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Age and tectonic implications of Paleoproterozoic mafic dyke swarms for the origin of 2.2 Ga enriched lithosphere beneath the Ungava Peninsula, Canada

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ABSTRACT

Mafic dyke swarms represent short-lived magmatic events that carry important temporal and chemical constraints for the evolution of the lithospheric mantle. Five baddeleyite U–Pb isotopic analyses of Paleoproterozoic mafic dyke swarms intruding the Ungava Peninsula yielded ages of 2508 ± 6, 2220 ± 1, 2212 ± 3, 2199 ± 5 and 2149 ± 3 Ma. These ages fall within the 2.5–2.0 Ga period previously defined by five other swarms, which together comprise a magmatic record of more than 500 Ma. The similar age, composition and surface area of two 2.51 Ga swarms, along with the lack of coeval supracrustal rocks, suggest they correspond to failed rifts. An important magmatic hiatus of 280 Ma follows, but ends with the intrusion of numerous dykes between 2.23 and 2.20 Ga in the thinnest lithosphere of the northern Ungava Peninsula. These dykes exhibit chemical signatures that vary from enriched older 2229–2212 Ma dykes ($\varepsilon Nd_{(t)} < +0.4$, La/Yb > 4) to relatively depleted 2209–2199 Ma voluminous younger dykes ($\varepsilon Nd_{(t)} > +1.4$, La/Yb < 4). The depleted character, great volume, and occurrence of these younger dykes in a thin lithosphere may represent decompression melting of the asthenosphere, following delamination of the Archean lithospheric keel *ca.* 2.21–2.20 Ga. Later dykes emplaced *ca.* 2.17 Ga within a rejuvenated Paleoproterozoic lithosphere also have depleted chemical compositions, and map the extent of rifting coeval with the emplacement of early basalts in the Labrador Trough. Dykes emplaced in the 2.15–2.00 Ga period further to the South are proximal to coeval continental basalts, with which they share enriched isotopic compositions ($\varepsilon Nd_{(t)} = -1.5$ to -7) and a positive correlation between La/Yb and Zr/Nb (La/Yb = 4–10; Zr/Nb = 7–20) that suggest assimilation of an Archean crustal component. A progressive decrease in the $\varepsilon Nd_{(t)}$ values of these magmas with decreasing age further implies increasing contamination, until the Archean lithosphere failed *ca.* 2.0 Ga and permitted the eruption of isotopically depleted basalts.

The *ca.* 2.2 Ga depleted northern dykes and the 2.1–1.9 Ga Povungnituk basalts of the Cape Smith foldbelt share a negative correlation between Zr/Nb and La/Yb that is expected for the incorporation of an enriched lithospheric component. This component is represented by the alkaline rocks comprised in the Circum-Ungava supracrustal belts (carbonatites, lamprophyric lavas, alkaline basalts) and by the Lac Aigneau lamprophyric dykes (1941 ± 3 Ma) intruding the Ungava Peninsula. These alkaline magmas collectively have 2.2–2.1 Ga depleted-mantle Nd model ages (T_{DM}) similar to a 2.15 Ga Sm–Nd isochron defined by the basaltic rocks of the supracrustal belts. Although these Nd T_{DM} ages and isochron are 100–300 Ma older than magmatic ages, they are identical with the *ca.* 2.2 Ga mafic dykes of the Ungava Peninsula. This time correlation, along with the similar chemical signature of the northern dykes and younger Povungnituk basalts, suggest that the composition of younger lavas and alkaline magmas was influenced by an enriched component associated with the pervasive metasomatism of the lithosphere, coeval with the emplacement of the many *ca.* 2.2 Ga dykes.

