# Petrography and Geochemistry of Early Proterozoic Granitoid Rocks in Wisconsin Magmatic Terranes of Penokean Orogen, Northern Wisconsin

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Chapter J

# Petrography and Geochemistry of Early Proterozoic Granitoid Rocks in Wisconsin Magmatic Terranes of Penokean Orogen, Northern Wisconsin

By P.K. SIMS, K.J. SCHULZ, ED DEWITT, and
BRUCE BRASAEMLE

A reconnaissance study carried out in
conjunction with regional geologic mapping

U.S. GEOLOGICAL SURVEY BULLETIN 1904

CONTRIBUTIONS TO PRECAMBRIAN GEOLOGY OF LAKE SUPERIOR REGION

P.K. SIMS and L.M.H. CARTER, Editors

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# Petrography and Geochemistry of Early Proterozoic Granitoid Rocks in Wisconsin Magmatic Terranes of Penokean Orogen, Northern Wisconsin

*By* P.K. Sims, K.J. Schulz, Ed DeWitt, *and* Bruce Brasaemle

## Abstract

Granitoid rocks in the Pembine-Wausau and Marshfield terranes (Wisconsin magmatic terranes) of the Early Proterozoic Penokean orogen compose two distinct and contrasting suites, calc-alkalic rocks that are broadly syntectonic and alkali granites that are post-tectonic. Rocks of the syntectonic suites are spatially associated with coeval tholeiitic and calc-alkalic volcanic rocks. Composition of the rocks in each suite is similar in both terranes.

In the Pembine-Wausau terrane, a syntectonic granodiorite suite (1,870–1,837 Ma) intrudes tholeiitic and calc-alkalic volcanic rocks (1,889–1,840 Ma). The syntectonic suite is calcic to calc-alkalic, average to rich in magnesium content, and sodic to very sodic; it has intermediate $SiO_2$ concentrations, intermediate to high $Al_2O_3$ (12.4–16.4 percent), high strontium concentrations, and low rubidium, niobium, and yttrium concentrations. The rocks are similar in composition to the Newingham Tonalite in the Dunbar, Wisconsin, area, which is interpreted as a volcanic-arc granite. The post-tectonic suite in the Pembine-Wausau terrane consists of three distinctive rock groups: the ≈1,836 Ma Athelstane Quartz Monzonite, a 1,835 Ma alkali-feldspar granite, and a ≈1,760 Ma granodiorite-granite group. The Athelstane Quartz Monzonite is mildly peraluminous; its $SiO_2$ content is high (68–77 percent), $Al_2O_3$ content is intermediate (12–15 percent), and it exhibits Na:K<1. The rocks are strongly enriched in iron and have distinctive rare-earth element patterns, exhibiting large negative europium anomalies. The Athelstane Quartz Monzonite is compositionally similar to younger Middle Proterozoic granites of the Wolf River batholith in Wisconsin. The 1,835 Ma alkali-feldspar granite is mildly peraluminous, alkali-calcic, and iron-rich; it contains very low strontium and high uranium concentrations and exhibits large negative europium anomalies. These rocks plot as within-plate granites. The ≈1,760 Ma granodiorite-granite group is coeval with the 1,760 Ma anorogenic rhyolite-granite terrane in south-central Wisconsin, but differs from these anorogenic rocks in being more variable in composition and in having somewhat lower FeO:(FeO+MgO) and higher strontium content. The granodiorite-granite group contains the most rubidium- and thorium-rich rocks in the area.

In the Marshfield terrane, a syntectonic tonalite-granodiorite suite contains a range of rocks from hornblende-biotite diorite to biotite trondhjemite; the suite is calc-alkalic to alkali-calcic. The rocks are mostly metaluminous, rich to very rich in magnesium, and sodic. The tonalite-granodiorite suite has been compared to Holocene orogenic andesite-dacite suites, and it is associated with tholeiitic and calc-alkalic volcanic rocks, tentatively dated at 1,860 Ma, which overlie an Archean basement. Available U-Pb zircon ages on the tonalite-granodiorite suite range from ≈1,840 Ma to 1,892 Ma, suggesting that the associated volcanic rocks are in part at least older than 1,860 Ma. A unit of limited areal extent, gneissic granite near Neillsville (1,871±5 Ma), has a more highly evolved chemical composition than the tonalite-granodiorite suite. The 1,835 Ma post-tectonic alkali-feldspar granite in the Marshfield terrane is petrographically and chemically identical to the alkali-feldspar granite in the Pembine-Wausau terrane.

The older rocks (1,870–1,852 Ma) of the granodiorite suite in the Pembine-Wausau terrane formed during volcanism initiated during southward subduction of oceanic crust prior to collision (1,852 Ma) of the Pembine-Wausau arc terrane and the continental margin along the Niagara fault zone. Younger (1,853–1,837 Ma) rocks in the granodiorite suite presumably formed during later north-dipping subduction along the Eau Pleine shear zone (≈1,840 Ma) that terminated with collision of the Marshfield minicontinent with the Pembine-Wausau terrane. The anorogenic Athelstane Quartz Monzonite was generated by partial melting of lower crust 5–10 million years after termination of orogenic episodes. At about the same time, the 1,835 Ma alkali-feldspar granite was generated by crustal melting and emplaced astride the Eau Pleine suture zone. The final product of crustal melting, the 1,760 Ma granodiorite-granite group, is variable in composition, probably indicating partial melting of different source materials.

The granitoid rocks in the arc terranes show a temporal progression from magnesium-rich granodiorite or trondhjemite to iron-rich granodiorite-granite. The syntectonic granodiorite suites in both terranes are primitive, magnesium-rich rocks typical of immature island or continental arcs. Iron content of plutonic rocks younger than ≈1,850 Ma ranges from average to rich to very rich. The post-tectonic Athelstane Quartz Monzonite and the 1,835 Ma red alkali-feldspar granite are uncommonly enriched in zirconium for evolved granites. Compared with other Proterozoic orogenic terranes in the western United States, the plutonic rocks of the Wisconsin magmatic terranes are notably sodic.

## INTRODUCTION

Reconnaissance sampling of granitoid rocks in northern Wisconsin during regional geologic mapping (Sims, 1992) provides a means of characterizing plutonic rock bodies in the Early Proterozoic Wisconsin magmatic terranes (Sims and others, 1989), previously a poorly known part of the Penokean orogen (Sims and Peterman, 1983). Concurrently, a systematic, detailed mapping and sampling program was conducted in the Dunbar area in northeastern Wisconsin (Sims and others, 1985; Sims and others, 1992).

Reconnaissance geologic mapping and sampling in the area began in 1975 and continued intermittently through 1987. Geologic maps of the Eau Claire-Green Bay (Sims, 1990a), Rice Lake (Sims, 1989), and Iron Mountain-Escanaba (Sims, 1990b) 1°×2° quadrangles have been published. A regional geologic map (scale 1:500,000) of Precambrian rocks of northern Michigan and Wisconsin also has been published (Sims, 1992) in cooperation with the Wisconsin Geological and Natural History Survey.

Most rock names used in this report are based on the chemical classification of DeLaRoche and others (1980). In the sample descriptions accompanying tables 1 and 2, rock names based on the IUGS (Streckeisen, 1976) classification are also listed for those samples that differ from the DeLaRoche classification. The DeLaRoche classification together with A/CNK values (molecular ratio of $Al_2O_3$:($CaO+Na_2O+K_2O$) is useful in identifying altered samples.

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## GEOLOGIC SETTING

The 1.90–1.83 Ga Penokean orogen consists of two distinct lithologic domains (fig. 1), a northern deformed continental margin prism overlying an Archean basement, and a southern assemblage of island arcs and (or) closed back-arc basins, known as the Wisconsin magmatic terranes, which for the most part lack an Archean basement (Sims and others, 1989). The northern domain includes the Marquette Range Supergroup in Michigan and Wisconsin (Cannon and Gair, 1970), which consists of a rifted passive-margin sequence overstepped northward by a synorogenic foredeep sequence (Hoffman, 1987; Barovich and others, 1989). Early Proterozoic deformation involved north-directed thrusting and folding of the supracrustal rocks and, at least locally, the Archean basement rocks (Gregg, 1993; Klasner and Sims, 1993) on the continental margin. Crustal thickening resulted in metamorphism and development of local basement gneiss domes (Sims and Peterman, 1983; Klasner and others, 1988; Holm and others, 1988; Attoh and Klasner, 1989).

The southern, magmatic terranes are composed of Early Proterozoic calc-alkalic and tholeiitic volcanic rocks and calc-alkalic and alkali granite plutonic rocks (Sims and others, 1989). The southernmost of the magmatic terranes, the Marshfield terrane, is at least partly underlain by Archean basement rocks. This Archean basement, in central Wisconsin, differs from the Archean gneiss basement of the continental margin in lacking rocks of Early Archean (3.6 Ga) age and in lacking granulite-facies gneisses. Therefore, the central Wisconsin Archean basement is not considered to be a rifted fragment from the nearby continental margin.

The Niagara fault zone, which separates the south-facing continental margin from the arc terranes in Wisconsin and Michigan, is a steep, south-dipping structure at the surface (Larue and Ueng, 1985; Sedlock and Larue, 1985), but it may flatten at depth to a shallow-dipping thrust. The fault zone contains a dismembered ophiolite and has been interpreted as a paleosuture (Schulz, 1987) along which the two terranes were juxtaposed at 1,860–1,850 Ma.

## WISCONSIN MAGMATIC TERRANES

The Wisconsin magmatic terranes comprise two distinct assemblages that are distinguished on the basis of rock types and structure: (1) a northern terrane, called Pembine-Wausau and (2) a southern terrane, called Marshfield (figs. 1, 2). The two terranes are juxtaposed along the Eau Pleine shear zone, a presumed south-verging paleosuture zone (Cannon and

**Figure 1 (facing page).** Geologic map of eastern part of Lake Superior region showing relationships of rocks within the Penokean orogen. M, Marquette; I, Ironwood; E, Eau Claire; W, Wausau; S, Stevens Point; H, Holcombe; P, Pembine. Precambrian Y, Middle Proterozoic (900–1,600 Ma); Precambrian X, Early Proterozoic (1,600–2,500 Ma); A, Archean (2,500–3,800 Ma) in the stratigraphic column. Modified from Sims and others, 1989.

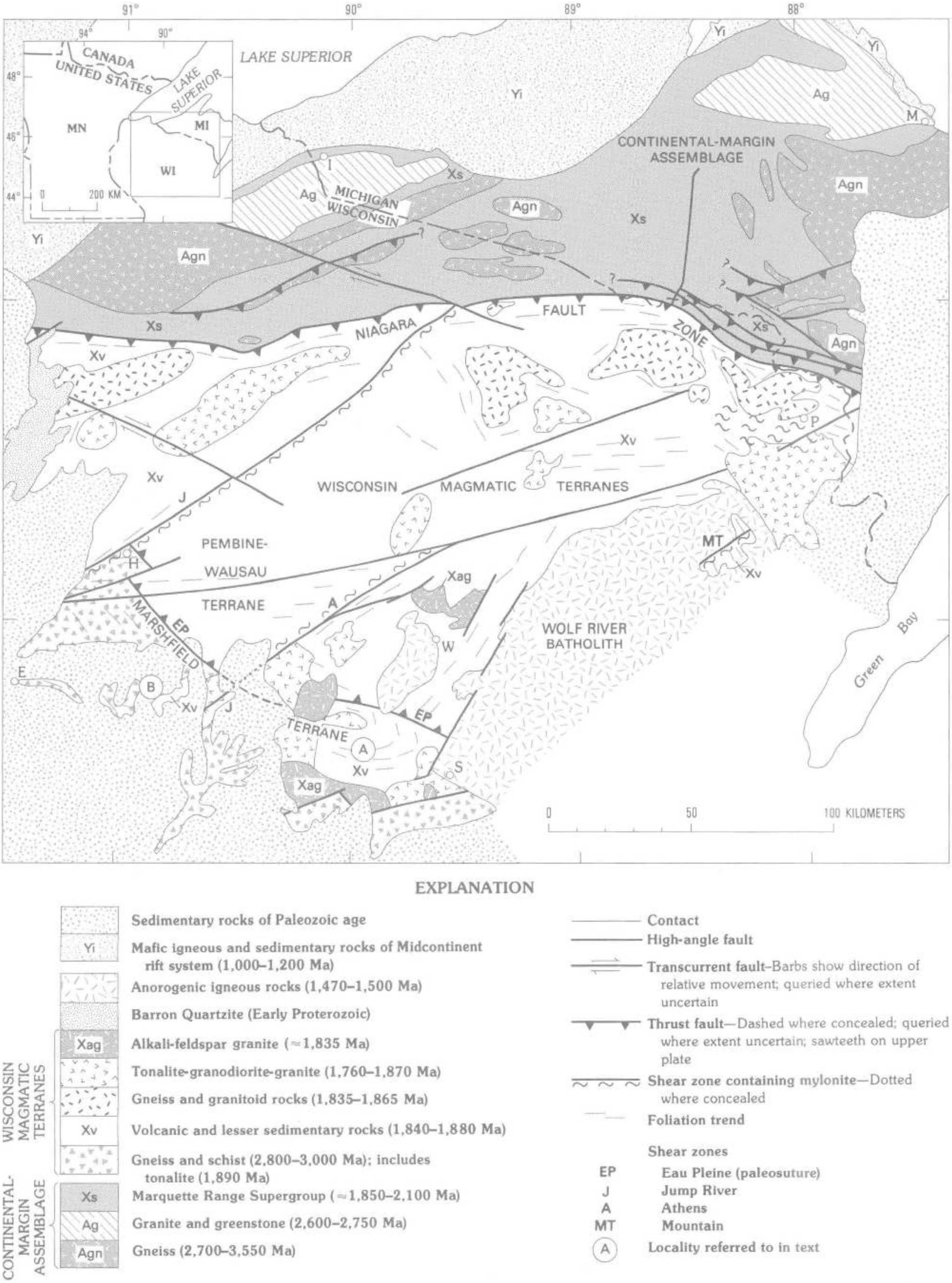
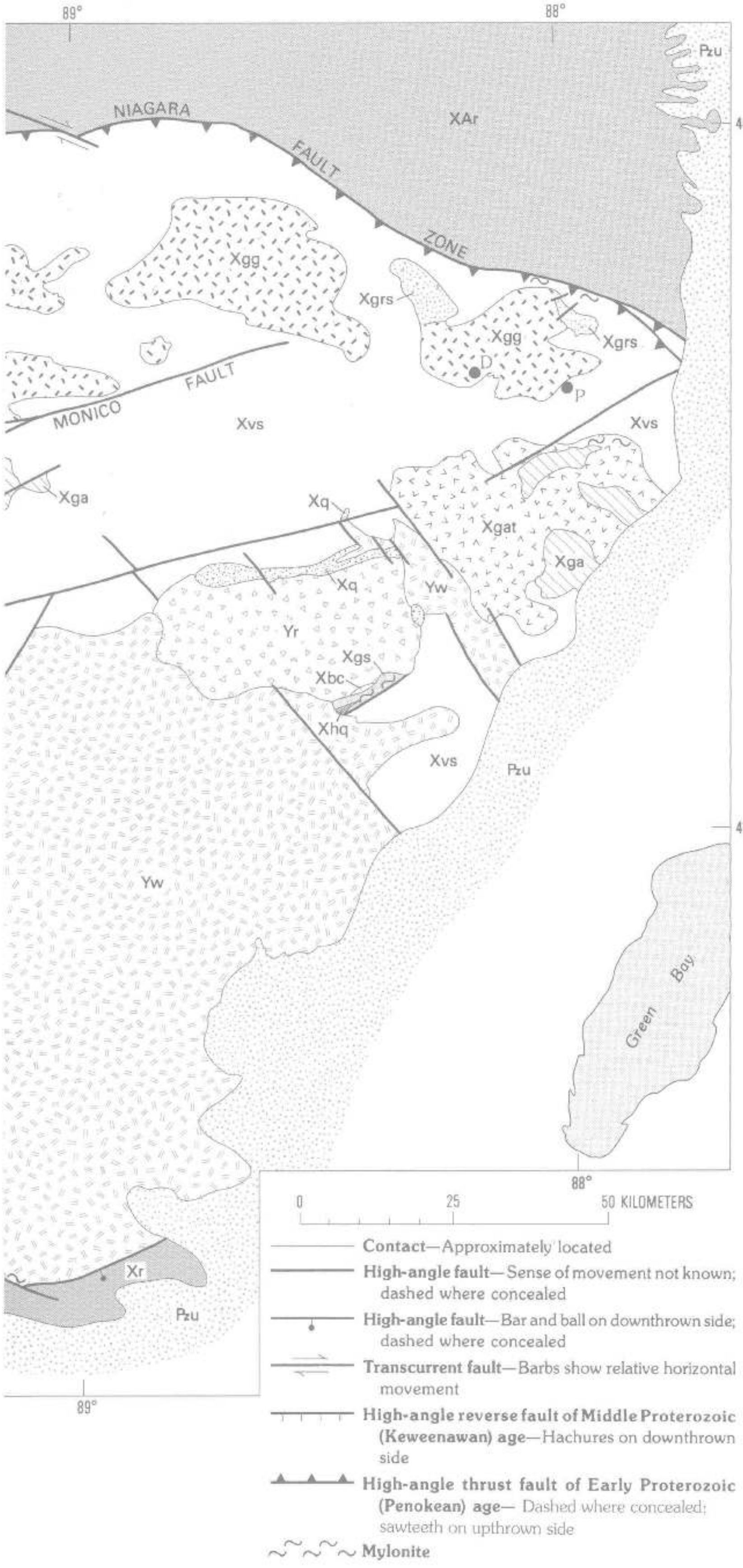

91°
90°
89°
88°
94°
90°
48°
46°
44°
CANADA
UNITED STATES
LAKE SUPERIOR
MN
MI
WI
0
200 KM
LAKE SUPERIOR
Yi
Ag
M
CONTINENTAL-MARGIN ASSEMBLAGE
Agn
Xs
I
MICHIGAN
WISCONSIN
Agn
?
46°
NIAGARA
FAULT
ZONE
Xv
Xs
WISCONSIN
MAGMATIC
TERRANES
PEMBINE-
WAUSAU
TERRANE
MARSHFIELD
TERRANE
J
H
A
EP
Xag
W
WOLF RIVER BATHOLITH
MT
P
45°
E
B
S
Green Bay
0
50
100 KILOMETERS
EXPLANATION
Sedimentary rocks of Paleozoic age
Yi Mafic igneous and sedimentary rocks of Midcontinent rift system (1,000–1,200 Ma)
Anorogenic igneous rocks (1,470–1,500 Ma)
Barron Quartzite (Early Proterozoic)
Xag Alkali-feldspar granite (≈1,835 Ma)
Tonalite-granodiorite-granite (1,760–1,870 Ma)
Gneiss and granitoid rocks (1,835–1,865 Ma)
Xv Volcanic and lesser sedimentary rocks (1,840–1,880 Ma)
Gneiss and schist (2,800–3,000 Ma); includes tonalite (1,890 Ma)
Xs Marquette Range Supergroup (≈1,850–2,100 Ma)
Ag Granite and greenstone (2,600–2,750 Ma)
Agn Gneiss (2,700–3,550 Ma)
WISCONSIN MAGMATIC TERRANES
CONTINENTAL-MARGIN ASSEMBLAGE
Contact
High-angle fault
Transcurrent fault–Barbs show direction of relative movement; queried where extent uncertain
Thrust fault–Dashed where concealed; queried where extent uncertain; sawteeth on upper plate
Shear zone containing mylonite–Dotted where concealed
Foliation trend
Shear zones
EP Eau Pleine (paleosuture)
J Jump River
A Athens
MT Mountain
(A) Locality referred to in text

**Figure 2 (above and facing page).** Geologic map of Wisconsin magmatic terranes and adjacent areas. Modified from Sims (1992). Br, Black River Falls; Ch, Cherokee; E, Eau Claire; Mo, Monico; Ma, Marshfield; Ne, Neillsville; D, Dunbar; L, Lugerville; P, Pembine; R, Rhinelander; S, Stevens Point; W, Wausau; Wr, Wisconsin Rapids. Circled letters designate localities discussed in text.



