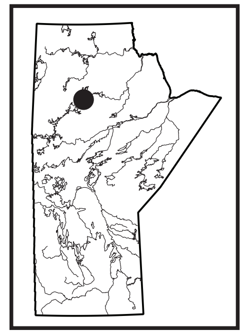
GS-11 Geological investigations at central Southern Indian Lake, north-central Manitoba (parts of NTS 64G1, 2, 7, 8)

by T. Martins



Martins, T. 2016: Geological investigations at central Southern Indian Lake, north-central Manitoba (parts of NTS 64G1, 2, 7, 8); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 126–134.

Summary

This report summarizes results from bedrock geological mapping in the central part of Southern Indian Lake during the summer of 2016. The purpose of this work was to close a gap that existed between recently updated bedrock geology maps covering the northern and southern portions of Southern Indian Lake, in advance of a comprehensive synthesis and mineral-potential assessment of the region. The area is underlain by Paleoproterozoic rocks of the Trans-Hudson orogen, including metamorphosed plutonic, sedimentary and volcanic rocks of the Southern Indian domain. Previous studies at Southern Indian Lake have identified exposures of late Archean to early Paleoproterozoic crust, which may have implications for diamond exploration in this part of northern Manitoba. Several mineral occurrences were identified, adding to the database of occurrences (Au, Zn and Cu) in the Southern Indian domain and emphasising the economic potential of this belt for a number of mineral-deposit types, including volcanogenic base-metal and intrusion-related Au mineralization.

Introduction

The Southern Indian Lake area was the target of early reconnaissance mapping by the Geological Survey of Canada (GSC; McInnes, 1913), and selected parts of Southern Indian Lake were later mapped at a scale of 1:15 840 by Wright (1953) and Quinn (1960). In the late 1960s, the Manitoba Geological Survey (MGS) mapped the area as part of the Southern Indian Lake Project (Cranstone, 1972; Thomas, 1972), and the Lower Churchill River area was later mapped at a scale of 1:100 000 by Lenton and Corkery (1981). Corkery (1993) followed up with 1:50 000 scale mapping of the area south of Partridge Breast Lake and west of Gauer Lake.

More recent work was undertaken in the early 2000s as part of the GSC's Targeted Geoscience Initiative, with the objective of providing an integrated and updated view on the regional geology and economic potential of the Trans-Hudson orogen (THO), including the Kisseynew, Lynn Lake–Leaf Rapids and Southern Indian domains in Manitoba and their equivalents in Saskatchewan (e.g., Corrigan et al., 1999, 2002, 2007; Maxeiner et al., 2001; Corrigan and Rayner, 2002; Rayner and Corrigan, 2004). The MGS followed up on this work with several mapping projects in the Southern Indian domain (Kremer 2008a, b; Kremer et al., 2009a, b; Kremer and Martins, 2014a; Martins, 2015a, b). Work in 2015 also included a Quaternary study by the MGS (Hodder, 2015), the objective of which was to define the main ice-flow directions and gain a better understanding of the complex ice-flow history of this area (Trommelen, 2015) in support of drift exploration. This year, the objective was to complete the geological mapping and thus have updated geology for the entire Southern Indian Lake area (Figure GS-11-1). The final objective of this project is a compilation of all work carried out by the MGS and GSC in the last decade.

Geological setting

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-11-1). It is predominantly composed of variably migmatitic metasedimentary rocks, various granitoid units and rare belts dominated by metavolcanic rocks (Corrigan et al., 2007). The metasedimentary and metavolcanic rocks have been historically assigned to the Sickle and Wasekwan groups, respectively (Cranstone, 1972; Frohlinger, 1972). The Southern Indian domain is bounded to the south by the Lynn Lake–Leaf Rapids domain and, to the north, was intruded by the voluminous ca. 1.86–1.85 Ga Chipewyan/Wathaman batholith (Corrigan et al., 2000), which stitches the Reindeer zone to the southern margin of the Hearne craton.

