Earth and Planetary Science Letters 386 (2014) 138–148

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Ferropicrite-driven reworking of the Ungava craton and the genesis of Neoarchean pyroxene-granitoids

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ARTICLE INFO

Article history:
Received 26 February 2013
Received in revised form 30 October 2013
Accepted 31 October 2013
Available online 25 November 2013
Editor: T.M. Harrison

Keywords:
Neoarchean
AFC
ferropicrite
crustal growth
charnockite

ABSTRACT

Voluminous, pyroxene-bearing, intermediate to felsic plutons were emplaced during a 20–50 million year long, spatially extensive Neoarchean igneous event that culminated in the cratonization of North America's ∼500 km-wide Ungava craton. The crystallization ages of pyroxene-bearing plutons coincide with the emplacement of numerous ca. 2.72–2.70 Ga, Fe-rich, ultramafic/mafic intrusions of the Qullinaaraaluk suite (Q-suite) that are scattered across the disparate domains of the Ungava craton. A high proportion of relatively sodic pyroxene-bearing granitoids with intermediate silica contents fall in a compositional gap between the Q-suite and pyroxene-free granitoids, suggesting that the pyroxene-granitoids may be formed by the simultaneous fractional crystallization and assimilation of older tonalitic and trondhjemitic (TT) crust by the Q-suite magmas. We estimate that pyroxene-granitoids containing ∼65 wt.% SiO_2 may reflect ∼40–50 wt.% contamination of mantle-derived picritic magma by trondhjemitic melts of the pre-2.74 Ga TTG crust. The craton-wide occurrence of the Q-suite intrusions and pyroxene-granitoids suggests that underplating by ferropicritic magmas played a key role in the cratonization of the Ungava craton at the end of Archean. A major contribution of mantle-derived magmas to the petrogenesis of the ca. 2.74–2.70 Ga pyroxene-granitoids is consistent with the proposed global generation of voluminous juvenile continental crust ca. 2.7 Ga.

1. Introduction

The Neoarchean Ungava craton (Fig. 1A) is a largely plutonic domain of the Archean Superior Province composed of the pre-2.74 Ga tonalite–trondhjemite–granodiorite (TTG), and the ⩽2.74 Ga high-K granite–granodiorite–monzogranite (GGM) and low-K pyroxene-granitoid suites (Boily et al., 2009; Maurice et al., 2009). Most of the pyroxene-granitoids and the GGM plutons of the Ungava craton were emplaced ca. 2.74–2.70 Ga, during an episode of extensive igneous activity, increased crustal contamination of mafic volcanic suites, and comprehensive reworking of the Ungava craton (Maurice et al., 2009). During this same time period, numerous, small, ultramafic to mafic intrusions (locally termed the Qullinaaraaluk, Couture, and Chateguay suites, herein collectively referred to as the Q-suite) were emplaced across the width of the craton (Simard, 2008). These intrusions commonly contain peridotitic cores inferred to have crystallized from Fe-rich, high-Mg basaltic to picritic parental magmas (MgO = 10–14 wt.%). In this paper, we present a geochemical model in which the voluminous pyroxene-granitoid suites of the Ungava craton are produced by craton-wide underplating by the mantle-derived magmas that were parental to the Q-suite. The pyroxene-granitoids are thus the mid-crustal expression of juvenile, mantle-derived magmatism that drove the reworking of the Northeastern Superior Province during a time of enhanced global formation of continental crust at ca. 2.7 Ga (Condie, 2000; Hawkesworth et al., 2009).

2. Plutonic rocks of the Ungava craton

The relatively sodic $(K/(K+Na) = 0.20 + 0.29/-0.10)$ TTG suites of the Ungava craton have positive Sr anomalies and steep REE profiles (Bédard, 2006; Boily et al., 2009; Bédard et al., 2013), characteristic of the majority of Archean TTGs (Martin, 1986; Moyen and Stevens, 2006; Moyen and Martin, 2012). Although there is a broad consensus that the geochemical signature of TTGs reflects an origin through fluid-absent partial melting of metabasite at pressures >1000 MPa where garnet is stable as a residual mineral, there are differing views regarding the geodynamic setting of Archean TTG (Moyen and Stevens, 2006; Moyen, 2011; Moyen and Martin, 2012). The end-member models call for: 1) A high pressure (2000 MPa) origin by partial melting of subducted oceanic crust, requiring geothermal gradients lower than 10 °C/km; 2) a medium pressure (1000–1500 MPa) origin, requiring geotherms of 10–12 °C; or 3) a low pressure origin (<1000 MPa) by partial melting of overthickened oceanic crust

