

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

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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 $\approx 1,836$ Ma Athelstane Quartz Monzonite, a 1,835 Ma alkali-feldspar granite, and a $\approx 1,760$ 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 $\text{Na}:\text{K} < 1$. 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 $\approx 1,760$ 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 $\text{FeO}:(\text{FeO}+\text{MgO})$

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 $\approx 1,840$ 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 \pm 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 ($\approx 1,840$ 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 $\approx 1,850$ 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) $1^\circ \times 2^\circ$ 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 : $(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$) 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).

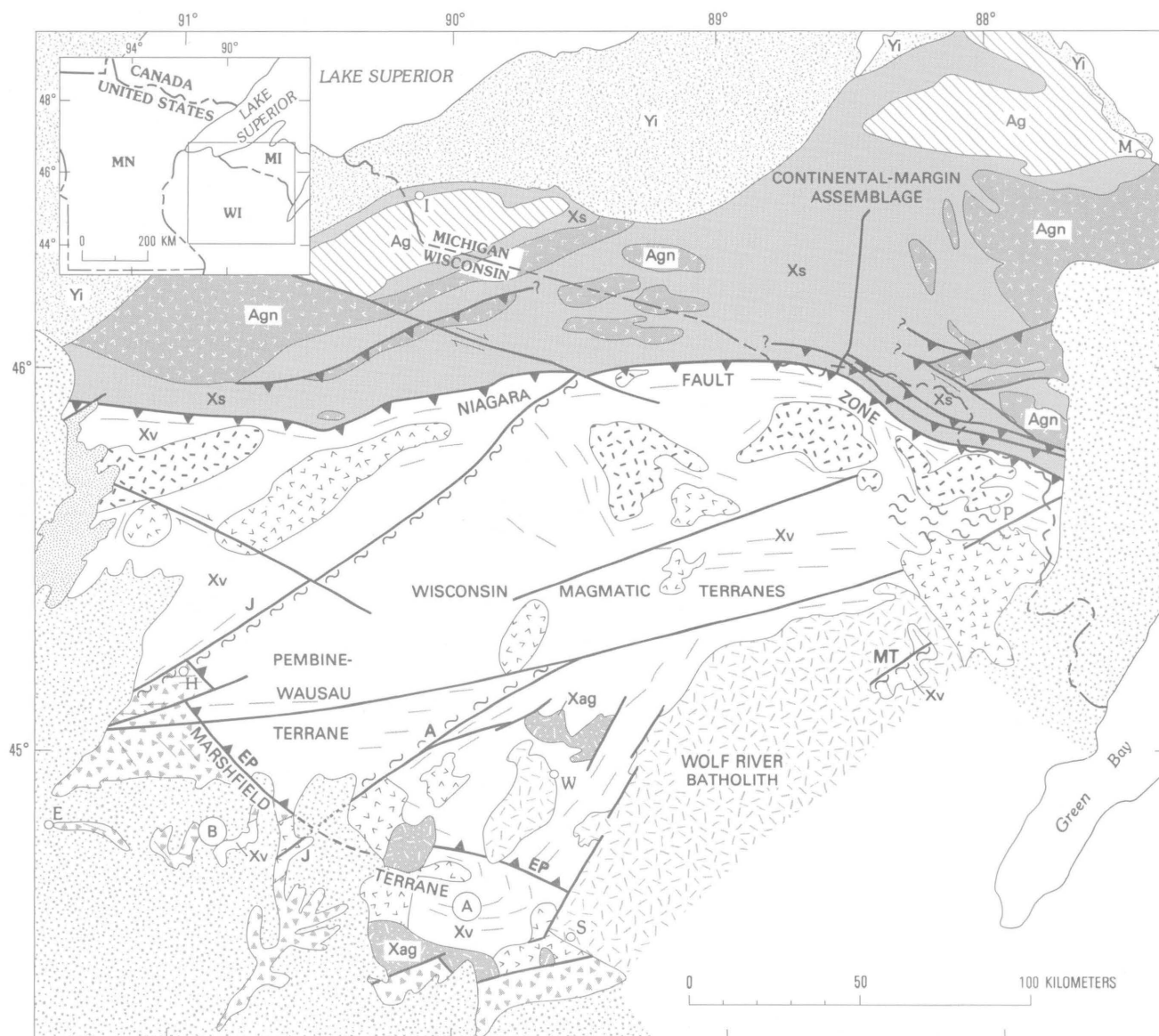
The southern, magmatic terranes are composed of Early Proterozoic calc-alkalic and tholeiitic volcanic rocks and calc-alkalic and alkali granite plutonic rocks (Sims and others, 1989). The southernmost of the magmatic terranes, the Marshfield terrane, is at least partly underlain by Archean basement 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.



