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Title: **Petrography, geochemistry and Nd isotope systematics of metaconglomerates and matrix-rich metasedimentary rocks: Implications for the provenance and tectonic setting of the Labrador Trough, Canada**

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Abstract

The New Quebec Orogen consists of a supracrustal belt that was reworked when the Superior craton collided with the Core Zone terrane during the Paleoproterozoic Trans-Hudson Orogeny. Within the New Quebec Orogen, the Kaniapiskau Supergroup can be divided into four terrigenous lithotypes metamorphosed at low-grade: one set with greater compositional and textural sedimentary maturity classified as quartz arenites and subarkoses, and another set with lower textural maturity classified as feldspathic wackes and mudrocks. In contrast, the Laporte Group includes homogeneous lithotypes represented by feldspathic and lithic wackes with a range of matrix contents metamorphosed at low to medium-grade.

The Kaniapiskau Supergroup rocks have a wide range of SiO_2 and Al_2O_3 contents (SiO_2/Al_2O_3 = 3.7-51) compared to the restricted compositional range of the Laporte Group rocks (SiO_2/Al_2O_3 = 4.4-6.8). In general, the geochemical variations in both formations of the Laporte Group are within the range of the main clast varieties from basal metaconglomerates, although the Deborah Formation (top unit), records higher TiO_2, P_2O_5, MgO and Ni contents and high Cr/Th, Co/Ba, Th/U and Rb/Sr ratios indicating additional mafic sources.

Our results support the hypothesis that the Kaniapiskau Supergroup was deposited along an intraplate continental margin with predominantly recycled ($\varepsilon Nd_{(1.87Ga)}$ -12) Paleoarchean sources (TDM 3.2 Ga). In contrast, the Laporte Group marks the transition from a continental forearc (Grand Rosoy Fm.) with a typical juvenile source, including granitic clasts ($\varepsilon Nd_{(1.83Ga)}$ -0.1 to +3.1), to a wedge-top depozone (Deborah Fm.) in the context of a collisional pro-foreland basin. This syn-collisional sedimentary environment is characterized by the presence of old crustal components ($\varepsilon Nd_{(1.83Ga)}$ -4.4 to -9.1).

Keywords: Provenance; Nd systematics; granitic clasts; juvenile sources; metasedimentary geochemistry.

1. Introduction

Sedimentary rocks with high textural maturity do not typically preserve mafic and intermediate sources as lithic fragments or as components in the main population of detrital zircons. Mafic to intermediate sources are usually easily weathered and deposited as fine-grained sediments (e.g., Nesbitt and Young, 1982; Nesbitt et al., 1996; Nesbitt and Young, 1996). Thus, the contribution of the mafic sources to a sedimentary basin requires an investigation of matrix-rich conglomerates, wackes and mudrocks.

The study of clasts in polymictic conglomerates provides a direct window to understand the principal sources for the basin (e.g., Naqvi et al., 1878; Reimer et al., 1985; Biševac et al., 2011; Henrique-Pinto et al., 2012). Likewise, matrix-rich sedimentary rocks require a combination of provenance tools to evaluate stratigraphic and tectonic settings (e.g., Bhatia, 1985; Cox et al., 1995; Mclennan et al., 1995; Henrique-Pinto et al., 2015).

Provenance studies provide key information about paleogeography, which may be challenging in cases where even well-studied geological sequences have ambiguous tectonic/stratigraphic interpretations (e.g., New Quebec Orogen in western Canada; Henrique-Pinto et al., 2017). This ambiguity can be resolved using combined complementary provenance tools, such as petrography, geochemistry, and Nd isotope systematics that have proven to be important instruments in determining the relative contributions of felsic and mafic sources, as well as the tectonic setting and crustal evolution trends for metasedimentary rocks (e.g., McLennan et al., 1990; McLennan and Hemming, 1991; McLennan et al., 1993).

The New Quebec Orogen (Hoffman, 1988; Hoffman, 1990a) is an exceptional example of one of the most ancient Wilson cycle sedimentary records from the Manikewan paleo-ocean (Stauffer, 1984). The closure and amalgamation of the continental blocks that once separated the Superior from the surrounding North Atlantic, Rae and Hearne cratons, marks the final phase of the Trans-Hudson Orogen (1.83-1.80 Ga) and the consolidation of a large continental block of Laurentia (Hoffman, 1989a; Hoffman, 1989b and Hoffman, 1990b) with the blocks of Siberia and Baltica (Meert, 2012) to form the Nuna super landmass (Hoffman, 1997), the largest core element of the Columbia Supercontinent (e.g., Rogers and Santosh, 2002; Zhao et al., 2004).

Within the New Quebec Orogen, the Labrador Trough consists of greenschist facies sedimentary and volcanic sequences (Kaniapiskau Supergroup; Frarey and Duffell, 1964), inferred to represent the rifted margin of the Superior Craton and a potential oceanic domain (e.g., Atlantic-type passive margin; Boone and Hynes, 1990). Further east, the Laporte Group (Fahrig, 1952;

Harrison, 1952) is composed of similar successions of unclear origin that were metamorphosed to higher grades.

The Kaniapiskau Supergroup includes two main volcano-sedimentary cycles (2.17-2.14 Ga and 1.88-1.87 Ga) and a third cycle that unconformably overlies the earlier strata (e.g., Clark, 1988). It generally accepted that the first cycle of sedimentation accumulated in an intracontinental rift-related environment (Clark and Wares, 2005, and references therein). The tectonic environment of the transition to subsequent cycles is debated and has been suggested to be represented by the transition from a rifted margin to a foreland basin (e.g., Hoffman, 1987, 1988, 1990a), or the transition from a rift to a passive margin in a shallow platformal ocean basin that was synchronous with upper plate continental forearc sedimentation in an Andean-type magmatic arc context (Van der Leeden et al., 1990).

In light of these contradictory tectonic interpretations, this contribution reports, for the first time, Sm-Nd isotopic data combined with geochemical and petrographic analyses of polymictic clasts from metaconglomerates and matrix-rich metasedimentary rocks of the Labrador Trough that shed light on the nature and evolution of different basins within the New Quebec Orogen.

2. Geological setting

2.1. Labrador Trough

The Labrador Trough is a NW-SE elongated supracrustal fold belt that extends more than 850 km from Ungava Bay, in the north, to the Grenville Province, in the south (Clark and Wares, 2005), separating the Superior Craton from the Core Zone (James et al., 1996). The Core Zone is considered an Archean to Paleoproterozoic microcontinent (Wardle et al., 2002; Corrigan et al., 2009) that collided in the east with the Nain Province block (North Atlantic Craton) at ca. 1.87-1.85 Ga to form the Torngat Orogen, and in the west with the Superior Craton ca. 1.82-1.77 Ga to form the New Quebec Orogen (Hoffman, 1988; Hoffman, 1990a) (Fig.1).

Both the New Quebec and Torngat orogens are considered subdivisions of the Trans-Hudson Orogen (Corrigan et al., 2009; Eaton and Darbyshire, 2010) that formed during the closure of the Manikewan Ocean (Stauffer, 1984). This ocean basin separated the Superior from the surrounding North Atlantic, Rae and Hearne cratons (collectively referred to as the Churchill Province; Hoffman, 1988; Lewry and Collerson, 1990).

The New Quebec Orogen (e.g., Hoffman, 1988; Wardle et al., 2002; Clark and Wares, 2005) is subdivided into four main lithotectonic domains: (1) the western autochthonous domain consisting of low-grade metavolcanic and metasedimentary rocks (Kaniapiskau Supergroup: Frarey and Duffell, 1964); (2) a central metavolcano-sedimentary belt with voluminous gabbro sills and pillow-lava basalts; (3) the east-central (allochthonous?) Rachel-Laporte Zone, consisting of medium- to high-grade supracrustal rocks (Laporte Group: Fahrig, 1952; Harrison, 1952) and gneissic-migmatitic Archean basement of poorly constrained origins (e.g., Boulder, Rénia and Moyer gneiss complexes: Gélinas, 1965), which, according to some authors, represent windows and tectonic slices of the Superior basement (James et al., 1996; James and Dunning, 2000; Simard et al., 2013); and (4) the eastern amphibolite facies schists and gneisses that border the Kuujjuaq Domain (Manereuille Complex? Girard, 1995) and possibly belonging to the Core Zone (e.g., Akiasirviup, Curot and False suites; Charette et al., 2016) (Fig. 2).

2.1.1. Kaniapiskau Supergroup

The beginning of the first cycle of sedimentation within the Kaniapiskau Supergroup is characterized by the Seward Group (2169 ± 4 Ma; Rohon et al., 1993), which represents an intracratonic rift basin that begins with the deposition of mainly immature arkosic arenites and conglomerates (Baragar, 1967), accompanied by contemporaneous mafic volcanic activity (Chakonipau Formation) (Fig. 3).

The Pistolet Group (2.17–2.14 Ga; Melezhik et al., 1997) marks the transition from rift to passive margin platform as suggested by the presence of dolomites, calc-arenites and mudrocks. The Pistolet Group is overlain by black shales, basalts and rhyolite dykes (Bacchus Formation) of the Swampy Bay Group (2142 ± 4 Ma; Rohon et al., 1993).

The end of the first cycle of sedimentation is marked by the presence of a dolomitic reef complex (Attikamagen Group). The reef was deposited under storm-influenced evaporitic conditions in the middle and outer portions of the shallow ramp of the Denault Formation (Zentmyer et al., 2011) but has a poorly defined age (see discussion in Henrique-Pinto et al., 2017).

The beginning of Ferriman Group sedimentation includes sandstones of the Wishart Formation and mudrocks of the Ruth Formation. These formations are followed by the Sokoman iron formation (e.g., Dimroth and Chauvel, 1973; Klein and Fink, 1976), reflecting a transitional sedimentary environment that consists of lagoonal platform sediments deposited in a warm and dry climate (Chauvel and Dimroth, 1974).

The upper Ferriman Group is consists of distal euxinic black shales and turbidites of the Menihek Formation, marking the second cycle of sedimentation of the Kaniapiskau Supergroup. Eastward correlation with the distal sedimentary sequences of the Koksoak Group (1870 ± 4 Ma; Machado et al., 1997) is reported by Clark and Wares (2005). Similarities between the Sokoman Formation and the middle units of the Baby Formation are suggested by lateral stratigraphic correlations and rare earth element profiles (Clark, 1988).

The red-bed arkoses and conglomerates from the Chioak and Tamarack River formations, unconformably overlie the earlier sequences and are interpreted as a fluvio-deltaic "synorogenic molasse" (Clark, 1988). These formations lack any volcanic association and mark the third cycle of sedimentation of the Kaniapiskau Supergroup (Clark and Wares, 2005) (Fig. 3).

2.1.2. Laporte Group

Girard (1995) divided the Laporte Group into two main formations. The Grand Rosoy Formation forms the base of the group and is dominated by arkosic metasedimentary rocks with local subordinate layers of metaconglomerate containing centimetric hematite clasts. The overlying Deborah Formation is thicker and is composed of phyllite and metawacke with thin layers of amphibolite and graphite schist (black shales).

