Geological investigations at Southern Indian Lake, Manitoba: implications for mineral exploration

T. Martins and T.J. Hodder

Introduction

In the summer of 2015, the Manitoba Geological Survey (MGS) conducted a mapping project with the main objective of updating the bedrock geology of the northern basin of Southern Indian Lake and assess the mineral potential of this area of the lake.

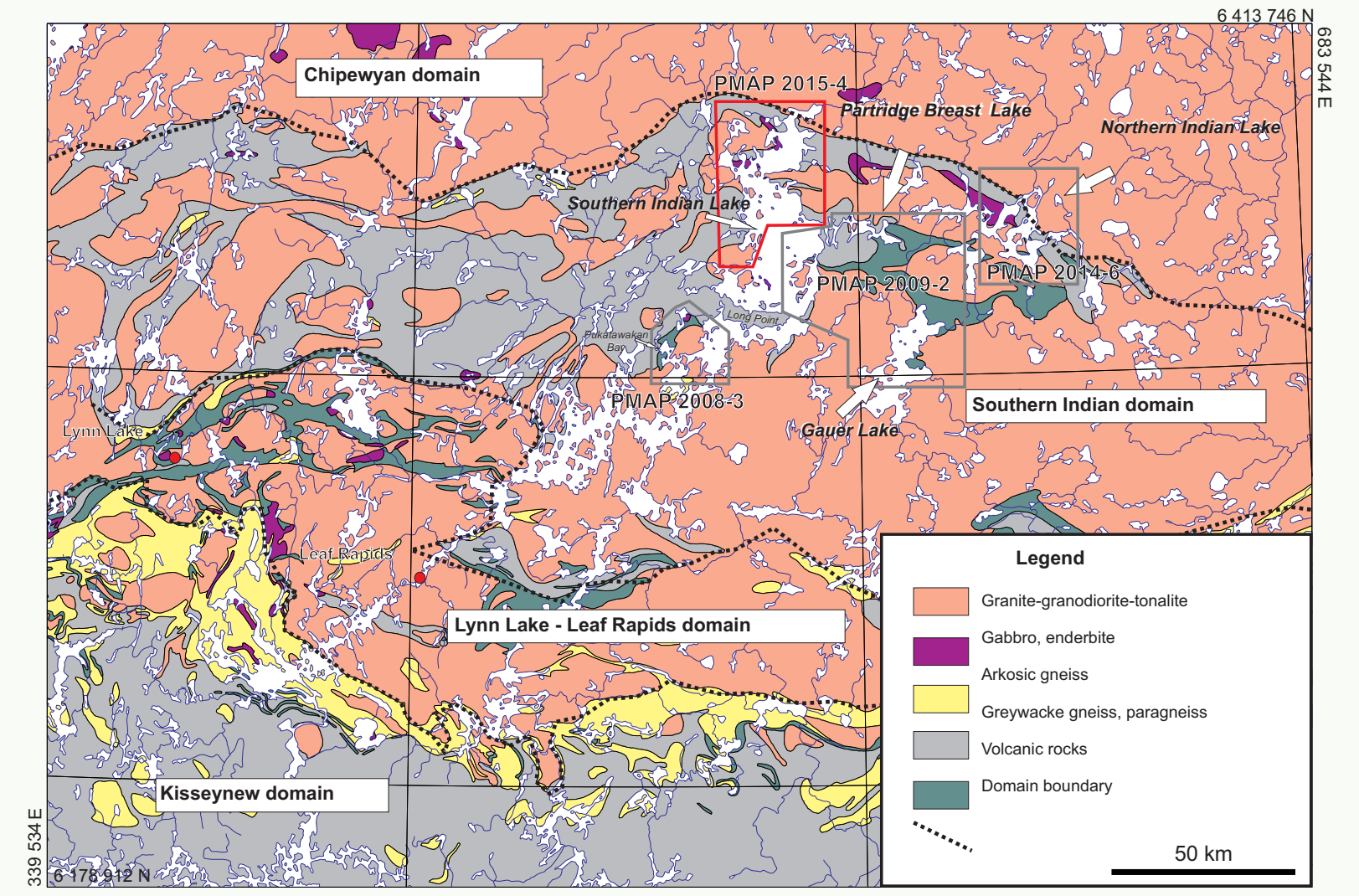
Field work conducted in this area in 2008 and 2009 focussed on the supracrustal rocks that occur in the central area of the lake. The northern basin is predominantly composed of granitoid rocks with few supracrustal units that have not been looked in detail since the 1970's.

Part of this project were two weeks of Quaternary geology fieldwork, which main objectives were:

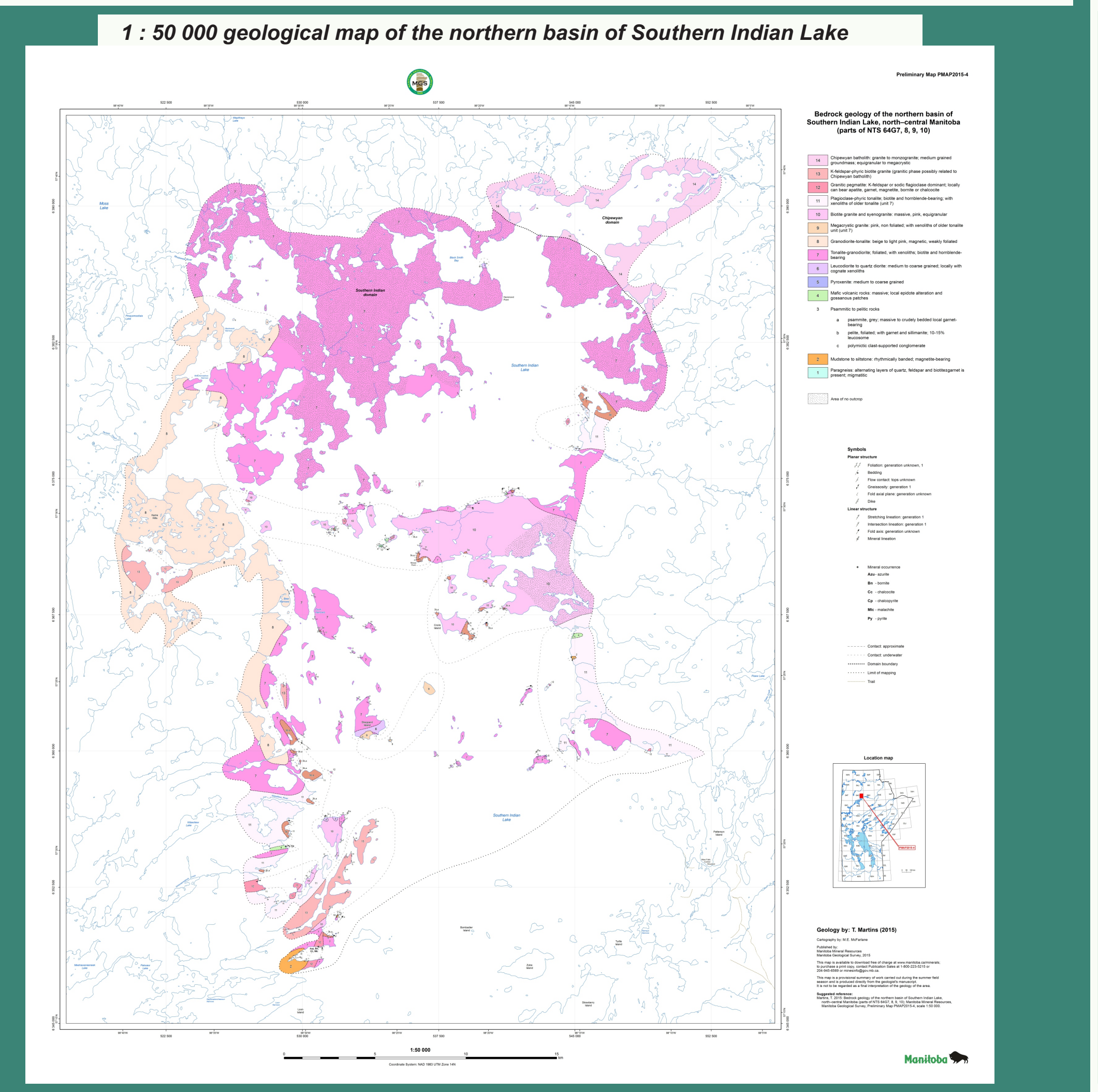
- To map outcrop paleo-ice flow indicators and establish relative-age relationships;
- To log boat-accessible Quaternary sections along the shoreline of Southern Indian Lake;
- And to sample till for lithological and geochemical analyses.

