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Age and evolution of the lower crust beneath the western Churchill Province: U–Pb zircon geochronology of kimberlite-hosted granulite xenoliths, Nunavut, Canada

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ABSTRACT

Zircon from granulite-facies xenoliths can preserve unique geodynamic records of deep and mostly inaccessible levels of the continental crust within Archean cratons. We present the first such records from beneath two Archean crustal blocks that were affected by multiple episodes of regional-scale Proterozoic metamorphism, and are located within the western Churchill Province, Nunavut, Canada. Zircon U–Pb geochronology and trace element analysis were carried out on samples that originated in the deep crust at the time of kimberlite eruption, as confirmed with Raman spectroscopy. Zircon was recovered from four metabasites (grt–cpx–plg) from the Rankin Inlet area of the Chesterfield block, and five metabasites (grt–cpx–plg ± hbl ± opx) and three metatonalite/anorthosites (plg–cpx–plg ± hbl ± opx) from the Repulse Bay area of the Rae craton. SEM-CL imaging reveals several types of growth zoning diagnostic of igneous and metamorphic zircon crystallization. The latter are related to local high-temperature recrystallization and micro-fracturing, and are spatially associated with zones of apparent Pb-loss and/or intracrystalline Pb-variability. Evidence for the formation of Paleoarchean/Mesoarchean to Neoarchean crust is preserved in oscillatory zoned, igneous cores having $^{207}Pb/^{206}Pb$ ages of ca. 3.5 Ga and ca. 3.0–2.6 Ga. Two periods of Paleoproterozoic metamorphism and zircon growth followed, with the oldest episode at ca. 2.0–1.9 Ga in the Chesterfield block. Metamorphic zircon rims from all twelve xenoliths have an age range of ca. 1.75 to 1.70 Ga. The trace element compositions of the metamorphic rims differ from those of older igneous and metamorphic cores, with the rims characterized by lower ΣHREE contents and low $(Lu/Gd)_N$, suggesting that garnet crystallization occurred syn- to pre-rim growth at ca. 1.75 Ga. The Archean and Paleoproterozoic ages correspond broadly to the upper crustal histories of the western Churchill Province; however, the prevalence of ca. 1.75–1.70 Ga metamorphic rims indicates regional-scale metamorphic reworking of the lower crust across the region, during a period of intracratonic extension and associated magmatism. Regional magmatic underplating and/or remobilization of the lithosphere at ca. 1.75–1.70 Ga, to an extent not widely appreciated, represents a terminal stage in western Churchill cratonization, including stabilization of reworked Archean crust relative to underlying diamondiferous mantle.

1. Introduction

U–Pb geochronology of zircon obtained from kimberlite-derived lower crustal xenoliths can yield unique age and petrogenetic information about the deep continental crust beneath Archean cratons. Owing to very sluggish ionic diffusion rates (Cherniak and Watson, 2003), it is possible to characterize multiple tectonothermal events spanning the entire history of continental crust formation. This has been documented in samples of the lower crust from the Slave and Superior cratons of the Canadian Shield (Davis, 1997; Moser and Heaman, 1997; Davis et al., 2003; Moser et al., 2008; Bowman et al., 2011; Zartman et al., 2013), the Kaapvaal craton of South Africa (Schmitz and Bowring, 2000; Moser et al., 2009), the McBride Volcanic Province, north Queensland, Australia (Rudnick and Williams, 1987), and the Siberian craton of Russia (Koreshkova et al., 2009). Information retained in such zircons include ages of initial craton formation (Davis, 1997; Davis et al., 2003; Moser et al., 2008), of reworking along the crust-mantle boundary and subsequent tectonothermal activity (Rudnick and Williams, 1987; Davis, 1997; Moser and Heaman, 1997; Schmitz and Bowring, 2000), and of deep crustal metasomatism (Bowman et al., 2011).