Girard (1995) classified the rocks of the Manereuille Complex as part of the Laporte Group. However, all contacts observed between the complex and the Deborah/Grand Rosoy formations in this study were consistently tectonic. Most rocks from the Manereuille Complex occur near the gneisses of the Kuujjuaq Domain, and whether they belong to the Rachel-Laporte Zone (Wardle et al., 2002) remains a matter of debate.

No minimum age of sedimentation, or detrital zircon provenance, has been reported for the Laporte Group. However, monazite and titanite geochronology of amphibolite-facies gneisses within the Rachel-Laporte Zone yielded ages 1793 ± 5 and 1769 ± 5 Ma (Machado et al., 1989: Machado, 1990). Rutile geochronology was also used to date the youngest and final metamorphic event of Hudsonian metamorphism in the New Quebec Orogen (1740 ± 5 Ma; Machado et al., 1989).

3. Analytical procedures

3.1. Rock samples

The samples used in this study are representative of the Kaniapiskau Supergroup and Laporte Group metasedimentary successions (Fig. 2) in terms of grain size, composition and textural maturity. The samples were collected from the best available exposures to avoid the effects of weathering. Thirty-two samples were selected for whole-rock geochemistry and twelve for Sm-Nd isotope analyses. The chemical analyses were preceded by petrographic studies and modal counting, with more than 700 points counted per thin section (Table 1).

3.2. Whole-rock chemistry

Geochemical analyses of 10 samples from Kaniapiskau Supergroup and 22 samples from Laporte Group were carried out at the Actlabs facility of Ontario (Canada) and the results are presented in the Table S1. Samples were first crushed in a steel jaw-crusher and then in an agate disk mill. Whole-rock major elements were analysed by heavy absorber fusion technique (Norrish and Hutton, 1969). Prior to fusion, loss on ignition (LOI) was determined from the weight lost after roasting the sample at 1,000°C.

The fusion disk was made by mixing 0.75 g equivalent of the roasted sample with a 9.75 g combination of lithium metaborate and lithium tetraborate, with lithium bromide as a releasing agent. Samples were analysed by Panalytical Axios Advanced wavelength dispersive X-Ray Fluorescence (XRF). The intensities were measured and the concentrations calculated against the standard G16. In general, the limit of detection is about 0.01 wt% for most elements.

Trace element compositions were obtained by pressed powder pellet made from 6 g of sample. Samples were measured by Panalytical Axios Advanced wavelength dispersive XRF with limits of detection between 1 and 5 ppm. Elements including Cd, Cu, Ag, Ni, Mo, Zn and S were obtained by total digestion-ICP-MS.

Ultra-trace element compositions for Au, As, Br, Cr, Ir, Sc, Sb and Se were obtained by INAA (Instrumental Neutron Activation), following the analytical protocol described in Hoffman (1992). Samples were analysed using a Varian Vista 735 ICP.

3.3. Sm-Nd analyses

Whole-rock Sm-Nd isotope analyses were performed on the same samples used for elemental geochemistry at the Geotop laboratory of Université du Québec à Montréal in Montreal (Canada). A 0.1 ± 0.01g subsample was weighed and spiked with a ^{150}Nd - ^{49}Sm tracer solution to determine Sm-Nd concentrations. A mixture of HF-HNO_3 acids was added and the mixture placed in an oven to dissolve the samples at a temperature of 150°C. The resulting salts were subsequently evaporated in perchloric acid to break up the fluoride salts and redissolved in 6 mol/L HCl in the oven for 12 h. The subsequent 6 mol/L HCl solution was loaded onto ion-exchange columns containing AG1X8 resin that retains the Fe in the sample but allowed the other elements to be eluted with 6 mol/L HCl. The samples were evaporated and 0.5 mL of 14 mol/L HNO_3 was added to convert the salts from chlorides to nitrates. The rare-earth elements (REE) were concentrated using Eichrom TRU Spec resin for which samples must be nearly Fe-free. About 1mL of TRU Spec resin was placed in the column washed with 3-4 mL of 0.05 mol/L HNO_3 and equilibrated using 2 mL of 1 mol/L HNO_3 prior to loading 1mL of the samples. The column was rinsed with 0.25 mL of 0.05 mol/L HNO_3 and the REE fractions collected using 1.75 mL of 0.05 mol/L HNO_3.

The Sm–Nd separation was achieved using columns containing about 2 mL of Eichrom LN Spec resin. These columns were conditioned with 0.2 mol/L HCl prior to loading the samples in the same acid. The light REE were eluted with 0.2 mol/L HCl and then Nd was collected using 0.3 mol/L HC and Sm was collected using 0.5 mol/L HCl.

The isotopic compositions and concentrations of Nd were analysed by thermal ionization mass spectrometry (TIMS) on a TRITON PLUS mass spectrometer. Nd and Sm were measured using a double Re filament assemblage with the samples loaded and evaporated on one filament and ionized by the second filament. The Sm and Nd samples were measured in static mode and the $^{143}Nd/^{144}Nd$ values were corrected internally for fractionation by using $^{146}Nd/^{144}Nd = 0.7219$ (O'Nions et al., 1979) and assuming exponential fractionation behaviour. Measurements of the Nd international standard JNdi yielded a value of $^{143}Nd/^{144}Nd = 0.512103 \pm 10$ (2σ) compared with the published value of 0.512115 ± 7 (2σ) (Tanaka et al., 2000). The εNd values were calculated using the present-day chondritic uniform reservoir (CHUR) value of 0.512638 for $^{143}Nd/^{144}Nd$ (Jacobsen and Wasserburg, 1984).

4. Petrography

4.1. Kaniapiskau Supergroup

The metasedimentary rocks of the Kaniapiskau Supergroup were subdivided into four terrigenous lithotypes based on modal proportions. Lithotypes characterized by greater compositional and textural sedimentary maturity are classified as quartz arenites and subarkoses, and lithotypes with medium to low textural maturity are classified as feldspathic wackes and mudrocks (Fig. 4 and Table 1).

Framework grains in the poorly sorted metarenites consist predominantly of rounded to sub-rounded monocrystalline quartz (6.5-100%) with a blue aspect in hand samples and typical undulose extinction under the microscope. Polycrystalline quartz (up to 75%) is sub-rounded to sub-angular, and it often exhibits deformation by diagenetic/metamorphic compaction and breakdown with recrystallization as quartz cement within the framework (Figs. 5A and B).

Other monomineralic framework grains include, sub-angular feldspars, predominantly plagioclases (up to 9.3%, An_{27-45}), and minor perthitic alkali feldspar grains (up to 4.6%) with no evident twining. Two samples are characterized by higher K-feldspar content (up to 22% in 093-A01; Baby Formation, and RP-2298; Denault Formation). One sample from the Baby Formation (coarse-grained metarenite RP-2292-B) shows a relative increase in lithic fragments from metasedimentary (schist and quartzite), granitic and intermediate rocks.

The feldspathic wackes and mudrocks record higher compositional maturity, with the exception for one feldspar-rich sample (RP-2261 A1), with poorer matrix content (up to 18%). One particular sample (CB-1093 A) contains abundant porphyroblastic biotites, tourmalines and very-fine detrital zircons.

4.2. Laporte Group

The Laporte Group (Grand Rosoy and Deborah formations) includes more homogeneous strata characterized by meta-feldspathic and meta-lithic wackes, with variable amounts of matrix (Fig. 4). Considering the post-depositional processes that affected these rocks during diagenesis and metamorphism, an uncertainty of >15% is assigned to the estimated modal proportions of matrix due to the growth of idioblastic muscovite and secondary carbonate during metamorphism.

Most Laporte Group samples have at least two metamorphic fabrics and metamorphic minerals such as lepidoblastic biotite, and rare garnet porphyroblasts with pressure shadows indicating syn-tectonic metamorphism. Retrograde parageneses are characterized by thin rims of chlorite and muscovite (Fig. 5C and D) on biotite. Accessory phases are represented by idiomorphic tourmaline, rutile, and allanite with overgrowths of epidote.

Very few minerals still preserve the original sedimentary petrofabric, including K-feldspar (Or_{92-95}) with typical microcline twinning and albite (Ab_{78-92}) with remarkable alteration (sericitization) and myrmekite textures.

Metamorphosed psephitic rocks within the Grand Rosoy Formation comprise polymictic matrix-supported conglomerates. The granitic clast population are mainly cobble and boulder size, with petrographic variations from quartz-rich leucogranodiorite to quartz-rich alkali-feldspar leucogranite (Figs. 6A to D). Additional sources are indicated by the presence of clasts of hematite-bearing iron formation (Fig. 6E and F).

5. Geochemistry

The geochemical signature of sedimentary protoliths can be preserved in high-grade conditions, if significant melt extraction did not occur, because of the low mobility of most major and trace elements during metamorphism (e.g., Cioffi et al., 2012). However, element mobility has been documented during the burial diagenesis of siliciclastic mudstones. For example, K_2O addition and CaO loss is correlated with the progressive illitization of smectite and with the dissolution of calcite. Addition of up to 20% Na_2O in some rocks may be caused by albitization of plagioclase (Wintsch and Kvale, 1994).

A chemical classification based on major elements (Herron, 1988) correlates well with petrography (Fig. 7). However, three Kaniapiskau Supergroup samples that classify as sublitharenite on a Log(Fe_2O_3/K_2O) versus Log(SiO_2/Al_2O_3) diagram disagree with the petrographic classification of subarkose (Fig.4). This may be due to the higher iron content of these rocks, which are stratigraphically correlated with banded iron formations in the Ferriman Group.

5.1. Comparison between Kaniapiskau Supergroup and Laporte Group rocks

In general, rocks from the Kaniapiskau Supergroup and Laporte Group do not differ significantly in terms of major and trace elements for similar SiO_2 contents (e.g., normal wackes). However, the Laporte Group rocks are more enriched in Sr (median; Kaniapiskau Supergroup = 40 ppm; Laporte Group = 242 ppm) and U (median; Kaniapiskau Supergroup = 1.1 ppm; Laporte Group = 2.4 ppm). Rocks from the Kaniapiskau Supergroup also have a large variation of SiO_2 and Al_2O_3 contents (SiO_2/Al_2O_3 = 3.7-51) compared to the more restricted range in Laporte Group rocks (SiO_2/Al_2O_3 = 4.4-6.8) (Supplementary Data I).

The rocks from the Laporte Group are enriched in REE compared to those from the Kaniapiskau Supergroup ($\sum$REE= 236 versus 80) and the REE profiles are less fractionated (La_N/Yb_N= 5.3 versus 15) with stronger negative Eu anomalies (on average, 0.31 versus 0.83

respectively) (Fig. 8). All variations in REE are within the range of the main varieties of granitic clasts in metaconglomerates of the Grand Rosoy Formation. The relative Eu enrichment in metawackes of the Deborah Formation compared to the metaconglomerate clasts (average Eu/Eu* of 0.66 versus 0.32, respectively) could reflect feldspar accumulation and/or mixing with additional sources.

In general, the geochemical variations in the Grand Rosoy and Deborah formations fall within the range of the main clast varieties. However, the higher TiO_2, P_2O_5, MgO and Ni contents and the high Cr/Th, Co/Ba, Th/U and Rb/Sr ratios in the Deborah Formation suggest the presence of additional mafic/intermediate sources that were not preserved as lithic fragments (Fig. 9).

