GS-14 Preliminary geochemical and isotopic results from the Gull Rapids area of the eastern Split Lake Block, northwestern Superior Province, Manitoba (parts of NTS 54D5 and 6)

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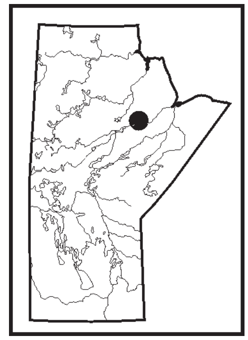

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Summary

The Gull Rapids area is located at the eastern margin of the Split Lake Block on the northwestern margin of the Superior Province. Initial results from the first year of research in the area include the production of detailed 1:500-scale maps and the acquisition of geochemical and geochronological data. These new results support and expand on previous research projects in the region (Corkery, 1985; Böhm et al., 1999), allowing for the development of a more complete geological framework.

Archean supracrustal rocks and orthogneiss constitute most of the exposures at Gull Rapids (Böhm et al., 2003a, b) and provide information on the tectonic setting and evolution of the area, while also allowing for comparisons with the Split Lake Block to the west. Based on field constraints and geochemistry, the authors interpret amphibolite that now forms the base of the supracrustal sequence at Gull Rapids to represent early mafic crust. Rafts of amphibolite within ca. 3.03–3.14 Ga orthogneiss indicate that mafic magmas most likely erupted prior to 3.0 Ga. The granitoid gneiss at Gull Rapids and the gneiss of the adjacent Split Lake Block share similar geochemical compositions that suggest their formation during volcanic-arc magmatism. Mafic granulite and layered amphibolite in the Split Lake Block and at Gull Rapids share very similar trace-element geochemical patterns, which implies that common processes were involved in their formation. Field relations and the similarity of the geochemical composition of the amphibolite to the metasedimentary rocks suggest that the layered amphibolite is a major source of detritus; however, the diversity of detrital zircon ages between ca. 2.70 and 3.3 Ga indicates that several sources, including the ca. 2.86 and 3.17 Ga orthogneisses at Gull Rapids, contributed detritus to these metasedimentary rocks.

Introduction

The abundance of supracrustal rocks at Gull Rapids (Figure GS-14-1; Böhm et al., 2003b) prompted Corkery (1985) to tentatively place the area within the Paleoproterozoic Churchill Province. However, the discovery of Mesoarchean metasedimentary rocks and orthogneiss in the Assean Lake area (Böhm et al., 2000, 2003c) indicates that supracrustal rocks along the Superior Boundary Zone may have a more complicated history than was originally contemplated by Corkery (1985). A 3.42 Ga reconnaissance Nd model age from a sedimentary gneiss at Gull Rapids (Böhm, unpublished data, 2000) further suggested that the area at Gull Rapids could be Archean in age. These extensive exposures of metasedimentary rocks have been chosen for study during this project as a method of investigating possible ancient components of the Superior Province paleomargin.

The tectonic environment of metasedimentary rocks at the Superior margin, as well as the nearby mafic volcanic rocks, orthogneiss and ubiquitous leucocratic injections, was largely unstudied prior to this project. Geochemistry, geochronology and careful geological observations are the primary methods used during this study. Geochemistry is a useful tool in deciphering the source region and the evolution of sedimentary and magmatic rocks. Isotopic systems, such as Sm-Nd, are useful for determining the average age of the components of a sediment or to characterize the mantle source and evolution of a magma. It is also a useful reconnaissance method to screen samples prior to the use of more accurate and costly geochronological techniques.

Geochronology is an important tool for determining the age of the components that form the metasedimentary rocks and their age of deposition. The age distribution of the minerals that make up a sediment can be quite varied, which requires analyses of a number of these components to understand the contribution from different sources. The age of deposition is typically constrained by the youngest detrital zircon and by features (usually intrusions) that occur just prior to, or crosscut the sediment. Understanding the number and magnitude of the metamorphic events that have occurred, and knowing how many of these events affected the metasedimentary rocks, can also provide some constraint

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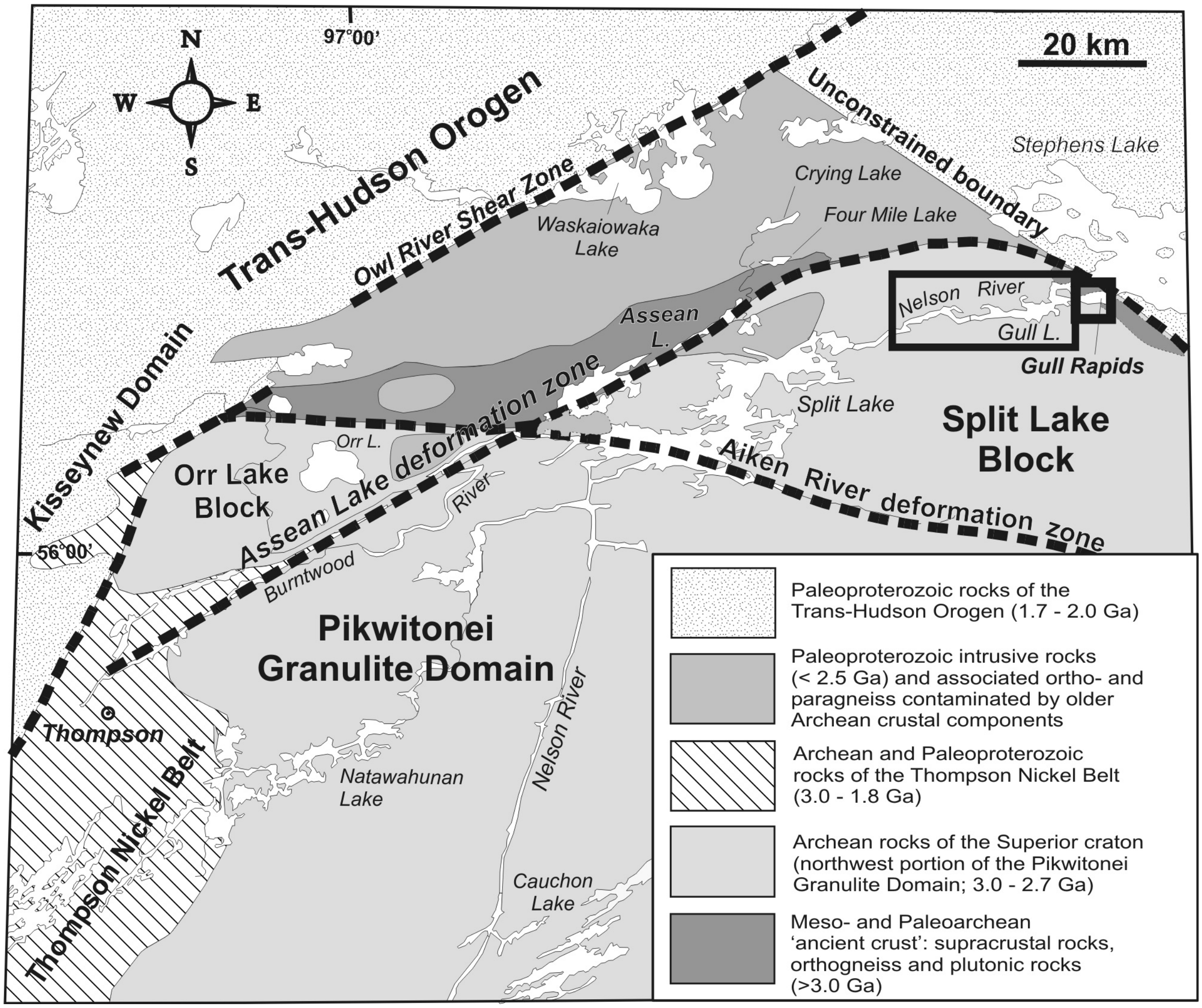

Figure GS-14-1: *Tectonic elements of the northwestern Superior Province margin, showing the location of the Gull Rapids field area in relation to the Split Lake Block and adjacent crustal terrains. Boxes indicate locations of study areas.*

on the timing of deposition.

