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Age and evolution of the deep continental root beneath the central Rae craton, northern Canada

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ABSTRACT

Canada is host to at least six separate cratons that comprise a significant proportion of its crustal extent. Of these cratons, we possess knowledge of the cratonic lithospheric roots beneath only the Slave craton and, to a lesser extent, the Superior craton, despite the discovery of many new diamond-bearing kimberlites in Canada's North. Here we present the first age, composition and geothermal information for kimberlite-borne peridotite xenoliths from two localities within the central Rae craton: Pelly Bay and Repulse Bay. Our aim is to investigate the nature and evolution of the deep lithosphere in these regions and to examine how events recorded in the mantle may or may not correlate with the complex history of crustal evolution across the craton.

Peridotite xenoliths are commonly altered by secondary processes including serpentinization, silicification and carbonation, which have variably affected the major element compositions. These secondary processes, as well as mantle metasomatism recorded in pristine silicate minerals, however, did not significantly modify the relative compositions of platinum-group elements (PGE) and Os isotope ratios in the majority of our samples from Pelly Bay and Repulse Bay, as indicated by the generally high absolute PGE concentrations and mantle-like melt-depleted PGE patterns. The observed PGE signatures are consistent with the low bulk Al_2O_3 contents (mostly lower than 2.5%) of the peridotites, as well as the compositions of the silicate and oxide minerals. Based on PGE patterns and Os model ages, the peridotites from both localities can be categorized into three age groups: Archean (3.0–2.6 Ga overall; 2.8–2.6 Ga for Pelly Bay and 3.0–2.7 Ga for Repulse Bay), Paleoproterozoic (2.1–1.7 Ga), and "Recent" (<1 Ga, with model ages similar to the ca. 546 Ma kimberlite eruption age). The Archean group provides the first direct evidence of depleted Archean lithospheric mantle forming coevally with the overlying Archean crustal basement, indicating cratonization of the Rae during the Archean. The subtle difference in Os model ages between Pelly Bay and Repulse Bay coincides with the age difference between crustal basement rocks beneath these two areas, supporting the suggestion that the Rae craton was assembled by collision of separate two Archean blocks at 2.7–2.6 Ga. The Paleoproterozoic peridotites are interpreted to represent newly formed lithospheric mantle, most likely associated with regional-scale underplating during the 1.77–1.70 Ga Kivalliq-Nueltin event via removal of the lower portion of Archean lithospheric mantle followed by replacement with juvenile Paleoproterozoic lithospheric mantle. The existence of multiple age clusters in the lithosphere at each locality is consistent with the observation of present-day seismic lithospheric discontinuities (Snyder et al., 2013, 2015) that indicate two or more layers of fossil lithospheric mantle fabric beneath this region. Our data define a shallow mantle lithosphere layer dominated by Archean depletion ages underlain by a layer of mixed Archean and Paleoproterozoic ages. This lithospheric mantle structure is probably a response to complex tectonic displacement of portions of the lithospheric mantle during Paleoproterozoic orogeny/underplating. The best equilibrated Archean and

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Paleoproterozoic peridotites at both Pelly Bay and Repulse Bay define a typical cratonic geotherm at the time of kimberlite eruption, with a ∼200 km thick lithospheric root extending well into the diamond stability field, in keeping with the diamondiferous nature of the kimberlites. Such thick lithosphere remains in place to the present day as suggested by seismic and magnetotelluric studies (Snyder et al., 2013, 2015; Spratt et al., 2014). The metasomatically disturbed peridotites in the Rae lithospheric mantle, yielding model ages indistinguishable from kimberlite eruption, may represent parts of the Rae craton mantle root that show anomalous magnetotelluric signatures.

1. Introduction

Continental-scale tectonic and evolutionary histories typically are constructed based upon bedrock mapping and petrographic, geochemical and geochronological studies of crustal rocks from the uppermost part of the lithosphere. Characterization of the deep roots of the continental lithosphere – the lithospheric mantle section – predominantly is inferred from seismic and magnetotelluric data that provide a snapshot of the present-day structure. Given that the cratonic lithospheric mantle is composed of peridotite with minor eclogite and pyroxenite, all showing similar geophysical properties (Kopylova et al., 2004), seismic data can generally best be applied to map large-scale, tectonic boundaries, such as sutures or plate boundaries at the present day (e.g., Snyder et al., 2013). Since mantle electrical conductivity is a function of a variety of factors including temperature, contents of volatiles and melts/fluids, and oxygen fugacity (e.g., Schock et al., 1989; Karato, 1990; Constable et al., 1992; Duba and Constable, 1993), magnetotelluric studies can also reveal the large-scale features of the mantle (e.g., Lizarralde et al., 1995). Yet, determination of the age, composition, structure and evolution of the cratonic lithospheric mantle is commonly derived from direct sampling by mantle xenoliths and xenocrysts brought to the surface by kimberlite eruptions (see review in Pearson et al., 2014). The xenolith-based picture of the mantle root is taken when the kimberlite erupts, and, hence, the seismic/magnetotelluric and xenolith-based studies may provide critical complementary data that reveal the recent evolution of the lithospheric root (e.g., Liu et al., 2011; Mather et al., 2011).

