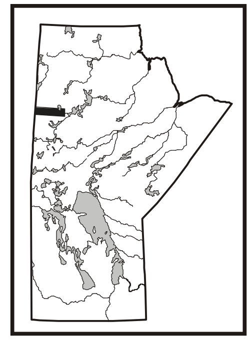
GS-18 U-PB AGE OF THE GABBRO AND OTHER PLUTONS AT LYNN LAKE (PART OF NTS 64C)



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SUMMARY

The ore-hosting 'EL' and the barren Fraser Lake gabbroic stocks, which intrude the Wasekwan Group arc-related volcanic rocks in the Lynn Lake belt, have yielded U-Pb zircon ages of 1871.3 ± 2.4 Ma and 1870 ± 6.2 Ma, respectively. The Pb isotopic composition of the feldspars from the gabbro bodies indicates a common source with a µ value of 9.36. However, the barren Fraser Lake body has components derived from a different source with a higher but still mantle-like µ value. The Eden Lake granite, which intrudes gneissic tonalite at the southeast end of the Lynn Lake belt, has yielded an age of 1870 ± 10 Ma, comparable to the age of the gabbro bodies and to published ages for the Hughes Lake and Norrie Lake tonalite bodies. The age for a tonalite north of the Fox mine, at the southwest end of the belt, is significantly younger at 1831 ± 3.7 Ma. Thus, the period of intrusive activity is 1831 to 1871 Ma, similar to the span of 'successor arc' magmatism elsewhere in the Trans-Hudson Orogen.

INTRODUCTION

The Lynn Lake greenstone belt (Fig. GS-18-1) is a Paleoproterozoic segment of the Trans-Hudson Orogen (Hoffman, 1981). The arc-related volcanic rocks (Syme, 1985; Zwanzig et al., 1999) have yielded U-Pb zircon ages of 1915 +7/-6 and 1910 ± 10 Ma (Baldwin et al., 1987). These are intruded by the previously undated Lynn Lake gabbro bodies that host ore deposits (depleted) of Ni, Cu and Co (Pinsent, 1980). The gabbro bodes are intruded by the Pool Lake suite of granodiorite to diorite, which has yielded U-Pb ages of 1876 +8/-7 Ma for the Hughes Lake quartz diorite and 1876 +8/-6 for the Norrie Lake tonalite (Baldwin et al., 1987). The plutons and the Wasekwan Group were deformed and subsequently overlain by the Sickle Group fluvial-alluvial arenite (Table GS-18-1). Polyphase deformation and upper greenschist to upper amphibolite metamorphism have affected all the rocks in the Lynn Lake belt, including a suite of post-Sickle plutons.

A general lack of zircons in the rocks of the Lynn Lake belt has hampered this and other radiometric-dating programs. Nevertheless, we have been able to obtain precise ages for the early Lynn Lake gabbro, and to extend the dating to granite that was considered to be relatively early but yielded a surprisingly young age, showing that some of the tonalite bodies intruding the Wasekwan Group have a post-Sickle age. The U-Pb and Pb-Pb ages relevant to this report are listed in Appendix GS-18-1.

ANALYTICAL PROCEDURES

Samples for radiometric dating were approximately 30 kg, except for sample L12, which was approximately 80 kg. After crushing, zircons were separated by standard procedures using the Wilfley table, Carpco™ and Frantz™ magnetic separators, and ethylene tetrabromide and methylene iodide heavy liquids. Zircon fractions selected for analysis were upgraded by abrasion and hand picking, and cleaned thoroughly by ultrasonic vibration in 50% nitric acid and ultra-pure water. Sample dissolution followed the techniques of Krogh (1973) and Parrish (1987), and samples were spiked with a mixed ^{208}Pb and ^{235}U tracer for the concentration measurements. The feldspar samples were separated similarly, using magnetic separators and heavy liquids. They were dissolved in Savillex™ Teflon™ vessels and spiked with natural ^{203}Tl-^{205}Tl to act as an internal standard.