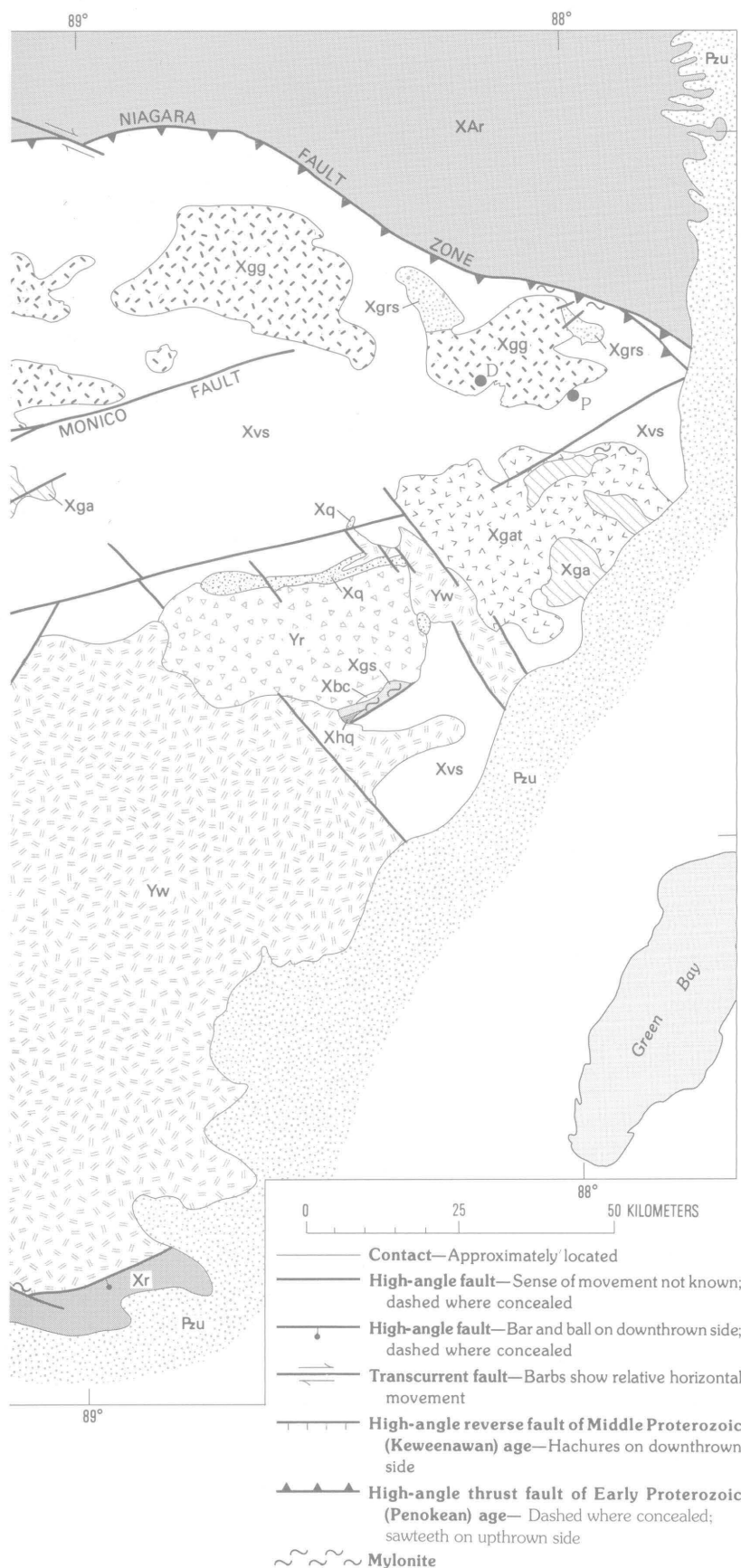
EXPLANATION

WISCONSIN MAGMATIC TERRANES		Sedimentary rocks of Paleozoic age
		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)
		Alkali-feldspar granite ($\approx 1,835$ Ma)
		Tonalite-granodiorite-granite (1,760–1,870 Ma)
		Gneiss and granitoid rocks (1,835–1,865 Ma)
CONTINENTAL- MARGIN ASSEMBLAGE		Volcanic and lesser sedimentary rocks (1,840–1,880 Ma)
		Gneiss and schist (2,800–3,000 Ma); includes tonalite (1,890 Ma)
		Marquette Range Supergroup ($\approx 1,850$ –2,100 Ma)
		Granite and greenstone (2,600–2,750 Ma)
		Gneiss (2,700–3,550 Ma)

	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.



EXPLANATION

PHANEROZOIC

- Pzu** Paleozoic rocks, undivided
- MIDDLE PROTEROZOIC (900–1,600 Ma)**
- Yk** Volcanic rocks of Keweenaw 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 ($\approx 1,515$ Ma)
- Ys** Anorogenic granitoid rocks of Stettin syenite pluton ($\approx 1,520$ Ma)

EARLY PROTEROZOIC (1,600–2,500 Ma)

- Pembine-Wausau terrane**
- Xbq** Barron Quartzite
- Xga** Granitoid rocks (1,760 Ma)
- Xhq** Hines Quartz Diorite ($1,812.7 \pm 3.6$ Ma)
- Xbc** Baldwin Conglomerate—Adjacent to Mountain shear zone
- Xgr** Alkali-feldspar granite (1,835 Ma)
- Xrg** Rhyolite and welded tuff
- Xgrs** Spikehorn Creek ($1,835 \pm 6$ Ma) and Bush Lake Granites
- Xgc** Granite near Cherokee ($1,853 \pm 21$ Ma)
- Xgat** Athelstane Quartz Monzonite ($1,836 \pm 15$ Ma)
- Xf** Felsic metavolcanic rocks ($\approx 1,835$ – $1,845$ 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 ($\approx 1,860$ Ma)
- Xv** Metavolcanic rocks in Eau Claire River valley ($\approx 1,860$ Ma)
- Xggr** Gneissic granite near Neillsville ($1,871 \pm 5$ Ma)

EARLY PROTEROZOIC AND ARCHEAN

- XAf** Fault rocks—Mylonite in Eau Pleine shear zone
- XAg** 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 $\approx 1,840$ 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 $\approx 1,835$ 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 $1,853 \pm 21$ 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 ($1,836 \pm 15$ Ma), we have assumed an age of $\approx 1,840$ 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 $\approx 1,860$ 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 km²) 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 $1,858 \pm 5$ Ma, and a subvolcanic tonalite within the Eau Pleine shear zone has a U-Pb zircon upper intercept age of $1,860 \pm 7$ 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 $1,892 \pm 9$ 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 $\approx 1,836$ 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 $\text{FeO}:(\text{FeO}+\text{MgO})$ 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 $1,846 \pm 11$ Ma (W317, analysis in table 1) and $1,838 \pm 6$ 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 $1,836 \pm 15$ Ma, 1,835 Ma alkali-feldspar granite, and $\approx 1,760$ Ma granodiorite-granite.

Athelstane Quartz Monzonite

The Athelstane Quartz Monzonite comprises a batholith of about 900 km^2 extent in northeastern Wisconsin (unit

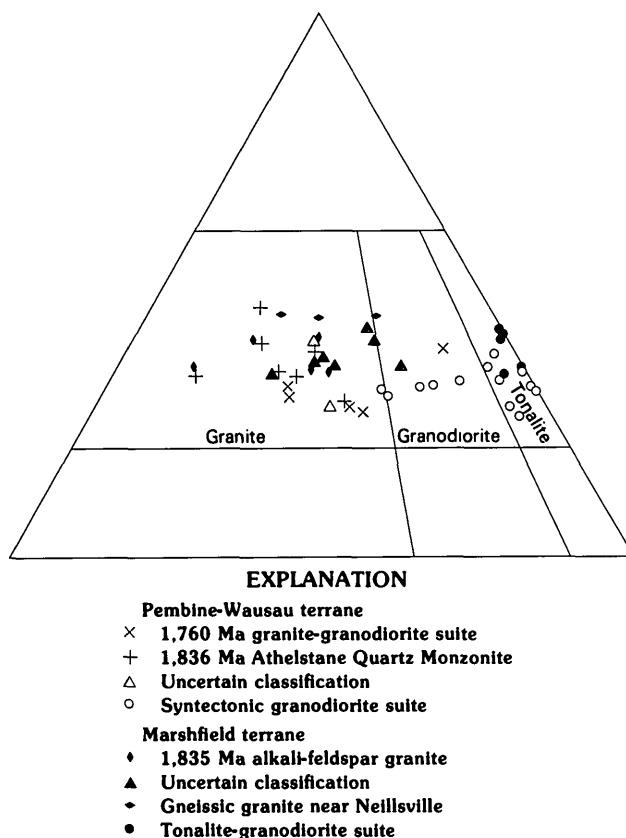


Figure 3. Quartz-alkali feldspar-plagioclase diagram showing composition of representative rocks in the Pembine-Wausau and Marshfield terranes.

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 $1,836 \pm 15$ 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 $1,853 \pm 21$ Ma (Sims, 1990a), which because of the large uncertainty is virtually indistinguishable from the $1,836 \pm 15$ 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 $\text{Na}:\text{K} < 1$. 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, H₂O, and CO₂ 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]

Sample No.---	Syntectonic granodiorite suite													Uncertain
	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 ₂ O 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 ₂ O 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 ₂ O	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 ₂ O	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 ₂ O ⁺	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 ₂ O ⁻	<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 ₂ O 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 SiO₂ 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 ($\approx 1,760$ 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 W384	1,760 Ma granodiorite-granite group					
W213	W1-1	W188	W549	W533	W556	W555		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 deuteritic alteration.