Research in the northwestern Superior Province to ascertain the timing or conditions of metamorphism is limited. Some constraints have been determined for the metamorphic history of the nearby Pikwitonei Granulite Domain (Mezger et al., 1989, 1990), but the conditions of metamorphism of the Split Lake Block, which is adjacent to the Gull Rapids area, have not been quantitatively studied. The number of deformation events that have affected the rocks of Gull Rapids and their relative timing and grade have been ascertained during the last two field seasons. Initial work using electron microprobe to date monazite has revealed the number and approximate age of metamorphic events at Gull Rapids. Specific information on the pressure and temperature conditions reached during these events will be part of future research in this project.

Information on the conditions during, and timing of, metamorphic events at Gull Rapids will be useful for comparisons to conditions determined from nearby terranes. The closest terrane to Gull Rapids is the Archean Split Lake Block. This study aims to determine the relationship between the Gull Rapids area and the adjacent Split Lake Block. The conditions and timing of metamorphism in the Gull Rapids area will be used in conjunction with a traverse along the Nelson River upstream into the Split Lake Block (*see* Hartlaub et al., GS-16, this volume) to improve understanding of the history of metamorphism across the northwestern Superior Province margin.

Geological background

Split Lake Block

The Split Lake Block forms part of the northern margin of the Superior Province in Manitoba. This shear-bounded slice of reworked Superior Province is dominated by granitoid gneiss with local exposures of mafic granulite and minor supracrustal units (Hartlaub et al., GS-16, this volume). The Split Lake Block shows evidence of granulite-grade metamorphism, but this is often overprinted by younger amphibolite-grade metamorphism and greenschist retrogression. The Pikwitonei Granulite Domain to the south is interpreted to have a common crustal history and petrogenesis to the Split Lake Block (Heaman et al., 1986; Mezger et al., 1990), although the lack of metamorphic information in the Split Lake Block limits the extent of comparison at the present time (Böhm et al., 1999).

Four major metamorphic events are exhibited nonuniformly throughout the Split Lake Block (Corkery et al., 1985). The first event, which is only rarely observed, is an amphibolite- to hornblende-granulite–grade episode termed M1a by Corkery (1985). A 2705 ±2 Ma metamorphic zircon within an enderbite from the Split Lake Block might be related to this event (Böhm et al., 1999). A subsequent granulite-grade event (M1b), which is somewhat altered by later deformation (Corkery, 1985), is responsible for partial melting of some rock types and produced zircon with a U-Pb age of 2695 +4/–1 Ma (Böhm et al., 1999). A 2620 Ma metamorphic event (Böhm et al, 1999), which was termed M2 by Corkery (1985) and produced amphibolite-grade assemblages, was accompanied by granodiorite and tonalitic magmatism. This latter event, which is variably preserved in the Split Lake Block, is most prominent in the eastern part of the block toward Gull Rapids. A subsequent greenschist-grade event (M3) is also most prominent in the eastern Split Lake Block and is interpreted to be a product of the Trans-Hudson orogeny (Corkery, 1985). The M3 greenschist retrogression has obscured higher grade mineral assemblages in the eastern Split Lake Block and at Gull Rapids, and has made deciphering the metamorphic history of this area more challenging.

The Split Lake Block shares many common rock types with the Gull Rapids area, including very similar orthogneiss. Exposures of the Split Lake Block along the Nelson River are dominated by granitoid gneiss with occasional mafic and supracrustal rafts (Hartlaub et al., GS-16, this volume). Based on field classifications, the composition of this granitoid gneiss ranges from enderbite to charnockite.

Also present in the Split Lake Block orthogneiss are rafts of mafic granulite, iron formation (garnetite) and metasedimentary rocks; the latter are locally present as discrete bodies exposed in more extensive outcrops. The mafic granulite shows various stages of retrogression that alters the modal abundance of the minerals present, but the major phases are always hornblende+plagioclase±clinopyroxene±orthopyroxene±garnet. In places, interbeds of iron formation in the mafic granulite occur and grade between these compositions. The iron formation contains abundant garnet (>50 modal %) with ilmenite+plagioclase+quartz, and closely resembles the one exposure of iron formation (garnetite) within the orthogneiss at Gull Rapids (Böhm et al., 2003b). The exposures of metasedimentary rocks in the Split Lake Block are compositionally banded and vary from semipelitic to psammitic compositions, with quartz+plagioclase+biotite±garnet ±sillimanite. There are no age constraints on the provenance of these metasedimentary rocks. Metamorphic mineral assemblages in the metasedimentary rocks are currently being used for quantifying metamorphic conditions affecting the Split Lake Block.

Gull Rapids area

The Gull Rapids area features many units that are similar in appearance to those exposed in the Split Lake Block. The Gull Rapids map area can be roughly divided in half, the eastern portion being dominated by supracrustal units and the western half dominated by orthogneiss (Böhm et al., 2003a, b).

The eastern portion of the Gull Rapids map area features a compositionally banded amphibolite unit that is crosscut by numerous veins and dikes of felsic injection. The mineralogy in this amphibolite is dominated by plagioclase, hornblende and clinopyroxene, with relict orthopyroxene in pods of leucosome. There is evidence for multiple episodes of deformation in the amphibolite, in the form of folds, boudinage and pods of partial melt (*see also* Downey et al., GS-15, this volume). Closely associated with the amphibolite are metasedimentary rocks of mafic composition with interbeds of iron formation, mafic clastic units and carbonaceous layers. The bulk composition of the metasediment is semipelitic, with rhythmic changes between more pelitic and psammitic compositions. Based on new geochemistry and isotope results, which are presented below, possible sources for these sediments are the nearby amphibolite at Gull Rapids and granitoid gneiss of the Split Lake Block. The metasedimentary rocks display deformation that is often defined by granitoid injection, most likely the same phases that are seen in the amphibolite.

A contact relationship between this amphibolite and the granodiorite gneiss to the west is ambiguous due to the lack of exposure, but there are numerous rafts of amphibolite within the orthogneiss at this boundary. Division of the granitoid gneiss is not possible using composition alone, which is somewhat variable but not in a predictable way. The texture of the orthogneiss changes to the west from compositionally banded gneiss through augen-textured gneiss to L-tectonite near the western edge of the map area (Downey et al., GS-15, this volume; Böhm et al., 2003b). Rafts of amphibolite are common in this orthogneiss, at times making it nearly agmatitic. The amphibolite rafts rarely show compositional banding and are dominated by hornblende, very different in appearance from the amphibolite units to the east at Gull Rapids. An approximately 10 m wide exposure of garnet-rich iron formation within the orthogneiss is most likely a large raft. This 'garnetite' resembles units that are seen in the Split Lake Block and is composed mostly of heavy minerals, such as garnet+ilmenite+titanomagnetite+hercynite±rutile±monazite.

Relative timing or separation of different phases of the leucogranitic intrusive rocks that pervasively inject the units at Gull Rapids (Böhm et al., 2003a, b; Downey et al., GS-15, this volume) are difficult to determine using field relationships, geochemistry and even radiogenic isotopes. They are known to postdate the metasedimentary rocks and to be deformed with them, but these injections predate the Paleoproterozoic dikes of this area (Heaman and Corkery, 1996).

The youngest unit within the Gull Rapids area is the relatively undeformed mafic dikes that crosscut all other rock types and the deformation therein (Böhm et al., 2003a, b; Downey et al., GS-15, this volume). These dikes range in thickness from centimetre-scale stringers to more than 50 m. The grain size usually ranges from fine (microscopic) at the margins to fairly coarse (3–4 mm phenocrysts) in the cores of larger dikes, with pegmatitic clots.

