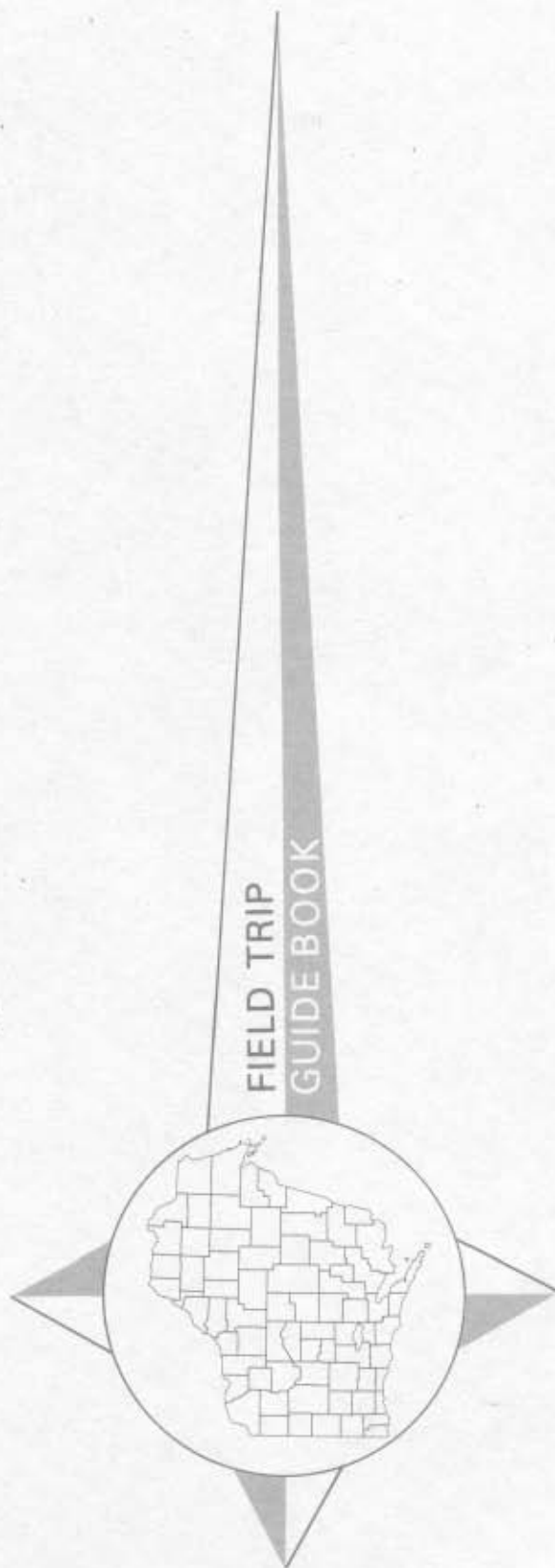


**PENOKEAN DEFORMATION
AND METAMORPHISM
IN CENTRAL WISCONSIN:
VOLCANIC ROCKS AND GNEISSES**

Prepared for

THE THIRTY-SECOND ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY
WISCONSIN RAPIDS, WISCONSIN
APRIL 28-MAY 4, 1986



Field Trip Guide Book

University of Wisconsin-Extensin
GEOLOGICAL AND NATURAL HISTORY SURVEY
Meredith E. Ostrom, State Geologist and Director

Penokean Deformation and Metamorphism in Central Wisconsin:
Volcanic Rocks and Gneisses

by R.S. Maass

Prepared for

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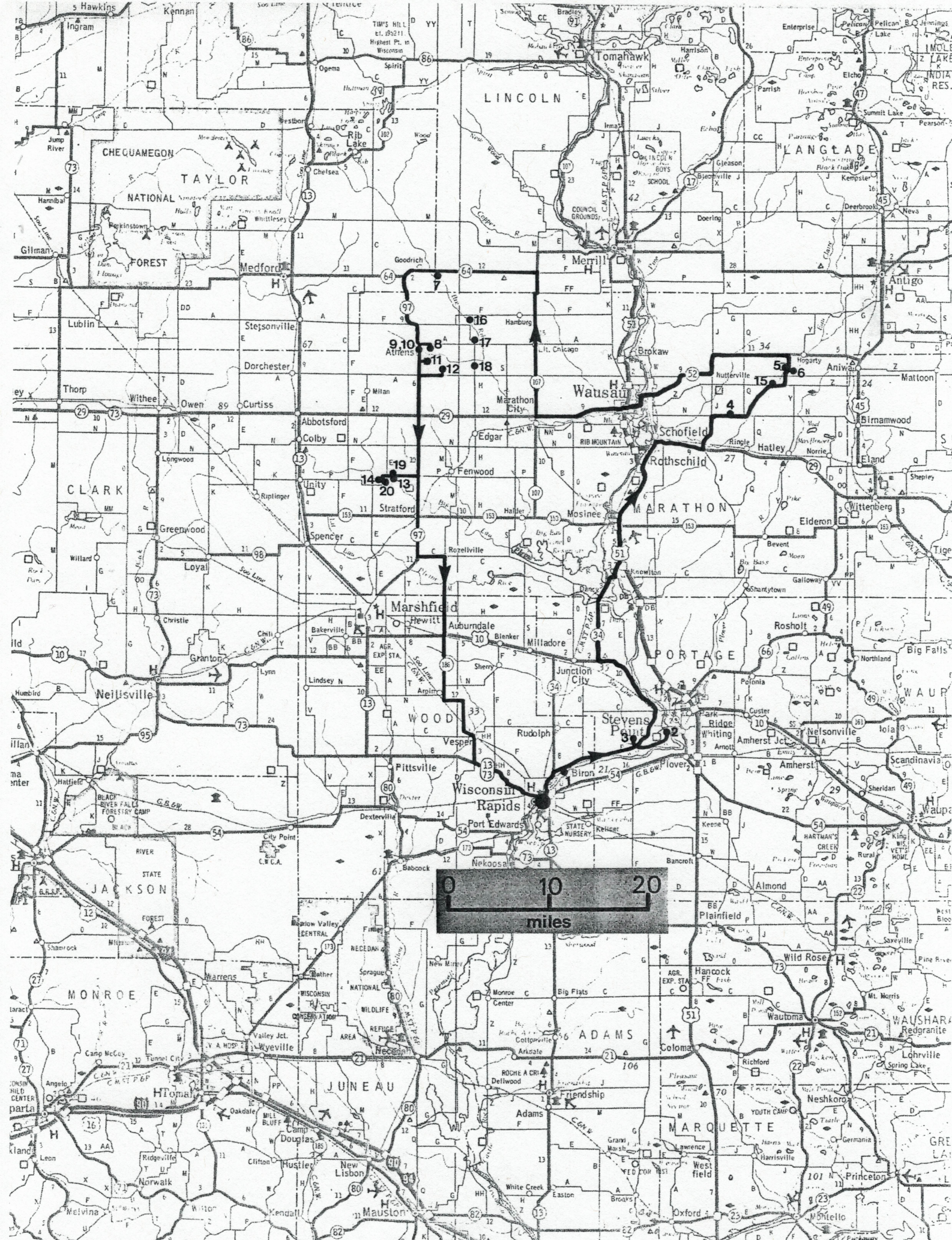
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The following map was omitted from the printed field guide and included as a hand out during the meeting. It has been included here in the PDF to address that omission. The file was added on May 29, 2019.



INTRODUCTION

Based primarily on radiometric data the Precambrian rocks of central Wisconsin have been divided into two terranes. The southern terrane consists of a mixture of Archean and lower Proterozoic rocks, whereas the northern terrane apparently lacks Archean rocks. At the present time the precise location of the boundary between the terranes is not known nor has its nature been established. This field trip visits exposures within the southern terrane (Wisconsin Rapids - Stevens Point Area), the northern terrane (Eau Claire Dells Area, Athens Area), and in the vicinity of the boundary (March Rapids Area). Structural and metamorphic data suggest that the rocks in all four of the field trip areas have been affected in a similar manner, and to a similar degree, by the Penokean orogeny (approximately 1900-1800 Ma).

One of the purposes of the field trip is to provide an opportunity to visit localities that have been the subject of opposing tectonic interpretations. Stops in the Eau Claire Dells, Athens, and March Rapids areas have been specifically chosen to examine the evidence for or against the existence of major Proterozoic shear zones in central Wisconsin. The hypothesis that central Wisconsin has been affected by an early Proterozoic pre-Penokean orogenic event is tested in the Athens and March Rapids areas.

WISCONSIN RAPIDS - STEVENS POINT AREA

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

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

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

Discussion

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

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

present, only a single phase of isoclinal folding is recognized in migmatite. It is interpreted to have occurred during the Penokean orogeny.

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

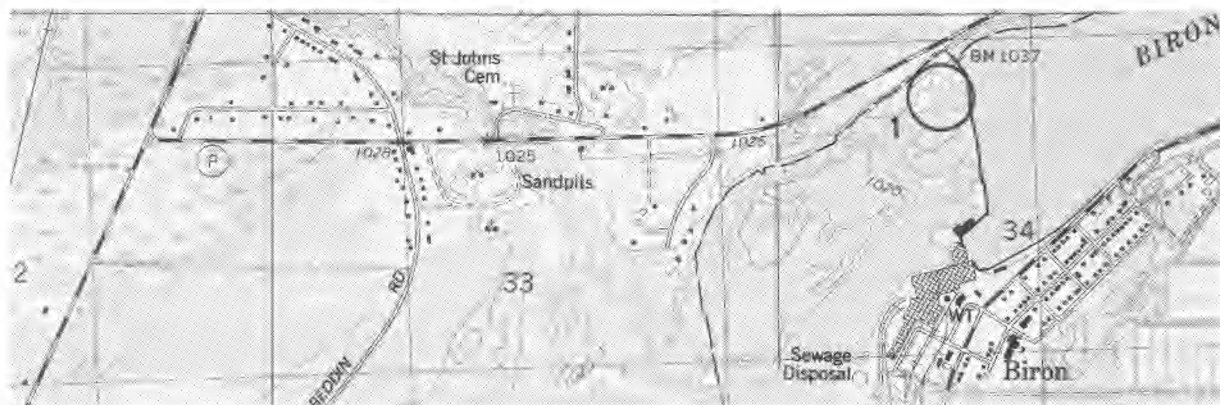
The foliated tonalites in the area can be divided into two geochemical suites (J.L. Anderson, written communication, 1985), suggesting that the age differences may be real. Unfortunately, foliated tonalite from Conants Rapids is not among the samples chemically analyzed. Geochemical modelling of the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

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

Stop 1

Title: Biron Dam - Penokean intrusive rocks

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



Author: R. S. Maass (1986)

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

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

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

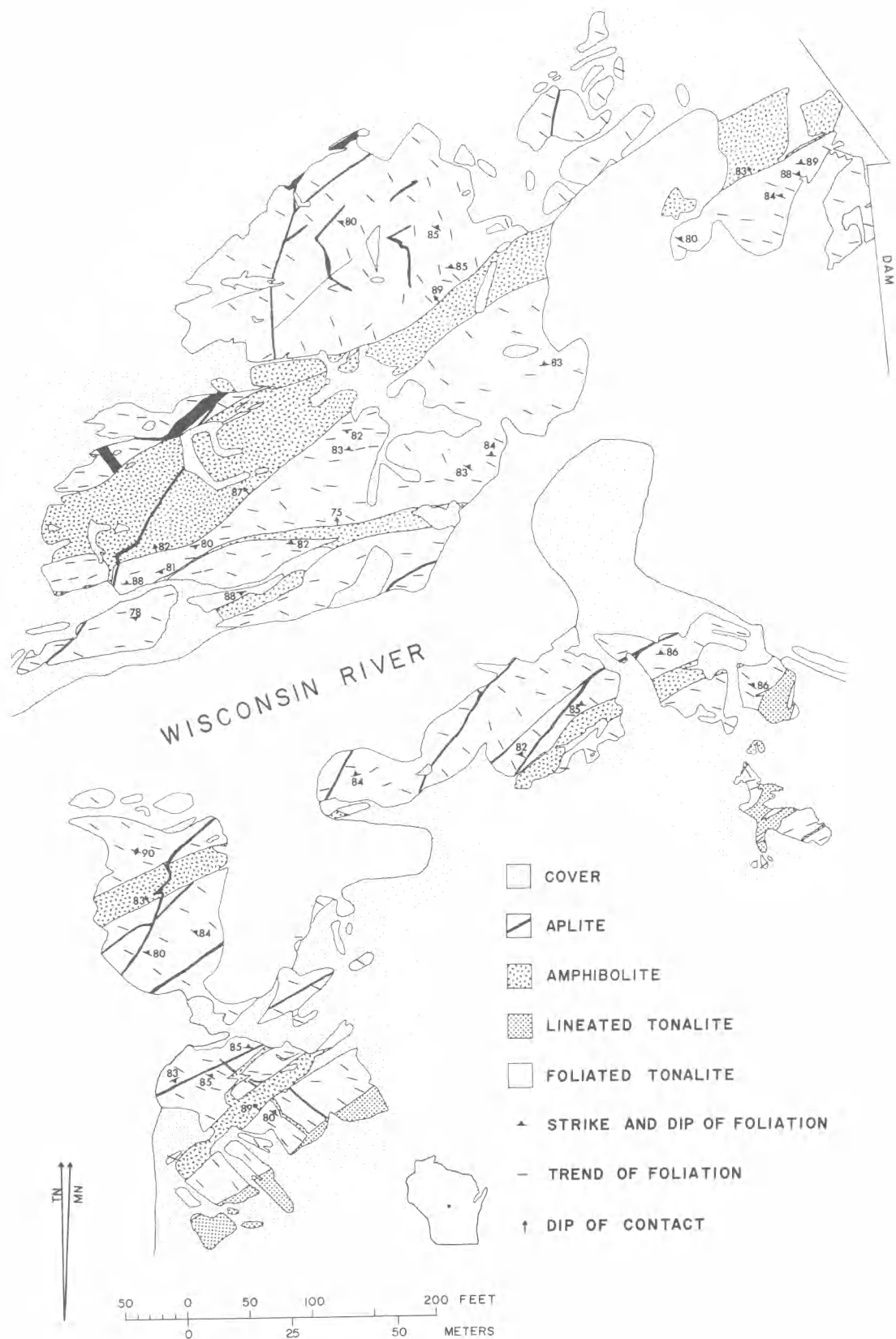


Figure 1. Geologic map of Biron Dam.

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

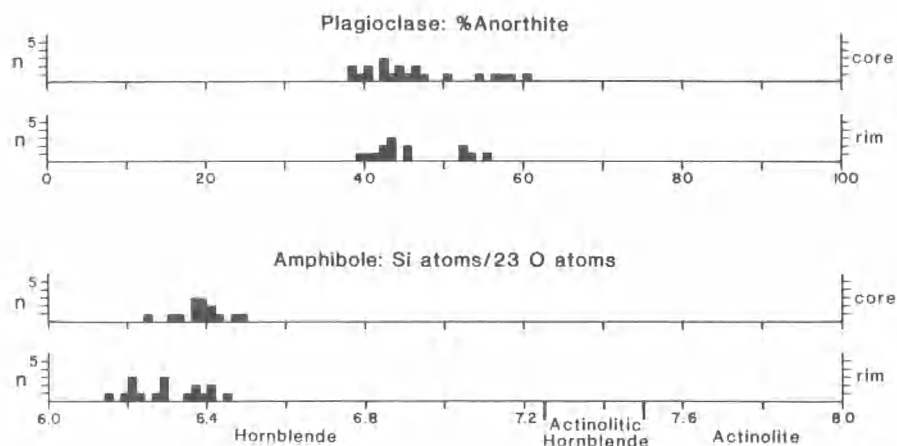


Figure 2. Electron microprobe analyses of coexisting amphibole and plagioclase in an amphibolite dike that crosscuts foliated tonalite. Sample BD-1. For this diagram, and all others like it, n is the number of analyzed points yielding the specified composition.

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

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

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

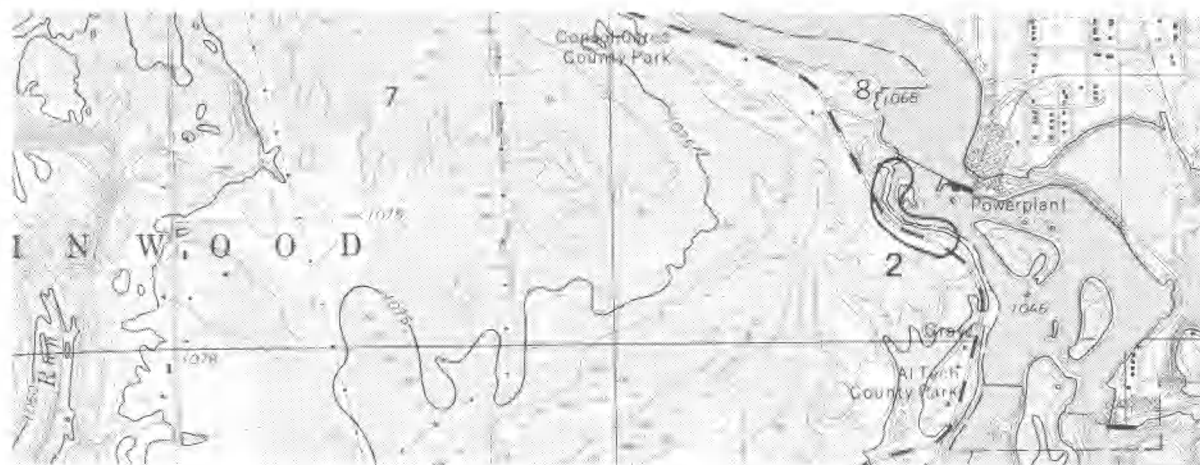
Sample:	BD-1	CR-19	CR-17	ATH-5	ATH-8	RR-4	ATH-15	March-6	March-8	March-5
<u>Plagioclase</u>										
SiO ₂	57.17	63.24	58.42	60.45	60.47	45.79	67.56	66.69	60.18	68.10
Al ₂ O ₃	26.85	22.98	26.05	24.85	24.86	33.86	19.78	20.87	24.54	20.14
Na ₂ O	6.69	9.05	7.22	8.29	8.29	1.14	11.45	11.17	8.10	10.92
CaO	9.20	4.78	8.10	6.01	5.75	18.62	0.86	0.74	6.80	1.17
K ₂ O	0.16	0.27	0.15	0.19	0.11	0.00	0.13	0.16	0.04	0.06
Total	100.08	100.32	99.94	99.70	99.48	99.41	99.78	99.63	99.67	100.39
%An	43.2	22.6	38.3	28.6	27.7	90.0	4.0	3.5	31.7	5.6
<u>Amphibole</u>										
SiO ₂	42.70	43.69	47.15	40.99	42.15	42.71	51.02	46.55	47.70	47.52
Al ₂ O ₃	14.77	10.25	9.28	15.89	15.11	15.57	2.19	9.71	7.08	8.99
Na ₂ O	1.45	1.31	0.78	1.22	1.61	1.11	0.48	0.84	0.94	0.65
CaO	11.84	11.82	12.49	12.19	12.20	11.93	12.27	12.61	12.18	12.25
K ₂ O	1.16	1.02	0.61	1.03	0.39	0.50	0.14	0.67	0.57	0.62
*FeO	16.86	19.42	17.37	19.55	17.10	17.21	15.27	14.03	18.55	17.14
MgO	9.19	9.33	10.96	6.83	8.61	7.68	13.73	12.48	9.94	10.54
TiO ₂	0.47	0.69	0.39	0.48	0.33	0.39	0.79	0.38	0.35	0.09
MnO	0.19	0.23	0.23	0.24	0.20	0.19	0.36	0.24	0.20	0.25
Total	98.63	97.78	99.27	98.42	97.70	97.28	96.24	97.51	97.50	98.60
Si/23 Oxygen	6.34	6.63	6.91	6.18	6.31	6.39	7.60	6.86	7.16	6.99

*Total Fe as FeO

Stop 2

Title: Conants Rapids - Archean gneiss and Penokean intrusive rocks

Location: West side of the Wisconsin River downstream of a Consolidated Paper Company dam. East side of River Road, across from a water treatment plant. A short gravel road leads to the northern end of the outcrop. NW¼, SE¼, Sec. 8, T. 23 N., R. 8 E. (Whiting 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986).

