI (SOUTH)	SEI (NORTH)
Description →	Brownish-gray	Coarse, dark gray	Pink syenite, with volcanic xenoliths	Medium-grained syenite
SiO_2	63.05	63.55	63.90	64.10
TiO_2	0.78	0.54	0.47	0.48
Al_2O_3	12.60	15.16	14.14	15.17
Fe_2O_3	1.91	1.25	5.42	4.58
FeO	7.72	3.48	1.32	1.44
MnO	0.34	0.16	0.14	0.12
MgO	0.41	0.16	0.45	0.09
CaO	2.66	1.72	1.35	1.50
Na_2O	4.80	5.52	6.32	5.17
K_2O	4.22	5.67	6.34	5.57
H_2O	0.76	0.42	0.56	0.26
P_2O_5	0.22	0.06	0.05	0.06
CO_2	0.28	1.92	0.62	0.09
BaO	0.094	0.066	0.024	0.036
ZrO_2	0.222	0.114	0.062	0.071
Rb ppm	154	118	80	80
Sr ppm	78	83	67	42

In comparison with Nockolds' (1954) average syenite composition (see Table), these quartz syenites are richer in SiO_2 and total iron and poor in alkalies and lime. Their Rb and Sr contents are also low compared to other similar rocks.

* From Sood, Myers, and Berlin, 1980, p. 21

Stop 4-04: Rotten granite quarry in Ninemile granite.

Location: Roehl Granite Co. quarry, Wisconsin Highway 107, SW 1/4 SW 1/4 Sec. 6, T 27N., R.6E., Marathon County, Wisconsin.

Stop Description: The Ninemile granite occupies the center part of the Wausau syenite complex. It is commonly assumed to be related to he syenite complex, although it is more silicic and occupies much more than the core of the complex. U-Pb data from three zircon fractions of this granite yield an age of 1502 ± 05 Ma (Van Schmus, unpublished). Discussion item: is the Ninemile granite an integral part of the Wausau complex or is it a precursor to Wolf River magmatism?

Prior Guidebook Reference: See LaBerge et al. (1986b) for description of a nearby locality.

Stop 4-05: Penokean Granite at Cherokee (optional)

Location: Outcrop on south side of County Road N, west of intersection with County Road F; North edge NE 1/4 NE 1/4 Sec. 23, T 28N., R 2E., Marathon County, Wisconsin.

Stop Description: This granite is a felsic member of the Penokean plutonic complex in Marathon County and has been dated by U-Pb (zircon) at 1853 ± 21 Ma (Van Schmus, unpublished data; Sims et al., 1989). It is one of several granitic Penokean plutons in the region that include the Wein granite (1857 ± 19 Ma) and the Little Rose granite (undated).

Prior Guidebook Reference: None

Stop 4-06: Archean gneiss east of Marshfield (optional)

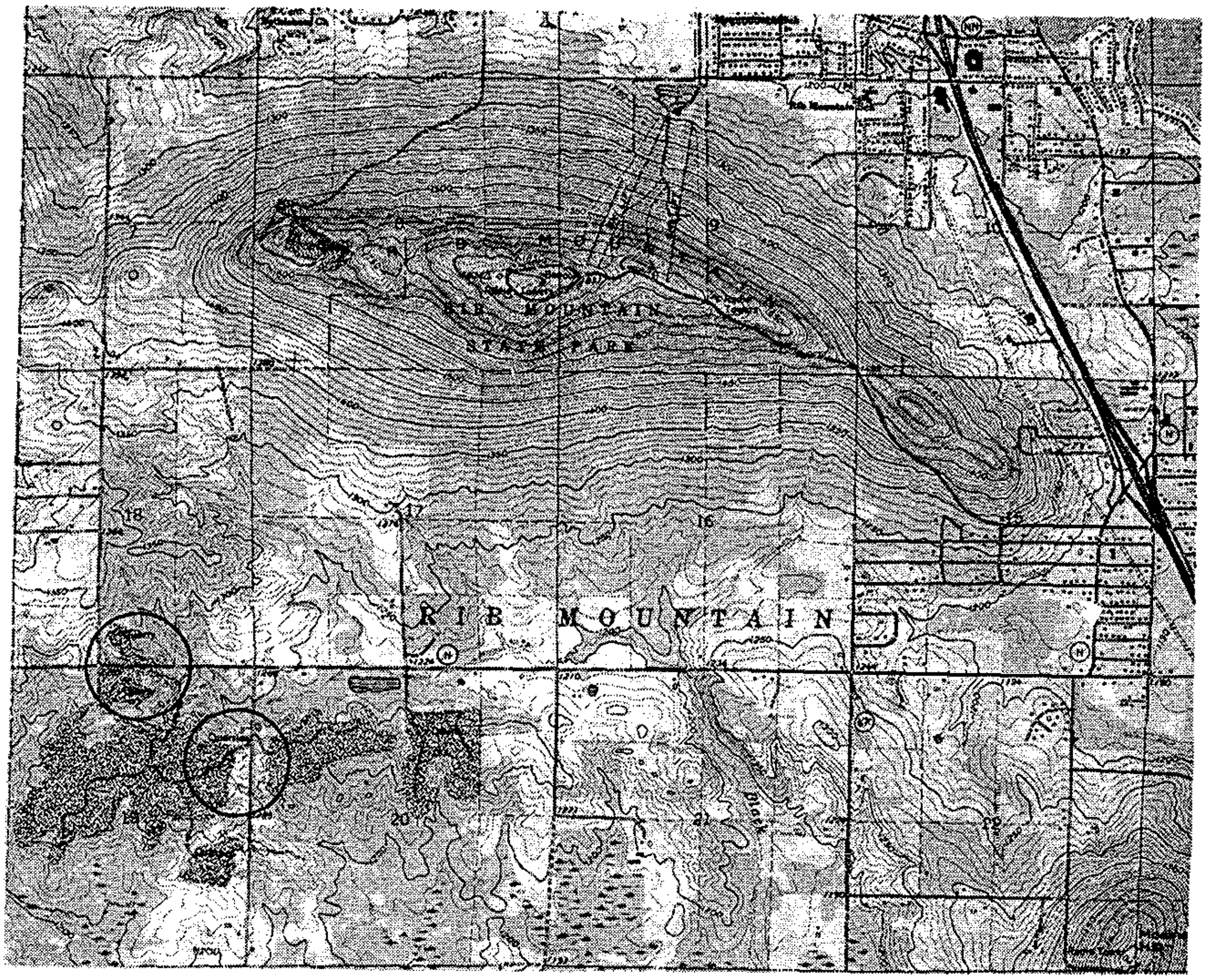
Location: Outcrops on north side of Little Eau Pleine River (Squaw Creek), center, SW 1/4 Sec. 31, T 26N., R 4E., Marathon County, Wisconsin

Stop Description: A large domain containing abundant Archean crust, commonly referred to as the Marshfield terrane, lies to the south of the Eau Pleine shear zone in west central Wisconsin. It consists of migmatitic gneisses of felsic to intermediate composition, with mafic members to the west, north of Eau Claire. Van Schmus (Sims et al., 1989; unpublished data) has analysed 16 multi-grain zircon fractions from this locality; the results do not define a simple discordia, but the more concordant fractions have Pb-Pb ages ranging from 2750 to 2850 Ma. The age of the protolith is estimated at 2900 Ma.

Prior Guidebook Reference: LaBerge (1980)

STOP 6

Title: County Highway N--Grus (rotten granite) Pits in Ninemile Pluton.



Location: South side of County Highway N, about 4 mi (6.5 km) west of U. S. Highway 51. Northern part of Sec. 19, T.28N., R.7E., Marathon County, on the Wausau West 7.5-minute quadrangle.

Authors: G. L. LaBerge, W. N. Mode and J. W. Attig, (1986), modified from Falster, A. U., and Myers, P. E., 1984.

Description: Grus ("rotten granite") is widely developed in a zone around the perimeter of the Ninemile pluton in central Marathon County (LaBerge and Myers, 1983). Like grus developed in the Wolf River Batholith, it appears to be restricted to margins of the pluton. Operating pits in the area indicate that grus occurs to depths of more than 100 ft (30 m) (Figure 1). The cause(s) and age of the disaggregation of granite to produce grus

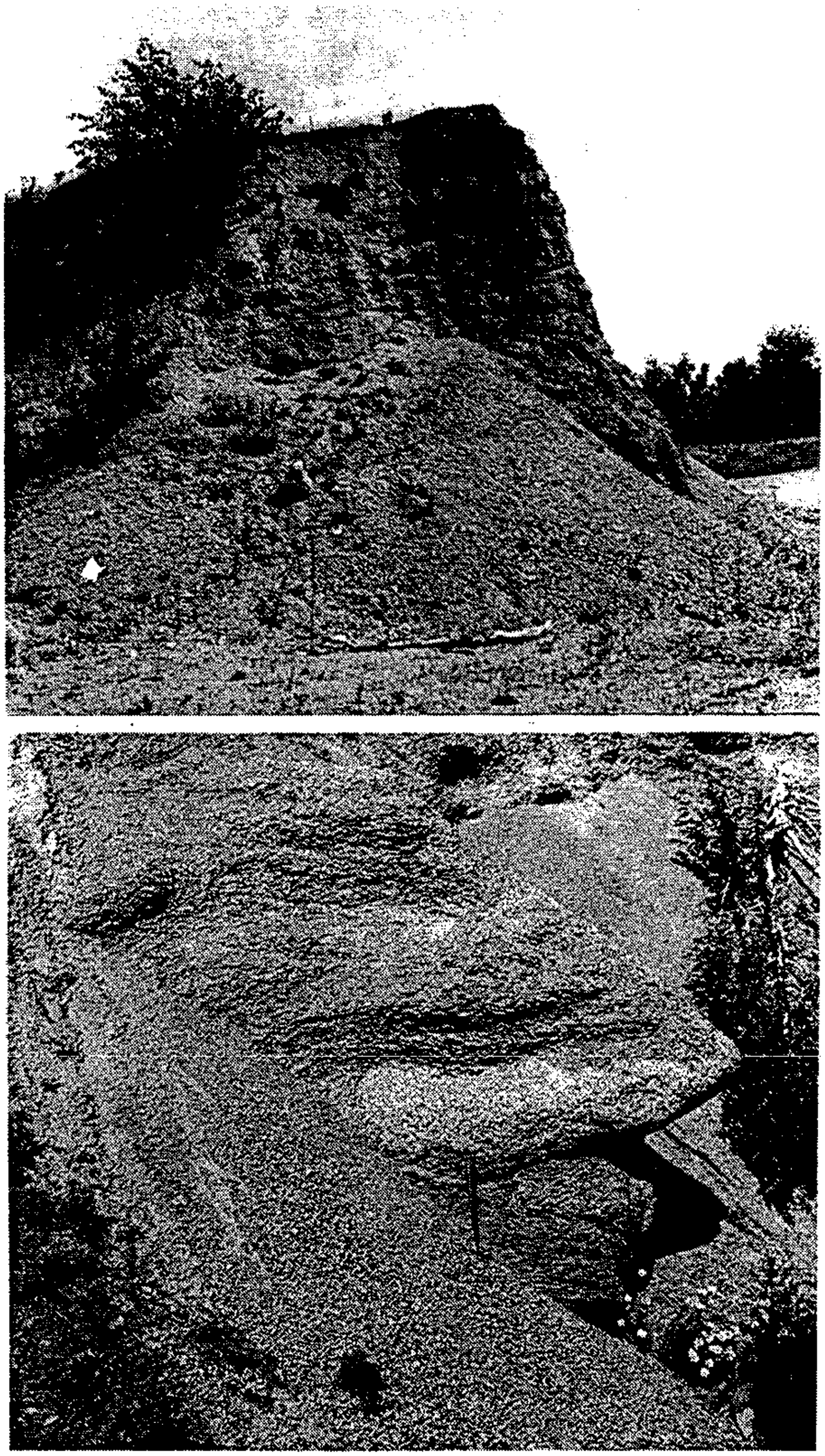


Figure 1. Grus pits in Ninemile pluton showing control from intersection of joints in upper photo and exfoliation in lower photo.

are problemmatical. If the grus is pre-Pleistocene, then the occurrence of glacial deposits in this area and farther south, requires that continental ice sheets must have moved over the grus without completely eroding all of it. This could have been accomplished if the grus were frozen or located near the ice margin where little erosion occurs. If the grus was developed after glaciation, how could it form in only several hundred thousand years? In the absence of abundant Pleistocene gravel deposits of commercial quality, grus is extensively used for road metal and fill in central Wisconsin.

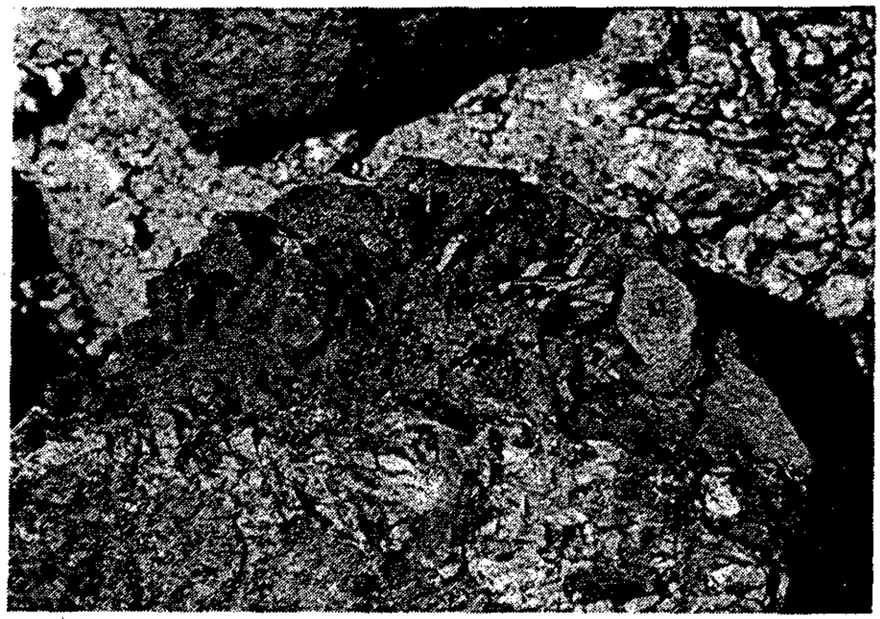


Figure 2. Microcline (m) and quartz (q) crystals in a "pocket" in pegmatite in the Ninemile pluton. Largest microcline crystals are 3 cm long.

The Ninemile pluton is an epizonal body emplaced at shallow depths (probably less than 2.5 mi (4 km)) into the core of the Rib Mountain pluton and into older (Early Proterozoic) metamorphic rocks. Pegmatite bodies are common and widespread within the pluton. More than 800 pegmatite bodies have been examined and described by Falster (1986). They occur as 1) small schlieren-like masses, 2) zoned dikes with miarolitic cavities, 3) simple, poorly zoned bodies with vugs in the intermediate zone, and 4) late stage bodies showing selective etching and crystallization of accessory minerals. Crystal lined (miarolitic) cavities average about 15 cm in maximum dimension, although pockets up to 4.5 X 1.2 X 1 m have been found. The main minerals (crystals) found in the cavities are microcline, smoky quartz, and albite; however, many varieties of silicates, oxides, sulfides, sulfosalts, and carbonates have been described (Falster, 1982). Smoky quartz crystals several inches (3 to 6 cm) long are relatively common (Figure 2), and crystals more than 10 in (25 cr) long are known. Many of the crystals were broken by shock effects during rupture of the cavities caused by boiling of water-rich fluids from which the pegmatites formed. (For more detailed discussion of the mineralogy and genesis of the pegmatites, see Falster, 1986; and Myers and others, 1984.)

REFERENCES CITED:

Falster, A. U., 1982, The Wausau Pluton: The Mineralogical Record.

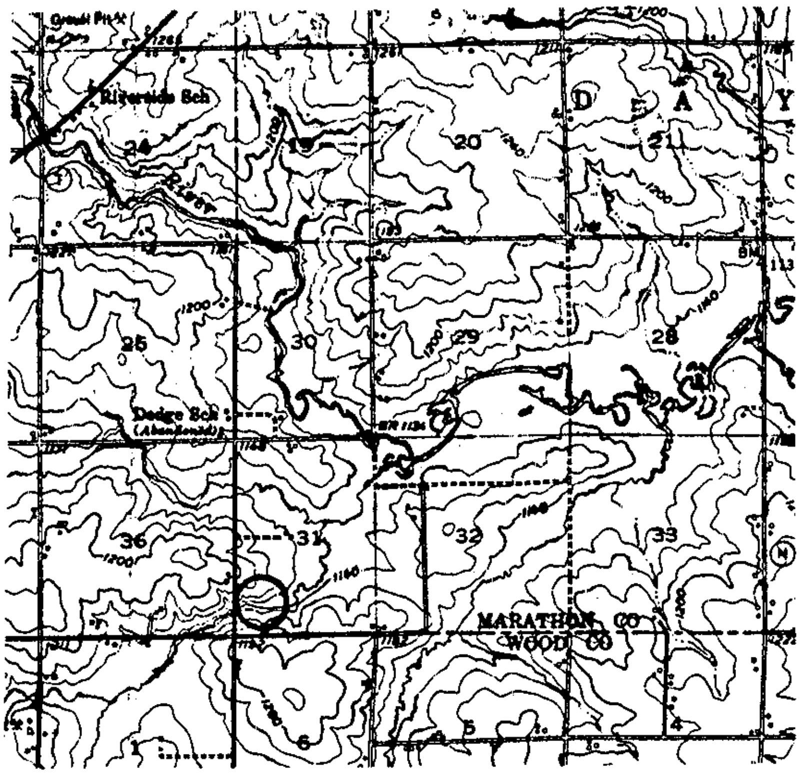
Falster, A. U., 1986, Minerals in Pegmatites of the Wausau Complex, Wisconsin, Abstract: 32nd Annual Institute on Lake Superior Geology, Wisconsin Rapids, WI.

LaBerge, G. L., and Myers, P. E., 1983, The Precambrian geology of Marathon county, Wisconsin: Wisconsin Geological and Natural History Survey Info. Circular 45, 88 p.

Myers, P. E., Sood, M. K., Berlin, L. A., and Falster, A. U., 1984, The Wausau Syenite complex, central Wisconsin: Guide Book, Field Trip 3, 30th Annual Institute on Lake Superior Geology, Wausau, Wisconsin, 58 p.

Title: Little Eau Pleine River - Gneiss.

Location: N½, SW¼, Sec. 31, T.26N., R.4E. Marathon County, Marshfield 15 minute quadrangle. (Get permission from Norbert Kolbeck, Rt. 2, Auburndale, WI, Box 148; Phone 715-384-8798.)



Author: Gene L. LaBerge

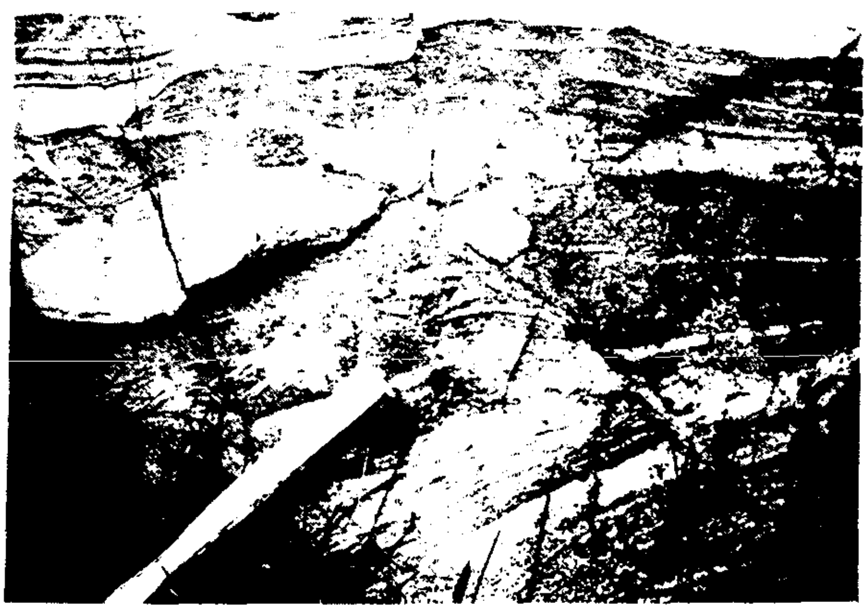
Description: Isolated blocks of high grade metamorphic rocks are present in rocks more typically metamorphosed to greenschist facies. This exposure represents a small block of gneiss and migmatite bounded on the north by a zone several hundred feet wide of ferruginous, sheared(?) quartz. Across the valley to the south the rocks are non-foliated granites and quartz monzonites that extend at least several miles south into Wood County. Other high grade metamorphic blocks include an amphibolite (metagabbro?) mass at the junction of Wis. Hwy. 97 and CTH-T in contact with a relatively unmetamorphosed ultramafic rock. The major rock type in the area is a prominently foliated quartz diorite.

This exposure is a small block (lens?) of high grade gneiss of approximately granodiorite composition. Some migmatite is present at the western end of the exposure. Small scale folds are relatively common in the gneiss with near horizontal fold axes. This is in contrast to the near vertical fold axes in low grade metasedimentary rocks about 3 miles northeast of here. Thus, it is anomalous in metamorphic grade and structurally anomalous with its surroundings.

Significance: An arcuate zone of extremely complex geology extends along the southern boundary of Marathon County. The zone consists of a wide variety of rock types, including volcanic, plutonic, sedimentary and metamorphic rocks with no apparent pattern. Most of the rocks have a prominent foliation and lineation. Rocks of very different metamorphic grade are in contact with one another, such as greenschist facies volcanics and sediments in contact with gneisses and amphibolites. Several ultramafic bodies (probably dunites) are present in the zone. Both shallow and vertical fold axes are present, along with a pervasive cataclasis (and local recrystallization) in plutonic rocks.

The mixture of lithologies and disparate metamorphic grade in a broad zone of complex structure suggests tectonic mixing of the various rock types. The area is suggestive of a megamelange, with a relatively deep level in the structure exposed along the southern part of Marathon County.

Van Schmus and Anderson (1977) dated migmatitic gneisses west of Pittsville 27 km south of this locality) at more than 2800 m.y. The gneisses may be the basement on which the Middle Precambrian volcanics were deposited. However, the structural complexity along the southern edge of Marathon County indicates a large-scale fault contact between the two terranes.



Migmatitic gneiss characteristic of the high-grade rocks exposed along the southern edge of Marathon County.

References:

Van Schmus, W. R., and Anderson, J. L., 1977, Gneiss and Migmatite of Archean Age in the Precambrian Basement of Central Wisconsin: Geology, vol. 5, pp. 43-48.

Stop 4-07: Penokean granite with Archean gneiss xenoliths, east of Marshfield

Location: Mathy-Overgaard quarry, NW 1/4 Sec. 2, T 25N., R.3E., Wood County, Wisconsin.

Stop Description: This quarry doesn't have much gneiss exposed as this guide is written, but the company is exposing new faces that should expose some good gneiss which we can examine during our visit. Gray tonalite cut by a later pink phase (granite) is always visible The Marshfield terrane can be characterized as Archean crust extensively intruded by Penokean plutons or as a Penokean plutonic complex with abundant Archean xenoliths and roof pendants, depending on the locality. Van Wyck (1995) obtained a 6-point U-Pb zircon age of 2904 ± 58 Ma with a lower intercept of 1749 ± 69 Ma for migmatitic banded gneiss Younger granite yielded a U-Pb zircon age 1749 Ma, indicating that this locality has both granitic rocks and metamorphic overprints associated with the 1760 Ma granite suite (Day 5)

Other Guidebook Reference: None; but see Van Wyck, 1995, p 248

Stop 4-08: Archean gneiss southwest of Pittsville (optional)

Location: Abandoned (and overgrown) quarry on west side of Turner Road, 0.75 miles south of County Highway B; Center, east edge, SE 1/4 Sec. 36, T.23N., R 2E., Wood County, Wisconsin.

Stop Description: Archean migmatitic felsic to intermediate gneiss are cut by metadiabase dike (south side) and an aphanitic (almost glassy) Penokean dike of dacitic composition. The dacitic dike yielded a U-Pb age of 1837 ± 9 Ma (Sims et al., 1989; Van Schmus, unpublished data)

Prior Guidebook Reference: LaBerge (1986), Stop 14.

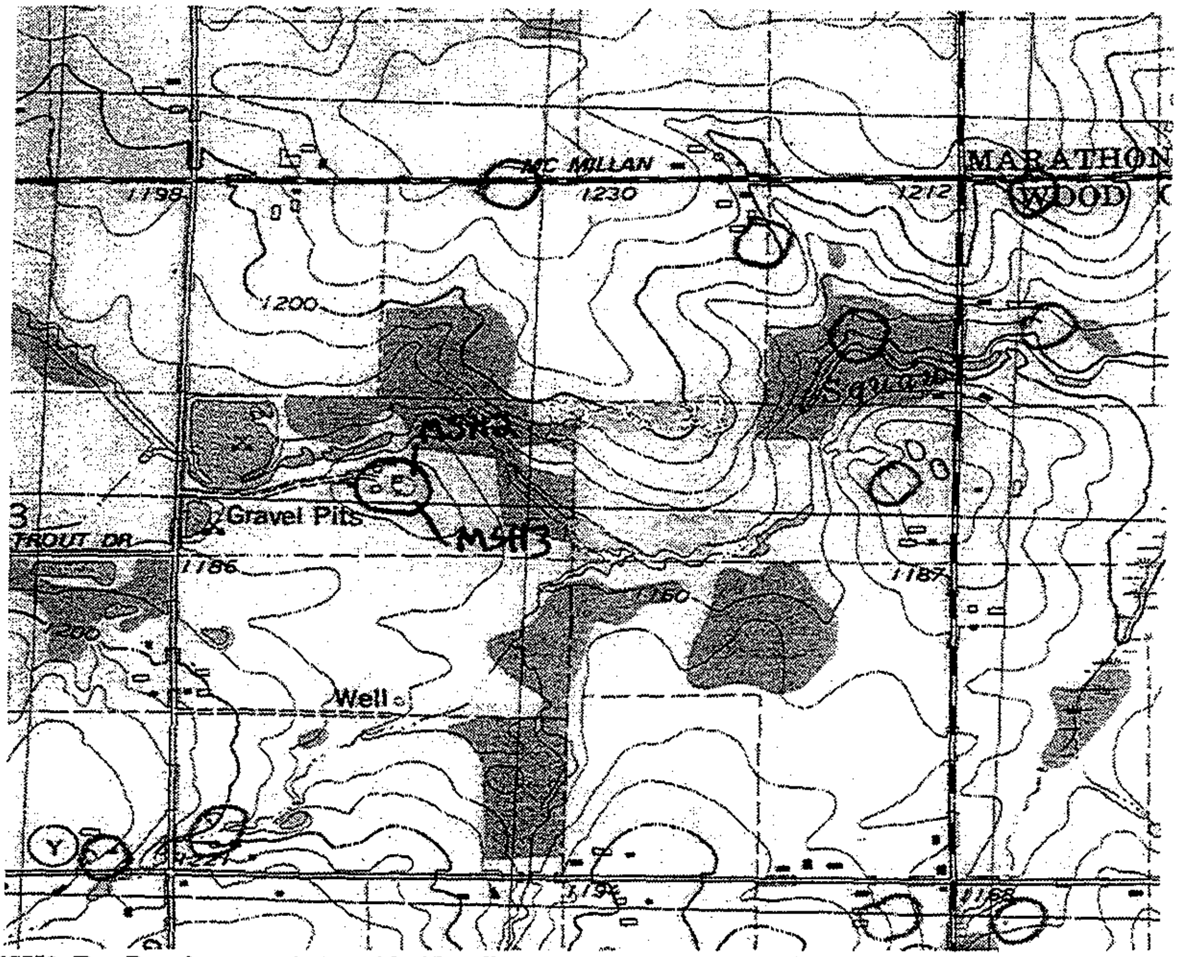
Stop 4-09: Penokean tonalite and amphibolite, Tork Quarry

Location: Abandoned (and overgrown) quarry on west side of Turner Road, 0 75 miles south of County Highway B; Center, east edge, SE 1/4 Sec 36, T.23N., R.2E., Wood County, Wisconsin

Stop Description: Gray tonalite and granodiorite are the main rock type; these are cut by light gray tonalite and amphibolite dikes. Fine-grained gray tonalite dikes and amphibolite dikes cut the main rock Van Wyck (1995) obtained a U-Pb age of 1826 ± 2 Ma for a tonalite dike and a Pb-Pb evaporation age of 1851 ± 7 Ma for the host granodiorite A metamorphic" zircon yielded 1753 ± 5 Ma and titanite from the amphibolite yielded and age of 1722 ± 7 Ma.

Prior Guidebook Reference: None, but see Van Wyck (1995), p 255.

(from Van Wyck, 1985)



MSH2 (Pre-Penokean gneiss) and MSH3 (Post-Penokean alkali-granite)
Location: Active crushed stone quarry off Stadt Road, approximately 2.5 miles east of Marshfield NW1/4 Sec 2, T 25 N, R 3 E. Hewitt 7.5 minute topographic quadrangle.

Description: Both samples were collected in working pit east of the main office and repair sheds. A coarse grained, grey unfoliated granite (MSH3) was exposed in the southwestern quarter. Close to the surface this unit develops a pinkish red color, due to weathering of the feldspars, but in places freshly blasted unaltered material was available for collection. This same granitic phase is seen as float blocks, frost heaves and in outcrop towards and beyond Marshfield, and can be identified on aeromagnetic maps over a wider area still. MSH2 is composed of subequal quartz, plagioclase, and microcline, biotite (mostly altered to chlorite), sphene, and zircon. Secondary epidote, trace carbonate. Interstital micrographic intergrowths are present and the rock is undeformed.
MSH2 was part of a banded gneiss package, prominantly exposed in the northern portion of the quarry. Several lithologies were present, and the sample was collected from a light colored migmatitic tonalite gneiss. The sample was composed of predominantly plagioclase and quartz, with minor biotite, zoisite, sphene and zircon.
As active quarry was occurring during sampling, it is likely that the shape and size of the pit will change over time.

WISCONSIN RAPIDS - STEVENS POINT AREA

Exposures along and near the Wisconsin River between Wisconsin Rapids and Stevens Point are among the best in central Wisconsin for deciphering the Precambrian tectonic history of central Wisconsin. The rocks in the area have been mapped in detail and have been the subject of radiometric, structural, and metamorphic studies (Weidman, 1907; Anderson, 1972; Van Schmus and Anderson, 1977; Maass, 1977; Van Schmus, 1980, 1984; Maass and others, 1980).

Major lithologic units in the area, from oldest to youngest are: (1) banded tonalitic gneiss with interlayered amphibolite, and similar 2,800 Ma paleosomes of migmatite, (2) diorite gneiss, (3) 1840 Ma foliated tonalite, (4) a series of approximately 1825 Ma lineated tonalites, (5) amphibolite dikes that represent metamorphosed basalt or diabase, and (6) a diabase dike. Anderson (1972; written communication, 1985) reports the presence of a massive tonalite series that is petrographically similar to the lineated tonalite series; its precise age relative to the rocks listed above has not been established. Van Schmus (1984) has obtained an age of 1890 Ma on a foliated tonalite in the area; possible interpretations of this age will be presented in the Discussion section.

Deformation during the Penokean orogeny (c.a. 1900 to 1800 Ma) produced steeply plunging isoclinal F_1, tight F_2, and open F_3 sets of folds (Maass and others, 1980). All three sets of folds are coaxial, and their axes are parallel to penetrative mineral lineation present in all rocks except massive tonalites and diabase dikes. Amphibolite-facies metamorphism affected all Archean and lower Proterozoic rocks of the area, with the possible exception of massive tonalites. Massive tonalites are thoroughly recrystallized (J.L. Anderson, written communication, 1985), but grade of metamorphism of these rocks has not been established. Undeformed and virtually unmetamorphosed diabase is thought to be related to approximately 1100 Ma Keweenawan igneous activity. The formation of leucosomes in migmatite has previously been interpreted to have occurred at 2800 Ma (Van Schmus and Anderson, 1977; Maass and others, 1980), but field relationships presented in this report suggest that the leucosomes may have formed during the Penokean orogeny.

Discussion

There are a number of important questions regarding the tectonic history of this area that remain to be resolved. Among these are the age and source of granite neosomes in migmatite, the age of isoclinal folds in migmatite, the age of intrusion of foliated tonalites and massive tonalites, and the source and evolutionary history of Penokean magmas. It has been assumed that all of the banded gneisses of the area are approximately 2800 Ma. This is based on overall similarity to dated banded gneiss paleosomes of migmatite, but this correlation has not been confirmed by radiometric methods. It has not been determined whether banded gneisses formed from sedimentary, volcanic, or plutonic rocks.

