GS-19 Preliminary Sm-Nd isotope results from granitoid samples from the Nejanilini granulite domain, north of Seal River, Manitoba (NTS 64P)

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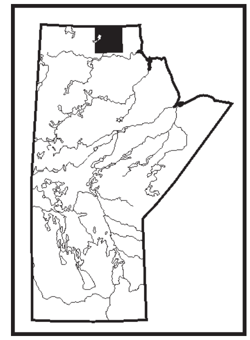

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Summary

The Nejanilini granulite domain is one of Manitoba's last large tracts of land that is relatively unknown and unexplored in terms of its geological nature, evolution and mineral potential. Previous mapping and petrographic studies suggest that the dominantly felsic intrusive rocks of the Nejanilini Domain form part of the southeastern Hearne craton margin. The authors have reevaluated this model by integrating Sm-Nd isotope data from rare archival samples of nine granitoid rocks and one metasediment. Neodymium (crustal residence) model ages of the granitoid samples, which include both rock types mapped as presumably Archean granulite-grade felsic basement and Proterozoic granitoid intrusions, cluster in the tight range 3.0–3.2 Ga. These data suggest that the younger granitoid intrusions, Paleoproterozoic and/or Neoarchean in age, inherited their Nd isotope composition from the Meso- to Neoarchean basement from which they were derived and through which they passed. Rare metasedimentary rocks of the Nejanilini Domain, as well as supracrustal sequences of the Seal River and Great Island domains to the south, likely form part of the regional 2.1–2.4 Ga Hurwitz Group. A ca. 2.8 Ga Nd model age of a metapelite from the Nejanilini Domain suggests a Neoarchean average sediment provenance, likely from the Hearne basement. At Nejanilini Lake, the metasedimentary rocks locally preserve granulite-facies mineral assemblages, which implies that Paleoproterozoic tectonothermal conditions in parts of the Nejanilini Domain reached granulite grade.

Introduction

Isotopic study of archival samples was carried out as a first pass at upgrading the current limited understanding of the geology of the Nejanilini Domain in northern Manitoba. The study area lies on the south flank of the Hearne Province of the Rae-Hearne Archean craton (Figure GS-19-1) and comprises Archean continental crust and Paleoproterozoic cover strata that have together been affected by varying degrees of Paleoproterozoic plutonism and thermotectonism.

This report presents a summary of the regional geology from Manitoba Industry, Trade and Mines (2002) and earlier publications, and uses new Sm-Nd isotopic results from a suite of 1970s archive samples that represent all of the major rock types of the Nejanilini Domain in Manitoba. These include 1) a suite of orthogneiss and foliated granitic rocks (foliated, hypersthene-bearing monzocharnockite) that define the granulite domain; 2) granitic rocks intrusive into the granulite-grade rocks; and 3) metasedimentary rocks from the Nejanilini Lake area that were previously interpreted to represent an eastward extension of the Wollaston Group in Saskatchewan.

Regional setting

The Nejanilini Domain covers much of the southeast margin of the Hearne Province of the Archean Rae-Hearne craton that extends into Nunavut and Saskatchewan (Figure GS-19-1). Hearne Province rocks in the Nejanilini Domain consist largely of Archean continental crust and Paleoproterozoic cover rocks and intrusions that have together been affected by varying degrees of Paleoproterozoic plutonism and thermotectonism. These rocks have been interpreted to be part of the Trans-Hudson Orogen and termed collectively the 'Cree Lake Ensialic Mobile Zone' by Lewry et al. (1978), Lewry and Sibbald (1980) and Lewry and Collerson (1990).