Contact—Approximately located

**High-angle fault**—Sense of movement not known; dashed where concealed

**High-angle fault**—Bar and ball on downthrown side; dashed where concealed

**Transcurrent fault**—Barbs show relative horizontal movement

**High-angle reverse fault of Middle Proterozoic (Keweenawan) age**—Hachures on downthrown side

**High-angle thrust fault of Early Proterozoic (Penokean) age**— Dashed where concealed; sawteeth on upthrown side

**Mylonite**

## EXPLANATION

| | |
|---|---|
| | PHANEROZOIC |
| Pzu | Paleozoic rocks, undivided |
| | MIDDLE PROTEROZOIC (900–1,600 Ma) |
| Yk | Volcanic rocks of Keweenawan Supergroup (1,100 Ma) |
| Yw | Anorogenic granitoid rocks of Wolf River batholith (1,470 Ma) |
| Yr | Rhyolite associated with Wolf River batholith |
| Ywa | Anorogenic granitoid rocks of Wausau pluton (≈1,515 Ma) |
| Ys | Anorogenic granitoid rocks of Stettin syenite pluton (≈1,520 Ma) |
| | EARLY PROTEROZOIC (1,600–2,500 Ma) |
| | Pembine-Wausau terrane |
| Xbq | Barron Quartzite |
| Xga | Granitoid rocks (1,760 Ma) |
| Xhq | Hines Quartz Diorite (1,812.7±3.6 Ma) |
| Xbc | Baldwin Conglomerate—Adjacent to Mountain shear zone |
| Xgr | Alkali-feldspar granite (1,835 Ma) |
| Xrg | Rhyolite and welded tuff |
| Xgrs | Spikehorn Creek (1,835±6 Ma) and Bush Lake Granites |
| Xgc | Granite near Cherokee (1,853±21 Ma) |
| Xgat | Athelstane Quartz Monzonite (1,836±15 Ma) |
| Xf | Felsic metavolcanic rocks (≈1,835–1,845 Ma) |
| Xgt | Granodiorite and tonalite (1,837–1,845 Ma) |
| Xq | Quartzite |
| Xgg | Granite to quartz diorite and granitoid gneiss (1,855–1,885 Ma) |
| Xgs | Gneiss and schist in Mountain shear zone |
| Xvs | Metamorphosed volcanic and sedimentary rocks (1,860–1,889 Ma); some rocks may be younger |
| | Marshfield terrane |
| Xr | Rhyolite of 1,760 Ma age group |
| Xgr | Alkali feldspar granite (1,835 Ma) |
| Xrg | Rhyolite and welded tuff |
| Xg | Granitic rocks, undivided |
| Xft | Foliated tonalite-granodiorite (1,840–1,892 Ma) |
| Xmc | Milladore Volcanic Complex (≈1,860 Ma) |
| Xv | Metavolcanic rocks in Eau Claire River valley (≈1,860 Ma) |
| Xggr | Gneissic granite near Neillsville (1,871±5 Ma) |
| | EARLY PROTEROZOIC AND ARCHEAN |
| XAf | Fault rocks—Mylonite in Eau Pleine shear zone |
| XAgt | Early Proterozoic tonalite and Archean gneiss (1,840–1,892 Ma) |
| | LATE ARCHEAN (2,500–2,800 Ma) |
| Wgn | Gneiss, migmatite, and amphibolite—Includes small bodies of Early Proterozoic rocks |
| | ROCKS NORTH OF NIAGARA FAULT |
| XAr | Metamorphosed sedimentary and volcanic rocks of Early Proterozoic Marquette Range Supergroup and Archean basement gneiss (2,600–3,650 Ma) and granitoid rocks (2,650–2,750 Ma) |

others, 1991). After amalgamation of the two terranes at ≈1,840 Ma, plutons of alkali-feldspar granite intruded and cogenetic silicic rhyolite erupted astride the Eau Pleine shear zone at 1,835 Ma. Controls on the age of the Eau Pleine shear zone are not tight. The shear zone is cut by a body of red alkali-feldspar granite dated at ≈1,835 Ma (unit Xgr, fig. 2), and therefore is older. Apparently also the shear zone is cut by the granite near Cherokee, which has an age of 1,853±21 Ma (Sims and others, 1989). Because of the large uncertainty in the age of the Cherokee and its probable correlation with rocks of the Athelstane batholith (1,836±15 Ma), we have assumed an age of ≈1,840 Ma for culmination of movement on the Eau Pleine shear zone.

## Pembine-Wausau Terrane

The Pembine-Wausau terrane has an exposed strike length of 275 km and a maximum width of 150 km (fig. 2); it is covered at both ends by Paleozoic rocks. Width of the terrane decreases to the west because of convergence of the Eau Pleine shear zone and the Niagara fault zone. The Pembine-Wausau terrane is composed mainly of a thick sequence of volcanic rocks (unit Xv, fig. 1; unit Xvs, fig. 2) deposited between about 1,889 and 1,860 Ma (Sims and others, 1989). These volcanic rocks are dominantly metamorphosed (mainly greenschist facies) tholeiitic basalt and basaltic andesite, but include calc-alkalic dacite, and rhyolite flows and pyroclastic rocks (Sims and others, 1989; Sims and others, 1992). A bimodal suite of high-aluminum basalt and basaltic andesite intercalated with dacite to rhyolite contains associated copper-zinc massive sulfide deposits (Mudrey, 1979; Sims, 1987 and references therein) in north-central Wisconsin (near Mo, fig. 2). This volcanic sequence is intruded by granitoid rocks (units Xgg, Xgt, Xgat, Xgc, Xgrs, Xgr, Xhg, and Xga, fig. 2) ranging in age from 1,870 Ma to 1,760 Ma. In Marathon County and vicinity (fig. 2), a calc-alkalic volcanic succession presumed to have formed in the interval 1,845–1,835 Ma apparently overlies mafic volcanic rocks interpreted to belong to the 1,889–1,860 Ma sequence (Sims, 1990a). This calc-alkalic volcanic sequence has associated subvolcanic granodioritic sills(?) (LaBerge and Myers, 1983) but lacks exposed deeper seated plutons of approximately the same age. Younger, 1,835 Ma alkali-feldspar granite (unit Xgr, fig. 2) forms abundant plutons in Marathon County and vicinity, in the southern part of the exposed magmatic terranes.

## Marshfield Terrane

The Marshfield terrane differs from the Pembine-Wausau terrane with respect to rock types and structure. Archean gneisses constitute more than 50 percent of the exposed rocks and probably underlie the Early Proterozoic volcanic rocks in much of the terrane (Sims, 1990a); the Pembine-Wausau terrane, in contrast, lacks an Archean basement. A steep foliation, lineation, and mylonitic fabric are superposed on older structures in Archean and Early Proterozoic rocks throughout most of the Marshfield terrane. This mylonitic structure developed before emplacement of the 1,835 Ma alkali-feldspar granite suite (unit Xgr, fig. 2), but after 1,860 Ma, the presumed age of the supracrustal volcanic rocks (units Xv, Xmc, fig. 2). Because of this structural overprint coupled with generally sparse exposures, knowledge of these pre-1,835 Ma Proterozoic rocks is rather meager.

Early Proterozoic volcanic rocks of mainly upper greenschist metamorphic grade crop out in two areas, and probably represent erosional remnants of a once-extensive volcanic cover. The larger area (locality A, figs. 1, 2) contains a sequence of interlayered felsic to mafic volcanic rocks, dacite porphyry, and sedimentary rocks—impure quartzite, ferruginous chert, conglomerate, and carbonaceous argillite (unit Xmc, fig. 2). The sedimentary rocks were assigned to the Baraboo interval of Dott (1983)—that is, an age between about 1,750 and 1,450 Ma—by Greenberg and Brown (1984; 1986) and Brown and Greenberg (1986). However, with the possible exception of ferruginous chert, the sedimentary rocks are deformed (have a steep mylonitic lineation) in the same way as the volcanic rocks, indicating that they are older than 1,835 Ma, and probably approximately contemporaneous with the volcanism at ≈1,860 Ma (Sims, 1990a; 1990c). The interlayered volcanic and sedimentary sequence is intruded by small bodies of comagmatic(?) metagabbro and metadiorite (Sims, 1990a) and by a large (35 km$^2$) pluton of foliated tonalite (unit Xft, fig. 2). Volcanic rocks exposed in the second area, the Eau Claire River valley (locality B, figs. 1, 2), consist of rhyolite and andesite as well as impure quartzite and conglomerate containing clasts of Archean granite gneiss (Sims, 1990a). Two rocks in these volcanic sequences have been dated. A felsic volcanic rock in the Eau Claire River valley (part of unit Xv, fig. 2) has a U-Pb zircon upper intercept age of 1,858±5 Ma, and a subvolcanic tonalite within the Eau Pleine shear zone has a U-Pb zircon upper intercept age of 1,860±7 Ma (Sims and others, 1989). The possibility exists, however, that the volcanic rocks are in part older, because foliated diorite (W283B, table 2 and appendix B) from the Stevens Point (S, fig. 2) area, which has a U-Pb upper intercept zircon age of 1,892±9 Ma (Sims and others, 1989), is chemically similar to dacite porphyry (sample W270A, table 2 and appendix B) in the volcanic sequence (locality A, fig. 1). Possibly, the 1,892 Ma tonalite is an early subvolcanic equivalent of the volcanic rocks.

# GRANITOID ROCKS

## Pembine-Wausau Terrane

Granitoid rocks in the Pembine-Wausau terrane are mainly granodiorite but range from tonalite and gabbro to alkali granite (table 1; figs. 3, 4). Outcrops of these rocks are most abundant in the northernmost part of the terrane, near the Niagara fault zone (fig. 2). The granitoid rocks can be grouped into two broad classes: (1) a syntectonic granodiorite suite and (2) a post-tectonic suite consisting of the ≈1,836 Ma Athelstane Quartz Monzonite, 1,835 Ma red alkali-feldspar granite, and a 1,760 Ma granodiorite-granite group.

## Syntectonic Granodiorite Suite

The syntectonic granodiorite suite is spatially associated with the major (1,889–1,860 Ma) sequence of volcanic rocks (unit Xvs, fig. 2) in the Pembine-Wausau terrane. The rocks in the syntectonic suite are foliated and mainly compose unit Xgg in figure 2. The granodiorite suite is calcic to calc-alkalic (fig. 4), average to rich in magnesium content (fig. 5), and sodic to very sodic (fig. 6); it has intermediate $SiO_2$ concentrations, intermediate to high $Al_2O_3$ (12.4–16.4 percent), high Sr concentrations, and low Rb, Nb, and Y concentrations. These rocks are compositionally similar to the Newingham Tonalite in the Dunbar, Wis., area (Sims and others, 1992), which is a normal volcanic-arc granite. On a FeO:(FeO+MgO) versus $SiO_2$ diagram (fig. 7), rocks of the syntectonic granodiorite suite plot mainly in the calc-alkalic (MgO-rich) field and lie within the synorogenic field of Anderson (1983) for Penokean granitoid rocks in Wisconsin. The synorogenic field is virtually distinct from the field for the Athelstane batholith and the 1,835 Ma alkali-feldspar granite, indicating distinctly different magmas for these syntectonic and post-tectonic rocks. The granodiorite suite has moderately enriched light REE (rare earth elements) accompanied by depleted heavy REE patterns generally showing no or positive europium anomalies (fig. 8). Four samples from this suite are extremely depleted in HREE. One sample has a negative europium anomaly.

Tonalite and granodiorite (unit Xgt, fig. 2) exposed in central Wisconsin are included in the granodiorite suite, but they are distinctly younger than most of the granitoids exposed farther north. Two analyzed samples have U-Pb zircon upper intercept ages of 1,846±11 Ma (W317, analysis in table 1) and 1,838±6 Ma (W314, analysis in table 1), respectively. These rocks are calc-alkalic to alkalic calcic, have high Fe:Mg ratios, and have Rb, Sr, Y, Nb, and Zr concentrations indicative of subduction-related magmas.

## Post-Tectonic Suite

The post-tectonic suite consists of the Athelstane Quartz Monzonite, which has an age of 1,836±15 Ma, 1,835 Ma alkali-feldspar granite, and ≈1,760 Ma granodiorite-granite.

### Athelstane Quartz Monzonite

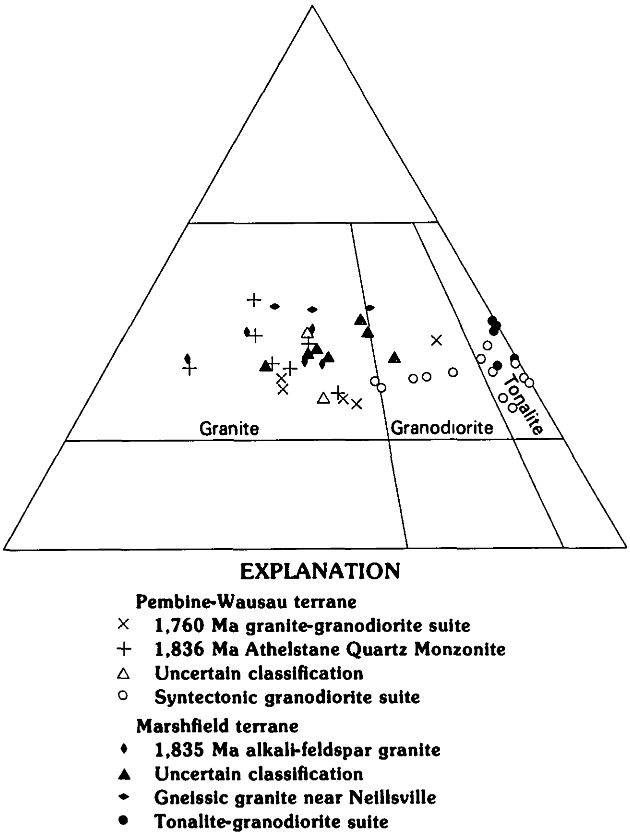


**Figure 3.** Quartz-alkali feldspar-plagioclase diagram showing composition of representative rocks in the Pembine-Wausau and Marshfield terranes.

The Athelstane Quartz Monzonite comprises a batholith of about 900 km$^2$ extent in northeastern Wisconsin (unit Xgat, fig. 2). It is a coarse-grained granite to granodiorite containing nearly equal amounts of microcline microperthite, plagioclase, and quartz and 5–10 percent biotite and (or) hornblende. Typically, the mafic minerals are interstitial and give the rock a clotty appearance. The rocks are massive except along the north margin of the batholith, where they have a steep ductile stretching lineation. The stretching lineation probably formed during uplift of the batholith subsequent to crystallization of the magma. Granite from a large quarry in the southern part of the batholith has a U-Pb zircon age of 1,836±15 Ma (Sims, 1990b). Granite near Cherokee (unit Xgc, fig. 2), southwest of Wausau, is similar compositionally to rocks in the Athelstane batholith, and it is tentatively considered correlative with these rocks. A sample of the granite near Cherokee has a U-Pb zircon upper intercept age of 1,853±21 Ma (Sims, 1990a), which because of the large uncertainty is virtually indistinguishable from the 1,836±15 Ma age on the Athelstane sample. The Athelstane Quartz Monzonite and the granite near Cherokee are mildly peraluminous, and have high $SiO_2$ (68–77 percent), intermediate $Al_2O_3$ (12–15 percent), and Na:K <1. These rocks have notably higher concentrations of Y, Zr, and Nb and are more highly evolved than the syntectonic granodiorite suite. The rocks are strongly enriched in iron and plot in the anorogenic

**Table 1.** Modes and chemical analyses of selected granitoid rocks in Pembine-Wausau terrane (exclusive of Dunbar area)

[Leaders (--), not determined. Tr, trace; X, present. Modal analyses by Bruce Brasaemle. Major oxide analyses by J.S. Wahlberg, A. Bartel, J. Taggart, and J. Baker. FeO, $H_2O$, and $CO_2$ by H. Neiman and G. Mason. Minor element analyses by X-ray fluorescence by Ross Yeoman. Minor element analyses by instrumental neutron activation by K.J. Schulz, J.S. Mee, and L.J. Schwarz]

| | Syntectonic granodiorite suite | | | | | | | | | | | | | Uncertain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.--- | IM12 | IM16 | W319A | W325 | W66 | W249B | W249A | W251 | W118 | W205B | W317 | W314 | W318 | SW AU 6-83 |
| | Modal analyses (volume percent) | | | | | | | | | | | | | |
| Plagioclase | 62.5 | 54.5 | 48 | 34 | 46 | 42 | 54 | 61 | 61 | 26 | 47.5 | 54 | 39 | --- |
| Quartz | 26 | 32 | 29.5 | 24.5 | 28 | 27 | 28 | 28 | 23 | 35.5 | 30 | 31 | 27 | --- |
| K-feldspar | 5 | 5 | 17.5 | 31 | 14 | 22 | 4 | 0.5 | 4.5 | 28 | 2.5 | 11 | 21.5 | --- |
| Biotite | 4 | 7 | 3.5 | 8.5 | 10 | 6.5 | 12 | 5.5 | 10 | 9 | 11 | 14.5 | 8 | --- |
| Muscovite | 1.5 | 0 | 0.5 | 0 | 0 | Tr | Tr | 0 | Tr | 0 | 0.5 | 0 | 0.5 | --- |
| Hornblende | 0 | 0 | 0 | 0 | 2 | Tr | 0 | 5 | 1 | 0.5 | 0 | 0.5 | 0 | --- |
| Epidote/ clinozoisite | 1 | 1 | 1 | 1 | Tr | 2 | 2 | 0 | Tr | 0.5 | 2 | 3 | 1 | --- |
| Sphene | 0 | 0 | 0 | 0 | 0 | Tr | 0 | Tr | Tr | Tr | 0 | 0 | 0 | --- |
| Chlorite | 0 | 0 | 0 | Tr | 0 | 0 | 0 | Tr | 0 | 0 | 0 | 0 | Tr | --- |
| Carbonate | 0 | Tr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | --- |
| Accessory minerals | Tr | 0.5 | Tr | 1 | Tr | Tr | Tr | Tr | 0.5 | 0.5 | Tr | 0.5 | 0.5 | --- |
| Allanite | 0 | X | X | 0 | 0 | X | X | X | X | X | 0 | X | X | |
| Apatite | 0 | X | X | X | 0 | X | X | X | X | X | X | X | X | |
| Opaque oxides | X | X | X | X | 0 | X | X | 0 | X | X | 0 | X | X | |
| Zircon | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| | Major oxides (weight percent) by X-ray fluorescence analysis | | | | | | | | | | | | | |
| $SiO_2$ | 72.6 | 69.8 | 73.4 | 67.0 | 68.5 | 71.2 | 69.3 | 65.7 | 69.7 | 71.7 | 69.3 | 68.9 | 71.8 | 72.3 |
| $Al_2O_3$ | 14.9 | 16.0 | 14.4 | 15.0 | 14.6 | 14.6 | 15.2 | 16.4 | 15.3 | 13.7 | 15.5 | 14.2 | 14.8 | 13.8 |
| $Fe_2O_3$ | 0.39 | 0.55 | 0.52 | 1.50 | 1.0 | 0.62 | 0.85 | 0.53 | 1.2 | 0.97 | 1.12 | 1.2 | 0.56 | 1.0 |
| FeO | 1.76 | 2.05 | 0.61 | 2.47 | 2.6 | 2.3 | 2.6 | 3.2 | 1.6 | 1.92 | 2.18 | 3.1 | 1.41 | 1.6 |
| MgO | 0.43 | 0.79 | 0.38 | 1.07 | 1.3 | 0.92 | 0.87 | 1.6 | 0.89 | 0.57 | 0.95 | 0.96 | 0.67 | 0.99 |
| CaO | 3.13 | 3.88 | 2.02 | 2.89 | 2.2 | 2.5 | 3.3 | 4.3 | 3.4 | 1.79 | 3.76 | 3.4 | 2.09 | 2.2 |
| $Na_2O$ | 3.92 | 3.43 | 3.49 | 2.62 | 3.1 | 3.1 | 3.4 | 4.0 | 3.8 | 2.70 | 3.91 | 3.5 | 3.45 | 2.6 |
| $K_2O$ | 1.30 | 2.32 | 3.69 | 5.23 | 4.2 | 3.8 | 2.2 | 1.7 | 2.0 | 4.94 | 1.56 | 3.0 | 3.52 | 4.6 |
| $H_2O^+$ | 0.52 | 0.53 | 0.39 | 0.96 | 0.29 | 0.64 | 0.61 | 0.76 | 0.48 | 0.59 | 0.73 | 0.77 | 0.64 | 0.81 |
| $H_2O^-$ | <0.01 | <0.01 | 0.03 | <0.01 | 0.18 | 0.10 | 0.15 | 0.13 | 0.08 | 0.04 | <0.01 | 0.01 | 0.01 | 0.38 |
| $TiO_2$ | 0.09 | 0.20 | 0.11 | 0.32 | 0.27 | 0.30 | 0.31 | 0.35 | 0.22 | 0.29 | 0.30 | 0.29 | 0.21 | 0.29 |
| $P_2O_5$ | <0.05 | 0.06 | <0.05 | 0.14 | 0.12 | 0.10 | 0.15 | 0.09 | 0.10 | 0.07 | 0.08 | 0.11 | 0.08 | 0.08 |
| MnO | 0.07 | 0.04 | 0.06 | 0.05 | 0.07 | 0.06 | 0.04 | 0.07 | 0.03 | 0.03 | 0.05 | 0.08 | 0.02 | 0.05 |
| $CO_2$ | <0.01 | 0.03 | <0.01 | <0.01 | 0.16 | 0.06 | 0.03 | 0.08 | 0.02 | <0.01 | <0.01 | 0.05 | <0.01 | 0.08 |
| Sum | 99.17 | 99.69 | 99.16 | 99.27 | 98.59 | 100.3 | 99.01 | 98.91 | 98.82 | 99.32 | 99.46 | 99.57 | 99.27 | 100.78 |
| A/CNK | 1.10 | 1.05 | 1.08 | 0.99 | 1.07 | 1.06 | 1.09 | 1.01 | 1.05 | 1.05 | 1.04 | 0.94 | 1.12 | 1.04 |

field in the FeO:(FeO+MgO) versus $SiO_2$ diagram (fig. 7). Although the rocks are evolved compared to the syntectonic granodiorite suite, they are not potassic, as are most highly evolved granites. The granite overlaps the upper part of the field for the younger Middle Proterozoic granites of the Wolf River batholith (Anderson, 1983, fig. 10c). The REE patterns are distinctive (fig. 9), exhibiting large negative Eu anomalies, relatively flat heavy-REE slope, and depletion in the light REE. In a Nb versus Y diagram (fig. 10), the Athelstane Quartz Monzonite plots with other post-tectonic granitoids in the region astride the fields for within-plate granites and volcanic-arc and syncollisional granites.