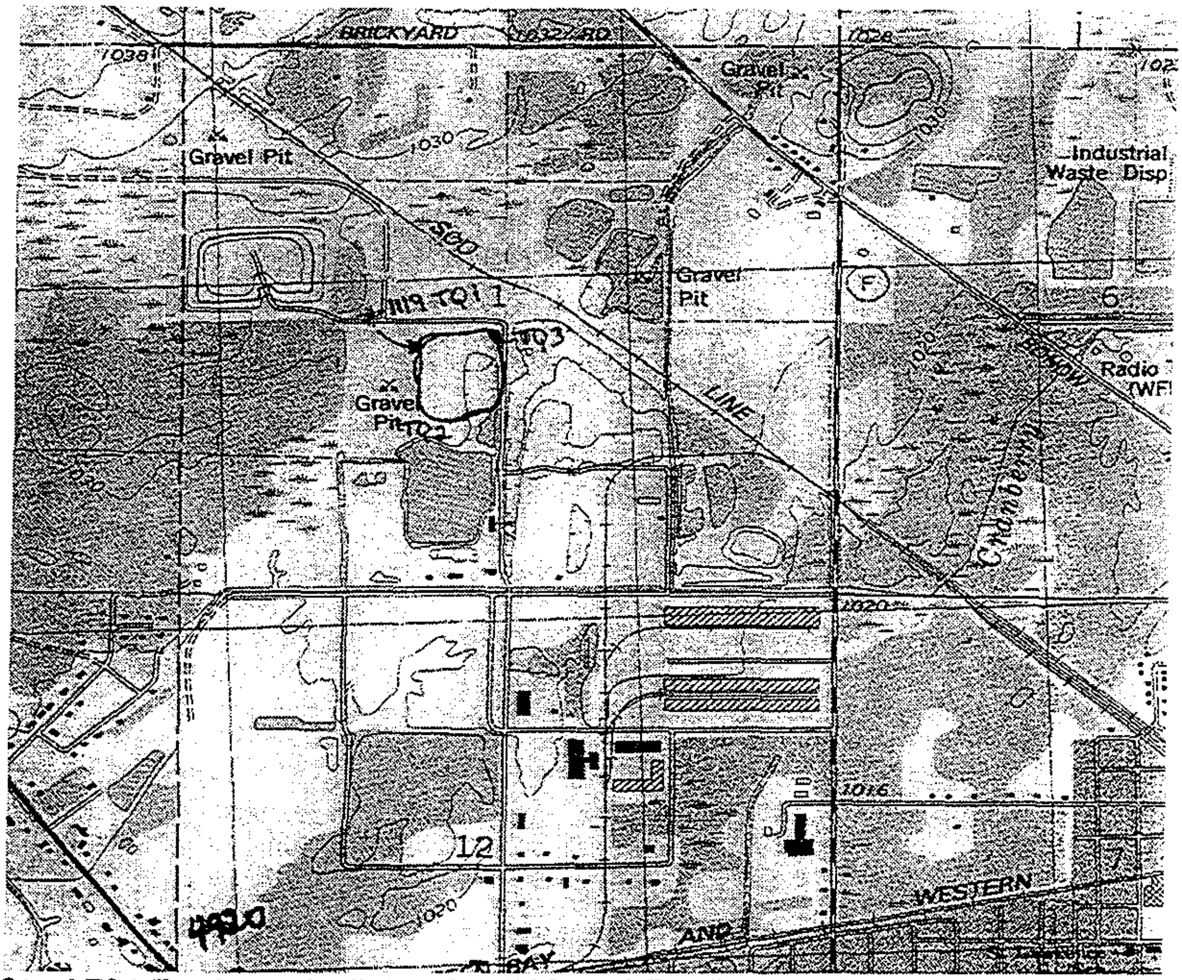
The two most likely possibilities for the age of formation of granite neosomes in migmatite are: (1) 2800 Ma, or (2) during the Penokean orogeny, shortly before intrusion of 1824 ± 25 Ma lineated tonalite. Based on field relationships, formation of neosomes during the Penokean orogeny is favored. The style of isoclinal folding in migmatite is convoluted, suggesting that isoclinal folding occurred at the time of formation of the neosomes. At present, only a single phase of isoclinal folding is recognized in migmatite. It is interpreted to have occurred during the Penokean orogeny.

A U-Pb zircon age of 1892 ± 9 Ma has been obtained for foliated tonalite at Conants Rapids (Van Schmus, 1984), and an age of 1842 ± 10 Ma has been obtained for foliated tonalite at Biron Dam (Van Schmus, 1980). These two rocks are structurally and petrographically similar, and they both contain small inclusions of diorite gneiss. Maass and others (1980) concluded that the foliated tonalites of the area were intruded during the late stages of isoclinal folding. This conclusion was based in part on parallelism of foliation in the two rock types, on poorer development of foliation in foliated tonalite relative to foliation in banded gneiss, and on the presence of tightly folded veins of foliated tonalite in isoclinally folded banded gneiss. In addition, foliated tonalite contains xenoliths of banded gneiss that were isoclinally folded before becoming xenoliths. These xenoliths have been tightly folded after incorporation in foliated tonalite, and the axial plane of this tight folding is parallel to the axial plane of isoclinal folding in adjacent banded gneiss. It is unlikely that foliated tonalite at Conants Rapids and Biron Dam were both intruded during the late stages of isoclinal folding if their crystallization ages differ by approximately 50 Ma, and thus either the structural model is incorrect or the radiometric ages are not the ages of crystallization.

The foliated tonalites in the area can be divided into two geochemical suites (J.L. Anderson, written communication, 1985), suggesting that the age differences may be real. Unfortunately, foliated tonalite from Conants Rapids is not among the samples chemically analyzed. Geochemical modelling of the foliated tonalites suggests that some have assimilated as much as 7 percent Archean gneiss (J.L. Anderson, written communication, 1985). If foliated tonalite at Conants Rapids has assimilated a larger proportion of Archean gneiss than foliated tonalite at Biron Dam the age difference between the two may be the result of inheritance of Archean zircon rather than difference in crystallization age. Banded gneiss is present at Conants Rapids but is not exposed at Biron Dam. To date, inherited Archean zircon has not been recognized in either of the two dated samples of foliated tonalite (W.R. Van Schmus, oral communication, 1985).

Penetratively foliated and lineated amphibolite dikes at Biron Dam and Conants Rapids that are intrusive into foliated tonalites and lineated tonalites are among the youngest known Penokean intrusive rocks in Wisconsin. These dikes have been metamorphosed to amphibolite facies, thus demonstrating that amphibolite facies metamorphism occurred during the latest stages of the Penokean orogeny (Maass and others, 1985). Recrystallized massive tonalites that petrographically resemble the lineated tonalites are probably the youngest Penokean rocks in the area.

(from Van Wyck, 1985)



TQ1and TQ4 (Penokean calc-alkalic suite), TQ5 and 6 (Post-Penokean dikes)
Location: Excellent exposure is seen in the Tork quarry located in an industrial park on the outskirts of Wisconsin Rapids NE1/4 SW1/4, Sec 1, T 22 N, R 5 E. Wisconsin Rapids North 7.5 minute quadrangle.

Description: Weakly foliated tonalite and granodiorite (TQ1 and 4) are intruded numerous mafic dikes. The dikes have in turn been metamorphosed to amphibolite grade (TQ5 and 6).
TQ1 is a well foliated, coarse grained granodiorite composed of quartz, plagioclase, microcline, biotite and hornblende, sphene, apatite and zircon Also present, but not sampled, are dark well foliated tonalites and there is probably a continum between foliated granodiorites and tonalites, showing various cross-cutting relations.
TQ4 is a medium grained, light grey colored tonalite that intrudes into lithologies equivalent to TQ1 Contacts are chilled TQ4 is composed of plagioclase, quartz, minor microcline, biotite, sphene, apatite and zircon The is also secondary epidote and zoisite.
TQ5 is a foliated amphibolite. The excellent exposures afforded by the quarry allow one to demonstrate unequivocally that these are cross-cutting mafic dikes, intrusive into the tonalite Following emplacement the dikes and the tonalites, have been metamorphosed to amphibolite grade The similarity in lithologies, cross-cutting relations, the close proximity, and identical trends of the dikes allow correlation to the well studied locality of Biron Dam (Maass et al, 1980)

Stop 4-10: Penokean tonalite at Biron Dam

Location: Large area of outcrop on west side of Wisconsin River, downstream from dam; NE 1/4 NW 1/4 Sec 34, T.23N., R.6E., Wood County, Wisconsin.

Stop Description: Foliated tonalite, lineated tonalite, amphibolite dikes, granitic aplite dikes and veins, and a diabase dike crop out downstream from a dam across the Wisconsin River near the town of Biron. All rocks with the exception of the diabase are interpreted as having been intruded, deformed, and metamorphosed during the Penokean orogeny. Foliated tonalite yields a U-Pb zircon age of 1842 ± 10 Ma (Van Schmus, 1980; unpublished data).

Prior Guidebook Reference: Maass (1986), Stop 1, p 4-7.

Stop 4-11: Archean gneiss at Linwood Township Quarry

Location: Quarry on south side of County Hghway PP, 0 9 km west of the intersection of Highway PP and Highway P; NW 1/4 SE 1/4 Sec. 15, T.23N., R.7E., Portage County, Wisconsin

Stop Description: Archean migmatitic gneiss and a Penokean lineated tonalite dike are exposed in the quarry. The neosomes in the gneiss are granitic in composition and are thought to represent lit-par-lit injection into tonalitic paleosome during Archean (?) anatexis. U-Pb analyses of zircons from the migmatite yield an age of 2780 ± 26 Ma (Van Schmus and Anderson, 1977; unpublished data). The lineated tonalite is part of a suite found at other outcrops in the region and has a U-Pb age of 1831 ± 7 ma (Van Schmus, 1980; unpublished data).

Prior Guidebook Reference: Maass (1986), Stop 3, p 11-13

Stop 4-12: Archean gneiss and Penokean tonalite at Conant's Rapids

Location: Outcrop at west end of dam and down stream from Consolidated Paper Company dam on west side of Wisconsin River; NW 1/4 SE 1/4 Sec. 8, T.23N., R 8E., Portage County, Wisconsin.

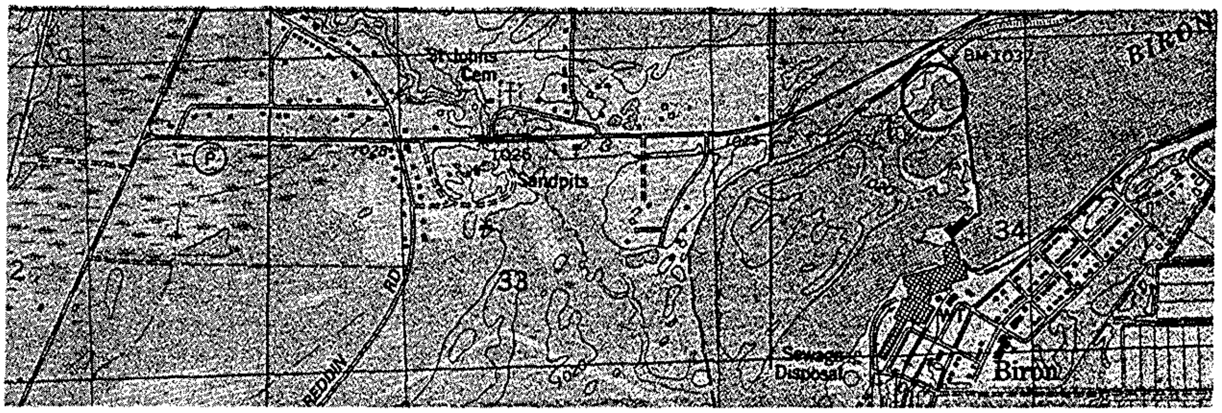
Stop Description: From youngest to oldest the main rock types at Conants Rapids are Archean tonalitic banded gneiss, Penokean foliated tonalite, lineated tonalite dikes, amphibolite dikes, and granitic aplites and pegmatites. Some of the latter may be offshoots of the nearby Wolf River batholith.

Prior Guidebook Reference: Maass (1986), Stop 2, p. 8-13

Stop 1

Title: Biron Dam - Penokean intrusive rocks

Location: County Highway P, west side of the Wisconsin River, downstream of a dam near the town of Biron. NE¼, NW¼, sec. 34, T. 23 N., R. 6 E. (Wisconsin Rapids North 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Foliated tonalite, lineated tonalite, amphibolite dikes, granitic aplite dikes and veins, and a diabase dike crop out downstream of a dam across the Wisconsin River near the town of Biron. The diabase dike is exposed a short distance to the south of the area shown in Figure 1. All rocks, with the exception of diabase, are interpreted to have been intruded, deformed, and metamorphosed during the Penokean orogeny (Maass and others, 1980).

Foliated tonalite from this locality yields a U-Pb zircon age of 1842 ± 10 Ma (Van Schmus, 1980). Foliated tonalite contains numerous small inclusions of diorite gneiss. Amphibolite dikes are interpreted to be younger than lineated tonalite based upon crosscutting field relationships at Conants Rapids (Stop 2). In the northwestern quarter of Figure 1 a schlieren-free amphibolite dike is transected by a schlieren-bearing amphibolite dike. Schlieren in amphibolite represent xenoliths of foliated tonalite. In only a few cases are unaltered cores of foliated tonalite preserved in schlieren. Heat from the magmatic protolith of amphibolite was sufficient to locally cause melting of foliated tonalite, producing rheomorphic veins of foliated tonalite into amphibolite in the northwest quarter of Figure 1. Two generations of deformed and metamorphosed granitic aplite dikes and veins are present at Biron Dam; the first generation is truncated by amphibolite dikes and the second crosscuts these same dikes. The diabase dike has to be the youngest rock because it is undeformed and virtually unaltered.

Foliated tonalite consists of medium-grained prophyroclasts of oligoclase-andesine in a fine-grained matrix of oligoclase-andesine, quartz, biotite, hornblende, microcline, epidote, chlorite, sphene, apatite, allanite, zircon, and an opaque mineral. Uniformly fine-grained lineated tonalite contains the same minerals as foliated tonalite. Photomicrographs and textural

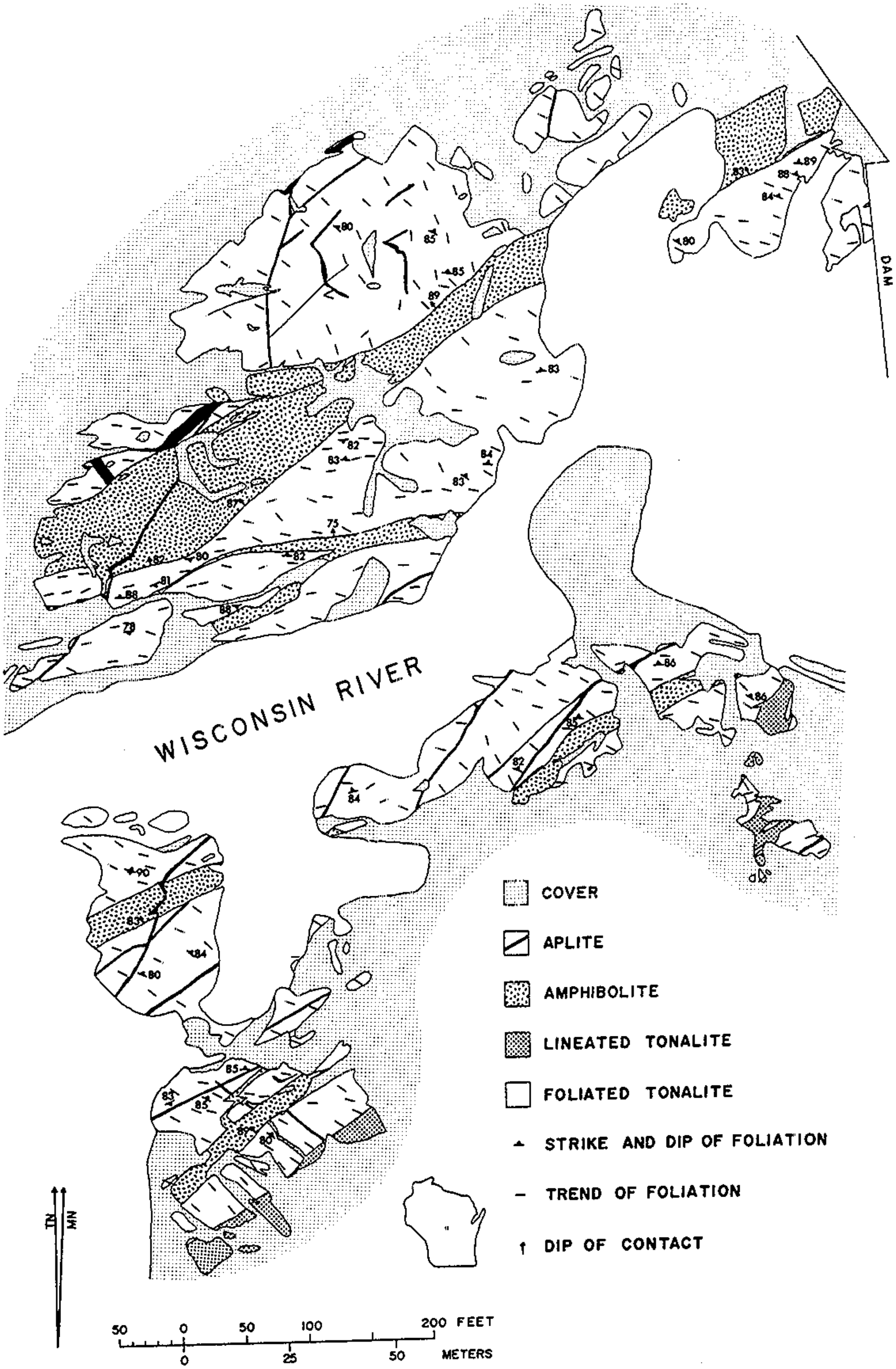


Figure 1. Geologic map of Biron Dam.

descriptions of foliated and lineated tonalites are presented in Maass and others (1980). Amphibolite dikes are mainly composed of plagioclase, dark-green amphibole, biotite, and opaque minerals. Quartz, epidote, sphene, apatite, allanite, and zircon are present in very small to trace quanitites. Electron microprobe analysis of an amphibolite dike indicates that hornblende coexists with andesine and labradorite (fig. 2). Representative analyses of amphibole and plagioclase are presented in Table 1. Granitic aplite dikes contain oligoclase, microcline, and quartz, and minor to trace amounts of biotite, muscovite, chlorite, allanite, zircon, and an opaque mineral. Fine-grained diabase with subophitic texture is made up of labradorite, augite, opaque minerals, olivine, biotite, serpentine, an unidentified amphibole, and an unidentified bright-green fibrous mineral. Minor alteration of diabase may have occurred during cooling rather than during a later metamorphic event.

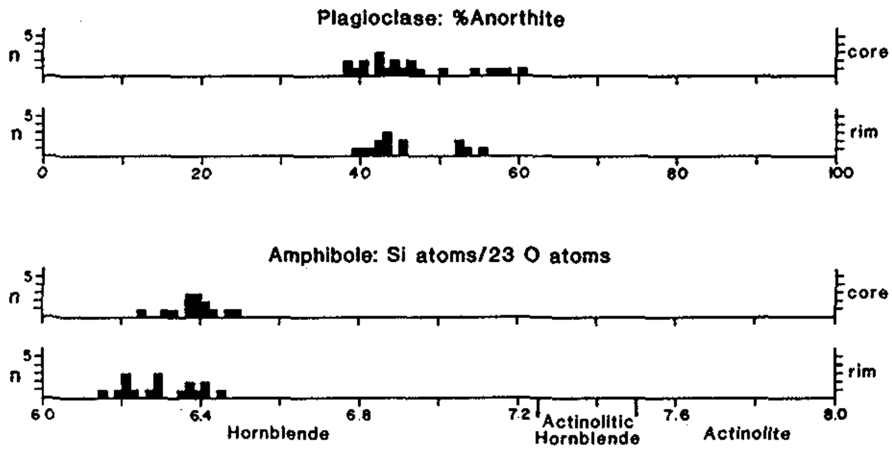


Figure 2. Electron microprobe analyses of coexisting amphibole and plagioclase in an amphibolite dike that crosscuts foliated tonalite. Sample BD-1. For this diagram, and all others like it, n is the number of analyzed points yielding the specified composition.

Isoclinal folding has produced penetrative axial-planar foliation in foliated tonalite (Maass and others, 1980). Foliation has subsequently been affected by tight F_2 and open F_3 folding. The axis of open folding, oriented N 70° E 80°, is parallel to penetrative mineral lineation present in all rocks except diabase (Maass and others, 1980).

The exposure at Biron Dam provides an excellent example of contrasting mechanical competencies of differing rock types. Northeast trending amphibolite dikes in foliated tonalite truncate northwest striking regional foliation in foliated tonalite (fig. 1). The amphibolite dikes possess a penetrative foliation that is parallel to the margins of the dikes, rather than parallel to regional foliation. The stresses responsible for open folding of foliated tonalite caused significant shearing in amphibolite dikes parallel to their margins. A granitic aplite dike in the southwestern quarter of Figure 1 is only slightly deformed where it is surrounded by foliated tonalite, but it is tightly folded where it crosses an amphibolite dike.

Table 1. Microprobe mineral compositions (sample references in text).

Sample:	BD-1	CR-19	CR-17	ATH-5	ATH-8	RR-4	ATH-15	March-6		March-8		March-5
Plagioclase												
SiO_2	57.17	63.24	58.42	60.45	60.47	45.79	67.56	66.69		60.18		68.10
Al_2O_3	26.85	22.98	26.05	24.85	24.86	33.86	19.78	20.87		24.54		20.14
Na_2O	6.69	9.05	7.22	8.29	8.29	1.14	11.45	11.17		8.10		10.92
CaO	9.20	4.78	8.10	6.01	5.75	18.62	0.86	0.74		6.80		1.17
K_2O	0.16	0.27	0.15	0.19	0.11	0.00	0.13	0.16		0.04		0.06
Total	100.08	100.32	99.94	99.70	99.48	99.41	99.78	99.63		99.67		100.39
%An	43.2	22.6	38.3	28.6	27.7	90.0	4.0	3.5		31.7		5.6
Amphibole												
SiO_2	42.70	43.69	47.15	40.99	42.15	42.71	51.02	46.55	51.49	47.70	50.56	47.52
Al_2O_3	14.77	10.25	9.28	15.89	15.11	15.57	2.19	9.71	3.78	7.08	3.84	8.99
Na_2O	1.45	1.31	0.78	1.22	1.61	1.11	0.48	0.84	0.34	0.94	0.65	0.92
CaO	11.84	11.82	12.49	12.19	12.20	11.93	12.27	12.61	13.00	12.18	12.25	12.00
K_2O	1.16	1.02	0.61	1.03	0.39	0.50	0.14	0.67	0.15	0.57	0.25	0.62
*FeO	16.86	19.42	17.37	19.55	17.10	17.21	15.27	14.03	13.48	18.55	17.64	17.14
MgO	9.19.	9.33	10.96	6.83	8.61	7.68	13.73	12.48	14.42	9.94	11.45	10.54
TiO_2	0.47	0.69	0.39	0.48	0.33	0.39	0.79	0.38	0.07	0.35	0.09	0.64
MnO	0.19	0.23	0.23	0.24	0.20	0.19	0.36	0.24	0.23	0.20	0.18	0.25
Total	98.63	97.78	99.27	98.42	97.70	97.28	96.24	97.51	96.98	97.50	96.92	98.60
Si/23 Oxygen	6.34	6.63	6.91	6.18	6.31	6.39	7.60	6.86	7.54	7.16	7.55	6.99

*Total Fe as FeO

Stop 4-13: Penokean tonalite north of Dancy (optional)

Location: Low railroad cut, south of bridge over Wisconsin River (to west of Wisconsin Highway 34), SW 1/4 NE 1/4 Sec. 29, T. 26N., R. 7E., Marathon County, Wisconsin.

Stop Description: Medium grained tonalite typical of intermediate composition plutons associated with the Penokean igneous complex in the Wausau area. U-Pb analyses of four fractions of zircon from this locality yield an age of 1860 ± 7 Ma (Sims et al., 1989; Van Schmus, unpublished).

Prior Guidebook Reference: None

Stop 4-14: Penokean tonalite near Mosinee

Location: Mathy-Overgaard (Cisler) quarry, NW 1/4 Sec. 5, T.26N., R.7E., Marathon County, Wisconsin.

Stop Description: Typical Penokean tonalite with mafic xenoliths and a late (Keweenawan?) diabase dike are well exposed within this active quarry.

Prior Guidebook Reference: None

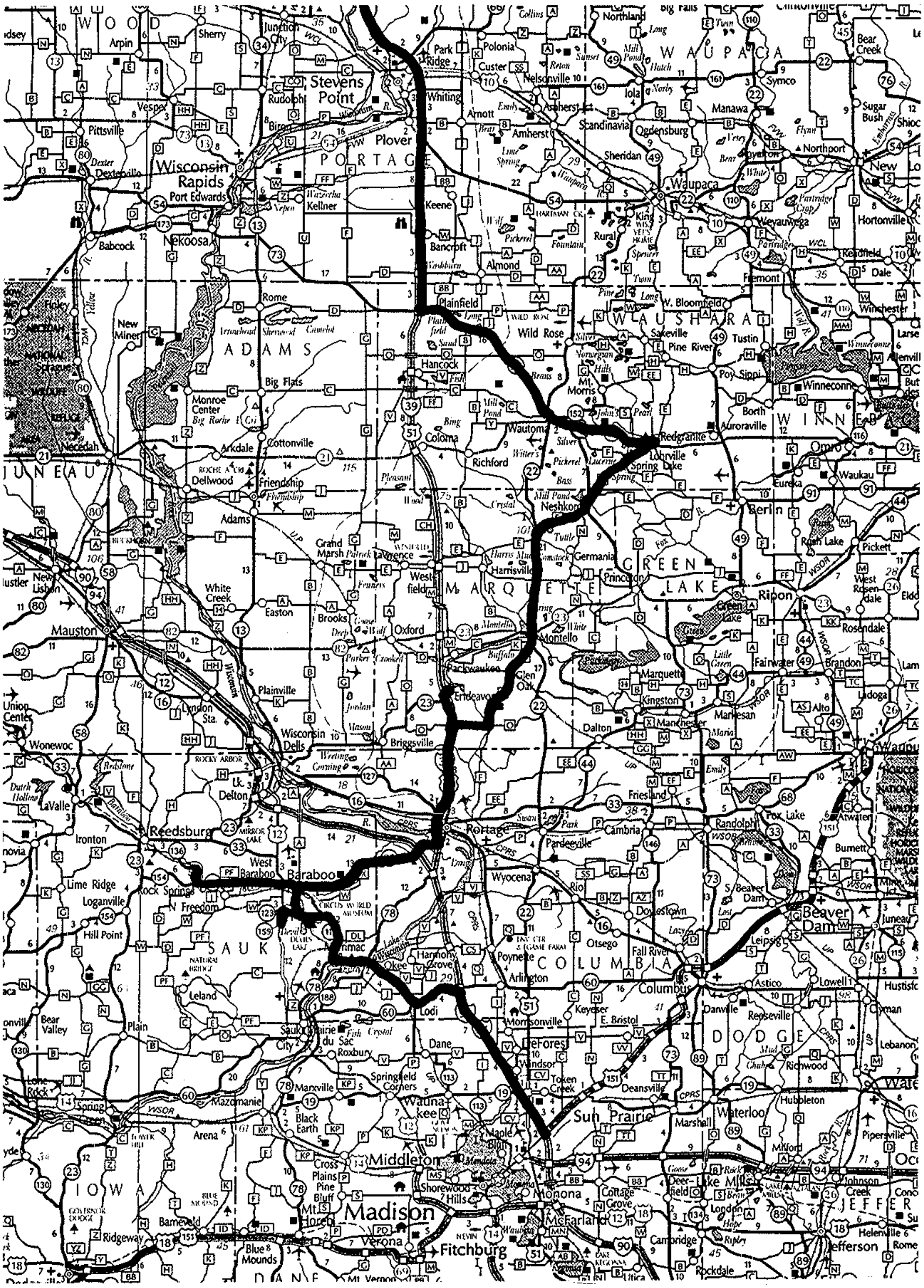
Field Trip Day 5
Wausau to Madison

Objectives:

The main objectives of the day are (1) to examine post-Penokean granite and rhyolite of the 1760 Ma igneous suite in south-central Wisconsin, (2) to examine quartzite of the Baraboo interval, (3) to present evidence for ca. 1630 Ma metamorphism and deformation, and (4) to discuss their regional implications.

Itinerary:

0800	Depart Wausau/Mosinee Holiday Inn
	Stop 5-01: Granite at Red Granite
	Stop 5-02: Granite at Flynn's Quarry, Spring Lake
	Stop 5-03: Granite at Montello
	Stop 5-04: Rhyolite at Observatory Hill (optional)
	Stop 5-05: Rhyolite at Endeavor
1200	Lunch
	Stop 5-06: Quartzite at Baraboo: Van Hise Rock
	Stop 5-07: Quartzite at Baraboo: East Bluff of Devil's Gorge
	Stop 5-08: Quartzite at Baraboo: Skillet Creek
1800	Arrive Madison
	Dinner
	Evening activities


WOOD
PORTAGE
WAUPACA
ADAMS
WAUSHARA
JUNEAU
MARQUETTE
GREEN LAKE
WINNEBAGO
SAUK
COLUMBIA
DODGE
IOWA
DANE
Stevens Point
Plover
Wisconsin Rapids
Port Edwards
Nekoosa
Babcock
Pittsville
Arpin
Sherry
Junction City
Rudolph
Biron
Vesper
Dexterville
Kellner
Whiting
Park Ridge
Custer
Polonia
Nelsonville
Amherst
Arnott
Amherst Jct.
Scandinavia
Iola
Northland
Manawa
Ogdensburg
Symco
Sugar Bush
Northport
New London
Sheridan
Waupaca
King
Rural
Weyauwega
Hortonville
Keene
Bancroft
Almond
Fremont
Dale
Plainfield
Wild Rose
W. Bloomfield
Tustin
Saxeville
Pine River
Poy Sippi
Winchester
Winneconne
Mt. Morris
Hancock
Redgranite
Lohrville
Spring Lake
Wautoma
Coloma
Richford
Neshkoro
Auroraville
Berlin
Eureka
Omro
Waukau
Rome
New Miner
Big Flats
Monroe Center
Arkdale
Cottonville
Friendship
Adams
Dellwood
Necedah
Finley
Grand Marsh
Lawrence
Westfield
Harrisville
Germania
Princeton
Ripon
Rush Lake
Pickett
White Creek
Easton
Brooks
Oxford
Montello
Kingston
Marquette
Green Lake
Fairwater
Brandon
Rosendale
Mauston
New Lisbon
Lyndon Sta.
Plainville
Packwaukee
Endeavor
Glen Oak
Dalton
Manchester
Markesan
Alto
Wisconsin Dells
Briggsville
Lk. Delton
Union Center
Wonewoc
LaValle
Ironton
Reedsburg
West Baraboo
Baraboo
Portage
Pardeeville
Cambria
Friesland
Randolph
Fox Lake
Beaver Dam
Waupun
Lime Ridge
Loganville
Rock Springs
N Freedom
Hill Point
Merrimac
Wyocena
Rio
Doylestown
Otsego
Fall River
Columbus
Leipsig
Lowell
Juneau
Leland
Plain
Bear Valley
Poynette
Arlington
Harmony Grove
Okee
Lodi
Keyeser
E. Bristol
Morrisonville
Danville
Reeseville
Sauk City
Prairie du Sac
Roxbury
Dane
DeForest
Windsor
Token Creek
Deansville
Marshall
Waterloo
Hubbleton
Lone Rock
Spring Green
Mazomanie
Arena
Black Earth
Marxville
Springfield Corners
Waunakee
Sun Prairie
Middleton
Cross Plains
Pine Bluff
Mt. Horeb
Madison
Shorewood Hills
Maple Bluff
Monona
McFarland
Cottage Grove
Deer-Lake Mills
London
Cambridge
Rockdale
Jefferson
Johnson Creek
Helenville
Verona
Fitchburg
Blue Mounds
Barneveld
Ridgeway
Mt. Vernon
Utica
Rome
Milford
Pipersville
Astico
Richwood
Burnett
Atwater

Stop 5-01: 1760 Ma granite at Redgranite

Location: City park on south side of old quarry, northeast of Wisconsin Highway 21 in the town of Redgranite; SE 1/4 SW 1/4 Sec. 8, T 18N., R 12E., Waushara County, Wisconsin

Stop Description: Granonphyric red granite similar to that at stops 5-02 and 5-03 is exposed around an abandoned quarry in the town of Redgranite. This quarry was operated from 1889 through 1931, with most of the product being used for paving blocks or crused stone

Other Guidebook Reference: Skirius, 1982; Barnick, 1982; See also Smith et al. (1978), Stop 1, p. 32-46.

Stop 5-02: 1760 Ma granite at Flynn's Quarry, Spring Lake

Location: Outcrops around abandoned quarries southeast of County Highway N, midway between towns of Lohrville and Spring Lake; SW 1/4 SE 1/4 Sec. 13, T. 18N., R. 11E., Waushara County, Wisconsin

Stop Description: The main rock type is fine- to medium-grained red, granophyric granite with micropegmatitic and myrmeketic texture. Quartz and alkali feldspar compose 90 to 98 percent of the rock. A granite porphyry dike is exposed in a smaller quarry to the northeast of the large quarry. This dike may be related to rhyolitic volcanic rocks of the region. Van Schmus (1978) obtained a U-Pb age of 1758 ± 10 Ma for two fractions of zircons from the granite porphyry dike at this locality.

Prior Guidebook Reference: Smith et al. (1978), Stop 1, p. 32-46.

Stop 5-03: 1760 Ma granite at Montello

Location: Outcrop behind (north of) post office on Wisconsin Highway 23 in Montello; SE 1/4 NW 1/4 SW 1/4 Sec. 9, T. 15N., R. 10E., Marquette County, Wisconsin

Stop Description: The outcrop to be visited is one of many around the granite hill and abandoned quarry in town. This outcrop may be sampled, but do not use hammers on outcrops in the city park to west. The Montello granite is one of the suite of 1760 Ma granophyric granites in south-central Wisconsin and is coeval with 1760 Ma granites to the north. Van Schmus (1978) obtained a slightly discordant Pb-Pb age of 1757 ± 10 Ma for one fraction of zircons from this granite elsewhere in Montello. This granite was extensively quarried from 1880 to 1976; President Grant's sarcophagus in New York City is carved from Montello granite.

Prior Guidebook Reference: see Smith et al. (1978), p. 16 and Stop 1, p. 34

Eugene I. Smith[1]

STOP 1 - GRANITE AND RELATED INTRUSIONS AT FLYNN'S QUARRY COUNTY PARK

Location: All exposures at this stop are reached by an easy walk from the Parking area (Fig. 2).

Description:

Granite

Fine-to medium-grained red (granophyric) granite with micropegmatitic and myrmeketic texture is exposed in three quarries within the boundaries of Flynn's Quarry County Park (Fig. 2). Quartz and alkali feldspar compose 90 to 98 percent of the rock, with biotite (partially or wholly altered to chlorite), sphene, hornblende, muscovite and zircon as subordinate minerals. The granite for the most part is texturally homogeneous. Locally however, grain alignments and fine-grained bands (dikes?) are observed. The mineralogy and texture of the granite (especially the intergrowths of quartz and alkali feldspar) suggest that it is a shallow intrusion.

Granite Porphyry Dike

In the northeast quarry, the granite is cut by a 200 m wide east trending granite porphyry dike (strike east-west, dip 75° to the south). The dike rock is characterized by large (5 mm) alkali feldspar phenocrysts set in a fine-grained matrix of quartz, biotite and chlorite. The finely disseminated chlorite gives the matrix of the dike rock a green color, thus making it easily distinguishable from the red granite. The contact between granite and dike rock is clearly visible on a ledge on the north wall of the northeast quarry (Fig. 3). In detail, the contact bends in and out, suggesting some assimilation of granite during intrusion. Fragments (xenoliths) of granite are found within the dike near the contact; also feldspar phenocrysts are concentrated and weakly aligned in the granite porphyry dike at the contact.