Simplified regional geology of the Trans-Hudson orogen in northern Manitoba

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. It is predominantly composed of variably migmatitic metasedimentary rocks, various granitoid units and rare belts dominated by metavolcanic rocks (Corrigan et al., 2007). 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 batholith (Corrigan et al., 2000), which stitches the Reindeer zone to the southern margin of the Hearne craton.



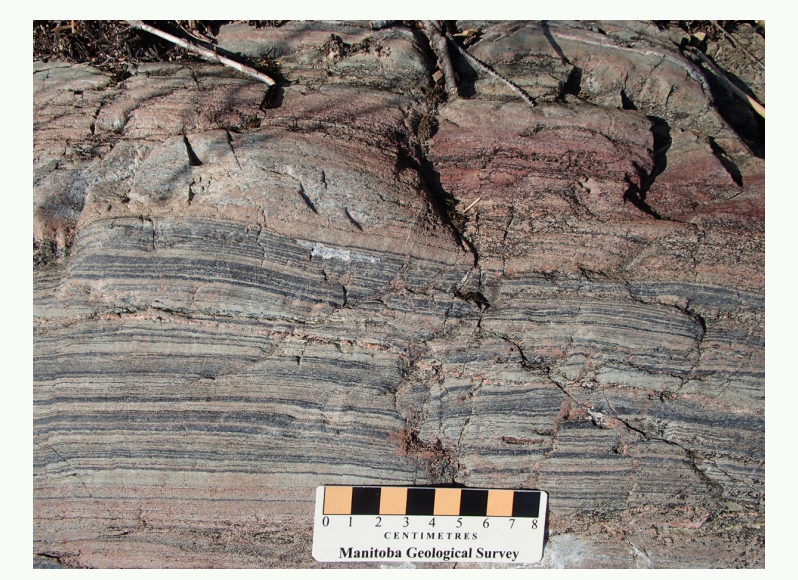
1 : 50 000 geological map of the northern basin of Southern Indian Lake



Bedrock geology of the northern basin of Southern Indian Lake

Supracrustal rocks

Paragneiss (unit 1): was identified at three locations in the map area; shows a strong compositional banding, interpreted to reflect primary layering, wherein leuco- and mesocratic lenticular layers of plagioclase and quartz alternate with locally thinner melanocratic layers of biotite and, in some areas, garnet and sillimanite.



Siliceous mudstone (unit 2; locally ferruginous) is thinly laminated with compositional layering consisting of alternating layers of mafic material (biotite and amphibole and locally mostly magnetite) with leucocratic layers (mostly feldspar and quartz).

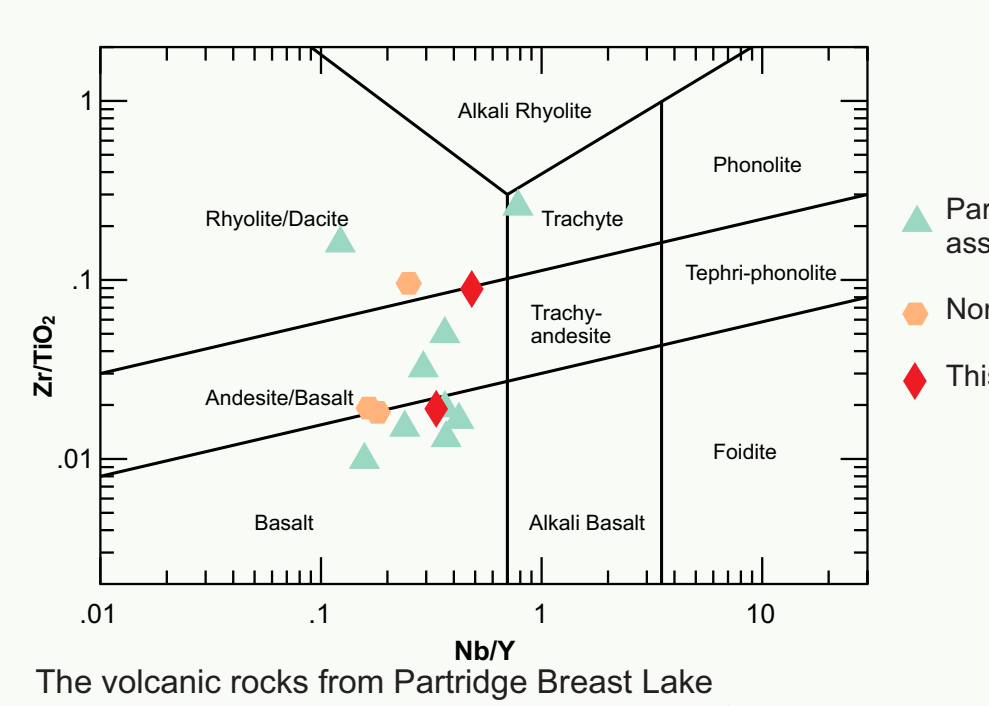
Feldspathic greywacke occurs interbedded with **aluminous greywacke** (unit 3a, b; in this photo with garnet and sillimanite). Garnet and sillimanite are thought to have been formed during peak, upper-amphibolite–facies metamorphism.

Polymictic clast-supported conglomerate (unit 3c)is moderately to strongly deformed; it appears to be well sorted and contains subrounded to subangular clasts 2– 20 cm long.

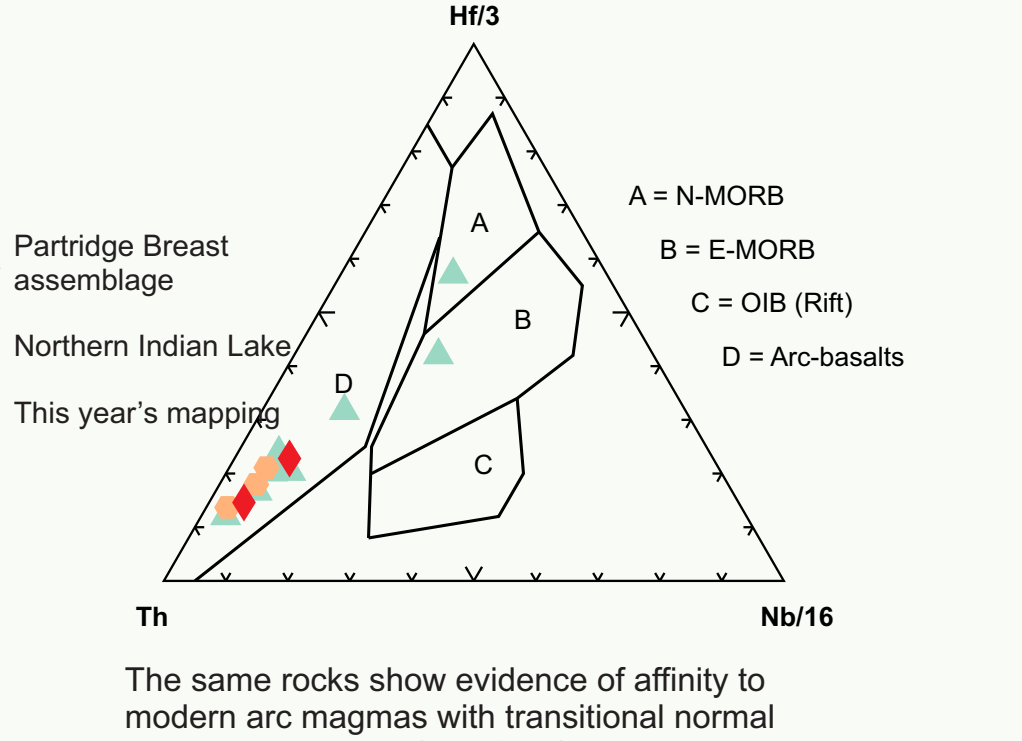
Amphibolite (unit 4) is typically fine-grained and foliated, such that primary features are difficult or impossible to discern. Light grey-green zones of calcsilicate (epidote) alteration occur in most exposures. At one outcrop, the calcsilicate alteration is accompanied by gossan derived from oxidation of disseminated sulphides, namely pyrite, chalcopyrite and pyrrhotite, which locally account for up to 20% of the rock.

