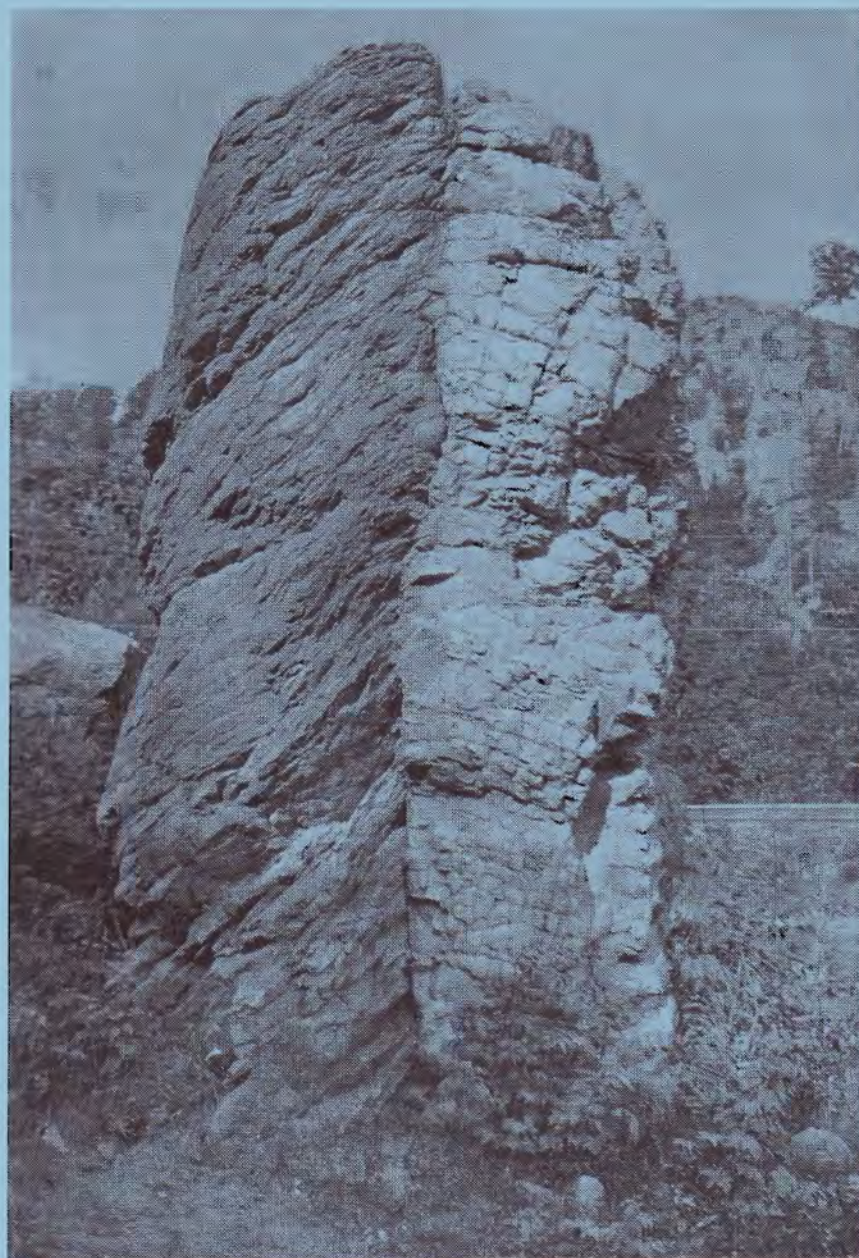


47th Annual Meeting Institute on Lake Superior Geology

**Proceedings Volume 47
Part 2—Field Trip Guidebook**



Madison, Wisconsin • May 9–12, 2001

INSTITUTE ON LAKE SUPERIOR GEOLOGY

**47th Annual Meeting
May 9-12, 2001
Madison, Wisconsin**

Hosted by:

**University of Wisconsin-Extension
Wisconsin Geological and Natural History Survey**

**University of Wisconsin-Madison
Department of Geology and Geophysics**

**Proceedings
Volume 47**

Part 2 - Field Trip Guidebook

47th Annual Meeting Institute on Lake Superior Geology

Volume 47 contains the following parts:

Part 1: Program and Abstracts

Part 2: Field Trip Guidebook

- 1 - Sedimentologic, Tectonic and Metamorphic History of the Baraboo Interval: New Evidence from Investigations in the Baraboo Range, Wisconsin
- 2 - Geology, Ore Deposits, and Cultural History of the Upper Mississippi Valley Zinc-Lead District
- 3 - Economic Geology of the Baraboo and Waterloo Quartzites of Southern Wisconsin

Reference to the material in this volume should follow the example below:

Medaris, L.G., Jr., Dott, R.H., Jr., 2001, Sedimentologic, Tectonic and Metamorphic History of the Baraboo Interval: New Evidence from Investigations in the Baraboo Range, Wisconsin: Institute on Lake Superior Geology Proceedings, 47th Annual Meeting, Madison, WI, 2001, v. 47, Part 2, p. 1-21.

Volume 47 is published by the Institute on Lake Superior Geology and distributed by the Institute Secretary-Treasurer:

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ISSN 1042-9964

Cover Illustration:

Van Hise Rock, Abelmans Gorge, SW1/4, sec. 28, T21N, R5E, Sauk County, Wisconsin from Salisbury, R.D., and W.W. Atwood, 1900, The Geography of the Region About Devil's Lake and the Dalles of the Wisconsin: Wisconsin Geological and Natural History Survey Bulletin V, Plate IX.

Charles R. Van Hise and Charles K. Leith used this outcrop as a laboratory to demonstrate the fundamental geometric relationship between slaty cleavage and bedding at an outcrop-scale for inferring larger-scale structures. See Field Trip Stop 4, this meeting, Part 2, p. 17

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Jennifer Lien, *The Kraemer Company*

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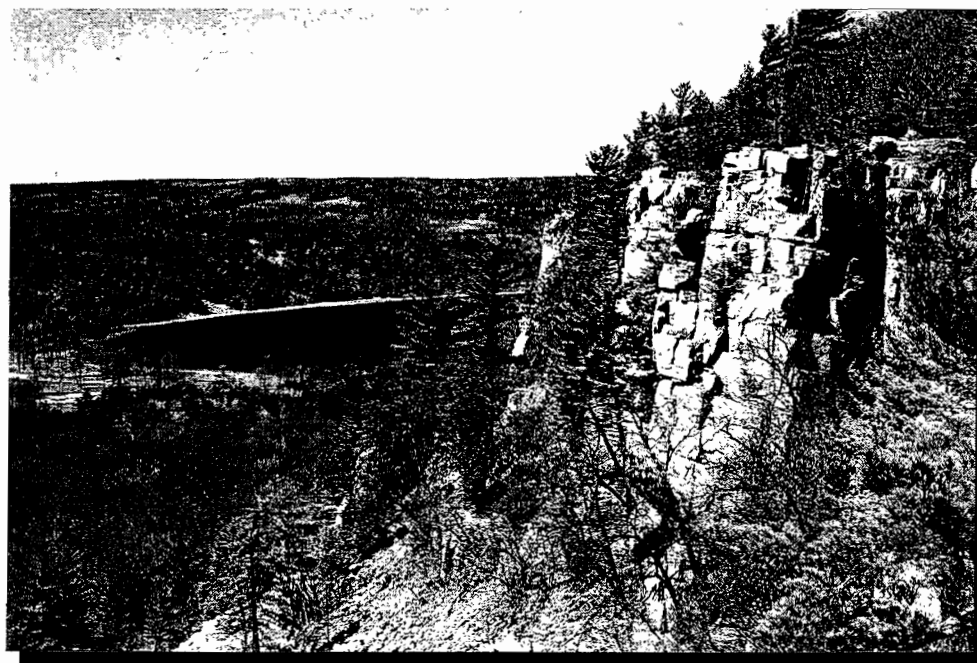
Field Trip 1

Sedimentologic, Tectonic and Metamorphic History of the Baraboo Interval: New Evidence from Investigations in the Baraboo Range, Wisconsin

by

L. Gordon Medaris, Jr. and Robert H. Dott, Jr.

Department of Geology and Geophysics
University of Wisconsin - Madison



View to the west along the East Bluff, Devil's Lake State Park
Baraboo Quartzite (foreground), Devil's Lake (background)

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FOREWORD

Geological investigations of the Baraboo Range began in 1852 and culminated in 1970 with publication of the monograph, "Geology of the Baraboo District, Wisconsin", by Dalziel and Dott. Despite its publication 30 years ago, this monograph (with accompanying detailed geological map) remains today the most comprehensive treatise on the Baraboo Range.

In 1996 a paleosol at the base of the Baraboo Quartzite was discovered in a drill core taken in Baxter Hollow (Medaris et al., 1996). Recognition of the paleosol, which was developed at the expense of granite underlying the quartzite, resolved any remaining question about the relative ages of the Baraboo Quartzite and Baxter Hollow Granite. This discovery subsequently inspired a new look at the Baraboo Range, using a variety of analytical techniques that were unavailable 30 years ago, and led to elaboration of a number of topics, including depositional age of the quartzite, paleoclimatic environment, sedimentary geochemistry, and conditions and age of metamorphism. The new data substantiate the conclusions originally drawn by Dalziel and Dott and provide additional insight into the processes responsible for producing the Baraboo Range. An especially exciting and unexpected new discovery is the occurrence of 1,460 Ma hydrothermal activity along the base of the Baraboo Quartzite, presumably driven by heat from Wolf River-type magmatism.

This field guide provides an updated overview of the Proterozoic evolution of the Baraboo Range, based on the results of our recent investigations, and describes several key outcrops, from which many of the new data were obtained.

INTRODUCTION

Red, supermature quartzites, most notably the Baraboo, Barron, and Sioux Quartzites, have long been recognized as distinctive and important Precambrian features in the southern Lake Superior region. The physical and chemical characteristics of the quartzites signify deposition in a stable cratonic setting under conditions of intense chemical weathering in the presence of significant free oxygen in the atmosphere. These quartzites are now known to be post-1,750 Ma in age (Dott et al., 1997; Holm et al., 1998), to have been folded and metamorphosed at ~1,630 Ma (Romano et al., 2000), and locally intruded by granitic rocks at ~1,450 Ma (Dott and Dalziel, 1972). The term, *Baraboo interval*, was introduced by Dott (1983) for this distinctive sequence of sedimentation, deformation, and metamorphism in the time span of 1,450 to 1,750 Ma. Our recent investigations not only validate the concept of the Baraboo interval, but also provide greater insight into the disparate geological events that shaped the southern Lake Superior region in mid-Proterozoic time.

REGIONAL SETTING

Baraboo interval sedimentary rocks are widely distributed in the southern Lake Superior region (Fig. 1), where they lie nonconformably on 1,750 Ma and older igneous and metamorphic rocks. The increase in sediment thickness from north to south, the general southerly direction of paleocurrents, the chemical maturity of the sedimentary rocks, and the occurrence of mature paleosols suggest that deposition occurred on a stable, passive continental margin on the southern edge of a Proto-North American craton (Dott, 1983). All of the quartzites in Figure 1, except for the Waterloo, have yielded detrital zircon grains with U-Pb ages in the range, 1,712 to 1,778 Ma (Dott et al., 1997; Holm et al., 1998; Van Wyck, 1995), and these data, combined with the inferred time of folding and deformation at ~1,630 Ma, established from $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages of basement amphibole and mica (Romano et al., 2000) and Rb-Sr resetting of granite and rhyolite (Dott and Dalziel, 1972; Van Schmus et al., 1975),

constrain deposition of the Baraboo interval sediments to between 1,710 and 1,630 Ma. Subsequently, the easternmost quartzites at McCaslin and Waterloo were intruded by granitic rocks of Wolf River age (Dott and Dalziel, 1972; Van Wyck, 1995).

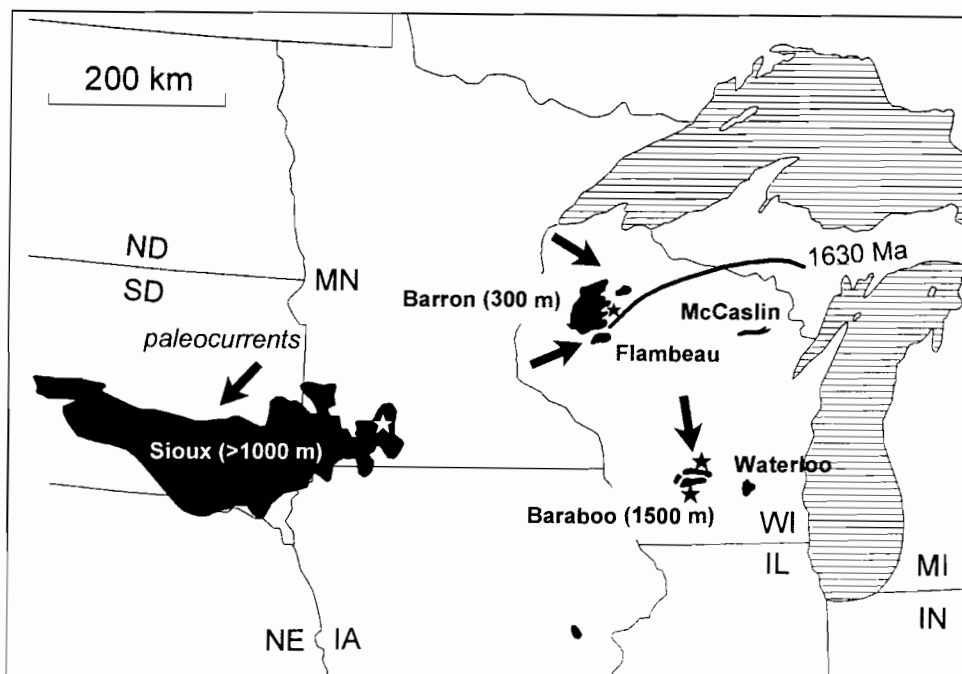


Figure 1. Distribution of Baraboo and correlative quartzites in the southern Lake Superior region, with average paleocurrent directions, thicknesses in meters, and paleosol localities (★). Heavy line is the inferred 1,630 Ma tectonic front, south of which quartzites have been folded (Holm et al., 1998)

IGNEOUS BASEMENT OF THE BARABOO RANGE

The Baraboo Quartzite is underlain by diorite near the town of Denzer, by granite in Baxter Hollow, and by rhyolitic lavas and pyroclastic rocks beneath both limbs of the syncline in its eastern part (Dalziel and Dott, 1970). U-Pb zircon ages of the Baxter Hollow granite and rhyolite are indistinguishable, and taken together, yield an age of $1,749 \pm 12$ Ma (Van Wyck, 1995). Chronologically and petrologically, the Baraboo basement is correlative with the subalkalic granite and rhyolite suite of the Fox River Valley (Smith, 1978; Anderson et al., 1980). The Fox River Valley igneous suite contains both metaluminous and peraluminous types, and recent chemical analyses demonstrate that Denzer diorite is metaluminous, Baxter Hollow granite is peraluminous, and rhyolite is both peraluminous and metaluminous (Fig. 2A). Among all the 1,750 Ma silicic lithologies, the Baxter Hollow granite is the least differentiated in terms of major elements, as measured by Fe-number and Ca-number (Fig. 2B). The Denzer diorite is metaluminous and plots outside the scales of Figure 2, containing 625-700 ppm Sr, an $\text{Al}_2\text{O}_3/(\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO})$ value of 0.70-0.82, Fe-number of 0.46-0.48, and Ca-number of 0.62-0.68.

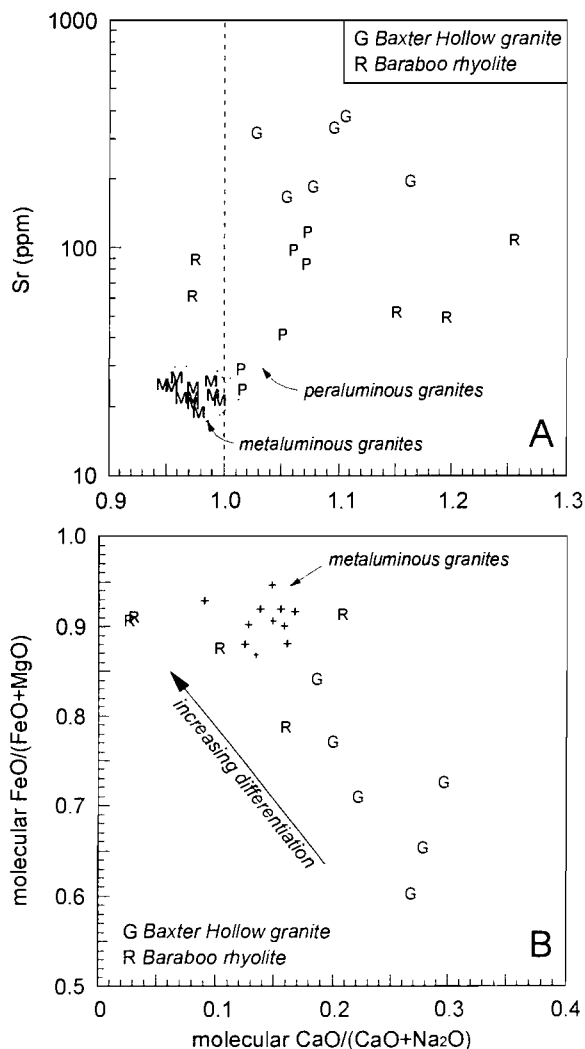


Figure 2. Chemical comparison of Baxter Hollow granite (G) and Baraboo rhyolite (R) with metaluminous (M) and peraluminous (P) granites of the Fox River Valley suite (data from Smith, 1978; Anderson et al., 1980; Medaris, unpublished)

Igneous textures are well preserved in all units of the Baraboo basement (Fig. 3), although recrystallization is extensive, with igneous minerals being partly to completely replaced by a variety of greenschist facies minerals. Typically, biotite is replaced by chlorite, plagioclase is transformed to albite and fine-grained epidote (saussurite), and intermediate alkali feldspar exsolves into an extremely fine-grained mixture of near end-member microcline and albite (Fig. 4). In Denzer diorite, hornblende is partly replaced by chlorite and intergrown actinolite and cummingtonite (Fig. 5).

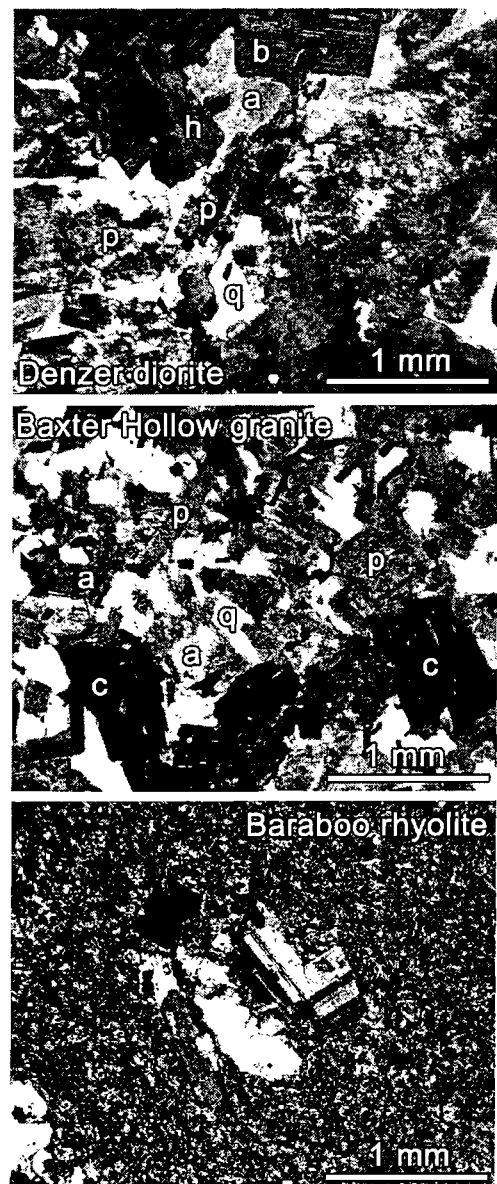


Figure 3. Photomicrographs of typical textures in Denzer diorite (subhedral granular, plane polarized light), Baxter Hollow granite (micrographic, plane polarized light), and Baraboo rhyolite (plagioclase microphenocrysts in aphanitic matrix, crossed polarizers). Abbreviations: a, alkali feldspar; b, biotite; c, chlorite after biotite; h, hornblende; p, plagioclase, mostly albite and saussurite; q, quartz.