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

Sample No.---	Syntectonic granodiorite suite													Uncertain
	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.
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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

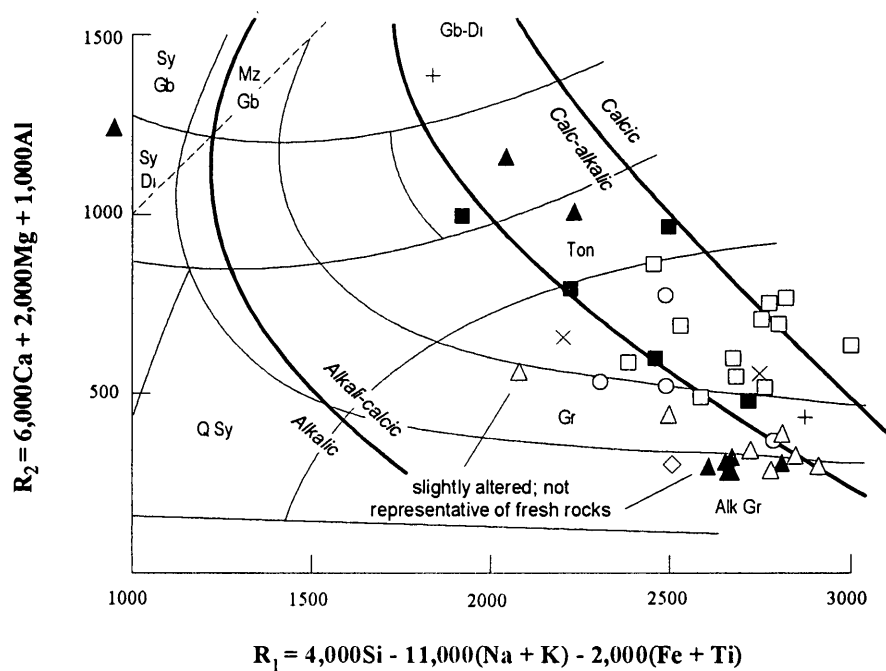
W213	Granite near Cherokee (alkali granite), NE ¹ / ₄ sec. 23, T. 28 N., R. 2 E. Age 1,853±21 Ma. Considered correlative with rocks of Athelstane batholith.
WI-1	Granite, sec. 23, T. 39 N., R. 6 W. Similar chemically to Athelstane Quartz Monzonite.
W188	Athelstane Quartz Monzonite (alkali granite), NE ¹ / ₄ sec. 15, T. 34 N., R. 19 E.
W549	Athelstane Quartz Monzonite (alkali granite), NE ¹ / 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), SW ¹ / ₄ sec. 13, T. 35 N., R. 20 E.
W555	Athelstane Quartz Monzonite (alkali granite), SW ¹ / 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.
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1,760 MA GRANODIORITE-GRANITE GROUP

W12B	Granite near Amberg, NE ¹ / ₄ SE ¹ / ₄ sec. 9, T. 35 N., R. 20 E. Age 1,752±8 Ma.
SPB-232-39	Granite near Amberg, NW ¹ / ₄ SW ¹ / ₄ sec. 31, T. 36 N., R. 21 E.
W54	Granodiorite (granite) near Lugerville, SW ¹ / 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, SW ¹ / ₄ sec. 6, T. 35 N., R. 11 E. Age 1,739±8 Ma.
W252	Granodiorite near Radisson, NE ¹ / ₄ sec. 22, T. 38 N., R. 7 W. Age 1,765±6 Ma.



EXPLANATION

- | Marshfield terrane | Pembine-Wausau terrane |
|------------------------------------|------------------------------------|
| ▲ 1,835 Ma alkali-feldspar granite | △ Athelstane Quartz Monzonite |
| ■ Syntectonic granodiorite | □ Syntectonic granodiorite |
| + Uncertain affinity | × Uncertain affinity |
| | ○ 1,760 Ma granodiorite-granite |
| | ◇ 1,835 Ma alkali-feldspar granite |

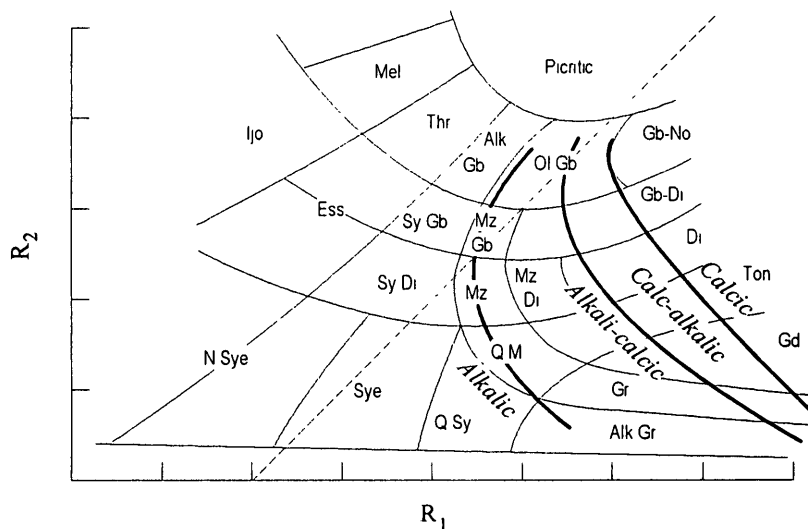
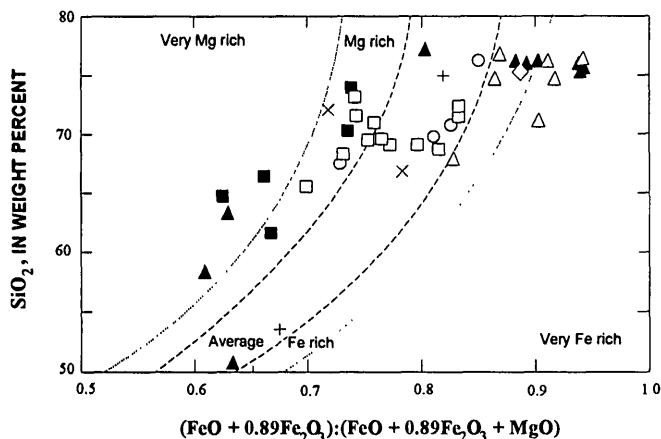


Figure 4. Classification of granitoid rocks, Pembine-Wausau and Marshfield terranes (modified from DeLaRoche and others, 1980). Classification of plutonic rocks: Gb-No, gabbro-norite; Ol Gb, olivine gabbro; Alk Gb, alkali gabbro; Thr, theralite; Mel, melteigite; Gb-Di, gabbro-diorite; Mz Gb, monzogabbro; 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.



EXPLANATION

Marshfield terrane

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

Pembine-Wausau terrane

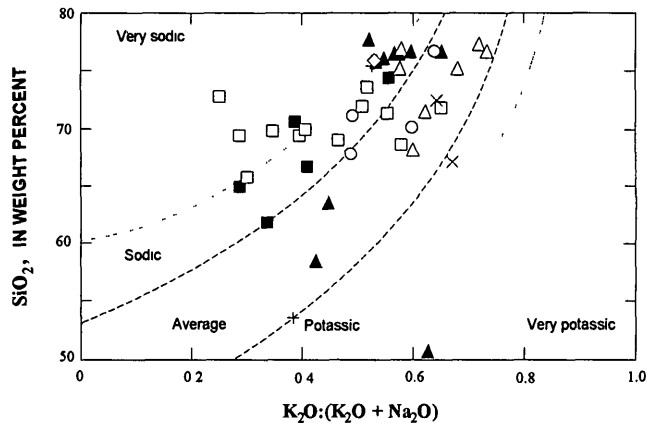
- △ Athelstane Quartz Monzonite
- Syntectonic granodiorite
- × Uncertain affinity
- 1,760 Ma granodiorite-granite
- ◇ 1,835 Ma alkali-feldspar granite

Figure 5. SiO_2 versus $(\text{FeO} + 0.89 \text{ Fe}_2\text{O}_3) : (\text{FeO} + 0.89 \text{ Fe}_2\text{O}_3 + \text{MgO})$ 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 $\text{FeO} : \text{FeO} + \text{MgO}$ (>0.80), $\text{Na}_2\text{O} : \text{K}_2\text{O}$ (<1.0), $\text{Ba} : \text{Sr}$ (>3.0), and $\text{K} : \text{Rb}$ (>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 ($1,752 \pm 8$ 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



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 6. SiO_2 versus $\text{K}_2\text{O} : (\text{K}_2\text{O} + \text{Na}_2\text{O})$ diagram (modified from DeWitt, 1989) showing compositions of plutonic rocks in Pembine-Wausau and Marshfield terranes.