Description: From oldest to youngest, the main rock-types at Conants Rapids are tonalitic banded gneiss, foliated tonalite, a series of lineated tonalites, and amphibolite dikes (plate 1, center of guidebook). Also present are a number of generations of granitic aplites and pegmatites.

Tonalitic banded gneiss consists primarily of oligoclase (An_{21-25}), quartz, biotite, hornblende, and microcline. Also present are minor to trace quantities of epidote, chlorite, sphene, allanite, zircon, magnetite, pyrite, ilmenite, and chalcopryrite. This rock contains numerous concordant layers and lenses of amphibolite, and a few concordant dikes and veins of granitic pegmatite. Banded gneiss is interpreted to represent the paleosome of migmatite at Linwood Township Quarry (Stop 3) (Anderson, 1972), which has yielded a U-Pb zircon age of 2800 Ma (Van Schmus and Anderson, 1977). Because of extensive deformation and metamorphism, no primary sedimentary, volcanic, or plutonic features are preserved. Based solely on composition, banded gneiss may have formed from graywacke, andesite, or tonalite. Amphibolite layers may represent basalt flows or transposed basalt dikes.

Foliated tonalite, amphibolite dikes, and granitic aplite dikes and veins are mineralogically and texturally similar to these rock types at Biron Dam, (see Stop 1 description). As at Biron Dam, foliated tonalite at Conants Rapids contains small xenoliths of diorite gneiss.

A series of fine-grained lineated tonalites, primarily composed of oligoclase, quartz, biotite, hornblende, and microcline crops out as dikes and irregular-shaped bodies. As determined by crosscutting relationships (found

mainly in boulder piles), the series varies systematically in mafic mineral content with age; the oldest members are mafic-rich and the youngest members are leucocratic. A corresponding decrease in the ratio of plagioclase to microcline also occurs with decreasing age, and a few of the youngest members are granodiorite. A single exception to this trend occurs; the youngest member of the series is mafic-rich. For mapping purposes the series has been separated into five divisions based on color (plate 1). All divisions except "fine-grained dark gray" contain more than one member of the series. U-Pb zircon ages of 1824 ± 25 Ma have been obtained from a dark gray member near the dam, and from a pink granodiorite member collected from the construction site of the water treatment plant on the west side of River Road (Van Schmus, 1980).

A concordant amphibolite layer in banded gneiss contains the mineral pair oligoclase + hornblende (fig. 3), and an amphibolite dike that crosscuts lineated tonalite contains andesine coexisting with hornblende (fig. 4). Calcic cores of plagioclase in the amphibolite dike (fig. 4) are interpreted to be relict igneous compositions. Concordant amphibolite contains minor quantities of sphene, biotite, apatite, zircon, an opaque mineral, and sericite. The amphibolite dike contains small amounts of sphene, epidote, allanite, an opaque mineral, and sericite. Representative analyses of amphibole and plagioclase from both rocks are presented in Table 1.

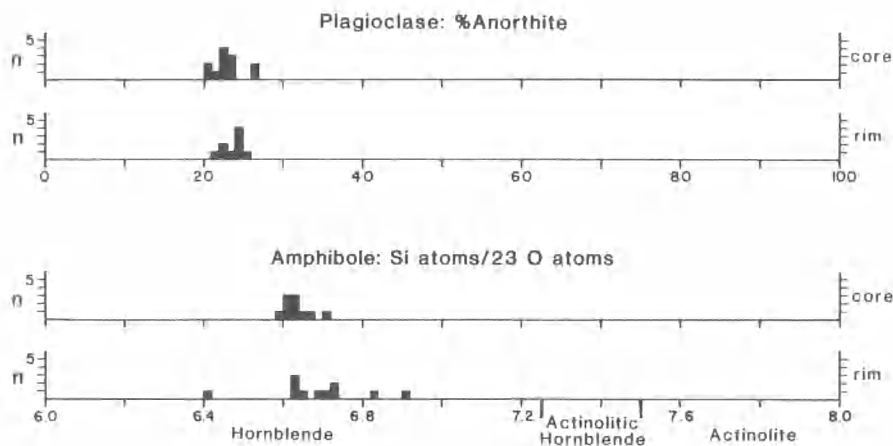


Figure 3. Electron microprobe analyses of coexisting amphibole and plagioclase in a concordant amphibolite layer in banded gneiss. Sample CR-19.

All lithologies at Conants Rapids, with the possible exception of the youngest pegmatites and aplites, were deformed during the Penokean orogeny. Penokean isoclinal F_1 , tight F_2 , and open F_3 folds are coaxial, and parallel to well-developed penetrative mineral lineation in banded gneiss, foliated tonalite, lineated tonalites, and amphibolite dikes (Maass and others, 1980). Fold axes and mineral lineation are oriented approximately S 22° E 61° . Banded gneiss was subjected to all three phases of folding and possesses a penetrative foliation that is axial-planar to isoclinal folds. Foliated tonalite is interpreted to have been emplaced during the late stages of F_1 .

folding because it possesses a penetrative foliation that is parallel to foliation in banded gneiss, but is not as well-developed as in banded gneiss. On average, foliation strikes E-W and dips 62° to the south. Some of the oldest members of the lineated tonalite series possess a very poorly developed foliation that probably formed during the very latest stages of F_1 folding, but most lineated tonalites are not foliated. Amphibolite dikes were intruded after F_2 folding and prior to F_3 folding. The dikes possess a penetrative foliation that is parallel to their margins (see discussion of this phenomenon at Stop 1). Penetrative mineral lineation is qualitatively equally well-developed in banded gneiss, foliated tonalite, lineated tonalites, and amphibolite dikes. Because the amphibolite dikes were only affected by open F_3 folding, F_3 is interpreted to have produced mineral lineation. It is not clear whether mineral lineation was also formed during F_1 and F_2 because of the parallelism of the axes of all three folding events.

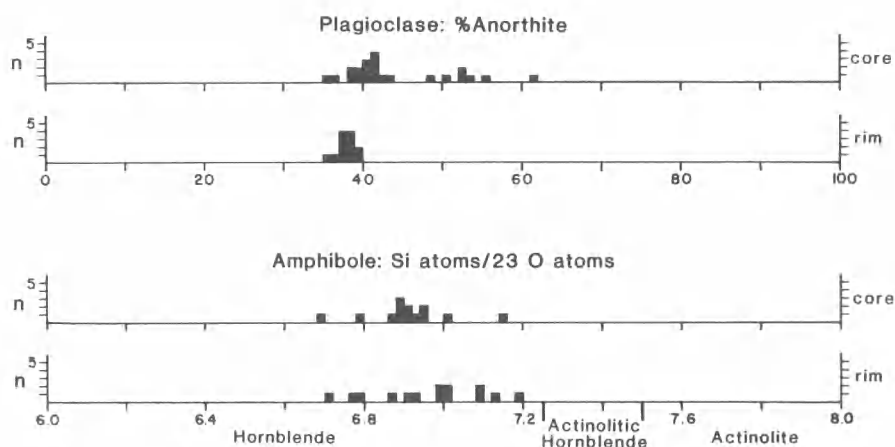
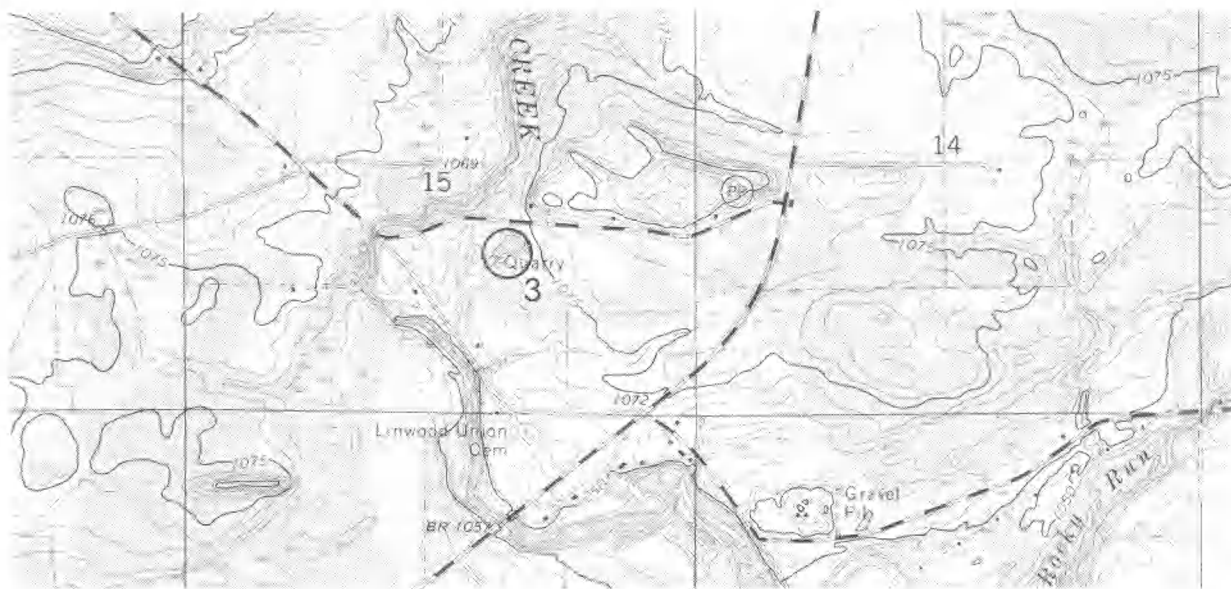


Figure 4. Electron microprobe analyses of coexisting amphibole and plagioclase in an amphibolite dike that crosscuts lineated tonalite. Sample CR-17.

Stop 3

Title: Linwood Township Quarry - migmatite and lineated tonalite

Location: South side of County Highway PP, 0.9 km west of the intersection of Highway PP and Highway P. An opening is present in the fence that runs along the south side of the road; please use this as the entrance. NW¼, SE¼, Sec. 15, T. 23 N., R. 7 E. (Meehan 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Migmatite and a lineated tonalite dike are exposed in the quarry. Migmatite consists of a paleosome of banded tonalitic gneiss and interlayered amphibolite, and a granite neosome. Anderson (1972) has interpreted the paleosome to be the equivalent of banded tonalitic gneiss and interlayered amphibolite exposed at Conants Rapids (Stop 2) and along the banks of small streams in the area. The granite neosome is anatectic in composition and is thought to represent lit-par-lit injection of magma into the banded paleosome (Anderson, 1972). Lineated tonalite is a member of the lineated tonalite series exposed also at Biron Dam (Stop 1) and Conants Rapids (Stop 2). The tonalite dike crops out on the south side of the quarry. U-Pb analysis of the paleosome of migmatite yields an age of approximately 2800 Ma (Van Schmus and Anderson, 1977). A sample of lineated tonalite from the quarry yields an age of 1824 ± 25 Ma (Van Schmus, 1980).

Migmatite possesses a penetrative foliation that is axial-planar to isoclinal folds. Axes of isoclinal folds plunge at angles ranging from shallow to the northwest, through vertical, to shallow to the southeast. Foliation and compositional layering have been folded in a contorted fashion by a younger event or events (F_2 or F_3 , or both; the division into F_2 and F_3 phases at Conants Rapids is based primarily on a break in style between tight and open folding, but no similar break in style is apparent in migmatite).

Poorly developed mineral lineation in the plane of foliation is oriented approximately S 28°, E 65°, parallel to mineral lineation in lineated tonalite and parallel to fold axes and mineral lineation at nearby Conants Rapids (Maass and others, 1980). Stereographic analysis of poles to foliation in migmatite does not yield a unique axis of late folding (F_2 or F_3 , or both), but suggests that late folding occurred on an axis that is approximately parallel to mineral lineation. Formation of mineral lineation is attributed to F_3 folding because this is the case at Conants Rapids and Biron Dam (Maass and others, 1980).

The contact of the dike of lineated tonalite with migmatite is extremely diffuse, and lineated tonalite interdigitates with layering in migmatite (fig. 5). Lineated tonalites elsewhere in the area have sharp contacts with country rock. At the present time there is no evidence that migmatite has been metamorphosed to a significantly higher grade than the other studied rocks of the area. The diffuse contact, relative to the other lineated tonalites of the area, is therefore not interpreted to be a result of diffusion during metamorphism. The preferred interpretation is that lineated tonalite was intruded shortly after migmatization, when migmatite was still at nearly magmatic conditions, thus allowing considerable ion migration. This would require that migmatization took place during the Penokean orogeny. This is in contrast to the previous proposals that migmatization occurred at 2800 Ma (Van Schmus and Anderson, 1977; Maass and others, 1980).

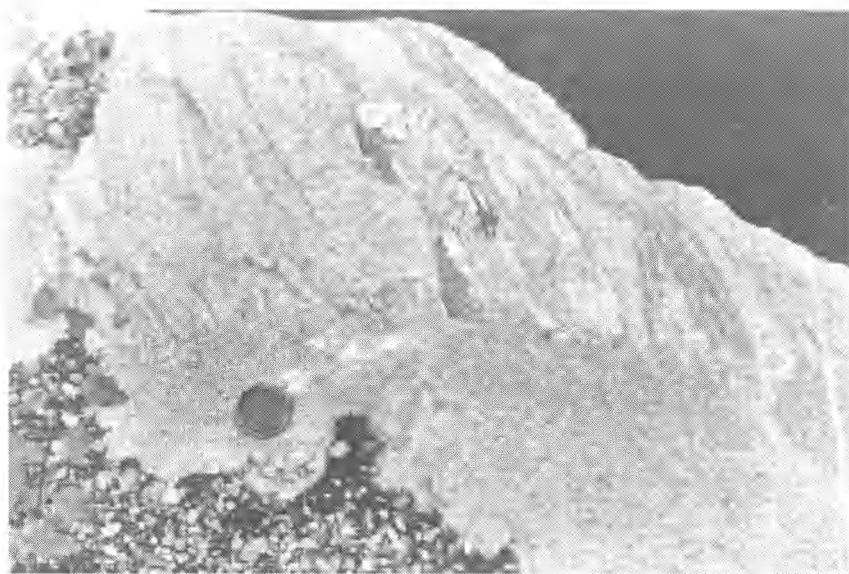


Figure 5. Lineated tonalite dike in migmatite. Note diffuse contact and interdigitation of dike with layering in migmatite.

The results of U-Pb zircon analysis of the paleosome of migmatite pose the major obstacle to the interpretation that migmatization occurred during

the Penokean orogeny. Zircon from the paleosomes shows no evidence of disturbance during the Penokean orogeny (W.R. Van Schmus, written communication, 1983), which suggests that migmatization did not occur at this time because it is generally believed that U-Pb systematics will be altered during a migmatization event. However, in a combined U-Pb and Rb-Sr study of a migmatite terrane in Finland, Hopgood and others (1983) report that U-Pb systematics in zircon were not reset during migmatization of a volcanic protolith.

Maass and others (1980) and Maass (1983) concluded that isoclinal F_1 , tight F_2 , and open F_3 folding in rocks along the Wisconsin River occurred during the Penokean orogeny. The possibility was left open that isoclinal folds in migmatite at Linwood Township quarry were formed at 2800 Ma, the presumed age of migmatization, because their convoluted style suggests that they formed during migmatization. Contorted isoclinal folding in migmatite contrasts with relatively orderly isoclinal folding in nearby banded gneiss at Conants Rapids. This contrast is explained if migmatization occurred during the Penokean orogeny. More divergent orientations of fold axes and more contorted styles of folding are expected in migmatite than in gneiss when both are subjected to similar stresses (MacKenzie, 1957; McLellan, 1984).

An attempt to establish the history of migmatite using Rb-Sr methods has so far proved relatively unsuccessful. Rb-Sr analysis of tonalitic paleosomes, amphibolite paleosomes, and granitic neosomes yields an "age" of 1663 ± 239 Ma, with an initial Sr ratio of 0.7130 ± 0.0030 (C.W. Montgomery, written communication, 1983). The Rb-Sr data are useful in that they demonstrate that migmatite has been affected by a post-Penokean event, or events.

EAU CLAIRE DELLS AREA

The rocks at Eau Claire Dells, located approximately 25 km east-northeast of Wausau, have been alternatively interpreted to be either deformed and metamorphosed volcanic rocks or mylonite. Weidman (1907) originally mapped the rocks at the Eau Claire Dells as "rhyolite schist." They were subsequently interpreted to be "felsic mylonite" by LaBerge (1972, 1976, 1980), LaBerge and Myers (1973, 1983), Freeman and others (1974), and Ard and Upadhyay (1982). According to LaBerge and Myers (1983, plate 1) the rocks at the Eau Claire Dells are in the center of a zone of felsic mylonite that extends over 25 km, with an average width of about 2 km.

Anderson (1975), Maass and Medaris (1980), and Maass (1983) have argued that the rocks at the Eau Claire Dells are volcanic rocks that have not undergone an unusual amount of strain. According to Maass (1983), deformation and metamorphism of the rocks at the Eau Claire Dells probably occurred during regional Penokean deformation and metamorphism.

