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U–Pb geochronology and Sr/Nd isotope compositions of groundmass perovskite from the newly discovered Jurassic Chidliak kimberlite field, Baffin Island, Canada

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ABSTRACT

We report the U–Pb age and Sr/Nd isotope composition for perovskite isolated from forty six kimberlite samples located in the newly discovered Chidliak field on Baffin Island, Canada. The minimum duration of kimberlite magmatism in this field was 17.9 m.y. from 157.0 to 139.1 Ma and represents a new Jurassic kimberlite field in NE Canada. The most prolific period of kimberlite magmatism occurred between 152 and 142 Ma (80% of dated kimberlites). Kimberlitic perovskite from these intrusions display a range in $^{87}Sr/^{86}Sr$ (0.7043 to 0.7030) and εNd_T values (+3.9 to −0.4), overlapping the isotopic field previously defined for southern African Group I kimberlites.

The ages and isotopic compositions obtained for Chidliak magmatism are identical to a number of Jurassic kimberlite fields in eastern North America and SW Greenland. Some of this Jurassic kimberlite magmatism has a link to one or more mantle plume hotspot tracks but the Chidliak kimberlites have an origin in the deep subcontinental lithospheric mantle and are part of a Jurassic magmatic province that erupted along both margins of Davis Strait; linked to upwelling asthenosphere, continental rifting, and Mesozoic–Cenozoic development of oceanic crust in the Labrador Sea basin. In contrast, the location of other eastern North American Jurassic kimberlites when plotted on a Jurassic continental reconstruction aligns closely to the northernmost projection of contours 2–4 of the African large low shearwave velocity province, consistent with a link to mantle plumes derived from the African mantle plume generating zone.

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1. Introduction

Kimberlites are volatile-rich intrusions of potassic ultrabasic magma that are derived from partial melting of carbonated garnet peridotite at various depths within the mantle (e.g., Eggler and Wendlandt, 1979; Wyllie, 1980; Edgar et al., 1988; Canil and Scarfe, 1990; Ringwood et al., 1992; Haggerty, 1994). Although they often form as small intrusions (pipes, blows, dykes, sills) and are difficult to find in the field, kimberlites are important magma types on Earth because during rapid ascent from the mantle they entrain mantle xenoliths and xenocrysts, including diamonds, and are one of the main vehicles for transporting mantle rock to the surface allowing their direct scientific study. Kimberlites are also important as the essential host to primary diamond deposits and a better understanding of their origin and emplacement patterns is vital for sustaining a vibrant diamond industry.

The geodynamic setting of kimberlite magmatism is controversial and multiple hypotheses have been proposed including origins linked to subduction of oceanic lithosphere (Helmstaedt and Doig, 1975; Helmstaedt and Gurney, 1997; McCandless, 1999), mantle plumes (Crough et al., 1980; Heaman and Kjarsgaard, 2000; Torsvik et al., 2010), continental rifting (Phipps, 1988; Phillips et al., 1998), and reactivation of previous zones of crustal weakness (Sykes, 1978). Often the setting of kimberlite magmatism is based on proximity to known tectonic elements or structures in the crust; however, more detailed evidence to constrain their specific mantle origin(s) is usually lacking. The combination of precise geochronology and accurate isotope tracer information (e.g., Sr, Nd, Pb, Hf, and O) can provide important clues to the origin of kimberlite magmatism, for example whether they are sourced from the subcontinental lithospheric mantle, asthenosphere or transition zone. Perovskite can also record progressive kimberlite magma

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contamination during ascent through the subcontinental lithospheric mantle (Malarkey et al., 2010).

A few kimberlites and related rocks were known to occur in Canada prior to the 1990s (Brummer, 1978), such as the Ile Bizard alnöite, Quebec (Mitchell, 1983), the Somerset Island kimberlites (Mitchell and Fritz, 1973; Mitchell, 1975), and the Upper Canada Mine kimberlite near Kirkland Lake (Lee and Lawrence, 1968). An explosion in kimberlite exploration occurred after 1991 with the discovery of multiple kimberlite intrusions in the Slave craton, N.W.T. (Kjarsgaard and Levinson, 2002). Since that time more than 800 kimberlites have been discovered in Canada.

In this study we report the U–Pb perovskite geochronology and perovskite Sr/Nd isotopic composition for 44 kimberlites from the newly discovered Chidliak kimberlite field on southern Baffin Island. The objectives of the study are to determine the exact timing and duration of kimberlite magmatism in this new field, evaluate the most active periods of magmatism and how a kimberlite field is created, investigate the nature of their mantle source region and interaction with lithosphere, and finally compare the evolution of this magmatism with synchronous kimberlite activity in eastern North America and SW Greenland to derive a robust model for their geodynamic setting.

2. Kimberlite geology

Focused exploration for primary diamond sources in southern Baffin Island has resulted in the discovery of 71 kimberlites at the Chidliak project and three more kimberlites on the adjacent Qilaq project that form a completely new Canadian kimberlite field extending across a 40 × 70 km area on the Hall Peninsula (Pell et al., 2008, 2013a; Fig. 1A), hereafter referred to as the Chidliak kimberlite field. The kimberlites occur as 0.5–4.0 hectare pipes, occasional smaller blows, and steeply dipping, northerly trending sheet-like bodies. Their location and distribution, dominantly intruding 2.92–2.80 Ga gneisses of the Hall Peninsula Block (Whalen et al., 2010; Steenkamp and St-Onge, 2014), are shown in Fig. 1B.