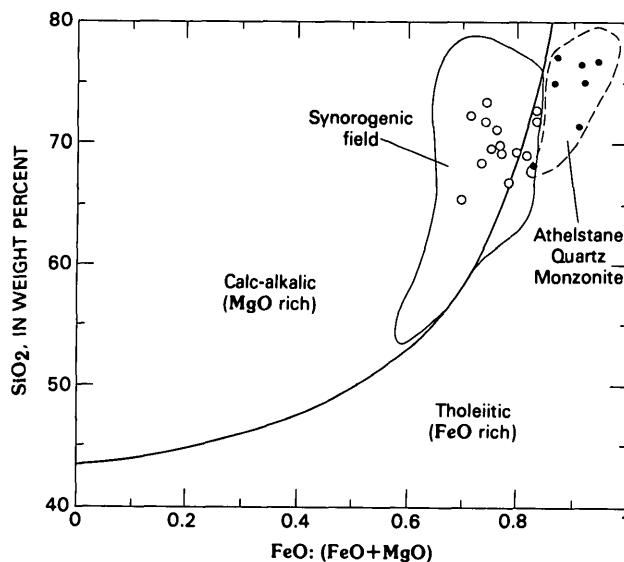


Figure 7. $\text{FeO} : (\text{FeO} + \text{MgO})$ versus SiO_2 diagram for the syntectonic granodiorite suite (open circles) and rocks of the post-tectonic Athelstane Quartz Monzonite (solid dots), Pembine-Wausau terrane. Synorogenic field of Anderson (1983) for Penokean granitoid rocks in Wisconsin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

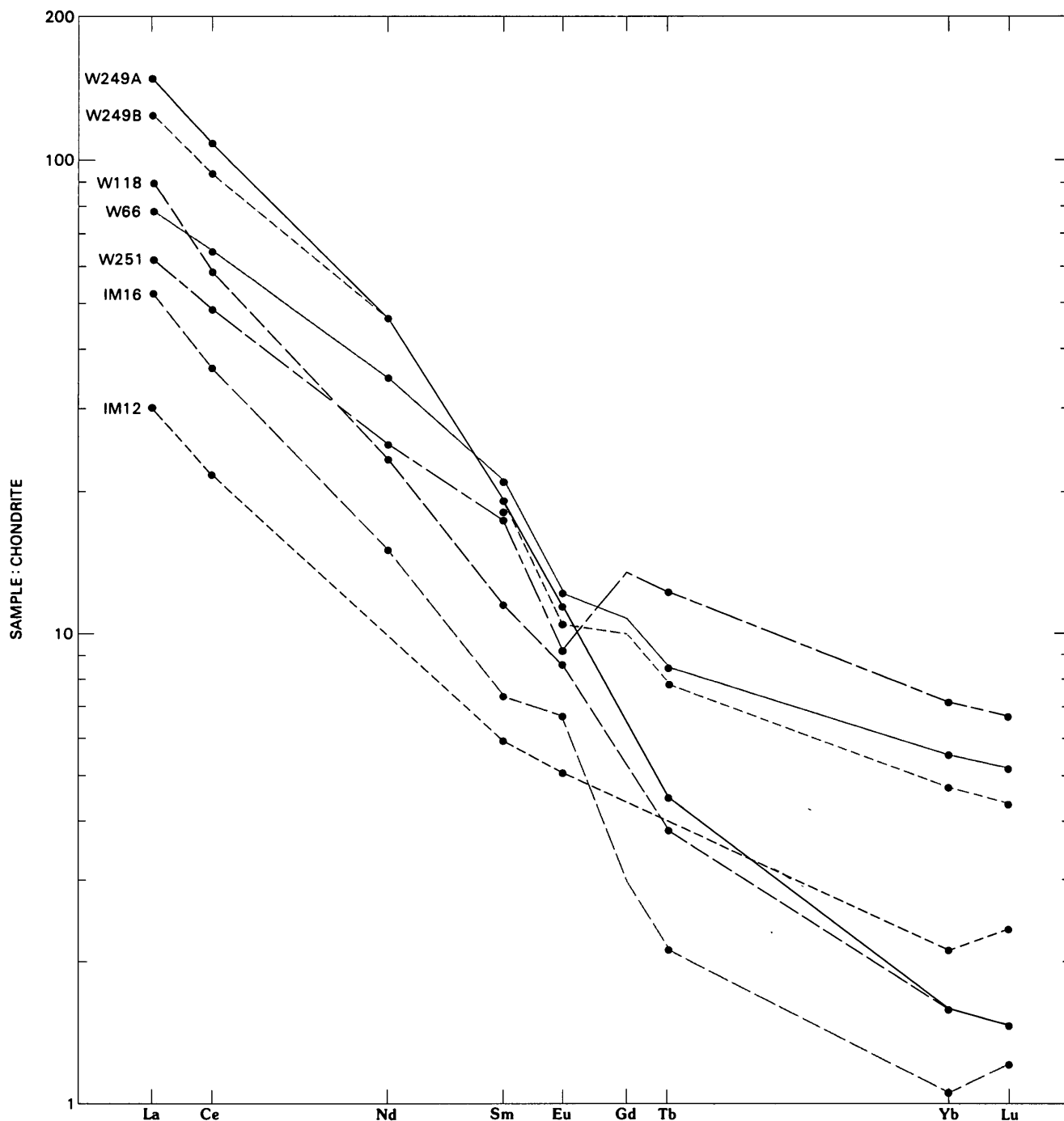


Figure 8. Chondrite-normalized REE plots for syntectonic granodiorite suite, Pembine-Wausau terrane. Analyses given in table 1. Gd, no data.

