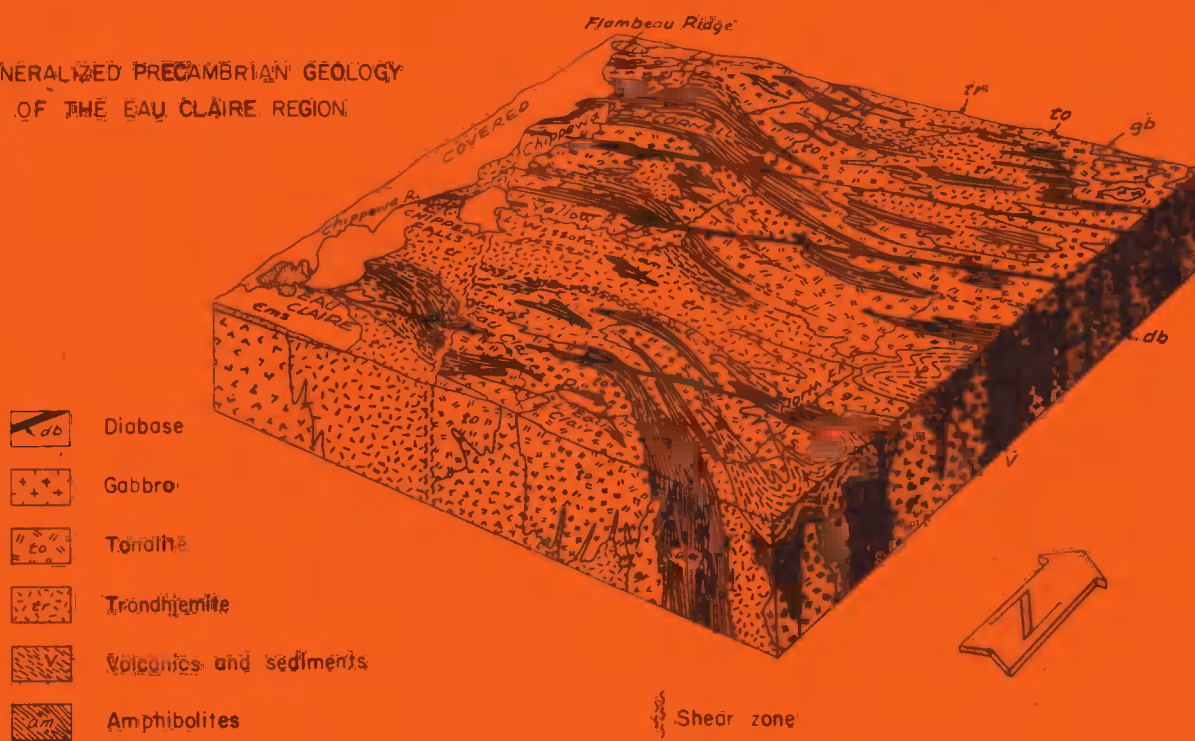




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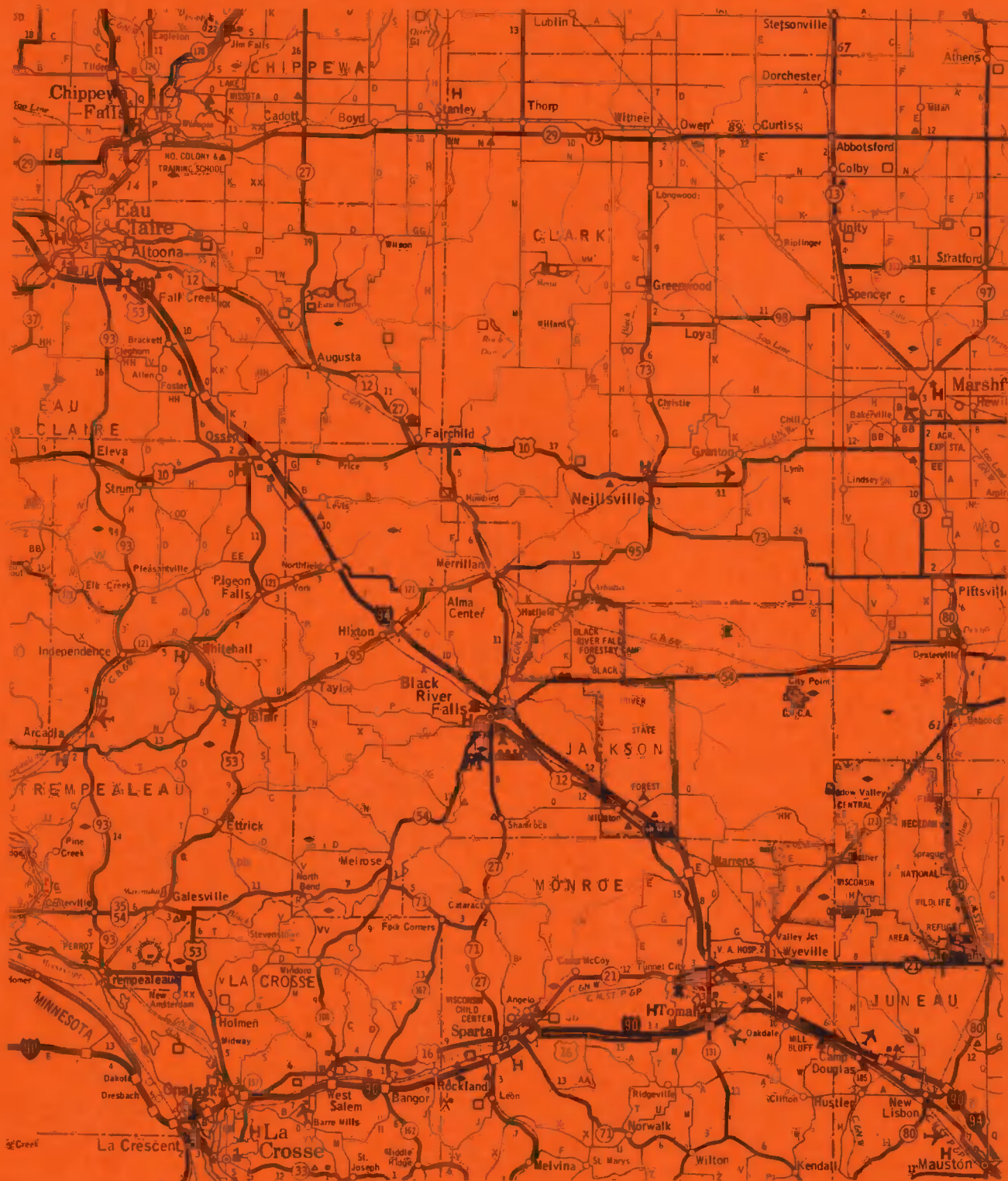
Precambrian Tectonic History of the Black River Valley

GENERALIZED PRECAMBRIAN GEOLOGY
OF THE EAU CLAIRE REGION



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University of Wisconsin-Eau Claire



PRECAMBRIAN TECTONIC HISTORY OF THE BLACK RIVER VALLEY

Field Guide

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INTRODUCTION

W. R. Van Schmus

The Precambrian bedrock exposed along the Black River in west-central Wisconsin, from Black River Falls to north of Neillsville, consists primarily of Archean gneissic rocks and early Proterozoic (Penocean) plutonic rocks. These Archean rocks are the westernmost exposures of an Archean terrane that extends from the Black River eastward to the Wisconsin River in the vicinity of Stevens Point and Wisconsin Rapids (Figure 1). Gneissic rocks also occur to the northwest, in Eau Claire and Chippewa Counties (Myers et al., 1980), as part of the Chippewa Amphibolite Complex, but they may not be Archean. One of the major problems in understanding the older rocks of the region is how they relate to similar rocks in the southern part of the Canadian Shield, either to the north in northern Wisconsin and Michigan or to the west in the Minnesota River Valley.

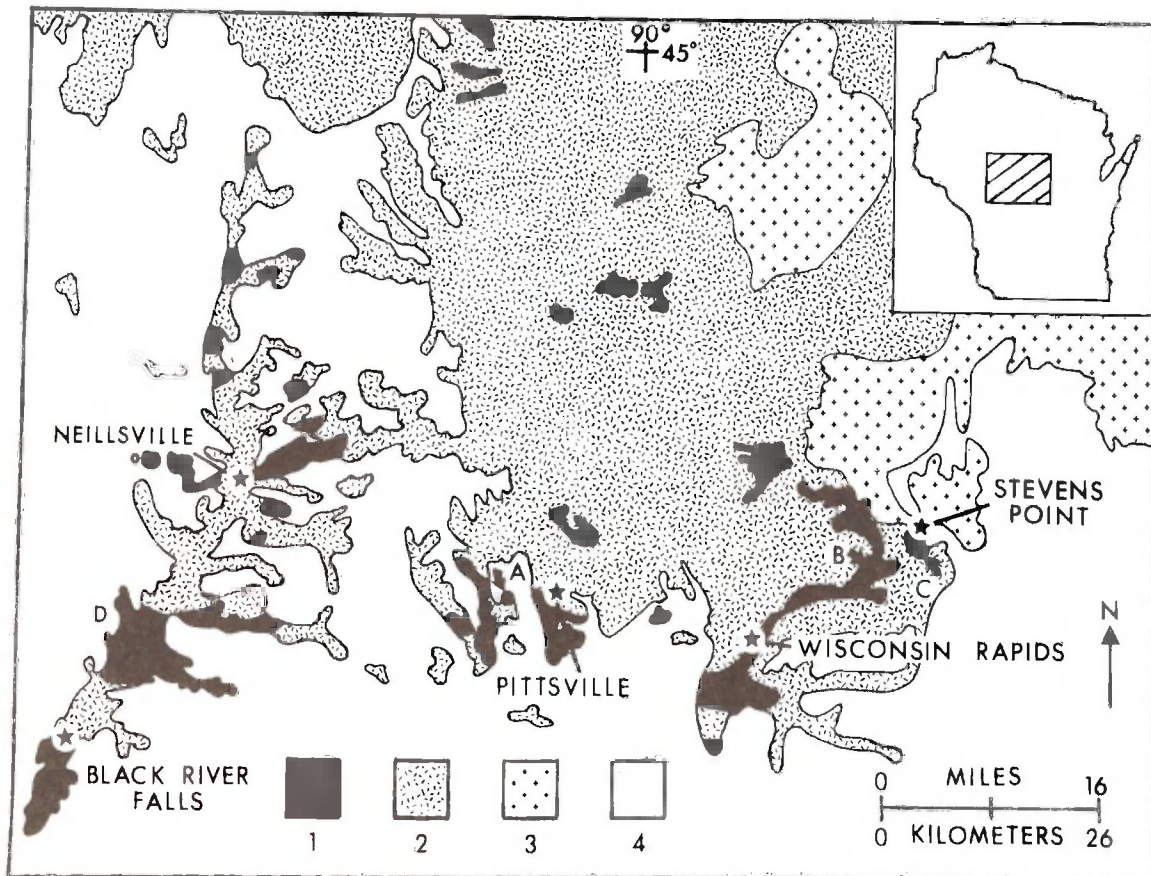


Figure 1. Geologic map of central Wisconsin showing the distribution of presumed Archean gneiss (1), Penocean igneous and metamorphic rocks (2), 1500 m.y. old plutonic rocks (3), and Paleozoic cover (4). The Hatfield Gneiss (Stop 7) occurs along the northern part of the block of gneiss (D) between Black River Falls and Neillsville. After Van Schmus and Anderson (1977).

Most of the known Archean rock in central Wisconsin consists of banded gneiss, migmatitic gneiss, or migmatite; Archean plutons are rare. Regional studies (Van Schmus and Anderson, 1977) have shown by U-Pb dating that the gneiss and migmatite in the eastern part of the area are about 2800 m.y. old. There is some indication from their Rb-Sr results that the protolith of the migmatitic gneiss in the Pittsville area may have had an earlier crustal history, but the results could also be explained by Rb loss during a later metamorphism. Recent studies in the Black River area (DuBois and Van Schmus, 1978; Van Schmus, unpub.) have confirmed an Archean age for those gneisses. The gneiss near Hatfield (Stop 7) yields zircons that are analytically indistinct in age from those of the Pittsville and the Wisconsin River areas (Figure 2); the mean age defined by all samples is 2815 ± 20 m.y. The zircons are tentatively interpreted as primary igneous zircon, rather than metamorphic or detrital zircon, so that the age of 2815 m.y. would represent the time of crystallization of the protoliths (plutons, volcanics) of the respective gneisses and migmatites.

Zircon from syenitic augen gneiss south of Neillsville (Stop 4) yields an age of 2535 ± 10 m.y. This zircon is also considered primary igneous zircon, indicating that the protolith to the augen gneiss was probably a syenitic pluton intruded into older gneiss about 2535 m.y. ago.

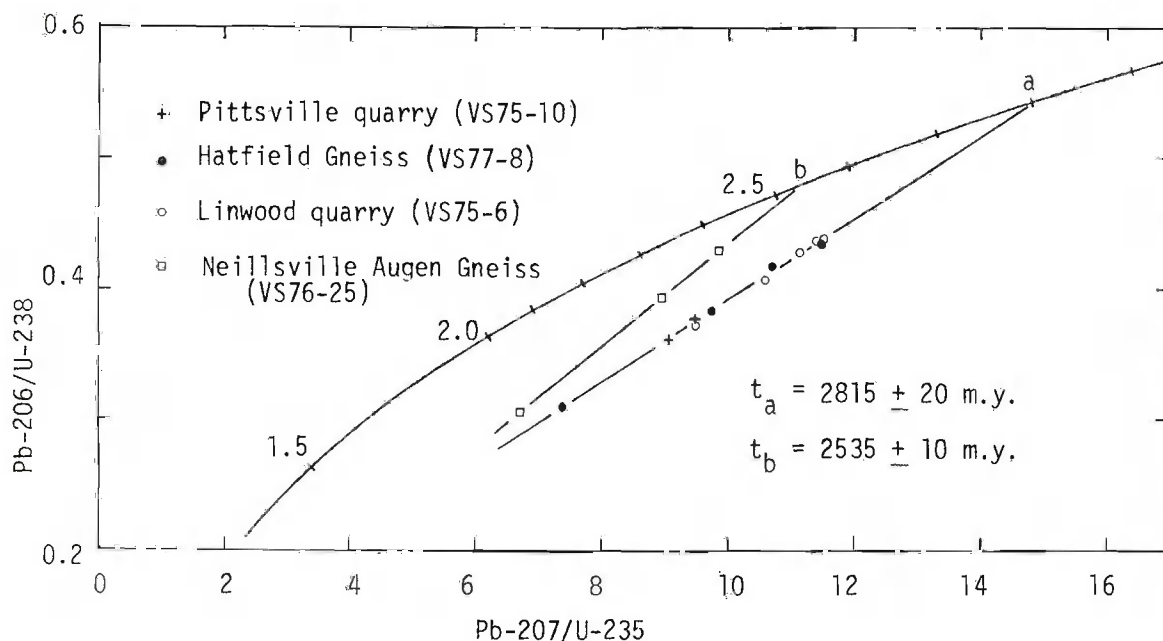


Figure 2. U-Pb plot of data for zircon fractions from Archean rocks in central Wisconsin (Van Schmus and Anderson, 1977; DuBois and Van Schmus, 1978; Van Schmus, unpub.). The Hatfield Gneiss is from near Stop 7, and the Neillsville Augen Gneiss is from near Stop 4. The ages given are for least squares fits to the data. Decay constants as in Steiger and Jäger (1977).

