Lithos 123 (2011) 50–72

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Geochemistry of anorthositic differentiated sills in the Archean (~2970 Ma) Fiskenæsset Complex, SW Greenland: Implications for parental magma compositions, geodynamic setting, and secular heat flow in arcs

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ARTICLE INFO

Article history:
Received 20 April 2010
Accepted 2 December 2010
Available online 13 December 2010

Keywords:
Fiskenæsset Complex
Archean
Anorthosite
Trace element
Magma differentiation

ABSTRACT

The Fiskenæsset Complex, SW Greenland, is one of the best preserved layered Archean intrusions in the world, consisting of an association of ca. 550-meter-thick anorthosite, leucogabbro, gabbro, and ultramafic rocks (dunite, peridotite, pyroxenite, and hornblendite). Despite poly-phase deformation and amphibolite to granulite facies metamorphism, primary cumulate textures and igneous layering are well-preserved in the complex.

This study reports new major and trace element data for three variably thick (1 to 5 m) differentiated (dunite, through peridotite, pyroxenite, gabbro leucogabbro, to anorthosite) sequences (Sequences 1, 2 and 3) in the Sinarssuk area of the Fiskenæsset region. On several variation diagrams, samples from these sequences plot along a well-defined liquid line of descent, consistent with in situ fractional crystallization. The average chemical compositions of these sequences are used to constrain their approximate parental magma compositions. Petrographic observations and geochemical data suggest that Sequences 2 and 3 solidified from evolved magmas that underwent olivine fractionation prior to their intrusion. In contrast, Sequence 1 appears to have been derived from a near-primary parental magma (SiO_2 = 43 wt.%, MgO = 20 wt.%, Al_2O_3 = 16 wt.%, CaO = 9.3 wt.%, Ni = 840 ppm, Mg-number = 80). The trace element patterns of this parental magma are comparable to those of Phanerozoic boninites, consistent with a supra-subduction zone geodynamic setting.

If the relative thickness of ultramafic layers, the sum of dunite, peridotite and pyroxenite layers, in differentiated sequences is taken as an analog for the original complex emplaced into Archean oceanic crust, the Fiskenæsset Complex might have had a minimum thickness of 1000 m, with a 500 m thick ultramafic unit at the bottom. The thickness of the ultramafic unit in the preserved complex is less than 50 m, suggesting that more than 90% of the original ultramafic unit was either delaminated and recycled back into the mantle as a residual cumulate, or was destroyed during thrusting and TTG intrusion.

Both the Fiskenæsset Complex and associated tholeiitic basalts display similar Th–Nb–LREE patterns and plot along the same differentiation trend on Zr versus incompatible trace element diagrams, suggesting a possible petrogenetic link between the two suites of rocks. However, basalts do not display the same differentiation trend as the complex on several major and trace element diagrams. In addition, basalts and parental magma to the complex do not plot along the same fractionation line on Al_2O_3/TiO_2 versus incompatible trace element diagrams, implying that the Fiskenæsset layered intrusive rocks were not derived from tholeiitic basalts through fractional crystallization, as previously thought. Accordingly, we infer that the Fiskenæsset Complex and spatially associated basalts were derived from different mantle sources. Parental magmas to the Fiskenæsset Complex originated from a mantle source that was metasomatized by highly aluminous slab-derived melts.

Layered anorthosite complexes are mostly restricted to the Archean and typically associated with tonalite–trondhjemite–granodiorite (TTG) gneisses. The petrogenesis of both suites appears to have been controlled mainly by slab melting, endorsing independent evidence for a secular change from slab-dominated melting to wedge-dominated melting in arc magmatism at the end of the Archean, reflecting higher geothermal gradients in Archean arcs than post-Archean counterparts.

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doi:10.1016/j.lithos.2010.12.003