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

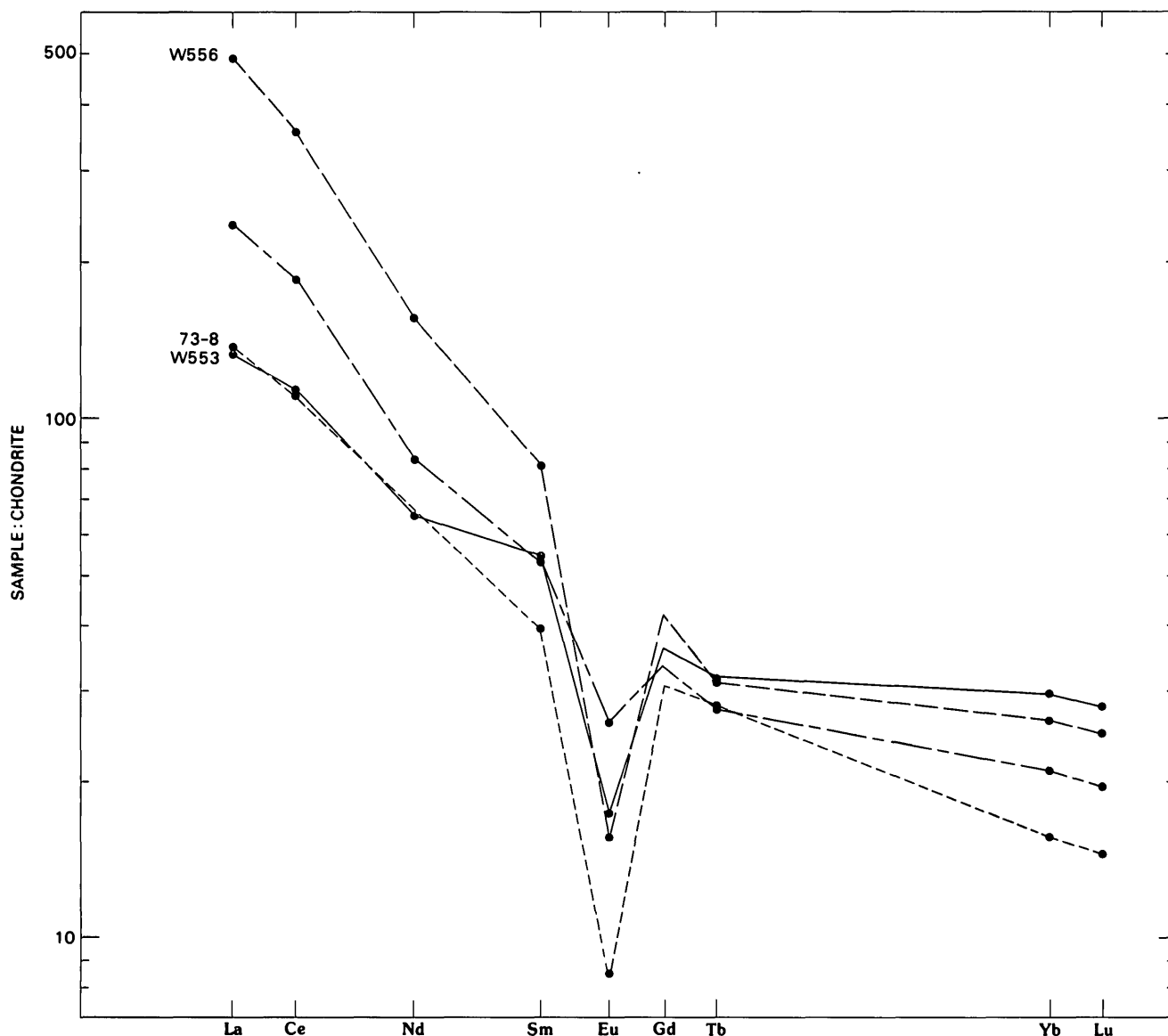


Figure 9. Chondrite-normalized REE plots for samples of Athelstone Quartz Monzonite, Pembine-Wausau terrane. Analyses given in table 1. Gd, no data.

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

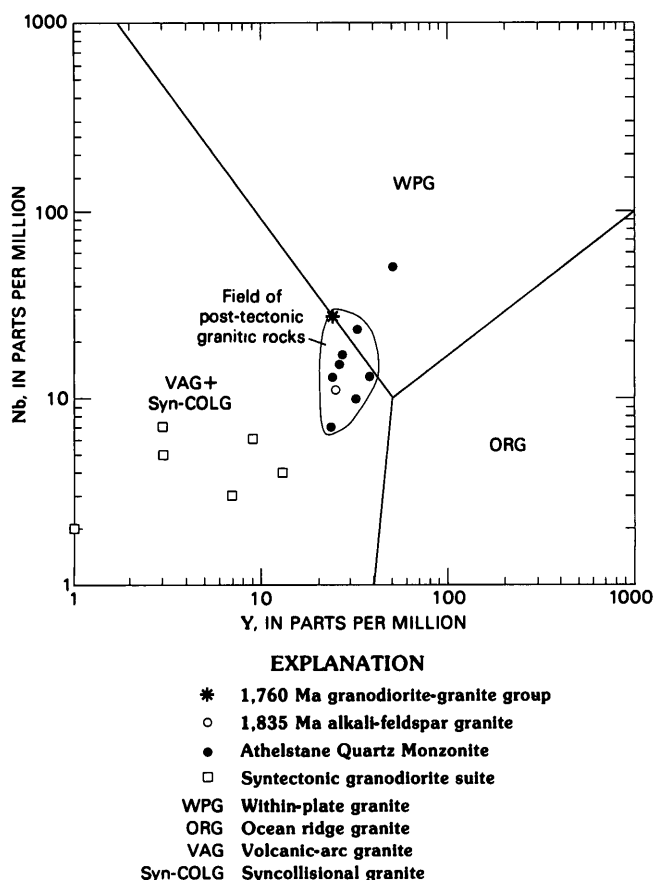


Figure 10. Nb versus Y diagram (modified from Pearce and others, 1984) for granitoid rocks in the Pembine-Wausau terrane. Excludes Dunbar area (Sims and others, 1992).

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 "lensepod" 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.