So far no other Archean ages have been obtained for gneissic rocks in central Wisconsin. Layered amphibolite gneiss at Big Falls in Eau Claire County yields a Penokean age of about 1850 m.y. and is indistinguishable from results for foliated tonalite at Little Falls, a few miles away (Figure 3; see also Myers et al., 1980). In the case of the Big Falls zircon the possibility still exists that they are metamorphic, formed during the Penokean Orogeny about 1850 m.y. ago (Van Schmus, 1980) and that the protolith to the gneiss is Archean, but for the present a Penokean primary age is preferred. Granitic gneiss near Greenwood (Locality 10) also yields zircon with an apparent age of 1850 m.y. (Figure 3). Thus, it is beginning to appear that the 1850 m.y. ages to the north and northwest of Neillsville are indicative of a younger gneissic terrane, formed during the Penokean Orogeny. So far no Archean ages are known in central Wisconsin north of a line between Neillsville and Stevens Point, so that the Archean terrane of central Wisconsin may not be continuous with Archean rocks to the north (Sims, 1976). This clearly represents a fundamental problem, and it is hoped present and future studies will help to place the central Wisconsin Archean terrane in proper geologic and geographic perspective.

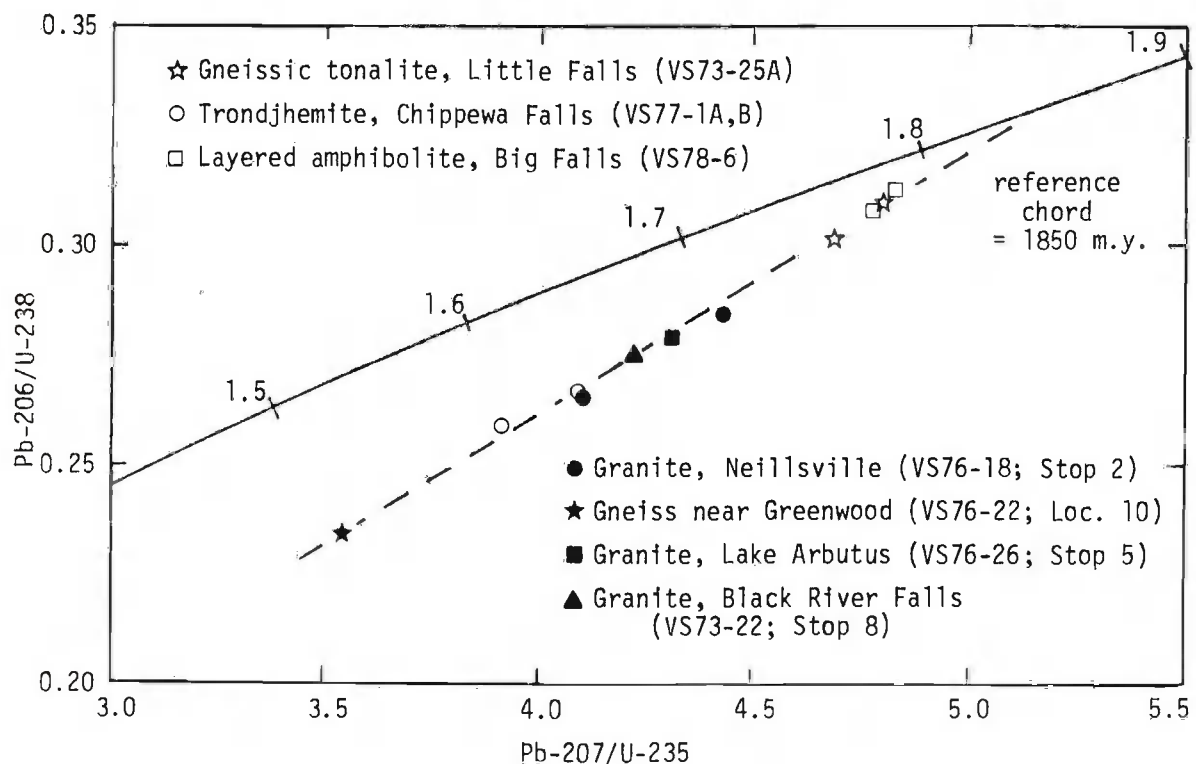


Figure 3. U-Pb plot of data for zircon fractions from Penokean plutonic and gneissic rocks in the western part of central Wisconsin (Van Schmus, 1980, unpub.). Note that the Neillsville Granite appears to be distinctly older than the main suite of samples. Decay constants as in Steiger and Jäger (1977).

Analytical results have also been obtained for zircon from three of the Penokean granitic plutons along the Black River (Figure 3). The Lake Arbutus and Black River Falls granites are apparently part of the main 1820-1850 m.y. old series of Penokean plutons throughout Wisconsin (Van Schmus, 1980), but the results for the Neillsville Granite suggest it is slightly older, extending the spread of Penokean plutonic activity back as far as about 1875 m.y. ago.

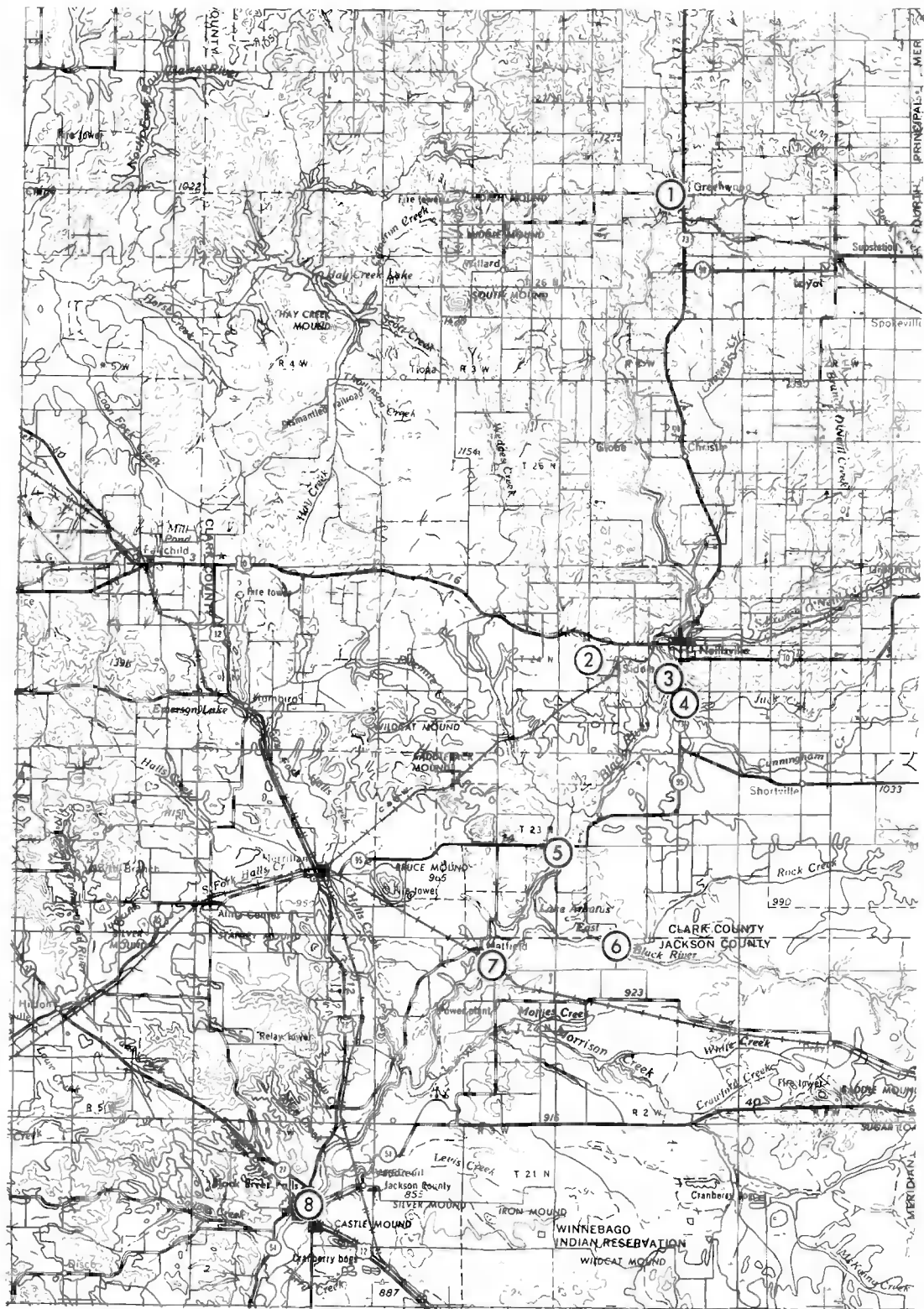
During this field trip we will stop at several localities and examine representative lithologies and structures of this terrane. Several aspects of the regional geology will be highlighted, including a) the nature and variability of the Archean units, b) comparison of deformational features of Archean and of Penokean units, and c) comparison of relative chronologies based on field relationships and those based on absolute age measurements.

In addition to descriptions for scheduled stops, we have provided location information and brief descriptions of additional localities in the Black River valley in order to provide as complete a guide as possible to these Precambrian rocks.

ITINERARY

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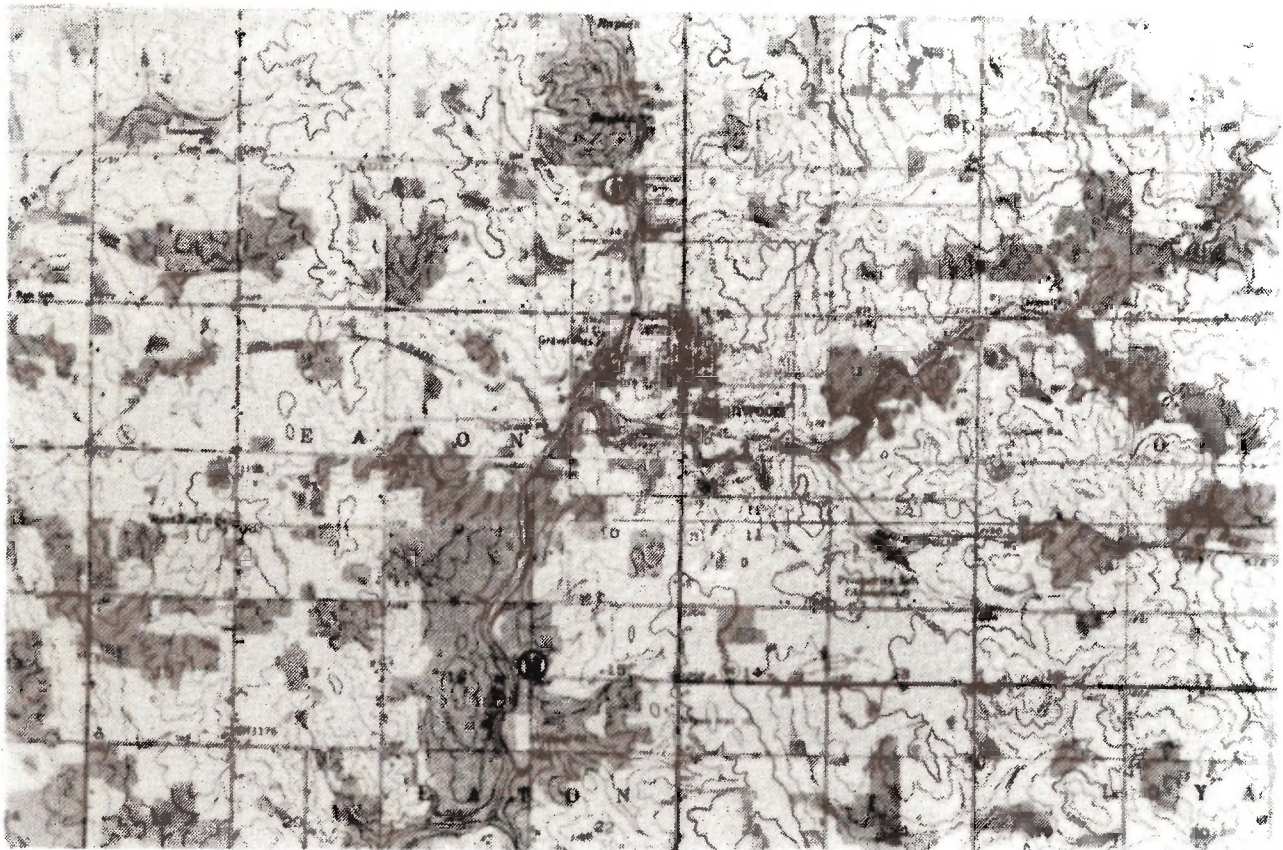


FIELD TRIP STOPS

STOP 1

TITLE: Banded gneiss and foliated tonalite at Greenwood

LOCATION: Former gravel pit, E $\frac{1}{2}$, NW $\frac{1}{4}$, Sec. 3, T.26N., R.2W. (Owen 15-minute topographic quadrangle, Clark County). Proceed about 0.1 mi. south from County Highway G on a dirt road, keeping to left when road splits, to a small outcrop of banded gneiss. Continue approximately 0.2 mi. further south on dirt roads and trails. A short trail down to the Black River from the crest of a small hill leads to foliated tonalite, and when water levels are low a peninsula of foliated tonalite and banded gneiss is exposed. The outcrop is located at a short westward jog of the Black River.



AUTHOR: R. S. Maass (1980)

SUMMARY: The four major lithologies that can be seen are banded tonalitic gneiss, amphibolitic xenoliths in foliated tonalite, and aplitic to pegmatitic veins. The older units are isoclinally folded, but apparently only one major phase of deformation is present. On this basis the rocks are tentatively interpreted as early Proterozoic (Penokean) rather than Archean in age.

DESCRIPTION: The first outcrop is a small patch (2' x 4') of tonalitic banded gneiss which has been tightly folded. The axial plane of the fold strikes N. 20° E. and dips 70° W.; the fold axis trends N. 15° E. and plunges 60°.

Four lithologies can be distinguished along the river. From oldest to youngest these are: banded gneiss, large amphibolite xenoliths in foliated tonalite, foliated tonalite, and aplitic to pegmatitic granitic veins. The gneiss is tonalitic in composition, faintly banded, and contains long, thin lenses of amphibolite. Isoclinal folds can be seen on close examination. Foliation strikes N. 20° E. and dips 85° W., and a weak mineral lineation in the plane of foliation plunges steeply to the north. The rock consists primarily of quartz, andesine (An 34-38), and biotite, with minor amounts of hornblende, sphene, and epidote. The foliation, which is parallel to the banding, is well defined by the orientation of biotite grains and, to a lesser extent by the orientation of hornblende. The gneiss is fine-grained, with minerals averaging between 0.25 and 0.75 mm.

