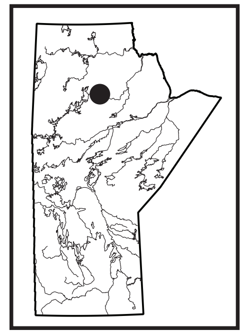
GS-12 Evidence of juvenile-arc magmatism at Northern Indian Lake: implications for base-metal exploration in north-central Manitoba (parts of NTS 64H3, 5, 6)

by T. Martins and C.R.M. McFarlane[1]



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Summary

This report presents new data from the Northern Indian Lake pluton—a composite tonalite to granodiorite intrusion hosted by volcanic and sedimentary rocks at Northern Indian Lake, in the northeastern extent of the Southern Indian Lake domain of the Trans-Hudson orogen. Whole-rock geochemical results indicate that the Northern Indian Lake pluton likely formed in a mature volcanic-arc setting. Zircons from the intrusion yield a robust U-Pb age of 1889 ±4 Ma, which is interpreted as the crystallization age of the pluton, making it one of the oldest known intrusions of this type in the Trans-Hudson orogen. Similar-aged subvolcanic intrusions elsewhere in the Trans-Hudson orogen, such as the Sneath Lake pluton in the Chisel basin of the Snow Lake belt, are associated with major volcanogenic massive-sulphide deposits, where they are thought to represent the heat source that drove seafloor hydrothermal-circulation systems from which the deposits formed. By extension, the pluton at Northern Indian Lake may indicate similar base-metal potential in a region that has traditionally been underexplored in comparison to the Lynn Lake, Rusty Lake, Flin Flon and Snow Lake belts.

Introduction

Northern Indian Lake is located along the Churchill River approximately 170 km northwest of Thompson, Manitoba (Figure GS-12-1). This part of the Trans-Hudson orogen (THO) has seen little to no exploration activity in the past several decades, and the most recent geological mapping in this area (1:50 000 scale) was conducted in 2014 by the Manitoba Geological Survey (MGS; Kremer and Martins, 2014a, b).

Samples collected during MGS mapping in the Southern Indian Lake area (Kremer et al., 2009a, b; Martins and Kremer, 2013; Martins, 2015a, b) have yielded anomalous values of base and precious metals, indicating potential for a number of different styles of mineralization, including volcanogenic massive-sulphide (VMS) deposits. During the 2014 field program at Northern Indian Lake, representative samples of different rock units were collected and have been studied in detail. Whole-rock geochemistry and geochronology results from a major pluton in the area have implications for VMS potential and are presented in this report, adding to the previously identified economic potential of the region (e.g., Corrigan et al., 2007; Kremer et al., 2009a, b; Martins, 2015a, b).

Regional geology

The Southern Indian domain is one of three major tectonostratigraphic entities that define the northern flank of the Reindeer zone of the THO in Manitoba (Figure GS-12-1). It is composed mainly of variably migmatitic metasedimentary rocks, with rare supracrustal belts dominated by metavolcanic rocks, which have been historically assigned to the Sickle and Wasekwan groups, respectively (i.e., Cranstone, 1972; Frohlinger, 1972). The Southern Indian domain is bounded to the south by the volcanic-dominated Lynn Lake–Leaf Rapids domain, and is intruded to the north by the voluminous ca. 1.86–1.85 Ga Wathaman-Chipewyan batholith (Chipewyan domain), which stitches the Reindeer zone along the southern margin of the Hearne craton. At Northern Indian Lake, metasedimentary and metaplutonic rocks that are part of the Southern Indian domain occur alongside granitoid rocks of the Chipewyan domain (Kremer and Martins, 2014a).