The Pb and U isotopic ratios were measured on a 90°, 25 cm mass spectrometer. The composition of Pb was measured on unspiked aliquots, and U and Pb concentrations and the U/Pb isotopic ratios were calculated from spiked aliquot runs; uncertainties in the U/Pb ratios are ±1.0% at the 95% confidence level. Isotopic ratios were corrected for mass fractionation, blank and initial common Pb. The mass-fractionation correction used was 0.10% per atomic mass unit. The Pb-blank correction was 12 or 70 pg Pb, depending on the size of the Teflon™ pressure bomb used. The composition of the blank used was $^{206}Pb/^{204}Pb$ = 18.7, $^{207}Pb/^{204}Pb$ = 15.7 and $^{208}Pb^{204}Pb$ = 38.4. Correction for the initial common Pb present was done using the Stacey and Kramers (1975) equations. The Pb-isotope composition of the feldspar samples was measured on an Nu Instruments™ 'Nu plasma' multicollector ICP–MS instrument. Mass fractionation of the Pb isotopes was corrected on the basis of mass bias observed for the added Tl internal standard of known isotopic composition.

Data reduction for the zircon samples followed the procedure of Ludwig (1982). Statistical evaluation of the results was done using the plotting and regression analysis of Ludwig (1999). For the U-Pb data, the regression provides the upper and lower concordia age intercepts and also provides two measures of goodness of fit: the mean square of weighted deviates (MSWD), which is a residual variance, and a probability of fit. The ages being reported here are within experimental error and the uncertainties are at the 95% confidence limit.

RESULTS

Of the 16 rock units sampled, only four contained zircons. The locations of all samples are shown on Figure GS-18-1 and their co-ordinates are given in Appendix GS-18-2. The analytical data are given in Tables GS-18-2 and -3, and are shown as concordia diagrams (Fig. GS-18-2 to -5) and as Pb-evolution plots (Fig. GS-18-6).

'EL' Gabbro (L12)

The 'EL' gabbro intrudes mafic to intermediate porphyritic flows of the high-LREE (light rare-earth elements) arc tholeiite (Wasekwan Group) in the northern belt (Zwanzig et al., 1999). This intrusion is a vertical pipe, 500 m in diameter, and hosts a high-grade Ni-Cu deposit that has been mined out from the 700 m level up to the surface. This stock is probably connected to the larger 'A' stock at the Lynn Lake townsite, which hosts several Ni-Cu orebodies. A sample of this gabbro yielded clear, colourless to light yellow zircons that were euhedral with some overgrowths, which were removed by abrasion. Five fractions were analyzed: one is concordant; three are discordant by less than 2%; and one plots above the concordia, which we attribute to the abrasion process. All five data sets are collinear within experimental limits and define a concordia age of 1871.3 ± 2.4 Ma with a lower intercept of 291 ± 183 Ma.

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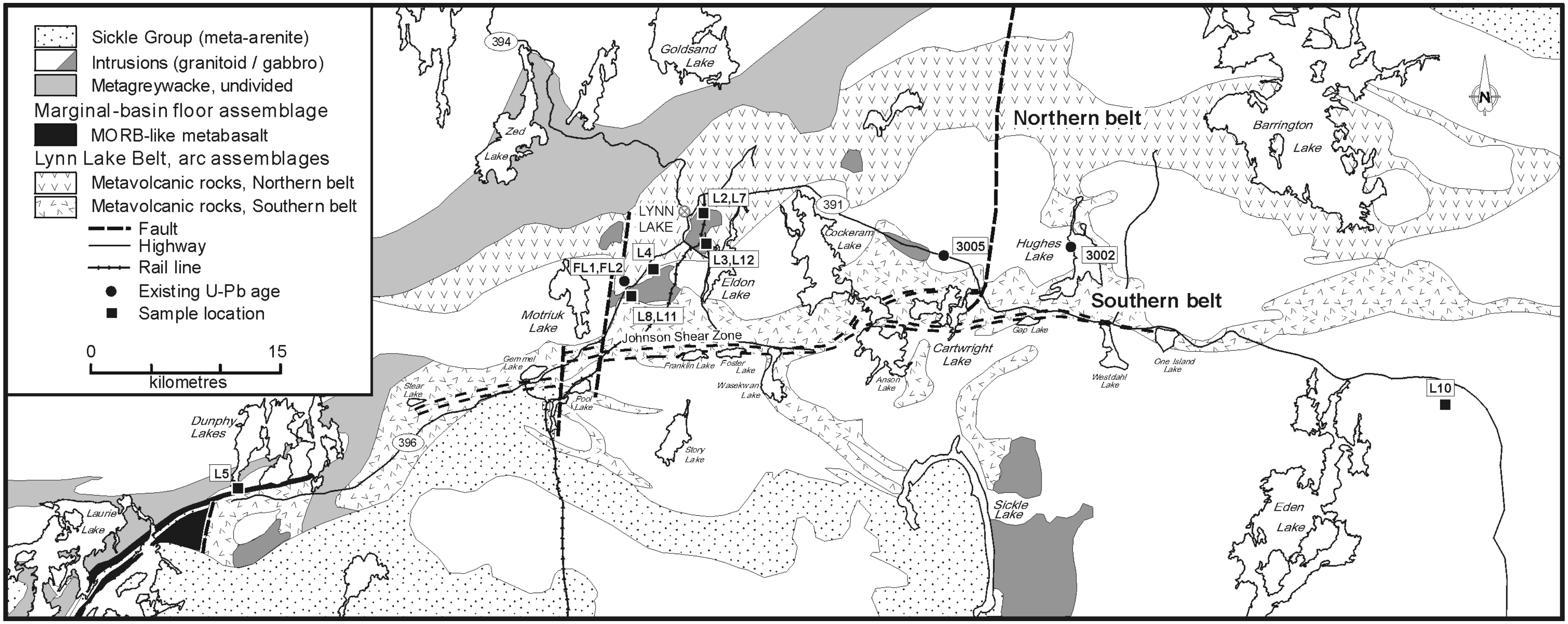