Amphibolite of undetermined origin occurs as large (up to 8' by 30') xenoliths in the foliated tonalite. This amphibolite does not appear to be of the same generation as the amphibolite lenses in the banded gneiss, based on structural and mineralogic grounds. The xenoliths are strongly lineated, but only weakly foliated, and in some cases unfoliated. They contain approximately 60% hornblende, 40% andesine (An 46-50), and very minor amounts of biotite and quartz.

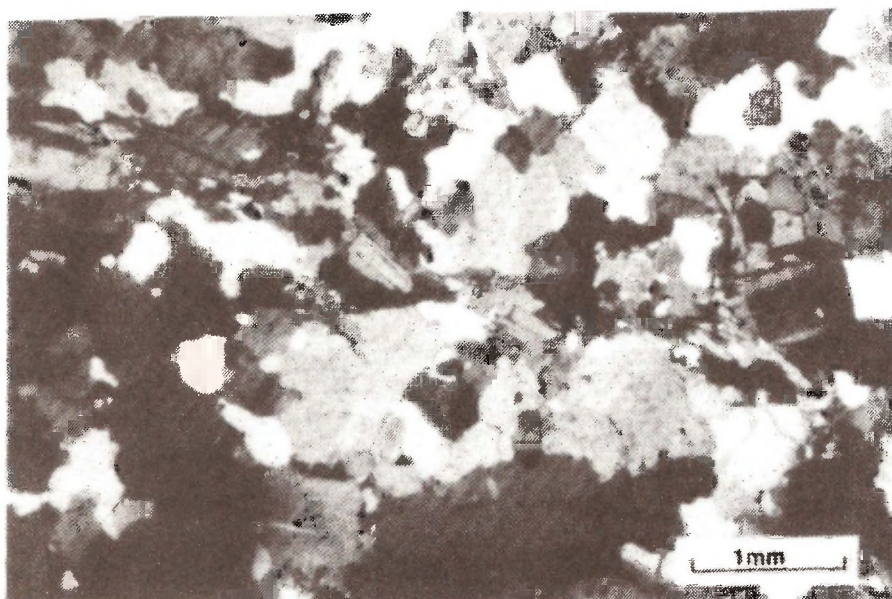


Figure 4. Photomicrograph of foliated tonalite showing granoblastic texture. The upper and lower halves of the section are composed primarily of quartz and feldspar; a biotite and hornblende rich segregation runs through the center of the section. Foliation trends from left to right.

The gray foliated tonalite consists of 2 to 10 mm segregations of felsic minerals and similarly sized segregations of mafic minerals, in which the individual grains are only 0.25 to 1 mm (Figure 4). The major minerals are quartz, andesine (An 33-36), biotite, and hornblende, with minor amounts of microcline, epidote, and sphene. The foliation, which strikes N. 20° E. and dips 78° W., is defined by the orientation of individual biotite grains and by the orientation of strung-out felsic mineral and mafic mineral segregations. Small inclusions of dioritic material are also flattened in the plane of foliation. A mineral lineation in the plane of foliation trends N. 15° E. and plunges 60°.

In addition to the amphibolite xenoliths, the foliated tonalite contains small inclusions of banded gneiss. Although the contact between the banded gneiss and the foliated tonalite is not exposed, the available outcrop requires that the contact be parallel or subparallel to the banding and foliation of the gneiss and the foliation of the tonalite. Measurements indicate that the foliation in these two units is parallel; the foliation can be seen to change slightly in orientation over large exposures of either unit.

Aplitic to pegmatitic granitic veins which intrude the banded gneiss and foliated tonalite have been openly to tightly folded. The axial planes of these folds are parallel to the foliation in the surrounding unit.

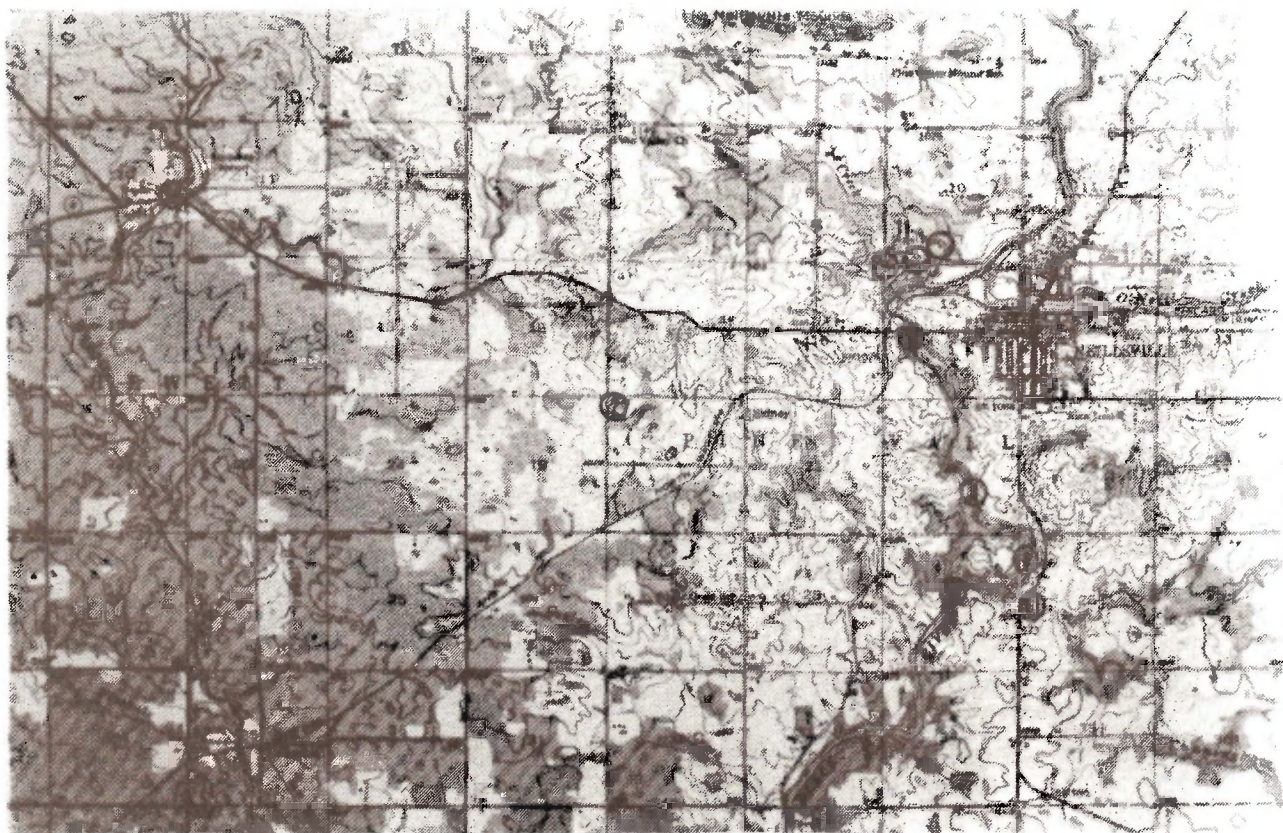
The banded gneiss at this locality may be early Proterozoic in age; support for this suggestion comes from a U-Pb (zircon) age of approximately 1850 m.y. from banded gneiss at Locality 10, only 2 miles to the south. In addition, structures in the banded gneiss appear to be the result of only one deformation, whereas gneisses of known Archean age, when sufficiently exposed, reveal structures indicative of polyphase deformation. Because exposure of the gneiss is poor, it cannot be definitively stated that it has been deformed only once; and further investigation, perhaps radiometric, is necessary before its age can be stated with certainty.

Foliated tonalites occurring throughout central Wisconsin have been radiometrically dated at between 1850 and 1830 m.y. (Van Schmus, 1980). The foliated tonalite at Greenwood is similar in composition, texture, and structural style to those dated units and is probably the same general age. If this is the case, deformation occurred during the Penokean Orogeny, as has been demonstrated along the Wisconsin River to the east (Maass and others, 1980).

STOP 2

TITLE: Neillsville Granite and Granodiorite

LOCATION: Quarry, NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 20, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). Approximately 1 mile south of U.S. Highway 10 on east side of Tower Road.



AUTHOR: R. S. Maass and W. R. Van Schmus (1980)

SUMMARY: The Neillsville Granite is a typical Penokean pluton, although geochronologic and structural data indicate that it is probably slightly older than most of the Penokean Granites in Wisconsin. At this location the granite shows pronounced lineation, but does not have a pronounced foliation. A cross-cutting dacite dike and overlying Mt. Simon sandstone are also exposed here.

DESCRIPTION: A recent quarrying operation has provided excellent exposure of pink Neillsville Granite, gray granodiorite, a dacite dike, and the Precambrian-Cambrian unconformity. The Neillsville Granite is exposed at the southern end of the quarry, both in place and as large fresh blocks in rubble piles. The blocks provide an opportunity to examine the structure in three dimensions and clearly show that the granite is lineated, but not foliated (Figure 5). Measurement of the lineation on three non-parallel surfaces, combined with stereographic techniques, reveals a trend of N. 25° E. and a plunge of 82°.

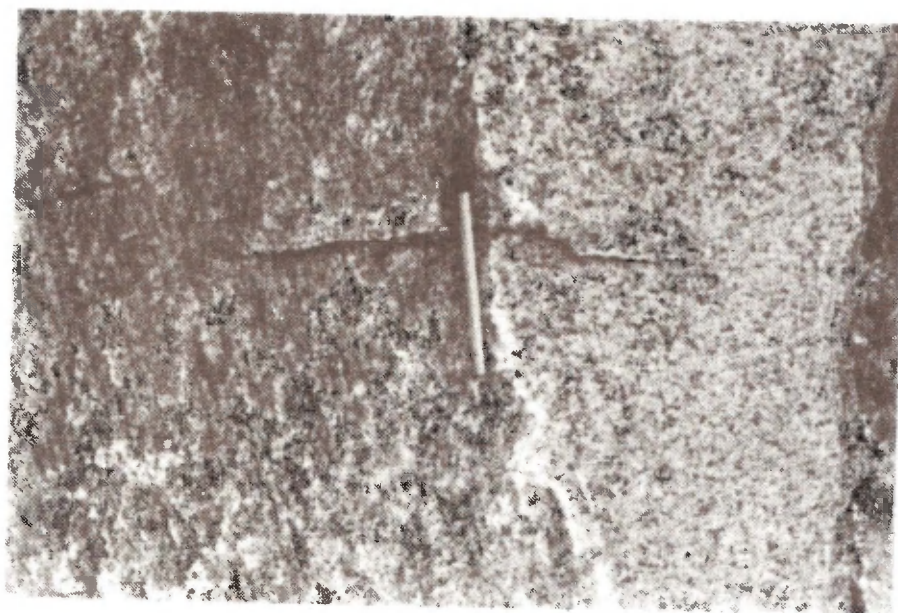


Figure 5. Two faces of a block of Neillsville Granite, approximately normal to each other, demonstrate the presence of lineation and the absence of foliation in this unit.

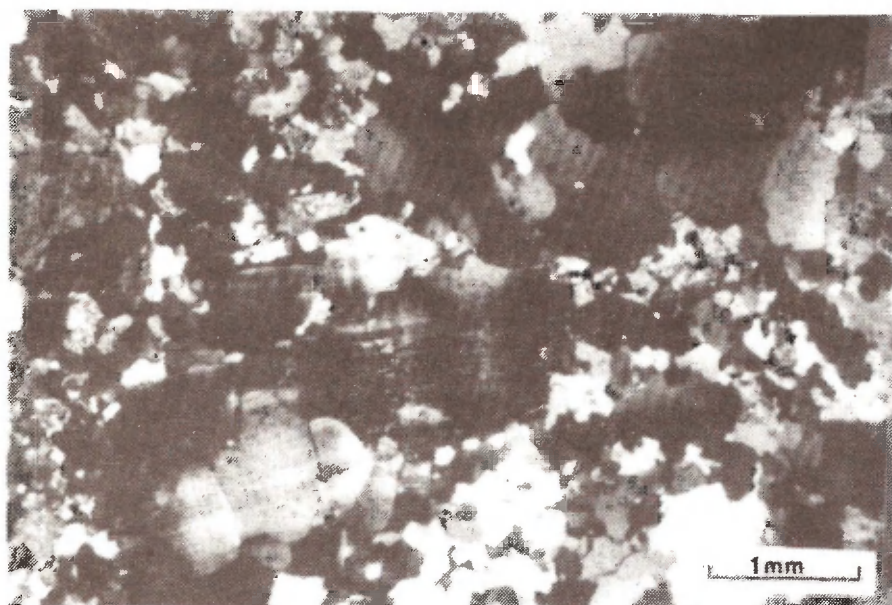


Figure 6. Photomicrograph of Neillsville Granite showing granoblastic texture. The section contains porphyroblastic microcline, large strained quartz grains, and fine-grained quartz, oligoclase, and microcline. The fine-grained quartz is nearly strain free.

The granite is composed of subequal amounts of quartz, microcline, and oligoclase (An 26-28); and approximately 2% biotite. Trace minerals include muscovite, epidote, chlorite, sphene, apatite, allanite, zircon, and opaque minerals. The grain size distribution is trimodal, consisting of 2 to 3 mm porphyroclastic microcline; 1 to 2 mm highly strained quartz; and 0.1 to 0.75 mm quartz, microcline, and oligoclase. The finer grained minerals exhibit gently curved grain boundaries (Figure 6). The lineation is defined by the orientation of individual biotite grains, aligned clusters of biotite, and trains of quartz grains. The absence of an observable foliation on the mesoscopic scale is supported by its absence on the microscopic scale.

The northern end of the quarry is a mixture of Neillsville Granite and a gray granodiorite which is texturally and structurally identical to the granite. Unclear contact relationships make it difficult to determine which unit is younger. Petrographic relationships are so similar that the two units may be comagmatic. The trimodal grain size distribution observed in the granite is also present in the granodiorite. The only difference is that the granodiorite contains twice as much biotite, the oligoclase is An 28-30, and microcline is less abundant.

Small patches of an oligoclase porphyry dacite dike are exposed along the floor and wall of the central portion of the quarry. An approximately N. 35° E. trend and steep dip can be determined from these scattered exposures. The dike contains a foliation which also trends N. 35° E., and dips steeply; a strong mineral lineation in the plane of foliation plunges steeply. Poor exposure prevents more exact structural measurements, but the mineral lineation in the dike is probably parallel to the mineral lineation in the granite and granodiorite.

The dike is composed of quartz, oligoclase (An 28-30), biotite and minor microcline. The texture is trimodal, consisting of 1 to 6 mm oligoclase porphyroclasts, 0.25 to 0.75 mm quartz in trains which may represent the remains of predeformational quartz phenocrysts, and a groundmass in which the grains are less than 0.1 mm. Microscopic deformation and recrystallization textures are nearly identical to those in the granite and granodiorite. The foliation in the dacite is presumed to have formed during the same deformation that left the granite and granodiorite unfoliated, suggesting that the mechanical properties of the rocks played a very significant role in determining the final structural expression of the event. The Neillsville Granite demonstrates that the structural expression of the event is also spatially variable. Two miles to the northeast (Locality 11) the granite crops out in a number of older quarries. Here the granite exhibits a moderately well developed foliation in addition to a mineral lineation.

