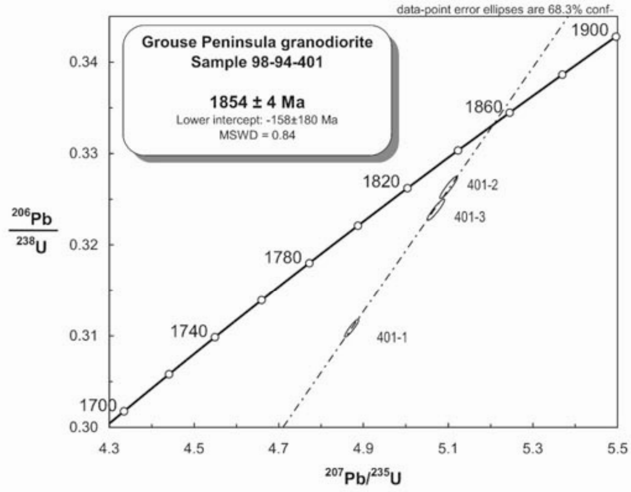
GP2006-1

GEOSCIENTIFIC PAPER

New uranium-lead geochronology results from the Lynn Lake greenstone belt, Manitoba (NTS 64C11–16)



By
C.J. Beaumont-Smith,
N. Machado
and D.C. Peck

Manitoba

Geoscientific Paper GP2006-1

New uranium-lead geochronology results from the Lynn Lake greenstone belt, Manitoba (NTS 64C11–16)

by C.J. Beaumont-Smith, N. Machado and D.C. Peck
Winnipeg, 2006

Science, Technology, Energy and Mines

Hon. Jim Rondeau
Minister

John Clarkson
Deputy Minister

Mineral Resources Division

John Fox
Assistant Deputy Minister

Manitoba Geological Survey

E.C. Syme
Director

Manitoba

When using information from this publication in other publications or presentations, due acknowledgment should be given to the Manitoba Geological Survey. The following reference format is recommended:

Beaumont-Smith, C.J., Machado, N. and Peck, D.C. 2006: New uranium-lead geochronology results from the Lynn Lake greenstone belt, Manitoba (NTS 64C11–16); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2006-1, 11 p.

NTS grid: NTS 64C11–16

Keywords: Lynn Lake, Manitoba, Lynn Lake greenstone belt, geochronology, U-Pb, zircon

External author addresses:

N. Machado
GEOTOP
Université du Québec à Montréal
201, rue Président Kennedy (local PK-7150)
Montréal, QC H2X 3Y7
(514) 987-3000 (ext. 3259)
E-mail: r30404@er.uqam.ca

D.C. Peck
Anglo American Exploration (Canada) Ltd.
700 West Pender Street, Suite 800
Vancouver, BC V6C 1G8
(604) 684-1454
E-mail: dpeck@angloamerican.ca

Published by:
Manitoba Science, Technology, Energy and Mines
Manitoba Geological Survey
360–1395 Ellice Avenue
Winnipeg, Manitoba
R3G 3P2 Canada
Telephone: (800) 223-5215 (General Enquiry)
(204) 945-4154 (Publication Sales)
Fax: (204) 945-8427
E-mail: minesinfo@gov.mb.ca
Website: http://www.gov.mb.ca/minerals

Cover illustration: Concordia diagram for sample 98-94-401-1, foliated metagranodiorite, Cartwright Lake, Lynn Lake greenstone belt, Manitoba.

ABSTRACT

Uranium-lead geochronology results for the Lynn Lake greenstone belt are presented. Three of the six samples collected for this study yielded zircons for analysis. A sample of granodiorite from Cartwright Lake returned an isotope dilution–thermal ionization mass spectrometry (ID-TIMS) age of 1854 ±4 Ma, which is interpreted as the crystallization age. A sample of granodiorite from Burge Lake returned an ID-TIMS age of 1857 ±2 Ma, which is also interpreted as the crystallization age. These plutons are interpreted to be related to Wathaman-Chipewyan successor-arc plutonism along the northern margin of the Kisseynew basin. Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) of detrital zircons from a sample of Sickle Group arkose returned a broad spectrum of ages between 1801 ±15 Ma and 2658 ±35 Ma, indicating a maximum depositional age of ca. 1830 Ma.

TABLE OF CONTENTS

TABLES

FIGURES

Introduction

The Lynn Lake greenstone belt consists of two east-trending supracrustal belts that record ca. 1890–1820 Ma juvenile- and successor-arc magmatism and sedimentation along the northern margin of the Trans-Hudson Orogen. Although much is known about the stratigraphy, geochemistry and mineral deposits of the belt, the temporal evolution of the belt is less well understood. This report presents geochronological data for three samples from the Lynn Lake greenstone belt, collected to constrain the age and tectonic evolution of the belt. Sample selection targeted all the major units in the Lynn Lake belt, with samples representing volcanic, plutonic and the overlying clastic sedimentary rocks. The samples were collected by the third author, and were prepared and analyzed by the second author at the GEOTOP laboratory at the Université du Montréal. Unfortunately, none of the volcanic rocks yielded sufficient zircon for analysis, so results can be reported only for the plutonic and clastic samples.

Regional geology

The Paleoproterozoic Lynn Lake greenstone belt is located within the internal Reindeer Zone (Stauffer, 1984; Lewry and Collerson, 1990) of the Trans-Hudson Orogen. The Lynn Lake belt consists of two east-trending, steeply north-dipping supracrustal belts located along the northern margin of the Kisseynew metasedimentary basin (Figure 1). The supracrustal rocks comprise a diverse tectonostratigraphy of contaminated and juvenile volcanic and epiclastic sedimentary rocks that are collectively assigned to the Wasekwan Group (Bateman, 1945), and younger, synkinematic, fluvial-alluvial molasse-type sedimentary rocks of the Sickle Group (Norman, 1933). The southern Lynn Lake belt is separated from the northern Lynn Lake belt by plutons of the Pool Lake suite (Manitoba Energy and Mines, 1986).