Although the Athelstane Quartz Monzonite makes up most of the Athelstane batholith, younger (≈1,760 Ma)

**Table 1.** Modes and chemical analyses of selected granitoid rocks in Pembine-Wausau terrane (exclusive of Dunbar area)—Continued

| Athelstane Quartz Monzonite | | | | | | | 1,835 Ma alkali-feldspar granite | 1,760 Ma granodiorite-granite group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W213 | WI-1 | W188 | W549 | W533 | W556 | W555 | W384 | W12B | SPB 232-39 | W54 | W55 | 824-7 | W252 |
| Modal analyses (volume percent) | | | | | | | | | | | | | |
| 20.5 | 26.5 | 34.5 | 28 | 26 | 16.5 | 13 | 41.5 | 27.5 | --- | 36 | 41 | 28.5 | 36.5 |
| 38.5 | 32.5 | 24.5 | 32.5 | 33.5 | 44 | 31.5 | 23 | 27 | --- | 25 | 26 | 30.5 | 28 |
| 38 | 27.5 | 27 | 35.5 | 38 | 35 | 49.5 | 46 | 36 | --- | 27 | 28 | 37.5 | 7.5 |
| 1.5 | 7.5 | 7 | 2 | 2 | 3.5 | 5 | 2 | 9.5 | --- | 9 | 5 | 3.5 | 21 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | --- | 1.5 | Tr | 0 | 0 |
| 1 | 5.5 | 6.5 | 1.5 | 0 | 0 | 0.5 | 0 | 0 | --- | 0 | 0 | 0 | 5 |
| Tr | 0 | Tr | Tr | Tr | Tr | Tr | 0 | Tr | --- | 1 | Tr | Tr | Tr |
| 0 | Tr | Tr | Tr | 0 | 0 | 0 | 0 | Tr | --- | 0 | Tr | 0 | 1 |
| 0 | 0 | 0 | 0 | Tr | 0 | 0 | 0 | Tr | --- | Tr | 0 | Tr | 0 |
| 0 | 0 | 0 | Tr | 0 | Tr | 0 | 0 | 0 | --- | 0 | 0 | 0 | 0 |
| 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 0.5 | Tr | --- | Tr | 0.5 | Tr | 1 |
| X | 0 | X | X | X | X | X | 0 | 0 | | 0 | X | 0 | X |
| X | X | X | X | 0 | X | X | 0 | 0 | | 0 | X | X | X |
| X | 0 | X | X | X | X | X | X | 0 | | 0 | X | 0 | X |
| X | X | X | X | X | X | X | 0 | X | | X | X | X | X |
| Major oxides (weight percent) by X-ray fluorescence analysis | | | | | | | | | | | | | |
| 76.7 | 71.4 | 68.1 | 75.0 | 75.0 | 77.1 | 76.5 | 75.7 | --- | 76.5 | 70.0 | 71.0 | --- | 67.7 |
| 11.9 | 12.4 | 15.2 | 12.3 | 12.3 | 12.0 | 12.2 | 12.7 | --- | 13.5 | 14.5 | 15.1 | --- | 15.8 |
| 0.90 | 1.17 | 0.77 | 0.56 | 0.44 | 0.28 | 0.54 | 0.35 | --- | 0.54 | 1.3 | 0.62 | --- | 1.5 |
| 0.91 | 2.96 | 2.87 | 1.83 | 1.99 | 1.38 | 1.52 | 0.55 | --- | 0.80 | 1.7 | 1.5 | --- | 2.9 |
| 0.11 | 0.44 | 0.75 | 0.37 | 0.22 | 0.25 | 0.20 | 0.11 | --- | 0.23 | 0.68 | 0.44 | --- | 1.6 |
| 0.43 | 1.64 | 2.11 | 1.20 | 0.83 | 0.46 | 0.72 | 0.43 | --- | 0.85 | 1.9 | 2.0 | --- | 3.6 |
| 3.40 | 2.92 | 3.35 | 2.51 | 3.30 | 2.32 | 2.23 | 4.09 | --- | 3.0 | 3.0 | 4.1 | --- | 3.3 |
| 4.61 | 4.73 | 4.96 | 5.26 | 4.44 | 5.81 | 6.0 | 4.56 | --- | 5.2 | 4.4 | 3.9 | --- | 3.1 |
| 0.41 | 0.50 | 0.55 | 0.34 | --- | 0.37 | 0.36 | 0.22 | --- | 0.45 | 0.64 | 0.47 | --- | 0.86 |
| <0.01 | 0.04 | <0.01 | <0.01 | --- | 0.05 | <0.01 | <0.01 | --- | 0.10 | 0.07 | 0.15 | --- | 0.13 |
| 0.14 | 0.45 | 0.54 | 0.26 | 0.12 | 0.20 | 0.21 | 0.05 | --- | 0.07 | 0.27 | 0.25 | --- | 0.58 |
| <0.05 | 0.10 | 0.10 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | --- | 0.07 | 0.09 | 0.09 | --- | 0.29 |
| <0.02 | 0.06 | 0.04 | 0.03 | 0.03 | <0.02 | <0.02 | <0.02 | --- | 0.04 | 0.04 | 0.02 | --- | 0.05 |
| <0.01 | 0.01 | 0.01 | 0.06 | --- | 0.05 | 0.01 | 0.09 | --- | 0.03 | --- | 0.08 | --- | 0 |
| 99.58 | 98.82 | 99.36 | 99.77 | --- | 100.33 | 100.56 | 98.92 | | 101.38 | 98.59 | 99.72 | | 101.40 |
| 1.05 | 0.96 | 1.03 | 1.03 | 1.05 | 1.10 | 1.07 | 1.02 | | 1.12 | 1.10 | 1.04 | | 1.03 |

bodies called Amberg Granite compose 25–30 percent of the batholith.

### 1,835 Ma Alkali-Feldspar Granite

Known post-tectonic granitoid rocks of the 1,835 Ma group are confined to Marathon County and adjacent areas, and truncate the Eau Pleine shear zone. Sample W384 (analysis in table 1), from the Granite Heights area, northeast of Wausau (unit Xgr, fig. 2) (LaBerge and Myers, 1983), is representative of these red alkali-feldspar granites. These rocks form generally small, separate plutons, some of which have been quarried for building stone. The plutons lack a penetrative foliation but contain abundant brittle fractures and exhibit extensive retrogressive metamorphism. Feldspars are reddened by hematite, and biotite is altered mainly to chlorite, probably as a result of deuteric alteration.

**Table 1.** Modes and chemical analyses of selected granitoid rocks in Pembine-Wausau terrane (exclusive of Dunbar area)—Continued

| | Syntectonic granodiorite suite | | | | | | | | | | | | | Uncertain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.--- | IM12 | IM16 | W319A | W325 | W66 | W249B | W249A | W251 | W118 | W205B | W317 | W314 | W318 | SW AU 6-83 |
| **Minor elements (parts per million) by X-ray fluorescence analysis and INAA for Ta, Hf, Sc, Cs, Th, and U** | | | | | | | | | | | | | | |
| Rb | 45 | 60 | 66 | 134 | 74 | 105 | 53 | 74 | 40 | 154 | 35 | 60 | 83 | 82 |
| Sr | 656 | 695 | 447 | 293 | 505 | 319 | 411 | 459 | 472 | 177 | 385 | 348 | 259 | 214 |
| Y | 3 | 1 | 0 | 9 | --- | --- | --- | --- | --- | 7 | 13 | --- | 3 | 24 |
| Zr | 37 | 64 | 50 | 88 | --- | --- | --- | --- | --- | 115 | 91 | --- | 141 | 154 |
| Nb | 5 | 2 | 1 | 6 | --- | --- | --- | --- | --- | 3 | 4 | --- | 7 | 13 |
| Ba | 1,317 | 733 | 1,503 | 1,742 | 1,306 | 800 | 838 | 175 | 930 | 1,483 | 859 | 960 | 1,226 | 1,040 |
| Cs | 0.50 | 0.52 | --- | --- | 1.38 | 1.01 | 1.05 | 2.96 | 0.56 | --- | --- | 1.35 | --- | 0.74 |
| Ta | 0.22 | 0.27 | --- | --- | 1.41 | 1.21 | 0.56 | 3.05 | 0.43 | --- | --- | 0.42 | --- | 0.40 |
| Hf | 1.2 | 2.15 | --- | --- | 2.21 | 4.14 | 4.26 | 2.46 | 3.2 | --- | --- | 3.4 | --- | 4.37 |
| Th | 0.71 | 3.2 | <15 | 16 | 8.22 | 18 | 9.1 | 11.6 | 5.4 | 23 | <15 | 7.01 | 19 | 8.67 |
| U | 0.15 | 0.8 | <15 | <15 | 8.4 | 2 | 0.81 | 2.7 | 0.9 | <15 | <15 | 2.7 | <15 | 1.5 |
| Sc | 1.9 | 3 | --- | --- | 8.68 | 5.5 | 3.86 | 8.71 | 4.3 | --- | --- | 9.18 | --- | 5.24 |
| Zn | 50 | --- | --- | --- | --- | --- | --- | --- | --- | 40 | 35 | --- | --- | 39 |
| **Minor elements (parts per million) by instrumental neutron activation analysis** | | | | | | | | | | | | | | |
| La | 9.31 | 16.1 | --- | --- | 24.2 | 38.7 | 44.9 | 18.9 | 26.3 | --- | --- | 26.9 | --- | 43.1 |
| Ce | 17.3 | 29.6 | --- | --- | 51.2 | 73 | 87.2 | 39.3 | 47 | --- | --- | 53.3 | --- | 71.4 |
| Nd | 7 | 9 | --- | --- | 21 | 28 | 28 | 15 | 14 | --- | --- | 19 | --- | 29 |
| Sm | 1.15 | 1.42 | --- | --- | 4.06 | 3.76 | 3.58 | 3.41 | 2.25 | --- | --- | 3.55 | --- | 5.24 |
| Eu | 0.37 | 0.49 | --- | --- | 0.9 | 0.77 | 0.85 | 0.67 | 0.63 | --- | --- | 0.8 | --- | 0.94 |
| Tb | --- | 0.10 | --- | --- | 0.4 | 0.37 | 0.21 | 0.58 | 0.18 | --- | --- | 0.44 | --- | 0.60 |
| Yb | 0.44 | 0.22 | --- | --- | 1.15 | 0.98 | 0.33 | 1.48 | 0.33 | --- | --- | 1.96 | --- | 1.49 |
| Lu | 0.08 | 0.04 | --- | --- | 0.17 | 0.15 | 0.05 | 0.23 | 0.05 | --- | --- | 0.34 | --- | 0.23 |

## SAMPLE DESCRIPTIONS AND LOCALITIES

Most rock names are based on chemical classification of DeLaRoche and others, 1980. Rock names based on Streckeisen (1976) classification given in parentheses where they differ. Rocks classed as alkali granites are identified.

### SYNTECTONIC GRANODIORITE SUITE

| | |
|---|---|
| IM12 | Granodiorite (tonalite), sec. 24, T. 38 N., R. 11 E. |
| IM16 | Granodiorite (tonalite), sec. 21, T. 37 N., R. 11 E. |
| W319A | Granodiorite, sec. 21, T. 37 N., R. 11 E. Age 1,870±7 Ma. |
| W325 | Granodiorite (granite), sec. 28, T. 34 N., R. 2 W. |
| W66 | Hornblende-biotite granodiorite (tonalite), sec. 19, T. 34 N., R. 6 W. |
| W249B | Biotite granodiorite, sec. 27, T. 37 N., R. 3 W. |
| W249A | Granodiorite (tonalite), sec. 27, T. 37 N., R. 3 W. |
| W251 | Foliated tonalite, sec. 20, T. 38 N., R. 5 W. |
| W118 | Biotite granodiorite (tonalite), sec. 22, T. 36 N., R. 6 W. |
| W205B | Granodiorite, Grandmother Dam, sec. 10, T. 33 N., R. 6 E. |
| W317 | Granodiorite (tonalite) near Dudley, sec. 23, T. 33 N., R. 8 E. Age 1,846±11 Ma. |
| W314 | Granodiorite, Grandfather Dam, sec. 30, T. 33 N., R. 6 E. Age 1,838±6 Ma. |
| W318 | Granodiorite, sec. 13, T. 32 N., R. 7 E. |

### UNCERTAIN

| | |
|---|---|
| SWAU 6-83 | Granite (alkali granite), sec. 34, T. 35 N., R. 20 E. |

**Table 1.** Modes and chemical analyses of selected granitoid rocks in Pembine-Wausau terrane (exclusive of Dunbar area)—Continued

| Athelstane Quartz Monzonite | | | | | | | 1,835 Ma alkali-feldspar granite | 1,760 Ma granodiorite-granite group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W213 | WI-1 | W188 | W549 | W533 | W556 | W555 | W384 | W12B | SPB 232-39 | W54 | W55 | 824-7 | W252 |
| Minor elements (parts per million) by X-ray fluorescence analysis and INAA for Ta, Hf, Sc, Cs, Th, and U | | | | | | | | | | | | | |
| 136 | 141 | 97 | 94 | 119 | 80 | 88 | 77 | --- | 163 | 131 | 118 | --- | 119 |
| 15 | 114 | 185 | 96 | 85.4 | 88.1 | 69 | 29 | --- | 83 | 346 | 603 | --- | 473 |
| 32 | 50 | 26 | 32 | --- | 38 | 24 | 25 | --- | 27 | --- | --- | --- | 24 |
| 152 | 292 | 234 | 285 | 164 | 154 | 257 | 107 | --- | 110 | 245 | 170 | --- | 233 |
| 23 | 50 | 15 | 10 | --- | 13 | 7 | 11 | --- | 17 | --- | --- | --- | 27 |
| 204 | 1,020 | 1,824 | 1,354 | 1,113 | 830 | 1,404 | 1,106 | --- | 870 | 1,934 | 1,305 | --- | 1,326 |
| --- | 1.5 | --- | --- | 2.1 | 1.6 | --- | --- | --- | 4.5 | 0.65 | 3.33 | --- | 1.88 |
| --- | 2.48 | --- | --- | 1.0 | 0.87 | --- | --- | --- | 1.76 | 0.59 | 1.55 | --- | 2.30 |
| --- | 13.2 | --- | --- | 6.35 | 10.1 | --- | --- | --- | 4.57 | 7.35 | 5.35 | --- | 6.45 |
| 18 | 37.8 | <15 | <15 | 13.6 | 8.67 | <15 | <15 | --- | 28.8 | 39.6 | 25.4 | --- | 30.8 |
| <15 | 2.2 | <15 | <15 | 1.5 | 1.5 | <15 | 17 | --- | 10 | 2.2 | 4.5 | --- | 3.10 |
| --- | 4.68 | --- | --- | 3.20 | 4.0 | --- | --- | --- | 3.03 | 3.96 | 2.21 | --- | 9.62 |
| 65 | --- | 74 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Minor elements (parts per million) by instrumental neutron activation analysis | | | | | | | | | | | | | |
| --- | 103 | --- | --- | 44.1 | 161 | --- | --- | --- | 41.5 | 105 | 58.3 | --- | 91.5 |
| --- | 201 | --- | --- | 99.6 | 311 | --- | --- | --- | 74.0 | 185 | 110 | --- | 164 |
| --- | 63 | --- | --- | 39 | 94 | --- | --- | --- | 22.5 | 52 | 25 | --- | 50 |
| --- | 12.6 | --- | --- | 9.65 | 14.68 | --- | --- | --- | 6.0 | 6.68 | 4.08 | --- | 7.29 |
| --- | 1.71 | --- | --- | 1.18 | 1.07 | --- | --- | --- | 0.42 | 1.02 | 0.91 | --- | 1.37 |
| --- | 1.99 | --- | --- | 1.45 | 1.48 | --- | --- | --- | 0.75 | 0.40 | 0.29 | --- | 0.56 |
| --- | 5.78 | --- | --- | 5.23 | 3.93 | --- | --- | --- | 2.88 | 0.60 | 0.49 | --- | 1.55 |
| --- | 0.82 | --- | --- | 0.84 | 0.61 | --- | --- | --- | 0.53 | 0.11 | 0.06 | --- | 0.22 |

### ATHELSTANE QUARTZ MONZONITE

| | |
|---|---|
| W213 | Granite near Cherokee (alkali granite), NE1/4 sec. 23, T. 28 N., R. 2 E. Age 1,853±21 Ma. Considered correlative with rocks of Athelstane batholith. |
| WI-1 | Granite, sec. 23, T. 39 N., R. 6 W. Similar chemically to Athelstane Quartz Monzonite. |
| W188 | Athelstane Quartz Monzonite (alkali granite), NE1/4 sec. 15, T. 34 N., R. 19 E. |
| W549 | Athelstane Quartz Monzonite (alkali granite), NE1/4 sec. 12, T. 35 N., R. 20 E. |
| W533 | Athelstane Quartz Monzonite (alkali granite), quarry at Mt. Tom, sec. 19, T. 33 N., R. 20 E. Age 1,836±15 Ma(?). |
| W556 | Athelstane Quartz Monzonite (alkali granite), SW1/4 sec. 13, T. 35 N., R. 20 E. |
| W555 | Athelstane Quartz Monzonite (alkali granite), SW1/4 sec. 14, T. 35 N., R. 20 E. |

### 1,835 MA ALKALI-FELDSPAR GRANITE

| | |
|---|---|
| W384 | Alkali-feldspar granite (alkali granite), sec. 31, T. 30 N., R. 8 E. |

### 1,760 MA GRANODIORITE-GRANITE GROUP

| | |
|---|---|
| W12B | Granite near Amberg, NE1/4SE1/4 sec. 9, T. 35 N., R. 20 E. Age 1,752±8 Ma. |
| SPB-232-39 | Granite near Amberg, NW1/4SW1/4 sec. 31, T. 36 N., R. 21 E. |
| W54 | Granodiorite (granite) near Lugerville, SW1/4 sec. 17, T. 38 N., R. 1 W. Age 1,773±8 Ma. |
| W55 | Biotite granodiorite (granite), sec. 6, T. 38 N., R. 3 E. |
| 824-7 | Granite near Monico, SW1/4 sec. 6, T. 35 N., R. 11 E. Age 1,739±8 Ma. |
| W252 | Granodiorite near Radisson, NE1/4 sec. 22, T. 38 N., R. 7 W. Age 1,765±6 Ma. |