Geochemistry

Geochemical analyses of major and trace elements were completed for samples all of major rock types along the Lower Nelson River from Gull Rapids to Birthday Rapids. Samples of clean, unaltered rock material were analyzed by Activation Laboratories Ltd. using XRF for major elements and inductively coupled plasma–mass spectrometry (ICP-MS) for trace elements. The major- and trace-element compositions of rocks from Gull Rapids can be used for classification as well as an improved understanding of their tectonic setting and petrogenesis. The geochemical composition of similar units from the Split Lake Block and Gull Rapids are useful for comparison to those at Gull Rapids, and will be used to help determine whether they share a similar history or are adjacent only due to tectonic juxtaposition.

Metamorphism may have caused element mobility, rendering some elements useless for geochemical comparisons. A method to test for element mobility was developed by Cann (1970), in which low-field-strength elements (LFSE) are plotted against high-field-strength elements (HFSE), which are usually immobile. If there has been no mobility of the HFSE, the bivariate plot will show a linear trend; a nonlinear trend will point toward alteration of element concentrations. Figure GS-14-2 shows two examples of the bivariate plots used to test possible effects of metamorphism and weathering in samples of granodiorite gneiss from Gull Rapids. Although the data are limited, the graphs of Nb versus Zr and La versus Zr display roughly linear correlations, indicating that these samples have not undergone significant geochemical alteration.

Metasedimentary rocks

The metasedimentary rocks at Gull Rapids range from mafic to felsic in composition (49–70 wt. % SiO_2). They are low in Al and, as a result, lack metamorphic phases normally expected for pelitic and semipelitic rocks. The mafic nature of these metasedimentary rocks and the local abundance of amphibolite clasts within them may indicate a mafic igneous protolith as a source of detritus (Figure GS-14-3). To test this hypothesis, a geochemical comparison of amphibolite and metasedimentary samples from Gull Rapids was conducted using trace-element patterns normalized to normal mid-ocean ridge basalt (N-MORB; Figure GS-14-4). The trace-element pattern of the metasedimentary rocks is very similar to that of the amphibolite at Gull Rapids. Their light rare earth elements (LREE) are enriched compared to the heavy rare earth elements (HREE), and both display a flat HREE pattern. Both metasedimentary and amphibolite samples display notable Nb depletion and slight enrichment in K and Pb. An overall greater fractionation of the LREE compared to the HREE in the metasedimentary rocks may reflect a contribution from a felsic source (e.g., granitoid gneiss of the Split Lake Block). A comparison between the compositions of the metasedimentary rocks and the Gull Rapids granodiorite gneiss supports the contention that an LREE-enriched source has contributed to these sedimentary rocks (Figure GS-14-5). This trace-element diagram, normalized to chondrite, shows the range of granodiorite gneiss composition to be very similar and slightly more enriched than that of the metasedimentary rocks. A negative Eu anomaly is present in some of the granodiorite compositions, similar to that displayed by the metasedimentary rocks.

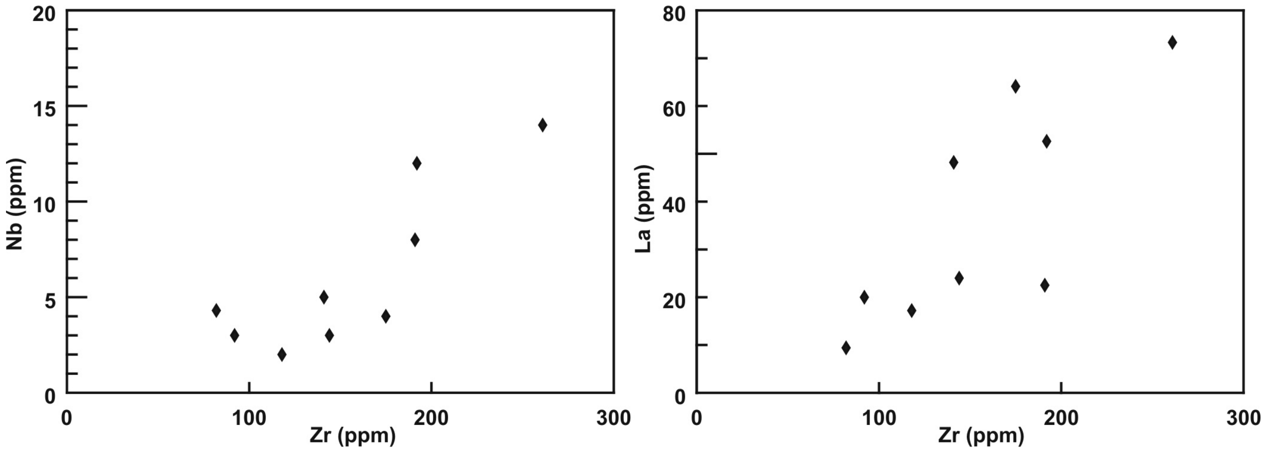

Figure GS-14-2: *Bivariate plots showing linear trends between low-field-strength and high-field-strength elements that attest to the immobility of trace elements in granodiorite gneiss samples from the Gull Rapids area during high-grade metamorphism.*

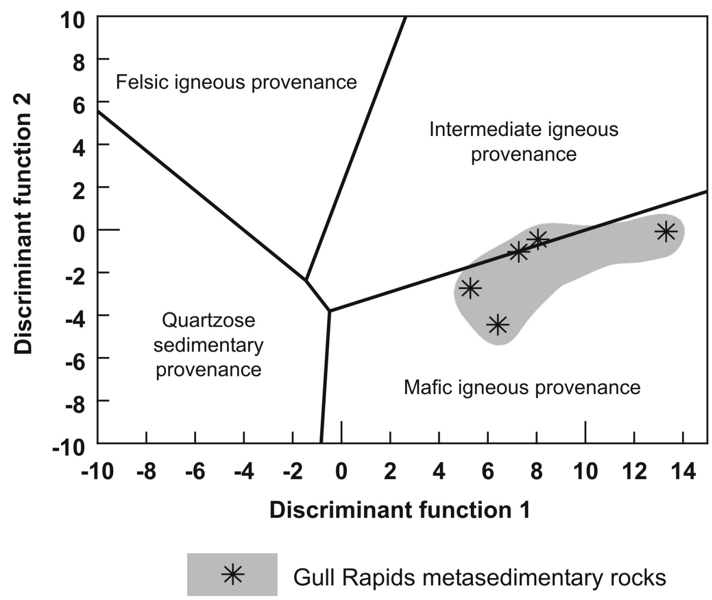

Figure GS-14-3: *Provenance diagram, using major-element composition to calculate discriminant functions that can be used to discern the provenance of clastic sediments. This diagram shows that the majority of sediment has a strong component of mafic igneous provenance. Discriminant function 1 =* $-1.733TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3 - 1.5MgO + 0.616CaO + 0.905Na_2O + 1.224K_2O - 9.09$. *Discriminant function 2 =* $0.445TiO_2 + 0.07Al_2O_3 - 0.25Fe_2O_3 - 1.142MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.8612$.

Mafic compositions

The supracrustal assemblage exposed at Gull Rapids includes metasedimentary rocks that are closely associated spatially with compositionally layered amphibolite. Samples of layered amphibolite are mafic to ultramafic in composition and contain 44–52 wt. % SiO_2 and 4.2–8.9 wt. % MgO. On a plot of total alkalis versus SiO_2 (TAS; Figure GS-14-6), amphibolite from Gull Rapids (open symbols) and mafic granulite from the Nelson River (filled symbols) both fall within the basalt field and show similar distributions. All mafic samples from the Split Lake Block and Gull Rapids plot within the tholeiite field in an alkali-FeO-MgO (AFM) diagram (Figure GS-14-7). Their similarity in geochemistry suggests that they have a common paragenesis.

