GS-7 Northwestern Superior craton margin, Manitoba: an overview of Archean and Proterozoic episodes of crustal growth, erosion and orogenesis (parts of NTS 54D and 64A)

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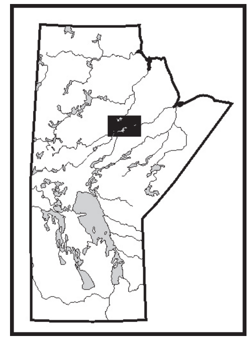

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Summary

The northwestern margin of the Superior Province in Manitoba represents a dynamic boundary zone with good potential for magmatic, sedimentary-hosted, and structurally controlled mineral deposits. The region has a history that commences in the early Archean with the formation of the Assean Lake Crustal Complex. This fragment of early to middle Archean crust was likely accreted to the Superior Province between 2.7 and 2.6 Ga, a major period of Superior Province amalgamation. Sediments derived from this amalgamation process were deposited at numerous locations along the northwestern margin of the Superior Province. During the Hudsonian orogeny, the margin of the northwestern Superior Province was once again a site of tectonism, magmatism and sedimentation. Paleoproterozoic sandstone and conglomerate overlie Middle Archean granite gneiss at Apetowachakamasik Lake (also known as 4-mile lake)[3]. The extent to which the Archean crust underlies Paleoproterozoic rocks of the Trans-Hudson Orogen is not completely understood. Although Archean xenocrystic zircons were not discovered in igneous rocks at Crying and Campbell lakes, metagreywacke at Campbell Lake contains abundant circa 2.45 Ga detrital zircon. The age of this detritus is consistent with a possible derivation from the Sask craton, an Archean microcontinent that underlies much of the Trans-Hudson Orogen in Saskatchewan and Manitoba.

Introduction

This paper presents a summary of results from three years of mapping and geochronology along the northwestern Superior Boundary Zone between Paleoproterozoic rocks of the Trans-Hudson Orogen and Archean rocks of the Superior craton (Figure GS-7-1). This dynamic boundary zone boasts a protracted history of crustal growth, erosion and sedimentation, and repeated orogenesis. The oldest known component of this boundary zone, the Assean Lake Crustal Complex (ALCC; Böhm et al., 2000, 2003), consists of a structural block with a history extending to >4 Ga. The early Archean growth of this ancient block has been recorded in detrital and xenocrystic zircon, and in the isotopic signature of Neoarchean granite bodies (Böhm et al., 2000; Hartlaub et al., in press). The ALCC extends along the Superior margin for at least 50 km, and may have a common history with other early Archean crustal fragments in northern Quebec and Greenland (Hartlaub et al., in press).

South of the ALCC, the Split Lake Block represents a variably retrogressed and shear zone–bounded granulite terrain that is dominated by plutonic rocks and mafic granulite (Hartlaub et al., 2003, 2004). Although the boundary between the ALCC and the Split Lake Block consists of a major shear zone, it likely originated as some sort of suture. This suture zone was the site of Neoarchean orogenesis, metamorphism, sedimentation and widespread magmatism (Böhm et al., 2003; Hartlaub et al., 2004; Kuiper, unpublished data, 2005). To the north of the ALCC, a major unresolved question is the extent to which Archean rocks underlie Paleoproterozoic rocks of the Trans-Hudson Orogen (Figure GS-7-1).

Assean Lake Crustal Complex (ALCC)

Assean Lake

The first evidence for ancient (>3.6 Ga) crust in Manitoba was discovered at Assean Lake (Böhm et al., 2000, 2003). Additional samples from Assean Lake were collected as part of this study to better constrain the timing of Archean sedimentation and magmatism in the area. Two samples of metagreywacke were collected from Assean Lake, one from the southwestern arm of the lake (9704-8172) and the other from a previously studied location (CB97-12; Böhm et al., 2000, 2003). Both samples contain abundant >3.5 Ga detrital zircons, with the youngest concordant metamorphic grains in both samples having an age of ca. 3.1 Ga.