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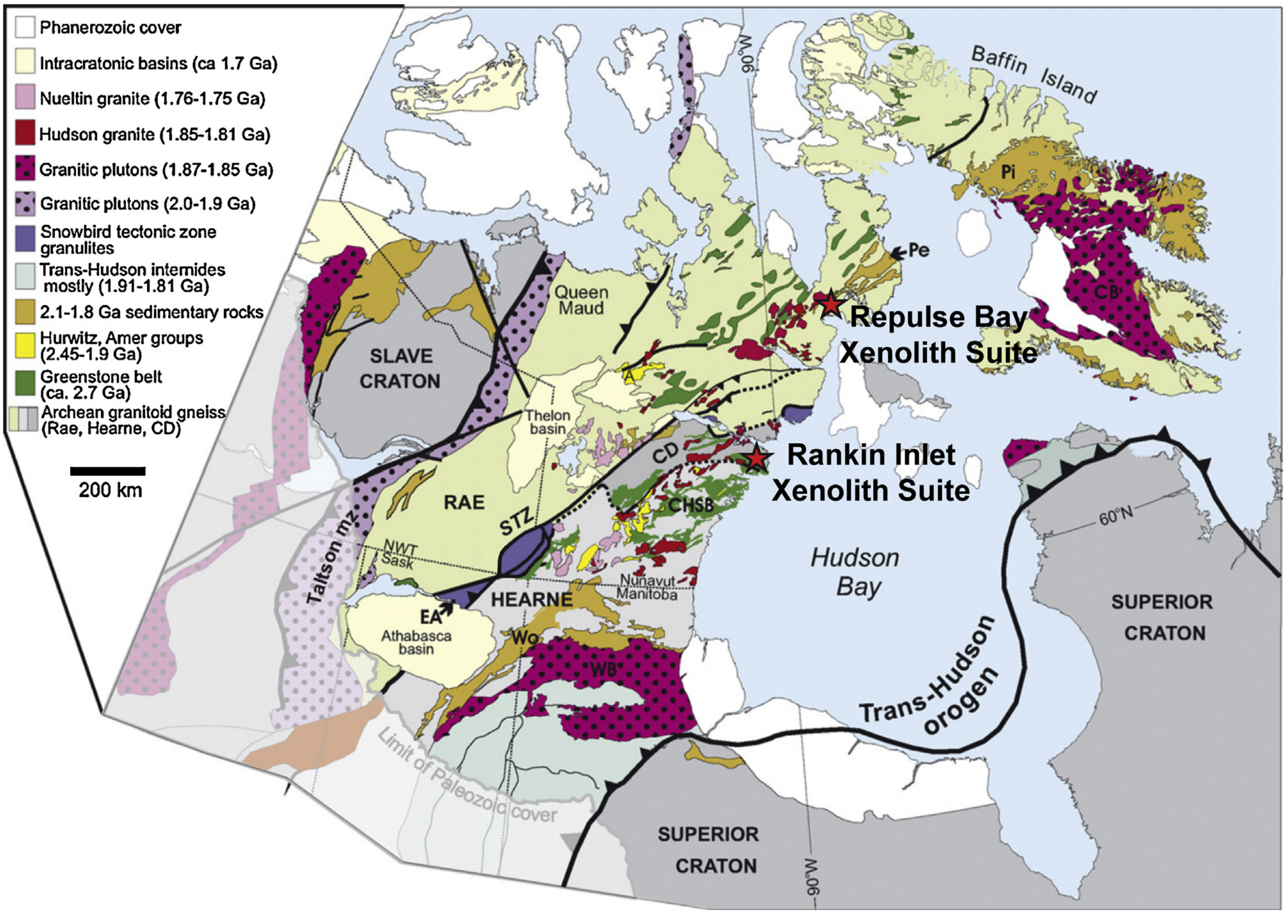

Fig. 1. Geological map of the western Churchill Province showing locations of the Rankin Inlet and Repulse Bay lower crustal xenolith suites (after Berman et al., 2005). Abbreviations, CB—Cumberland batholith, CD—Chesterfield block, CHSB—central Hearne supracrustal belt, EA—east Athabasca mylonite zone, NWT—Northwest Territories, Pe—Pehnryn group, Pi—Piling group, STZ—Snowbird Tectonic Zone, WB—Wathaman batholith, Wo—Wollaston group.

The western Churchill Province of northern Canada (Fig. 1) is one of the largest Archean cratonic blocks within the Canadian Shield. It is composed mostly of Archean gneissic plutonic rocks and volcanic-sedimentary supracrustal rocks, which were overlain by younger Paleoproterozoic sedimentary sequences, prior to being reworked during the Paleoproterozoic Arrowsmith, Taltson–Thelon and Trans-Hudson Orogenies (Hanmer et al., 1995). Vestiges of Hadean geologic history include a 4043 ± 10 Ma inherited zircon within the ca. 2.67 Ga Super Mario granite (Martel et al., 2008). Large-scale plutonic and volcanic crust forming events at ca. 2.75–2.60 Ga (Zaleski et al., 2000; Skulski et al., 2003; Davis et al., 2004, 2006), were followed by multiple episodes of orogenesis and associated tectonothermal activity between ca. 2.50 and 1.75 Ga (Hoffman, 1988; Hanmer et al., 1995; Berman et al., 2005, 2007; Martel et al., 2008; Berman, 2010). The age and chemical information acquired by these studies highlight the complex nature of western Churchill Province evolution, with significant gaps remaining in the geological dataset. Foremost among these gaps is the absence of geochronologic knowledge for the deeper levels of the region. Here we present the first such information for the western Churchill Province from two locations that are separated by ~450 km (Fig. 1), and report the U–Pb geochronology, trace element chemistry, and Raman spectroscopy of zircon obtained from kimberlite-hosted lower crustal xenoliths from the Chesterfield block (Rankin Inlet) and Rae craton (Repulse Bay).

2. Geological setting

The surface geology of the Churchill Province is dominated by Neoarchean reworked gneissic granitoid rocks and volcanic-sedimentary supracrustal rocks, which are overlain by extensive Paleoproterozoic intracratonic sedimentary rocks (Fig. 1). It is also transected by the Snowbird Tectonic Zone, a 2800 km long, high-pressure metamorphic structure that juxtaposes domains of contrasting lithological and structural/metamorphic character, the Rae craton to the northwest and the Hearne craton to the southeast. The origin of the Snowbird Tectonic Zone remains controversial; some advocate that it represents a ca. 1.9 Ga suture between the two cratons (e.g., Hoffman, 1988; Berman et al., 2007), whereas others have proposed that it represents a long-lived intracontinental fault zone (Hanmer et al., 1995; Mahan and Williams, 2005; Flowers et al., 2006). The Chesterfield block, formerly considered part of the Hearne craton (i.e., 'northwestern Hearne domain' of Davis et al., 2006) constitutes a third distinctive domain in this region.

Neoarchean crust in the Rae craton and Chesterfield block consists mostly of 2.74–2.67 Ga volcanic-sedimentary supracrustal rocks, intruded by extensive 2.68–2.65 Ga tonalite and 2.61–2.58 Ga felsic plutons (Skulski et al., 2003; Davis et al., 2006; Berman et al., 2007; Martel et al., 2008). The Neoarchean volcanic-sedimentary supracrustal units of the Rae craton are predominantly mafic volcanic rocks that contain sequences of fuchsite-bearing