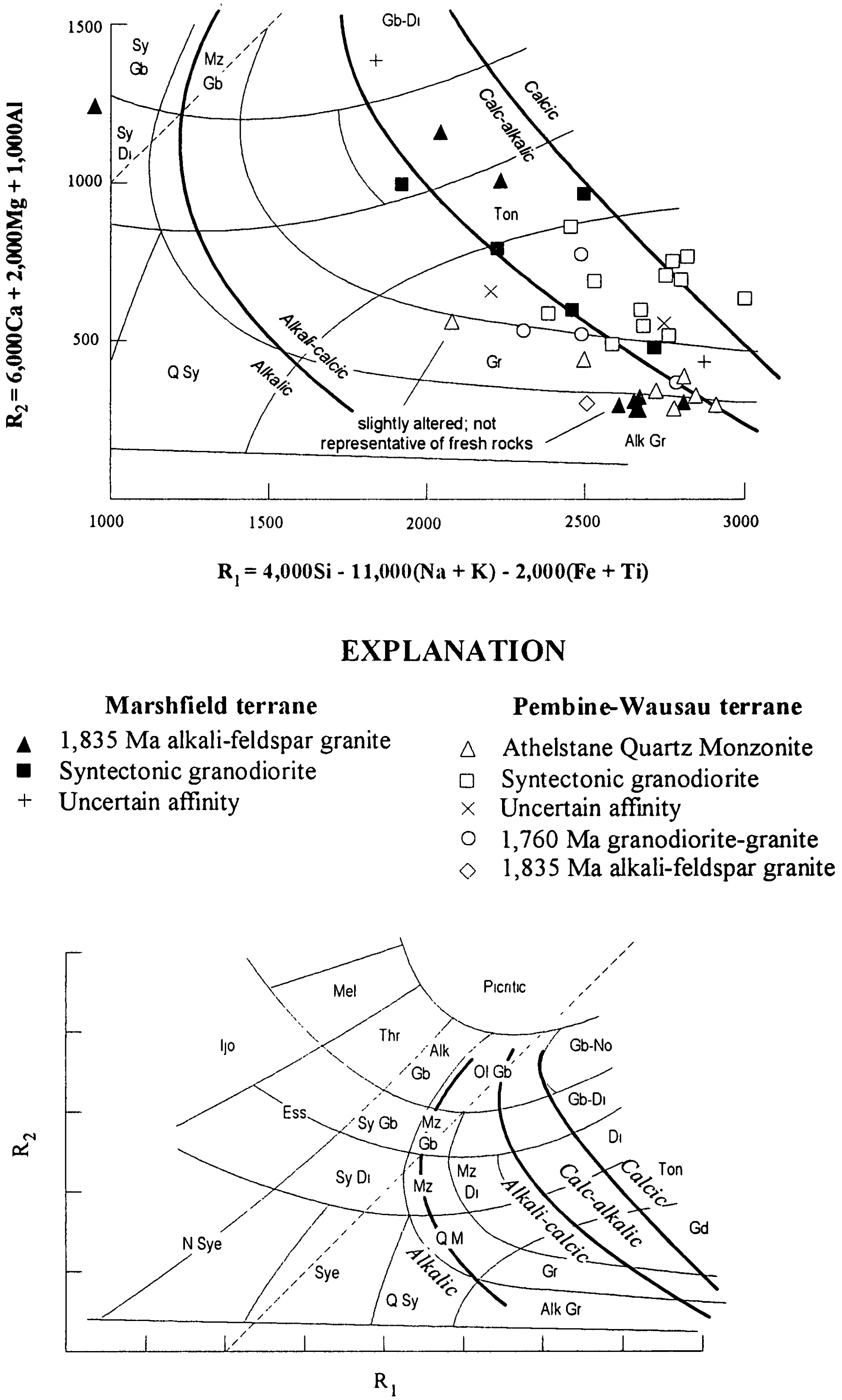


**Figure 4.** Classification of granitoid rocks, Pembine-Wausau and Marshfield terranes (modified from DeLaRoche and others, 1980). Classification of plutonic rocks: Gb-No, gabbronorite; Ol Gb, olivine gabbro; Alk Gb, alkali gabbro; Thr, theralite; Mel, melteigite; Gb-Di, gabbro-diorite; Mz Gb, monzogabbro; Sy Gb, syenogabbro; Ess, essexite; Ijo, ijolite; Di, diorite; Mz Di, monzodiorite; Mz, monzonite; Sy Di, syenodiorite; Gd, granodiorite; Gr, granite; Alk Gr, alkali granite; Q M, quartz monzonite; Q Sy, quartz syenite; Sye, syenite; N Sye, nepheline syenite.

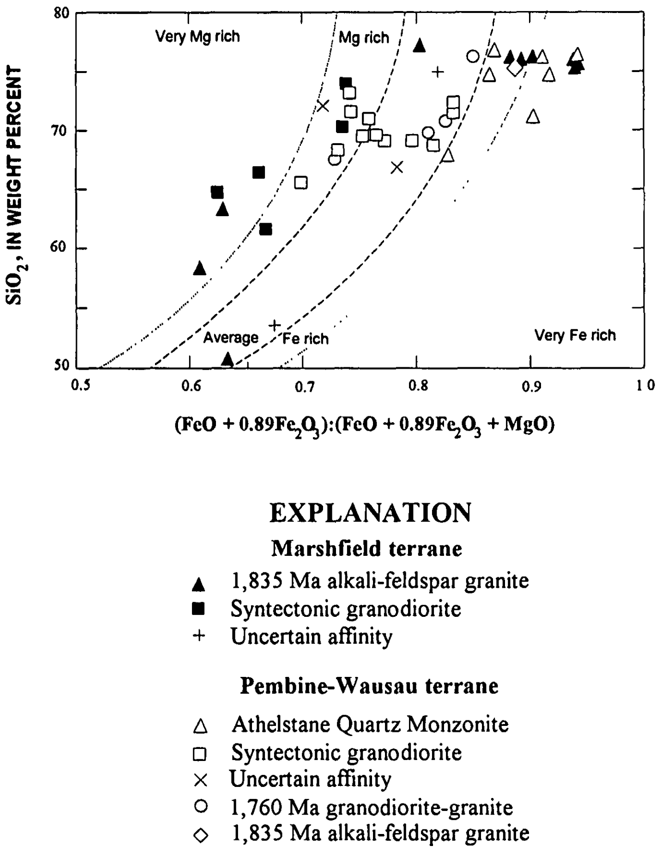


**Figure 5.** $SiO_2$ versus ($FeO+0.89\ Fe_2O_3$):($FeO+0.89\ Fe_2O_3+MgO$) diagram (modified from DeWitt, 1989) showing compositions of plutonic rocks in Pembine-Wausau and Marshfield terranes.

The alkali-feldspar granite is mildly peraluminous, alkali-calcic, Fe rich, and sodic, and has very low Sr, and high U (Sims and others, 1989, fig. 9), high FeO:FeO+MgO (>0.80), $Na_2O$:$K_2O$ (<1.0), Ba:Sr (>3.0), and K:Rb (>300), and large negative Eu anomalies (Sims and others, 1989, fig. 10), similar to the Athelstane batholith. On a Ta-Yb diagram (Sims and others, 1989, fig. 11), these granite bodies plot as within-plate granite.

### 1,760 Ma Granodiorite-Granite Group

The 1,760 Ma granodiorite-granite group crops out as scattered small plutons (unit Xga, fig. 2) across northern Wisconsin (see appendix A). Except for the pluton south of Monico (Mo, fig. 2), these rocks intrude older granitic rocks. The principal cluster of these young intrusions is in the Athelstane batholith, where three bodies of Amberg Granite (1,752±8 Ma) intrude the Athelstane Quartz Monzonite (Sims, 1990b). The 1,760 Ma rocks lack a penetrative foliation but are cut by ductile-brittle shear zones, such as the Twelvefoot Falls shear zone in northeastern Wisconsin. Zircon ages average approximately 1,760 Ma but range from

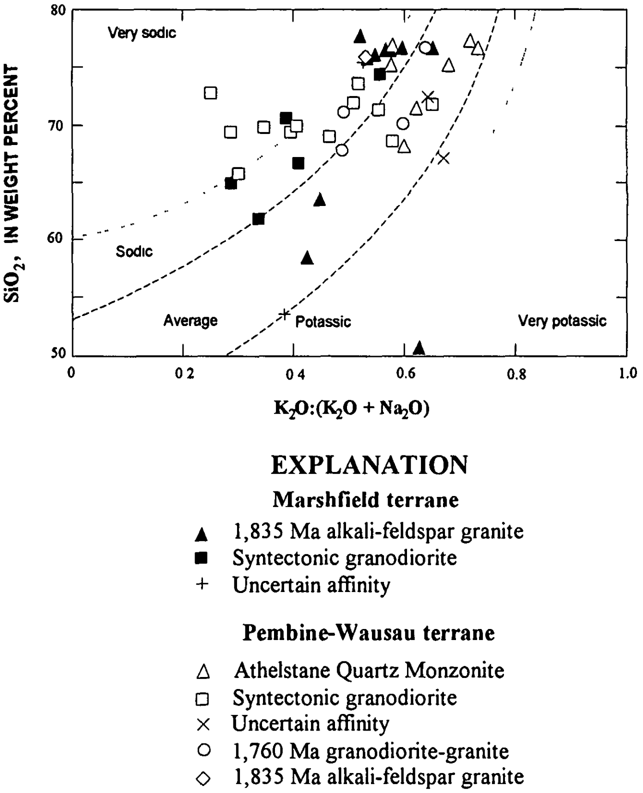


**Figure 6.** $SiO_2$ versus $K_2O$:($K_2O+Na_2O$) diagram (modified from DeWitt, 1989) showing compositions of plutonic rocks in Pembine-Wausau and Marshfield terranes.

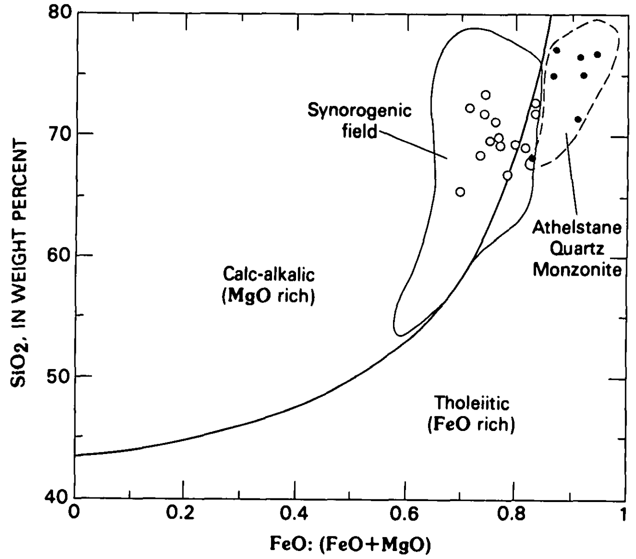


**Figure 7.** FeO:(FeO+MgO) versus $SiO_2$ diagram for the syntectonic granodiorite suite (open circles) and rocks of the post-tectonic Athelstane Quartz Monzonite (solid dots), Pembine-Wausau terrane. Synorogenic field of Anderson (1983) for Penokean granitoid rocks in Wisconsin shown for comparison.

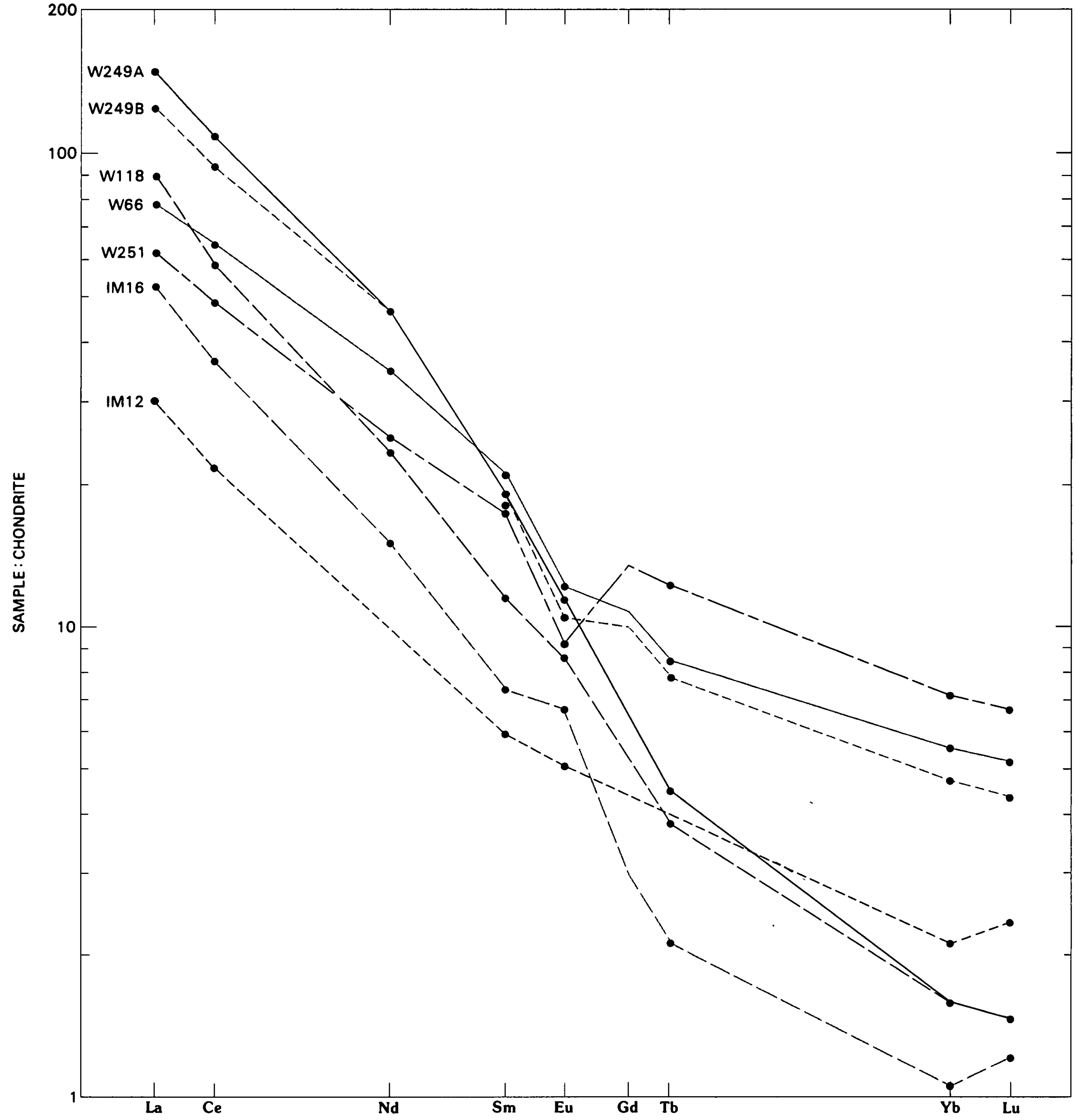


**Figure 8.** Chondrite-normalized REE plots for syntectonic granodiorite suite, Pembine-Wausau terrane. Analyses given in table 1. Gd, no data.

1,773±8 Ma to 1,739±8 Ma (Sims and others, 1989). The plutons are coeval with the anorogenic rhyolite-granite terrane in south-central Wisconsin (Anderson and others, 1980; Smith, 1983; Sims, 1990d), which probably overlies buried rocks of the Wisconsin magmatic terranes, but they differ from these anorogenic rocks in being more variable in composition and in having somewhat lower FeO:(FeO+MgO) and higher Sr.

The rocks have variable REE patterns with enriched light-REE concentrations (fig. 11). The four samples for which REE have been determined include two from near Lugerville (L, fig. 2) in northwestern Wisconsin (W54, W55) that display steep REE patterns. The sample of Amberg Granite (SPB–232–39) from northeastern Wisconsin and the sample of granite from near Radisson (W252) in northwestern Wisconsin, in contrast, have less depleted

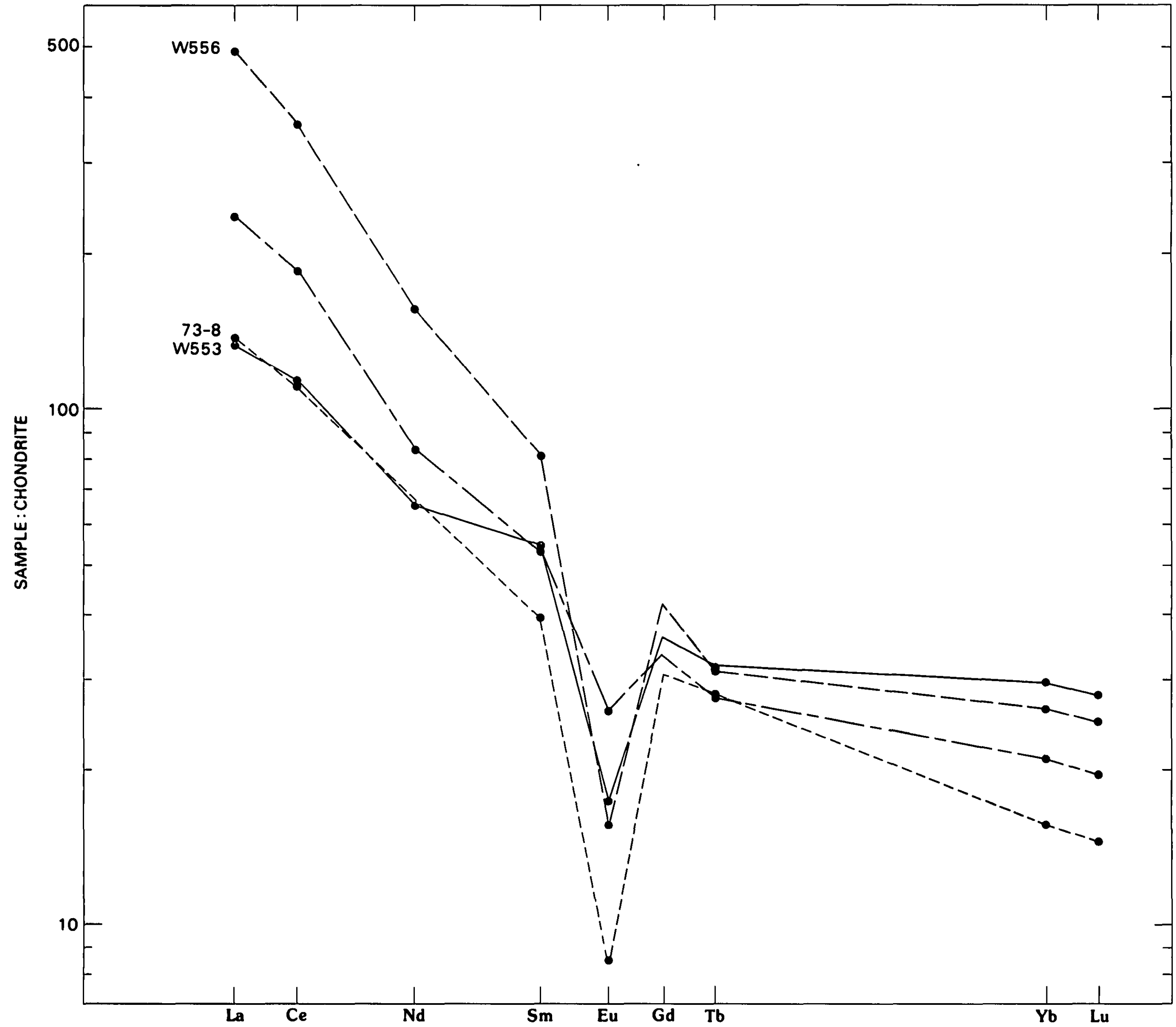


**Figure 9.** Chondrite-normalized REE plots for samples of Athelstane Quartz Monzonite, Pembine-Wausau terrane. Analyses given in table 1. Gd, no data.

heavy-REE and small (Radisson) to large (Amberg) negative Eu anomalies. The variability in composition of the 1,760 Ma granodiorite-granite group from the Pembine-Wausau terrane probably reflects differences in the source materials that were melted. The variability of these sources appears to have been greater than that in sources for the 1,760 Ma anorogenic rhyolite-granite group in south-central Wisconsin (Smith, 1983).