6. Sm-Nd isotope data from matrix-rich metasedimentary rocks and granitic clasts

The calculation of the initial Nd isotope compositions ($\varepsilon Nd_{(t)}$) are based on the sedimentation ages of the different units. The best estimate of a sedimentation age for the second cycle of the Kaniapiskau Supergroup was obtained from rhyolites of the Doublet Group that were dated at 1870 ± 4 Ma (Machado et al., 1997). However, there is no minimum age of sedimentation for the volcanic rocks within the Laporte Group, so we used the maximum age of 1834 ± 2.4 Ma, determined from the detrital zircon population (Henrique-Pinto et al., 2017). The time between maximum and minimum age of sedimentation was likely relatively short as metamorphism of the Laporte Group began as early as 1793 ± 2 Ma (U-Pb monazite; Machado et al., 1989).

Previously, the only Sm-Nd isotope data for sedimentary rocks of the Labrador Trough were three samples from the Baby Formation of the Kaniapiskau Supergroup (Dia et al., 1990), although only one sample yielded an unperturbed depleted mantle model age (Nd TDM) of 2.8 Ga and an $\varepsilon Nd_{(1.87\ Ga)}$ value of -10.

New Sm-Nd isotope data for the Kaniapiskau Supergroup were obtained from two samples from the Baby Formation, two metabasalts from the Hellancourt Formation and one metagabbro from the Montagnais Sills. The results span approximately the same TDM range indicated by the earlier work (2.7 to 3.2 Ga), although the ƐNd values of the Baby Formation samples are slightly more negative (-12).

The metabasalt samples from the Hellancourt Formation yielded important differences. The sample from the western part of the Kaniapiskau Supergroup (CB-1024) has a slightly negative $\varepsilon Nd_{(1.87\ Ga)}$ value of -2.3, in contrast to the pillow basalt (RP-2301) from the eastern part that yielded a juvenile $\varepsilon Nd_{(1.87\ Ga)}$ value of +3.3.

The subvolcanic Montagnais sample (CB-1102) also has a slightly negative $\varepsilon Nd_{(1.87\ Ga)}$ value (-1.9) and, like the metabasalt from the eastern part of Kaniapiskau Supergroup, yielded an older TDM age (>2.7 Ga).

The ƐNd variation in metawackes from the Grand Rosoy Formation ($\varepsilon Nd_{(1.83\ Ga)}$ -0.1 to +2.8) overlap the compositions ($\varepsilon Nd_{(1.83\ Ga)}$ +2.9 to +3.2) from the main varieties of juvenile granitic clasts from metaconglomerates of the same formation. In contrast, rocks from the Deborah Formation have negative $\varepsilon Nd_{(1.83\ Ga)}$ values (-4.4 to -9.1), suggesting a contribution from more evolved sources with TDM ages between 2.7 and 2.8 Ga (Fig. 10).

7. Inferences on tectonic environment

Rocks with high compositional and textural sedimentary maturity, such as the quartz arenites and subarkoses of the Kaniapiskau Supergroup, are typical of a craton interior and transitional continental settings (e.g., Dickinson, 1985). The elevated iron contents for some samples of the Denault and Baby formations resemble iron formation units within the Ferriman Group, supporting the interpretation that they are stratigraphically associated (e.g., Wardle et al., 1990; Clark et al., 2008; Zentmyer et al., 2011; Henrique-Pinto et al., 2017).

In contrast, rocks from the Laporte Group represent a more homogeneous group of feldspathic and lithic wackes with variable matrix contents with quartz cement and secondary metamorphic minerals such as idioblastic muscovite and secondary carbonate. Given the overprint of the sedimentary petrofabric, a geotectonic QFL-diagram is not applicable (see discussion in Cox and Lowe, 1996).

The plot of Laporte Group samples on a K_2O/Na_2O vs. SiO_2 diagram (Roser and Korsh, 1986) suggests a depositional setting typical of an active continental margin (Fig.11). Thus, the Laporte Group metaconglomerates should contain, in addition to the dominant felsic granitic clasts, fine-grained, volcanic sedimentary detritus (Fig. 12).

As already indicated by a detrital zircon provenance study (Henrique-Pinto et al., 2017) the presence of matrix-rich metasedimentary rocks in the Grand Rosoy Formation and juvenile granitic clasts with slightly negative to positive $\varepsilon Nd_{(1.83\ Ga)}$ values in the metaconglomerates is consistent with an andesitic arc-related sedimentary basin (Fig. 13). However, the lower $\varepsilon Nd_{(1.83\ Ga)}$ values (-4.4 to -9.1) in metawackes of the Deborah Formation suggest a contribution from older (> 1.8 Ga) crustal components (Figs. 13 and 14).

Four Kaniapiskau Supergroup samples record significant diagenetic/metamorphic albitization with the introduction of secondary carbonates, which hinders the interpretation of its tectonic setting through the use of major element discriminant diagrams (Fig. 11). Nevertheless, the abundance of recycled mature polycyclic detritus in the Kaniapiskau Supergroup rocks is consistent with an intraplate continental margin environment and negative εNd values suggest that the sediment provenance included Paleoarchean sources.

8. Discussion

The Laporte Group has been considered a high-grade metamorphic equivalent of some formations within the Kaniapiskau Supergroup since the 1950s (e.g., Harrison, 1952; Taylor, 1979; Wardle et al., 2002; Wardle and Bailey, 1981; Poirier et al., 1990; Girard, 1995). However, in light of the differences in their detrital zircon populations (Henrique-Pinto et al., 2017), it is unlikely that the metasedimentary rocks of the Kaniapiskau Supergroup and the Laporte Groupe received terrigenous material from the same source. This conclusion is also supported by contrasting geochemical signatures. For example, the Laporte Group rocks have higher REE enrichment with less fractionated patterns and slightly negative Eu anomalies compared to Kaniapiskau Supergroup rocks.

First cycle sedimentation within the Kaniapiskau Supergroup began in an intracontinental rift-related environment (Clark and Wares 2005; Fig. 15-A) and Hoffman (1987, 1988, 1990a) proposed a foreland model for the second cycle of sedimentation of the Kaniapskau Supergroup. However, the foreland model is difficult to reconcile with an age-gap of more than 150 Ma between the crystallization and depositional ages of the detrital zircon population from the Denault and Baby formations. The age-gap is more consistent with those of detrital zircons from passive continental margins (Henrique-Pinto et al., 2017). This hypothesis is corroborated by the Sm-Nd isotope data of this study that indicates sediment sources derived exclusively from Paleoarchean terrains (TDM 3.2 Ga; εNd = -12.) (Fig. 15-B).

The metabasalt from the western part of the Kaniapiskau Supergroup records a slightly negative $\varepsilon Nd_{(1.88\ Ga)}$ value (-2.3) that could indicate that the magmas were contaminated by assimilation of sedimentary rocks within the passive margin. In contrast, pillow basalt from the eastern part of the Kaniapiskau Supergroup yields a positive $\varepsilon Nd_{(1.87\ Ga)}$ value (+3.3) that is consistent with a depleted MORB-like ocean floor spreading eastward, as has been suggested by some authors (e.g., Van der Leeden et al., 1990; Boone and Hynes, 1990). More robust conclusions would require further investigation.

Two main formations of the Laporte Group (Girard, 1995) are the Grand Rosoy formation (basal), including polymictic metaconglomerates, and Deborah Formation (upper unit), which records higher TiO_2, P_2O_5, MgO and Ni contents and high Cr/Th, Co/Ba, Th/U and Rb/Sr ratios.

These features suggest the presence of additional sediment sources that were probably of mafic/intermediate composition and were not preserved as lithic fragments.

Van der Leeden et al. (1990) proposed that the Kaniapiskau Supergroup coexisted eastward with a forearc accretionary wedge (Laporte Group) bordering the De Pas Batholith in an Andean-type magmatic arc environment. Henrique-Pinto et al. (2017) proposed that <100 Ma age-gap between the crystallization and depositional ages for the detrital zircon population within the Grand Rosoy Formation is consistent with detrital zircon provenance recognized in forearc settings and the Andean-type magmatic arc model. The positive $\varepsilon Nd_{(1.83\ Ga)}$ values of the matrix-rich metasedimentary rocks and juvenile granitic clasts in metaconglomerates of the Grand Rosoy Formation are also consistent with deposition in a continental forearc setting, with exposed and dissected early-arc infrastructure (Fig. 15-C).

The development of a forearc basin (and its basement) in modern orogens is followed by crustal thickening with the development of a wedge-top depozone in the upper plate during the continental collision phase. Examples of this evolution are found in the southern Taiwan foreland basin (Chiang et al., 2004; Malavieille and Trullenque, 2009) and the Himalayan Orogen in southwestern Tibet (Wang et al., 2015).

Following this model, the Deborah Formation would have been deposited above the forearc basin and the model is consistent with the detrital zircon age pattern of the Deborah Formation (Henrique-Pinto et al., 2017) (Fig. 15-D). The negative $\varepsilon Nd_{(1.83\ Ga)}$ values (-4.4 to -9.1) from the Deborah formation suggest a contribution from more evolved sources, possibly derived from the passive margin exposed in the accretionary wedge, and from exposed crustal levels of the Core Zone terrane.

9. Concluding remarks

The petrography, geochemistry and Sm-Nd isotopic data of matrix-rich conglomerates, wackes and mudrocks were used as provenance tools to characterize the tectonic settings of the Labrador Trough. The following conclusions can be drawn from our study:

(i) Rocks from the Kaniapiskau Supergroup have geochemical and isotopic signatures akin to cratonic interior and transitional continental paleo-environments, and record greater compositional maturity, with a wide range of textural maturity that is typical of an intraplate continental margin basin;

(ii) Compared to the Kaniapiskau Supergroup, the Laporte Group rocks have less fractionated REE patterns and slight negative Eu anomalies, which supports the interpretation that metasedimentary rocks of the Kaniapiskau Supergroup and Laporte Group received terrigenous material from different source areas;

(iii) The higher TiO_2, P_2O_5, MgO and Ni contents and high Cr/Th, Co/Ba, Th/U and Rb/Sr ratios of the Deborah Formation suggest the presence of additional mafic/intermediate sources during deposition;

(iv) Nd isotopes of matrix-rich metasedimentary rocks and juvenile granitic clasts within metaconglomerates of the Grand Rosoy Formation (Laporte Group) are consistent with an arc-related sedimentary environment, possibly a continental forearc with juvenile dissected early-arc substrate as the main source area; and

(v) As expected in a collisional pro-foreland basin especially in a wedge-top depozone, the sedimentary record of the Deborah Formation (Laporte Group) includes contributions that were probably derived from the passive margin exposed in the accretionary wedge and eroded crustal levels of the Core Zone terrane.

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FIGURE CAPTIONS

Fig. 1: Easternmost part of the Circum-Ungava Belt (modified from Henrique-Pinto et al., 2017).

Fig. 2: Geological map of the Labrador Trough (north) showing parts of the Kaniapiskau Supergroup and Laporte Group, and the locations of dated samples (modified from http://sigeom.mines.gouv.qc.ca).

Fig. 3: Schematic stratigraphy of the Kaniapiskau Supergroup (modified from Clark and Wares, 2005). CC= Castignon Lake Carbonatite Complex.