Based on recent mapping and results from lithogeochemical and geochronological analyses (Rayner and Corrigan, 2004; Kremer, 2008a, b; Kremer et al., 2009a, b), supracrustal rocks of the Southern Indian domain have been subdivided into several distinct lithotectonic assemblages. Massive to pillowed, juvenile basaltic rocks and associated basinal sedimentary rocks make up the Pukatawakan Bay assemblage (Kremer, 2008a, b). At Southern Indian Lake, this assemblage is intruded by the ca. 1890 Ma Turtle Island complex (Rayner and Corrigan, 2004), which provides a minimum age of deposition. The Turtle Island complex is a layered, intermediate to ultramafic intrusion of dikes and sills, and is similar in age to, and possibly represents the subvolcanic equivalent of, bimodal continental-arc volcanic and volcaniclastic rocks that constitute the Partridge Breast Lake assemblage. Both the Pukatawakan Bay and Partridge Breast Lake assemblages are intruded by several generations of plutonic rocks ranging in age from ca. 1880 to 1830 Ma, and are unconformably overlain by fluvial-alluvial

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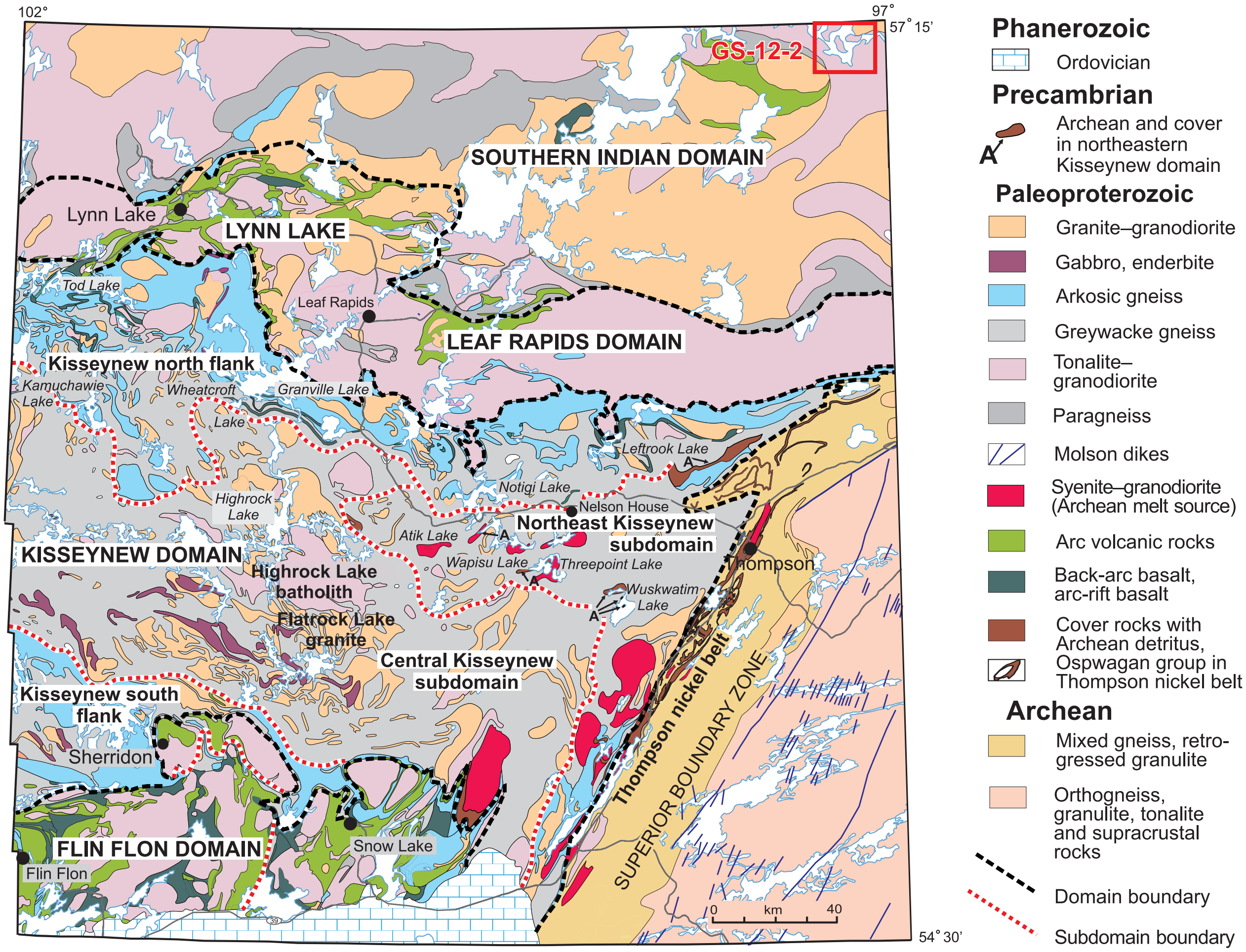