Zircon has been separated from a sample of Neillsville granite collected at this quarry. The zircons are euhedral, light brown in color, and somewhat stubby (length:width is about 2:1). In transmitted light they show normal igneous growth zoning; older cores or younger overgrowths are absent. U-Pb analyses have been performed on two fractions so far, and the results (Introduction, Fig. 3) suggest that the Neillsville Granite is slightly older than most Penokean granitic plutons so far dated in Wisconsin. A more precise estimate of the age must await further analyses, but a preliminary estimate is 1875 ± 25 m.y.

STOP 3

TITLE: Gneiss at Humphrey Farm

LOCATION: SE¼, Sec. 22, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). Discontinuous outcrop for 0.5 mi. along the east bank of the Black River, approximately 0.3 mi. west of State Highways 73-95, behind the Thomas E. Humphrey farm (ask permission before crossing land).

See Stop 2 for map.

AUTHOR: R. S. Maass (1980)

SUMMARY: Three types of gneiss are present: tonalitic banded gneiss, mafic to ultramafic orthogneiss, and tonalitic "injection gneiss." The units have been subjected to polyphase deformation and interference folds are present. The rocks have not been dated, but the complex folding indicates Archean ages for the older units.

DESCRIPTION: This stretch of the Black River displays a diverse and complex group of gneisses plus some mildly deformed dikes crosscutting the gneisses. Three sets of gneiss are present; the oldest is a banded gneiss thought to be a paragneiss; the next youngest is an orthogneiss of mafic to ultramafic composition; the youngest is an "injection gneiss" formed when leucotonalite intruded the paragneiss and orthogneiss. The percentage of leucotonalite varies widely in the scattered exposures, from less than 5% up to 100%. A narrow gabbroic dike (now amphibolite) in the banded gneiss may be related to the orthogneiss. Both sets of gneiss have been intruded by diabase and porphyritic dacite dikes. All units have been metamorphosed at amphibolite facies.

Furthest upstream (to the north), the outcrop consists of thin to thickly layered banded gneiss of tonalitic composition containing quartz, oligoclase-andesine, biotite, and hornblende. The banding is due to alternating biotite (+ hornblende) rich layers with biotite poor layers. The earliest deformation discernible in the banded gneiss has produced isoclinal folds, forming an axial planar foliation. Although F_1 folds are rarely seen, highly attenuated boudinage structures from this event are abundant. Due to the lack of three dimensional exposure, it is not possible to measure either the fold axes or the elongation of the boudins. The foliation, which is parallel to the banding, has been openly to tightly folded during F_2 deformation; the axial planes of these folds are at a high angle to the foliation. F_2 fold axes are not consistently oriented, but their general trend is to the southwest with plunges of 50° to 85° .

The banded gneiss at this end of the exposure has been intruded by a 6 to 8 inch wide mafic dike which appears to have been originally a medium to coarse-grained gabbro, but is now a fine-grained amphibolite. The dike has been openly folded. The gabbroic dike is truncated by a 12 to 15 foot wide unfolded dike which was formerly a diabase, but is

now also a fine grained amphibolite. Despite the amphibolite facies metamorphism, chilled margins can still be recognized. The dike is unfoliated, but a moderately well developed mineral lineation exists, trending S. 50° W. and plunging 60°.

The best exposure of the injection gneiss occurs a short distance downstream. The medium-grained leuco-tonalite phase which has intruded the banded gneiss and mafic and ultramafic orthogneiss is composed of nearly equal amounts of quartz and oligoclase (An 27-29), and minor (2-3%) biotite. The oligoclase is 1 to 5 mm, and the quartz is 0.1 to 2 mm, but the quartz appears granulated; it may have once been the same size as the oligoclase. The orthogneiss, which is now amphibolite, is generally gabbroic in composition, but the leuco-tonalite also contains inclusions of ultramafic gneiss which consists of as much as 99% hornblende. The foliation in the injection gneiss is chaotic; blocks of the ortho and paragneisses (with their earlier foliation) have been rotated into random orientations, and the foliation in the leuco-tonalite swirls in almost all directions. The foliation in the leuco-tonalite appears to be a primary flow foliation.

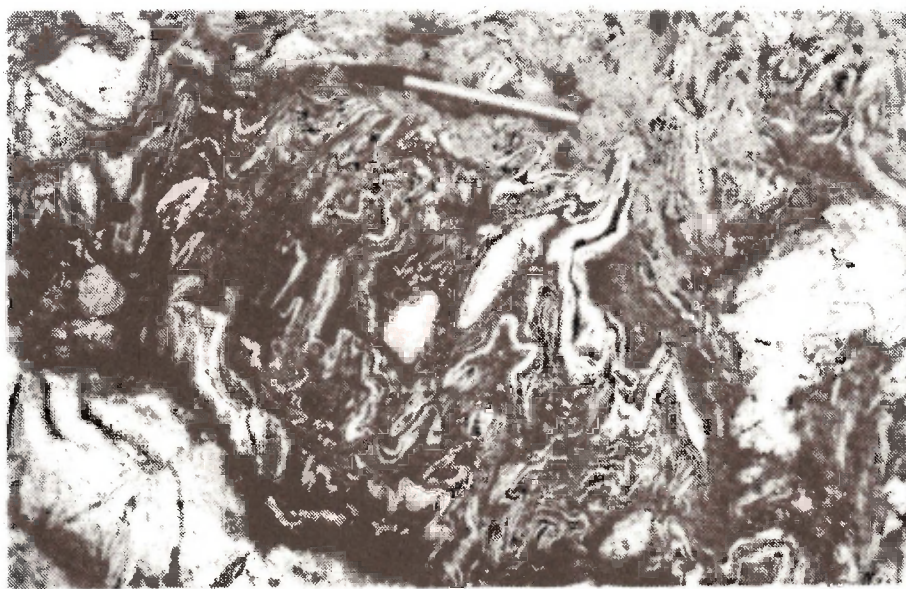


Figure 7. Highly contorted banded gneiss displaying interference patterns due to the folding of the axes of isoclinal F_1 folds.

STOP 4

TITLE: Neillsville Augen Gneiss

LOCATION: Black River at Miller Farm. NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 26, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). Approximately 0.1 mi. west of State Highway 73-95, on the east bank of the Black River. Follow a small ravine located 0.1 mi. south of the Miller farmhouse down to the Black River, then turn upstream; outcrop is semi-continuous for 0.3 mi. upstream.

See Stop 2 for map.

AUTHORS: R. S. Maass and W. R. Van Schmus (1980).

SUMMARY: The Neillsville Augen Gneiss is a spectacular, strongly foliated rock with microcline porphyroclasts up to 5 cm in length. The rock is syenitic in composition and is interpreted to be derived from an Archean pluton that was intruded into the older gneisses of the region. It is 2535 ± 10 m.y. old and, thus, the youngest Archean rocks identified so far in central Wisconsin.

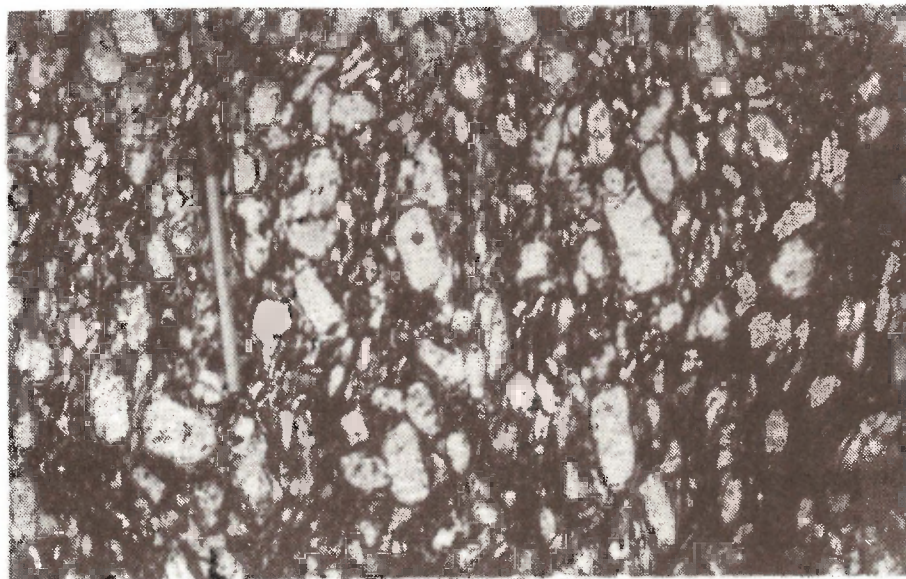


Figure 8. Neillsville Augen Gneiss. Both highly deformed and nearly undeformed microcline porphyroclasts occur in a fine-grained matrix of quartz, biotite, and feldspar.

DESCRIPTION: The spectacular syenitic Neillsville Augen Gneiss, containing microcline porphyroclasts up to 5 cm in length, crops out along the Black River behind the Miller farm. Many of the original microcline phenocrysts are highly deformed, but some have retained their initial euhedral shape (Figure 8). However, the majority of those that still appear euhedral are internally fractured. The porphyroclasts comprise as much as 50% of the gneiss. The matrix, in which the minerals are generally less than 0.2 mm in diameter, consists of approximately equal amounts of microcline, orthoclase, quartz, biotite, and untwinned plagioclase.

In addition to the previously mentioned minerals, the gneiss contains minor quantities of epidote and sphene and trace quantities of muscovite, chlorite, apatite, allanite, zircon, and opaque minerals. Quartz grains that are coarser than the rest of the matrix minerals are frequently found in "trains" which may represent the remains of formerly much larger quartz grains. Mortar texture around the microcline porphyroclasts is still evident, but recrystallization has healed the fragments, and most matrix minerals have gently curved grain boundaries. Recrystallization during deformation produced myrmekite around the margins of some of the porphyroclasts.

The predominant strike of the foliation in the gneiss is between N. 75° E. and N. 85° E., and the average dip is 87° to the south. A strong mineral lineation in the plane of the foliation trends S. 80° W. and plunges 55° on the average, but extremes in the plunge of 42° and 68° have been recorded. Three small zones of intense shearing cut across the foliation, but they are only 8 inches, 4 inches, and 1 inch in width. They strike between N. 55° E. and N. 65° E. and dip vertically. All three zones have been recrystallized.

Zircons have been extracted from an outcrop of the Neillsville Augen Gneiss on the west side of Highway 73, just north of Cunningham Creek. The zircons are brown, euhedral and show igneous zoning; there is no evidence of relict cores or metamorphic overgrowths. U-Pb analyses on three fractions of zircon yield an age of 2535 ± 10 m.y.; this age is interpreted as the age of crystallization of the protolith of the gneiss and is the youngest Archean age measured so far in Wisconsin. The highly deformed state of this rock clearly shows that the Archean terrane was subjected to major tectonism in late or post-Archean time (e.g., < 2535 m.y. ago). It is not known for certain where in the interval 2500-1850 m.y. ago that this deformation occurred (Penokean or pre-Penokean?).

Upstream from the Neillsville Augen Gneiss, a series of thin to thickly layered gneisses of intermediate to mafic composition is exposed. Some of the units are porphyroclastic, but the porphyroclasts are smaller than those in the augen gneiss; they are far less abundant, and they are generally plagioclase rather than microcline. Some of the units, both porphyroclast bearing and porphyroclast free, contain abundant metamorphic hornblende. The layering of the gneiss at this end of the outcrop makes it

possible to study the style of deformation in more detail than in the unlayered augen gneiss. Numerous small scale and large scale tight folds, and a few isoclinal folds, can be observed here. Their axes trend S. 80° W. and plunge between 50° and 55°, which is parallel to the trend and plunge of the mineral lineation in the augen gneiss. The axial planes are parallel to the dominant direction of layering, which is parallel to the foliation in the augen gneiss. These structures indicate that all units were affected by the same folding event.

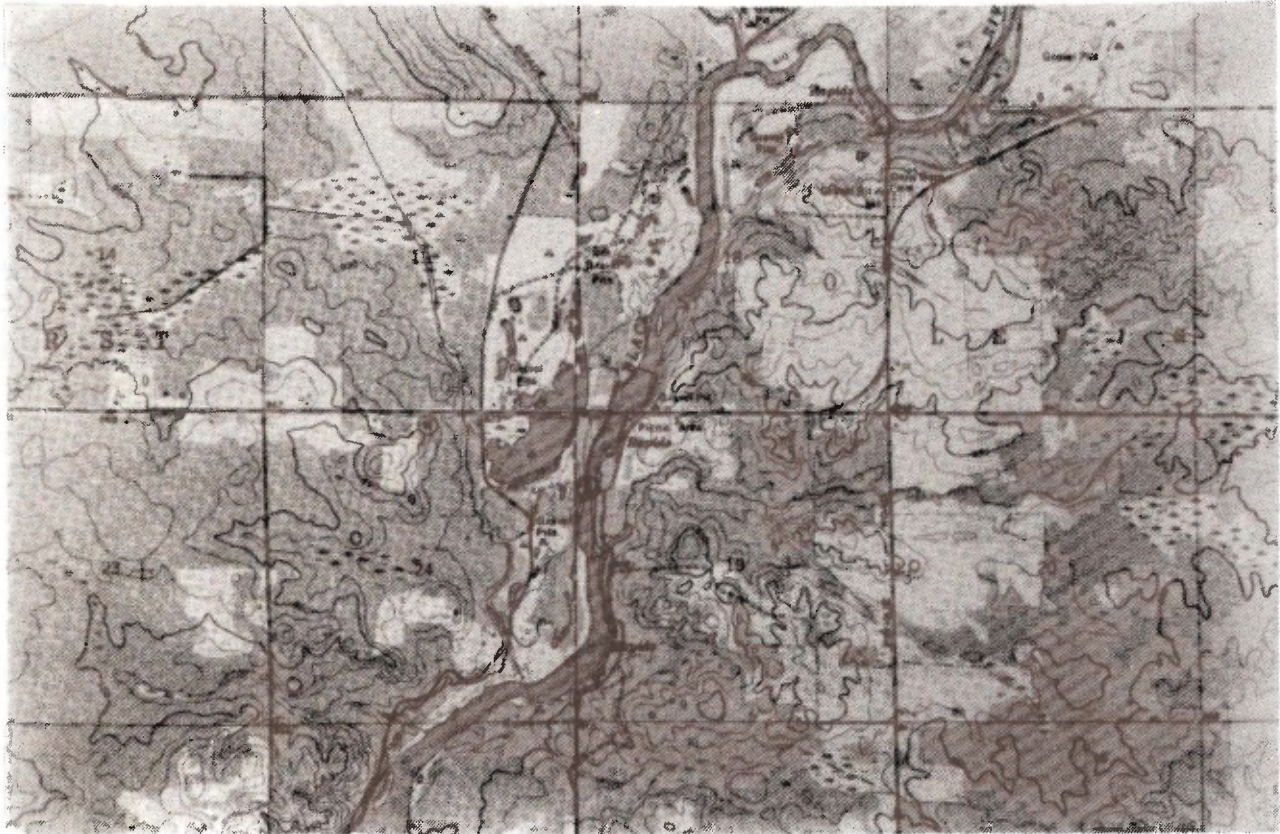
Downstream from the Neillsville Augen Gneiss is a biotite schist (see Locality 14 for description), and then more interlayered porphyroclast bearing and porphyroclast free units (see Locality 15) similar in appearance to those upstream. These upstream and downstream units probably represent sedimentary and volcanic rocks into which the augen gneiss protolith was intruded.

