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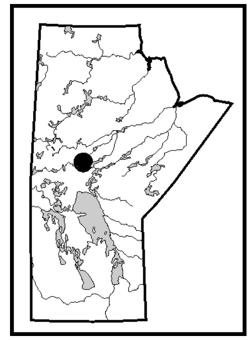
GS-16 Field relations, U-Pb zircon ages and Nd model ages of granitoid intrusions along the Thompson Nickel Belt–Kisseynew Domain boundary, Setting Lake area, Manitoba (NTS 63J15 and 63O2)



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Summary

New field observations and seven preliminary U-Pb zircon ages with Sm-Nd isotope data from granitoid intrusions in the Setting Lake area suggest that several episodes of felsic magmatism have occurred at the northwest margin of the Thompson Nickel Belt. About 1870 to 1880 Ma, much earlier than anticipated in previous tectonic models, melts of predominately Archean basement gneiss and/or its cover intruded Paleoproterozoic, rift-related mafic rocks along the margin of the Kisseynew Domain. These plutons, with Nd crustal residence ages (T_{CR}) of 2.7 to 2.9 Ga, imply the presence of Archean rocks in the crust where these are unexpected. About 1835 Ma, more juvenile (T_{CR} = 2.4 Ga), potassium-rich plutons were intruded across the boundary into rocks that must had been juxtaposed during collision between the Superior Craton and the internides of Trans-Hudson Orogen, earlier than previously speculated. Leucogranitoid bodies with high Archean inheritance (T_{CR} = 2.7–3.3 Ga) that are probably collision related may have a protracted history of intrusion, possibly starting at ca. 1850 Ma and continuing to (or recurring during) the 1820 Ma beginning of high-grade regional metamorphism. The inferred presence of Archean crust along the margin of the Kisseynew Domain may expand the geographic limits for effective nickel exploration.

Introduction

The structurally complex boundary zone between the Thompson Nickel Belt (TNB) and the Kisseynew Domain is locally heavily intruded by Paleoproterozoic granitoid plutons. The bodies are hosted by Archean basement migmatite and Ospwagan Group cover rocks in the southeast, and by juvenile Paleoproterozoic paragneiss and amphibolite in the west. The intrusive relationships to the host rocks are complicated by the effects of continental collision, such that newly acquired crystallization ages have furnished a few surprises, leading to remapping of some areas in the summer of 2003. The Paleoproterozoic granitoid plutons have been studied mainly in the Setting Lake area, where they have a wide range of compositions and constitute nearly half the bedrock (Fig. GS-16-1).

Preliminary Sm-Nd isotope work (CAMIRO Project 97E-02) suggested that the plutons vary from juvenile Paleoproterozoic to nearly wholesale melts of Archean crust. The structural style of the plutons varies from migmatitic and highly gneissic to locally massive, and indicates that plutonism occurred at various stages of a protracted history of deformation (Zwanzig, 1998). The ages of crystallization acquired during this study can help to establish a new timeframe for the tectonic history, but the discordance of much of the U-Pb zircon data and abundance of inherited and metamorphic zircon grains require further testing of the ages. This report provides a preliminary subdivision of the granitoid plutons based on the new age data and crustal or mantle origin inferred from the Sm-Nd data, aspects that may require rethinking of the crustal evolution of this part of the Superior Boundary Zone.

Field relations

The field relations between the granitoid plutons and their host rocks at Setting Lake were established during 1:25 000-scale mapping (Albino and Macek, 1981a, b). Subsequently, the maps were modified and extended (Thompson Nickel Belt Geology Working Group, 2001), and the stratigraphy revised to suggest that most of the plutons intruded the Grass River Group, the youngest sedimentary unit in the area. The general geology of the Setting Lake area is outlined in Figure GS-16-1 and described in Zwanzig (1997, 1998, 1999).

The southeastern part of the area is underlain by Archean basement of predominantly orthogneiss and multicomponent migmatite containing structural keels of the unconformably overlying Ospwagan Group of rift to continental-terrace sedimentary deposits and upper mafic volcanic rocks and sills (Bah Lake assemblage). These basement and