Fig. 4: Labrador Trough samples plotted on a QFL ternary diagram: Q=quartz, F=feldspar, L=lithic fragments. Fields after Dott (1964), McBride (1963) and Pettijohn (1975).

Fig. 5: Photomicrographs of metasedimentary rocks of the Kaniapiskau Supergroup and Laporte Group (left, parallel polarizers; right, crossed polarizers). A- subarkose from the Denault Formation; B- quartz arenite from the Baby Formation; C- feldspathic wacke from the Grand Rosoy Formation; D- quartz wacke from the Deborah Formation. Abbreviations: Qzp%= polycrystalline quartz; Qzm%= monocrystalline quartz; Qt%= total quartz; L%= lithic fragments; Ft%= total feldspars; Kfs= K-feldspar; Pl= plagioclase; Cb= carbonate; Op. min.= opaque minerals; Acc= Accessory.

Fig. 6: Main clast variety of psephitic rocks from the Grand Rosoy Formation. A- quartz-rich leucocratic granodiorite; B- mesocratic monzogranite; C- leucocratic monzogranite; D- quartz-rich leucocratic alkali-feldspar granite; E and F- hematite-bearing iron formation.

Fig. 7: Chemical classification diagram [log (SiO_2/Al_2O_3) versus log(Fe_2O_3/K_2O)] (Herron, 1988) for samples from the Kaniapiskau Supergroup and Laporte Group.

Fig. 8: Chondrite-normalized (Taylor and McLennan, 1985) rare-earth element patterns for metasedimentary rocks of the Labrador Trough.

Fig. 9: Trace element variation diagrams versus SiO_2 in metasedimentary rocks of the Laporte Group. Grey shaded areas represent the range of granitic clast compositions.

Fig. 10: ƐNd versus TDM (Ga) diagram for metamudrocks and metawackes from the Kaniapiskau Supergroup and Laporte Group. DM = depleted mantle curve from De Paolo (1988).

Fig. 11: Labrador Trough samples plotted on a K_2O/Na_2O vs. SiO_2 diagram (Roser and Korsch, 1986).

Fig. 12: Provenance signatures using discriminant function analysis from Roser and Korsch (1988) applied to rocks from the Kaniapiskau Supergroup and Laporte Group. The discriminant functions are:

F1 =(-(1,773*TiO_2)+(0,607*Al_2O_3)+(0,76*Fe_2O_3)-(1,5*MgO)+(0,616*CaO)+(0,509*Na2O)-(1,224*K_2O)-9,09);

F2=(0,445*TiO_2)+(0,07*Al_2O_3)-(0,25*Fe_2O_3)-(1,142*MgO)+(0,438*CaO)+(1,475*Na_2O)+(1,426*K_2O)-6,861);

F1*=(((30,638*TiO_2)/Al_2O_3)-(12,541*Fe_2O_3)/Al_2O_3)+((7,329*MgO)/Al_2O_3)+((12,031*Na_2O)/Al_2O_3)+((35,402*K_2O)/Al_2O_3)-6,382); F2* = (((56,5*TiO_2)/Al_2O_3)-((10,879*Fe_2O_3)/Al_2O_3)+((30,875*MgO)/Al_2O_3)-((5,404*Na_2O)/Al_2O_3)+((11,112*K_2O)/Al_2O_3)-3,89). Legend as in Figure 10.

Fig. 13: Plot of ƐNd versus Th/Sc ratio (McLennan et al., 1990) for metamudrocks and metawackes of the Kaniapiskau Supergroup and Laporte Group.

Fig. 14: Plot of *ƒ*Sm/Nd versus ƐNd (McLennan and Hemming, 1991) for metamudrocks, metawackes and metavolcanic rocks of the Kaniapiskau Supergroup and Laporte Group.

Fig. 15: Preferred tectonic model for the evolution of the New Quebec Orogen.

TABLE CAPTION

Table 1: Modal mineralogy of metasedimentary rocks from the Kaniapiskau Supergroup and Laporte Group. Abbreviations: Qzp%= polycrystalline quartz; Qzm%= monocrystalline quartz; Qt%= total quartz; L%= lithic fragments; Ft%= total feldspars; Kfs= K-feldspar; Pl= plagioclase; Cb= carbonate; Op. min.= opaque minerals; Acc= Accessory. *1= quartz arenite; *2= subarkose; *3= feldspathic wacke and *4= mudrock.

Table 2: Sm-Nd isotope data for metamudstones of the Kaniapiskau Supergroup and Laporte Group.

SUPPLEMENTARY DATA

Table S1: Results of chemical analyses on metasedimentary rocks of the Kaniapiskau Supergroup and Laporte Group.

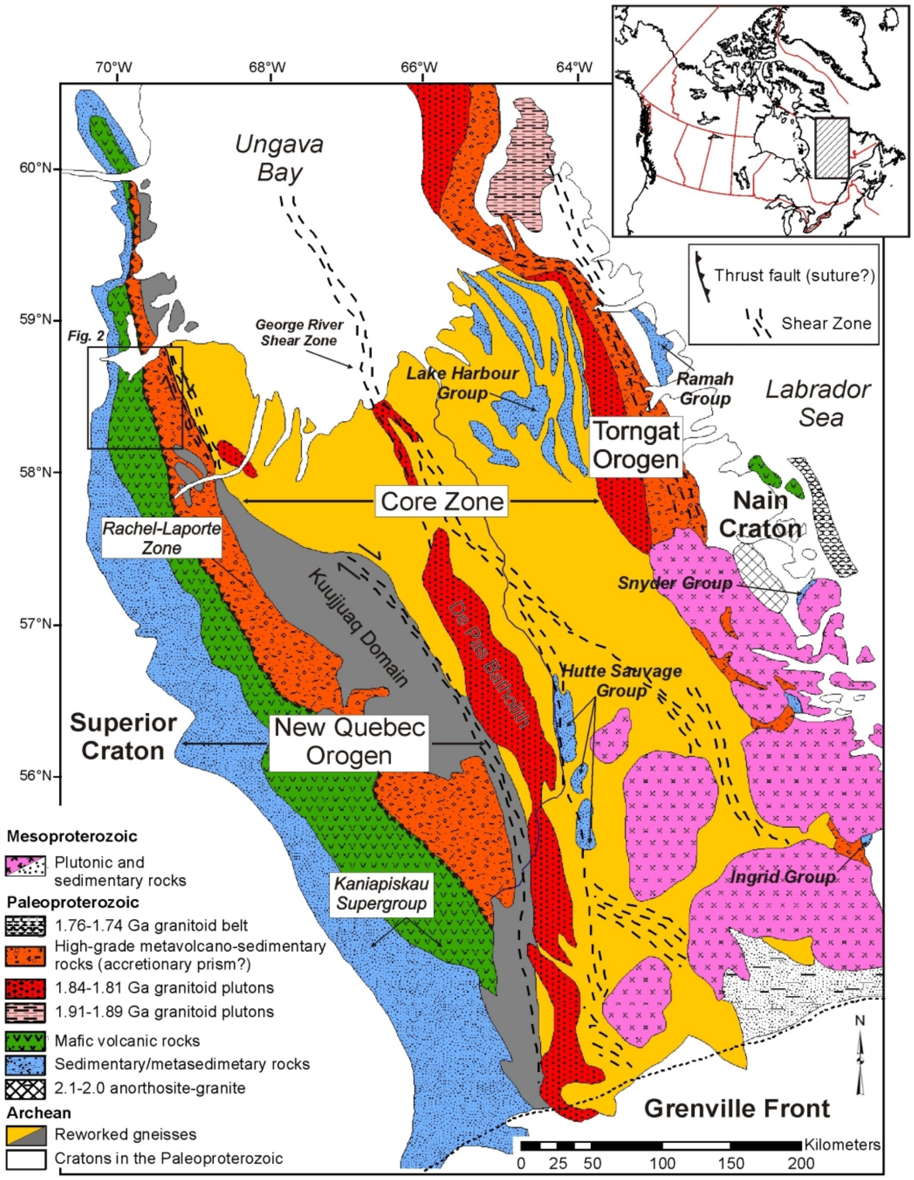

Fig. 1: Easternmost part of the Circum-Ungava Belt (modified from Henrique-Pinto et al., 2017).

182x237mm (300 x 300 DPI)

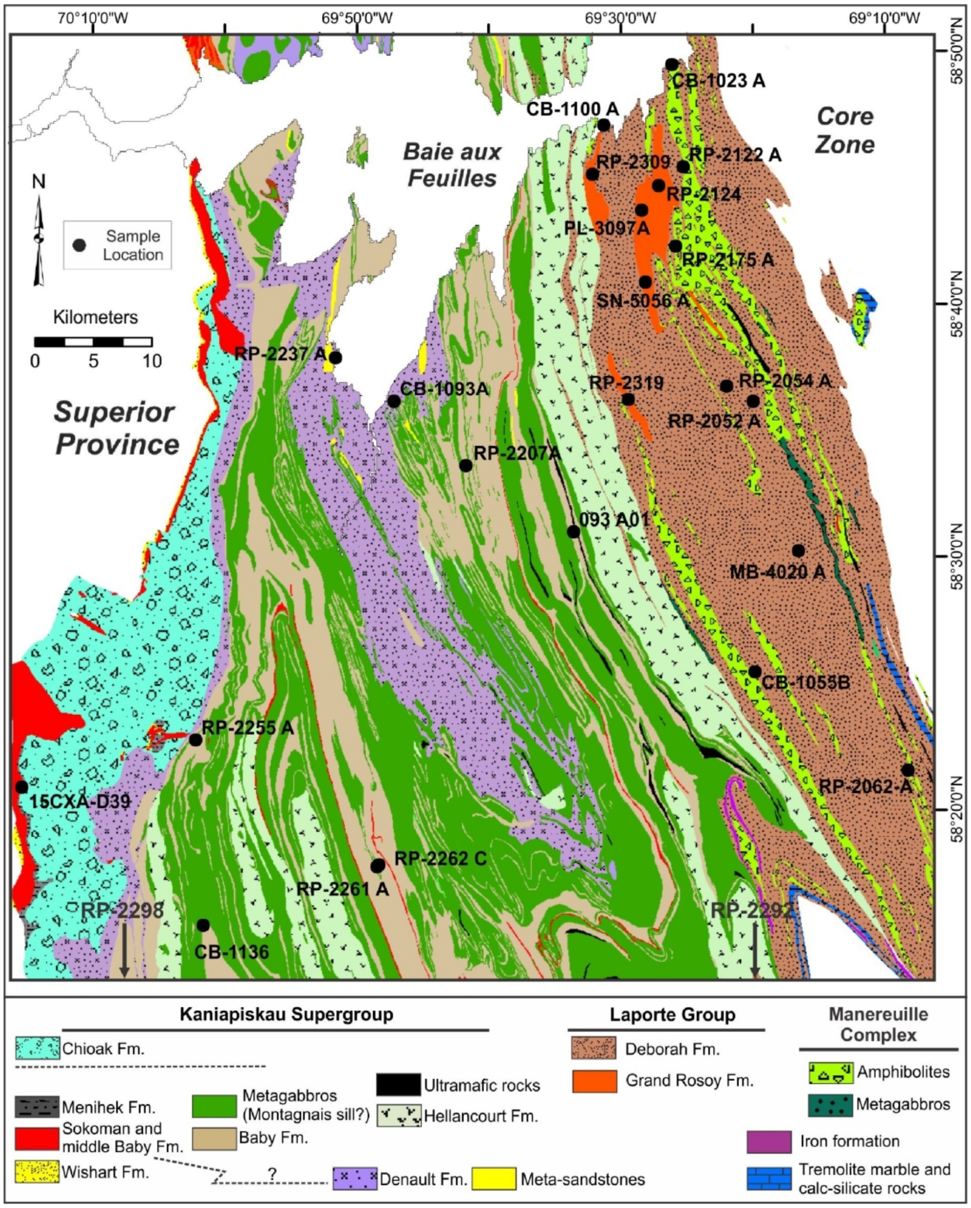

Fig. 2: Geological map of the Labrador Trough (north) showing parts of the Kaniapiskau Supergroup and Laporte Group, and the locations of dated samples (modified from http://sigeom.mines.gouv.qc.ca).