## Marshfield Terrane

Granitoid rocks of Early Proterozoic age in the Marshfield terrane are mainly tonalite-granodiorite and alkali-feldspar granite, but range from gabbro-diorite to alkali granite (fig. 3). In general, tonalite and granodiorite (unit Xft, fig. 2) are more abundant in the eastern part of the terrane, between Marshfield and Stevens Point, where they intrude Archean basement (fig. 2). A body of gneissic granite (granite near Neillsville (Ne); unit Xggr, fig. 2) at least 30 km long (east-west) and 3–5 km wide is exposed in the Black River valley and its tributaries. The gneissic granite intrudes previously deformed Archean gneisses and itself has a pronounced mylonitic foliation and lineation. Red alkali-feldspar granite of the 1,835 Ma group (unit Xgr, fig. 2) is widespread in the southern part of the terrane, west of Wisconsin Rapids (Wr, fig. 2). Other granitoid rocks are exposed discontinuously, but they are too poorly known to be characterized either petrographically or chemically; they are assigned to unit Xg in figure 2. The granitoid rocks can be grouped on the basis of composition, structure, and age into

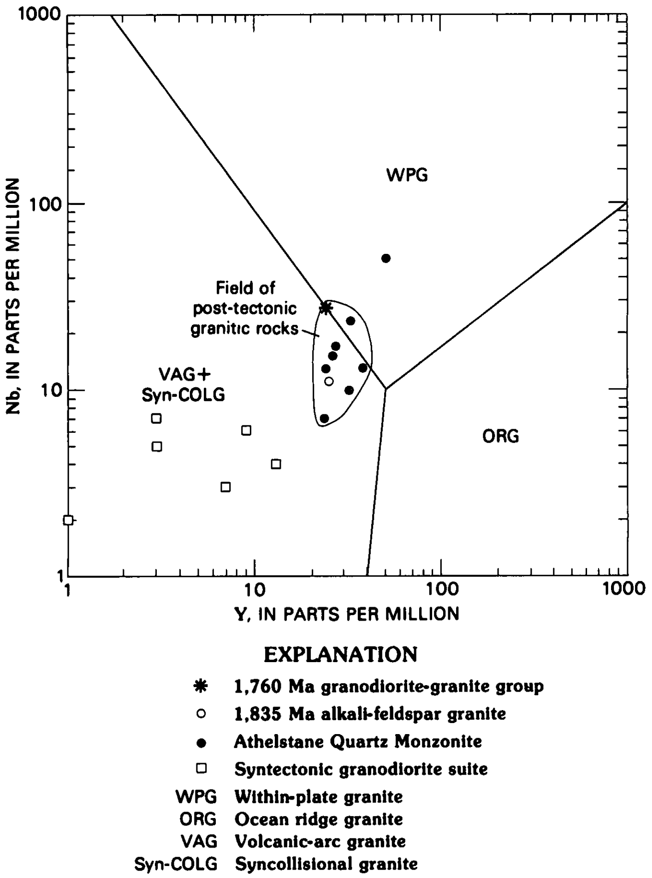


**Figure 10.** Nb versus Y diagram (modified from Pearce and others, 1984) for granitoid rocks in the Pembine-Wausau terrane. Excludes Dunbar area (Sims and others, 1992).

two classes: (1) a syntectonic tonalite-granodiorite suite and gneissic granite near Neillsville, and (2) post-tectonic alkali-feldspar granite of the 1,835 Ma group.

### Syntectonic Tonalite-Granodiorite Suite

The tonalite-granodiorite suite is exposed intermittently in the Wisconsin River valley and its tributaries west of Stevens Point (S, fig. 2), predominantly in unit XAgt. Unit XAgt consists of Archean gneiss intruded by numerous, generally small bodies of Early Proterozoic tonalite-granodiorite. Excellent exposures at Conants Rapids, south of Stevens Point, have been mapped in detail and described by Maass and others (1980). Earlier, Anderson (1972) described the field relations and the petrology of tonalitic bodies in Mill Creek and in other tributaries west of the Wisconsin River. Anderson and Cullers (1987) described the geochemistry of the tonalitic-granodioritic rocks.

The granodiorite-tonalite in the Stevens Point area crops out as small irregular bodies and dikes, and is divided into three textural-structural groups. From oldest to youngest these groups are: (1) foliated biotite-hornblende granodiorite to diorite, (2) lineated granodiorite to granite, and (3) massive granodiorite to tonalite. Anderson (1972) and Anderson and Cullers (1987) referred to each of these three rock groups as tonalites, as did Sims (1990c). The textural groups are believed to represent decreasing ductile deformation intensity during granodiorite-diorite emplacement (Sims, 1990c).

The foliated granodiorite to diorite is a gray to pale-reddish-brown, medium-grained gneiss. A foliation expressed by biotite, with or without hornblende, that wraps around plagioclase (oligoclase-andesine) defines a "lense-pod" fabric (Anderson, 1972). The granodiorite typically forms small irregular bodies and dikes (1–3 m thick) that have sharp contacts with Archean gneiss. Although contacts with the gneiss are discordant, foliation in the two units is parallel. The foliated granodiorite has a xenomorphic inequigranular assemblage of blocky plagioclase porphyroclasts (2–4 mm) surrounded by granular, finer grained plagioclase and quartz. Aligned biotite and hornblende in the groundmass yield a prominent foliation. The texture is typical IP mantle (or mortar) structure (Hanmer, 1982) characteristic of mylonitic rocks. Except for the relict plagioclase porphyroclasts, and perhaps part of the hornblende, the major rock constituents are recrystallized, commonly to finer grained aggregates, as a consequence of ductile deformation. The rocks can be classed as protomylonite or orthomylonite (Wise and others, 1984). The hornblende-andesine ($An_{26-32}$) assemblage indicates metamorphism at the amphibolite facies. Typical modes (W283B, W260, and W254B) are given in table 2. According to the chemical data reported in Anderson and Cullers (1987), the foliated granodiorite to diorite ranges from calc-alkalic granodiorite to alkali-calcic to calc-alkalic tonalite-granodiorite.

The lineated granodiorite to granite is gray to pale reddish brown, medium to fine grained (1–3 mm), and finer grained than associated foliated granodiorite. These lineated rocks form small irregular bodies and dikes (3 cm–3 m) that sharply cut older rocks. In contrast to the Archean gneiss and foliated granodiorite, the lineated tonalite is generally not folded. The lineation, defined by elongate, oriented grains of minor hornblende and biotite and elongate aggregates of these minerals with quartz, plunges steeply, generally to the southeast, and is parallel to that in the foliated granodiorite. A photograph showing this penetrative lineation is reproduced in Maass and others (1980, fig. 7). The lineated granodiorite to granite consists of a xenomorphic granular assemblage of oligoclase ($An_{20-25}$) that may be weakly zoned, microcline, biotite, and minor hornblende. Because of the lack of distinctive, large porphyroclasts, the degree to which the rocks were recrystallized during ductile deformation is equivocal. Typically, the rocks are bimodal in texture and consist of aligned streaks of fine-grained, oriented biotite, quartz, and plagioclase in a coarser grained assemblage of the same minerals; they can be classified as either protomylonite or orthomylonite. A mode for a typical lineated granodiorite (W283A) is listed in table 2.

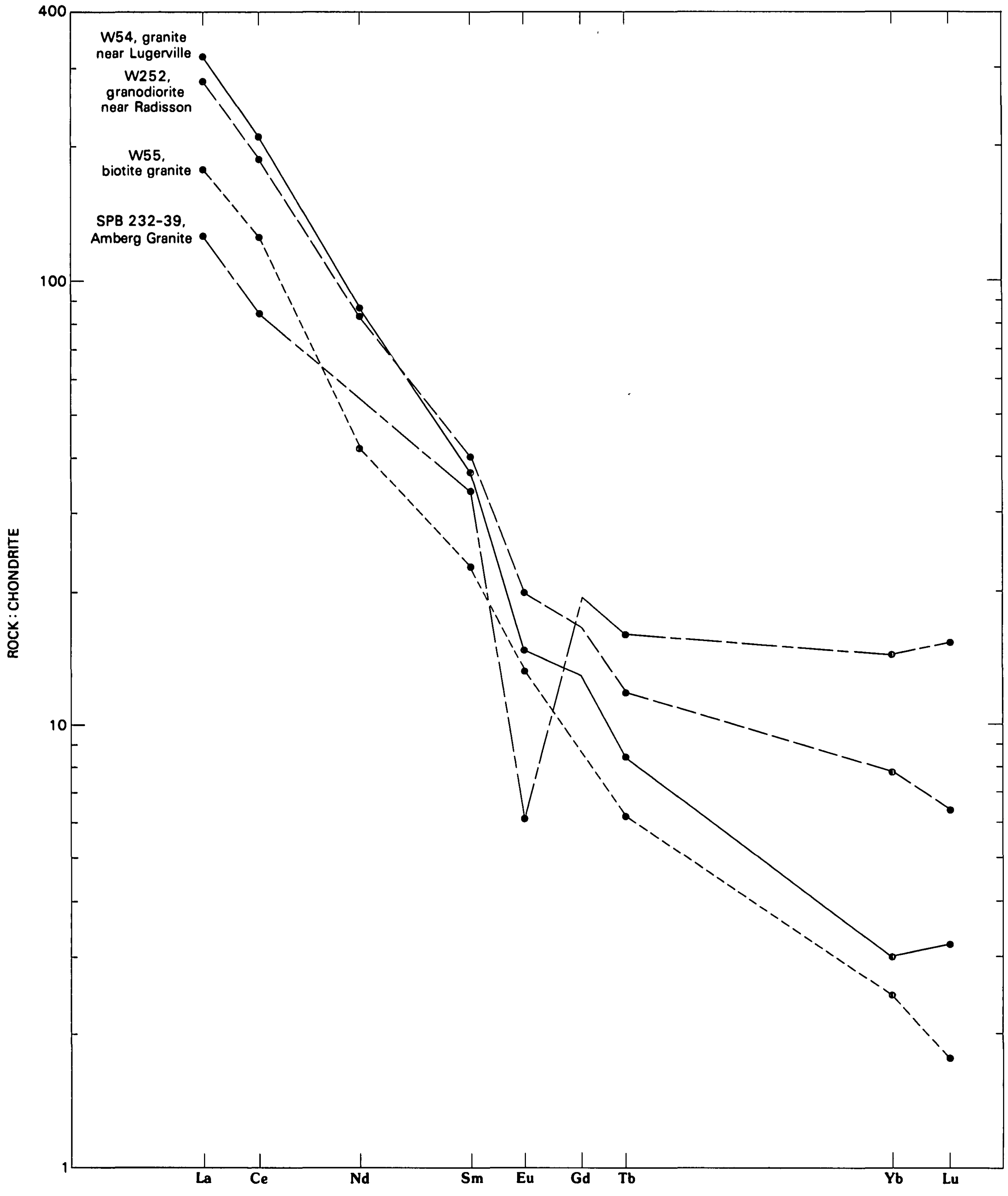


**Figure 11.** Chondrite-normalized REE plots for samples of 1,760 Ma granodiorite-granite group. Gd, no data.

The third group, massive granodiorite to tonalite, lacks penetrative structures and cuts deformed granodiorite bodies. Where observed in secs. 1 and 12, T. 23 N., R. 7 E., adjacent to Rocky Run, and southwest of Stevens Point, granodiorite is gray, medium grained (≈3 mm), and has a hypidiomorphic granular texture modified by weak

**Table 2.** Modes and chemical analyses of selected Early Proterozoic granitoid rocks in Marshfield terrane

[Leaders (--), not determined. Tr, trace; X, present. <, less than. Modal analyses by Bruce Brasaemle. Major oxide analyses by J.S. Wahlberg, A. Bartel, J. Taggart, and J. Baker. FeO, $H_2O$, and $CO_2$ analyses by H. Neiman and G. Mason. Minor element analyses by X-ray fluorescence by Ross Yeoman. Minor element analyses by instrumental neutron activation by K.J. Schulz, J.S. Mee, and L.J. Schwarz]

| | Syntectonic tonalite-granodiorite suite | | | | | | | | | | | Granitoid rocks of uncertain classification | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Granite near Neillsville | | | | | | | | | | |
| Sample No.-- | W283B | W214-2 | W270A | W260 | W254B | W237 | W283A | W214-1 | W309C | W390 | 21-84 | W284 | W285-1 | W288 | W285 | W305 | 26-84 | W306 | W859 |
| **Modal analyses (volume percent)** | | | | | | | | | | | | | | | | | | | |
| Plagioclase | 57 | — | — | 52 | 63 | 45.5 | 56 | — | 36 | 26.5 | 21 | 43 | 35.5 | 32 | 30 | 35.5 | 32 | 24 | — |
| Quartz | 20 | — | — | 28 | 28 | 33 | 30.5 | — | 43 | 41.5 | 42.5 | 33 | 41 | 36 | 34 | 36 | 33 | 32 | — |
| K-feldspar | 1 | — | — | 0 | 0 | Tr | 3 | — | 18 | 26.5 | 32.5 | 18 | 20.5 | 30.5 | 31.5 | 19.5 | 27.5 | 38.5 | — |
| Biotite | 11.5 | — | — | 11 | 7 | 17.5 | 10 | — | 1 | 4.5 | 3.5 | 5.5 | Tr | 1 | 0.5 | 3 | 6 | 4.5 | — |
| Muscovite | 0 | — | — | 0 | 0 | Tr | 0 | — | 1 | 0.5 | Tr | Tr | Tr | 0 | Tr | 0 | 0.5 | 0 | — |
| Hornblende | 9 | — | — | 8 | 0 | 0 | 0 | — | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.5 | 0 | 0 | — |
| Epidote/ clinozoisite | Tr | — | — | Tr | 1.5 | 1 | 0 | — | Tr | Tr | 0 | Tr | 1 | Tr | 2 | Tr | 0.5 | Tr | — |
| Sphene | 1 | — | — | 0.5 | Tr | 0.5 | 0 | — | Tr | 0.5 | Tr | 0 | 0 | 0 | 0 | Tr | 0 | Tr | — |
| Chlorite | 0 | — | — | 0 | 0 | 0 | 0 | — | 0 | Tr | 0 | 0 | 0 | Tr | 0 | 0 | Tr | 0 | — |
| Carbonate | 0 | — | — | 0 | 0 | 1.5 | 0 | — | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | — |
| Accessory minerals | 0.5 | — | — | 0.5 | 0.5 | 1 | 0.5 | — | 1 | Tr | 0.5 | 0.5 | 2 | 0.5 | 2 | 0.5 | 0.5 | 1 | — |
| Allanite | X | | | X | X | 0 | X | | X | X | 0 | 0 | 0 | X | 0 | X | X | X | |
| Apatite | X | | | X | 0 | X | X | | X | X | 0 | X | X | 0 | X | X | X | X | |
| Fluorite | 0 | | | 0 | X | 0 | 0 | | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Opaque oxides | X | | | X | X | X | X | | 0 | X | X | 0 | X | X | X | X | 0 | X | |
| Zircon | X | | | X | X | X | X | | X | X | X | X | 0 | 0 | 0 | X | X | X | |
| **Major oxides (weight percent) by X-ray fluorescence analysis** | | | | | | | | | | | | | | | | | | | |
| $SiO_2$ | 61.8 | 66.6 | 64.9 | — | — | — | 70.5 | 74.2 | — | — | — | — | — | — | — | — | — | 75.2 | 53.6 |
| $Al_2O_3$ | 17.5 | 15.7 | 16.2 | — | — | — | 15.4 | 13.8 | — | — | — | — | — | — | — | — | — | 13.1 | 15.9 |
| $Fe_2O_3$ | 1.18 | 1.1 | 0.83 | — | — | — | 0.75 | 0.68 | — | — | — | — | — | — | — | — | — | 0.63 | 10.6 |
| FeO | 3.72 | 2.5 | 2.98 | — | — | — | 1.74 | 0.84 | — | — | — | — | — | — | — | — | — | 0.91 | |
| MgO | 2.40 | 1.8 | 2.25 | — | — | — | 0.88 | 0.52 | — | — | — | — | — | — | — | — | — | 0.33 | 4.63 |
| CaO | 4.98 | 3.7 | 5.02 | — | — | — | 2.36 | 1.7 | — | — | — | — | — | — | — | — | — | 1.50 | 7.90 |
| $Na_2O$ | 4.35 | 4.1 | 3.86 | — | — | — | 4.33 | 3.4 | — | — | — | — | — | — | — | — | — | 3.43 | 2.90 |
| $K_2O$ | 2.18 | 2.8 | 1.54 | — | — | — | 2.70 | 4.2 | — | — | — | — | — | — | — | — | — | 3.76 | 1.78 |
| $H_2O^+$ | 0.78 | 0.57 | 1.18 | — | — | — | 0.41 | 0.60 | — | — | — | — | — | — | — | — | — | 0.18 | 1.42 |
| $H_2O^-$ | 0.02 | 0.19 | | — | — | — | 0.03 | 0.23 | — | — | — | — | — | — | — | — | — | <0.01 | |
| $TiO_2$ | 0.55 | 0.48 | 0.42 | — | — | — | 0.32 | 0.16 | — | — | — | — | — | — | — | — | — | 0.18 | 1.04 |
| $P_2O_5$ | 0.20 | 0.14 | 0.14 | — | — | — | 0.1 | 0.05 | — | — | — | — | — | — | — | — | — | <0.05 | 0.23 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MnO | 0.08 | 0.07 | 0.04 | — | — | — | 0.04 | 0.04 | — | — | — | — | — | — | — | — | — | 0.02 | 0.15 |
| $CO_2$ | 0.04 | 0.03 | — | — | — | — | — | 0.02 | — | — | — | — | — | — | — | — | — | 0.02 | — |
| Sum | 99.78 | 99.78 | 99.36 | | | | 99.57 | 100.44 | | | | | | | | | | 99.32 | 100.15 |
| A/CNK | 0.94 | 0.95 | 0.95 | | | | 1.08 | 1.05 | | | | | | | | | | 1.06 | 0.76 |

**Minor elements (parts per million) by X-ray fluorescence analysis and INAA for Ta, Hf, Sc, Cs, Th, and U**

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rb | 71 | 80 | 39 | — | — | 63 | 87 | 84 | 55 | 228 | — | — | — | — | — | — | — | 82 | 38 |
| Sr | 663 | 639 | 809 | — | — | 400 | 359 | 316 | 72 | 45 | — | — | — | — | — | — | — | 201 | 443 |
| Y | 10 | 15 | <10 | — | — | 6 | 9 | 16 | 24 | 8 | — | — | — | — | — | — | — | 8 | 20 |
| Zr | 113 | 134 | 112 | — | — | 123 | 101 | 116 | 116 | 31 | — | — | — | — | — | — | — | 114 | 112 |
| Nb | 6 | <5 | <5 | — | — | 4 | 8 | 13 | 15 | 8 | — | — | — | — | — | — | — | 6 | 8 |
| Ba | 707 | 747 | 616 | — | — | — | 669 | 1300 | — | — | — | — | — | — | — | — | — | 896 | 470 |
| Cs | — | 1.02 | 1.19 | — | — | — | — | 0.91 | — | — | — | — | — | — | — | — | — | — | 0.59 |
| Ta | — | 0.55 | 0.33 | — | — | — | — | 1.15 | — | — | — | — | — | — | — | — | — | — | 0.59 |
| Hf | — | 3.57 | 2.44 | — | — | — | — | 3.23 | — | — | — | — | — | — | — | — | — | — | 3.22 |
| Th | 41 | 7.5 | 6.02 | — | — | 8 | 15 | 8.69 | 11 | 7 | — | — | — | — | — | — | — | <15 | 3.67 |
| U | <15 | 2.6 | 1.11 | — | — | 15 | <15 | 4.0 | 24 | 17 | — | — | — | — | — | — | — | <15 | 1.22 |
| Sc | — | 8.04 | 6.88 | — | — | — | — | 2.15 | — | — | — | — | — | — | — | — | — | — | 28.2 |
| Zn | 78 | 57 | 61 | — | — | 68 | 47 | 30 | 44 | 44 | — | — | — | — | — | — | — | — | 97 |

**Minor elements (parts per million) by instrumental neutron activation analysis**

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La | — | 32.4 | 35.0 | — | — | — | — | 18.0 | — | — | — | — | — | — | — | — | — | — | 26.8 |
| Ce | — | 55.2 | 53.1 | — | — | — | — | 30.4 | — | — | — | — | — | — | — | — | — | — | 54.4 |
| Nd | — | 28.0 | 15.1 | — | — | — | — | 15 | — | — | — | — | — | — | — | — | — | — | 25.0 |
| Sm | — | 4.07 | 2.56 | — | — | — | — | 2.55 | — | — | — | — | — | — | — | — | — | — | 4.95 |
| Eu | — | 0.92 | 0.85 | — | — | — | — | 0.50 | — | — | — | — | — | — | — | — | — | — | 1.38 |
| Tb | — | 0.38 | 0.27 | — | — | — | — | 0.28 | — | — | — | — | — | — | — | — | — | — | 0.58 |
| Yb | — | 1.17 | 0.51 | — | — | — | — | 1.27 | — | — | — | — | — | — | — | — | — | — | 1.87 |
| Lu | — | 0.17 | 0.09 | — | — | — | — | 0.18 | — | — | — | — | — | — | — | — | — | — | 0.27 |