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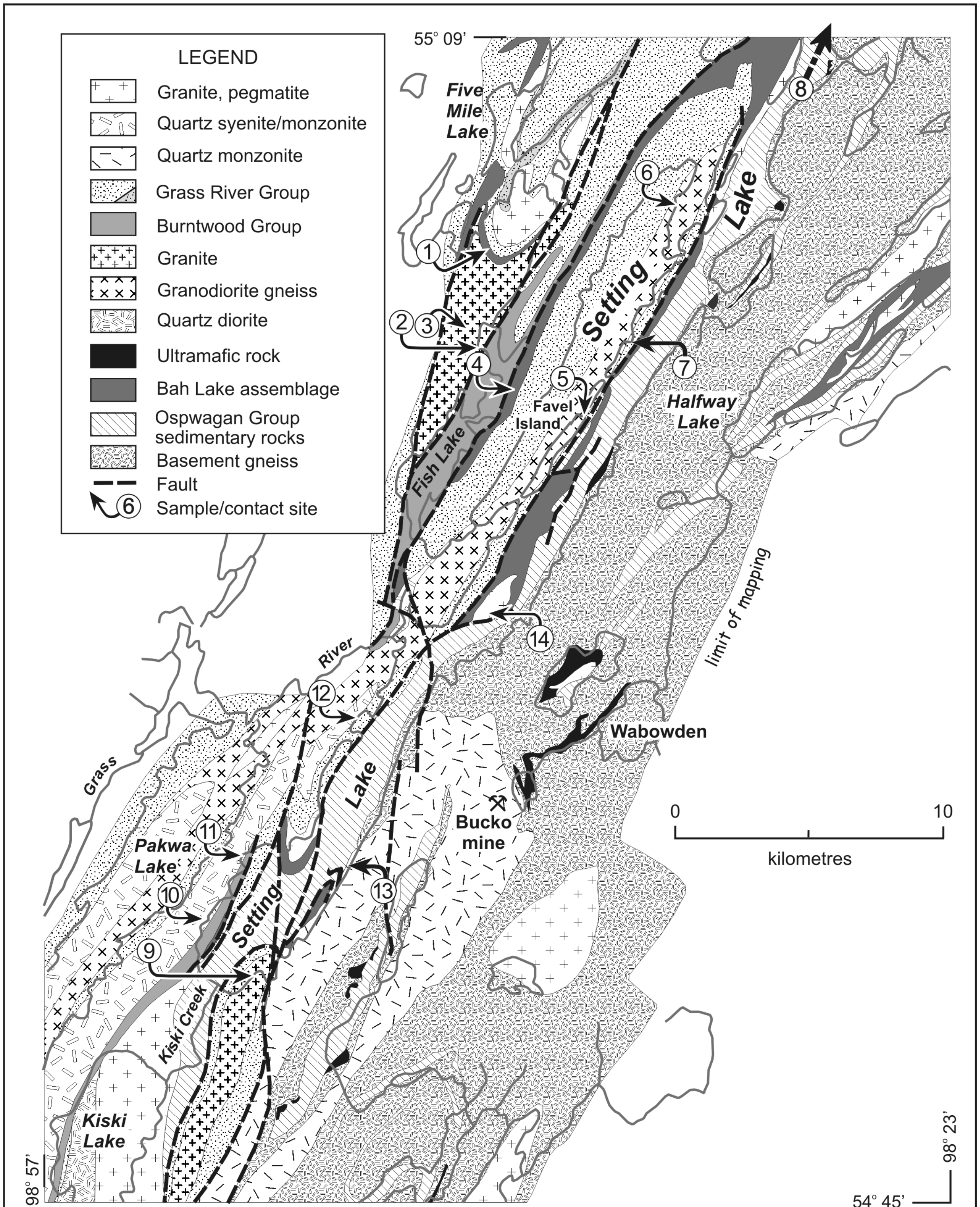

Figure GS-16-1: Simplified geology of parts of the Thompson Nickel Belt and Kisseynew Domain, Setting Lake area (modified after Thompson Nickel Belt Geology Working Group, 2001), showing the sampling sites and key contact locations discussed in the text.

supracrustal rocks are intruded by the Bucko quartz monzonite southwest of Wabowden and by a similar pluton southeast of Halfway Lake. The regional structure (Zwanzig, 1999) suggests that the shape of the Bucko pluton represents the mantle of a steeply east-plunging dome or sheath fold with structurally overlying basement gneiss and a window of deeper level basement gneiss and Ospwagan Group in the core. Foliations suggest that the pluton was flattened into a sheet-like body before doming. Smaller plutons of leucogranite, on the other hand, are locally massive.

The transition zone between the TNB and the Kisseynew Domain extends along Kiski and Pakwa lakes and along the northwest side of Setting Lake. This zone is characterized by a basal conglomerate facies in the Grass River Group, which has been interpreted to lie unconformably on the Bah Lake assemblage (Zwanzig, 1998). The lithology, internal stratigraphy, bedding characteristics, detrital zircon spectrum (Machado, unpublished data, 2000) and Nd model ages (Zwanzig and Böhm, unpublished data, 2002) of the Grass River Group (Zwanzig, 1997) suggest correlation with the Missi and Sickle groups, which were probably deposited from 1.85 to 1.83 Ga (e.g., Machado et al., 1999). The anticlinal core of this zone is occupied by a highly elongate complex of granodiorite gneiss that is mantled by elongate potassium-feldspar–phyric plutons of quartz monzonite and quartz syenite to monzodiorite between Pakwa Lake and Setting Lake (Fig. GS-16-1). An early syncline, developed in the Grass River Group, has been refolded by the elongate anticline. The syncline was tightly appressed, sheared and faulted on the southeast side of the anticline in the Setting Lake fault zone. Although the plutons in the complex have been interpreted to be intrusive into the Grass River Group, only the potassic bodies have recognizable intrusive contacts. The contact between the granodiorite gneiss and the Grass River Group northwest of Favel Island is unexposed but assumed from magnetic maps. Shearing and ductile-brittle faulting have obscured the contact in the east (e.g., east side of Favel Island in Fig. GS-16-1). A visit to this area during low water this summer (2003) has confirmed the presence of conglomerate along the sheared contact, locally above a lens of amphibolite that is probably Bah Lake assemblage. Like elsewhere, this contact may be a sheared unconformity at the base of the Grass River Group.

The area extending from Fish Lake north beyond Five Mile Lake features paragneiss and migmatite derived from Burntwood Group greywacke and Grass River Group arenite, typical of the Kisseynew Domain. Nevertheless, amphibolite, some with remnant pillow structure like that in the Bah Lake assemblage, adjoins the Grass River Group, as at Setting Lake. The granite plutons in this area have been assumed to intrude the Grass River Group, and remapping has confirmed this relation for biotite granite on Five Mile Lake. Remapping of parts of the Fish Lake porphyroclastic granite, however, has shown that this pluton contains a local roof zone and inclusions of Bah Lake–type amphibolite. This zone is overlain by a 0.4 m thick unit of basal quartzite, 6 m of garnet-biotite pelite grading up into metagreywacke and meta-arenite, and then typical arkosic arenite of the Grass River Group with 1 m of hornblende-bearing arenite near the base (*see* location (1) in Fig. GS-16-1). The garnet-biotite pelite is a distinctive unit that also occurs between the amphibolite and Grass River Group on Five Mile Lake. The quartzite and garnet-biotite pelite are interpreted to form the base of the Grass River Group in a distal, conglomerate-free facies, and the contact with the amphibolite is probably an unconformity. Elsewhere, the Fish Lake granite has highly sheared or unexposed contacts with the Grass River and Burntwood groups.