The Cree Lake Ensialic Mobile Zone, dominating the southeast margin of the Hearne Province, has been regionally subdivided into six geological domains in Saskatchewan and Manitoba: the Mudjatik, Peter Lake (present only in Saskatchewan), Wollaston, Seal River, Great Island and Nejanilini domains (Figure GS-19-1). The domains are defined by their cover rocks, the proportion or absence of basement rocks, and their dominant structural trends. Samples from the present study are restricted to the Nejanilini Domain (outlined in Figure GS-19-1). South of the Nejanilini Domain, the metasedimentary and metavolcanic rocks of the Seal River Domain are separated from accreted juvenile Paleoproterozoic terranes to the south by the Wathaman-Chipewyan plutonic complex, the remnant of a continental magmatic arc (Figure GS-19-1; Meyer et al., 1992).

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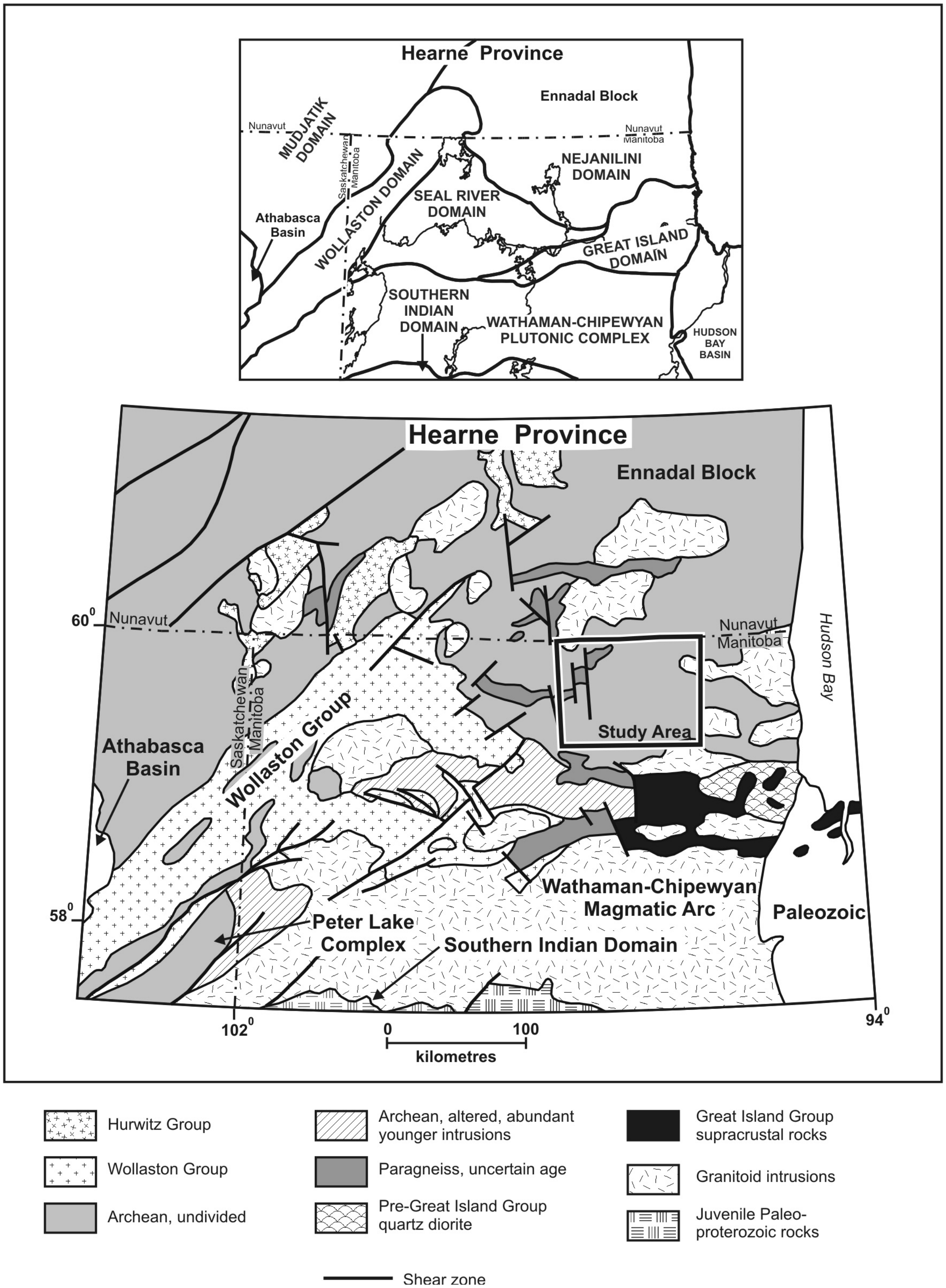