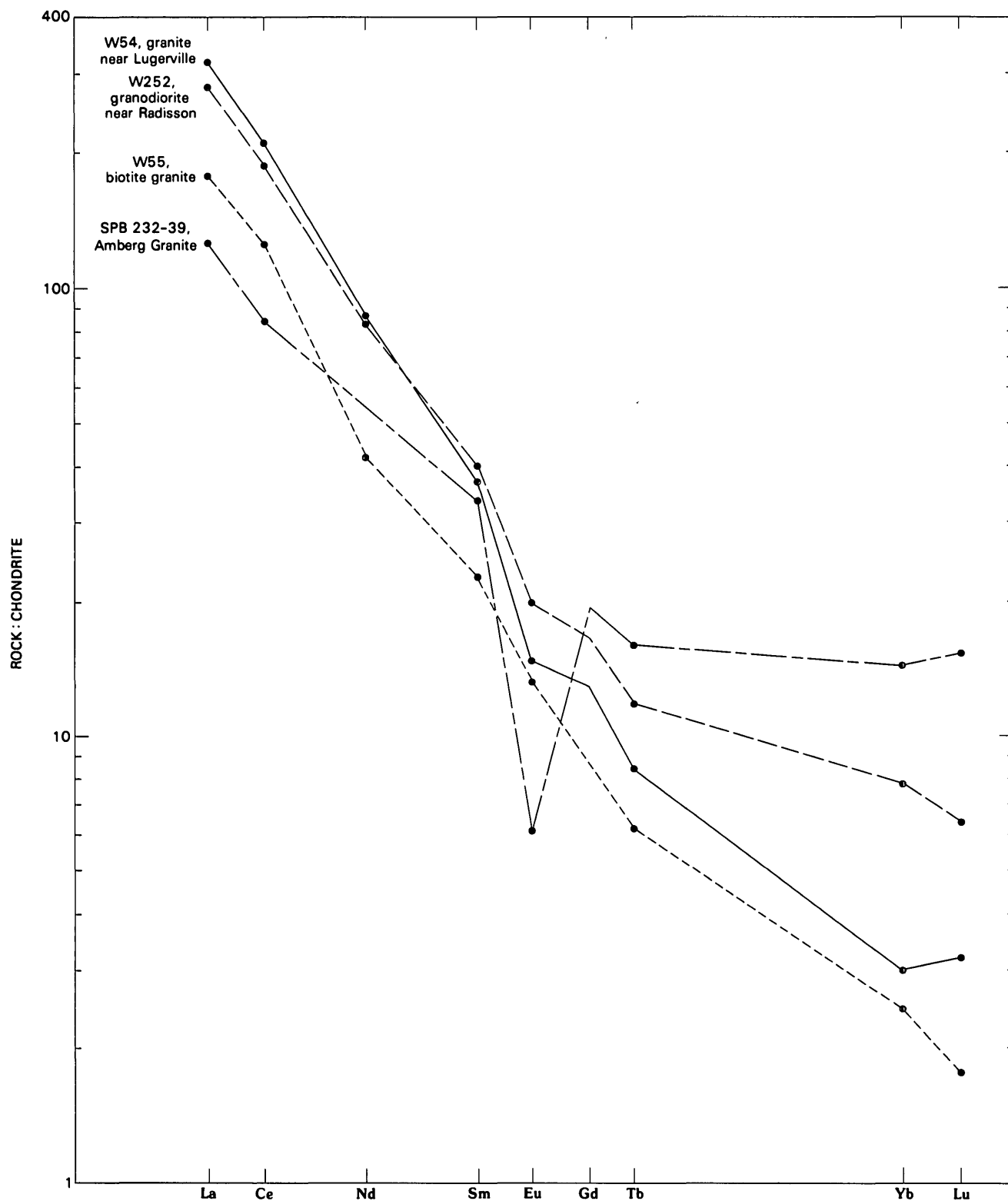


Figure 11. Chondrite-normalized REE plots for samples of 1,760 Ma granodiorite-granite group. Gd, no data.

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, H₂O, and CO₂ 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 ₂ O ₃	17.5	15.7	16.2	---	---	---	15.4	13.8	---	---	---	---	---	---	---	---	---	13.1	15.9
Fe ₂ O 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 ₂ O	4.35	4.1	3.86	---	---	---	4.33	3.4	---	---	---	---	---	---	---	---	---	3.43	2.90
K ₂ O	2.18	2.8	1.54	---	---	---	2.70	4.2	---	---	---	---	---	---	---	---	---	3.76	1.78
H ₂ O ⁺	0.78	0.57		---	---	---	0.41	0.60	---	---	---	---	---	---	---	---	---	0.18	} 1.42
H ₂ O ⁻	0.02	0.19	1.18	---	---	---	0.03	0.23	---	---	---	---	---	---	---	---	---	<0.01	
TiO ₂	0.55	0.48	0.42	---	---	---	0.32	0.16	---	---	---	---	---	---	---	---	---	0.18	1.04
P ₂ O 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 ₂ O ₃	12.0	11.6	---	---	12.2	11.9	11.8	11.7	12.2	15.8	14.9	14.9
Fe ₂ O 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 ₂ O	3.38	3.46	---	---	3.06	3.79	3.76	3.55	3.45	3.43	2.97	3.12
K ₂ O	4.37	3.71	---	---	5.64	4.53	4.26	4.75	5.03	2.74	4.9	2.28
H ₂ O ⁺	0.22	0.31	---	---	0.23							
H ₂ O ⁻	0.02	<0.01	---	---	0.03	0.35	0.60	0.33	0.50	0.29	1.29	1.15
TiO ₂	0.19	0.16	---	---	0.18	0.12	0.15	0.14	<0.08	0.58	0.91	0.99
P ₂ O 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, SE¼ NW¼ 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, SW¼ NE¼ 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

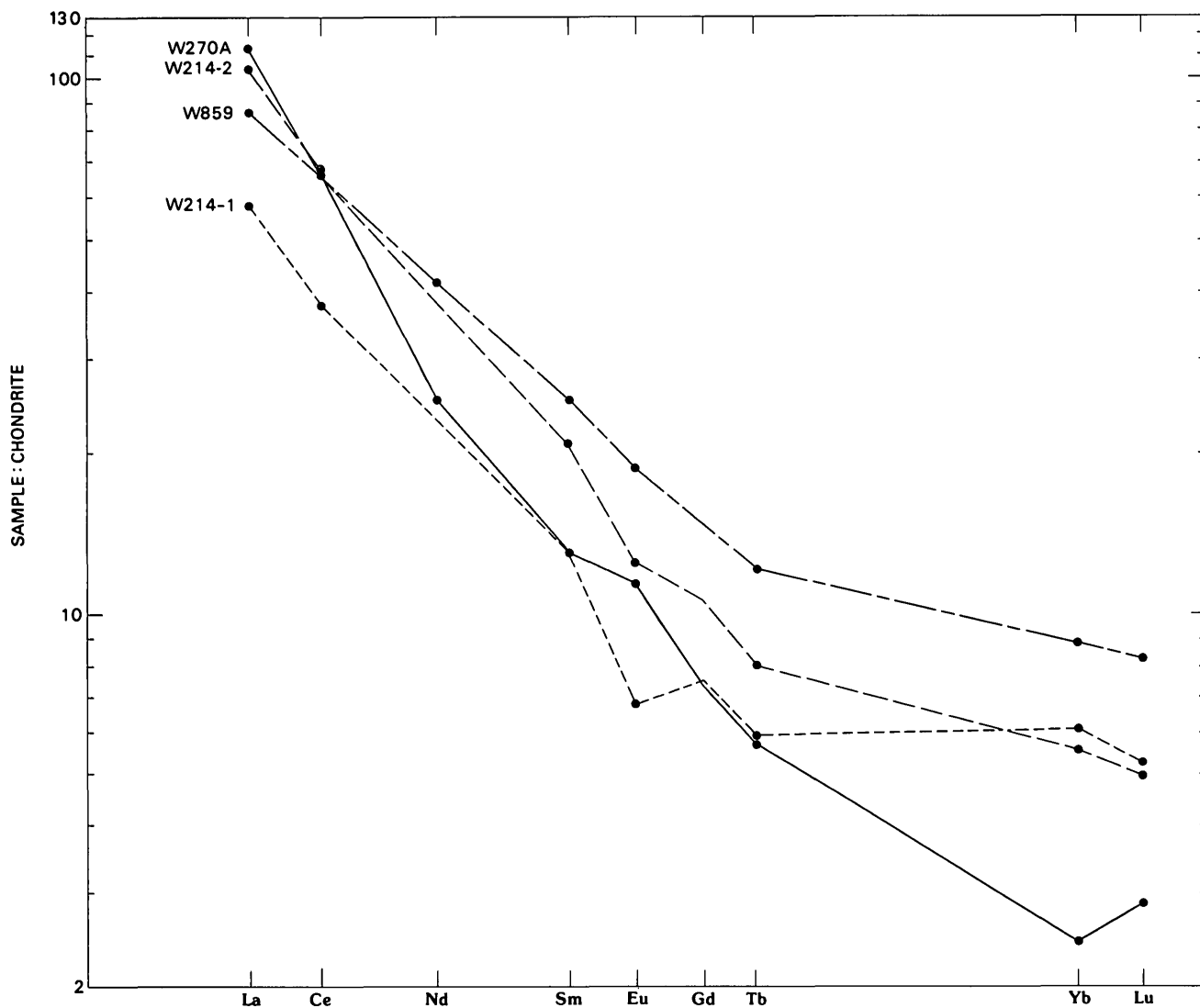


Figure 12. Chondrite-normalized REE plots for samples of syntectonic granodiorite suite, Marshfield terrane. Analyses given in table 2. Gd, no data.