U-Pb zircon ages and Nd model ages

Sources of data and methods

During mapping between 1997 and 2000, unaltered, uniform, 0.5 to 3 kg samples were collected for geochemical work and a few specimens were collected for Sm-Nd isotope work. The samples were processed at the University of Saskatchewan under the auspices of CAMIRO Project 97E-02. During 2002, samples 12-02-610 and 12-02-9001 to -9004 were collected from outcrops and from diamond-drill core for collaborative Sm-Nd isotope work with R. Creaser at the Department of Earth and Atmospheric Sciences, University of Alberta (Table GS-16-1). Calculations were made of Nd model ages of crustal residence (T_{CR}) or the time of separation from the mantle, the rationale for which is briefly described in Zwanzig and Böhm (2002) and references therein.

Relatively unaltered and homogeneous samples, 15 to 35 kg in weight, were collected for U-Pb zircon, monazite and titanite dating, variously by some of the authors and J. Macek during 1990, 1994 and 1997–2002. Seven samples were processed during 2001 and 2002 (Table GS-16-1). All sample preparation, mineral separation, chemical treatment and mass spectrometry were carried out using the facilities in the GEOTOP laboratory at Université du Québec à Montréal (UQAM), except for samples 12-02-610 and 12-02-9005, which were processed and analyzed under collaborative contract at the Department of Earth and Atmospheric Sciences, University of Alberta. Zircons processed at GEOTOP were carefully observed under a binocular microscope in order to select preferably the mineral grains devoid of fractures, inclusions and other imperfections. Because only a few grains with these characteristics were found

Table GS-16-1: Geological and analytical details for the samples from the Setting Lake area.

Sample	Location	Unit	Sm-Nd iso-tope work	U-Pb age	Laboratory
12-98-551-5	(4)	Bah Lake assemblage	x		U. of Sask.
12-98-552-1	(4)	Bah Lake assemblage	x		U. of Sask.
12-02-9005	(2)	Fish Lake granite		x	U. of Alberta
12-99-915-1	(3)	Fish Lake granite	x		U. of Sask.
12-97-99-1	(5)	Favel Island complex	x		U. of Sask.
90.8	(6)	Favel Island complex		x	GEOTOP
12-02-9001	(6)	Favel Island complex	x		U. of Alberta
12-02-9002	(6)	Favel Island complex	x		U. of Alberta
TB 20-59A	(9)	Kiski Creek granite		x	GEOTOP
12-98-624-1	(9)	Kiski Creek granite	x		U. of Sask.
90.1	(10)	Southwest Setting intrusion		x	GEOTOP
12-97-34-3A	(10)	Southwest Setting intrusion	x		U. of Sask.
12-97-122-2	(7)	Dike in Grass River Gp.	x		U. of Sask.
12-02-610	(8)	Late-kinematic intrusion		x	U. of Alberta
12-02-610	(8)	Late-kinematic intrusion	x		U. of Alberta
12-02-9003	(14)	Late-kinematic intrusion		x	GEOTOP
12-02-9003	(14)	Late-kinematic intrusion	x		U. of Alberta
90.2	(10)	Late-kinematic intrusion		x	GEOTOP
12-97-258-1	(11)	Late-kinematic intrusion	x		U. of Sask.

in each sample, some of the analyses had to be carried out on grains with red spots and other imperfections. As a result, the content of common Pb is unusually high in some analyses. Ages were calculated at the 95% confidence level and by using the decay constants of Steiger and Jäger (1977). The applied U-Pb analytical methods at the University of Alberta are described in Böhm et al. (1999).

Bah Lake assemblage (Fish Lake)

The Bah Lake assemblage on the east shore of Fish Lake and in the roof of the Fish Lake granite consists of medium-grained uniform amphibolite and fine-grained amphibolite with variably preserved pillow selvages (locally complete) that are interpreted to be metabasalt with associated sills, unconformably overlain by the Grass River Group at both localities. A sample with pillow structure was taken from the roof pendant at location (1) this summer (2003), for future analysis to complement two processed samples from the east shore of Fish Lake at location (4) in Figure GS-16-1. The metabasalt at (4) has a εNd value of –0.3 and +1.4 calculated at 1.9 Ga (Table GS-16-2). The data are consistent with a Paleoproterozoic age for the basalt if it was moderately contaminated by Archean crust, as suggested by its geochemistry.

Table GS-16-2: Nd model ages of the samples from the Setting Lake area.

Sample	Location	Unit	Description	T_{CR} (Ga)	εNd (xst)	$T_{(xst)}$ (Ma)
12-98-551-5	(4) Fish Lake, east shore	Bah Lake assemblage	Pillow basalt–amphibolite	n/a	1.4	??1900
12-98-552-1	(4) Fish Lake, east shore	Bah Lake assemblage	Pillow basalt–amphibolite	n/a	-0.3	??1900
12-99-915-1	(3) Fish Lake, northwest shore	Fish Lake granite	Porphyroclastic granite	2.94	-13.9	1871
12-97-99-1	(5) Setting Lake, north	Favel Island complex	Granodiorite gneiss	2.93	-7.8	ca. 1880
12-02-9001	(6) Setting Lake, northwest	Favel Island complex	Granodiorite gneiss	2.88	-7.1	ca. 1880
12-02-9002	(6) Setting Lake, northwest	Favel Island complex	Quartzitic inclusion	3.06	-13.4	??1900
12-98-624-1	(9) Setting Lake, south	Kiski Creek granite	Porphyroclastic granite	2.74	-8.4	ca. 1870
12-97-34-3A	(10) Setting Lake, southwest	Southwest Setting intrusion	Quartz syenite–monzonite	2.42	-2.4	1835
12-97-122-2	(7) Setting Lake, central	Dike in Grass River Gp.	Hornblende-phyric intermediate dike	2.42	-2.9	?1836
12-02-610	(8) Soab Lake, east of	Late-kinematic intrusion	Leucogranodiorite	3.08	-11.0	?1820
12-02-9003	(14) Setting Lake, central	Late-kinematic intrusion	Leucogranodiorite	3.13	-8.7	?1853
12-97-258-1	(11) Setting Lake, southwest	Late-kinematic intrusion	Leucogranite	2.66	-7.8	ca. 1818