Figure GS-19-1: *Lithotectonic elements of the Trans-Hudson Orogen–Rae-Hearne craton region (*modified after *Manitoba Industry, Trade and Mines, 2002).*

Geology of the Nejanilini Domain

The Nejanilini Domain comprises mainly foliated granitic and granitoid rocks of granulite metamorphic grade and presumably Archean ages. The felsic granulite contains enclaves of migmatized supracrustal rocks and is intruded by younger, presumably Paleoproterozoic plutons (e.g., Manitoba Industry, Trade and Mines, 2002, and references therein). The basement and cover rocks both contain middle to upper amphibolite grade Paleoproterozoic metamorphic mineral assemblages produced during Hudsonian thermotectonism.

The orthogneiss and foliated granitic rocks are hypersthene-bearing monzocharnockite, which shows varying degrees of alkali metasomatism and contains widely scattered, discontinuous inclusions of hypersthene-bearing, intermediate to mafic gneiss. Clark and Schledewitz (1988) referred to this complex of presumably Archean rocks as the Nejanilini granulite massif. They interpreted a sample of monzocharnockite to be Archean in age, based on its Rb-Sr age of 2577 ±42 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7057.

West of Nejanilini Lake, the Nejanilini Domain comprises foliated grey tonalite to granodiorite gneiss. This unit extends into Nunavut, where it is considered to be equivalent to the Archean Kasba grey gneiss (Eade, 1973; Loveridge et al., 1987) and to grey tonalitic gneiss in the Mudjatik Domain to the west. The Kasba grey gneiss yielded U-Pb zircon ages of 3274 ±18 Ma and 2777 +95/–66 Ma (Loveridge et al., 1987), possibly indicating that the grey tonalite was emplaced at ca. 2.78 Ga and contains ca. 3.27 Ga zircon inheritance.

Segments and remnants of an east-trending belt of metasedimentary gneiss of uncertain age occur within the foliated tonalite and granodiorite on the west side of Nejanilini Lake, and within monzocharnockite on the east side of the lake (Figure GS-19-2). This undated sequence of semipelitic biotite gneiss, calcsilicate, marble, and quartzite is lithologically similar to lower parts of the Wollaston Group in Saskatchewan, suggesting it may be Paleoproterozoic in age and lay unconformably on the Archean grey tonalite and monzocharnockite. Nevertheless, the metasedimentary rocks locally contain granulite-facies mineral assemblages (cordierite-sillimanite, hypersthene-cordierite-sillimanite-garnet-biotite, and hypersthene-garnet-biotite), which are more compatible with their granulite-facies Archean host. It is also possible, however, that these granulite-facies mineral assemblages were produced during Hudsonian thermotectonism at temperatures and pressures slightly above the typical Paleoproterozoic middle to upper amphibolite metamorphic grade.

The western boundary of the Nejanilini Domain coincides with the Wolverine River fault system (Figure GS-19-2). This boundary, extending from Little Duck Lake southeast to Barr Lake, corresponds with a pronounced, striped, linear magnetic pattern approximately 12 km wide and 42 km long. A paucity of bedrock exposures in this area leaves the cause of this pronounced magnetic pattern indeterminate. Foliations in this region parallel the magnetic pattern, as do a series of elongate amphibolite exposures near Nejanilini Lake. The southern contact of the Nejanilini Domain with younger rocks of the Seal River and Great Island domains is occupied by a zone of younger, presumably Paleoproterozoic granitic rocks. These younger granitic plutons are also present throughout the Nejanilini Domain, forming discrete intrusions with broad K-feldspar alteration haloes (Clark and Schledewitz, 1988). The zones of alteration are mappable as a colour change from the characteristic greenish brown of the unaltered monzocharnockite to pink on the margins of younger granitic intrusions.

