Geology and Geochronology of Granitoid and Metamorphic Rocks of Late Archean Age in Northwestern Wisconsin

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1292-C

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By P. K. SIMS, Z. E. PETERMAN, R. E. ZARTMAN, *and* F. C. BENEDICT

CONTRIBUTIONS TO THE GEOLOGY OF THE LAKE SUPERIOR REGION

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A description of Archean rocks in the Puritan batholith

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1985

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Library of Congress Cataloging in Publication Data

Geology and geochronology of granitoid and metamorphic rocks of late Archean age in northwestern Wisconsin.

(Contributions to the geology of the Lake Superior Region)(Geological Survey Professional Paper ; 1292–C)
iii, 17 p.
Bibliography: p. 15–17
Supt. of Docs. No.: I 19.16:1292–C
1. Granite—Wisconsin. 2. Rocks, Metamorphic. 3. Geological time. 4. Geology, Stratigraphic—Archean.
I. Sims, P. K. (Paul Kibler), 1918– . II. Series. III. Series: Geological Survey professional paper ; 1292–C.
QE462.G7G43 1985 552′.3 84–600033

For sale by the Branch of Distribution
U.S. Geological Survey
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Alexandria, VA 22304

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GEOLOGY AND GEOCHRONOLOGY OF GRANITOID AND METAMORPHIC ROCKS OF LATE ARCHEAN AGE IN NORTHWESTERN WISCONSIN

By P. K. SIMS, Z. E. PETERMAN, R. E. ZARTMAN, and F. C. BENEDICT

ABSTRACT

Granitoid rocks of the Puritan Quartz Monzonite and associated biotite gneiss and amphibolite in northwestern Wisconsin compose the southwestern part of the Puritan batholith of Late Archean age. They differ from rocks in the Michigan segment of the batholith in having been deformed by brittle-ductile deformation and partly recrystallized during shearing accompanying development of the midcontinent rift system of Keweenawan (Middle Proterozoic) age.

Granitoid rocks ranging in composition from granite to tonalite are dominant in the Wisconsin part of the batholith. To the north of the Mineral Lake fault zone, they are massive to weakly foliated and dominantly of granite composition, whereas south of the fault zone they are more strongly foliated and mainly of tonalite composition. Massive granite, leucogranite, and granite pegmatite cut the dominant granitoid rocks. Intercalated with the granitoid rocks in small to large conformable bodies are biotite gneiss, amphibolite, and local tonalite gneiss. Metagabbro dikes of probable Early Proterozoic age as much as 15 m thick cut the Archean rocks.

Rubidium-strontium whole-rock data indicate a Late Archean age for the granitoids and gneisses, but data points are scattered and do not define a single isochron. Zircon from two samples of tonalitic gneiss for uranium-thorium-lead dating define a single chord on a concordia diagram, establishing an age of $2,735 \pm 16$ m.y. The lower intercept age of $1,052 \pm 70$ m.y. is in close agreement with rubidium-strontium and potassium-argon biotite ages from the gneisses.

Two episodes of deformation and metamorphism are recorded in the Archean rocks. Deformation during the Late Archean produced a steep west-northwest-oriented foliation and gently plunging fold axes and was accompanied by low amphibolite-facies metamorphism of the bedded rocks. A younger deformation resulting from largely brittle fracture was accompanied by retrogressive metamorphism; this deformation is most evident adjacent to the Mineral Lake fault and took place during Keweenawan rifting about 1,050 m.y. ago. The Mineral Lake fault is one of several northwest-trending faults in the Lake Superior region that originated in the Late Archean and were reactivated intermittently during the Proterozoic, including Keweenawan time. The faults dominantly have right-lateral displacements.

The Archean rocks of the Puritan batholith exposed in northwestern Wisconsin compose part of the greenstone-granite terrane, as defined in the Lake Superior region. These rocks were formed 2,750–2,600 m.y. ago. The long dimension of the Puritan batholith as well as that of several batholiths in adjacent Minnesota are oriented subparallel to the boundary between the greenstone-granite terrane and the older gneiss terrane, to the south. This conformity in trend is interpreted as indicating that the granite probably was emplaced after the two basement crustal segments had been joined.

INTRODUCTION

As a part of regional studies of the boundary between the two Archean crustal segments recognized in the Lake Superior region (Morey and Sims, 1976; Sims, 1980), geologic reconnaissance and isotopic dating were carried out in an area south of Mellen, in Ashland and Bayfield Counties, northwestern Wisconsin. Exposures of granite, granitic gneiss, and amphibolite had previously been reported in this area (Dutton and Bradley, 1970; Hotchkiss, 1915; Hotchkiss and Bean, 1929), but the rocks had not previously been systematically examined.

Our studies have shown that the granitoid and associated metamorphic rocks in northwestern Wisconsin are grossly correlative with those described in the western part of northern Michigan (Schmidt, 1976), and accordingly should be included in the large batholith of Archean granitoid rocks extending from the vicinity of Lake Gogebic, Mich., southwestward into northwestern Wisconsin (fig. 1), which we have called the Puritan batholith (Sims and others, 1984). The Archean rocks in northwestern Wisconsin differ from those in the Michigan segment of the batholith, however, in having been deformed by brittle-ductile deformation and partly recrystallized during shearing accompanying development of the midcontinent rift system of Keweenawan (Middle Proterozoic) age. K-Ar (potassium-argon) biotite ages of 1,050 m.y. are given by deformed rocks as much as 15 km from the Keweenawan mafic volcanic and intrusive rocks that occupy a large part of the rift system. So far as we know, this is the first observation in the Lake Superior region of severe disturbance of isotopic systems by brittle-ductile deformation in pre-Keweenawan rocks at a moderately great distance from the Keweenawan rift system. Low-grade metamorphism of country rocks was noted at some 15 km from the Mellen Intrusive Complex of Keweenawan (Middle Proterozoic) age (Schmidt, 1976), in the Ironwood, Mich., area; and isotopic disturbance by thermal effects has been noted in Minnesota (Goldich and others, 1961).

Our studies in northwestern Wisconsin support the conclusion reached from studies in the Marenisco, Mich., area (Sims and others, 1984) that the Archean layered rocks associated with the batholith probably were deformed in Late Archean time by lateral compression related to impingement of the Archean gneiss terrane against the more stable Archean greenstone-granite terrane. In other parts of the greenstone-granite terrane, deformation of the layered greenstone generally is attributed to the diapiric emplacement of Late Archean granite into the volcanic pile (Schwerdtner and others, 1979).

So far as we know, the Early Proterozoic Penokean tectonothermal event had no appreciable effect on the Archean rocks in the Puritan batholith. Neither penetrative structures nor isotopic disturbances that can be attributed to Penokean tectonism have been definitely recognized in the Archean rocks. The apparent absence of a Penokean structural overprint on the Archean rocks contrasts with observations at the northeast end of the batholith, in Michigan, where conspicuous penetrative structures were superposed on Archean structures during the Penokean event (Sims and others, 1984).

The reconnaissance mapping was done at intervals during the summers of 1975, 1976, and 1978. M. G. Mudrey, Jr., K. J. Schulz, and J. K. Greenberg assisted in the fieldwork. Mudrey also assisted in collecting samples for isotopic analyses, at times under arduous conditions. Personnel of the Soo Line assisted in transporting samples collected along the railway.

GEOLOGIC SETTING

The Puritan batholith, as designated herein, is a body of Archean granitoid rocks of the Puritan Quartz Monzonite and associated metamorphic rocks that is about 125 km long and has an exposed width of generally more than 15 km (fig. 1). Its actual width is not known because the Archean rocks are unconformably overlain on the northwest and southeast by Proterozoic rocks. Thus, the batholith is similar in size at the present erosional level to the Giants Range batholith in northern Minnesota (Sims and Viswanathan, 1972), one of the larger known granitoid bodies in the Archean greenstone-granite terrane of the Lake Superior region and adjacent areas (Morey and others, 1982).

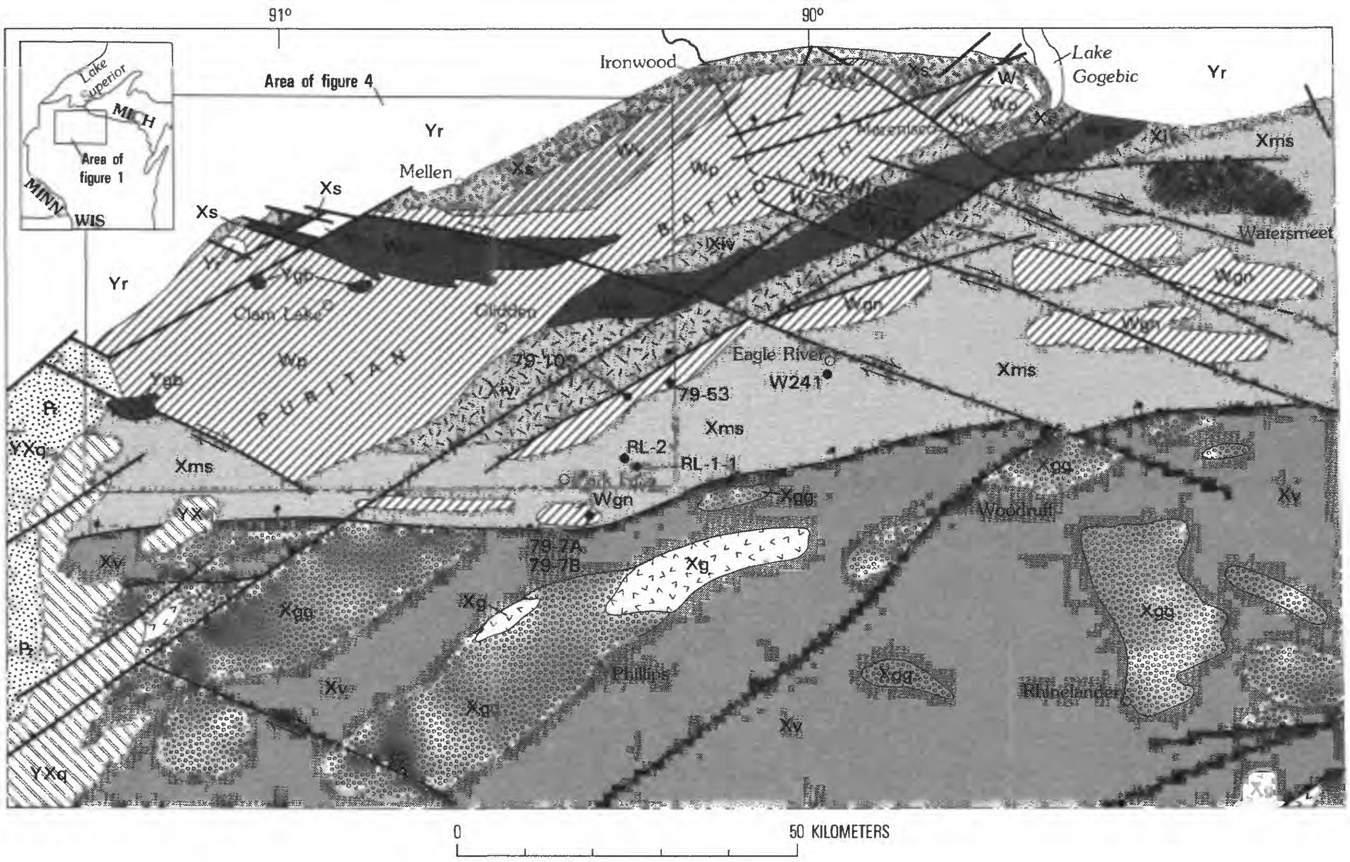
In the western part of northern Michigan, the batholith consists mainly of granitic rocks but includes bodies of migmatite that have a biotite schist or amphibolite paleosome and a granite or pegmatite neosome. In this area, the major rock type is a pink, equigranular to slightly porphyritic, generally massive leucocratic granite that has been named (Schmidt, 1976) the Puritan Quartz Monzonite. The granite intrudes metavolcanic rocks, called the Ramsay Formation, east of Ironwood, and biotite schist at the northeastern extremity of the batholith. In the Ironwood area, Schmidt (1976) delineated a few bodies of rather mafic foliated rocks. One such body is a foliated hornblende tonalite named the Whiskers Creek Gneiss, which is either an early intrusive phase or a hybrid rock resulting from contamination of granitic magma by older mafic volcanic rocks. On the basis of Rb-Sr (rubidium-strontium) data, the age of the Whiskers Creek Gneiss is indistinguishable from that of the Puritan Quartz Monzonite (2,650 ± 140 m.y.; Sims and others, 1977). The granitoid rocks that have been dated have an initial $^{87}Sr/^{86}Sr$ ratio of 0.7015 ± 0.0017, which is interpreted as indicating a lower-crust or mantle source.