The kimberlites are characterized by opaque- and perovskite-bearing, monticellite–carbonate–serpentine ± phlogopite groundmass mineralogy. The majority of pipe-like bodies comprise either volcaniclastic or coherent kimberlite infill and can contain crustal and mantle xenoliths. The crustal xenoliths include basement gneisses and 1–15 modal percent carbonate and minor clastic sedimentary xenoliths derived from now-eroded Late Ordovician to Early Silurian strata (Zhang and Pell, 2013). The closest known outcrop of similar age sedimentary strata occurs more than 150 km west of the study area. A number of other kimberlite occurrences; Victoria Island (286–256 Ma), Churchill (225–170 Ma), Attawapiskat (180–156 Ma), Jericho-Muskox (173 Ma), Kirkland Lake (165–152 Ma), Timiskaming (155–134 Ma) and Somerset Island (105–88 Ma) contain stratigraphically equivalent sedimentary carbonate xenoliths. The presence of these sedimentary xenoliths, along with other textural features, suggests that these coherent kimberlites are not hypabyssal intrusions but are extrusive conduit infill, either effusive or clastogenic in origin (Pell et al., 2012, 2013b). The volcanology of the Muskox (Hayman et al., 2008) and Victor (van Straaten et al., 2011) kimberlites share similarities and consequently may be regarded as model-eruptive analogues for the Chidliak kimberlite field.

3. Results

The starting material for all samples was <0.25 mm powder remaining after indicator mineral analysis. In most of the samples investigated here, perovskite occurs as dark orange to brown euhedral crystals in the groundmass, but some differences occur. For example, in kimberlite CH-7 perovskite occurs as larger (>200 μm) euhedral zoned crystals (Fig. 2A) and in others the groundmass perovskite can occur as very small (<50 μm), visibly homogeneous, rounded and irregular crystals (Fig. 2B). A U–Pb geochronology and combined Sr–Nd isotopic study was conducted on the same fresh hand-picked groundmass perovskite fractions. U–Pb dating was conducted using conventional isotope dilution thermal ionization mass spectrometry (ID-TIMS) following closely the procedure outlined in Heaman and Kjarsgaard (2000). Perovskite has very low $^{87}Rb/^{86}Sr$ (<0.0001) so ingrowth of radiogenic strontium is negligible in Mesozoic kimberlites, for this reason the strontium isotope compositions can be determined by TIMS directly on purified Sr aliquots. The isotopic compositions of purified Sm and Nd aliquots were analysed on a Nu Plasma I inductively coupled plasma mass spectrometer. The complete analytical procedures are outlined in Appendix A.

3.1. Perovskite U–Pb geochronology

Perovskite U–Pb ID-TIMS dates for forty four kimberlite bodies from the Chidliak kimberlite field (63% of known intrusions) have been determined so far (42 from Chidliak and 2 from Qilaq) and the results presented here represent one of the most extensive geochronology studies of a kimberlite field on any craton. The perovskite U–Pb results are compiled in Table 1 and all age uncertainties in the text are reported at 2 sigma. For two of the Chidliak intrusions (pipes CH-7 and CH-31), two samples were analyzed from each (denoted A and B in Table 1). The two samples from CH-7 represent a surface sample (CH-7A) and a drill core sample (CH-7B), interpreted to be the same kimberlite unit based on spatial distribution and textural and mineralogical similarities. The two samples from CH-31 were collected from different surface outcrops of the intrusion. The majority of perovskite fractions analyzed consisted of small multi-grain, hand-selected aliquots of orange–brown cubes and/or fragments that weighed between 8 and 350 μg. The majority of samples contained abundant, easy to identify perovskite. However, a few samples have low perovskite abundance and the grain size is minuscule (i.e., <30 μm). In two cases, distinguishing perovskite from other minerals with similar habit and colour (e.g., spinel, dull lustre sulfide etc.) proved to be challenging and mixed mineral fraction analyses were identified by their corresponding low uranium contents (i.e., <30 ppm U) and/or low Th/U (i.e., <3). This is the interpretation for fractions selected from CH-1 and CH-10-2 where the analyses have <12 ppm U (data are not shown in Fig. 3). In the case of CH-1, individual perovskite crystals were not recovered so composite grains were intentionally selected that contained minuscule (<20 μm) perovskite inclusions and the low uranium concentrations are an artifact of dilution with phlogopite. A summary of the U and Th concentration data for these perovskite fractions is displayed in Fig. 3, they display a large range in U (40–265 ppm), Th (40–8000 ppm) and Th/U (2–75). The high-Th end of the compositional range (Fig. 3) is represented by two perovskite fractions from CH-3; the more typical Th range is 40–3000 ppm.

The U–Pb results for 85 perovskite fractions from Chidliak/Qilaq kimberlites are presented in Table 1. For most of the 44 kimberlites, multiple perovskite fractions were analyzed to evaluate reproducibility. The ratio of radiogenic to common Pb (Pb*/Pbc in Table 1) in the perovskite analyses typically varies between 1 and 4, indicating that the analyses are slightly sensitive to the initial common Pb isotopic composition chosen (see Appendix A), but any age shift is less than the quoted uncertainty. For most kimberlite samples where there are multiple perovskite U–Pb analyses, the age results are in excellent agreement within analytical uncertainty. For example the 3 perovskite fractions analyzed from CH-14 have $^{206}Pb/^{238}U$ dates that vary only slightly between 143.1 and 143.9 Ma. In a few samples the perovskite dates vary more than

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