Samples and results

Table GS-19-1 presents a summary of the granitoid samples analyzed for Sm-Nd isotopes. The sample locations, Nd model ages (in billions of years) and εNd values (calculated at 2.70 Ga) are shown in Figure GS-19-2.

Based on their lithology and map relationships, the analyzed samples can be subdivided into three groups: 1) granulite-grade tonalite to granite and derived gneissic rocks of presumably Archean age (‘basement’; samples 24-7-1020-B, -1099-1A, -1101, -1142, -1147, -1248); 2) younger granite mapped as Paleoproterozoic intrusions (‘granite intrusions’; samples 24-7-1015-2, -1094, -1290); and 3) one metasediment (sample 24-7-1198-B).

Neodymium model ages (crustal residence ages calculated for samples with $^{147}Sm/^{144}Nd$ <0.14, according to the model of Goldstein et al., 1984) of all samples range from 2.8 to 3.2 Ga. Interestingly, the greywacke metapelite (sample 24-7-1198-B) yielded the youngest model age of 2.8 Ga, whereas both samples of felsic granulite and granitic intrusion yielded a rather tight range of model ages from 3.0 to 3.2 Ga. Based on these data, two general conclusions can be drawn. First, assuming that the 2.8 Ga Nd model age of the metasediment represents the average provenance age, and based on the slightly older Nd model ages of the Nejanilini felsic intrusive samples, the sediment provenance is likely a mix of Archean basement, such as the Nejanilini felsic granulite and possibly younger rocks of uncertain nature and age. Second, there is no significant difference between the Nd model ages of the older, presumably Archean felsic granulite (‘basement’) and younger, presumably Paleoproterozoic granitic intrusions. If the granitic intrusions are Paleoproterozoic,