Geological mapping and lithogeochemical and geochronological results were used to subdivide supracrustal rocks of the Southern Indian domain into two lithotectonic assemblages, named after local geographic features: the Pukatawakan Bay and Partridge Breast Lake assemblages (Rayner and Corrigan, 2004; Kremer, 2008a; Kremer et al., 2009a, b). The Pukatawakan Bay assemblage is composed of massive to pillowed, juvenile metabasaltic rocks and associated basinal metasedimentary rocks (Kremer, 2008a). This assemblage was intruded by the ca. 1889 ±11 Ma Turtle Island complex (Rayner and Corrigan, 2004), which provides a minimum age of deposition. The Partridge Breast Lake assemblage is composed of bimodal continental-arc volcanic and volcaniclastic rocks and is inferred to be in fault contact with late Archean to early Paleoproterozoic orthogneiss (ca. 2520–2380 Ma) in west-central Southern Indian Lake (Kremer et al., 2009b). Exposures of this orthogneiss are limited to a group of small islands. However, the range of ages of its zircon

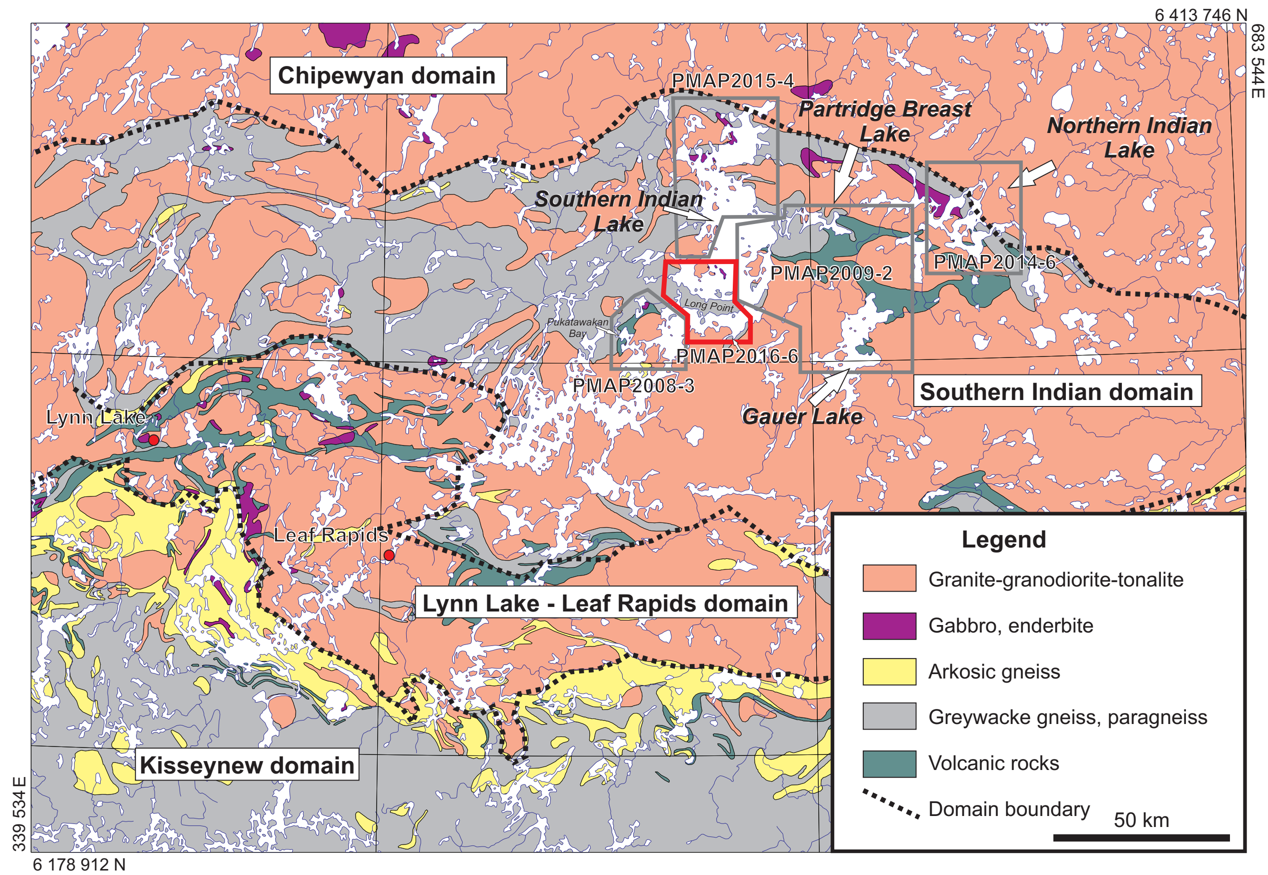


Figure GS-11-1: *Simplified regional geology of part of the Trans-Hudson orogen in northern Manitoba. Areas of recent mapping by the MGS in the Southern Indian domain area, as well as the limits of the current mapping, are outlined. Pukatawakan Bay and Partridge Breast Lake are type localities for the rock assemblages of the same name. Previous mapping: PMAP2008-3 (Kremer, 2008b), PMAP2009-2 (Kremer et al., 2009a), PMAP2014-6 (Kremer and Martins, 2014b), PMAP2015-4 (Martins, 2015b).*