Whole rock geochemistry

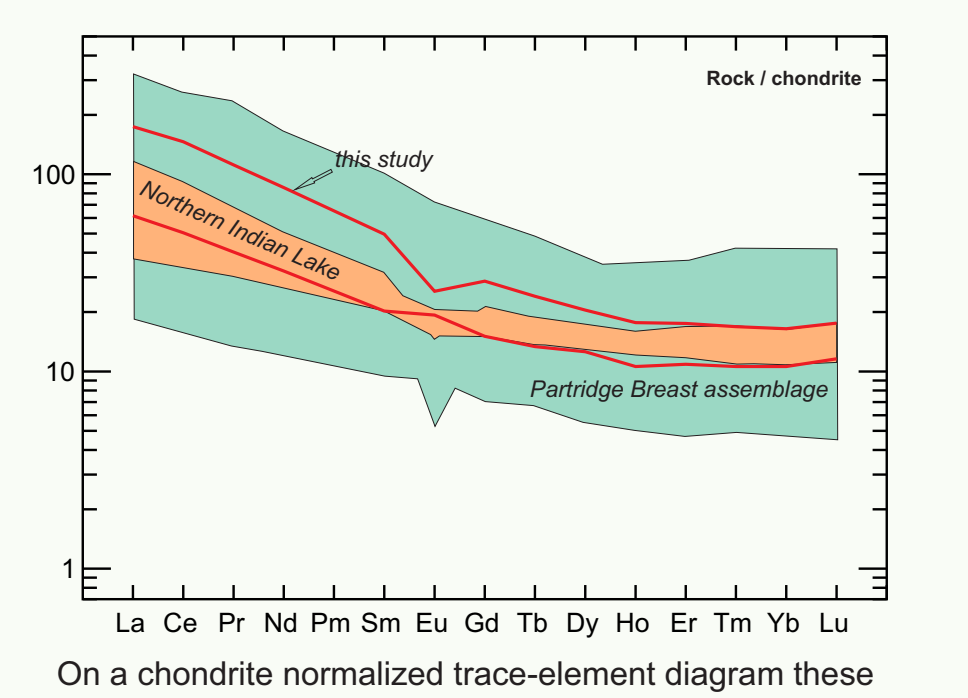
Rare-earth-element (REE) and trace element geochemistry indicates that the mafic volcanic rocks collected during this summer's field season are comparable to volcanic rocks that constitute the Partridge Breast assemblage as well as volcanic rocks mapped at Northern Indian Lake (Kremer and Martins, 2014).



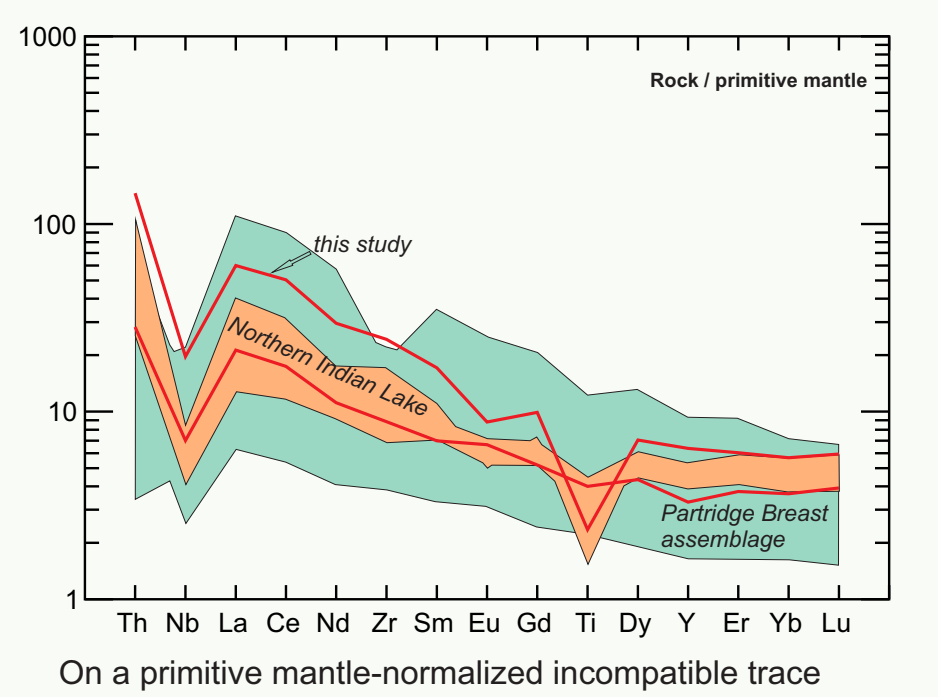
The volcanic rocks from Partridge Breast Lake assemblage, Northern Indian Lake and results from this year's mapping plot in the basalt, andesite, rhyolite-dacite and trachyte fields (diagram modified after Winchester and Floyd, 1977).



The same rocks show evidence of affinity to modern arc magmas with transitional normal middle ocean ridge (N-MORB) basalt and enriched (E)-MORB (diagram from Wood, 1980).



On a chondrite normalized trace-element diagram these rocks show a slight negative slope with light rare-earth-elements (LREE) enrichment (normalizing values from McDonough and Sun, 1995).



On a primitive mantle-normalized incompatible trace element diagram the signature includes positive Th and, negative Zr anomalies, and depletion in Nb and Ti (normalizing values from Sun and McDonough, 1989).

Granitoid rocks

Tonalite-granodiorite (unit 7) is white to beige, medium to coarse grained, moderately to strongly foliated, and contain xenoliths. The tonalite is composed of plagioclase (<40%), quartz (30–40%), variable amounts of biotite and hornblende (up to 15%), K-feldspar (<5%), and locally disseminated sulphide and magnetite. The granodiorite has a very similar composition but with more K-feldspar (10–15%).

Granodiorite-tonalite (unit 8) is beige to light pink, medium to coarse grained, weakly to moderately foliated, and magnetic. It contains plagioclase (30–40%), quartz (25–40%), K-feldspar (10–15%), biotite-hornblende (up to 15%) and magnetite (1–2%), with trace amounts of disseminated chalcopyrite, pyrite and minor pyrrhotite. This unit is interpreted to postdate unit 7 based on field relationships.

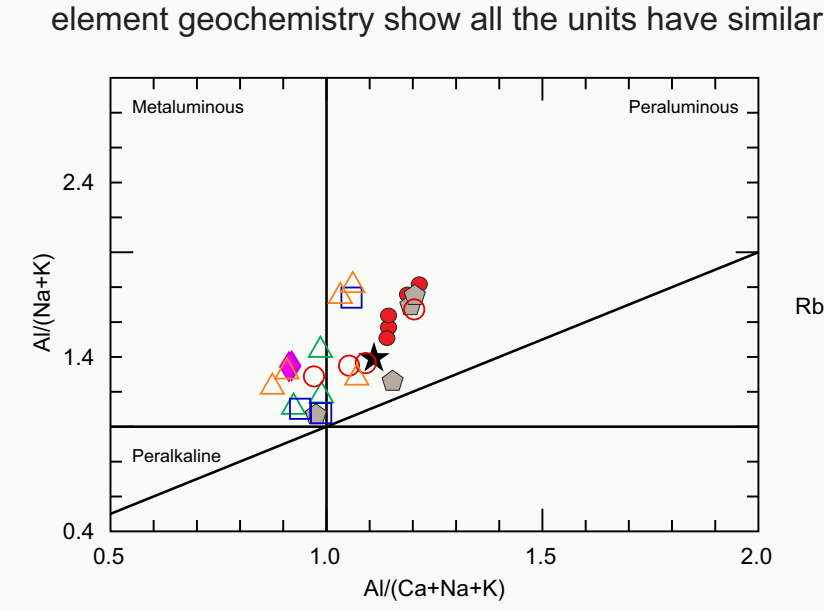
Megacrystic granite (unit 9) is pink, coarse to very coarse grained, weakly magnetic and massive. This unit is characterized by K-feldspar crystals up to 8 cm in size in a medium-grained groundmass of quartz, K-feldspar and plagioclase. The bulk-mineral assemblage of this unit comprises K-feldspar (40–50%), quartz (25–35%), plagioclase (10–30%) and biotite (<5%).

Granitic pegmatites (unit 12) are abundant and intrude most of the units found at Southern Indian Lake. The pegmatite bodies are albite dominant (white pegmatite bodies) or K-feldspar dominant (pink pegmatite bodies). Their strike is variable, but main strikes are oriented north-northeast, south-southeast and southwest, and are steeply dipping. Most of the pegmatite bodies are <2 m thick, unzoned or very crudely zoned, and mineralogically simple. Characteristic textures of granitic pegmatite, such as graphic texture, comb texture (perpendicular growth to the margins of the dikes) and line rock (rhythmical banding) are observed in most of the pegmatite bodies. Apatite, garnet and magnetite (crystals up to 3 cm) are common accessory phases.