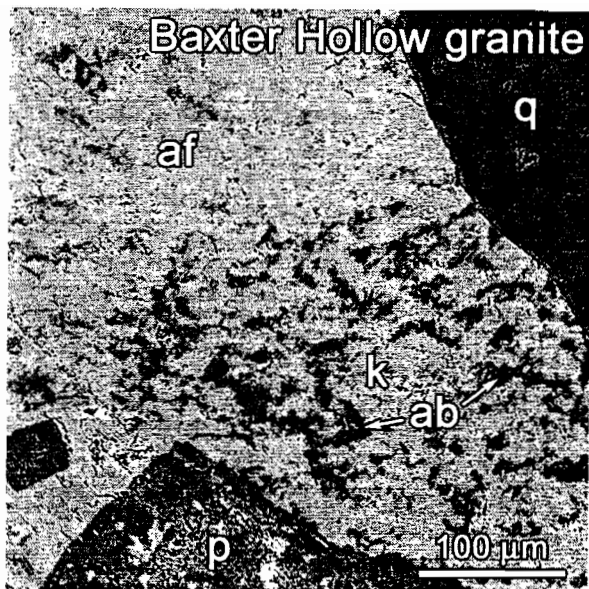


Figure 4. Back-scattered electron image, showing partial replacement of relict igneous alkali feldspar, af (Or 54-70) by K-feldspar, k (Or 98.5) and albite, ab (Ab 96.4). p, epidote and albite after plagioclase; q, quartz.

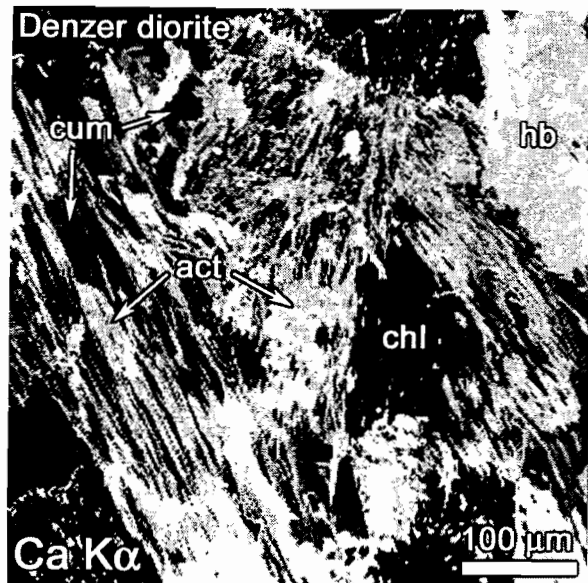


Figure 5. Ca K α X-ray map of amphibole in Denzer diorite. Relict igneous hornblende, hb, partly replaced by chlorite, chl, and an intergrowth of actinolite, act, and cummingtonite, cum.

BARABOO QUARTZITE

The Baraboo Quartzite is 1,500 m thick and is overlain conformably by the black Seeley Slate (100 m), Freedom Dolomite with iron formation (300 m), Dake Quartzite (65 m), and Rowley Creek Slate (45m). The Baraboo Quartzite consists of 85-90% of quartz arenite and subordinate quartz wacke, which are characterized by prominent cross bedding (Fig. 6) and ripple marks, 5-10% of conglomerate, and 5-10% of siltstone (Fig. 7) and pelite (Fig. 8). Although all of these rock types have experienced low grade metamorphism, the original clastic textures are remarkably well-preserved in quartzite (Fig. 9) and

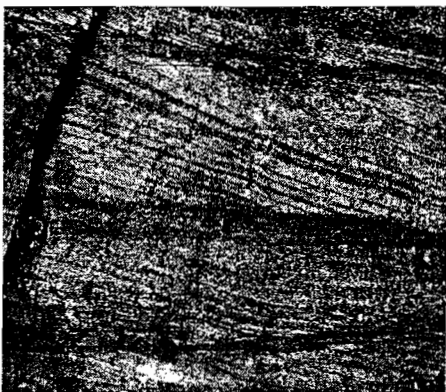


Figure 6. Typical quartzite with prominent cross bedding.

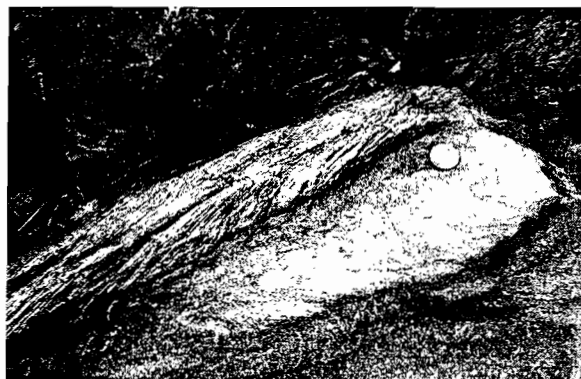


Figure 7. Typical metasiltstone with refracted cleavage, Field Locality 2. Coin is 2.5 cm in diameter.



Figure 8. Metapelite near Larue, with chevron folds and crenulation cleavage.

metasiltstone (Fig. 10). Complete recrystallization has occurred only in metapelite layers, where it is accompanied by development of crenulation cleavage (Fig. 8), and in interstitial domains in quartzite and metasiltstone.

The chemical maturity of the Baraboo Quartzite has long been inferred from the near absence of detrital feldspar, the abundance of pyrophyllite, and the predominance of zircon, magnetite, rutile, and apatite among heavy minerals. Metasiltstone and metapelite from the Baraboo, Sioux, and Barron quartzites chemically consist almost entirely of SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , and H_2O , with extremely low concentrations of K_2O , Na_2O , CaO , MgO , and MnO . The Chemical Index of Alteration is exceptionally high, ranging from 96.8 to 98.6. The remarkable degree of chemical maturity is readily apparent when the rock compositions are normalized to average shale and compared to average shale of different ages (Fig. 11). The extreme chemical maturity of the Baraboo interval sediments implies a source region that experienced intense

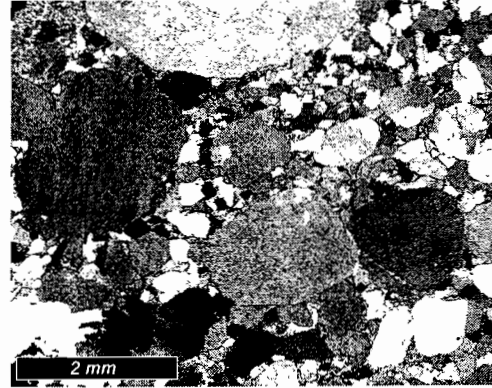


Figure 9. Photomicrograph of typical quartzite with relict clastic texture (partly crossed polarizers).

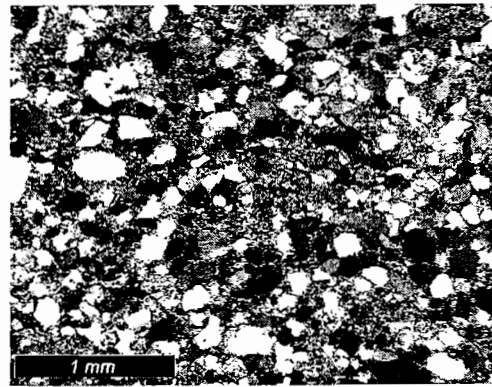


Figure 10. Photomicrograph of metasiltstone with relict clastic texture (partly crossed polarizers).

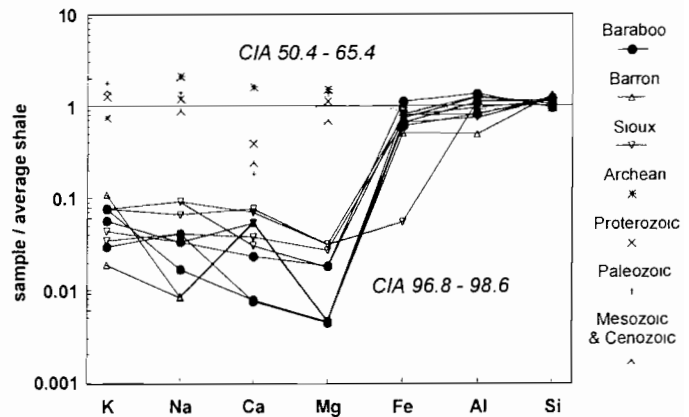


Figure 11. Compositions of fine-grained Baraboo interval metasedimentary rocks, normalized to average shale (Taylor and McLennan, 1985) and compared to average shale over the ages. Elements arranged in order of decreasing ionic radius. $\text{CIA} = 100 \times \text{molar Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO})$

chemical leaching and produced detritus consisting largely of quartz, kaolinite, and hematite.

The persistent question about the relative ages of the Baraboo Quartzite and Baxter Hollow granite was resolved with the discovery of the sub-Baraboo paleosol in drill core from Baxter Hollow (Medaris et al., 1996) and subsequent recognition of saprolite in outcrop in Baxter Hollow granite and in rhyolite beneath the east end of the syncline (Medaris et al., 1997). Further confirmation of the post-1,750 Ma depositional age of the quartzite was provided by U-Pb analyses of detrital zircon from near the base of the quartzite, using the single-grain evaporation technique. Among the seven grains analyzed, six are slightly discordant and one is more so, with one grain yielding a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1,866 Ma, and the other six ranging from 1,691 to 1,779 Ma (Fig. 12; Dott et al., 1997). Although the two grains with ages of 1,691 and 1,715 Ma are highly radiogenic and may not be reliable, the other grains are "well behaved" and indicate that deposition may have begun as late as ~1,710 Ma.

METAMORPHISM

Although the structure of the Baraboo Range has been well studied, little attention has been devoted to metamorphism, other than identifying pyrophyllite in metapelite. It is now known that all lithologic units in the Baraboo Range have been recrystallized to varying degrees by low-grade metamorphism (Medaris et al., 1998). Because of the extreme chemical maturity of many rock types, the critical mineral assemblages can be adequately represented in the system, $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$ (KASH) (Fig. 13). Baraboo quartzite, metasiltstone, and metapelite contain quartz and pyrophyllite plus accessory hematite, rutile, and svanbergite (a strontian aluminophosphate-sulfate diagenetic mineral); metapaleosol consists of quartz, muscovite, hematite, and rutile; hydrothermal veins near the base of the quartzite contain pyrophyllite, muscovite, and diaspore; and the metaigneous basement is characterized by quartz, microcline, and albite +/- muscovite, hematite, chlorite, epidote, titanite, actinolite, and cummingtonite, depending on

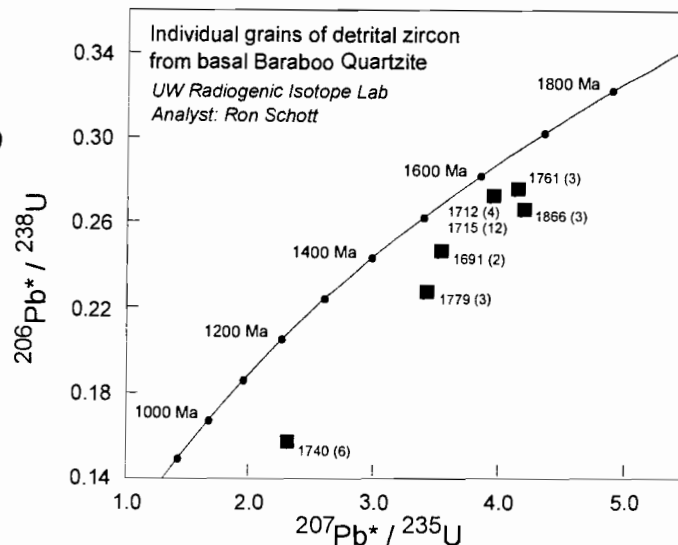


Figure 12. U-Pb concordia diagram for detrital zircon grains from the Baraboo Quartzite. $^{207}\text{Pb}/^{206}\text{Pb}$ ages are given for individual grains; 2σ standard deviations are shown in parentheses.

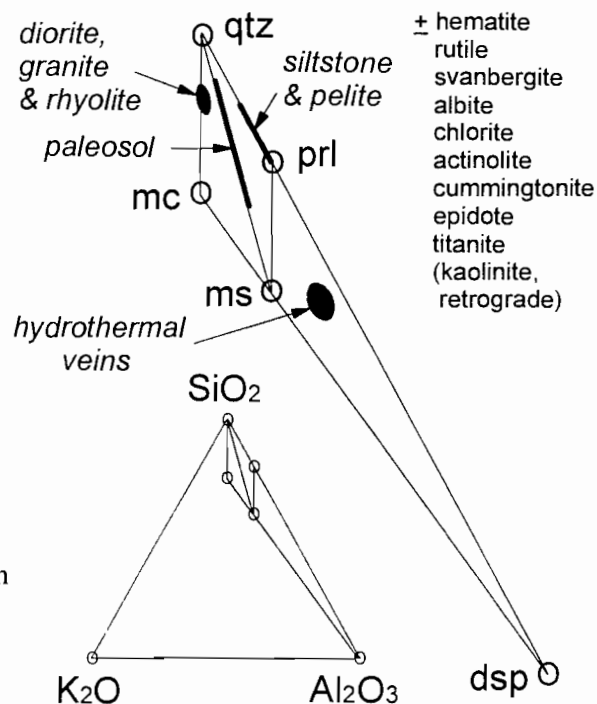


Figure 13. Rock compositions and mineral assemblages in the Baraboo Range, projected into the system, KASH. Abbreviations: dsp, diaspore; mc, microcline; ms, muscovite; qtz, quartz; prl, pyrophyllite.

specific bulk composition. Where kaolinite occurs, textural relations indicate that it is a retrograde product.

Phase equilibria in the system, KASH, have been calculated at unit H_2O activity by means of the GeoCalc thermodynamic data base (Brown et al., 1989), resulting in the topology shown in Figure 14. The stable association of quartz and pyrophyllite in the absence of kaolinite or an aluminosilicate phase (andalusite or kyanite) constrains the temperature of metamorphism to between 285°C and 360°C at 1 kbar. The coexistence of pyrophyllite and diasporite in hydrothermal veins at the base of the Baraboo Quartzite restrict the temperature further to between 305°C and 345°C. At reduced H_2O activity, 0.9 for example, these temperature limits would be lowered to 275 and 350°C, and 290 and 335°C, respectively. Fluid inclusion studies are underway in an effort to establish more precisely the conditions of Baraboo metamorphism.

Until recently, no meaningful metamorphic mineral ages were available from the Baraboo Range. However, in 1975 Van Schmus recognized that there was widespread resetting of Rb-Sr systems in the southern Lake Superior region at ~1,650 Ma and that igneous rocks from Baraboo and the Fox River Valley yielded an apparent whole-rock Rb-Sr isochron age of $1,635 \pm 33$ Ma ($\lambda = 1.42 \cdot 10^{-11} \text{ yr}^{-1}$). Subsequently, it was suggested that such Rb-Sr resetting was caused by regional low-grade metamorphism related to foreland deformation associated with the ~1,650 Ma Mazatzal orogeny in the southwest U.S. (Dott, 1983; Van Schmus et al., 1993), with the implication that folding and metamorphism of the Baraboo Range also occurred at this time. The position of a tectonic front marking the extent of foreland deformation in northern and central Wisconsin (see Fig. 1) was established by $^{40}\text{Ar}/^{39}\text{Ar}$ analyses of hornblende and biotite in basement rocks (Holm et al., 1998; Romano et al., 2000); the tectonic front separates post-Penokean ages in the south from Penokean and older ages to the north.

A $^{40}\text{Ar}/^{39}\text{Ar}$ investigation of hornblende and muscovite in the Baraboo Range was recently undertaken in an effort to confirm a metamorphic age of 1,630 Ma (Naymark et al., 2001). However, rather than obtaining evidence for 1,630 Ma metamorphism, a strong overprint at ~1,460 Ma was found, presumably related to the activity of hydrothermal fluids driven by a thermal pulse from Wolf River magmatism. These significant new results are discussed further in the following sections on Field Localities 1 and 2.

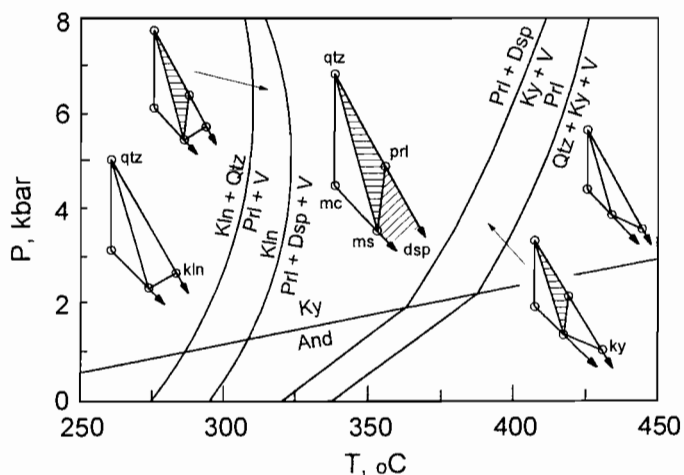


Figure 14. Stable reactions in the system, KASH, calculated for $a(H_2O) = 1$.

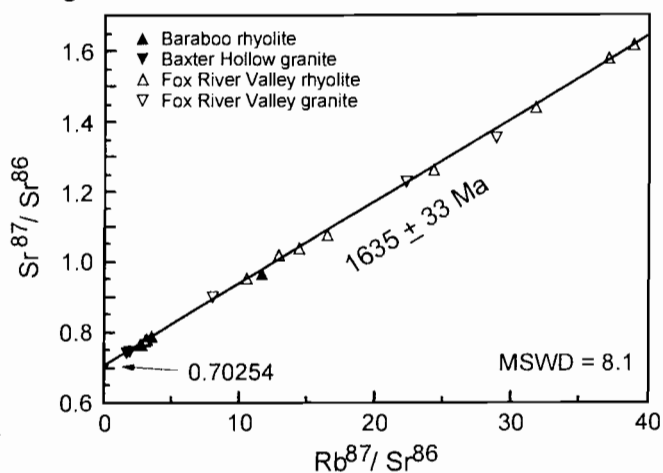


Figure 15. Rb-Sr isochron for granite and rhyolite from Baraboo and the Fox River Valley. Age and intercept recalculated from data of Dott and Dalziel (1972) and Van Schmus et al. (1975).

DESCRIPTIONS OF FIELD TRIP LOCALITIES

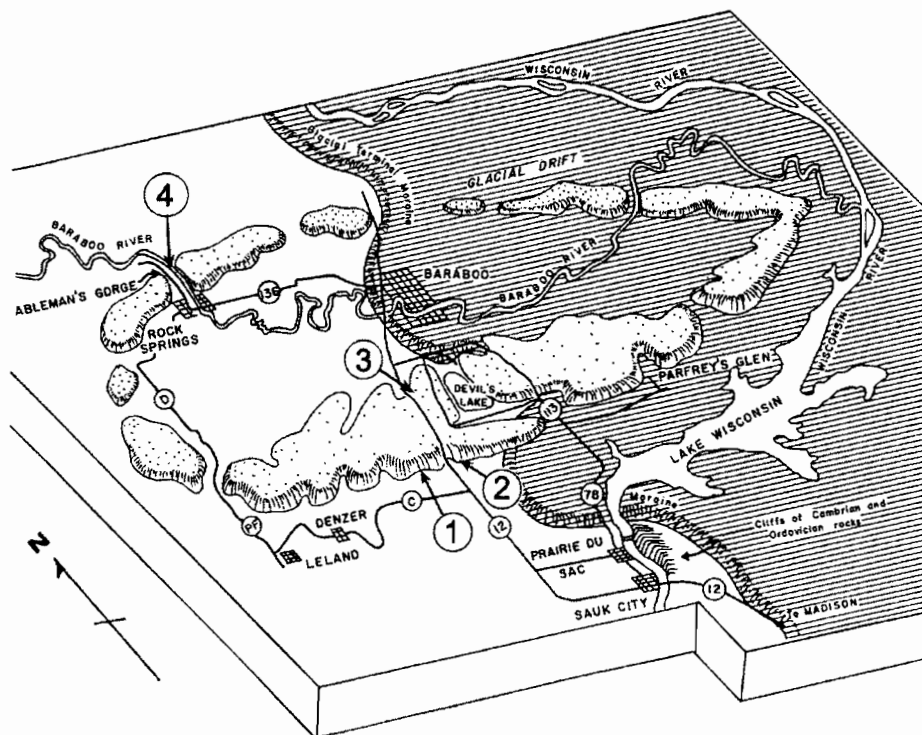


Figure 16. Perspective sketch map of the Baraboo Range, showing Field Trip Localities 1-4, distribution of quartzite in the Baraboo syncline (light stipple), extent of glacial drift (parallel lines), and important geographic features (modified from map by L.J. Maher).