Discussion

The schists in the vicinity of the Eau Claire Dells are interpreted to be lower Proterozoic volcanic and sedimentary rocks that have been affected by regional deformation during the Penokean orogeny. They are not considered to be mylonites. Quartz phenocrysts, some with preserved crystal faces and embayment texture, are present in rocks at the Eau Claire Dells; at an undescribed outcrop to the south, on the east side of Thornapple Creek Road (NE¼, NW¼, Sec. 24, T. 29 N., R. 9 E.); and at another undescribed outcrop in a ditch on the north side of county Highway N, 0.1 km west of the Eau Claire River (SE¼, SW¼, Sec. 33, T. 29 N., R. 9 E.). Preservation of quartz phenocrysts is considered to be compelling evidence that these rocks are not mylonites because quartz deforms readily during cataclasis and forms "ribbons" in mylonites. Thin and thick layers of schist at the Eau Claire Dells contain blocky to rectangular feldspar phenocrysts with relict crystal faces. Many of the elongate feldspar phenocrysts are oriented at a high angle to foliation, suggesting that these layers are not highly strained. It is thought to be extremely unlikely that schists in the area that are uniformly fine grained for thicknesses of tens to hundreds of meters represent ultramylonites rather than originally fine-grained volcanic and sedimentary rocks.

The rocks that flank the schists in the Eau Claire Dells area are younger granites. The granite to the west is an approximately 1825 Ma (Van Schmus, 1980) post-kinematic Penokean pluton, and the granite to the east (Stop 6) is a member of the anorogenic 1485 Ma Wolf River Batholith. Neither rock is a suitable protolith for the schists of the area if the schists are interpreted to be mylonites produced by late shearing.

To what extent the orientation of layering and foliation in schist is related to intrusion of the Wolf River Batholith is an unanswered question at the present time. Because the Penokean orogeny produced nearly vertical structures throughout central Wisconsin (Maass, 1983) and northeastern Wisconsin (Greenberg and Brown, 1983), there is no need to attribute steeply dipping layering and foliation in the Eau Claire Dells area to deformation associated with emplacement of the batholith. Anderson (1975) and LaBerge and Myers (1983), however, show northeast striking foliation gradually becoming close to parallel to the margin of the batholith as the batholith is approached from

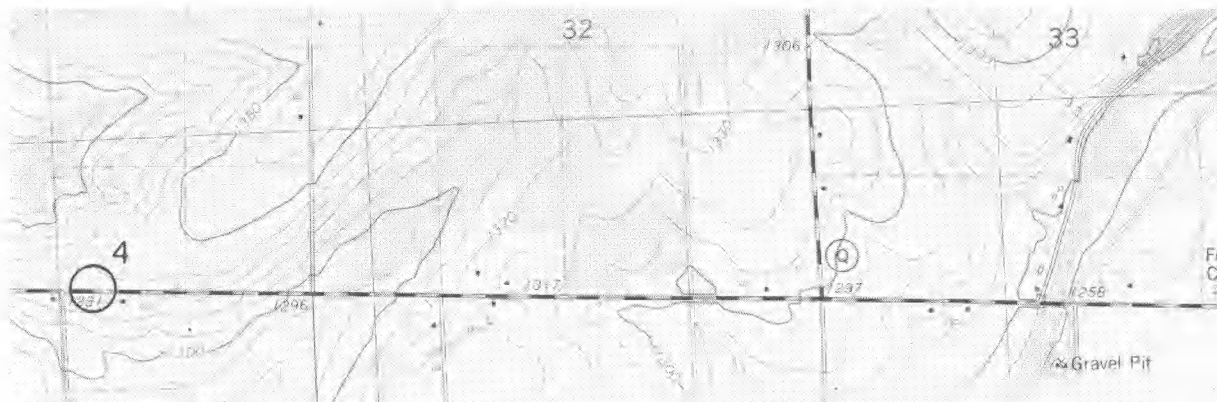
the west, suggesting that the batholith may have slightly reoriented foliation. Strike of foliation does not reach complete parallelism. Foliation at the Eau Claire Dells strikes N 40-47° E, whereas the margin of the batholith strikes N 20° E. Exposed metagabbros and metabasalts in the area, such as at Stop 15, tend to be unfoliated, suggesting that there was little deformation associated with intrusion. Metagabbros encountered in drill core south of the Eau Claire Dells contain narrow shear zones (W. P. Scott, oral commun., 1985) that may be related to stress accompanying intrusion of the batholith.

Schist has probably been subjected to a minimum of two metamorphic events. Textures at the Eau Claire Dells indicate that most, if not all, metamorphic minerals were produced during a dynamic event. Micas and amphibole are aligned parallel to foliation, and porphyroblastic minerals are either parallel to foliation or have foliation wrapping around them. Metamorphism either outlasted deformation or a second period of metamorphism occurred, because gabbros and basalts are statically recrystallized. Static metamorphism is potentially related to intrusion of the Wolf River Batholith, but is not necessarily so because statically metamorphosed gabbros are present throughout a large part of central Wisconsin (Stop 17; Maass, unpublished data). The age of static metamorphism of these gabbros has not been established. Potential ages include (1) during the very latest stages of the Penokean orogeny; (2) at 1760 Ma, the time of formation of granites and rhyolites in Wisconsin; (3) at 1630 Ma, the time of a poorly understood "event" that is recorded in Rb-Sr systematics; or (4) at 1485 Ma, in association with intrusion of anorogenic granitic rocks. A detailed mineralogic study to determine the possible contact effects in the Eau Claire Dells area has not been performed, but recrystallization textures suggest that the Wolf River Batholith has affected the area to some extent.

Stop 4

Title: County Highway N, west of the Eau Claire River - schist

Location: North side of County Highway N, approximately 3 km (1.8 mi) west of the Eau Claire River, and 2.7 km (1.7 mi) east of County Highway J. The outcrop is a short distance east of the intersection of Clubhouse Road and County Highway N. SW corner, E½, SE¼, Sec. 31, T. 29 N., R. 9 E. (Ringle 7.5-minute topographic quadrangle)



Author: R. S. Maass (1986)

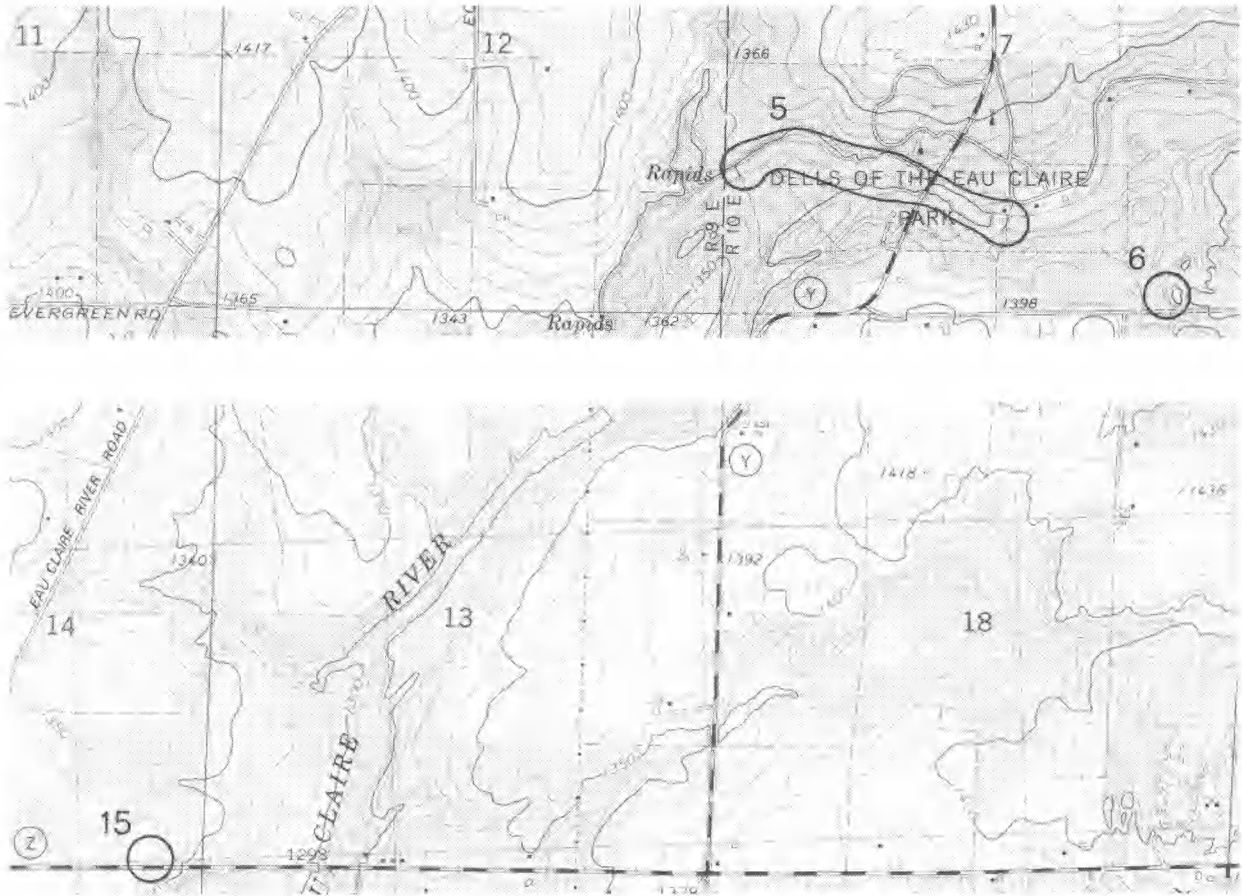
Description: Schist derived from volcanic rocks is exposed along the north side of County Highway N. Strike of nearly vertical layering and foliation is N 83° E at the west end of the outcrop and N 62° E at the east end. Mapping by Anderson (1975) and LaBerge and Myers (1983) suggests that the nearly E-W orientation of foliation at this locality is slightly anomalous for the area; foliation in nearby rocks strikes between N 60° E and N 35° E. A possible explanation for variation of orientation of foliation is large-scale folding.

Klasner and LaBerge (1985) report that there are two generations of foliation at this locality, and that their presence provides evidence for the existence of the proposed "Eau Claire Dells shear zone." According to Klasner and LaBerge, approximately east-west striking regional foliation is overprinted by narrow zones of northeast striking cataclastic foliation related to the shear zone. The present author has not observed evidence of the presence of two separate foliations at this locality; narrow northeast striking structures are interpreted to be joints rather than foliation.

Stop 5

Title: Eau Claire Dells County Park - schist

Location: County Highway Y, approximately 2.3 km north of County Highway Z, Southern ¼, Sec. 7, T. 29 N., R. 10 E. (Hatley 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Schist is exposed on both banks of the Eau Claire River at Eau Claire Dells County Park, between a dam in the eastern part of the park and a footbridge at the western edge of the park. Schist also crops out just beyond the northeast boundary of the park, and for a considerable distance southwest of the park. Schist is interpreted to be derived from an interbedded sequence of volcanic rocks and sedimentary rocks.

Medium-grained mafic schist crops out in woods on the northwest side of the river, about 50 m beyond the park boundary. This rock is nearly identical to schist described at Stop 6 except that clinopyroxene has not been found and recrystallization texture is marginally less well-developed.

Schist within the park is fine-grained to extremely fine-grained and is quartzofeldspathic except for a few semipelitic layers and a few thin mafic layers. The primary constituents of quartzofeldspathic schist are quartz, feldspar, muscovite, biotite, and chlorite. Feldspar staining of hand samples of layers that are interpreted to have originally been volcanic rocks indicates that they are rhyolitic to dacitic in composition.

Schist along the upstream half of the section of the river between the dam and Highway Y is commonly layered on a scale ranging from 1 mm to a few centimeters in width. A number of layers are semi-pelitic, containing greater than average amounts of muscovite and biotite. Garnet (fig. 9 in Maass, 1983) is present in many of these layers, and andalusite has been found in an outcrop on the south side of the river approximately 100 m from the dam. Schist along the downstream half of this section of the river is more massive in character. Near Highway Y, massive schist contains numerous leucocratic lenses that are tentatively interpreted to represent lapilli. Approximately 50 m east of Highway Y, on the north side of the river, schist is intruded by two narrow mafic dikes and a granitic vein. Thin section examination of one of the dikes indicates that it is thoroughly recrystallized, primarily consisting of plagioclase and dark-green amphibole. It possesses a very poorly developed foliation that appears to be at an angle to foliation in schist. The granitic vein appears to be undeformed, but has not been examined in thin section. Tightly folded felsic veins, with axial planes of the tight folds parallel to foliation in schist, are also present in this vicinity.

Extremely fine-grained schist derived from a massive feldspar porphyry crops out a short distance downstream of Highway Y, in the vicinity of a small waterfall. Blocky to lath-shaped feldspar phenocrysts up to 2 mm in diameter in this rock commonly possess crystal faces, and a large percentage of the feldspar phenocrysts have not been rotated into the plane of foliation (fig. 6, this report; fig. 7 in Maass, 1983). Glomeroporphyritic texture is developed locally.

Along the north bank of the river, for a distance of approximately 400 m downstream of the feldspar porphyry, the majority of schist is massive and uniformly fine grained. It is "streaky" in many places, the streaks being biotite-rich wisps. Corundum, surrounded by rims of muscovite, is present within a biotite-rich layer located 300 m downstream of Highway Y.

A high "wall" of schist crops out a short distance upstream of the footbridge at the western end of the park. A few thin layers of mafic schist crop out along the river bank upstream of the wall. Mafic schist is compositionally layered on a 0.5-3.0 mm-scale, and is predominantly composed of medium-green to dark-green amphibole coexisting with plagioclase. A few layers contain clinopyroxene coexisting with amphibole, quartz, and a minor quantity of carbonate. The rock that makes up the wall contains quartz phenocrysts (fig. 7, this report; fig. 8 in Maass, 1983) in a fine-grained matrix of quartz, feldspar, muscovite, biotite, chlorite, andalusite, and tourmaline. Pale-yellow masses of an exceedingly fine-grained mineral, or minerals, may represent completely altered cordierite. The rock is tentatively interpreted to be a tuffaceous quartz porphyry.

It is believed that layering in schist at the Eau Claire Dells represents volcanic and sedimentary layering. Mineral foliation parallel to layering, which strikes N 40-47° E and dips approximately vertically, is primarily tectonic in origin. If the layers of schist that had volcanic protoliths were

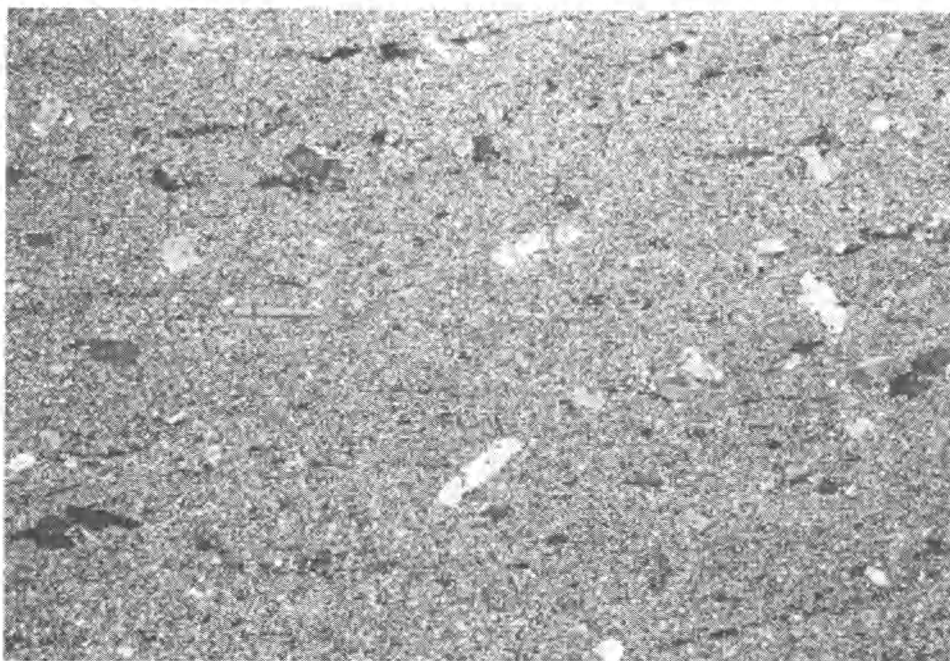


Figure 6. Photomicrograph of feldspar porphyry about 50 m west of County Highway Y. Foliation trends from left to right. Note rectangular shape of feldspar phenocrysts and lack of rotation into the plane of foliation of some phenocrysts. Field of view approximately 30 mm.

tuffs, then a significant layer-parallel fabric may have existed in these rocks prior to folding. At the present time no unequivocal evidence of isoclinal folding has been found, but felsic veins in schist are tightly folded. Mineral lineation is poorly developed in most of the rocks at this locality. Mineral lineation trends N 45° E and plunges 75-85°.

Foliation wraps around garnet (fig. 9 in Maass, 1983) and andalusite and amphibole are aligned parallel to foliation. These features suggest that schist was subjected to medium-grade synkinematic metamorphism. Thorough recrystallization of the previously described nearly unfoliated mafic dike suggests that metamorphism outlasted deformation or that the area was subjected to a younger metamorphic event (see Eau Claire Dells Area Discussion).

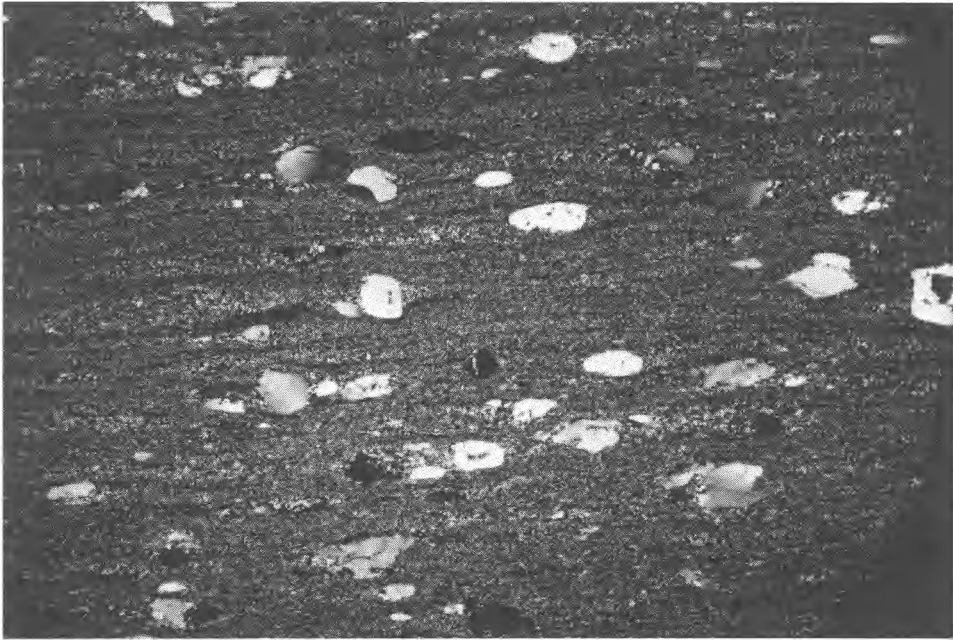


Figure 7. Photomicrograph of quartz porphyry near footbridge at west end of park. Crystal faces and embayment texture are preserved in one of the phenocrysts (for close-up see fig. 8 in Maass, 1983). Field of view is approximately 30 mm.