***Figure GS-12-1:** Simplified regional geology of the northern flank of the Reindeer zone, showing the several domains and subdomains of the THO in Manitoba (after Zwanzig and Bailes, 2010). Red square locates the 2014 Northern Indian Lake mapping project.*

sedimentary rocks with maximum age constraints ranging from ca. 1860 to 1830 Ma (Rayner and Corrigan, 2004; Kremer et al., 2009b).

Geology of the Northern Indian Lake pluton

In this part of the Southern Indian domain, the metavolcanic and metasedimentary rocks are highly deformed and are preserved as large screens and xenoliths within several phases of younger felsic plutonic rocks (Kremer and Martins, 2014a, b; Figure GS-12-2). The Northern Indian Lake pluton is the oldest granitoid unit identified during the 2014 mapping project and it is found frequently as xenoliths within the younger granitoid units.

Granodiorite and tonalite of the Northern Indian Lake pluton are white to beige, medium to coarse grained and strongly foliated (Kremer and Martins, 2014a; Figure GS-12-3). The pluton is composed of quartz (23–40%), plagioclase (26–30%), K-feldspar (5–20%), biotite (5–9%), hornblende (4–12%), titanite (1–2%) and trace amounts (<1%) of zircon, apatite, disseminated pyrite and magnetite. Rare myrmekite intergrowths are present and minor replacement of plagioclase and potassium feldspars is observed. Biotite, hornblende and titanite form aggregates that define the foliation in the unit. Titanite is subhedral to euhedral and occurs mainly associated with hornblende and biotite. Zircon is found mainly as inclusions in hornblende and biotite.

Partially digested xenoliths of metasedimentary and gabbroic rocks are common in this unit (Figure GS-12-3) but do not occur in all exposures. Locally, the xenoliths account for up to 60% of some exposures. The xenoliths vary from angular to rounded, are highly flattened and vary in size from 5 to 75 cm. Dikes of pegmatite up to 30 cm wide intrude this unit and locally contain up to 10% magnetite (Kremer and Martins, 2014a).

Methodology

The samples described in this report were collected during bedrock mapping at Northern Indian Lake in 2014 (Kremer and Martins, 2014a). The samples collected