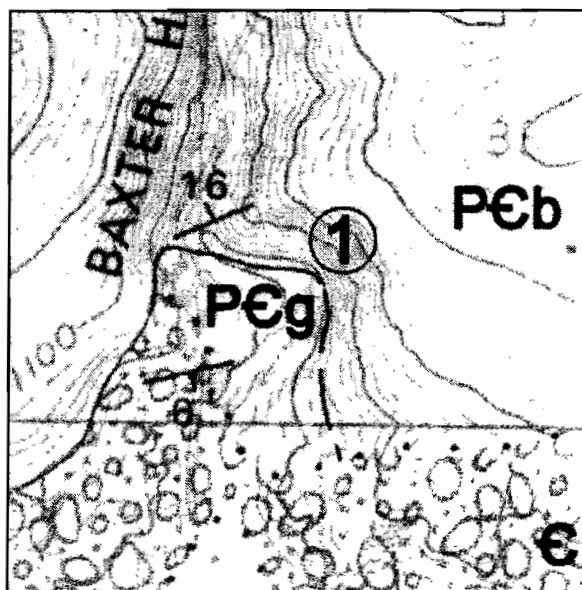


Figure 17. Locality 1, Baxter Hollow. Symbols: PEG, Baxter Hollow granite; Pcb, Baraboo Quartzite; E, Upper Cambrian quartzite conglomerate and conglomeratic sandstone. This and other locality maps from Dalziel and Dott, 1970.

Locality 1: Baxter Hollow

(SW¼, Sec 33, T11N, R6E; Figure 17)

Relation between Baxter Hollow granite and Baraboo Quartzite; sub-Baraboo paleosol

Note that the outcrops in Baxter Hollow are on private property, and permission is required for access.

Although the contact between Baxter Hollow granite and Baraboo Quartzite is not exposed, the closest outcrops of the two rock types being 20 feet apart, Dalziel and Dott (1970) concluded that quartzite is nonconformable on granite, because of the absence of granitic dikes in quartzite, quartzite xenoliths in granite, and contact metamorphic effects in quartzite. The uppermost outcrops of granite in Baxter Hollow are commonly sheared, most likely due to concentration of deformation along the quartzite-granite contact by differential slip between two competent lithologic units during folding.

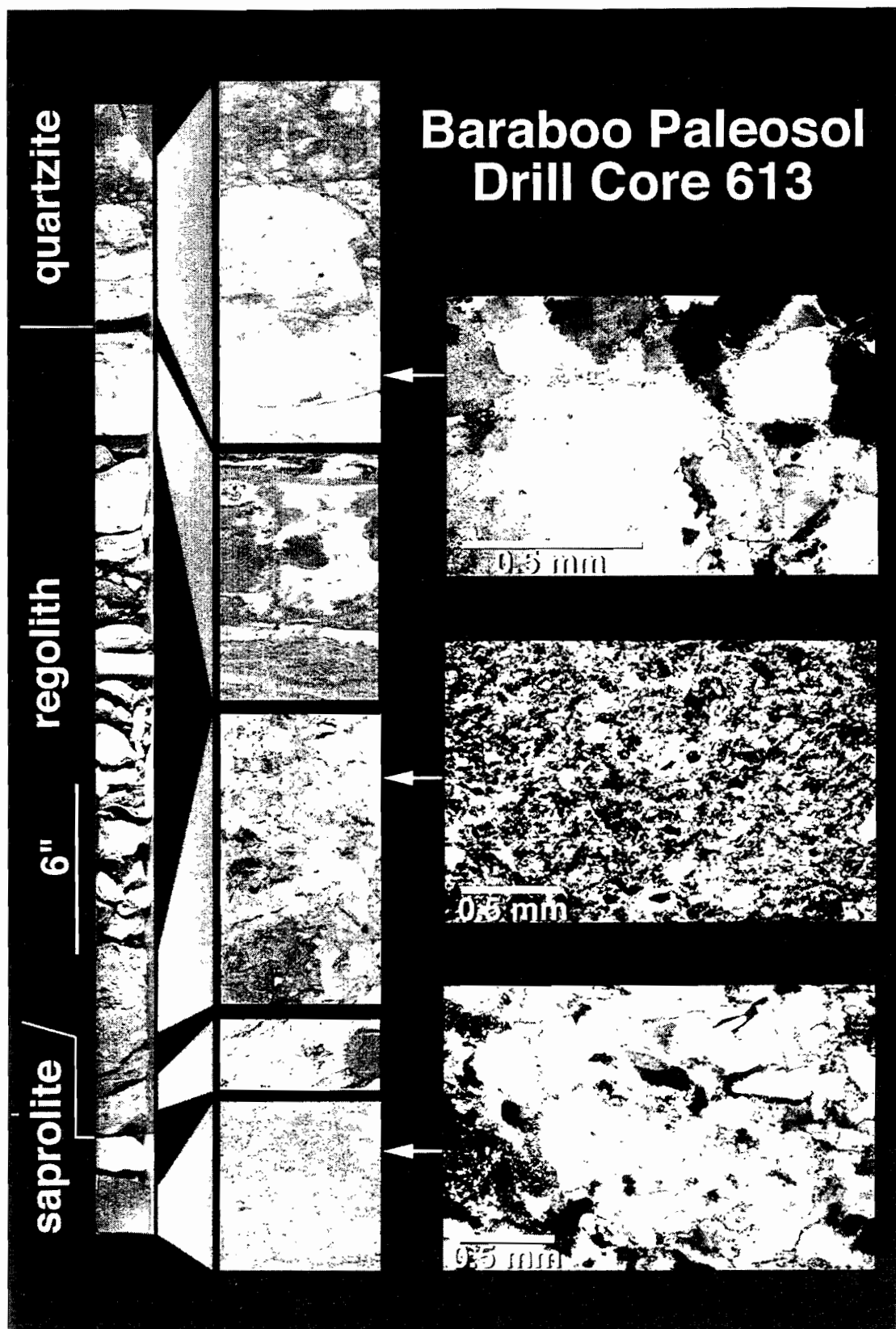


Figure 18. Composite figure of Baraboo paleosol in Drill Core 613. Left: boxed drill core with recovered quartzite, regolith, and saprolite; center: enlargements of selected intervals; right: photomicrographs of quartzite (note SiO_2 overgrowths on detrital quartz grains), regolith (pedogene), and saprolite.

The lower 100-200 meters of quartzite exposed uphill to the north are characterized by red, sand-sized strata with pebble beds and lenses. Metapelite layers are rare. Pebbles average 30 mm in diameter, but range up to 68 mm near the base. Throughout the formation, milky vein quartz pebbles predominate, but red cherty granules and pebbles form a persistent lesser component. The latter probably include clasts of devitrified groundmass from the 1,750 Ma rhyolites. Stratification here consists mostly of long, low-angle cross bedding in both tabular and wedge sets up to 50 cm thick. Several sets of these cross laminae show syndepositional overturning beneath their upper truncation surfaces. A sudden increase of shear velocity scoured grains from the bed and disturbed pore fluid and grain packing, causing incipient liquefaction during which the upper part of the cross bed set deformed as if entirely liquid. Such distorted cross bedding in low-angle sets is most characteristic of fluvial and tidal sands, which experience large fluctuations of current velocity.

The quartzite-granite contact was penetrated by eight holes drilled in 1959 by the U.S. Army Corps of Engineers, and although material from the contact was recovered in only one drill core, this single recovery was fortuitous, because it demonstrates the existence of a paleosol beneath the quartzite (Medaris et al., 1997). In drill core 613 (Fig. 18) overlying pebbly quartzite is separated from underlying granitic saprolite by a 2½ foot-thick, reddish-purple pedogenic zone, consisting of fine-grained hematite, quartz, and muscovite ($\pm$ kaolinite). Granitic texture is preserved in saprolite, but biotite is largely replaced by hematite, and feldspar is completely replaced by muscovite. The first feldspar to appear in drill core is ~30 feet below quartzite. Note that the uppermost part of the saprolite (2" thick) has a pronounced planar fabric (Fig. 18), which is similar in style, if not in scale, to that in the sheared granite outcrops.

Chemical weathering in the paleosol, expressed as % change in oxides, has been calculated by comparing paleosol samples to the average of two unweathered granites from outcrops ~30 and 40 feet below the contact, and normalizing to Al_2O_3 , which is assumed to be immobile during weathering (Fig. 19). The most notable chemical changes are effective removal of Mg, Ca, and Na, and enrichment in K.

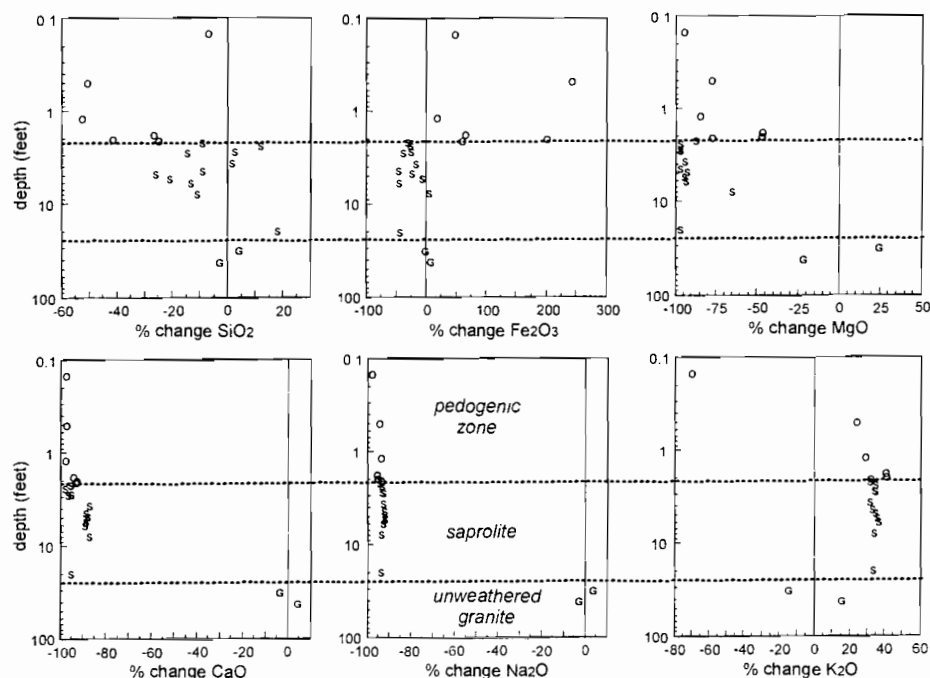


Figure 19. Depth variation in % change of selected oxides in the Baraboo paleosol. O, pedigree; S, saprolite; G, granite.

We believe that all feldspar was altered during weathering and that K leaching occurred, but that K was reintroduced during later metasomatism associated with fluid flow along the sub-Baraboo nonconformity. Note that detrital feldspar is rare in quartzite, and interlayered, fine-grained metasedimentary rocks are impoverished in K, Na, and Ca. A model for Baraboo saprolite, prior to K metasomatism, is provided by the Barron saprolite, which is unmetamorphosed and located north of the inferred 1,630 Ma tectonic front (Fig. 1; Medaris, 2000). A comparison of the two saprolites (Fig. 20) reveals a close similarity in most elements, except for the enrichment of K and Rb in Baraboo saprolite. The chemical features of the Baraboo and Barron paleosols are similar to those of modern-day, mature weathering profiles developed in warm, humid climates.

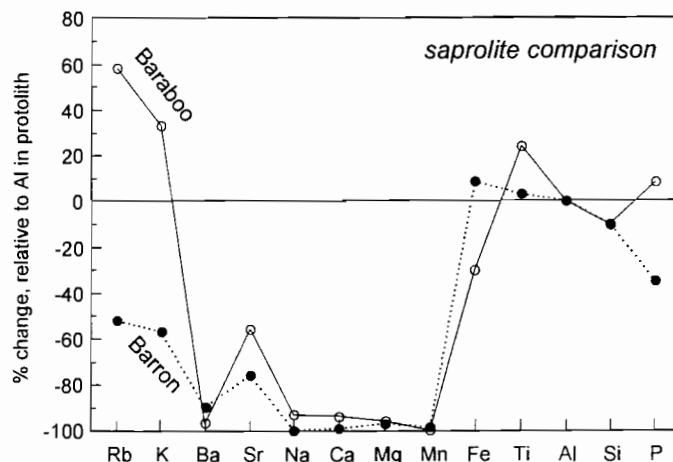


Figure 20. Chemical comparison of Baraboo and Barron saprolites.

An apparent whole-rock Rb-Sr isochron age of the paleosol is 1336 ± 75 Ma (Fig. 21), and muscovite from metasaprolite yields a discordant ^{39}Ar release spectrum, with a well-defined plateau at 1456 ± 11 Ma (Fig. 22; Naymark et al., 2001). These data provide the first substantial evidence for a Wolf River imprint on the Baraboo Range, due most likely to the effects of hydrothermal fluids that were channeled along the sub-Baraboo nonconformity and driven by a thermal pulse generated by regionally extensive magmatism of Wolf River age.

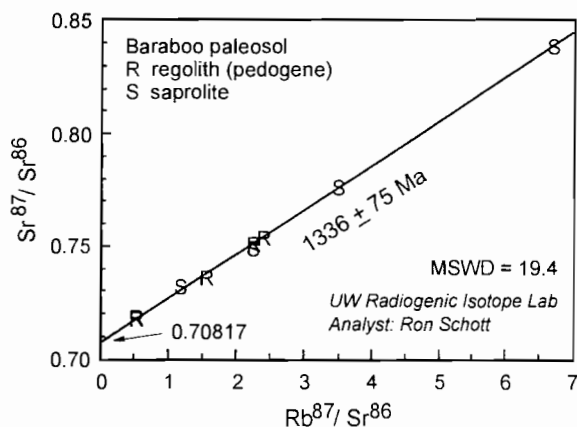


Figure 21. Rb-Sr whole-rock isochron for the metamorphosed Baraboo paleosol.

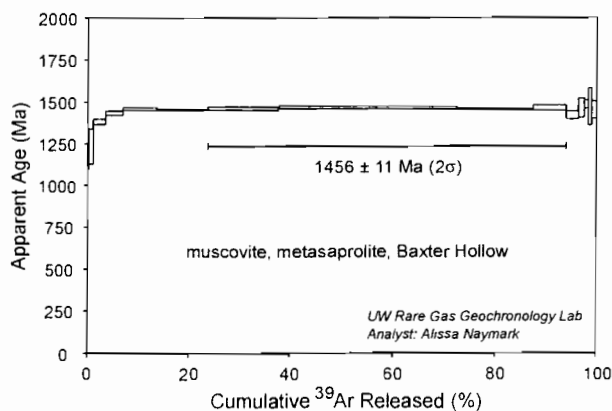


Figure 22. ^{39}Ar release spectrum for muscovite from the metamorphosed Baraboo saprolite.

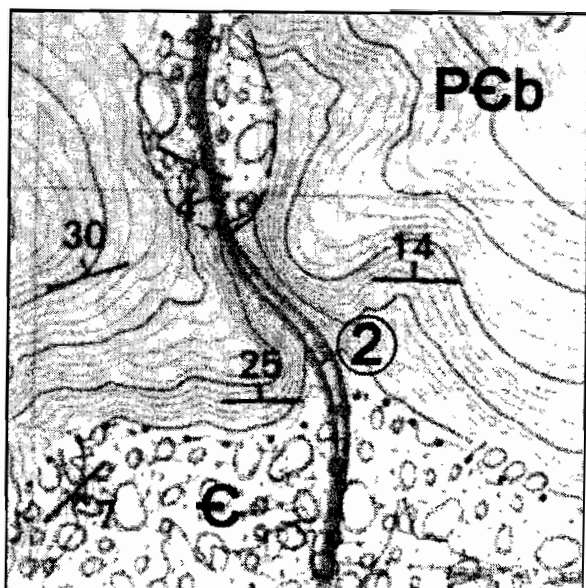


Figure 23. Locality 2, hydrothermal veins in quartzite. Symbols as in Fig. 17.

Locality 2: Hydrothermal Veins, Hwy 12
(SW1/4, NE1/4, Sec 34, T11N, R6E; Figure 23)
Diaspore-muscovite-pyrophyllite veins in Baraboo Quartzite, near the base of the section



Figure 24. Diaspore-muscovite-pyrophyllite veins in quartzite.

A few meters east of Highway 12 is a dark red outcrop of Baraboo Quartzite, which contains a network of thin, white hydrothermal veins (Fig. 24), consisting of diaspore, muscovite, and pyrophyllite. The veins are commonly zoned, with diaspore occurring in the center and intergrown muscovite and pyrophyllite along the margins (Fig. 25). Kaolinite occurs as a retrograde replacement of pyrophyllite.

Locally, fine-grained sedimentary rocks, originally quartz-bearing, near the base of the quartzite have been pervasively replaced by diaspore, muscovite, pyrophyllite, and hematite, resulting in a soft, purple-red stone that was quarried by Native Americans for the production of pipes. This mineral assemblage is the same as that in the classic pipestone (catlinite) from the Sioux Quartzite (Medaris et al., 1999). The formation of diaspore at 300-350°C in the SiO₂-rich environment of the Baraboo and Sioux quartzites is surprising, and requires the influence of a fluid phase with an extremely low activity of SiO₂, on the order of 0.01.

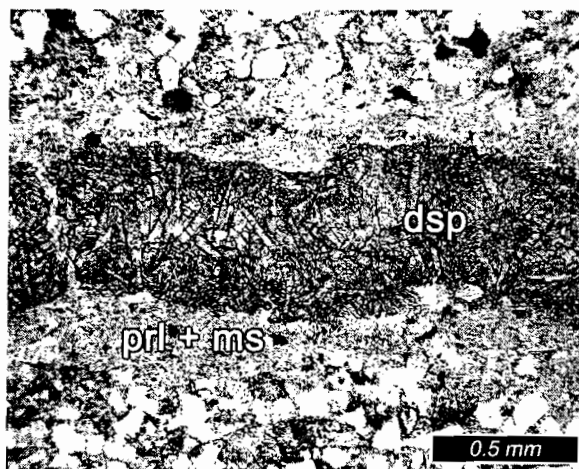


Figure 25. Photomicrograph of hydrothermal vein in quartzite (plane polarized light). Abbreviations: dsp, diaspore; ms, muscovite; prl, pyrophyllite.

Muscovite in a sample of vein from Locality 2 yields a discordant ^{39}Ar release spectrum with a plateau age of $1,467 \pm 11$ Ma, which is within error of the 1,456 Ma plateau age for muscovite from metasaprolite. Thus, the age of fluid activity responsible for K-metasomatism in the Baraboo Range is well established at $\sim 1,460$ Ma. Although large-scale fluid migration was probably driven by heat from Wolf River magmatism, the source and composition of such fluid remains unknown and deserves investigation.

Figure 26. ^{39}Ar release spectrum for muscovite from hydrothermal vein in quartzite, Highway 12.