Abbreviations: T_{CR}, crustal residence age; $T_{(xst)}$, time of crystallization

Fish Lake granite

The 12 km long pluton of strongly foliated granite northwest of Fish Lake typically contains 12 to 50 mm long porphyroclasts of potassium feldspar, 10 to 20% metamorphic biotite-hornblende aggregates and generally 2% magnetite. A minor quartz diorite phase is locally associated with mafic xenoliths. Some xenoliths in the main phase of granite have an intermediate composition. The pluton has shear zones along straight west and southeast contacts; it intrudes Bah Lake–type amphibolite along a folded northern contact that is not exposed. The main porphyroclastic phase is locally cut by a deformed stockwork of medium- to fine-grained granite.

A sample of the main phase taken near the southeast contact at location (2) in Figure GS-16-1 yielded a large quantity of complex-looking zircons of various sizes and morphologies, and exhibiting visible zonation, core and overgrowth structures. Relatively clean and clear zircons devoid of inclusions, fractures and visible internal structures were abraded and the best quality crystals and fragments selected for U-Pb age dating. Analyses z#1 and z#4, of prismatic, colourless to light tan, euhedral (to subhedral) single zircon crystals, yielded slightly discordant $^{207}Pb/^{206}Pb$ ages of ca. 1867 and 1873 Ma. Linear regression of analyses z#1 and z#4 resulted in concordia intercept ages of ca. 450 Ma and ca. 1871 Ma (Fig. GS-16-2). Analysis of z#5, the clean half of a nonabraded, colourless, euhedral prismatic single crystal, yielded a 2.3% discordant $^{207}Pb/^{206}Pb$ age of ca. 1844 Ma. Regression of z#4 and z#5 resulted in concordia intercept ages of ca. 950 Ma and 1868 Ma. Analyses z#1, z#4 and z#5 have similar U concentrations (376–643 ppm) and similarly high Th/U ratios (0.8–1.2), suggesting a magmatic origin for these grains. Based on these data, ca. 1871 Ma is interpreted to represent the age of granite emplacement. Analysis z#2, a tan, short, prismatic single grain, yielded a near concordant age of ca. 1793 Ma, interpreted as the age of metamorphic overprint based on the relatively high U concentration (2160 ppm) and low Th/U ratio (0.14), which can be characteristic of metamorphic zircon growth.

A sample taken at locality (3) in the core of the pluton (Fig. GS-16-1) for geochemical analysis and Sm-Nd isotope work provided a Nd model age of 2.94 Ga (Table GS-16-2). This is similar to model ages of the Archean detritus in the Ospwagan Group in the adjacent part of the TNB (Zwanzig and Böhm, 2002) and indicates that the ca. 1.87 Ga granite is reworked Neoarchean crust or a mixture of Archean and Paleoproterozoic material. The amphibolite in the roof zone of the pluton, which is correlated with the Paleoproterozoic Bah Lake assemblage, and the Sm-Nd isotope data from identical amphibolite on the east shore of Fish Lake (*see* above) suggest that the Fish Lake granite intruded Paleoproterozoic basaltic upper crust and that the 1.87 Ga zircon fraction does, in fact, provide the age of crystallization, despite its much older, Archean Nd model age. The data consequently indicate that the basalt is older than 1.87 Ga.

Granodiorite gneiss

A granitoid intrusive complex (Favel Island complex) extends from the north end of Setting Lake for nearly 60 km, at least to the southwest end of Pakwa Lake, but is only 0.7 to 2.0 km wide (Fig. GS-16-1). The complex is premetamorphic and has an early gneissic foliation locally cut by foliated intermediate dikes and narrow mafic-ultramafic dikes. Compositions in the complex include hornblende tonalite, normal to leucotonalite, granodiorite and younger leucogranite and pegmatite. These phases are interlayered, locally dike like or agmatitic or heavily injected by pegmatite. The fabric ranges from moderately foliated and gneissic to strongly cataclastic. Screens include mafic-ultramafic rock, garnet-hornblende–bearing gneiss of unknown origin and quartz-rich rafts, some of which were previously interpreted to belong to the Grass River Group (Zwanzig, 1998).

The northern part of the complex is dominated by the medium grey tonalite to granodiorite main phase that was sampled for U-Pb dating in the north at locality (6) in Figure GS-16-1 and for Sm-Nd isotope work on Favel Island at a compositionally very similar site (5). Very small zircons belonging to a population of subequant, faceted, colourless and limpid grains were analyzed in four fractions. One analysis (90.8.2, Fig. GS-16-2) was slightly discordant (0.5%) and yielded a $^{207}Pb/^{206}Pb$ age of 1879 Ma. Two others (90.8.1 and 90.8.4) were more discordant (1.5 and 2.8%) and yielded $^{207}Pb/^{206}Pb$ ages of 1872 and 1884 Ma. Analysis 90.8.3 was highly discordant (21%) and gave a $^{207}Pb/^{206}Pb$ age of 1802 Ma. The three small grains in analysis 90.8.4 were probably insufficiently abraded. A two-point regression, calculated using analyses 90.8.1 and 90.8.2, yielded a concordia upper intercept age of 1884 Ma (not shown), whereas a three-point regression (analyses 90.8.1, 90.8.2 and 90.8.3) yielded a concordia upper intercept age of 1878 ±34 Ma (Fig. GS-16-2). The data indicate that the main phase in the Favel Island complex crystallized ca. 1.88 Ga.