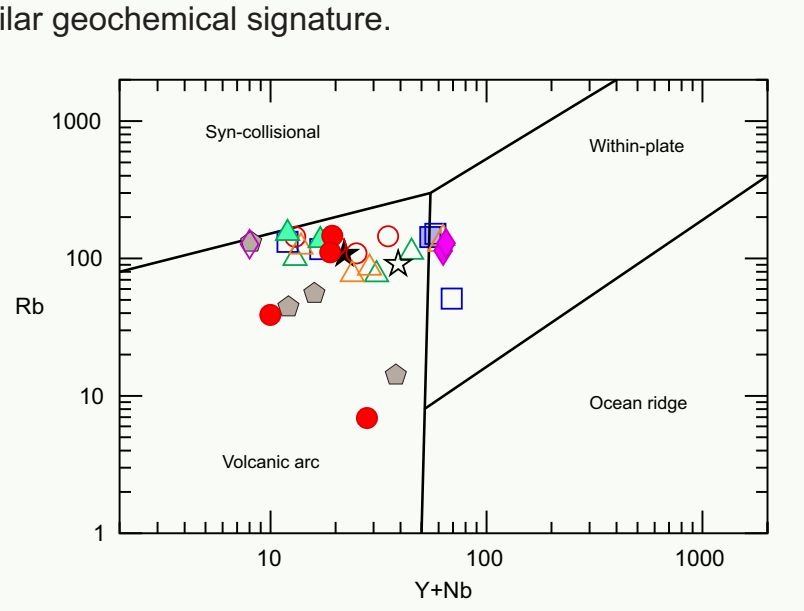
Biotite granite (unit 13) with phenocrysts of K-feldspar has a very similar in texture to the Chipewyan batholith (unit 14). This unit is pink when fresh, weakly magnetic, massive to weakly foliated and contains rare xenoliths of metasedimentary rocks. The estimated bulk mineralogy of the rock comprises K-feldspar (30–40%), quartz (20–30%), biotite and hornblende (10–12%), plagioclase, and trace magnetite. This granite is interpreted as a satellite pluton of the Chipewyan batholith.

Whole rock geochemistry

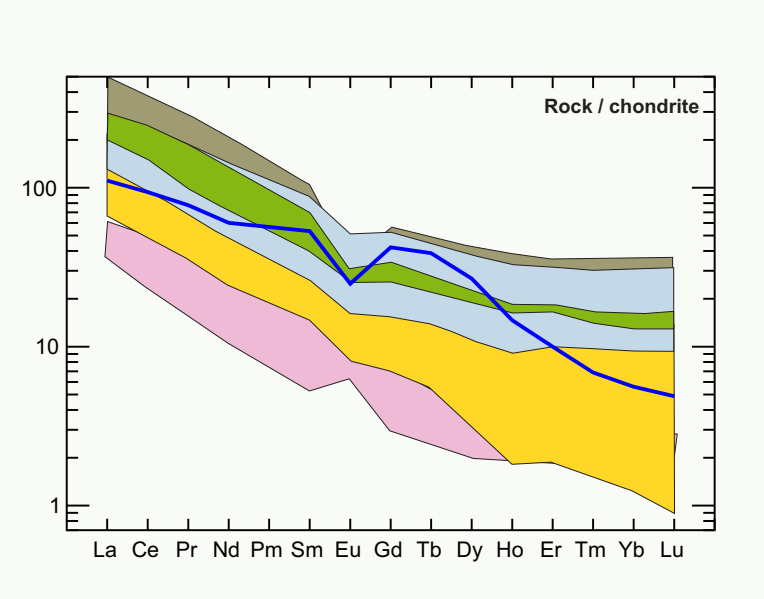
The felsic plutonic rocks mapped in the northen basin of Southern Indian domain are peraluminous and metaluminous and fall in the volcanic arc field of the Rb vs. Y+Nb diagram. REE and trace element geochemistry show all the units have similar geochemical signature.



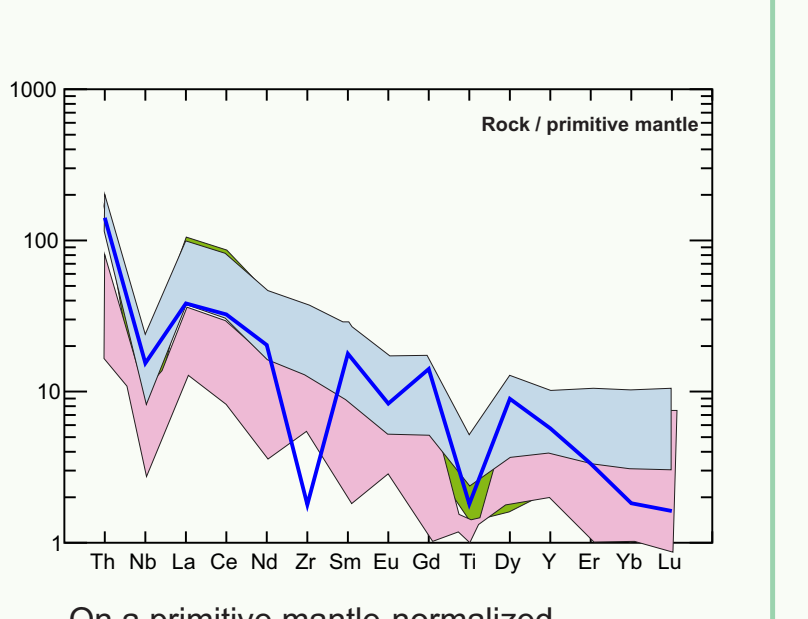
Al/ (NA+K) vs. Al/(Ca+Na+K) diagram (Shand's Index) showing the granitoid rocks plotted in the metaluminous and peraluminous field (after Maniar and Piccoli, 1989).



Rb vs. Y+Nb diagram showing the volcanic arc affinity of the granitoid rocks from the northern basin of Southern Indian Lake (modified after Pearce et al., 1984).



On a chondrite normalized trace-element diagram the granitoid rocks show a negative slop with light rare-earth-element (LREE) enrichment and overall an Eu negative anomaly (normalizing values from McDonough and Sun, 1995).



On a primitive mantle-normalized incompatible trace element diagram the signature includes positive Th anomaly, and depletion in Nb and Ti. Pegmatite shows depletion in Zr (blue line; normalizing values from Sun and McDonough, 1989).

Mineral Potential

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,c).

Geoscience data, both in Manitoba and Saskatchewan, are establishing temporal links between volcanic rocks in the Southern Indian Lake, Rottenstone, Lynn Lake - Leaf Rapids domains, and therefore indicate the possible presence of a variety of mineral deposit types at the regional scale (e.g. VMS, orogenic lode gold, magmatic Ni-Cu-PGE). Some of the prospects identified include:

VMS

Assay results up to 2.2% Cu from a narrow malachite-rich fracture in volcanic rocks of the Whyme Bay assemblage (Frohlinger, 1972);

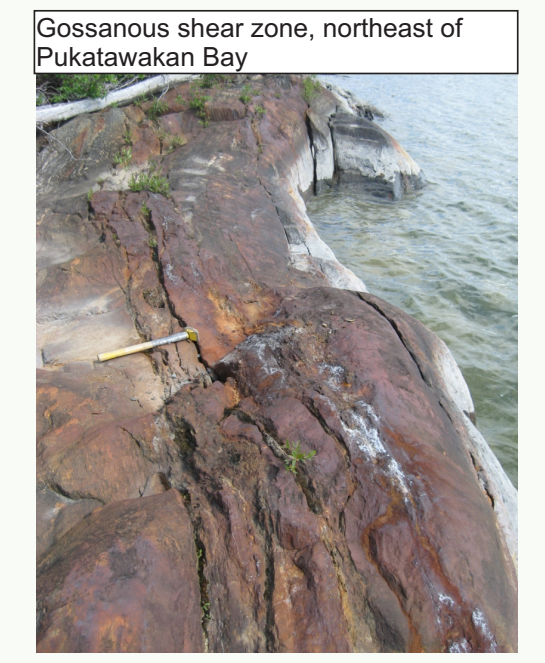
Surface grab samples collected from trenches around Peanut Lake (immediately north of Partridge Breast Lake) returned Cu values of 4.74% and 6.85%. The samples consisted of disseminated and laminated pyrite, chalcopyrite and pyrrhotite hosted in garnet-biotite-quartz-hornblende-magnetite gneiss (in Manitoba Assessment File 93051).

Of particular note this field season was the identification of 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.

Orogenic Lode Gold

Pyrite ± chalcopyrite ± pyrrhotite occur as disseminations and stringers along the sheared contact between Archean gneiss and the Proterozoic successions to the northwest and to the east of Pukatawakan Bay. The localized mineralization in the shear zones is associated with siliceous ± carbonate ± chloritic ± sericitic alteration.