Figure GS-18-1: Geological sketch map showing location of samples (modified from *Beaumont-Smith and Rogge, 1999).*

*Table GS-18-1: Table of formations (*adapted from *Gilbert et al., 1980). Unit numbers are those used by Gilbert et al. (1980).*

Supracrustal rocks		**Intrusive rocks**			**U-Pb age**	
Unit	Rock type	Unit	Rock type	Unit	Rock type	Age (Ma)
		Post-Sickle intrusive rocks				
		18-22	Diorite, tonalite, granite, granodiorite, pegmatite, porphyry			
		16	Tonalite, quartz diorite	16	Fox Mine tonalite[b]	1831 ± 3.7
Sickle Group						
11-12	Conglomerate, sandstone and gneiss					
Burntwood Group						
1	Greywacke, mudstone, siltstone					
	Sickle or Wasekwan Group					
10	Conglomerate with sedimentary, volcanic and granitoid clasts					
---------- Unconformity ----------						
		Pre-Sickle intrusive rocks				
		16-17	Diorite, tonalite, granite, granodiorite, aplite, pegmatite	17 16 16	Eden Lake granite[b] Hughes Lake diorite[a] Norrie Lake tonalite[a]	1871 ± 10 1876 ± 7.5 1876 ± 7
		13-15	Gabbro,diorite, norite, diabase	15 15	Fraser Lake gabbro[b] 'EL' gabbro[b]	1870 ± 6.2 1871 ± 2.4
Wasekwan Group						
8-9	Conglomerate, coarse- to fine-grained sedimentary rocks, paragneiss					
5-7	Intermediate and felsic volcanic rocks, dacite, rhyolite and felsic gneiss			7	Lynn Lake rhyolite[a]	1915 ± 6.5 1910 ± 12
2-4	Aphyric basalt, porphyritic basalt, mafic and intermediate volcanic rocks, amphibolite					

[a] Age from Baldwin et al. (1987).
[b] Age from this study.

Table GS-18-2: Analytical data for zircons from Lynn Lake.

Sample detail[a]				**Concentration**		**Atomic ratios**					**Apparent ages (Ma)[e]**		
Sample No.	Magnetism	Grain size(µm)	Weight (mg)	U (ppm)	Pb (ppm)	[b] $^{204}Pb/^{206}Pb$	[c] $^{208}Pb/^{206}Pb$	[c] $^{207}Pb/^{206}Pb$	[d] $^{207}Pb/^{235}U$	[d] $^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
'EL' gabbro (L12)													
A	m0	114	0.3	76	42	0.01001	0.46768	0.22960	5.156	0.3276	1827	1845	1866
B	m0	114	0.4	75	41	0.00785	0.43719	0.20498	5.461	0.3456	1914	1895	1873
C	m0	114	0.2	122	46	0.00186	0.18673	0.11518	5.338	0.3377	1876	1875	1874
D	m0	62	1.9	251	90	0.00011	0.18348	0.11410	5.066	0.3223	1801	1830	1864
E	m0	114	1.1	225	82	0.00019	0.17930	0.11411	5.146	0.3270	1824	1844	1866
Fraser Lake gabbro (L11)													
A	m0	114	2.0	286	107	0.00085	0.18923	0.12450	5.161	0.3281	1829	1846	1865
B1	m4	114	1.3	472	169	0.00159	0.23638	0.13363	4.636	0.2969	1676	1756	1852
CC	m0	62	8.0	350	107	0.00048	0.15509	0.11836	4.289	0.2776	1579	1691	1833
CX	m0	62	2.7	451	156	0.00024	0.13791	0.11362	4.966	0.3170	1775	1813	1858
Eden Lake granite (L10)													
A	m1	114	2.3	618	215	0.00060	0.12768	0.12096	5.012	0.3209	1794	1821	1853
B	m2	114	1.1	550	169	0.00053	0.12385	0.11616	4.333	0.2853	1618	1700	1802
C	m2	114	0.9	778	246	0.00034	0.11601	0.11489	4.559	0.2971	1677	1742	1821
D	m1	114	2.0	746	232	0.00024	0.10368	0.11377	4.528	0.2959	1671	1736	1816
Fox mine tonalite (L5)													
B	m0	62	1.4	367	135	0.00174	0.12507	0.13427	5.109	0.3312	1844	1838	1830
C	m0	114	0.3	427	142	0.00108	0.09824	0.12077	4.809	0.3135	1758	1787	1820
D	m0	62	3.6	494	163	0.00038	0.07817	0.11643	4.915	0.3193	1786	1805	1827
E	m1	62	1.1	858	244	0.00036	0.07228	0.11300	4.167	0.2775	1579	1668	1781