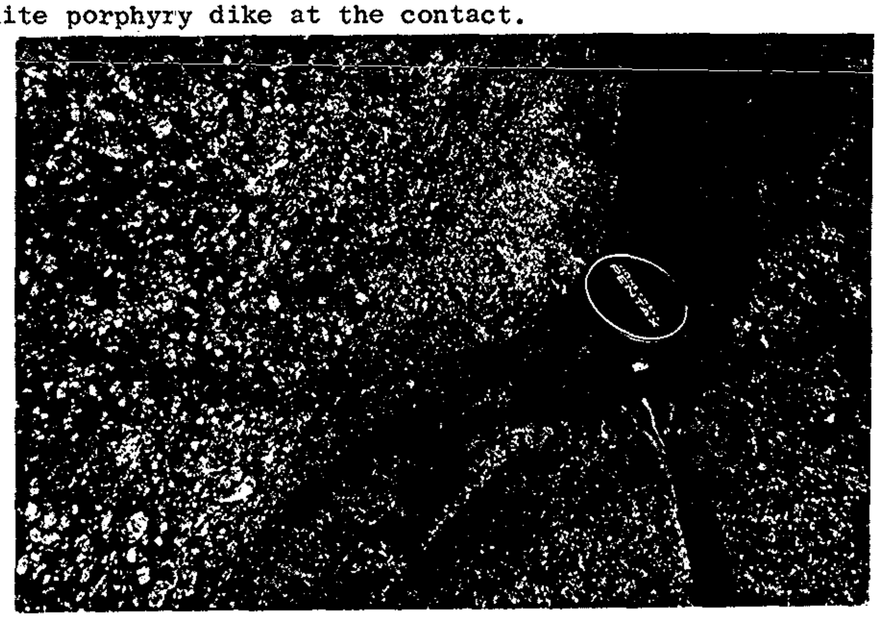


Figure 3. View of the contact between the granite porphyry dike and granite in Flynn's Quarry County Park (dashed line traces contact). Note that the feldspar phenocrysts are concentrated and weakly aligned in the dike rock near the contact.

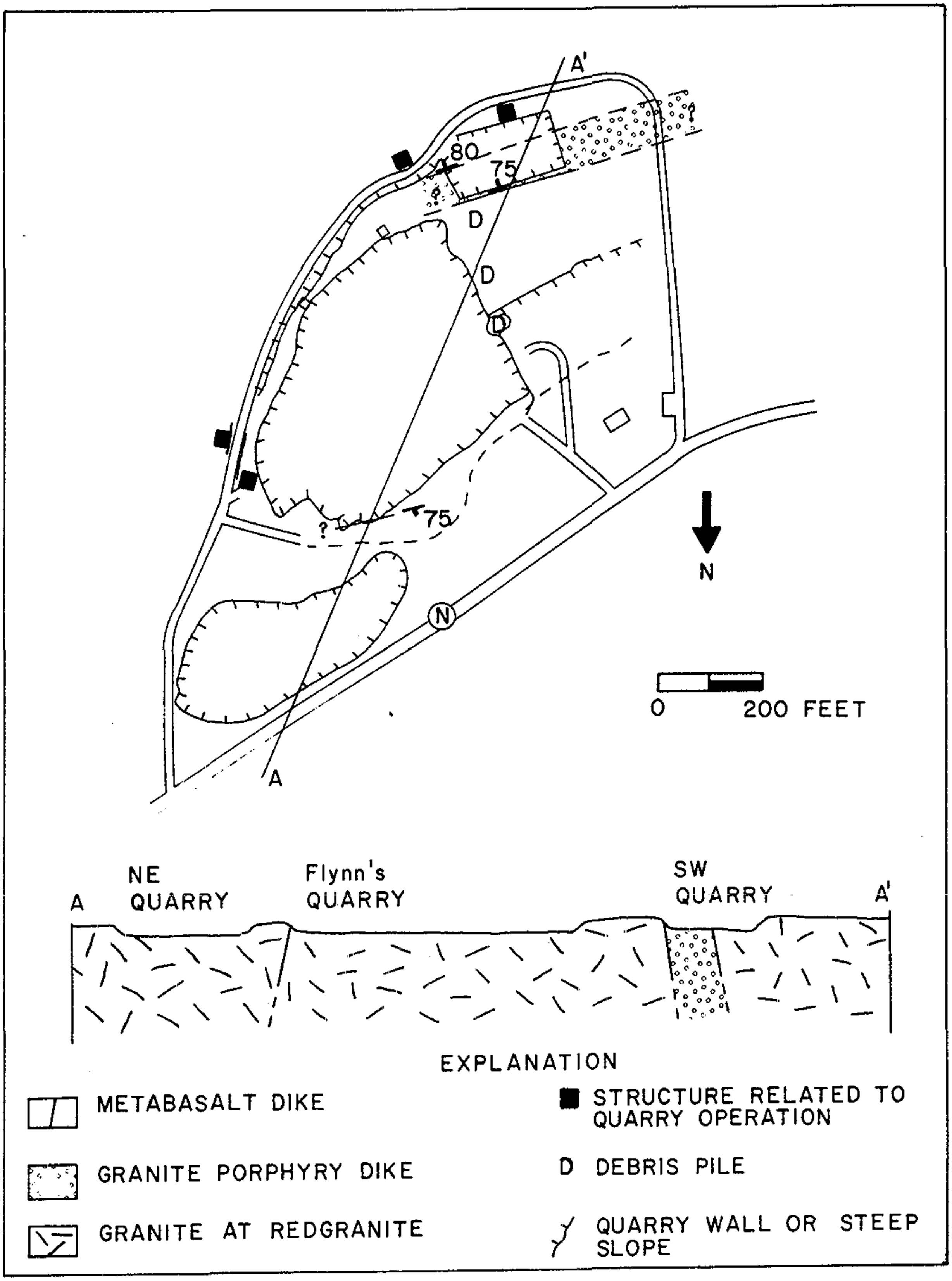


Figure 2. Pace and compass map of Flynn's Quarry County Park, Waushara County.

Chemically, the dike is a less differentiated phase of the granite. It is lower in SiO_2, and K_2O and higher in Al_2O_3, FeO + Fe_2O_3 and CaO when compared to the Flynn's Quarry granite (Table 1, analyses 18 and 31). In terms of trace elements the dike is higher in Ba, and has a lower Rb/Sr ratio than the granite.

Metabasalt Dike

On the north wall of the main quarry, the granite is cut by a thin (2 m wide) metabasalt dike striking N. 80 E. and dipping 70° to the south (Fig. 2). The dike rock is fine grained and has a distinctive green color on both weathered and fresh surfaces. In thin section, the metabasalt displays intergranular texture with laths of plagioclase enclosing mats of epidote, clinozoisite and iron oxide. The contact between the metabasalt and granite is clearly observed on a ledge just above water level (Fig. 4). Here lenses of granite are completely enclosed by stringers of metabasalt. Except for these lenses, no granite fragments were noticed within dike rock. These contact relationships suggest that the metabasalt intruded primarily by the dilation of country rock.

Comparison of Flynn's Quarry Granite to Granite in Nearby Areas:

Redgranite to Pine Bluff- Granites and Dikes

Granites similar in mineralogy and texture to that at Flynn's Quarry are exposed in discontinuous outcrops from the city of Redgranite to Pine Bluff (Fig. 5). Dikes of metabasalt trending east-west and approximately N. 45E. cut the granite in many localities. One of the most easily visited of these dikes forms a distinct ridge jutting into the quarry lake north of S.T.H. 22 in downtown Redgranite (just north of Griffs' Cafe). A coarse-grained diorite dike cuts granite in a small quarry in the N 1/2, Sec. 27, T.18 N. R. 11 E. (Fig. 5). The dike is about 5 m thick and trends N. 40 E. (dip vertical). In thin section, flow-aligned plagioclase laths surround clots of chlorite and epidote.

Montello Granite

Another granite similar in lithology to that at Flynn's Quarry and at Red Granite is located in the city of Montello (Buckley, 1898). There is also an exposure to the east of Montello in the SE 1/4, Sec. 9, T. 15 N., R. 10 E. This granite was extensively quarried from 1880 to 1976. President Grant's sarcophagus in New York City is carved from Montello Granite. The rock in the Montello quarry is a red granite composed of intergrown quartz and alkali feldspar crystals (myrmeketic and micropegmatitic textures are common) with chlorite, biotite, and euhedral zircon as accessory minerals. Attempts to date this rock by the fission-track technique failed because an insufficient number of zircon grains were separated and most of the separated zircons were metamict. The Montello granite is cut by thin metabasalt dikes (plagioclase and sausserite as dominant minerals) which trend northeast, north-south and northwest. Quarry faces at Montello are commonly bounded by these dikes. The metabasalt dikes are closely sheared at their margins; several dikes are sheared throughout. The granite commonly shows a dark red bake zone extending 2 to 5 cm inward from the intrusive contacts, also small grains of pyrite are more common in granite near metabasalt than farther away from the granite-dike contacts.

Figure 4A. View of a thin metabasalt dike that cuts granite in Flynn's Quarry County Park. The dike in this view is 2 meters thick. The southern contact (left) dips about 10° to the north (dashed line). Granite (G) to the north of the dike appears as a window in the dike rock (D).

Figure 4B. Close-up of the contact between the metabasalt dike and granite. Basalt intruded granite along closely spaced joints.

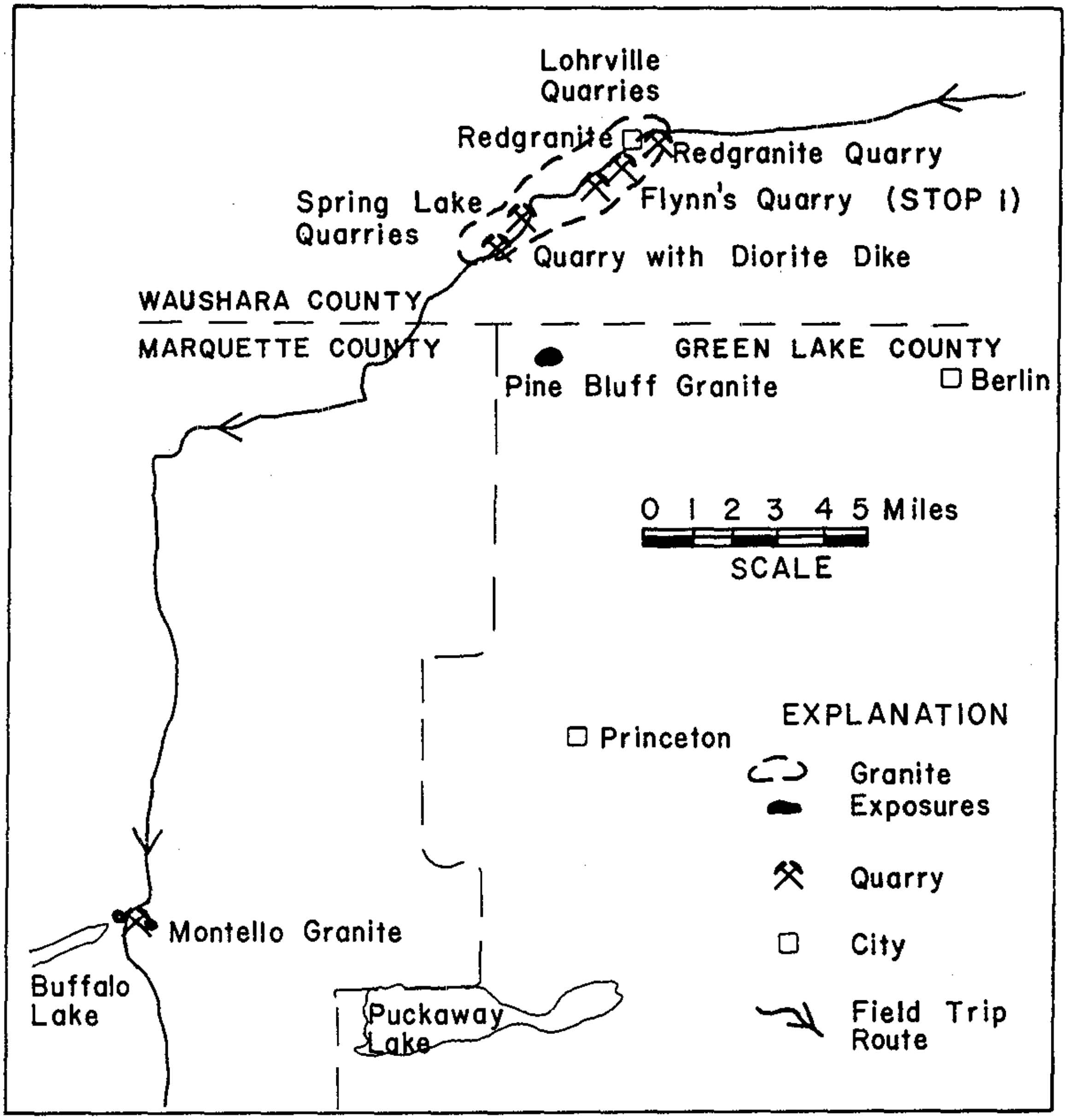


Figure 5. Detailed route map from Redgranite to Montello showing granite exposures and locations of important quarries.

Stop 5-04: 1760 Ma rhyolite at Observatory Hill

Location: Outcrops northeast of road, on southwest slope of Observatory Hill; SW 1/4 SW 1/4 Sec 8, T 14N., R 10E., Marquette County, Wisconsin

Stop Description: This locality is one of several examples of rhyolite in south-central Wisconsin (Smith et al., 1978) and demonstrates the varieties of felsic volcanism associated with the 1760 Ma granite-rhyolite suite in the region Van Schmus (1978) obtained a U-Pb age of 1755 ± 25 Ma from three fractions of zircons from this locality. Will be visited if time allows.

Other Guidebook Reference: Smith et al. (1978), Stop 2, p. 48-54

Stop 5-05: 1760 Ma rhyolite at Endeavor

Location: Outcrop and small quarry workings behind house at W5854 North Island Drive (Lou Torngren), Endeavor; South side SW 1/4 SE 1/4 Sec. 5, T 14N., R.9E., Marquette County, Wisconsin

Stop Description: Good examples of flow-banded quartz-porphyry rhyolite (probably ignimbrite) occur in several outcrops in the village of Endeavor The southeastern half of Marquette County is underlain by rhyolitic volcanic rocks that represent a major pyoclastic province Similar rhyolites underlie quartzite of the Baraboo syncline (next stop)

Prior Guidebook Reference: None

Stop 5-06: Quartzite at Baraboo: Van Hise Rock

Location: Van Hise Rock, Upper Narrows of the Baraboo River; NW 1/4 SW 1/4 Sec 28, T 12N R 5E, Sauk County, Wisconsin

Stop Description: Van Hise Rock has long been a "must" stop for geological field trips in the Baraboo area; it is particularly informative as an example of cleavage refraction and is dedicated to pioneer structural geologist C. R Van Hise. The Baraboo Quartzite overlies 1760 Ma rhyolites and was deformed, along with the underlying rhyolite basement, into a broad regional syncline This quartzite is one of several in the Wisconsin-Minnesota region that represent cratonic clastic sedimentation following erosion of the older Proterozoic basement There are no excat depositional ages from the Baraboo or related sequences, although outcrops near Waterloo, Wisconsin are cut by pegmatite dikes of Wolf River age. It has generally been presumed that the Baraboo quartzite was deposited prior to the 1630 Ma resetting of Rb-Sr systems in the underlying granite and rhyolite. Recent work by Holm et al (1998) using Ar-Ar methods has confirmed and extended this interpretation, so that depositional of these quartzites is constrained between 1760 Ma and 1630 Ma.

Prior Guidebook Reference: Dalziel and Dott (1970), p. 99 (Stop 2); Brown and Ostrom (1990)

STOP 2 - RHYOLITE AT OBSERVATORY HILL

Location:

Observatory Hill (Hobbs and Leith, 1907) is one of five porphyritic rhyolite inliers in south-central Wisconsin (others are at Endeavor, Taylor Farm, Utley and Berlin). The hill is formed by steeply dipping flows of quartz-and alkali feldspar-bearing rhyolite tuffs, cut by coarse-grained and fine-grained rhyolite dikes. Observatory Hill is surrounded by outcrops of Upper Cambrian sandstone and conglomerate (Fig. 7).

The traverse to the summit of Observatory Hill will follow an easy but sometimes indistinct trail. Please stay together during the climb. It is quite easy to become lost on the slopes surrounding Observatory Hill.

Description:

Stop 2A

The climb to the summit of Observatory Hill begins at exposures of Cambrian sandstone just to the east of the bend in Gillette Road (north side of road) (Fig. 7). The outcrop at this stop is about 300 m to the south of rhyolite outcrops on Observatory Hill and is composed of a friable reddish-brown quartz sandstone. No fragments of rhyolite are found here; they are quite common, however, in sandstone exposures closer to the rhyolite ledges.

Stop 2B

Walk from stop 2A to the northwest over the low rise to the first northeast trending valley (Fig. 7). Note the outcrops of Cambrian sandstone and conglomerate on the southeast side of the valley (Fig. 8). A conglomerate bed in this exposure is approximately 40 cm thick and contains rhyolite fragments lithologically similar to rhyolite cropping out 200 m to the north. The fragments within the conglomerate are rounded and reach 10 cm in size (Fig. 9). Occasionally, quartzite is found as small rounded pebbles in the conglomerate. The source of these clasts may be in the large area of quartzite to the northeast of Observatory Hill (Smith, 1978c) or from vein quartz within the rhyolite.

Figure 8. View of Cambrian sandstone outcrops at stop 2B on the south flank of Observatory Hill.

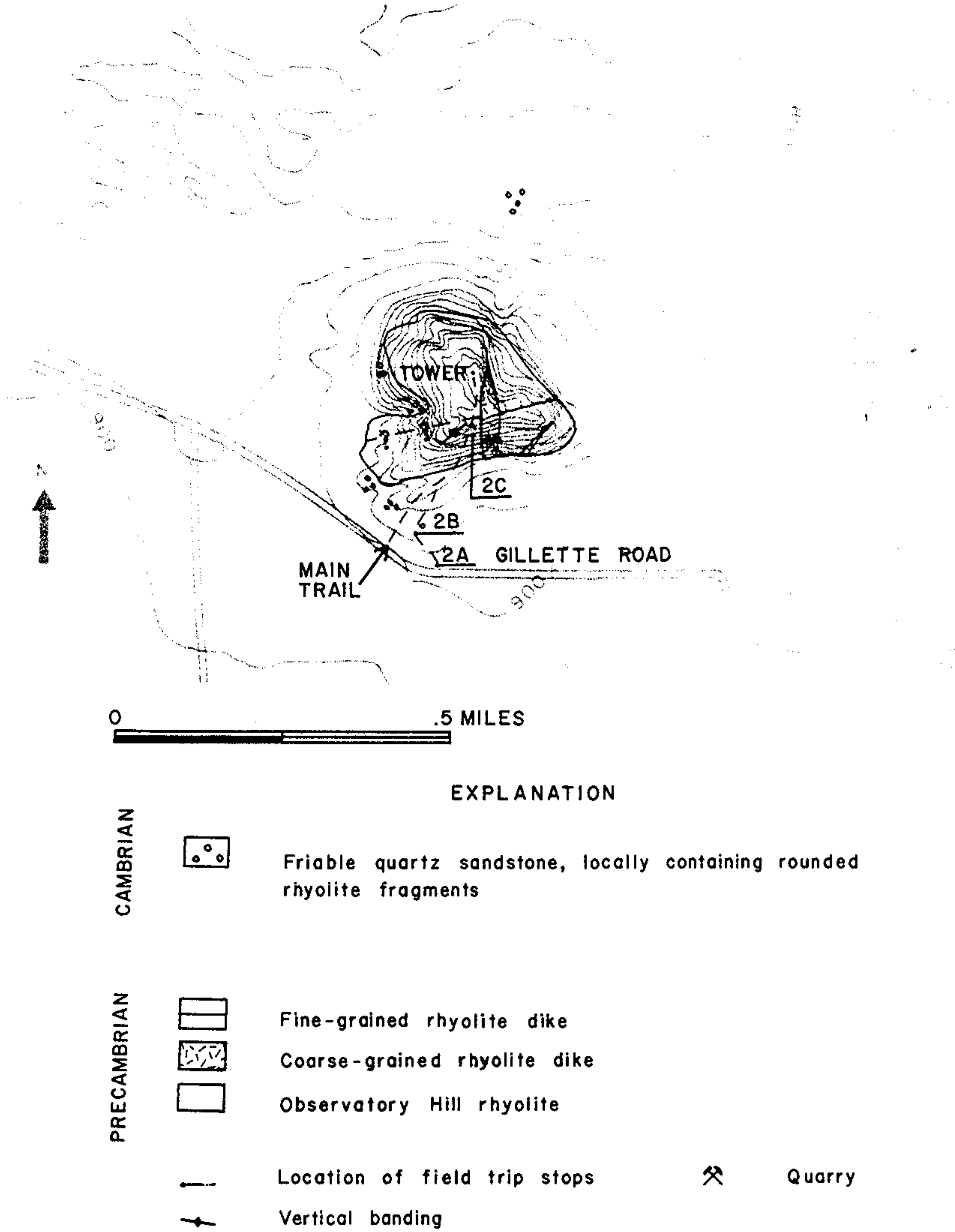


Figure 7. Geologic map of Observatory Hill adapted from Hobbs and Leith (1907). Approximate locations of field trip stops are superimposed. Contour interval 20 feet between 800 and 960 feet; above 960 feet the interval is 10 feet. Contour lines between 900 and 960 feet are approximately located.

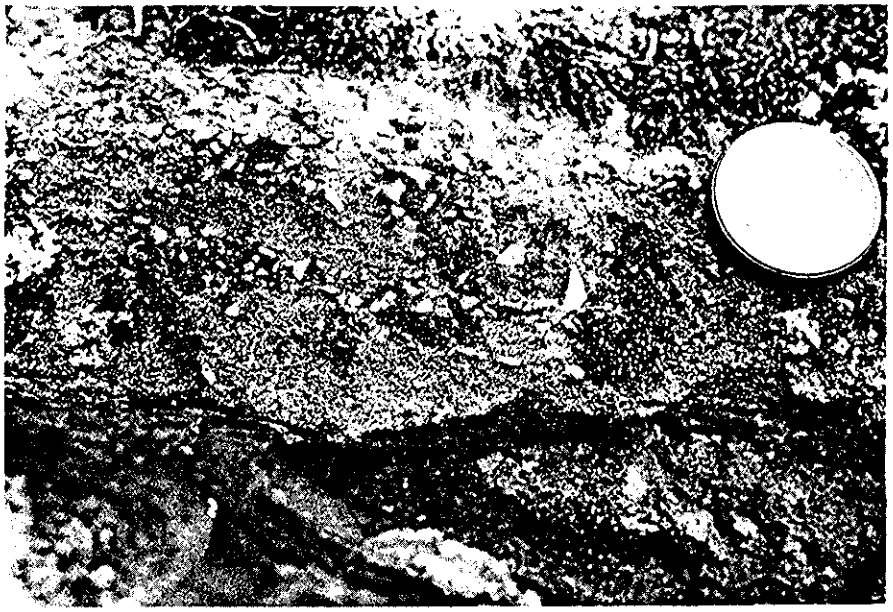


Figure 9A. Close-up of a conglomerate layer interbedded with Cambrian sandstone at stop 2B. In these bands, fragments are angular (compare with Fig. 9B). Most of the fragments are porphyritic rhyolites similar to those cropping out on Observatory Hill.

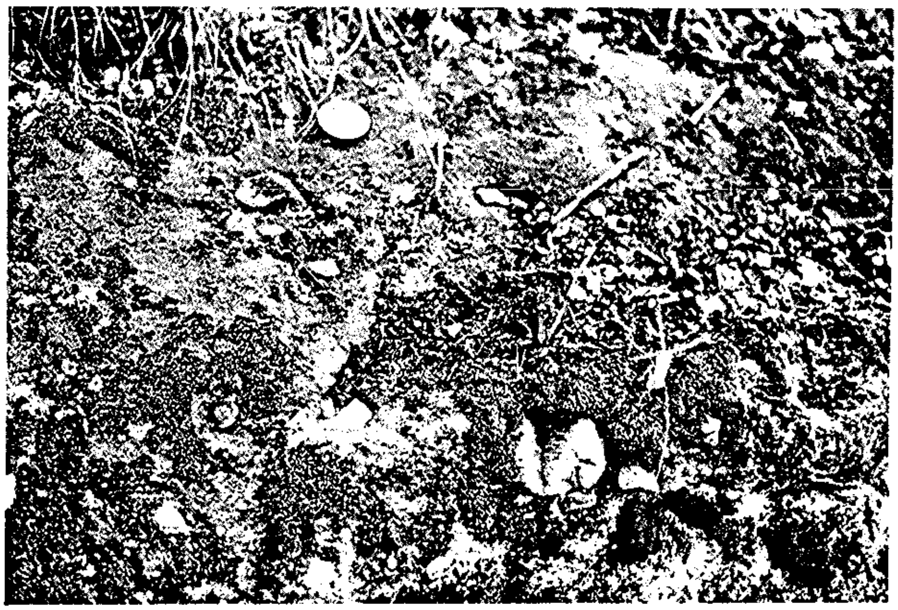


Figure 9B. View of large rhyolite fragments (up to 10 cm in size) in a conglomerate layer at stop 2B. In this band, fragments are rounded (compare with Fig. 9A).

On Observatory Hill exposures of conglomerate containing rhyolite pebbles are usually restricted in occurrence to a zone 5 to 20 m wide about the rhyolite ledges. The conglomerate layer at Stop 2B is located an unusually large distance from rhyolite exposures (200 m), and its deposition probably reflects a relatively short lived and highly energetic event. In the Baraboo region Dott and Dalziel (1970) reported large boulders of Baraboo Quartzite entrapped within Cambrian sandstone. They envisaged transport of cobbles and boulders by waves and strong currents generated by violent tropical storms that pounded the Baraboo islands during Cambrian time. Observatory Hill probably existed as a small island in late Cambrian time and was probably also hit by violent tropical storms. Strong currents generated during these storms are probably responsible for the transport of rhyolite fragments away from the Observatory Hill island, thus forming the conglomerate band observed at Stop 2B.

Stop 2C

From Stop 2B climb the ridge above the sandstone exposure and join a trail running along the crest of the ridge. Follow this trail to where it joins the main trail and then continue up the hill on the main trail (Fig. 7).

Note the first outcrops of rhyolite to your left and straight ahead. There is at least 500 feet of relief on the Precambrian surface in the vicinity of Observatory Hill. Just ahead rhyolite exposures are at an elevation of 1080 feet. About 1200 m to the northwest of Observatory Hill, rhyolite was encountered in an irrigation well at a depth of 300 feet (480 feet above sea level).

Cross into the rhyolite exposures and continue to the trail junction. Follow the trail to the right (south). The fork to the left (north) goes to the summit where a lookout tower was once located in the early 1920's (Fig. 7). The ruins of the tower can still be observed along the inscriptions carved into the rhyolite by several of the workers who manned the tower.

Follow the trail (south) to a large area of bare rock which forms the sharp southern edge of Observatory Hill (hereafter called the south bluff). From the south bluff the Marcellon rhyolite exposures (20 km to the south) and the Baraboo Hills (30 km to the southwest) can be easily seen on a clear day. At this stop, we will examine the Observatory Hill rhyolite and a coarse-grained rhyolite dike.

Observatory Hill Rhyolite

The Observatory Hill rhyolite is typical of porphritic rhyolites exposed in south-central Wisconsin. It contains phenocrysts of quartz ($<$1 mm in size and rounded) and pink to white alkali feldspar (1 to 5 mm in size) set in a dark gray to black matrix. On close examination, the matrix of the rhyolite shows faint flow structure formed by flattened shards and pumice fragments. In general, these bands dip steeply and strike N. 50°E. The rhyolite is an ash-flow tuff and is remarkably texturally homogenous over the entire hill.

Petrographic studies indicate that the rhyolite is composed of pheno-crysts of quartz and alkali feldspar set in a coarsely devitrified ground-mass. The quartz is anhedral and is usually strained (7%). Some of the quartz is deeply embayed. Alkali feldspar (23%) is probably orthoclase and may display carlsbad twinning. Accessory minerals are chlorite, biotite (?), epidote, iron oxide and zircon. The matrix commonly contains aligned and flattened Y shaped and cuspate shards.

In terms of major and minor element chemistry, the rhyolite belongs to chemical group 3 (Table 1, analysis 16; Fig. 6), of Smith (1978a) and is therefore similar in chemistry to granophyric granites and porphyritic rhyolites in the Fox River Valley. The group 3 rhyolites and granites are distinguished from other south-central Wisconsin igneous rocks by high SiO_2, K_2O/Na_2O, La, Zr, Y and Rb/Sr; and low CaO, Al_2O_3 and Ba (Table 1).

Coarse-Grained Rhyolite Dike

A coarse-grained rhyolite dike strikes north south across Observatory (Fig. 7). The dike is about 70 m wide at the south bluff but pinches out to the north. A thin (15 m thick) dike of similar coarse-grained rhyolite strikes N. 50 E. across the southeast slopes of Observatory Hill. These dikes were originally identified by Hobbs and Leith (1907) who referred to them as granite dikes.

The contact between the dike and the Observatory Hill rhyolite is well displayed on the east edge of the south bluff. The contact shows complex interfingering of dike rock into Observatory Hill rhyolite (Fig. 10) and in locality a rhyolite zenolith is found in dike rock close to the contact. Locally the Observatory Hill rhyolite is intensely fractured near the contact (Fig. 11). Also, quartz veins are concentrated on either side of the contact.

Extending 5 to 10 m into the dike from the intrusive contact is a fine-grained contact zone (chill zone?). The rock in this zone is gray-green in color and contains large plagioclase phenocrysts.

Petrographic studies of the dike rock of the contact zone reveal subhedral zoned plagioclase phenocrysts (30%) with cores altered to sausserite and unaltered rims, subhedral alkali feldspar (5%), fractured and broken quartz (3%) and small subhedral feather-like grains of biotite (1%). The matrix is a microbreccia containing fragments of fine-grained rhyolite, basalt and eutaxitic rhyolite.

At this locality also notice the glacial polish and grooving. Here glacial striations trend N. 70° W.

Walk to the east of the south bluff to the first major outcrop. Here rhyolite in the central part of the dike is well exposed. This rhylite is similar in mineralogy to that of the contact zone, but differs by having a coarser-grained matrix than the contact-zone rock. Also, it is pink to red in color in outcrop, not green in color like the contact-zone rock. Petrographic examination indicates that plagioclase is the dominant phenocryst (46%). Alkali feldspar is present in micropegmatitic intergrowths with quartz (21%). Quartz, in addition to its occurrence in alkali feldspar-quartz

Figure 10. View of the contact between the coarse-grained rhyolite dike (below), and the Observatory Hill rhyolite (above). Note the fingers of coarse-grained rhyolite extending into the Observatory Hill rhyolite (dashed line). Also noteworthy are the numerous veins of quartz that roughly parallel the contact.

Figure 11. Close-up view of the shattering of the Observatory Hill rhyolite at the contact with the coarse-grained rhyolite dike.

intergrowths, is present as small anhedral phenocrysts (2%). Accessory minerals (10%) include chlorite in irregular clots, epidote, clinozoisite, and iron oxide. These minerals are set in a finely devitrified groundmass (21%).

This dike and a fine-grained granite at Baxter Hollow (Gates, 1942) are similar in chemistry, and form chemical group 1 of Smith (1978a) (Table 1, analyses 1 and 2; and Fig. 6). The rocks are distinguished from the other granites and rhyolites in the Fox River Valley and Baraboo area by higher TiO_2, CaO, Ba, V and Sr and by lower SiO_2 and Rb/Sr ratio. Both the Observatory Hill rhyolite and the Baxter Hollow Granite are younger than the Fox River Valley and Baraboo rhyolites. Baxter Hollow Granite intrudes rhyolite (Gates, 1942) but its relationship to the overlying Baraboo Quartzite is unclear (Dott and Dalziel, 1972). This stratigraphic and chemical evidence suggests that the intrusion of the Baxter Hollow Granite and the Observatory Hill rhyolite was a discrete igneous event that occurred after the emplacement and folding of the widespread rhyolite ash-flow sheets.

The coarse-grained rhyolite dike was quarried for a short time at the turn of the century. This operation is evidenced by a large area of broken dike rock located just below and to the east of the south bluff.

Labradorite Porphyry Dike

Hobbs and Leith (1907) reported an east-trending "labradorite porphyry" dike just to the north of the south bluff. A careful search for this dike revealed an east-trending fine-grained quartz-feldspar rhyolite dike about 5 m in width. This dike is truncated by the north-trending coarse-grained rhyolite dike as is the "labradorite porphyry" dike described by Hobbs and Leith. In terms of location, orientation and stratigraphy, it is almost certainly the same dike mapped by them. In thin section, this rock contains rounded and embayed quartz phenocrysts (2%) and alkali feldspar with perthitic texture (altered to sericite and dusted with iron oxide) (3%). These minerals occupy a fine-grained matrix (devitrified) with iron oxide accentuating a crude banding (95%). The only evidence of metabasalt on Observatory Hill is found on the south bluff. Here a green metabasalt that occurs in an outcrop only 3 m long and 0.3 m wide may intrude rhyolite.

Other Exposures of Porphyritic Rhyolite:

Other exposures of porphyritic rhyolite (Endeavor, Utley, Berlin, and Taylor Farm) are mineralogically, texturally, and chemically similar to the rhyolite at Observatory Hill. However, common in the Utley rhyolite are zones of spherulites and lithophysae, also disk-shaped coarse-grained inclusions may represent recrystallized collapsed pumice. Rhyolite is locally sheared at Berlin (Weidman, 1898) and slickensided surfaces are found at Utley (Gram, 1947). Rhyolite at Utley is intruded by rhyolite, dacite and metabasalt dikes.

PART II - THE BARABOO INTERVAL ROCKS OF CENTRAL WISCONSIN

(B. A. Brown and J. K. Greenberg)

The second day of the field trip will be spent examining rocks of the Baraboo interval (1760-1500 Ma). Outcrops have been selected to illustrate the diversity of sedimentary rocks deposited during this time, and to show the relationship of the sediments to contemporary intrusive and extrusive igneous rocks as well as to older basement rocks.

The Baraboo interval was named by Dott (1983) for the classic outcrops of Proterozoic quartzite around Baraboo in south-central Wisconsin (fig. 14). Dott originally defined the Baraboo interval as a period of widespread continental to shallow marine sedimentation during which some of the earliest red-bed sequences were deposited. The interval was defined from a sedimentological/stratigraphic perspective, based on Dott's work on the Baraboo, Barron, and Sioux Quartzites.

Greenberg and Brown (1983, 1984) redefined the Baraboo interval as a period of anorogenic magmatic and sedimentary activity which took place on continental crust stabilized after the Penokean orogeny (1850 Ma). Baraboo interval sedimentation was an integral part of a series of anorogenic tectonic events which began with the eruption of rhyolites and emplacement of related granitic rocks at about 1760 Ma (Smith, 1978; 1983), continued with clastic sedimentation, regional uplift and deformation (1630 Ma), and ended with 1500 Ma magmatism (Wolf River batholith). This series of events is interpreted to be part of a general process of "cratonization" which affected the crust after orogenesis here in Wisconsin and in other areas worldwide (Greenberg and Brown, 1984; Rogers and others, 1984).