Stop 6

Title: Eau Claire Dells Area - contact between mafic schist and Wolf River granite

Location: North side of a gravel road, 1 km east of County Highway Y. SE¼, SE¼, Sec. 7, T. 29 N., R. 10 E. (Hatley 7.5-minute topographic quadrangle). See Stop 5 for location map.

Author: R. S. Maass (1986)

Description: Mafic schist and Wolf River granite crop out near each other on the north side of a gravel road, a short distance beyond the southeast corner of Eau Claire Dells County Park. Mafic schist is exposed in a low area to the west of a hill of granite. The distance between exposures of the two rock-types is a few tens of meters. Wolf River granite is a member of the 1485 Ma Wolf River Batholith (Van Schmus and others, 1975).

Foliated and lineated schist consists of andesine (An_{39-41}), hornblende, quartz, clinopyroxene, magnetite, and cummingtonite, in decreasing order of abundance. Also present are small to trace quantities of carbonate, chlorite, sericite, and apatite. Magnetite is present in such a large quantity that a compass is useless in the vicinity of schist.

Coarse-grained granite is undeformed, and foliation in schist at this locality is developed to approximately the same degree as foliation in schist kilometers away from the contact. Foliation and lineation in schist are interpreted to have formed prior to intrusion of granite. Of the studied rocks in the Eau Claire Dells area, recrystallization texture in schist is better developed at this locality than at any other locality, suggesting contact metamorphism by granite.

ATHENS AREA

Two very different interpretations have been presented for the tectonic history of the rocks in the vicinity of Athens. The first proposes the existence of a major tectonic boundary in the area. According to this hypothesis a north-northeast trending fault zone, referred to as the "Athens Fault zone," passes through the town of Athens (LaBerge and Palmer, 1980; Palmer, 1980; LaBerge and Myers, 1983, 1984, 1985). The fault zone is reported to sharply juxtapose rocks of dissimilar metamorphic grade and contrasting styles of deformation. The fault zone is reported to extend for a distance of over 100 km, and locally consists of zones of "felsic mylonite" nearly 3 km thick. Sims and Peterman (1983) consider the fault zone to be the southeastern margin of a zone of unusually intense early Proterozoic deformation that they term the "Milan shear zone."

According to LaBerge and Myers (1984), the rocks to the northwest of the fault constitute an early Proterozoic sequence that was metamorphosed to amphibolite facies and deformed during a pre-Penokean orogenic event. They suggest that the rocks to the southeast are younger, and that these younger rocks were metamorphosed to lower greenschist facies and deformed during the Penokean orogeny. According to their model, folding occurred about northwest trending axes in amphibolite facies rocks and about northeast trending axes in lower greenschist facies rocks.

In contrast to the preceeding hypotheses, the second interpretation does not recognize the presence of a major tectonic boundary, or any other form of major boundary, in the Athens area (Maass and others, 1985). The rocks in the vicinity of Athens are considered to be a sequence of Penokean volcanic rocks with minor interbedded sedimentary rocks that has been intruded by Penokean plutonic rocks. These rocks are proposed to have been subjected to regional Penokean deformation and metamorphism shortly after their formation. Metamorphic grade is interpreted to change gradually and continuously from greenschist to amphibolite facies. The folding history is interpreted to be essentially identical in all rocks of the area. Rocks mapped as mylonites by other workers are instead considered to be regionally deformed and metamorphosed volcanic rocks that have undergone approximately the same type and amount of strain as surrounding rocks.

Discussion

The majority of the rocks exposed in the Athens area are variably deformed and metamorphosed felsic, intermediate and mafic volcanic rocks. Additional rock types present include deformed and metamorphosed volcanogenic sedimentary rocks, synkinematic to post-kinematic tonalite to granite plutons, and metagabbro (Palmer, 1980; LaBerge and Palmer, 1980; LaBerge and Myers, 1983). Volcanic textures are well-preserved in greenschist facies rocks, and relict volcanic phenocrysts are recognizable in some of the amphibolite facies rocks (Stops 9 and 16) located a short distance upgradient of greenschist facies rocks. Relatively fine grain size, combined with abundance of mafic layers and absence of pelitic and calcareous layers, suggests that many of the highest-grade rocks were also originally volcanic rocks.

Mineral assemblages in rocks of mafic and intermediate composition indicate that the northwestern part of the area is metamorphosed to amphibolite facies and the southeastern part to greenschist facies. Recrystallization

textures (figs. 9, 11, 15, and 16) suggest a gradual and continuous decrease in metamorphic grade from northwest to southeast. The limited metamorphic data that exist for the Athens area suggest that the zone of transition from greenschist facies to amphibolite facies strikes parallel or nearly parallel to the strike of lithologic layering and foliation.

Penetrative foliation and mineral lineation are consistent in orientation throughout the entire Athens area (fig. 8, this report; Palmer, 1980; plate 1 in LaBerge and Myers, 1983), as are axes of folds of unidentified style (fig 48 in Palmer, 1980). Foliation is parallel to lithologic layering, striking northeasterly and dipping steeply to the northwest. Foliation is interpreted to be the product of isoclinal folding because it is axial-planar to isoclinal folds where they have been observed, such as at Goodrich Dells (Stop 7). Penetrative mineral lineation is readily identified at most outcrops and is prob-

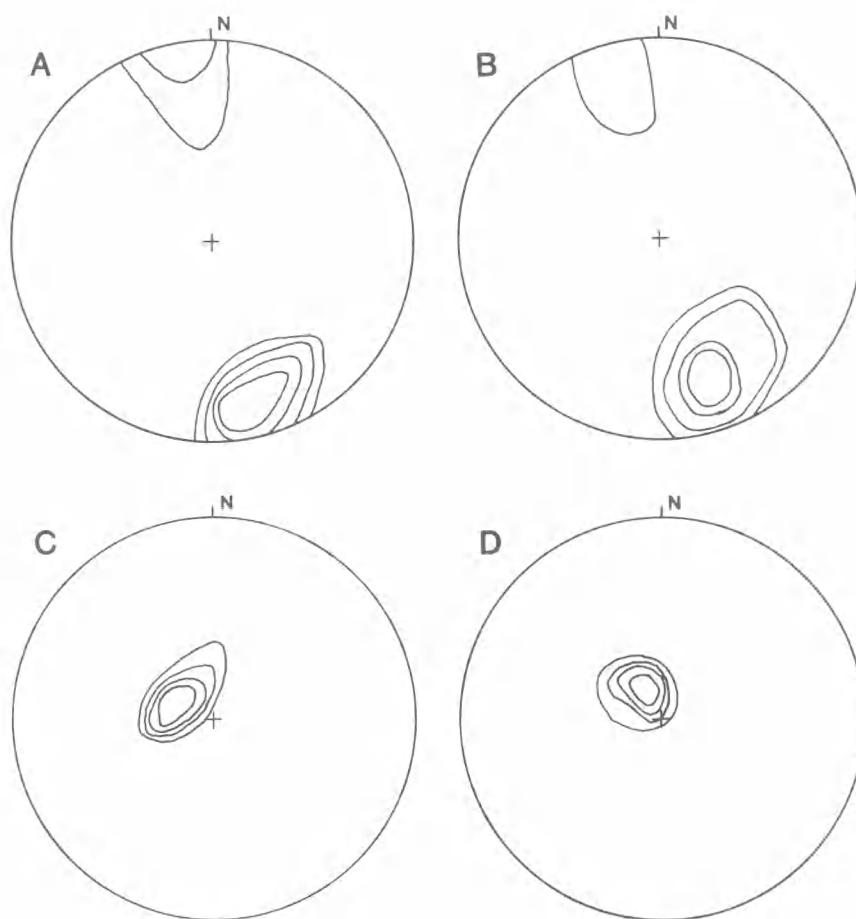


Figure 8. Structural elements in amphibolite-facies and greenschist-facies rocks in the vicinity of Athens, Wisconsin (after Palmer, 1980). A) Poles to foliation in amphibolite-facies rocks, 79 measurements. B) Poles to foliation in greenschist-facies rocks, 269 measurements. C) Mineral lineation in amphibolite-facies rocks, 54 measurements. D) Mineral lineation and clast elongation in greenschist-facies rocks, 27 measurements. Contour intervals in percent per 1% area: A and B, 10, 20, 25, 35; C and D, 5, 15, 25, 35.

ably present at all outcrops. At a number of outcrops mineral lineation is better developed than foliation. Mineral lineation may be the product of isoclinal folding, but supporting data are not yet available.

The gradual and continuous change in metamorphic grade from amphibolite facies to greenschist facies indicates that the Athens area was subjected to a single regional metamorphic event. The essentially identical orientation of foliation, mineral lineation, and fold axes in both amphibolite facies rocks and greenschist facies rocks suggests that deformation in rocks of both facies occurred at the same time (Palmer, 1980, p. 112; Maass and others, 1985). Van Schmus (1984; written commun., 1985) has obtained a U-Pb zircon age of 1846 ± 18 Ma for a sample of "tonalite gneiss" located a short distance southeast of Goodrich Dells (see Stop 7). This age, in conjunction with local and regional structural and metamorphic data, suggests that the rocks in the Athens area were deformed and metamorphosed during the Penokean orogeny.

No evidence has been found that would support the existence of the "Athens Fault" of LaBerge and Palmer (1980) and LaBerge and Myers (1983, 1984, 1985), or the "Milan Shear Zone" of Sims and Peterman (1983). Structural style is identical throughout the Athens area with the exception that structures are best developed in the highest grade rocks. No major lithologic break has been recognized in the vicinity of the postulated fault; mafic to felsic volcanic rocks are present in the northwestern and southeastern parts of the area.

LaBerge and Myers (1983, 1984) report that their fault sharply juxtaposes amphibolite facies rocks in the northwestern part of the area with lower greenschist facies rocks in the southeastern part of the area. Near the town of Athens a gap of nearly 3 km exists between exposure of documented amphibolite facies rock (Stop 11) and probable greenschist facies rock (Stop 12). Along the Big Rib River the distance between documented amphibolite facies rock (Stop 16) and documented greenschist facies rock (Stop 18) is slightly over 4 km. Recrystallization texture of schist located halfway between Stops 16 and 18 (Stop 17) is suggestive of metamorphism to an intermediate grade, but too little is known about the rocks at this locality to definitively assign metamorphic grade. No mineral assemblages have been found that are diagnostic of lower greenschist facies. At Athens County Park, located 1.2 km southeast of the fault of LaBerge and Myers (1983, plate 1), electron microprobe analysis of coexisting amphibole and plagioclase in a mafic rock indicates that this locality has been metamorphosed to amphibolite facies rather than to lower greenschist facies.

As part of their Athens Fault, LaBerge and Myers (1983, plate 1) map a wedge-shaped zone of "felsic mylonite" over 10 km long and up to 3 km wide, starting in Athens and extending to the northeast. Rocks within this zone are interpreted to be deformed and metamorphosed felsic volcanic rocks rather than mylonite. There are a number of reasons for reaching this conclusion. Most importantly, foliation is only poorly to moderately well-developed in these rocks (figs. 10 and 13) and it is developed to the same degree as in rocks outside of the fault zone. Thin to thick layers that lack megacrysts should be extreme examples of ultramylonite if these rocks are mylonite, yet these layers commonly exhibit poorly developed foliation. Rather than being lensoidal, feldspar phenocrysts are blocky to rectangular with well-preserved crystal faces in many cases, and feldspar phenocrysts are commonly not rotated into the plane of foliation. Glomeroporphyritic texture, characteristic of

volcanic rocks, is present in some of the rocks. Ribbon quartz that should be present in mylonite is absent.

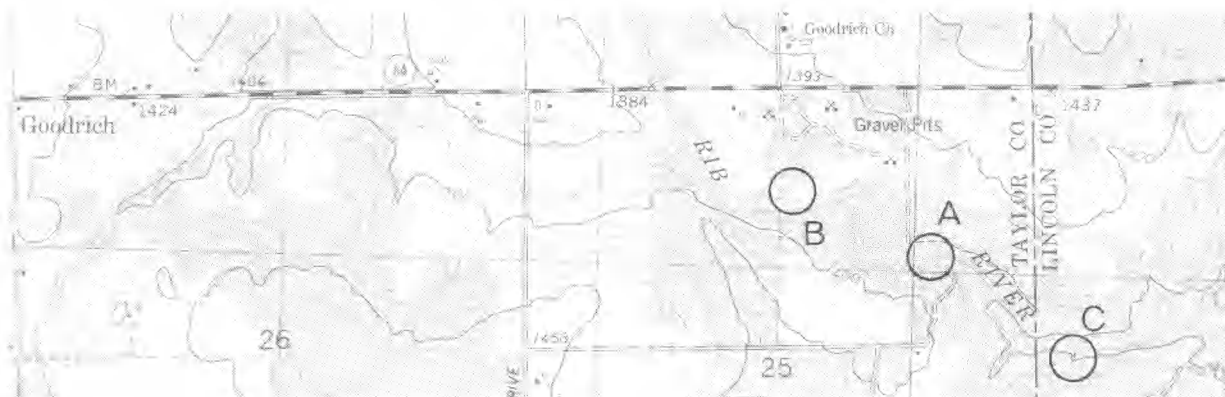
The Athens Fault is reported to transect undeformed granites to the southwest and northeast of Athens (LaBerge and Myers, 1983, 1985). Preliminary examination of granites located approximately 15 km southwest of Athens suggests that there may be two granites in this vicinity, one synkinematic and one very late kinematic. Compelling evidence for a fault contact rather than an intrusive contact between these granites has not been observed. To the northeast of Athens the fault forms the southern margin of a "granodiorite" body located 15-20 km from Athens. Because no outcrop is present in the vicinity of the southern edge of the granodiorite body (LaBerge and Myers, 1983, plate 1), it seems that it would be difficult to establish that the southern boundary is a fault contact rather than an intrusive contact. As mapped by LaBerge and Myers this fault is truncated by "volcanogenic metasedimentary rocks" that they interpret to be older than the granodiorite. This relationship is difficult to explain.

All data suggest that there is not a major boundary of any type in the Athens area. In addition, the data are inconsistent with the two-orogeny hypothesis of LaBerge and Myers (1984), which proposes that the rocks in the northwestern part of the area were deformed and metamorphosed during a pre-Penokean orogeny. It is proposed that the rocks in the Athens area represent a sequence of Penokean volcanic rocks that were intruded by synkinematic to very late kinematic Penokean plutonic rocks. Deformation and metamorphism is interpreted to have occurred during the Penokean orogeny.

Stop 7

Title: Goodrich Dells - gneisses

Location: Gneiss is exposed in three areas along the Big Rib River near Goodrich. The field trip stop (locality A) is at "dells" in the river that rise about 3-4 m above water level. Access is via a dirt road and a dirt path off of State Highway 64. The field trip stop is in the SE¼, NE¼, Sec. 25, T. 31 N., R 3 E. (Goodrich 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Fine-grained felsic to mafic banded gneiss and medium-grained massive tonalitic gneiss crop out in the "Goodrich Dells" area. The gneisses consist of varying proportions of quartz, plagioclase, alkali feldspar, biotite, and hornblende. A layer of mafic gneiss at locality C is garnet-rich. Massive tonalitic gneiss contains xenoliths of banded gneiss, and deformed intrusion breccia is present locally (c.f. fig. 4 in LaBerge and Myers, 1983).

Banded gneiss and massive tonalitic gneiss possess a poorly developed to moderately well-developed penetrative foliation. Foliation is axial-planar to isoclinal folds in banded gneiss, and to tight folds of the contact between banded gneiss and massive tonalitic gneiss. Foliation strikes approximately N 60° E and dips 70-80° NW. Very well-developed penetrative mineral lineation in both types of gneiss trends N 47° W and plunges 68°.

The rocks in the Goodrich Dells area have been metamorphosed to amphibolite facies. A sample of mafic gneiss from locality C consists of approximately 40% oligoclase-andesine (An_{28-32}), 35% hornblende, 15% biotite, 10% quartz, minor quantities of apatite and an opaque mineral, and trace quantities of allanite and zircon. Recrystallization texture is extremely well-developed (fig. 9).

Banded gneiss is interpreted to have formed primarily, or perhaps exclusively, from felsic to mafic volcanic rocks. This interpretation is based on abundance of layers of mafic composition, lack of pelitic or calcareous layers, and relatively fine grain-size of banded gneiss. Massive tonalite gneiss

represents a deformed plutonic rock. It is similar to Penokean plutonic rocks of Wisconsin that have elsewhere been referred to as "foliated tonalite" (Maass and others, 1980; Van Schmus, 1980, 1984; Maass, 1983). It differs only in being slightly more deformed and slightly better recrystallized.