population mimics the dominant and subdominant detrital zircon populations in most Paleoproterozoic assemblages in the area, indicating it may be more extensive than its limited exposure would suggest. Additionally, zircons of similar age are ubiquitous as inherited grains in Paleoproterozoic plutonic and volcanic rocks found at both Southern Indian and Partridge Breast lakes (Rayner and Corrigan, 2004; Kremer et al., 2009b). The late Archean to early Paleoproterozoic orthogneiss at Southern Indian Lake may represent a window, or fault-bounded tectonic fragment, of Hearne craton in the Reindeer zone of the THO. Alternatively, it may represent a fragment of exotic continental crust, analogous to the Sask craton (e. g., Corrigan et al., 2007). Both the Pukatawakan Bay and Partridge Breast Lake assemblages were intruded by several generations of plutonic rocks, ranging in age from ca. 1880 to 1830 Ma (Corrigan et al., 2007).

Bedrock geology of the central part of Southern Indian Lake

Metasedimentary and metavolcanic rocks mapped and identified in the central part of Southern Indian Lake are interpreted to belong to the Partridge Breast assemblage, which is defined to include psammitic to pelitic sedimentary rocks, greywacke-mudstone turbidites, local resedimented volcaniclastic rocks, minor conglomerate, and mafic volcanic and volcaniclastic rocks (Kremer et al., 2010). Metagranitoid rocks belonging to the Southern Indian domain, with minor rafts of metavolcanic and metasedimentary rocks, were also observed in the central part of the lake. Although the majority of rocks in the Southern Indian Lake area have been metamorphosed, the 'meta' prefix is omitted below to improve the readability of the text. Described mineral modal abundances are based on visual estimates from outcrop and hand samples. The unit numbers in this report correspond to those on Preliminary Map PMAP2016-6 (Martins, 2016), and Figure GS-11-2 represents a simplified version of this map.

Calcareous mudstone (unit 1)

Calcareous mudstone (locally ferruginous) is only found northwest of Loon Island (Figure GS-11-2). This unit is thinly laminated (Figure GS-11-3a), with alternating