The northern Lynn Lake belt consists of submarine, tholeiitic, mafic and ultramafic volcanic and volcaniclastic rocks, and subordinate epiclastic and chemical sedimentary rocks. The isotopic composition of the northern belt includes contaminated ca. 1890 Ma and juvenile ca. 1865 Ma felsic volcanic rocks (Beaumont-Smith and Böhm, 2002, 2003). Gilbert et al. (1980) interpreted the Lynn Lake belt as a regional-scale overturned antiform, which places the northern belt on the upright macroscopic limb. The subhorizontal macroscopic enveloping surface results in an overall north-facing, steeply dipping volcanic succession (Beaumont-Smith and Böhm, 2004). The identification of regional-scale shear zones, along with the geochemical and isotopically diverse volcanic stratigraphy, suggest a complex early history for the northern belt (Beaumont-Smith and Böhm, 2004).

The southern Lynn Lake belt consists largely of submarine tholeiitic to calcalkaline metavolcanic and metavolcaniclastic rocks, and minor amounts of mid-ocean-ridge basalt (MORB). The southern belt comprises a collage of older (ca. 1890 Ma), isotopically contaminated volcanic rocks, forming the western portion of the southern belt, and a mixture of presumably older and younger (ca. 1855 Ma), juvenile-arc volcanic rocks that make up the balance of the southern belt. The mid-ocean-ridge basalt (MORB), of uncertain age (Zwanzig et al., 1999; Beaumont-Smith and Böhm, 2003), is generally restricted to the western portion of the belt west of Dunphy Lake, where it is structurally intercalated with ca. 1890 Ma contaminated arc-tholeiite basalt. This juxtaposition reflects the intersection of the Granville deformation zone with the contaminated-arc volcanic rocks of the Lynn Lake belt (White et al., 2000; Zwanzig, 2000).

The southern belt has been interpreted as an overturned homoclinal volcanic succession, which represents the overturned limb of the major antiformal structure responsible for the distribution of the northern and southern supracrustal belts (Gilbert et al., 1980). Structural analysis of the Lynn Lake belt demonstrates that the belt is highly transposed (Beaumont-Smith and Rogge, 1999; Beaumont-Smith and Böhm, 2002), and the difference in the geochemistry and isotopic diversity of the northern and southern belts (Zwanzig et al., 1999) suggests a more complex deformational geometry.

Both southern and northern belts are unconformably overlain by clastic successions. To the south, the southern belt is structurally underlain by unconformably overlying (i.e., inverted) fluvial-alluvial conglomerate and arkosic sedimentary rocks of the Sickle Group (Norman, 1933). The Sickle Group also unconformably overlies the Pool Lake intrusive suite, and the basal conglomerate is characterized by a high proportion of proximally derived plutonic clasts. The deposition of the Sickle Group appears to be broadly synkinematic with the main regional deformation responsible for the east-west transposition of the Lynn Lake belt. The age of the Sickle Group has not been determined directly, but it is intruded by the ca. 1830 Ma (post-Sickle) suite of plutons. The composition, stratigraphic position and contact relations of the Sickle Group correlate well with the 1850–1840 Ma MacLennan Group in the La Ronge greenstone belt in Saskatchewan (Ansdell et al., 1999).

The northern belt is unconformably overlain to the north by marine conglomerate and turbiditic metasedimentary rocks, known as the Ralph Lake conglomerate and Zed Lake greywacke, respectively (Gilbert et al., 1980). This clastic succession is largely derived from the supracrustal Wasekwan Group and older plutonic rocks, with the majority of the detrital zircons returning Wasekwan (ca. 1890 Ma) ages (N. Rayner, pers. comm., 2002).

The supracrustal rocks of the Lynn Lake belt are intruded by at least three suites of plutonic rocks. The oldest intrusive rocks are gabbroic to granodioritic plutons that range in age from ca. 1876 to 1871 Ma (Baldwin et al., 1987; Turek et al., 2000). This older suite, together with a second suite of plutons ranging from ca. 1857 Ma (this study) to ca. 1847 Ma (Beaumont-Smith and Böhm, 2003), form the Pool Lake intrusive suite (Manitoba Energy and Mines, 1986). The youngest suite of plutons ranges from ca. 1832 Ma (Turek et al., 2000) to ca. 1820 Ma (Beaumont-Smith and Böhm, 2002). The Pool Lake suite was emplaced into the greenstone belt prior to deposition of the synkinematic Sickle Group, whereas the ca. 1830 Ma plutons (the post-Sickle plutons of Milligan, 1960) intrude all supracrustal rocks in the Lynn Lake belt, including the Sickle