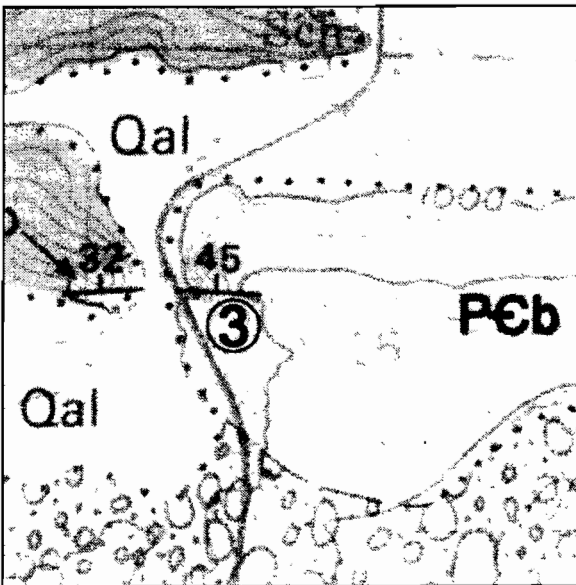
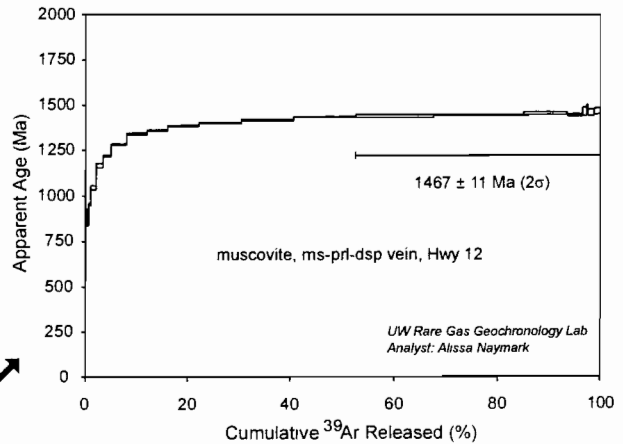


Figure 27. Locality 3, Baraboo quartzite and metapelite. Symbols: Qal, Quaternary alluvium; other symbols as in Fig. 17.

Locality 3: Quartzite and Metapelite, Hwy 12 (NW1/4, Sec 15, T11N, R6E; Figure 27)

Sedimentary and metamorphic features of Baraboo quartzite and metapelite



Figure 28. Quartzite outcrop at Locality 3, illustrating a reactivation surface (left arrow) and contorted cross sets (right arrow). DO NOT HAMMER THIS OUTCROP!

The upper stratigraphic portion of the Baraboo quartzite differs in several ways from the lower part at Baxter Hollow. Pebbly layers are rare, metapelite layers are more common (the thickest known zone is exposed here), and the style of stratification is different. Cross bedding is higher angle and occurs in sets mostly 10 to 20 cm thick. Master bedding surfaces are commonly defined by thin metapelite. Individual cross laminae are slightly concave upward; sets of cross laminae are mostly tabular, but some trough-shaped sets occur in this roadcut. Excellent asymmetric, sinuous-crested ripple marks visible on one surface in the middle of the exposure indicate the dominant south-flowing paleocurrent direction typical for the entire formation.

On the south-facing cliff, several reactivation surfaces and some contorted cross sets are exposed in cross section (Fig. 28). Reactivation surfaces are convex-up truncations of cross bed sets. They indicate spasmodic activation of dune forms that produce cross bedding, and are most characteristic of

tidal systems. The dominant tidal flow activates dunes, which migrate to form cross laminations, then the subordinate flow partially erodes the dunes to form the convex-up surface. When the tide turns again, the dominant flow reactivates the dunes to form a new set of cross laminae, which bury the reactivation surface. In this cliff, the dominant current's bed shear occasionally disturbed the grain packing and caused deformation of cross laminae as described for Locality 1. Reactivation surfaces suggest that the upper half of the Baraboo Quartzite is of shallow marine origin, indicating a gradual northward transgression during its deposition; the overlying Precambrian formations are all considered to be normal marine.

A prominent metapelite layer is exposed at the north end of the roadcut and at the top of the hill, where one can see excellent exposures of chevron folds and crenulation cleavage in metapelite (Fig. 29). Red quartzite boudins are common in metapelite, as are folded white quartz veins, which appear to emanate from the quartzite boudins. The metapelite is inferred to have originally been a kaolinite-rich shale, based on its bulk chemical composition. The present mineral assemblage in metapelite, which is typical for metapelite throughout the Baraboo Range, consists mostly of pyrophyllite with subordinate amounts of recrystallized quartz, thin tablets of black hematite, small grains of rutile, and minor

retrograde kaolinite (Fig. 30). Trace amounts of Ce-bearing svanbergite, $\text{SrAl}_3(\text{PO}_4)(\text{SO}_4)(\text{OH})_6$, 10 to 20 μm in diameter, are scattered through the metapelite (Medaris and Fournelle, 1998). The occurrence of this diagenetic aluminophosphate-sulfate mineral is significant because it bears on the phosphorus flux in the oceans.

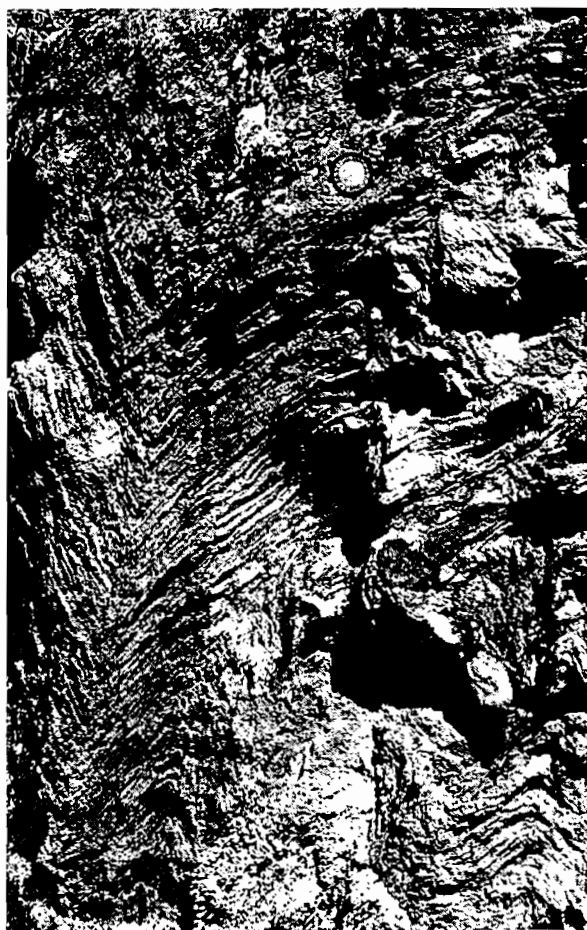


Figure 29. Chevron folds and crenulation cleavage in metapelite, Locality 3. The scale coin, enhanced by a black circle, is 2.5 cm in diameter. DO NOT HAMMER THIS OUTCROP!

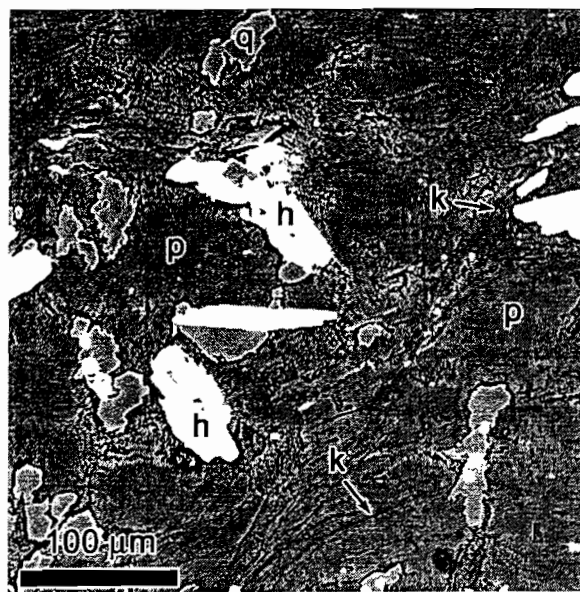
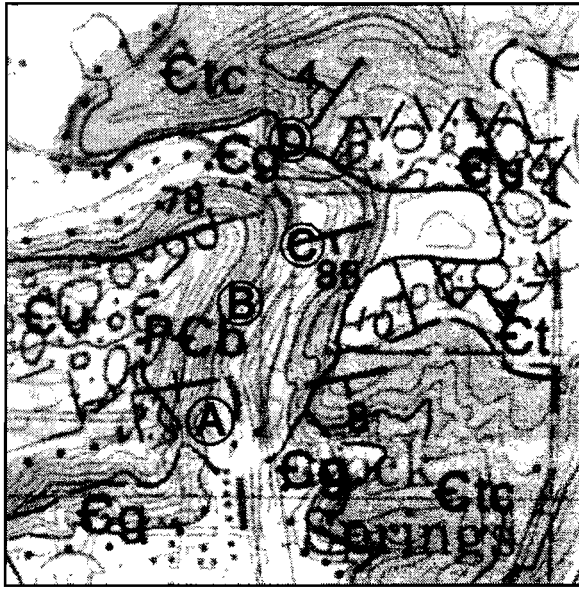


Figure 30. Back-scattered electron image of metapelite, Locality 3. Abbreviations: h, hematite; k, kaolinite; p, pyrophyllite; q, quartz.



Locality 4: Ableman's Gorge

(SW 1/4, Sec 28/29, T12N, R5E; Figure 31)

Angular unconformity between Upper Cambrian conglomerate and Baraboo Quartzite; ripples and metasiltstone layers in quartzite; quartzite breccia zone; Van Hise Rock; Upper Cambrian eolian dunes

Figure 31. Locality 4, Ableman's Gorge. 4A: angular unconformity between Upper Cambrian conglomerate and Baraboo Quartzite; 4B, quartzite breccia; 4C, Van Hise Rock; 4D, angular unconformity and Cambrian eolian dunes. Symbols: Eg Upper Cambrian Galesville Sandstone; Etc, Upper Cambrian Tunnel City Group; other symbols as in Fig. 17.

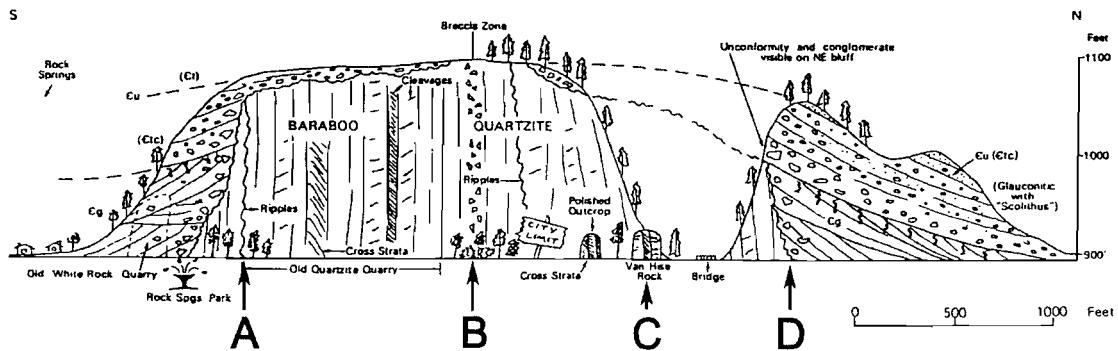


Figure 32. Cross section through Ableman's Gorge (looking west), with Field Localities indicated by letters A - D. Note the symmetry of Cambrian strata butting against buried quartzite cliffs at both ends of the gorge. Modified from Dalziel and Dott (1970).

4A: Upper Cambrian - Precambrian angular unconformity; quartzite features

The abandoned quarry on the west side of Ableman's Gorge (Fig. 32) exposes vertical quartzite with cross bed sets and thin metasiltstone layers visible in the old quarry face. At the top of the cliff, one can see the angular unconformity between red quartzite and brown-weathering Upper Cambrian conglomerate with coarse quartzite boulders (binoculars help).

The south end of the quarry is a spectacular ripple marked face resembling great-grandmother's wash board. What we see are casts of the ripples on the bottom of the overlying bed. Unlike the ripples at Locality 3, the crests of these are relatively straight and symmetric, which indicate formation by waves. These exposures must be in the marine, upper part of the Baraboo.

4B: Quartzite Breccia Zone

Exposed on the west wall of the gorge is a breccia zone, consisting of angular red quartzite blocks cemented by a stockwork of white quartz veins (Fig. 33). The vein quartz is generally massive, but locally euhedral quartz crystals, some of which are coated by dickite (a member of the kaolinite mineral group), occur in vugs (Fig. 34). The euhedral quartz crystals commonly show growth zoning, and preliminary investigation indicates that quartz is zoned with respect to oxygen isotopes as well, with $\delta^{18}\text{O}$ ranging from 9.33 to 18.95 ‰ (VSMOW) in one crystal (Fig. 35). S. W. Bailey reported a temperature of 105-107°C for fluid inclusions in the quartz, which is consistent with the presence of dickite (cited in Dalziel and Dott, 1970).

In some places in the breccia zone, the quartzite fragments appear to be slightly separated pieces of a jigsaw puzzle, giving the impression that the quartzite might have been fragmented by some type of explosive activity. Perhaps brecciation was caused by passage of a low-temperature (sub critical point) hydrothermal fluid from the fluid to the vapor field as it migrated from deeper to shallower levels along the quartzite strata in the north limb of the syncline. The age of such hydrothermal activity is unknown, other than being Precambrian, because boulders and cobbles of quartzite breccia occur in the overlying Upper Cambrian conglomerate.



Figure 33. Quartzite breccia, Martin-Marietta Quarry, along strike and ~ 1 km east of Field Locality 4B.

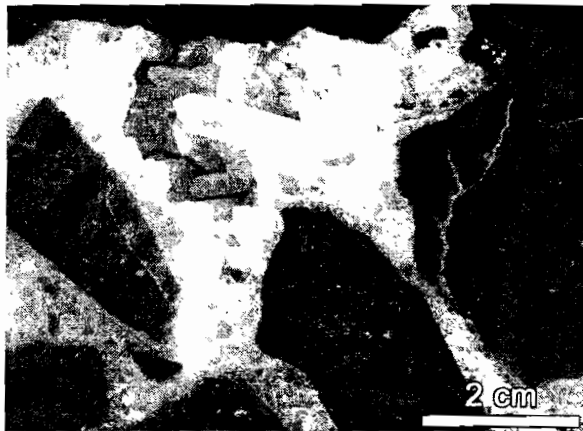


Figure 34. Polished slab of quartzite breccia, showing a vug lined by euhedral quartz crystals.

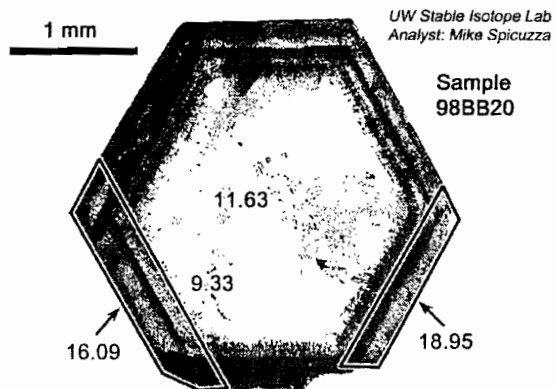


Figure 35. Variation of $\delta^{18}\text{O}$ (‰, VSMOW) in a zoned euhedral quartz crystal from the quartzite breccia.

The breccia zone is ~100 meters thick and oriented parallel to the adjoining quartzite layers, with an east-west strike and vertical dip. Outcrops of quartzite breccia occur along the north limb of the Baraboo syncline over a distance of ~20 kilometers, and thin quartz veins with incipient breccia features, also oriented east-west and vertical, are scattered throughout the syncline. The development of quartzite breccia is thus a widespread feature in the Baraboo Range. It remains to be seen whether the hydrothermal fluids associated with brecciation are cooler and shallower variants of the Wolf River-age fluids that modified the base of the quartzite (Localities 1 and 2), or whether the Baraboo Range was affected by two different and unrelated episodes of hydrothermal alteration.

About 100 meters north of the breccia zone, a subtle exposure has tan-colored, Cambrian-type quartz sandstone enclosing angular fragments of quartzite within an outcrop of vertical quartzite. What is this doing here at least 200 feet below the unconformity that we just saw? We interpret it as Cambrian sand that filtered down fissures produced by weathering along bedding and joints in the quartzite as is seen behind the artesian spring at the south end of the gorge (Fig. 32). 100 meters north and just west of the highway, an outcrop of quartzite has an exceptional polish. In the 1930s, W.H. Twenhofel suggested that wind blasting by sand and silt during Pleistocene time probably produced this unusual surface. We do not have a better idea. Cross bedding and a widely-spaced cleavage can also be seen in the quartzite here.

4C: Van Hise Rock

Van Hise Rock on the east side of the highway (Fig. 36) is of special historic interest for geologists, as described by a 1923 metal plaque and a 1999 historic sign. Charles R. Van Hise and his protégé, Charles K. Leith, used this as a laboratory to demonstrate the fundamental geometric relationship between slaty cleavage and bedding as an outcrop-scale clue for inferring larger-scale structures, which are typically not clear in vegetated country. Stimulated by the commencement of iron mining, the U.S. Geological Survey had established in 1882 a district office at Madison headed by Van Hise and later Leith to study the Precambrian geology of the Lake Superior region. Their team perfected the use of cleavage, drag folds, cross bedding and ripple marks for determining structural facing direction or 'way-up.' The accessibility and clarity of Van Hise Rock has made this an essential stop for field trips for a century; hundreds of students and professionals visit annually. In May, 1999, the Rock was declared a National Historical Landmark.

The vertical dark band in the center of the rock was deposited as a silty mudstone within the upper part of the Baraboo Quartzite. Today it shows slaty cleavage dipping northward about 20 degrees; note that this cleavage refracts (flattens) into the coarser pink quartzite on either side. In addition, cross bedding is visible in each of these two quartzite beds. Although we can not see the larger structure of which Van Hise Rock is a part, we assume that the cleavage roughly parallels the axial surface a large fold. We then infer that that structure must be a syncline with its axis to the south of Ableman's Gorge. The truncated cross bedding is consistent with this, for its geometry shows that the 'way up' must also be to the south (as did the ripple-cast washboard wall).



Figure 36. Van Hise Rock viewed from the east, with the slaty central layer bounded by cross-bedded quartzite on either side.

4D: Basal Cambrian Unconformity and Eolian Dunes

From Van Hise Rock, we can see the basal Cambrian unconformity again to the northeast (Fig. 32, right end). The flat-lying strata high on the wall at the top of the Gorge are Cambrian conglomerates. As shown in Figure 32, Cambrian sandstones underlie these and terminate against buried cliffs of quartzite. Large, sweeping cross beds in these sandstones were formed within eolian dunes blown up against those cliffs. Rare, scattered angular blocks of quartzite occasionally fell from the cliffs to be buried, but not abraded, by the eolian sand. The arrival here of the encroaching Late Cambrian sea is recorded by a sharp boundary with overlying rounded quartzite conglomerate, which is underlain by a sandstone layer with marine worm burrows called *Skolithos* (closely spaced, straight, parallel vertical tubes about 1 mm in diameter and from 3 - 20 mm long).

Ableman's Gorge provides a geologic vest pocket sample of most of the important features of the Baraboo Hills. Baraboo Quartzite was deposited, then folded and metamorphosed within a mountain range, which was then eroded. In Late Cambrian time (500 Ma ago), an elliptical ring of quartzite hills began to be buried by wind deposits. Then, as the Cambrian sea encroached, those hills were converted to an atoll-like ring of islands. North America lay in the tropics at about 15 degrees south latitude, so passing tropical storms generated huge waves, which broke upon the sea cliffs and tore away quartzite blocks. Repetition of this scenario rounded boulders up to 1.5 m in diameter, and occasionally swept some of them offshore for half a kilometer or so. Gradually the islands became buried by sediment, testimony of which is nowhere more clearly revealed than here. The Ableman island disappeared by the end of Cambrian time, but the highest islands were not finally buried until the end of the Ordovician Period (ca 440 Ma).

Acknowledgments

We are indebted to many of our departmental colleagues for their interest, encouragement, and technical expertise. These include John Fournelle (electron microprobe), Brad Singer (rare gas isotopes), Clark Johnson (radiogenic isotopes), John Valley (stable isotopes), and Phil Brown (fluid inclusions), who provided analytical facilities that made possible acquisition of many of the new Baraboo data. Several students and technicians performed analyses that are reported here, including Robb Bunge, Alissa Naymark, Ron Schott, and Mike Spicuzza. Brian Hess prepared various types of high-quality thin sections, and Mary Diman created the marvelous composite diagram of the Baraboo paleosol.