As described in chapter A , a belt of gneiss, amphibolite, and granitoid rocks, about 5 to 10 km wide, lies southeast of the batholith proper in the Marenisco area and is separated from the batholith by a 5- to 10-km-wide belt of infolded bedded rocks of Early Proterozoic age (Sims and others, 1984). The Archean bedded rocks are intruded by small bodies of granite and pegmatite that are considered as satellitic bodies from the main Puritan batholith. The bedded rocks were deformed and metamorphosed in Late Archean time, and together with the granite were deformed and metamorphosed again during the Early Proterozoic, about 1,800 m.y. ago.

The rocks of the Puritan batholith are overlapped on the north by steeply dipping homoclinal sedimentary rocks (Marquette Range Supergroup) of the Gogebic Range (fig. 1), and on the south by folded and metamorphosed volcanic rocks (Xiv unit, fig. 1) that probably are grossly correlative with those of the Gogebic Range. Southwest of the Gogebic Range, volcanic rocks of the Keweenawan (Middle Proterozoic) midcontinent rift system directly overlie the Archean rocks. Schmidt (1980) has described the Proterozoic strata in the Gogebic Range; we have described the Proterozoic rocks on the south flank of the batholith (Sims and others, 1984), which also were previously discussed by Allen and Barrett (1915).

The previously noted Archean layered and granitoid rocks are part of the greenstone-granite terrane, as delineated in the area east of the midcontinent gravity high (Sims, 1980). The southwestern termination of the greenstone-granite terrane is tentatively interpreted as a right-lateral fault of large displacement. (See Sims and Peterman, 1983.)

The position of the boundary between the greenstone-granite terrane and the gneiss terrane is not known accurately in northwestern Wisconsin, but is inferred to lie just southeast of the northeast-trending belt of gneiss, amphibolite, and granitoid rocks (Wga unit, fig. 1) that is southeast of the Puritan batholith. Presumably the boundary underlies the



EXPLANATION

PALEOZOIC

- Sandstone and siltstone

MIDDLE PROTEROZOIC (800-1,600 M.Y.)

- Gabbroic rocks
- Yr — Lava, layered gabbroic rocks, and sedimentary rocks of midcontinent rift system

MIDDLE AND EARLY PROTEROZOIC

- YXq — Platform quartzite

EARLY PROTEROZOIC (1,600-2,500 M.Y.)

- Xg — Granite (age, 1,760 m.y.)

Marquette Range Supergroup

- Xs — Menominee and Chocolay Groups in Gogebic Range
- Xms — Dominantly metasedimentary rocks; includes Michigamme Formation in Michigan
- Xiv — Dominantly metavolcanic rocks; includes Blair Creek Formation in Michigan
- Xv — Mafic to felsic metavolcanic rocks
- Xgg — Gneiss, amphibolite, and foliated granitoid rocks

LATE ARCHEAN (2,500 M.Y. AND OLDER)

- Wp — Granitoid rocks of Puritan Quartz Monzonite (age, about 2,650 m.y.)
- Wga — Gneiss, amphibolite, and granitoid rocks; includes metagraywacke in area southeast of Lake Gogebic
- Wv — Metavolcanic rocks; includes Ramsay Formation
- Ws — Biotite schist and migmatite
- Wgn — Gneiss; may include older rocks

LATE TO EARLY ARCHEAN

- Gneiss, amphibolite, and granitoid rocks (age, 2,600-3,550 m.y.)

CONTACT—Approximately located

FAULT—Arrows show relative horizontal movement, where known. Bar and ball on downthrown side, where known

W241● LOCALITY OF AGE-DATED SAMPLE

FIGURE 1.—Generalized geologic map of part of northern Wisconsin and adjacent Michigan. (Modified from Morey and others, 1982.)

Early Proterozoic metavolcanic rocks (Xiv unit, fig. 1) that lie immediately southeast of the gneiss belt previously discussed. The elliptical domes of gneiss, amphibolite, and granitoid rocks (Wgn unit, fig. 1) are components of the Archean gneiss terrane. These rocks have been described from the dome north of Watersmeet, Mich. (fig. 1), and are in part as old as 3,550 m.y. (Sims and others, 1984).

Recently completed U-Pb (uranium-lead) zircon dating (W. R. Van Schmus, oral commun., 1982) of rocks to the southeast of the Puritan batholith (fig. 1) has disclosed that layered gneisses at Fifield, Wis., 6.5 km south of Park Falls, Wis., and interlayered biotite gneiss and amphibolite, 20 km east-northeast of Butternut, Wis. (fig. 4), which is 10 km north of Park Falls, are Late Archean. Associated with these rocks are biotitic schists, such as those exposed near Powell, Wis. (about 50 km east of Butternut) and near Park Falls, that are Early Proterozoic in age. Two zircon size fractions from a sample (RL–2) of biotite schist from the north end of Blockhouse Lake, Wis., which is 10 km northeast of Park Falls, give a discordia intercept age of 1,853 m.y. (fig. 2). The Rb-Sr whole-rock isochron age for this sample and for two other biotite schist samples in the area (fig. 3), including a kyanite-staurolite-garnet biotite schist from near Powell, is indistinguishable from the zircon age of sample RL–2. These radiometric age data are interpreted as indicating that Archean and Early Proterozoic rocks in this area are intercalated, probably as a result of northeast-trending faulting that has juxtaposed rocks of the two ages. The deformation was accompanied, or preceded, by metamorphism to amphibolite grade, with the local development of the high-pressure mineral kyanite. These Archean and Early Proterozoic rocks are interpreted as being integral parts of the Archean gneiss terrane; they could be underlain by older gneisses, perhaps of Middle Archean age.

The rocks southeast of Park Falls and vicinity differ in both age and lithology from those previously described. They are metavolcanic rocks (Xv unit, fig. 1) and granitoid rocks, including gneiss and amphibolite (Xgg unit, fig. 1); the granitoid rocks are exposed in the cores of domes and the gneiss and amphibolite stratigraphically underlie the metavolcanic rocks. Scattered samples of the granitoid rocks from the area have been dated by both the U-Pb zircon method (Van Schmus, 1980) and the Rb-Sr whole-rock isochron method (Sims and Peterman, 1980) at about 1,850 m.y. Inasmuch as outcrops are poor in the area, our current interpretation of the relationship between the granitoid and metavolcanic rocks is based largely on analogy with the geology of northeastern Wisconsin, where Early Proterozoic gneiss and amphibolite demonstrably underlie metavolcanic rocks assigned to the Quinnesec Formation (Sims and others, 1982), and both the gneiss and the Quinnessec are intruded by granitoid rocks. Because of the differences in the age and lithology of these rocks with respect to those near Park Falls and areas to the northwest and north, a major fault or shear zone is inferred to separate the two lithostructural domains, as shown on figure 1.

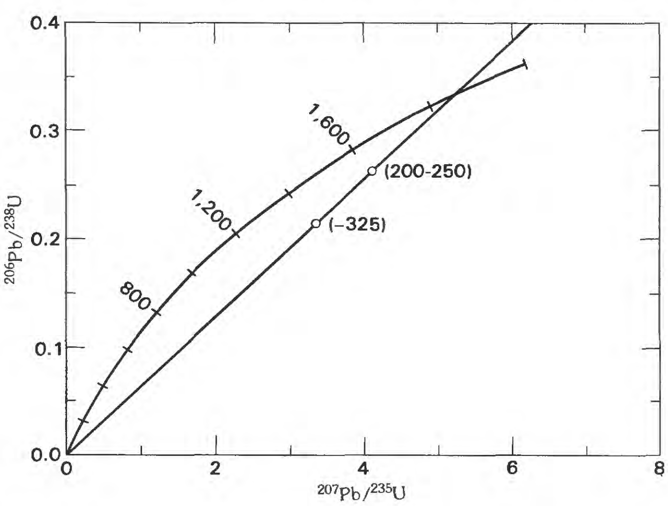


FIGURE 2.—Concordia diagram of zircon data for sample RL–2, biotite schist, from vicinity of Blockhouse Lake, northwestern Wisconsin. Intercepts defined by two size fractions are 1,852±6 m.y. and 5±29 m.y. Numbers in parentheses designate size fractions.