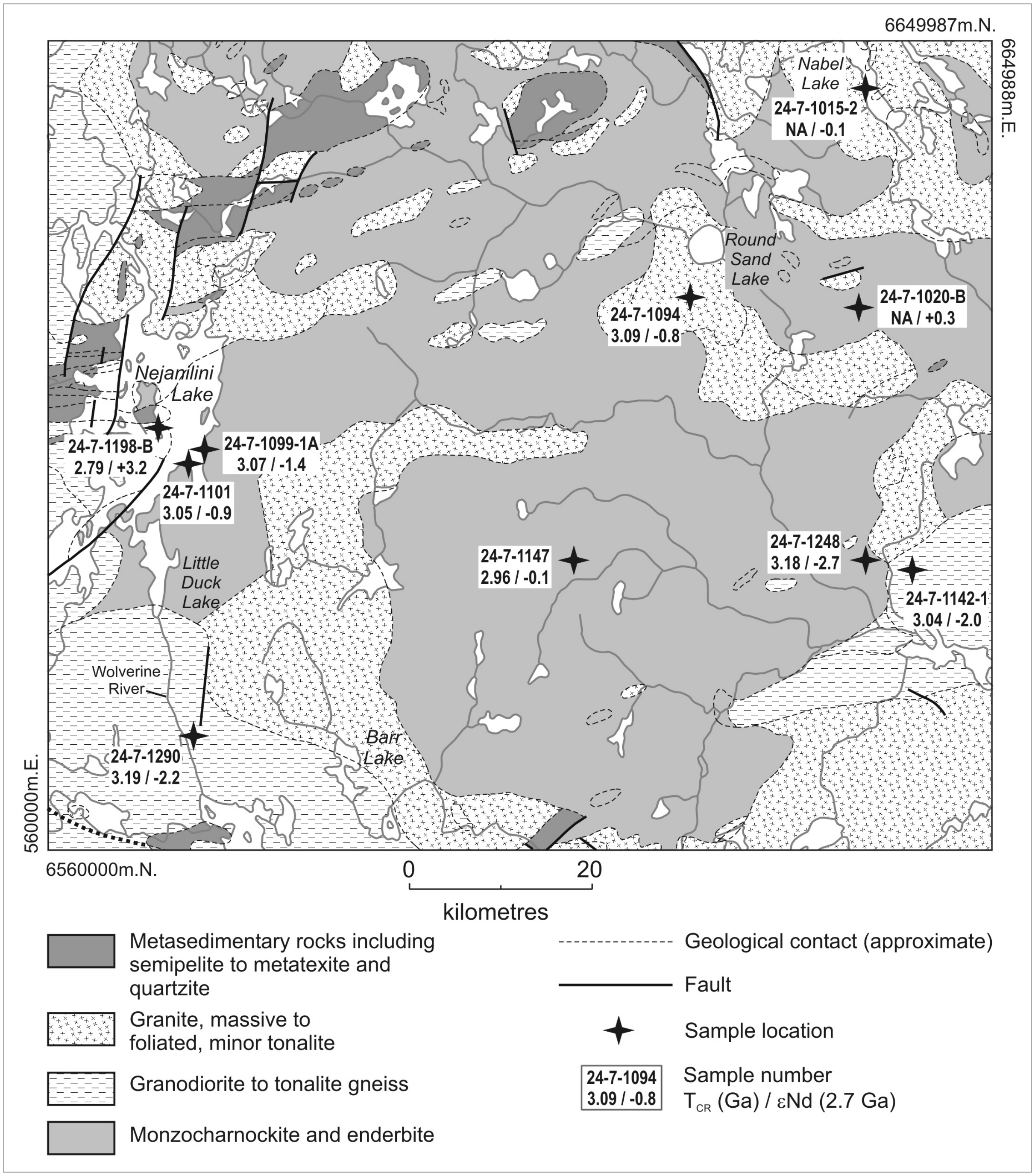

***Figure GS-19-2:** Simplified geology of the Nejanilini Domain, showing locations of samples analyzed for Sm-Nd isotopes, including Nd model ages and εNd values (calculated at 2.7 Ga).*

then either they are completely derived from the felsic granulite or both suites of rocks are derived from Archean basement of uncertain age and origin. Alternatively, the granitic intrusions could be Neoarchean, which seems to be most consistent with the observation that some, if not all, granitic intrusive samples contain hypersthene and therefore share the granulite metamorphic grade with the felsic basement. As well, many of the archived samples of tonalite to granodiorite gneiss from the study area have retained pseudomorphed granoblastic granulite textures and are interpreted to have been retrograded. Some caution is warranted, however, because metasedimentary rocks of the Nejanilini Domain locally contain granulite-facies mineral assemblages. Although the absolute age of these metasedimentary rocks is unknown, similar supracrustal rocks from the western Churchill Province have Paleoproterozoic pre-Hudsonian ages.

Table GS-19-1: Archival samples from the Nejanilini Domain (ND) for Sm-Nd isotope analysis.

Sample no.	Lithology	Location (see Figure GS-19-1)
24-7-1290	Granodiorite gneiss	Wolverine, southwest ND
24-7-1101	Opdalite	Nejanilini Lake, west ND
24-7-1099-1A	Foliated biotite enderbite	Nejanilini Lake, west ND
24-7-1198-B	Greywacke metapelite	Nejanilini Lake, west ND
24-7-1015-2	Hypersthene-bearing charnockite	Nabel Lake, northeast ND
24-7-1020-B	Hypersthene-bearing charnockite	Northeast ND
24-7-1142-1	Granodiorite-tonalite	Southeast ND
24-7-1147	Enderbite	South-central ND
24-7-1248	Enderbite	Southeast ND
24-7-1094	Charnockite	South of Round Sand Lake, northeast ND