Near the middle of the exposure, the Neillsville Augen Gneiss is intruded by a sizeable body of coarse-grained granitic augen gneiss. The augen are once again microcline, but they are only half as large as those in the older augen gneiss, and the younger unit contains much less biotite. The mineral lineations in both units are equally well developed and parallel to each other; however, the younger unit is only weakly foliated or even unfoliated. At present it is not clear whether the younger unit was emplaced after the foliation-forming state of deformation, and prior to the lineation-forming stage; or whether it was emplaced prior to the entire deformation and simply responded differently due to mechanical dissimilarities. The granitic augen gneiss is unlike any known early Proterozoic rocks and is petrographically somewhat similar to the Neillsville Augen Gneiss; therefore an Archean age seems most likely. If this is the case, the structural difference is attributed to the mechanical properties of the rock, since structures observed are thought to have formed during the Penokean Orogeny (see final discussion).

STOP 5

TITLE: Lake Arbutus Granite

LOCATION: NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 19, T.23N., R.2W. (Hatfield 7 $\frac{1}{2}$ -minute topographic quadrangle, Clark County). Abandoned bridge abutment 0.25 mi. south of State Highway 95 bridge over Black River, west bank of Black River. 2 mi. north of Lake Arbutus.



AUTHORS: R. S. Maass and W. R. Van Schmus (1980)

SUMMARY: The Lake Arbutus Granite is a typical undeformed, late-tectonic Penokean granite that is intrusive into the Archean gneiss complex.

DESCRIPTION: The Lake Arbutus Granite is a medium-grained reddish granite that contains quartz, perthitic alkali feldspar, and andesine (An 31-32) in the approximate ratios 1:1.5:1.

The feldspars, which range from 0.5 to 3 mm, have ragged boundaries and are slightly fractured internally (Figure 9). A few quartz grains which have survived deformation relatively intact are as large as 2 mm, but most of the quartz has been granulated to less than 0.5 mm. Quartz

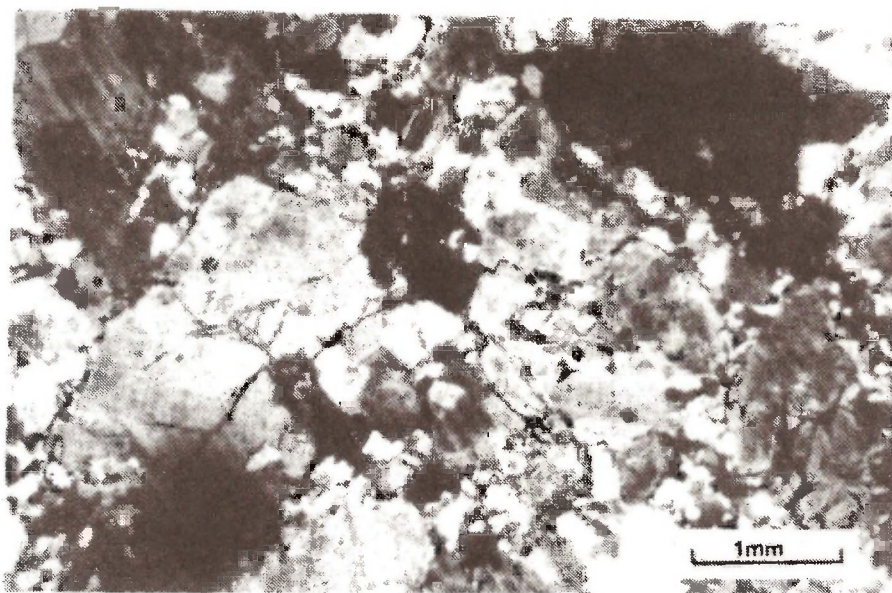


Figure 9. Photomicrograph of Lake Arbutus Granite showing granulated and recrystallized quartz and moderately fractured feldspar. The feldspar is cloudy due to sericitization.

grain boundaries are generally gently curved, indicating moderate post deformational recrystallization. The granite is biotite free, but contains approximately 1% chlorite which probably represents retrograded biotite. Alteration of opaque minerals, and sericitization of the feldspar may be weathering phenomena.

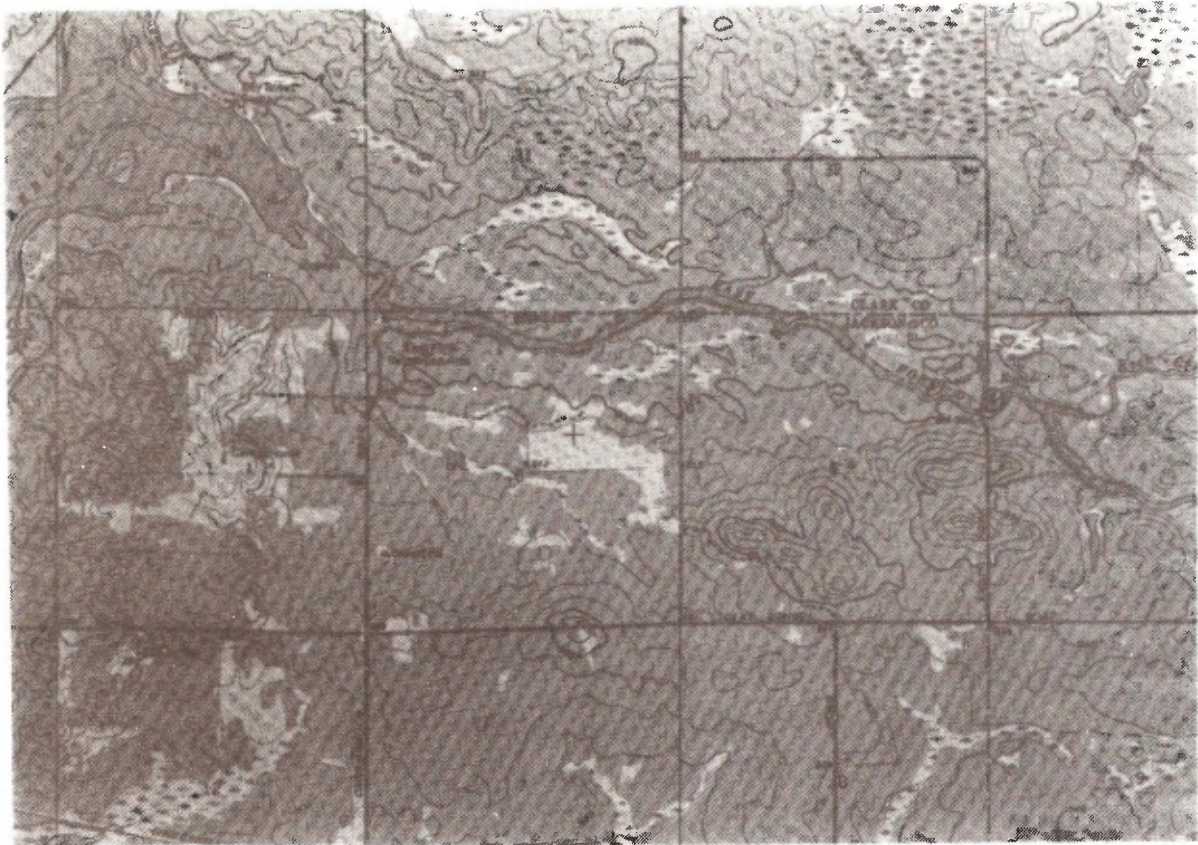
Although microscopic textures indicate that the granite was deformed and recrystallized, no foliation or lineation can be detected on either the microscopic or mesoscopic scale. The granite appears to have been emplaced during the late stages of Penokean deformation and metamorphism.

Zircons were separated from a sample of the granite collected at the base of the old bridge abutment on the opposite (east) side of the river. The zircons are euhedral, brown in color, and exhibit igneous zoning. U-Pb analysis of one fraction (Introduction, Fig. 3) indicates that the Lake Arbutus Granite belongs to the main population of Penokean granite plutons and is about 1840 ± 20 m.y. old. A more precise estimate of the age will have to await additional analyses.

STOP 6

TITLE: East Fork Gneiss

LOCATION: NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 4, T.22N., R.2W. (Hatfield 7.5-minute topographic quadrangle, Jackson County). Outcrop is along north shore of the East Fork of the Black River, east of the bridge on East Fork Road.



AUTHOR: R. S. Maass (1980)

SUMMARY: The gneiss exposed here is different from most of the other gneisses in the region in that it is amphibole rich rather than biotite rich. Both F_1 and F_2 folding are present, and the gneiss is cut by post-deformational dikes of granite and of diabase.

DESCRIPTION: In contrast to the other banded gneisses in the region, the East Fork Gneiss is amphibole rich rather than biotite rich. Some of the melanocratic layers contain as much as 70% hornblende. In addition to hornblende, the gneiss contains quartz and andesine (An 33-35), and minor amounts of microcline, chlorite, epidote, sphene, and opaque minerals.

The middle section of the outcrop is banded gneiss exhibiting large scale tight folds which are attributed to F_2 deformation. The gneiss has been intruded by a diabase dike (which is now amphibolite) and by a porphyritic dacite dike which is very weakly foliated, but strongly lineated. The foliation in the dacite strikes N. 25° E. and dips vertically, and the mineral lineation trends S. 25° W. and plunges 86° . The 0.5 to 3 mm phenocrysts in the dacite consist of euhedral microcline and andesine and slightly fractured quartz. Grain size in the recrystallized matrix is less than 0.1 mm.

Near the downstream end of the exposure the banded gneiss becomes more felsic than usual. Biotite is less abundant, and hornblende rarely accompanies the biotite. There are small lenses and thin layers of quartzite, which are not present elsewhere in the gneiss. The banding becomes extremely contorted in this vicinity. F_2 deformation is responsible for the random orientation of the axial planes of folds, but the folding of axes of isoclinal F_1 folds has resulted in interference patterns (Figure 7) and may be interpreted in a number of ways. The four most likely explanations are: 1) F_1 folding was inhomogeneous, resulting in curvilinear axes; 2) F_2 folding was inhomogeneous; 3) some intermediate deformation folded the axes of the F_1 folds, prior to F_2 axes (remember that F_2 axes upstream are very inconsistent in orientation). At this locality the second explanation is preferred since interference patterns are only observed where F_2 deformation has become unusually convoluted, and inhomogeneous F_2 deformation is also the simplest explanation for the inconsistent orientation of F_2 fold axes upstream. Why folding is so complex only at one small portion of the outcrop is open to speculation, but one possibility is that we are in the core of a large unrecognized tight fold. In the Hatfield Gneiss (Stop 7) exposure is complete enough to see an example of extreme contortion in the core of a large tight fold.

Green subhedral to euhedral hornblende ranges from 0.5 mm to 2 mm; the quartz and feldspar are generally smaller, from 0.25 to 1.5 mm. Chlorite is present in some samples in amounts up to 5%. It occurs as layered parallel aggregates, and as an alteration product of hornblende. The epidote content of the gneiss varies appreciably, from trace quantities, to as much as 5%. In certain specimens the plagioclase is so thoroughly saussuritized and sericitized that it is almost unrecognizable in thin section. The orientation of quartz and chlorite grains defines the foliation, while quartz, chlorite, and hornblende elongation defines the lineation. Quartz has been crystallographically oriented during recrystallization to the extent that nearly all quartz grains in some thin sections go to extinction at approximately the same time.

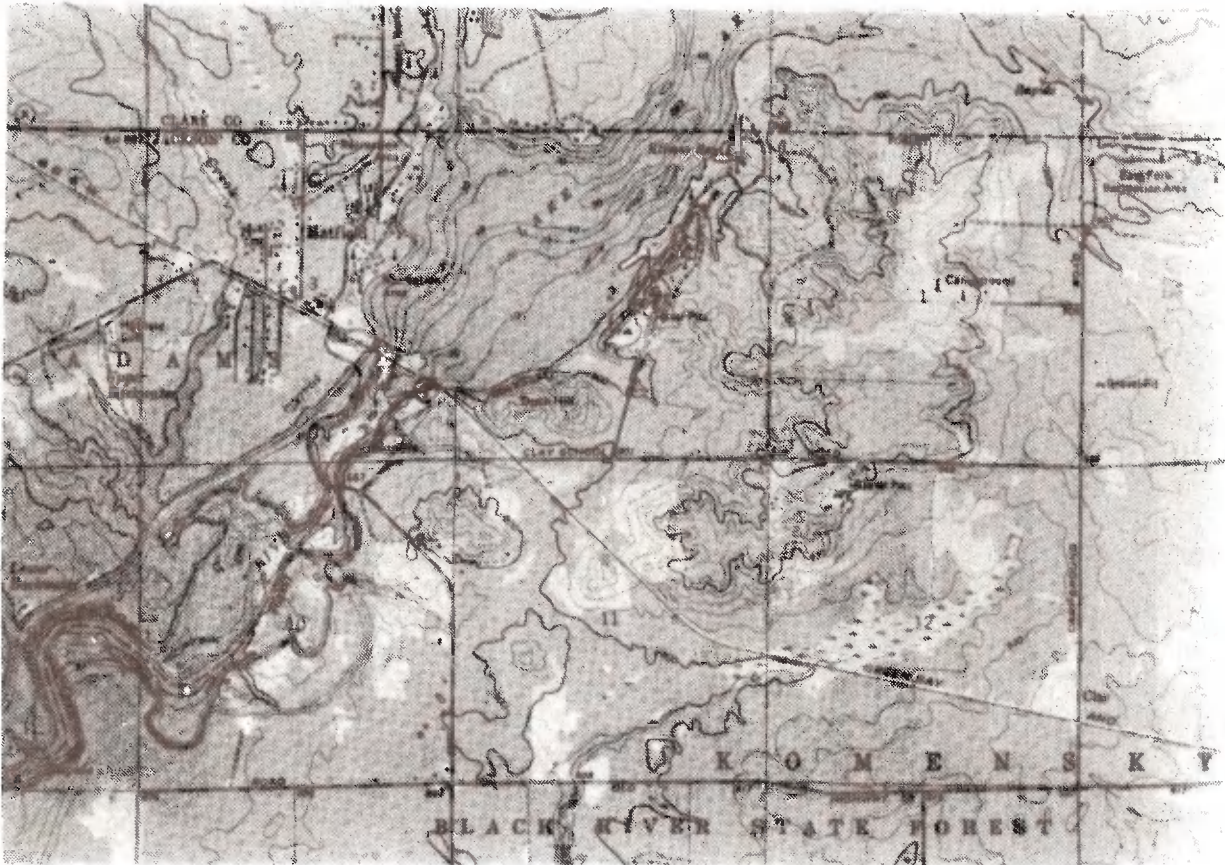
A narrow granite dike composed of subequal amounts of quartz, plagioclase, and alkali feldspar has intruded the banded gneiss. The dike also contains approximately 1% chlorite and trace amounts of epidote. The granite differs from both the Lake Arbutus Granite (Stop 5) and the Black River Falls Granite (Stop 8) in that it appears less deformed, but this is only apparent in thin section.