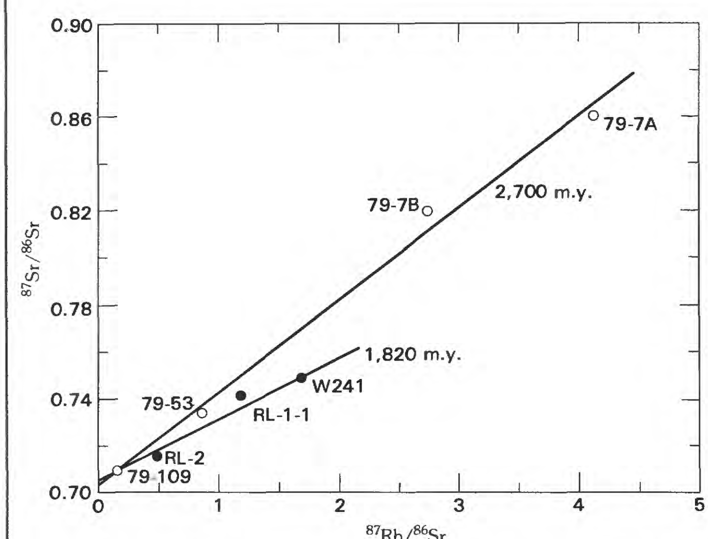


FIGURE 3.—Rubidium-strontium isochron plot for samples of Early Proterozoic schist (RL–2, RL–1–1, and W241) and Late Archean gneiss (79–109, 79–53, 79–7B, and 79–7A) from northwestern Wisconsin. Data for Archean samples scatter about a reference isochron of 2,700 m.y. For the Early Proterozoic samples, data points for RL–2 and W241 lie near a reference isochron of 1,820 m.y. for metagraywacke from the Marenisco, Mich., area; sample RL–1–1 is disturbed.

PURITAN BATHOLITH

In northwestern Wisconsin, granitoid rocks and associated metamorphic rocks in the Puritan batholith are exposed sporadically over an area of about 1,500 km^2 (fig. 4). Most of the exposures are along the Bad River in the vicinity of Cayuga and Morse (see fig. 5), and these together with those along the Marengo River and its tributaries in extreme eastern Bayfield County (lat 46°15′ N., long 91°00′ E.; fig. 4) were examined during our study. Because of poor exposures south of these localities, the general outline of the southern extremity of the Puritan batholith is delineated by widely scattered outcrops and drill-hole data in published reports (Hotchkiss, 1915; Hotchkiss and Bean, 1929) and unpublished reports of the Wisconsin Geological and Natural History Survey. The area of granitoid rocks in the southwestern part of the batholith includes two pronounced negative Bouguer gravity anomalies (Ervin and Hammer, 1974), as shown on figure 4. Electromagnetic data suggest that granite underlies the strong negative gravity anomalies, and migmatite or gneiss underlies intervening areas (M. G. Mudrey, Jr., written commun., 1982).

ROCK UNITS

Granitoid rocks ranging in composition from granite to tonalite are the dominant rocks exposed in the southwestern part of the Puritan batholith. Biotite gneiss and amphibolite are intercalated with the granitic rocks in a broad zone south of the Mineral Lake fault, and compose local mappable units of mixed rocks (fig. 5). In the Morse-Cayuga area, a tonalite gneiss of probable intrusive origin occupies a narrow belt between the two metamorphic rock units. The biotite gneiss and amphibolite and the tonalite gneiss are included with granite and tonalite in the Puritan batholith.

GRANITOID ROCKS

The granitoid rocks vary in structure as well as in composition. The rocks exposed north of the Mineral Lake fault zone (fig. 4) are dominantly massive to weakly foliated, and the rocks are physically similar to those in northern Michigan (Schmidt, 1976; Sims and others, 1977); whereas those south of the fault zone are moderately to weakly foliated and at places have a gneissic structure. The gneissic structure has mainly resulted from ductile deformation; the biotite and felsic components are streaked out and an augen structure is developed locally.

Three principal varieties of granitoid rocks occur in this segment of the batholith. The dominant granitoid rocks are pinkish gray or gray, fine to medium grained, and equigranular to slightly porphyritic. Both microcline and plagioclase compose the phenocrysts in inequigranular varieties. Modal compositions range from granite to tonalite (table 1). Textures are typically hypidiomorphic granular except where cataclastic structures—mortar structures and shears—and accompanying recrystallization have obliterated the primary texture. Plagioclase (An_{20-25}) commonly has a weak concentric zoning and is myrmekitic adjacent to microcline. Microcline occurs both as phenocrysts and as interstitial material, and it is both twinned and untwinned. Except locally, quartz commonly is highly strained or broken and recrystallized. Biotite is brown and forms two generations in many rocks—an older, typically frayed and partly altered one and a younger, fine-grained, fresh brown variety. Moderate alteration is widespread. Biotite characteristically is partly altered to chlorite and epidote/clinozoisite, and plagioclase is partly altered to sericite and epidote/clinozoisite.

Pink to gray, massive granite and leucogranite and coarse granite pegmatite commonly cut the dominant granitoid rocks, mainly as dikes as much as a few meters thick. Porphyritic varieties of the younger granite are also common. Sample W61–1B (table 1) is typical of these rocks. To the south of the Mineral Lake fault, these rocks are cataclastically deformed to varying degrees.

The third variety, tonalitic gneiss, is a medium- to dark-gray, medium- to coarse-grained, irregularly layered gneiss, which at places is cut by massive granite dikes. Thin sections show a moderate to strong mortar structure somewhat annealed by recrystallization (W61, table 1). Plagioclase and biotite are altered similarly to that in other granitoid rocks, and two generations of biotite are common.

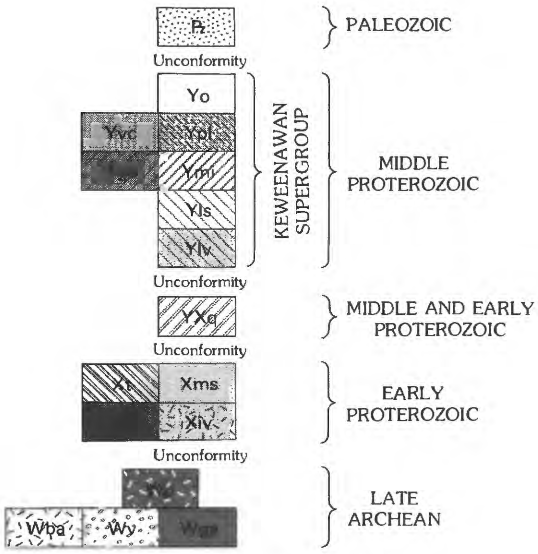
BIOTITE GNEISS AND AMPHIBOLITE

Biotite gneiss and amphibolite are intercalated at various scales with the granitoid rocks and form mappable units in the vicinity of Morse and Cayuga (fig. 5).

Biotite gneiss is dominantly a medium-gray, fine-grained, thinly layered rock but includes coarser grained biotitic gneisses and migmatitic gneisses. Hornblende is a minor constituent in many samples. The rocks have granoblastic textures. Plagioclase (about An_{30}) is anhedral, typically twinned, and locally myrmekitic. Quartz occurs both as discrete grains and as aggregates. Biotite generally has two orientations, with the younger generation being associated with cataclastic textures and recrystallization. Sphene, opaque oxides, and zircon are principal minor minerals.

Amphibolite and associated hornblende gneiss are dark-gray, massive to layered rocks that contain some quartz and biotite. Not uncommonly they have thin layers of granite or granite pegmatite (leucosome) and

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

PALEOZOIC

Pz — Sandstone and siltstone

MIDDLE PROTEROZOIC

Yo — Sedimentary rocks of Oronto Group

Yvc — Chengwatana Volcanic Group of Hall (1900)

Ypl — Portage Lake Volcanics

Gabbroic rocks

Ymi — Mellen Intrusive Complex (age, about 1,000 m.y.)

Yls — Sedimentary rocks

Ylv — Mafic lavas

MIDDLE AND EARLY PROTEROZOIC

YXq — Quartzite

EARLY PROTEROZOIC MARQUETTE RANGE SUPERGROUP

Xt — Tyler Formation

Xms — Unnamed biotite schist containing garnet, staurolite, and kyanite

Ironwood Iron-formation and Palms Formation

Xiv — Unnamed metavolcanic rocks and lesser sedimentary rocks, including Iron-formation

ARCHEAN

Dominantly granite and tonalite of Puritan Quartz Monzonite

Wba — Biotite schist and amphibolite

Wy — Metavolcanic rocks

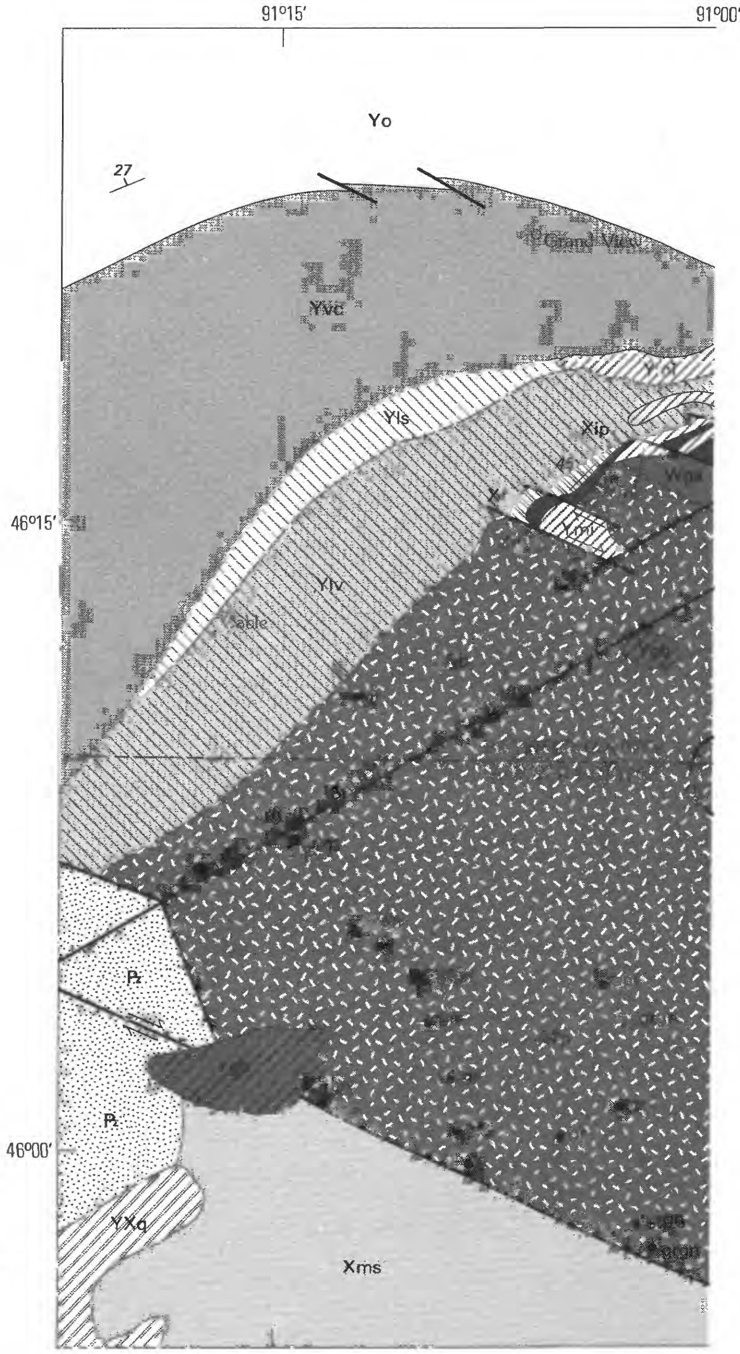
Biotite gneiss, in part migmatitic; amphibolite; and foliated tonalite and granite