[a] Relative magnetic susceptibility of zircons is reported as m0 (nonmagnetic) to m4 (paramagnetic) and is related to the inclination of the Frantz isodynamic separator using maximum current of 2 A. Grain size is an average; sieves used were 85, 150, 75, 38 µm.
[b] Measured ratio.
[c] Blank corrected.
[d] Blank and nonradiogenic Pb corrected.
[e] Decay constants used: $\lambda^{238}U = 1.55125 \times 10^{-10}$ year^{-1}; $\lambda^{235}U = 9.8485 \times 10^{-10}$ year^{-1} (Steiger and Jäger, 1977).

Table GS-18-3: Isotopic composition of Pb in feldspars from gabbroic stocks at Lynn Lake.

Sample detail	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
'A' stock gabbro (L2)	15.639	15.201	35.134
'A' stock gabbro (L7)	15.663	15.215	35.516
Fraser Lake tonalite (L4)	15.905	15.319	35.426
Fraser Lake gabbro (L11)	15.994	15.321	35.380
Fraser Lake gabbro (L8)	15.844	15.258	35.308
'EL' stock gabbro (L3)	16.110	15.281	35.477
'EL' stock gabbro (L12)	17.205	15.415	35.708

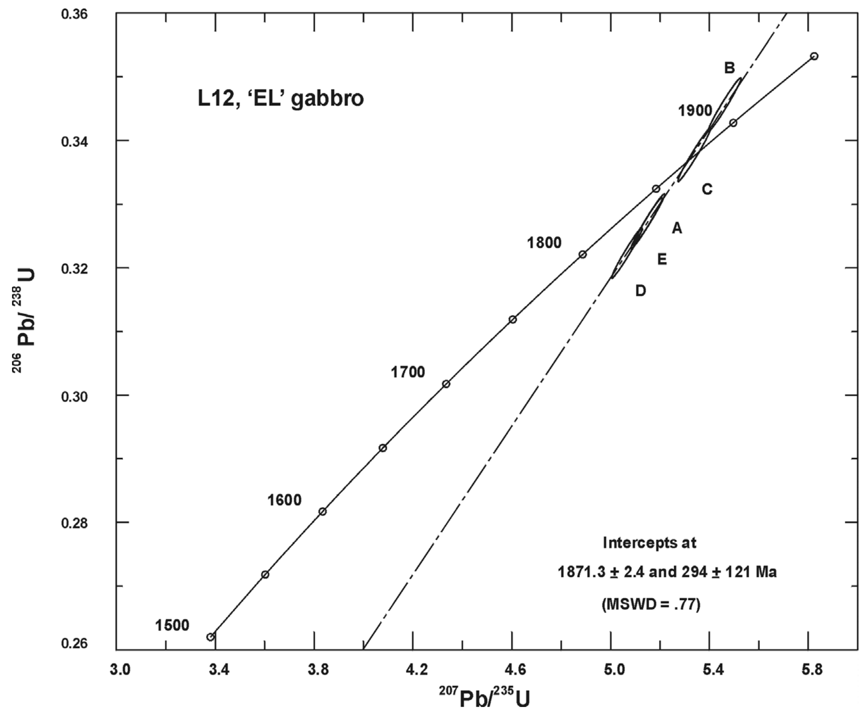

Figure GS-18-2: Concordia diagram for the 'EL' gabbro. A, B, C, D and E are separate zircon fractions.