To test the age of felsic magmatism in the ALCC, a sample of medium-grained biotite tonalite (CB96-48a) from northwestern Assean Lake was collected for geochronology. The sample yielded a laser-ablation multicollector inductively coupled plasma–mass spectrometry

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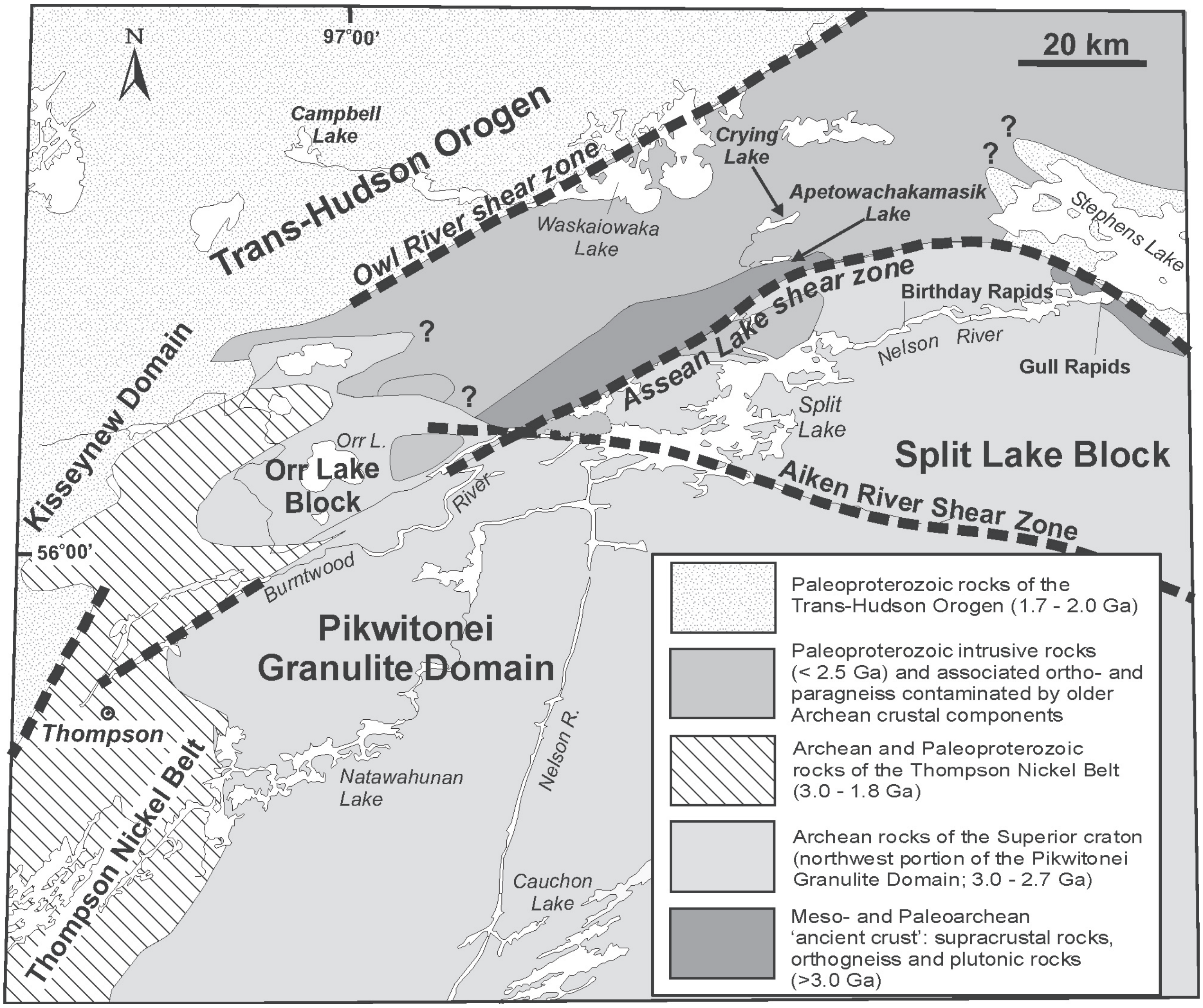

Figure GS-7-1: *General geology of the northwestern Superior craton margin and the Superior Boundary Zone.*

(LA-MC-ICPMS; Simonetti et al., 2005) upper-intercept U-Pb zircon age of 3169 ±10 Ma. The authors interpret this to be the time of tonalite crystallization, similar, within error, to a 3179 ±16 Ma sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon age for a leucotonalite from north-central Assean Lake (Böhm et al., 2003). Although the timing of metamorphism at Assean Lake is not yet fully understood, 3.14, 2.68 and 2.61 Ga metamorphic zircon overgrowth ages have been reported (Böhm et al., 2003).