The granodiorite gneiss at sites (5) and (6) provided Nd model ages of 2.93 and 2.88 Ga, whereas an inclusion of quartz-rich paragneiss gave a Nd model age of 3.06 Ga (Table GS-16-2). The analyses indicate that the ca. 1.88 Ga crystallization was from a melt having a source with Neoarchean crustal history or a mixture of Archean and

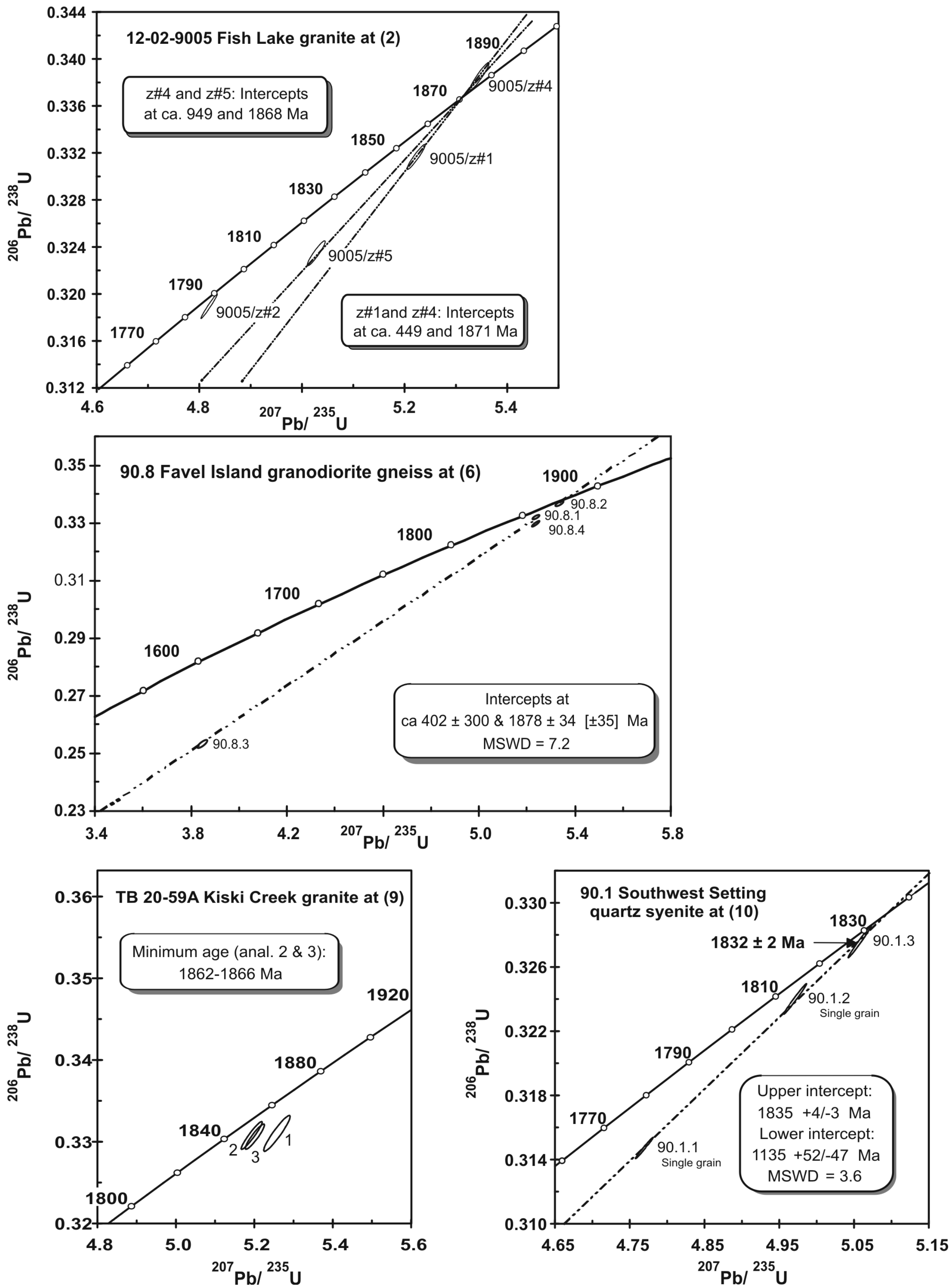

Figure GS-16-2: Concordia diagrams of gneissic to strongly foliated granitoid rocks.

Paleoproterozoic material, as has been suggested for the Fish Lake granite. At least some of the xenoliths are sedimentary rocks of Archean detritus and none may belong to the Grass River Group, which is younger than the main phase of the Favel Island complex.

Kiski Creek granite

The elongate pluton east of Kiski Creek consists of porphyritic granite to augen gneiss with 50 to 60% potassium feldspar in euhedral to sigmoidal grains up to 15 to 20 mm long. Mafic-ultramafic dikes in the pluton are folded or boudinaged, and a stockwork of medium-grained granite is also deformed.

A granite sample from locality (9) in Figure GS-16-1 yielded relatively abundant zircons of reasonable quality from the main phase of the pluton. The zircons are colourless to light brown and may represent a single population. The pervasive cloudiness, however, precludes a firm visual evaluation of core-overgrowth relationships. Two single-grain analyses (analyses 2 and 3, Fig. GS-16-2) were 1.2% and 1.5% discordant and yielded similar $^{207}Pb/^{206}Pb$ (minimum) ages of 1862 Ma and 1866 Ma. One analysis of two zircons (analysis 1) was more discordant (2.4%) and yielded a $^{207}Pb/^{206}Pb$ (minimum) age of 1883 Ma. A possible interpretation of these data is that the rock crystallized after 1862 to 1866 Ma and contains inherited zircon with a minimum age of ca. 1883 Ma.

The Kiski Creek granite has a Nd model age of 2.74 Ga (Table GS-16-2) and is interpreted to be derived from melted Archean crust and/or detritus mixed with a smaller amount of juvenile Paleoproterozoic melt.