**Table 2.** Modes and chemical analyses of selected Early Proterozoic granitoid rocks in Marshfield terrane—Continued

| | 1,835 Ma alkali-feldspar granite | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.– | W307B | W307A | W398 | W394 | W286 | W849 | W299 | W851-2 | SWI 8-86 | W851-1 | W851-3 | W851-4 |
| **Modal analyses (volume percent)** | | | | | | | | | | | | |
| Plagioclase | 33 | 27.5 | 29.5 | 19 | 12 | — | — | — | — | — | — | — |
| Quartz | 33 | 37.5 | 32.5 | 39 | 34.5 | — | — | — | — | — | — | — |
| K-feldspar | 30 | 29 | 32 | 39.5 | 52 | — | — | — | — | — | — | — |
| Biotite | 1.5 | 5 | 5.5 | 1.5 | 0.5 | — | — | — | — | — | — | — |
| Muscovite | 0.5 | 0.5 | 0 | 0 | 0 | — | — | — | — | — | — | — |
| Hornblende | 0 | 0 | 0 | 0 | 0 | — | — | — | — | — | — | — |
| Epidote/ clinozoisite | 0.5 | Tr | 0 | 0 | 0 | — | — | — | — | — | — | — |
| Sphene | Tr | Tr | 0 | 0 | 0 | — | — | — | — | — | — | — |
| Chlorite | Tr | 0 | Tr | Tr | 0.5 | — | — | — | — | — | — | — |
| Carbonate | 0 | 0 | 0 | 0 | 0 | — | — | — | — | — | — | — |
| Accessory minerals | 1.5 | 0.5 | 0.5 | 1 | 0.5 | — | — | — | — | — | — | — |
| Allanite | X | X | X | | | | | | | | | |
| Apatite | 0 | X | X | X | | | | | | | | |
| Fluorite | 0 | 0 | 0 | X | | | | | | | | |
| Opaque oxides | X | X | X | X | | | | | | | | |
| Zircon | X | X | X | X | | | | | | | | |
| **Major oxides (weight percent) by X-ray fluorescence analysis** | | | | | | | | | | | | |
| $SiO_2$ | 76.3 | 77.5 | — | — | 76.5 | 75.9 | 75.6 | 76.3 | 76.5 | 63.5 | 50.8 | 58.5 |
| $Al_2O_3$ | 12.0 | 11.6 | — | — | 12.2 | 11.9 | 11.8 | 11.7 | 12.2 | 15.8 | 14.9 | 14.9 |
| $Fe_2O_3$ | 1.31 | 0.59 | — | — | 0.87 | 0.39 | 0.43 | 0.34 | 1.11 | 1.03 | 1.8 | 1.53 |
| FeO | 0.73 | 0.88 | — | — | 0.40 | 1.40 | 1.58 | 1.24 | | 3.72 | 6.48 | 5.54 |
| MgO | 0.13 | 0.35 | — | — | 0.16 | 0.11 | 0.13 | 0.19 | 0.11 | 2.75 | 4.71 | 4.46 |
| CaO | 0.59 | 0.57 | — | — | 0.31 | 0.53 | 0.66 | 0.77 | 0.34 | 5.26 | 6.97 | 6.06 |
| $Na_2O$ | 3.38 | 3.46 | — | — | 3.06 | 3.79 | 3.76 | 3.55 | 3.45 | 3.43 | 2.97 | 3.12 |
| $K_2O$ | 4.37 | 3.71 | — | — | 5.64 | 4.53 | 4.26 | 4.75 | 5.03 | 2.74 | 4.9 | 2.28 |
| $H_2O^+$ | 0.22 | 0.31 | — | — | 0.23 | 0.35 | 0.60 | 0.33 | 0.50 | 0.29 | 1.29 | 1.15 |
| $H_2O^-$ | 0.02 | <0.01 | — | — | 0.03 | | | | | | | |
| $TiO_2$ | 0.19 | 0.16 | — | — | 0.18 | 0.12 | 0.15 | 0.14 | <0.08 | 0.58 | 0.91 | 0.99 |
| $P_2O_5$ | <0.05 | <0.05 | — | — | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.22 | 0.96 | 0.49 |
| MnO | <0.02 | <0.02 | — | — | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 0.07 | 0.14 | 0.1 |
| $CO_2$ | 0.02 | 0.02 | — | — | 0.01 | — | — | — | — | — | — | — |
| Sum | 99.32 | 99.22 | | | 99.65 | 99.08 | 99.03 | 99.37 | 99.38 | 99.72 | 96.83 | 99.12 |
| A/CNK | 1.06 | 1.08 | | | 1.04 | 0.99 | 0.99 | 0.95 | 1.04 | 0.87 | 0.65 | 0.80 |

**Minor elements (parts per million) by X-ray fluorescence analysis and INAA for Ta, Hf, Sc, Cs, Th, and U**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rb | 93 | 89 | — | — | 150 | 94 | 70 | 66 | 120 | 73.1 | 111 | 42.4 |
| Sr | 60 | 62 | — | — | 17 | 32 | 41 | 46 | 25 | 601 | 3,820 | 710 |
| Y | 71 | 78 | — | — | 29 | 54 | 54 | 55 | 30 | 13 | — | — |
| Zr | 291 | 281 | — | — | 141 | 267 | 395 | 333 | 125 | 149 | 184 | 230 |
| Nb | 25 | 29 | — | — | 17 | 28 | 27 | 27 | 18 | 9 | — | — |
| Ba | 1,482 | 793 | — | — | 256 | 1,236 | 1,390 | 1,294 | 631 | 1,370 | 6,170 | 1,120 |
| Cs | — | — | — | — | — | 0.32 | 0.2 | 0.15 | 1.35 | 0.95 | — | — |
| Ta | — | — | — | — | — | 2.48 | 2.18 | 2.3 | 1.51 | 0.93 | 0.54 | 1.08 |
| Hf | — | — | — | — | — | 9.69 | 10.4 | 9.11 | 4.45 | 4.1 | 5.28 | 4.98 |
| Th | 27 | 22 | — | — | — | 16.7 | 15.6 | 15.3 | 21.0 | 11.7 | 8.63 | 6.7 |
| U | <15 | <15 | — | — | — | 4.29 | 3.66 | 3.68 | 5.70 | 3.33 | 2.24 | 1.8 |
| Sc | — | — | — | — | — | 0.78 | 1.04 | 1.16 | 3.22 | 13.2 | 2.24 | 1.8 |
| Zn | — | — | — | — | — | 28 | 19 | 33 | 35 | 48 | 194 | 100 |

**Minor elements (parts per million) by instrumental neutron activation analysis**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| La | — | — | — | — | — | 81.9 | 101 | 103 | 49.8 | 52.7 | 74.7 | 61.6 |
| Ce | — | — | — | — | — | 159 | 194 | 197 | 97.9 | 91 | 144 | 115 |
| Nd | — | — | — | — | — | 62 | 73.9 | 77 | 37.1 | 30.8 | 62.8 | 44.5 |
| Sm | — | — | — | — | — | 12.8 | 14.45 | 14.77 | 7.67 | 5.28 | 11.08 | 7.99 |
| Eu | — | — | — | — | — | 1.61 | 2.19 | 2.05 | 0.47 | 1.21 | 3.04 | 1.87 |
| Tb | — | — | — | — | — | 1.61 | 1.69 | 1.72 | 0.82 | 0.45 | 0.94 | 0.70 |
| Yb | — | — | — | — | — | 6.76 | 6.48 | 6.70 | 3.06 | 1.27 | 2.09 | 1.92 |
| Lu | — | — | — | — | — | 0.94 | 0.93 | 0.92 | 0.45 | 0.17 | 0.32 | 0.29 |

### SAMPLE DESCRIPTIONS AND LOCALITIES (TABLE 2)

#### SYNTECTONIC TONALITE-GRANODIORITE SUITE

| | |
|---|---|
| W283B | Foliated diorite (tonalite) at Conants Rapids, sec. 8, T. 23 N., R. 8 E. Age 1,892±9 Ma. |
| W214–2 | Foliated tonalite at Conants Rapids. |
| W270A | Dacite porphyry in Milladore Volcanic Complex (Sims and others, 1989), sec. 18, T. 25 N., R. 6 E. |
| W260 | Foliated tonalite, sec. 11, T. 23 N., R. 7 E. |
| W254B | Foliated tonalite, sec. 1, T. 23 N., R. 6 E. |
| W237 | Foliated tonalite, sec. 8, T. 25 N., R. 5 E. |
| W283A | Lineated granodiorite (tonalite) at Conants Rapids, sec. 8, T. 23 N., R. 8 E. |
| W214–1 | Same as W283A. |
| W309C | Granite gneiss (granodiorite) near Neillsville, sec. 15, T. 24 N., R. 2 W. Contains 12 ppm Cu. |
| W390 | Granite gneiss near Neillsville, sec. 17, T. 24 N., R. 2 W. Age 1,871±5 Ma. Contains 14 ppm Cu. |
| 21-84 | Granite gneiss near Neillsville, sec. 2, T. 24 N., R. 2 W. |

#### GRANITOID ROCKS OF UNCERTAIN CLASSIFICATION

| | |
|---|---|
| W284 | Mylonitic granodiorite, Biron Dam, sec. 33, T. 23 N., R. 6 E. Cuts tonalite that has age of 1,841±10 Ma. |
| W285–1 | Leucogranite near Marshfield, sec. 9, T. 25 N., R. 2 E. |
| W288 | Leucogranite, sec. 10, T. 23 N., R. 3 E. |
| W285 | Leucogranite, sec. 9, T. 25 N., R. 2 E. |
| W305 | Lineated granite, sec. 33, T. 27 N., R. 2 W. |
| 26–84 | Granite, sec. 21, T. 26 N., R. 2 W. |
| W306 | Leucogranite, sec. 3, T. 26 N., R. 2 W. |
| W859 | Diorite, Hemlock Creek, SE¼NW¼ sec. 23, T. 23 N., R. 4 E. |

#### ALKALI-FELDSPAR GRANITE

| | |
|---|---|
| W307B | Biotite granite (alkali granite), sec. 27, T. 26 N., R. 2 W. |
| W307A | Biotite granite (alkali granite), sec. 27, T. 26 N., R. 2 W. |
| W398 | Red granite at Black River Falls, sec. 14, T. 21 N., R. 4 W. Age 1,835±6 Ma. |
| W394 | Red granite, Granite Heights, sec. 19, T. 23 N., R. 2 W. |
| W286 | Red granite (alkali granite), sec. 21, T. 24 N., R. 3 E. |
| W849 | Red granite, quarry, SW¼ sec. 25, T. 24 N., R. 2 E. Age 1,833±4 Ma. |
| W299 | Red granophyric granite (alkali granite), Cary Mound, SW¼ sec. 34, T. 24 N., R. 2 E. |
| W851–2 | Red granophyric granite (alkali granite), NW¼ sec. 1, T. 23 N., R. 2 E. |
| SWI–8–86 | Red alkali-feldspar granite (alkali granite), Vesper, SW¼NE¼ sec. 2, T. 23 N., R. 4 E. |
| W851–1 | Diorite (tonalite), fine-grained, same locality as W851–2. |
| W851–3 | Lamprophyre(?), same locality as W851–2. |
| W851–4 | Diorite, medium-grained, same locality as W851–2. |

mylonitization (protomylonite). Within restricted narrow shears, plagioclase, quartz, hornblende, and biotite are recrystallized into aligned aggregates of finer grain size. Hornblende within the recrystallized shears is distinctly blue green, whereas outside of shears, it is dark green; sphene is associated with blue-green hornblende and biotite and its presence suggests slight retrograding during the ductile deformation.

A body of foliated granodiorite (unit Xft, fig. 2) similar to that in the Stevens Point area, 16 km long and 5 km wide, cuts volcanic rocks of the Milladore Volcanic Complex (Xmc) in an area northeast of Marshfield. The granodiorite is medium gray, medium grained, and equigranular, and it contains widely scattered xenoliths of mafic and felsic volcanic rocks of the Milladore Volcanic Complex. The rock is variably foliated as a result of ductile deformation and is now protomylonite to orthomylonite. Type IP mantle aggregates (Hanmer, 1982) are common. A mode (W237) is given in table 2.

The relationship of the granodiorite-diorite bodies exposed near Stevens Point (unit XAgt, fig. 2) to the volcanic rocks of the Milladore Volcanic Complex is uncertain. If the foliated tonalite (W237, unit Xft, fig. 2; table 2) that cuts rocks of the Milladore Volcanic Complex is correlative with the tonalite-granodiorite suite in the Stevens Point area, then all tonalitic rocks are essentially coeval with the volcanic rocks. Such an interpretation is supported by major- and minor-element compositions of both the granodiorite-diorite and the Milladore Volcanic Complex. The chemistry of a sample (W270A, table 2) of dacite porphyry from the Milladore Volcanic Complex is very similar to that of a sample of foliated diorite from Conants Rapids (W283B, table 2). The foliated diorite at Conants Rapids has a U-Pb zircon upper intercept age of 1,892±9 Ma, however, which is substantially older than ages determined directly from volcanic rocks within the Milladore Volcanic Complex (approximately 1,860 Ma). A preliminary age of 1,842±10 Ma was reported earlier for this same sample (W283B) of foliated diorite, and an age of 1,824±25 Ma was reported for a lineated tonalite at Conants Rapids (Van Schmus, 1980, p. 162). Maass and others (1980) interpreted these ages as representing the time span of Penokean deformation, a premise no longer tenable (Sims and others, 1989). With present data, deformation in this terrane can only be bracketed as younger than 1,860 Ma, the apparent age of the Milladore Volcanic Complex, and older than 1,835 Ma, the age of the post-tectonic granite.

Foliated granodiorite at Biron Dam, north of Wisconsin Rapids (fig. 2), has a U-Pb zircon age of 1,841±10 Ma (Sims and others, 1989). All the rocks exposed here, including amphibolite dikes in the foliated granodiorite, have the same deformational style (Maass and others, 1980, fig. 3).

The granodiorite to tonalite group in the Stevens Point area ranges from hornblende-biotite diorite to biotite trondhjemite and is calc-alkalic to alkali-calcic (fig. 4 and Anderson and Cullers, 1987). The rocks are mostly metaluminous but include peraluminous varieties for silica values in excess of 65 weight percent. The rocks range from alkali-calcic to calc-alkalic tonalite to granite, are Mg rich to very Mg rich, metaluminous to mildly peraluminous, and sodic; and they contain high Sr and low Rb and Zr. Anderson and Cullers (1987) showed that these plutons are analogs of modern orogenic andesite-dacite suites; REE patterns are

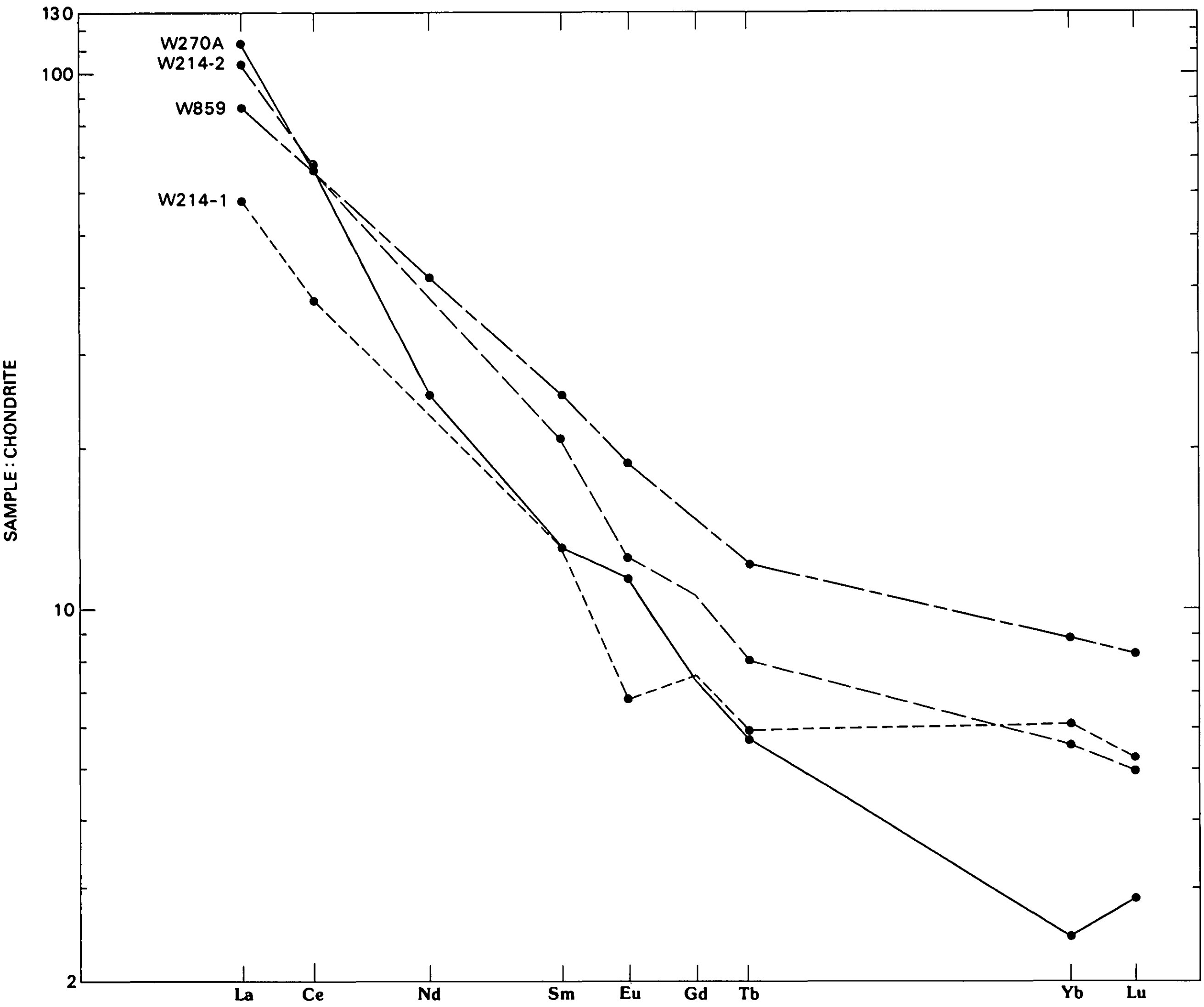


**Figure 12.** Chondrite-normalized REE plots for samples of syntectonic granodiorite suite, Marshfield terrane. Analyses given in table 2. Gd, no data.

similar to those of high-potassium andesites, with similar negatively sloping light-REE to heavy-REE patterns and minor or nonexistent Eu anomalies (fig. 12). A small amount of Archean material may have been incorporated during tonalite emplacement (Anderson and Cullers, 1987). Anderson and Cullers interpreted these tonalitic magmas as being derived by partial melting of an eclogitized, altered tholeiitic source, possibly a subducted oceanic slab. Their interpretation is consistent with the location of tonalite-granodiorite samples in the volcanic-arc granite field on a diagram of Rb versus Y+Nb (fig. 13).

## Gneissic Granite Near Neillsville

The gneissic granite near Neillsville (Ne; unit Xggr, fig. 2) is moderate red to pale red, and medium to fine grained; it has a mylonitic foliation and a conspicuous steep mylonitic lineation. The granite intrudes layered and previously deformed Late Archean gneiss and amphibolite, as noted on the east bank of the Black River at the west edge of Neillsville, and has a U-Pb zircon upper intercept age of 1,871±5 Ma (Sims and others, 1989). Texture varies according to the degree of mylonitization and recrystallization (grain-size reduction). In a quarry 4 km west of Neillsville, a felsic dike (W390, table 2) that cuts the granite has the same structural fabric as the granite. The gneissic granite has the composition of leucogranite, ranging locally to granodiorite (table 2). Potassium feldspar is microperthitic (as much as 5 mm in diameter); typically, adjacent plagioclase (oligoclase) is myrmekite. Quartz is present as sutured, recrystallized grains. Muscovite forms coarse porphyroblasts. The granite has a high quartz content (>40 volume percent) and

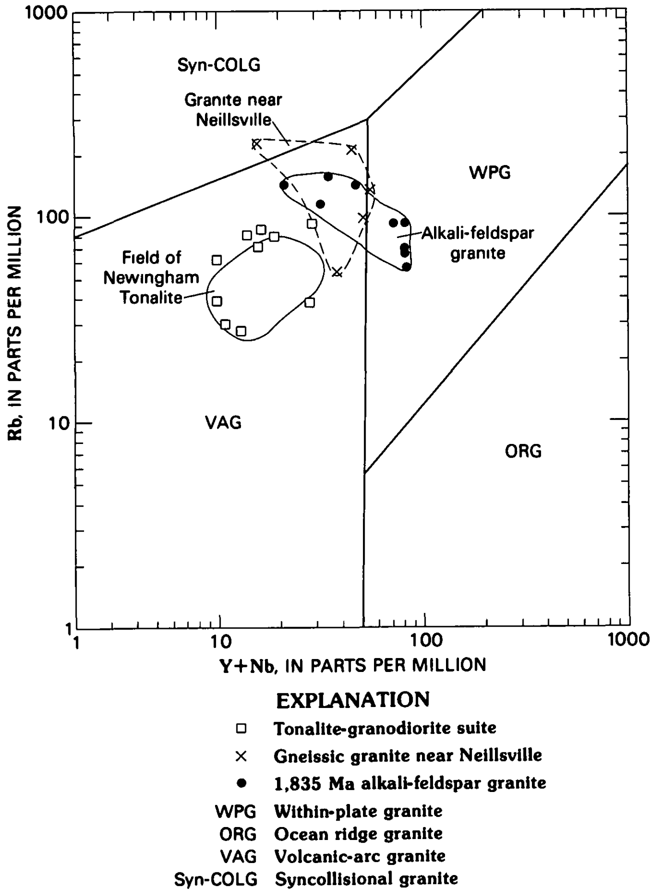


**Figure 13.** Rb versus Y+Nb diagram (modified from Pearce and others, 1984) showing granitoid rocks of the Marshfield terrane. Field of Newingham Tonalite modified from Sims and others (1992).

commonly contains accessory fluorite. On a Rb versus Y+Nb diagram (fig. 13), this gneissic granite plots mainly with volcanic-arc granites, but overlaps the fields of syncollisional granites and within-plate granites, which indicates a much more highly evolved chemical composition than that of the tonalite-granodiorite suite. The granite near Neillsville has a much more highly evolved composition than would be expected for its age group.