Gossanous shear zone, northeast of Pukatawakan Bay



Gossanous shear zone east of Pukatawakan Bay

Magmatic Ni-Cu-PGE

Sulphidic and graphitic sedimentary horizons and iron formation on the northwestern shore of Turtle Island contain up to 70% pyrite and pyrrhotite with minor chalcopyrite. Perhaps more interesting is the fact that this sequence is intruded by the sulphide-bearing, ultramafic to intermediate Turtle Island intrusive complex, which shows evidence of multiple injections in a fluidly dynamic magma chamber. The host sedimentary rocks may have provided the source of sulphur to the intruding magma which allowed for the fractionation of magmatic Ni-Cu platinum-group element sulphides.

Igneous layering in Turtle Island intrusive complex

Sulphide-bearing fault zone in Turtle Island intrusive complex

Sulphidic and graphitic sedimentary horizons

Silicate and sulphide facies iron formation

Diamonds

An exotic fragment of latest Archean to earliest Paleoproterozoic (ca. 2.5-2.3 Ga) orthogneiss exposed at Southern Indian Lake marks the first occurrence of crust of this age in this part of the THO. Zircons of this age are present as detrital and inherited grains in sedimentary, volcanic and plutonic rocks throughout the region (Kremer et al., 2009a; Rayner and Corrigan 2004), which suggests that this isolated continental fragment is an important geotectonic component in the evolution of and may underlie significant portions of the Southern Indian domain.

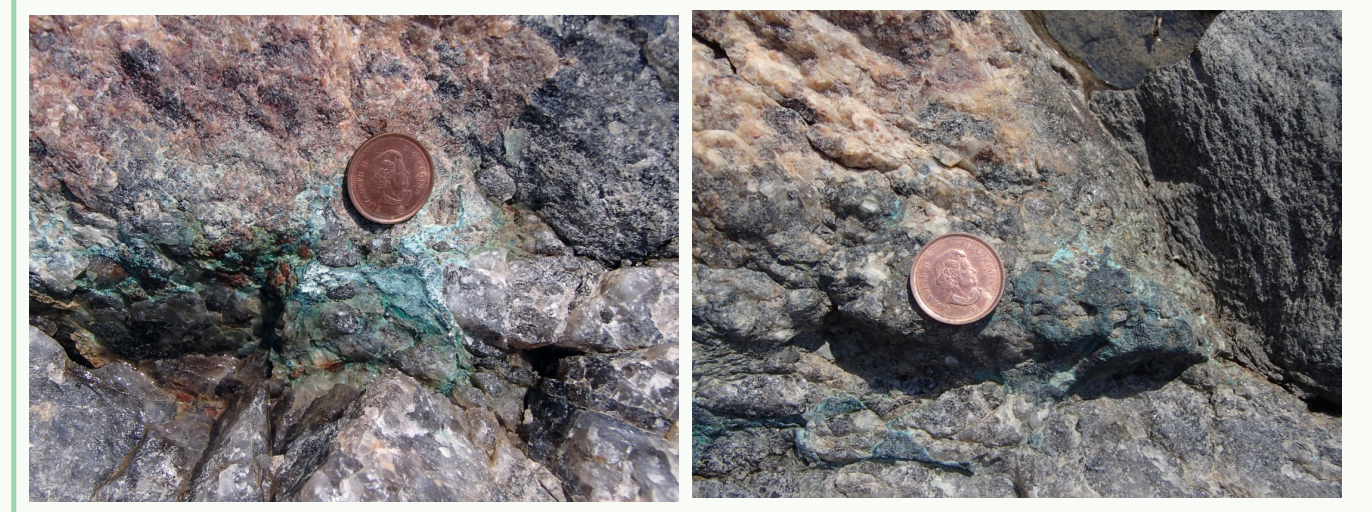
The Chipewyan batholith is interpreted as a continental magmatic arc formed in response to subduction under the southeastern Hearne craton margin and stitches the Southern Indian domain to the Hearne craton. This batholith shows evidence of increasing crustal contamination northward, which is interpreted to represent greater interaction with the Hearne craton in that direction (MacHattie, 2001). This stands in contrast to arc rocks associated with the Partridge Breast Lake assemblage, which have documented contamination interpreted to result from interaction with Arcehan-Paleoproterozoic-aged rocks exposed at Southern Indian Lake prior to accretion to the Hearne craton and the emplacement of the Chipewyan batholith. This data suggests that the two domains could be underlain by separate cratonic entities.

The margins of Archean cratons are considered important regional vectors for diamond exploration. The diamondiferous Pikoo kimberlite is located in E-central Saskatchewan and, along with the Fort à la Corne kimberlite field, marks the second major diamond occurrence in areas thought to be underlain at depth by the mostly buried Sask craton. A better constraining of the Archean crustal architecture in northern Manitoba could have significant bearing on diamond exploration in the region.

Intrusion related Au deposits

Malachite, azurite, bornite and chalcocite were also identified in 2015 within a narrow fracture in pink pegmatite. A grab sample of this material yielded values of **4.7 g/t Au**, **>1% Cu** , **4.6g/t Ag**, **2200 ppm Bi**, **>0.5% Pb** and **736 ppm Se**.
This outcrop is the second gold occurrence at Southern Indian Lake associated with pegmatite. The Au-Cu-Ag, Bi geochemical signature of this occurrence is similar to that of other intrusion-related gold systems, for example in the Fairbanks district of Alaska (namely the Fort Knox and the Pogo deposits). 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).

Unusual polymetallic **Be-Au-Zn-Bi mineralization** associated with a pegmatite on Turtle Island (central area of Southern Indian Lake; Kremer et al., 2009a; Martins and Kremer, 2013) is restricted to the altered contact zone with the basalt hostrocks and occurs as a band (5–10 cm thick) of semi-massive to massive pyrite and chalcopyrite within the pegmatite. The semi-massive sulphide contains abundant white to pale green beryl crystals (1–3 cm). Samples from this zone returned high values of Be, Au, Ag, Bi, Zn, Nb and Ta. Moreover, this association is analogous to the Fort Knox deposit in Alaska, which is also associated with granitoid plutons and pegmatite (Quandt et al., 2008).



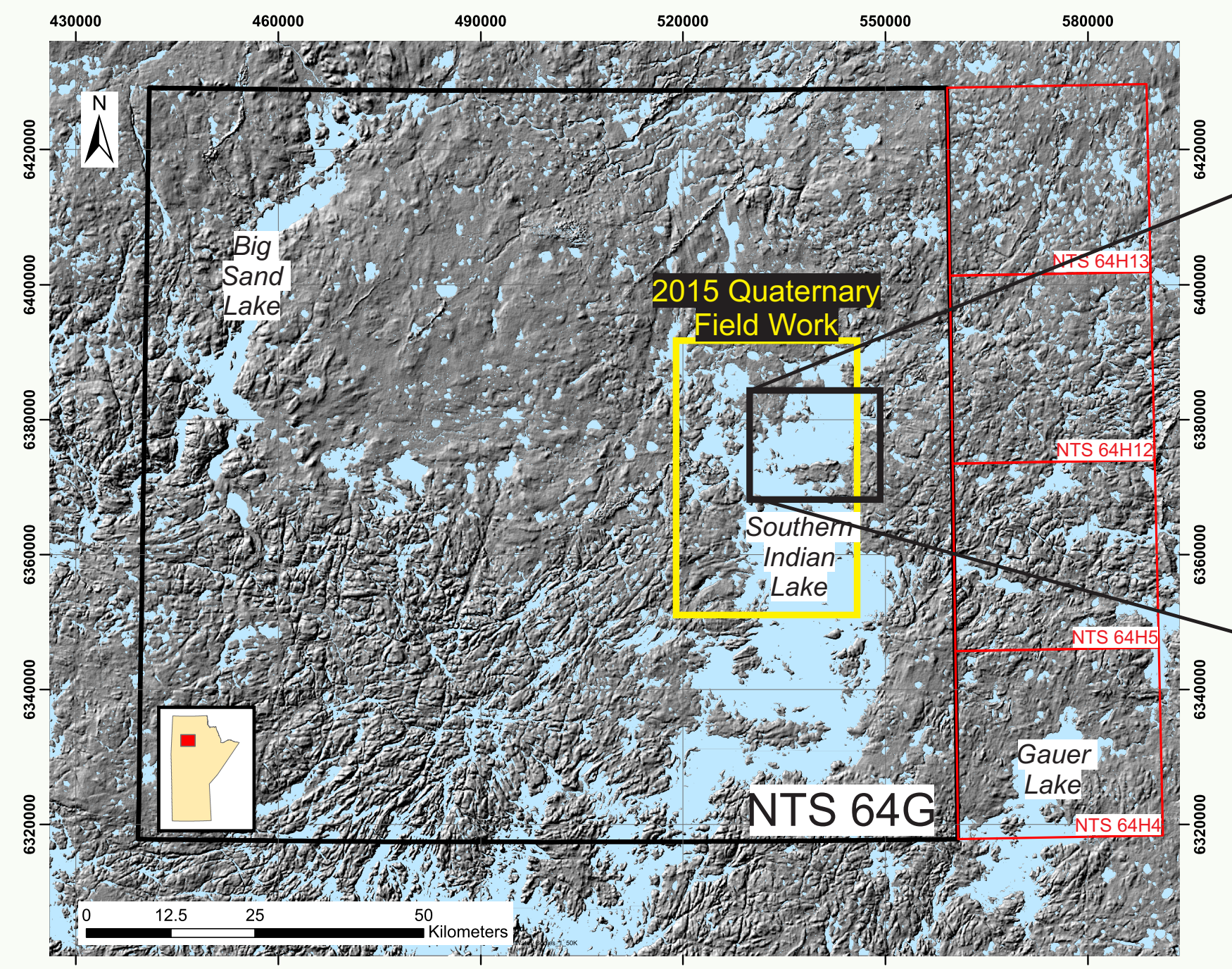
K-feldpsar dominant pegmatite with fracture filled Cu-sulphide phases and weathering products (malachite and azurite). Assay values: **Au** values of 4.7 g/t and > 1% **Cu**.