190x236mm (300 x 300 DPI)

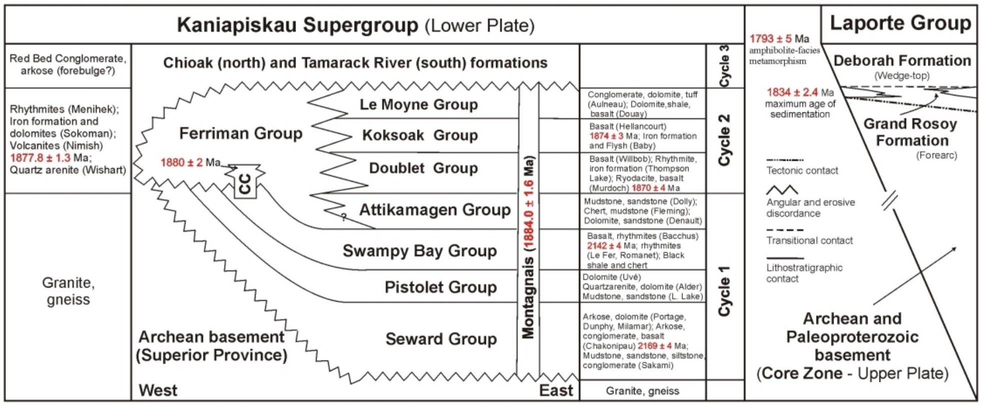

Fig. 3: Schematic stratigraphy of the Kaniapiskau Supergroup (modified from Clark and Wares, 2005). CC= Castignon Lake Carbonatite Complex.

236x98mm (300 x 300 DPI)

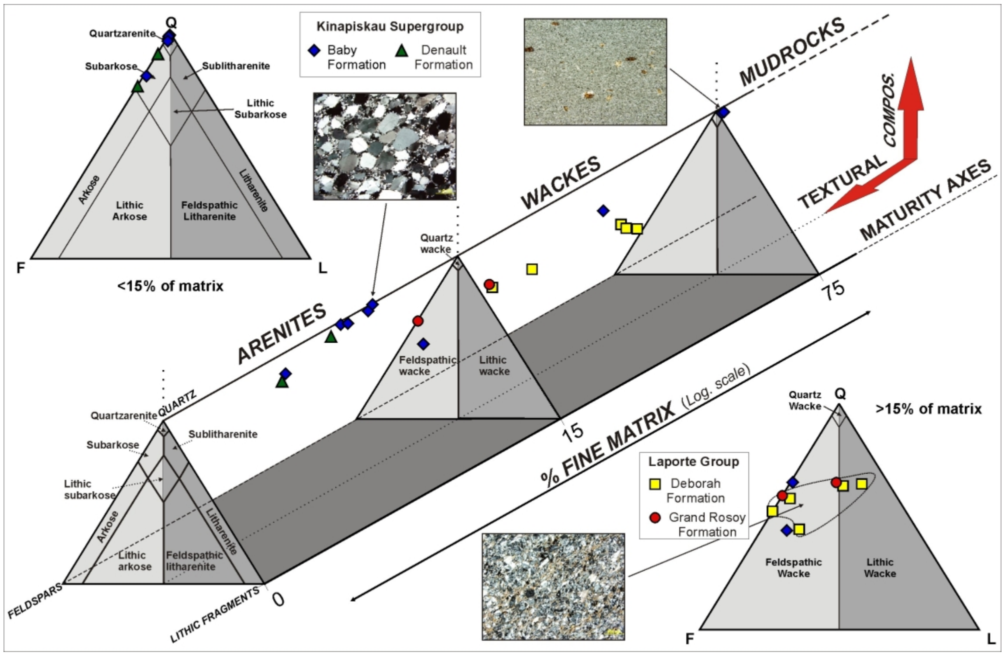

Fig. 4: Labrador Trough samples plotted on a QFL ternary diagram: Q=quartz, F=feldspar, L=lithic fragments. Fields after Dott (1964), McBride (1963) and Pettijohn (1975).

237x153mm (300 x 300 DPI)

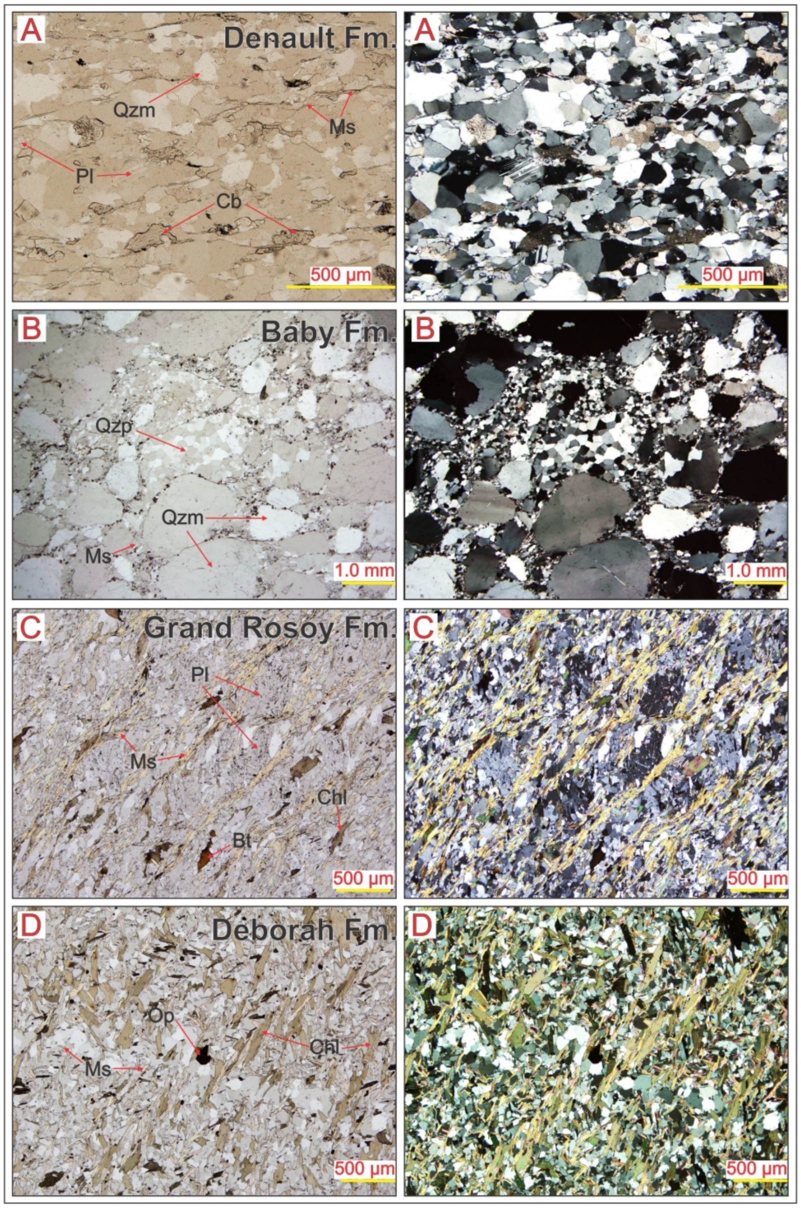

Fig. 5: Photomicrographs of metasedimentary rocks of the Kaniapiskau Supergroup and Laporte Group (left, parallel polarizers; right, crossed polarizers). A- subarkose from the Denault Formation; B- quartz arenite from the Baby Formation; C- feldspathic wacke from the Grand Rosoy Formation; D- quartz wacke from the Deborah Formation. Abbreviations: Qzp%= polycrystalline quartz; Qzm%= monocrystalline quartz; Qt%= total quartz; L%= lithic fragments; Ft%= total feldspars; Kfs= K-feldspar; Pl= plagioclase; Cb= carbonate; Op. min.= opaque minerals; Acc= Accessory.

139x210mm (300 x 300 DPI)

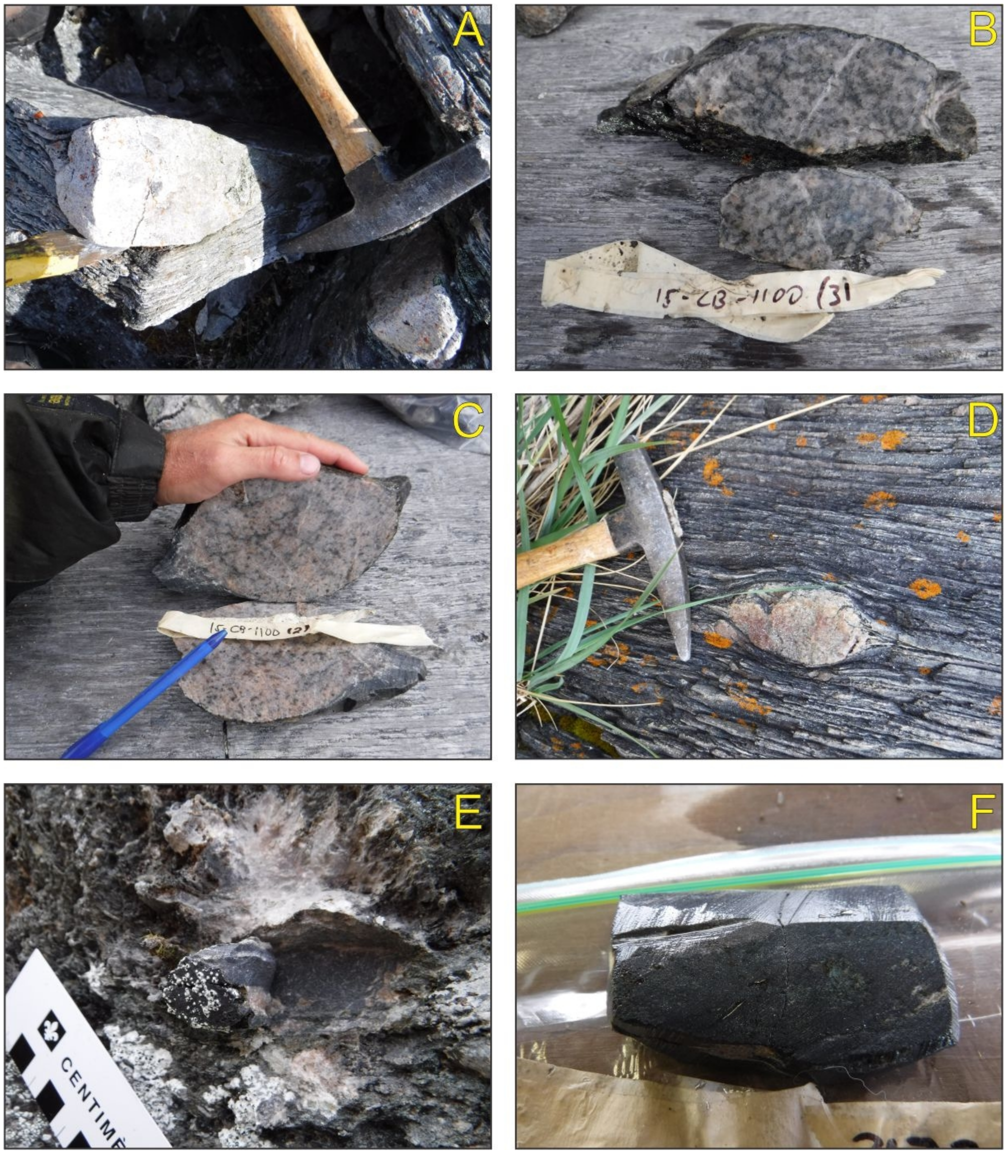

Fig. 6: Main clast variety of psephitic rocks from the Grand Rosoy Formation. A- quartz-rich leucocratic granodiorite; B- mesocratic monzogranite; C- leucocratic monzogranite; D- quartz-rich leucocratic alkali-feldspar granite; E and F- hematite-bearing iron formation.