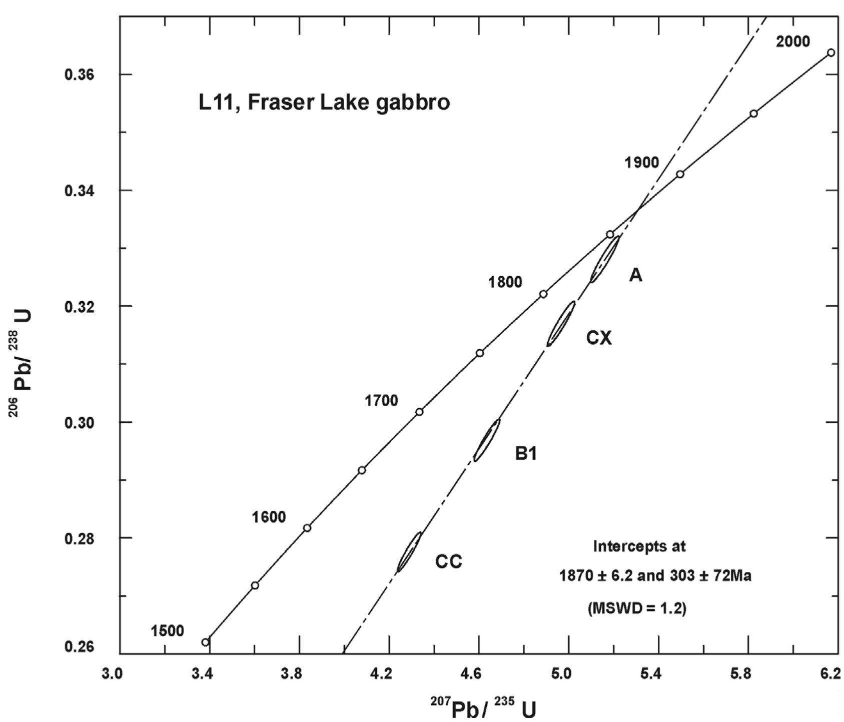

Figure GS-18-3: Concordia diagram for the Fraser Lake gabbro. A, B1, CC and CX are separate zircon fractions.

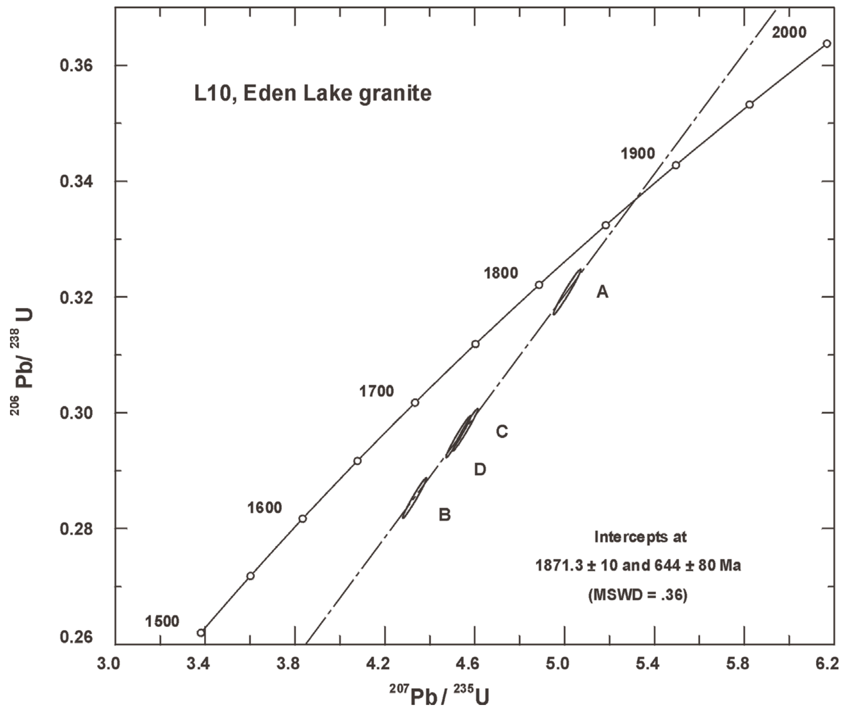

Figure GS-18-4: Concordia diagram for the Eden Lake granite. A, B, C and D are separate zircon fractions.