Apetowachakamasik Lake

Apetowachakamasik Lake is located north of the Split Lake Block at the boundary between Paleoproterozoic sedimentary rocks of the Trans-Hudson Orogen and Archean rocks of the ALCC (Figure GS-7-1). New mapping in the summer of 2005 (Figure GS-7-2) indicates that the boundary, which trends east down the centre of the lake, is both lithological and metamorphic in nature. The north shore comprises predominantly greenschist-facies conglomerate and sandstone, whereas a mixed suite of upper-amphibolite–facies Archean granite gneiss with injected leucogranite is exposed along the south shore.

Granite gneiss

The basement granite gneiss is composed mainly of two components: older granite to granodiorite paleosome and younger leucogranite neosome. Although the leucogranite neosome appears in places to be injected, it lies parallel to gneissosity in the paleosome and could represent the product of in situ anatexis. The basement granite locally contains mafic, biotite-rich enclaves that may represent xenoliths of older rock or disrupted dikes.

In order to test whether the granite-gneiss basement at Apetowachakamasik Lake is part of the Superior Province or an extension of the ALCC, two samples of the basement were collected for geochronology in 1998 and additional samples were collected in 2005. Sample

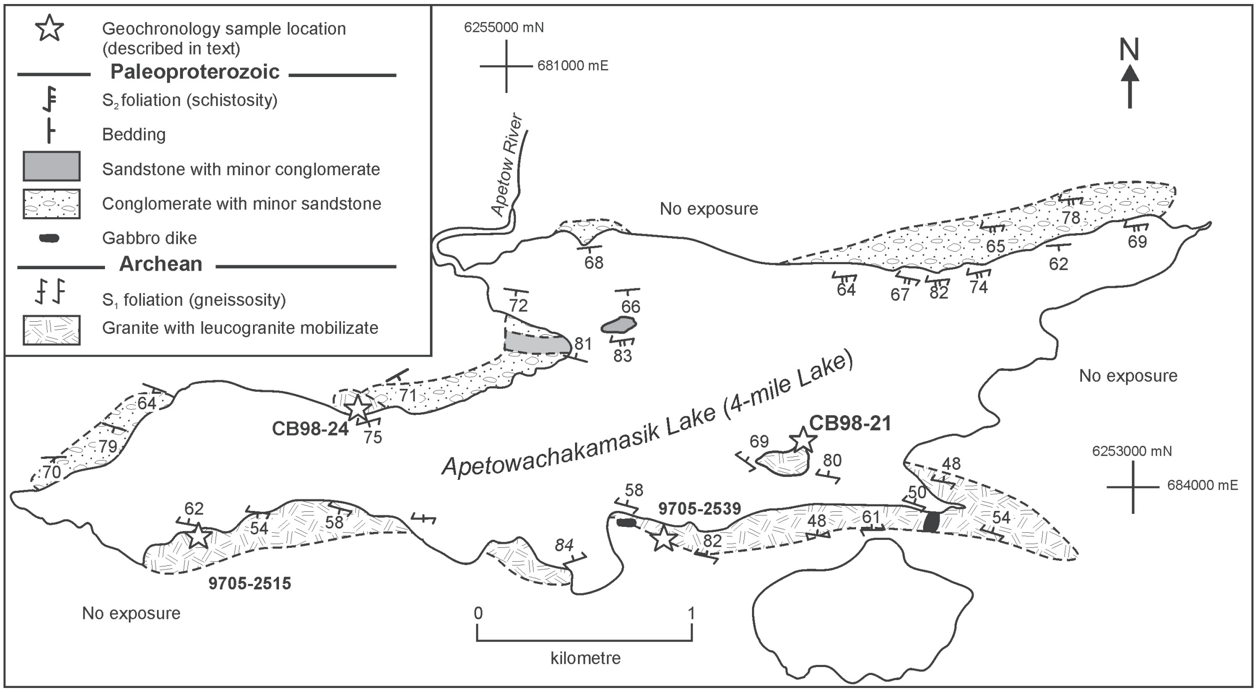

Figure GS-7-2: *Simplified geology of Apetowachakamasik Lake.*

CB98-21 (Figure GS-7-2) consists of pink, medium- to coarse-grained granite gneiss and was analyzed for U-Pb zircon ages by LA-MC-ICPMS. The sample is dominated by circa 3.2 Ga zircon prisms that the authors interpret to record the crystallization age of the granite. A single ca. 2.7 Ga metamorphic zircon and a single ca. 3.6 Ga xenocrystic zircon were also identified in this sample. Sample CB98-24 is a pink-weathering leucogranite that may represent a large segregation of the neosome from the gneiss. This sample has a complex zircon population, which includes ca. 3.1 Ga zircon, interpreted to have formed during crystallization, and zircon with $^{207}Pb/^{206}Pb$ ages between 3.2 and 3.8 Ga, interpreted to be xenocrystic. This sample has also been strongly affected by a poorly constrained ca. 2.7 Ga metamorphic event. The sample site from which CB98-24 was collected contains several mafic enclaves, possibly representing xenoliths from which some of the old xenocrystic zircons were derived.