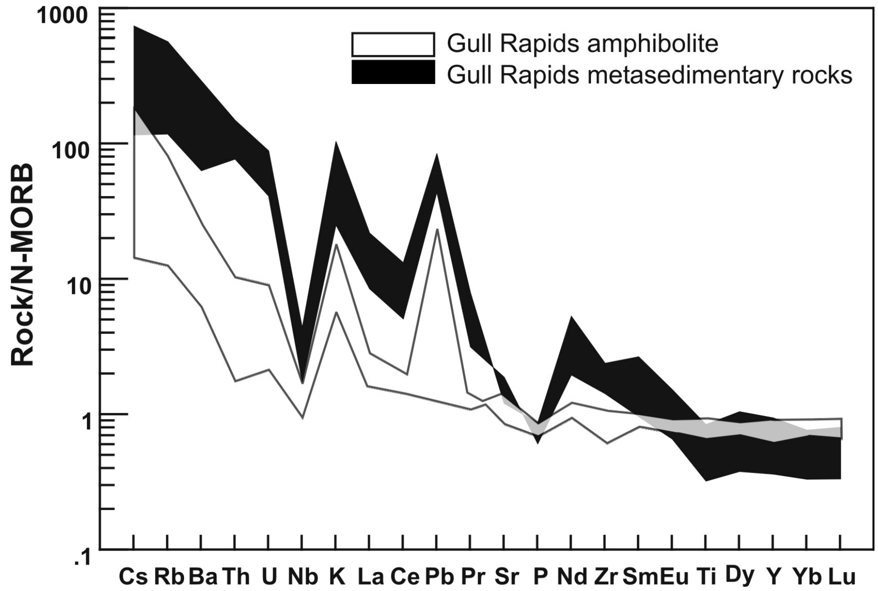

Figure GS-14-4: *Trace-element distributions of metasedimentary rocks and amphibolite from Gull Rapids, normalized to normal mid-ocean ridge basalt (N-MORB;* after *Sun and McDonough, 1989). The Gull Rapids amphibolite and metasedimentary rocks are compared for the purpose of testing that the amphibolite provided a significant source of detritus for the sediments. Compared to the amphibolite samples, the trace-element pattern for the metasedimentary rocks is more fractionated. Many enrichments and depletions in the trace-element patterns of these two rock types are similar, which suggests that the amphibolite contributed to the Gull Rapids metasedimentary rocks.*

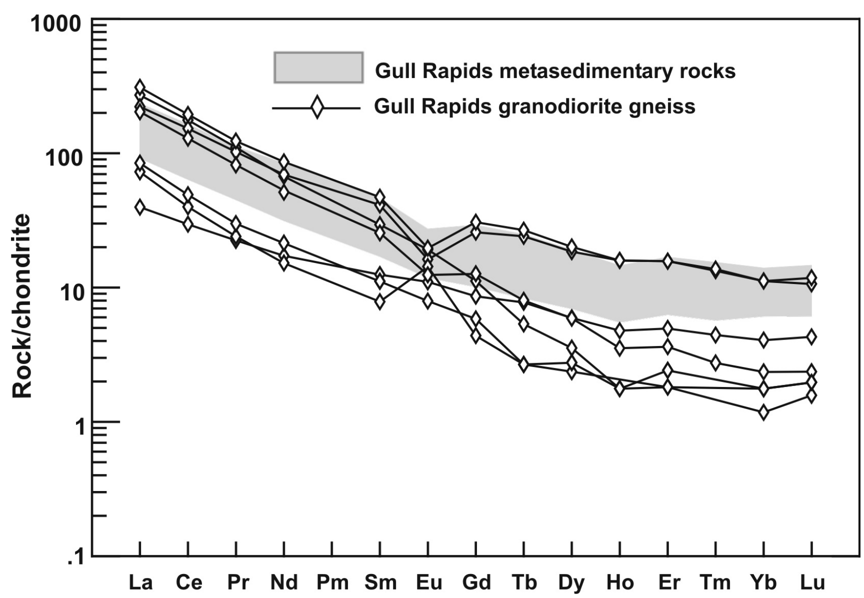

Figure GS-14-5: *Trace-element distributions of granodiorite gneiss and metasedimentary rocks from Gull Rapids, normalized to chondrite. The trace-element patterns are somewhat similar in shape with a slight Eu depletion, which suggests that there is some component of orthogneiss detritus in the metasedimentary unit.*

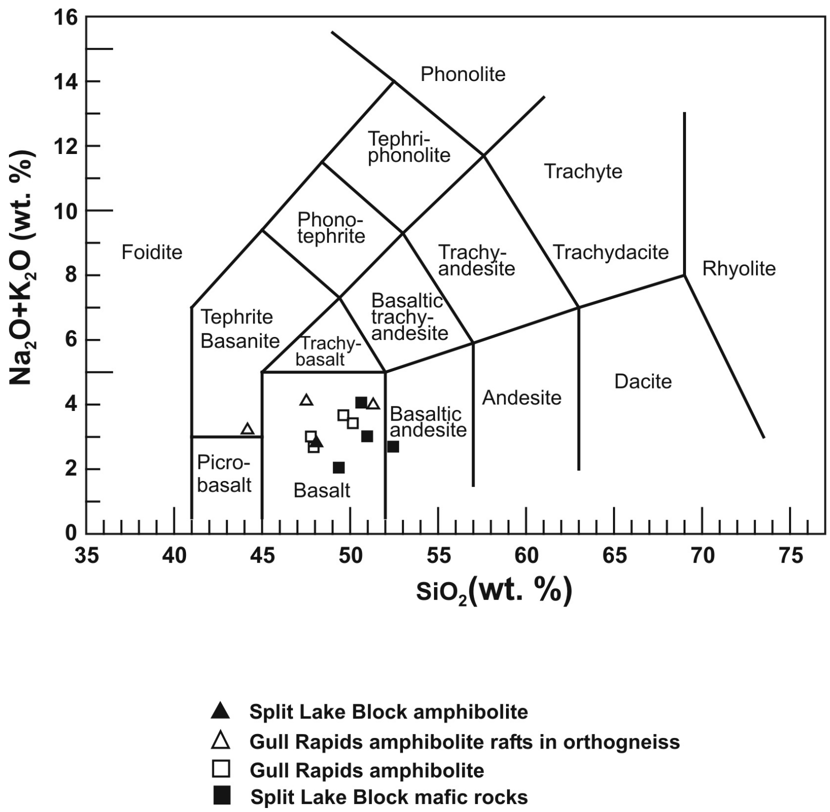

Figure GS-14-6: *Total alkalis versus SiO_2 plot of amphibolite and amphibolite rafts in orthogneiss from Gull Rapids (open symbols) and mafic granulite and amphibolite from the Split Lake Block (filled symbols). Nearly all samples fall within the basalt field and there is no particular distinction between SiO_2 and total alkali compositions of mafic samples from the Split Lake Block and Gull Rapids.*

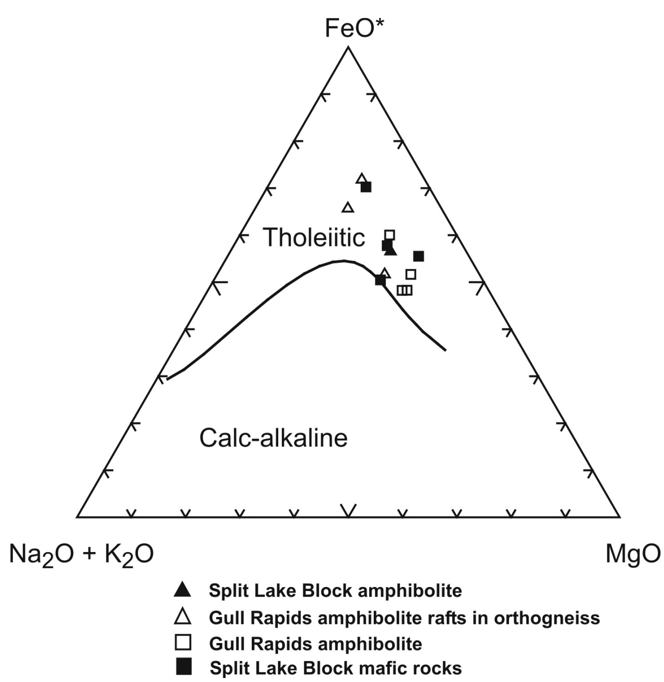

Figure GS-14-7: *Alkali-FeO-MgO (AFM) ternary plot of the same samples in Figure GS-14-4. All samples plot in the tholeiitic field and form a roughly linear trend. No particular distinction between the Split Lake Block and Gull Rapids samples is apparent from this diagram.*

Granitoid gneiss

Tectonic discrimination diagrams are one way of using geochemistry to understand more about the nature and origin of granitoid magmas. One of the problems with this method is that these diagrams (e.g., Pearce et al., 1984) use modern tectonic analogues to establish their fields. Therefore, determining the tectonic association of Mesoarchean granitoid with these plots is only valid if processes operating in the Mesoarchean are similar to those in modern systems. For this reason, plotting Mesoarchean samples on these discriminant diagrams is a useful method of comparing samples but less reliable as a means of interpreting their tectonic affinity.