102x117mm (300 x 300 DPI)

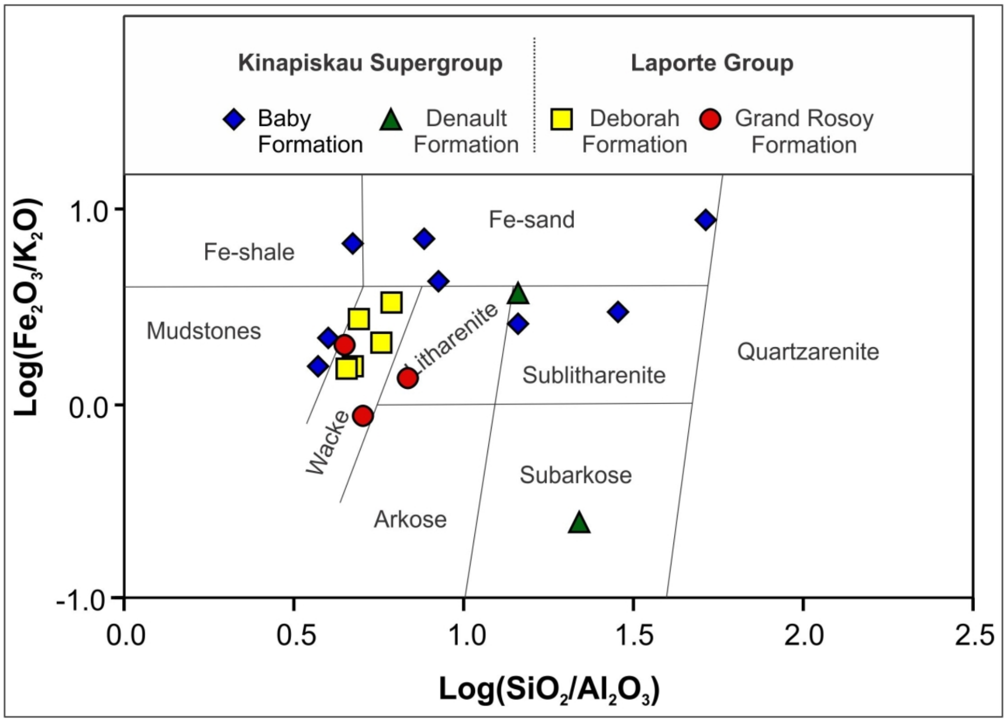

Fig. 7: Chemical classification diagram [log (SiO2/Al2O3) versus log(Fe2O3/K2O)] (Herron, 1988) for samples from the Kaniapiskau Supergroup and Laporte Group.

187x134mm (300 x 300 DPI)

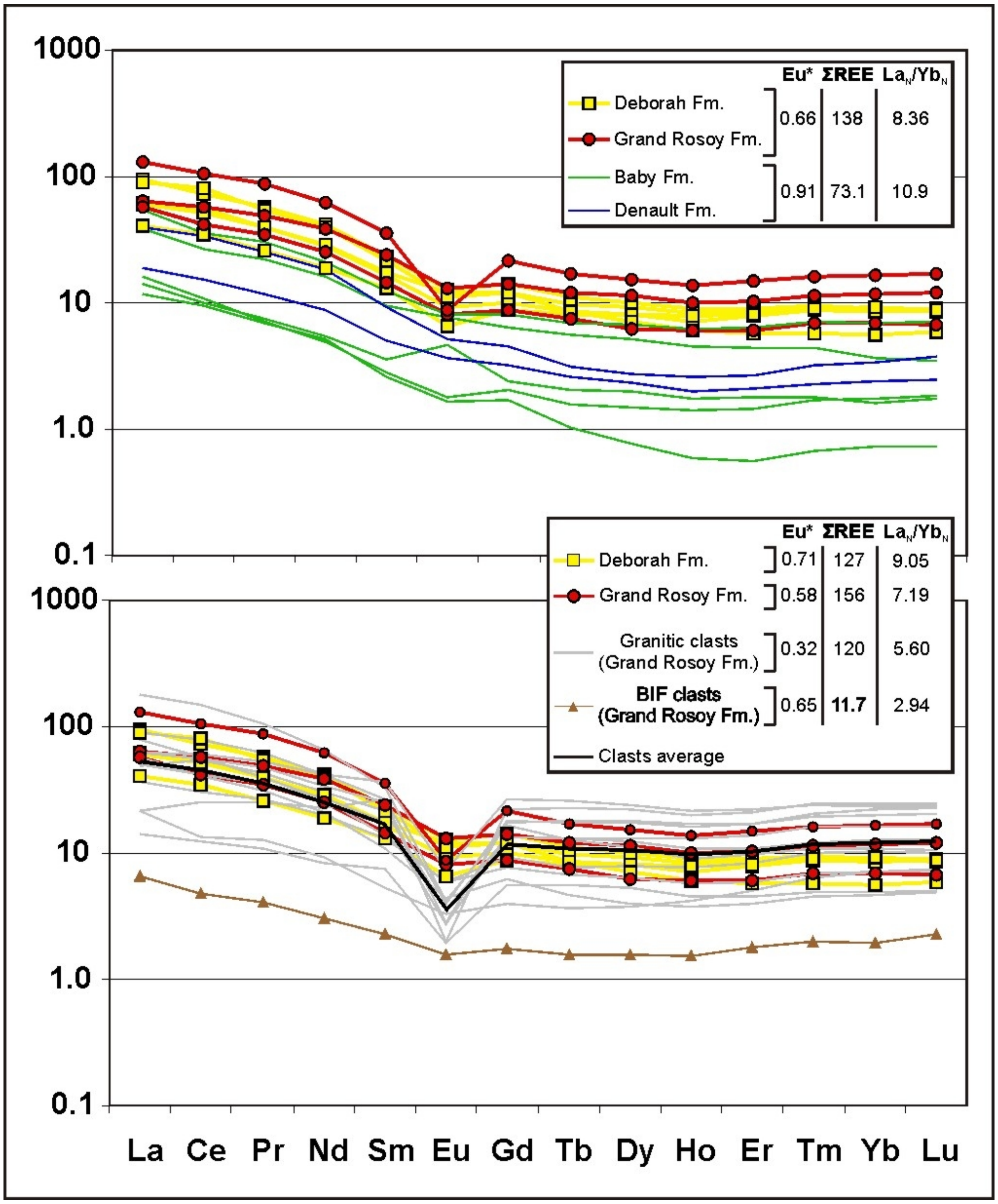

Fig. 8: Chondrite-normalized (Taylor and McLennan, 1985) rare-earth element patterns for metasedimentary rocks of the Labrador Trough.

86x103mm (300 x 300 DPI)

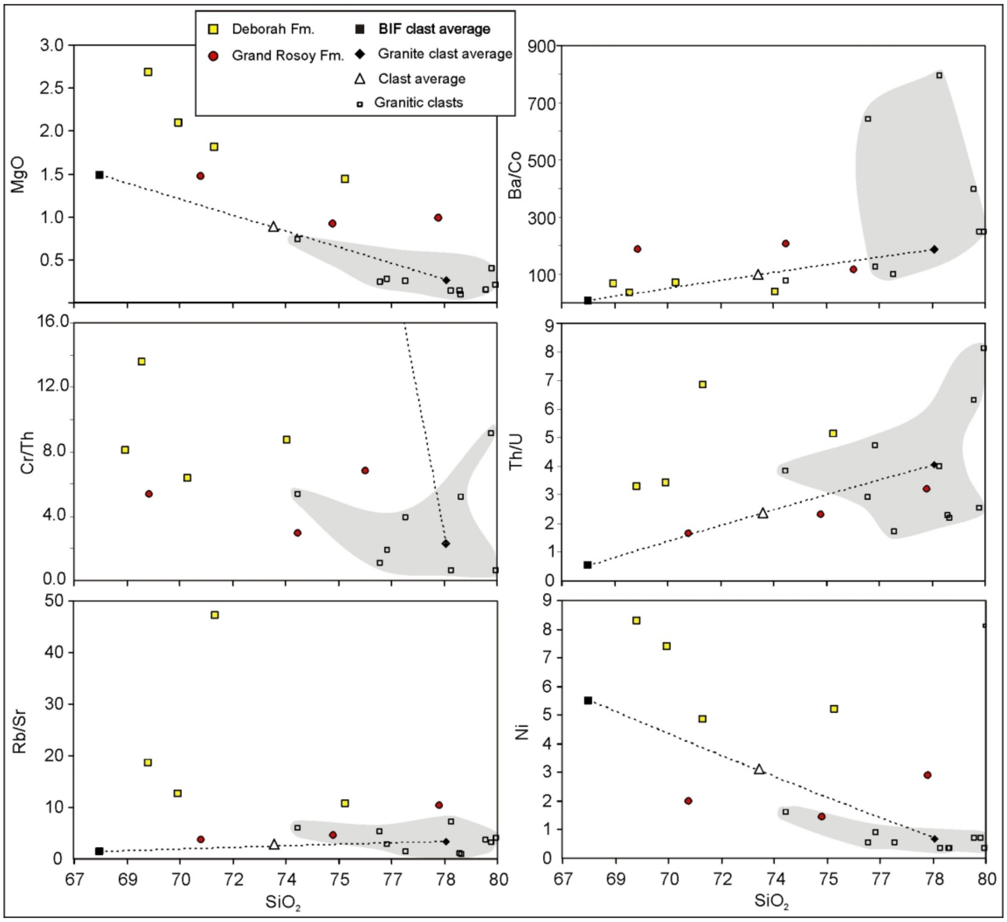

Fig. 9: Trace element variation diagrams versus SiO2 in metasedimentary rocks of the Laporte Group. Grey shaded areas represent the range of granitic clast compositions.