A medium-grained diabase containing pyroxene, plagioclase laths, sphene, and opaque minerals has intruded the banded gneiss. Based on scattered exposure, the diabase appears to be a 30 to 40 foot wide dike with chilled margins. The dike is unfoliated, unlineated, and shows no signs of deformation in thin section. The original minerals have been extensively altered to chlorite, epidote, and sericite. The diabase may be related to the gabbro at Stop 7, since both are structurally and mineralogically similar.

Isoclinal F_1 folding in the gneiss produced an axial planar foliation which is parallel to the banding, except in fold hinges where it transects banding. The foliation has been subsequently tightly folded during F_2 deformation. F_2 fold axes are nearly horizontal, trending both N. 70° E. and S. 70° W. The maximum plunge of the axes is 25° ; the mean plunge is 0° . Synformed structures with an average axial plane striking N. 70° E. and dipping 70° N. predominate at this locality.

TITLE: Hatfield Gneiss, Lake Arbutus Dam

LOCATION: SE $\frac{1}{4}$, Sec. 3, T.22N., R.3W. (Hatfield 7 $\frac{1}{2}$ -minute topographic quadrangle, Jackson County). Outcrop along the Black River below the east half of Arbutus Dam. Approach is on 0.2 mi. long gravel road that intersects Clay School Road 0.15 mi. west of Green Bay and Western RR tracks. Additional outcrop occurs for 0.7 mi. downstream from dam.



AUTHORS: W. R. Van Schmus and R. S. Maass (1980)

SUMMARY: The main outcrop area immediately below the dam is one of the largest, if not the largest, outcrops of Archean rocks in Wisconsin. The principal unit is the Hatfield Gneiss, an interlayered sequence of quartzofeldspathic gneisses and minor amphibolite. The rocks are interpreted as a metavolcanic sequence that was formed 2815 m.y. ago and deformed at least twice, with the latest deformation and metamorphism occurring during the Penokean Orogeny, 1850 m.y. ago. Post-deformational cross-cutting mafic dikes are also present at this locality.

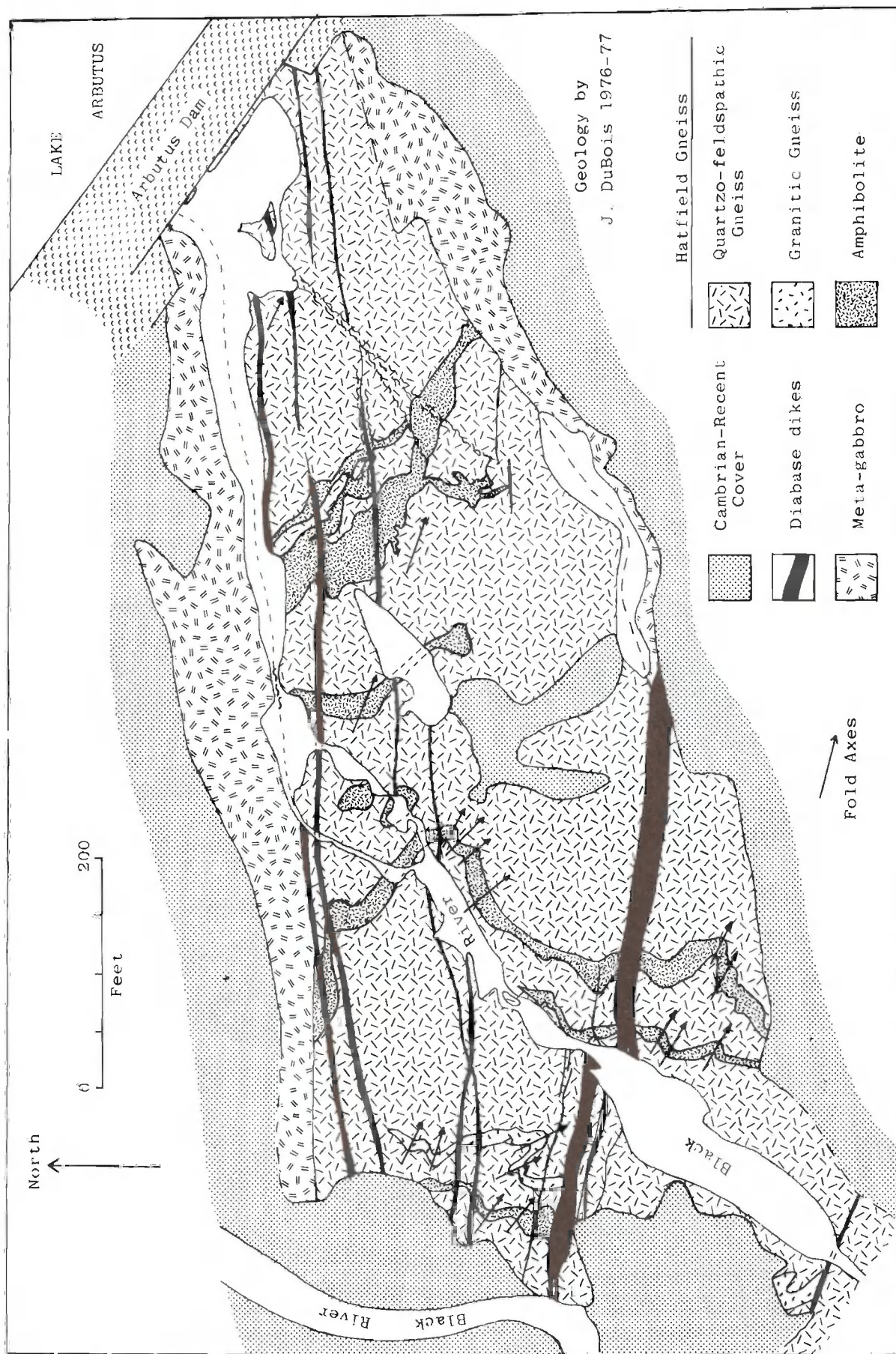


Figure 10. Geologic map of Archean bedrock exposed south of Arbutus Dam. (Stop 7)

The principal unit exposed (Figure 10) is the Hatfield Gneiss, an interlayered sequence of granitic to tonalitic gneiss with concordant layers of amphibolite. Over much of the outcrop the layers are 0.1 to 3 cm thick, pink to gray, quartzo-feldspathic gneiss. In some parts the layers are thicker, approaching several meters of massive gneiss. Folding and foliation are best displayed in the thinner-banded portions. The quartzo-feldspathic gneiss has a granoblastic texture and consists of subequal amounts of quartz, plagioclase, and microcline. Mafic minerals represent less than 10% in most instances. Normative abundances based on bulk chemical analyses show that the quartz abundance is approximately constant and that plagioclase/orthoclase ratios vary from about 1:1 (adamellite) to primarily plagioclase (tonalite).

The amphibolite is interlayered with the quartzo-feldspathic gneiss and consists primarily of hornblende with about 20% epidote. The amphibolite has been deformed along with the rest of the gneiss and is interpreted as originally concordant. The entire assemblage is interpreted as having formed from an interlayered sequence of volcanic flows, pyroclastics, or sills (DuBois and Van Schmus, 1978). The major metamorphism currently recorded by the rocks is amphibolite facies. Relict pyroxene has been found in some of the quartzo-feldspathic gneiss samples, suggesting either primary volcanic pyroxene or an earlier, higher grade period of metamorphism.

The Hatfield Gneiss has been subjected to an isoclinal folding event (F_1) which produced an axial planar foliation parallel to the layering, except in fold hinges where the foliation transects the layering. The foliation was then tightly to openly folded during F_2 deformation; the axial planes of these folds are at high angles to the foliation. F_1 folds are rarely visible, but F_2 folds are conspicuous wherever the banding is readily apparent.

Lineations (fold axes, crenulations, mineral lineations) and foliation were measured in the gneiss along a 0.4 mi. long stretch of the river. Poles to foliation define a β axis which is essentially identical to the orientation of the main grouping of the linear structural elements (Figure 11). Fold axes, when plotted separately, fall into the two groups in the southeast quadrant of the stereonet, with the vast majority plotting in the main group.

A group of F_1 fold axes in the core of a large tight F_2 fold were plotted separately from the rest of the linear structural elements. The folding in this vicinity is highly complex, resulting in numerous and diverse interference patterns from the folding of F_1 axes. Figure 12 illustrates one of the simple interference patterns. The axes of these F_1 folds plot in all four quadrants of the stereonet with plunges ranging from horizontal to vertical. Girdles which would indicate a later simple folding pattern of the F_1 axes do not exist, and the interference patterns are therefore believed to be the result of inhomogeneous deformation in the core of the F_2 fold.

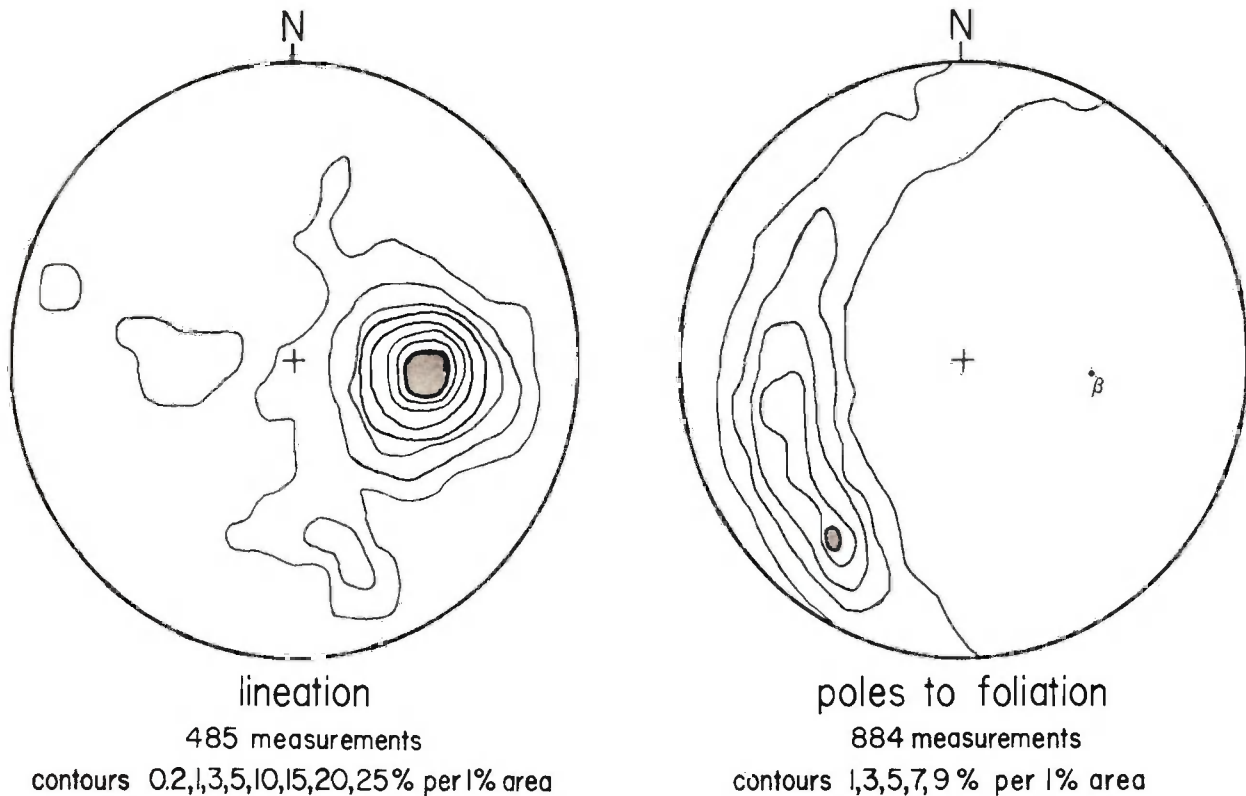


Figure 11. Lower hemisphere stereographic projections of structures in the Hatfield Gneiss. (left) Lineations defined by fold axes, crenulations, and mineral elongations. The mean orientation of the lineations is S. 84° E. with a plunge of 51° ESE. (right) Plot of poles to foliation yields a mean for β trending S. 84° E. with a plunge of 52° ESE, virtually identical to the mean orientation for the lineations.

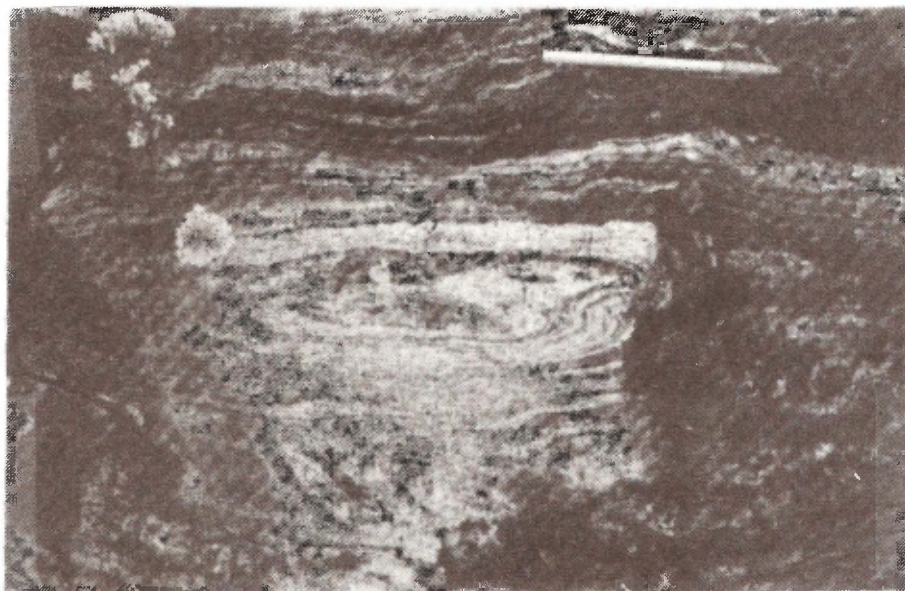


Figure 12. Photo of the Hatfield Gneiss showing interference pattern due to folding of the axis of an isoclinal F_1 fold. The interference pattern occurs in the core of a large, tight F_2 fold.

Although F_2 deformation is inhomogeneous in this relatively small area of the outcrop; the outcrop as a whole exhibits homogeneous deformation, as demonstrated by the tight distribution of 94.5% of the linear structural elements. F_1 fold axes are never exposed in 3 dimensions (except in the anomalous area just discussed), thus their trend and plunge are unknown. The age of F_1 folding is unclear, but F_2 folding is probably Penokean (see final discussion).