One issue with using discrimination diagrams based on the Rb content is the fact that this element can often become mobile during granulite-grade metamorphism (Hansen et al., 2002). An alternative tectonic discrimination diagram by Pearce (1984) plots Nb versus Y for the same purpose as his Rb versus Y+Nb diagram. All geochemical samples were plotted in both diagrams and yielded the same conclusions, confirming the validity of the Rb versus Y+Nb diagram.

Most of the gneiss samples from the Gull Rapids area fall within the volcanic-arc field (Figure GS-14-8) on a Rb versus Y+Nb tectonic discrimination diagram. The composition of the granodiorite gneiss samples varies, with some approaching the syncollisional and within-plate granitoid fields.

Granitoid gneiss from the Split Lake Block overlaps the range of trace-element compositions of the Gull Rapids orthogneiss. They all plot within the volcanic-arc granitoid field (Pearce et al., 1984; Figure GS-14-9) but, unlike the Gull Rapids orthogneiss, none of the Split Lake Block granitoid gneiss samples approach the within-plate granitoid composition (Figure GS-14-8) and only a few approach the syncollisional granitoid composition (Figure GS-14-9).

Leucocratic intrusions

Although the leucocratic granitoid rocks at Gull Rapids have field relationships that suggest more than one phase of magmatism, these phases cannot be separated on the basis of geochemistry. The Rb content of these late granitoid bodies is very uniform, producing a linear pattern when the samples are plotted on a tectonic diagram based on trace elements (Figure GS-14-10). Most of the samples fall within the volcanic-arc field and close to syncollisional granitoid in the tectonic discrimination diagram of Pearce et al. (1984), which might reflect the transition from an arc-tectonic environment toward syncollisional magmatism near the end of this phase of magmatism.

Geochronology and isotopic analysis

Isotopic analysis of Sm-Nd and U-Pb have been performed on samples from the main rock types of the Gull Rapids area (Figure GS-14-11) using a number of methods. Reconnaissance techniques commonly used in the initial stages

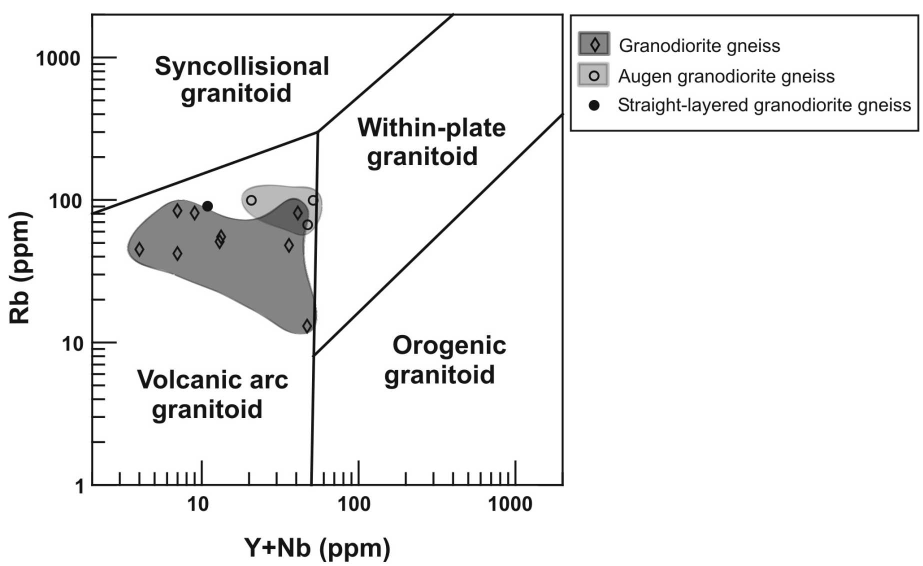

***Figure GS-14-8:** Tectonic association diagram (*from *Pearce et al., 1984), based on trace-element compositions of the granodiorite gneiss at Gull Rapids, with samples being categorized according to texture. All orthogneiss samples plot within the volcanic-arc field close to the within-plate granitoid field and may therefore show the progression of the tectonic setting from one type to another.*

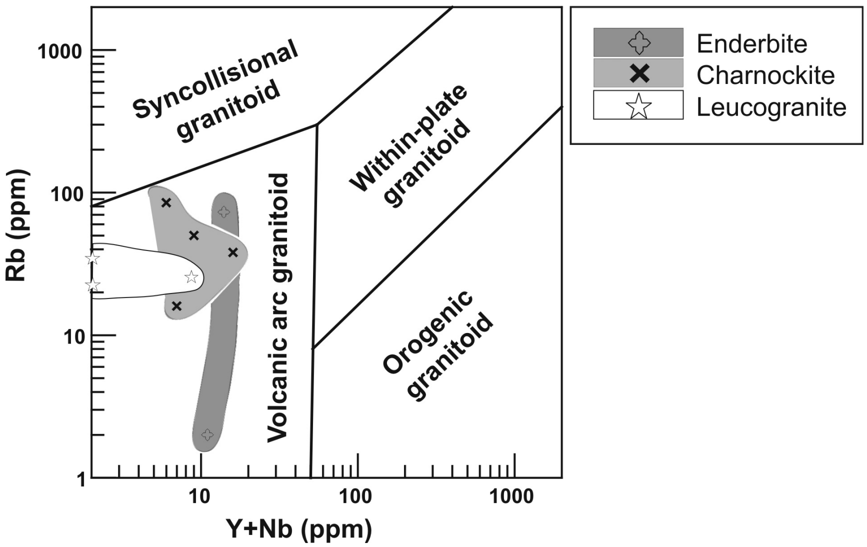

*Figure GS-14-9: Tectonic association diagram (*from *Pearce et al., 1984), based on trace-element compositions of orthogneiss samples from the Split Lake Block that are grouped on the basis of field classifications. Similar to the Gull Rapids orthogneiss samples (Figure GS-14-8), the Split Lake Block orthogneiss samples all plot in the volcanic-arc field.*

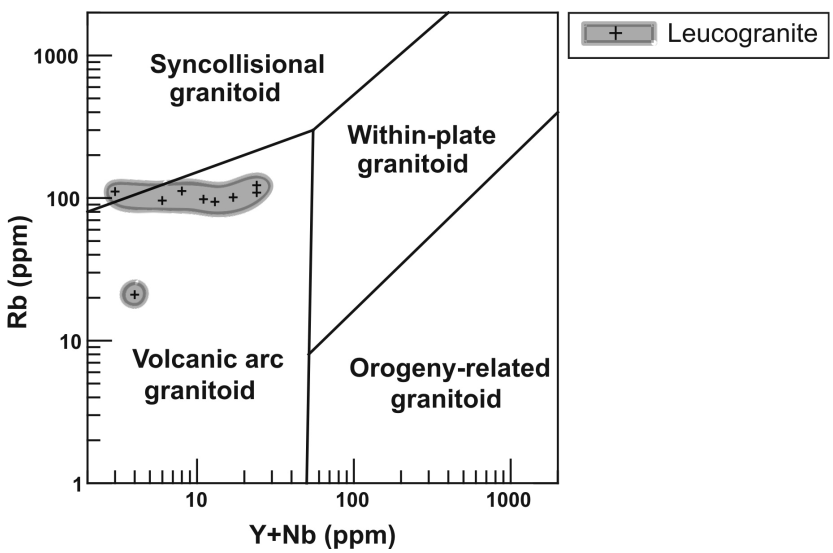

*Figure GS-14-10: Tectonic association diagram (*from *Pearce et al., 1984), based on trace-element compositions of leucogranite samples from Gull Rapids. The leucocratic granitoid has uniform Rb concentration and may show a progression from a volcanic-arc tectonic environment to syncollisional granitoid.*

of a geochronology project are Sm-Nd isotope analysis of whole rocks and electron microprobe chemical dating of monazite. In cases where more precise ages are required, conventional isotope-dilution thermal ionization–mass spectrometry (ID-TIMS) and laser-ablation, multicollector, inductively coupled plasma–mass spectrometry (LA–MC–ICP-MS) U-Pb isotope methods are preferred.