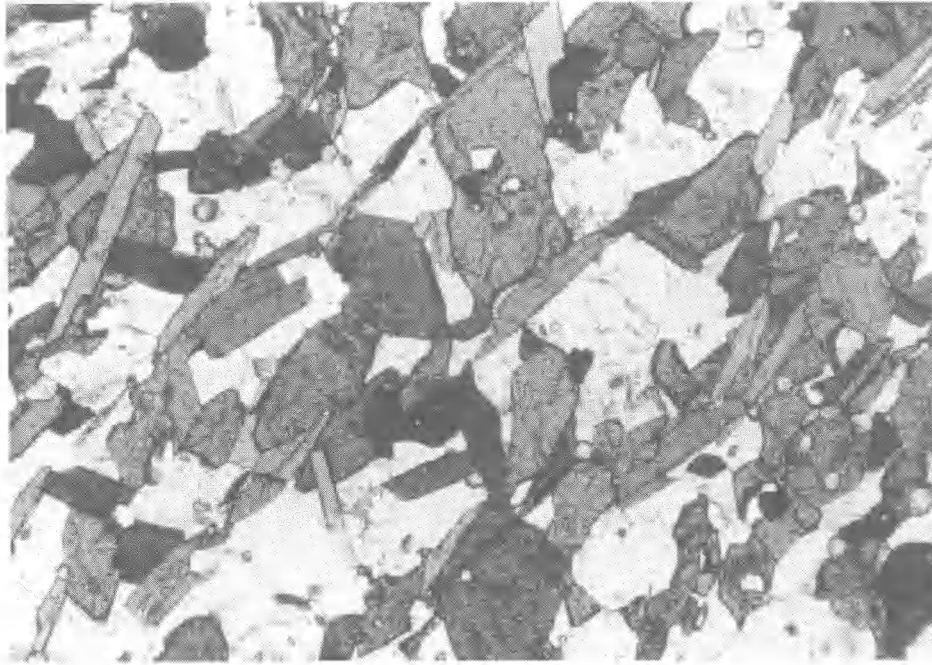
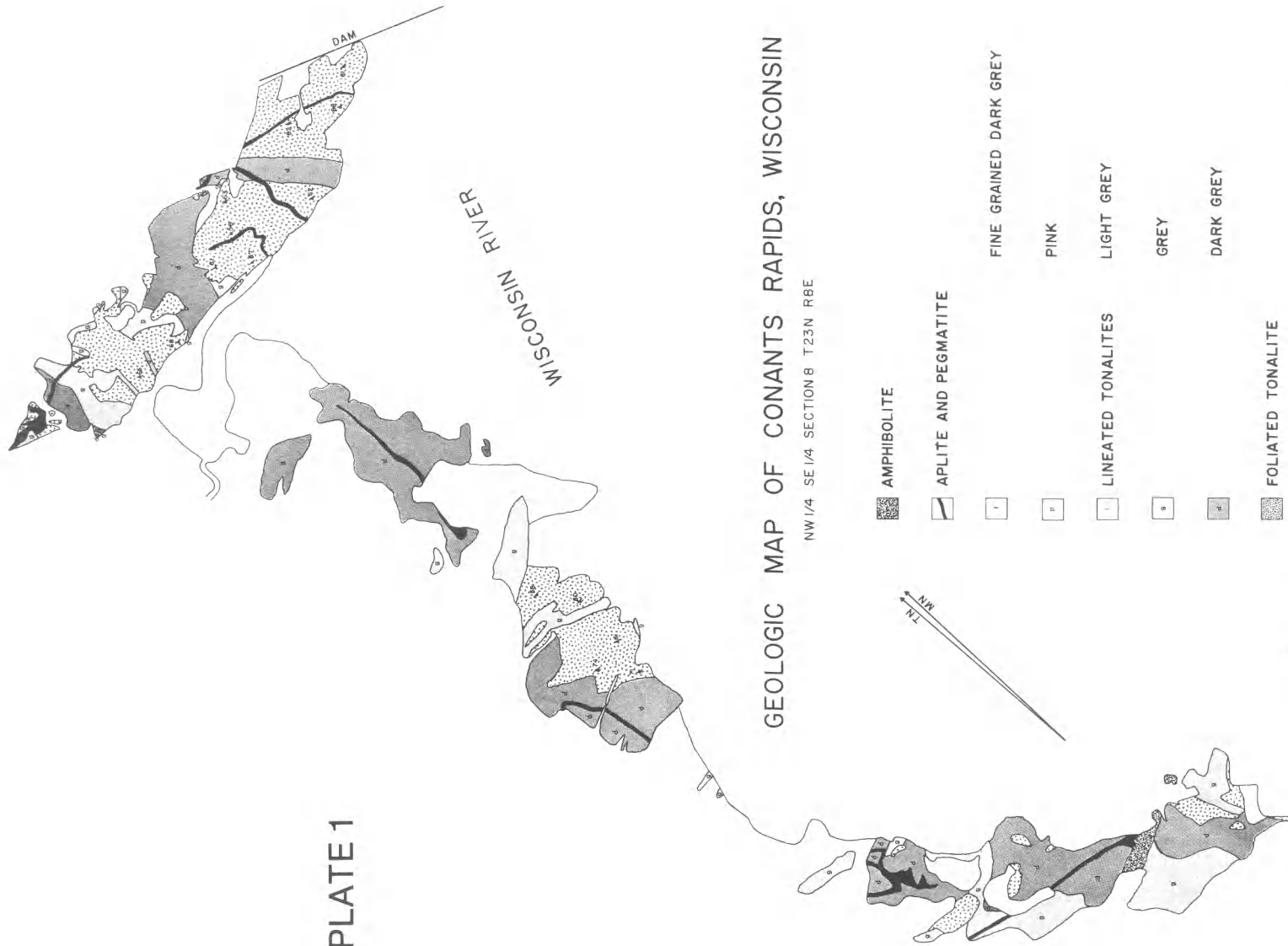


Figure 9. Photomicrograph of mafic gneiss at Goodrich Dells (locality C). Field of view 2.4 mm. Plane polarized light.

A tonalitic rock from the east side of a gravel road near a gravel pit 2 km southeast of the field trip stop (SE¼, SE¼, Sec. 30, T. 31 N., R. 4 E.) has yielded a U-Pb zircon age of 1846 ± 18 Ma (Van Schmus, 1984). The dated rock is described by W. R. Van Schmus (written communication, 1985) as "tonalite gneiss." The age suggests that deformation and metamorphism in the Goodrich Dells area occurred during the Penokean orogeny.

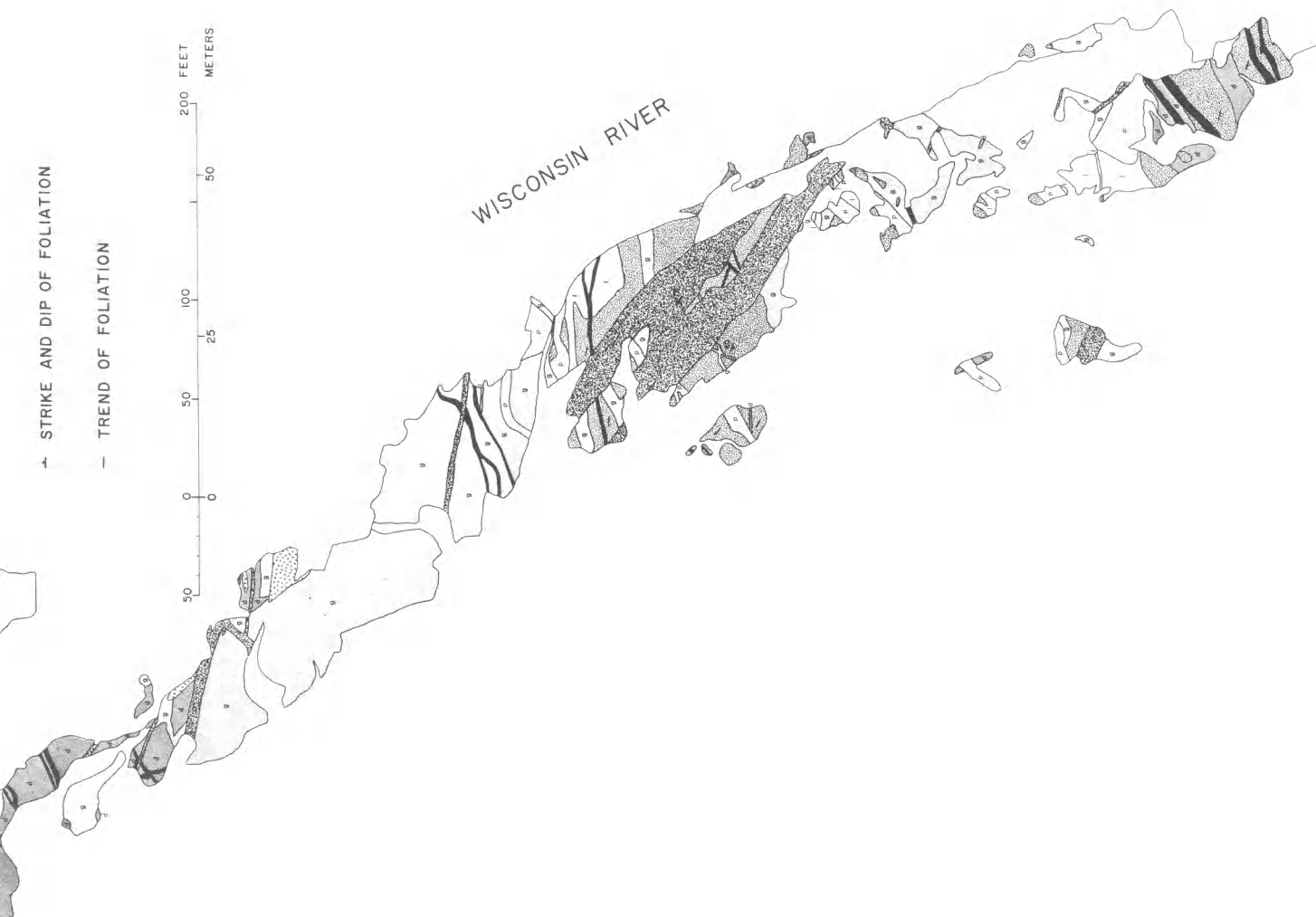
PLATE 1



GEOLOGIC MAP OF CONANTS RAPIDS, WISCONSIN

NW 1/4 SE 1/4 SECTION 8 T23N R8E

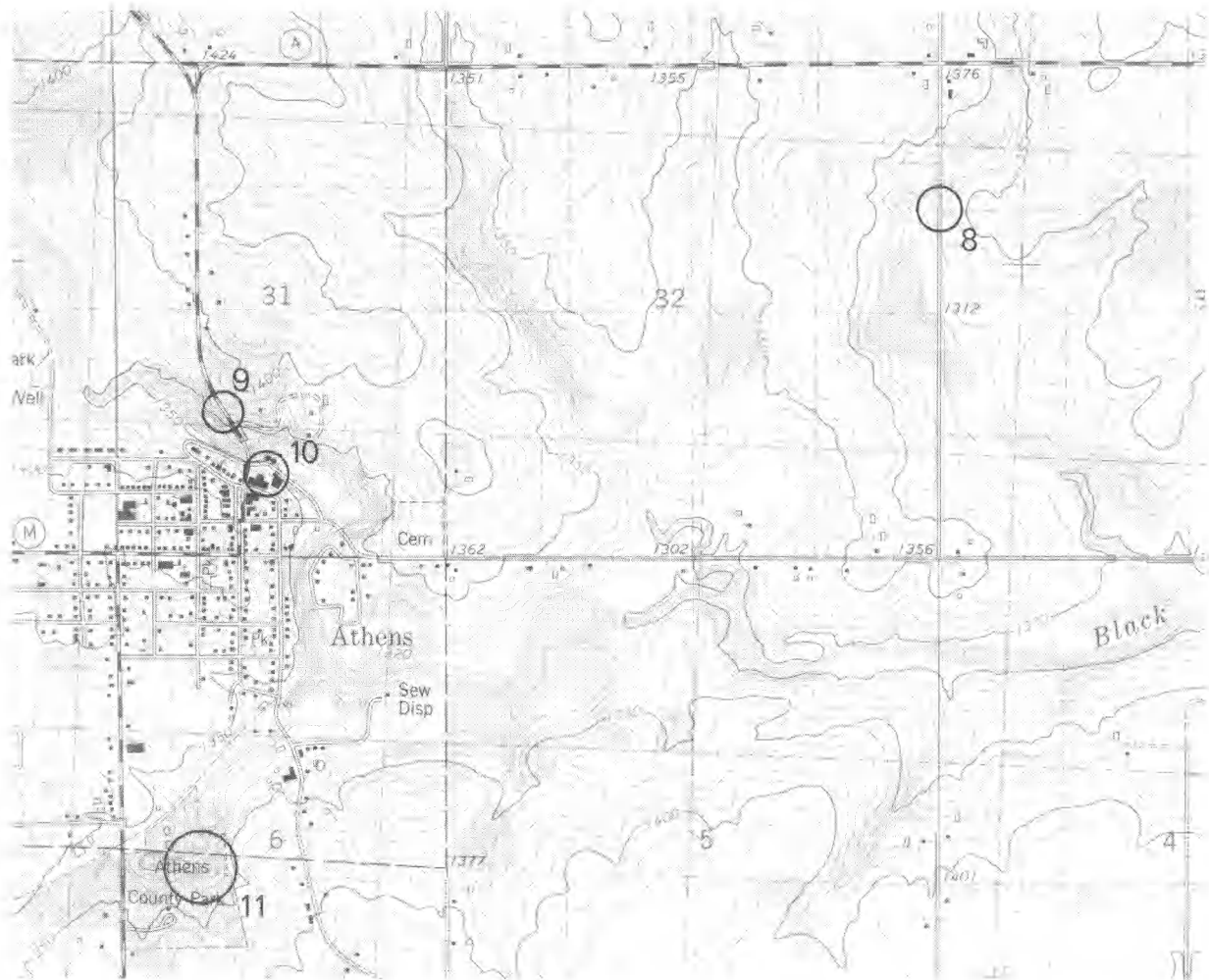
- AMPHIBOLITE
- APLITE AND PEGMATITE
- FINE GRAINED DARK GREY
- PINK
- LINEATED TONALITES
- LIGHT GREY
- GREY
- DARK GREY
- FOLIATED TONALITE



Stop 8

Title: Nehrbass Road, northwest of Athens - felsic schist of volcanic origin

Location: A small outcrop of felsic schist is present on the east side of Nehrbass Road, about 0.5 km south of County Highway A. Felsic schist is also present in the form of small blocks of rubble in a field on the west side of the road, SW¼, NW¼, Sec. 33, T. 30 N., R. 4 E. (Athens 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Very fine-grained foliated and lineated felsic schist at this locality is interpreted to be derived from porphyritic and nonporphyritic felsic volcanic rocks. The primary constituents of schist are quartz, microcline, and albite. Biotite and muscovite are present in moderate to minor amounts. Layering, ranging in width from a millimeter to about a meter, is defined by compositional differences, grain-size differences, and presence or absence of phenocrysts. Sparse to abundant albite phenocrysts up to 3 mm in

diameter are present in porphyritic layers. Average grain size of matrix minerals is 0.1-0.02 mm. Feldspar staining of three samples of porphyritic schist suggests that two are rhyolitic and one is dacitic.

Felsic schist at this outcrop is in the center of a wide zone of "felsic mylonite," as mapped by LaBerge and Myers (1983, plate 1). Felsic schist is interpreted to represent metamorphosed and moderately deformed volcanic rocks rather than mylonite for the following reasons: (1) foliation is relatively poorly developed and plagioclase phenocrysts have commonly not been rotated into the plane of foliation (fig.10); (2) plagioclase phenocrysts are generally blocky to rectangular and possess relict crystal faces; (3) glomeroporphyritic texture is present; and (4) "ribbon quartz" is absent. Uniformly fine-grained layers would have to represent extreme development of ultramylonite if the rocks at this locality are mylonite, yet these layers are no more foliated than adjacent layers containing megacrysts. Because foliation wraps around plagioclase phenocrysts their shape and orientation is not attributed to post-kinematic metamorphic growth.

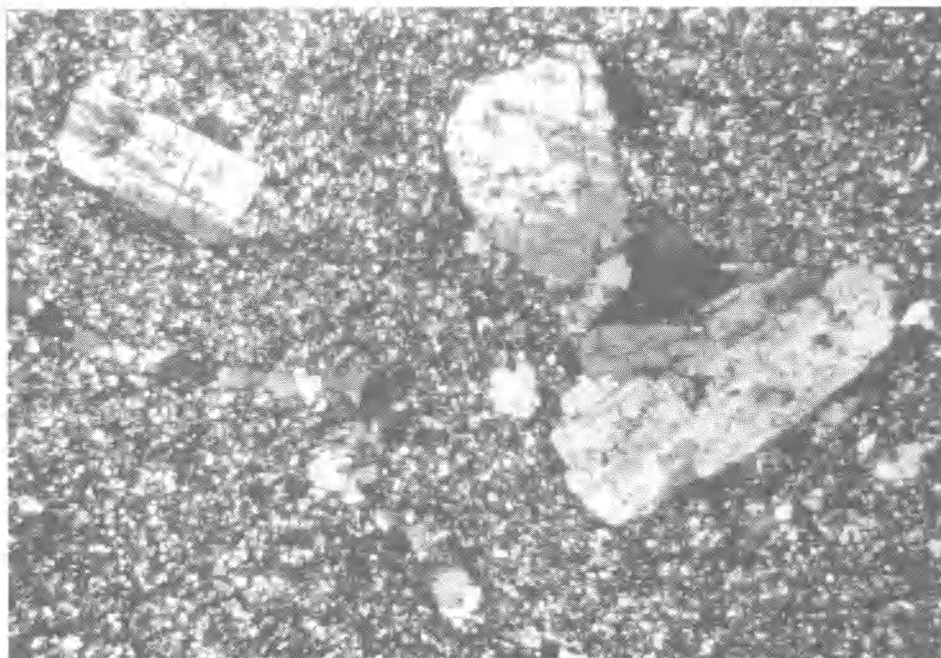


Figure 10. Photomicrograph of felsic schist. Foliation is poorly developed, phenocrysts have relict crystal faces, and phenocrysts have not been fully rotated into the plane of foliation. Field of view 6 mm.

Stop 9

Title: Black Creek, North edge of Athens - schist

Location: Outcrop is present along the north bank of Black Creek, approximately 150 m upstream of the State Highway 97 bridge over Black Creek. An abandoned dam along Black Creek marks the upstream end of the outcrop. Walk to the west from Highway 97, starting approximately 150 m north of the bridge. NW¼, SW¼, Sec. 31, T. 30 N., R. 4 E. (Athens 7.5-minute topographic quadrangle). See Stop 8 for location map.

Author: R. S. Maass (1986)

Description: A moderate-size outcrop of fine-grained schist of felsic, intermediate, and mafic composition crops out as a nearly vertical face along the north bank of Black Creek. Texture of schist and presence of mafic layers suggest that it represents deformed and metamorphosed volcanic rocks. A medium- to coarse-grained mafic rock that may be a metamorphosed gabbro is also present.

Layering in schist, defined by compositional and textural differences, ranges in width from a few tens of centimeters to a few meters. Layering, and layer-parallel foliation, strikes N 65° E and dips 70° NW (Palmer, 1980; LaBerge and Myers, 1983). Foliation varies from poorly developed to moderately well-developed. Penetrative mineral lineation trending N 58° W and plunging 71° (Palmer, 1980) is commonly better developed than foliation.

One of the most felsic layers of schist is rhyolitic in composition. It is primarily composed of microcline, quartz, untwinned plagioclase, biotite and muscovite. Sphene, apatite, zircon, allanite, and an opaque mineral are present in minor to trace quantities. This layer contains sparse microcline phenocrysts up to 3 mm in diameter in a matrix with an average grain size of 0.1 mm.

A felsic layer of schist with prominent bimodal grain-size distribution consists of albite (An_{5-10}) and quartz phenocrysts in a matrix of albite, quartz, alkali feldspar, chlorite, biotite, allanite, zircon, apatite, epidote, and an opaque mineral. Albite and quartz phenocrysts in a ratio of 4:1, respectively, constitute approximately 40% of this layer. Albite phenocrysts reach 5 mm in diameter and quartz phenocrysts are as large as 3 mm in diameter. Average grain-size of matrix minerals is 0.05 mm. This layer of schist contains only about 1% alkali feldspar and the protolith is interpreted to be an alkali feldspar-poor dacite. In a thin section oriented normal to mineral lineation, albite phenocrysts are blocky to rectangular and commonly possess one or more relict crystal faces. Quartz phenocrysts are not single grains, but are instead multigranular aggregates of quartz that are considered to represent the product of deformation and recrystallization of single grains. In support of this interpretation, some of the multigranular aggregates have nearly straight margins on one or more sides that appear to represent relict crystal faces.