In Nunavut, rifting in the Hurwitz Group is constrained by a U-Pb zircon and baddeleyite age of 2094 +26/–17 Ma from gabbro sills and flows in the lower to middle Ameto Formation (Patterson and Heaman, 1991). Cratonic basin sedimentation in the <2.4 Ga underlying Padlei and Kinga formations progressed to a period of crustal subsidence and tectonic destabilization, documented in the >2.1 Ga Ameto and younger formations of the Hurwitz Group, that led to the opening of the Manikwan Sea (Aspler and Bursey, 1990). The 2.4–2.1 Ga Hurwitz Group in Nunavut unconformably overlies the Archean Ennadai Lake metavolcanic belt.

In Saskatchewan, mafic pillowed and massive flows in the Courtenay Lake Formation of the Wollaston Group have a minimum age of 2.1 Ga and unconformably overlie garnet-biotite gneiss of uncertain age (Fossenier et al., 1995; Annesley et al., 1997). This mafic igneous activity at ca. 2.1 Ga may be related to the opening of the Manikwan Sea.

Samples of quartzite and metagreywacke of the Great Island Group in Manitoba yielded 2.1–2.0 Ga Rb-Sr isochron ages (Clark and Schledewitz, 1988). An age of 2052 ±41 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7150 for a sample of quartz-feldspar porphyry that intrudes the Seal River metavolcanic rocks provides a minimum age for these volcanic rocks. Although a model for the temporal evolution of ^{87}Sr in the quartz-feldspar porphyry has been interpreted to be more consistent with a Neoarchean than a Paleoproterozoic age (Clark and Schledewitz, 1988), the high $^{87}Sr/^{86}Sr$ ratio for this age could be due to contamination by Archean material.

The Great Island Domain may therefore also be the remnant of a cratonic basin, similar to the one occupied by metasedimentary rocks of the Hurwitz Group in Nunavut. Supracrustal rocks of the Great Island Domain display an abrupt change from cratonic basin-and-platform sedimentation (silicate iron formation, dolomitic marble or an interlayered quartzite phyllite sequence) to deposition of an immature metagreywacke. The timing of this change is uncertain but may coincide with continental rifting recorded in the Wollaston Group and the Hurwitz Group.

In summary, the present interpretation is that, between 2.4 and 2.1 Ga, sedimentary rocks of the Hurwitz Group and Great Island and Wollaston domains were deposited unconformably on Archean basement rocks of the Hearne Province.

The Wathaman-Chipewyan plutonic complex was emplaced between 1865 and 1855 Ma (Van Schmus and Schledewitz, 1986; Meyer et al., 1992), possibly as a continental-margin magmatic arc related to a northerly subduction flip. This magmatic arc lies between the Archean Rae-Hearne craton margin and an accreted terrane consisting of the Rottenstone Domain, the Southern Indian Domain, and the La Ronge and Lynn Lake greenstone belts. The magmatic arc effectively stitched together the craton and the Paleoproterozoic accreted-arc terranes. At Knife Lake, near the northern margin of the Wathaman-Chipewyan plutonic complex, Sm-Nd isotope analysis of a sample of biotite syenogranite provided a εNd value of –9.6 (calculated at 1.86 Ga, the approximate known emplacement age; Corrigan, pers. comm., 2004), indicating that this part of the batholith is strongly contaminated or underlain by Archean crust. Recalculating this εNd value to 2.7 Ga to compare it with data in Figure GS-19-2 for the Nejanilini Domain, the εNd value for the Knife Lake syenogranite sample becomes +3.45. In comparison, εNd values of all granitic samples from the Nejanilini Domain are consistently more negative, which might be further evidence that these rocks are Neoarchean.

Summary and regional tectonic synthesis

Rocks of the Nejanilini Domain evolved as a terrane of Archean basement unconformably overlain by sedimentary basins that constituted the foreland zone of the Rae-Hearne craton and were involved in the Paleoproterozoic plutonism and thermotectonism related to the Trans-Hudson orogeny.