1. Introduction

Mafic dyke swarms can be traced back in time to the Archean-Proterozoic transition (*ca.* 2.5 Ga), and reflect magmatic events that are common to all Archean cratons. Genetic models for their origin have focused largely on their geographic patterns (Fahrig, 1987; Ernst et al., 1995), the loci of giant radiating swarms being interpreted by many as the sites of rising mantle plumes (LeCheminant and Heaman, 1989; Ernst and Buchan, 2001a), whereas other workers interpret these patterns to reflect lithospheric stresses due to plate tectonic activity (McHone et al., 2005). Because they appear to have been emplaced rapidly over large regions, mafic dyke

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swarms are also believed to be ideal markers with which to constrain regional stress fields and track the timing of supercontinent fragmentation (Bleeker and Ernst, 2006). Recent investigations, however, support an important role for pre-existing lithospheric weaknesses in controlling dyke emplacement (Jourdan et al., 2004; Mège and Korme, 2004), as a large range of magmatic ages are found within apparent individual dyke swarms (French et al., 2004; Jourdan et al., 2006).

Over the past decades, studies of the Superior Province of Canada have produced many insights into the timing and extent of the numerous Paleoproterozoic mafic dyke swarms intruding the craton (Fig. 1, see compilation by Buchan and Ernst, 2004). Although some geochronological work (Buchan et al., 1998) has been carried out on mafic dykes of the Northeastern Superior Province of the Ungava Peninsula, recent geological mapping of this area has increased our knowledge, and resulted in the recognition of a number of previously unknown dyke swarms. An appraisal of their distribution, age and chemical signatures provide insights for the possible tectonic environments in which they were intruded. These mafic dykes also convey key information with which to constrain the chemical evolution of the lithospheric mantle between *ca.* 2.5 and 2.0 Ga, a period which saw the emplacement of both mafic dykes and mobile belts surrounding the Ungava Peninsula.

This paper presents six new U–Pb ages, and thirty-nine neodymium isotopic determinations acquired on Paleoproterozoic mafic and lamprophyric dykes of the Ungava Peninsula. The U–Pb results give new insights into the breakup of the Superior Province, document an important Paleoproterozoic event that led to the emplacement of numerous dyke swarms with differing trends *ca.* 2.2 Ga, and have important implications for the secular evolution of its underlying mantle. We show that the Nd isotopic composition of the *ca.* 2.0–1.9 Ga volcanic and alkaline rocks of the Circum-Ungava mobile belts requires an enriched component whose age is coeval with the voluminous mafic dykes emplaced *ca.* 2.2 Ga. We propose that the remobilization of a metasomatized mantle, perhaps emplaced coevally with the delamination of the lithospheric mantle, controlled the composition of the more recent Paleoproterozoic magmas.

2. Geological background

2.1. Archean Northeastern Superior Province

Little knowledge about the interior of the Ungava Peninsula was gained after the pioneering work of Stevenson (1968), until regional mapping programs of the Northeastern Superior Province by the Geological Survey of Canada (Percival et al., 1997 and references therein) and the *Ministère des Ressources naturelles et de la Faune* of Québec (Simard, 2008 and references therein). Its magmatic and metamorphic evolution spans more than a billion years (3.8–2.6 Ga), as defined by over 200 U–Pb ages (see compilation in Simard, 2008), and it is comprised dominantly of Neoarchean plutonic suites, in which amphibolite- to granulite-grade greenstone belts occur as thin keels (1–10 km). The Northeastern Superior Province is separated into two isotopically distinct regional terranes; to the East, the Rivière Arnaud Terrane (RAT) groups Archean rocks having juvenile isotopic signatures (depleted mantle model ages—T_{DM} < 3.0 Ga), while to the West, the Hudson Bay Terrane (HBT) is the remnant of a reworked Meso- to Paleoarchean craton, with Nd model ages as old as 3.8–4.3 Ga (O'Neil et al., 2008; Boily et al., 2009).

2.2. Paleoproterozoic volcano-sedimentary belts

Paleoproterozoic supracrustal belts emplaced during the Trans-Hudson Orogeny (Lewry and Collerson, 1990) surround the Archean rocks of the Northeastern Superior Province (the 'Circum-Ungava geosyncline' of Dimroth et al., 1970, Figs. 2 and 3). These belts include the Labrador Trough (New Québec Orogen) to the East, the Cape Smith Foldbelt (Ungava Trough) to the North, and the Belcher Islands and associated coastal continental basalts (the Richmond Gulf and Nastapoka groups), to the West.