Zircons from two additional samples of the granite basement (9705-2515 and 9705-2539) were analyzed by the novel technique of LA-MC-ICPMS U-Pb dating of petrographic thin-sections. Initial results indicate that the U-Pb zircon ages of these samples are ca. 3.1–3.2 Ga, consistent with the other basement samples.

Paleoproterozoic sedimentary rocks

The greenschist-facies sedimentary rocks exposed on the north shore of Apetowachakamasik Lake are predominantly matrix-supported polymictic conglomerate. Clasts range from pebbles to cobbles and include granite, gabbro, vein quartz and sandstone. The matrix of the conglomerate is sandstone that has a green colour, likely related to the presence of abundant chlorite and epidote. Carbonate cement is locally important and results in a distinctive recessive weathering of the rock. The conglomerate contains trace magnetite in some locations. Overall, the conglomerate is poorly bedded, and no grading was identified. Sandstone horizons within the conglomerate can be upwards of 10 m thick and locally display highly deformed crossbedding. A moderate to strong deformation of the sedimentary rocks is also indicated by the variable flattening of pebbles and cobbles. These clasts have a length:width ratio that ranges from 1:1 to 10:1. The largest and most diverse set of clasts was identified near the single outcrop of granite basement on the north shore of the lake (Figure GS-7-2). In this area, granite and gabbro cobbles are relatively abundant compared to other outcrops on the north shore of the lake. This change may be related to the proximity of an unconformity; however, the contact between sedimentary rocks and basement is not exposed.

Dikes and late deformation

Several large gabbroic dikes cut the granite basement but do not appear to transect the overlying conglomerate and sandstone. These dikes show evidence of low-grade metamorphism but appear to have been emplaced after upper-amphibolite–facies metamorphism that affected the basement granite. The conglomerate is cut by a much younger set of thin (10–20 cm wide) granite dikes. These thin dikes are, in turn, cut and offset by small-scale sinistral faults.

Split Lake Block

Nelson River from Split Lake to Gull Rapids

Due to the predominance of plutonic rocks in the Split Lake Block (Hartlaub et al., 2003, 2004), a large number of samples was collected in order to better constrain the main magmatic episodes. A granodiorite (9704-2302) from west-central Split Lake yielded an ID-TIMS U-Pb zircon age of 2663 ±11 Ma. This granodiorite contains xenoliths of anorthosite and anorthositic gabbro, therefore indicating that the anorthosite complex (Hartlaub et al., 2004) was formed prior to 2.66 Ga.

In order to better constrain the timing of metamorphic events in the Split Lake Block, a sample of biotite-garnet gneiss (9704-2003) was collected from northeastern Split Lake. The sample contains abundant, clear, reddish zircon balls that yielded a LA-MC-ICPMS U-Pb age of 2684 ±35 Ma. The authors interpret this age to roughly reflect the timing of high-grade metamorphism in the Split Lake Block. This age overlaps with the granodiorite crystallization age (9704-2302) and with a 2696 Ma age for leucosome in the Split Lake Block (Böhm et al., 1999), together indicating that regional high-grade metamorphism was associated with felsic plutonism.

Garnet-sillimanite-biotite gneiss is exposed at several locations just east of Split Lake, near Birthday Rapids (Figure GS-7-1; Hartlaub et al., 2003). The rock, which the authors interpret to be pelitic sediment, is rusty brown weathering and comprises quartz, feldspar, biotite, garnet and sillimanite with trace sulphides±graphite. Detrital zircon was separated from a sample (9703-2115) in order to constrain the age of deposition and examine sediment provenance. Sixty LA-MC-ICPMS analyses indicate that zircon grains have $^{207}Pb/^{206}Pb$ ages ranging from ca. 2.65 to 3.8 Ga (Figure GS-7-3). The youngest concordant detrital zircon has an age of ca. 2.7 Ga. This result, combined with the high-grade metamorphic and plutonic