From the Wisconsin Geological and Natural History Survey, Bruce Brown provided access to the Baxter Hollow drill core, the examination of which prompted us to take a new look at the Baraboo Range, and Mike Mudrey informed us of the Barron paleosol, which serves as a model for unmodified Baraboo paleosol.



Cleopatra's Needle, overlooking Devil's Lake

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Field Trip 2

Geology, Ore Deposits, and Cultural History of the Upper Mississippi Valley Zinc-Lead District

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Headframe of a southwestern Wisconsin zinc-lead mine circa 1930
(photograph courtesy of Platteville Mining Museum).

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BACKGROUND

The Upper Mississippi Valley Zinc-Lead District of southwestern Wisconsin was one of the oldest continuously producing mining districts in the United States. The largest and most productive parts of the district extended across five Wisconsin counties and into small areas in Illinois and Iowa (fig. 1). Over 1.2 million tons of zinc and nearly 100,000 tons of lead were recovered from the Wisconsin part of the Upper Mississippi Valley District from 1910 to 1974. Heyl and others (1959) suggested that an additional 250,000 tons of zinc and 350,000 tons of lead were produced in the Wisconsin part of the district from 1800 to 1910. This field trip provides a geologic, mineral deposit, and cultural overview of the area. Numerous detailed geologic reports about the area have been prepared; the most significant by Heyl and others (1959) documents

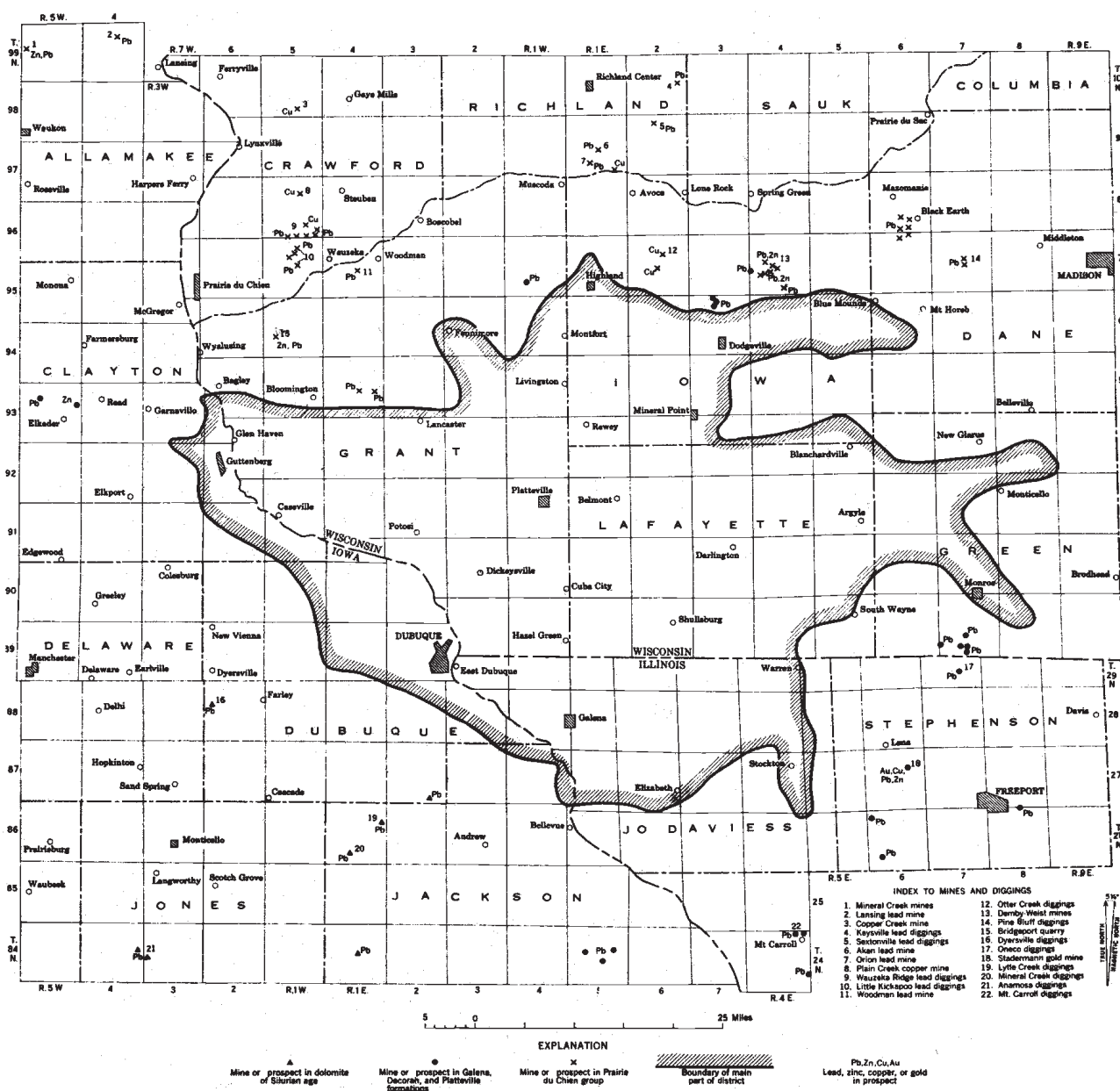


Figure 1. Map of the main part of the Upper Mississippi Valley district and mineral deposits in outlying parts of the district (from Heyl and others, 1959).

hundreds of mineral properties in Illinois, Iowa, and Wisconsin. A good summary of the geology and economic geology of the district is given by Heyl and others (1970). In addition, more than 1,000 square miles have been mapped and published on standard 1:24000, 7.5-minute topographic maps.

The zinc and lead mines of southwestern Wisconsin are part of the earliest producing zinc-lead mining districts in the United States—the Upper Mississippi Valley District. There was a small amount of production in Minnesota. Production prior to 1800 was very small. Use of galena and mining were reported by explorers Jean Nicolet in 1634 and by Nicolas Perrot in 1692. In 1788 Julien Dubuque obtained permission from the Sauk and Fox to work lead mines in the area. Dubuque mined, with these Native Americans as his labor force; on the west bank of the Mississippi River in the vicinity of what is now Dubuque, Iowa. This was the principal mining center in the region from 1788 until Dubuque's death in 1810.

Early white miners worked the properties during the summer, returning south in the winter. The arrival of permanent settlers in 1825, the Winnebago Peace Treaty, and “lead rush of 1827” established the Upper Mississippi District as a major mineral producer and resulted in the states of Illinois, Iowa, and Wisconsin. The Mexican War of 1847, the California Gold Rush of 1849, and the cholera epidemic of 1854 brought the district into decline, but by 1859 and the Civil War, production of lead increased, and eventually zinc production began. The District remained in production until 1978 with the close of the Eagle–Picher mine in Shullsburg.

Around 1906, systematic mine mapping was begun by students and faculty at the Wisconsin School of Mines, now University of Wisconsin–Platteville. In 1946 systematic geologic mapping was initiated by the U.S. Geological Survey. This mapping program was built on the foundation of mine maps and mineral reserve studies initiated during World War II. The cooperation of the former U.S. Bureau of Mines, U.S. Geological Survey, University of Wisconsin–Platteville, and the Wisconsin Geological and Natural History Survey led to the development of the Wisconsin Mineral Development Atlas (Heyl and Broughton, 1980). In a series of atlas plates at 1:2400-scale, mine workings, drillhole location and number, and selected surface features (roads, lead digs) are shown. The details of the 30,000 drillholes are kept in approximately two dozen large binders covering Grant, Iowa, and Lafayette Counties. Supplemental data include Green County. From this information Broughton (1991) estimated 12.5 million tons of ore averaging 4.94 percent zinc and 0.47 percent lead remain in place. There are large areas for which there is no modern (post-1900) mineral exploration, and little exploration data below the base of the Sinipee Group.

The field trip begins in Madison, Wisconsin, proceeds to Platteville (Stop 1) for an overview of the district at the Bevan Mine and Rollo Jamison Museum. The Bevan Mine is an 1845 lead mine that produced more than two million pounds of lead ore in one year. The underground workings include two dioramas, one of an 1840 crevice lead mine, and the other a 1935 zinc mine. The Mining Museum includes numerous dioramas about the regional geology and mineral deposits and how miners in the 19th century went about their business.

The geologic stop will be west of Dickeyville on Potosi Hill (Stop 2). This road cut contains St. Peter sandstone (Ancell Group) at the base to Galena Dolomite (Sinipee Group) at the top. Two stops will be made to address mine reclamation: west of New Diggings (Stop 3), where one of the few remaining area of lead digs is preserved (natural reclamation from 1840), and Shullsburg at the former Eagle–Picher mine (Stop 4). The trip ends with a tour of Pendarvis State Historical Site (Stop 5), which recreates the cultural–historical setting of the 1840s mine district.

Geology and Ore Deposits

The zinc-lead deposits of southwestern Wisconsin are a classic example of the stratabound Mississippi Valley-type zinc-lead deposits. Although deposits are known to occur in most of the lower Paleozoic dolomite and sandstone units of the district (fig. 2), all important ore bodies are in the Middle Ordovician Sinnipee Group (Platteville, Decorah, and Galena Formations). The most common type of deposits (fig. 3) are (1) those associated with vertical or steeply inclined joints or fractures, called gash-vein or crevice deposits (dominantly galena with gangue);

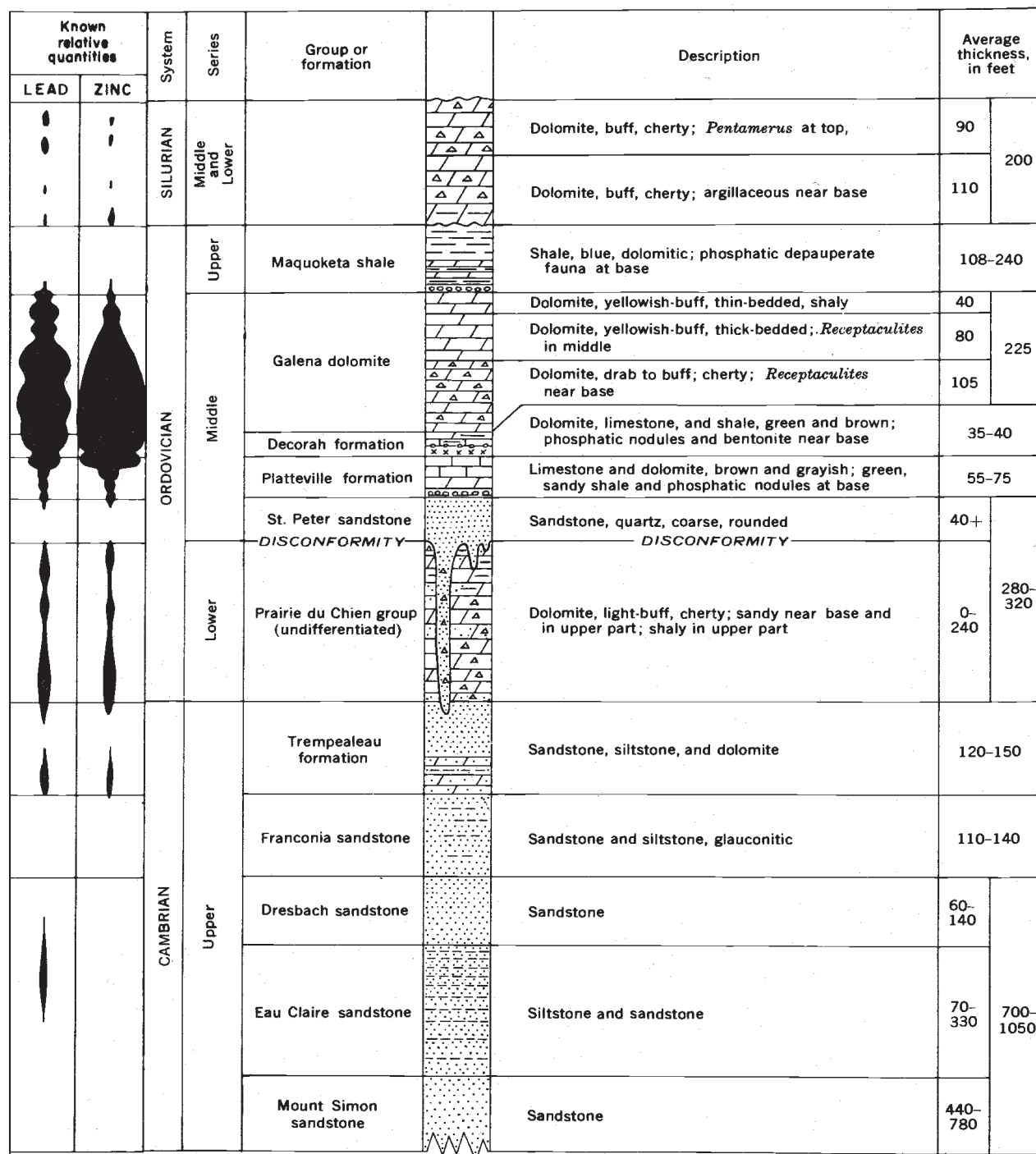


Figure 2. Simplified stratigraphic section showing relative quantitative stratigraphic distribution of lead and zinc in the Upper Mississippi Valley district (from Heyl and others, 1978).

(2) those associated with inclined and horizontal fractures, called pitch-and-flat deposits (sphalerite with minor galena and gangue); (3) those consisting of fine galena and sphalerite scattered through the country rock, called disseminated deposits; and (4) those consisting of angular breccia or country rock fragments cemented with ore and associated minerals, called breccia deposits.

The most abundant gangue minerals with the ore minerals sphalerite and galena are calcite, pyrite, marcasite, barite, and rarely, chalcopyrite. The ore deposits are contained within weak structures produced by gentle folds in the dolomite strata. The ore deposits show vertical and regional zoning. Copper, barium, nickel, and arsenic are abundant in the east-central part of the district. Vertically, lead is greater in the higher part of a mineralized area; zinc, iron sulfides, nickel, and secondary dolomite are more abundant in the deeper deposits, generally conforming to structural control. Details of the district and individual properties are given in Heyl and others (1959).

The paragenetic sequence generally involves early deposition of quartz, dolomite, pyrite, marcasite, with several generations of sphalerite and galena. Mineralization of cobaltite, chalcopyrite, chalcocite, millerite, and enargite are reported. Late gangue minerals include most of the calcite. It should be emphasized that the paragenetic sequence is generalized. Deposition

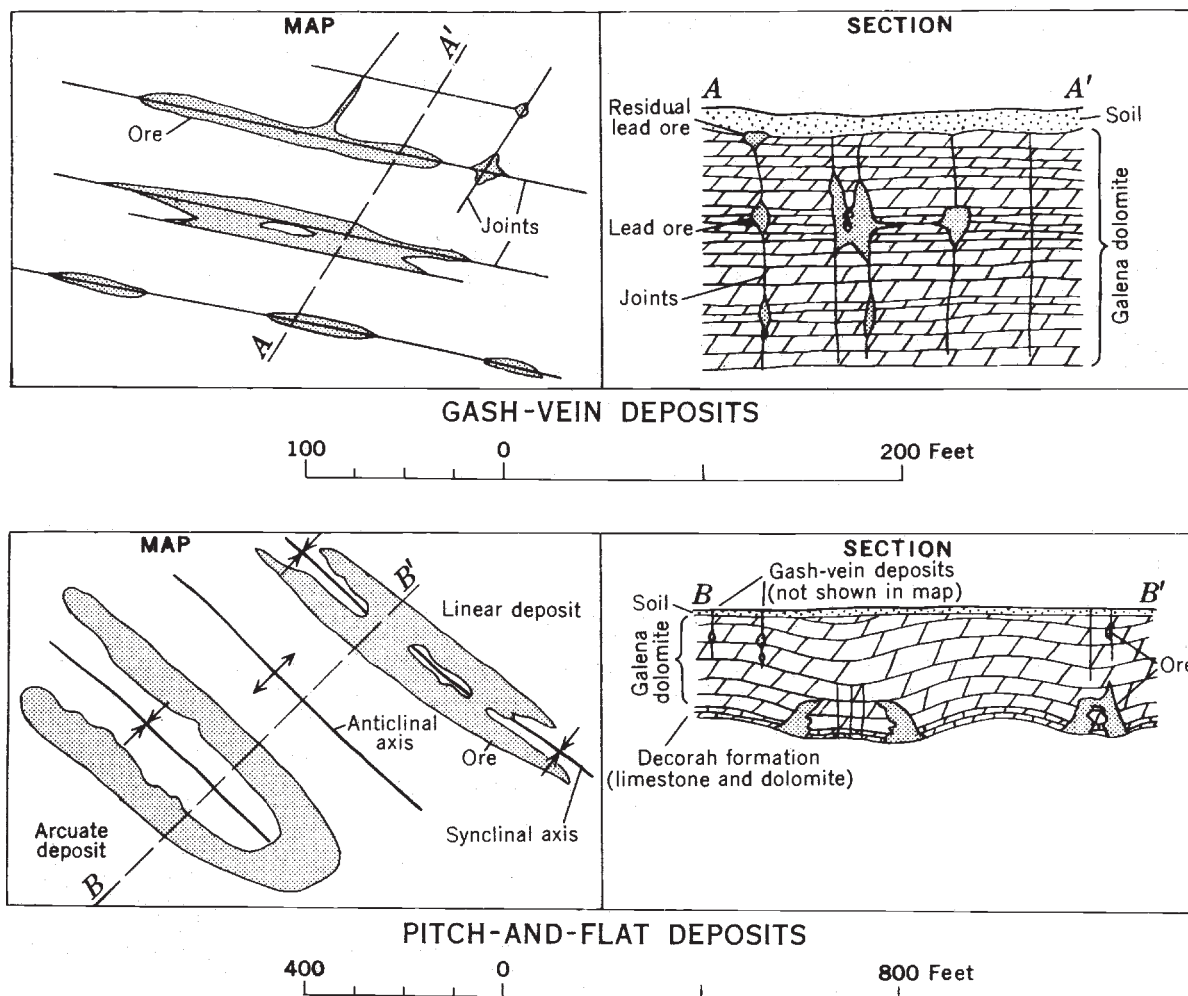


Figure 3. Diagrammatic plans and sections illustrating typical patterns of gash-vein lead deposits and underlying pitch-and-flat deposits of the arcuate and linear types and their stratigraphic position to one another (from Heyl and others, 1978).

throughout the general sulfide period took place under conditions of rhythmic oscillations in composition and temperature; such oscillations formed the hundreds of minute color bands characteristic of all the main minerals. McLimans and Barnes (1975) argued that most, if not all, of the distinct color-banding in sphalerite from mine to mine and area to area are coeval. McLimans and Barnes (1975) also argued for warmer temperatures (up to 220°C) for the deposits; most other workers suggest 150°C is a maximum. The high temperature seems to be supported by Rowan and Goldhaber (1996) and Zimmerman (1986), but their interpretations differ. Rowan and Goldhaber argued for a relatively thin Paleozoic cover (less than 3,000 ft) and higher heat flow; Zimmerman argued for normal geothermal gradients, but deeper burial (up to 9,000 ft). Outside of ore deposits, regional maximum temperatures were quite low (50 to 90°C, Blabaum, 1995). I interpret these data to suggest that the region was not deeply buried, but that high temperature mineral solutions were restricted to faults and fracture channels, and hence ore deposits were hotter than country rock.

Extensive lead isotope data clearly identify unconformable lead that varies regionally; lead isotope ratios are lowest to the west and south. It is generally thought that mineralization of the district occurred during the Permian–Pennsylvanian by long-distance transport of metal-bearing brine from the adjacent Illinois basin.

FIELD TRIP

The field trip (fig. 4) will visit the Platteville Mining Museum and Bevan Mine (Stop 1), examine Ordovician geologic exposures at Potosi Hill (Stop 2), an historic unreclaimed area of 1830 lead digs near New Diggings (Stop 3), modern metallic mine reclamation at the former Shullsburg zinc–lead mine/mill site (Stop 4), and the Pendarvis State Historical Site (Stop 5).