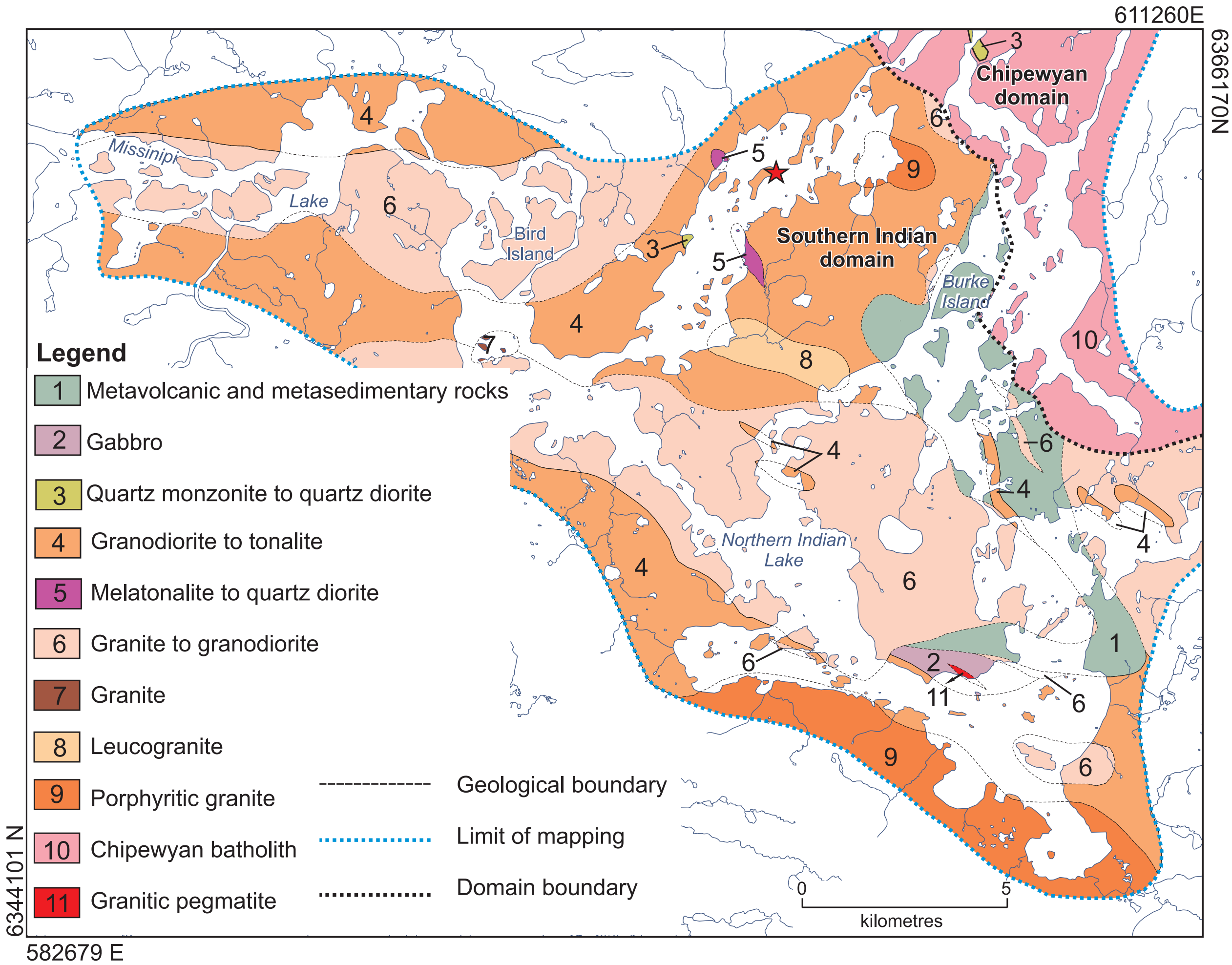


Figure GS-12-2: *Simplified geology of the Northern Indian Lake area (after Kremer and Martins, 2014a). Red star marks the location of the geochronology sample.*

Figure GS-12-3: *Outcrop photograph of strongly foliated hornblende-biotite granodiorite to tonalite (unit 4) with resorbed xenoliths, Northern Indian Lake (Kremer and Martins, 2014a, b).*

for whole-rock geochemistry consisted of about 5 kg of least altered and homogeneous granodiorite, whereas the sample collected for geochronology (sample 113-14-1112) consisted of 10–15 kg of the same material. Samples were trimmed to remove weathered surfaces, altered fractures or inhomogeneities, and the clean rock pieces were crushed, pulverized and homogenized at the MGS Midland Sample and Core Library for whole-rock geochemistry. The powders were submitted to Activation Laboratories Ltd. (Ancaster, Ontario) and underwent dissolution by lithium metaborate/tetraborate fusion followed by nitric-acid digestion, with analysis by inductively coupled plasma–emission spectroscopy (ICP-ES) for the major elements and selected trace elements (Ba, Sc, Sr, V, Y, Zr), and by inductively coupled plasma–mass spectrometry (ICP-MS) for trace- and rare-earth elements.