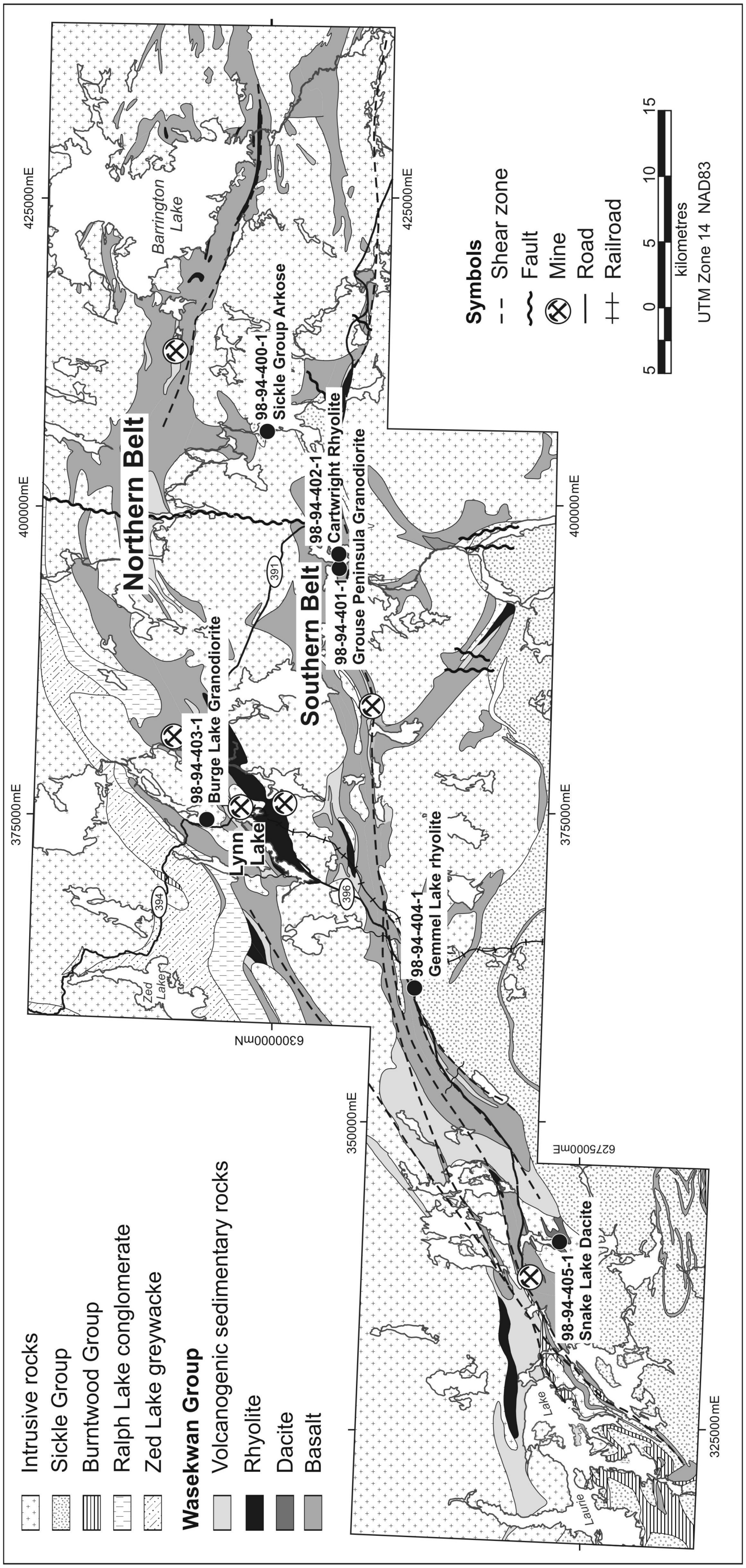


***Figure 1:** General geology of the Lynn Lake greenstone belt, with geochronology sample locations.*

Group. The apparent age distribution of magmatism in the Lynn Lake belt appears to be similar to the early, middle and late successor-arc plutons identified in the Flin Flon Belt (Whalen et al., 1999), thereby suggesting a similar complex magmatic evolution in the Lynn Lake greenstone belt.

Analytical techniques

Six samples, each consisting of 40–50 kg of fresh unaltered rock, were collected for this study: three of volcanic rocks, two of plutonic rocks and one of arkose (Table 1). The samples of volcanic rock did not yield zircon, as is typical of volcanic rocks from the Reindeer Zone of the Trans-Hudson Orogen. All samples collected were crushed with a jaw crusher and disk mill. Mineral separation used a Wilfley™ table, heavy liquids (methylene iodide) and a Frantz™ isodynamic separator. The crusher and disk mill were disassembled and cleaned thoroughly prior to sample crushing. Zircon concentrates were further separated into four magnetic and two diamagnetic (least magnetic) fractions. The least magnetic fractions were hand picked, only those grains that were free of alteration, inclusions and fractures being selected for analysis. Isotope dilution–thermal ionization mass spectrometry (ID-TIMS) zircon analyses were carried out on single-component fractions, or multigrain fractions containing grains with identical morphology and colour. All zircon grains were abraded following the procedure of Krogh (1982). The air pressure for abrasion was regulated so that zircon grains remained intact during the procedure.

Zircon was washed with 7N HNO_3 and H_2O, and dried with acetone prior to dissolution, which was carried out in Teflon bombs with a mixture of HF and 2–4N HNO_3 (Krogh, 1973). Uranium and lead were isolated from zircon with anion exchange resin in HCl medium (Krogh, 1973) in 50–60 µL columns. The reagents used were all purified by sub-boiling distillation. A mixed ^{205}Pb-^{233}U-^{235}U tracer solution was added to each fraction prior to a 4–5 day digestion. Lead and uranium were loaded onto outgassed Re filaments with Si gel and H_3PO_4, and analyzed between 1420 and 1550°C on a VG Sector mass spectrometer equipped with Daly and Faraday detectors. Analytical blanks were below 15 pg Pb and below 2 pg U. All isotope dilution results are quoted at the 95% confidence (2σ) level, and regressions were calculated and data plotted using Isoplot/Ex software (Ludwig, 2000).

Zircons from the arkose were selected for analysis by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), following the same criteria described above for isotope dilution analysis. The selected grains are representative of the zircon population present in the sample in terms of chromatic and morphological characteristics. Of particular interest are the ages of the zircon crystals devoid of or with a minimum of percussion marks, as these are the most likely to yield a minimum age for the deposition of the arkose. For each sample, single-component (without core or overgrowth) zircon grains larger than ~80 µm and devoid of alteration, inclusions and fractures were selected for analysis.

It has been shown that the LA-ICP-MS method yields reliable $^{207}Pb/^{206}Pb$ ages on zircon and monazite using a 1064 nm laser coupled to an ICP-quadrupole mass spectrometer (Feng et al., 1993; Machado and Gauthier, 1996). The method does not yield reliable U-Pb values, but allows the determination of $^{207}Pb/^{206}Pb$ values with a precision better than 10%, generally ~5%. Although $^{207}Pb/^{206}Pb$ ages are, in principle, minimum ages, previous work (Feng et al., 1993; Machado and Gauthier, 1996) shows that they are identical within error to the U-Pb ages measured on the same samples.