Southwest Setting quartz syenite

Porphyritic quartz syenite or augen gneiss occurs on the southeast side of the granodiorite gneiss core of the Favel Island complex at Pakwa Lake. The body is more than 25 km long and 2 km wide, and was intruded into the granodiorite gneiss and the Burntwood and Grass River groups. Preliminary petrographic and geochemical work suggests that the body is a mildly alkaline hornblende-quartz syenite grading into monzonite and monzodiorite. Its margins are slightly more mafic than its core but contain up to 30% leucogranite dikes and local pegmatite stockwork. The main phase contains 10 to 25% hornblende (<8 mm) and generally 10% biotite, plus quartz, magnetite, titanite and apatite. Feldspar phenocrysts (15–25%) are up to 8 cm long and zoned, but augen <5 cm in length are more common. Augen have phenocrysts in the core and feldspar or granite overgrowth in the pressure shadows. The augen are locally sigmoidal and suggest east-side-up sinistral shear during their overgrowth and deformation.

Zircon grains from a sample taken at locality (10) in Figure GS-16-1 belong to a single population of small, needle-shaped, colourless prisms. One analysis was concordant within error at 1832 ±2 Ma (90.1.3, Fig. GS-16-2) and, together with two other analyses, defined a discordia with a concordia upper intercept at 1835 +4/–3 Ma. Previously obtained titanite ages of 1799 ±5 and 1793 ±5 Ma on the same sample are clearly younger (Machado, unpublished data) but similar to metamorphic zircon in the Fish Lake granite.

The quartz syenite has a Nd model age of 2.42 Ga, indicating that it had a mantle origin or juvenile Paleoproterozoic crustal source and was only moderately contaminated by Archean granitic crust.

Bucko quartz monzonite

A large body of hornblende-quartz monzonite intrudes the Archean basement gneiss and the Ospwagan Group east of the southern half of Setting Lake. The rock contains hornblende porphyroblasts <5 mm long and, rarely, larger grains with a core of orthopyroxene in a finer grained matrix dominated by plagioclase. Locally, the quartz diorite is gneissic along the contact. Previous work from locality (13) yielded a U-Pb zircon age of 1836 +5/–3 Ma (Bleeker et al. 1995) and a chemically similar hornblende-phyric dike in the Grass River Group at (7) has a Nd model age of 2.42 Ga, indicative of juvenile Paleoproterozoic source material that is moderately contaminated by Archean crust.

Leucogranodiorite

Small bodes of distinctive, light grey– to white-weathering leucotonalite to leucogranite, scattered throughout the area but particularly concentrated in fault zones, have been considered to be the regionally youngest granitoid rocks. Although mylonitic in the fault zones and strongly foliated in sheeted bodies separated by sedimentary screens and schlieren, these rocks are locally massive and little deformed. They contain pegmatitic areas and some (including the analyzed samples) are highly fractionated with very low rare earth element contents.

Core from diamond-drill hole 102525, situated northeast of the Setting Lake area at location (8) in Figure GS-16-1 and provided by Inco Technical Services Ltd., consists of foliated leucogranodiorite with abundant screens of Ospwagan Group paragneiss (unit P2) The rock yielded a large, complex population of zircon of various sizes. A large number of best quality, euhedral, larger crystals without fractures or inclusions was abraded. Two single-grain analyses of such short prismatic to equant, stubby zircons (z#1, z#2) resulted in discordant $^{207}Pb/^{206}Pb$ ages of ca. 2508 and 2356 Ma. In comparison, analyses z#3 to z#5, of smaller distinct-looking morphologies, have younger, nearly concordant to discordant $^{207}Pb/^{206}Pb$ ages ranging between ca. 1802 and 1692 Ma. Analyses z#3 to z#5 have relatively high U concentrations (1808–3693 ppm) and low Th/U ratios (0.04–0.02), characteristic of metamorphic zircon growth. The younger zircon ages, ranging from ca. 1787 Ma ($^{207}Pb/^{206}Pb$ age of z#5), through ca. 1802 Ma ($^{207}Pb/^{206}Pb$ age of z#4) to ca. 1820 Ma (linear regression upper intercept age of z#3 and z#4, Fig. GS-16-3), are therefore interpreted as being metamorphic. Assuming major Pb loss at ca. 1.8 Ga, zircon analyses z#1 and z#2 indicate inherited ages of ca. 2.66 and 2.68 Ga, respectively (Fig. GS-16-3), consistent with the origins suggested above. None of the six zircon analyses, however, seems to represent the emplacement age of the granodiorite. Either the granodiorite did not crystallize (much) magmatic zircon, or emplacement was contemporaneous with (early, ca. 1.82 Ga) metamorphism. Ion microprobe dating could further unravel the age and nature of these complex granodiorite zircons.

A massive sample containing muscovite and only a trace of biotite was taken from a small intrusion into Ospwagan Group metasedimentary rock (Setting Formation) and amphibolite (Bah Lake assemblage) at locality (14) in Figure GS-16-1. The rock has a very similar chemical composition to the sample at (8), but yielded only a small amount of small zircons that display what appear to be colourless cores surrounded by thin brownish overgrowths. Given the poor quality of most grains, it was impossible to positively identify chromatic characteristics of these components. In addition, a few colourless and euhedral crystals devoid of overgrowth are also present. Five analyses of single grains and one analysis of two grains were performed and plotted in Figure GS-16-3. Although analyses of composite grains whose brown component was abraded yielded $^{207}Pb/^{206}Pb$ (minimum) ages of 2319 and 2452 Ma (analyses 2 and 4), three other discordant analyses (1, 3 and 6) yielded minimum ages of 2114, 1901 and 1976 Ma. An analysis of a single, euhedral, colourless crystal is concordant at 1853 ±6 Ma. This grain has a very high U content (12004 ppm) but a Th/U ratio of 0.3, within the range of igneous zircon, and it may have crystallized with the granodiorite melt.