### 1,835 Ma Alkali-Feldspar Granite

The post-tectonic red alkali-feldspar granite in the Marshfield terrane is petrographically and compositionally similar to the red granite in the Pembine-Wausau terrane. All are mildly peraluminous and alkali-calcic, range from alkali granite to normal granite, and are similar to but slightly more alkali-enriched than the Athelstane batholith. A granite from Rock Township (north of Cary Mound; locality C, fig. 2) has a U-Pb zircon upper intercept age of 1,833±4 Ma, and a sample from Black River Falls (Br, fig. 2) has an upper intercept age of 1,835±6 Ma (Sims and others, 1989). The close similarity in these ages, as well as compositional similarities of the red granites, suggests that all red granites in this and the adjacent Pembine-Wausau terrane are coeval. The REE patterns are distinctive (fig. 14), exhibiting large negative Eu anomalies and a relatively flat heavy-REE slope. On a Rb versus Y+Nb diagram (fig. 13), five samples of alkali-feldspar granite from the Marshfield terrane plot in the within-plate field and four samples plot in the field of volcanic-arc granites. Three dioritic samples (W851-1, W851-3, W851-4; table 2) associated with the red granite at Cary Mound have lamprophyric affinities with most having high Ba and Sr (table 2) and steep REE patterns (fig. 15). That these dioritic rocks are related, in a narrow sense, to the 1,835 Ma alkali-feldspar granite is doubtful; if they were, they should have alkali-calcic affinities.

Two samples of alkali-feldspar granite (W307A, W307B) of 1,835 Ma group listed in table 2 are deformed ductilely, but they are included in this group because they chemically resemble undeformed red granites of the 1,835 Ma group. The deformation of these rocks is attributed to shearing in the Athens shear zone at about 1,815 Ma, the age determined for the Mountain shear zone (Sims and others, 1989; Sims and others, 1990). On a Nb versus Y diagram, the alkali-feldspar granite plots mainly in the within-plate granite field (fig. 16).

## SUMMARY AND CONCLUSIONS

The granitoid rocks in the Pembine-Wausau and Marshfield terranes compose two distinct suites, calc-alkalic rocks such as those that commonly are emplaced within primitive island or Andean arcs (for example, Sierra Nevada batholith), and alkali granite suites (fig. 17). The rocks in each class are remarkably similar in composition in both terranes.

The syntectonic granodiorite suite in the Pembine-Wausau terrane is the product of the two collisional events recognized in the Wisconsin magmatic terranes: (1) continent-arc collision along the Niagara fault zone at ≈1,852 Ma and (2) arc-minicontinent collision along the Eau Pleine shear zone at about 1,840 Ma (Sims and others, 1989). The syntectonic granodiorite suite in the Pembine-Wausau terrane is mainly coeval with major tholeiitic and calc-alkalic arc volcanism (1,889–1,860 Ma) and is calc-alkalic to calcic (Sims and others, 1992, fig. 5; fig. 4). Brown (1982) has related such compositional changes to progressive arc evolution, spanning immature island arcs, mature arcs and continental margins (calc-alkalic rocks), and continental collision zones. The Pembine-Wausau terrane granitoids are mainly volcanic-arc granodiorites, as represented by the Newingham Tonalite in the Dunbar area, which developed during southward subduction of oceanic crust prior to collision of the Pembine-Wausau terrane with the continental margin to the north. In the Dunbar dome of northeastern Wisconsin, adjacent to the Niagara fault zone, granitoid

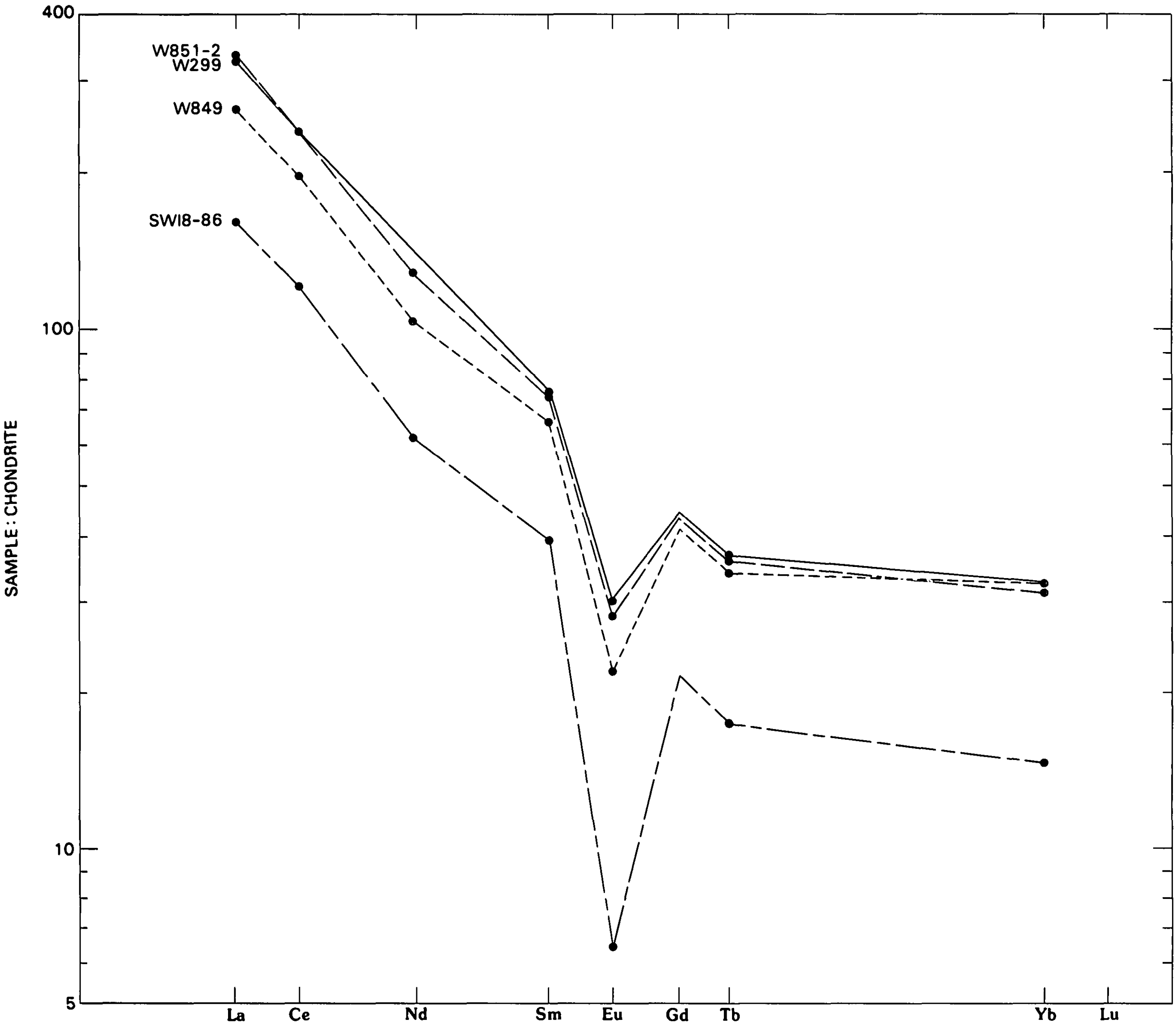


**Figure 14.** Chondrite-normalized REE plots for samples of red alkali-feldspar granite, Marshfield terrane. Gd, no data.

rocks are generally more evolved than the Newingham Tonalite (Sims and others, 1992), which suggests that they were derived from different sources and, potentially, formed in a different tectonic setting. The Dunbar granitoid rocks are characterized by relatively high K, Rb, Ba, Th, Nb, Ta, and light-REE. High Ta and Nb are particularly diagnostic. These potassium-enriched rocks cross the fields for volcanic-arc granite into syncollisional granites (see Sims and others, 1992, fig. 30). Accordingly, we conclude that granites adjacent to the Niagara fault zone are syn- to post-collisional granites, as defined by Harris and others (1986).

Barovich and others (1989) presented Nd isotopic data for selected granitoid rocks from the Pembine-Wausau terrane, and found a wide range of $\varepsilon_{Nd}(T)$ values, from −4.5 to +4.0; the authors noted that the more negative $\varepsilon_{Nd}(T)$ values are in samples near the Niagara fault zone, the suture between the Pembine-Wausau terrane and Archean crust to the north. Their model explained these results as due to mixing of variable amounts of new crustal material and recycled Archean detritus, with the proportion of added Archean detritus being greatest closest to the collisional boundary. Although this model accounts for the observed isotopic variations, it does not explain enrichment of high-field-strength elements (HFSE), particularly Ta and Nb, for many of the granitoid rocks along the Niagara fault zone (Sims and others, 1992). Both new crustal material of the Pembine-Wausau terrane (the volcanic and related intrusive rocks) and the detritus derived from Archean crust show HFSE depletions. Mixing between and partial melting of such sources cannot account for the HFSE enrichments observed in some of the terrane's granitoids (Thompson and others, 1984).

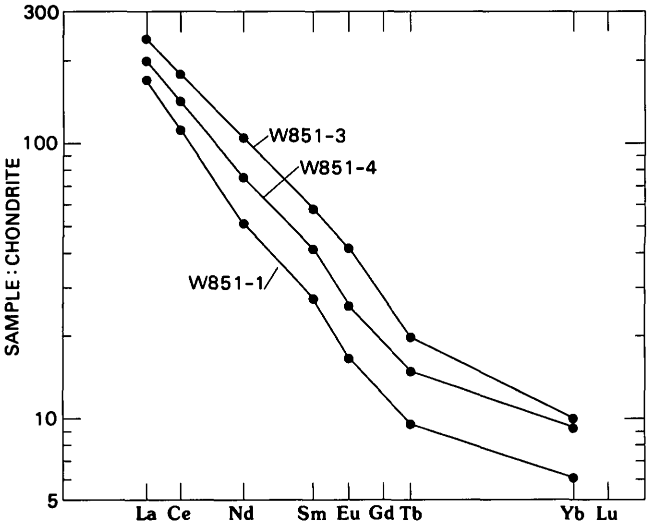


**Figure 15.** Chondrite-normalized REE plots for samples of diorite and lamprophyre associated with alkali-feldspar granite, Marshfield terrane. Gd, no data.

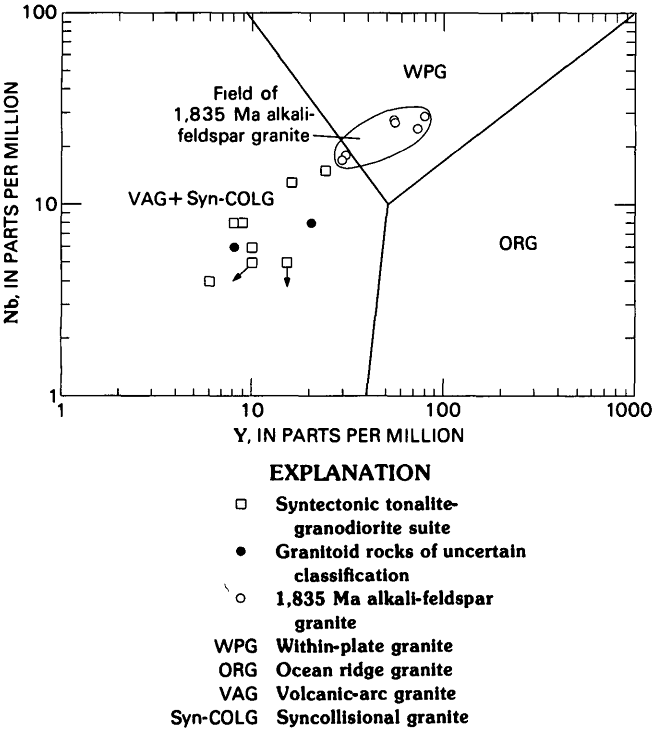


**Figure 16.** Nb versus Y diagram (modified from Pearce and others, 1984) showing granitoid rocks of the Marshfield terrane. Arrows indicate less than values shown.

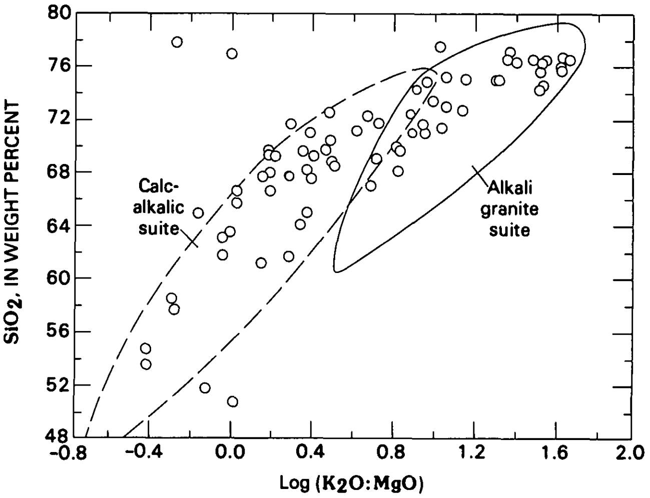
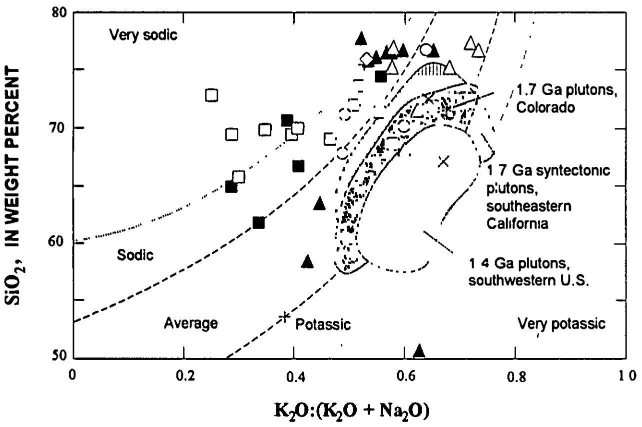


**Figure 17.** $SiO_2$ versus $\log_{10}$ ($K_2O$:MgO) diagram showing distinction between calc-alkalic and alkali granite suites in Wisconsin magmatic terranes (modified from Greenberg, 1980). Includes samples from the Dunbar, Wis., area (Sims and others, 1992).

As a modification of the mixing model of Barovich and others (1989), Sims and others (1992) suggested that granitoids near the Niagara fault zone enriched in HFSE (for example, sample W251, table 1) may have been derived through partial melting of mantle-derived basalts having within-plate compositions (for example, Early Proterozoic basalt of the Marquette Range Supergroup). In this model, the negative $\varepsilon_{Nd}(T)$ values for these samples would at least in part reflect that of the basaltic source. Partial melting would have occurred during collision and overthrusting of the Pembine-Wausau terrane onto the continental margin. For those granitoids with negative $\varepsilon_{Nd}(T)$ and depleted HFSE, some crustal material and Archean detritus probably were incorporated in the source prior to collision.

Younger, late-tectonic granodiorite-tonalite bodies in the Marathon County area (unit Xgt, fig. 2) presumably formed during north-dipping subduction of oceanic crust that terminated with collision of the Marshfield (minicontinent) terrane with the Pembine-Wausau terrane. The resulting granite-granodiorite suite is calc-alkalic to alkali calcic. The suite appears more evolved than the Newingham Tonalite and other older volcanic-arc granodioritic rocks.

The Athelstane Quartz Monzonite has a composition similar to that of granitic rocks of the Middle Proterozoic Wolf River batholith (Anderson and Cullers, 1978; Anderson, 1983, fig. 10C) and other Middle Proterozoic anorogenic complexes in North America. Rare earth element abundances are also similar to those of the Wolf River batholith (see Anderson, 1983, fig. 11). Anderson and Cullers (1978) have argued for an origin of the Wolf River batholith through partial melting of a quartz diorite to granodioritic crustal source, such as the syntectonic granodiorite suite discussed in this report. A similar source is proposed for the Athelstane Quartz Monzonite. Crustal melting followed orogenic episodes in the region by a few million years. Possibly the heat necessary for crustal melting was generated by the earlier northward subduction of the Marshfield terrane beneath the Pembine-Wausau terrane.



**EXPLANATION**

**Marshfield terrane**

- ▲ 1,835 Ma alkali-feldspar granite
- ■ Syntectonic granodiorite
- \+ Uncertain affinity

**Pembine-Wausau terrane**

- △ Athelstane Quartz Monzonite
- □ Syntectonic granodiorite
- × Uncertain affinity
- ○ 1,760 Ma granodiorite-granite
- ◇ 1,835 Ma alkali-feldspar granite

**Figure 18.** $SiO_2$ versus $K_2O:(K_2O+Na_2O)$ diagram showing comparison of compositions of plutonic rocks in Pembine-Wausau and Marshfield terranes with those in Proterozoic terranes in Colorado, southeastern California, and southwestern United States. Plutonic rocks in the Wisconsin terranes are markedly more sodic than those in western parts of the United States. Compiled by Ed DeWitt, 1992.

Approximately 5–10 m.y. after suturing of the Pembine-Wausau and Marshfield terranes along the Eau Pleine shear zone, red alkali-feldspar granite and cogenetic subaerial rhyolite were emplaced in the vicinity of the shear zone; they postdate collision. The alkali-feldspar granites are mainly alkalic and share characteristics of within-plate and volcanic-arc granites (fig. 16).

Syntectonic granitoid rocks within the Marshfield terrane are mainly calc-alkalic granodiorites; they are similar in composition to the syntectonic granodiorite suite of the Pembine-Wausau terrane. The tonalite-granodiorite suite overlaps the compositional field of the Newingham Tonalite. Possibly the tonalite-granodiorite rocks were generated by a southward-dipping subduction zone beneath the Marshfield terrane prior to collision along the Eau Pleine shear zone. The granite near Neillsville also could have been generated in this manner, but it is more highly evolved chemically than the tonalite-granodiorite suite.

Plutonic rocks of the Pembine-Wausau and Marshfield terranes record changing types of magmatism over time. Prior to ≈1,850 Ma, intrusive rocks are calcic to calc-alkalic, magnesium rich, sodic to very sodic, high-strontium granodiorite to trondhjemite typical of immature island or continental arcs. Rocks younger than ≈1,850 Ma are characteristically alkali-calcic, iron rich to very iron rich, sodic to average granodiorite to granite typical of more mature island arcs and somewhat evolved continental arcs. The post-tectonic 1,760 Ma plutons are the most chemically evolved, having the highest Rb and Th concentrations, but they do not differ much from 1,835 Ma rocks, as they are alkali-calcic, iron rich to average, sodic to average granodiorite to granite.

Distinctive and as yet unexplained features of the igneous rocks of the Pembine-Wausau and Marshfield terranes include: (1) Zr concentrations (300–400 ppm) of the Athelstane Quartz Monzonite and the possibly related red alkali-feldspar granite are anomalously high. Evolved granites such as the Athelstane typically contain only 150–200 ppm. (2) In some pre-1,850 Ma granodiorite bodies in the Pembine-Wausau terrane, HREE values are anomalously low (only 2–3 times greater than chondrite abundances). (3) Magmatism from ≈1,890 to ≈1,500 Ma in northern Wisconsin exhibits an overall sodic nature (fig. 18). Other orogenic terranes in the western United States typically evolved to potassic or even highly potassic magmatism over time, but the Wisconsin terranes remained sodic to average. Source areas beneath both Wisconsin magmatic terranes certainly had a major role in controlling the temporal chemical variations. Perhaps further studies will result in explanations for some of the anomalous features revealed by this investigation.

## REFERENCES CITED

Anderson, J.L., 1972, Petrologic study of a migmatite-gneiss terrain in central Wisconsin and the effect of biotite-magnetite equilibria on partial melts in the granite system: Madison, Wis., University of Wisconsin M.S. thesis, 103 p.

______1983, Proterozoic anorogenic granite plutonism of North America, *in* Medaris, L.G., Jr., Byers, C.W., Mickelson, D.M., and Shanks, W.C., eds., Proterozoic geology—Selected papers from an international Proterozoic symposium: Geological Society of America Memoir 161, p. 133–154.