A sample of mafic schist is composed of approximately 70% dark-green amphibole, 15% quartz, 10% biotite, 2% plagioclase, and minor quantities of sphene, epidote, and an opaque mineral. Recrystallization texture is relatively well-developed (fig. 11). Mafic schist contains the amphibolite facies mineral pair hornblende-calcic oligoclase (fig. 12). Representative analyses of hornblende and plagioclase are presented in Table 1.

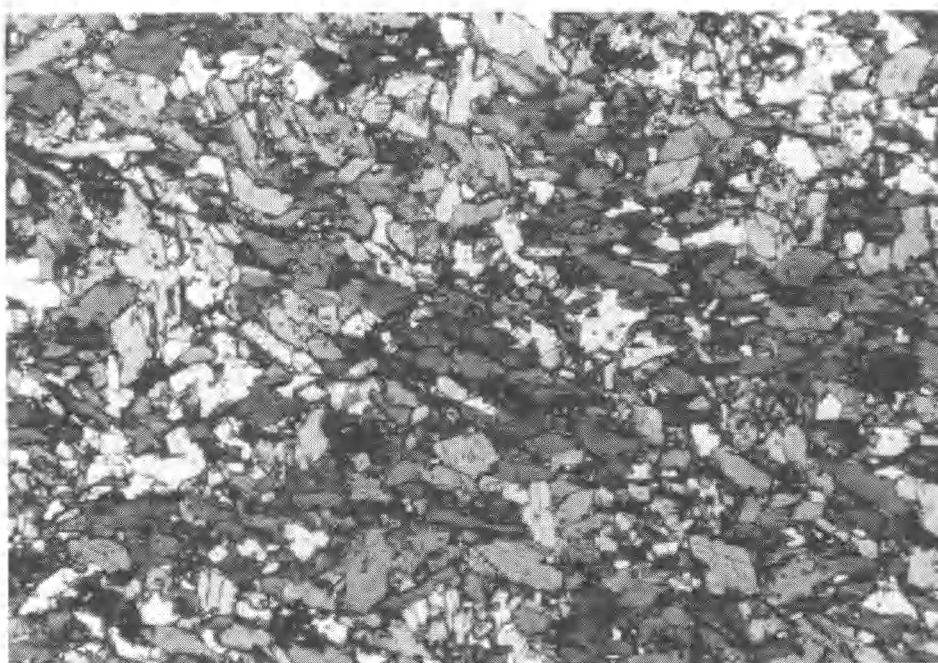


Figure 11. Photomicrograph of mafic schist. Field of view 2.4 mm. Plane polarized light.

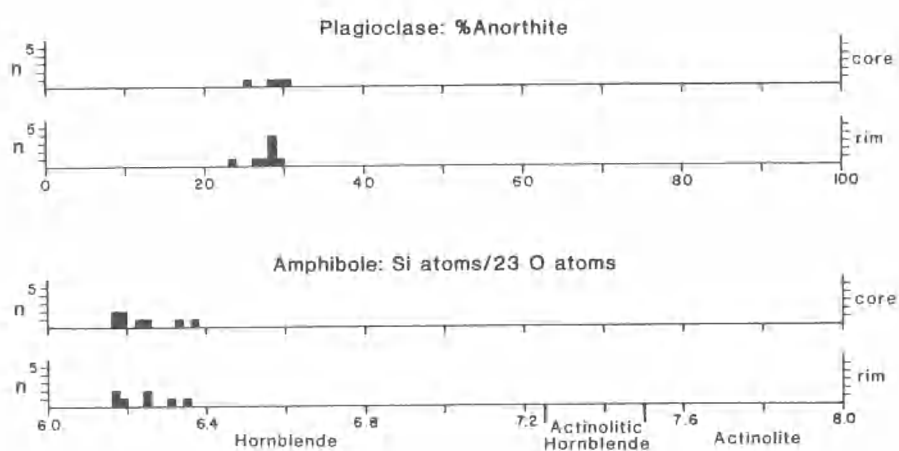


Figure 12. Electron microprobe analyses of coexisting amphibole and plagioclase in mafic schist. Sample ATH-5.

Stop 10

Title: Athens - felsic schist of volcanic origin

Location: A couple of small knobs of felsic schist crop out at the north end of the town of Athens, between a Midland Cooperative store and Black Creek. The exposures are approximately 50 m east of State Highway 97 and 50 m south of Black Creek. SE¼, SW¼, Sec. 31, T. 30 N., R. 4 E. (Athens 7.5-minute topographic quadrangle). See Stop 8 for location map.

Author: R. S. Maass (1986)

Description: Very fine-grained felsic schist of rhyolitic composition is composed of subequal amounts of quartz, microcline, and plagioclase, approximately 5% chlorite, 1% or less each of epidote, sphene, biotite, and an opaque mineral, and trace quantities of apatite, allanite, and zircon. Schist contains a moderate quantity of relict plagioclase phenocrysts (fig. 13) and rare megacrysts of microcline and quartz that probably also represent relict phenocrysts. Plagioclase phenocrysts reach 2 mm in diameter; average grain-size of matrix minerals is slightly less than 0.1 mm.

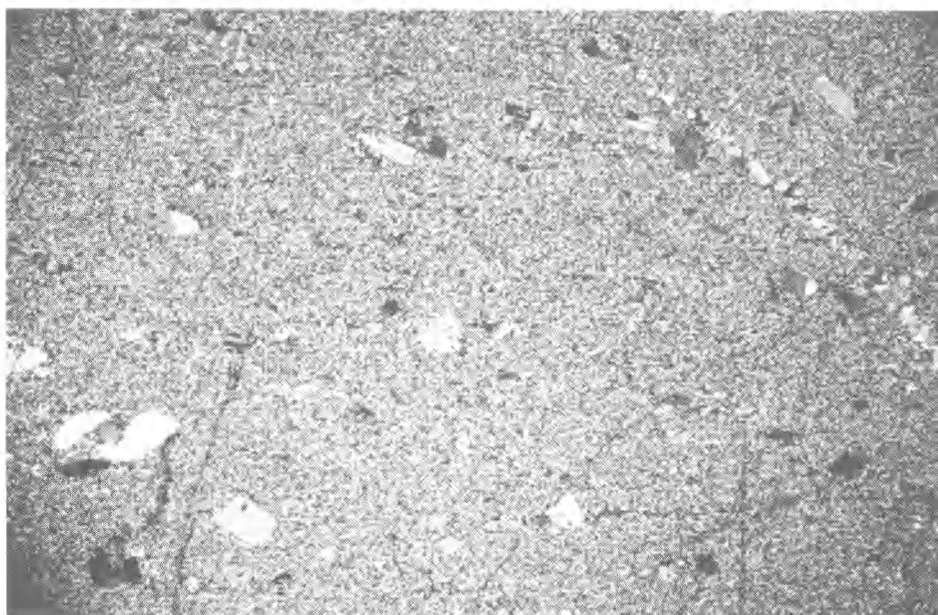


Figure 13. Photomicrograph of relict feldspar phenocrysts in felsic schist. Note poor development of foliation. Field of view approximately 30 mm.

Foliation in schist strikes roughly N 50° E and dips 62-67° NW, if the knobs of schist are in-place. Schist possesses a very faint steeply plunging mineral lineation. Because schist is structurally flanked by amphibolite facies rocks (Stops 9 and 11) it is interpreted to be metamorphosed to amphibolite facies.

Schist has been mapped as "felsic mylonite" by LaBerge and Myers (1983, plate 1) and used as a line of evidence for their proposed "Athens Fault zone" (LaBerge and Myers, 1983, 1984, 1985). Palmer (1980) has also suggested that a major fault is present in this vicinity. Schist is not considered to be mylonite for the following reasons: (1) foliation is only poorly to moderately well-developed and plagioclase phenocrysts are commonly not rotated into the plane of foliation (fig. 13); (2) plagioclase phenocrysts are generally blocky to rectangular rather than lensoidal; and (3) quartz "ribbons" are absent.

Stop 11

Title: Athens County Park - schist and amphibolite

Location: Schist crops out along Potato Creek in the northeastern quarter of Athens County Park. NW¼, SW¼, Sec. 6, T. 29 N., R. 4 E. (Athens 7.5-minute topographic quadrangle). See Stop 8 for location map.

Author: R. S. Maass (1986)

Description: Exposure of fine-grained schist of intermediate composition and fine-grained amphibolite occurs along Potato Creek in Athens County Park. Schist of intermediate composition greatly exceeds amphibolite in abundance. LaBerge and Palmer (1980, p. 43) report the presence of deformed felsic rocks in a small ravine to the east of a shelter in the park, and also a short distance northeast of the park boundary along Potato Creek. Poorly developed foliation in schist strikes N 70-80° E and dips 55-65° N. Mineral lineation plunging steeply to the northwest is moderately well-developed.

The main components of schist, in decreasing order of abundance, are oligoclase-andesine, biotite, quartz, hornblende, epidote, chlorite, and an opaque mineral. Grain size distribution is bimodal; hornblende and plagioclase megacrysts up to 1 mm in diameter are surrounded by matrix minerals that average 0.1--0.05 mm in diameter. Multigranular aggregates of quartz up to 2 mm in diameter are tentatively interpreted to represent the deformed and recrystallized remains of quartz megacrysts. Based on grain-size and composition, schist is interpreted to have formed from andesite or graywacke.

Amphibolite is composed of approximately 75% dark-green amphibole, 20% plagioclase, and minor amounts of epidote, chlorite, quartz, sphene, and an opaque mineral. The amphibolite facies mineral pair hornblende plus oligoclase-andesine is present (fig. 14). Recrystallization texture (fig. 15) is not as well developed as in amphibolite facies mafic schist at Stop 9 (c.f. fig. 13). The wide range of amphibole and plagioclase compositions in amphibolite suggests disequilibrium. Representative analyses of hornblende and plagioclase are presented in Table 1.

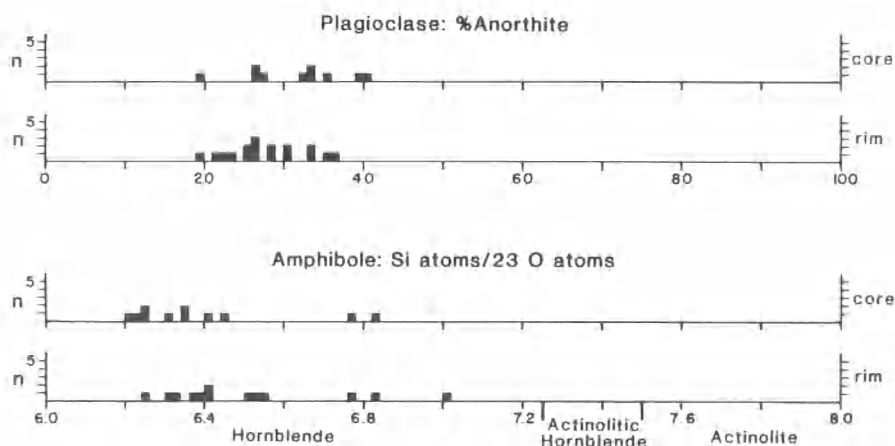


Figure 14. Electron microprobe analyses of coexisting amphibole and plagioclase in amphibolite. Sample ATH-8.

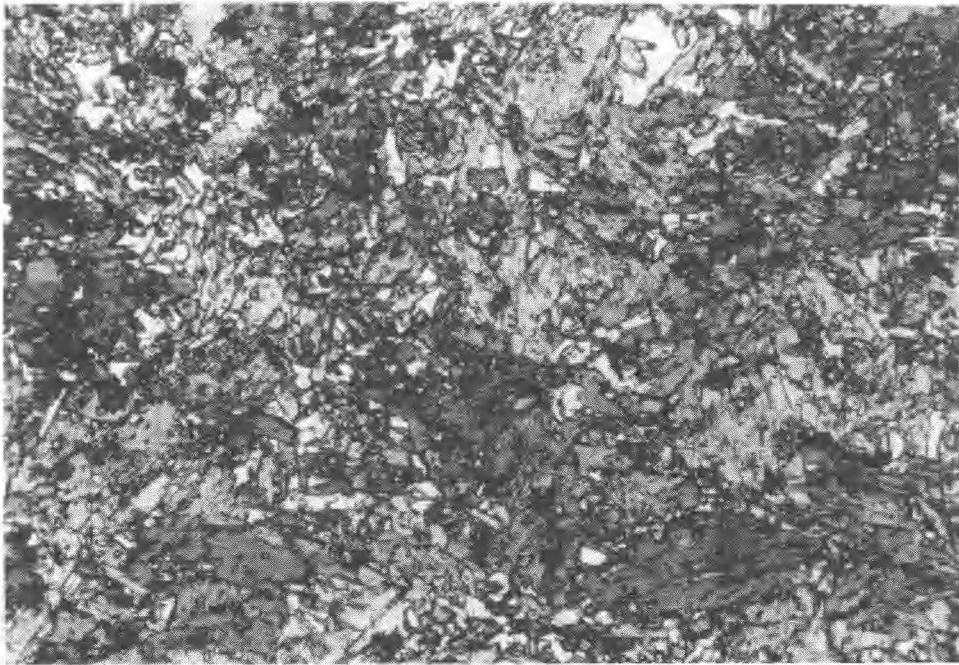
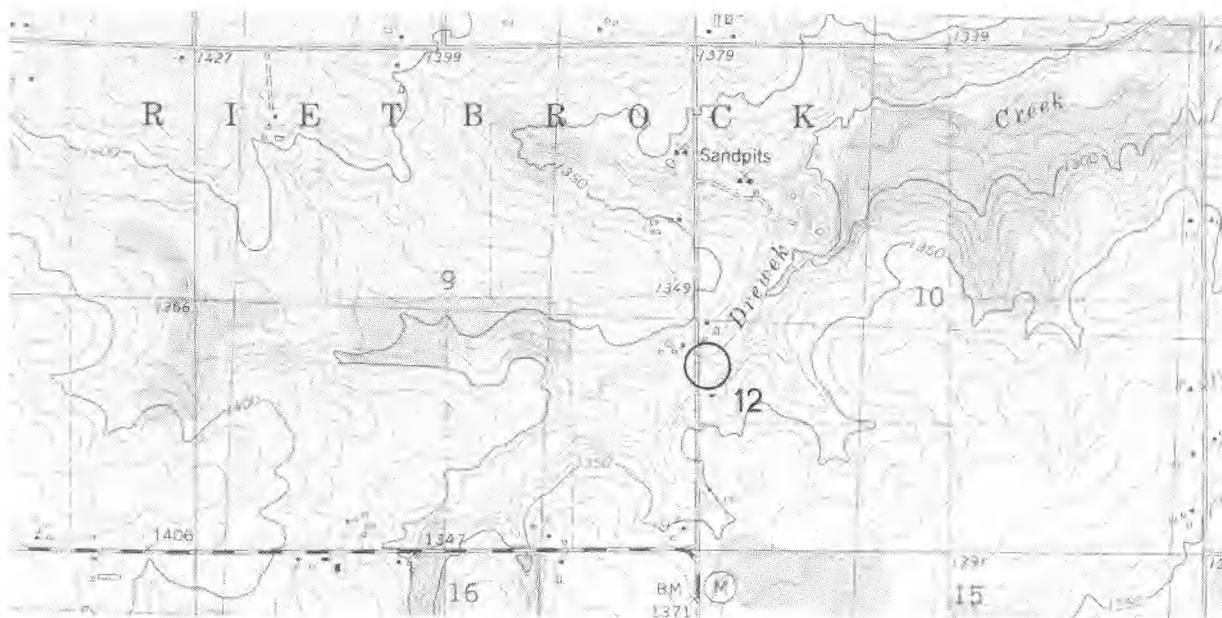


Figure 15. Photomicrograph of amphibolite. Field of view 2.4 mm. Plane polarized light.

Stop 12

Title: Drewek Creek - felsic schist

Location: North side of Drewek Creek, east side of a gravel road. About 5 km SE of Athens. NW¼, SW¼, Sec. 10, T. 29 N., R. 4E. (Athens 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Small outcrops of extremely fine-grained felsic schist of volcanic origin are present on the east side of the road on the north side of Drewek Creek. Schist occurs in both porphyritic and nonporphyritic varieties. Foliation strikes N 75° E and dips 80° N, and ellipsoidally-shaped deformed quartz phenocrysts define a mineral lineation that plunges steeply to the NW.

A specimen of a quartz and plagioclase phyric portion of schist contains approximately 10% quartz phenocrysts reaching 10 mm in diameter, and 2-3% albite phenocrysts up to 1 mm in diameter. The matrix consists of 70% albite plus quartz, 20-25% chlorite, 5-10% white mica, small quantities of alkali feldspar and an opaque mineral, and trace quantities of either zoisite or clinozoisite. Examination of the matrix using luminescence and EDS spectra on an electron microprobe indicates that the quartz to albite ratio in the matrix is 1:1 or greater. Average grain-size of matrix minerals is 0.01-0.05 mm.

Anorthite content of albite is 1.5-5.6%, as determined by electron microprobe analysis. Phenocrysts and matrix albite overlap in composition. As a result of the absence of a calcium-rich phase coexisting with plagioclase (except for a trace quantity of zoisite or clinozoisite), the composition of plagioclase is not considered to be useful for determination of metamorphic grade. However, the relatively poor recrystallization texture of schist (fig. 16) is strongly suggestive of greenschist facies metamorphism.

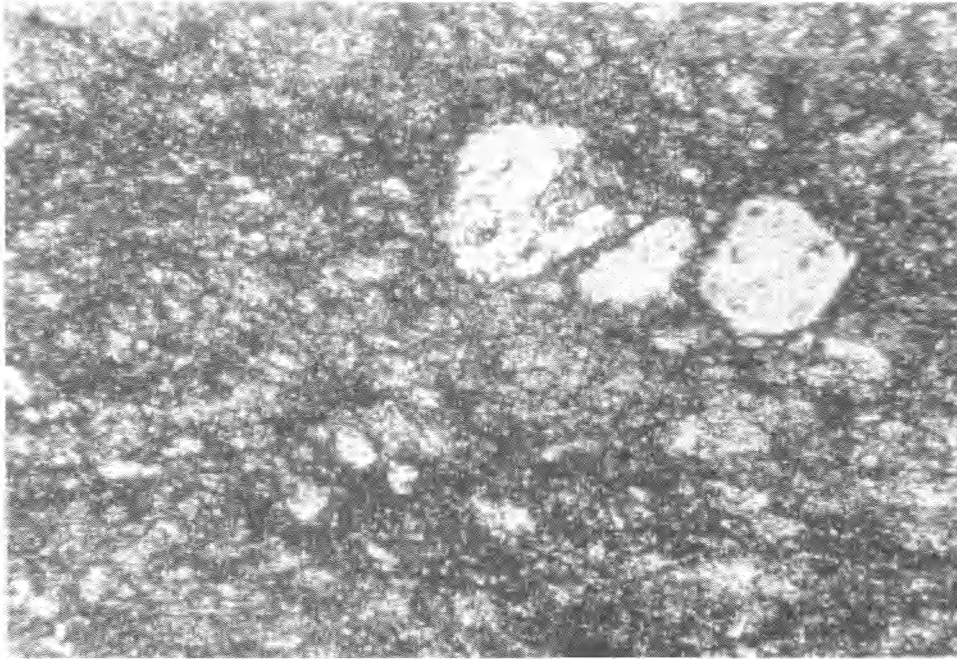


Figure 16. Photomicrograph of felsic schist. Relict feldspar phenocrysts in a quartz and feldspar phyric portion of schist. Matrix minerals are extremely fine-grained and poorly crystallized. Field of view 2.4 mm. Plane polarized light.