Both analyzed samples have an old Nd model age (3.08 and 3.13 Ga, Table GS-16-2) consistent with large amounts of Archean zircon inheritance. The presence of muscovite is consistent with an origin for the leucogranodiorite as an S-type intrusion, specifically a partial melt formed during high-grade metamorphism of Ospwagan Group sedimentary rock and Archean basement gneiss, presumably at a deeper crustal level than the host rock, which is not a true migmatite.

Granite sheets

Veins, dikes and larger sheets of fine-grained potassic leucogranite cut the Southwest Setting quartz syenite, most notably at the margin of the pluton. They predate or are coeval with sinistral shear bands, but are locally only very weakly deformed.

A sample from location (10) in Figure GS-16-1 provided three zircon fractions belonging to a single population of small, euhedral, colourless prismatic crystals. Analyses of one and two grains (90.2.3, 90.2.1, 90.2.3) are plotted together with that of a previously analyzed monazite (Machado unpublished data) and define a discordia line with an upper intercept age of 1818 ±11 Ma (Fig. GS-16-3). The large error in the calculated age is the result of scattering of analytical data along the discordia line, possibly due to insufficient abrasion of the small grains. The Th/U ratios are low (0.10–0.18), so a metamorphic origin is possible. The single population and grain morphology suggest, however, that the age represents the time of crystallization of the granite.

A similar sample from location (11) has a Nd model age of 2.66 Ga, which indicates an Archean history for some of the source material.

Discussion

Field relations, U-Pb zircon crystallization ages and Sm-Nd isotope data suggest that there are three or four groups of granitoid intrusions along the margin of the TNB and Kisseynew Domain in the Setting Lake area (Fig. GS-16-4). Each of these has important implications for the tectonic history of the TNB and possibly its economic potential. The evolution of granitoid magmatism may establish a much earlier link between the Superior Craton and the internal zone of the Trans-Hudson Orogen than previously proposed.

A group comprising ca. 1880 Ma granodiorite gneiss and >1862 to 1871 Ma porphyroclastic granite plutons has

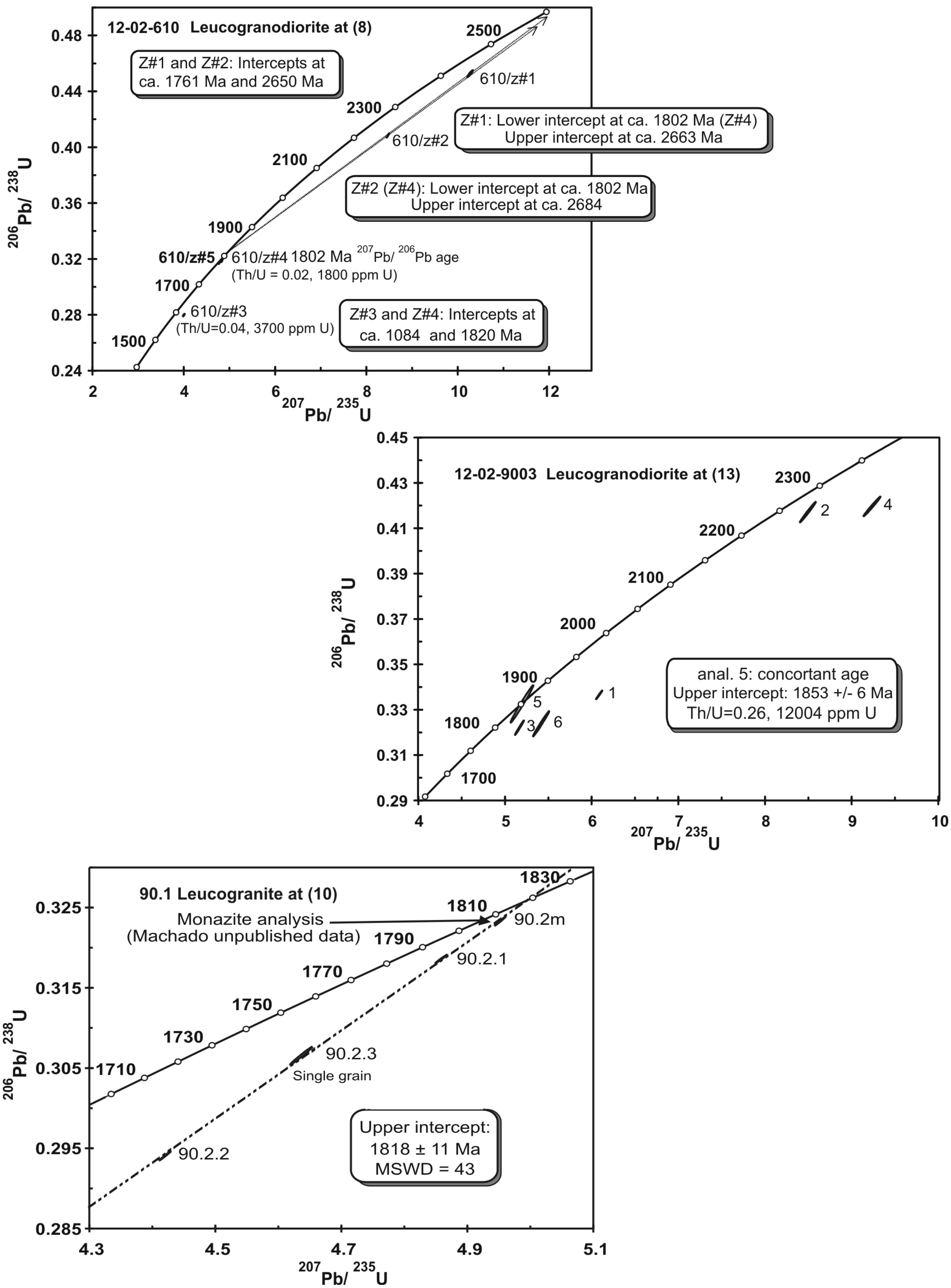

Figure GS-16-3: Concordia diagrams of syn- to late-kinematic leucogranitoid intrusions.