Baraboo Interval Sedimentation

At the time the Baraboo interval was first defined (Dott, 1983), it was thought that the Baraboo, Barron, and Sioux Quartzites, predominantly red quartz arenites, were, with the exception of slates and carbonate iron formation from the top of the Baraboo section, the dominant, if not only, important rocks representative of this period. Mapping in central Wisconsin has shown that a diverse suite of rocks, including argillaceous rocks, iron formation, bedded chert, and micaceous or feldspathic quartzites and conglomerates are also important constituents of the Baraboo interval stratigraphic record (Brown, 1986).

Based on his study of the orthoquartzites, Dott (1983) interpreted the Baraboo sediments as predominantly fluvial deposits formed in a coastal plain environment which was succeeded by a shallow marine environment. The marine transgression is represented by the argillaceous and chemical sediments of the upper part of the Baraboo section. Dott visualized the Baraboo, Barron, and Sioux quartzites as a broad sand blanket, much like the Cambrian sandstones of the region. Greenberg and Brown (1984) suggested two alternative models for Baraboo interval sedimentation based on their observation that lithologies other than orthoquartzite were more widely distributed than previously known. In particular, the occurrence of marine sediments overlying older basement without a significant underlying orthoquartzite section introduced a complexity that could not be explained by the sand blanket model of Dott (1983).

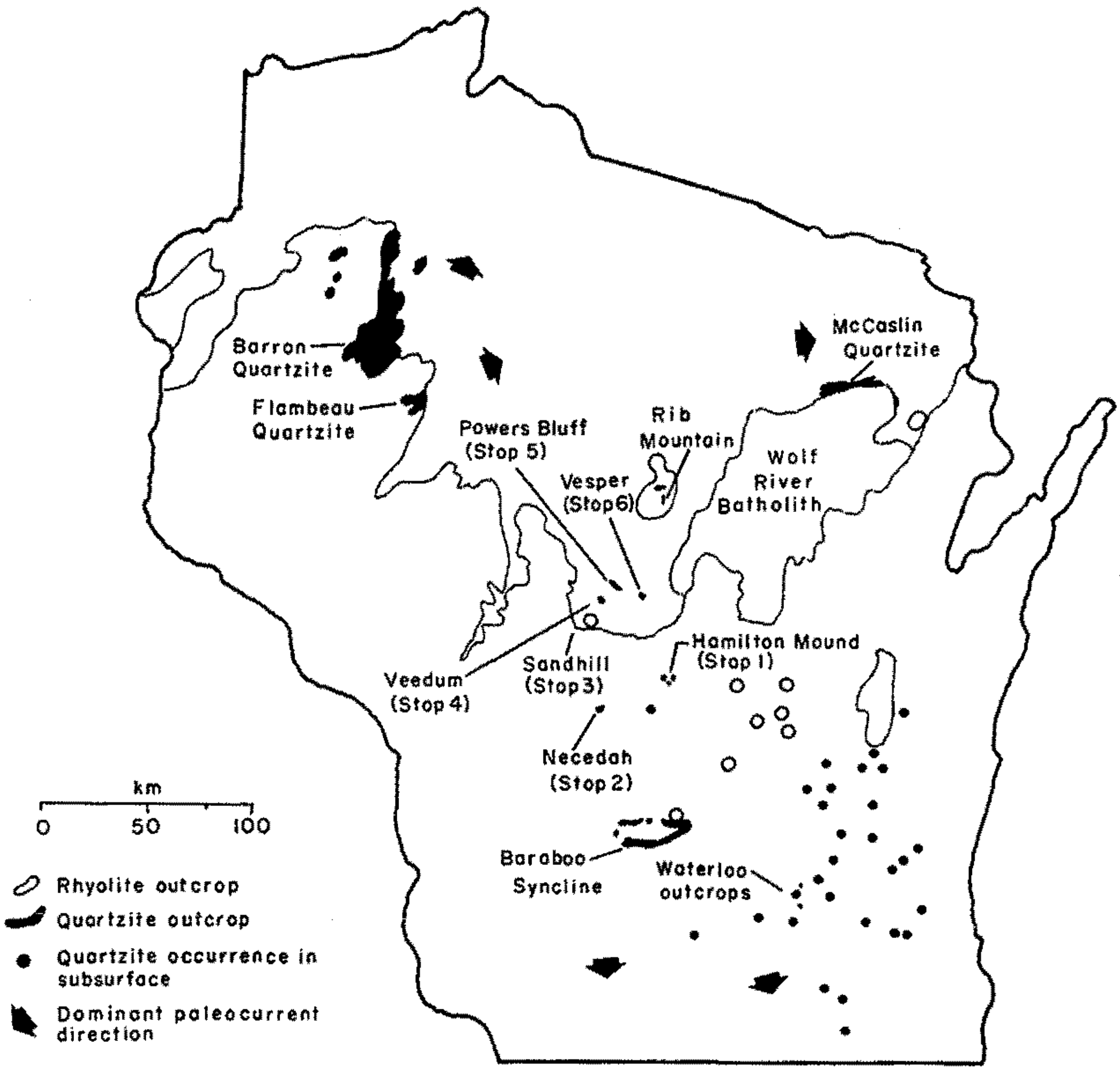


Figure 14. Map of Wisconsin showing location of Baraboo interval rocks.

The observed stratigraphy of Baraboo interval rocks in Wisconsin may be better explained by a complex basin/marine transgression model in which thick orthoquartzites accumulated in local basins, controlled by basin and range-type faulting (Greenberg and Brown, 1984). The entire region was subsequently covered by the transgressing marine environment which deposited argillaceous and chemical sediments in central Wisconsin and above the orthoquartzites at

Baraboo. This model, (fig. 15a) is consistent with the observation that marine facies directly overlie basal conglomerate and volcanogenic sediments in central Wisconsin whereas orthoquartzite was deposited both in the north (McCaslin, Rib Mountain, Barron) and in the south (Baraboo, Waterloo, southeast Wisconsin subsurface). At the time the orthoquartzites were deposited, central Wisconsin was a positive area where only locally derived sediments accumulated until late in the period of sedimentation, when marine conditions covered this region. Morey (1984) has suggested that deposition of the Sioux Quartzite of Minnesota may also have been controlled by local fault-bounded basins.

Additional support for the complex basin model is provided by limited paleocurrent data (Olson, 1984). Measurements in northern Wisconsin (Barron, McCaslin) suggest eastward transport in the quartzites, those in the south (Baraboo, Sioux) suggest southward transport (fig. 1). A regional southward transport would be expected in a fluvial dominated coastal plane with source to the north and shoreline to the south. Paleocurrent data for the Barron (Johnson, 1985) indicate a change to a bipolar-bimodal pattern in the upper part of the section, consistent with transition to tidal-dominated shallow marine conditions.

Rb-Sr dating of biotites in northern Wisconsin by Peterman and others (1985) suggests that periodic uplift of crustal blocks occurred in the region throughout Baraboo interval time. At present, evidence is accumulating which favors deposition of the Baraboo interval sediments on relatively unstable crust subject to epeirogenic activity, rather than a stable continental margin coastal plane (Greenberg and Brown, 1984; Rogers and others, 1984).

Greenberg and Brown (1984) introduced a second model which involved multiple sedimentary sequences. In this model (fig. 15b), the marine and volcanogenic sediments of central Wisconsin would represent an early sequence, partially removed by erosion. These rocks were in turn covered by the fining-upward transgressive sequence described by Dott (1983). The distribution of lithologies seen today is the product of erosion and later uplift, in which overlying orthoquartzites were removed from central Wisconsin. The complex basin model is favored for reasons already presented, in particular the marked similarity of the cherty, argillaceous, and ferruginous sediments of central Wisconsin to the Seeley and Freedom formations at Baraboo, which in the multiple sequence model would belong to a younger depositional series. Because the Baraboo interval lasted over 200 Ma, and a small fraction of these sediments are exposed, the possibility of multiple sequences cannot be dismissed. Also, no evidence has been found to suggest a major unconformity of regional extent within the Baraboo interval sequence. However, more work needs to be done before a comprehensive sedimentary/tectonic model can be proposed.

Structure of the Baraboo interval rocks

Very little is known about the regional structural geology of the Baraboo interval rocks. Detailed structural studies have only been conducted on the rocks of the Baraboo Syncline. Most of these studies have been concerned primarily with the evolution of the syncline and the problems of deformation mechanics and cleavage development (Van Hise, 1893; Dalziel and Dott, 1970; Jank and Cambray, 1986; Hempton and others, 1986). The timing of the folding of the Baraboo interval rocks has remained uncertain. It is commonly thought to have occurred around 1630 Ma, a time of widespread disturbance of Rb-Sr ages in the region (Van Schmus and others, 1975). It is known that deformation occurred prior to regional 1500 Ma magmatism, based on the age of pegmatite dikes which cut folded quartzite at Waterloo, and the occurrence of deformed quartzite in the Wolf River batholith and related rocks (Brown, 1986).

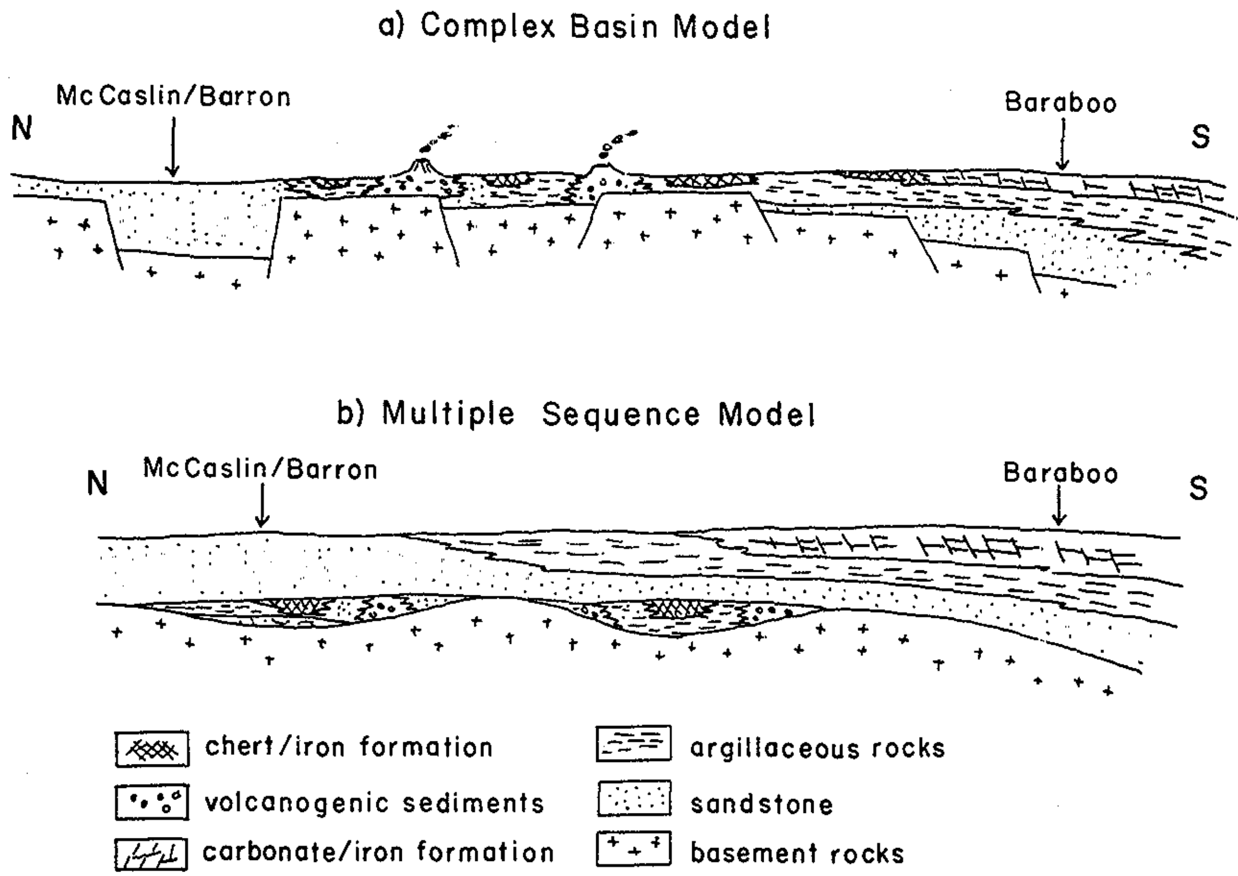


Figure 15. Models for deposition of Baraboo interval rocks.

Figure 16 is a summary of what is known from outcrop data and geophysics of regional structural trends in the Baraboo interval rocks of Wisconsin. Two striking features of this map are the increase in intensity of deformation from west to east, and the distribution of structures with respect to the area of central Wisconsin underlain by the 1500 Ma Wolf River batholith. This and other evidence suggests that deformation of the Baraboo interval rocks and the 1500 Ma magmatism may be related (Brown and Greenberg, 1981, 1982; Greenberg and Brown, 1984). The Baraboo rocks may have been folded by a thin-skin mechanism in which these rocks slid off of a major crustal uplift in central Wisconsin at 1630 Ma, which was a precursor to the 1500 Ma magmatism. This idea is consistent with the distribution of structures and the southward overturning of the Baraboo Syncline, and may be ultimately testable by deep drilling (Brown and others, 1984).

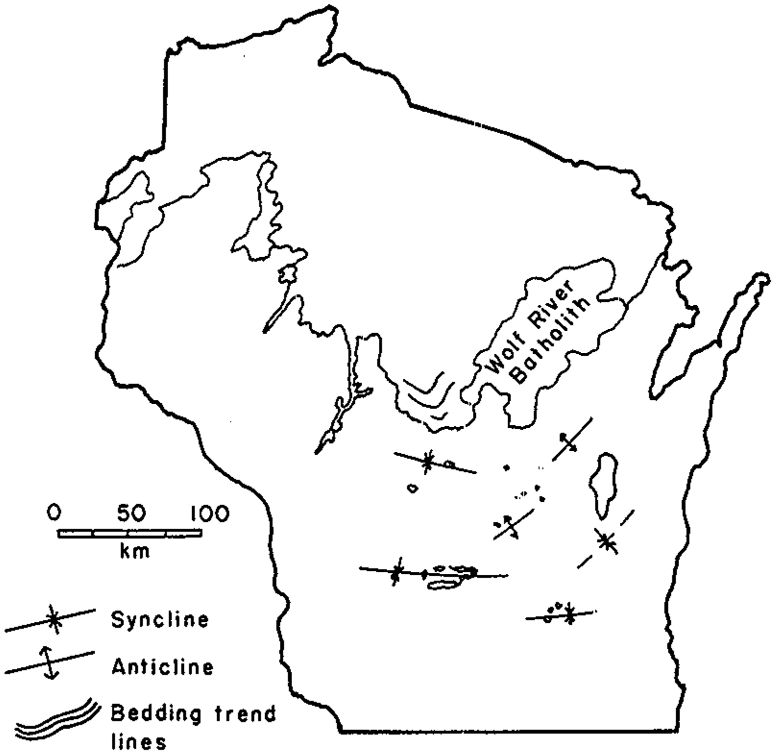


Figure 16. Major structures in the Baraboo interval rocks.

The Field Trip

The six planned stops will provide an overview of the Baraboo interval rocks of central Wisconsin. Stop 1, Hamilton Mound, illustrates typical Baraboo-type red orthoquartzite folded and intruded by a 1760 Ma granite. Stop 2, Necedah is another example of intruded quartzite, which provides a classic example of brecciation and the effects of contact metamorphism. Exposures in the Sandhill refuge (Stop 3), provide a look at quartzite in contact with 1760 Ma(?) rhyolite, and some excellent examples of rhyolite textures. Stop 4, the Veedum area, exposes what is thought to be locally derived basal Baraboo interval beds overlying 2800 Ma, Pittsville gneiss, one of the oldest rocks in the region. Stop 5 provides a rare opportunity to look at the argillaceous and cherty sediments of the Baraboo interval at Powers Bluff. Stop 6 is a probable basal contact of the quartzite overlying early Penokean granite in an abandoned quarry near Vesper.

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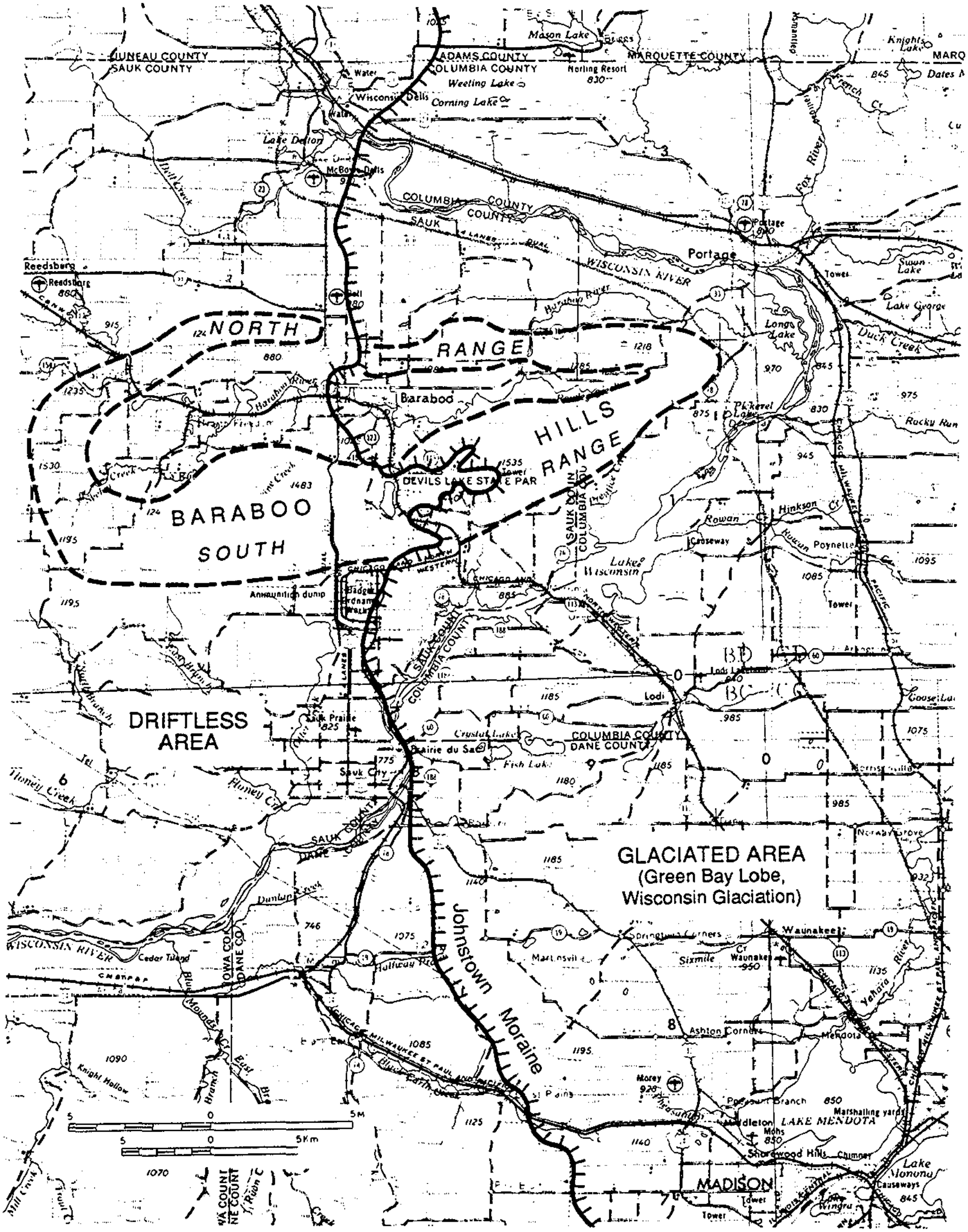

Figure B. Geology of the Baraboo region.

The Upper Narrows and Van Hise Rock

Location. West side of the Upper Narrows of the Baraboo River, along Highway 136 between the Rock Springs and the bridge over the Baraboo River, E1/2, SE1/4, sec. 29, and the W1/2, SW1/4, sec. 28, T12N, R5E, Sauk County (Rock Springs, Wisconsin, Quadrangle, 7.5-minute series, topographic, U.S. Geological Survey, 1975) (fig. 1). *Caution*: This is a busy highway and a dangerous curve. Watch for traffic. Park at the parking area on the east side of the highway south of Van Hise Rock.

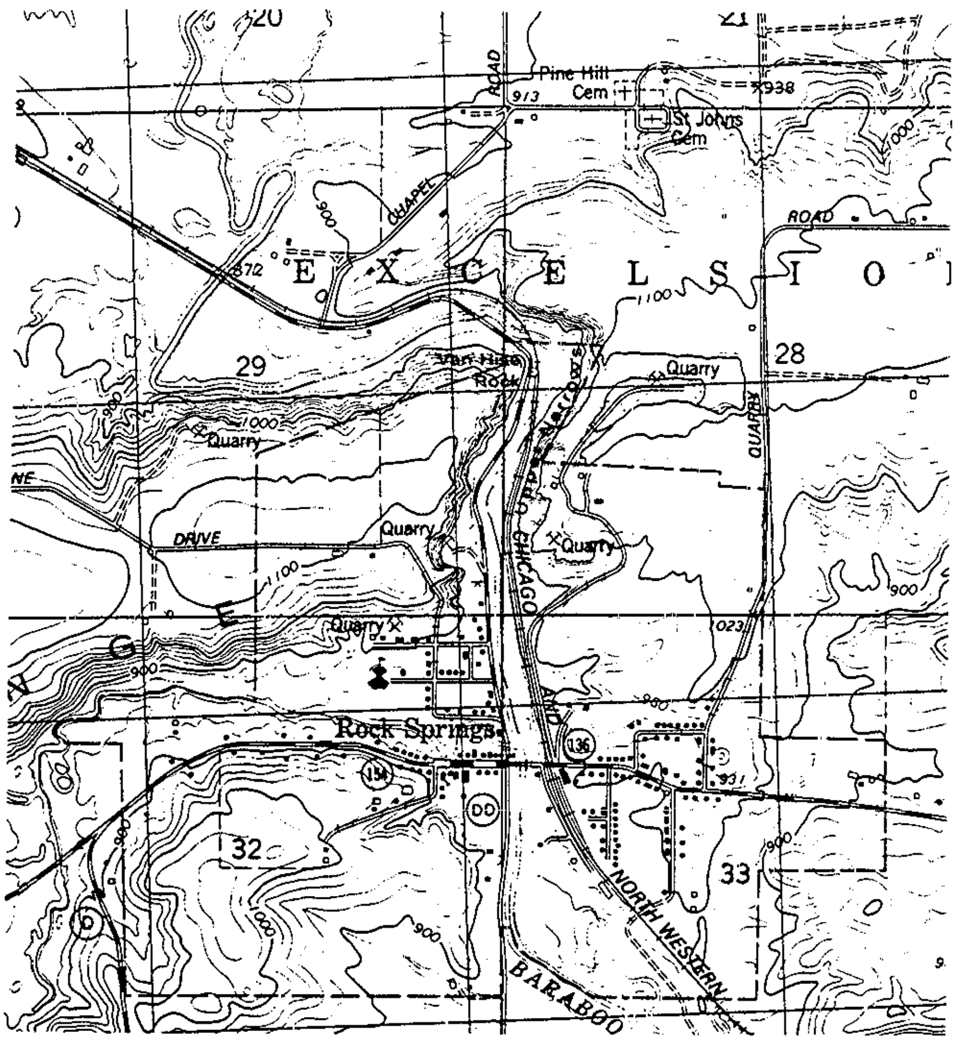

Figure 1. *Location of Van Hise Rock and the Upper Narrows area.*

Authors. B.A. Brown and M.E. Ostrom, 1990 (modified from Dalziel and Dott, 1970).

Introduction. The Upper Narrows, formerly called Ablemans Gorge or Rock Springs Gorge, provides an opportunity to examine significant lithologic characteristics and structural relationships in the Proterozoic quartzite of the Baraboo Formation. The upper bluffs and the ends of the gorge also show the onlapping relationship of the Upper Cambrian formations. Exposures are on both sides of the Baraboo River for 0.8 km from the river bridge at the north end of the gorge to the old sandstone quarry on the south end. The accompanying geologic map (fig. 2) and diagrammatic cross section (fig. 3) taken from Dalziel and Dott (1970) provide a guide to the important geologic features. Van Hise Rock, located south of the bridge and east of the highway, is an excellent example of cleavage refracted from a phyllitic bed into a massive quartzite layer on the north limb of the Baraboo Syncline. This rock has long been used as an example of cleavage refraction; it bears a plaque dedicated to pioneer structural geologist C.R. Van Hise, who first described this phenomenon in the Baraboo Hills.

Description The Upper Narrows provides a cross section through the vertical north limb of the Baraboo Syncline. The features visible on the west side of the river along Highway 136 are summarized in figure 3.

Van Hise Rock consists of two massive beds of Baraboo quartzite separated by a finer-grained bed of phyllite (fig. 4). The phyllite layer, which was originally an argillaceous fine sandstone, is not traceable into the cliff west of the highway. This bed appears to be a lens that pinches out to the west, although similar phyllite beds typical of the middle to upper part of the Baraboo quartzite are visible in the face of the roadcut. Consistent orientation of structures in Van Hise Rock and throughout the gorge area suggests that the rock is in place.

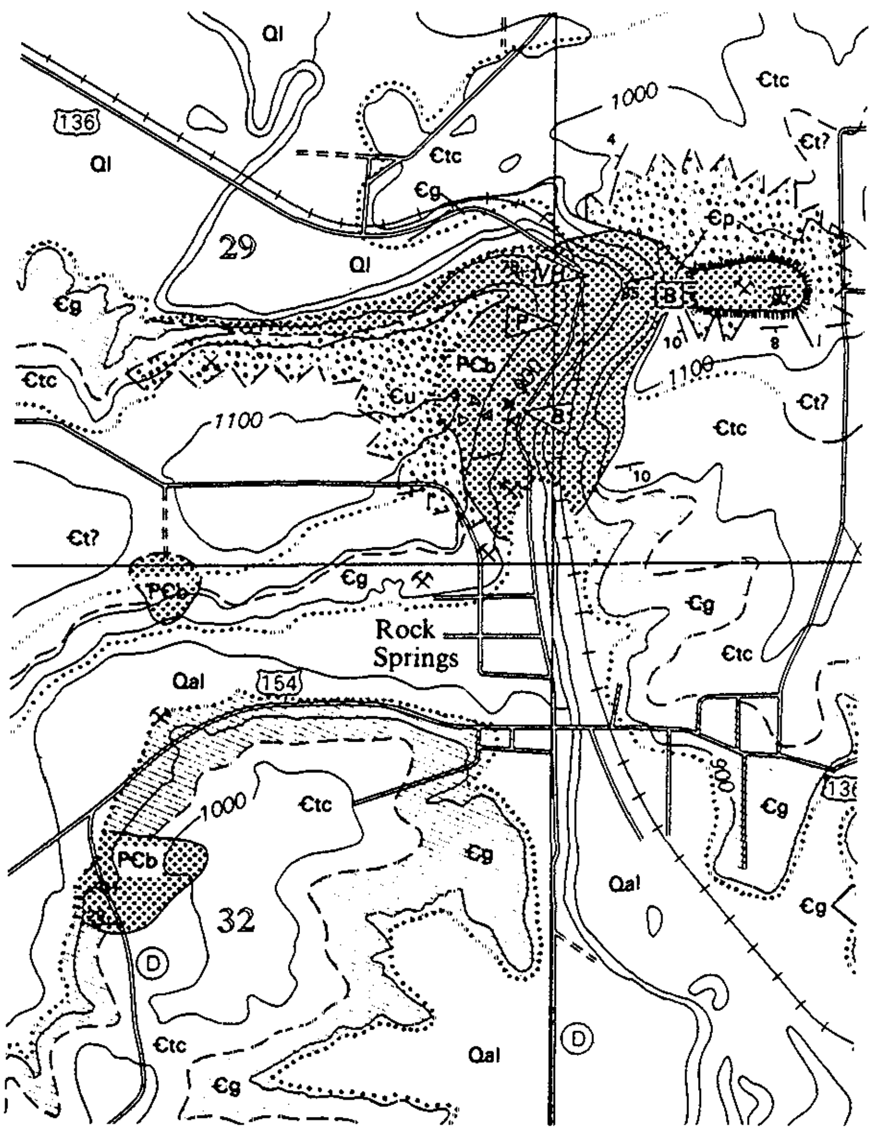

Figure 2. Geologic map of Upper Narrows (Rock Springs) area. On west side of gorge: VH = Van Hise Rock; P = polished quartzite surface; B = breccia zone. Note initial dips and distribution of conglomeratic facies in Cambrian rocks. P€b = Baraboo Quartzite; €g = Galesville Member; €tc = Tunnel City Formation; €t = Trempealeau Group; €p = conglomeratic sandstone of the Parfreys Glen Formation; Qal = river alluvium; Ql = glacial lake beds (modified from Usbug, 1968; Dalziel and Dott, 1970, fig. 21).

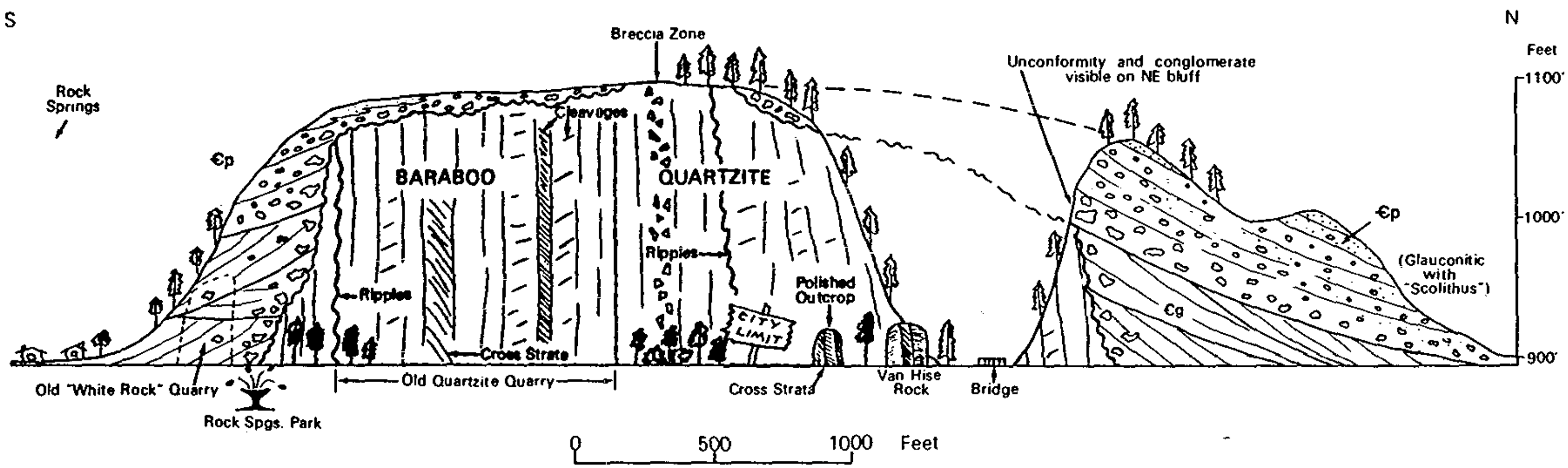

Figure 3. *Diagrammatic cross section of Upper Narrows of the Baraboo River looking west, showing key geologic features. €p = Parfreys Glen Formation (Dalziel and Dott, 1970, fig. 22).*

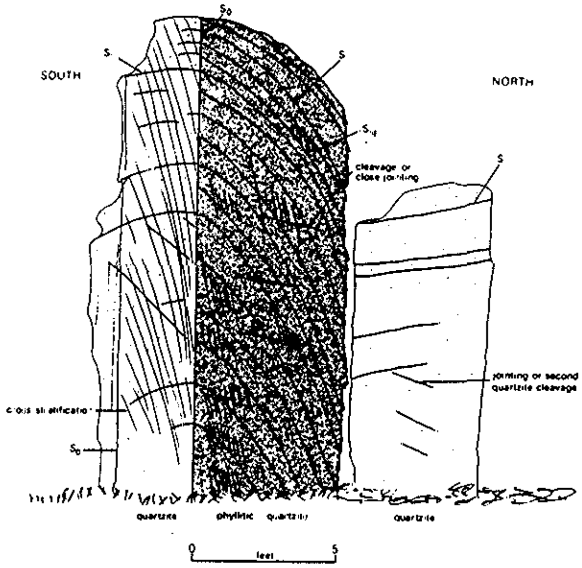

Figure 4. *Sketch of structures in Van Hise Rock as seen from the east (Dalziel and Dott, 1970, fig. 23).*

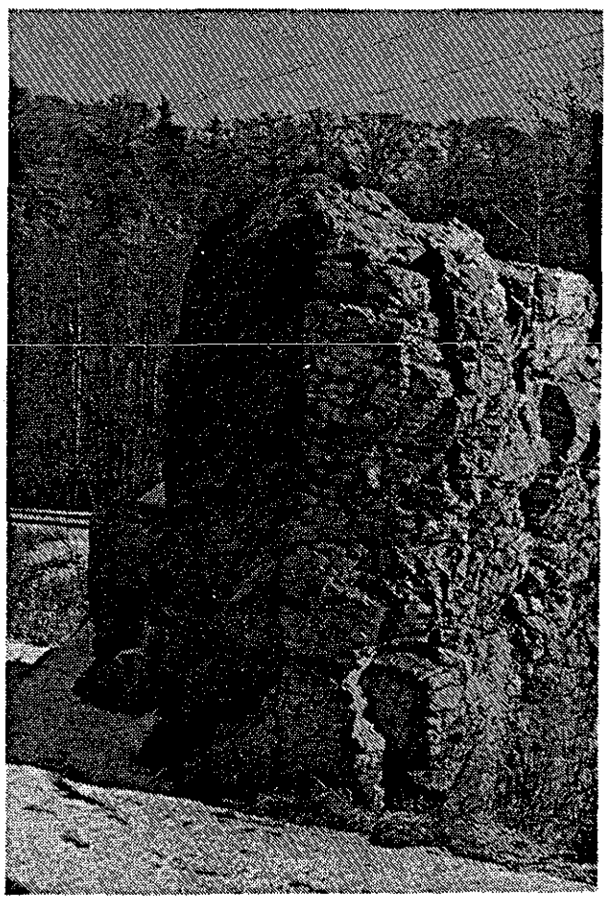

Figure 5. *Photograph of Van Hise Rock looking northeast from Highway 136. Phyllite bed is dark bed on left. Cliff in background is Baraboo quartzite capped by Cambrian sandstone and conglomerate.*

The most striking feature of Van Hise Rock is the refraction of cleavage between the quartzite and phyllite layers. Gently south-dipping cleavage in the quartzite is refracted into phyllite cleavage dipping about 40° to the north (fig. 5). The bedding or cleavage intersection is nearly horizontal and oriented east-west, roughly parallel to the axis of the Baraboo Syncline. A prominent set of joints, often quartz-filled, is developed at high angles to the bedding/cleavage intersection and was interpreted by Dalziel and Dott (1970) to be extensional fractures at right angles to the regional least-compressive stress. Well developed tension gash bands are visible on the north side of Van Hise Rock. Dalziel and Dott (1970) provide a more complete discussion of the structural geology of the Baraboo Syncline.

