The granulite–TTG connection in the Neoarchean Kapuskasing uplift, Canada

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Summary

Tonalite-trondhjemite-granodiorite (TTG) suites are a ubiquitous component of Archean cratons worldwide. Partial melting of a subducted slab vs. the lower crust as a source for TTGs is debated. Trace element concentrations in TTGs are commonly used to distinguish between these two origins. However, opportunities to link TTGs directly to a potential source are rare, as exposures of Archean lower crust are scarce. The Neoarchean Kapuskasing uplift in the Superior Province, Canada is a crustal cross section where both mid-crustal TTGs and lower-crustal anatectic metabasites are accessible. The potential link between these rocks is tested using whole rock geochemical data, U-Pb zircon and Lu-Hf garnet geochronological data, and models of partial melt composition of the anatectic metabasites. The TTGs of the Kapuskasing uplift are divided into two groups based on trace element trends, which are reproduced in the modelled melts. However, the models predict that the two groups were produced by sources metamorphosed under different apparent thermal gradients: high *T/P* and moderate to low *T/P*. Our interpretation is that TTGs of the Kapuskasing uplift were produced in two different tectonic settings, by melting of granulite- and eclogite-facies metabasites respectively. This is supported by the geochronological record of the area, which shows that TTG emplacement was both synchronous with and prior to granulite facies metamorphism in the lower crust. U-Pb geochronology targeting the two geochemical groups is underway to shed further light on the origin of the TTGs, and more broadly the geodynamic history of the Kapuskasing uplift.

Background

The tectonic regime that generated the TTGs preserved worldwide in Archean cratons is currently disputed. Experiments and modelling indicate that partial melting of hydrated mafic crust is a suitable source for TTGs (Rapp et al. 1991; Palin et al. 2016); however, whether this mafic source was in a subduction zone (e.g. Drummond & Defant, 1990) or the lower crust (e.g. Bédard, 2006) remains unclear. The depth of melting is commonly inferred from the trace element composition of TTGs (Moyen & Martin, 2012), as important trace element reservoirs in the source — garnet, plagioclase, or rutile — have strongly pressure-dependent *P–T* stability fields. The major and trace element composition of the source also influences the composition of the TTG melt, though this is typically unknown as potential sources are scarce in the geological record. Therefore, recent modelling studies aiming to link partial melting of Archean mafic rocks to TTGs have relied on upper crustal rocks for source compositions (e.g., Johnson et al. 2017). However, possible sources may be accessed directly in rare deep crustal exposures, allowing the link to be tested more comprehensively by combining geochemical, petrological, and geochronological data from lower crustal rocks and associated TTGs.

The Neoarchean Kapuskasing uplift of the Superior Province, Canada represents a continental cross section that comprises three domains: the upper crustal Michipicoten Greenstone Belt, the mid crustal Wawa Gneiss Domain (WGD), and the lower crustal Kapuskasing Structural Zone (KSZ; Percival et al., 2012). Plutons and gneisses of TTG affinity dominate the WGD, whereas the KSZ is composed mainly of upper amphibolite to granulite facies intermediate to mafic gneisses. The WGD records a long history of igneous activity, with U–Pb zircon crystallization ages from ca. 2925 to 2645 Ma (Moser et al., 1996). Mafic granulites of the KSZ show widespread evidence of anatexis, reaching *P*–*T* conditions of 850 ± 50 °C and 1.0 ± 0.1 GPa (Hartel & Pattison, 1996; this study). U-Pb data from metamorphic zircon in granulites-facies rocks yield a geochronological record from ca. 2700 to 2580 Ma (Krogh, 1993; Benn & Kamber, 2009; Bowman et al., 2011).

Given that the KSZ is interpreted to have underlain the WGD and the overlapping U-Pb zircon record of these domains, the anatectic mafic granulites represent a potential source for the TTGs, and the present study tests this hypothesis by modelling the composition of melt produced by the granulites. Together with geochemical data from TTGs and new geochronological data from the region, the results have important implications for the geodynamic setting of the Kapuskasing uplift.

Methods

A sampling campaign was conducted from 2017 to 2019 to collect a suite of rocks from across the WGD and KSZ. TTG samples of the WGD were analyzed by XRF and ICP-MS for whole rock major and trace element compositions respectively. Phase diagrams were produced for two anatectic metabasites using the THERMOCALC software package, and the trace element composition of anatectic melt was calculated by a mass balance approach using the batch melting equation. For Lu-Hf garnet geochronology of the granulites, garnet separates and whole rock powders were dissolved and purified Lu and Hf aliquots were obtained by column chromatography; these were analyzed by MC-ICP-MS. U-Pb zircon ages will be obtained from separates of selected TTG samples using LA-ICP-MS.

Preliminary Results

Geochemical analysis of TTGs from the WGD revealed that these rocks comprise two groups (Fig. 1A, B), Group 1 (positive Sr and Eu anomalies, high Sr/Y, strong negative Nb and Ta anomaly, strongly depleted heavy rare earth elements) and Group 2 (negative Sr and Eu anomalies, low Sr/Y, weak to moderate negative Nb and Ta anomaly, weakly depleted heavy rare earth elements). Modelling of two granulites from the KSZ revealed that melt compositions similar to Group 2 may be produced along an elevated apparent thermal gradient consistent with that represented by the granulites (~850–1000 °C/GPa; Fig. 1C, D). Group 1 trace element trends are best reproduced by modelled melts in equilibrium with plagioclase-free assemblages; in the models, this is restricted to apparent thermal gradients < 500 °C/GPa (Fig. 1C, E). These results indicate that two different sources are required to produce the TTGs, eclogite (Group 1) and granulite (Group 2). Lu-Hf garnet geochronology indicates that granulite facies metamorphism and partial melting in the KSZ were underway by ca. 2685 Ma. Along with the zircon record from the KSZ, these results support the implication of the modelling that anatectic granulites of the KSZ were not the only source of the WGD TTGs.