A Fisons-VG LaserProbe, coupled to a Fisons-VG PQII$^+$ ICP-MS equipped with a SX-260 type quadrupole and a Galileo discrete dynode Channeltron® electron multiplier, was used for this study. The LaserProbe uses a Spectron SL-242 Nd:YAG 350 mJ pulsed laser operating at 1064 nm with a 40–50 µm beam diameter, which precludes the analysis of grains smaller than 80 µm. The operating conditions are indicated in Table 2. The analytical procedure and other details can be found in Machado and Gauthier (1996). The correction of the mass bias is made relative to an in-house zircon standard (UQ-Z1) analyzed under the same conditions as those used for the samples. This standard has been precisely dated by U-Pb ID-TIMS, and yielded an age of 1143 ±1 Ma (Machado and Gauthier, 1996). The method allows the determination of $^{207}Pb/^{206}Pb$ values with a precision better than 10%, generally ~5%. Although $^{207}Pb/^{206}Pb$ ages are, in principle, minimum ages, previous work (Feng et al., 1993; Machado and Gauthier, 1996) shows that they are identical within error to the U-Pb ages measured on the same samples. The LA-ICP-MS results (Table 4) are quoted at the 70% confidence level.

Table 1: Descriptions of geochronology samples collected during this study.

Sample	Unit	Rock type	Location	UTM zone 14, NAD83	
				Easting	Northing
98-94-400-1	Sickle Group arkose	Well-sorted, feldspathic arkose	Northeast corner of Hughes Lake	405983	6300240
98-94-401-1	Grouse Peninsula granodiorite	Foliated, medium-grained granodiorite	Southern peninsula on Cartwright Lake	396005	6294413
98-94-402-1	Cartwright Lake rhyolite	Aphyric rhyolite	Southeastern Cartwright Lake	396747	6293602
98-94-403-1	Berge Lake granodiorite	Foliated biotite granodiorite	East of Provincial Road 392 at airport	374653	6307108
98-94-404-1	Gemmel Lake rhyolite	Plagioclase porphyritic dacite	West side of Mcveigh road intersection	361567	6288886
98-94-405-1	Snake Lake dacite	Bedded, K-feldspar porphyritic dacite	Southeast side of Snake Lake	340519	6276634

Table 2: Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) operating conditions for analysis of samples from the Lynn Lake greenstone belt.

LaserProbe:	**Fisons VG Nd:YAG at 1064 nm**	
	Laser mode:	Q-switched
	Flash lamp voltage:	590 V
	Frequency:	4 Hz
	Output power:	2–3 mJ
	Pulse width:	5 ns
ICP-MS: Fisons VG PQII+		
	Forward power:	1350 W
	Reflected power:	0 W
	Cool gas:	14 L/m
	Aux. gas:	0.9 L/m
	Carrier gas:	1.1 L/m
Acquisition parameters - peak jumping mode:		
	Dwell time:	10.24 ms
	Quad settle time:	10 ms
	Points/peak:	3
	DAC/step:	1
	Aquisition time:	7 s
	No. of isotopes:	7
	No. of repeats:	5

Gas blank: Mass	**cps**
	(1σ)
202	730 ±150
204	180 ±60
206	70 ±30
207	130 ±60
208	153 ±70
232	8 ±8
235	11 ±10
238	9 ±9

Typical net intensities on the standard UQ-Z1:

	cps	**Sensitivity: (cps/ppm)**
^{202}Hg	5–50	not determined
^{204}Pb	<15	<LOD
^{206}Pb	20000–30000	530–798
^{207}Pb	1800–2200	620–760
^{208}Pb	1800–2200	581–710
^{232}Th	10000–12000	158–190
^{235}U	800–1200	444–667
^{238}U	100000–160000	400–625

Results

Sample 98-94-401-1

This sample of a medium-grained, foliated metagranodiorite, collected from the northern end of southern peninsula on Cartwright Lake, is thought to represent an intrusive equivalent of the adjacent calcalkaline volcanic rocks of the Wasekwan Group, based on petrogenetic modelling (Peck, 1986). The sample yielded a small amount of poor quality zircon, with most crystals displaying core-overgrowth textures. The analytical strategy adopted involved choosing for analysis pyramidal terminations physically separated from the core-bearing crystals in order to maximize the possibility of analyzing exclusively the magmatic component. Three fractions were prepared for analysis: fraction 1 contained two pyramidal terminations displaying parallel zoning, possibly of magmatic origin; and fractions 2 and 3 contained three and four similar pyramidal terminations, respectively. The three analyses are between 2.1% and 7% discordant (Table 3, Figure 2) and define a discordia line with an upper intercept at 1854 ±4 Ma, taken as the age of crystallization of the granodiorite.

Sample 98-94-403-1

This sample of biotite granodiorite from the pluton southeast of Burge Lake (‘Burge Lake pluton’) was collected from the power line right-of-way northeast of Provincial Road 394, approximately 1 km northeast of the northern limit of the Lynn Lake airport compound. This sample is a homogeneous unit in outcrop, aside from minor late, massive, pink aplite veins that were avoided during sample collection. The sample yielded a moderate amount of zircon. Many of the crystals are primary, but many also display cores, and colourless metallic inclusions are ubiquitous. Three fractions of short, prismatic, subequant and colourless crystals without obvious cores were prepared for analysis. Fraction 1 consisted of a single, pale pink zircon with a colourless inclusion. Fraction 2 consisted of the four best crystals that were smaller than the one in fraction 1; these grains also contained small colourless inclusions. Fraction 3 consisted of eight smaller crystals of poorer quality with a few fractures and more colourless inclusions than the zircons in either fraction 1 or 2. Analyses 1 and 2 are concordant at 1857 Ma and 1856 Ma, respectively, whereas analysis 3 is 4.8% discordant (Table 3, Figure 3). The three analyses define a discordia with an upper intercept at 1857 ±2 Ma, which is taken as the age of crystallization of this granodiorite.

Sample 98-94-400-1

This sample of moderately well sorted Sickle Group arkose was collected from an outcrop approximately 30 m west of the northwestern shore of Hughes Lake (Table 4, Figure 4). Zircons are mostly rounded and pitted, but a few subrounded and equant crystals are also present. The $^{207}Pb/^{206}Pb$ ages range from 2658 ±35 Ma to 1801 ±15 Ma and are distributed in two groups: one in the interval 1800–2100 Ma, with a prominent mode in the 1800–1900 Ma class; and the other in the interval 2200–2700 Ma, with most ages in the 2200–2400 Ma class. Taking into consideration the errors associated with the method, the ages of the younger crystals — 1801 ±30 Ma to 1835 ±34 Ma (at the 95% confidence level) — suggest that the maximum age of deposition for the Sickle Group arkose is 1.83 Ga.