CONTACT—Approximately located

FAULT—Arrows show relative horizontal movement, where known. Bar and ball on downthrown side, where known

25 BEARING AND PLUNGE OF MINOR FOLDS

65 STRIKE AND DIP OF BEDS



80 STRIKE AND DIP OF FOLIATION

STRIKE OF VERTICAL FOLIATION

60 30 STRIKE AND DIP OF FOLIATION AND PLUNGE OF LINEATION

ABANDONED IRON MINE OR PROSPECT

X OUTCROP

● DRILLHOLE

-50 -60 BOUGUER GRAVITY CONTOUR—In milligals. Hachures indicate closed gravity lows

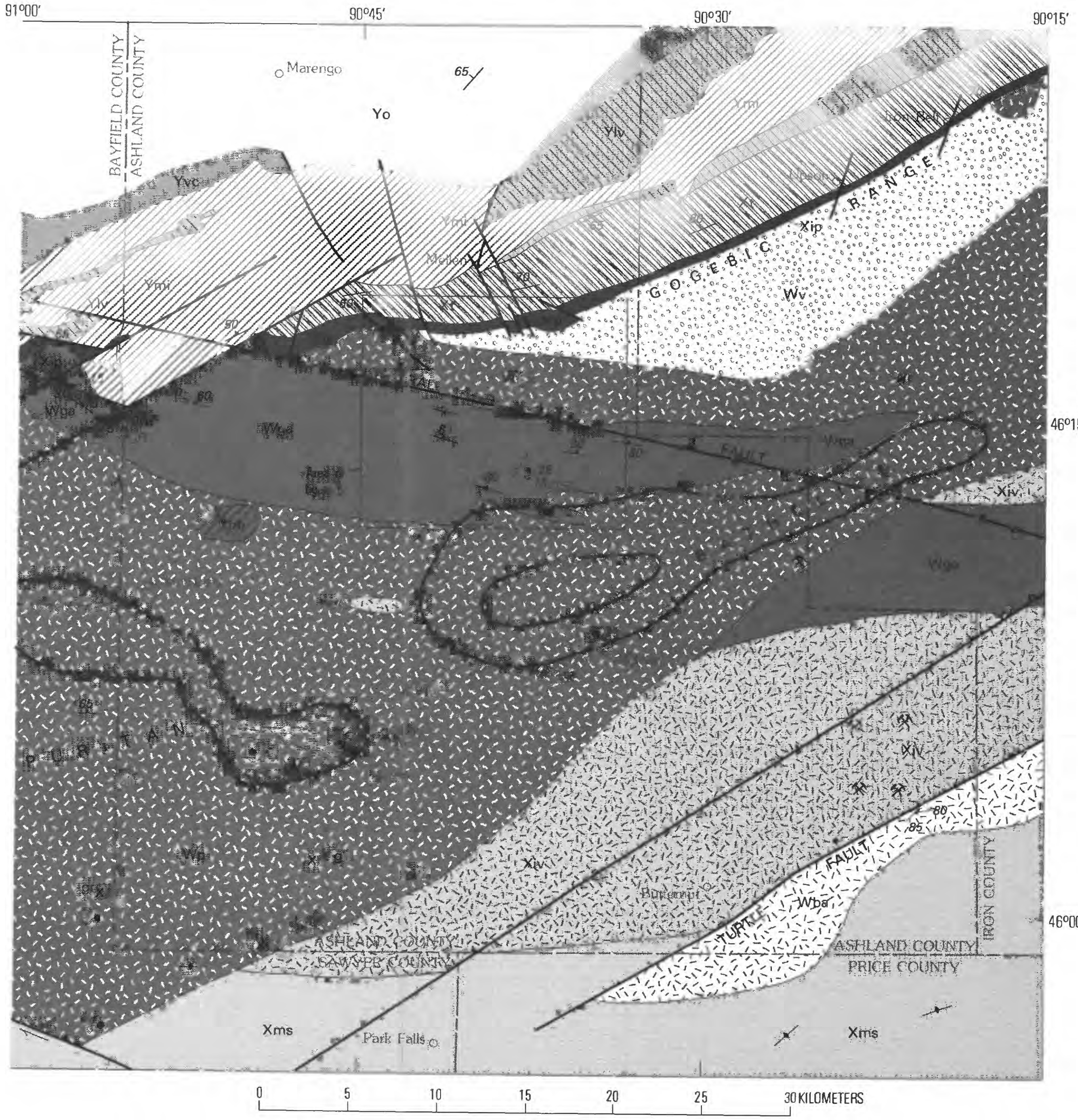
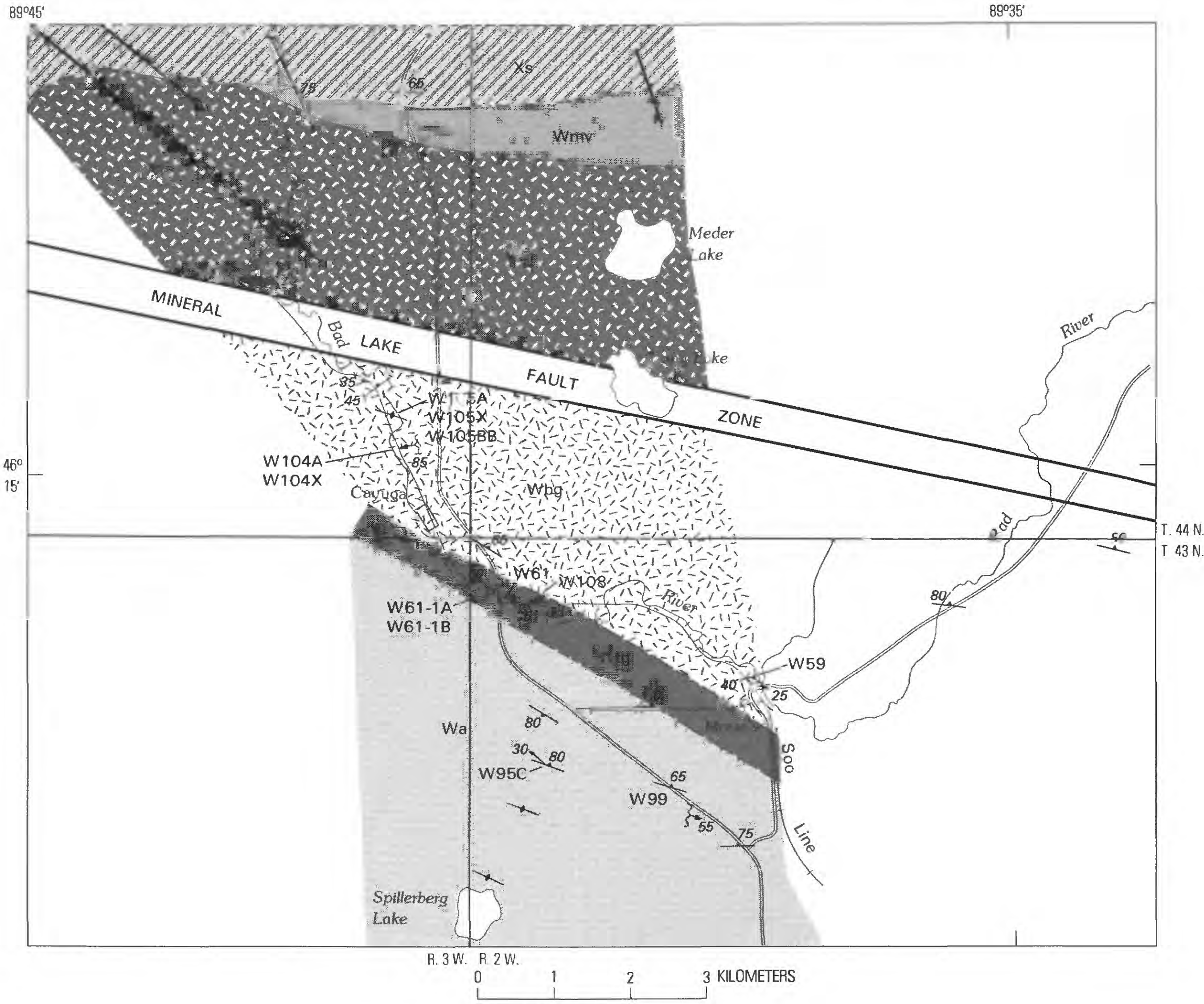


FIGURE 4.—Geologic map of Precambrian rocks in part of northwestern Wisconsin. Principal rock types reported in outcrops (x) and drillholes (•) (see text for sources) are: gr, granite; gn, gneiss; grgn, granite gneiss; am, amphibolite; and d, diabase. Gravity contours are from Ervin and Hammer (1974). (Modified from Sims and others, 1978.)



EXPLANATION

MIDDLE AND EARLY PROTEROZOIC

- Granite
- Xs — Sedimentary rocks of Gogebic Range

LATE ARCHEAN

- Granite-tonalite, granite gneiss, and amphibolite
- Wmv — Metavolcanic rocks
- Tonalite gneiss
- Wbg — Dominantly biotite gneiss and granite-tonalite
- Wa — Dominantly amphibolite and granite-tonalite

CONTACT—Approximately located

APPROXIMATE CONTACT BETWEEN LITHO-TECTONIC ZONES

FAULT—Approximately located

25 — BEARING AND PLUNGE OF MINOR FOLDS

50 — STRIKE AND DIP OF BEDS

45 — STRIKE AND DIP OF FOLIATION

STRIKE OF VERTICAL FOLIATION

55, 40 — STRIKE AND DIP OF FOLIATION AND PLUNGE OF LINEATION

W59 — SAMPLE LOCALITY

FIGURE 5.—Geologic sketch map of Morse area, northwestern Wisconsin, showing sample localities for radiometric age determinations. Geology by P. K. Sims and M. G. Mudrey, Jr., 1976.