Details of pale green to white beryl and vuggy area of sulphide semi-massive mineralized contact area of a pegmatite on Turtle Island. Assay values: 2865 ppm **Be**, 1.55 g/t **Au**, 2 g/t **Ag**, 681 ppm **Bi**, 4100 ppm **Zn**.

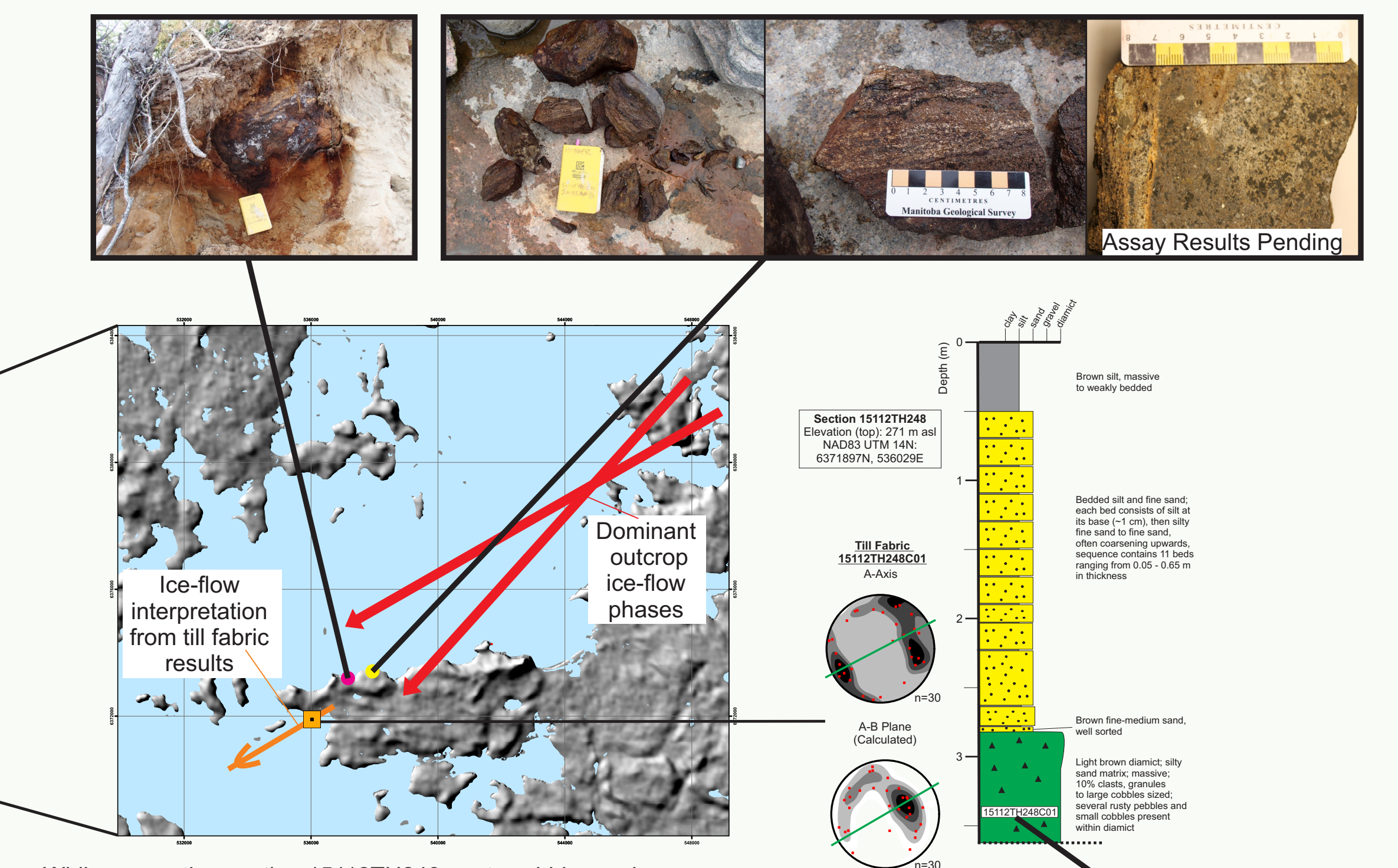
Quaternary mapping

Quaternary geology fieldwork was conducted in the northern area of Southern Indian Lake (NTS G7–10) in the summer of 2015.

Recent 1:50 000 scale mapping and till sampling has been conducted within the Gauer Lake – Wishart Lake, regions (NTS 64H4, 5, 12, 13; Trommelen, 2015). Archived samples from fieldwork conducted by Geological Survey of Canada in the late 1980s were re-analyzed recently (Lenton and Kaszycki, 2005) and results for NTS 64G are discussed.



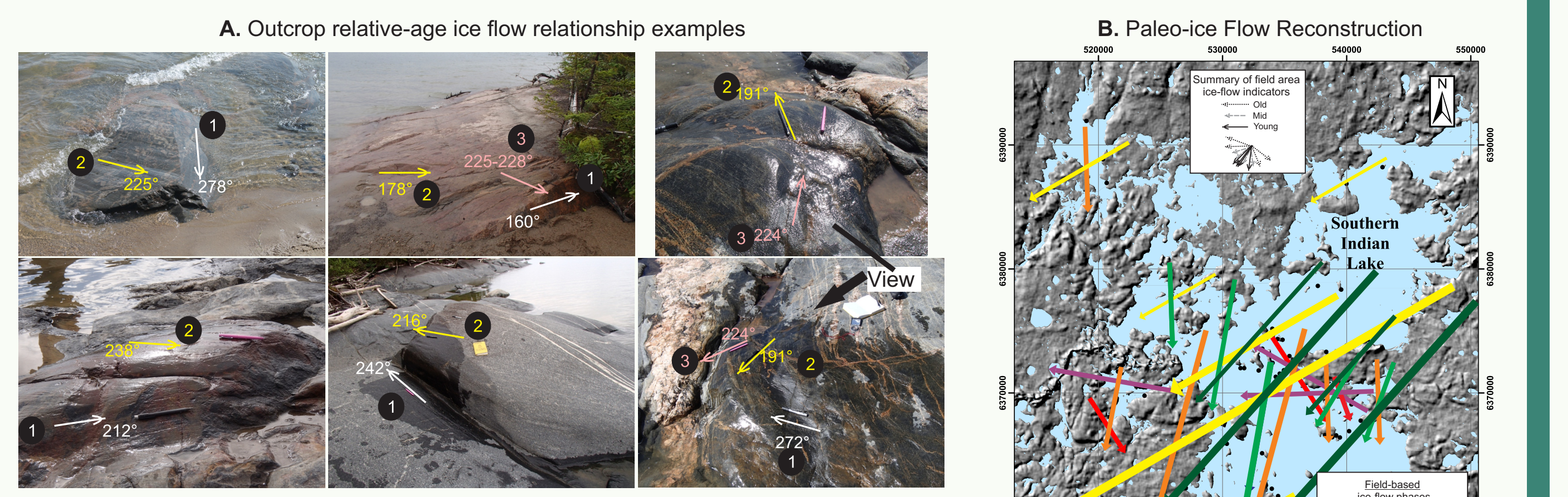
Sulphide-bearing boulders and cobbles



While excavating section 15112TH248, rusty cobbles and pebbles were recovered in-situ from till. Interestingly, stations visited along the shore to the northeast of the section observed several occurrences of rusty cobbles and boulders. Till-fabric analysis suggests deposition by a southwest-trending ice-flow phase.