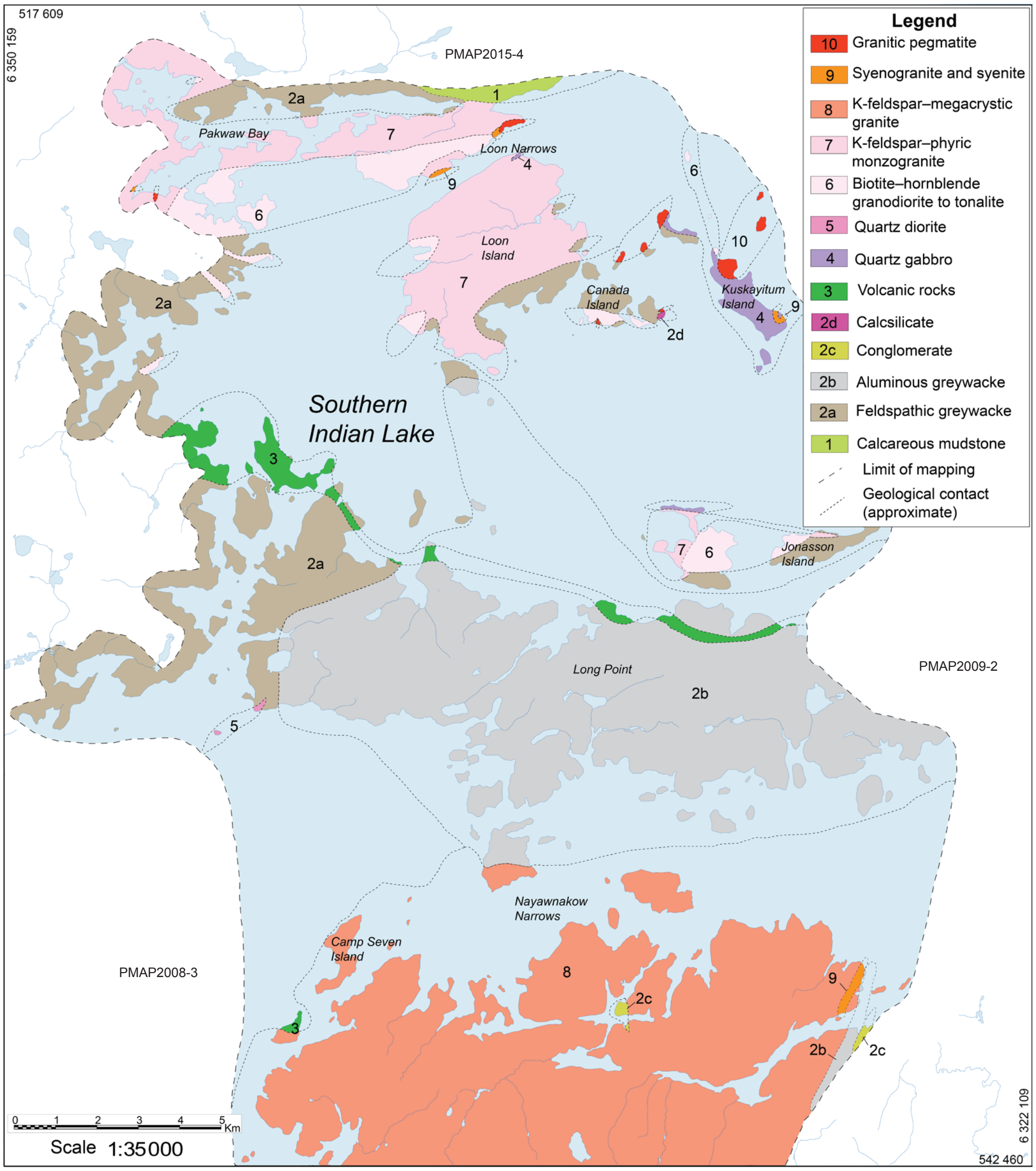


Figure GS-11-2: *Simplified geology of the central part of Southern Indian Lake (after Martins, 2016). 'Previous mapping: PMAP2008-3 (Kremer, 2008b), PMAP2009-2 (Kremer et al., 2009a), PMAP2015-4 (Martins, 2015b).*

melanocratic (rich in biotite, amphibole, magnetite, titanite, pyrite and chalcopyrite) and leucocratic (rich in feldspar, quartz and apatite) layers. The layers show a variety of colours, such as purple, green and light blue, depending on the mineralogy. This unit is intruded by megacrystic K-feldspar monzogranite (unit 7). Layering is attributed to intense transposition during D_2 deformation, with the main foliation striking northeast, as described by Kremer (2008a) in other parts of Southern Indian Lake.

Greywacke, conglomerate and calcsilicate rocks (unit 2)

This unit is the most abundant in the central part of Southern Indian Lake. Feldspathic greywacke occurs interbedded with aluminous greywacke, which is well exposed along Long Point (Figure GS-11-2). The feldspathic greywacke (subunit 2a) is generally bedded (most beds are <20 cm thick), foliated and nonmagnetic, and contains 10–20% leucosome. This rock weathers dark grey, is medium grained and massive to crudely bedded, and locally contains garnet. The aluminous greywacke (subunit 2b) is medium grey and fine grained, and contains garnet and sillimanite (Figure GS-11-3b) that likely formed during peak, upper-amphibolite–facies metamorphism (Kremer, 2008a). This unit corresponds to the "migmatite garnet greywacke paragneiss" described by Kremer et al. (2009a, b). In both the feldspathic and the aluminous greywacke, quartzofeldspathic mobilizate (varying up to 20% of the outcrop) occurs as stringers, veins and dikes that are generally oriented subparallel to