All analyses were preformed at the Radiogenic Isotope Facility and the Electron Microprobe Laboratory of the University of Alberta. As a reconnaissance tool, the Sm-Nd isotopic system can be used for sedimentary and igneous rocks as a geochemical tracer. Neodymium model ages (crustal residence ages after Goldstein et al., 1984) provide average protolith and provenance ages of felsic igneous and sedimentary samples, respectively. The Sm-Nd samples were analyzed according to the methods outlined in Creaser et al. (1997), and model ages were calculated using an age of 2.7 Ga and the model of Goldstein et al (1984).

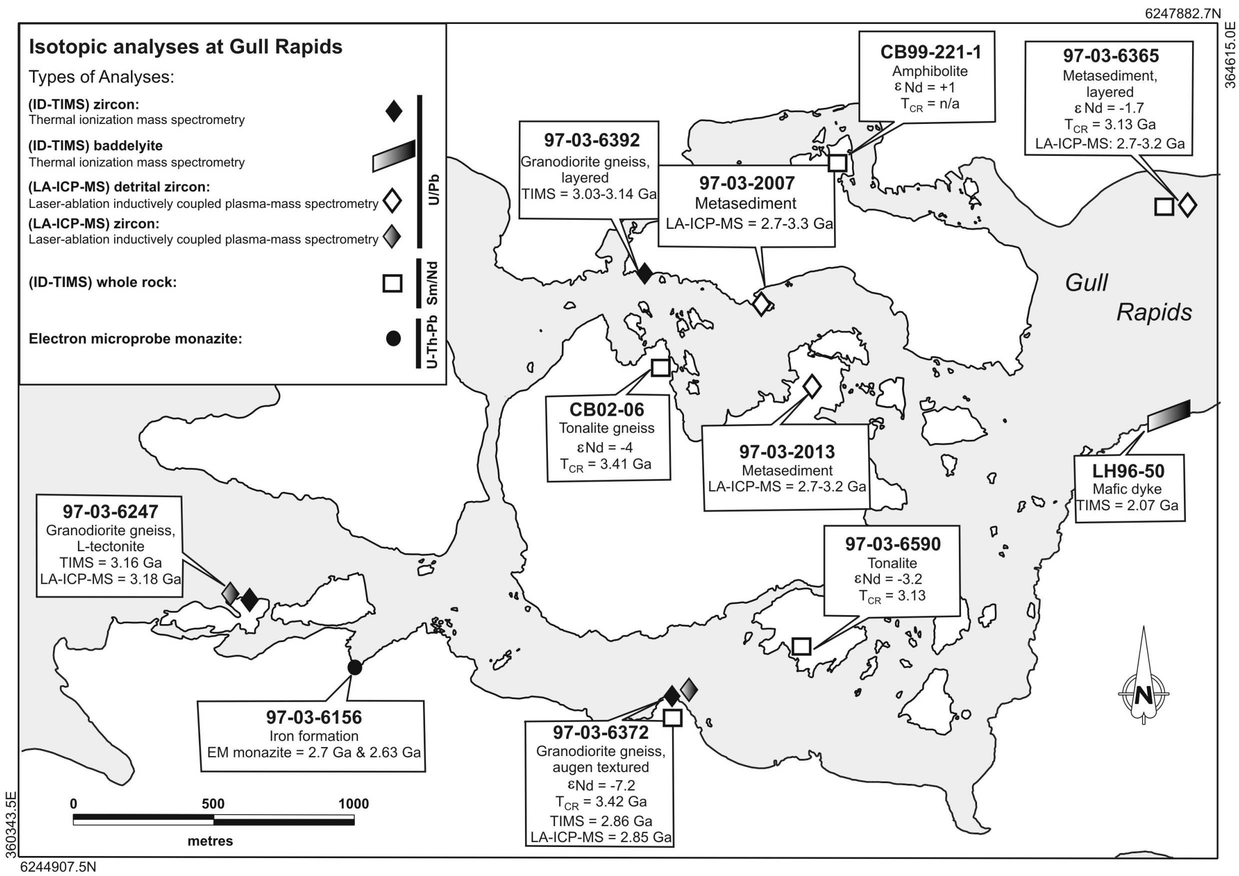

Figure GS-14-11: *Locations of samples processed for isotopic analysis, Gull Rapids area. The εNd values are calculated for 2.7 Ga.*

Another relatively inexpensive reconnaissance technique is the chemical dating of monazite by the analysis of U-Th-Pb with an electron microprobe. Monazite is a mineral that is very rich in U and Th, which allows accumulation of Pb concentrations that are sufficiently high to be quantitatively measured by electron microprobe (Montel et al., 1996). Details on the development of this relatively new technique can be found in Montel et al. (1996) and Cocherie and Albarede (2001). Monazite dating is usually accurate to within 45–120 Ma, depending on the ages and concentrations (Cocherie and Albarede, 2001), and should be used in combination with other dating methods (e.g., ID-TIMS U-Pb) when better age precision is required.

The U-Pb isotopic composition can be measured using a variety of techniques. Uranium-lead zircon dating using ID-TIMS methods in this study follows the techniques presented in Böhm et al. (1999). A new addition to the Radiogenic Isotope Facility at the University of Alberta is the laser-ablation inductively coupled plasma–mass spectrometer (LA–ICP-MS), which is capable of in situ U-Pb analysis of zircons, among other things. This technique is commonly used for detrital zircon studies or samples with diverse zircon populations. The analytical procedure for the LA–ICP-MS is outlined in Simonetti et al. (2004).

The isotope techniques described above have been applied to address several of the outstanding questions surrounding this area. Characterizing the source region and gaining knowledge of the underlying crust are two reasons why Nd analyses were preformed on the granitoid gneiss at Gull Rapids. The true magmatic age of the gneiss is a question to be answered using U-Pb radiogenic isotopes. Although a single method may be appropriate, the use of both ID-TIMS and LA–ICP-MS is sometimes necessary to obtain robust age information. The metasedimentary unit at Gull Rapids has very little in terms of age constraints. The use of Nd isotopes will give an average age of the components of the sediment that forms these rocks, but U-Pb analyses are necessary to truly characterize the distribution of ages of zircon in the sediment. This will allow inferences to be made regarding the possible source region or regions that have contributed to these metasedimentary rocks. Constraining the time of metamorphism is a complicated job for petrography and petrology combined with geochronology. Preliminary work using electron microprobe dating of monazite from Gull Rapids is a way to find out how many events have affected Gull Rapids and their approximate timing. Future isotopic work will hopefully allow these events to be better constrained. All of these isotopic analyses will facilitate a comparison between Gull Rapids and what is currently known about the Split Lake Block and its evolution.

Amphibolite

Determining the crystallization age of mafic compositions is normally difficult due to their often fine-grained nature and lack of datable magmatic minerals. The only isotopic information available for a mafic composition at Gull Rapids is from the layered amphibolite, which has an εNd value of +1.0 (Böhm, unpublished data, 2004; Figure GS-14-11, sample CB99-221-1). The positive εNd value indicates a juvenile-mantle origin with only small amounts of crustal contamination. To determine the timing of metamorphic events at Gull Rapids, the authors plan to apply U-Pb dating of zircon, which commonly forms as a metamorphic mineral but is rarely present as a primary phase in mafic rocks such as amphibolite.