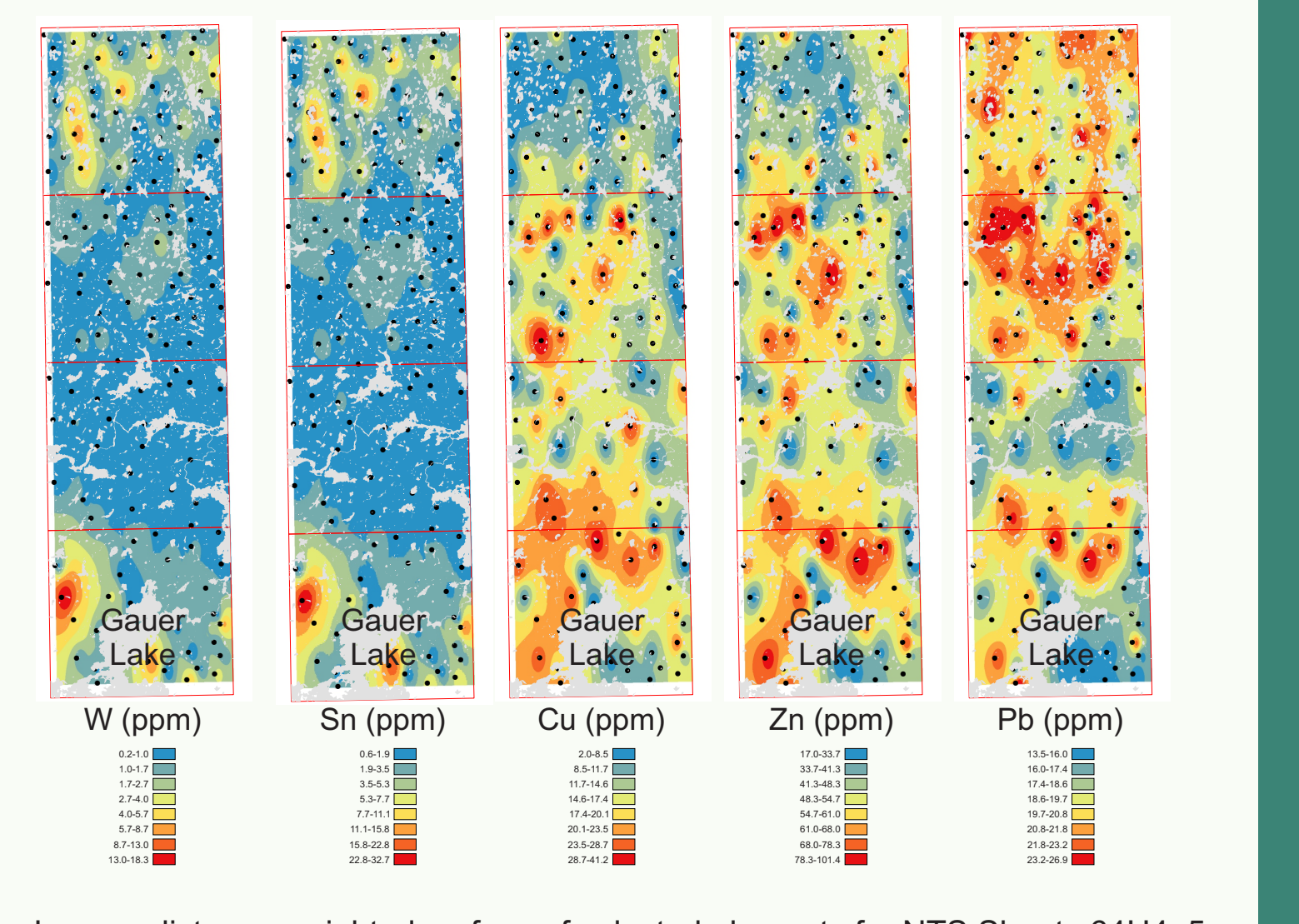
This is in agreement with the dominant paleo-ice flow trajectory mapped at outcrops in the area. These observations suggest the possibility of a dispersal train and unknown mineralization to the northeast of these stations.

Paleo-ice flow mapping



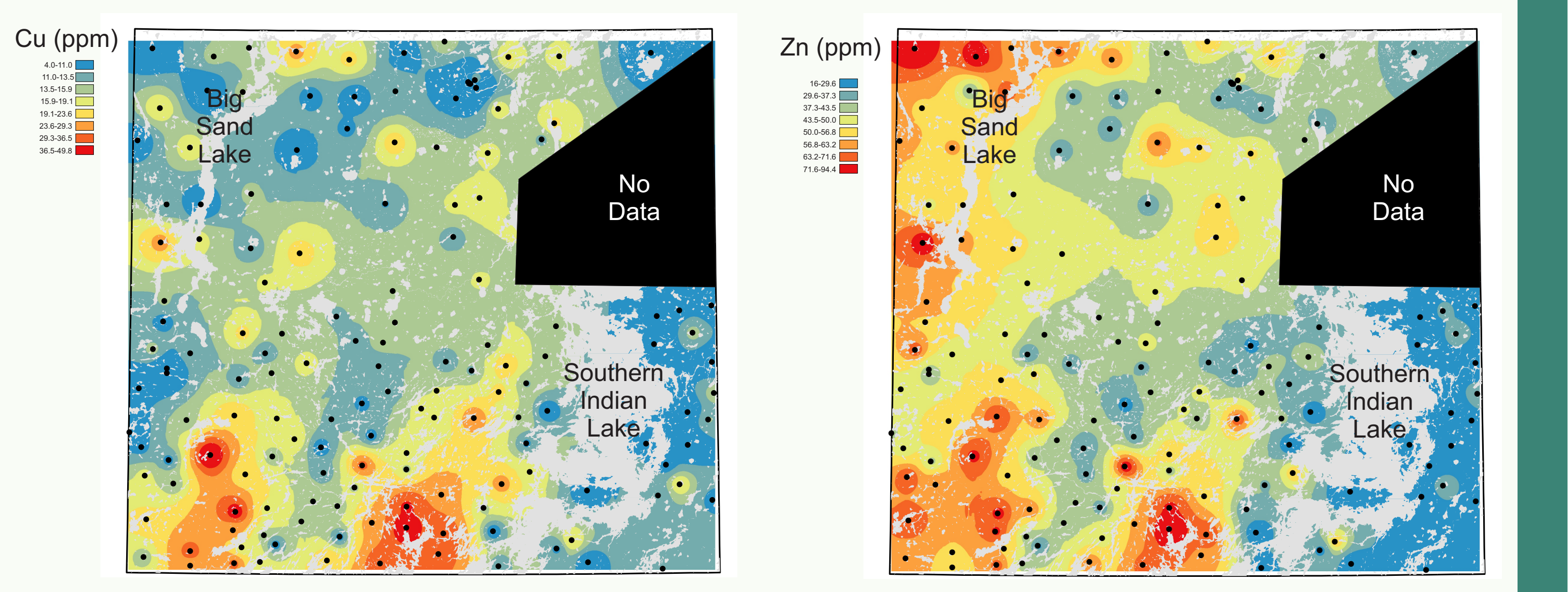
A.) Example of ice-flow relative-age relationships observed during field work. **B.)** Paleo-ice flow reconstruction of the northern area of Southern Indian Lake. The oldest mapped flows are southeast (phase I, 137–164°), west to northwest (phase II, 268–297°) and south (phase III, 173–208°). These ice-flow phases were followed by a southwest (phase IV, 230–253°) ice-flow phase, which is overprinted by a south to southwest (phase V, 187–225°) ice-flow phase. Paleo-ice–flow phases IV and V are the dominant erosional indicators observed at outcrops visited. Thus, the implied dominant dispersal trend in the study area is to the south to southwest; however, caution must be exercised in this complex glacial landscape, since glacial dispersal as a result of early (phases I and II) and later ice-flow phases (phases III–V) remains a possibility, which could produce complex palimpsest dispersal trains.