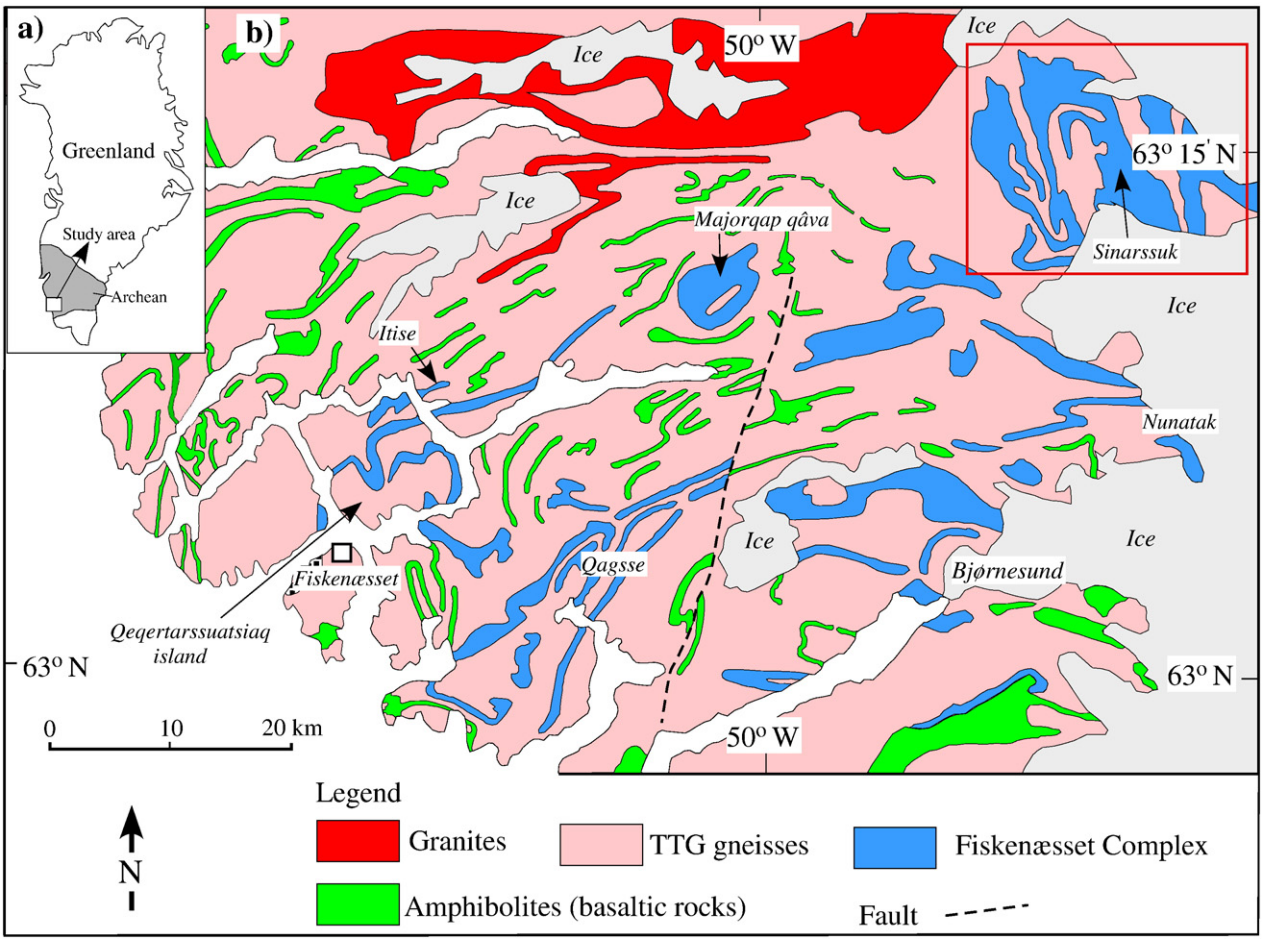

Fig. 1. (a) General location of the study area in Greenland. (b) Simplified geological map of the Fiskenæsset region, showing the distribution of TTG gneisses, Fiskenæsset Complex, amphibolites (basalts), and granites (Myers, 1976b). Red rectangle outlines the Sinarssuk area where the samples of this study came from.

1. Introduction

Archean layered anorthosite complexes are composed mainly of anorthosite, leucogabbro, gabbro and peridotite, occurring in variably deformed and metamorphosed tonalite–trondhjemite–granodiorite (TTG) gneiss complexes (Ashwal, 1993; Ashwal and Myers, 1994; Windley and Smith, 1974). These anorthosite occurrences range in age from 3.7 to 2.7 Ga (Ashwal, 1993), and are a key component of the early crust holding critical information on petrogenetic and geodynamic processes that operated in the early Earth (Ashwal, 1993; Myers, 1985; Polat et al., 2009; Windley and Smith, 1974). However, the source characteristics, petrogenesis, differentiation processes, and geodynamic setting of these anorthosite complexes have, so far, been poorly understood. Only a few high-precision trace element and isotopic studies have been conducted on Archean anorthosites and associated volcanic rocks (Ashwal and Myers, 1994; Ashwal et al., 1983, 1985, 1989; Polat et al., 2009, 2010; Weaver et al., 1981, 1982 and references therein).

Archean anorthosite complexes are best developed in SW Greenland (Ashwal, 1993; Dymek and Owens, 2001; Myers, 1985; Owens and Dymek, 1997; Windley and Garde, 2009, and references therein). The Fiskenæsset Complex contains the world's best preserved and well-exposed, Archean layered anorthosite–leucogabbro–gabbro–ultramafic rock association (Figs. 1, 2; Escher and Myers, 1975; Ghisler, 1976; Myers, 1975, 1976a,b, 1985; Windley and Smith, 1974; Windley et al., 1973). This complex occurs within a multiply-deformed amphibolite to granulite facies gneissic terrane (Fig. 1; Bridgwater et al., 1974, 1976; Myers, 1976b, 1985; Windley et al., 1973). Anorthosites, leucogabbros, gabbros, and ultramafic rocks in the

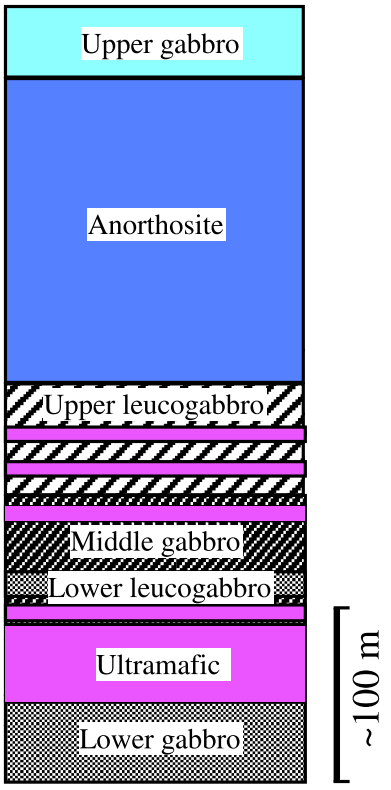

Fig. 2. Simplified stratigraphy for the Fiskenæsset Complex (modified after Myers, 1985).