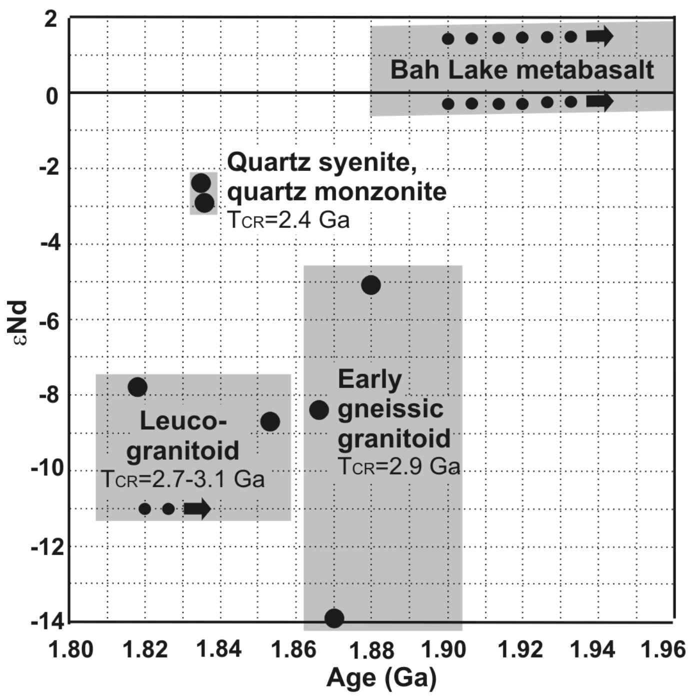

Figure GS-16-4: Grouping of magmatic rocks by U-Pb crystallization ages and εNd (calculated at the time of crystallization). Shaded boxes representing the groups show the analytical error limits for the data. Dotted lines with arrows represent a minimum age for leucogranite or relative ages for Bah Lake metabasalt.

Archean Nd model ages ranging from 2.74 to 2.94 Ga. These plutons were derived mainly from crustal rocks with an Archean history, either Archean basement gneiss or overlying sedimentary rocks that had an Archean provenance or both. It has been proposed that such crustal melts are crystal rich and form under conditions of high water influx at relatively low temperature in environments of crustal thickening (Miller et al., 2003). The plutons intrude amphibolite derived from pillow basalt and gabbro, part of the Bah Lake assemblage that forms the top of the Ospwagan Group in the main part of the TNB. Parts of the plutons appear to be unconformably overlain by the youngest sedimentary rocks in the area, the Grass River Group. Most contacts, however, are highly sheared or unexposed and may be faults. The present work implies that, directly following the extensional magmatism represented by the 1883 Ma Molson dikes (Heaman et al., 1986) near the Superior Craton boundary, rift-related amphibolite at the margin of the Kisseynew Domain was intruded by melts derived from underlying Archean crust. Such crust may be exotic or stretched crust of the Superior Craton, but its presence has not been predicted by current or previous tectonic models and cannot be easily explained by them.

A younger group of 1835 Ma plutons with a Nd model age of 2.4 Ga formed mainly from a mantle, mafic or juvenile Paleoproterozoic crustal source with only moderate or minor Archean crustal contamination, although these bodies are mildly alkaline or relatively potassium rich. They extend across the boundary between the TNB and the Kisseynew Domain, and imply an earlier collision between these terranes than previously speculated (e.g., Lucas et al., 1999). If the provisional age of ca. 1853 Ma for the earliest leucogranodiorite can be confirmed, this may have been the time of collision. The massive structure of the leucogranodiorite is possibly due to long-lived strain partitioning in the Setting Lake fault zone, but ion microprobe dating is required to resolve its age.

Small leucocratic intrusions, such as the one containing the 1853 Ma zircon, are widespread and have Nd model ages ranging from 2.7 to 3.1 Ga. Some appear undeformed, cut the Grass River and Burntwood groups or the 1835 Ma pluton, and must be younger. Such leucocratic bodies, however, seem notoriously difficult to date by conventional U-Pb dating methods, mostly because they did not crystallize much or any magmatic zircon but contain abundant, complex inherited zircons. The youngest provisional age for small leucogranite intrusions is ca. 1818 Ma, which is also the beginning of regional high-grade metamorphism and migmatite generation.

Good evidence for ca. 1820 Ma metamorphic zircon exists in the leucogranodiorite and for ca. 1793 Ma metamorphic zircon in the Fish Lake granite. Titanite ages range from ca. 1800 to ca. 1780 Ma (Machado, unpublished data), and provide evidence for up to 40 m.y. with high-temperature conditions.

The magmatic and metamorphic evolution of this part of the Superior Boundary Zone shows remarkable similarity to the history of the internal (juvenile) zone of the Trans-Hudson Orogen for a period of 100 m.y., starting ca. 1880 Ma (Whalen et al, 1999). Only the extensive involvement of Archean crust and absence of open ocean environments are completely different. A change from an extensional to a compressional (active?) margin ca. 1880 Ma and early (1850 Ma?) collision may explain the high metamorphic grade and deformation in the TNB compared to other parts of the Superior Boundary Zone. Confirmation of the provisional ages given here and consideration of the geochemistry of the igneous rocks are still required before a new tectonic model can be developed.

Economic considerations

One of the objectives of this work along the western boundary of the TNB is to define more clearly the geographic limit for effective nickel exploration. Because all known economic nickel deposits occur in the Ospwagan Group, the regional extent of this succession must be known precisely. The present work has shown that Archean basement rocks and/or remnants of Ospwagan-like supracrustal rocks with Archean Nd model ages extend into the margin of the Kisseynew Domain. The results given here have now defined the components at that boundary and how these can be identified. Future work may define their extent and the presence or absence of ultramafic bodies.

High-grade metamorphism and severe deformation have limited the understanding of the TNB. A better grasp of the tectonic history of the belt may provide the means to ameliorate this problem.

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