TABLE 1.—*Approximate modes, in volume percent, of representative samples of Archean rocks in the Puritan batholith, northwestern Wisconsin*

[Tr, trace; leaders (--), not determined]

Sample No.	W68	W71	W72B	W60	W90Y	W95A	W99	W105B	W61-1B	W57	W105A	W59A	W61	W88	W104A	W90X	W95B	W95C
Plagioclase	49.5	54.3	60	30	29	40	54	32	37	53	56	63	52	48	54	42	50	57
Quartz	38.5	34	24	37	33	29	19	33	44	38	28.5	27	30	39	27	5.5	20	12.5
Potassium feldspar	9	3	6	23	32	21	17	33	7.5	3	7	0	0	0	0	0	0	0
Biotite	3.5	8	10	10	5	7.5	6.5	2	11.5	5.5	8	10	18	7	18	1.5	2	2.5
Hornblende	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	36	27	21.5
Epidote	0	0	0	0	0	.5	1.5	0	0	0	0	Tr	Tr	2	Tr	14	Tr	1
Opaque oxides	Tr	0	0	0	Tr	.5	1	Tr	0	Tr	0	Tr	Tr	1	Tr	Tr	Tr	3
Accessory minerals	Tr	.7	Tr	Tr	1	1.5	1	Tr	Tr	.5	.5	Tr	Tr	1	1	1	1	2.5
Plagioclase composition	An_{25}	An_{25}	An_{25}	An_{25}	An_{20}	An_{20}	--	--	An_{25}	An_{25}	An_{25}	An_{25}	An_{25}	An_{28}	An_{32}	An_{29}	An_{25}	An_{25}

SAMPLE DESCRIPTIONS AND LOCALITIES

W68—SW¼SW¼ sec. 23, T. 44 N., R. 3 W. Pinkish-gray, medium-grained tonalite.
W71—Ne¼SW¼ sec. 23, T. 44 N., R. 3 W. Porphyritic tonalite.
W72B—SE¼NW¼ sec. 23, T. 44 N., R. 3 W. Porphyritic tonalite; contains cataclastic streaks.
W60—NW¼SE¼ sec. 8, T. 43 N., R. 2 W. Foliated porphyritic granite.
W90Y—SW¼ sec. 36, T. 44 N., R. 5 W. Porphyritic granite.
W95A—SE¼SE¼ sec. 7, T. 44 N., R. 2 W. Gray foliated granite.
W99—NE¼NE¼ sec. 17, T. 43 N., R. 2 W. Foliated granodiorite.
W105B—NE¼NW¼ sec. 36, T. 44 N., R. 3 W. Pink, fine-grained granite.
W61-1B—SW¼NW¼ sec. 6, T. 43 N., R. 2 W. Pinkish-gray, fine-grained tonalite dike.
W57—NE¼SW¼ sec. 16, T. 43 N., R. 2 W. Weakly foliated tonalite; has mortar texture.
W105A—Same locality as W105B. Foliated tonalite.
W59A—NW¼NE¼ sec. 9, T. 43 N., R. 2 W. Layered tonalite gneiss.
W61—SE¼NW¼ sec. 6, T. 43 N., R. 2 W. Gray, medium- to coarse-grained layered tonalite gneiss.
W88—NE¼NE¼ sec. 35, T. 44 N., R. 5 W. Layered biotite gneiss; has some mortar texture.
W104A—SE¼NW¼ sec. 36, T. 44 N., R. 3 W. Fine-grained, layered biotite gneiss.
W90X—Same locality as W90Y. Layered amphibolite.
W95B—Same locality as W95A. Weakly foliated hornblende gneiss.
W95C—Same locality as W95A. Hornblende gneiss.

have a conspicuously banded appearance. The hornblende is green or bluish green and commonly elongated, giving a prominent mineral lineation. Opaque oxides, sphene, biotite, and chlorite are minor minerals. Generally, the rock is moderately altered; sericite has replaced plagioclase and epidote forms rims on hornblende.

MAFIC DIKES AND LATE GRANITE

Metagabbro dikes as much as 15 m thick cut the Archean rocks. They seem to lack any systematic pattern of orientation and instead occupy diversely oriented fractures. At places the dikes are deformed, mainly by mild folding or by breaking into boudins. Despite the deformation, however, primary ophitic textures commonly are retained, although plagioclase in the rocks may be comminuted and recrystallized in fine-grained aggregates. The cataclastically deformed rocks also have crosscutting veinlets of epidote/clinozoisite. The dikes are mainly massive, and consist of pale-green hornblende and actinolitic hornblende, albite or, at places, zoned plagioclase, and minor amounts of sphene, leucoxene, opaque oxides, epidote/clinozoisite, chlorite, and sericite.

In addition to the late-stage metagabbro dikes, a small body of epizonal granite was observed along the

TABLE 2.—*Chemical composition of representative samples of Archean rocks in the Puritan batholith, northwestern Wisconsin*

[Rubidium and strontium analyses given in table 3. Chemical analyses of samples W99, W108, and W59A by Hezekiah Smith, samples W61, W104A, and W105A by Z. A. Hamlin, and samples W105BB, W61-1B, W61-1A, W104X, W105X, and W95C by Z. A. Hamlin and Nancy Skinner. Uranium and thorium analyses by H. T. Millard, Jr., and others. Leaders (--), not determined]

Major oxides (in weight percent)												
Sample No.--	W99	W105BB	W61-1B	W105A	W59A	W61	W61-1A	W104A	W104X	W105X	W108	W95C
SiO_2--------	68.7	73.2	70.9	68.8	69.3	69.8	62.7	67.6	61.5	74.7	60.5	50.8
Al_2O_3-------	15.2	13.2	14.1	16.8	15.2	15.2	16.6	16.2	15.8	11.9	17.5	16.0
Fe_2O_3-------	1.1	.88	1.1	.6	.78	.8	1.7	.71	2.4	1.2	1.3	4.1
FeO---------	2.2	1.2	2.2	1.0	2.6	2.0	3.7	2.0	4.5	1.7	4.8	7.0
MgO---------	.88	.3	.81	.79	1.1	1.3	2.1	1.6	2.6	.46	2.4	4.5
CaO---------	2.0	1.2	1.7	3.0	3.5	3.1	4.8	3.7	6.6	2.5	4.7	8.4
Na_2O--------	3.7	3.5	4.4	4.8	4.2	3.8	3.9	4.2	3.9	3.7	4.1	4.0
K_2O---------	4.2	4.8	2.2	2.1	1.7	1.6	1.8	1.4	.66	1.6	1.8	1.1
H_2O^+--------	.69	.63	.88	.7	.55	.9	1.1	.75	.86	.64	1.2	1.1
H_2O^---------	.14	.04	.06	.09	.13	.1	.07	.13	.03	.04	.16	.04
TiO_2--------	.33	.18	.35	.16	.35	.3	.57	.38	.68	.21	.59	1.4
P_2O_5--------	.15	.05	.12	.08	.11	.09	.18	.17	.20	.07	.21	.26
MnO---------	.05	.03	.04	.02	.05	.04	.09	.04	.08	.01	.08	.16
CO_2---------	.06	.02	.02	.12	.08	.01	.02	.02	.06	.07	.05	.04
Sum---------	99	99	99	99	100	99	99	99	100	99	99	99
Trace elements (in parts per million)												
U-----------	1.1	--	--	1.1	0.7	0.5	--	3.2	--	--	0.6	--
Th----------	35.0	--	--	5.3	11.5	1.6	--	8.8	--	--	2.5	--

SAMPLE DESCRIPTIONS AND LOCALITIES

Modes and sample localities for W99, W61–1B, W105A, W59A, W61, W109A, and W95C are given in table 1.

W105–BB—NE¼NW¼ sec. 36, T. 44 N., R. 3 W. Pink, fine-grained granite.

W61–1A—SW¼NW¼ sec. 6, T. 43 N., R. 2 W. Gray, medium-grained tonalite gneiss.

W104X—SE¼NW¼ sec. 36, T. 44 N., R. 3 W. Layered biotite gneiss.

W105X—NE¼NW¼ sec. 36, T. 44 N., R. 3 W. Medium-grained foliated tonalite; contains 42 percent plagioclase, 46 percent quartz, 8 percent potassium feldspar, and 4 percent biotite.

W108—SE¼NW¼ sec. 6, T. 43 N., R. 2 W. Tonalite gneiss.

railway tracks adjacent to the Bad River, 4 km north of Cayuga (fig. 5). The granite is a pale-red, fine-grained, slightly porphyritic massive rock. In thin section, it is seen to be partly altered but, except for undulose extinction of feldspars and quartz, it is not visibly deformed. The rock contains slightly perthitic microcline, concentrically zoned plagioclase, dark-brown biotite, and traces of green hornblende. The plagioclase is mildly altered to sericite, clinozoisite, and zeolite(?) minerals. Biotite is partly altered to epidote/clinozoisite, chlorite, and quartz. Sphene, zoned zircon, opaque oxides, allanite, and calcite are minor minerals. A Rb-Sr determination indicates that the granite is Keweenawan.

CHEMICAL COMPOSITIONS

Analyses of selected samples of Archean rocks in the area are listed in table 2. Samples W99 and W105BB fall within the range of granite, as defined by Streckeisen (1976). The other felsic samples are either granodiorite or tonalite in composition on the basis of their chemistry. Sample W95C, the hornblende gneiss, has the composition of a tholeiitic basalt.

Samples W99 and W105BB are similar in mineralogy, major elements, and rubidium and strontium contents to the main granitic phase of the Puritan Quartz Monzonite in Michigan. The other samples, including biotite gneiss and amphibolite, form a well-defined sodic trend on a K_2O-Na_2O-CaO diagram (fig. 6) and show little evidence for potassium enrichment with decreasing calcium, which would indicate a compositional linkage with the granitic rocks.

The tonalitic and granodioritic rocks are also characterized by high strontium and low rubidium contents, and have rubidium to strontium ratios in the range of 0.09 to 0.21—features that also distinguish these from the granitic rocks.

The compositional features shown by these limited data suggest that the tonalitic and granodioritic rocks probably were derived from different sources than those of the main granitic phase of the batholith.

GEOCHRONOLOGY

Rb-Sr analyses were made of selected whole-rock samples and biotite, and K-Ar ages were determined for the biotites. U-Th-Pb (uranium-thorium-lead) analyses were made for zircons from two samples. Isotopic and decay constants used in all of the age calculations are those recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger, 1977). Analytical uncertainties are the same as those reported in Peterman and others (1980).