Zircon grains from the granodiorite were liberated by a combination of electro-pulse disaggregation and heavy-mineral concentration by Overburden Drilling Management Limited (ODM). The clearest euhedral zircon grains were hand-picked using a binocular microscope, mounted in epoxy and polished to their centres. Prior to analysis, the grains were imaged using transmitted- and reflected-light microscopy and with an optical cathodoluminescence (CL) system. The zircon grains were dated by laser-ablation ICP-MS. Zircons in grain mount were analyzed with a crater size of 26 µm, a 3 Hz repetition rate and a 30 s ablation time following 30 s of background collection (refer to DRI2016006[2] for detailed analytical description). The ICP-MS data file (data as counts/sec) and laser-sequence log file were combined offline in Iolite version 3.32 and ages calculated using the VizualAge U-Pb geochronology data-reduction scheme described by Petrus and Kamber (2012).

Results

Whole-rock geochemistry

Representative whole-rock geochemical data for the Northern Indian Lake pluton are given in Table GS-12-1 and plotted on discriminant diagrams designed to identify tectonic environments of magma

Table GS-12-1: Representative whole-rock geochemical analyses for the Northern Indian Lake pluton.

Sample:	113-14-1112[(1)]	113-14-1129	107-14-134
Oxides (wt.%):			
SiO_2	62.96	70.93	68.64
Al_2O_3	16.77	15.2	14.92
$Fe_2O_3^t$	5.58	2.83	3.91
MnO	0.084	0.028	0.053
MgO	2.61	0.54	1.53
CaO	5.18	1.02	3.48
Na_2O	4.27	2.98	3.68
K_2O	2.06	5.91	2.97
TiO_2	0.527	0.441	0.329
P_2O_5	0.19	0.12	0.11
LOI	0.66	0.62	0.56
Total	100.9	100.6	100.2
Trace elements (ppm):			
Sc	11	5	8
Be	1	1	2
V	89	29	61
Ba	789	1355	791
Sr	551	220	409
Y	14	24	14
Zr	101	370	111
Cr	60	20	40
Co	16	3	10
Ni	40	<20	20
Cu	10	<10	40
Zn	70	60	50
Ga	20	20	17
Ge	1	1	2
As	<5	<5	<5
Rb	59	194	65
Nb	5	13	5
Trace elements (ppm):			
Mo	<2	2	<2
Ag	0.9	2.3	0.5
In	<0.2	<0.2	<0.2
Sn	1	2	1
Sb	<0.5	<0.5	<0.5
Cs	0.9	0.6	0.7
La	19.6	131	23
Ce	38.8	260	43.4
Pr	4.58	27.5	4.66
Nd	18	92.2	16.1
Sm	3.2	13.5	3
Eu	0.87	1.09	0.58
Gd	2.6	7.3	2.6
Tb	0.4	1	0.4
Dy	2.2	4.9	2.3
Ho	0.4	0.9	0.5
Er	1.3	2.4	1.7
Tm	0.2	0.34	0.26
Yb	1.3	1.9	1.6
Lu	0.2	0.26	0.26
Hf	2.4	8.4	3.1
Ta	0.3	0.5	0.3
W	<1	1	<1
Tl	0.4	1	0.3
Pb	6	22	9
Bi	<0.4	<0.4	<0.4
Th	4	39.7	6.5
U	0.6	2	1.4

[(1)] sample used for geochronology
Abbreviations: LOI, loss-on-ignition

[2] MGS Data Repository Item DRI2016006, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Growth, Enterprise and Trade, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

genesis (Figure GS-12-4a). The data show that these rocks likely formed in a volcanic-arc environment: rare-earth element (REE) diagrams indicate an affinity with mature-arc felsic volcanic rocks, with elevated light rare-earth element contents and with heavy rare-earth element contents at 10 times chondrite (Figure GS-12-4b). The overall geochemical characteristics are similar to, but show significant differences from, comparable data from VMS-associated felsic magmatic rocks of similar age in the THO (Figure GS-12-4b, c), including the Sneath Lake pluton (Snow Lake belt; Bailes and Galley, 1999) and the Lynn Lake rhyolite (Beaumont-Smith, 2008). The geochemical similarities likely reflect a common origin in a volcanic-arc setting, whereas the differences probably reflect subtle differences in petrogenesis, likely related, in part, to emplacement depth (e.g., Hart et al., 2004).