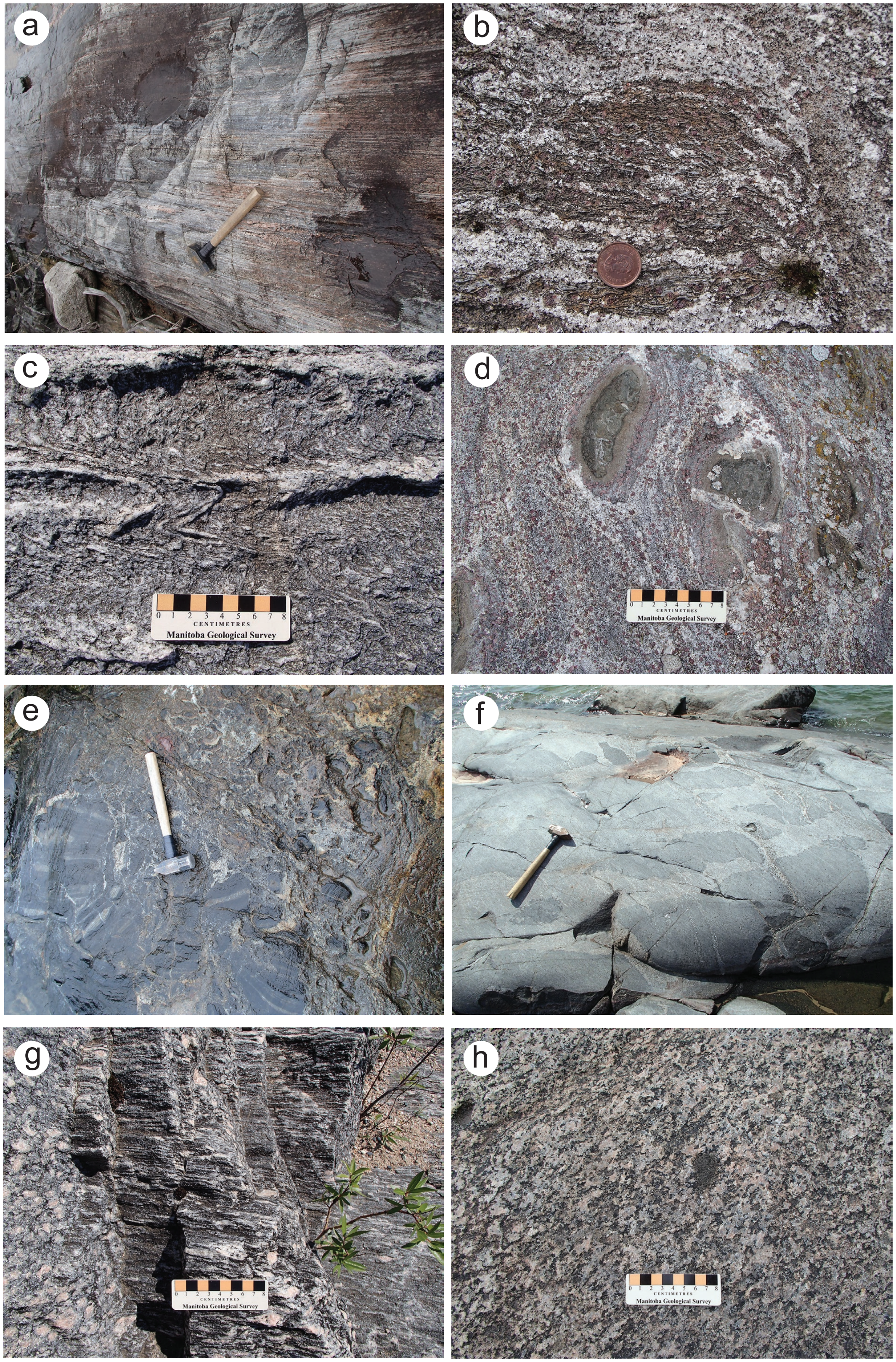


***Figure GS-11-3:** Outcrop photographs of map units in the central part of Southern Indian Lake: **a)** thinly layered calcareous mudstone (unit 1); **b)** aluminous greywacke (subunit 2b) with garnet and sillimanite; **c)** fold with Z-asymmetry in feldspathic greywacke (subunit 2a); **d)** pervasive garnet in outcrop of polymictic conglomerate (subunit 2c); **e)** broken pieces of altered volcanic rocks in a granodioritic matrix (unit 3); **f)** cognate xenoliths in quartz gabbro (unit 4); **g)** stretching lineation in K-feldspar crystals in tectonized K-feldspar–phyric monzogranite (Loon Island intrusion; unit 7); **h)** detail of K-feldspar–megacrystic granite (unit 8).*

the main transposition fabric in the sedimentary rocks. Also in both types, the main foliation (S_1) is folded by steeply dipping isoclinal F_2 folds of predominantly Z-asymmetry (Figure GS-11-3c), with a northeast-striking S_2 axial-plane foliation. This is in accordance with the structural history described for the Southern Indian lake area (Kremer, 2008a). Numerous outcrop-scale shear zones are observed in both the feldspathic and the aluminous greywacke, with kinematic indicators providing evidence for a strong dextral shear component associated with D_2 (as described by Kremer, 2008a).

Poorly exposed underwater outcrops of polymictic clast-supported conglomerate (subunit 2c) occur on the east shore of Canada Island (Figure GS-11-2). This conglomeratic unit is moderately deformed, appears to be moderately to well sorted, and contains subrounded felsic lithic clasts varying from 8 to 20 cm in size. Locally interbedded with this conglomerate is a rusty layer with abundant pyrite and chalcopyrite, interpreted as sulphide-facies iron formation. Xenoliths in K-feldspar–megacrystic granite (unit 8) south of Long Point include polymictic conglomerate that is foliated and matrix supported, with subrounded to rounded clasts. The different lithic clasts include volcanic rocks (unit 3) and greywacke (subunits 2a and 2b), and well-rounded pebbles of quartz and feldspar. Locally, garnets are present throughout the polymictic conglomerate; these are interpreted to be associated with a late hydrothermal event (Figure GS-11-3d).