Rb-Sr data (table 3) for the tonalitic gneisses and associated rocks in the Puritan batholith generally indicate a Late Archean age, but do not define a single isochron, because of appreciable scatter of data points that exceed analytical errors (fig. 7). Biotite separates from two samples (W104A and W61–1A, table 3, fig. 5) have Rb-Sr ages of about 900 m.y., and K-Ar ages are slightly greater at 1,053 m.y. and 1,043 m.y., respectively (table 4). We interpret these ages as reflecting brittle-ductile deformation and recrystallization during the Keweenawan.

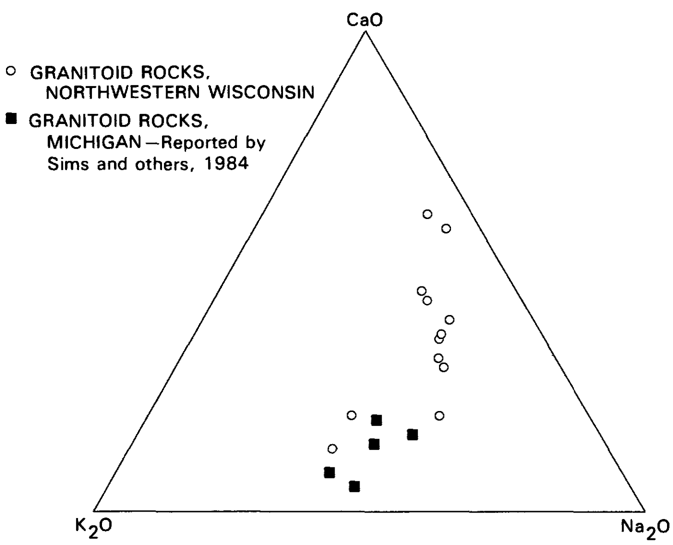


FIGURE 6.—K_2O-Na_2O-CaO diagram for granitoid rocks in Puritan batholith, northwestern Wisconsin and Michigan.

As previously described, sample W67 is an undeformed and only slightly altered granite from a small

TABLE 3.—*Rubidium and strontium data for whole-rock samples and biotite separates, Puritan batholith, and for miscellaneous samples from northwestern Wisconsin*

[Analyst: Kiyoto Futa. Suffix letters: WR, whole rock; Bi, biotite]

Sample No.	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
		Puritan batholith		
W59(WR)	59.2	277.4	0.619	0.7277
W61(WR)	33.4	260.2	.372	.7174
W61-1A(WR)	39.6	336.6	.341	.7157
W61-1A(Bi)	209.0	13.85	46.31	1.3216
W61-1B(WR)	43.1	204.3	.611	.7284
W95C(WR)	16.8	286.1	.170	.7074
W99(WR)	107.1	453.3	.685	.7260
W104(WR)	47.3	717.0	.191	.7104
W104(Bi)	367.0	13.83	84.77	1.7650
W104X(WR)	14.4	243.4	.171	.7073
W105A(WR)	65.1	763.6	.247	.7112
W105X(WR)	42.8	294.7	.421	.7174
W105BB(WR)	147.4	184.3	2.333	.7848
W108(WR)	38.2	370.5	.298	.7148
		Miscellaneous samples		
W67(WR)	188.7	151.9	3.617	0.7639
RL-1-1(WR)	64.6	159.2	1.179	.7412
RL-2(WR)	96.0	574.3	.484	.7155
W241(WR)	101.6	174.7	1.689	.7488
79-7A(WR)	126.2	89.8	4.130	.8597
79-7B(WR)	100.9	107.7	2.741	.8196
79-53(WR)	86.0	289.9	.862	.7337
79-109(WR)	20.0	390.2	.148	.7094

SAMPLE DESCRIPTIONS AND LOCALITIES

W59 through W108—Rock names and localities are given in tables 1 and 2.

W67—Pink, medium-grained biotite granite. SW¼ sec. 23, T. 44 N., R. 3 W.

RL–1–1—Pinkish-gray, fine-grained, garnetiferous biotite schist. SW¼SW¼ sec. 11, T. 40 N., R. 1 E.

RL–2—Gray, medium-grained garnetiferous biotite schist. NW¼SE¼ sec. 11, T. 40 N., R. 1 E.

W241—Gray, coarse-grained, kyanite-, staurolite-, and garnet-bearing biotite schist. NE¼NW¼ sec. 33, T. 42 N., R. 4 E.

79–7A—Gray, fine-grained biotite gneiss from abandoned railway in Fifield. SE¼SW¼ sec. 6, T. 39 N., R. 1 E.

79–7B—Light-gray, medium-grained biotite gneiss; interlayered with 79–7A. Same location as 79–7A.

79–53—Gray, fine-grained, layered garnet-biotite gneiss, north side of Flambeau River. SW¼NE¼ sec. 4, T. 41 N., R. 2 E.

79–109—Dark-gray, weakly layered amphibolite. SE¼SE¼ sec. 3, T. 41 N., R. 1 E. Collected from Pete's landing.

TABLE 4.—*Potassium and argon data for biotite separates from rocks in Puritan batholith*

[Analyses: Harald Mehnert (Ar) and Paul Klock (K_2O); Ar*, mean radiogenic Ar; sample localities given in tables 1 and 2]

Sample No.	K_2O (pct)	$^{40}Ar^*$ (moles/g)	$^{40}Ar^*$ (pct)	Age (m.y.)
W61-1A	8.69	1.766×10^{-8}	99.3	1,043±17
W104A	8.84	1.827×10^{-8}	99.0	1,053±17
	8.90			

plug adjacent to the Mineral Lake fault (fig. 5). A model Rb-Sr age is 1,180 m.y., based on a mantle-like initial $^{87}Sr/^{86}Sr$ ratio of 0.7027. If the rock has remained a closed system with respect to rubidium and strontium since crystallization, this model age is a maximum value. Higher initial ratios would lower the model age, for example, to 1,138 m.y. with an initial ratio of 0.705, and 1,042 m.y. with an initial ratio of 0.710. Even with these uncertainties, the model calculations clearly establish the granite as Keweenawan. The lack of significant deformation indicates that it was emplaced after the major movement along the Mineral Lake fault.

The excessive scatter in the whole-rock data for the Archean samples probably results from open-system behavior during cataclasis and recrystallization. In addition, the systems would have been highly susceptible to surficial alteration because of the internal discordances of the minerals as indicated by the Rb-Sr biotite ages.

Zircon separated from two samples of tonalitic gneiss for U-Th-Pb dating (table 5) establishes a Late Archean age for these units. Zircon from W105X is brown, somewhat rounded, highly fractured, and iron stained. Its morphology is simple prism and pyramidal faces with length-to-width ratios of 2:1 to 3:1. As might be expected from much lower uranium and thorium contents (table 5), zircons from W61–1A are much less degraded physically than those from W105X. A large proportion of the W61–1A population is clear and unfractured with a gradation to darker and somewhat fractured grains. Sharp face intersections are typically well preserved. The grains are more elongate, on the average, than those from W105X, and the terminations are much steeper pyramids.

Two hand-picked size fractions of each sample define a single chord on the concordia diagram (fig. 8) with an upper intercept of 2,735±16 m.y. The regression is that of Ludwig (1982), and the fit of the chord is well within analytical uncertainty as indicated by a MSWD (mean square of the weighted deviates) of 0.58. (A value of less than 1 indicates a fit within the assigned analytical errors.) Accordingly, we interpret the upper intercept as the primary age of the tonalitic rocks. The lower intercept age of 1,052±70 m.y. is of particular interest in that it agrees with the Rb-Sr and K-Ar biotite ages. The well-defined chord is best interpreted as resulting from discordance (lead loss) imposed at the time indicated by the lower intercept. This age lends further support to the effects of a Keweenawan disturbance on these rocks.

The age of 2,735±16 m.y. is somewhat greater than the Rb-Sr age of 2,650 m.y. for the main granitic phase of the Puritan Quartz Monzonite in Michigan, but the latter has a large uncertainty of ±140 m.y. Within error, the zircon age is identical to the 2,750 m.y. age obtained for zircon from a tonalitic gneiss interlayered with amphibolite southeast of Marenisco (Peterman and others, 1980). It is also similar to a zircon age of 2,718±67 m.y. for a tonalitic phase of the Giants Range batholith in Minnesota (USGS, unpub. data).

On the Rb-Sr diagram (fig. 7), two reference isochrons corresponding to the zircon age are constructed through the respective samples. Data for the other whole-rock samples generally scatter about these lines. Sample W105BB, a granite, has a much higher Rb/Sr ratio than do the tonalites, and the model age of 2,480 m.y. indicates some disturbance.

CORRELATION

The massive and foliated varieties of granitoid rocks in the area are considered correlative with the Puritan Quartz Monzonite as delineated by Schmidt (1976) in the western part of northern Michigan and described by Sims and others (1977) for a broader area in Michigan. The proportion of tonalite apparently is higher in northwestern Wisconsin than in northern Michigan, however, and in this regard the granitoid rocks in the Wisconsin area are similar to the satellitic bodies of Puritan Quartz Monzonite in the Marenisco area described by us in chapter A (Sims and others, 1984). The tonalite gneiss has no known correlative in northern Michigan, but it could be comparable to the Whiskers Creek Gneiss. The biotite gneisses and amphibolite are grossly correlative with the metavolcanic rocks in Michigan that have been formally named the Ramsay Formation. The biotite gneisses had a dacitic or volcanogenic graywacke protolith and the amphibolite had a mafic lava or pyroclastic protolith.

STRUCTURE AND METAMORPHISM

Two major episodes of deformation and metamorphism are recorded in the Archean rocks in this area, an older one that produced west-northwest-oriented layering and foliation and was accompanied by low amphibolite-facies metamorphism of the bedded rocks, and a younger deformation resulting from brittle-ductile deformation that was accompanied by retrogressive metamorphism. The former occurred during the Late Archean and the latter during Keweenawan (Middle Proterozoic) rifting.

The Archean deformation produced penetrative, steeply dipping structures and minor folds that plunge moderately to either west or east. The structures were mainly formed by ductile deformation, as indicated by alined platy minerals in foliation planes and elongated minerals oriented parallel to fold axes. The foliation in the granitoid rocks is interpreted as having resulted from intrusion of magma into the bedded rocks during the Late Archean deformation; apparently deformation ceased before the granite crystallized entirely.

The younger deformation produced a west-northwest-trending cataclastic foliation that locally obliterated the older structures in the Archean rocks. Commonly, however, two or more S-surfaces are visible in outcrop, both being defined mainly by oriented biotite and hornblende. This deformation was not pervasive; instead, it was intense along and immediately south of the Mineral Lake fault zone and locally intense in areas farther south.