In the adjoining Nunavut area to the north, the Kasba grey gneiss of the Ennadai Block preserves a long history of crustal development extending as far back as 3.27 Ga. Basement rocks of the Nejanilini Domain are interpreted to be continuous with the Ennadai Block and, therefore, to have shared a similar, protracted crustal history.

Results of this study are interpreted to indicate that a significant part of the Nejanilini Domain consists of Archean gneissic and granitoid rocks. The reported 3.0–3.2 Ga Nd model ages and observation of widespread retrograde granulite textures in the field and in archive specimens are interpreted to indicate that most of the gneissic and plutonic rocks of the Nejanilini Domain are Archean in age, and that they formed the basement to the Paleoproterozoic, possibly 2.1–2.4 Ga sedimentary rocks in the area. The widespread Paleoproterozoic amphibolite metamorphic overprint and general lack of contact/intrusive relationships in this region of sparse outcrop make it difficult to distinguish younger Paleoproterozoic felsic magmatism associated with the Trans-Hudson Orogen from Archean basement rocks.

The younger granitic plutons in the Nejanilini Domain reported by Clark and Schledewitz (1988) may thus be Neoarchean rather than Paleoproterozoic in age. Alternatively, part or all of these granitic magmas may be Paleoproterozoic and derived completely from melting of Archean granulite, thus retaining their Sm-Nd isotopic signature. Uranium-lead geochronology of archived and new samples is planned to further investigate the absolute ages of felsic granulite and granitic intrusions of the Nejanilini Domain.

Paleoproterozoic metasedimentary sequences of the Great Island and Hurwitz domains are metamorphosed only to amphibolite grade, except in the Nejanilini Lake area where granulite grade is locally indicated. The possibility of local Paleoproterozoic granulite-grade metamorphism further complicates the interpretation and extent of Archean granulite in the area.

In the Paleoproterozoic, this region formed the foreland zone of the Hearne Province, upon which continental sediments were deposited and subsequently involved in the Trans-Hudson orogeny. The south margin of the Hearne craton likely extended southward beneath part of the ca. 1.86 Ga Wathaman-Chipewyan plutonic complex.

Economic considerations

The Archean granulitic rocks of the Nejanilini Domain form part of a stable cratonic crust that may have developed a deep lithospheric keel adequate for diamond formation. In addition, the Nejanilini and adjacent crustal domains form the margin of the large Archean Rae-Hearne craton. Both aspects make the study area a prime target for kimberlite exploration that will be facilitated by improved knowledge of the nature and evolution of the Nejanilini Domain.

Nustar Resources Inc., with BHP Billiton Diamonds Inc. of Vancouver, reported in press releases from September 2004 that BHP had identified a target of potentially kimberlitic rock in the Seal River area. Diamond-drilling by Nustar to test the anomaly is planned for this winter.

Indications of base- and precious-metal concentrations are confined to the Seal River metavolcanic rocks and the unconformably overlying Great Island Domain. Past exploration in the Seal River metavolcanic and igneous rocks on the Seal River, 66 km downstream from Great Island, indicates the presence of volcanogenic massive sulphide–type mineralization. The metavolcanic rocks farther west at Great Island are very similar to those along the lower Seal River but may have been underexplored due to the presence of overlying metasedimentary rocks of the Great Island Group.

Gold occurs in trace amounts in volcanogenic massive sulphides hosted by Seal River metavolcanic rocks. In addition, a younger, structurally controlled phase of gold mineralization is spatially associated with iron formation in both the Seal River metavolcanic rocks and the overlying rocks of the Great Island Domain. The structural control of the younger gold deposits is suggested by occurrence of known gold mineralization along an easterly trending shear zone at the northwest corner of Great Island, and by a northeasterly trending shear zone in Seal River metavolcanic rocks.

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