Discussion

The ages of the two plutonic samples are consistent with ages reported for Wathaman-Chipewyan batholitic rocks throughout the northern Trans-Hudson Orogen (Corrigan et al., 2001; Rayner and Corrigan, 2004), and represent the first Wathaman-Chipewyan ages reported in the Lynn Lake belt. They are younger than the ca. 1875 Ma ages of pre–Sickle Group plutonic rocks reported by Baldwin et al. (1987) and Turek et al. (2000), and slightly older than the ca. 1847 Ma age of the Dunphy Lake tonalite (Beaumont-Smith and Böhm, 2003). One implication of the identification of two pre-Sickle suites of intrusive rocks, as determined by age, is that, other than plutons that clearly intrude the Sickle Group, map patterns within the volcanic-dominated portions of the belt are not a useful criterion for the determination of pluton age. This is particularly evident in the examples of the post–Sickle Group plutons in the western portion of the belt (Figure 5).

The age of the Burge Lake pluton provides several important constraints on the tectonic evolution of the Lynn Lake belt. The ca. 1857 Ma age provides a minimum age for the Ralph Lake conglomerate and Zed Lake greywacke, as it intrudes both units. Secondly, the pluton appears to stitch the northern margin of the northern Lynn Lake belt prior to the regional transpositional D_2 deformation; thus, it represents a minimum age for this deformation.

The Wathaman-Chipewyan age of the Grouse Peninsula granodiorite (1854 ±4 Ma) is significant in light of its interpretation as the intrusive equivalent of the Cartwright Lake rhyolite (Peck, 1986). Although largely based on their geochemical similarity, this interpretation and the implication of a younger age of volcanism in the Lynn Lake belt are further supported by the determination of similar ages of felsic volcanism elsewhere in the Lynn Lake belt (Beaumont-Smith and Böhm, 2003).

The analysis of detrital zircons from the Sickle Group arkose yielded a broad spectrum of ages, reflecting the varied provenance of material shed into the Kisseynew Basin. The majority of the zircons analyzed reflect relatively local provenance, with ages dominated by supracrustal and plutonic rocks in the map area. Unfortunately, the precision of LA-ICP-MS does not allow for a precise estimate of the age of deposition of the Sickle Group. The youngest dated zircon (1801 ±15 Ma) suggests an age of deposition that is slightly younger than the accepted age for similar rocks in the La Ronge greenstone belt in Saskatchewan (Ansdell et al., 1999), but the morphology of the zircons does not preclude the possibility that this zircon is metamorphic (*see* Beaumont-Smith and Böhm, 2003). The multiple ca. 1830 Ma zircon ages more likely reflect the maximum age of Sickle Group deposition. The older ages suggest that both Archean and early Proterozoic basement rocks were exposed within the basin. The Archean ages probably represent sediment shed from the Hearne Province hinterland to the Trans-Hudson Orogen. The early Proterozoic ages span a range

Table 3: Isotope dilution–thermal ionization mass spectrometry (ID-TIMS) U-Pb analytical data for samples of intrusive rocks, Lynn Lake greenstone belt.

Analysis	Mineral (no. of grains)(1)	Weight (mg)	Concentration (ppm)(3)			Pb_{common} (pg)(4)	Atomic ratios(6)							Apparent ages (Ma)			Discordance (%)
			Pb_{rad}(2)	U	Th		$^{206}Pb/^{204}Pb$(5)	$^{207}Pb/^{235}U$	Error (% @ 1σ)	$^{206}Pb/^{238}U$	Error (% @ 1σ)	$^{207}Pb/^{206}Pb$	Error (% @ 1σ)	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$	
Metagranodiorite, northern end of southern peninsula on Cartwright Lake (sample 98-94-401):																	
401-1	Z (2)	0.002	231.1	739.8	131	29	1030	4.872	0.23	0.311	0.21	0.114	0.06	1797	1745	1859	7.0
401-2	Z (3)	0.001*	268*	812*	171*	21	828	5.101	0.27	0.326	0.25	0.113	0.10	1836	1820	1854	2.1
401-3	Z (4)	0.003	212.5	656.1	105.7	17	2371	5.071	0.27	0.324	0.24	0.114	0.13	1831	1808	1857	3.0
Biotite granodiorite, Burge Lake pluton (sample 98-94-403):																	
403-1	Z (1)	0.015	42.7	124.0	36.7	35.0	1136	5.212	0.21	0.333	0.19	0.114	0.08	1854	1852	1857	Conc.
403-2	Z (4)	0.006	59.6	172.7	52.5	6.3	3486	5.213	0.22	0.333	0.21	0.114	0.11	1855	1853	1856	Conc.
403-3	Z (8)	0.018	80.0	243.1	69.5	22.0	3997	4.985	0.16	0.318	0.16	0.114	0.05	1817	1781	1858	4.8

Notes:

(1) Z, zircon (number of grains indicated in parentheses)

(2) radiogenic Pb

(3) Concentrations are known to 20% for weights below 20 µg. An asterisk indicates that sample weight is below the sensitivity of the microbalance (below 1 µg); therefore, listed concentrations are minimum values.

(4) Total common Pb present in analysis corrected for Pb in spike.

(5) Measured ratio, corrected for fractionation only.

(6) Ratios corrected for spike, fractionation, blank and initial common Pb. Errors quoted are in % at the 1σ confidence level.

Maximum total blanks for zircon analyses are 15 pg for Pb and 2 pg for U.

Isotopic composition of initial common Pb was calculated using the two-stage model of Stacey and Kramers (1975).