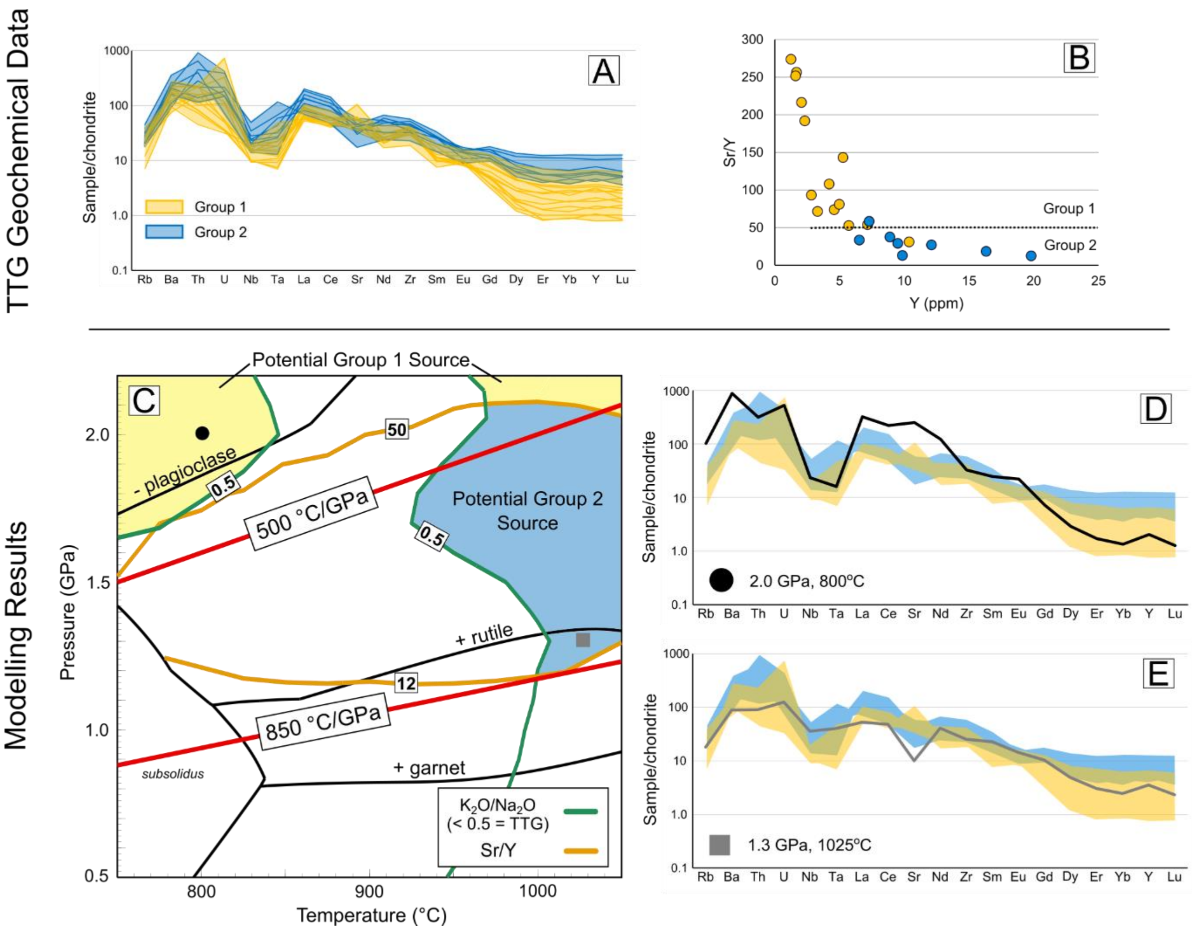

Figure 1. Geochemical data from TTG samples and results of melt composition modelling of one anatectic metabasite. A) Chondrite-normalized spider diagrams and B) Sr/Y vs.Y plot illustrating geochemical characteristics of the two groups of TTGs. C) Simplified phase diagram of one metabasite sample with contours of modelled melt K_2O/Na_2O and Sr/Y, which isolate *P*–*T* fields where the TTG groups may be reproduced by the model. D) Modelled melt composition at a single *P*–*T* point in the plagioclase-absent field, with trends resembling Group 1. E) Modelled melt composition at a single *P*–*T* point with trends resembling Group 2.

Conclusions

Two geochemically distinct groups of TTGs exist in the WGD, and their trace element trends can be reproduced by modelling the composition of melt produced by anatectic metabasites in the KSZ. The models indicate that the two groups were generated by melting of eclogite and granulite in a moderate to low *T/P* and high *T/P* thermal regime respectively. Our preliminary conclusion is that the two groups of TTGs record different tectonic processes operating in the region of the Kapuskasing uplift, likely at different times. U-Pb zircon geochronology will be used to evaluate the relative timing of emplacement of TTG group, and therefore establish a sequence of tectonic events in the Kapuskasing uplift.

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