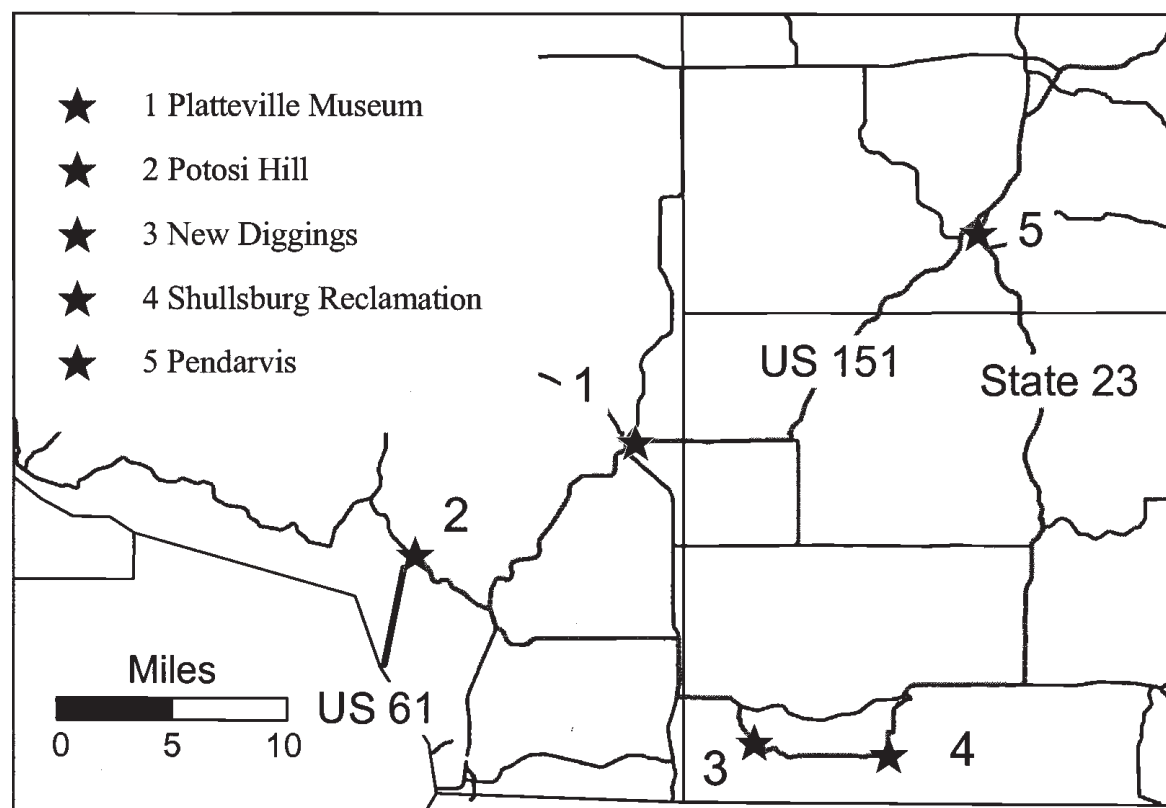


Figure 4. Map showing field trip stops.

Stop 1: Platteville Mining Museum and Rollo Jamison Museum

Location: SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 15, T3N, R1W, Grant County, Wisconsin (Platteville 7.5-minute topographic quadrangle, 1952).

Authors: Modified from <<http://platteville.wi.us/visitors/mining.html>>.

Description: The Platteville Mining Museum traces the development of lead and zinc mining in the Upper Mississippi Valley through models, dioramas, artifacts, and photographs. The surface part of the museum includes dioramas of mining and a mosaic of maps showing at 1:24,000-scale the geology and structure of the district. The underground part of the Museum, the Bevan Lead Mine, is an 1845 lead mine which produced over two millions pounds of lead ore in one year and is accessed via a walk down decline. The diorama in the mine shows how mining was accomplished in the 1840s (crevice deposits of lead), and in the 1930s (pneumatic jackleg drill and mine carts). Ceiling bolting is extensive in the underground mine; this was a demonstration area in the the past on how to install mine bolts. A small, reconstructed headframe and hoist and a track with a 1931 locomotive and ore cars complement the underground mine.

For more information contact: City of Platteville Museum Department, 405 East Main Street, P.O. Box 780, Platteville, Wisconsin 53818; telephone (608) 348-3301.

Stop 2: Potosi Hill—Ordovician Sinnipee Group

Location: Roadcut at east side of U.S. Highway 61 in the SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 7, T2N, R2W, Grant County (Potosi 7.5-minute topographic quadrangle, 1972; fig. 5).

Author: M.G. Mudrey, Jr. (modified from Ostrom, 1987).

Description: This is an excellent and easily accessible exposure of the upper part of the Ancell Group (St. Peter and Glenwood Formations), and the Sinnipee Group (Platteville, Decorah, and Galena Formations). The exposure consists of a lengthy roadcut on the north side of U.S. Highway 61 (Whitlow and West, 1966). At least two east–west faults are recognized in the outcrop, the most significant (about 10 ft of throw) is in the valley between the upper and lower exposures. On the southeast wall of the quarry at the north end of the roadcut can be seen an example of the pitch and flat structure that hosts the zinc–lead mineralization in the district.

The Sinnipee Group is the principal host of zinc and lead mineralization in the Upper Mississippi Valley Base-Metal District. This locality has been well studied over the past 50 years. The lithologic description given is that of Agnew (1956) with modifications by Ostrom (1978, 1987), and Mudrey (field reviews from 1976 to 2001). Agnew’s descriptions are the most comprehensive; however, slumping and outcrop deterioration and road construction have changed the ease with which individual parts of the exposure may be examined. The description given here is a composite of Agnew, Ostrom, and Mudrey.

Figure 6 shows the geologic section exposed at the Potosi Hill roadcut. The base of the section consists of Ordovician sandstone of the St. Peter Formation, Ancell Group. The Tonti Member is the thickest of the three members in the formation, and consists dominantly of friable fine- to coarse-grained sandstone. Thickness can vary considerably, from absent to over 100 m thick. This variation is attributed to deposition on an erosional surface; deep channels are recognized elsewhere, particularly in La Crosse County. The basal unit of the St. Peter is the clay-rich Readstown Member, which may be a reworked residual regolith. The upper unit of the St. Peter seen in this exposure is a bluish-gray silt to shale, which can be locally absent in the region. Bioturbation in this unit is common. The St. Peter appears to be a near-shore deposit (Dott and others, 1986). In the area of the type locality, St. Paul, Minnesota, it appears to be entirely ma-

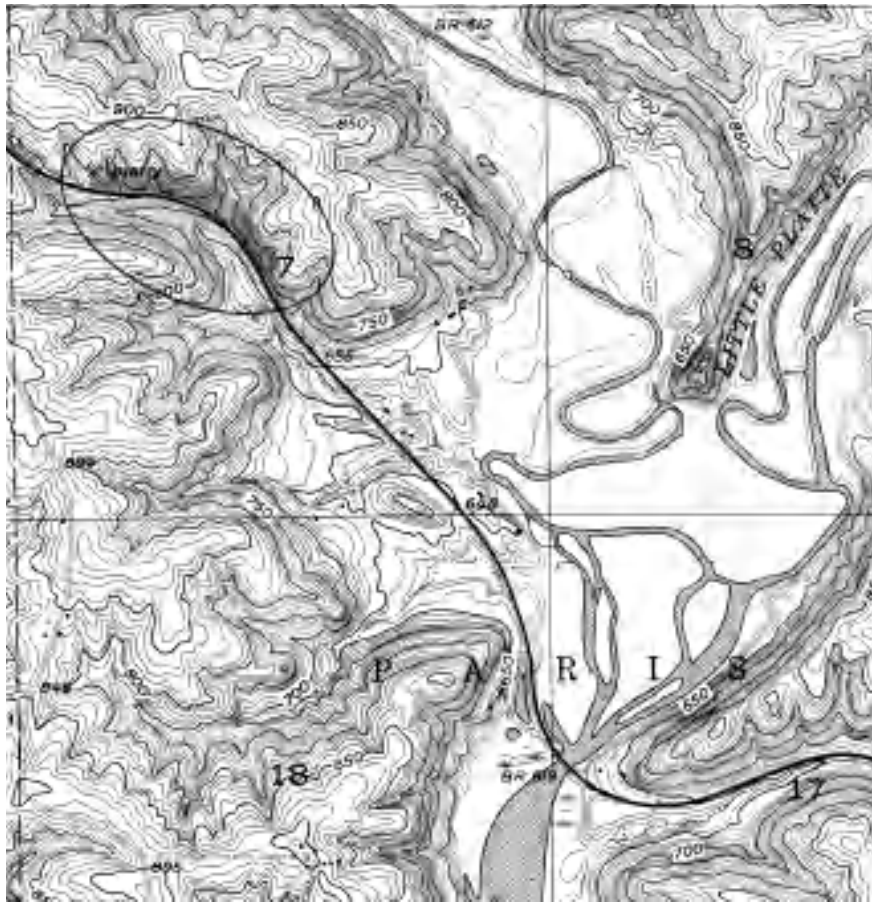


Figure 5. Topographic map showing location of field trip stop 2.

rine; in the Madison and southern Wisconsin area, it is entirely nonmarine (Winfrey and Dott, 1983).

Locally the St. Peter is well cemented, ranging from silica to hematite. Habermann (1978) interpreted most of the cementation as the result of duricrust development during the Ordovician; however, in places, notably in area of known zinc-lead sulfide mineralization, some of the hematite cementation appears to be the result of weathering of minor sulfide ore bodies.

The overlying Ordovician Sinnipee Group consists of a basal Platteville Formation of several dolomitic lime-

stone to dolomite members; the Decorah Formation, a shaly dolomite; and the uppermost Galena Formation, a vuggy weathering cherty dolomite.

The lowermost member of the Platteville Formation, the Pecatonica Member, was formerly quarried in the district for building stone. The Quimbeys Mill Member, the uppermost member of the Platteville, is a sublithographic dolomite. This less than 1-m thick bed is very distinctive and is used through the district as a marker to the base of the mining horizon (termed *glass rock* because of the conchoidal fracture).

The overlying Decorah Formation has been defined in many ways over the years, but is generally mapped as the shaly, dolomite part of the Sinnipee Group. Members in the Decorah are easily recognized. The basal Spechts Ferry Member is overlain by the Guttenberg (pronounced GUT-ten-berg), which contains brown petroliferous shale partings. This unit recognized in the mining district as “oil rock” and is a source bed for petroleum in Iowa and Michigan, where it is deeply buried. The Ion Member overlies the Guttenberg and consists of a blue unit and a gray unit, both very shaly dolomite with minimal structural strength. Most of the zinc-lead mineralization in the area is hosted by the Ion.

Thickly bedded Galena Dolomite overlies the Decorah Formation. In the absence of fossils, field mapping has relied on the abundance of chert to divide the unit into a lower cherty unit and an upper relatively non-cherty unit that is less dolomitized. Weathering of the unit results in a mosaic outcrop pattern (locally termed *honey-comb*), where the less dolomitic parts of the rock are dissolved in preference to the harder, more indurated well-dolomitized parts. *Receptaculites* is abundant in the upper, non-cherty part of the section.

Potosi Hill Section
SE ¼NW ¼ sec, 7, T2N, R2W
Grant County, Wisconsin

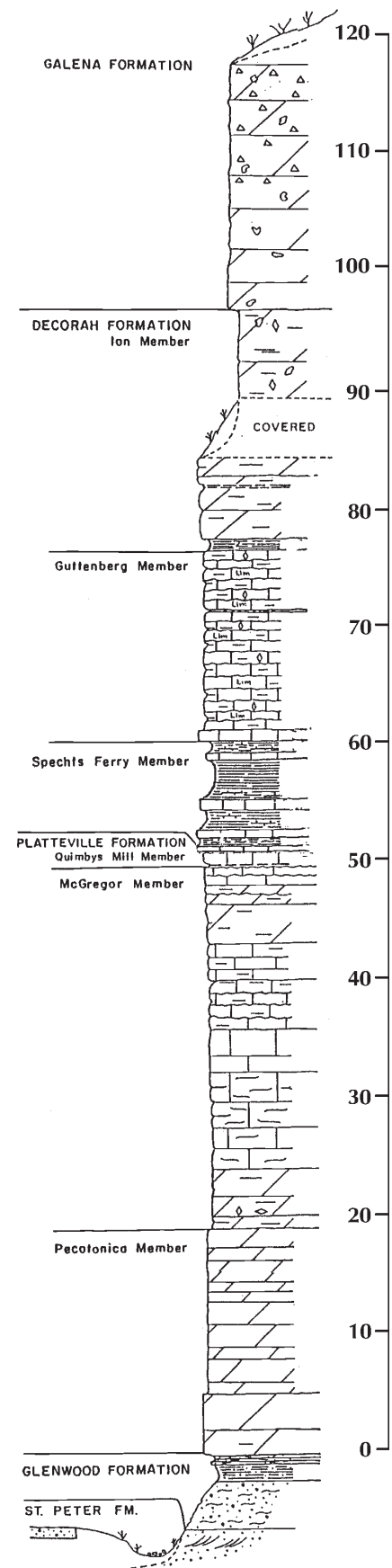


Figure 6. Potosi Hill section; explanation on following pages. (Modified from Ostrom, 1987.)

Unit	Thickness (ft)	Member thickness (ft)
Sinnipee Group		
Galena Dolomite Formation		
Prosser Member		
(upper cherty)		
Dolomite, olive drab to light brown, thick- to thin-bedded; medium to coarse grained, vuggy, abundant white chert; Receptaculites near top	4.0	44+
(lower Receptaculites Zone)		
Lower Receptaculites Zone; dolomite, olive drab to light brown, thick-bedded, medium-to-coarse-grained, abundant chert, abundant Receptaculites	16.0	
(lower cherty)		
Lower Cherty Zone; dolomite, olive drab to light brown, thick- to medium-bedded, medium to coarse grained, bands of chert nodules	14.5	
(buff)		
Lower Buff Zone; dolomite, light brown, slight green mottling; thick-bedded	9.5	
Decorah Formation		
<i>Ion Dolomite Member</i>		
(Gray Unit)		
Dolomite, olive to gray, medium- to thick-bedded, vuggy, green shale partings throughout, sparry calcite present	13.5	19.5
(Blue Unit)		
Blue unit; dolomite, purplish gray, medium grained, slightly fossiliferous. Green shale present as partings, and as 0.5-ft bed, 0.8 ft below the top of the Interval, calcite present	5.1	
Shale, green dolomitic shale in middle of interval	0.9	

Guttenberg Limestone Member (Oil Rock)

Limestone, pinkish to purplish brown, fine grained to sublithographic, fossiliferous, upper 1 ft fine- to medium-grained, red-brown shale present as parting, calcite and limonite and iron sulfide present in small amounts	4.6	15.3
Shale metabentonite, brownish orange, crumbly, sticky when wet	0.1	
Limestone, purplish brown, sublithographic, thin wavy bedding, fossiliferous, brown carbonaceous shale present as thin beds and partings, calcite and limonite present. Thin metabentonite bed at base	9.6	
Limestone, brown gray, fine grained, thick-bedded	1.0	

Spechts Ferry Shale Member (Clay Bed)

Shale, orange gray, calcareous, and limestone, tan gray, fine grained, limestone 0.4 to 0.7 ft from base of unit	0.8	8.8
Limestone, gray, fine-grained, thin bedded	0.6	
Shale, gray, green, brown, fissile, some beds fossiliferous, limestone present as thin lenses near middle of the interval	3.2	
Limestone, tan with iron oxide mottling, fine grained, thin bedded	0.8	
Shale, gray-green-brown. Fissile with thin lenses of gray fine-grained limestone	1.7	
Limestone, dark to light gray, thin-bedded fossiliferous	0.7	
Shale, brown-green-orange-gray, brown carbonaceous shale parting at top	0.5	
Limestone, purplish brown, fine grained, thin-bedded, very fossiliferous, fucoids at base	0.5	
Metabentonite, orange, sticky when wet, with brown shale partings	0.2	

Platteville Formation

Quimbys Mill Member (Glass Rock)

Limestone, dark purplish gray, sublithographic, thick-bedded, conchoidal fracture, irregular upper surface, shale at base	0.8	0.8
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MacGregor Member (Magnolia)

Limestone, light grayish tan, fine grained, dense, partings of yellowish platy shale, very fossiliferous, thin 2 in. to 10 in. beds, upper 5 ft generally thicker bedded	14.5	29.5
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Mifflin Sub-member

Limestone, light grayish brown, fine-grained, dense, medium-to thick-bedded, discontinuous partings of bluish-green shale, fossiliferous	15.0	
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Pecatonica Member (Quarry Beds)

Dolomite, brownish gray, fine to medium crystalline, sugary texture, thin-to medium-bedded, even-bedded, beds 0.1 to 18 in. thick. Weathered surface shows distinct but discontinuous thinner beds	3.0	23.6
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Dolomite, bluish, medium-grained, granular, sugary textured, argillite	1.0	
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Dolomite, brownish gray, fine to medium grained, crystalline, sugary texture, thin- to medium-bedded, even-bedded, beds about 1in. thick	8.0	
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Dolomite, bluish, medium grained, granular, sugary textured, argillite	1.0	
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Dolomite, brownish gray, fine to medium grained, crystalline, sugary texture, medium-bedded, even-bedded, beds thicker than 1 ft	6.0	
--	-----	--

Dolomite, brownish gray, fine to medium grained crystalline, sugary texture, medium-bedded, even-bedded, beds about 1 ft thick	4.6	
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Ancell Group

Glenwood Formation

Hennepin Member (Shale)

Very silty, sandy dolomite, yellowish brown, abundant phosphatic pellets up to 2 mm in diameter, scattered round medium quartz sand grains, poorly sorted, iron-oxide cemented	0.5	0.5
--	-----	-----

Harmony Hill Member

Silty shale, brown and bluish green grading downward to bluish green with some redish brown, little rounded medium grained quartz sand, abundant pale green clay in matrix, reworked/bioturbated texture	1.5	1.5
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St. Peter Formation

Tonti Member (Sandrock)

Sandstone, light yellowish gray, very fine to medium grained, Some light brown stains cross-bedded		
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Base of exposure in drainage ditch		
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Stop 3: New Diggings Lead Digs

Location: Intersection of County Highways J and W, NW¼NW¼SW¼ sec. 22, T1N, R1E, Lafayette County, Wisconsin (New Diggings, 7.5- minute quadrangle, 1952).

Author: M.G. Mudrey, Jr. (2001).

Description: The area south of the intersection was extensively mined for residual lead in the early part of the nineteenth century. Miners would dig down over surface occurrences of galena, collecting residual galena in the soil. At some depth, depending principally on the competency of the soil profile, the dig was abandoned, and another started adjacent to the first dig. Once the area had been mined, miners would move on to another area. There was no attempt at active reclamation or deeper mining at that time.

The area north of the intersection was also heavily mined; however, leveling of the surface in the 1950 for agriculture effectively removed the topographic evidence of mining. The high alkalinity of the soil derived from the Sinnipee Group dolomite neutralizes any acid mine drainage from oxidation of sulfide minerals and allows native plant communities to rapidly recover.

Stop 4: Shullsburg Mine Site—Metallic Mine Reclamation

Location: East side of Lafayette County O, 2 miles south of Shullsburg, sec. 22, T1N, R1E, Lafayette County (Shullsburg 7.5-minute topographic quadrangle, 1972; fig. 7).

Authors: T.C. Hunt (University of Wisconsin–Platteville) and M.G. Mudrey, Jr., 2001.