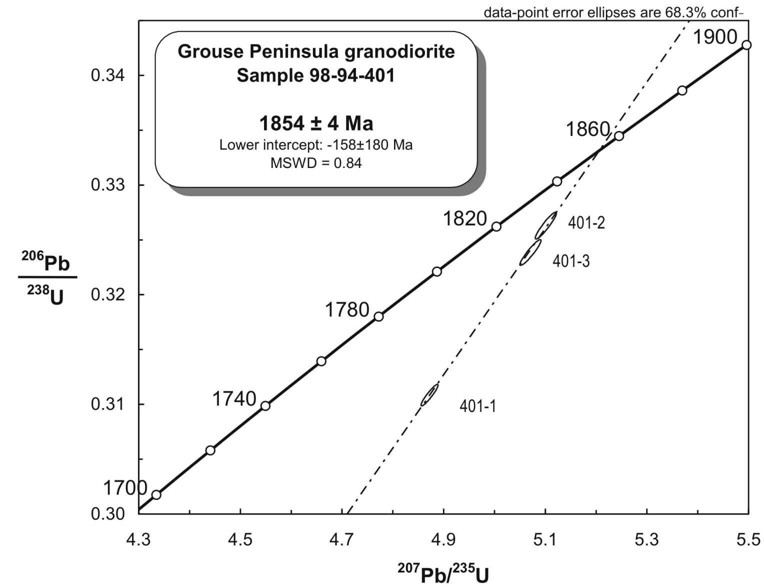


***Figure 2:** Concordia diagram for sample 98-94-401-1, foliated metagranodiorite, Cartwright Lake, Lynn Lake greenstone belt.*

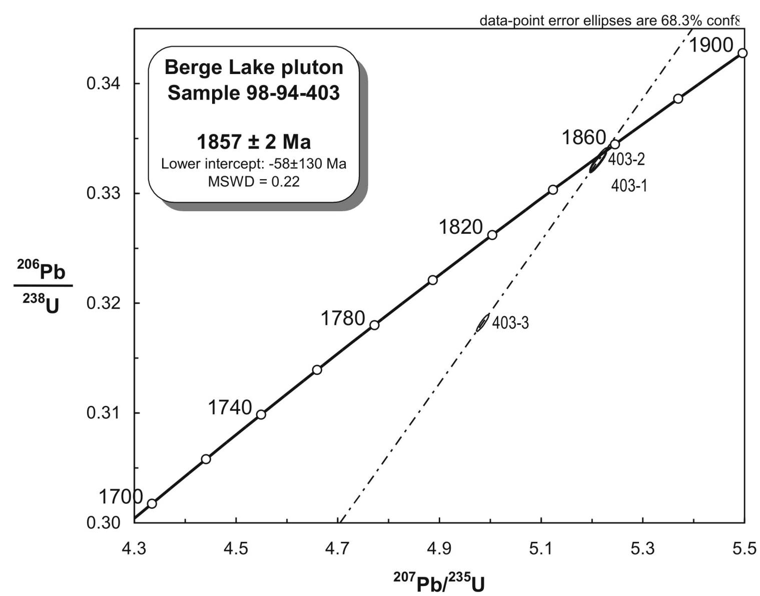


***Figure 3:** Concordia diagram for sample 98-94-403-1, biotite granodiorite, Burge Lake pluton, Lynn Lake greenstone belt.*

consistent with that of the Sask Craton and are the result either of the incorporation of material shed from exposed Sask Craton or of inherited zircons derived from the Sask Craton. Although the former interpretation is possible and known from the southern margin of the Kisseynew basin (Lucas et al., 1996), the later interpretation is favoured based on the demonstration of Sask Craton–age inheritance in the Southern Indian Lake area (*see* Rayner and Corrigan, 2004).

Summary

The results of a U-Pb geochronology study in the Lynn Lake greenstone belt demonstrate that Wathaman-Chipewyan-age plutonism is spatially continuous along the northern flank of the Trans-Hudson Orogen in Saskatchewan and Manitoba. A sample of Burge Lake biotite granodiorite returned a U-Pb zircon age of 1857 ±2 Ma, and a sample of Grouse Peninsula granodiorite was dated at 1854 ±4 Ma. A previous interpretation, that the Grouse Peninsula granodiorite is the intrusive equivalent to the Cartwright Lake rhyolite, suggests that the Lynn Lake greenstone belt contains at least two different ages of felsic volcanism (ca. 1890 Ma and ca. 1855 Ma).

Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) analysis of detrital zircon from a sample of Sickle Group arkose from the Hughes Lake area yields a broad spectrum of Neoarchean to Paleoproterozoic ages. The oldest Neoarchean age suggests involvement of the Hearne Province at the time of Kisseynew basin infill. A number of Early Paleoproterozoic zircons suggest the presence

Table 4: Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) $^{207}Pb/^{206}Pb$ analytical data for sample 98-94-400-1, Sickle Group arkose, Hughes Lake, Lynn Lake greenstone belt.

Sample	Grain #	Age	+/-
98-94-400			
DIA	1	2316	9
N=13	2	2297	18
	3	1853	25
	4	1801	15
	5	1830	41
	6	1971	51
	7	1931	40
	8	1951	74
	9	1868	50
	10	1835	17
	11	2274	20
	12	2658	35
	13	2037	49
M1	14	2048	56
N=11	15	1894	33
	16	1872	17
	17	2347	21
	18	1880	13
	19	2286	42
	20	1857	47
	21	2338	18
	22	2424	25
	23	2400	22
	24	2513	14
	Max.	2658	35
	Min.	1801	15