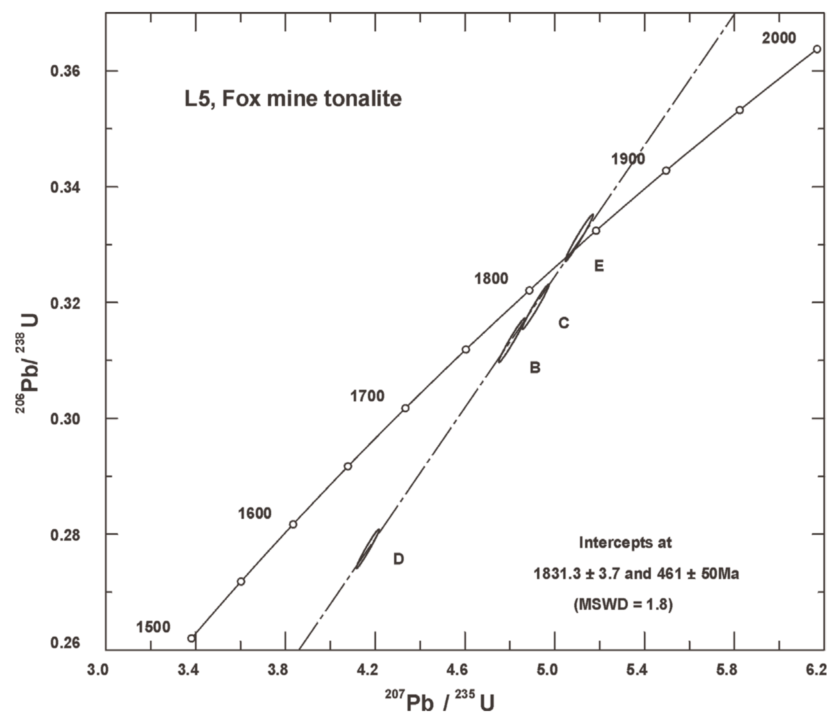

Figure GS-18-5: Concordia diagram for the Fox mine tonalite. B, C, D and E are separate zircon fractions.

Fraser Lake Gabbro (L11)

This pluton is a gabbro similar to the 'EL' and 'A' bodies, but it does not contain any sulphide mineralization. It intrudes the core of an early anticline and stitches rocks in the northern belt to those in the southern belt. The zircons separated from the gabbro sample are transparent and colourless to light pink. The four fractions analyzed are 2 to 20% discordant, but are collinear within experimental error and define a concordia age of 1870 ± 6.2 Ma with a lower intercept of 303 ± 72 Ma. The minimum $^{207}Pb/^{206}Pb$ age is 1865 Ma.

Eden Lake Granite (L10)

A sample of K-feldspar porphyritic granite from a batholith to the southeast of the main greenstone belt yielded a heterogeneous population of euhedral zircons. There appear to be two populations of zircons, cloudy white opaque crystals and orange-brown and iron-stained opaque crystals. Four fractions were analyzed: A is a strongly abraded and D a slightly abraded mixture of both populations, whereas B and C are not abraded but are hand-picked fractions of the white and orange-brown crystals, respectively. As is evident from the concordia plot, the data points are collinear but discordant by 6 to 22%. The concordia age is