Both the Northern Indian Lake pluton and the Lynn Lake rhyolite show chemical affinity to FI and FII felsic rocks (Hart et al., 2004; Figure GS-12-4d), with $(La/Yb)_n$ values of 7.13–45.13 and 6.00–7.49, respectively; gently sloping REE patterns (Figure GS-12-4b); and high to moderate Zr/Y values of 4.90–11.91 and 6.67–7.70, respectively. In contrast, the data for the Sneath lake pluton plot in the area corresponding to FIIIa and FIV felsic rocks (Hart et al., 2004), with $(La/Yb)_n$ values of 0.46–2.31, flat REE patterns (Figure GS-12-4b) and low Zr/Y (2.01–8.40).

Geochronology

Zircons extracted from the Northern Indian Lake pluton are colourless to pale brown and vary from elongate (3:1 aspect ratio) to equant (100–300 µm long). They show a combination of planar oscillatory and local sector zoning, as revealed by optical and CL imaging. Most of the grains display microfractures and terminations,

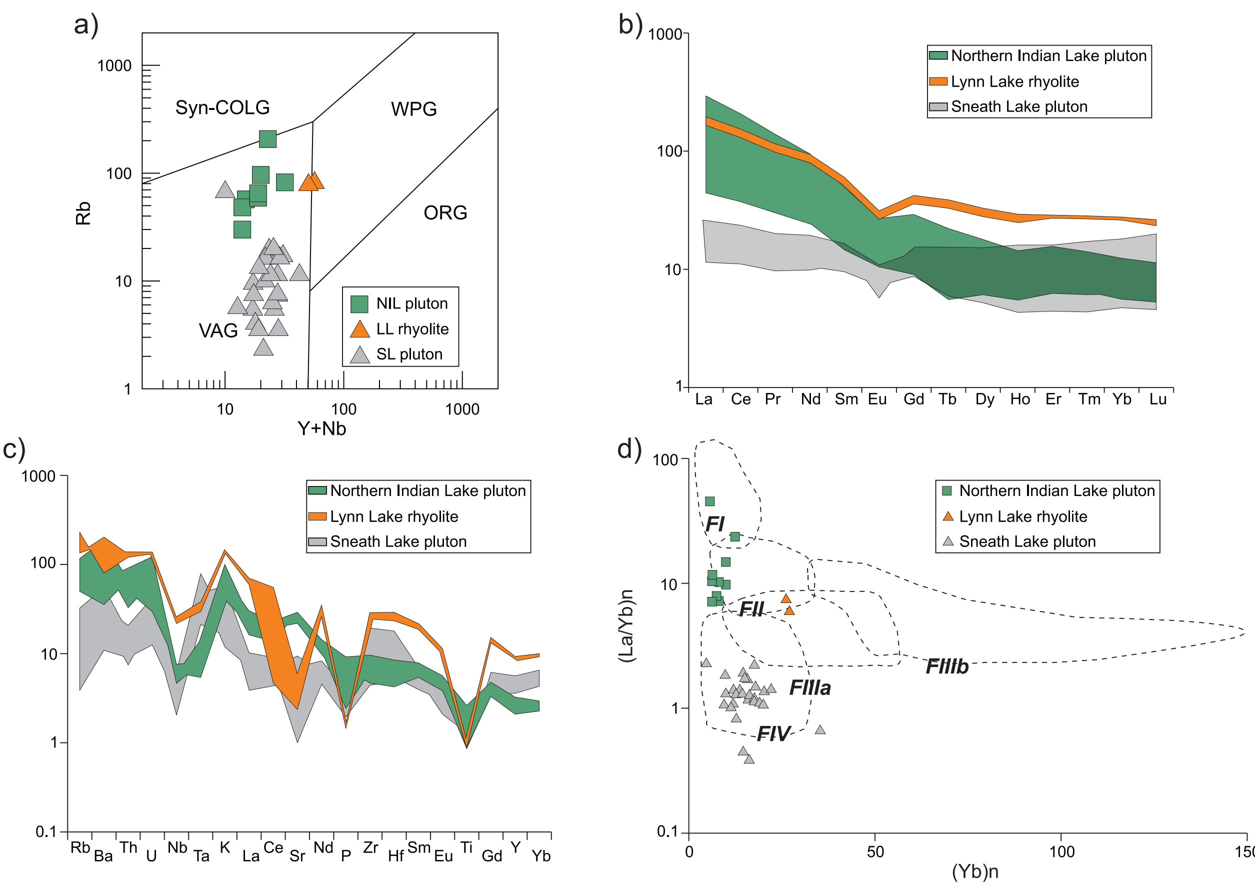
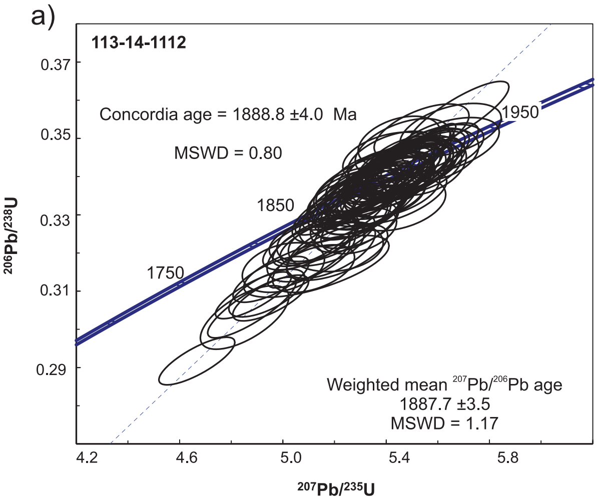