182x166mm (300 x 300 DPI)

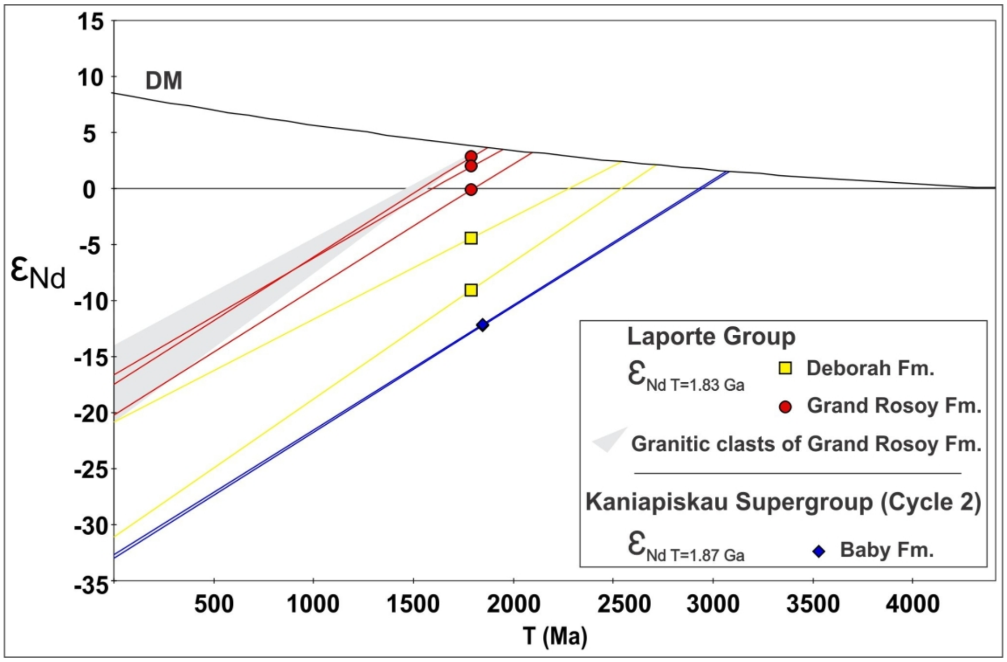

Fig. 10: ƐNd versus TDM (Ga) diagram for metamudrocks and metawackes from the Kaniapiskau Supergroup and Laporte Group. DM = depleted mantle curve from De Paolo (1988).

173x113mm (300 x 300 DPI)

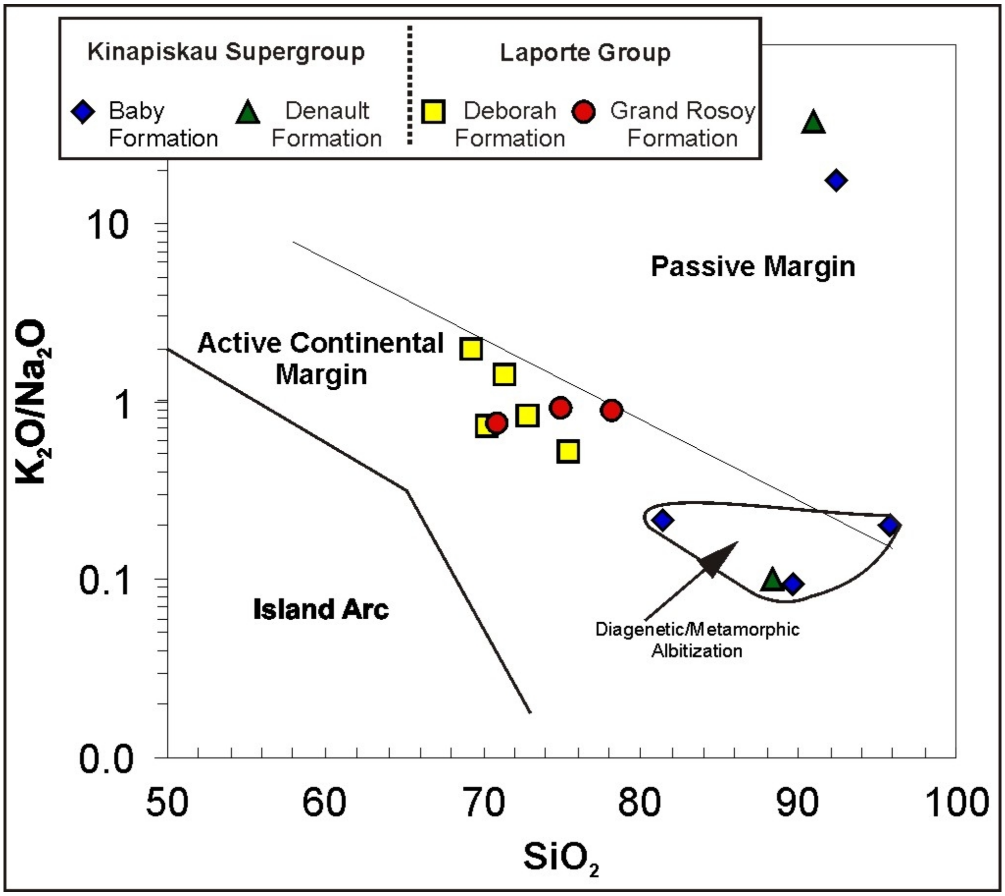

Fig. 11: Labrador Trough samples plotted on a K2O/Na2O vs. SiO2 diagram (Roser and Korsch, 1986).

86x76mm (300 x 300 DPI)

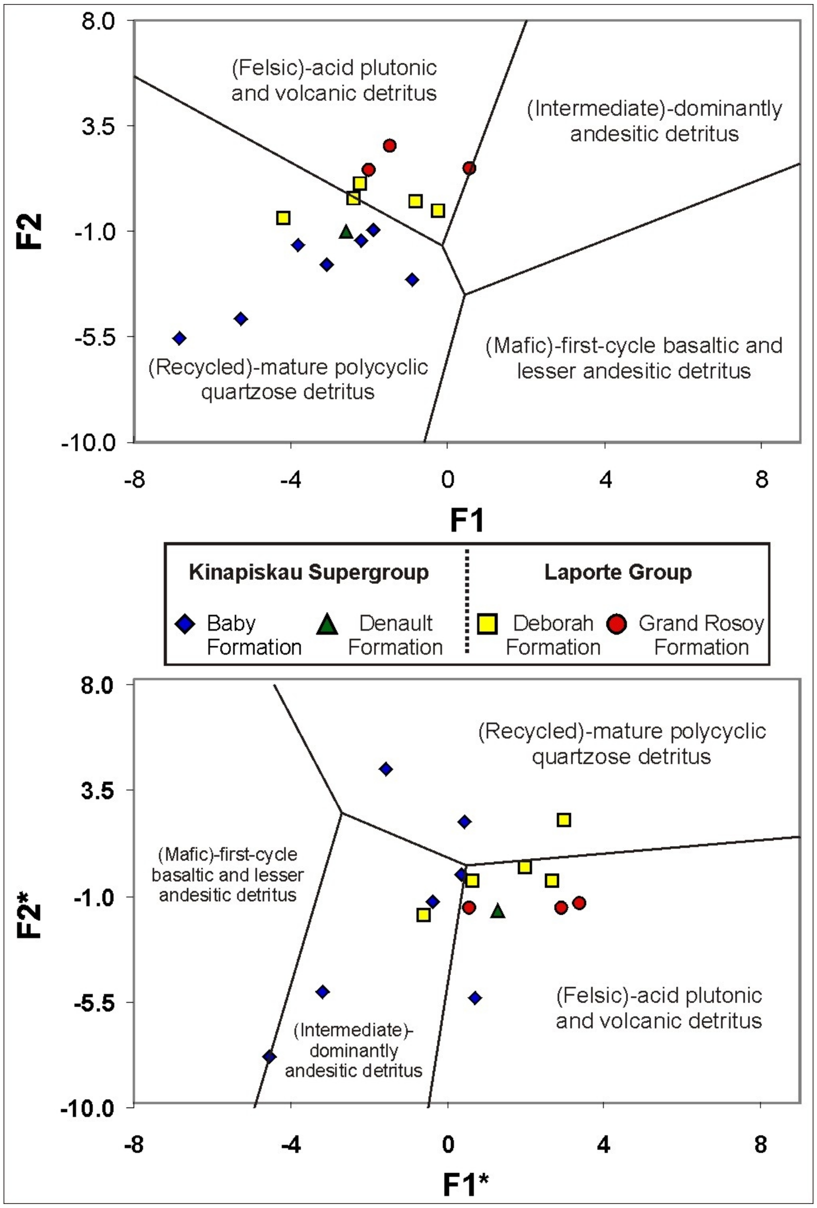

Fig. 12: Provenance signatures using discriminant function analysis from Roser and Korsch (1988) applied to rocks from the Kaniapiskau Supergroup and Laporte Group. The discriminant functions are:F1 =(-(1,773*TiO2)+(0,607*Al2O3)+(0,76*Fe2O3)-(1,5*MgO)+(0,616*CaO)+(0,509*Na2O)-(1,224*K2O)-9,09);F2=(0,445*TiO2)+(0,07*Al2O3)-(0,25*Fe2O3)-(1,142*MgO)+(0,438*CaO)+(1,475*Na2O)+(1,426*K2O)-6,861);F1*=(((30,638*TiO2)/Al2O3)-(12,541*Fe2O3)/Al2O3)+((7,329*MgO)/Al2O3)+((12,031*Na2O)/Al2O3)+((35,402*K2O)/Al2O3)-6,382);F2* = (((56,5*TiO2)/Al2O3)-((10,879*Fe2O3)/Al2O3)+((30,875*MgO)/Al2O3)-((5,404*Na2O)/Al2O3)+((11,112*K2O)/Al2O3)-3,89).

86x127mm (300 x 300 DPI)

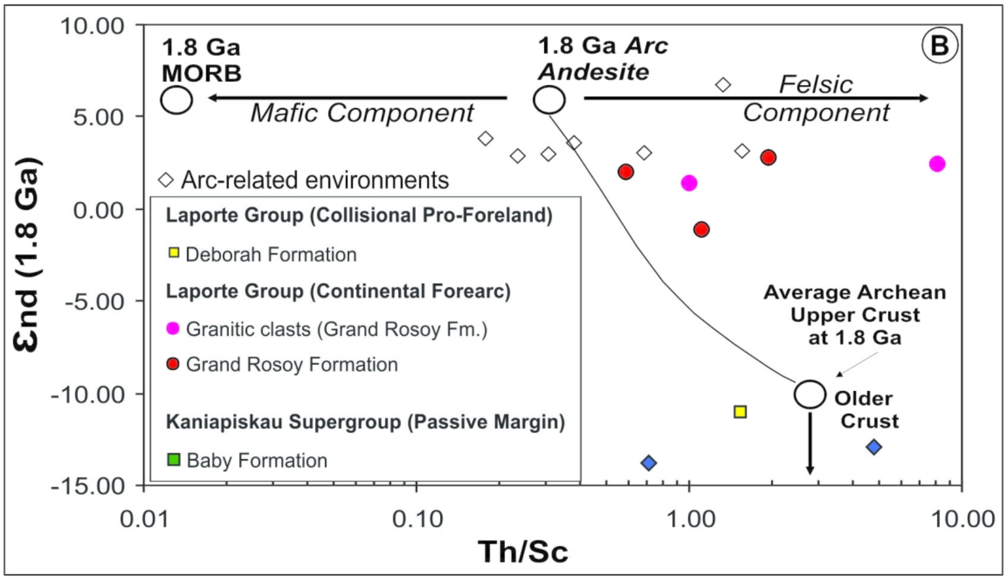

Fig. 13: Plot of ƐNd versus Th/Sc ratio (McLennan et al., 1990) for metamudrocks and metawackes of the Kaniapiskau Supergroup and Laporte Group.