Associated with this conglomeratic unit are calcsilicate rocks (subunit 2d) with pervasive carbonate and epidote alteration. These rocks are only found outcropping on the south shore of Canada Island (Figure GS-11-2). Thy are fine to medium grained and show compositional layering, with pink layers composed of K-feldspar, quartz, hornblende and titanite; purple-green layers composed of garnet, epidote, amphibole, quartz, calcite, biotite, magnetite and titanite; and green layers composed of quartz, epidote, titanite and calcite. This calcsilicate unit is cut by granitic pegmatite (unit 10).

Mafic volcanic rocks (unit 3)

Altered mafic volcanic rocks were observed as xenoliths within granitoid units but occur mainly in association with the feldspathic and aluminous greywacke along the north shore of Long Point, where they form extensive outcrops, some extending for up to 100 m (Figure GS-11-2). This unit seems to be predominantly massive, although pillowed basalt was identified at one location. The mafic volcanic rocks are typically fine grained, dark grey and foliated, such that primary features are difficult to discern. Light grey-green zones of calcsilicate (epidote) alteration are evident in a few exposures. Along the north shore of Long Point, and to the west and south of it, an intrusion breccia of massive basaltic flows is found interbedded with the feldspathic and aluminous greywacke (Figure GS-11-3e). Locally gossanous patches (resulting from weathering of pyrite and chalcopyrite) and epidote and carbonate alteration are associated with this unit (assay results for these occurrences are pending). Garnet, which is often associated with the gossanous areas in these altered volcanic rocks, is interpreted to be related to a late hydrothermal event.

Quartz gabbro (unit 4)

Quartz gabbro occurs primarily on Kuskayitum Island (Figure GS-11-2), where outcrops vary in size from 5 to 30 m. This unit is fine to medium grained, but a coarse-grained, pyroxene-phyric phase was locally observed. The quartz gabbro is dark grey when weathered and very dark grey when fresh; it is magnetic, homogeneous and weakly foliated. Cognate xenoliths were observed (Figure GS-11-3f) and, locally, several xenoliths of epidote-altered volcanic rocks were found associated with massive magnetite aggregates varying in size up to 20 cm. The mineralogy of the most homogeneous phase of the quartz gabbro comprises biotite (15–20%), pyroxene (20–30%), quartz (5–10%), titanite (3–5%) and magnetite (2–3%), with the remainder being plagioclase feldspar. Quartz gabbro also outcrops on the north shore of Loon Island. A distinct texture, consisting of aggregates of subhedral to euhedral crystals of plagioclase, magnetite, pyroxene and quartz, was observed locally at this location. In the same location, potassic and chloritic alteration associated with euhedral crystals of titanite, magnetite and pyrite forms pockets within the quartz gabbro. This unit is cut by late K-feldspar–dominant pegmatites (unit 10).

Quartz diorite (unit 5)

Outcrops of quartz diorite are not abundant in the map area. This rock is mottled black and white to dark grey on fresh surfaces, massive to weakly foliated, medium to very coarse grained and weakly magnetic. It is mainly homogeneous but locally contains cognate xenoliths as well as xenoliths of amphibolite (interpreted as altered volcanic rocks). Mineral composition of this unit is mostly plagioclase (40–50%), biotite and hornblende (30–35%), and quartz (10–15%). Garnet is present locally (up to 20% of mode). The presence of garnet is always associated with gossanous occurrences and, at these locations, the rock is reddish brown; these gossans are interpreted to result from hydrothermal alteration.

Biotite-hornblende granodiorite to tonalite (unit 6)

The biotite-hornblende granodiorite to tonalite usually occurs in association with the porphyritic monzogranite of Loon Island (Figure GS-11-2). Based on field relationships, this unit could be related to the Loon Island monzogranite because a gradational transition from one unit to the other is locally observed. The biotite-hornblende granodiorite to tonalite is white to beige when weathered and grey when fresh, fine to medium grained, nonmagnetic to weakly magnetic and moderately foliated, and contains veinlets of quartz and K-feldspar. These rocks comprise quartz (25–30%), biotite (10–12%), hornblende (<5%) and K-feldspar (10–15%), the remainder being plagioclase. Foliation is marked by the biotite and hornblende crystals, which strike northeast, subparallel to the S_2 foliation (defined by Kremer, 2008a). This unit is cut by K-feldspar–dominant pegmatite.