Figure GS-12-4: *Geochemistry of the Northern Indian Lake pluton, shown in comparison to VMS-associated felsic magmatic rocks of similar age in the Trans-Hudson orogen, including the Sneath Lake pluton (Bailes and Galley, 2001) and the Lynn Lake rhyolite (Beaumont-Smith, 2008):* ***a)*** *granite tectonic-discrimination diagram from Pearce et al. (1984);* ***b)*** *chondrite-normalized REE (after McDonough and Sun, 1995) patterns, showing a primitive-arc signature for the Sneath Lake pluton and a mature-arc signature for the Northern Indian Lake pluton (note the colour changes where data overlap) and the Lynn Lake rhyolite;* ***c)*** *primordial mantle–normalized extended-element plots; normalizing values are from McDonough and Sun (1995);* ***d)*** *$(La/Yb)_n$ vs. $(Yb)_n$ plot, indicating different fields of felsic volcanic rocks associated with VMS deposits (after Hart et al., 2004); normalizing values from McDonough and Sun (1995). Abbreviations: COLG, collision granites; LL, Lynn Lake; NIL, Northern Indian Lake; ORG, ocean-ridge granites; SL, Sneath Lake; VAG, volcanic-arc granites; WPG, within plate granite.*

and elongate grains are typically subrounded. A total of 130 zircon analyses, mostly targeting unfractured rims and obvious terminations, were obtained from the zircon separates. This was done to help avoid issues of mixing between truly magmatic versus inherited domains. The majority of the spots (n = 125) encountered highly radiogenic Pb (%Pb* >99.5%). Of this total number of analyses, a subset of 94 spots that are <10% discordant was included in the concordia and probability-density plots shown in Figures GS-12-5a and b, respectively. The zircon U-Pb data are contained in DRI2016006.