Metamorphism of the Archean gneisses and amphibolite during the folding produced andesine and a green hornblende in the mafic rocks and oligoclase-andesine and, locally, almandine garnet in the biotitic rocks. Although the granitoid intrusive rocks were foliated in part during this tectonism, they were not appreciably metamorphosed. The younger metamorphism that ac-

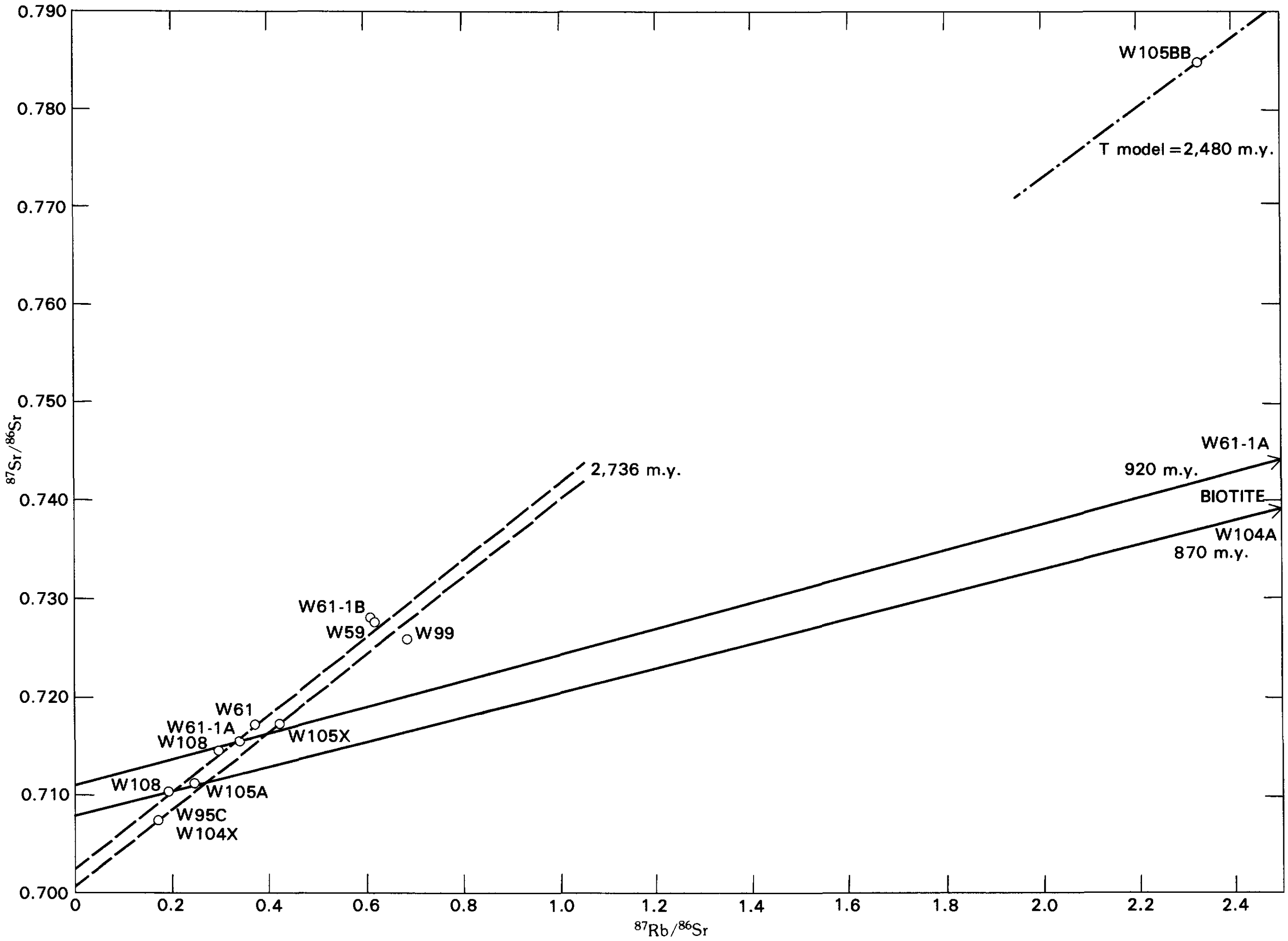


FIGURE 7.—Rubidium-strontium isochron diagram for rocks and minerals, Puritan batholith. Solid lines are isochrons drawn through data points for biotite and their respective whole-rock samples. Dashed lines are reference isochrons based on the uranium-lead zircon ages for samples W105X and W61–1A. Dash-dot line through sample point W105BB corresponds to the model age of this sample.

TABLE 5.—*Uranium, thorium, and lead data for zircons*

[Isotopic composition of initial lead is assumed to be ^{204}Pb:^{206}Pb:^{207}Pb:^{208}Pb = 1:12.12:13.77:32.05 for samples W61–1A and W105X and = 1:15.47:15.26:35.10 for sample RL–2. Numbers in parentheses below atom ratios, ages in millions of years. Analyst: Loretta Kwak]

Sample No.[1]	Concentration (ppm)			Isotopic composition of lead (atom pct)				Atom ratios			
	U	Th	Pb	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
W61-1A(100-150)	190.5	49.1	91.1	0.015	79.44	14.33	6.21	0.4405 (2,353)	10.8089 (2,507)	0.1782 (2,636)	0.1196 (2,284)
W61-1A(200-270)	190.1	50.4	96.4	.020	78.47	14.41	7.10	.4612 (2,445)	11.4755 (2,563)	.1807 (2,659)	.1388 (2,627)
W105X(50-100)	762.4	312.3	351.3	.018	76.53	13.39	10.07	.4086 (2,209)	9.6922 (2,406)	.1722 (2,579)	.1202 (2,294)
W105X(-270)	773.2	394.2	347.9	.031	75.47	13.14	11.37	.3926 (2,135)	9.1539 (2,354)	.1693 (2,551)	.1031 (1,984)
RL-2(200-250)	804.3	514.2	243.2	.026	75.38	8.88	15.71	.2634 (1,507)	4.1114 (1,657)	.1132 (1,852)	.0788 (1,533)
RL-2(-325)	747.4	532.8	184.1	.012	74.68	8.61	16.69	.2140 (1,250)	3.3396 (1,490)	.1132 (1,851)	.0635 (1,244)

[1]Numbers in parentheses after sample numbers are screen sizes of the zircons.

companied the cataclastic deformation was retrogressive. Assemblages containing sericite, epidote/clinozoisite, biotite, and chlorite were developed at this time. This greenschist facies metamorphism is well shown by mineral assemblages in the metagabbro dikes in the area. They contain pale-green hornblende and actinolite, albite, and varying amounts of leucoxene, sphene, opaque oxides, chlorite, sericite, epidote, and zeolite(?) minerals, indicative of greenschist facies metamorphism.

The retrogressive alteration apparently caused a partial breakdown of biotite to potassium feldspar, for barrel-shaped lenses of potassium feldspar commonly occur in biotites in granitoid rocks. This alteration is similar to that described in chapter A in Archean rocks of the Marenisco area (Sims and others, 1984).

Of the numerous known and inferred faults in the area, the Mineral Lake fault is particularly worthy of discussion. It belongs to a family of northwest-trending faults in the Lake Superior region that originated in the Late Archean and were reactivated intermittently during the Early and Middle Proterozoic (Sims and Peterman, 1982). The faults dominantly have had right-lateral displacements. As can be seen on figure 2, the Mineral Lake fault cuts and displaces the Early Proterozoic iron-formation and associated strata on the west end of the Gogebic Range, and has an apparent horizontal displacement of about 6 km; other faults of this trend to the south displace the same rocks lesser distances. The iron-formation terminates to the south against a fault of this trend. Clearly, the Mineral Lake fault was the locus of major movement during the Keweenawan rift event. Although it is not exposed in this area, and its location is inferred mainly by offsets of lithologic units and by a lineament on magnetic maps, subsidiary mylonitic fracture zones are abundant in the vicinity of the fault. We interpret the faulting and related cataclasis as having culminated about 1,050 m.y. ago, at the time when K-Ar biotite ages were reset in some rocks and when the U-Pb systems in the zircon record a lead-loss event.

DISCUSSION

The Archean rocks that compose the Puritan batholith are definitely part of the greenstone-granite terrane, as defined in the Lake Superior region (Sims, 1980). Previously, we had tentatively considered the gneisses south of the Mineral Lake fault as being a part of the Archean gneiss terrane (Sims and others, 1978; Sims, 1980). The ages obtained on rocks from northwestern Wisconsin are indistinguishable from those in other parts of the greenstone-granite terrane in the region (Peterman, 1979), and it is becoming increasingly certain that all the rocks in this terrane within the region were formed 2,750–2,600 m.y. ago.

The long dimension of the Puritan batholith, as defined herein, and internal structures within it are subparallel to the boundary between the two Archean terranes identified in the region, as shown on figure 9. In the same way, the elongate Giants Range batholith and adjacent granitic bodies are oriented roughly parallel to the boundary, as is the northern complex of the

Marquette Range. The Archean structures in the greenstone-granite terrane seem to reflect the sigmoidal structure of the boundary zone, which in part has resulted from the northwest-trending faults that displace the boundary. This conformity of major granitoid bodies in the greenstone terrane with the basement boundary possibly could have several explanations, but we prefer a model whereby the granite was emplaced after the two basement crustal segments had been joined, and one in which the strain field in the vicinity of the boundary was controlled by interaction of the two Archean crustal segments. As discussed here and in our report concerning the Marenisco area (Sims and others, 1984), the Archean metavolcanic-metasedimentary rocks adjacent to the boundary were deformed on axes subparallel to it, and granitoid bodies were emplaced near the end of or after the deformation, and accordingly generally escaped deformation. Possibly the granitoid bodies were emplaced during periods of extension oriented approximately at right angles to the boundary.

The parallelism of Archean and younger Proterozoic structures (Sims and Peterman, 1984) with the basement boundary supports our previous contention (Sims and Peterman, 1981; Sims and others, 1980) that the feature is a major crustal structure in the upper midcontinent region. It has been named the Great Lakes tectonic zone (Sims and others, 1980). The boundary between the two crustal segments was a zone of weakness that was repeatedly reactivated, and to a large extent younger Precambrian tectonic features mimicked the older, primary structural grain.