K-feldspar–phyric monzogranite (Loon Island intrusion; unit 7)

This unit varies in composition from quartz monzonite to monzogranite and outcrops mostly on Loon Island and Pakwaw Bay (Figure GS-11-2). It is beige to light pink, nonmagnetic, porphyritic, folded and variably deformed. Fabric strikes northeast, which coincides with the S_2 foliation defined by Kremer (2008a). This unit is tectonized at the northeastern tip of Loon Island and on the north shore of Loon Narrows. In these outcrops, a stretching lineation defined by K-feldspar crystals was observed (Figure GS-11-3g). This unit is cut by pink pegmatite and late syenitic plugs. Rare rafts of greywacke were observed. This monzogranite is composed of quartz (20–35%), hornblende and biotite (10–15%) and K-feldspar (20–30%), the remainder being plagioclase.

K-feldspar–megacrystic granite (unit 8)

This unit outcrops south of Long Point (Figure GS-11-2) and forms a large granitoid pluton extending to Whyme Bay (Kremer, 2008a, b) that is easily recognized on the residual total-field aeromagnetic map (Coyle and Kiss, 2008). This granite is porphyritic, beige to cream colour when weathered and light pink when fresh, nonfoliated to weakly foliated and moderately magnetic, and has xenoliths of amphibolite and greywacke. Its distinctive characteristic is the presence of K-feldspar megacrysts measuring up to 5 cm (15–20%; Figure GS-11-3h) in a medium- to coarse-grained groundmass of plagioclase (25–30%), quartz (20–25%), variable amounts of biotite and hornblende (up to 10%), and locally disseminated sulphide and magnetite. In a few outcrops, it is associated with a later syenogranite intrusion (unit 9). Metre-scale xenoliths of conglomerate (subunit 2c) are locally observed. A similar rock type was described by previous authors (e.g., Corrigan et al., 2000; Kremer, 2008a), and U-Pb geochronology indicates an age of ~1829 Ma for similar bodies outcropping in the vicinity of Whyme Bay (Rayner and Corrigan, 2004).

Quartz syenite to syenogranite (unit 9)

Outcrops of quartz syenite and syenogranite occur in the northeastern corner of the map area and associated with the K-feldspar–megacrystic granite south of Long Point (Figure GS-11-2). This unit is fine to medium grained, weakly magnetic to magnetic, nonfoliated and homogeneous, pink when weathered and buff pink when fresh, and has xenoliths of leucogabbro. Granitic pegmatite dikes cut this quartz syenite. This unit comprises quartz (15–35%), biotite (5–8%), hornblende (1–5%), magnetite (1–2%) and K-feldspar (10–15%), the remainder being plagioclase.

Granitic pegmatite (unit 10)

Granitic pegmatite dikes are abundant and intrude most of the units found at Southern Indian Lake. The pegmatite bodies are albite dominant or K-feldspar dominant. They dip steeply and have variable strikes (mainly oriented north-northeast, south-southeast and southwest). Most of the pegmatite bodies are less than 2 m thick (up to a maximum of 10 m), unzoned or very crudely zoned and mineralogically simple (mostly feldspar, quartz, biotite and, rarely, muscovite). Characteristic textures of granitic pegmatite, such as graphic texture, comb texture and rhythmic banding, were observed in most of the pegmatite bodies. Albite-dominant pegmatite is composed mostly of albite, quartz and K-feldspar, along with common accessory biotite, garnet and apatite. Green apatite is typically associated with white pegmatite and occurs either isolated within the pegmatite or closely associated with concentrations of biotite. Potassium-feldspar–dominant pegmatite is composed mostly of K-feldspar, quartz, albite and biotite. Garnet and magnetite (crystals up to 1.5 cm) are common accessory phases.

Discussion

A comprehensive suite of samples was collected during the course of this year's mapping for thin-section petrography, whole-rock lithogeochemical analysis and isotopic studies. These results will help to further characterize, classify and compare plutonic and supracrustal rocks from this part of Southern Indian Lake in relation to those mapped throughout the region (Kremer, 2008a; Kremer et al., 2009b; Kremer and Martins, 2014a; Martins, 2015a, b).