The roadcut on the west side of Highway 136 opposite Van Hise Rock contains some excellent examples of bedding and cross stratification in the Baraboo quartzite. To the south, at the Rock Springs village limit, a trail leads to the west into an old quartzite quarry. Ripple marks are visible on some bedding surfaces; at the south end, the quartzite becomes a breccia cemented by white vein quartz. These breccias are common in other exposures of the Baraboo interval quartzites. The fragments are angular and appear as if they could be fitted back perfectly. These zones show no evidence of a tectonic origin, no rounding of clasts or cataclasis as would be expected if they originated as fault zones. Greenberg (1986) described similar breccias at Hamilton Mounds and at Waterloo, attributing them to hydrothermal activity.

Farther south, a large quartzite quarry behind Rock Springs Park provides another opportunity to see sedimentary structures such as ripple marks and cross-bedding. At this location the unconformity between the quartzite and the overlying conglomerate of the Parfreys Glen Formation is visible as it was at the north end of the gorge. Rounded clasts of quartzite up to 1 m in diameter are contained in a sandstone matrix.

At the south end of the Upper Narrows, an old quarry produced building stone from sandstone of the Parfreys Glen Formation that is relatively free of the typical coarse quartzite clasts. This sandstone was deposited in the interior of the basin formed by the Baraboo Syncline. Scarce angular blocks of quartzite in the sandstone suggest that this material was deposited in a relatively wave-free area in the lee of the quartzite knob to the north.

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Stop 5-07: Quartzite at Baraboo: East Bluff of Devil's Gorge

Location: Near the junction of the Potholes Trail and the Devils Doorway at the top of the east-west part of East Bluff, in Devils Lake State Park; NE 1/4 SE 1/4 Sec 24, T.11N., R.6E and NW 1/4 SW 1/4 Sec 19, T.11N., R.7E., Sauk County, Wisconsin.

Stop Description: The Devils Lake Gorge was cut through the quartzite of the South Range sometime before the Late Cambrian The gorge has been filled and exhumed several times, with the most recent associated with draining of Pleistocene glacial lakes. The quartzite consists of cross-bedded and plane-bedded, subrounded to angular, quartzose, very fine to fine sand that has undergone low-grade metamorphism. It is white to dark gray, commonly with pink, red, or purple tinge. Beds of conglomerate and phyllite are also present in some parts of the formation

Prior Guidebook Reference: Clayton and Attig, 1990.

Stop 5-08: Quartzite at Baraboo: Skillet Creek

Location: Exposure on the east side of U. S. Highway 12, o.3 mi (o.5 km) south of the junction with Wisconsin Highway 159; SW 1/4 NW 1/4 Sec 15, T.11N., R.6E., Sauk County, Wisconsin

Stop Description: This outcrop provides an opportunity to examine both the quartzite and the phyllite facies of the Baraboo Quartzite. This is a classic exposure that ehibits important sedimentary and tectonic structures typical of the Baraboo interval rocks of Wisconsin (Greenberg and Brown, 1983, 1984; Brown, 1986)

Prior Guidebook Reference: Brown (1987)

East Bluff of Devils Lake gorge

Location. Near the junction of the Potholes Trail and the Devils Doorway Trail at the top of the east-west part of East Bluff, in Devils Lake State Park, in the NE1/4 SE1/4 sec. 24, T11N, R6E, and NW1/4 SW1/4 sec. 19, T11N, R7E, Sauk County (Baraboo, Wisconsin, Quadrangle, 7.5-minute series, topographic, U.S. Geological Survey, 1975) (fig. 1). East Bluff can be reached on footpaths from the parking lot on the southeast side of Devils Lake. Follow the path from the north edge of the lot, cross the railroad track, turn left, and follow the Balanced Rock Trail up to the Devils Doorway Trail at the top of the bluff, or cross the track, and turn right and follow the Grottos Trail to the Potholes Trail or CCC Trail up to the Devils Doorway Trail.

Alternatively, park in the lot on the northeast side of Devils Lake and follow the East Bluff Trail to the top of the bluff and south to the Devils Doorway Trail.

Location maps occur at intervals along the trails.

Authors. Lee Clayton and John W. Attig, 1990.

Baraboo Hills. The Baraboo Hills consist of the North Range and the South Range, which join at their ends in the form of an oval. The Baraboo Hills are the surface expression of the Baraboo Syncline. The North Range, 8 km north of here, is less conspicuous than the South Range. The more prominent South Range is 40 km long, from east to west, and is 5 km wide. Devils Lake, in Devils Lake gorge, is near the middle of the South Range (Clayton and Attig, 1990).

Baraboo Formation. The South Range is made up primarily of the Baraboo Formation, which consists of 1.5 km of Early Proterozoic quartzite that dips to the north about 15°. The quartzite consists of cross-bedded and plane-bedded, subrounded to angular, quartzose, very fine to fine sand that has undergone low-grade metamorphism. It is white to dark gray, commonly with a pink, red, or purple tinge. Beds of conglomerate and phyllite are also present in some parts of the formation. Bedding planes with wave ripple marks can be seen in several places along the trails going up the bluff face, indicating a shoreline environment.

Devils Lake gorge. The best views of Devils Lake gorge are from East Bluff and West Bluff. The gorge, which is the only one cutting across the South Range of the Baraboo Hills, is 6 km long and 1 km wide. It is now 150 m deep, but before Pleistocene sediment was deposited in the bottom of the gorge, it was at least 110 m deeper.

The gorge was originally cut through the quartzite of the South Range sometime before the Late Cambrian Epoch (Attig and others, 1990). It was then filled with sediment during the Late Cambrian and the later Paleozoic; remnants of sandstone of the Parfreys Glen Formation can be seen in several parts of the gorge, such as near the southwest shore of Devils Lake. The gorge was later exhumed, perhaps starting during the Mesozoic or Cenozoic. The last surge of erosion occurred when an early version of glacial Lake Wisconsin drained through the gorge (Clayton and Attig, 1989). (Contrary to popular opinion, the preglacial Wisconsin River never flowed this way.) During the Wisconsin Glaciation, and perhaps during earlier ones as well, the gorge was clogged with glacial, fluvial, and lacustrine sediment, which is at least 135 m thick beneath the moraine southeast of Devils Lake. This plug of sediment prevented Lake Wisconsin from again spilling this way, forcing it instead to spill to the northwest, down the Black River (northeast of La Crosse).

Johnstown moraine. Devils Lake occupies a basin created by plugs of material across the gorge north and southeast of the lake. This material is part of a moraine formed during the Johnstown Phase of the Wisconsin Glaciation. The Johnstown moraine can be traced from Johnstown in southeastern Wisconsin, then south and west of Madison, to the Badger Army Ammunition Plant south of the South Range. From there it can be traced up around Devils Nose, down the east end of South Bluff, across the floor of the gorge about 1 km east of the southeast shore of Devils Lake, up the east

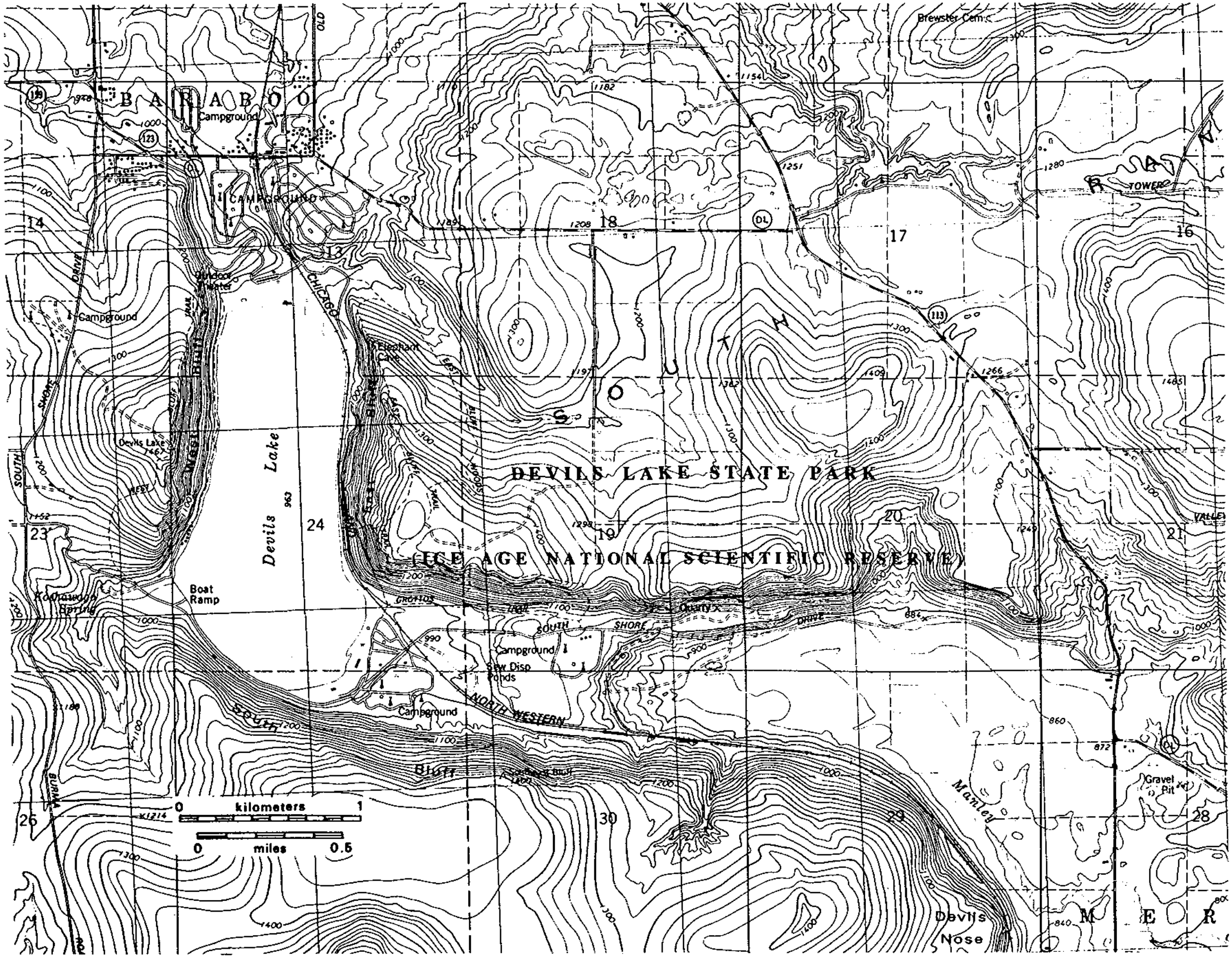

Figure 1. Location of East Bluff of Devils Lake gorge.

end of East Bluff to the crest of the South Range 6 km east of the lake, then back to the north end of Devils Lake and northwest to West Baraboo. As viewed from the east part of East Bluff, the moraine to the southeast of the lake is a conspicuous ridge across the gorge. Its west side is 20 m high and its east side is 50 m high. The moraine to the north of the lake is 20 m high and has been breached by a channel now occupied by the railroad. Where the moraine crosses the higher parts of the South Range, it is typically only about 15 m high.

Summit plateaus. The highest summits of the South Range are nearly flat plateaus above an elevation of 425 m (1,400 ft). Summit plateaus occur at the tops of East Bluff, West Bluff, and South Bluff. Devils Doorway Trail is at the south edge of the East Bluff summit plateau. Thwaites (1935, p. 395, 401-402; 1958, p. 140-141, 145-147; 1960, p. 36-38) suggested the plateaus were cut by wave action during the Ordovician Period.

Talus. The talus fans along the walls of Devils Lake gorge are up to 100 m high and are composed of angular boulders of Baraboo quartzite, some more than 3 m across. The boulders were eroded from the cliffs at the top of the gorge during the Wisconsin Glaciation and earlier. The abrupt termination of the talus on South Bluff at the west edge of the Johnstown moraine indicates that the talus formed before the moraine formed or as it formed, not after -- probably when permafrost was present and frost action was most active in the cliffs (Smith, 1949, p. 199-203). We know of no evidence that the talus is still accumulating.

Potholes. The quartzite surface on the south side of the summit plateau above South Bluff is pitted with a few dozen potholes (Black, 1964; 1974, fig. 66). Most occur within 100 m west of the junction of Potholes and Devils Doorway Trails, but some occur along the Potholes Trail, a few tens of metres below the plateau. They range from several centimetres to about 1 m in diameter and depth. The potholes were cut by stones in eddies at the bottom of a river. In a few places the quartzite surface between the potholes is polished as a result of sandblasting on the river bed.

Black (1964; 1968; 1974) suggested that the potholes were cut by a glacial meltwater river during Pleistocene time; he also suggested that those along Potholes Trail are plunge pools of a meltwater cascade over the cliff rather than potholes, but we know of no evidence that meltwater ever flowed here. More likely, they formed in the bottom of a river flowing here when the South Range was beginning to be exhumed during the Mesozoic or early Cenozoic, as argued by Thwaites and Twenhofel (1921).

Windrow Formation. The Windrow Formation was named after Windrow Bluff, west of Tomah in west-central Wisconsin (Thwaites and Twenhofel, 1921). It occurs as small isolated bodies of stream gravel on uplands in western and southwestern Wisconsin and adjacent areas. "A pint or so" of what would later be called Windrow gravel was observed in one of the East Bluff potholes by Salisbury (1895, p. 657); K.I. Lange, Devils Lake State Park naturalist, collected a pail of Windrow gravel from one of the potholes along Potholes Trail (verbal communication, 1986), but few other observers appear to have actually seen in-place Windrow Formation here. The "Windrow gravel" commonly reported at East Bluff instead consists of scattered loose pebbles on the quartzite surface or pebbles in Pleistocene hillslope deposits that were in part originally derived from the Windrow Formation. The pebbles consist of polished chert; many are well rounded and some contain Silurian fossils.

Black (1964) suggested that the Windrow gravel at East Bluff was deposited by a Pleistocene meltwater stream, but there is no evidence that meltwater ever flowed across the area. More likely it was deposited by a river that flowed here when the South Range began to be exhumed during the Mesozoic or early Cenozoic, as suggested by Thwaites and Twenhofel (1921).

Andrews (1958) defined an "East Bluff member" of the Windrow Formation, but no type section was designated. However, it seems unlikely that he actually saw any in-place Windrow gravel at East Bluff -- more likely he observed the pebbles in Pleistocene deposits that had originally been eroded from the Windrow Formation. For this reason, his "East Bluff member" is considered an invalid stratigraphic name. Andrews correlated his East Bluff member with the Ostrander Member of the Dakota Formation (Early Cretaceous) of southeastern Minnesota, but we know of no evidence that any of the Windrow Formation correlates with the Ostrander.

Quartzite blocks. In the unglaciated part of the South Range, block streams occur on the lower slopes below the summit plateaus. These lobate masses formed when permafrost was present during glaciation (Smith, 1949, p. 203-207). The block streams can be traced up slope to their source, which was commonly a low cliff of quartzite below the edge of a summit plateau. In a few places, angular blocks of quartzite can be seen next to a cliff, caught in the act of being separated from the cliff when the permafrost episode ended.

One much-illustrated quartzite block, upslope from a block field, is next to the service road from Steinke Basin, north of East Bluff. Black (1964, p. 169-171, figs. 1 and 6; 1968, p. 143, fig. 11; 1970, p. 72-73, fig. 15; 1974, p. 106, figs. 65 and 81) thought that it and others like it were glacial erratics. He argued that they are at the crest of the South Range and that no processes other than glaciation could have moved them there. However, this block is at least 10 m below the crest, and all the other large blocks here are also well below the crest, where they probably slid, rolled, or were rafted by solifluction when permafrost was present. Only small quartzite blocks occur on the crest; they lie directly on in-place quartzite or were frost-heaved onto the thin layer of wind-blown silt blanketing the plateau.

Boulders of igneous and metamorphic rock are present on the summit, but they are at the edge of service roads and were removed from the fill used to construct the roads. We have seen no evidence here for glaciation above East Bluff, although the east end of the bluff was clearly glaciated.

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Baraboo Quartzite at Skillett Creek, Wisconsin

B. A. Brown, Wisconsin Geological and Natural History Survey, 3817 Mineral Point Road, Madison, Wisconsin 53705

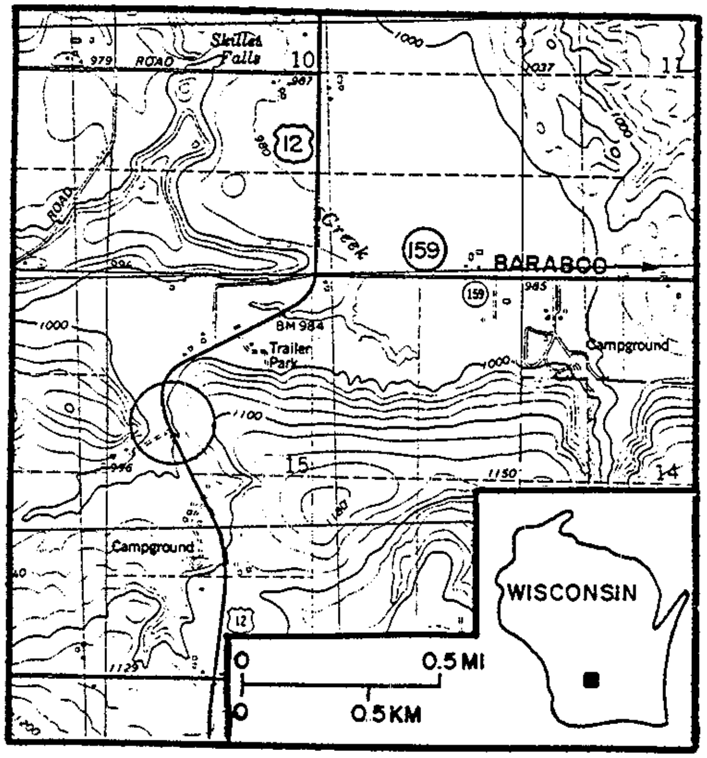

Figure 1. Location map.

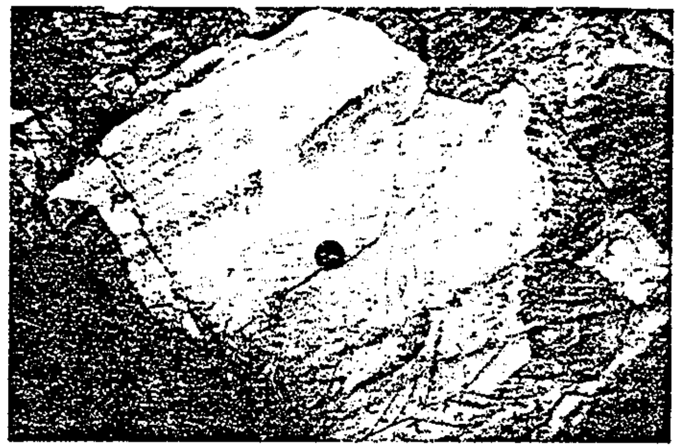

Figure 2. Cross-bedding in Baraboo Quartzite, lower part of exposure near road. Lens cap is 2 in (5 cm) in diameter.

Figure 3 Boudinaged and folded beds of quartzite interlayered with phyllite, upper part of exposure, above massive quartzite. Long dimension is approximately 6.5 ft (2 m).

LOCATION

The exposure is on the east side of U.S. 12, 0.3 mi (0.5 km) south of the junction with Wisconsin 159, SW¼,NW¼,Sec.15,T.11N.,R.6E., North Freedom 7½-minute Quadrangle (Fig. 1). **Caution:** Traffic on U.S. 12 is heavy, and there is a blind curve just north of the outcrop.

SIGNIFICANCE

This outcrop provides an opportunity to examine both the quartzite and phyllite facies of the Baraboo Quartzite. This is a classic exposure that exhibits important sedimentary and tectonic structures typical of the Baraboo interval rocks of Wisconsin (Greenberg and Brown, 1983, 1984; Brown, 1986).

DESCRIPTION

Pink quartzite, dipping 15° north, is exposed at the southern end of the outcrop. Good examples of sedimentary structures typical of the Baraboo Quartzite, including cross-bedding (Fig 2) and ripple marks, are present at this exposure. Dalziel and Dott (1970) refer to this exposure as an excellent example of the paleocurrent indicators that suggest a southward sediment transport direction at Baraboo. Locally, cross-bedding in individual sets of laminae shows contortion, particularly oversteepening, which Dalziel and Dott attributed to synsedimentary deformation.

At the north end of the exposure and on top of the cliff, argillaceous beds up to 6.5 ft (2 m) in thickness occur interbedded with thin (1.5 ft or less; 0.5 m) beds of quartzite, (Fig. 3). The thin quartzite beds within the less competent phyllite provide some spectacular examples of boudinage and parasitic folding. The S_1

cleavage, related to the formation of the Baraboo syncline, is nearly parallel to bedding in the phyllite at this location. Later crenulation cleavages and small-scale conjugate kinks cut the S_1 foliation at high angles. Late veins of white quartz cut the thin quartzite beds at a high angle to bedding. In thin section (Fig. 4), crenulation in the phyllite is quite apparent. Mineralogy is quartz, muscovite, and sometimes pyrophyllite, indicating a maximum of upper greenschist facies metamorphism. Recent road construction has uncovered additional exposures about 300 ft (90 m) to the north, around the curve of U.S. 12. This cut exposes the dip slope of the quartzite and contains some excellent tectonic structures, particularly refracted cleavage, in both the quartzite and phyllite.

This is an exemplary teaching outcrop and field trip stop. Please keep hammering and destructive sampling to a minimum.

Figure 4. Photomicrograph of crenulated phyllite. Note crenulations at high angle to phyllitic foliation. Field of view is about 8 mm in long dimension.

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International Geological Correlation Project 426: Granite Systems and Proterozoic Lithospheric Processes

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1998 International Field Conference: Proterozoic Granite Systems of the Penokean Terrane in Wisconsin

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Field Guide and Proceedings Volume

Part III

Technical Program and Abstracts

Technical Session Program
IGCP-426 1998 Field Conference

Holiday Inn, Wausau/Mosinee, Wisconsin
Thursday 17 September

Morning Session

0820	01	OPENING REMARKS: J. S. Bettencourt, O. T. Rämö, & W. R. Van Schmus
0830	02	STYLE AND DISTRIBUTION OF GRANITIC ROCKS IN THE PENOKEAN TERRANE OF NORTH-CENTRAL WISCONSIN, USA. J. K. Greenberg
0850	03	A TALE OF TWO BATHOLITHS: COMPARATIVE ANATOMY OF THE SHERMAN AND WOLF RIVER BATHOLITHS. B. R. Edwards & C. D. Frost.
0910	04	ORIGIN AND EVOLUTION OF THE WOLF RIVER BATHOLITH AND OTHER ANOROGENIC MAGMATIC COMPLEXES: INFERENCES FROM A COMPARATIVE STUDY. Hanna Nekvasil.
0930	05	EMPLACEMENT OF A VITROPHYRIC LAVA DOME IN THE ST. FRANCOIS TERRANE OF MISSOURI: CONSTRAINTS IMPOSED BY AMPHIBOLE. G. R. Lowell
0950		Coffee Break
1020	06	THE 1.88-1.87 GA POST-KINEMATIC PLUTONS OF THE CENTRAL FINLAND GRANITOID COMPLEX: A SHIFT IN THE AGE OF C-TYPE AND A-TYPE MAGMATISM DURING LITHOSPHERIC CONVERGENCE. M. Nironen, B. A. Elliott, & O. T. Rämö.
1040	07	1.88-1.87 Ga POST-KINEMATIC PYROXENE-BEARING PLUTONS OF THE CENTRAL FINLAND GRANITOID COMPLEX: CONTRASTING A-TYPE AND C-TYPE AFFINITIES. B. A. Elliott, M. Nironen, O. T. Rämö.
1100	08	Nd AND Pb ISOTOPIC COMPOSITION OF POST-KINEMATIC AND RAPAKIVI GRANITOIDS IN THE FINNISH SVECOFENNIAN: EVIDENCE FOR TWO MICROCONTINENTS. O. T. Rämö, M. Nironen, B. A. Elliott.
1120	09	PETROGENESIS OF THE BIMODAL RAPAKIVI-RELATED VOLCANITES OF THE ISLAND OF HOGLAND, 1.64 GA WIBORG BATHOLITH, RUSSIA. A. M. Belyaev, Y.B. Bogdanov, & O.A. Levchenkov.
1140	10	TWO DIFFERENT TYPES OF NEOPROTEROZOIC TIN-BEARING GRANITES IN THE BAIKAL MOUNTAIN REGION. A.M. Larin, L.A. Neymark, A.A. Nemchin, & E.Yu. Rytsk
1200		Lunch
[*]	11	PB-PB AND SM-ND CONSTRAINTS OF THE VELHO GUILHERME INTRUSIVE SUITE AND VOLCANIC ROCKS OF THE UATUMÃ GROUP, SOUTH-SOUTHEASTERN PARÁ, BRAZIL. N. P. Teixeira, J. S. Bettencourt, C. A. V. Moura, & R. Dall'Agnol. [*POSTER]

Afternoon Session:

1330 12 SHRIMP U-PB GEOCHRONOLOGY ON HIGH-U ZIRCON AND COEXISTING TITANITE GRANITES FROM THE PROTEROZOIC TELFER DISTRICT, WESTERN AUSTRALIA. J.M. Dunphy & N.J. McNaughton.

1350 13 PETROLOGY OF THE ANOROGENIC, OXIDIZED JAMON AND MUSA GRANITES, AMAZONIAN CRATON: IMPLICATIONS FOR THE GENESIS OF PROTEROZOIC A-TYPE GRANITES. R. Dall'Agnol, O. T. Rämö, M. Sacramento de Magalhães, & M. J. B. Macambira.

1410 14 MAGMATISM OF THE IRIRI FORMATION AND ASSOCIATED AU-SULFIDE MINERALIZATION IN THE CEDRO BOM AREA, SOUTHEASTERN AMAZON CRATON. M. A. S. B. Pinho, F. Chemale, F. E. C. Pinho, E. F. Lima.

1430 15 U-Pb AND Sm-Nd ISOTOPIC DATA OF THE BASEMENT ROCKS IN THE EASTERN PART OF THE RONDÔNIA TIN PROVINCE, BRAZIL. B. L. Payolla, M. Kozuch, W. B. Leite, Jr., J. B. Bettencourt, & W. R. Van Schmus.

1450 Coffee Break

1520 16 GRANITIC ROCKS FROM THE CABAÇAL BELT, ALTO JAURU GREENSTONE BELT, MATO GROSSO-BRAZIL. F. E. C. Pinho.

1540 17 PROTEROZOIC GRANITOIDS IN SW MATO GROSSO, BRAZIL: EVIDENCE FOR PARALLEL MAGMATIC ARCS IN SW AMAZONIA. M. C. Geraldes, W. R, Van Schmus, M. Kozuch, A. H. Fetter, C. C.G. Tassinari, & W. Teixeira.

1600 18 THE LATE PRECAMBRIAN PLURISERIAL MAGMATIC SYSTEM IN THE RIBEIRA BELT, SE BRAZIL. E. Wernick.

1620 Adjourn

1630 BUSINESS MEETING (J. S. Bettencourt, O. T. Rämö, & W. R. Van Schmus, moderators).

Papers presented by correspondence:

C1 PETROLOGICAL TYPES AND STRUCTURAL POSITION OF THE UKRAINIAN SHIELD'S PROTEROZOIC GRANITOID ASSOCIATIONS. V. P. Kirilyuk, A. M. Lyssak, & V. G. Pashchenko.

C2 PETROGENESIS OF EARLY PROTEROZOIC DONGARGARH AND MALANJKHAND GRANITOIDS OF CENTRAL INDIA: A REAPRAISAL. Santosh Kumar.

C3 PROTEROZOIC AND PHANEROZOIC COLLISION GRANITE SYSTEMS AS MARKERS OF MANTLE CELLS MODIFICATION: THE NORTHERN SIBERIA CASE STUDY. O. M. Rosen.

C4 BREATHING GRANITE-MAGMA GENERATION ALONG THE PALEOPROTEROZOIC FENNOSCANDIA-SARMATIA SUTURE ZONE: GRANITES DIVERSITY IN THE NORTH-WESTERN UKRAINIAN SHIELD. E. M. Slivko & B. I. Malyuk

C5 TYPES AND TECTONIC POSITION OF THE EARLY PROTEROZOIC GRANITOIDES IN THE SARMATIA (ON THE EXAMPLE OF THE UKRAINIAN SHIELD). K. I. Sveshnikov

C6 PETROLOGIC RANGES OF AURIFEROUS GNEISSES AND GRANITOIDS IN THE EARLY PROTEROZOIC PROTOPLATFORMS (EXEMPLIFIED BY THE UKRAINIAN SHIELD). G. M. Yatsenko & E. M. Slivko

PETROGENESIS OF THE BIMODAL RAPAKIVI-RELATED VOLCANITES OF THE ISLAND OF HOGLAND, WIBORG BATHOLITH, RUSSIA

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The island of Hogland is situated in the eastern part of the Gulf of Finland near the southern margin of the 1.62 – 1.65 Ga Wiborg rapakivi granite batholith (WB). The basement is composed of Svecofennian supracrustal and plutonic rocks that are overlain by a subhorizontal, 0 to 20 m thick quartzite conglomerate. These rocks are covered by anorogenic rapakivi-related volcanic rocks.

The volcanic succession comprises a 0 to 10 m thick quartz porphyry (at the bottom), a 0 to 40 m thick basalt plagioclase porphyrite, and up to 100 m thick quartz porphyry (at the top). The basalt plagioclase porphyrites have an ε_{Nd}(at 1640 Ma) value of –1.8 [1] and might be syngenetic with the gabbro-anorthosites or diabase dykes of the WB and the Suomenniemi batholith (SB) [2]. Geochemically, the plagioclase porphyrites of Hogland are alkaline basalts similar to the gabbro-anorthosite-related diabases of WB and SB [cf. 2]. However, these basalts exhibit extreme variations in Na_2O and K_2O (0.15 – 5.5 wt.% and 1.3 – 4.7 wt.%, respectively) and the K_2O/Na_2O-ratio (0.3 to 20). Basaltic tuffs and lava breccias have the Na_2O contents as low as 0.15 wt.% (K_2O/Na_2O = 20).

Granular quartzites are intercalated with the basalts as 0.5 – 2 m thick layers and have 76.4 – 78.6 wt.% SiO_2, 3.6 – 3.7 wt.% K_2O, and 0.15 wt.% Na_2O. The remarkable enrichment in potassium may indicate that these rocks were initially formed as chemical sediments. Pillow structures are typical of some of the plagioclase porphyrites overlying the quartzites. Spherical pillows 0.5 to 1 m across are encompassed by a 1 – 5 cm thick film of fine-grained quartzite. Typically, the outer zones of the pillows are enriched in K_2O (3 – 4 wt.%) and relatively poor in Na_2O (2.8 – 3.8 wt.%) compared to their cores (K_2O = 1.3 – 1.8 wt.%, Na_2O = 3.9 – 5.5); K_2O/Na_2O increases from 0.33 up to 0.9 – 1.5 towards the outer parts of the pillows. We suppose that these variations were caused by interaction between basaltic magmas erupted at the shallow-submarine environment and hot, K-rich, Na-poor water.

Conventional U-Pb dating of zircons gave a 1640 (11 Ma upper intercept age for the quartz porphyry underlying the basalt plagioclase porphyrite. The age of the quartz porphyry of the overlying upper strata was previously well-constrained to 1638 (4 Ma [1]. These data confirm that the bimodal volcanites of Hogland were formed contemporaneously with the rapakivi granites of WB and SB.

The upper quartz porphyry has an ε_{Nd}(T) of –1, similar to that in the rapakivi granites from WB and SB [2]. This indicates that rapakivi granites and the upper quartz porphyries of Hogland might have been derived from the same Svecofennian crustal source. The lower quartz porphyries gave an $\varepsilon_{Nd}(T)$ of −4.8. It is likely that the initial magma for these rocks was derived from mixed Archean and Proterozoic sources, similarly to the current interpretation of Sm-Nd-data for the rapakivi granites of the 1.54 Ga Salmi batholith, Karelia [2, 3]. The lower and upper quartz porphyries are, however, nearly identical in chemical composition and REE patterns.

Pillow-like structures were recognized in the quartz porphyries on the north-east coast of the island. We suggest that the felsic volcanites of Hogland might, at least in part, have been formed at submarine conditions. The quartz porphyries of Hogland are similar to the ovoid-bearing rapakivi granites of WB in the sense of their bulk composition and REE patterns. However, the porphyries display unique proportions of K_2O (6 – 8.9 wt.%) relative to Na_2O (0.2 – 0.75 wt.%). Their K_2O/Na_2O-ratio varies from 10 to as high as 50 which substantially exceeds that in the rapakivi granites.

The abnormal proportions of alkalies in the quartz porphyries and the presence of the pillow-like structures are interpreted here as a consequence of interaction between magmas and hot, K-rich, Na-poor water. Textural and chemical evidence supporting this idea was found also in the granite gneisses of the basement which have been metasomatically altered, overheated, recrystallized and, sometimes, partially melted due to heat conducted from the overlying volcanic pile. For example, the content of potassium and the K_2O/N_2O ratio are much higher in the granite gneisses that underwent metasomatism, recrystallization and re-melting compared to those that did not.

We assume that both the compositional pattern of the alkaline components in the volcanites and reworking of the underlying granite gneisses were caused by water-magma and water-rock interaction. Our data allow us to speculate that a potassium-saturated hydrotermal system was formed due to release of fluids from the rapakivi-granite magma.