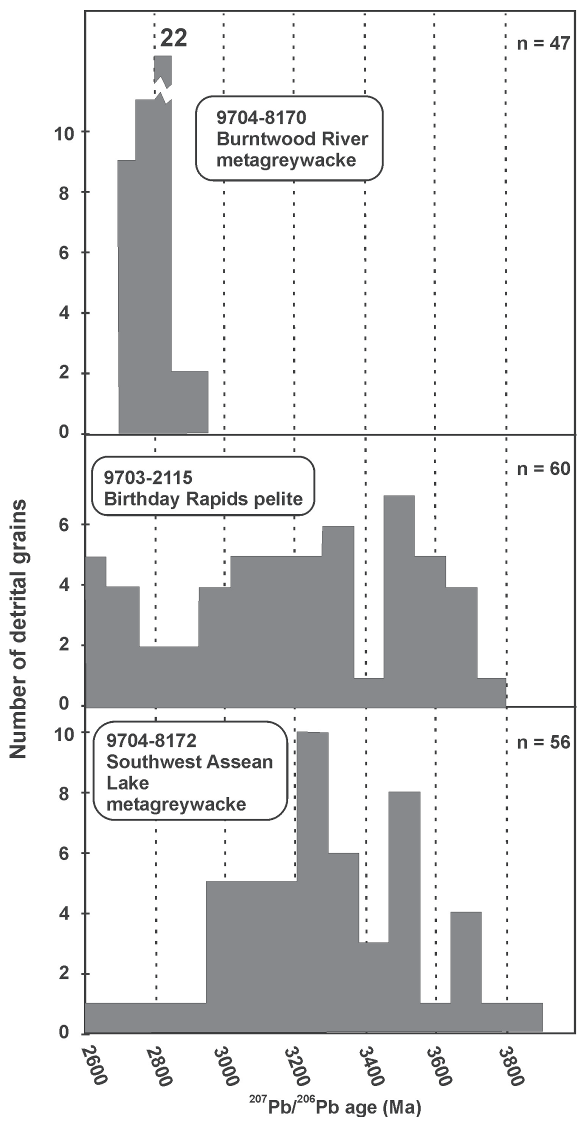

Figure GS-7-3: *Age histograms of detrital zircon results from study of three metasedimentary samples from the north-western Superior Boundary Zone.*

overprinting on the sample (Hartlaub et al., 2003), indicates that sedimentation occurred between ca. 2.7 and 2.66 Ga. The older detrital ages indicate that the source terranes likely included the ALCC.

Aiken River shear zone and transition into the Pikwitonei Granulite Domain

The character of rocks changes as one progresses southward across the Aiken River shear zone (Kuiper et al., 2004) into the Pikwitonei Granulite Domain in southern Split Lake. The predominant mix of mafic granulite and orthogneiss of the Split Lake Block (Corkery, 1985; Hartlaub et al., 2004) gives way to large intrusions of pink granite, and migmatite that is dominated by granite leucosome. The aeromagnetic character of the rocks also changes from a magnetic low in the Split Lake Block to a relative high in the Pikwitonei Granulite Domain. Samples of the granite suites and leucosome were collected in the summer of 2005, and initial geochronology is in process.

A sample of metagreywacke (9704-8170) was collected along the Burntwood River, west of Split Lake. The metagreywacke lies roughly on the boundary between the ALCC and the Superior Province, and its depositional age was unknown. Initial results from 47 U-Pb LA-MC ICPMS analyses of detrital zircon from the sample indicate that deposition likely occurred at ca. 2.7 Ga (Figure GS-7-3). The oldest grain in the sample is 2.95 Ga, much younger than crust in the ALCC but consistent with ages found throughout the Superior Province (e.g., Card, 1990). This result is interesting because the sample from Birthday Rapids (9703-2115), which was likely deposited about the same time, shows clear evidence of derivation from the ALCC.

Influence of Archean crust in the Trans-Hudson Orogen

Crying Lake

A sample of grey granodiorite-tonalite gneiss (CB98-26) was collected from Crying Lake. The felsic gneiss is migmatitic and contains abundant fine mafic and granitic layers. This sample contains prismatic zircon and rutile that together yielded a U-Pb age of 1.86 Ga. Although Crying Lake is located just north of Apetowachakamasik Lake (Figure GS-7-1), no evidence of Archean inheritance was found in this sample.

