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Origin of Mesoarchaean arc-related rocks with boninite/komatiite affinities from southern West Greenland

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ABSTRACT

We report whole-rock elemental and Sm–Nd isotope geochemical data from mafic–ultramafic supracrustal rocks from the Nunatak 1390 area in southern West Greenland. Additionally, we report the metamorphic temperature history for these rocks as derived from tourmaline thermometry on a tourmalinite inlier, as well as in situ U–Pb, Hf and O isotopic data from zircons extracted from tonalite–trondhjemite–granodiorite (TTG) gneisses that intruded the mafic–ultramafic sequence.

The supracrustal rocks from the Nunatak 1390 area have a minimum age of c. 2900 Ma defined by U–Pb zircon ages of cross-cutting aplite sheets of TTG composition. The supracrustal sequence comprises mafic rocks with pillow structures and ultramafic rocks with no evidence of their protolith. They all have amphibolite-facies mineral assemblages and a peak metamorphic temperature of approximately 550 °C. The mafic sequence has relatively flat trace element patterns (La_N/Sm_N of 0.70–2.4) and mostly negative Nb-anomalies (Nb/Nb* of 0.30–1.0) and resembles modern island arc tholeiites. The mafic sequence can be divided into a high- and low-Ti group, where the former group has lower MgO, and significantly higher contents of incompatible elements such as TiO_2, P_2O_5, Zr, Nb and Th. The ultramafic rocks have major and trace element compositions similar to Ti-enriched/Karasjok-type komatiites described in the literature. However, there are no textural indications that the ultramafic rocks from Nunatak 1390 are komatiites sensu stricto.

The low-Ti group of the mafic sequence appears to have been derived from a N-MORB source, whereas the high-Ti group and the ultramafic rocks appear to have been derived from a mantle source that is more enriched than the N-MORB source. However, there is no difference in the initial εNd of the mafic and ultramafic rocks. Additionally, assimilation–fractional–crystallisation (AFC) modelling is consistent with this enrichment being caused by introduction of juvenile low-silica adakite (slab–melt) into the mantle source region. Accordingly, we propose that the mafic and ultramafic rocks were derived from a similar type of mantle source, but that the ultramafic rocks were derived from a previously depleted mantle source that was refertilised by slab melts in a subduction zone setting. The high MgO contents of the ultramafic rocks could thus reflect a second stage of partial melting of a refractory mantle in a process similar to that which is suggested for the formation of modern boninites.

We propose that the mafic–ultramafic sequence represents an island arc that evolved initially as a juvenile complex (c. 3000 Ma). However, inherited zircon grains in aplites and Hf isotope data recorded by the second intrusive TTG phase (c. 2850–2870 Ma), show that mixing with older pre-existing crust occurred during this event. Because the regional crust is dominated by TTGs of this younger age, our data suggests that it likely formed by accretion and melting of arcs of different ages and/or contamination of juvenile arcs by pre-existing continental crust rather than entirely by juvenile arc differentiation or melting. Our data thus supports melting of thickened mafic crust in an accretionary setting, rather than direct slab melting, as a mechanism for Archaean crust formation.

1. Introduction

The interpretations of the geodynamic formation environment of Archaean supracrustal belts in southern West Greenland have thus

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far exclusively pointed to an arc-related setting (e.g. Dilek and Furnes, 2011; Friend and Nutman, 2010; Furnes et al., 2009; Garde, 2007; Hoffmann et al., 2011; Polat et al., 2002, 2008, 2010, 2011a; Szilas et al., in press-a, in press-b; Szilas et al., 2012; Windley and Garde, 2009). None of these studies have demonstrated the presence of komatiites in the Archaean supracrustal belts of southern West Greenland. Although abundant ultramafic lenses are observed within the supracrustal belts and within the TTG orthogneiss terrain, they are generally interpreted as either cumulates (Polat et al., 2011b), mantle restites (Bennett et al., 2002; Friend et al., 2002) or volcanic rocks of boninitic origin (Polat et al., 2002).

In this paper we present new data from the supracrustal rocks located on Nunatak 1390 (Fig. 1) with a focus on the geochemistry of ultramafic rocks for which a komatiite origin has previously been suggested (Scherstén and Stendal, 2008). Given that komatiites are commonly regarded as having formed in a plume-related geodynamic environment (e.g. Arndt and Nisbet, 1982; Arndt et al., 2008), their identification would apparently be in conflict with the current arc models, which is the predominate setting proposed for the origin of Archaean supracrustal rocks in southern West Greenland as mentioned above.

We explore different possible origins for the ultramafic rocks found on Nunatak 1390 and assess the implications of our interpretation for the general geodynamic environment of the Archaean supracrustal belts of southern West Greenland.