The analyses reveal a relatively homogeneous zircon population only, with minimal evidence of inheritance or resetting. Using only the least discordant (<10%) analyses, the data define an essentially unimodal population with a $^{207}Pb/^{206}Pb$ age of ca. 1890 Ma, interpreted as the crystallization age of the pluton, and only very minor ca. 2100–2000 Ma ages, interpreted to be inherited cores.

a)



b)

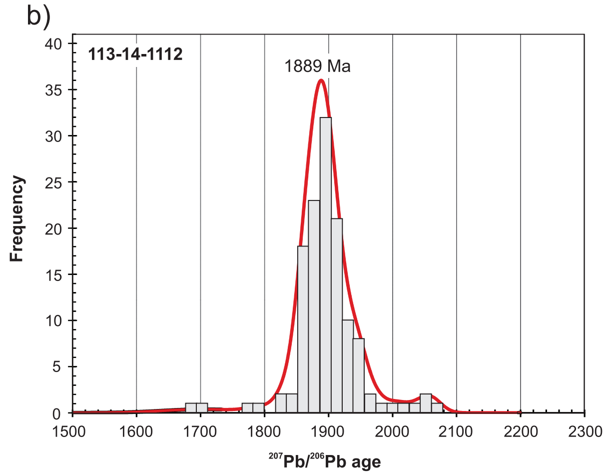


***Figure GS-12-5:** Plots of U-Pb analytical data for zircon from the Northern Indian Lake pluton; **a)** U-Pb concordia diagram; **b)** combined frequency histogram and probability-density distribution curve of $^{207}Pb/^{206}Pb$ ages (Ma).*

Economic considerations

The data reported herein for the Northern Indian Lake pluton indicate ca. 1889 Ma emplacement in a calcalkalic volcanic-arc setting, which is comparable in terms of chemistry and age to VMS-associated felsic magmatism elsewhere in the THO, including the world-class Flin Flon, Snow Lake and Rusty Lake belts. In the Snow Lake belt, for example, the Sneath Lake pluton was dated at 1886 +17/–9 Ma (Bailes et al., 1991) and is interpreted as a subvolcanic intrusion that provided the heat engine for the seafloor hydrothermal systems that produced the major VMS deposits in the Chisel basin (e.g., Walford and Franklin, 1982; Bailes and Galley, 1999). The geochemistry of the Northern Indian Lake pluton indicates a different petrogenesis than the Sneath Lake pluton (Figure GS-12-4b); however, VMS deposits in the Chisel basin occur in both primitive- and mature-arc sequences (e.g., Bailes and Galley, 1999), indicating that petrogenetic path may be less important than other critical variables, such as timing of emplacement in relation to synvolcanic faulting (e.g., Hart et al., 2004).

The VMS potential of the Southern Indian domain has previously been suggested, based on temporal links between the bimodal arc-volcanic rocks of the Partridge Breast Lake assemblage at Southern Indian Lake and volcanic rocks in the Lynn Lake–Leaf Rapids domain (Corrigan and Rayner, 2002) that host the Ruttan and Fox Lake VMS deposits. Quartz-porphyry rhyolite associated with the Ruttan deposit is dated at 1883+/–2 Ma (Rayner and Corrigan, 2004), within error of the age reported herein for the Northern Indian Lake pluton.

North of Partridge Breast Lake, garnet-biotite schist with laminated pyrite, pyrrhotite and chalcopyrite stringers contains up to 6.85% Cu (Assessment File 71519, Manitoba Growth, Enterprise and Trade, Winnipeg) and possibly represents metamorphosed VMS-style mineralization. In addition, a gossanous outcrop of epidote-altered amphibolite containing disseminated pyrite, chalcopyrite and pyrrhotite returned assay values of 476 ppm Cu and 152 ppm Zn (Martins, 2015a). Coupled with the new data presented in this report, these assay results reinforce the base-metal exploration potential of the Southern Indian domain.

Acknowledgments

Comments from C. Böhm and S. Anderson greatly improved this contribution.

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