Campbell Lake

Two samples from Campbell Lake (Figure GS-7-1) were collected: granodiorite (CB99-217) to examine the timing of magmatism, and metagreywacke (CB99-215-2) to study the timing and source of sedimentation. The granodiorite contains a single population of clear, colourless prismatic zircon that yielded a U-Pb age of 1891 ±26 Ma, based on 17 LA-MC-ICPMS analyses. This result is considered a good estimate for the crystallization age of the granodiorite. Although there is a lack of Archean contamination in the plutonic rocks at Crying and Campbell lakes, Nd tracer isotope results indicate that Archean crust may underlie much of the region (Böhm et al., 2000).

The Campbell Lake metagreywacke contains abundant brown to colourless, clear, moderately rounded zircon prisms. Initial results from 23 analyses of these detrital zircons indicates that they represent a single population with a crystallization age of ca. 2.45 Ga. This result is somewhat surprising because very few rocks of that age are presently exposed in the region. The nearest known exposed rocks of similar age are the 2.45–2.48 Ga igneous rocks in the Sask craton (Ashton et al., 1999), located just west of the Saskatchewan-Manitoba border. Extension of the Sask craton beneath western Manitoba is consistent with the data of Rayner and Corrigan (2004) from the Southern Indian Lake area, directly northwest of Split Lake. They reported 2.3–2.5 Ga detrital zircon ages from a conglomerate and 2.4–2.5 Ga inherited zircon in a quartz diorite.

Discussion: Archean orogenic episodes at the northwest Superior margin

The project involved detailed geological mapping and sample collection from selected areas of the northwestern Superior margin (Hartlaub et al., 2003, 2004, this paper). The reconnaissance geochronology reported herein was conducted to complement geological mapping and to better constrain the timing of orogenic episodes at the northwestern Superior margin. One of the clear outcomes of this work is the discovery of circa 3.16–3.2 Ga magmatism throughout the Assean Lake Crustal Complex (ALCC; Figure GS-7-1). This Mesoarchean magmatism impinges on protoliths that date back to 3.9 Ga and have Hf isotope signatures indicating an even longer crustal history (Hartlaub et al., in press). The tectonic setting of this 3.16–3.2 Ga magmatism is unclear, but it appears to have been followed closely by a high-grade metamorphic event that occurred ca. 3.10–3.14 Ga. Unresolved questions include the timing of ALCC accretion to the Superior Province, and the method by which this accretion was accomplished. A Neoarchean, southward-dipping subduction zone appears to be the most likely scenario, because ca. 2.7–2.6 Ga metamorphism in the ALCC was not accompanied by the intrusion of igneous rocks. Magmatic rocks of ca. 2.66–2.68 Ga age and coeval metamorphism are, however, well identified in the Split Lake Block. In addition, the large volume of mafic granulite, both as coherent bodies and as xenoliths, may represent remnants of oceanic rocks that were caught up in the collisional process. Neoarchean sedimentation along the northwestern Superior margin occurred at several locations at roughly the same time (ca. 2.7 Ga, Figure GS-7-3; Bowerman et al., 2004). Although the exact relationship between sedimentation and tectonic setting is not yet well understood, an important constraint is that most of the exposed Archean sedimentary rocks at the northwestern Superior margin are pelite or greywacke. In addition, although the sediments from which these types of rocks were derived are usually deposited in deeper water, they contain detrital zircon of continental derivation.

Additional geochronology, tracer isotope and geochemistry will be conducted in order to improve geological constraints on the orogenic episodes of the northwestern Superior margin. In particular, the isotopic and geochemical characteristics of felsic plutons and mafic granulite units needs to be better constrained.

Economic considerations

The economic potential for the northwestern Superior Province margin and the Superior Boundary Zone is not restricted to the possible extension of the Thompson Nickel Belt. Exploration targets may include VMS-style mineralization in mafic granulite units of the Split Lake Block. This mafic granulite, although now highly metamorphosed, was likely of volcanic origin in an unknown tectonic setting. Several gold deposits along the Assean Lake shear zone underwent exploratory drilling in 2005. There is significant potential for additional deposits all along the Assean Lake and Aiken River shear zones. As noted by Hartlaub et al. (2004), the differentiated anorthosite igneous complex exposed on northwestern Split Lake has potential for ilmenite±magnetite titanium mineralization (e.g., Duchesne, 1999). The Paleoproterozoic sedimentary rocks that overlie the northwestern margin of the Superior Province have reasonable potential for Pb-Zn SEDEX and Carlin-type gold mineralization. The abundance of calcareous-feldspathic sedimentary rocks overlying a crystalline basement, followed by later tectonic compression, provides the basic requirements for the formation of both deposit types, and all of these criteria are seen at Apetowachakamasik Lake.

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