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0012-821X/$ – see front matter
http://dx.doi.org/10.1016/j.epsl.2013.10.051

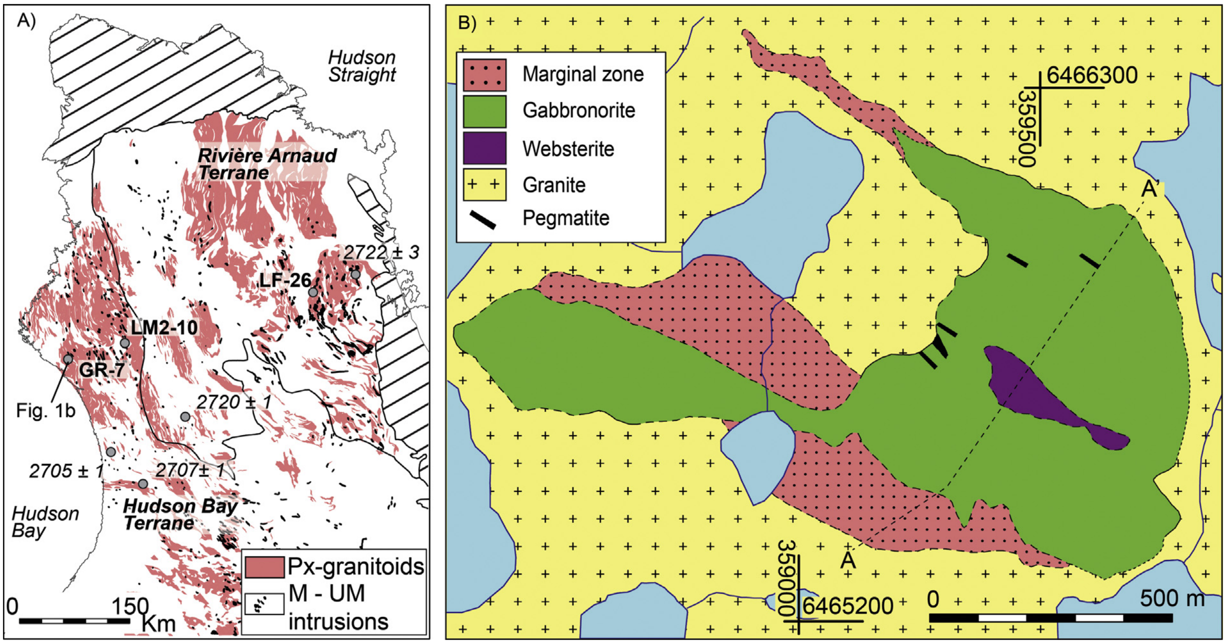

Fig. 1. A) Map of the Ungava craton showing the distribution of the pyroxene-granitoids and the mafic/ultramafic intrusive rocks, adapted from Simard (2008). Grey circles – previously dated MRNF Q-suite samples (ages shown) and samples dated in this study (bold labels). Location of map in Fig. 1B is shown for reference. **B)** Geological map of the Gladel River intrusion, and the location of transect A–A′ shown in Fig. 5.

or underplated hydrous basalt, requiring steep geothermal gradients of 20–30 °C/km. In contrast to the TTG suite, the granitoids of the GGM suite are significantly more potassic ($K/(K+Na) = 0.40 + 0.18/-0.30$) and show stronger enrichments in the light rare-earth (LREE) and large ion lithophile (LILE) elements. Isotopic and geochemical data indicate that partial melting of the pre-existing TTG in the middle-upper crust is the dominant process for the genesis of the GGM suite (Bédard, 2006; Boily et al., 2009; Huang et al., 2013).