Although the lithospheric mantle is well documented beneath the Slave craton (e.g., Griffin et al., 1999; Aulbach et al., 2004, 2011; Heaman and Pearson, 2010) and to a lesser extent beneath the Superior craton (e.g., Pearson et al., 1997; Scully et al., 2004; Smit et al., 2014), little is known about the deep continental roots beneath significant portions of Canada's vast North, despite the discovery of many new diamond-bearing kimberlites. In this paper, we report the first age, composition and geothermal information for kimberlite-borne peridotite xenoliths from two localities that sample lithospheric mantle beneath the central Rae craton of the western Churchill Province: Pelly Bay and Repulse Bay (Fig. 1). The combined new data allows us to constrain the nature of the lithospheric mantle beneath these regions. Along with recently published seismic and magnetotelluric studies, our new results are applied to understanding the formation and evolution of the cratonic lithosphere and investigating the influence of orogenic/plutonic events recorded in the crust. The study also provides new context for understanding diamond mineralization and destruction in the Rae cratonic mantle root.

2. Geological setting and samples

Located in the western part of the Churchill province, one of the largest Precambrian crustal blocks that constitute the Canadian Shield (Fig. 1), the Rae craton is predominantly composed of Meso- to Neoarchean amphibolite- to granulite-grade granitoid gneisses and komatiite-bearing greenstone belts (e.g., Jackson, 1966; Frisch, 1982; Fraser, 1988; MacHattie, 2008; Peterson et al., 2010; Wodicka et al., 2011; Pehrsson et al., 2013; LaFlamme et al., 2014; Sanborn-Barrie et al., 2014). Similar Meso- to Neoarchean formation ages are also recorded in the lower crustal xenoliths (Petts et al., 2014a). Of note in the Archean supracrustal packages that comprise the Rae craton is the presence of mafic volcanic rocks, including komatiite, that suggesting a thin lithosphere that allowed extensive adiabatic melting at 2.97 Ga (Richan et al., 2015) and at 2.74–2.70 Ga (Skulski et al., 2003). The Rae craton was intruded by widespread ca. 2.6 Ga granitoid plutons (Hinchey et al., 2011 and references therein), while the western Rae craton was subsequently also impacted by the ca. 2.5 Ga Queen Maud granite event (Fig. 1; Schultz et al., 2007; Berman et al., 2013a).

Since its stabilization, the Rae craton experienced widespread circum-craton subduction and collisional accretion through the Neoarchean to Paleoproterozoic, as manifested by at least seven major events discernable within the crust (Fig. 1) including in time sequence: (1) the ca. 2.7–2.6 Ga amalgamation of the Chesterfield block along the southern margin (Davis et al., 2006); (2) the ca. 2.56–2.50 Ga MacQuoid orogeny along the south-eastern margin (Berman, 2010; Pehrsson et al., 2013); (3) the ca. 2.5–2.3 Ga Arrowsmith orogeny along the western margin (Berman et al., 2005, 2013a); (4) the ca. 2.0–1.92 Ga Taltson–Thelon orogeny along the western margin (e.g., Hoffman, 1988; Hanmer et al., 1992); (5) the ca. 1.92–1.90 Ga Snowbird orogeny and the accretion of the Hearne craton along the southern margin (Berman et al., 2007; Martel et al., 2008); (6) the ca. 1.87 Ga collision of the Meta Incognita–Sugluk–Hall Peninsula block (MISH) in the northeast (e.g., St-Onge et al., 2006a; Berman et al., 2010); and (7) the ca. 1.82 Ga collision with the Superior craton in the south-southeastern margin during the ca. 1.9–1.8 Ga Trans-Hudson orogeny (e.g., Ansdell and Norman, 1995; Stern et al., 1995; St-Onge et al., 2006b). These orogenic events involved multiple tectonometamorphic episodes that impacted the Rae craton, forming associated metamorphic and plutonic rocks (e.g., the 1.85–1.81 Ga Hudson granitic plutons; Fig. 1). In addition, there is evidence for extensive crustal reworking through the Paleoproterozoic, culminating at ca. 1.77–1.70 Ca with widespread post-orogenic granitic magmatism – the Kivalliq-Nueltin event (Peterson et al., 2015) – considered to reflect major basaltic underplating (Peterson et al., 2002, 2015; Petts et al., 2014a).

Kimberlite eruptions pierced the thick lithosphere of the central Rae craton in late Neoproterozoic times, transporting deep-seated crustal and lithospheric mantle xenoliths along with diamonds. The peridotite xenoliths studied here are from the kimberlite fields south of Pelly Bay (Amaruk, $n = 18$; N68°10′41.9″ W90°37′12.5″) and north-northeast of Repulse Bay (Qilalugaq, $n = 31$; N66°35′28.5″ W86°07′53.7″; Fig. 1). Both kimberlite clusters have been dated to be ca. 546 Ma (Scully, 2004; Kienlen et al., 2008; Kupsch and Armstrong, 2013). The Amaruk kimberlite cluster at Pelly Bay contains 22 kimberlite bodies (Kienlen et al., 2008) intruding Rae basement affected by the Boothia uplift