MARCH RAPIDS AREA

LaBerge and Myers (1984) have suggested that an unconformity exists in the March Rapids area near the Big Eau Pleine River in southwestern Marathon County. According to their general model the unconformity separates an early Proterozoic sequence of rocks metamorphosed to amphibolite facies during a pre-Penokean orogeny from an early Proterozoic sequence of rocks metamorphosed to lower greenschist facies during the Penokean orogeny. Folding is reported to have occurred about northwest trending axes in the older sequence, and about northeast trending axes in the younger sequence. Klasner and LaBerge (1985) have subsequently proposed that a shear zone, defined by the presence of breccia, may separate the two sequences. According to the above models the old sequence is present in the southern part of the area and the young sequence is exposed in the northern part of the area. On the basis of very preliminary work, Maass and others (1985) suggested that neither an unconformity nor a fault is necessary to explain the geology of the area.

Discussion

The oldest rocks in the vicinity of March Rapids are a series of volcanic rocks in the northern part of the area. Where these rocks are exposed, felsic compositions predominate over mafic compositions. It has not yet been determined whether volcanic rocks of intermediate composition are present in significant quantity. Following volcanism, the area was intruded by granitoid plutons that crop out in the southern portion of the area. A tonalite pluton northwest of March Rapids County Park (Stop 14) contains xenoliths of volcanic rock.

Isoclinal folding followed volcanism and plutonism and produced a penetrative cataclastic foliation in plutonic rocks that is axial-planar to isoclinal folds (Stop 14). Foliation produced during isoclinal folding of volcanic rocks may have also been cataclastic in nature, but these rocks were originally too fine grained to have developed readily recognizable cataclastic texture such as porphyroclasts or ribbon quartz. Metamorphism is interpreted to have accompanied isoclinal folding because amphibole is aligned parallel to the axial-plane of isoclinal folds. Granite mylonite east of March Rapids County Park (Stop 20) is proposed to represent a zone of high strain developed in association with isoclinal folding. Foliation in mylonite is similar in orientation to cataclastic foliation that is axial-planar to isoclinal folds at Stop 14, as well as being similar in orientation to foliation in all other rocks of the area. Recrystallization texture in mylonite is qualitatively the same as in the other deformed rocks of the area, suggesting that mylonite may have formed during regional synkinematic metamorphism. An andesitic dike at Stop 14 is post-kinematic.

Foliation is affected by mesoscopic open to tight folds at a number of outcrops, and large-scale folding of this type is suggested by variation in orientation between scattered exposures at a couple of outcrop areas. Mega-scopically open to tight folding on steeply plunging axes is proposed to be responsible for variation between outcrop areas.

Three samples of mafic schist contain hornblende, actinolitic hornblende, and actinolite coexisting with plagioclase (Stops 13, 14, 19). In all three samples, rims of amphibole are commonly more actinolitic than cores, but the reverse trend also occurs. In two of the samples optically distinct grain

boundaries between the three varieties of calcic amphibole do not exist. Actinolite and actinolitic hornblende are tentatively interpreted to represent retrograde products after hornblende. Based on this interpretation, two albite-bearing samples are metamorphosed to the transition zone between greenschist facies and amphibolite facies and an oligoclase- and andesine-bearing sample is metamorphosed to amphibolite facies. Based upon texture, the oligoclase- and andesine-bearing sample is only marginally higher-grade than the albite-bearing samples. If the three varieties of amphibole are prograde, then all three samples fall in the transition zone between greenschist and amphibolite facies. The above results are counter to the proposal of LaBerge and Myers (1984) that rocks metamorphosed to grades between lower greenschist facies and amphibolite facies are absent in central Wisconsin.

Evidence for late metamorphism occurs in the form of static metamorphism of an andesitic dike at Stop 14. The dike contains abundant epidote and minor chlorite. Static metamorphism of the dike may have occurred during the waning stages of the metamorphism described above, or could have occurred as a separate event. The possible retrograde metamorphism of schist may have likewise taken place during cooling or during a younger event.

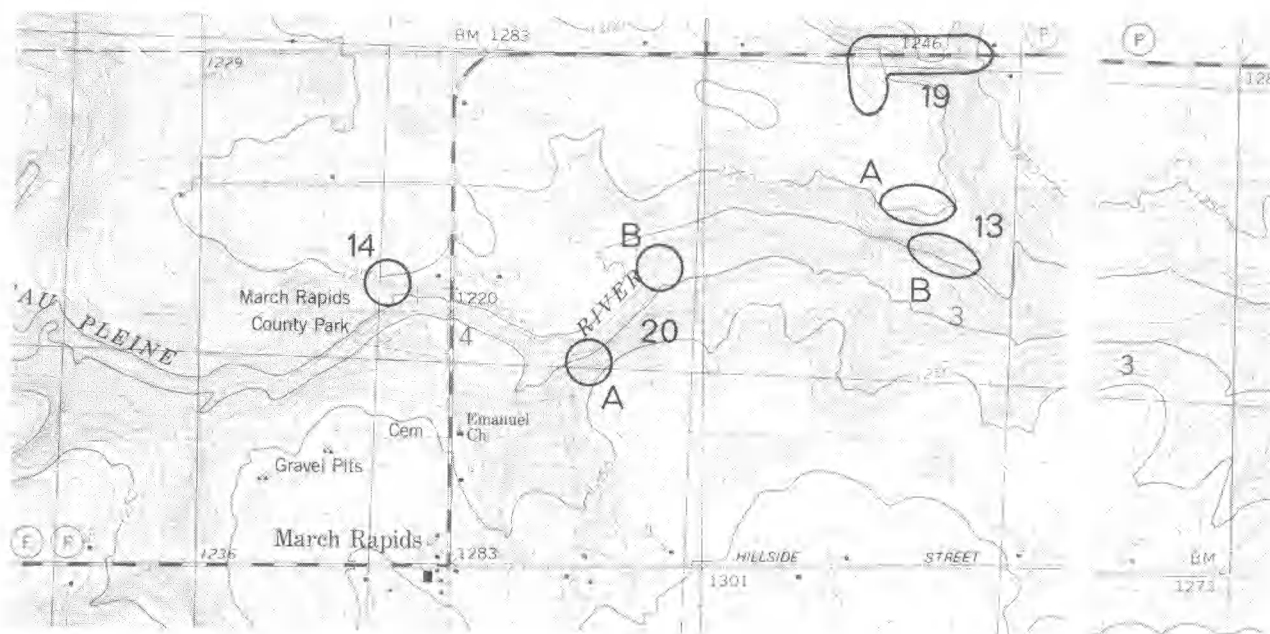
The present investigation has found no supporting evidence in the March Rapids area for the two-orogeny hypothesis of LaBerge and Myers (1983, 1984) that involves the presence of an unconformity in the area, or the same general hypothesis involving major faulting (Klasner and LaBerge, 1985). All rocks in the March Rapids area are interpreted to have been deformed and metamorphosed during the Penokean orogeny. No major break in metamorphic grade is recognized in the vicinity of the proposed unconformity or fault. According to the above models, the rocks in the southern part of the area are significantly older than the rocks in the northern part of the area. The current study concludes that the opposite age relationship exists. The rocks in the southern part of the area are interpreted to be plutonic rocks that are intrusive into volcanic rocks of the northern part of the area.

Breccia in felsic schist of volcanic origin along the Big Eau Pleine River (Stop 13) is used by Klasner and LaBerge (1985) as evidence for the presence of a brittle fault zone separating their proposed older and younger sequences. This breccia, and breccia in other schist of volcanic origin in the area, is interpreted to be volcanic breccia rather than fault breccia. This interpretation is based upon restriction of breccia to rocks of volcanic origin and to the absence of a zonal distribution of breccia. In addition, breccia is neither restricted to the vicinity of the proposed fault nor is it more common in this vicinity. Mylonite discovered during the present investigation is located well to the south of the contact between deformed plutonic rocks and schist and therefore does not separate the two rock types. As previously discussed, mylonite is interpreted to be the product of isoclinal folding rather than faulting. The ductile character of mylonite contrasts with the brittle character of breccia in schist, and the two are not considered to be related.

Stop 13

Title: March Rapids Area, quarry and river exposures - schist of volcanic origin

Location: Schist is exposed in a quarry (locality A) and along the north bank of the Big Eau Pleine River (locality B). Access to the quarry is via a gravel road located 3.3 km (2.1 mi) west of State Highway 97. An intermittent stream has to be crossed to reach the quarry. SE¼, NW¼, Sec. 3, T. 27 N., R. 3 E. (Little Rose 7.5-minute topographic quadrangle).



Author: R. S. Maass (1986)

Description: Very fine-grained felsic and mafic schist of volcanic origin crops out in the quarry. The majority of schist in the quarry is felsic in composition, but a few narrow layers and lenses of mafic schist are also present. Outcrops are small and widely scattered; most schist is in the form of rubble. Schist is locally brecciated. Average strike of layering and foliation is N 65-70° E with a very steep dip. Small-scale open to tight folds are present, and large-scale open to tight folding in the quarry is suggested by strikes as divergent as N 75° W and N-S in some of the scattered outcrops.

A sample of mafic schist from the quarry is composed of medium-green amphibole, plagioclase, epidote, sphene, allanite, and an opaque mineral. Amphibole is strained and exhibits undulatory extinction. Electron microprobe analysis indicates that plagioclase is albite, and amphibole is a mixture of hornblende, actinolitic hornblende, and actinolite (fig. 17). There is a general tendency for rims of amphibole grains to be more actinolitic than cores (fig. 17), but the reverse trend also occurs in a number of the analyzed grains. Optically distinct grain boundaries between the three varieties of

calcic amphibole do not exist. The mineral assemblage is considered to be indicative of metamorphism to the transition zone between greenschist and amphibolite facies (Turner, 1981; Maruyama and others, 1983) with a possible greenschist facies overprint. Representative amphibole and plagioclase analyses are presented in Table 1.

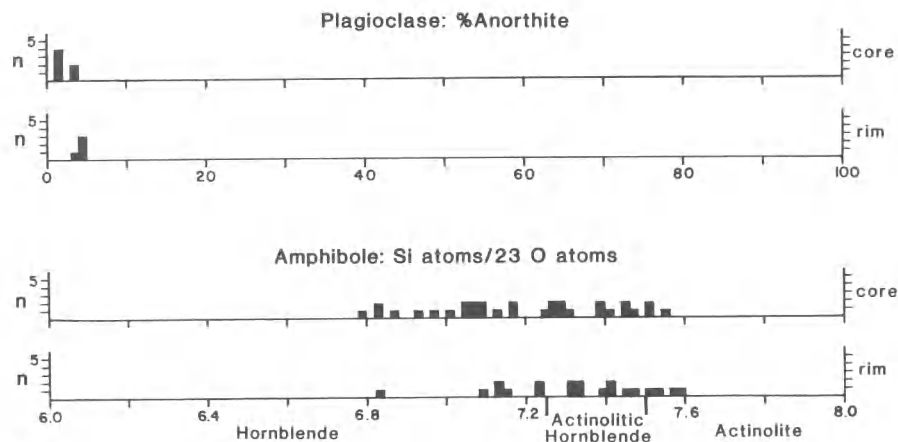


Figure 17. Electron microprobe analyses of coexisting amphibole and plagioclase in mafic schist. Sample March-6.

Felsic schist of the same variety as that in the quarry is discontinuously exposed for a distance of about 300 m along the north bank of the Big Eau Pleine River. Strike of layering varies from N 60° E to E - W to N 70° W. Layering dips 77-88° to the NW. There are a number of segments of schist that appear to have originally been volcanic breccia. This breccia has been interpreted by Klasner and LaBerge (1985) to be evidence for the presence of a northwesterly trending brittle fault zone (see March Rapids Area Discussion).

Stop 14

Title: Northwest edge of March Rapids County Park - foliated tonalite, schist, and an andesitic dike.

Location: The exposure is a short distance beyond the northwest corner of March Rapids County Park, along a hillside on the north side of the Big Eau Pleine River. SE¼, NW¼, Sec. 4, T. 27 N., R. 3 E. (Little Rose 7.5-minute topographic quadrangle). See Stop 13 for location map.

Author: R. S. Maass (1986)

Description: Medium-grained foliated tonalite containing xenoliths of mafic to felsic schist of volcanic origin crops out as small scattered exposures. Foliated tonalite is intruded by a narrow andesitic dike. Poorly developed to moderately well-developed penetrative foliation in tonalite, and within xenoliths of very fine-grained schist, strikes N 55-60° W and dips 70° NE. Foliation is axial-planar to isoclinally folded felsic veins in foliated tonalite and to isoclinal folds in layered schist. Foliation is affected by small-scale tight to open folds with steeply plunging axes. Both rock-types possess a penetrative mineral lineation that plunges steeply within the plane of foliation. The andesitic dike is not folded and does not have a preferred orientation of minerals.

Foliated tonalite consists of normally zoned plagioclase (An_{20-36}), quartz, amphibole, biotite, chlorite, microcline, epidote, sphene, apatite, allanite, and zircon. In addition to normal zoning, some plagioclase grains also exhibit faint oscillatory zoning. Plagioclase, especially in cores, is moderately to extensively sericitized and saussuritized. Amphibole is dark-green with locally developed blue-green rims. Penetrative cataclastic deformation of foliated tonalite has eliminated most crystal faces on feldspar and has caused granulation of quartz (fig. 18).

A sample of a mafic layer in a xenolith of schist contains medium-green amphibole, plagioclase, zoisite, epidote, sphene, biotite, and an opaque mineral. Amphibole coexisting with plagioclase is actinolite, actinolitic hornblende, and hornblende (fig. 19). Optically distinct grain boundaries between the three varieties of calcic amphibole are not present. If it is assumed that actinolite and actinolitic hornblende represent retrograde metamorphism of hornblende, then metamorphic grade is amphibolite facies because coexisting plagioclase is oligoclase and andesine (fig. 19). If all three phases of calcic amphibole are prograde, then metamorphism to the upper part of the transition zone between greenschist facies and amphibolite facies is suggested (Turner, 1981; Maruyama and others, 1983). Representative analyses of amphibole and plagioclase in schist are presented in Table 1. The possibility that schist has been affected by retrograde metamorphism receives some support from evidence of static metamorphism of the andesite dike at this locality (discussed below). In addition, rims on amphibole in foliated tonalite are potential evidence of retrograde metamorphism, although these might be metamorphic rims on igneous amphibole.

Foliated tonalite is interpreted to have undergone the same metamorphic history as the xenoliths of schist because the two rock types have been isoclinally folded together, and metamorphism is interpreted to be synkinematic with respect to isoclinal folding. The proposal that metamorphism was

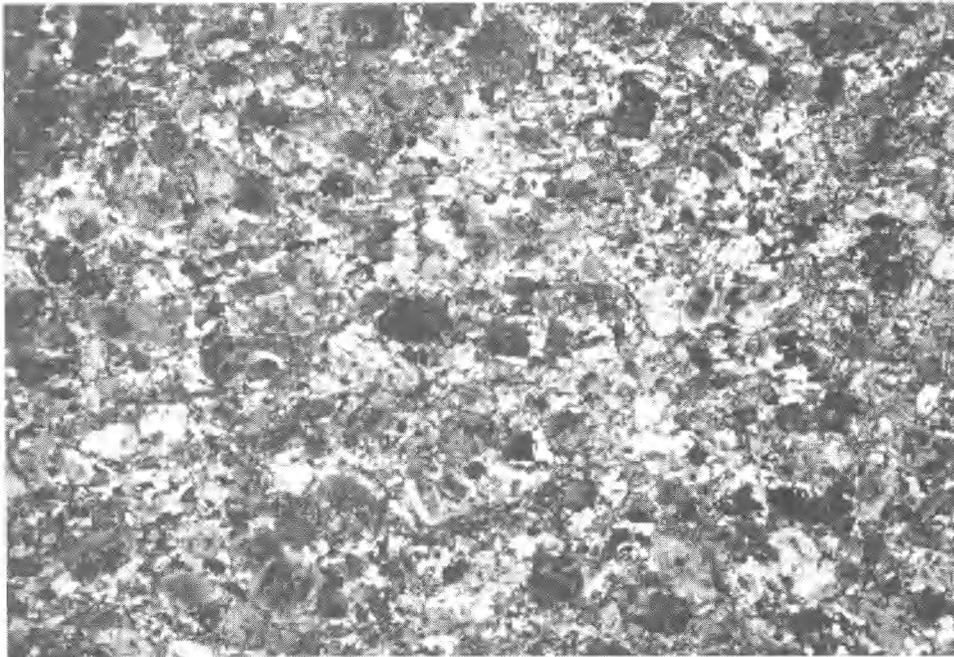


Figure 18. Photomicrograph of cataclastic foliation in foliated tonalite. Foliation trends from left to right. Field of view approximately 25 mm.

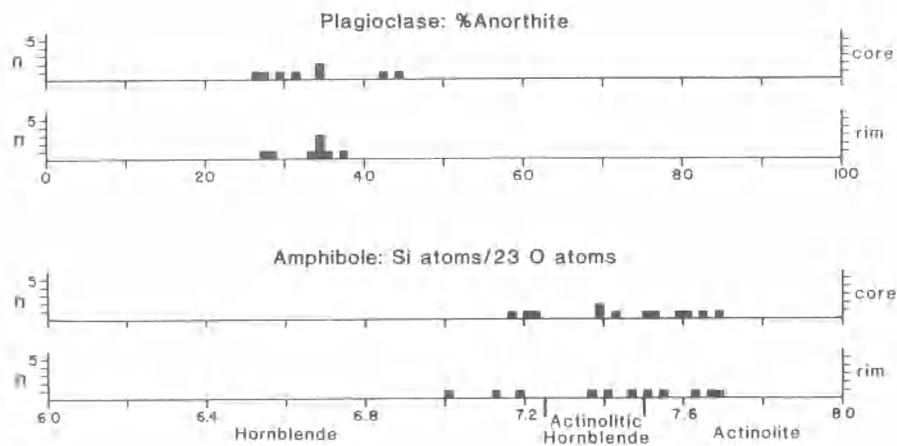


Figure 19. Electron microprobe analyses of coexisting amphibole and plagioclase in mafic schist. Sample March-8.

synkinematic is based on alignment of amphibole grains parallel to the axial plane of isoclinal folds. Cataclasis is interpreted to have occurred during isoclinal folding because penetrative cataclastic foliation in foliated tonalite (fig. 18) is parallel to the axial plane of isoclinal folds.