2. Regional geology

Nunatak 1390 is part of the Tasiusarsuaq Terrane (Friend and Nutman, 2001, 2005; Hollis et al., 2006; Kolb and Stendal, 2007; Næraa and Scherstén, 2008; Stendal, 2007; Stendal and Scherstén, 2007). This area is located southeast of Kangerdluarssenguup in southern West Greenland and is part of the North Atlantic Craton (Fig. 1). The Tasiusarsuaq Terrane is dominated by tonalitic gneiss and granodiorite yielding ages of 2920–2860 Ma, but mafic rocks are also present as supracrustal belts and as inclusions in the orthogneisses (Fig. 1; Crowley, 2002; Friend and Nutman, 2001; Næraa and Scherstén, 2008; Schiøtte et al., 1989). The metamorphic grade ranges from amphibolite to granulite facies conditions, with peak metamorphism dated at c. 2790 Ma (Pidgeon and Kalsbeek, 1978). The supracrustal rocks comprise pillow lavas, layered amphibolites, gabbros and ultramafic pods. The thicknesses of the mafic to ultramafic sequences vary from 5 m up to more than 1000 m.

Alteration is common within the amphibolites with calc-silicate formation within pillow lava sequences, and the presence of intercalations of 1–2 m wide rusty, sulphide-bearing layers interpreted as exhalative rocks (Stendal, 2007). Occurrences of garnet–sillimanite–biotite rocks are relatively common and likely formed by metasomatic alteration followed by metamorphism. Tourmalinite beds have also been observed and such an occurrence is described from Nunatak 1390. The Tasiusarsuaq Terrane rocks are cross-cut by brown-weathering E–W-trending dolerite dykes (up to 30 m wide) with well-developed chilled margins.

Nunatak 1390 is located at 63°42.96′N–49°16.89′ W within the Tasiusarsuaq Terrane (Fig. 1) and has previously been referred to as 'Nunatak 1390 m East of Alangordlia' by Escher and Pidgeon (1976). It comprises tonalite–trondhjemite–granodiorite (TTG) gneiss to the SE and mafic to ultramafic supracrustal rocks to the NW (Fig. 2). According to Escher and Myers (1975): '*Ultramafic sills with rhythmic igneous layering also occur within the pillow lava sequence and some pass laterally into ultramafic pillows. The pillow lavas are cut by a large number of thin, fine grained, grey dykes of intermediate composition. The dykes are irregular in thickness and in some cases interfinger with*

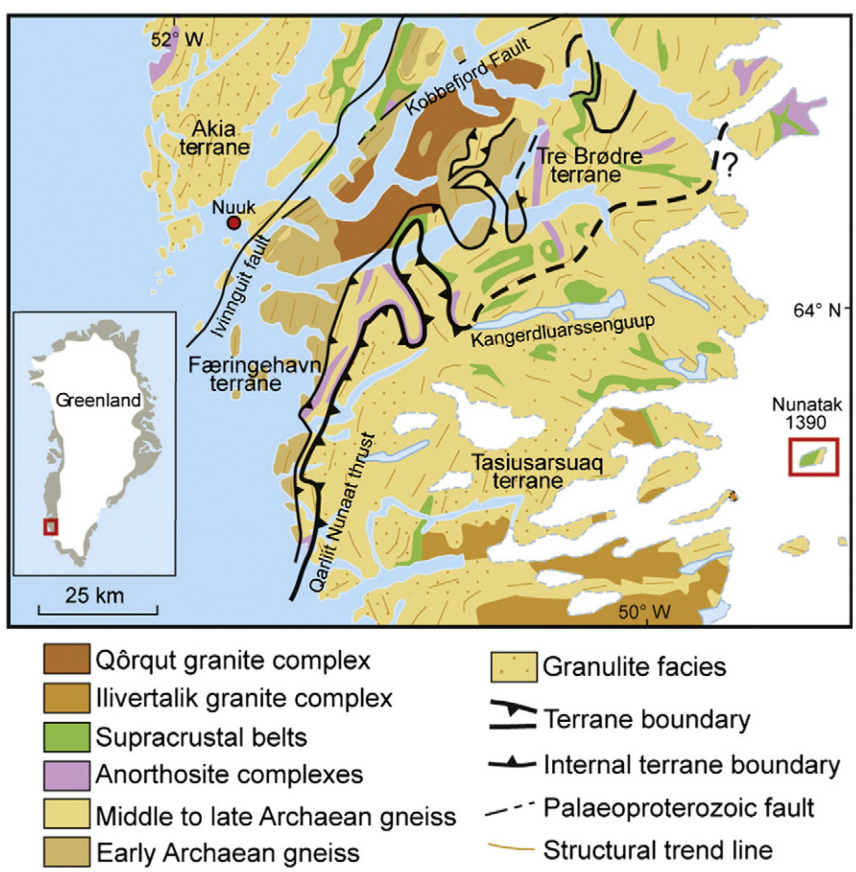

Fig. 1. Map of the Nuuk region and the Tasiusarsuaq Terrane with Nunatak 1390 marked with a red box in the east. The structural trends on the map refer to the foliation in the gneisses.