Leucocratic intrusions

Granitoid intrusions are common throughout the Gull Rapids field area and crosscut most of the other rock types. From field observations, the injections appear to postdate deposition of the metasedimentary rocks and occur prior to at least one of the major generations of deformation (*see* Downey et al., GS-15, this volume). Determining exact ages for granitoid rocks is complicated by the diverse populations of zircon that are often found within these leucocratic, strongly fractionated magmas. For example, it is often difficult to determine whether zircons in these leucogranite bodies are primary constituents of the magma or are 'inherited'. Field relations suggest that, although most of the granitoid injection appears to be very similar in composition, a tonalitic phase appears to be older than most of the leucogranite phases. A sample of this tonalitic phase yielded a Mesoarchean Nd model age (T_{CR}) of 3.13 Ga (Figure GS-14-11, sample 97-03-6590) and an εNd value of –3.2, indicative of moderate degrees of contamination by Mesoarchean crust.

Metasedimentary rocks

Determining the age of the metasedimentary rocks at Gull Rapids is integral to understanding the nature and paragenesis of the host supracrustal package. Although the metasedimentary rocks were initially considered to belong to the Paleoproterozoic Burntwood Group (Corkery, 1985), a sample from the Gull Rapids suite yielded a Mesoarchean Nd model age of 3.13 Ga and an εNd of –1.7 (Figure GS-14-11, sample 97-03-6365). This indicates that the average provenance age (age of source rocks) is Mesoarchean and therefore not consistent with them belonging to the Paleoproterozoic Burntwood Group. To constrain the ages of the detrital components in the sediment, zircons were separated from several samples of metasedimentary rocks and analyzed by LA–MC–ICP-MS U-Pb dating. This technique allows for the rapid analysis of large zircon populations (Simonetti et al., 2004). The analysis of more than 100 detrital grains from three samples indicates that sediment sources range in age from ca. 2.7 to ≥3.3 Ga (Hartlaub, unpublished data, 2004; Bowerman, unpublished data, 2004). The majority of grains are between 2.7 and 2.8 Ga, which agrees well with the U-Pb ages obtained for rocks in the nearby Split Lake Block. The youngest detritus is considered a maximum age constraint for the sedimentary rocks, which means that the metasedimentary rocks exposed at Gull Rapids are ca. 2.70 Ga, or possibly younger, in age.

Garnetite (iron formation)

The garnetite unit at Gull Rapids is a relatively small outcrop but has proven to be very useful in roughly determining the age of metamorphism in the area. Monazite ages, determined using the electron microprobe, are given in Figure GS-14-12, together with ages of metamorphism in the Split Lake Block (*from* Böhm et al., 1999) plotted for comparison. Monazite ages from the garnetite sample range from ca. 2.4 to 3.0 Ga, with a major peak at 2.7 Ga that is somewhat bimodal, comprising possibly separate peaks at 2.78 and 2.72 Ga (Bowerman, unpublished data, 2004; Figure GS-14-11). In addition, there is a minor peak of monazite ages at 2.63 Ga and scattered analyses as old as 2.99 Ga. The main peaks of metamorphic monazite age are in agreement with ages for high-grade metamorphism of ca. 2.70 and 2.62 Ga reported for the Split Lake Block (Böhm et al., 1999). The microprobe monazite ages provide possible evidence for pre–2.7 Ga metamorphic event(s), but these older monazites could also be detrital grains within the iron formation.

Orthogneiss

The orthogneiss at Gull Rapids texturally and compositionally resembles that of the adjacent Split Lake Block.

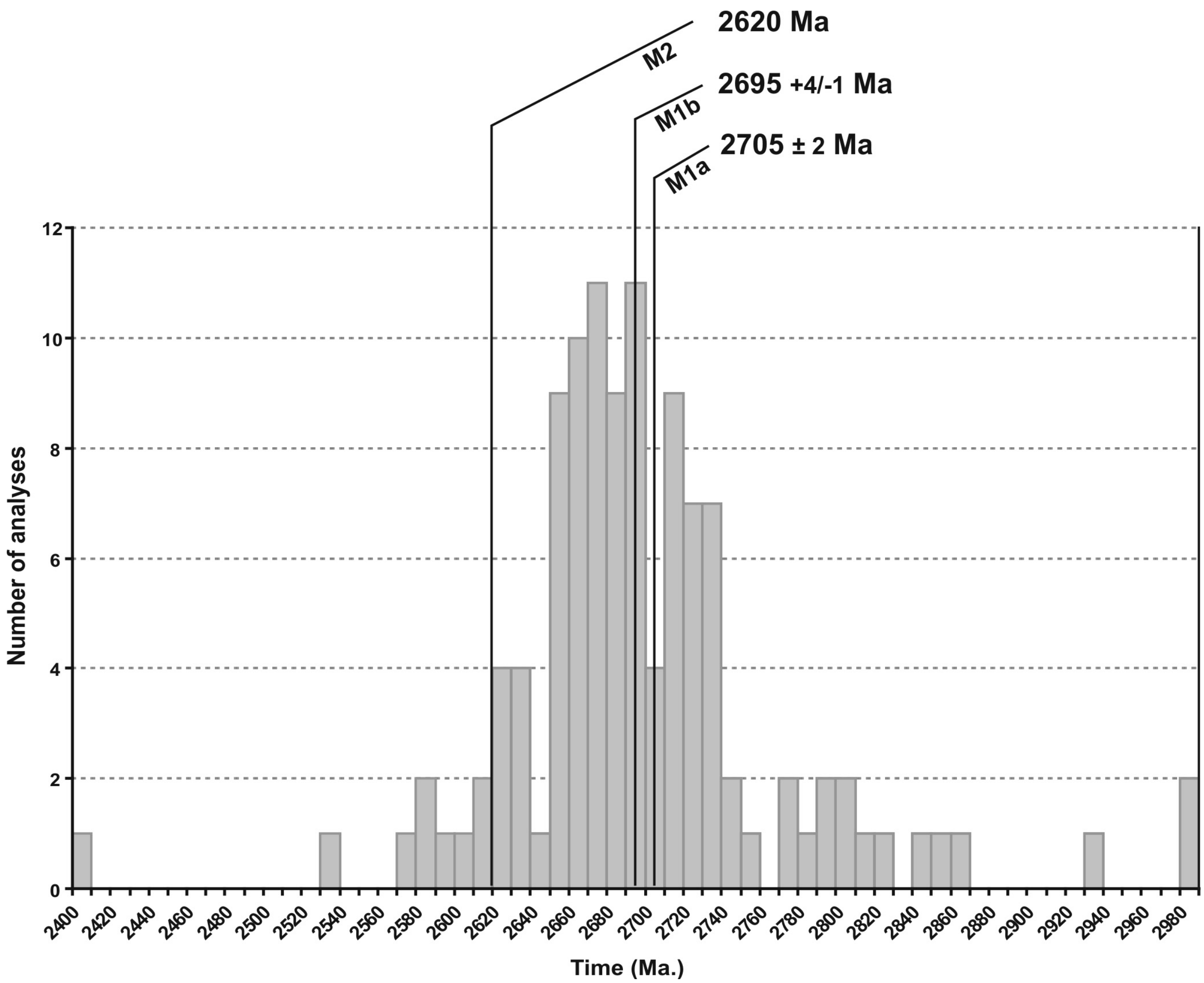

Figure GS-14-12: *Distribution of electron-microprobe U-Th-Pb chemical ages for monazite from the Gull Rapids area. Main ages of metamorphism in the Split Lake Block (Böhm et al., 1999) are shown for comparison.*

Previous U-Pb zircon studies on granitoid gneiss of the Split Lake Block suggested that the granodiorite gneiss may contain components as old as 3.35 Ga (Böhm et al., 1999). This report presents the first Sm-Nd isotope and U-Pb geochronology results that provide constraints on the ages and petrogenesis of orthogneiss samples from the Gull Rapids area. A sample of augen-textured gneiss from the south shore of Gull Rapids (sample 97-03-6372) yielded a Nd model age of 3.42 Ga and an εNd value of –7.2 (Figure GS-14-11, sample 97-03-6372). This implies that the granodiorite protolith is likely of Mesoarchean age and that the granodiorite formed from a source relatively enriched in incompatible elements, such as Mesoarchean felsic crust. Other samples of granitoid gneiss from Gull Rapids yielded similar Sm-Nd isotopic results that reinforce the hypothesis of a Mesoarchean protolith age. A tonalite gneiss from the central island in Gull Rapids yielded a Nd model age of 3.41 Ga and an εNd value of –4 (Figure GS-14-11, sample CB02-06). The ID-TIMS U-Pb analysis of zircons from a sample of layered granodiorite gneiss from the north-central part of Gull Rapids yielded minimum ($^{207}Pb/^{206}Pb$) ages between 3.03 and 3.14 Ga (Figure GS-14-11, sample 97-03-6392).