Gauer Lake to Wishart Lake (NTS 64H4, 5, 12, 13) geochemical trends



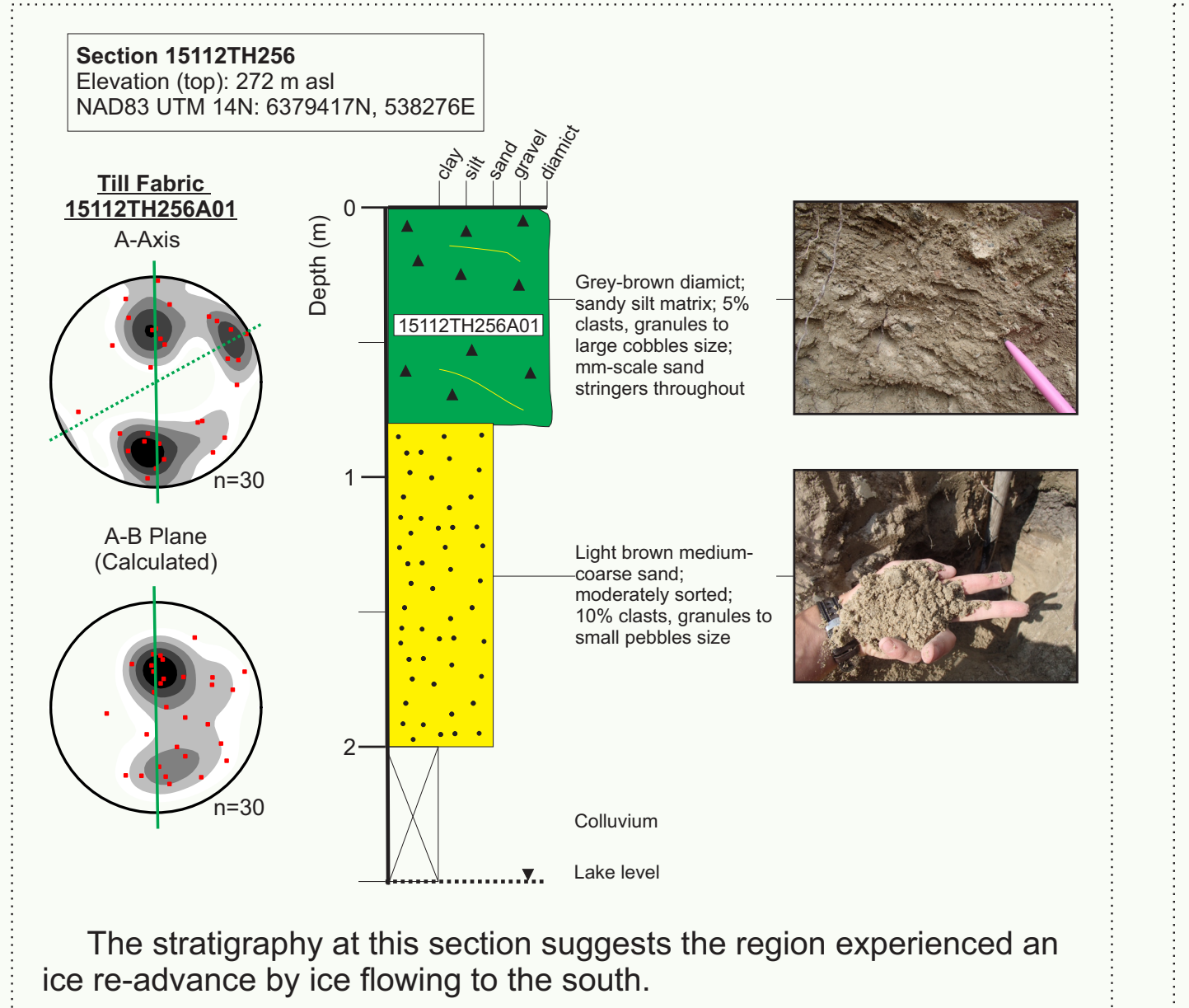
Inverse distance weighted surface of selected elements for NTS Sheets 64H4, 5, 12, 13. Tungsten and Sn values follow a near identical trend and are elevated relative to background northwest of Gauer Lake. Data is from Trommelen (2015). Classification is by natural breaks (Jenks) classification.

Regional (NTS 64G) Cu and Zn trends

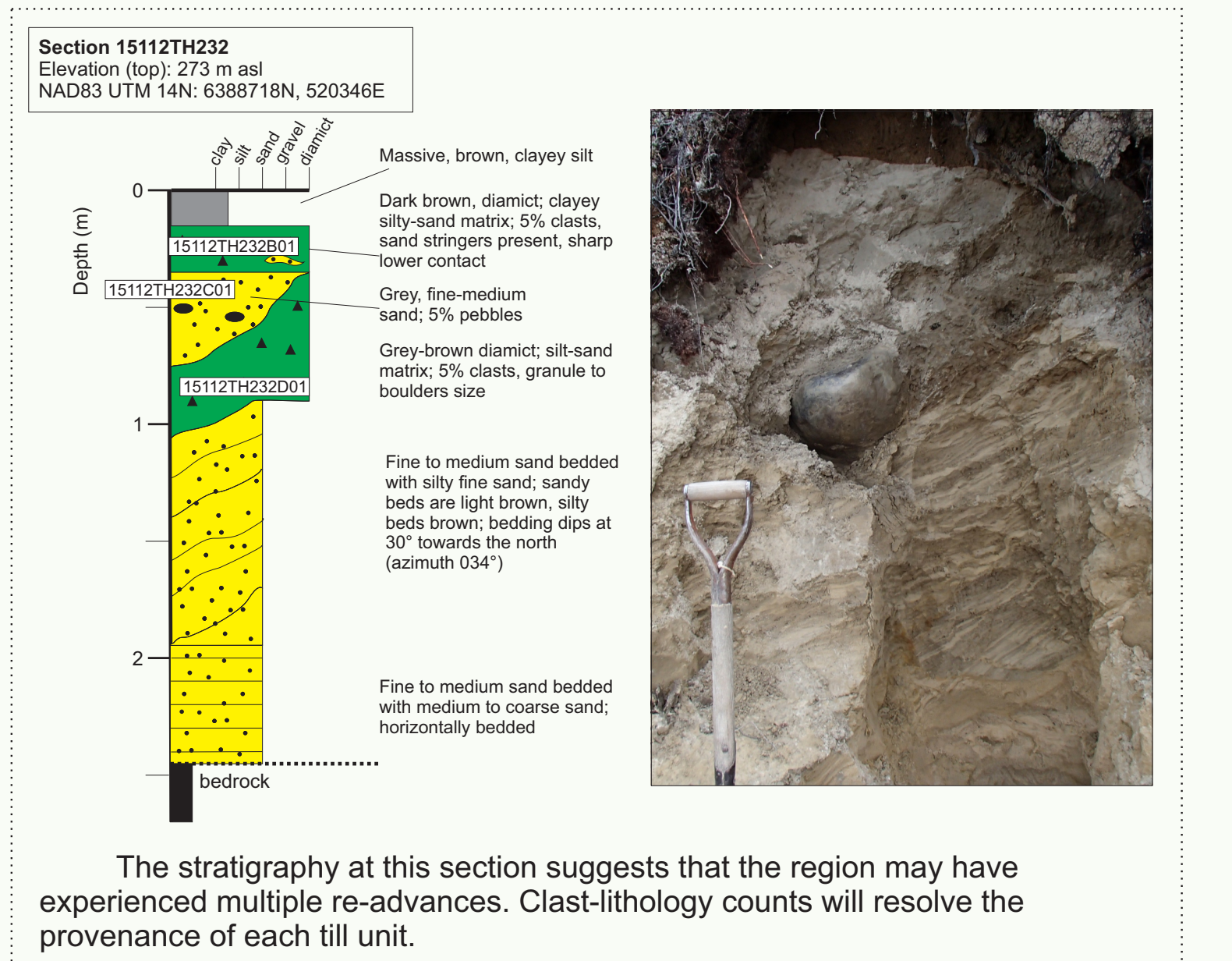


Inverse distance weighted surface of Cu and Zn in the Southern Indian Lake area. Copper values southwest of Southern Indian Lake are elevated relative to background values. Data from Lenton and Kaszycki (2005). Classification is by natural breaks (Jenks) classification.

Quaternary stratigraphy



The stratigraphy at this section suggests the region experienced an ice re-advance by ice flowing to the south.



The stratigraphy at this section suggests that the region may have experienced multiple re-advances. Clast-lithology counts will resolve the provenance of each till unit.

Implications for mineral exploration

The dominant paleo-ice flow trajectory in this study is to the southwest, although the complex paleo-ice flow history has the potential to produce more complex palimpsest dispersal trains.

The source of the sulphide-bearing erratics is currently unknown. Based on the ice-flow history the likely source is to the northeast or north. More detailed follow-up work may be able to discover the source.

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Acknowledgments

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