The role of crustal recycling during the assembly of the supercontinent NUNA: Geochemical and isotopic constraints from felsic magmatism in the Makkovik Province, Labrador.

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Summary

The Makkovik Province of Labrador documents the early stages of the Great Proterozoic Accretionary Orogen recording part of the amalgamation of the supercontinent NUNA. During this supercontinent amalgamation, most continental crustal growth occurred in a relatively short period of time between 1900 and 1800 Ma. Insight into the assembly of NUNA is preserved in the felsic rocks from the Aillik Domain of the Makkovik Province. Major and trace element lithogeochemical signatures indicate compositions typical of "A-type" rhyolites and granites. Extended trace and rare earth element patterns are typical of the compositions of melts derived by partial melting of sialic crust, with strongly negative Nb and Ti anomalies; typical of crustal derived melts related either to the subduction processes or to crustal contamination processes. The trace element ratios, such as high $La/Yb_{(PM)}$ and Zr/Y ratios, are indicative of a low degree of partial melting at high temperatures (~850 - 900 ^{o}C) where garnet and amphibole were stable in the residue. The felsic volcanic rocks and synvolcanic intrusions have $\varepsilon Nd_{(T)}$ values that range from -0.86 to -4.62, with $T_{(DM)}$ model ages that range from 2160 Ma to 2775 Ma, suggesting derivation by partial melting sialic crust of predominantly Late Archean to Paleoproterozoic age. The neodymium crustal index (NCI) indicates a crustal neodymium contribution ranging from 31% to 61%, with an average of 46%, suggesting an equal amount of recycling of crust relative to the addition of juvenile crust during the derivation of the felsic rocks. The Aillik Group and associated plutonic equivalents formed in a back-arc setting, with the data suggesting the substrate of the arc could have either been relatively juvenile crust or reworked ca. 2.6 to 2.3 Ga Archean cratonic material.

Introduction

The assembly of Nuna was punctuated and diachronous with an early stage of accretionary orogenesis at 2.2-2.0 Ga for only six supercontinents; and culminating in amalgamation by ca. 1.80 (Pehrsson et al., 2016). During the formation of the supercontinent NUNA, collisional peaks occurred between 2100 and 1900 Ma; however, most continental crust growth occurred in a relatively short period of time between 1900 and 1800 Ma (Condie, 2013; Pisarevsky et al., 2014; Zhao et al., 2002). NUNA represents the initial supercontinent amalgamation of the Great Proterozoic Accretionary Orogen (GPAO) that formed along the southern margin of Laurentia recording a major period of crustal growth between 2.0 and 1.0 Ga via accretionary orogenesis (Whitmeyer and Karlstrom, 2007; Condie, 2013, 2014; Pehrsson *et al.*, 2016 and references there in). The Makkovik Province of Labrador preserves the assembly of the GPAO, where the southern margin of the Archean North Atlantic Craton (NAC) was reworked during the Makkovikian orogeny, and juvenile terranes were accreted during a period of protracted collisional events along strike, an event broadly coeval with the Ketilidian Orogeny of southern Greenland. Insight into the assembly of NUNA is preserved in the felsic rocks from the Aillik domain, providing the opportunity to evaluate the growth of continental crust during the first supercontinent amalgamation associated with modern plate tectonics.

Method

Major and trace element lithogeochemical data, along with Sr–Nd isotopic data for felsic volcanic rocks of the Paleoproterozoic Aillik group and associated syn-volcanic hypabyssal, porphyry granites of the Measles Point Granite Suite are presented. These rocks are particularly relevant as they are mostly composed of weakly deformed rocks that experienced low-grade metamorphism and that were not overprinted by the later Grenville Orogen, and thereby preserve primary features.

Results and Discussion

The geochemical and geological features presented herein support the interpretation that the Aillik Group is similar to continental back-arc sequences. Major and trace element signatures indicate compositions typical of "A-type" rhyolites. On multi-element geochemical diagrams, REE patterns show LREE enrichment with marked negative Eu anomalies and flat but depleted HREE profiles; signatures that are typical of the compositions of melts derived by partial melting of sialic crust (Menuge et al., 2002; Brewer *et al.*, 2004). Felsic volcanic samples also display strongly negative Nb and Ti anomalies; signatures that are typical of crustal derived melts (Arculus et al., 1999; Kemp and Hawkesworth, 2003). Features such as enriched LILE and light REE are also indicative of crustally derived, fluid and/or melt, contributions to the magmas; interpreted to be related to either subduction process or to intracrustal contamination processes. The felsic samples have strongly depleted HREE and Y, high $(La/Yb)_{PM}$ and Zr/Y ratios, and pronounced negative Eu anomalies; indicative of low degrees of partial melting at high temperatures (~850-900 ^{o}C) where garnet and amphibole were stable in the residue.

Nd-isotopic compositions can potentially shed light on whether the crustal signature in the arc volcanic rocks was derived from significantly older sources. The felsic volcanic rocks and synvolcanic intrusions have $\varepsilon Nd_{(T)}$ values that range from -0.86 to -4.62, with $T_{(DM)}$ model ages that range from 2160 Ma to 2775 Ma. These results suggest that the felsic volcanic rocks were derived by partial melting of sialic crust of predominantly Late Archean to Paleoproterozoic age.

Mixing lines were calculated for the $\varepsilon Nd_{(T)}$ data plotted against trace element and isotopic ratios that reflect increasing crustal influence on magma compositions ($^{147}Sm/^{144}Nd$, Zr/Yb, Th/Yb, and La/Yb). Key features of note are that the felsic samples are too juvenile compared to those of the Archean NAC; suggesting that the latter is too evolved with too long of a crustal residence time to explain the isotopic attributes of the felsic rocks from this study. The felsic rocks were likely formed at high levels in the crust. The neodymium isotopic data reflect the felsic magma source regions, and thus provide the best estimates of crustal involvement. In an attempt to provide a quantitative assessment of crustal influence, the neodymium crustal index (NCI) is utilized (DePaolo et al., 1992). The results of the calculations indicate a crustal neodymium contribution ranging from 31% to 61%, with an average of 46%, indicating that equal amounts of recycled and juvenile crust would have been required to explain the εNd signature of the felsic rocks.

Subduction-related magmatism in the Makkovik Orogen resulted in significant crustal reworking and juvenile crustal growth. The Aillik Group formed in a back-arc setting, with the data suggesting the substrate of the arc could have either been relatively juvenile crust or reworked ca. 2.6 to 2.3 Ga Archean cratonic material. In the latter case, the substrate may be related to similar aged blocks preserved in the Southeast Churchill Province, or equivalents that extended south of the NAC.

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