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PETROLOGY OF THE ANOROGENIC, OXIDIZED JAMON AND MUSA GRANITES, AMAZONIAN CRATON: IMPLICATIONS FOR THE GENESIS OF PROTEROZOIC A-TYPE GRANITES

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The 1.88 Ga Jamon and Musa granites are magnetite-bearing anorogenic, A-type granites of Paleoproterozoic age. They intrude the Archaean rocks of the Rio Maria Granite-Greenstone Terrain in the eastern part of the Amazonian Craton in northern Brazil. Biotite ± amphibole monzogranite to syenogranite, with associated dacite porphyry (DP) and granite porphyry (GP) dykes, dominate in this suite that vary from metaluminous to peraluminous and show high FeO/(FeO + MgO) and K_2O/Na_2O. In spite of their broad geochemical similarities, the Jamon and Musa granites show some significant differences in their REE patterns and in the behaviour of Y. The Jamon granites are related by fractional crystallization of plagioclase, potassium feldspar, quartz, biotite, magnetite ± amphibole ± apatite ± ilmenite. Geochemical modelling and Nd isotopic data indicate that the Archaean granodiorites, trondhjemites and tonalites of the Rio Maria region are not the source of the Jamon Granite and associated dyke magmas. Archaean quartz diorites, differentiated from the mantle at least 1000 m.y. before the emplacement of the granites, have an adequate composition to generate DP and the hornblende-biotite monzogranite magmas by different degrees of partial melting. A larger extent of amphibole fractionation during the evolution of the Musa pluton can explain some of the observed differences between it and the Jamon pluton. The studied granites crystallized at relatively high fO_2 and are anorogenic magnetite-series granites. In this aspect, as well as concerning geochemical characteristics, they display many affinities with the Proterozoic A-type granites of south-western United States. The Jamon and Musa granites differ from the anorthosite - mangerite - charnockite - rapakivi granite suites of north-eastern Canada and from the reduced rapakivi granites of the Fennoscandian Shield in several aspects, probably because of different magmatic sources.

SHRIMP U-PB GEOCHRONOLOGY ON HIGH-U ZIRCON AND COEXISTING TITANITE GRANITES FROM THE PROTEROZOIC TELFER DISTRICT, WESTERN AUSTRALIA

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SHRIMP (Sensitive High Resolution Ion MicroProbe) U-Pb studies on accessory mineral phases such as zircon have often been used to place constraints on the age and evolution of geological samples. Commonly, zircons with relatively low U contents are analysed, as a correlation between high U concentrations and Pb loss and/or high common Pb has frequently been noted. This is due to the degeneration of the zircon structure as a result of radioactive decay of the U, which causes the grains to become metamict and susceptible to mobility of the daughter products (Pb). In some circumstances, however, no suitable low-U grains can be found, resulting in poor data quality, which translates into large uncertainties in the calculated ages. Under such conditions it may be more useful to turn to other co-existing accessory phases such as titanite, monazite and/or xenotime in order to extract more meaningful data. Titanite commonly contains trace amounts of U and its structure generally excludes initial (common) Pb, hence making it ideal for U-Pb radiometric dating. In this paper we will present SHRIMP U-Pb data for both zircon and co-existing titanite from several granitoids of the Proterozoic Telfer district (Paterson Province, Western Australia). We demonstrate that in highly fractionated granites such as these, U-Pb dating using zircon produces unreliable and erroneously low ages, whereas coexisting titanite gives ages which are both precise and accurate.

Telfer is one of Australia's largest gold producers with more than 4 million ounces (125 tonnes) of gold produced since 1977 (Rowins et al. 1997). An epigenetic origin for the mineralisation has been proposed, with gold predominantly contained in stratabound to strataform gold-copper sulphide reefs with associated stockwork and sheeted veining (Goellnicht et al. 1989; Rowins et al. 1997). A currently accepted model for the deposit involves mobilisation of metals in a hydrothermal cell, focusing of the fluids and deposition in structurally and chemically favourable traps. Goellnicht et al. (1989) postulated that the heat source and possibly the fluid source for the system was nearby, spatially-associated granites. Approximately 20% of the Telfer district is underlain by granites which have been classified into two main groups on the basis of geological field relationships, petrology, geochemistry, relative timing and Pb isotopic composition (Goellnicht, 1992). The Mount Crofton suite consists of generally undeformed, late- to post-tectonic, fractionated (>71 wt% SiO_2), magnetite-bearing granites which have a Pb-Pb isochron age of 678 ± 36 Ma (Goellnicht, 1992). The Minyari suite has an indistinguishable Pb-Pb age of 643 ± 34 Ma and consists predominantly of less fractionated, ilmenite-bearing granites (Goellnicht, 1992).

In an effort to better resolve the temporal evolution of the Telfer region, we analysed several samples from both the Mount Crofton and Minyari suites using standard U-Pb SHRIMP methods. A summary of the results and previous zircon studies is presented in Table 1.

Table 1. Summary of published and preliminary U-Pb SHRIMP results for Telfer granitoids.

	zircon[3]	U (ppm)	titanite[3]	U (ppm)
<u>Minyari suite</u>				
Biotite syenogranite (M21)[1]	630±8	115-2235	631±5	66-221
Biotite monzogranite (M34)[1]	627±9	109-7720	645±5	97-426
Biotite monzogranite[2]	633±13	170-4008	not analysed	
<u>Mount Crofton suite</u>				
Biotite monzogranite (CG3)[1]	ca. 599	126-2880	654±9	76-269
Biotite monzogranite (CG2)[1]	min. 595	353-8375	not yet available	
Biotite monzogranite (C85b)[1]	622±6	126-935	639±9	69-224
Biotite monzogranite[2]	621±13	221-9564	not analysed	

[1]This study [2]Nelson, 1995 [3]($^{206}Pb/^{238}U$ ages in Ma)

Both the Mount Crofton and Minyari suites are highly fractionated (Goellnicht, 1992) and their zircons have correspondingly high U-contents and accompanying Pb-loss from radiation-damaged areas of some zircon grains. Coexisting titanite, in comparison, has significantly lower U-contents and does not appear to have suffered Pb-loss, giving consistent and concordant age data which is generally older than the zircon data. Although inherited titanites may also explain the older titanite data, analyses for each sample form a single age population, suggesting they are not of xenocrystic origin. The data therefore suggest that the crystallisation age of the granites is best determined by the titanite data, with the zircon data providing a minimum age. The overlapping ages for samples from the Minyari and Mount Crofton suites suggests they are coeval. This result, coupled with the geochemical and isotopic studies of Goellnicht (1992), suggests that they were derived at the same time from different sources, and that these sources must have already been juxtaposed at ca. 654-632 Ma.

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A TALE OF TWO BATHOLITHS: COMPARATIVE ANATOMY OF THE SHERMAN AND WOLF RIVER BATHOLITHS

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The Sherman (1.43 Ga) and Wolf River (1.49 Ga) batholiths share many characteristics that make them distinctive among the 50+ magmatic bodies that perforated North America during the middle Mesoproterozoic (1.5-1.4 Ga). The 9200 km^2 Wolf River batholith comprises 11 separate plutons (Anderson, 1980) with a range in rock types including : anorthosite, Ol-Cpx monzonite, rapakivi granite (Wolf River granite), coarse- (Belongia coarse granite), and medium-grained biotite hornblende granite (Belongia fine granite). The 1300 km^2 Sherman batholith has a minimum of eight lithologically distinct units including the same suite of rocks found in the Wolf River batholith: Ol-Cpx quartz monzonite (Blair Road quartz monzonite), rapakivi granite (Sherman granite), coarse-, and medium-grained biotite hornblende granite (Lincoln granite). The Sherman batholith also contains two sets of minor monzodiorite intrusions / dikes. Although not included within the boundaries of the Sherman bathlith, a large, contemporaneous body of anorthosite, the 1.43 Ga Laramie Anorthosite complex, is located immediately northwest of the batholith.

The volumetrically dominant intrusions of the Sherman and Wolf River batholiths, the Sherman and Wolf River granites, are petrologically similar. They both are coarse-grained, biotite hornblende quartz monzonites and granites with accessory zircon, titanite, and flourite. In both intrusions rapakivi textures are common. They also share many geochemical characteristics including anomalously high K_2O contents (>5 wt. % at 70 wt. % SiO_2) and extreme enrichments in FeO relative to MgO (FeO/FeO+MgO >0.9). Both have recently been recognized as the type examples of reduced rapakivi, anorogenic granitic magmatism in North America (Frost and Frost, 1997). Reduced rapakivi-type granites are a subset of anorogenic or A-type granites that are characterized by rocks formed under dry and relatively reducing conditions (oxygen fugacities 1-3 log units below FMQ; Frost and Frost, 1997). The Sherman and Wolf River batholiths share a similar geologic and tectonic setting as well. The Wolf River batholith was emplaced at relatively shallow depths (~3.8 km; Anderson, 1980) in predominantly calc-alkaline Paleoproterozoic rocks accreted to the edge of the Archean Superior craton (Anderson et al., 1980). The Sherman batholith intruded mainly calc-alkaline Paleoproterozoic rocks along the southern margin of the Archean Wyoming craton, although at slightly deeper depths (6-12 km; Frost et al., in prep). Both batholiths formed in an anorogenic tectonic environment, possibly in response to crustal heating and extension associated with intrusion of mantle-derived magmas into the lower crust.

The main differences between the two batholiths arise from the details of their petrogenesis. The Sherman batholith has a much larger documented volume of associated, contemporaneous mafic magmatism than the Wolf River batholith. Abundant field and geochemical evidence demonstrates that mixing and mingling between mafic and granitic magmas was locally important in the Sherman batholith; if existent, such processes are not well documented in the Wolf River batholith. Also, in the Wolf River batholith fractional crystallization is considered to be an important differentiation process accounting for some of the chemical variations between low silica and higher silica intrusions (e.g., Wolf River granite - Belongia coarse granite - Belongia fine granite differentiation trend; Anderson 1980). However, in the Sherman batholith variations in source region appear to better account for geochemical differences between intrusions than does fractional crystallization.

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1.88-1.87 Ga POST-KINEMATIC PYROXENE-BEARING PLUTONS OF THE CENTRAL FINLAND GRANITOID COMPLEX: CONTRASTING A-TYPE AND C-TYPE AFFINITIES

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A suite of post-kinematic, 1.88 - 1.87 Ga, silicic plutons crosscut 1.89 - 1.88 Ga synkinematic granitoids in the Central Finland Granitoid Complex (CFGC) in south-central Finland. This post-kinematic suite may be divided into three groups based on petrography, mineralogy, outcrop characteristics, and mineral chemical variation: the Type 1 plutons are granodiorites and granites and flank the CFGC in the south, the Type 2 plutons are biotite ± hornblende monzogranites concentrated in the western and southern CFGC, and the Type 3 plutons have a pyroxene ± olivine assemblage (Type 3a), or contain pyroxene throughout (Type 3b, situated mainly in the eastern part of the CFGC) (Elliott et al., 1998, in press). This study emphasizes a comparison of the two groups of pyroxene-bearing plutons: Jämsä and Petäjävesi (Type 3a), and Rautalampi, Konnevesi and Haukivesi (Type 3b).

The Type 3a plutons have higher SiO_2, higher $FeO/(FeO+MgO)$, and K_2O values and lower CaO, MgO, P_2O_5, Al_2O_3, and TiO_2 than the Type 3b plutons. The Type 3a plutons define a more tholeiitic trend similar to the rapakivi granites of southeast Finland, and the Type 3b more calc-alkaline on the AFM diagram. The REE plots of the Type 3a and 3b are similar and rather flat; however, the marginal assemblage of the Type 3a plutons show a slight positive Eu anomaly, whereas the central assemblage has a slightly negative Eu anomaly.

The 1.88-1.87 Ga post-kinematic plutons register a shift in age as well as magma type: a general trend of older plutons with C-type characteristics in the northeast to younger plutons with many A-type features in the southwest of the CFGC (cf. Nironen et al., this volume). Differences in geochemistry are also reflected in mineralogy and conditions of formation. The Type 3a plutons contain a fayalite-bearing assemblage, a notable feature in many A-type granites (Kilpatrick and Ellis, 1992). Also, hornblende is perhaps the most common mafic silicate of Type 3a plutons and, like fayalite, absent in the Type 3b plutons. The olivine and pyroxenes of the Type 3a plutons are considered to be restite phases, and are commonly reacted to hornblende and annite biotite. The main mafic silicates of the Type 3b plutons are orthopyroxene, clinopyroxene, and biotite. The presence of early biotite in the Type 3b plutons are suggestive of an anhydrous, high temperature enviroment during crystallization. Thus, the Type 3b plutons have a C-type character, whereas the Type 3a plutons have a "mixed" character between C-type and A-type.

The Type 3a plutons record emplacement conditions during cooling (amphibole barometry and amphibole-plagioclase thermometry) of 750° to 875°C at 2.5 to 4.9 kbar. Olivine-pyroxene barometry calculations for Type 3a suggest pressures between 3.3 and 6.8 kbar, and a minimum pressure calucualtion for orthopyroxene in Type 3b around 4.2 to 6.9 kbar at a temperature range of 800° to 1000°C. QUIIF equilibria calculations from the Type 3a plutons probably reflect re-euilibration during cooling at temperatures between 450° and 800°C, and oxygen fugacities between -0.3 and -1.7 ΔFMQ.

The 1.88-1.87 Ga pyroxene-bearing granites of the CFGC were probably derived from a hot, relatively reduced, dry source. The pressure calculations estimatate depths of 18 to 25 km, probably recording conditions in a mid-crustal magma chamber. The plutons that comprise an olivine-pyroxene marginal assemblage (Type 3a) were emplaced at a relatively more shallow level (8-15 km), under more oxidizing conditions (0.65 to -1.6 ΔFMQ), probably the result of progressive hydration during cooling. The Type 3b plutons with C-type magma characteristics reflect a hotter, more anhydrous source material, and deeper level of emplacement.

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PROTEROZOIC GRANITOIDS IN SW MATO GROSSO, BRAZIL: EVIDENCE FOR PARALLEL MAGMATIC ARCS IN SW AMAZONIA

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SW Amazonia consists of several NW-SE trending belts that become younger from the Archean nucleus (>2.5 Ga) to the southwest, beginning with the 2.25 to 1.8 Ga Ventuari-Tapajós Province (VTP) and the 1.75 to 1.5 Ga Rio Negro-Juruena province (RNJP). Next youngest is the Rondonia-San Ignacio Province (RSIP) exposed in Brazil and Bolivia. The RSIP is parallel to and outboard of the RNJP; it consists of older sialic basement metamorphosed between 1.45 and 1.25 Ga (≈ 1.30 Ga San Ignacio orogeny in Bolivia [1]) and includes A-types granites grouping at ca. 1.0 Ga, 1.2 Ga, 1.4-1.5 Ga and 1.57 Ga [2]. Limited data suggest that some of the basement in the RSIP is a SW extension of the RNJP. The youngest belt in the Amazon Craton is the Sunsas Province (SP). It is sub-parallel to and west of RSIP and is best exposed in Bolivia. Major metamorphism and plutonism in the Sunsas orogen occurred from 1.1 to 0.9 Ga [1]. The RSIP and SP are similar in many ways to the Grenville province, which has lead to suggestions regarding spatial as well as temporal correlation [3]. Although this correlation has been based on a chronology for SW Amazonia that is largely controlled by K-Ar and Rb-Sr ages, Bettencourt et al. [4] reported paleomagnetic data for ca. 1000 Ma that support the spatial relationships.

We have carried out 4 U/Pb and Sm/Nd analyses from units in the Pontes e Lacerda area where rocks of RNJP and SP occur and whole rock analysis for major and trace elements. The U/Pb analyses were carried out on granitoids of: (1) The Alto Guaporé Metamorphic Complex (AGC). Three zircon fractions plotted on a U-Pb concordia diagram yield an upper intercept at 1450 ± 13 Ma. The Sm/Nd crustal formation age (TDM) is 1.55 Ga. (2) Santa Helena Granite-Gneiss (SHGG) is represented by gray to pink, usually equigranular, foliated biotite granites. Zircon fractions from this unit yield an upper intercept (crystallization age) of 1434 ± 07 Ma. The Sm/Nd crustal formation age (TDM) for this unit is 1.62 Ga. (3) The Maraboa Granite is an isotropic granite included in the SHGG in existing geologic maps. The U-Pb results of MG yield an upper intercept (crystallization age) at 1475 ± 35 Ma. The Sm/Nd crustal formation age (TDM) for this unit is 1.70 Ga. (4) Three zircon fractions from hornblende tonalite were analyzed and this rock is informally referred to here as the Lavrinha Tonalite. The rock is gray to green, isotropic, with medium to coarse grain size. Three zircon fractions analysed plotted on a U-Pb concordia diagram yield an upper intercept (crystallization age) at 1463 ± 4 Ma; all three analyses fall near concordia, resulting in a high-precision age. The Sm/Nd crustal formation age (TDM) for this unit is 1.53 Ga.

The agreement among all the crystalization ages indicate their formation in a short time interval related to an important wide-spread granite-forming event. The Nd data suggest that the original granite magma was derived from a source containing a significant older crustal component (for the granites) and the tonalite originated from a source containing a very little, if any, older crust.

Table 1. U/Pb ages and Sm/Nd Isotopic Properties of Samples Studied.

No.	Number	Rock Description	U/Pb age (Ma)*	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(t)$	TDM**
1.	97-102	Orthogneiss (AGC)	1450 ± 13	-15.4	3.1	1.55
2.	97-115	SHGG	1434 ± 07	-8.9	3.1	1.62
3.	29-697	Maraboa Granite	1475 ± 35	-7.1	2.6	1.70
4.	30-545	Lavrinha Tonalite	1463 ± 04	-13.1	3.8	1.53

AGC = Alto Guaporé Complex; SHGG = Santa Helena Granite-Gneiss. (*)=2σ. (**)=Ga

The major and trace elements analyses (n=15) show a variation from quartz monzogabbro and tonalites to granodiorites and granites *sensu latu*, following a Streckeisen [5] diagram. The SiO_2 amount ranges from 50 to 56% in the more primitive rocks\, 66.5 to 69% in the intermediate rocks,and reaches 70.9 to 77.5% in the more fractioned rocks. CaO ranges from 6.8 to 10.9, 3 to 3.2, and 0.1 to 0.9%, respectively. MgO ranges from 6.8 to 11.4, 0.7 to 1.7, and 0.03 to 0.6%, respectively. The Al_2O_3 contents indicate that the rocks are metaluninous and peraluminous. The results indicate a volcanic arc granites (VAG) affinity for the primitive and intermediates rocks, and the granits plot near the boundary of VAG and within plate granites (WPG), following the Pearce et. al. [6] tectonic discrimination diagram. The REE patterns indicate a higher frationation betwen LREE and HREE in the primitive rocks than in the intermediate and fracionated ones with a positive Eu anomaly in the primitive rocks, a light negative Eu anomaly in the intermediate rocks, and a strong Eu negative anomaly in the granites.

Our results clearly show that much of the inferred chronology for the region, based on Rb/Sr and K/Ar ages, needs to be revised as new U/Pb ages using zircons and Sm/Nd crustal formation ages are obtained. As a preliminary working model, we present the following interpretations:

1. Igneous and meta-igneous rocks in the Pontes e Lacerda region represent magmatic activity that occurred about 1440 to 1470 Ma. We tentatively conclude that the granites, orthogneisses, and tonalite are all components of a ca. 1450 ± 20 Ma NW-trending volcano-plutonic arc (Santa Helena Arc).

2. The relatively young Sm/Nd crustal formation ages for this complex suggest that parts of it represents juvenile crust and is probably the result of cratonic manifestations of igneous activity associated with the Santa Helena Arc, in which the associated subduction zone dipped east under the 1.7 to 1.8 Ga continental margin. The Santa Helena Arc probably represents the eastern part of SE extensions of the Rondonia-San Ignacio Province [7].

3. The age pattern of 1450 Ma rocks intruded into or adjacent to 1.7 to 1.8 Ga continental crust is similar to relationships along the eastern and southern margin of Laurentia prior to 1400 Ma and would be compatible with tectonic models [3] which propose proximity between Laurentia and Amazonia about 1800 to 1400 Ma.

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STYLE AND DISTRIBUTION OF GRANITIC ROCKS IN THE PENOKEAN TERRANE OF NORTH-CENTRAL WISCONSIN, USA

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Northern Wisconsin contains an impressive variety of "granites", considering the rather small area (about 50,000 square kilometers) of sparsely exposed Precambrian crystalline rock. The Penokean-aged orogeny, ca. 1900 to 1810Ma is represented by two terranes, a northern block dominated by Archean sialic basement and a complex southern terrane which includes the great majority of Proterozoic intrusive exposures. Most investigators consider the southern terrane to represent material accreted to the north during Penokean convergence(1,2). Ages, chemical affinities and geophysical signatures of the respective rock units on either side of the terrane boundary are in sharp contrast, indicating a major tectonic discontinuity, perhaps a suture zone. However, there is no evidence (Na/K ratios, etc.) indicating subduction polarity or other zonation within either of the terranes.

Penokean granitic rocks south of the terrane boundary are all consistent with their derivation from orogenic activity and relatively "depleted" Proterozoic sources. Compositions range from dioritic suites of tonalite, quartz diorite and granodiorite to true granites. Mineral, chemical and field characteristics place all known units in the category of I-type and calcalkaline. Rock fabrics vary from highly deformed and migmatized granitic gneiss to exposures displaying no sign of deformation during or after crystallization. Penokean intrusions are typically exposed at mid-crustal levels associated with low to moderate metamorphic conditions, lower greenschist to middle amphibolite facies.

Distinctly post-orogenic ca. 1760Ma granites and rhyolites occur within the southern Penokean terrane and more commonly south of the exposed Precambrian, as inliers among Cambrian sandstone(3). These units are also calcalkaline but exhibit no sign of deformation. The granite/rhyolite association is exposed at high crustal levels. They are not associated with any tectonic "event" and have no known correlation with other magmatic rocks outside the region. There is the slightest hint of bimodality indicated from two exposures in southcentral Wisconsin where there are minor basaltic enclaves or dikes. It is thought that this stage of Wisconsin magmatism is genetically related to the deposition of Baraboo Interval sediments, now mostly represented by quartzites(4,5). Although the 1760Ma granites are compositionally rather homogeneous, they display a variety of textural types, including, granophyric, spherulitic, aplitic as well as idiomorphic and porphyritic. Most contain one hypersolvus feldspar.

The Wolf River batholith and its smaller satellite plutons of ca. 1485 Ma age are located in the southeastern part of Wisconsin's exposed Precambrian. These rocks include a bimodal suite of compositions, ranging from one and two-feldspar porphyritc granites (rapakivi included) to minor exposures of associated monzonite and anorthosite(6). The satellitic Wausau pluton also contains peralkaline syenite. Geophysical data indicate that the batholith forms a sheet of variable thickness that is tilted to the south, thus exposing some of the deeper lithologies to the north. This anorogenic suite is considered part of a transcontinental association of early to late Proterozoic intrusions that are exposed from the southwestern U.S., through Colorado, Missouri, Wisconsin, southeastern Canada and into Scandinavia and the Baltic. Compositional traits and features such as rapakivi texture and mafic associations clearly distinguish the 1485Ma granites from earlier granitic magmatism in Wisconsin.

As a province, the Penokean of Wisconsin possesses granites with unusually little economic mineralization. A few minor occurrences of mineralization exist (Li and Mo in 1835Ma granite and U and Zr in granite of 1485Ma), but depth of erosion, paucity of exposure, or perhaps derivation from depleted sources may explain why this region has not shown more economic potential. The progressive change in style of granitic magmatism occurred as the region underwent cratonization (7).

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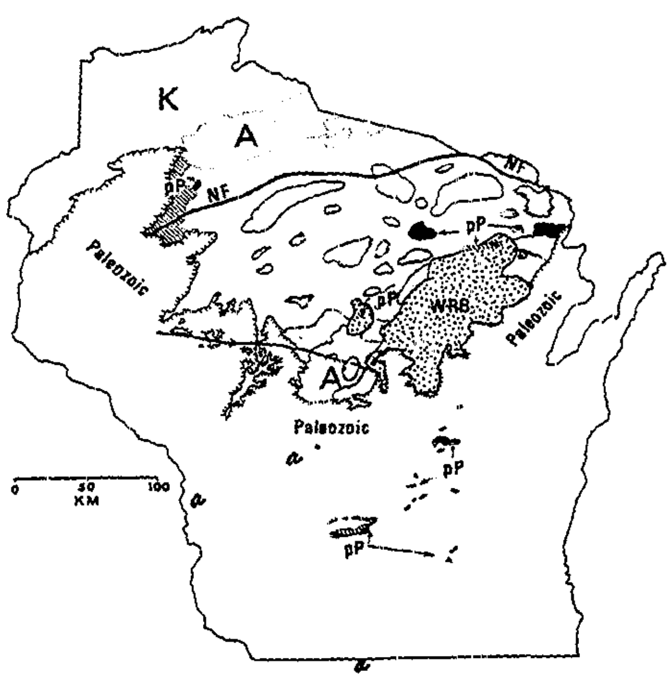

Granitic Rocks of Wisconsin:
*Penokean intrusions shown by enclosed fields, no pattern
*1760Ma suite shown by pP and black pattern
*1485Ma suite shown by WRB, stippled pattern and by lower-case 'a' in the south
*'K' represents ca.1Ga rifted terrane
*'A' represents major areas of Archean rock exposure
*'NF' marks the Niagara Fault zone as the boundary Separating the southern Penokean terrane from the Northern.

PETROLOGICAL TYPES AND STRUCTURAL POSITION OF PROTEROZOIC GRANITOID ASSOCIATIONS OF THE UKRAINIAN SHIELD

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The Ukrainian Shield is situated in the southwestern part of the East European Craton and occupies about 300,000 km^2. Six fault-bounded structural domains are recognized in the shield: Volyn, Dnestr-Bug, Ros-Tikich, Kirovograd (Ingul-Ingulets), Semi-Dniepr, and Azov. In addition, in the extreme north-western part of the shield, a rather extensive structural element known as the Osnitsk-Mikashevitchi Volcano-Plutonic Belt is present. The lithologic association comprises amphibolite, granulite facies Neoarchean metamorphic rocks, and granitoids and, at higher structural levels, Paleoproterozoic metamorphic and plutonic rocks. Proterozoic granitoids are widespread in all the domains of the shield and show variation in structure, composition, and petrogenesis.

In domains characterized by Neoarchean metamorphic rocks, Paleoproterozoic granitoids are widespread. They inherit their mineral and general chemical composition from the surrounding supracrustal rocks and are connected with them by gradual transitions and blurred contacts. These rocks yield ages between 1900 and 2200 Ma.

Distinct two-feldspar granitoid plutons are widespread in the Paleopoterozoic domains. These 2100 – 1900 Ma granitoid associations have been generated as a result of anatectic and metasomatic processes in a deep crustal environment. Large plutons of rapakivi are situated in the Volyn and Kirovograd domains, the upper stratigraphic parts of which are composed of Paleoproterozoic zonally metamorphosed sedimentary rocks. In the Azov domain alkaline plutons (syenite to alkaline granite) occupy large areas and are clearly magmatic in origin. These granitoid associations were generated between 1900 and 1650 Ma.

The Osnitsk-Mikashevitchi Volcano-Plutonic Belt is an independent structure in the Ukrainian Shield. It is occupied by granodiorite-granite intrusions with isotopic ages of 2030 to 1950 Ma and resembles the Riphean rift-related structures.

PETROGENESIS OF EARLY PROTEROZOIC DONGARGARH AND MALANJKHAND GRANITOIDS OF CENTRAL INDIA: A REAPPRAISAL

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The Central Indian Suture (CIS) in the region of Nagpur-Balaghat-Bilaspur separates the two major ancient cratonic blocks, i.e., Bundelkhand Protocontinent (BP) and Deccan Protocontinent (DP). The Dongargarh granitoids (DG) are exposed approximately 100 km south of the Malanjkhand granitoids (MG). Both DG and MG, being an integral of BP, represent Early Proterozoic felsic magmatism of central India, which is spatially and temporally associated with CIS and has implications for Precambrian crustal evolution and metallogeny of central India. The beginning of subduction in the Early Proterozoic of central India was marked by the emplacement of potential Cu(-M0) hosting, calc-alkaline, I-type MG (2405 ± 63 Ma) and continued until emplacement of high-K, calc-alkaline DG (2770±90 Ma) which constituted the Dongargarh hills in the Rajnandgaon district. The DG intrude the Bijli rhyolite and Pitepani andesite, whereas MG intrude the dacite, andesite, and metabasics of the basement complex. Employing the field and geochemical database of dominant granitoid types from Dongargarh and Malanjkhand regions (Ghose, 1982; Krishnamacharlu, 1985; Yedeker et al., 1990; Panigrahi et al., 1993; S. N. Sarkar, 1994; S. C. Sarkar, 1996; Santosh, in prep.), and applying modern petrologic approaches, thia paper critically examines the comparative petrogenesis of DG and MG.

The DG largely corresponds to adamellite, granodiorite, monzogranite, and qtz-monzonite belonging to calc-alkaline-monzonite (high potassium) series, whereas MG bear tonalite, granodiorite, and monzodiorite compositions belonging to calc-alkaline-granodiorite (medium- to high-potassium) series. The DG can be geochemically characterized largely metaluminous with a few evolved peraluminous and peralkaline types (magmatic >> other enclave types; SiO_2 = 69-76 wt%; $Na_2O \geq 3.0$ wt%; K_2O/Na_2O = 1.0-1.5; $Fe_2O_3/FeO < 1.0$ molar; A/CNK = 0.70-1.30; CIPW corundum < 1.0%; and U, Th, REE metallization). However, the MG host lode-type Cu(-Mo) porphyry deposits and less frequent (<< 1 vol%) magmatic enclaves, showing affinity with metaluminous (I-type) granite (hb+bt+ep+tit with mg>il; SiO_2 = 65-75 wt%; $Na_2O \geq 4.0$ wt%; $K_2O/Na_2O < 1.0$; Fe_2O_3/FeO up to 6.0; molar A/CNK ≤ 1.10; CIPW *diopside* ≥ 1.0%; *initial* $^{87}Sr/^{86}Sr \leq 0.705$; magnetic susceptibility > $2x10^{-4}$ emu/g).

Frequent enclaves of various shapes and sizes representing the metabasics, metarhyolites, porphyritic and non-porphyritic granitoids, etc. are hosted within DG. The enclaves are up to 50 cm across in MG, however, and are dark-coloured, spherical to ellipsoidal in shape, medium- to coarse-grained igneous-looking, and have a fine felsic streak around them. These enclaves cannot necessarily be restite and/or an indicator of *in situ* granitization. Rather, they may represent xenoliths (country-rock or deeper lithology), cognate/autoliths (cumulate), restite (refractory mineral residue), and/or microgranular (agent of coeval basic or hybrid magmas) as described elsewhere (e.g., Didier and Barbarin, 1991). Microstructural and geochemical features relevant to these processes are being examined.

The derivation of DG melt from partial melting of high-K_2O (Amgaon) granite gneisses has been discarded due to its peraluminous chemistry. The calc-alkalic volcanic rocks abundant in the region seem to be the most suitable source material which directly plot in high-K calc-alkaline field itself, but the DG experienced, other than fractional crystallization, mixing with mantle-derived alkalic (?) basic magma. Geochemical signatures reveal the tectono-magmatic affiliation of DG as largely syn-COLG and VAG, which seems to suggest the tectonic setting of protoliths. The inferred tectonic environment cannot be considered appropriate unless the degree of melting and protolith assessment are constrained reasonably, which is a subject under examination.

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TWO DIFFERENT TYPES OF NEOPROTEROZOIC TIN-BEARING GRANITES IN THE BAIKAL MOUNTAIN REGION

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The Baikal Mountain Region (BMR) is situated in the southern margin of the Siberian platform on the boundary with the Central Asian fold belt. The BMR includes the Bodaibo-Patom, Baikal-Muya, and Barguzin-Vitim tectonic zones. The first zone is a Neoproterozoic passive margin of a Paleoproterozoic continent, the second a Neoproterozoic fold belt mainly composed of juvenile crust, and the third a Paleoproterozoic microcontinent. The rocks of BMR underwent complex polycyclic tectonic evolution in the early Precambrian, Neoproterozoic, early and late Paleozoic, and Cenozoic. Our geological, geochronological and isotopic studies revealed three major crust-forming events that occurred in Neoarchean, early Paleoproterozoic, and Neoproterozoic. The BMR also contains products of tectono-magmatic reworking during the Caledonian and Hercynian orogenies, and of Cenozoic continental rifting. The BMR includes a number of ore deposits such as the gigantic pyrite Pb-Zn Kholodninskoye deposit, the Mama muscovite pegmatite belt, the Lena-Bodaibo Au province and different smaller Cu-Ni, Pt, Fe and rare metal deposits. Tin deposits, which are connected with Neoproterozoic granites, were discovered in the BMR relatively recently. Two distinct Sn ore regions of Neoproterozoic age, Tuyukan and Bambukoy, are presently known in the BMR.

The Tuyukan ore region belongs to the Bodaibo-Patom tectonic zone that is a passive continental margin of Neoproterozoic age with rift troughs of the same age. Tin deposits associate here with small intrusive stocks and dykes of the Yazov spherulitic granite-porphyry. Typical accessory minerals of the granite-porphyry are cassiterite, scheelite, and acanthite. The deposits are linear stockworks with quartz and quartz-muscovite veins and linear zones of tourmaline-muscovite-quartz, microcline-muscovite-quartz, and albite-quartz metasomatites with cassiterite. The host rocks are Paleoproterozoic black shists and granites. Ore bodies contain 0.5% to 15% sulfides (pyrite, arsenopyrite, galena, sphalerite), acanthite, native gold, and bismuthine.

The Bambukoy ore region is situated in the Neoproterozoic Baikal-Muya fold belt, which is mainly composed of a juvenile crust. Tin deposits are located in the 50 by 30 km Bambukoy volcano-plutonic structure. The marginal part of the structure consists of early basalts, basaltic andesites, dacites, and rhyolites. The later granite forms a large plate-like intrusive body. This subvolcanic laccolith and several extrusive bodies of the latest granite-porphyry, rhyolite and ignimbrite occur in the central part of the structure. Cassiterite is a typical accessory mineral of the acid magmatic rocks. The host rocks of the Sn deposits are the hypabyssal Bambukoy granites. Ore bodies are hematite-magnetite-microcline metasomatites and have a complex form of branching pipes and veins. The main ore minerals are hematite, magnetite, cassiterite, chalcopyrite, and bornite.

U-Pb zircon isochron ages obtained for the latest Bambukoy acid volcanites (723 (4 Ma) and the Yazov granite (726 (12 Ma) suggest contemporaneous emplacement. Geochemical features of the Yazov granite are typical of the within-plate subalkaline granites and A-type granites. The Yazov granites are high in K, Nb, Ta, Zr, Hf, U, Th, Y, REE (except Eu) and have high K/Na and Fe/Mg ratios, are enriched in the LREE (La_N/Yb_N = 7.5), and have moderate negative Eu anomaly (Sm_N/Eu_N = 3.3). In contrast, the acid rocks of the Bambukoy structure demonstrate geochemical features of the S-type granites and are similar to granites of active continental margins. These peraluminous granites (ASI up to 1.6) are enriched in Rb and Ba and depleted in the HFSE and Sr. Compared to Yazov granite they are less enriched in the LREE (La_N/Yb_N = 4.2 – 5.3) and also have a moderate Eu anomaly (Sm_N/Eu_N = 2.7 – 3.8).