Results of isotopic work on selected samples will be used to identify additional occurrences of Archean to earliest Paleoproterozoic crust in the northern part of Southern Indian Lake. To date, zircon of this age has only been identified in orthogneiss in the west-central part of the lake (Kremer et al., 2009b) and as inherited grains in younger Paleoproterozoic plutonic rocks in the area (Rayner and Corrigan, 2004). The orthogneiss may represent a relatively small tectonic wedge of Archean to earliest Proterozoic crust. Alternatively, the orthogneiss, in addition to the common xenocrystic and detrital zircons of similar age throughout this portion of the THO, could indicate that the extent of late-Archean crust is much greater than is presently known (Corrigan et al., 2007). Results from isotopic analyses will help resolve this question.

Economic considerations

The Southern Indian Lake area has seen little exploration activity in the past decades, despite the recent identification of several potential mineral-exploration targets (e. g., Corrigan et al., 2007; Kremer et al., 2009b; Martins, 2015a). Recent Quaternary studies in this area indicate that the predominant ice-flow directions are south and southwest (Hodder, 2015; Trommelen, 2015). This type of information is essential for drift exploration in Manitoba's northern region and can help exploration companies identify and locate new targets.

The potential for volcanogenic massive sulphide (VMS) deposits at the regional scale is indicated by temporal links between 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), which host the Ruttan and Fox Lake VMS deposits. Recent geochronological data for early 'juvenile-arc' magmatism in the Southern Indian domain (1889 ±4 Ma; Martins and Macfarlane, GS-12, this volume) suggest a broadly coeval timing for early magmatism in several volcanic-arc terranes across the Reindeer zone, including the Lynn Lake belt (e.g., the 1892 ±3 Ma Lynn Lake rhyolite; Beaumont-Smith and Böhm, 2002) and the Snow Lake belt (e.g., the 1886 +17/–9 Ma Sneath Lake pluton; Bailes et al., 1991), supporting a correlation of these belts across the Trans-Hudson orogen (Zwanzig and Bailes, 2010). Values up to 6.85% Cu were reported from garnet-biotite schist with laminated pyrite, pyrrhotite and chalcopyrite stringers north of Partridge Breast Lake (Assessment File 71519, Manitoba Growth, Enterprise and Trade, Winnipeg), and assay results of up to 2.2% Cu were obtained from a narrow fracture in volcanic rocks of the Whyme Bay assemblage (Frohlinger, 1972). Malachite showings also occur near the base of the clastic sedimentary sequence around Partridge Breast Lake (Kremer et al., 2009b). Martins (2015a) identified a gossanous outcrop of epidote-altered amphibolite that contained disseminated pyrite, chalcopyrite and pyrrhotite, and returned assay values of 476 ppm Cu and 152 ppm Zn.

Recent work also indicates potential for intrusion-related Au mineralization. A grab sample of a narrow fracture with malachite, azurite, bornite and chalcocite in pink pegmatite yielded values of 4.7 g/t Au, >1% Cu, 4.6 g/t Ag, 2200 ppm Bi, >0.5% Pb and 736 ppm Se. The Au-Cu-Ag-Bi geochemical signature of this occurrence is similar to that of other intrusion-related Au systems (e.g., the Fort Knox and Pogo deposits in the Fairbanks district of Alaska). The Au-Bi association is particularly interesting given its similarity to that of the Pogo deposit, where mineralized intervals contain elevated Ag, Te, Bi, As, Sb, Cu, Pb, Mo and/or Co, and exhibit a strong correlation between Au and Bi (Smith et al., 1999). Another example of a possible intrusion-related Au system is unusual polymetallic Be-Au-Zn-Bi mineralization associated with a pegmatite on Turtle Island (central part of Southern Indian Lake; Kremer et al., 2009b; Martins and Kremer, 2013).

The margins of Archean cratons can be important regional vectors for diamond exploration. In east-central Saskatchewan, two diamond occurrences are located in areas thought to be underlain at depth by the mostly buried Archean crust of the Sask craton (the Fort à la Corne kimberlite field and the Pikoo kimberlite). Determining the potential extent of Archean crust in the Southern Indian Lake area (i.e., by isotopic studies) may help to inform diamond exploration in the region. In 2016, a regional-scale kimberlite-indicator mineral study was carried out by the MGS to further knowledge of the diamond potential of this part of northern Manitoba (Hodder, GS-20, this volume).

Acknowledgments

Logistical support provided by E. Anderson, N. Brandson and E. Amyotte is greatly appreciated. Help of technical staff V. Varga and C. Epp, and summer student C. Stocki, at the Midland Sample and Core Library is gratefully appreciated, as well as GIS and digital cartography support by L. Chackowsky. Many thanks to C. Norris-Julseth and A. Schmall for field assistance. Both E. Yang and S. Anderson are acknowledged for improving this report with their comments. Lastly, a word of appreciation goes to C. Boe and the boat patrol team from Manitoba Hydro.

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