DIA, diamagnetic zircons

M1, zircons magnetic at 1º of the Frantz chute

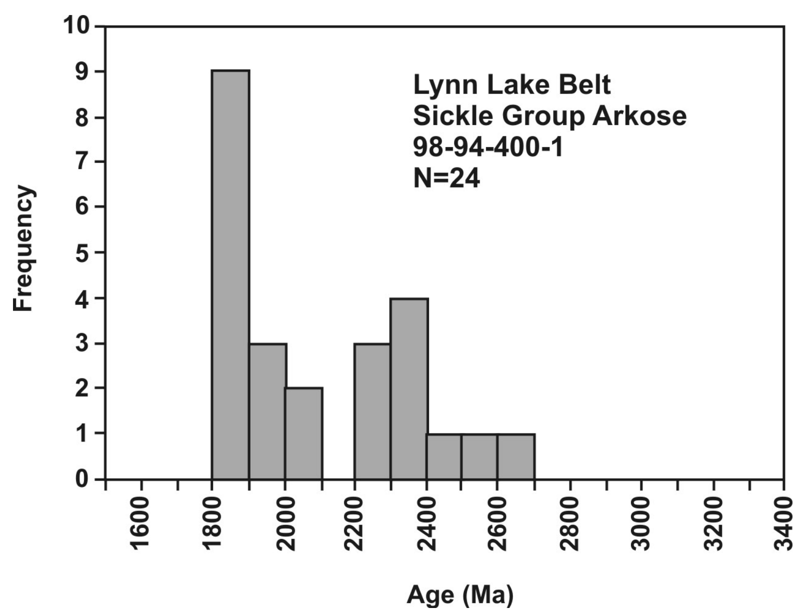


Figure 4: *Histogram of laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS)* $^{207}Pb/^{206}Pb$ *analytical data for sample 98-94-400-1, Sickle Group arkose, Hughes Lake, Lynn Lake greenstone belt.*

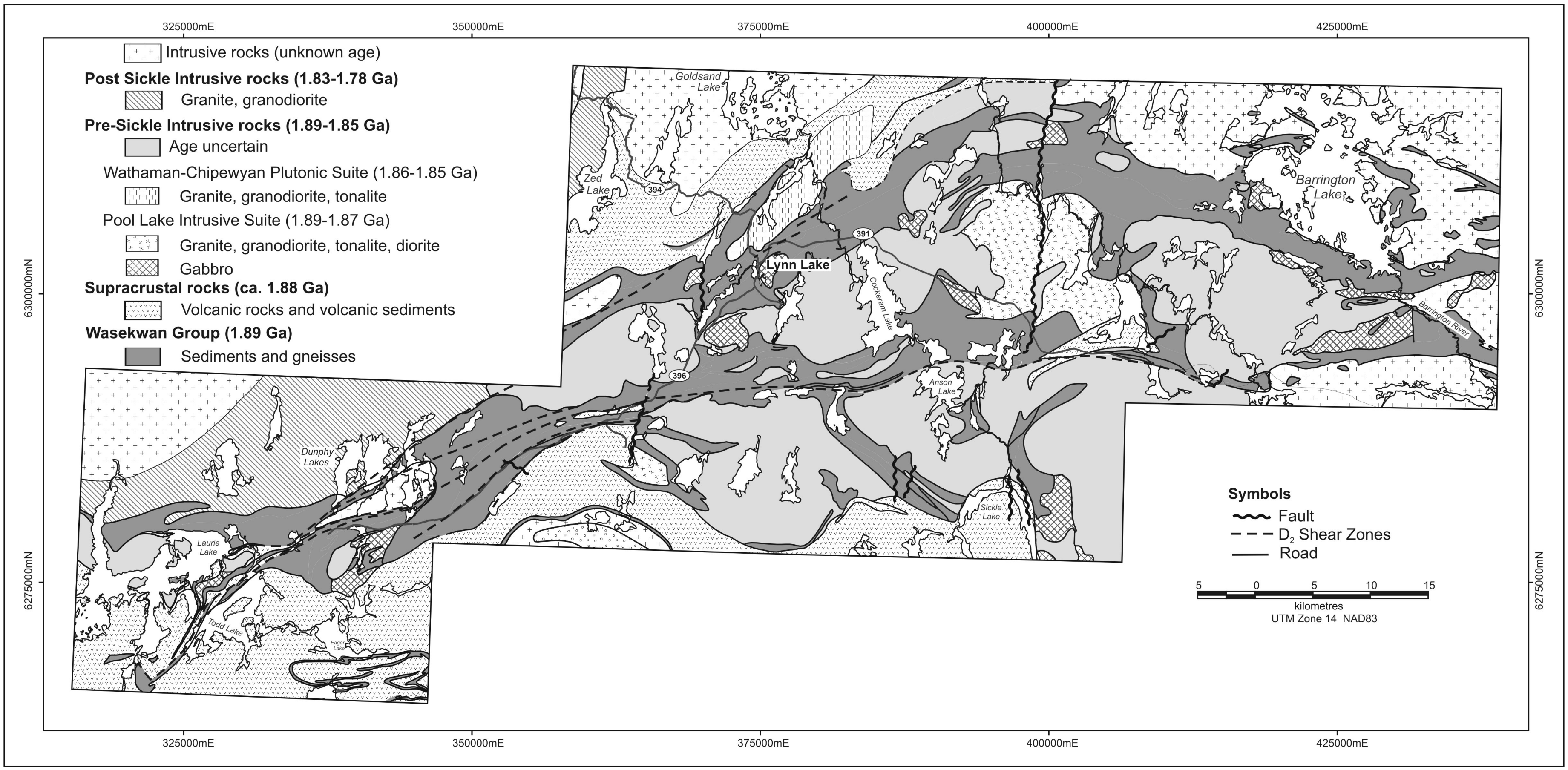


Figure 5: *Geology of the Lynn Lake greenstone belt, including the subdivision of plutons based on available geochronology data (based on additional data from Baldwin et al., 1987; Beaumont-Smith and Böhm, 2002, 2003; Turek et al., 2000).*

of Sask Craton within the internal portion of the Trans-Hudson Orogen. The zircon analysis yielded a single ca. 1800 Ma age, which may represent metamorphic zircon growth, whereas a number of ca. 1830 Ma zircons are probably representative of the maximum age of deposition of the Sickle Group.

Acknowledgments

N.M. acknowledges financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) and is grateful to G. Gauthier (Université de Montréal) for the time and effort spent to obtain the detrital zircon results. Christian Böhm and Herman Zwanzig are thanked for illuminating discussions on the geology and geochronology of the Lynn Lake area. Ed Kowalyk provided enthusiastic field assistance during the sampling. The thorough reviews of Tim Corkery and Scott Anderson greatly improved the manuscript.