Initial ε_{Nd} values of the Yazov granites are uniform at –7.8 to –8.2 and are very similar to the $\varepsilon_{Nd}(T)$ values of the coeval rhyolite of the Olokit rift in the same tectonic zone. In ε_{Nd} vs. age diagram the data plot above the evolution path for the Paleoproterozoic basement. Depleted mantle model ages of the granites (1800 to 1900 Ma) are younger than the model ages of the basement rocks (2280 to 2450 Ma). These data require that the Yazov granites were originated from mixing between a crustal component similar to the evolved Paleoproterozoic basement rocks, and a more primitive component, which could have derived from depleted mantle. Unlike the Yazov granites, the later Hercynian granites of the same tectonic zone demonstrate typical crustal Nd isotopic features (ε_{Nd}(at 350 Ma) = –16.4 to –16.8, model age 2450 Ma). In ε_{Nd} vs. age diagram they plot within the evolution path of the Paleoproterozoic crust. Thus, we can suggest an ascent of a mantle diapir causing anatexis of the lower crust and formation of the parental magma for the Yazov granite by interaction of a mantle-derived basaltic magma with secondary anatectic magma.

The latest granite-porphyry in the Bambukoy structure has a more radiogenic Nd isotopic composition than the Yazov granites. Its initial ε_{Nd} value is –5.8 and model age 1920 Ma suggesting that the crustal (sedimentary?) protolith of the Bambukoy granitoids most likely formed as a result of mixing between a young juvenile crust and an old Paleoproterozoic crustal component. Noteworthy, neighboring later Hercynian (~350 Ma) collision granites of the same fold belt were formed from a pure crustal source similar to the source of the Bambukoy acid rocks. Initial ε_{Nd} values for these Hercynian granites vary from –10.8 to –12.5 and model ages from 1680 to 2070 Ma. In ε_{Nd} vs. age diagram the data for these younger granites as well as the data for the Bambukoy acid rocks plot between evolution paths of Paleoproterozoic and Neoproterozoic crust thus demonstrating that a mixed crustal source existed till the Hercynian collision event.

Our data show that two different geodynamic types of contemporaneous tin-bearing granites were formed in the Baikal Mountain Region in the Neoproterozoic. The Yazov granites were intruded in a within-plate environment of continental extension while the Bambukoy igneous rocks were formed in an active continental margin. In both cases the granites were derived from mixed sources involving Paleoproterozoic crust and other younger crustal or mantle components.

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EMPLACEMENT OF A VITROPHYRIC LAVA DOME IN THE ST. FRANCOIS TERRANE OF MISSOURI: CONSTRAINTS IMPOSED BY AMPHIBOLE

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A silicic dome complex centered on Buford Mountain (37°42.5'N, 90°42.5'W) produced nearly 2km^3 A-type vitrophyric dacite-rhyolite lava known as the Buford Volcanic Series (BVS). The BVS intrudes 1.48 Ga ignimbrites related to the Butler Hill Caldera and is cut by pegmatite dikes of the 1.38 Ga Graniteville Granite. The eruptive sequence of the BVS consists of an initial pyroclastic vent facies, an exogenous outflow lava sheet (48km^2), and two late endogenous plugs lacking outflow equivalents. The vent facies occurs as phenocryst-poor, pumice-bearing ignimbrite clasts in the lava sheet, whereas the lavas contain abundant phenocrysts set in microlite-free glass that has devitrified to spherulitic, micropoikilitic, and felsitic textures. Phenocrysts in the lavas exhibit an inverse size-abundance relation and pronounced glomerocrystic tendency. The main crystallization sequence is: amphibole-FeTi oxides-plagioclase-alkali feldspar+quartz, but these were preceded by the appearance of ferroaugite, zircon and apatite which occur as inclusions in amphibole. Alkali feldspar commonly forms rims on rounded plagioclase grains; this antirapakivi texture, coupled with phenocrystic amphibole, is rare in the St. Francois Terrane and suggests a relationship between the BVS and ring plutons of the Taum Sauk Caldera (Lowell & Darnell, 1996).

BVS amphibole habit tends to be ragged in solitary phenocrysts, subhedral in amphibole clusters, and euhedral if enclosed by antirapakivi tablets. Amphibole grains range from 0.8 to 1.6 mm in length and invariably show some degree of subsolidus alteration (fibrous actinolitic rims, replacement by epidote, biotite and opaque material, K-Na exchange). The cores of amphiboles enclosed (at least partially) by feldspar exhibit uniform optical character (α = olive, β = dark green, and γ = dark blue-green) and minimal alteration effects. No exsolution features are visible at the optical scale or in BSE images.

Microprobe analysis of BVS amphiboles produced 262 analyses acceptable to the CLASAMPH program (Currie, 1997) which utilizes IMA rules (Leake, 1997) to determine formula, site occupancy, and formal name. The amphiboles are nepheline-normative ferrous calcic amphiboles with $Ca+Al^{iv} > 2.5$ and $Si+Na+K < 8.0$ despite hostrock agpaitic ratios ≈ 0.9. Average compositions of BVS amphiboles are: 1) ferrohornblende (Mg/Mg+Fe = 0.39) in vent facies; 2) ferro-edenite (Mg/Mg+Fe = 0.16) in outflow lava; and 3) ferro-edenite (Mg/Mg+Fe = 0.14) in one vent plug. No amphibole survives in the other vent plug, but the amphibole pseudomorphic assemblage (opaque granules, epidote group, Fe-rich biotite, chlorite, feldspar) suggests similar but perhaps more Fe-rich composition. Core-rim traverse data indicates negligible Fe:Mg variation and minor oscillatory variation related to $NaAl^{iv}{:}\square_A Si$ ("edenite-substitution") during amphibole growth.

Amphibole stability requires a minimum of 4 wt% H_2O in the melt and high phenocryst content (18-41%) that include alkali feldspar in the dome and outflow facies indicate eruption well below melt liquidus temperature. These considerations suggest an approach to equilibration requirements of the Al-in-hornblende barometer (Schmidt, 1992) which yields the following: vent facies (2.0 kb), lava outflow facies (5.5 kb), dome plug (4.7 kb). The amphibole-plagioclase thermometer (Blundy & Holland, 1990) yields 731° C for the dome plug (plagioclase data not yet available for other facies). Considering the effects of Fe^{2+}-rich composition and f_{O_2} on amphibole stability (FMQ buffer conditions implied by mineral assemblage) these P-T conditions with log f_{O2} $\leq$ -17 appear reasonable estimates for amphibole crystallization.

Detailed studies of the Mt. St. Helens eruptions demonstrate that silicic dome building magmas are capable of rapid rates of ascent (i.e., 2 km/hr), decompression and H_2O loss to the conduit. The hallmarks of rapid ascent are quenching of microlite-free glass and the absence of amphibole breakdown rims which are traits of one BVS dome plug and the lava outflow sheet. Paradoxically, the lava sheet (SiO_2 = 71.4%) has the largest effective viscosity (10^{40} poise) and greatest map distribution of BVS units (eroded distal edge 6.4km from vent site). Evidently, this is an example of the "permeable foam" effusive mechanism proposed by Eichelberger et al. (1986).

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ORIGIN AND EVOLUTION OF THE WOLF RIVER BATHOLITH AND OTHER ANOROGENIC MAGMATIC COMPLEXES: INFERENCES FROM A COMPARATIVE STUDY

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The Wolf River Batholith (WRB) is a plutonic complex that has been likened lithologically to the large rapakivi massifs of Fennoscandia (Van Schmus et al., 1975) and consists of a suite of associated quartz monzonite, syenite, granite, monzonite and anorthosite. This association is commonly repeated in anorthosite suites such as that from the Laramie Anorthosite Complex. Although some mafic rocks have been found associated with the Wolf River batholith, little is known about their general relation to the WRB or the details of their similarities with the mafic rocks associated with anorthosite suites. However, through comparative studies with other well-studied suites it is possible to make some predictions as to the nature of these associated rocks and the origin of the Batholith.

The major oxides of the rocks of the WRB are very similar to those of the Laramie Anorthosite Complex (LAC). The close correlation of the rock compositions of these two complexes suggests that the well studied LAC rocks may be used to gain insight into the processes that were involved in the evolution of the WRB.

The lithologies of the LAC consist of high Al gabbro, anorthosite, ferrodiorite, monzonite, syenite and granite. A variety of studies suggest that the anorthosite is the crystalline accumulation product of fractionation of high Al gabbro to produce ferrodiorite which in turn fractionates to monzonite and syenite. The Sherman granite and that from the Maloin Ranch pluton of the LAC, as well as the silicic rocks of the WRB lie on the same extension of this trend, speaking strongly to the possibility of fractionation being a major control in their origin. The varied isotopic signatures of the different lithologies of the LAC, as well as the heterogeneities within similar lithologies, suggests that not only must some crustal assimilation have place for most of the units, but that each magmatic unit may have seen a different assimilation history. Therefore, it is highly unlikely that the different lithologies are related through *in-situ* fractionation.

Experimental data from Scoates et al. (1996) indicates that a ferrodioritic liquid which is close in composition to high Al gabbro can evolve through clinopyroxene, plagioclase, and ilmenite crystallization to liquids very similar to the high K ferrodiorites, monzonites and syenites of the LAC. The majority of the high Al gabbros lie at the emanation point of this trend and it appears likely that they can be the parental liquids of the suite. Importantly, these high Al gabbros are far from being primary mantle melts and have seen a significant amount of fractionation before the formation of the anorthosites and ferrodiorites.

The feldspar/liquid relations of the LAC provide further support for crystal fractionation with an almost continuous trend from the hi-Al gabbros to the granites. This potassic trend yields feldspars of highly ternary character, in keeping with both the high temperatures of the magmas and the clinopyroxene control on the fractionation path of the magmas. Although reintegrated feldspar compositions are not available for the WRB rocks, the normative feldspar components of the rocks and hence, presumably of the liquids (as evidenced by similarities of the plutonic WRB and LAC lithologies to the SRP lavas, as discussed below), are very similar again to those of the LAC.

Volcanic analogs for the LAC and WRB can be found in the Snake River Plain (SRP) complex. The SRP tholeiites are very similar to the high Al gabbros of the LAC, while the Craters of the Moon suite contains rocks very similar to the ferrodiorites, monzonites and syenites of the LAC. The SRP rhyolites form the end of the trend and are similar to the granites of the LAC and WRB. These similarities lend support for using the main plutonic compositions of the LAC (other than the rocks with obvious cumulate texture such as the anorthosite and some of the syenites) and WRB as indicative of liquid compositions. Furthermore, the similarities suggest that the main differentiation process that led to the formation of the LAC and, by analogy, the WRB are not restricted to Proterozoic time.

THE 1.88-1.87 GA POST-KINEMATIC PLUTONS OF THE CENTRAL FINLAND GRANITOID COMPLEX: A *SHIFT* IN THE AGE OF C-TYPE AND A-TYPE MAGMATISM DURING LITHOSPHERIC CONVERGENCE

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Much of the Svecofennian Orogen in Finland is occupied by the Central Finland Granitoid Complex (CFGC). It consists mainly of granodiorites and granites, with mafic and supracrustal rocks in minor volume. These 1.89-1.88 Ga rocks are generally foliated and considered as synkinematic with respect to compressional crustal movements. The synkinematic rocks are crosscut by a 1.88-1.87 Ga suite of weakly to non-foliated post-kinematic granites. These plutons may be divided into three types on mineralogical and petrological criteria (Elliott et al., 1998). The Type 1 plutons are granodiorites and granites that flank the southern margin of the CFGC. The Type 2 granites occur mainly in the western and southern CFGC and typically comprise biotite ± hornblende monzogranite. The Type 3 plutons are located mainly in the eastern CFGC. They are granites or quartz monzonites that usually contain a pyroxene ± olivine -bearing quartz monzonitic margin (Type 3a) but in the northeastern CFGC the plutons contain pyroxene throughout (Type 3b).

The division of the post-kinematic granites is valid also in terms of their chemical composition. The chemistry of the three types was compared with a group of synkinematic granitoids of the CFGC as well as the 1.6 Ga rapakivi granites of southern Finland. Compared to the synkinematic granitoids, the post-kinematic granites are generally higher in K and Zr and lower in Mg, Ca and Sr at similar SiO_2 contents. The post-kinematic plutons plot between the trends of the synkinematic granitoids and the rapakivi granites in many variation diagrams (e.g. Ba vs Sr). In tectonomagmatic variation diagrams the post-kinematic suite plots between the synkinematic granitoids (volcanic arc granite field) and rapakivi granites (within plate granite field) so that the Type 2 granites are mostly in the within plate granite field. The "mixed" tectonic affinity may be explained by a Paleoproterozoic protolith with a major volcanic arc component.

The REE patterns of the post-tectonic granite groups are grossly similar; the negative Eu anomalies are less pronounced in Type 3 than in the other two types. The Type 1 plutons are peraluminous and relatively low in Fe/Mg (similar to the synkinematic group) and thus have calc-alkaline characteristics. This pattern and the location of the plutons within the supracrustal belt adjacent to the CFGC suggest a source with a relatively large sedimentary component. The Type 2 and Type 3 plutons shift from metaluminous to peraluminous with increasing SiO_2 content. The Type 2 plutons have high Fe/Mg ratios and show clear tholeiitic trends like the rapakivi granites. Moreover, the elevated Rb and F values of the Type 2 granites conform with an A-type magmatic affinity. The Type 3 plutons have relatively high TiO_2 and P_2O_5 and low CaO values at low (55-65%) SiO_2 contents. These features are characteristic of magmatic charnockites (Kilpatrick and Ellis, 1992).

In general the post-kinematic plutons are located at or close to major crustal weak zones in the CFGC, especially the Type 2 plutons in the western CFGC are aligned along these zones. This feature suggests that the post-kinematic granites were emplaced in an extensional or transtensional crustal regime.

The growth of the Svecofennian crust has been ascribed to accretion of an arc complex (volcanic arc assemblages and an older Paleoproterozoic nucleus) to an Archean continental margin 1.91 ago, followed by collision of another arc complex against the accreted one 1.89 Ga ago (Lahtinen 1994, Nironen 1997). The synkinematic magmatic event occurred during the collision of the two arc complexes, and convergence continued until 1.80 Ga. Lithospheric convergence that resulted in crustal thickening may also have caused extension in the crust, enabling the post-kinematic plutonism.

New U-Pb age data as well as previously published datings from the post-kinematic plutons show a decrease in U-Pb ages from northeast (1.885 Ga) to south (1.88 Ga) and west (1.87 Ga). There is a relatively large age range within the Type 2 plutons, from 1881 to approximately 1870 Ma. Likewise, the Type 3 plutons cover an age range from 1886 Ma to 1871 Ma.

We conclude that the post-kinematic granites of the CFGC register a shift of extensional or transtensional tectonics from the northeastern part of the CFGC to the western part of it. The shift took place in quite a short time period of ca. 15 Ma and during a process of overall lithospheric convergence. Moreover, both C-type (charnockitic) and A-type magmatism occurred within these 15 Ma.

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U-Pb AND Sm-Nd ISOTOPIC DATA OF THE BASEMENT ROCKS IN THE EASTERN PART OF THE RONDÔNIA TIN PROVINCE, BRAZIL

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Limited geologic and geochronologic data demonstrate that SW part of the Amazonian craton is made up of at least four Proterozoic tectonic provinces arranged in a successive sub-parallel NW-SE belts. These provinces are in a decreasing age from NE to SW: Ventuari-Tapajós (1.95-1.80 Ga), Rio Negro-Juruena (1.80-1.70 Ga), Rondonian-San Ignacio (1.50-1.30 Ga), and Sunsas (1.25-1.00 Ga)[1,2,3]. More recently, Sm-Nd crustal formation ages (T_{DM}) indicate that main events of continental accretion are related to Ventuari-Tapajós and Rio Negro-Juruena provinces[4]. In the Rondônia Tin Province (RTP) the Proterozoic basement rocks of the rapakivi suites consists of igneous and metamorphic rocks belonging to Rio Negro-Juruena and Rondonian-San Ignacio provinces[5,6]. Here we report additional U-Pb and Sm-Nd isotopic data for Proterozoic basement rocks in the Ariquemes-Samuel dam area, covering ca. 14,000 km^2 in the eastern part of the RTP.

The Ariquemes-Samuel dam area includes Proterozoic igneous and metamorphic rocks intruded by two rapakivi granite suites, Santa Clara Intrusive Suite (1082 to 1074 Ma), and Younger Granites of Rondônia (998 to 974 Ma)[7]. The basement rocks are subdivided into six units on 1:100,000 geological mapping. These are: 1- grayish tonalitic gneisses, 2- pinkish to greenish orthogneisses, 3- paragneisses, 4- União massif, 5- grayish granitoid rocks and orthogneisses, and 6- fine grained gneisses. U-Pb and Sm-Nd results for units 1, 2, 5, and 6 are presented here.

The zircon separations and whole-rock sample preparations were done in the DPM (IGCE-Unesp), and the isotopic analyses were carried out in the Isotopic Geochemistry Lab of the University of Kansas. The Sm-Nd isotopic analyses of two samples with SHRIMP U-Pb zircon age presented by Tassinari *et al.*[6] and one sample with U-Pb zircon age showed by Bettencourt *et al.*[7] were carried out in the Geochronology Lab of the University of Brasília and in the Institute of Precambrian Geology and Geochronology, Russian Academy of Science, respectively (Table 1).

Unit 1 (grayish tonalitic gneisses). Zircon fractions from a homogeneous portion of well banded tonalitic gneisses at granulite-facies condition (sample WB-70) yield an upper intercept of 1730±21 Ma on concordia (good representation of the protolith age). The Sm-Nd crustal formation age (T_{DM}) for this rock is 2.06 Ga, indicating that the original magma was derived from a source containing significant older crust. A similar Sm-Nd crustal formation age (T_{DM}=2.20 Ga) is obtained for the 1.75 Ga homogeneous, strongly foliated tonalitic gneiss (sample B-335).

Unit 2 (pinkish to greenish orthogneisses). Six zircon fractions of the greenish charnockitic orthogneisses (sample WB-46/A) plotted on a U-Pb diagram yield an upper intercept at 1477±14 Ma. However, SHRIMP U-Pb analyses from zircon of the same rock give an age of 1559±12 Ma (Pimentel & Bizzi, personal communication). We think that this age is a better representation of the protolith crystallization age. The Sm-Nd crustal formation age (T_{DM}) is 1.86 Ga, indicating that the magma was derived from a source containing significant older crust.

Four zircon fractions of the pinkish biotite syenogranite orthogneiss (sample WB-44/A) plotted on a U-Pb concordia diagram yield an reasonably well constrained upper intercept (crystallization age of the protolith) at 1526±12 Ma. The Sm-Nd crustal formation age (T_{DM}) for this rock is 1.84 Ga, indicating that the original magma was derived from a source containing a significant older crustal component.

Unit 5 (grayish granitoid rocks and orthogneisses). The U-Pb results of the K-feldspar megacrystic monzogranite (sample AR-3/1), when plotted on a U-Pb concordia diagram, yield a well constrained upper intercept (crystallization age) at 1544±5 Ma. The Sm-Nd crustal formation age (T_{DM}) for this rock is 1.89 Ga, indicating that the original magma was derived from a source containing a significant older crustal component.

Unit 6 (fine-grained gneisses). Two zircon fractions from a homogeneous portion of the banded fine-grained syenogranitic gneiss (sample WB-51) plotted on a U-Pb concordia diagram yield a concordant age at 1418±11 Ma, interpreted as the protolith crystallization age. The Sm-Nd crustal formation age (T_{DM}) for this rock is 1.75 Ga, indicating that the original magma was derived from a source containing significant older crustal component.

The U-Pb and T_{DM} ages reveal three distinct groups of rocks in the Ariquemes-Samuel dam area: 1- grayish tonalitic gneisses (1.75-1.73 Ga U-Pb ages and 2.20-2.06 Ga T_{DM} ages); 2- granitoids and orthogneisses (1.57-1.53 Ga U-Pb ages and 1.89-1.84 Ga T_{DM} ages); and 3- fine grained gneisses (1.42 Ga U-Pb ages and 1.75 Ga T_{DM} ages). All the Sm-Nd crustal formation ages (T_{DM}) indicate that the original magma was derived from a source containing a significant older crustal component.

The grayish tonalitic gneisses are interpreted as part of remanent older crust formed during the magmatic-arc evolution of the Rio Negro-Juruena province. The granitoids and orthogneisses might represent three intra-plate bimodal magmatic activities developed over the Rio Negro-Juruena crust at 1.57-1.56 Ga, 1.54 Ga, and 1.30 Ga. The 1.57-1.56 Ga magmatic event is correlated to the crystallization age of the rapakivi granites of the Serra da Providência Intrusive Suite, and not to an younger magmatic system of the Rio Negro Juruena province as interpreted by Tassinari *et al.*[6]. The 1.42 Ga fine-grained gneisses represent a magmatic activity temporally related to the evolution of the Rondonian-San Ignacio province.

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Table 1. U/Pb ages and Sm/Nd isotopic properties of samples studied.

Unit number	Sample number	Rock descripition	U/Pb age (Ma) ±2σ	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(t)$	T_{DM} (Ga)
1	B-335	homogeneous hornblende-biotite tonalitic gneiss	1750±24*(1)*	-19.16	-1.49	2.20
1	WB-70	banded garnet-orthopyroxene-hornblende tonalitic gneiss	1730±21	-16.38	0.14	2.06
2	M-S-6030	hornblende syenogranitic orthogneiss	1570±17*(1)*	-13.38	0.96	1.87
2	WB-46/A	charnockitic orthogneiss	1477±14	-14.57	-0.06	1.86
2	WB-44/A	biotite syenogranitic orthogneiss	1526±12	-15.31	0.51	1.84
4	WB-36	hornblende quartz syenite	1532±4.5 *(2)*	-14.67	0.25	1.88
5	AR-3/1	biotite monzogranite	1544±5	-16.25	0.04	1.89
6	WB-51	syenogranitic fine-grained gneiss	1418±11	-11.26	1.04	1.75

(1) Tassinari *et al.*[6]; *(2)* Bettencourt *et al.*[7]

GRANITIC ROCKS FROM THE CABAÇAL BELT, ALTO JAURU GREENSTONE BELT, MATO GROSSO-BRAZIL.

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The Amazonian Craton covers an area of about 4.5 million square kilometers, including French Guyana, Surinam, Guyana and parts of Venezuela, Colombia, Bolivia, and most areas in the Amazonian region of Brazil. Its evolution is punctuated by episodic crustal accretion events during the Proterozoic. There is a clear variation of ages that divides the Amazonian Craton into an ancient nucleus, the Central Amazonian Province. This nucleus is surrounded by the Early to Middle Proterozoic provinces: Maroni-Itacaiunas (2.25-1.90Ga), Rio Negro-Juruena (1.75-1.50Ga), and Rondinian-Sunsas (1.45-0.90Ga) (Cordani et al., 1979; Teixeira et al., 1986)

The Alto Jauru Greenstone Belt is located in the southern part of the Amazonian Craton, State of Mato Grosso, mid-west Brazil. It is included in the Rio Negro-Juruena Province. It comprises three belts of volcano-sedimentary sequence intruded by felsic to basic, Early do Middle Proterozoic rocks. The belts are trending NW with 60-100 km of length and 10-20 km of width. The volcanic rocks represent a bimodal suite of Early Proterozoic age (Pinho and Leite, wr. com.; Figueiredo et al., 1995). The internal stratigraphy of the Alto Jauru Greenstone Belt has been documented (Monteiro et al., 1986; Saes et al., 1986). The volcano-sedimentary sequence is divided in three units: i) base: massive tholeiitic volcanic, pillows and flow breccias, and minor volcanoclastic units komateiitic affinity, ii) middle: felsic tuff interlayered with felsic-intermediate lava, detrital and chemical sediments, iii) top: chemical and detrital sediments with minor intercalations of mafic-felsic volcanic. Intrusives rocks are Early Proterozoic tonalites and gabbros, and Middle Proterozoic granites

The Cabaçal Belt covers an area of approximately 350 square kilometers. It is a narrow NNW trending belt of metamorphosed volcano-sedimentary rocks, separated from the Araputanga Belt in the West boundary by the Metamorphic Complex (gneisses basement terranes). The East boundary is represented by the Aguapeí Group. The belt is made up of volcano-sedimentary rocks of Early Proterozoic age. A bimodal suite characterizes the volcanic rocks, while sediments are clastic and chemical. During the Early and Middle Proterozoic, felsic and basic plutonic rocks intruded into the belt, and sedimentary covers from the Aguapeí Group deposited on the region. In the Cabaçal Belt intrusive bodies are represented by the Cabaçal Tonalite, the Alvorada Granite, and the Cabaçal Gabbro. Gabbro samples were not analyzed in the present paper. Felsic intrusions exhibit limited hydrothermal alteration, except for some areas in the Cabaçal Tonalite. Altered samples are depleted in Rb, Ba, K, Na, Zr, Ni, Co, Hf, and LREE, and enriched in Ca, Sr, and Ga. The typical petrographic alteration is an epidotization. Altered samples will not be used to calculate average sample values.

The Cabaçal Tonalite samples show SiO_2 values ranging from 61.74 to 66.35wt.%. Al_2O_3 values range between 13.53 and 15.51wt.%, with an average of 14.25wt%. Values of MgO and CaO are relatively high (3.09ppm and 4.07wt.% on average, respectively). This tonalite shows enrichment in some trace elements such as Cr, Ni, Co, V, Rb, Ba, Sr, and Zr (76.17, 20.50, 17.00, 107.92, 33.57, 940.43, 395.07, and 117.71ppm in average, respectively). The Alvorada Granite samples display consistent values for all analyzed elements. SiO_2 values range from 71.61 to 73.20wt.%, and Al_2O_3 values are between 13.80 and 14.50wt.%. When plotted in the diagram of normative Ab - An - Or, samples from the Cabaçal Tonalite are classified as tonalite-granodiorite-trondhjemite. Most of the samples plot in the boundaries among these three types of rocks. Samples from the Alvorada Granite plot in the granite field, with one sample on the boundary granite-adamelite. The Cabaçal Tonalite when classified in the Streckeisen (1976) diagram, according to mineral contents, shows tonalite and quartz diorite as lithologic types. In the variation diagram Na_2O+K_2O - FeO* - MgO (Irvine and Baragar, 1971), both the Alvorada Granite and the Cabaçal Tonalite show a calc-alkaline magmatic affinity.

The Cabaçal Tonalite presents a REE pattern with a high fractionation of LREE, and an almost flat pattern of HREE. $(La/Sm)_N$ ratios= 3.04 to 3.23. There is a small Eu anomaly, probably related to plagioclase fractionation. The alterated samples show a relative depletion in LREE and no Eu anomaly. The Alvorada Granite shows a similar REE pattern, however with an enrichment of LREE and a more expressive negative Eu anomaly. $(La/Sm)_N$ ratios= 5.09 to 5.43. Rb/Sr ratios for the Alvorada Granite have an average value of 0.49, and for the Cabaçal Tonalite is of 0.09. The very low Rb/Sr ratio suggests a primitive source for the Cabaçal Tonalite. Values of Mg# = 49.59 on average, agreeing with this theory. Mg# values for the Alvorada Granite are 24.57 in average. The increase in Ni and Co with MgO increase suggest olivine fractionation during the Cabaçal Tonalite origin.

The inadequacies of oxide percentage bivariante diagrams and their ambiguities have been discussed from long ago by Chayes (1964) and Pearce (1969). Batchelor and Bowden (1985) again discussed this issue and suggested an alternative approach to the discrimination of different series of granitoids using cationic/molecular values. The R1 - R2 multicationic diagram (de la Roche et al., 1980) is the base used for the new discriminant plot suggested. Samples from the Cabaçal Belt granitoides, plotted in the Batchelor and Bowden (1985) diagram, lie in two different fields. The Cabaçal Tonalite samples in the Pre-plate collision field, and the Alvorada Granite samples in the Syn-collision field.

Pearce et al. (1984) using a data bank with over 600 high quality trace element analyses of granites from known tectonic settings, subdivided granites in four groups: ocean-ridge granites (ORG), volcanic arc granites (VAG), within plate granites (WPG), and syn-collision granites (COLG). Projections of Y - Nb and (Y+Nb) - Rb, among others, were considered very effective in classify granite tectonic setting. Distribution of the samples from the Cabaçal Tonalite and the Alvorada Granite in these diagrams is in the arc granites field. The Alvorada Granite samples plot in the same field, however they are very close to the boundaries among VAG-WPG-synCOLG. In the Y - Nb one sample lies in the WPG field. Ocean-ridge granite-normalized K_2O, Rb, Ba, Th, Ta, Nb, Ce, Hf, Zr, Sm, Y, and Yb diagram (Pearce et al., 1984) has been used to systematically characterize granites from different tectonic environments. ORG-normalized diagrams for samples from the Cabaçal Tonalite show an enrichment in Ce and Sm relative to Ta, Nb, Hf, Zr, Y, and Yb which is characteristic of volcanic arc granites from calc-alkaline series (Pearce et al., 1984). Samples from the Alvorada Granite show high ratios of Rb and Th relative to Ta and Nb. These ratios are considered to be typical of "crust-dominated" pattern (Thirlwall and Jones, 1983; Pearce et al., 1984). The pattern tends to be flat from Ta to Yb, and shows Hf and Yb close to the normalizing values. The Alvorada Granite shows patterns compatible with those for within-plate granites.

The Cabaçal Tonalite is considered to be generated in an island arc environment, probably related to the same magmatic event that generated the felsic volcanics. Also, the felsic volcanic rocks from the Manuel Leme Formation show chemical characteristics that classify them as rocks created in an island arc environment. U/Pb ages of 1769±29Ma and 1724±30Ma were reported by Pinho and Leite (wr. Com.). The Alvorada Granite is classified as syn-collision and shows a weakly peraluminous characteristic because of the composition of the biotite, and an age between 1520-1440 Ma, and initial $^{87}Sr/^{86}Sr$ ratio between 0.703 and 0.705 (Monteiro et al., 1986; Figueiredo et al., 1995). It is possible to relate this granite to the Rondonian-Sunsas event in South America.

MAGMATISM OF THE IRIRI FORMATION AND ASSOCIATED AU-SULFIDE MINERALIZATION IN THE CEDRO BOM AREA, SOUTHEASTERN AMAZON CRATON

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The Cedro Bom area is located near Aripuanã city in the northern part of the Mato Grosso state, Brazil. It is situated in southeastern portion of Amazon Craton.

In the study area, we recognize two major lithological associations which are Archean to Paleoproterozoic granite-gneiss terrane and Paleo to Mesoproterozoic volcano-sedimentary cover plus lowlevel granitic intrusion. The latter one are considered as part of the Iriri Formation. This formation comprises herein felsic to mafic flows and low-level granitic intrusions with intercalation of volcaniclastic and sedimentary rocks (such as conglomerates, sandstone and siltstones). In most part of the area the surface (S_0) is oriented E-W with a steep dipping (up to 70 degrees) to the north. Gold and sulfide ores are associated with the Iriri Formation.

The felsic rocks occur as rhyolitic lava flows, explosive eruptions and granite. The rhyolites show a porphyritic texture with phenocrysts of micropheritic alkali feldspar. Corrosions are observed in the alkali feldspar and quartz. The groundmass is microcrystalline to felsofiric with sinuous contours of the phenocrysts caused by magmatic flow that suggests a laminate rheology. The explosive segment is characterized by ignimbritic rocks generated by pumice flows. They are partially welded developing an eutaxitic texture. Sometimes shards are observed to be replaced by microcrystalline alkali feldspar-quartz material. In addition, clastic fragments of feldspar and quartz are observed, ranging from 0.5 to 4 mm. Rare rhyolitic fragments are present.

The granitic intrusion occurs completely altered by hydrothermalism. It is the richest rock in sulfides. The intermediate to mafic rocks are represented by andesites and basalts. The texture is sub-ophitic or microporphyritic. Microphenocrysts (< 1mm) and phenocrysts (2mm in average) of plagioclase and clinopyroxene are surrounded by fine-grained groundmass. Phenocrysts and groundmass are partially altered. However it is possible to recognize the original association andesine-augite.

Chemical analyses, carried out in the 1970's by the RadamBrasil Project, show a sub-alkaline composition for rocks of the Iriri Formation.

Sulfide portion

Minerographic and mineral chemistry studies were carried out at the sulfide portion of the Cedro Bom area. These studies show that the sulfide and gold are associated with low-level felsic intrusion strongly modified by hydrothermal alteration. It is possible to recognize alkali feldspar and quartz as phenocrysts. They are dispersed in a completely altered zone with silicification, carbonatization, sericitization, choritization and sulfidization. Silicification around pyrite crysts are frequent. Some samples show moderate foliation, interpreted as result of intense percolation of fluids associated with the hydrotermal process.

Sulfides occur disseminated in the rocks or in veins. Pyrite is the most abundant sulfide. Pyrite changes from idiomorphic to hypidiomorfic texture and milimetric to centimetric grained. More than one generation of pyrite is indicated by clean boards that involve poikilitic nuclei rich in inclusions from matrix. Locally occurs some crystals of arsenopyrite. Energy Disperse Spectrometer analyses show Bi-Te inclusions into the pyrite. Chalcopyrite mainly occurs in millimetric veins around pyrite or cross-cutting the rock. Galena is rare, however when it occurs, shows a planar contact with chalcopyrite in the veins phase. Ilmenite appears as oxide. It is as pyrite inclusion or disseminated in the matrix. Ilmenite shows corrosive aspect, and it was probably crystallized before sulfides. The presence of ilmenite suggests sudden changes at oxygen fugacity, causing good conditions to precipitation of gold. Seventy chemical analyses (Au, Cu, As, Pb and Zn) were carried out by BZi Mineração in this area. The results show anomalous grades in few samples (1,26 pppm Au and 0,214% Cu). When observed in a statistic graphic, these data show a good correlation between Au and As.