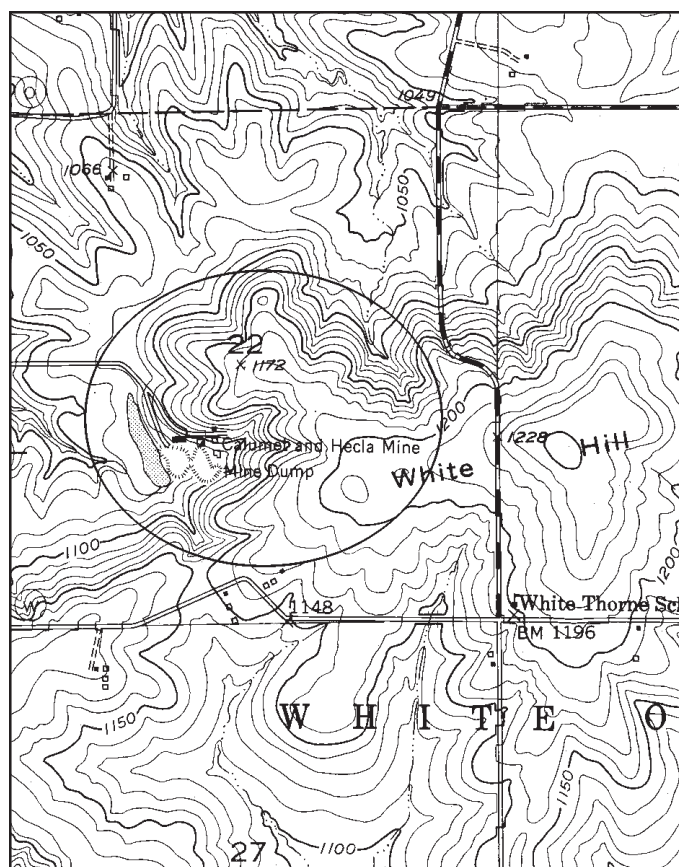


Figure 7. Topographic map showing location of field trip stop 4.

Description: The Shullsburg/Blackstone mining unit, known as the Calumet and Hecla Mine, was discovered by Calumet and Hecla Consolidated Copper Company about 1947 in a systematic exploration drilling program. In 1949 a 360-ft shaft was sunk on the property. Typically in the Upper Mississippi Valley Base Metal District, small ore bodies were identified from surface drilling exploration, and cross-cuts and drifts were driven from existing areas of mining to the newly discovered ore. Mining was by room and pillar methods. Within the mine, many of the drifts converged to make this complex one of the largest producers in the district. Galena and sphalerite were the principal ores mined. The most abundant minerals associated with the ore minerals were calcite, pyrite, marcasite, barite, and more rarely, chalcopyrite. Some individual intersections of ore over a 10-ft vertical interval assayed at more than 14 percent zinc. The ore was processed by

an on-site 1,000 ton per day flotation mill. The mill feed ranged between 4 to 6 percent zinc (Heyl and others, 1959; Heyl and others, 1970). The ore was hosted in the Decorah Formation, about 280 ft below the pre-mine groundwater surface. Groundwater pumping to dewater the mine ranged from 4 to 17 million gallons per day, and the cone of depression extended over 12 square miles (Evans and Cieslik, 1985).

Eagle Picher Company (EP) acquired the properties in 1954. EP operated this site continuously from 1954 until 1979. The zinc and lead ore body was accessed via a decline that was built to replace the shaft that had succumbed to fire. EP extracted about 1,000 tons per day using a modified room and pillar mining method and processed about 1,500 tons of ore per day in the flotation mill on-site. Ore was also received from the nearby Bear Hole mine (Reinke, 1977).

In the 1970s Wisconsin changed its mining laws to require a reclamation plan and financial bonding in conjunction with a mining permit. On April 18, 1978, Eagle-Picher received a permit from the Wisconsin Department of Natural Resources to mine zinc and lead at the site. The permit to mine was secured with only an approved reclamation plan; no bond was required because the operation was permitted as a nonconforming project site (Wisconsin Department of Natural Resources, April 18, 1978). The permitted mining site covered 72 acres at the Shullsburg mine and mill and an additional acre at the Blackstone pump site.

In 1981, Inspiration Development Company gained ownership of four nonconforming mining units in southwestern Wisconsin that were under permit with the Wisconsin Department of Natural Resources; the Shullsburg site was among them. Most of these sites had been developed decades earlier, but were not permitted until mid to late 1970s. Only the Bear Hole (a nearby ore deposit) and Shullsburg units produced ore after they were permitted. The mining units in southwestern Wisconsin were shut down permanently during the period of 1978 and 1979.

IDC never produced ore after its purchase, but IDC assumed responsibility for the reclamation of the site which is currently in different phases of reclamation. The primary environmental concerns were groundwater and surface water pollution, dusting from waste piles, stockpiles, and roads, aesthetics, and safety concerns.

Following the closure of the Shullsburg Mine water quality in some nearby private water-supply wells deteriorated. Affected wells were located within the cone of depression created by pumping to keep the underground mine dewatered (fig. 8). Following mine closure, groundwater from these wells showed increased levels of sulfate, iron, calcium, magnesium, and total dissolved solids. The mechanism of contamination was postulated to be the following sequence: (1) oxidation of sulfide minerals, (2) formation of soluble sulfate mineral phases, (3) breakdown of carbonate host rock by acid produced during sulfide oxidation, and (4) dissolution of soluble materials by groundwater with rock strata that was previously dewatered during active mining (Evans and others, 1983; Evans and Cieslik, 1985). The impacted wells were reconstructed or abandoned and new wells constructed into the underlying sandstone aquifer.

Numerous relic mine waste piles exist nearby this site including flotation tailings, jig tailings, waste-rock piles, and junk piles. Waste materials were trucked off-site as merchantable by-product for purposes of construction or agriculture. The decline portal has been backfilled, graded, top dressed, and stabilized with vegetation. Surface drainage has been restored so that runoff water is discharged from the sites without significant erosion. Observable subsidence or caving has not occurred at this site.

This site predates topsoil salvage requirements. Generally, no topsoil remained for redistribution during reclamation activities, but where it was available in the form of dikes and berms, it was used to topdress the site. IDC has routinely used cow manure as a substitute for topsoil to

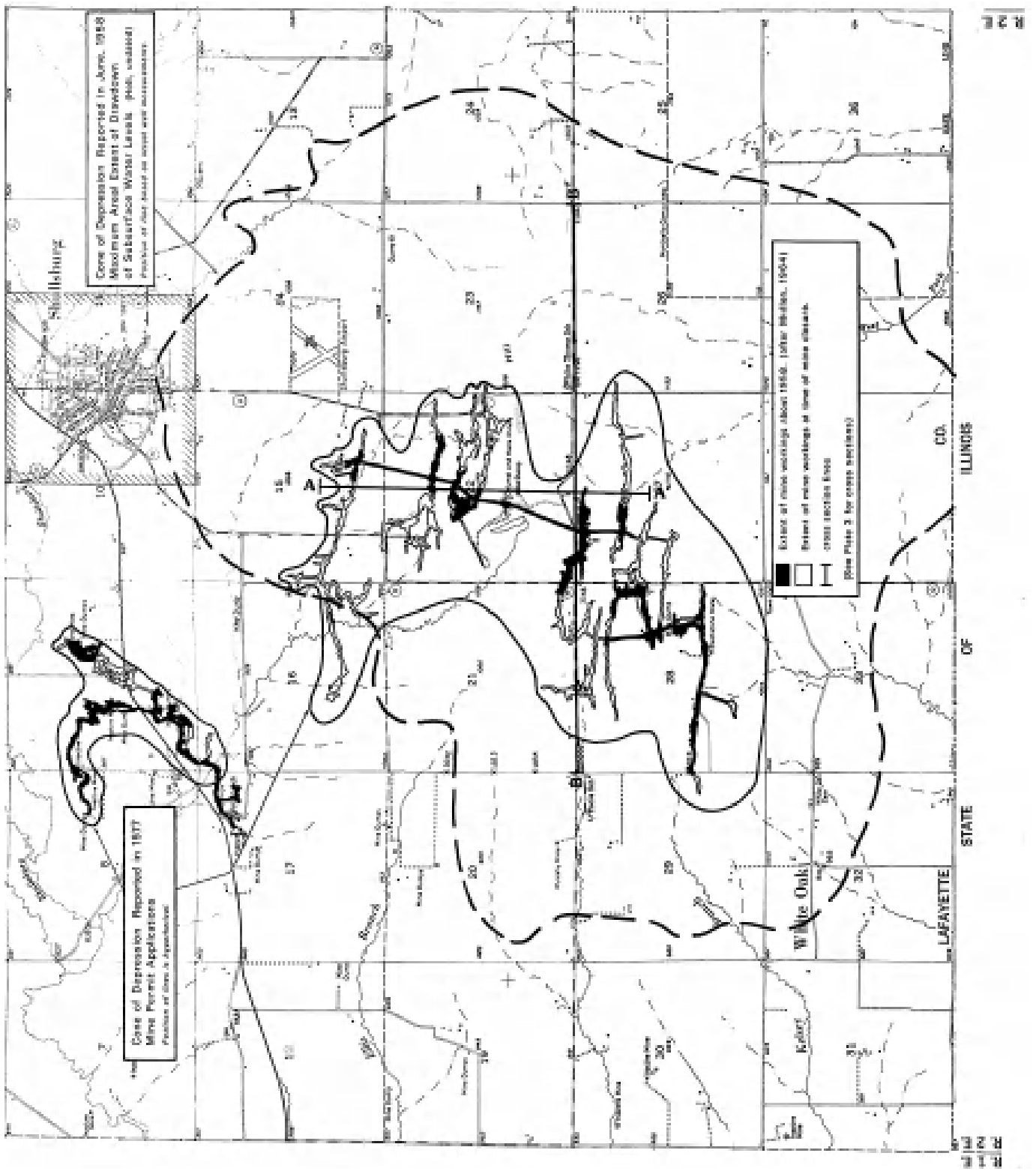


Figure 8. Areal extent of cone of depression developed around the Bear Hole and Shullsburg Mines, Lafayette County, Wisconsin (from Evans and others, 1983).

effect the establishment of vegetation. Most of the site is reasonably well stabilized with vegetation. Introduced pasture grasses and legumes were approved by the Wisconsin Department of Natural Resources for the last phase of final reclamation at this site. During the first phase of final revegetation in the mid-1980s, native trees, grasses, and shrubs were installed (Hunt, 1989).

The area is not sited in wetland habitat. Proximity to a perennial stream may have impacted the riparian area, but baseline data are scarce. Presently, the impacts appear minimal. The existence of on-site settling ponds have created wetland habitat, albeit small and of marginal value.

The designated post-mining land use for the nonconforming Shullsburg mining unit is a designated wildlife area, which is compatible with the adjacent land-use pattern. The current management level of this site is low, but there are plans to conduct a prescribed fire to help revitalize the native vegetation. The topography of this site is modified by waste piles, steep-sided settling ponds, and relic mine openings and artifacts. The existing vegetation is a mixture of introduced agronomic pasture grasses and native vegetation. The existing oak groves present on these sites represent pre-settlement vegetation.

Stop 5: Pendarvis State Historical Site (Mineral Point)

Location: NE¼SE¼ sec. 31, T4N., R3E., Iowa County, Wisconsin (Mineral Point 7.5-minute topographic quadrangle, 1980).

Author: Modified from <<http://www.shsw.wisc.edu/sites/pend/>>.

Description: The museum consists of a series of stone buildings salvaged in the 1930s by Robert Neal and Edgar Hellum, who formed a partnership to acquire, restore and rebuild the few remaining cottages built by Cornish miners in the early 19th century. Their venture, called Pendarvis after an estate in Cornwall, preserves the regional cultural legacy of the early history of mining in southwest Wisconsin. Early miners extended their search for lead from northwestern Illinois into Wisconsin around 1820. Much of this early mining was seasonal, with the miners returning south to Illinois in the winter. With the arrival of Cornish miners and their families in the late 1830s, small villages were developed in proximity to the lead mines. In the hill south of Pendarvis is the Merry Christmas Mine. Originally lead was mined by recovering residual galena from the soil (the hill side is extensively pockmarked with lead digs). Once the residual lead was recovered, the early miners sunk shallow shafts (above the water table) to recover galena from bedrock.

For more information: Pendarvis State Historical Site, 114 Shake Rag Street, Mineral Point, Wisconsin 53565; telephone (608) 987-2122.

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Field Trip 3

Economic Geology of the Baraboo and Waterloo Quartzites of Southern Wisconsin

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Stockpiles of Baraboo quartzite aggregate, LaRue Quarry.

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INTRODUCTION

The Proterozoic quartzites of the Baraboo Range and the Waterloo area of south-central Wisconsin have been quarried for a variety of industrial mineral products since the late nineteenth century. The extreme hardness and refractory properties of the quartzite were recognized early, and both areas were important producers of refractory blocks, mill liners, grinding pebbles, and several types of abrasives. Grinding pebbles were used in place of steel balls in mills that ground clay and feldspar for the ceramic industry, talc and other materials for the cosmetic industry, and in grinding some types of metallic ores. The most commonly used pebbles were flint beach pebbles, of 3 to 4 inch size, hand picked from beaches in northern Europe. Wisconsin State Geologist William O. Hotchkiss was instrumental in promoting Wisconsin quartzite for this use when European sources were cut off during World War I. The early operations used pebbles from gravels derived from the Paleozoic conglomerates formed adjacent to the quartzite, such as we will see at Stop 2. Later, grinding balls were manufactured by crushing quartzite, sorting for size and shape, and tumbling to achieve rounding. The last grinding ball producer, the Baraboo Quartzite Co., ceased operations in the 1980s.

Today the primary uses for southern Wisconsin quartzite are crushed stone aggregates, riprap, and breakwater stone. For many years, the hard, abrasive nature of the quartzites, which average 98 percent silica, made crushed quartzite aggregates prohibitively expensive due to excessive wear on crushing and screening equipment. Crusher jaws quickly wore out, and steel wire screens commonly had to be replaced daily to maintain tight gradation specifications. Modern alloys, combined with the use of plastic and rubber-faced screens, have increased efficiency and reduced the cost of producing railroad ballast and a variety of quartzite aggregates.

This guide is intended to provide the locations of stops and a brief outline of the geology and industrial process and products at each site that we intend to visit. Additional handouts relating to products, testing, specifications, and history will be provided on the day of the trip. We have not provided lengthy detailed descriptions of each stop because the geologic features we will see will likely change with the next round of production blasting. Wherever possible, we have tried to cite appropriate published field guides that explain the geology of nearby or relevant exposures regularly accessible to the public.

We will visit six active quarrying operations on Trip 3. Company personnel will be available to describe the geology, mining, and processing methods, and the products made at each site. Because these are active operations, we will need to sign releases and MSHA Part 46 site-specific hazard training forms. ***Please remember to observe all safety rules and use common sense at all times. Especially stay away from highwalls and unstable slopes.***

GEOLOGY OF THE QUARTZITES

Because the primary focus of this trip is on economic geology, only a brief discussion of the geologic history of the Baraboo Interval rocks of southern Wisconsin is included. The reader is referred to general discussions of tectonic setting (Greenberg and Brown, 1984) and previous guides to the Waterloo area (Luther, 1992, 1997), and the Baraboo area, (Dalziel and Dott, 1970; Malone and others, 1997; Medaris and Dott, 2001).

The Baraboo and Waterloo quartzites belong to a group of sedimentary rocks that include the McCaslin, Rib Mountain, Necedah, Hamilton Mound, Flambeau, Barron quartzites of Wisconsin and probably the Sioux Quartzite of Minnesota that were deposited on continental crust formed during the 1850 Ma Penokean Orogeny (Greenberg and Brown, 1984). For many years the exact age of the quartzites and the timing of deformation and metamorphism were hotly debated. Recent work summarized by Medaris and Dott (2001) suggested that the Baraboo quartzite was deposited on a basement of 1,760 Ma. Granite and rhyolite, and that most of the

metamorphism and alteration at Baraboo resulted from hydrothermal activity accompanying emplacement of the Wolf River Batholith at around 1,460 Ma. The Waterloo quartzite is intruded by pegmatite of Wolf river age, suggesting that recrystallization and metamorphism may also be related to this regional thermal event. Both the Baraboo and Waterloo quartzites have been deformed. The Baraboo Range is an isolated doubly plunging syncline, slightly overturned to the south. The Waterloo outcrop area is in the nose of a broad eastward-plunging synclinal structure. Several possible models for deposition and subsequent deformation of the quartzites have been proposed (Greenberg and Brown, 1984), but the timing of deformation is still debated, possibly related to a regional 1,630 Ma thermal event, but certainly after about 1,720 Ma and prior to the 1,460 hydrothermal event. Quartzite, presumably equivalent to the Baraboo and Waterloo quartzites, is the most common basement lithology found in deep wells throughout southeastern Wisconsin.

The stratigraphic sequence at Baraboo consists of 1,500 m of red to purple quartzite, overlain by 100 m of Seeley slate, 300 m of Freedom Formation (dolomite and carbonate iron formation), 65 m of pebbly Dake quartzite and 45m of Rowley Creek slate (Dalziel and Dott, 1970). The quartzite is well exposed, but the overlying formations, except for the Dake, are known from drill core. All of the operations that we will visit are located in or adjacent to the lower quartzite sequence. The upper formations are rarely exposed, being covered by Paleozoic sandstone and Quaternary glacial deposits in the interior of the syncline. At Stop 5 we will be near the site of two of the three historic iron mines that, before closing in the early 1920s, briefly mined the iron-rich carbonates of the Freedom Formation. The stratigraphic sequence at Waterloo is poorly known because of very limited exposure. Most of the known outcrop is in the area of the Michels Quarry, and consists of gray pebbly quartzite interbedded with argillite beds that have been metamorphosed to andalusite schist (Luther, 1992, 1997). Outlying exposures that show less evidence of metamorphism tend to have the more typical reddish-purple color and hydrothermal quartz veins and breccias seen in other Baraboo Interval quartzites.

Stop 1: Michels Materials Waterloo Quarry

Location: NE¼ sec. 33 and NW¼ sec. 34, T 9N, R13E, 1.5 miles east of Portland, Wisconsin, on Highway 19 (Waterloo 7.5-minute topographic quadrangle, 1976; fig. 1).

Leaders: Frank Luther, Sue Courter, and Bruce A. Brown.

Description: The Michels Waterloo Quarry was opened in 1988 by the Edward E. Gillen Co., a Milwaukee marine contractor involved in harbor and breakwater construction on the Great Lakes. Exploratory core drilling indicated massive bedding up to 2 to 3 m thick that would allow for quarrying of individual blocks up to 20 tons in size. The rock was tested and proved to exceed all Corps of Engineers specifications for breakwater stone, particularly resistant to freeze-thaw. The quarry site is also conveniently located for transport of blocks to Milwaukee by rail or truck. The Gillen Co. soon began to accumulate a large pile of waste blocks too small for breakwater stone and brought in crushing equipment to convert this material into railroad ballast and other aggregate. A rail loading facility was built 1 mile south of the quarry and ballast is moved to the site by truck.

The rock is gray to reddish gray in color and consists of thoroughly recrystallized sand-sized quartz grains, with interlayered pebbly beds containing pebbles of quartz, chert, jasper, and iron formation up to 1.5 cm. The massive beds of quartzite are separated by 10 to 20 cm argillite beds that are metamorphosed to andalusite schist. The thick east-dipping beds facilitate quarrying of large blocks, but make maintaining a flat quarry floor difficult. Glacial till overburden thickens to the east, and contains abundant quartzite boulders. Paleozoic sandstone conglomerate similar to the Parfrey's Glen Formation of the Baraboo area locally occurs above the quartzite.