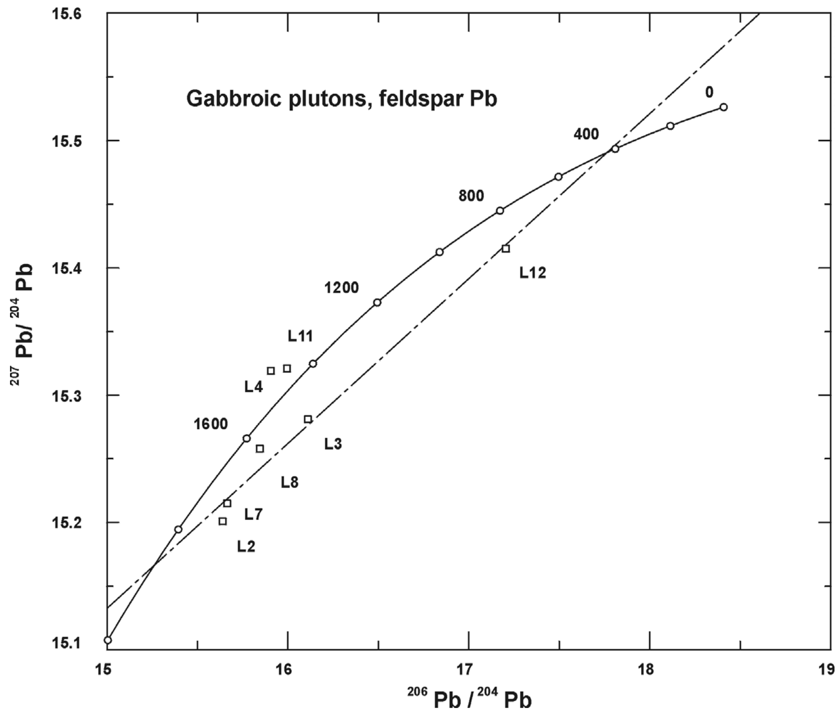

Figure GS-18-6: Pb isotopic composition of feldspars from the gabbro plutons. The Pb-evolution curve has a m value of 9.36. Growth curve intercepts are 1870 and 430 Ma. The MSWD of the regression is 0.957. Samples L2 and L7 are from the 'A' stock; samples L3 and L12 are from the 'EL' stock; and samples L8, L4 and L11 are from the Fraser Lake stock.

1870 ± 10 Ma with a lower intercept of 644 ± 80 Ma. The minimum $^{207}Pb/^{206}Pb$ age is 1853 Ma.

Fox Mine Tonalite (L5)

This body, granodiorite to tonalite in composition, cuts off the Hatchet Lake mid-ocean ridge (MORB)-like basalt (Zwanzig et al., 1999), a narrow unit of sedimentary rocks, and the fault between them. Zircons separated from a tonalite sample are stubby, transparent and pink. Fractions B and C are strongly abraded, and fractions D and E are lightly abraded. Fraction E is concordant, whereas B, C and D are 3 to 20% discordant. The data define a discordia within experimental error. The indicated age is 1831 ± 3.7 Ma with a lower intercept of 461 ± 50 Ma.

Gabbro Plutons, Feldspar Analysis

The isotopic composition of Pb was measured on feldspars separated from the following samples: L2, L3, L4, L7, L8, L11 and L12. Feldspars were used because they concentrate Pb and therefore retain low U/Pb ratios. ICP–MS analysis of the feldspars used here indicates the presence of some U. Nevertheless, these analyses represent the best chance of approaching initial Pb isotopic compositions. The isotopic compositions are given in Table GS-18-3 and shown as a Pb-evolution diagram in Figure GS-18-6.

DISCUSSION

The four U-Pb zircon ages measured here, together with the four ages published by Baldwin et al. (1987), provide a useful though far from adequate control on the evolution of the Lynn Lake greenstone belt. The 'A' and 'EL' gabbro stocks carry economic sulphide mineralization, while the Fraser Lake gabbro, which has been extensively explored by geophysical methods and drilling by Sherritt Gordon Mines Ltd., is barren. The ages obtained here for the 'EL' and Fraser Lake gabbro bodies are 1871 ± 2.4 and 1870 ± 6.2 Ma, respectively. These ages are statistically identical at the 95% level and are also indistinguishable from those for the Pool Lake suite tonalite, which intrudes the gabbro. This important intrusive event must be approximately 5 Ma younger than the felsic volcanism in the adjacent Rusty Lake greenstone belt, with which it was previously thought to be coeval (Baldwin et al., 1987). The 1870 ± 10 Ma age of the Eden Lake granite, reported here, is also statistically part of this intrusive activity. Cameron (1988) has shown that the Eden Lake granite is relatively late in the sequence of igneous activity. Its pre-Sickle age suggests that the main pulse of arc magmatism may have waned earlier in the Lynn Lake–Rusty Lake region than previously thought. However, the age obtained for the Fox mine tonalite is much younger at 1831 ± 3.7 Ma. This age is the same as the 1832 Ma age for late-tectonic quartz diorite at Veronica Lake, to the north of the area (Van Schmus and Schledewitz, 1986).

The Pb isotopic composition of feldspars separated from the gabbroic stocks shows that the ore-hosting 'A' and 'EL' stocks both lie on a straight line that intersects the growth curve with a μ value of 9.36 at 1870 Ma and are therefore probably derived from the same source. Feldspars from the Fraser Lake body are from gabbro (L11 and L8) and tonalite (L4). Sample L8 lies, within error, on the same chord, but the other two Fraser Lake samples are above that curve. This suggests that the Fraser Lake body may be derived from two sources, one being the same as that of the 'A' and 'EL' stocks (with a μ value of 9.36) and another having a higher but still mantle-like μ value. Thus, there is some difference isotopically between the ore-hosting gabbroic stocks and the barren Fraser Lake stock.