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 $1,871 \pm 5$ 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 micropertitic (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

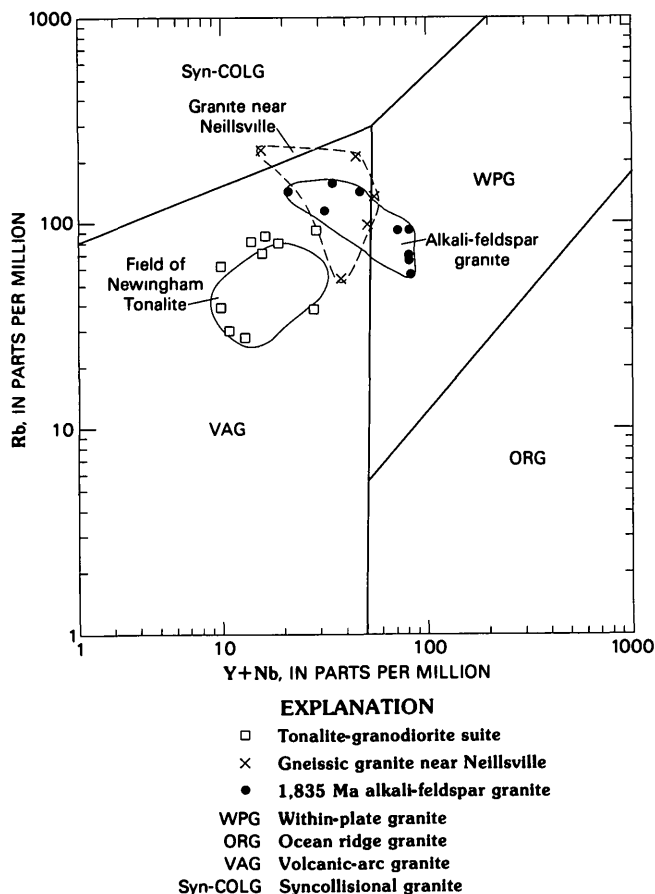


Figure 13. Rb versus Y+Nb diagram (modified from Pearce and others, 1984) showing granitoid rocks of the Marshfield terrane. Field of Newingham Tonalite modified from Sims and others (1992).

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 $1,833 \pm 4$ Ma, and a sample from Black River Falls (Br, fig. 2) has an upper intercept age of $1,835 \pm 6$ 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 $\approx 1,852$ 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

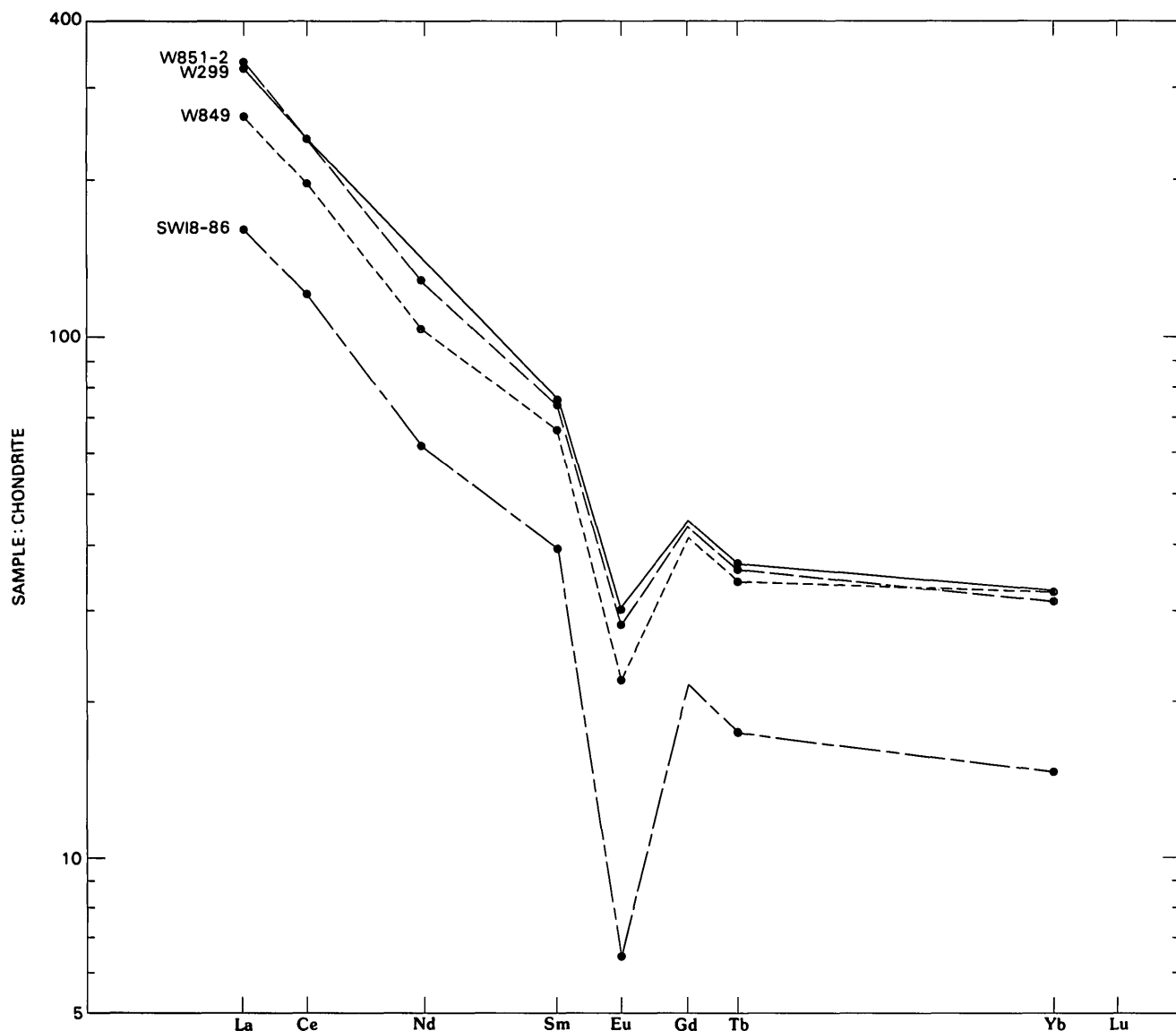


Figure 14. Chondrite-normalized REE plots for samples of red alkali-feldspar granite, Marshfield terrane. Gd, no data.

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 $\epsilon_{Nd}(T)$ values, from -4.5 to $+4.0$; the authors noted that the more negative $\epsilon_{Nd}(T)$ 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).

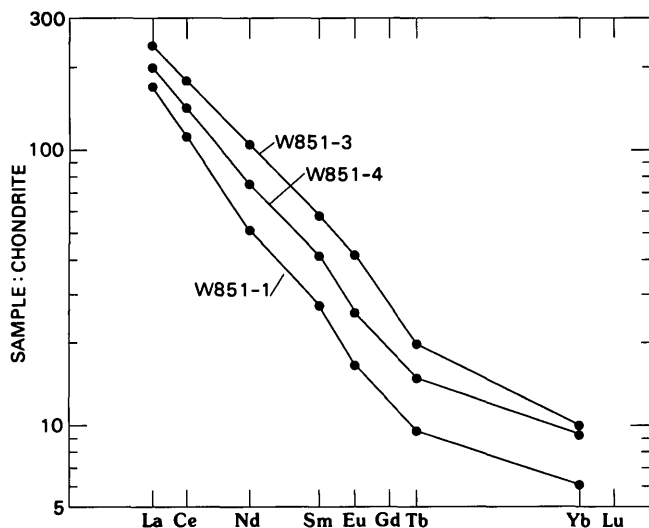


Figure 15. Chondrite-normalized REE plots for samples of diorite and lamprophyre associated with alkali-feldspar granite, Marshfield terrane. Gd, no data.