141x81mm (300 x 300 DPI)

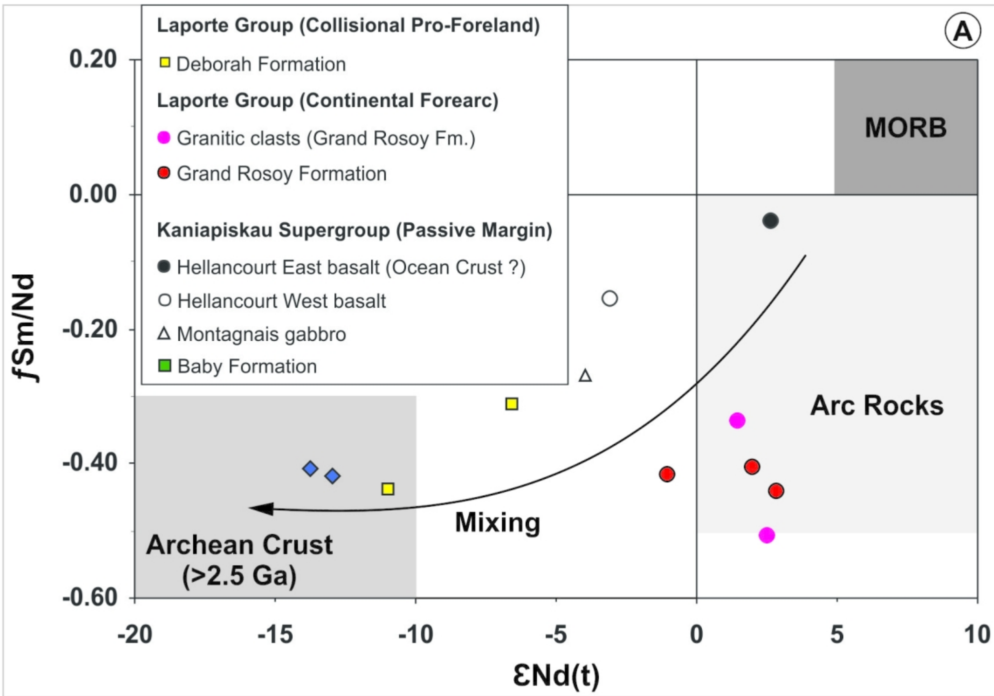

Fig. 14: Plot of ƒSm/Nd versus ƐNd (McLennan and Hemming, 1991) for metamudrocks, metawackes and metavolcanic rocks of the Kaniapiskau Supergroup and Laporte Group.

142x99mm (300 x 300 DPI)

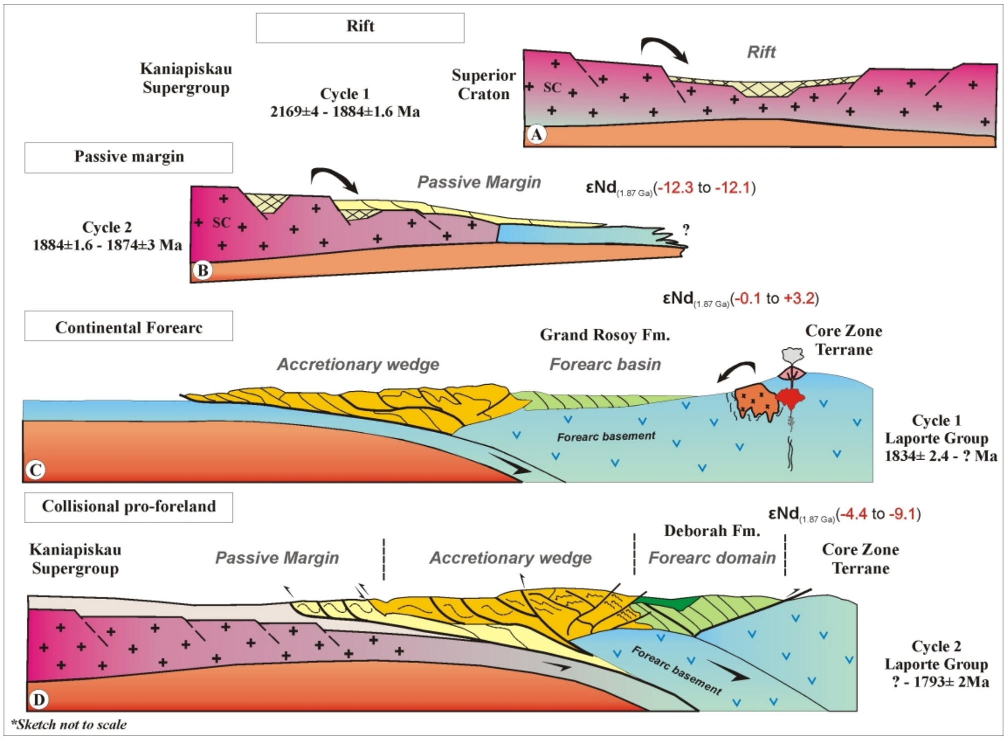

Fig. 15: Preferred tectonic model for the evolution of the New Quebec Orogen.

247x181mm (300 x 300 DPI)

	Samples	Qz-mon	Qz-poli	Kfs	Pl	lithic	accessory	fine-grain Ms	Cb	Op	total	Matrix%	Qzp%	Qzm%	Qzt%	L%	Ft%	Kfs%	Pl%
Kaniapiskau Supergroup	RP-2231 A3 (Baby Fm.) *1	396	-	-	-	-	17	-	63	145	621	0	0	100	100	0	0	0	0
	RP-2298 (Denault Fm.) *2	31	333	103	11	-	20	19	38	1	556	3	70	6	76	0	24	22	2
	093-A01 (Baby Fm.) *2	233	232	45	38	5	10	24	13	-	600	4	42	42	84	0,9	15	8	7
	RP-2237-A (Denault Fm.) *1	91	312	12	29	1	18	27	69	-	559	5	70	20	91	0,2	9	3	7
	RP-2262-C (Baby Fm.) *1	282	175	-	14	-	7	41	35	1	555	7	37	60	97	0	3	0	3
	RP-2255 (Baby Fm.) *1	109	321	-	2	-	5	55	31	16	539	10	74	25	100	0	0,5	0	0,5
	RP-2292-B (Baby Fm.) *2	54	203	18	20	98	7	56	53	10	519	11	52	14	65	25	10	5	5
	RP-2261 A1 (Baby Fm.) *3	181	226	13	43	-	4	113	37	-	617	18	49	39	88	0	12	3	9
	RP-2292-A (Baby Fm.) *3	75	161	9	5	-	7	212	55	7	531	40	64	30	94	0	6	4	2
	CB-1093-A (Baby Fm.) *4	147	-	-	-	-	42	555	-	-	744	75	0	100	100	0	0	0	0
	RP-2207-A (Baby Fm.) *4	146	-	-	-	-	9	460	-	-	615	75	0	100	100	0	0	0	0

	Samples	Qz	Kfs	Pl	lithic	accessory	phyllosilicate	Cb	Op	total	Matrix%	-	-	Qt%	L%	F%	Kfs%	Pl%
Laporte Group	RP-2309-B (Grand Rosoy Fm.)	405	81	2	-	33	104	-	-	625	17	-	-	89	0	11	11	0
	RP-2052-A (Deborah Fm.)	343	43	-	-	43	123	-	-	552	22	-	-	99	0	1	1	0
	RP-2319-A (Grand Rosoy Fm.)	355	59	3	-	2	135	7	-	561	24	-	-	85	0	15	14	0,7
	MB-4020-A (Deborah Fm.)	389	96	-	-	17	168	-	-	670	25	-	-	100	0	0	0	0
	CB-1023-A (Deborah Fm.)	363	4	-	-	12	200	3	-	582	34	-	-	80	0	20	20	0
	PL-3247-A (Deborah Fm.)	344	4	-	-	8	182	-	-	538	34	-	-	99	0	1	1	0
	RP-2054-A (Deborah Fm.)	256	-	-	-	18	275	-	-	549	50	-	-	83	0	17	17	0,4

		sample name	**age**	**Nd** (ppm)	**Sm** (ppm)	**Sm/Nd**	**143/144Nd**	**error** (2σ)	**εNd**(0)	**εNd**(t)	**TDM**	**Th/Sc**	**ƒSm/Nd**	**εNd**(TDM)
Laporte Group	**Grand Rosoy Fm (clast-metaconglomerate)**	SN-5056(2)	1.82	47.2	7.45	0.0953	0.511572	0.000010	-20.8	2.9	2.0	8.08	-0.52	5.4
	Grand Rosoy Fm (clast-metaconglomerate)	CB-1100(3)	1.82	14.0	2.85	0.1234	0.511922	0.000010	-14.0	3.2	2.1	1.00	-0.37	5.4
	Grand Rosoy Fm (meta-feldsphatic wacke)	CB-1055	1.82	25.7	4.98	0.1170	0.511785	0.000079	-16.6	2.0	2.1	0.58	-0.41	5.2
	Grand Rosoy Fm (meta-feldsphatic wacke)	RP-2319	1.82	45.1	8.21	0.1100	0.511744	0.000093	-17.4	2.8	2.1	1.94	-0.44	5.4
	Grand Rosoy Fm (meta-feldsphatic wacke)	RP-2309	1.82	17.6	3.23	0.1109	0.511605	0.000011	-20.1	-0.1	2.3	1.11	-0.44	4.8
	Deborah Fm (meta-wacke)	RP-2054	1.82	13.5	2.83	0.1262	0.511568	0.000005	-20.9	-4.4	2.7	0.93	-0.36	3.8
	Deborah Fm (meta-wacke)	CB-1023	1.82	27.3	4.65	0.1027	0.511045	0.000014	-31.1	-9.1	2.9	1.53	-0.48	3.4
piskau Super	**Hellancourt (metabasalt) W part**	CB-1024	1.87	18.0	4.16	0.1401	0.511823	0.000007	-15.9	-2.3	2.7	-	-0.29	3.9
	Hellancourt (meta-pillow basalt) E part	RP-2301	1.87	8.79	2.82	0.1940	0.512774	0.000019	2.7	3.3	-	-	-0.01	3.7
	Montagnais (metagabbro)	CB-1102	1.89	12.3	3.30	0.1614	0.512101	0.000048	-10.5	-1.9	-	-	-0.18	3.2
	Baby Fm (meta-mudrock)	RP-2261	1.87	15.1	2.77	0.1109	0.510961	0.000114	-32.7	-12.1	3.2	4.74	-0.44	2.6
	Baby Fm (meta-subarkose)	RP-2207	1.87	11.5	2.10	0.1107	0.510949	0.000014	-32.9	-12.3	3.2	0.71	-0.44	2.6