Zircon has been separated from a tonalitic layer of the gneiss on the west bank of the Black River, about 0.6 mi downstream from the dam. The zircons are brown, euhedral crystals with normal igneous zoning and no signs of significant overgrowths or relict cores. U-Pb analyses on several fractions show that this unit is essentially the same age (2815 $\pm$ 20 m.y.) as other Archean gneisses in central Wisconsin (Introduction, Fig. 2). This age is interpreted as the time of crystallization (volcanism) of the protolith of the Hatfield Gneiss. Rb-Sr analyses from several samples collected in the area of Stop 7 and further downstream do not plot coherently on an isochron diagram, indicating partial resetting during subsequent metamorphism. However, these are no indications of crustal history exceeding 2.8 b.y.

STOP 8

TITLE: Black River Falls Granite

LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 15, T.21N., R.4W. (Black River Falls 15-minute topographic quadrangle, Jackson County). Outcrop occurs along river downstream from dam and north of State Highway 54.



AUTHORS: R. S. Maass and W. R. Van Schmus (1980)

SUMMARY: The Black River Falls Granite is a typical, largely undeformed late-tectonic Penokean granite that is intrusive into the Archean gneiss complex.

DESCRIPTION: The Black River Falls Granite crops out below a power generating dam in the heart of Black River Falls. The pink, medium-grained biotite granite consists of subequal amounts of quartz, alkali feldspar, and normally zoned andesine-oligoclase (An 25-33). Biotite comprises approximately 5% of the unit, and retrograde chlorite derived from biotite constitutes another 1%. Trace minerals include sphene, allanite, and epidote.

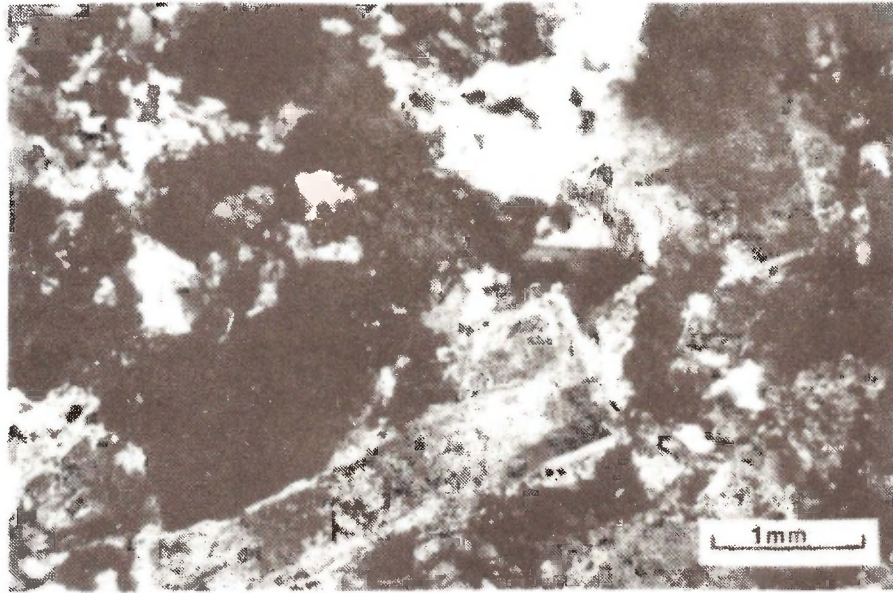


Figure 13. Photomicrograph of Black River Falls Granite. Nearly euhedral, zoned andesine-oligoclase is surrounded by fractured feldspars and granulated and recrystallized quartz. A biotite grain is visible in the center of the figure.

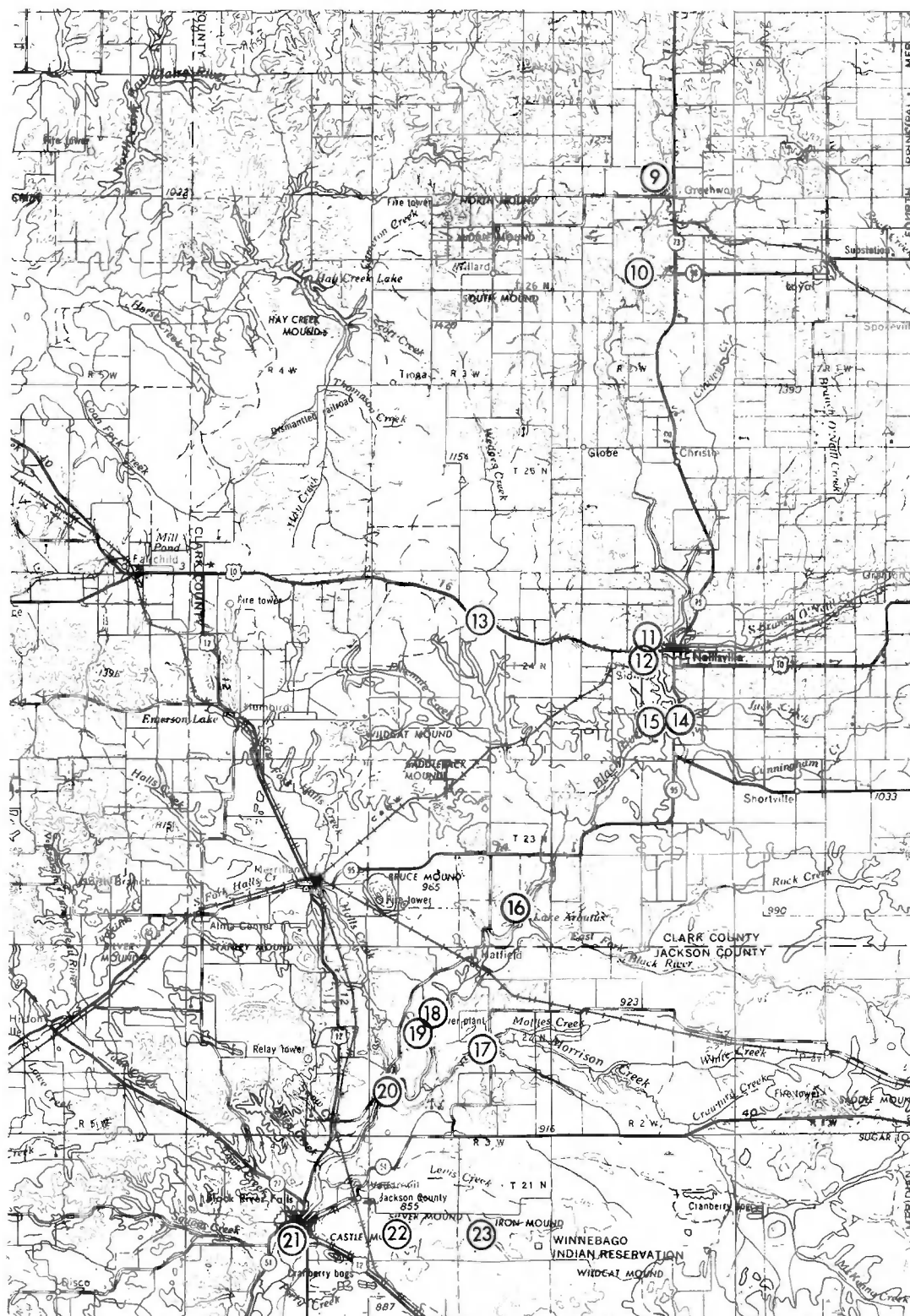
The feldspars, which often exhibit nearly euhedral outlines (Figure 13) range from 1 to 4 mm. The alkali feldspars consist of both microcline and perthite, with microcline dominating. Granulated and recrystallized quartz grains, from 0.1 to 1 mm, have been derived from quartz grains which were originally as large as 2 mm. Anhedral to subhedral biotite is often partially or completely replaced in chlorite. Selective sericitization of the feldspars has resulted in extensively altered plagioclase, moderately altered perthite, and nearly unaltered microcline.

On both the microscopic and mesoscopic scales, the Black River Falls Granite appears unfoliated and unlineated, despite microscopic textures which indicate that it has been deformed and recrystallized. As with the Lake Arbutus Granite (Stop 5), this unit was probably emplaced during the late stages of Penokean deformation.

U-Pb analyses on two zircon fractions (Van Schmus, 1980) indicate that the Black River Falls Granite is also part of the main population of Penokean granitic plutons and, like the Lake Arbutus Granite, is about 1840 ± 20 m.y. old.

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SUPPLEMENTAL LOCALITIES

SUPPLEMENTAL LOCALITIES

LOCALITY 9: Foliated tonalite, Greenwood Park

LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 34, T.27N., R.2W. (Owen 15-minute topographic quadrangle, Clark County). See Stop 1 for locality map. Exposure is on the west bank of the Black River, which requires a walk across a farmer's field or wading the Black River from Greenwood Park.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The foliated tonalite at Greenwood Park is nearly identical to the foliated tonalite at Stop 1, 1.2 miles to the south. The major difference is that the foliation, which is slightly better developed here, has been open to tightly folded. A fold axis trending S. 70° W. and plunging 75° has been determined for this locality by plotting poles to foliation on a stereonet. Mineral lineation in the foliated tonalite could not be accurately measured due to lack of proper exposure, but it is roughly parallel to the statistically determined fold axis. Granitic aplites similar to those at Stop 1 have intruded the foliated tonalite. Small faults with movement on the order of a few inches strike between N. 60° E. and N. 70° E. and dip steeply.

LOCALITY 10: Granitic Gneiss south of Greenwood

LOCATION: SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 15, T.26N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). See Stop 1 for locality map. Rock is exposed in bottom of old sand and gravel quarry. Turn west on gravel road at junction of State Highway 98 with State Highway 73. Road ends after 1.0 mi.; turn north for 0.1 mile to quarry.

AUTHOR: W.R. Van Schmus (1980)

DESCRIPTION: The exposed bedrock consists of granitic gneiss with lenses of amphibolite; a tonalite dike cuts the gneissic rocks. The granitic gneiss consists of fresh microcline, plagioclase, and quartz; the amphibolite is mostly fresh hornblende with quartz and plagioclase; the tonalite consists of quartz, plagioclase, minor microcline, and biotite. U-Pb analysis of one zircon fraction from the granitic gneiss has yielded a Penokean age (Introduction, Fig. 3), suggesting that the rocks at this locality are not part of the Archean terrane to the south.

LOCALITY 11: Neillsville Granite, Neillsville

LOCATION: S. half, SW $\frac{1}{4}$, Sec. 10, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). Several granite quarries exist in this area; see Stop 2 for detailed map.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The Neillsville Granite is exposed in a number of old quarries to the northwest of Neillsville. The granite in this vicinity differs from that at Stop 2 in that it is foliated, whereas the granite at Stop 2 is not. In all other respects the granites are identical, and there is no reason to believe that they are not the same unit. Exposures here are too badly weathered to accurately measure the foliation, but best estimates are that it strikes N 45° W (+ 10°) and dips 30° (+10°) to the southwest.

LOCALITY 12: Sunburst Village; gneiss, granite, sandstone

LOCATION: N. edge SW $\frac{1}{4}$ and S. edge NW $\frac{1}{4}$, Sec. 15, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). See Stop 2 for detailed location map. To get to the outcrop, go one block south of U.S. Hwy. 10 in Neillsville to Sunburst Village School. The outcrop is both north and south of the U.S. Hwy. 10 bridge over the Black River, on the east bank.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The outcrop consists of massive quartzofeldspathic gneiss, banded gneiss of tonalitic composition, mafic gneiss, and an aplitic granitic dike. The massive quartzofeldspathic gneiss and banded gneiss appear very similar to the Hatfield Gneiss (Stop 7). Isoclinal F_1 folds and tight F_2 folds occur throughout the gneiss. F_1 fold axes cannot be measured, but F_2 axes can; they trend to the northwest and plunge almost vertically.

The mafic gneiss occurs as large blocks and thick concordant (?) layers in the surrounding, more felsic, gneiss. Although the mafic layers have been metamorphosed to amphibolite facies, they do not appear as highly deformed or as thoroughly recrystallized as the rest of the gneiss. One possibility is that they are remnants of sills, but they have not been studied in enough detail to warrant any firm conclusions.

A fine-grained biotite-poor granite dike has been intruded into the banded gneiss. A mineral lineation in the dike trends S. 45° W. and plunges approximately 80°, which is close enough to the orientation of the F_2 fold axes to imply a connection between the F_2 folding event and the formation of the mineral lineation in the granite.

The Cambrian Mt. Simon Formation is exposed on the south side of U.S. Hwy. 10, just to the east of the Black River.

LOCALITY 13: Gneiss and granite at Snyder Dam

LOCATION: NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 10, T.24N., R.3W. (Neillsville 15-minute topographic quadrangle, Clark County). See Stop 2 for locality map. Outcrop is on the north side of U.S. Hwy. 10, along Wedges Creek, just below Snyder Dam.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The gneiss below Snyder Dam is unlike any other gneiss observed up to this point in the Black River region. It is wispy rather than banded, and it is highly micaceous and quartz rich. The average quartz content is over 50%, with biotite and muscovite being the other major constituents. Microcline content is generally below 10%. The gneiss contains a well developed foliation and lineation, but due to its unlayered nature it is not possible to detect isoclinal F_1 folds, even though the unit was probably subjected to this deformation. Tight F_2 folding has folded the foliation, which is presumed to have formed during F_1 folding.

A pink biotite-poor granite which has intruded the gneiss is unfoliated, unlineated, and as best can be determined in thin section, undeformed. The age of the granite is unknown; it may be just slightly younger than the 1850 m.y. old granites, or it may be related to the 1765 m.y. old granites found throughout the state.

The Cambrian Mt. Simon Formation overlies the gneiss and the granite along the west bank of Wedges Creek.

LOCALITY 14: Schist and gneiss, Cunningham Creek

LOCATION: NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 26, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). See Stop 2 for detailed location map. Outcrop is east of State Hwy. 73-95, on the north bank of Cunningham Creek.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: Biotite schist, quartzofeldspathic gneiss, and augen gneiss are exposed a short distance upstream from the Hwy. 73-95 bridge over Cunningham Creek. The biotite schist is composed primarily of quartz and biotite, with subordinate feldspar. Quartzofeldspathic bands and augen bearing bands are interlayered with the biotite schist. All of these units have been metamorphosed to amphibolite facies and display granoblastic textures. Augen gneisses similar to those described at Stop 4 also occur here. The biotite schist and interlayered gneisses have been isoclinally folded during F_1 deformation, and tightly folded during F_2 deformation. F_2 fold axes plunge steeply in all directions, but the dominant trend is S. 56° W. with a plunge of 80°.