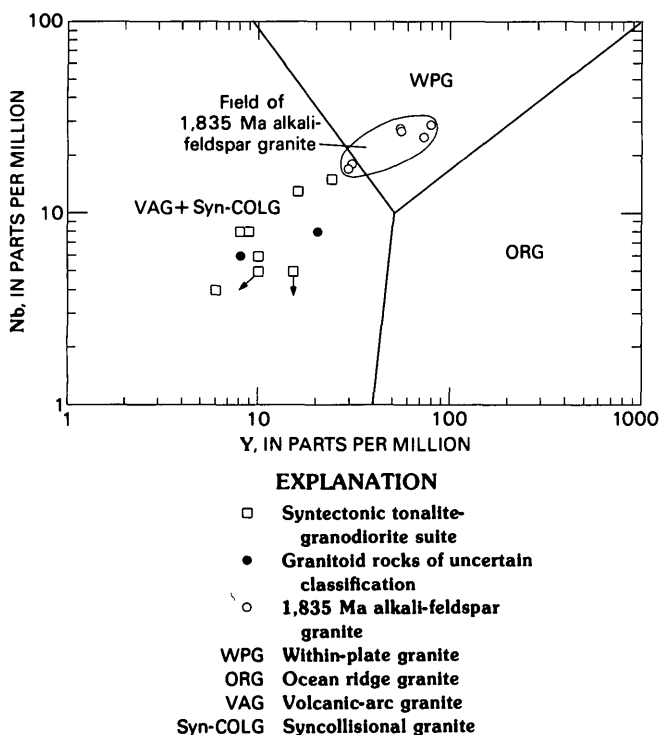


Figure 16. Nb versus Y diagram (modified from Pearce and others, 1984) showing granitoid rocks of the Marshfield terrane. Arrows indicate less than values shown.

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

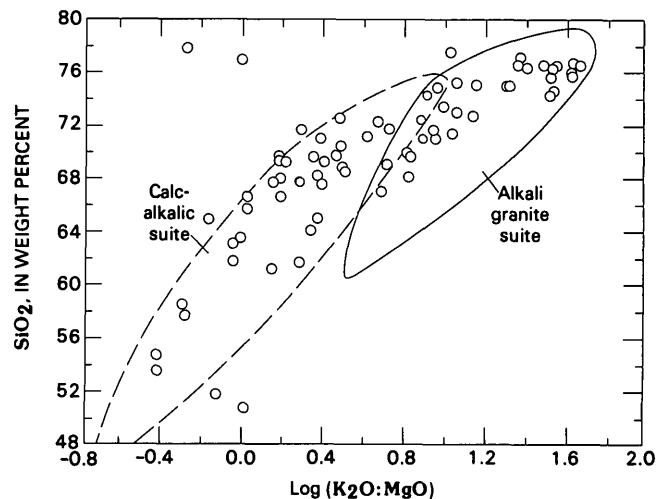


Figure 17. SiO_2 versus $\log_{10} (\text{K}_2\text{O}:\text{MgO})$ diagram showing distinction between calc-alkalic and alkali granite suites in Wisconsin magmatic terranes (modified from Greenberg, 1980). Includes samples from the Dunbar, Wis., area (Sims and others, 1992).

within-plate compositions (for example, Early Proterozoic basalt of the Marquette Range Supergroup). In this model, the negative $\epsilon_{\text{Nd}}(\text{T})$ 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 $\epsilon_{\text{Nd}}(\text{T})$ 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.

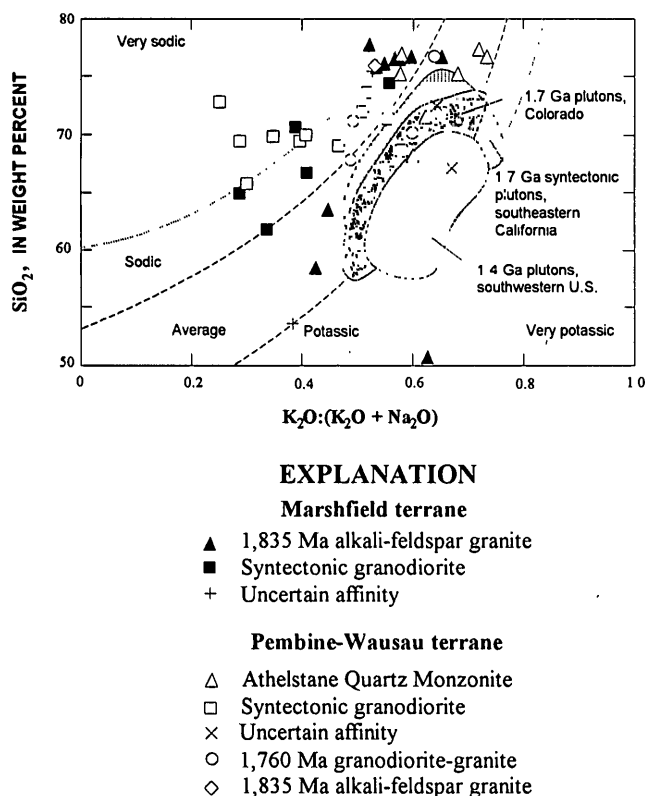


Figure 18. SiO_2 versus $\text{K}_2\text{O}/(\text{K}_2\text{O}+\text{Na}_2\text{O})$ diagram showing comparison of compositions of plutonic rocks in Pembine-Wausau and Marshfield terranes with those in Proterozoic terranes in Colorado, southeastern California, and southwestern United States. Plutonic 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 Claire 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 Claire 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 $\approx 1,850$ 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 $\approx 1,850$ 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 $\approx 1,890$ to $\approx 1,500$ 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.

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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

IM16

W319A

W325

W66

W249B

W249A

W251

W118

W205B

W317

leucogranite dike with cataclastic foliation expressed by oriented muscovite.

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.

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.

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.

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.

Pinkish-gray, medium- to coarse-grained, foliated granodiorite. Plagioclase (An_{20–25}) has weak normal concentric zoning and is myrmekitic adjacent to potassium feldspar.

Light-olive-green, medium-grained granodiorite (tonalite). Plagioclase has strong concentric zoning. Potassium feldspar is interstitial. Epidote has replaced biotite.

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.

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.

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.

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, NW¹/₄SW¹/₄ 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.	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).
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.	26-84	Gray, fine- to medium-grained lineated granite; contains graphic intergrowths in microcline. Muscovite is an alteration product.
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.	W306	Gray, fine- to medium-grained, foliated and strongly lineated leucogranite. Rock is protomylonite. Rock is near the 1,831±7 Ma age locality.
W214-1	Same as W283A.	W859	Diorite, Hemlock Creek.
1,835 MA ALKALI-FELDSPAR GRANITE			
	GRANITE NEAR NEILLSVILLE	W307B	Gray, medium-grained foliated biotite granite (alkali granite) that cuts foliated granite (W307A). Plagioclase is An ₁₃₋₁₈ . Rock is protomylonite.
W309C	Same as W390, but granodiorite in composition.	W307A	Gray, medium-grained foliated biotite granite (alkali granite) cut by both ductile and brittle fractures.
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.	W398	Red, medium-grained massive granite containing microperthite and concentrically zoned plagioclase (An ₈). Rock is protomylonite.
21-84	Same as W390, but entirely recrystallized to average grain size of about 0.5 mm.	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.
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.	W286	Red, medium-grained alkali-feldspar granite (alkali granite). Microperthite is dominant feldspar. Biotite is altered to chlorite and opaque oxides.
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.	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.
W288	Pinkish-red, medium-grained, massive leucogranite.	W299	Red, coarse-grained graphic alkali-feldspar granite. Somewhat fractured.
W285	Pink, medium-grained, inequigranular, massive leucogranite. Cut by brittle fractures, but lacks penetrative structures.	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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