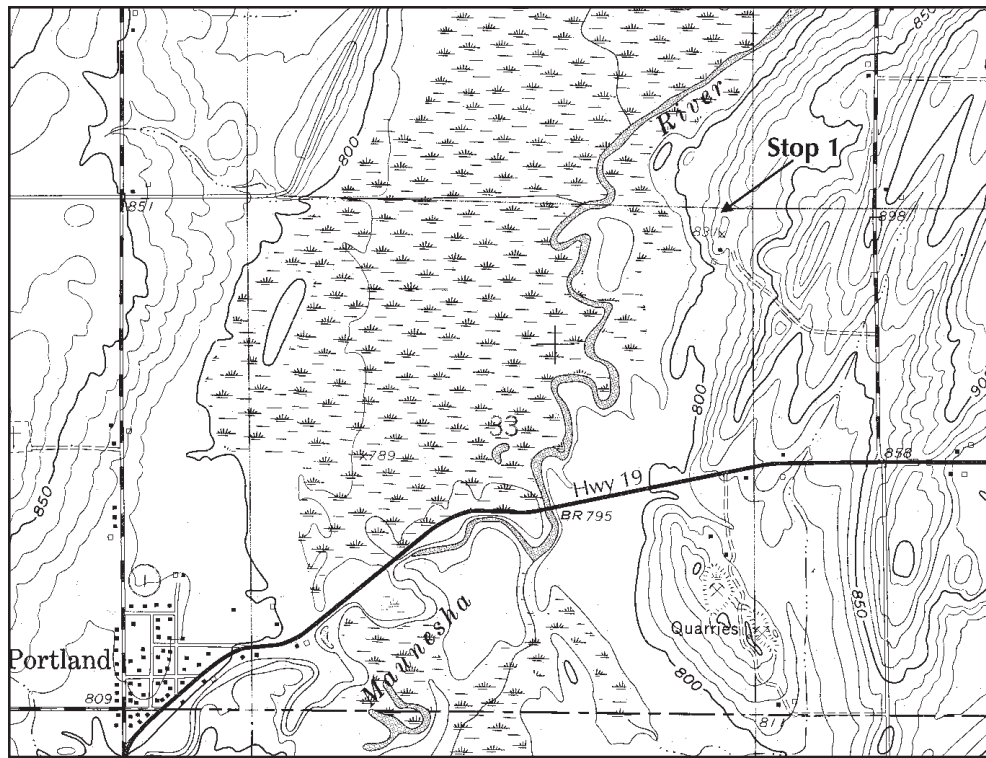


Figure 1. Topographic map showing location of Stop 1.

We will examine the quarry geology, mining and crushing methods, and products. From Waterloo we will proceed northwestward across the glaciated terrane of eastern Dane County to Stop 2, located at the east end of the Baraboo Range. On the way we will have the opportunity to see some classic examples of drumlins and other glacial landforms.

Stop 2: The Kraemer Co. Williams Quarry

Location: SE¼, NE¼ sec. 19, T 12 N, R 8,E, Columbia County, south side of Highway 33, about 3 miles west of I-90-94 (Pine Island 7.5-minute topographic quadrangle, 1975; fig. 2).

Leaders: Jennifer Lien, Phil Fauble, and Bruce A. Brown.

Description: The Williams Quarry and another operation 0.5 mile to the west were opened in the Parfreys Glen Formation (Clayton and Attig, 1990), a time-transgressive, proximal conglomeratic facies formed by wave and storm action around the Baraboo Range as it was slowly buried by advancing seas during Cambrian and Ordovician time. The face at Williams has now advanced far enough into the hillside to expose three distinct lithologic units. At the base of the highwall, steeply dipping quartzite of the Baraboo north range is exposed. The quartzite is cut by numerous white quartz veins, and is locally brecciated and recemented by white hydrothermal quartz. Vugs and cavities in the breccia zone are filled with white clay and lined with quartz crystals up to 20 cm in length.

Overlying the quartzite is a poorly sorted deposit consisting of clasts ranging from sand sized up to rocks 2 to 3 m in diameter (fig. 3). Fauble and Lien (2001) suggested that this unit may have originated as a debris flow because of the lack of sorting and evidence of reworking by wave action. Overlying and lapping onto the debris flow are beds of pebble conglomerate and sandstone typical of the Parfreys Glen Formation. These beds contain sedimentary structures and trace fossils typical of near-shore marine deposits. Abundant glauconite suggests equivalence to

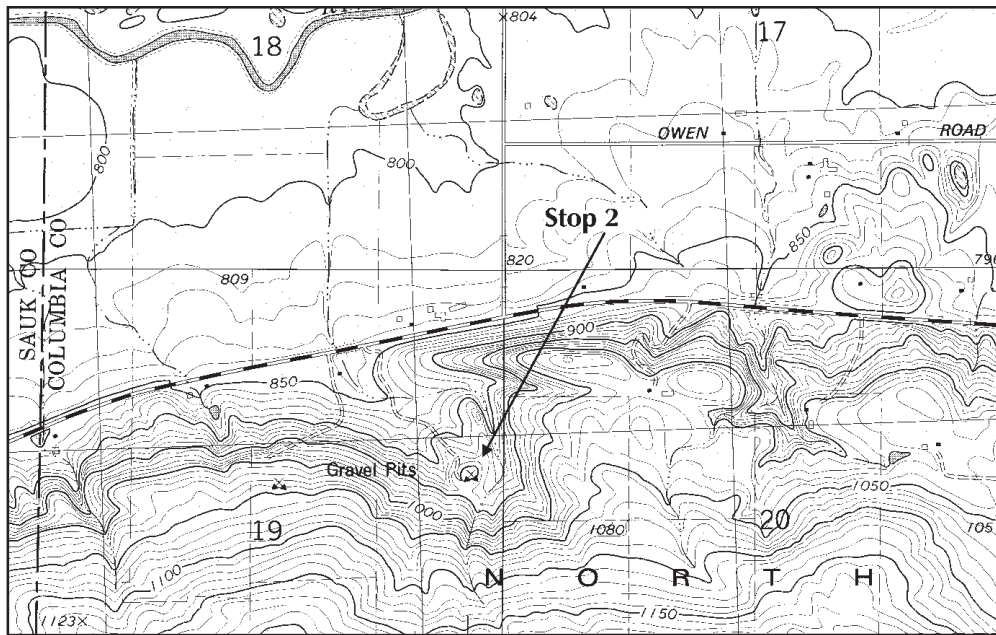


Figure 2. Topographic map showing location of Stop 2.



Figure 3. South face at Williams Quarry showing Parfreys Glen conglomerate over coarse debris flow deposit overlying quartzite with white veins and clay pockets.

the Tunnel City Group away from the Baraboo Range.

The Williams Quarry produces base course and a small amount of riprap. Crushing and screening are done intermittently as needed, using portable equipment, typical of smaller quarry operations throughout rural Wisconsin.

Location: SW¼ NE¼ sec. 33, T12N, R7E, south side of Highway 33, 0.3 mile east of the Lower Narrows of the Baraboo River (Lewiston 7.5-minute topographic quadrangle, 1975; fig. 4).

Description: We will stop at this old road cut to examine the rhyolite that underlies the Baraboo quartzite. This rock is typical of the 1,760 Ma metarhyolites exposed along the northern and southern edges of the Baraboo syncline and to the northeast in the Fox Valley (Smith, 1978). The rock is a dark reddish brown color, and contains quartz and feldspar phenocrysts in a fine-grained matrix. A tuffaceous texture is visible in thin section and hand specimen. Flattened shards and pumice fragments can commonly be seen on weathered outcrop surfaces. The rhyolites have never been commercially quarried in the Baraboo area, but were extensively quarried for paving blocks in the Fox Valley at Berlin and Utley (Buckley, 1898).

As you return to the van, notice the shoulder stone along Highway 33, and the aggregate used in the asphalt pavement. The shoulder stone was likely from the Williams Quarry. The asphalt contains a high percentage of quartzite aggregate. Wisconsin Department of Transportation has been slow to embrace quartzite as an aggregate for asphalt mixes because the dense quartzite does not absorb asphalt readily. This pavement seems to be performing well with no sign of deterioration after several years of use. Quartzite has performed well as a concrete aggregate in Wisconsin, outlasting the cement and fine aggregate matrix in many older pavements and sidewalks. In the city of Madison, examples of concrete with quartzite aggregate poured in the 1920s are still in use.

We will drive through the Lower Narrows, where the Baraboo River cuts through the North Range on our way to the next stop. The quarry at the southwest end of the narrows was formerly operated by the Baraboo Quartzite Co., a producer of mill linings and grinding balls for many years. This was the last active producer of grinding media in the district, closing in the early 1980s.

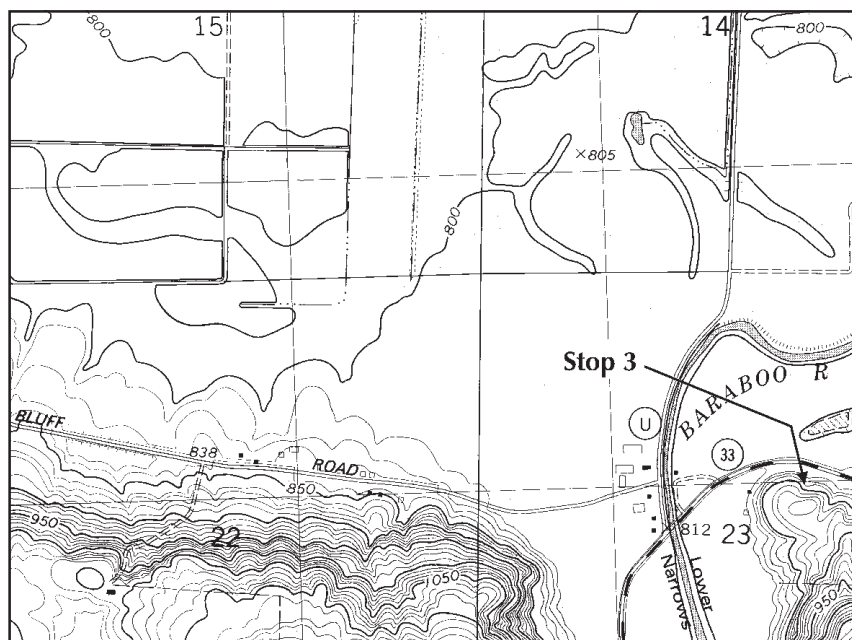


Figure 4. Topographic map showing location of Stop 3.

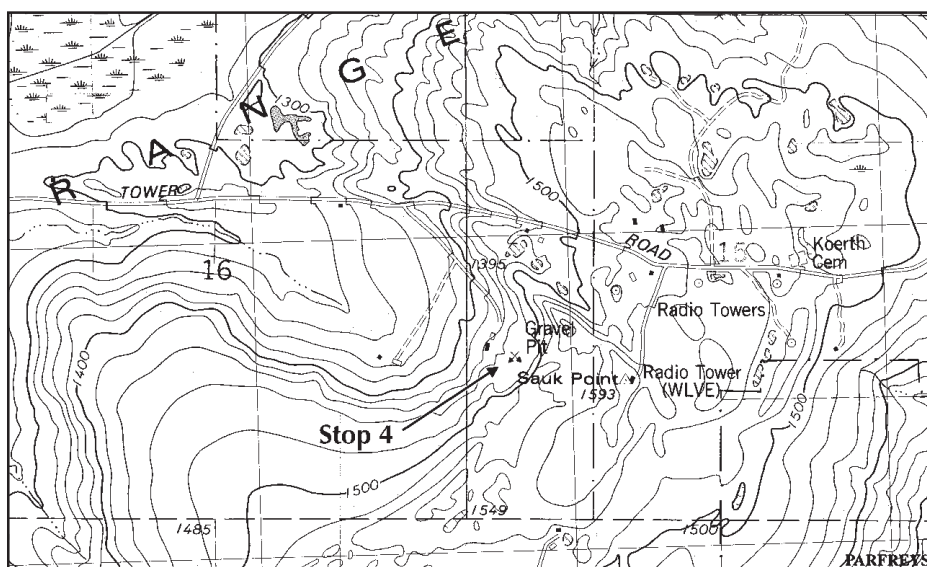


Figure 5. Topographic map showing location of Stop 4.

Stop 4: Milestone Materials Jesse Pit and Quarry

Location: NW¼SW¼ sec. 15, T11N, R7E, 2 miles east of Highway 113 on south side of Tower Road, Sauk County (Baraboo 7.5-minute topographic quadrangle, 1994; fig. 5).

Leader: Jim Schmitt.

Description: The Jesse Pit began as a sand and gravel operation along the terminal glacial moraine. As the pit was deepened, quartzite was exposed and quarrying began (fig. 6). We are now on the south limb of the Baraboo syncline, and the exposed quartzite dips to the north at a low angle. The dip surface is a bedding plane, and in many areas excellent examples of ripple marks can be seen.

The Jesse Pit is an example of a growing number of sand and gravel operations that have encountered bedrock and begun to produce crushed stone as well. Gravel is in demand for concrete aggregate, but many gravel deposits lack sufficient coarse crushing material needed to achieve the percentage of fractured surfaces required to meet modern asphalt mix design standards. Operations such as Jesse Pit have the advantage of being able to furnish concrete and asphalt aggregate plus a variety of other products ranging from sand to landscape boulders.

We will examine the quartzite exposures and look at some of the glacial material as well as discuss some of the reclamation activities currently in progress at this site.

Stop 5: Milestone Materials Fox Ridge Asphalt Plant and Sales Yard

Location: SE¼ sec. 22, T12N, R6E, 2 miles north of Baraboo on Fox Hill Road.

Leader: Jim Schmitt.

Description: At this stop we will examine some of the 27 products produced at or marketed from the Fox Ridge Pit. The list includes seven quartzite products ranging from base course to washed sand and seal coat chips. The quartzite is hauled in to this site from quarries such as Jesse and Rock Springs. We will discuss the uses of quartzite for asphalt aggregate as well as a variety of construction uses.



Figure 6. View of Jesse Pit looking north. Working face in quartzite in foreground; sand and gravel face behind. Slope in background near tree line is reclaimed pit area ready to be seeded.

Stop 6: Martin Marietta Aggregates Rock Springs Quarry

Location: SW¼ sec. 28, T11N, R5E, 0.5 miles north of Rock Springs (Rock Springs 7.5-minute topographic quadrangle, 1975; fig. 7).

Leader: Bruce A. Brown (Joe Michels).

Description: This large quarry was opened in 1958 by the C&NW Railroad and operated exclusively as a source of railroad track ballast for many years. At the time it was opened, the large-scale production of quartzite ballast was not considered cost effective because of the hard abrasive nature of the rock and the resulting equipment maintenance costs. The C&NW ultimately proved that the superior performance of quartzite under heavy, high-speed train traffic was worth the cost in the long run. The angular quartzite interlocked to form a stable, well-drained track base, and did not break down under heavy traffic, as did limestone.

Today the quarry is operated by Martin Marietta and it remains one of the largest ballast producers in Wisconsin. We are directly across the Upper Narrows of the Baraboo River from Van Hise rock, and several historic quarries. The old quarries are now part of a Wisconsin Department of Natural Resources Natural Area; originally they were operated for refractory and grinding media, with some early limited production of crushed stone. The bedding in this area is nearly vertical as at Williams Quarry (Stop 2). Hydrothermal breccias cemented with white quartz are also common in this area. The geology of the Narrows area is described in detail by Medaris and Dott (2001) as Locality 4 of Field Trip 1 for this meeting.

We will tour the quarry and examine the large modern crushing and screening plant. As we drove up the hill to the quarry office, we passed a large pile of fines created by years of ballast production. This material at one time was eroding and washing into the Baraboo River

below. It has since been stabilized and vegetation is beginning to take hold. Does anyone have any good ideas for marketing this stuff?

Stop 7: Kraemer Company LaRue Quarry

Location: NW¼ sec. 22,
T11N, R5E (Rock Springs
7.5-minute topographic
quadrangle, 1975; fig. 8).

Leaders: Jennifer Lien and
Bruce A. Brown.

Description: The LaRue
Quarry is a historic operation
in the Baraboo region. At
one time this quarry
produced ballast and was connected to the C&NW at North Freedom by the track now used by
the Midcontinent Railway Museum. We may be in time to see the steam train pull into the quarry
on one of its runs. Foundations of the old permanent crushing and screening plant and a few
ruined buildings remain from the earlier operation. As we drive into LaRue Quarry, the leaders
will point out the sites of two historic iron mines also served by this branch line from 1900 to
around 1922. The quarry is now operated on an as-needed basis with portable crushing and
screening equipment. The principal product is construction aggregate, primarily base course.

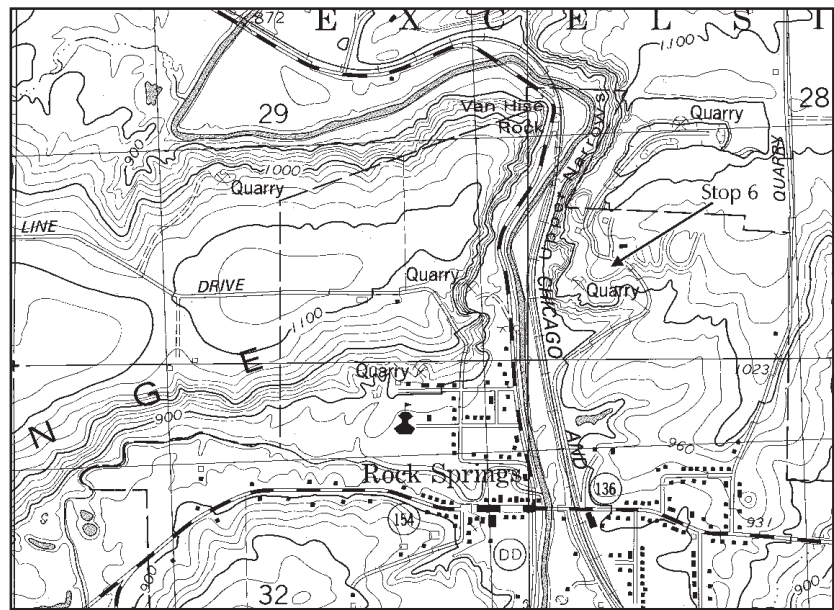


Figure 7. Topographic map showing location of Stop 6.

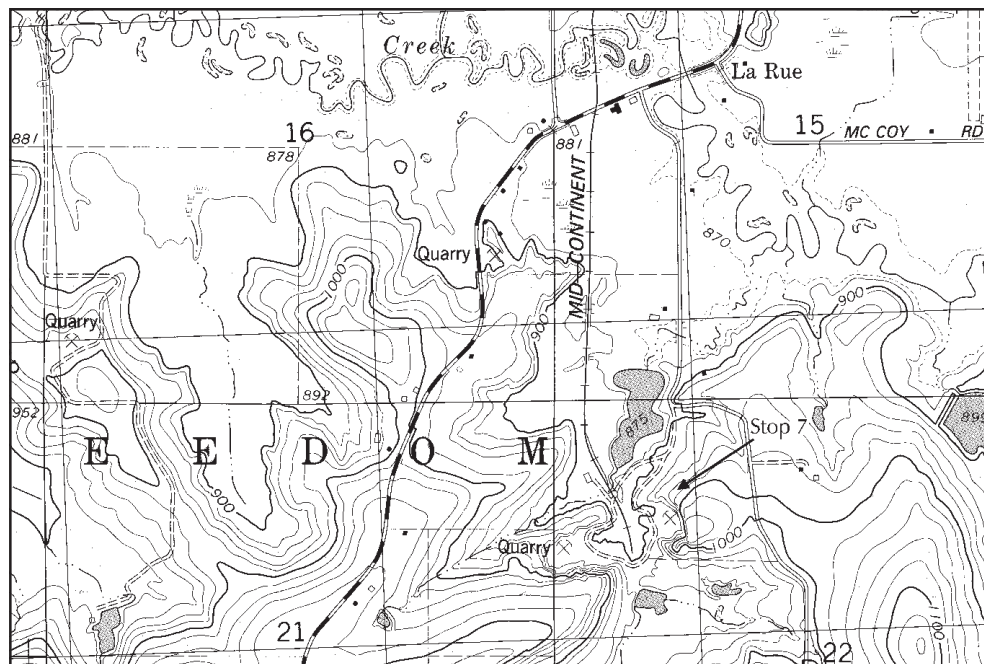


Figure 8. Topographic map showing location of Stop 7.



Figure 9. East face of LaRue Quarry, showing unconformity of Paleozoic sandstones overlying Baraboo quartzite.

LaRue is on the south range and, as at Jesse Pit, beds dip at a low angle to the north. Thin argillite beds are present and cross-bedding can be seen on joint surfaces. Ripple marks are common on bedding surfaces. LaRue provides some excellent views of the unconformity between the quartzite and the onlapping Cambrian-Ordovician sandstones (fig. 9). Alteration along joint surfaces has produced a weathering pattern similar to spheroidal weathering in granite. Rounded boulders can be found in which the interior is fresh purple quartzite surrounded by a rind of bleached sandstone resembling the overlying sediments.

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