LOCALITY 15: Schist and gneiss, Black River south of Cunningham Creek

LOCATION: Center Sec. 27, T.24N., R.2W. (Neillsville 15-minute topographic quadrangle, Clark County). See Stop 2 for detailed location map.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: A diverse group of schists, gneisses, and metavolcanic rocks occurs along a 0.6 mi. long stretch of semi-continuous outcrop along the Black River, downstream from the mouth of Cunningham Creek. The same biotite schist with interlayered quartzofeldspathic units as that at Locality 14 appears at the mouth of Cunningham Creek. Metamorphosed basaltic and dacitic dikes crosscut the schist; the basalt is now an amphibolite. Mafic banded gneisses with augen bearing layers and augen free layers similar to those upstream from the Neillsville Augen Gneiss (Stop 3) crop out near the major bend in the Black River. Further downstream, an augen gneiss containing feldspar porphyroclasts up to 4 cm is exposed. The next unit encountered is a banded gneiss consisting of sharply defined quartzite, quartzofeldspathic, and amphibolite layers. The final outcrop is a layered metadacite to metarhyolite sequence, which on the basis of structural grounds appears to be younger than the gneisses. The dacites and rhyolites are porphyritic, containing quartz and feldspar porphyroclasts up to 2mm in a matrix of grains less than 0.1 mm. The metavolcanic rocks have been significantly granulated and moderately recrystallized. The layering, which varies from 1 mm to 2 cm thick, strikes N. 40° E. and dips 68° NW.

LOCALITY 16: Banded gneiss, Big Spring

LOCATION: NW¼, SE¼, Sec. 25, T.23N., R.3W. (Hatfield 7½-minute topographic quadrangle, Clark County). The gneiss crops out along the western shore of Lake Arbutus at Big Spring; a small island occurs offshore at this locality. See p. 30 for general map location.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The banded gneiss at Big Spring is mineralogically and structurally similar to the East Fork gneiss at Stop 6. Exposure here is poorer than at Stop 6, but this is a more accessible location. The melanocratic layers of the gneiss are hornblende bearing, just as in the East Fork gneiss. F₂ fold axes trend N. 85° E. and S. 85° W. with plunges ranging up to 35° in each direction.

LOCALITY 17: Gneiss at Morrison Creek

LOCATION: NE corner, Sec. 22, T.22N., R.3W. (Hatfield 7½-minute topographic quadrangle, Jackson County). Outcrop occurs in bed of Morrison Creek, downstream from County Hwy. K bridge over the creek. See map, page 30, for general location.

AUTHORS: W.R. Van Schmus and R.S. Maass (1980)

DESCRIPTION: The unit is a pink, fine-grained quartzofeldspathic gneiss that is similar to much of the gneiss along the Black River downstream from Arbutus Dam. Rb-Sr analyses on samples of gneiss from Morrison Creek do not define a good isochron, but they appear to be less disturbed than those from near Arbutus Dam and are consistent with an age of 2.8 b.y. for the gneiss. It appears that the effects of Penokean metamorphism were less severe here with regard to chemical alteration. The gneiss does have a pronounced foliation, roughly transverse to the stream with a general strike of N. 16° W. and a dip of 78° E.

LOCALITY 18: Gneiss, Powerhouse on Black River

LOCATION: NW¼, Sec. 16, and SE¼, sec. 9, T.22N., R.3W. (Black River Falls 15-minute topographic quadrangle, Jackson County). Semi-continuous exposure occurs on both banks of the Black River for approximately 1 mile upstream of the powerhouse. See map on following page for detailed location.

AUTHOR R.S. Maass (1980)

DESCRIPTION: This is an excellent exposure of Archean gneisses and presumed early Proterozoic andesitic and dacitic dikes, plus a gabbro of unknown age. The gneisses are thinly to massively layered, ranging in composition from granitic to dioritic, with tonalitic to granodioritic compositions dominating. Many of the layers are augen gneisses containing feldspar porphyroclasts averaging 1 cm in size, but also containing quartz porphyroclasts. The gneisses have been intruded by andesitic to dacitic dikes which have been deformed and recrystallized. Some of the dikes are porphyritic. A gabbro unit near the powerhouse is weakly foliated, but the origin of the foliation is unclear. The gneisses have been metamorphosed to amphibolite facies, but it cannot be ascertained at what grade the crosscutting dikes were recrystallized.

Isoclinal F_1 folding produced an axial planar foliation in the gneisses which is relatively consistent in orientation in the downstream three-quarters of the exposure, striking N. 45° W. and dipping vertically. Tight F_2 folds become progressively more common toward the upstream end of the outcrop. At the upstream end of the exposure, F_2 folding is disharmonic (Figure 14).



Map for localities 18, 19, 20



Figure 14. Disharmonic F_2 folding in the gneiss at the upstream end of the Powerhouse outcrop. Interference patterns here may be due to folding of isoclinal F_1 folds, as at Stops 3 and 7.

LOCALITY 19: Banded gneiss at quarry near Powerhouse

LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 17, T.22N., R.3W. (Black River Falls 15-minute topographic quadrangle, Jackson County). See map on preceeding page. Proceed approximately 0.1 mile south from Powerhouse Road on a gravel and sand road to an overgrown dirt road. The dirt road leads to a small, abandoned quarry.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: A banded gneiss consisting of alternating thin to thick biotite free and biotite rich quartzofeldspathic layers is exposed in a small quarry near the Black River. Many of the leucocratic and melanocratic layers contain alkali feldspar porphyroclasts which sometimes reach 3 cm in length. Both isoclinal F_1 and tight F_2 folds are present in the gneiss.

LOCALITY 20: Gneiss at Halls Creek

LOCATION: NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 30, T.22N., R.3W. (Black River Falls 15-minute topographic quadrangle, Jackson County). See preceeding page for location map. Outcrop is located along Halls Creek between County Hwy. E and the Black River, and on the west bank of the Black River just downstream from the mouth of Halls Creek.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The basement rocks at this locality crop out just below the unconformity with the Cambrian Mt. Simon Formation. They are micaceous felsic units and clayey intermediate to mafic units. The best exposures are along Halls Creek where the relationship with the Mt. Simon Formation is clearly visible. There are two possible interpretations for the rocks at this locality: a) they are low grade early Proterozoic sedimentary or volcanic units; or b) they are extremely weathered Archean gneisses. The latter possibility is strongly preferred since, 1) the rocks appear very similar to the deeply weathered portions of the Hatfield Gneiss exposed at Stop 7, which is also just below the unconformity; 2) some of the units here consist entirely of clay minerals plus quartz, which suggests weathering rather than low grade metamorphism; and 3) there are no known low grade early Proterozoic sediments or aluminous volcanic rocks elsewhere in the Black River region.

LOCALITY 21: Gneiss and tonalite, Black River Falls

LOCATION: NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 22, T.21N., R.4W. (Black River Falls 15-minute topographic quadrangle, Jackson County). See Stop 8 for detailed map. East bank of the Black River, 0.2 mi. west of U.S. Hwy. 12. Dirt path starting near sharp bend in road leads to outcrop.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The gneiss is banded and consists of quartz, plagioclase, alkali feldspar, biotite, hornblende, chlorite, and epidote. Thin to thick layering in the gneiss varies from compositional extremes of quartzofeldspathic bands containing as much as 40% alkali feldspar to bands consisting entirely of hornblende, plagioclase, and minor quartz. The gneiss has been intruded by fine-grained diorite and diabase dikes which have been metamorphosed to amphibolite facies and by a fine grained lineated tonalite which was probably subjected to the same grade of metamorphism. Age relationships among the intrusive units have not been established due to lack of suitable field relationships. Isoclinal F_1 folding produced an axial planar foliation which has been openly to tightly folded during F_2 deformation. F_2 fold axes in the gneiss, statistically defined β from a stereographic plot of poles to foliation, and mineral lineations in the intrusive units are essentially colinear, trending southeasterly and plunging between 50° and 75°.

LOCALITY 22: Quartzite, Silver Mound

LOCATION: NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 20, T.21N., R.3W. (Black River Falls 15-minute topographic quadrangle, Jackson County). See Stop 8 for detailed map. Follow a dirt road from Bauer Road to reach Silver Mound.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The quartzite at Silver Mound is white, nearly pure, and strongly lineated. It is poorly exposed, occurring mostly as loose blocks on top of, and along the sides of, the mound. It is believed to have formed from chert beds associated with the Archean volcanic rocks of the region.

LOCALITY 23: Jackson County Iron Mine

LOCATION: SW $\frac{1}{4}$, Sec. 15, T.21N., R.3W. (Black River Falls 15-minute topographic quadrangle, Jackson County). See p. 30 for map.

AUTHOR: R.S. Maass (1980)

DESCRIPTION: The Jackson County Iron Mine is in a banded magnetite iron formation which contains a lenticular talc schist zone in its center. The iron formation is surrounded on both sides by aluminous quartzofeldspathic schists. Previously, magnetite was believed to be the only primary iron oxide present (secondary hematite due to weathering caps the deposit), but recently primary hematite was encountered in the northwest corner of the pit. The other major minerals include quartz, iron-rich amphiboles, and garnet. The schist consists of three dominant mineral assemblages: 1) quartz-chlorite-muscovite-andalusite; 2) quartz-biotite-chlorite-staurolite-garnet-andalusite-muscovite; and 3) quartz-biotite-plagioclase-muscovite (Jones, 1978).

Isoclinal F_1 folding produced a penetrative axial planar foliation. F_1 fold axes plunge steeply and are accompanied by parallel mineral lineation defined by the orientation of amphiboles. Axes of open to tight F_2 folds are also parallel to the mineral lineation; thus, F_1 and F_2 fold axes are believed to be colinear. Structurally the iron formation is essentially identical to the Archean gneiss terrane. Jones (1978) concluded that the iron formation does not fit the early Proterozoic Superior-type model, but rather it appears to be of the Archean Algoma-type. It may have been deposited in a small basin on the flanks of a volcanic center.

Jones (1978) defined two distinct metamorphic events; the first was amphibolite facies, the second was upper greenschist facies. Based on textural features he concluded that the second event was a major thermal pulse, not merely a retrograde effect. The possibility of an earlier, much higher grade event than these two is suggested by the presence of kyanite, but the phase relationships of this mineral are not at all clear.

DISCUSSION OF THE TECTONIC HISTORY

In recent years it has become increasingly apparent that the Penokean Orogeny was a major igneous, metamorphic, and deformational event in central Wisconsin. This has been documented along the Wisconsin River between Stevens Point and Wisconsin Rapids (Maass and others, 1980), and as this guidebook illustrates, along the Black River as well. Studies in progress indicate that the entire central portion of Wisconsin has been subjected to regional amphibolite facies metamorphism and polyphase folding during the Penokean Orogeny.

Penokean deformation began with isoclinal F_1 folding which produced a penetrative axial planar foliation parallel to banding in gneisses, schists, and iron formation, except in fold hinges where the layering is transected by foliation. Subsequently the foliation was tightly to openly folded during F_2 ; the nonpenetrative axial planes of these folds are at small to large angles to F_1 foliation. Along the Wisconsin River there is a distinct break between tight and open fold styles, thus folding can be separated into F_2 and F_3 phases, but along the Black River there is a complete continuum from tight to open folds and no division is possible. The nonpenetrative axial planes of F_3 folds along the Wisconsin River are always at a high angle to the foliation. All fold axes are colinear, and parallel to a penetrative mineral lineation which is present in the Archean gneisses and most of the early Proterozoic intrusive rocks. The colinearity of structures suggests that they were formed under similar stress conditions during an extended Penokean deformational and metamorphic event.

The complete Penokean deformational history is recorded in gneisses of confirmed Archean age, but the presence of these structures is not sufficient evidence by itself for assigning an Archean age to a rock, since there may also be early Proterozoic units which were subjected to the entire period of Penokean deformation. A banded gneiss at Big Falls in Eau Claire County contains structures indicative of polyphase deformation similar to those in Archean rocks elsewhere in the terrane, yet the unit yields an early Proterozoic age (Introduction: Fig. 3). However, this gneiss is one of the most thoroughly recrystallized units in the region, and it is not yet clear that the age obtained is the primary age of the gneiss.

In the Black River valley there is a strong correlation between the age of emplacement of early Proterozoic intrusive rocks and the character of the structure present within them. The oldest units are foliated and lineated; younger units may contain a foliation, but are generally only lineated; and the youngest units tend to be completely devoid of any preferred orientation. However, even in the unfoliated and unlineated rocks, microscopic textures reveal that some of them have been granulated and recrystallized (Lake Arbutus Granite, Black River Falls Granite). Post kinematic granitic rocks in central Wisconsin, dated at 1760 m.y., may or may not be assigned to the Penokean Orogeny; structurally they are distinctly different from the rest of the Penokean intrusives.

Emplacement of the early Proterozoic intrusive rocks occurred throughout the waning stages of F_1 deformation and continued beyond the final stages of kinematic activity. F_1 deformation produced the foliation present in some of the intrusive rocks, and the older intrusives, having been subjected to F_1 deformation for a greater period of time than the younger intrusives, generally contain a better developed foliation. However, the Neillsville Granite demonstrates that using the degree of development of foliation as an indicator of age can be an unreliable method. Due to inhomogeneous deformation the granite is foliated in some areas and unfoliated in others. In addition, the mechanical properties of a given rock significantly influence its structural response to a deformational event. The Neillsville Granite, which is unfoliated at Stop 2, is intruded at this locality by a dacite dike which is strongly foliated.

Although the vast majority of linear Penokean structures plunge steeply, some are nearly horizontal. There may also be considerable variation in the trend of the structures from outcrop to outcrop. The two most likely explanations for this variance are that the fold axes and mineral lineations were folded during a later event, or that folding was originally noncylindrical. Stereographic plots of linear structural elements have not revealed any patterns of refolding, therefore the second possibility is preferred. In numerous localities noncylindrical folding has been observed on a mesoscopic scale, and there is no reason to believe that it did not also occur on a macroscopic scale. Unlike northern Wisconsin, where northeasterly structural trends seem to dominate, there is no dominant structural trend in the Black River valley.

One intriguing question which remains to be resolved is whether or not deformation and metamorphism occurred in central Wisconsin during the Archean. Three localities suggest that it did. A migmatite of Archean age (Van Schmus and Anderson, 1977) is exposed in a quarry near the Wisconsin River, in Linwood Township. A steeply plunging mineral lineation which formed during the Penokean Orogeny transects the hinges of gently plunging isoclinal folds in the migmatite. The relationship requires that the folds be older than the mineral lineation, and the gentle plunge of the folds does not fit the pattern of Penokean folding in the area, suggesting that the folds are Archean in age (Maass and others, 1980). The other two localities are in the Black River valley: in the Hatfield Gneiss and in the Jackson County Iron Mine. The Hatfield Gneiss contains relict hypersthene (Dubois and Van Schmus, 1978), and the iron formation contains significant quantities of kyanite (Jones, 1978). These minerals, and their textures, suggest that there might have been an earlier metamorphic event in the upper amphibolite to granulite facies. In addition there is one unexplained, isoclinally refolded, isoclinal fold in the Hatfield Gneiss which may be evidence for an older folding event.

These lines of evidence are not conclusive, and the features could be attributed to an early Proterozoic event. On the other hand, many of the Archean gneisses in the Black River Valley were derived from a volcanic-plutonic terrane, and it would be reasonable to expect that the volcanic rocks were deformed during emplacement of the plutons or during an orogeny associated with the igneous activity. Finally, most other Archean terranes in the Lake Superior region contain significant Archean deformation and metamorphism, so that we assume the same is true for the Archean rocks of the Black River valley. However, Penokean effects have largely obliterated any Archean tectonic features.

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