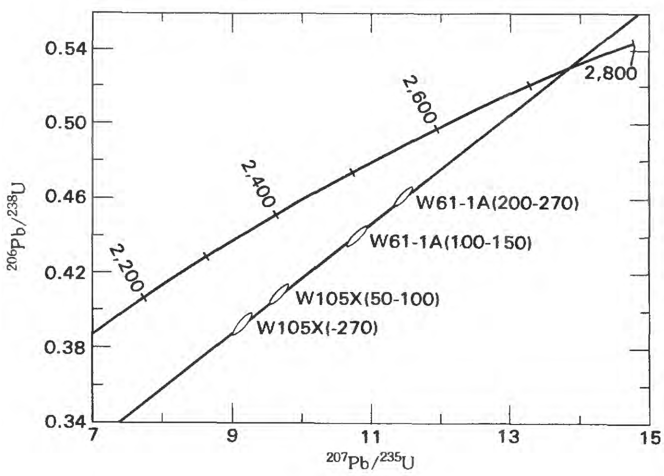


FIGURE 8.—Uranium-lead concordia diagram for zircons from samples W105X and W61–1A, Puritan batholith. Intercepts are 2,735±16 m.y. and 1,052±70 m.y. Numbers in parentheses designate size fractions. The ellipses correspond to assigned analytical error.

REFERENCES CITED

Allen, R. C., and Barrett, L. P., 1915, Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geological Survey Publication 18, Geologic Series 15, p. 13–164.

Dutton, C. E., and Bradley, Reta, 1970, Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–631, scale 1:500,000.

Ervin, C. P., and Hammer, S. H., 1974, Bouguer anomaly gravity map of Wisconsin: Wisconsin Geological and Natural History Survey, scale 1:500,000.

Goldich, S. S., Nier, A. O., Baadsgaard, Halfdan, Hoffman, J. H.,and Krueger, H. W., 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geological Survey Bulletin 41, 193 p.

Hall, W. C., 1900, The Chengwatana Series of the Keweenawan: American Association for the Advancement of Science, New York, Proceedings, v. 49, p. 191.

Hotchkiss, W. O., 1915, Mineral land classification: Wisconsin Geological and Natural History Survey Bulletin 44, Economic Series 19, 377 p.

Hotchkiss, W. O., and Bean, E. F., 1929, Mineral lands of part of northern Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 46, Economic Series 21, 212 p.

Ludwig, K. R., 1982, Programs for filing and plotting U-Pb isotope data for concordia diagrams, using an HP–9830 computer and HP–9832 plotter: U.S. Geological Survey Open-File Report 82–386, 22 p.

Morey, G. B., and Sims, P. K., 1976, Boundary between two Precambrian W terranes in Minnesota and its geologic significance: Geological Society of America Bulletin, v. 87, p. 141–152.

Morey, G. B., Sims, P. K., Cannon, W. F., Mudrey, M. G., Jr., and Southwick, D. L., 1982, Geologic map of the Lake Superior region, Minnesota, Wisconsin, and northern Michigan: Minnesota Geological Survey State Map Series S–13, scale 1:1,000,000.

Peterman, Z. E., 1979, Geochronology and the Archean of the United States: Economic Geology, v. 74, p. 1544–1562.

Peterman, Z. E., Zartman, R. E., and Sims, P. K., 1980, Tonalitic gneiss of early Archean age from northern Michigan, *in* Morey, G. B., and Hanson, G. N., eds., Selected studies of Archean and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 125–134.

Schmidt, R. G., 1976, Geology of the Precambrian W (lower Precambrian) rocks in western Gogebic County, Michigan: U.S. Geological Survey Bulletin 1407, 40 p.

———1980, The Marquette Range Supergroup in the Gogebic iron district, Michigan and Wisconsin: U.S. Geological Survey Bulletin 1460, 96 p.

Schwerdtner, W. M., Stone, D., Osadetz, K., Morgan, J., and Stott, G. M., 1979, Granitoid complexes and the Archean tectonic record in the southern part of northwestern Ontario: Canadian Journal of Earth Sciences, v. 16, p. 1965–1977.

Sims, P. K., 1980, Boundary between Archean greenstone and gneiss terranes in northern Wisconsin and Michigan, *in* Morey, G. B., and Hanson, G. N., eds., Selected studies of Archean and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 113–124.

Sims, P. K., Cannon, W. F., and Mudrey, M. G., Jr., 1978, Preliminary geologic map of Precambrian rocks in northern Wisconsin: U.S. Geological Survey Open-File Report 78–318, scale 1:250,000.

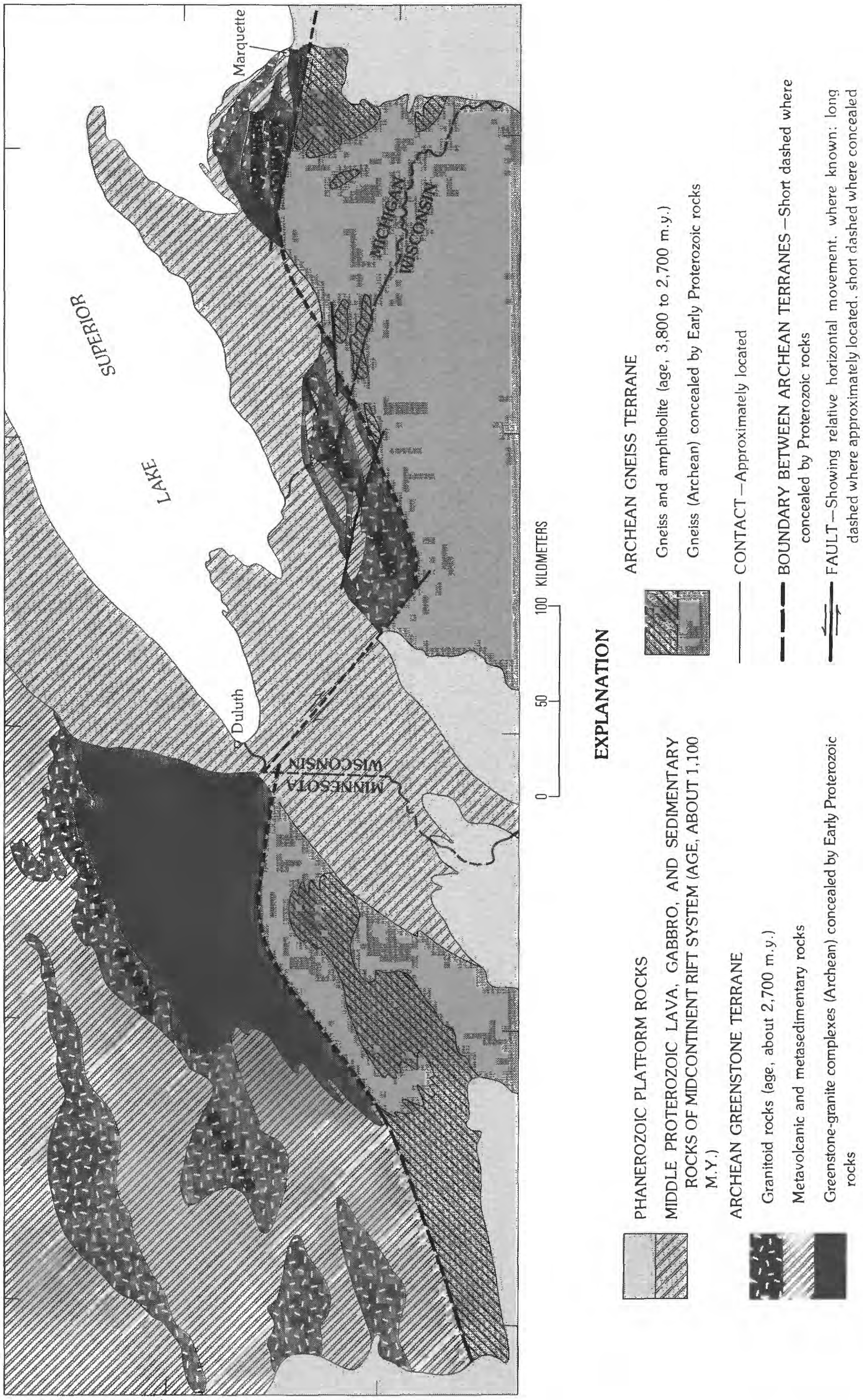


Figure 9.—Generalized geologic map of the Lake Superior region showing relationship of elongate batholiths in the Archean greenstone-granite terrane to Archean gneiss terrane boundary (Great Lakes tectonic zone). (Compiled by P. K. Sims, 1981.)

Sims, P. K., Card, K. D., Morey, G. B., and Peterman, Z. E., 1980, The Great Lakes tectonic zone—A major crustal structure in central North America: Geological Society of America Bulletin, Part I, v. 91, p. 690–698.

Sims, P. K., and Peterman, Z. E., 1980, Geology and Rb-Sr age of lower Proterozoic granitic rocks, northern Wisconsin, *in* Morey, G. B., and Hanson, G. N., eds., Selected studies of Archean and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 139–146.

———1981, Archean rocks in the southern part of the Canadian Shield—A review, *in* Glover, J. E., and Groves, D. I., eds., Archaean geology—Second International Symposium, Perth, 1980: Geological Society of Australia Special Publication 7, p. 85–98.

———1983, Evolution of Penokean foldbelt, Lake Superior region, and its tectonic environment, *in* Medaris, L. G., Jr., ed., Early Proterozoic geology of the Great Lakes region: Geological Society of America Special Paper 160, p. 3–14.

Sims, P. K., Peterman, Z. E., and Prinz, W. C., 1977, Geology and Rb-Sr age of Precambrian W Puritan Quartz Monzonite, northern Michigan: U.S. Geological Survey Journal of Research, v. 5, p. 185–192.

Sims, P. K., Peterman, Z. E., Prinz, W. C., and Benedict, F. C., 1984, Geology, geochemistry, and age of Archean and Early Proterozoic rocks in the Marenisco-Watersmeet area, northern Michigan: U.S. Geological Survey Professional Paper 1292–A, p. A1–A41.

Sims, P. K., Peterman, Z. E., and Schulz, K. J., 1982, Dunbar gneiss dome and implications for the Proterozoic stratigraphy of northern Wisconsin [abs.]: Annual Institute on Lake Superior Geology, 28th, International Falls, Minnesota, Proceedings, p. 44.

Sims, P. K., and Viswanathan, S., 1972, Giants Range batholith, *in* Sims, P. K., and Morey, G. B., eds., Geology of Minnesota—A centennial volume: Minnesota Geological Survey, p. 120–139.

Steiger, R. H., and Jäger, E., 1977, Subcommission on geochronology—Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

Streckeisen, A. L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Van Schmus, W. R., 1980, Chronology of igneous rocks associated with the Penokean orogeny in Wisconsin, *in* Morey, G. B., and Hanson, G. N., eds., Selected studies of Archean and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 159–168.

☆ U. S. GOVERNMENT PRINTING OFFICE 1985/576-049/20,027

Contributions to the Geology of the Lake Superior Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1292

This volume was published as chapters A and B, and chapter C

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