The age determinations reported here are consistent with those of Baldwin et al. (1987) but suggest that the main 'successor-arc' magmatism in the Lynn Lake region may have peaked at ca. 1.87 Ga, earlier than elsewhere in the Trans-Hudson Orogen. The isotopic composition of the feldspars indicates a mantle origin, with no crustal contribution. This also supports the paleomagnetic evidence of Dunsmore and

Symons (1990) and Symons (1991), which indicates a wide separation of the Superior and Hearne–Rae cratons during the main stage of formation of the Lynn Lake greenstone belt.

The Fox mine pluton provides an important minimum age for the fault between the Hatchet Lake basalt and the Burntwood Group turbiditic metasedimentary rocks to the northwest (Zwanzig et al., 1999). The fault has been interpreted as part of a system of crustal-scale structures along which the turbidites in the Kisseynew Domain underthrust the arc volcanic rocks in the Lynn Lake belt (White et al., 2000). With an age of greater than 1831 ± 3.7 Ma, the faulting is coeval with the thrusting between the Burntwood Group and the volcanic rocks in the Flin Flon greenstone belt (Connors, 1996).

CONCLUSIONS

A limited number of U-Pb zircon ages suggest that the bulk of plutonic activity, mafic and felsic, in the Lynn Lake area took place around 1870 to 1876 Ma. The emplacement of the 'A' and 'EL' gabbro plutons with their massive sulphide orebodies took place at 1871 ± 2.4 Ma. The larger but barren Fraser Lake gabbro has a similar age of 1870 ± 6.2 Ma. While all three gabbro bodies are derived from a common mantle source with a µ value of 9.36, the Fraser Lake pluton also contains material derived from a mantle source with a higher µ value. These ages are not significantly different from the 1876 Ma ages reported for the Norrie Lake tonalite and the Hughes Lake tonalite (Baldwin et al., 1987), as well the 1871 ± 10 Ma age of the Eden Lake granite. The younger 1831 ± 3.7 Ma age of the Fox Lake tonalite constrains the timing of faulting at the tectonically active south margin of the Lynn Lake belt.

ACKNOWLEDGMENTS

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Appendix GS-18-1: Compilation of U-Pb and Pb-Pb isotopic ages for the Lynn Lake area: Lynn Lake Domain, South Indian Domain, Leaf Rapids Domain.

Lynn Lake Domain			
Eden Lake granite	U-Pb	1871 ± 10	this study
Fox mine tonalite	U-Pb	1831 ± 3.7	
Fraser Lake gabbro	U-Pb	1876 ± 7.5	
'EL' gabbro	U-Pb	1871 ± 3.5	
Rhyolite (FL1)	U-Pb	1915 +7/-6	Baldwin et al. (1987)
Rhyolite (FL2)	U-Pb	1910 +15/-10	
Pre-Sickle intrusive rocks			
Hughes Lake quartz diorite (3002)	U-Pb	1876 +8/-7	Baldwin et al. (1987)
Norrie Lake tonalite (3005)	U-Pb	1876 +8/-6	
South Indian Domain			
Veronica Lake			
Quartz diorite (MAN84-4)	U-Pb	1832	Van Schmus and Schledewitz (1986)
Leaf Rapids Domain			
Rusty Lake Belt			
Karsakuwingmak rhyolite (R1)	U-Pb	1878 ± 3	Baldwin et al. (1987)
Karsakuwingmak rhyolite (R2)	U-Pb	1874 +8/-7	
Ruttan mine, Leaf Rapids			
Sulphide ore (SP-2318)	Pb-Pb	1768	Sangster (1978)

Appendix GS-18-2: Sample location co-ordinates.

Sample	Unit	Latitude	Longitude
L2	Lynn Lake 'A' plug, hornblende-quartz gabbro	56°51'09"N	101°02'12"W
L3	Lynn Lake 'EL' plug, hornblende gabbro	56°49'14"N	101°01'55"W
L4	Fraser Lake tonalite	56°48'23"N	101°06'34"W
L5	Fox mine tonalite	56°38'25"N	101°38'41"W
L7	Lynn Lake 'A' plug, hornblende gabbro	56°51'05"N	101°02'00"W
L8	Fraser Lake hornblende-quartz gabbro	56°47'49"N	101°05'12"W
L10	Eden Lake porphyritic granite	56°41'15"N	99°57'06"W
L11	Fraser Lake quartz-hornblende gabbro	56°47'49"N	101°05'12"W
L12	Lynn Lake 'EL' plug, gabbro	56°49'14"N	101°01'55"W