The supracrustal rocks of the Labrador Trough formed between *ca.* 2.17 and 1.80 Ga in three volcano-sedimentary depositional episodes (Clark and Wares, 2006, Fig. 3). The age of the first cycle is constrained by a *ca.* 2.17 Ga basal basalt unit (#1, Fig. 3), with deposition continuing to *ca.* 2.14 Ga (crosscutting felsic granophyre, #2, Fig. 3), and possibly as recently as *ca.* 2.06 Ga (#3, Fig. 3, Clark and Wares, 2006). The second depositional episode includes a platform sequence composed of sandstones, iron formation, turbidite and basalts lying uncomformably on both the Archean craton and the first depositional cycle. Its age is constrained by gabbroic sills (*ca.* 1.88 Ga), the Lac Lemoyne carbonatite (<1.87 Ga), and the Lac Castignon lamprophyre (*ca.* 1.88 Ga #4, Fig. 3). The third depositional episode is interpreted to have occurred *ca.* 1.80 Ga and produced synorogenic foredeep sediments (Hoffman, 1987).

The E–W striking Cape Smith foldbelt is interpreted as the foreland thrust-belt of the Ungava Orogen, and contains volcano-sedimentary rocks deposited after the rifting of the Superior craton (Hynes and Francis, 1982; Lamothe, 1994). An older depositional episode comprises the Povungnituk Group in the South, which is divided into a sedimentary and a volcanic sequence (Fig. 3). The volcanics are dominated by flat to light REE-enriched tholeiitic basalts that lack the negative Nb–Ta anomalies typical to continental flood basalts (Modeland et al., 2003), and a small volume of alkaline basalt that occurs near Kenty Lake (Gaonac'h et al., 1992). A gabbroic sill intruding the sedimentary rocks near the base of this group sets the beginning of the rifting event before 2.04 Ga (#5, Fig. 3), while the age of a rhyolite located within the upper part of the volcanic sequence indicates that deposition in the Povungnituk Group continued to *ca.* 1.96 Ga (#6, Fig. 3). The next magmatic episode is comprised of light REE-depleted picritic to tholeiitic basalts of the overlying Chukotat Group (Francis et al., 1983) that are coeval with the second depositional cycle of the Labrador Trough (Fig. 3). The age of this group is constrained by comagmatic sills near the base (1.92 Ga) and top (1.88 Ga) of the sequence (#7 and #8, Fig. 3). Further to the North, the Watts Group comprises a dismembered suite of oceanic rocks including layered mafic to ultramafic rocks, basalts, and minor sedimentary rocks that has been dated at *ca.* 2.00 Ga (#9, Fig. 3).

Paleoproterozoic volcano-sedimentary rocks also outcrop in the western part of the Ungava Peninsula, on the Ottawa and Belcher islands, and along the eastern shore of Hudson Bay. The coastal basalts of the Richmond Gulf and Nastapoka groups lie uncomformably on the Archean basement (Chandler, 1988). Isotopic analyses made on diagenetic apatite grains in a sandstone unit at the base of the Richmond Gulf Group yielded an age of 2.03 ± 0.03 Ga (#10, Fig. 3). To the West, the Belcher Islands expose continental and shallow water marine sedimentary sequences which contain two intercalated continental basalt units (the Eskimo and Flaherty formations) whose ages are not well established (Ricketts and Donaldson, 1981; Legault et al., 1994). A Pb–Pb isochron from samples taken at the base of the Flaherty flows defines an imprecise age of 1.96 ± 0.08 Ga (#11, Fig. 3).

2.3. Alkaline rocks

The 2.04–1.88 Ga Circum-Ungava supracrustal belts host a wide variety of alkaline rocks (Fig. 2), including alkaline basalts near Kenty Lake (*ca.* 1.96 Ga, Gaonac'h et al., 1992; Modeland et al., 2003), carbonatites near Lac Lemoyne (<1.87 Ga, Wright et al., 1999), and ultramafic lamprophyres near Lac Castignon (*ca.* 1.88 Ga, Chevé and