References

Ansdell, K.M., Corrigan, D., Stern, R. and Maxeiner, R. 1999: SHRIMP U-Pb geochronology of complex zircons from Reindeer Lake, Saskatchewan: implications for timing of sedimentation and metamorphism in the northwestern Trans-Hudson Orogen; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, v. 24, p. 3.

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A. and Stevens, R.P. 1987: U-Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: two ages of Proterozoic magmatism; Canadian Journal of Earth Sciences, v. 24, p. 1053–1063.

Bateman, J.D. 1945: McVeigh Lake area, Manitoba; Geological Survey of Canada, Paper 45-14, 34 p.

Beaumont-Smith, C.J. and Böhm, C.O. 2002: Structural analysis and geochronological studies in the Lynn Lake greenstone belt and its gold-bearing shear zones (NTS 64C10, 11, 12, 14, 15 and 16), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 159–170.

Beaumont-Smith, C.J. and Böhm, C.O. 2003: Tectonic evolution and gold metallogeny of the Lynn Lake greenstone belt, Manitoba (NTS 64C10, 11, 12, 14, 15 and 16), Manitoba; *in* Report of Activities 2003, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 39–49.

Beaumont-Smith, C.J. and Böhm, C.O. 2004: Structural analysis of the Lynn Lake greenstone belt, Manitoba; *in* Report of Activities 2004, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 55–68.

Beaumont-Smith, C.J. and Rogge, D.M. 1999: Preliminary structural analysis and gold metallogeny of the Johnson Shear Zone, Lynn Lake greenstone belt (parts of NTS 64C/10, 11, 15); *in* Report of Activities 1999, Manitoba Energy and Mines, Geological Services, p. 61–66.

Corrigan, D., Maxeiner, R.O. and Harper, C.T. 2001: Preliminary U-Pb results from the La Ronge – Lynn Lake bridge project; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 2001-4.2, CD-ROM, p. 111–115.

Feng, R., Machado, N. and Ludden, J. 1993: Lead geochronology of zircon by LaserProbe inductively coupled plasma mass spectrometry; Geochimica et Cosmochimica Acta, v. 57, p. 3479–3486.

Gilbert, H.P., Syme, E.C. and Zwanzig, H.V. 1980: Geology of the metavolcanic and volcaniclastic metasedimentary rocks in the Lynn Lake area; Manitoba Energy and Mines, Geological Services, Geological Paper GP80-1, 118 p.

Krogh, T.E. 1973: A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations; Geochimica et Cosmochimica Acta, v. 37, p. 485–494.

Krogh, T.E. 1982: Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique; Geochimica et Cosmochimica Acta, v. 46, p. 637–649.

Lewry, J.F., and Collerson, K.D. 1990: The Trans-Hudson Orogen: extent, subdivisions and problems; *in* J.F. Lewry and M.R. Stauffer (ed.), The Early Proterozoic Trans-Hudson Orogen of North America, Geological Association of Canada, Special Paper 37, p. 1–14.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, p. 602–629.

Ludwig, K.L. 2000: Users manual for Isoplot/Ex v. 2.3: a geochronological toolkit for Microsoft Excel; Berkeley Geochronology Centre, Berkeley, California, Special Publication 1a.

Machado, N. and Gauthier, G. 1996: Determination of $^{207}Pb/^{206}Pb$ ages on zircon and monazite by laser ablation-ICPMS and application to a study of sedimentary provenance and metamorphism in southeastern Brazil; Geochimica et Cosmochimica Acta, v. 60, p. 5063–5073.

Manitoba Energy and Mines 1986: Granville Lake, NTS 64C; Manitoba Energy and Mines, Minerals Division, Bedrock Geology Compilation Map Series, NTS 64C, scale 1:250 000.

Milligan, G.C. 1960: Geology of the Lynn Lake district; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 57-1, 317 p.

Norman, G.W.H. 1934: Granville Lake district, northern Manitoba; Geological Survey of Canada, Summary Report, 1934, Pt. C, p. 23–41.

Peck, D.C. 1986: The geology and geochemistry of the Cartwright Lake area: Lynn Lake greenstone belt, northwestern Manitoba; M.Sc. thesis, University of Windsor, Windsor, Ontario, 270 p.

Rayner, N. and Corrigan, D. 2004: Uranium-lead geochronological results from the Churchill River–Southern Indian Lake transect, northern Manitoba; Geological Survey of Canada, Current Research 2004-F1, 14 p.

Stacey, J.S. and Kramers, J.D. 1975: Approximation of terrestrial lead isotope evolution by a two-stage model; Earth Planetary Science Letters, v. 6, p. 15–25.

Stauffer, M.R. 1984: Manikewan: an Early Proterozoic ocean in central Canada, its igneous history and orogenic closure; Precambrian Research, v. 25, p. 257–281.

Turek, A., Woodhead, J. and Zwanzig, H.V. 2000: U-Pb age of the gabbro and other plutons at Lynn Lake (parts of NTS 64C); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 97–104.

Whalen, J.B., Syme, E.C. and Stern, R.A. 1999: Geochemical and Nd isotopic evolution of Paleoproterozoic arc-type granitoid magmatism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; *in* NATMAP Shield Margin Project, Volume 1, S.B. Lucas (ed.), Canadian Journal of Earth Sciences, v. 36, no. 2, p. 227–250.

White, D.J., Zwanzig, H.V. and Hajnal, Z. 2000: Crustal suture preserved in the Paleoproterozoic Trans-Hudson Orogen, Canada; Geology, v. 29, p. 527–530.

Zwanzig, H.V. 2000: Geochemistry and tectonic framework of the Kisseynew Domain–Lynn Lake belt boundary (part of NTS 64P/13); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 91–96.

Zwanzig, H.V., Syme, E.C. and Gilbert, H.P. 1999: Updated trace element geochemistry of the ca. 1.9 Ga metavolcanic rocks in the Paleoproterozoic Lynn Lake belt; Manitoba Industry, Trade and Mines, Geological Services, Open File Report 99-13, 46 p. plus accompanying map and diskette.