The very fine-grained andesitic dike in foliated tonalite is composed of normally zoned plagioclase (minimum range An_{12-53}), quartz, biotite, epidote, orthoclase, chlorite, apatite, sphene, zircon, and an opaque mineral. The dike contains sparse euhedral phenocrysts of plagioclase up to 2 mm long and multigranular clusters of biotite up to 4 mm in diameter. Igneous texture is well-preserved; subhedral plagioclase laths in the matrix are randomly oriented. Static metamorphism of the dike has produced abundant fine-grained epidote and a minor quantity of chlorite. Plagioclase phenocrysts are extremely altered to sericite and saussurite.

SUPPLEMENTAL STOPS

Stop 15

Title: Eau Claire Dells Area, County Highway Z - metagabbro, metabasalt

Location: County Highway Z, 0.6 km west of the Eau Claire River. SE¼, SE¼, Sec. 14, T. 29 N., R. 9 E. (Hatley 7.5-minute topographic quadrangle). See Stop 5 for location map.

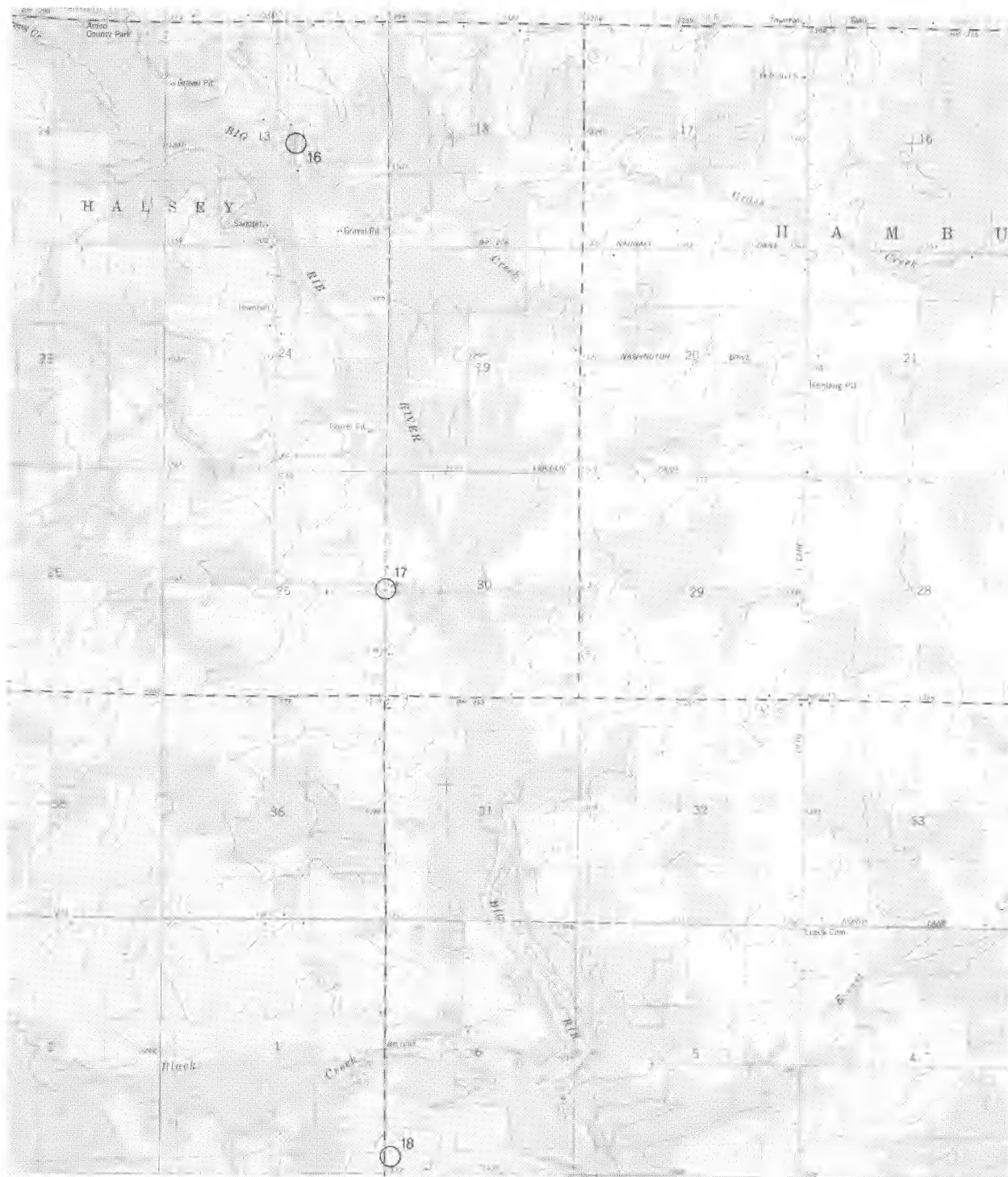
Author: R. S. Maass (1986)

Description: Very small, poor outcrops of metagabbro and metabasalt are present along the north side of County Highway Z near the crest of a hill. The best "exposure" of metagabbro is actually a rock pile in a field at the crest of the hill. Undeformed medium-grained metagabbro consists of approximately equal amounts of plagioclase (andesine and labradorite) and amphibole, and minor to trace quantities of epidote, quartz, carbonate, and an opaque mineral. Amphibole has medium-green cores and dark-green rims. Extremely fine-grained metabasalt is composed of plagioclase, dark-green amphibole, and an opaque mineral. Of two samples of metabasalt examined in thin section, one lacks fabric and the other possesses a very faint foliation. These rocks may have been contact metamorphosed and stained by the Wolf River Batholith (see Eau Claire Dells Area Discussion).

Stop 16

Title: Athens area, Big Rib River - felsic and mafic schist

Location: East bank of the Big Rib River, approximately 0.9 km south of County Highway F on a dead end gravel road. Approximately 2 km southeast of Amco County Park and 10 km northeast of Athens. NW corner, SE¼, Sec. 13, T. 30 N., R. 4 E. (Hamburg 7.5-minute topographic quadrangle).



Author: R. S. Maass

Description: A small exposure of felsic and mafic schist is present along the steep east bank of the Big Rib River. Schist is poorly foliated, but possesses an extremely well-developed penetrative mineral lineation. Biotite aggregates in a layer of nearly unfoliated felsic schist have maximum length-to-width ratios of 10:1 or greater.

Felsic schist consists primarily of variable proportions of microcline, quartz, albite (An_{2-5}), biotite, and muscovite. Grain-size distribution is bimodal; quartz, albite, microcline, and muscovite megacrysts up to 3 mm in diameter are set in a matrix with an average grain-size of 0.1 mm. Albite megacrysts are blocky to rectangular in shape and generally possess one or more crystal faces. Quartz megacrysts are multigranular aggregates that are believed to have been single grains prior to deformation and metamorphism. Albite and quartz megacrysts are interpreted to represent relict phenocrysts, and felsic schist is interpreted to have formed from porphyritic rhyolite.

Two samples of mafic schist are similar to each other, being composed of approximately 65-70% amphibole, 25-30% quartz, 1-4% plagioclase, 2% opaque mineral, and minor to trace quantities of sphene, zoisite, apatite, and an unidentified high-relief reddish mineral. Average grain-size is 0.1-0.3 mm, and recrystallization texture is moderately well-developed. Electron microprobe analysis of coexisting amphibole and plagioclase in mafic schist indicates that it contains the amphibolite facies mineral pair hornblende plus bytownite-anorthite. Representative analyses of amphibole and plagioclase are presented as sample RR-4 in Table 1. This outcrop is the southernmost documented exposure of amphibolite facies rock along the Big Rib River. It is probably metamorphosed very slightly beyond the transition zone between green-schist facies and amphibolite facies.

Stop 17

Title: Athens area, County Highway H, North of County Highway A - schist and metagabbro

Location: East and west sides of County Highway H, 0.3-0.7 km north of County Highway A. Approximately 9 km east-northeast of Athens. NE¼, SE¼, Sec. 25, T. 30 N., R. 4 E.; and E edge, SW¼, Sec. 30, T. 30 N., R. 5 E. (Hamburg 7.5-minute topographic quadrangle). See Stop 16 for location map.

Author: R. S. Maass (1986)

Description: Small exposures of schist and metagabbro crop out along County Highway H. Schist is present in the southern portion of the area of exposure and metagabbro crops out in the northern portion. LaBerge and Myers (1983, plate 1) map schist as "volcanogenic metasedimentary" rock and metagabbro as "ultramafic" rock. This locality is reported to be on the lower greenschist facies side of the Athens Fault of LaBerge and Myers (1983, 1984).

Very fine-grained layered schist ranges from quartzofeldspathic to pelitic. A sample of a chlorite- and muscovite-rich layer of schist consists primarily of varying proportions of chlorite, muscovite, and quartz. Chlorite plus muscovite comprise up to 90% of some of the thin layers within the sample. The specimen contains "clots" of chlorite up to 2 mm in diameter within the very fine-grained matrix. Some of the clots are made up of single chlorite grains and others are comprised of a number of separate grains.

Metagabbro is composed of 50% pale-green amphibole, 40% normally zoned andesine-labradorite, 5% epidote, 4% chlorite, and 1% opaque mineral plus associated sphene. Amphibole and chlorite occur in the form of pseudomorphs of pyroxene. Metagabbro is undeformed, and ophitic texture is relatively well-preserved. Original pyroxene grains were as large as 2 cm in diameter.

Schist has not been chemographically analyzed to determine whether it is chlorite zone or whether it has the wrong bulk chemistry to contain minerals that are diagnostic of a higher grade of metamorphism. It is not known whether chlorite clots are porphyroblasts or pseudomorphs. Interpretation of metamorphism of schist is complicated by its proximity to gabbro, which allows the possibility that it has been contact metamorphosed in addition to regionally metamorphosed. Metamorphism of gabbro may represent a late stage of the metamorphic event that dynamically metamorphosed schist, or a significantly younger metamorphic event.

Recrystallization texture of schist is intermediate between that of schist 3.4 km to the north that has been metamorphosed to amphibolite facies (Stop 16) and that of schist 4.0 km to the south that has been metamorphosed to greenschist facies (Stop 18), suggesting that it is metamorphosed to the vicinity of the transition zone between greenschist and amphibolite facies. No evidence has been presented that demonstrates that schist has been metamorphosed to no higher a grade than lower greenschist facies.

Stop 18

Title: Athens area, County Highway H, Near Black Creek - schist

Location: East side of County Highway H, 0.7 km south of Black Creek, and 3.1 km south of County Highway A. Approximately 9 km east-southeast of Athens. SW¼, SW¼, Sec. 6, T. 29 N., R. 5 E. (Hamburg 7.5-minute topographic quadrangle). See Stop 16 for location map.

Author: R. S. Maass (1986)

Description: A small outcrop of extremely fine-grained schist derived from volcanic rocks or volcanogenic sediments, or both, is present on the east side of County Highway H near the crest of a hill. Compositional layering in schist ranges in width from 1 mm to tens of centimeters. Schist is primarily felsic in composition.

A sample of a layer of schist of either intermediate or mafic composition contains approximately 55% combined plagioclase and quartz, 20% epidote, 10% amphibole, 10% opaque mineral, 5% chlorite, and a trace quantity of carbonate. Blocky and lath-shaped phenocrysts of plagioclase up to 0.3 mm in diameter constitutes up to 25% of some of the layers in the sample. The individual percentages of quartz and plagioclase in schist have not been determined because of the extremely fine-grain size of these minerals (less than 0.05 mm) in the majority of the sample. Lensoidal rock fragments up to 2 mm in length are present.

Electron microprobe analysis of coexisting amphibole and plagioclase in schist indicates that it contains the greenschist facies mineral pair actinolite + albite ($An_{3.3-5.5}$). Representative analyses of amphibole and plagioclase are presented as sample ATH-15 in Table 1. This locality is the northernmost documented exposure of greenschist facies rock in the vicinity of the Big Rib River.

Stop 19

Title: County Highway P, northeast of March Rapids - felsic to mafic schist of volcanic origin

Location: North and south sides of County Highway P, 3.9-4.3 km (2.4-2.7 mi) west of State Highway 97. SE¼, SW¼, Sec. 34, T. 28 N., R. 3 E.; and NE¼, NW¼, Sec. 3, T. 27 N., R. 3 E. (Little Rose 7.5-minute topographic quadrangle) See Stop 13 for location map.

Author: R. S. Maass (1986)

Description: Small exposures of fine-grained felsic to mafic schist derived from volcanic rocks are present on both sides of County Highway P, in the vicinity of two branches of an intermittent stream. A number of small knobs of schist also crop out in a field located a short distance southwest of the exposures along the road.

On average, lithologic layering and foliation strike N 70-75° E and dip very steeply. Foliation is axial-planar to isoclinal folds. Small-scale open to tight folds are present within individual outcrops, and large-scale folding of this type is suggested by variation in orientation of foliation from knob to knob in the above mentioned field. There is some uncertainty as to whether this is evidence of large-scale folding because some of the knobs may be out of place. Schist is brecciated at a number of the outcrops.

A sample of mafic schist from the north side of the road consists primarily of subequal amounts of feldspar and dark-green amphibole. Feldspar is predominantly extensively sericitized plagioclase, but within and adjacent to abundant fractures in schist the feldspar is orthoclase. Other fractures are filled with chlorite plus epidote, or with quartz. Mafic schist contains coexisting hornblende and albite (fig. 20). This mineral pair is stable in the

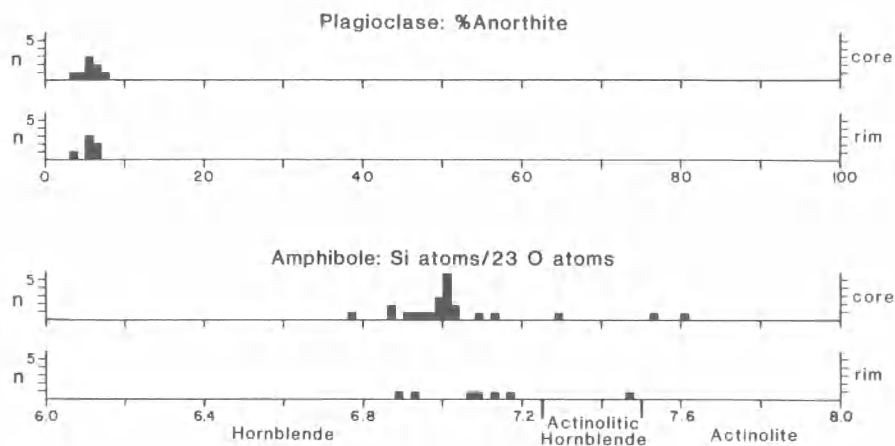


Figure 20. Electron microprobe analyses of coexisting amphibole and plagioclase in mafic schist. Sample March-5.

transition zone between greenschist and amphibolite facies (Turner, 1981; Maruyama and others, 1983). Actinolite and actinolitic hornblende grains in schist are extremely rare discrete grains that are fibrous, in contrast to prismatic hornblende. They may be retrograde (see March Rapids Area Discussion). Representative analysis of hornblende and albite are presented in Table 1.

Stop 20

Title: Big Eau Pleine River east of March Rapids County Park - deformed plutonic rocks

Location: South side of the Big Eau Pleine River, east of March Rapids County Park. The first area of exposure (locality A) is on a steep hillside in the woods; the second (locality B) is along the river bank. NE¼, SE¼, and SE¼, NW¼, Sec. 4, T 27 N., R. 3 E. (Little Rose 7.5 minute topographic quadrangle). See Stop 13 for location map.

Author: R. S. Maass (1986)

Description: Medium-grained granite mylonite crops out at locality A. Mylonite is composed of subequal amounts of microcline, plagioclase (An_{27-28}), and quartz, and minor to trace quantities of biotite, epidote, muscovite, apatite, allanite, zircon, and an opaque mineral. Porphyroclasts of microcline and plagioclase are round to lensoidal, and quartz occurs in the form of recrystallized "ribbons" (fig. 21). Penetrative foliation strikes N 80° E and is approximately vertical. A poorly developed mineral lineation is present; its orientation has not been determined.

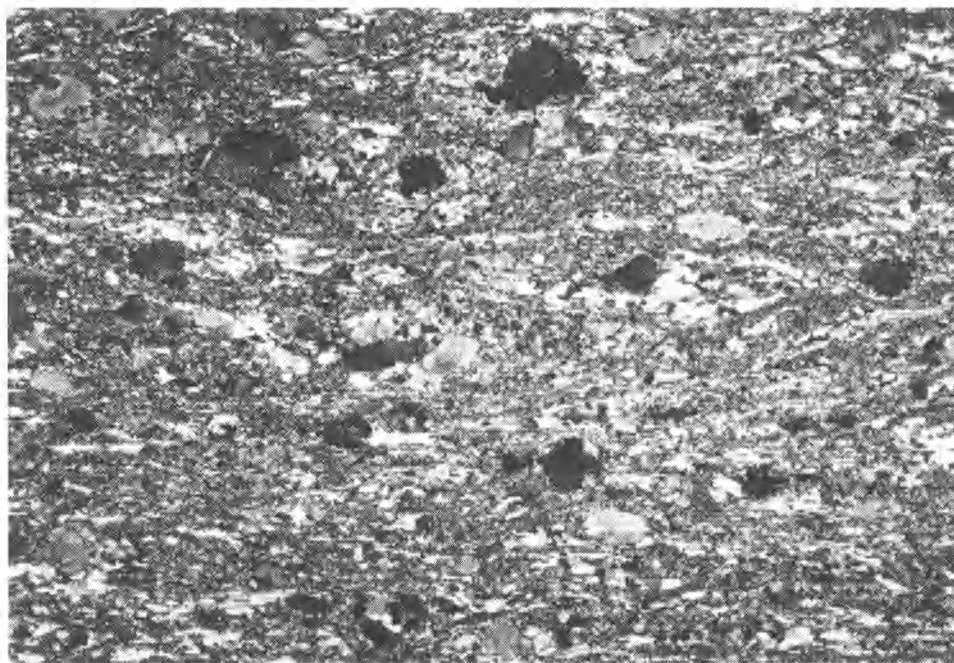


Figure 21. Photomicrograph of mylonite. Note "ribbons" of quartz that have been recrystallized. Field of view approximately 25 mm.

Outcrops at locality B are of a medium-grained foliated leucocratic plutonic rock, or rocks. Cataclastic deformation of a granodioritic sample has produced rounded feldspar and has granulated quartz. Quartz is moderately

well-recrystallized. Penetrative cataclastic foliation strikes N 70° W and dips nearly vertically. Degree of development of foliation is intermediate between that at locality A and that at Stop 14. Cataclastic foliation at all three localities is interpreted to have been produced during isoclinal folding (see Stop 14 and March Rapids Area Discussion).

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