Nd AND Pb ISOTOPIC COMPOSITION OF POST-KINEMATIC AND RAPAKIVI GRANITOIDS IN THE FINNISH SVECOFENNIAN: EVIDENCE FOR TWO MICROCONTINENTS

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The Svecofennian Orogen in Finland consists of a metamorphic crust that was differentiated from the mantle 1.9 Ga ago (e.g., Huhma, 1986). Much of this Paleoproterozoic crust is occupied by granitoid rocks that range in age from ca. 1.9 to 1.6 Ga. The youngest granitoid suite is composed of the classic 1.65–1.54 Ga rapakivi granites that show the typical petrographic, mineralogical, and geochemical traits and magmatic association of the subalkaline A-type granites (Rämö and Haapala, 1995). The Finnish rapakivi granites have been modeled as the derivatives of high-temperature, low a_{H2O} melts from a relatively felsic crustal protolith that was fused in response to prolonged mafic underplating (e.g., Rämö, 1991). Recent studies in the Central Finland Granitoid Complex (Elliott et al., 1998; Nironen et al., this volume) have revealed a complex set of 1.88–1.87 Ga post-kinematic granitoid rocks that were formed very shortly after the main compressional deformation of the Finnish Svecofennian. They show many of the salient features of the rapakivi granites and were probably derived from a similar deep crustal source and by grossly similar processes as the rapakivi granites further to the south. New Nd whole-rock and Pb alkali feldspar isotopic data on the 1.88–1.87 Ga granites show:

(1) ε_{Nd} (at 1.875 Ga) values between –1.1 and +0.5 with mean at –0.1 ± 0.4 (1 σ, n=15)
(2) neodymium model ages (DePaolo, 1981) averaging 2.18 ± 0.06 Ga
(3) time-integrated $^{238}U/^{204}Pb$ ratios (Stacey and Kramers, 1975) of 9.58 ± 0.12 (1 σ, n=16)
(4) time-integrated $^{232}Th/^{238}U$ ratios of 3.63 ± 0.10.

The corresponding values for the 1.65–1.54 Ga rapakivi granites (Rämö, 1991; unpublished data) are:

(1) ε_{Nd} (at 1.6 Ga) values of –1.7 ± 0.6 (1 σ, n=27)
(2) neodymium model ages averaging 2.06 ± 0.03 Ga
(3) $^{238}U/^{204}Pb$ of 9.78 ± 0.12 (1 σ, n=16)
(4) $^{232}Th/^{238}U$ of 3.73 ± 0.16.

These data suggest that the deep crustal protolith of the 1.88–1.87 Ga granitoids had lower overall Sm-Nd and U-Pb ratios than that of the 1.65–1.54 Ga rapakivi granites. The two granitoid suites may thus have derived from two different crustal terranes – the source of the 1.88–1.87 Ga granitoids having a slightly older signature.

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PROTEROZOIC AND PHANEROZOIC COLLISION GRANITE SYSTEMS OF NORTHERN SIBERIA

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During compilation of the Tectonic Map of the Kara and Laptev Seas and North Siberia (scale of 1:2 500 000), the petrology and tectonics of granite systems were assessed for the north Siberian craton and the Taymyr fold province situated nearby to the north.

On the Siberian craton collisional granites (identified as such according to the geochemical criteria of Pearce, 1983, 1996, among others) accompanied by 1.9 Ga migmatites (Rosen et al., 1994) occur inside Paleoproterozoic 10 to 30 km wide decollement zones mainly composed of tectonic melange. Along these zones the Archean terranes were collided and thrusted to the SW. In the Taymyr fold province there are two collisional granite episodes (Vernikovsky, 1966). The first appeared in the older terranes of the Taymyr Proterozoic-Paleozoic accretionary belt where gneiss complexes are cut by collisional granites melted at 850 Ma out of a 1.8 – 1.9 Ga crust. The second intruded at 300 Ma **(C3-P1)**, and 264 Ma (P2) into metasediments of the Kara zone and can be observed in the North Taymyr fold zone. The Kara plate is assumed to have been collided with and thrusted onto the Taymyr accretionary belt which was part of the Siberian Craton at that time. The orientation of the Paleoproterozoic collision zones in the Siberian craton vary in anticlockwise direction from (1) the longitudinal Sayan-Taymyr collision belt in the central part of the Craton (1.8 Ga, strike 0 – 180^o, collision of the Tungus granite-greenstone superterrane and the Anabar granulite-gneiss superterrane collided westward) to (2) the NW-SE Kotuykan collision (1.9 Ga, strike 315 – 135^o) zone between the Magan and Daldyn granulite Archean terranes and (3) to the WNW-ESE Khapschan collision zone where the Birekte granite-greenstone terrane was thrusted onto the Daldyn terrane (1.9 Ga, strike 340 – 160^o). These three main zones are clearly marked by the isotopically dated collision granites. They clearly mark the continental plate transposition to a south-westward - westward direction at 1.8 – 1.9 Ga.

In the Paleoproterozoic, the collisional events that resulted in granite melts were connected with thrusting of (1) the Riphean (Neoproterozoic) Taymyr accretionary belt onto the Siberian craton (850 Ma) and (2) the Kara plate onto the Taymyr accretionary belt that was part of the Siberian Craton at that time. Both collisional zones show a strike of 65 – 245^o and point to plate movement in a south-eastward direction. The data above manifest a clear change of the plate movement direction relatively to the Siberian craton: from west-southwestward at the end of the Paleoproterozoic to south-southeastward in mid-Neoproterozoic.

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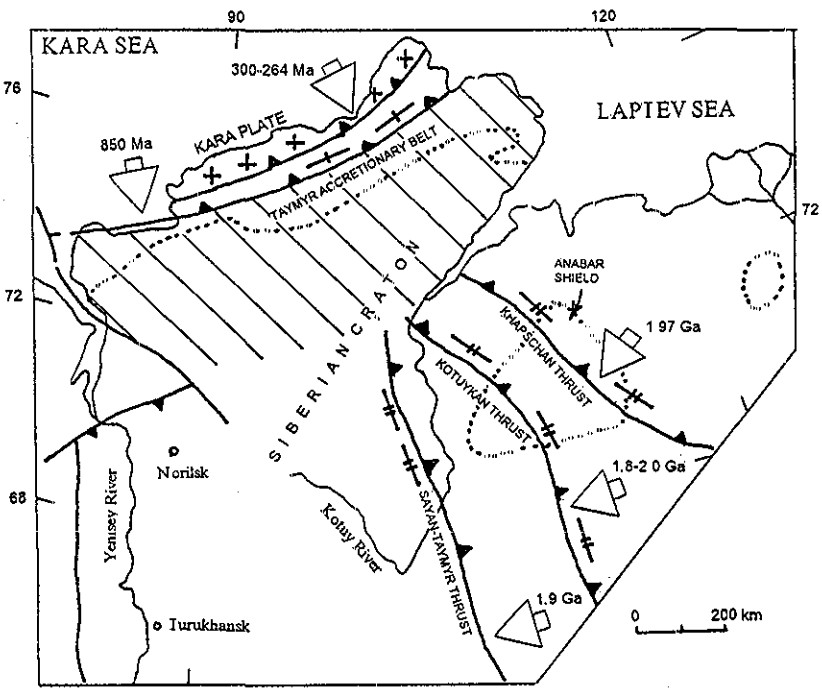

Figure 1. Collisional granites age and location in the north Siberian Craton, Taymyr Accretionary Belt and Kara Plate.

Early Proteozoic potassium granites and migmatites. 1 9±0 1 Ga

Late Proterozoic (Riphean) sodium granite-gneisses, granites and migmatites, 850 Ma intrusion from the 1 8-1 9Ga substratum

Late Paleozoic granite massifs 300 and 264 Ma

Direction of the plate movements and age of the collisional ganites

Thrust faults (sutures of collisonal zones assumed)

Deep seated crystalline basement under folded cover

Boundary of areas cropped out

GRANITE MAGMA GENERATION ALONG THE PALEOPROTEROZOIC FENNOSCANDIA-SARMATIA SUTURE ZONE: GRANITE DIVERSITY IN THE NORTH-WESTERN UKRAINIAN SHIELD

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The Ukrainian Shield comprises a partly exposed portion of the Sarmatia crustal segment in the southern part of the Precambrian basement of the East European Platform. According to the modern concept (Figure 1, after Bogdanova et al., 1996; 1997), the Precambrian basement can be subdivided into three large segments, Fennoscandia, Sarmatia and Volgo-Uralia, which were joined together during Paleoproterozoic accretion events. The junction between Fennoscandia and Sarmatia is in the far north-western part of the Ukrainian Shield. While the most of the shield is composed of predominantly Archean high-grade terrains there is considerable amount of Proterozoic geological record in the shield's north-western part, including numerous granite intrusions occurring both as separate bodies and in randomly overprinted complexes.

In general, the north-western part of the Ukrainian shield is characterized by a highly complicated geological framework including variable magmatic, metamorphic, metasomatic and other Precambrian records. Proterozoic granitoids are grouped into the Kigovograd-Zhitomir, Osnitsk, Korosten and Pergha intrusive complexes (Semenenko et al., 1975). At least 9 granite types have been distinguished within the area of about 150 by 150 km:

Zhitomir type (**Zt**, 1850–1700 Ma) – gray fine-grained garnet-bearing granites.

Rapakivi type (**Rl**, 1800–1700 Ma) – typical rapakivi granites.

Rapakivi-like type (**Rp**, 1860–1730 Ma) – biotite and biotite-hornblende non-augen and fine-augen granites.

Osnitsk type (**Os**, 1645–1600 Ma) – gray, pink-gray biotite two-feldspar granites, commonly cataclastic, sometimes silicified.

Ustinovka type (**Us**, 1300–1230 Ma) – gray-pink coarse-grained leucocratic two-feldspar biotite granites with abundant gray, rounded quartz grains. Evidence for metasomatism.

Lvovkivka type (**Lv**, 1300–1230 Ma) – medium-grained massive biotite-bearing alkaline or two-feldspar granites of granoblastic and porphyritic texture; sometimes syenitic.

Khotchino type (**Kh**) – coarse-grained biotite-bearing alkaline-feldspar granites; massive to gneissic.

Syrnitsa type (**Sr**, 1300–1230 Ma) – grey-pink medium-grained massive granites with blue and violet quartz. Porphyritic, sometimes granophyric. Cataclasis, mylonitization, silicification, greisenization.

Pergha type (**Pg**, 1380–1190 Ma) – muscovite±biotite-bearing porphyritic two-feldspar granites that contain siderophyllite, muscovite, zircon, cyrtolite, genthelvite, cassiterite. Cataslasis, silicification, albitization, chloritization, greisenization. Subparallel occurrence of coarse siderophyllite flakes is characteristic, banding is conformable to general elongation of the Fennoscandia-Sarmatia junction.

The granites can be related to a periodically activated, or "randomly-breathing", deep-crustal region (see Ranally and Murphy, 1987). Once appeared at the beginning of the Fennoscandian subduction beneath the Sarmatia, such a layer of weakness at the base of the crust could have produced various amounts of granite magma with variable composition depending on the heat and fluid budget. Significant amounts of granite with tholeiitic affinity (see Figure 2) also calls for mantle contribution in their generation, perhaps via introduction of basaltic magma into regions where granite magma was generated.

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Figure 1

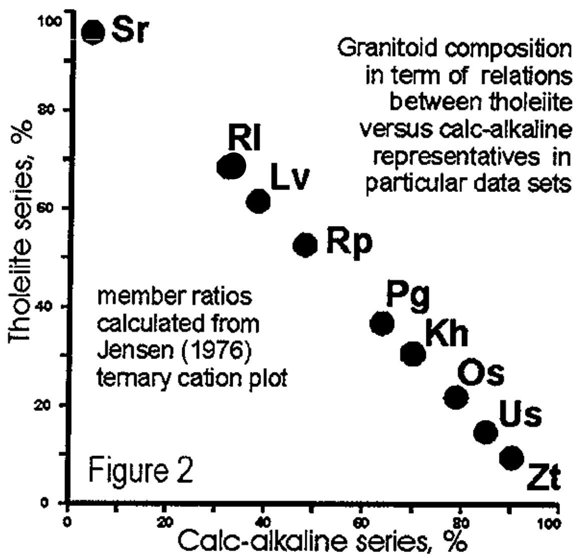

Figure 2

TYPES AND TECTONIC SETTING OF EARLY PROTEROZOIC GRANITOIDS IN THE SARMATIA: AN EXAMPLE FROM THE UKRAINIAN SHIELD.

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The Ukrainian shield is only the outcrop in the southwest part of the Voronezh-Ukrainian geoblock (Sarmatia) - the large integral structure in the southern part of the East-European platform's basement. The shield (and Sarmatia as a whole) was formed by Early Archean granulite nucleii and submeridional amphibolite-gneissic and greenshist fold belts, with overlying granulitic basement of Middle and Late Archean age. The youngest stratified rocks are an Early Proterozoic *metamorphosed volcano-sedimentary series, which form three large depressions in the central part* and near Sarmatia`s west and east boundaries, correspondingly. The Early Proterozoic granitoids occupy about 50% of the Ukrainian shield's territory. All of them may be divided for four groups.

1. The autochtonous ultrametamorphic granitoids are the most ancient. Their composition and structural position are connected with Archean highmetamorphic series. The ultrametamorphic processes began in the Early Archean (about 3400±100 Ma) and ended in the Early Proterozoic (about 2000 Ma). The ultrametamorphic granitization had different character in different parts of the Ukrainian shield, which shows the existence of different tectonic structures in the shield's (and Sarmatia's) territory during this stage. The origin of the Sarmatia, as an integral, partly stable structure, was connected with the termination of ultrametamorphic processes.

2. The allochtonous S-type granite massives of the second group (2100-1990 Ma) are mainly located in the Early Proterozoic depressions and more rarely in their Archean basement. The location of the S-type granite bodies was submitted to the three-radial symmetry, integral for Sarmatia as a whole. Most of them are located in three wide plutonic belts, which stretch from east, west and north Sarmatia boundaries to the point, laid on the south boundary, which correspond to the south-central part of the Ukrainian shield, where the large Early Proterozoic Kirovograd depression is known. The distribution of the granite massives within these belts is also submitted to some regularity. The largest massives are known near the point of belts' junction. The massifs sizes diminish to the North, at the same time their composition changes from biotite granites to two-mica granites. The origin of S-type granites ended the processes of *Sarmatia's structure forming.*

3. The I-type magmatic associations, forming the system of the Andean type volcano-plutonic belts along the north part of the Sarmatia, emerged during the next tectonic stage (about 2050-1950 Ma). These belts were obviously connected with the collision processes between Sarmatia and more nothern parts of the East-European platform`s basement. When the forming of the volcano-plutonic belts was finished, Sarmatia and other parts of the platform were fused into the integral structure.

4. The activation processes in the southwest part of the platform's basement caused the rise of the two A-type granitoid plutonic belts. First of them consists from the chain of large rapakivi-like and rapakivi granite, granosyenite, syenite massives (1800-1700 Ma in the Ukrainian shield) which stretch in the North-West direction from the East part of the Ukrainian shield up to the Baltic shield in the North platform's part. The second belt is formed by the chain of granophyre-granite massifs (1500-1400 Ma) which stretch in sublatitudal direction from the south coast of the Baltic sea to the east through the north part of the Ukrainian shield and Sarmatia as a whole. Thus, the origin of the Early Proterozoic granitoids in the Ukrainian shield was connected with tectonic

structures of different "levels". In many cases such granitoids were brought together in space and partly coincided in time. Only the investigations of their spatial position within large areas allow to show that such massifs belong to different tectonic structures and have different geodynamic nature.

The investigation of such plutonic or volcano-plutonic belts allow to distinguish the natural granitoid associations and to examine their main features from classification point of view. In many cases these associations form lateral rows of plutonic bodies, which average composition can vary from dioritic to alaskitic. Nevertheless, all bodies belonging to one association have some common features - first of all the same main mineral paragenesis and the same level of the alkality. The data from the Ukrainian shield and other regions of the former USSR allow to distinguish several types of granitoid allochtonous natural associations - plagiogranitic, I-type biotite granitic, S-type biotite granitic, two-mica granitic (peraluminous), granosyenitic (subalkaline) and alkali syenitic. From the classification point of view, all these associations form the homological rows (series) of plutonic bodies, which composition can vary, as it was said, from dioritic to alaskitic in each row. So, though different dioritic, granitic, or alaskitic plutonic bodies are similar between themselves, they can belong to different homological rows and will possess in such case different petrochemical, geochemical, and metallogenic features. The system of the homological granitoid rows is close to the well-known system of M-, S-, I-, A-types of granitoides, but allows to discriminate granitoides more precisely. The previous data show that ore-bearing plutonic bodies, belonging to different rows, have different ore composition even if they are similar by the average petrochemical or petrographical composition. The most important is, that from the classification point of view, the ore-bearing massives occupy in each row the definite places. In other words, the potential ore-bearance is probably connected with petrochemical features of granitoid bodies in each homological row separately.

PB-PB AND SM-ND CONSTRAINTS OF THE VELHO GUILHERME INTRUSIVE SUITE AND VOLCANIC ROCKS OF THE UATUMÃ GROUP, SOUTH-SOUTHEASTERN PARÁ, BRAZIL.

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The anorogenic magmatism of the Amazonian Craton is the most impressive and is a key piece of the understanding of Proterozoic tectontic evolution on a world-wide scale. It comprises a huge volume of plutonic granitoid and associated volcanic rocks, and subordinated amounts of mafic, mangeritic, and charnockitic plutons [2,3,4,8,11].

A number of granitoid massifs occur along the south-southeast region of the state of Pará (Brazil) which belong to the Velho Guilherme Intrusive Suite (VGIS) [12]. The granitoids intrude 1) deformed Archean granitoid rocks [7,15] and volcanic-sedimentary sequences (greenstone belt) of the Tucumã Group [7]; 2) Paleoproterozoic calc-alkaline granitoids [7]; and 3) sedimentary rocks of the Triunfo Formation [19]. Extensive fissural volcanism related to the granites is represented by andesitic and rhyolitic eruptions of the Uatumã Group [5]. The granitoids of the different plutons are hololeucocratic to leucocratic reduced granites, syeno to monzogranitic in composition as well as subordinated alkali-feldspar granite bearing biotite (annitic). Hastingsitic or edennitic amphibole as well as biotite (annite) occur in the less evolved facies. Geochemically they are mainly peraluminous subalkaline rocks, show mainly features of typical A-type and within-plate granites [6,14], and belong to the rapakivi series [9,11].

We have carried out Pb-Pb analyses (whole rock and feldspar) and Pb-Pb (single zircon evaporation) in three granitoid plutons of the VGIS as well as in andesites and rhyolites, respectivelly of the Sobreiro and Iriri Formations, both being part of the Uatumã Group (UATG). The zircon separation and analyses were carried out in the Isotope Geology Laboratory of the University of Pará – Brazil. Whole rock powders from Antônio Vicente Massif (AVM) and Rio Xingu Massif (RXM) were analysed for their Sm and Nd isotopic composition at the CPGeo – University of São Paulo, and all the results are summarized in Table 1.

Table 1

UNIT	MASSIF/ FORM.	ROCK TYPE	Pb-Pb age (Ma; 2 sigma)	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(t)$	TDM (Ga)
VGIS	AVM	SYENOGRANITE TO MONZOGRANITE	1896±9(wr) 1867±4(zr)	-30.49	-11.93 -12.20	3.25
VGIS	RXM	SYENOGRANITE	1906±29(wr) 1866±3(zr)	-35.05	-11.87 -12.36	3.02
VGIS	MM	SYENOGRANITE	1862±32(wr)	Nd	-13.45	Nd
VGIS	VGM	SYENOGRANITE	1874±32(wr)	Nd	Nd	Nd
UATG	SF + IF	ANDESITE+RHYOLITE	1875±79(wr)	-28.05	-10.16	3.10

VGIS=Velho Guilherme Intrusive Suite; AVM=Antônio Vicente massif; RXM=Rio Xingu massif; MM=Mocambo massif; UATG=Uatumã Group; SF=Sobreiro Formation; IF=Iriri Formation.

ANTÔNIO VICENTE MASSIF (AVM): Pb-Pb whole rock and feldspar isotope data for biotite syeno to monzogranite and biotite syenogranite yield an age of 1896±9 Ma (MSWD = 4.47). Pb-Pb single zircon evaporation analysis gives an age of 1867±4 Ma.

RIO XINGU MASSIF (RXM): the Pb-Pb isochron obtained from porphyritic syenogranite gives an age of 1906±29 Ma (Pb-Pb whole rock, MSWD = 0.06) and 1866±3 Ma (Pb-Pb single zircon evaporation analisis).

MOCAMBO MASSIF (MM): the Pb-Pb data for the porphyritic syenogranite yield an average age of 1862±32 Ma (Pb-Pb evaporation in zircon monocrystal); one zircon crystal gives an age of 1865±2 Ma.

SOBREIRO FORMATION AND IRIRI FORMATION OF THE UATUMÃ GROUP (UATG): Integrated samples of andesite and rhyolite, respectivelly of both formations, were also analysed for Pb-Pb (whole rock) and an age equivalent to 1875±79 Ma (MSWD = 5.95) was given.

The Pb-Pb ages of the granitoids so far obtained in this study agree well with the existing whole rock Pb-isotope data [13] for the VGM which corresponds to an age of 1874±32 Ma (MSWD = 1.53). These are interpreted as crystalization ages which indicate contemporaneity of the magmatic episode. Moreover the petrographic, geochemical, and metallogenetic similarities of the massifs [21] are also supporting the assumption of a consanguinity. The age of the volcanics at *ca.* 1.87 Ga is thought to represent the age of the UATG volcanism in the study area and overlap the VGIS magmatism between *ca.* 1.90 and 1.86 Ga.

Preliminary Sm-Nd data for the AVM, RXM and andesitic rocks of UATG (Table 1) yielded T_{DM} ages of *ca.* 3.25 Ga, 3.02 Ga and 3.11 Ga, respectivelly. The average T_{DM} value *ca.* 3.1 Ga of both granitoids and volcanic rocks represents age of crust formation of an Archean protolith that estimate the time of fracionation of the Sm/Nd ratio during the formation of new continental crust from a depleted mantle.

Also, both granitoids and volcanics clearly show a range of strongly negative $\varepsilon_{Nd}(t)$ (−13.4 to −10.16), indicating a major old Archean source component. Our Sm-Nd data (T_{DM} - $\varepsilon_{Nd}(t)$) are indicating that the VGIS's rocks are derived by crustal melting, of an Archean magmatic arc source, quite different and much older than the source materials of the rapakivi suites form North America, Finland, northeast Australia and northeast China [17]. However the T_{DM} model ages so far obtained are a bit closer to those of the Jamon and Musa granitoids which occur at the south-southeast part of the Pará State – Brazil [10], as well as the Salmi Batholith in Finland (2.73 to 2.85 Ga) as reported by [16].

The ancient Archean rocks of the Pium Complex, which occur within the Itacaiunas Shearing Belt (3050±44 Ma; Pb-Pb whole rock) [18], are very similar to the protolith of the granitoids and volcanics and thus may be interpreted as representing the protoliths of granitoids or volcanics. If this assumption proves valid, the granitoid and volcanic rocks emplaced along the Archean border derive from a magma which is still a late expression of distal reflected activity of the development of the Maroni-Itacaiunas orogeny at the margin of an Archean craton [20]. Linkage between the intrusions and extensional tectonics caused by mantle plumes (hot spots) or underplating processes might be considered.

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THE LATE PRECAMBRIAN PLURISERIAL MAGMATIC SYSTEM IN THE RIBEIRA BELT, SE BRAZIL.

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The Late Precambrian Ribeira Belt runs with more than 2800 km and an overall NE-SW direction parallel to the southamerican Atlantic coast from the State of Espírito Santo (SE Brazil) to Uruguay. Its oldest magmatism, a basic plume head ones, linked to the break up (rifting) of the Pre-Brasiliano basement have ages between 1000 and 950 Ma and its final post-tectonic granitoid magmatism ages around 570 (State of São Paulo, SE Brazil) or 480 Ma (State of Rio de Janeiro, SE Brazil). The belt evolved in a dominantly transpressional stress regime which results in an about 200 km wide anastomotic tectonic stripe with an overall regional positive flower structure and built up mainly by dextral wrench faults with associated expressive movements of crustal blocks resulting in a rather complex geological mosaic.

For systematic purposes the convergence/collision tectonic evolution of the Ribeira Belt can be divided in three phases. The oldest is essentially a thrust phase in a transpressive regime (with the *press* many larger/larger than the *trans*-component). The second is mainly a transcurrent phase developed in a transpressional (with the *trans* larger/equal than the *press* component) to transtensional (with the *trans* equal/minor than the *tensional* component) stress regime. The last phase is dominated by normal faults developed in an essentially tensional regime.

In the State of São Paulo, beside the dominant NE-SW fault system, also a somewhat younger E-W dextral transcurrent fault system occurs bending the regional NE-SW metamorphic foliation with the development of megasigmoidal structures bounded by successive parallel to subparallel transcurrent faults. Also the older synconvergence Ribeira granitoids are affected by this deformation with the development of "S" and "hockey stick" shapes. By this the E-W transcurrent fault system represents an important time marker for the relative dating of the Ribeira granitoid magmatism which age is concentrated between 630 (possible 660) and 580 Ma.

At the ending of the Ribeira magmatism occurred the development of the wide-spread Pluriserial Magmatic System 590 (PSMS-590) represented by plenty intrusive bodies beside rare volcanic and volcanoclastic rocks with the following main characteristics:

01 – The major part of the plutons have ages between 600 and 580 Ma.

02 – The PSMS-590 comprises bodies with frequent areas between 30 and 80 km^2.

03 – The bodies are simple, isolated, or multiple, a result of the assemblage of several intrusions ascended side by side along a same magma conduit.

04 – The depth of emplacement of the bodies varies from deep to high levels with the later associated in some cases with basic to felsic volcanic/volcanoclastic rocks.

05 – The country-rocks of the plutonsare represented either by low grade metasedimentary and volcanic rocks, medium to high grade schists, gneisses and migmatites or older Ribeira synconvergence calc-alkaline batholiths.

06 – The emplacement of the plutons is controlled by transcurrent faults of the transtensional stress phase or normal faults and arched structures from the later tensional stress phase. By this some of the plutons are cut and dislocated by the transtensional transcurrent faults; other bodies are cut but little affected by them and still other plutons cut the transcurrent faults. In the two first cases the development of complex bodies comprising several magmatic pulses and magmatic cycles is typical due to the successive income of magma during the several regeneration episodes of the faults.

07 – The plutons contacts varies from dominantly magmatic to essentially tectonic but the normal feature is the coexistence of both types of contact in a same body.

08 – The thermal regime during the emplacement of the pluton was very variable. In some of them, mainly in the basic deeper ones, the magma melts a small ring of the enclosing host-rocks (as in the case of the Santa Angélica pluton, State of Espírito Santo); in other cases the country-rocks became ductil molding themselves plastically around the plutons (as in the case of the Capituba syenite, State of Minas Gerais, SE Brazil) with frequently well-developed flow structure parallel to their contacts (as in the case of the Pedra Branca syenite, State of Minas Gerais); in other more high-level plutons, brecciation of the wall-rocks is a normal feature (as in the case of the Itu rapakivi complex, State of São Paulo).

09 – The PSMS-590 comprises mainly four magmatic series:

I. High-K rarely weakly calc-alkaline to dominantly alkali-calcic plutons, similar to some I-Caledonian intrusions and of essentially deep crustal origin.

II. High-K alkali-calcic rapakivi granites of essentially deep crustal origin.

III. Transalkaline to peralkaline potassic rocks, the first group comprising (quartz) gabbros, (quartz) monzogabbros, (quartz) diorites, (quartz) monzodiorites, (quartz) monzonites, (quartz) syenites and granites and the second a suite of undersaturated, saturated and oversaturated syenites.

IV. A weakly alkaline to peralkaline sodic series comprising (quartz) syenites and granites with biotite, aegerine, riebeckite and arfvedsonite.

10 – Typical is the spatial association of the four series. The synconvergence Socorro batholith (States of São Paulo and Minas Gerais), is cut by younger plutons of type I and II; in the Serra do Mar Province (States of São Paulo, Paraná and Santa Catarina, SE/S Brazil) plutons of series I and III occur side by side and the multiple centered Itu Complex (State of São Paulo) is built up by three plutons of type II and one of type I.

11 – Following general features of the PSMS-590 can be stressed:

A - Its wide-spread occurrence appoint to rather uniform tectonic and thermal conditions in the whole Ribeira Belt between 600 and 580 Ma ago.

B – The tectonic features at that time were characterized by large movements and uplifts of crustal blocks with the development of expressive horst and graben. This structure allowed the ascent of the magmas by deep faults, the genesis of the mantle derived magmas by pressure releasing processes and the generation of magmas with geochemical features transitional between "magmatic arc" and "intraplate" tectonic environments.

C – The close spatial and temporal coexistence of the magmatic series I + II, I + III and I + IV indicates the simultaneous melting of mantle and deep crustal protoliths but the occurrence of basic rocks associated with plutons from series I and II is very rare. The melting of the deep crustal protolith can be debt to an upwelling of the isotherms during the post-collisional tectonic relaxation stage with the formation of local "heat pillows".

D – The alkaline rocks display geochemical features indicating their derivation from metassomatized mantle protolith which typical chemical composition probably were developed during the subduction (convergence) phase of the Ribeira Belt with its associated emplacement of plenty huge calc-alkaline batholiths.

E – The intensive association between plutons from series I and II suggest that the rapakivi granites from fault/shear belts may represent a particular evolutional path (by ACF and MASH processes) of the I-Caledonian magmatism which comprise many plutons with rapakivi like geochemical features. Both series are also characterized by a continuous gradual increasing in the alkalinity from the older to the younger plutons.

PETROLOGIC RANGES OF AURIFEROUS GNEISSES AND GRANITOIDS IN THE EARLY PROTEROZOIC PROTOPLATFORMS (EXEMPLIFIED BY THE UKRAINIAN SHIELD)

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In the Ukrainian shield granitoid-meta-terrigenous complexes are of preferential spatial distribution, and these are the units with which the Kirovograd, Volyn', and Priazovski geoblocks of the Early-Precambrian stabilization built up. They differ in composition and structure of interconnected gneissic and granitoid formations, as well as in metallogenic peculiarities – in addition to known rare-metals, recently their gold specialization has been also established [4].

Composition and structure of the protoplatform geoblocks. Their framework is characterized by two-layer structure, decreased thickness of the Earth's crust (to 40-45 km), involvement of mantle diarpirs [2], and generally decreased but differentiated heat flow. Geoblocks achieved their patterns due to 1.9 Ga stabilization. Broken into the high-order blocks, Archean basement of the blocks is composed of charnockite-granulite and plagiogranitoid-amphibolite complexes. In the protoplatform cover (thickness of 0-10 km) gneissic rocks predominate (metagreywacke terranes of flysch-like structure), associated with granitoides of potassic affinity. The fields of amphibolite and granulite metamorphic facies have been mapped. Autochthonous ultrametamorphic granitoides are isochemical to replaced piles. With time, the process changed to enrichment of granitoid rocks in potassium and reduction of their volume, followed by transition to veined aplite-pegmatoid varieties [3]. Mixed ranks formed of metamorphic (ultrametamorphic formations, reflecting horizontal foliation of complexes; see table). Plutons are enveloped by zones of blastomylonites and fluidizites; granite-like blastites have been formed as a result of blastesis, sometimes of regional scale. These rocks reflect specific a kind of granitoid rocks formation. Having the same patterns but differing in particular rock association features, the ranks are traced in the basement complexes too.

Table 1. Ranks of the Early Proterozoic metamorphic rocks and granitoides of the Kirovograd geoblock of the Ukrainian shield

Gneissic terranes	Isochemical granitoids	Allochemical granitoids
Biotite gneisses and their varieties – with garnet, hypersthene, amphibole, cordierite, interbedding with diopside-plagioclase-quartz crystalline schists (flysch-like metagreywacke formation)	Porphyry biotite and garnet-biotite granite-gneisses and granites (granitic formation in the zones of crush)	Leucocratic biotite granite-gneisses and granites
Leptite biotite and garnet-biotite plagioclase and two-feldspar gneisses of leucocratic outlook (formation of leptite gneisses)	Leucocratic biotite plagioclase and two-feldspar granite-gneisses (granite-gneiss formation of domes)	Aplite-like and pegmatoid granites of veined type

Within ranks, metamorphic and ultrametamorphic rocks contain comparable mineral facies summarized as follows:

Metamorphic	Ultrametamorphic
Epidote-amphibolite	*Helsinkite*
Amphibolite	*Granite-gneisses*
Granulite	*Enderbite*
Eclogite	*Anorthosite*
Dynamic-schist	*Blastite*

Previously the variants to distinguish facies of comparison have been proposed by P.Escola and the other scientists [1]. Among large tectonic forms granite-gneissic domes can be distinguished, autochthonous Kirovograd, Dolyna, and other massifs of porphyroblastic and other granitoides of the Kirovograd-Zhitomir complex, and the Novoukrainsky massif of trachytoid potassic granites.

Metallogenic peculiarities of the protoplatform geoblocks. The Early-Proterozoic protoplatform structures, with the boundary of 1.7 Ga already having been destroyed by the first great activization processes, accompanied by respective metallogenic impulse. At this stage the Korosten' and the Korsoon'-Novomirgorod massifs of gabbro, anorthosites and rapakivi granites have been formed, associated with rare-metal and gold deposits. Ore-bearing structures comprise fault systems around granitoid massifs and other structures. In these structural-metallogenic zones (width – first tens, extension – hundreds of km) the ore fields and zones distinguished, which include tectonic-metasomatic structures with the deposits. Rare-metal and gold-bearing objects within structural-metallogenic zones are placed separately.

Gold deposits (Klyntsi etc.) are of plane-parallel type, traced to the depth of 500 meters. Linear ore bodies are located in fault-metasomatism zones of first kilometers long and tens of meters in width. Progressive Fe-Mg-Ca metasomatism occurs and regressive alkali-silicic one, which accompanied by gold deposition. Cummingtonite-biotite metasomatites are characteristic named as "klyntsovites". Such a type of metasomatites has been described at some Precambrian gold-bearing objects elsewhere, for instance, it is appeared at Homestake deposit. Essential role in ore genesis has played by oligoclase-quartz units of veined type.

Geochemical peculiarities of the ores and deposits' position allow to suppose the different sources of gold, fluids and fluidizates (mantle, ultrametamorphogenic, connected with the granitoid massifs of the Kirovograd-Zhitomir complex, and metamorphogenic). It is assumed digestion of fluids and fluidizates at the conditions of redox-oxidation transition. The ores seems to locate in metasomatically modified metamorphic pararocks in favorable lithologic and structural conditions. In linear ore-bearing structures within magmatic hosts only dykes of metamorphosed intermediate, basic and subalkaline rocks and veined aplite-pegmatoid granites occur, which are barren themselves. The new **Klyntsi** type of gold deposits has been distinguished representing tectono-metasomatic group of ore deposits. So, the Proterozoic paragneissic regions in the Precambrian metallogeny are of independent significance, just as the Archean granite-greenstone terranes.

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