Plutonic suites containing primary magmatic pyroxene were initially recognized in the Ungava by Percival et al. (1992). Such rocks have subsequently been referred to as charnockites (Percival and Mortensen, 2002; Frost and Frost, 2008), enderbites and clinopyroxene-tonalites (Bédard, 2003), or more simply pyroxene-granitoids (Boily and Maurice, 2008) or pyroxene-TTGs (Boily et al., 2009). The pyroxene-granitoid rocks range in composition from diorite to granite ($SiO_2 \geqslant 50$–78 wt.%), and are a volumetrically significant component of the Ungava craton, accounting for more than 20% of its exposed surface (Fig. 1A; Simard, 2008; Maurice et al., 2009).

The pyroxene-granitoids were emplaced at mid-crustal pressures (500 ± 100 MPa) at high temperatures (1100–810 °C), and subsequently underwent prolonged cooling during which subsolidus mineral re-equilibration and hydration occurred (Percival and Mortensen, 2002; Bédard, 2003). The pyroxene-granitoids have a wide range of SiO_2 contents that are positively correlated with light rare-earth element/heavy rare-earth element (LREE/HREE) ratios (Boily and Maurice, 2008). In contrast to the GGM and TTG suites, the pyroxene-granitoid suite includes a significant proportion (37%) of rocks with intermediate SiO_2 (<65 wt.%) contents (Fig. 2). Pyroxene-granitoids with intermediate SiO_2 are characterized by relatively uniform Y + HREE contents ($Yb_{MORB} = 0.5 + 0.4/-0.3$; $Gd/Yb_{MORB} = 3 + 3/-1$) and La/Yb_{MORB} (<80) ratios that in most cases fall outside the range of Archean TTGs (Martin, 1986; Moyen and Martin, 2012), suggesting that garnet did not have a significant role in their petrogenesis. Furthermore, the Mg-numbers (0.45 ± 0.15; defined as $Mg/(Mg + Fe)$) of the intermediate-SiO_2 pyroxene-granitoids are lower than those of the globally widespread late Archean high-Mg sanukitoids (Shirey and Hanson, 1984; Martin et al., 2005; Rapp et al., 2010). The felsic pyroxene-granitoids ($SiO_2 > 65$ wt.%) exhibit a systematic decrease in Y + HREE concentration and a concomitant increase in REE fractionation with increasing SiO_2 content.

The majority of the Ungava pyroxene-granitoids are relatively sodic ($K/(K+Na) = 0.22 + 0.32/-0.12$) and geochemically similar to deep plutons formed in Phanerozoic magmatic arcs (Percival and Mortensen, 2002; Boily and Maurice, 2008; Frost and Frost, 2008). This similarity has led to the development of plate tectonic models that argue for their evolution in a supra-subduction zone environment during the docking and assembly of the NNE–SSW trending domains that make up the Ungava craton (Stern et al., 1994; Percival et al., 2001; Percival and Mortensen, 2002). Percival and Mortensen (2002) originally proposed a model in which dry (<2 wt.% H_2O), mantle-derived, dioritic parental liquids evolved through early crystallization of pyroxenes, plagioclase, and biotite to form the intermediate-SiO_2 compositions of the pyroxene-granitoids. Percival and Mortensen (2002) argued that the fusion of a hot Neoarchean mantle wedge would generate voluminous, water-undersaturated melts that would evolve to dioritic compositions through the assimilation (10–20%) of mid-lower felsic crust. Implicit in this model is the existence of a number of simultaneously active subduction zones in order to generate voluminous, coeval pyroxene-granitoids across the Ungava craton, and the dominant role of fractional crystallization in producing the compositional spectrum of the pyroxene-granitoid suites.

More recent studies (Bédard, 2003; Boily et al., 2009; Maurice et al., 2009) have argued against a plate tectonic model for the development of the Ungava craton. The identification of isotopically-distinct Rivière Arnaud and Hudson Bay terranes (Fig. 1A; Boily et al., 2009) and greenstone belts that once formed a laterally continuous ca. 2.78 Ga volcanic cover sequence on the Rivière Arnaud terrane (Maurice et al., 2009) provide a compelling argument against a major episode of arc assembly ca. 2.74–2.70 Ga. A tectonic model presented by Maurice et al. (2009), suggests the amalgamation of Rivière Arnaud and Hudson Bay terranes between 2.76 and 2.74 Ga, and subsequent large-scale melting of the proto-craton ca. 2.74–2.70 Ga. Furthermore, the presence of widespread