Uranium-lead zircon dating of the granodiorite augen gneiss (sample 97-03-6372) by ID-TIMS yielded a concordant age of ca. 2.86 Ga. Due to the varied nature of the zircon population, further investigation was done using the LA–ICP-MS. The majority of the zircons in the sample yielded an age near 2.85 Ga and were magmatic zircons, which confirms the TIMS magmatic age of 2.86 Ga. A sample of L-tectonite granodiorite gneiss from southwestern Gull Rapids (sample 97-03-6247) has an ID-TIMS U-Pb zircon age of 3.16 Ga and an LA–ICP-MS age of 3.18 Ga, which is most likely the emplacement age of this granodiorite.

Discussion

The few projects in the Split Lake Block to study the metamorphism, structure and evolution (Corkery, 1985; Heaman and Corkery, 1996; Böhm et al., 1999; Hartlaub et al., 2003) of this area have gradually led to an understanding of the nature and basic history of this granulite terrane. Now, with the discovery of the antiquity of the supracrustal packages at Gull Rapids, the nature of this terrane and its relationship to the Split Lake Block are under investigation.

More information about the geological units and the processes that formed the units at Gull Rapids has been obtained by the integration of the geochemical and isotopic data obtained by this study. It is now known that the earliest unit exposed at Gull Rapids appears to be the amphibolite unit that erupted through thin, likely mafic crust to produce tholeiitic magma. The age of this event is not known at this time, other than that the basalt predates the granodiorite gneiss, which is proven by the presence of mafic rafts within the orthogneiss. The basalt was later intruded by felsic plutons of various tonalitic to granitic, but dominantly granodioritic, compositions with ages of ca. 2.86 Ga (Gull Rapids granodiorite augen gneiss) and 3.17 Ga (Gull Rapids L-tectonite). These ages of felsic magmatism are very similar to those in the Split Lake Block, which features tonalitic magmatism at 2.84 Ga with possible <3.35 Ga inheritance (Böhm et al., 1999). Many of the mafic rafts that are found within the granitoid gneiss have very similar mineral assemblages, textures and geochemical compositions to those of the Gull Rapids amphibolite, and are therefore interpreted as belonging to the contiguous amphibolite exposures seen in the map area.

It is known that there are four episodes of deformation that are 2.7 Ga and younger (Corkery 1985; Böhm et al., 1999), but evidence for an older event that may have affected the granitoid and basalt prior to this has not been found. The preliminary monazite data suggest some metamorphic monazite growth before 2.7 Ga and possibly as early as 3.0 Ga, but more work is needed to verify this conclusion. The first episode of major metamorphism recorded in the Split Lake Block is an amphibolite- to granulite-grade event with associated felsic magmatism and partial melting at 2705 Ma (Gull Lake granite; Böhm et al., 1999). There is no evidence preserved at Gull Rapids that would suggest this area was affected by this first event, but the ages of tonalite and leucocratic granite injections at Gull Rapids are currently unknown. It is possible that the overprinting by subsequent metamorphic events was so complete that they have completely erased the 2705 Ma metamorphic event, or that this event never took place in the Gull Rapids area.

It is likely that the metasedimentary rocks at Gull Rapids were sourced from mafic rocks and orthogneiss of the Split Lake Block and Gull Rapids area shortly after ca. 2.70 Ga granulite-grade metamorphism. This is reflected in the high proportion of ca. 2.70 Ga zircons found in the metasedimentary rocks. These metasedimentary rocks, as well as the adjacent layered amphibolite, were injected by copious amounts of granitoid melt, likely in an arc setting. This entire package of metasedimentary rock, basalt and felsic injection was then subsequently metamorphosed by granulite-grade metamorphism. The timing of this granulite event is most likely similar to the second granulite event that affected the Split Lake Block at ca. 2695 Ma (Böhm et al., 1999). The granulite-grade metamorphic mineral assemblage is rarely visible or preserved at Gull Rapids due to a strong amphibolite-grade overprint that may correspond to the 2.62 Ga amphibolite-grade metamorphic event in the Split Lake Block.

The relationship between the Split Lake Block and the Gull Rapids area was previously very poorly understood. Due to the distinct package of supracrustal rocks at Gull Rapids, a separate evolution from the Split Lake Block seemed the most likely origin for this area. With the addition of geochemical and isotopic information, it has become apparent that these two areas share many similarities in the nature of their components and the timing of metamorphic events. There do not appear to be strong differences between the orthogneiss of Gull Rapids and the neighbouring granitoid gneiss in the Split Lake Block. The mafic rocks of both terranes share similar geochemistry but are texturally different, which may be a product of the strong retrogression at Gull Rapids or an indicator of a difference in the origin of this basalt. The relative timing of these units being older than the granitoid gneiss still holds true. As for the origin of the sedimentary rocks at Gull Rapids, the mafic rocks and orthogneiss exposed at the margin of the Split Lake Block appear to be the source of sediment for these supracrustal rocks. The feeling, at this point in the study, is that the Gull Rapids area is likely an extension of the Split Lake Block, although further exploration of the metamorphic history of Gull Rapids should allow for a stronger case.

Economic considerations

The northwestern Superior craton margin is the site of many exploration targets, including nickel in the economic Thompson Nickel Belt and shear-hosted gold associated with ancient crust and regional deformation zones at Assean Lake. The extent of the Thompson Nickel Belt and Assean Lake ancient crust, both forming part of the Superior Boundary Zone, have only been delineated to a certain extent, but the extensions of these zones have been economic targets for some time. Further mapping along the Superior craton margin contributes to an understanding of the tectonic configuration of this complex zone and therefore provides a valuable tool for outlining possible new targets for nickel and gold exploration.

The presence of promising kimberlite-indicator-mineral trends and a greater understanding of ice-flow direction during glaciation has led to northeastern Manitoba being targeted as a likely source for the indicators (e.g., Manitoba Geological Survey, 2003). One of the necessary features of kimberlite fields is the presence of thick, Archean cratonic lithosphere. Isotopic investigations using Nd in the Split Lake Block, as well as other locations along the Superior Boundary Zone (Böhm et al., 2000), has proven the existence of ancient crust, which is reinforced by the present investigations at Gull Rapids.

The Gull Rapids project was initiated because of the need to provide a detailed geological record of Gull Rapids, the site of a possible future hydroelectric dam, and to document the geology upstream of Gull Rapids along the Nelson River. The mapping produced by this project will allow future projects in the area to plan structures and to act as a record in the event that these areas are flooded by hydroelectric projects.

Future work

The second field season of the Gull Rapids project saw a more directed sampling program, with the senior author's thesis in mind, as well as detailed mapping integral to both research and industry. Research in the coming year will be focused on determining whether the Gull Rapids area is an exotic terrane, distinct from the Superior Province, and whether its metamorphic history is similar to that of the adjacent Split Lake Block. Further constraints on the tectono-metamorphic story of this area will be determined by geothermobarometry and U-Pb geochronology.

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