Anderson, J.L., and Cullers, R.L., 1978, Geochemistry and evolution of the Wolf River batholith, a late Precambrian rapakivi massif in North Wisconsin, U.S.A.: Precambrian Research, v. 7, p. 287–324.

______1987, Crust-enriched mantle-derived tonalites in the Early Proterozoic Penokean orogen of Wisconsin: Journal of Geology, v. 95, p. 139–154.

Anderson, J.L., Cullers, R.L., and Van Schmus, W.R., 1980, Anorogenic metaluminous and peraluminous granite plutonism in the mid-Proterozoic of Wisconsin, U.S.A.: Contributions to Mineralogy and Petrology, v. 74, p. 311–328.

Attoh, Kodjopa, and Klasner, J.S., 1989, Tectonic implications of metamorphism and gravity field in the Penokean orogen of northern Michigan: Tectonics, v. 8, p. 911–933.

Barovich, K.M., Patchett, P.J., Peterman, Z.E., and Sims, P.K., 1989, Nd isotopes and the origin of 1.9–1.7 Ga Penokean continental crust of the Lake Superior region: Geological Society of America Bulletin, v. 101, p. 333–338.

Brown, B.H., and Greenberg, J.K., 1986, Bedrock geology of Wood County, Wisconsin: Wisconsin Geological and Natural History Survey Map 86–4, scale 1:100,000.

Brown, G.C., 1982, Calc-alkaline intrusive rocks—Their diversity, evolution, and relation to volcanic arcs, *in* Thorpe, R.S., ed., Andesites: New York, John Wiley, p. 437–461.

Cannon, W.F., and Gair, J.E., 1970, A revision of stratigraphic nomenclature of middle Precambrian rocks in northern Michigan: Geological Society of America Bulletin, v. 8, p. 2843–2846.

Cannon, W.F., Lee, M.W., Hinze, W.J., Schulz, K.J., and Green, A.G., 1991, Deep crustal structure of Precambrian basement beneath northern Lake Michigan, midcontinent North America: Geology, v. 19, p. 207–210.

DeLaRoche, H., Letterrier, J., Grandclaude, P., and Marchal, M., 1980, A classification of volcanic and plutonic rocks using $R_1R_2$-diagram and major-element analyses—Its relationships with current nomenclature: Chemical Geology, v. 29, p. 183–210.

DeWitt, Ed, 1989, Geochemistry and tectonic polarity of Early Proterozoic (1700–1750 Ma) plutonic rocks, north-central Arizona, *in* Jenny, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Ariz., Arizona Geological Society Digest 17, p. 149–163.

Dott, R.H., Jr., 1983, The Proterozoic red quartzite enigma in the north-central United States—Resolved by plate collision?, *in* Medaris, L.G., ed., Early Proterozoic geology of the Great Lakes region: Geological Society of America Memoir 160, p. 129–141.

Greenberg, J.K., 1980, Characteristics and origin of Egyptian Younger Granites: Geological Society of America Bulletin, v. 92, pt. 1, p. 224–232; pt. 2, p. 749–840.

Greenberg, J.K., and Brown, B.A., 1984, Cratonic sedimentation during the Proterozoic—An anorogenic connection in Wisconsin and the upper Midwest: Journal of Geology, v. 92, p. 159–171.

______1986, Bedrock geology of Portage County, Wisconsin: Wisconsin Geological and Natural History Survey Map 86–3, scale 1:100,000.

Gregg, W.J., 1993, Structural geology of parautochthonous and allochthonous terranes of the Penokean orogeny in Upper Michigan—Comparisons with northern Appalachian tectonics: U.S. Geological Survey Bulletin 1904–Q, 28 p.

Hanmer, S.K., 1982, Microstructure and geochemistry of plagioclase and microcline in naturally deformed granite: Journal of Structural Geology, v. 4, p. 197–213.

Harris, N.B.W., Pearce, J.A., and Tindle, A.G., 1986, Geochemical characteristics of collision-zone magmatism, *in* Coward, M.P., and Ries, A.C., eds., Collision tectonics: Geological Society of London Special Publication 19, p. 67–81.

Hoffman, P.F., 1987, Early Proterozoic foredeep, foredeep magmatism, and Superior-type iron-formations of the Canadian Shield, *in* Kroner, A., ed., Proterozoic lithospheric evolution: Geodynamics Series, v. 17, American Geophysical Union, p. 85–98.

Holm, D.K., Holst, T.B., and Ellis, M., 1988, Oblique subduction, footwall deformation and imbrication—A model for the Penokean orogeny in east-central Minnesota: Geological Society of America Bulletin, v. 100, p. 1811–1818.

Klasner, J.S., and Sims, P.K., 1993, Thick-skinned, south-verging backthrusting in the Felch and Calumet troughs area of the Penokean orogen, northern Michigan: U.S. Geological Survey Bulletin 1904–L, 28 p.

Klasner, J.S., Sims, P.K., Gregg, W.J., and Gallup, Christina, 1988, A structural traverse across a part of the Penokean orogen illustrating Early Proterozoic overthrusting in northern Michigan: Institute on Lake Superior Geology Field Trip Guidebooks, v. 34, part 2, Marquette, Michigan, p. C1–C36.

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

Larue, D.K., and Ueng, W.L., 1985, Florence-Niagara terrane—An Early Proterozoic accretionary complex, Lake Superior region, U.S.A.: Geological Society of America Bulletin, v. 96, p. 1179–1187.

Maass, R.S., Medaris, L.G., Jr., and Van Schmus, W.R., 1980, Penokean deformation in central Wisconsin, *in* Morey, G.B., and Hanson, G.N., eds., Selected studies of Archean gneisses and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 147–157.

Mudrey, M.G., Jr., 1979, The massive sulfide occurrences in Wisconsin: Wisconsin Geological and Natural History Survey Paper 79–2, 20 p.

Pearce, J.A., Harris, N.B.W., and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 25, p. 956–983.

Schulz, K.J., 1987, An Early Proterozoic ophiolite in the Penokean Orogen: Geological Association of Canada Program and Abstracts, v. 12, p. 87.

Sedlock, R.L., and Larue, D.K., 1985, Fold axes oblique to the regional plunge and Proterozoic terrane accretion in the southern Lake Superior region: Precambrian Research, v. 30, p. 249–262.

Sims, P.K., 1987, Metallogeny of Archean and Proterozoic terranes in the Great Lakes region—A brief overview: U.S. Geological Survey Bulletin 1694–E, p. 55–74.

______1989, Geologic map of Precambrian rocks of Rice Lake 1°×2° quadrangle, northern Wisconsin: U.S. Geological Survey Miscellaneous Investigations Series Map I–1924, scale 1:250,000.

______1990a, Geologic map of Precambrian rocks of Eau Claire and Green Bay 1°×2° quadrangles, central Wisconsin: U.S. Geological Survey Miscellaneous Investigations Series Map I–1925, scale 1:250,000.

______1990b, Geologic map of Iron Mountain and Escanaba 1°×2° quadrangles, northeastern Wisconsin and northwestern Michigan: U.S. Geological Survey Miscellaneous Investigations Series Map I–2056, scale 1:250,000.

______1990c, Geologic map of Precambrian rocks of Neillsville-Stevens Point area, central Wisconsin: U.S. Geological Survey Miscellaneous Investigations Series Map I–1926, scale 1:100,000.

______1990d, Geologic setting and ages of Proterozoic anorogenic rhyolite-granite terranes in the central United States, *in* The Midcontinent of the United States—Permissive terrane for an Olympic Dam-type deposit?: U.S. Geological Survey Bulletin 1932, p. 40–47.

______1992, Geologic map of Precambrian rocks, southern Lake Superior region, Wisconsin and northern Michigan: U.S.

Geological Survey Miscellaneous Investigations Series Map I–2185, scale 1:500,000.

Sims, P.K., Klasner, J.S., and Peterman, Z.E., 1990, The Mountain shear zone, northeastern Wisconsin, U.S.A.—A ductile deformation zone within the Early Proterozoic Penokean orogen: U.S. Geological Survey Bulletin 1904–A, 15 p.

Sims, P.K., and Peterman, Z.E., 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 Memoir 160, p. 3–14.

Sims, P.K., Peterman, Z.E., and Schulz, K.J., 1985, The Dunbar Gneiss-granitoid dome—Implications for early Proterozoic tectonic evolution of northern Wisconsin: Geological Society of America Bulletin, v. 96, p. 1101–1112.

Sims, P.K., Schulz, K.J., and Peterman, Z.E., 1992, Geology and geochemistry of Early Proterozoic rocks in the Dunbar area, northeastern Wisconsin: U.S. Geological Survey Professional Paper 1517, 65 p.

Sims, P.K., Van Schmus, W.R., Schulz, K.J., and Peterman, Z.E., 1989, Tectonostratigraphic evolution of the Early Proterozoic Wisconsin magmatic terranes of the Penokean orogen: Canadian Journal of Earth Sciences, v. 26, p. 2145–2158.

Smith, E.I., 1983, Geochemistry and evolution of the early Proterozoic, post-Penokean rhyolites, granites, and related rocks of south-central Wisconsin, U.S.A., *in* Medaris, L.G., Jr., ed., Early Proterozoic geology of the Great Lakes region: Geological Society of America Memoir 160, p. 113–128.

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

Thompson, R.N., Morrison, M.A., Hendry, G.L., and Parry, S.J., 1984, An assessment of the relative roles of crust and mantle in magma genesis—An elemental approach: Philosophical Transactions of the Royal Society of London, v. A310, p. 549–590.

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 gneisses and lower Proterozoic rocks, southern Canadian Shield: Geological Society of America Special Paper 182, p. 159–168.

Wise, D.U., and others, 1984, Fault-related rocks—Suggestions for terminology: Geology, v. 12, p. 391–394.

# APPENDIX A. PETROGRAPHIC DESCRIPTIONS OF ROCK SAMPLES LISTED IN TABLE 1

## SYNTECTONIC GRANODIORITE SUITE

| | |
|---|---|
| IM12 | Light-gray, medium- to coarse-grained, weakly foliated granodiorite (tonalite) containing irregular clots of brown biotite. Has steep northeast-trending mylonitic foliation. Plagioclase has weak concentric zoning. Quartz has strain shadows. Microcline is interstitial. Tonalite is cut by a leucogranite dike with cataclastic foliation expressed by oriented muscovite. |
| IM16 | Gray, foliated granodiorite (tonalite) with weak mylonitic foliation. Plagioclase has weak concentric zoning, quartz has strain shadows, and biotite (greenish brown) is oriented in mylonitic zones. Contains euhedral epidote/clinozoisite. |
| W319A | Gray, medium- to coarse-grained, foliated granodiorite that cuts migmatitic amphibolite and is cut by fine-grained tonalitic dikes. Has weak northwest-trending mylonitic foliation. Plagioclase has weak concentric zoning and quartz has strain shadows. |
| W325 | Pink, massive, medium-grained, altered granodiorite (granite), sheared in northern part of outcrop. Plagioclase is altered to epidote/clinozoisite, sericite, and stilpnomelane and biotite is chloritized. |
| W66 | From drill core HT–4, depth 15 m, of Bear Creek Mining Co. Reddish-brown, medium-grained, equigranular, hornblende-biotite granodiorite (tonalite). Plagioclase has concentric zoning. Has strong foliation and lineation. |
| W249B | Pinkish-gray, medium- to coarse-grained, foliated granodiorite. Plagioclase ($An_{20-25}$) has weak normal concentric zoning and is myrmekitic adjacent to potassium feldspar. |
| W249A | Light-olive-green, medium-grained granodiorite (tonalite). Plagioclase has strong concentric zoning. Potassium feldspar is interstitial. Epidote has replaced biotite. |
| W251 | Medium-gray, medium-grained, foliated tonalite. Plagioclase has weak concentric zoning. Biotite is grayish yellow to grayish red and slightly altered to chlorite and iron oxides. |
| W118 | Medium- to light-gray, medium-grained, foliated biotite granodiorite (tonalite). Plagioclase ($An_{22-30}$) has conspicuous concentric zoning. Biotite is moderate yellow to olive gray and fresh. Hornblende is dusky blue green. |
| W205B | Pinkish-gray, medium-grained, weakly foliated biotite granodiorite. Plagioclase ($An_{38-42}$) has weak concentric zoning, quartz has strain shadows, biotite is brown to grayish brown, and hornblende is green to blue green. |
| W317 | Gray foliated granodiorite (tonalite). Plagioclase ($An_{26-34}$) has strong concentric oscillatory zoning, quartz has strain shadows, |

and biotite is brown to reddish brown. Rock is protomylonite.

| | |
|---|---|
| W314 | Medium-gray, medium-grained foliated granodiorite. Plagioclase has weak concentric zoning. Rock is protomylonite. |
| W318 | Gray, medium-grained foliated granodiorite. Plagioclase has weak concentric zoning, is myrmekitic, and is moderately sericitized. Biotite is altered to chlorite, epidote/clinozoisite, and muscovite. Rock is protomylonite. |

### UNCERTAIN

| | |
|---|---|
| SW AU 6–83 | Coarse-grained granitoid similar to W188. |

### ATHELSTANE QUARTZ MONZONITE AND COEVAL ROCKS

| | |
|---|---|
| W213 | Granite near Cherokee. Pink to red, coarse-grained granite (alkali granite) with clots of biotite. Has a mylonitic foliation. Plagioclase (An$_{14-18}$) is fractured. Potassium feldspar occurs as large irregular grains of microperthite. Quartz has strain shadows. |
| WI–1 | Coarse-grained granite. Plagioclase has weak concentric zoning; myrmekite present adjacent to potassium feldspar. |
| W188 | Athelstane Quartz Monzonite. Pinkish-gray, coarse-grained, massive granite (alkali granite). Plagioclase and potassium feldspar (microcline and microperthite) occur as large rectangular grains. Hornblende is olive green and altered to biotite and opaque oxides. Biotite is brown to reddish brown. |
| W549 | Same as W188. |
| W533 | Same as W188. |
| W556 | Same as W188. Zircon is common. |
| W555 | Same as W188. |

### 1,835 MA ALKALI-FELDSPAR GRANITE

| | |
|---|---|
| W384 | Red, medium- to coarse-grained, massive leucogranite (alkali granite). Plagioclase (An$_{8-10}$)is fractured and potassium feldspar is dominantly microperthitic. Biotite is dark olive green. |

### 1,760 MA GRANODIORITE-GRANITE GROUP

| | |
|---|---|
| W12B | Amberg Granite. Gray, fine-grained mylonitic granite gneiss. Plagioclase (An$_{25-27}$) has moderate concentric zoning, potassium feldspar is microperthitic, and biotite is frayed. Lies within Twelve-foot Falls shear zone (Sims, 1990b). |
| SPB 232–39 | Amberg Granite, NW¼SW¼ sec. 31, T. 36 N., R. 21 E. |
| W54 | Granodiorite (granite) near Lugerville. Pinkish-gray, medium-grained, weakly foliated, equigranular biotite granite. Hypidiomorphic granular texture. Plagioclase (An$_{24-30}$) has weak concentric zoning and albite rims. Potassium feldspar is microperthite. Biotite is grayish olive, moderately frayed, and partly chloritized. |
| W55 | Light-gray, medium-grained, equigranular, weakly foliated biotite granodiorite (granite). Plagioclase has normal concentric zoning and locally is myrmekitic. Biotite is olive gray. |
| 824–7 | Granite near Monico. Pink to grayish-pink, coarse-grained, slightly inequigranular leucogranite. Plagioclase (An$_{21-24}$) has moderate concentric zoning and narrow albite rims adjacent to microperthite. Biotite is moderately altered to chlorite, epidote, and zeolite(?). |
| W252 | Grayish-pink, coarse-grained foliated granodiorite. Hypidiomorphic-granular texture. Plagioclase has concentric zoning; potassium feldspar is microperthitic. |

## APPENDIX B. PETROGRAPHIC DESCRIPTIONS OF ROCK SAMPLES LISTED IN TABLE 2

### SYNTECTONIC TONALITE-GRANODIORITE SUITE

| | |
|---|---|
| W283B | Gray to pale-reddish-brown medium-grained foliated diorite (tonalite) containing plagioclase porphyroclasts with strong concentric zoning and a groundmass of fine-grained granular plagioclase, potassium feldspar, quartz, biotite, and hornblende. Some myrmekite. Mode of potassium feldspar may be underestimated. A prominent mylonitic foliation is produced by aligned minerals. |
| W214–2 | Foliated tonalite at Conants Rapids. |
| W270A | Gray, inequigranular, mylonitic, lineated dacite porphyry. Relict phenocrysts of concentrically zoned plagioclase in a finer grained finely comminuted groundmass of quartz, plagioclase, biotite, and sparse hornblende. |
| W260 | Gray, medium-grained foliated tonalite that crosscuts a foliated tonalite. Rock is |

| | |
|---|---|
| | protomylonite. Plagioclase has weak concentric zoning. |
| W254B | Gray, medium-grained foliated tonalite. Cuts coarser grained foliated tonalite. Plagioclase ($An_{26-28}$) has weak concentric zoning. Quartz is strained. Rock is protomylonite. |
| W237 | Medium-gray, mottled, medium-grained, nearly equigranular foliated tonalite. Moderate alteration. Plagioclase has concentric zoning. Rock has mylonitic foliation. |
| W283A | Gray to pale-reddish-brown, medium- to fine-grained (1–3 mm) granodiorite (tonalite). A mylonitic lineation is expressed by elongate grains of biotite and aggregates of biotite and quartz. Plagioclase has weak concentric zoning. Cuts foliated tonalite. Mode of potassium feldspar may be underestimated. |
| W214–1 | Same as W283A. |

### GRANITE NEAR NEILLSVILLE

| | |
|---|---|
| W309C | Same as W390, but granodiorite in composition. |
| W390 | Moderate-red to pale-red, medium- to fine-grained mylonitic leucogranite gneiss. Plagioclase ($An_{8-10}$) has weak concentric zoning. Potassium feldspar is microperthite and forms megacrysts as much as 5 mm in diameter; strong, steep lineation expressed by elongate clots of biotite and quartz rods. |
| 21–84 | Same as W390, but entirely recrystallized to average grain size of about 0.5 mm. |

### GRANITOID ROCKS OF UNCERTAIN CLASSIFICATION

| | |
|---|---|
| W284 | Gray, fine- to medium-grained lineated granodiorite with bimodal texture; is protomylonite. Cuts foliated tonalite that has an age of 1,841±10 Ma. |
| W285–1 | Pink, medium-grained equigranular leucogranite. Cut by brittle shears, but lacks penetrative foliation. Plagioclase has weak concentric zoning and is moderately altered to sericite and epidote/clinozoisite. |
| W288 | Pinkish-red, medium-grained, massive leucogranite. |
| W285 | Pink, medium-grained, inequigranular, massive leucogranite. Cut by brittle fractures, but lacks penetrative structures. |
| W305 | Pinkish-gray, medium-grained granite gneiss with a strong stretching lineation expressed by biotite-hornblende streaks. Sample is near age-sample locality 16, "Foliated tonalite, Greenwood," 1,831±7 Ma (Sims, 1990a). |
| 26–84 | Gray, fine- to medium-grained lineated granite; contains graphic intergrowths in microcline. Muscovite is an alteration product. |
| W306 | Gray, fine- to medium-grained, foliated and strongly lineated leucogranite. Rock is protomylonite. Rock is near the 1,831±7 Ma age locality. |
| W859 | Diorite, Hemlock Creek. |

### 1,835 MA ALKALI-FELDSPAR GRANITE

| | |
|---|---|
| W307B | Gray, medium-grained foliated biotite granite (alkali granite) that cuts foliated granite (W307A). Plagioclase is $An_{13-18}$. Rock is protomylonite. |
| W307A | Gray, medium-grained foliated biotite granite (alkali granite) cut by both ductile and brittle fractures. |
| W398 | Red, medium-grained massive granite containing microperthite and concentrically zoned plagioclase ($An_8$). Rock is protomylonite. |
| W394 | Red, medium-grained alkali-feldspar granite. Contains microperthite and oligoclase ($An_{10-12}$). Quartz has strain shadows and brown biotite is partly altered to chlorite. |
| W286 | Red, medium-grained alkali-feldspar granite (alkali granite). Microperthite is dominant feldspar. Biotite is altered to chlorite and opaque oxides. |
| W849 | Red alkali-feldspar granite containing alkali-feldspar and finely comminuted quartz. Rock is fractured and biotite is largely altered to opaque oxide minerals plus chlorite. Age is 1,833±4 Ma. |
| W299 | Red, coarse-grained graphic alkali-feldspar granite. Somewhat fractured. |
| W851–2 | Red granophyric granite (alkali granite). |
| SWI–8–86 | Red alkali-feldspar granite. |
| W851–1 | Diorite (tonalite), Cary Mound. |
| W851–3 | Lamprophyre(?), Cary Mound. |
| W851–4 | Diorite, Cary Mound. |

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