Evidence for a > 200 km thick diamond-bearing root beneath the Central Mackenzie Valley, Northwest Territories, Canada? Diamond indicator mineral geochemistry from the Horn Plateau and Trout Lake regions

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Introduction

The Horn Plateau and Trout Lake Candidate Protected Areas are located in the Central Mackenzie Valley of the Northwest Territories, Canada. This region, between the western margin of the Slave Craton and the eastern edge of the Cordillera, occupies a portion of the Phanerozoic Western Canadian Sedimentary Basin. Below the > 1 km sequence of Phanerozoic platform rocks lie Precambrian rocks, known from a few deep oil exploration wells. The Precambrian rocks of the Central Mackenzie Valley are believed to be a complex series of magmatic arcs and terranes making up the 2.2-1.8 Ga Wopmay Orogen that formed by subduction of Paleoproterozoic lithosphere below the western Slave Craton. Both LITHOPROBE (Cook et al. 1982) and more recent regional-scale surface wave seismic studies (Schaefer and Lebedev 2014) indicate the likely presence of thick, cold lithospheric mantle extending into the diamond stability field. The Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) transect line 1 also indicates a relatively deep lithosphere-asthenosphere boundary at ~180 km within the region (Cook and Erdmer 2005 and references therein). These studies support the idea that a thick cold subcontinental lithospheric mantle – favourable for diamond exploration – existed prior to rifting of the late-Precambrian supercontinent Rodinia and may still exist at depth, underpinning an area of several hundreds of km^2 within the Central Mackenzie Valley. Although this region is not a traditional Archean “cratonic” setting – a widely accepted pre-requisite for the occurrence of diamondiferous kimberlites (Janse 1994) – many discoveries of primary diamond occurences in North America were made in similar settings (e.g. Buffalo Head Hills, northwestern Alberta) suggesting the diamond potential in this region should be further examined.

The Central Mackenzie Valley south of Great Bear Lake, has seen relatively little diamond exploration. Diapros Canada Ltd. first recovered kimberlite indicator minerals (KIM) in the late 1970s in the northwestern Northwest Territories. Currently only Olivut Resources Ltd. is conducting an exploration program in the Central Mackenzie Valley region and have reported the discovery of at least twenty-nine kimberlites (two diamondiferous) since the commencement of their HOAM Project in 1993 (Pitman 2014). The reported KIM chemistry of discovered kimberlites (Pitman 2014), however, differs from that obtained during regional stream sediment and till sampling (Mills 2008, Pronk 2008), suggesting the possible presence of additional, potentially diamondiferous sources. Here we present new major, minor, trace element and isotopic geochemistry on regional Central Mackenzie Valley KIM discovered to date, with the aim of obtaining geotherm, depth of mantle sampling constraints and diamond potential estimates.

Samples

The Horn Plateau region (25,233 km^2) lies east and north of the Mackenzie River, > 180 km to the west-southwest of Yellowknife, while the Trout Lake region (10,680 km^2) lies > 330 km southwest of Yellowknife, north of the 60th parallel and south of the junction of the Mackenzie and Liard Rivers. In total, ~ 3600 (Horn Plateau) and ~ 640 (Trout Lake) KIM were picked from the 0.25-2.0 mm size fractions, from stream sediments in the Horn Plateau region and till in the Trout Lake region. For the

Horn Plateau, peridotitic garnets dominate the KIM inventory (46 %), followed by ilmenite (26 %), with decreasing individual proportions (< 15 %) of chromite, olivine, chrome-diopside and eclogitic garnet. Trout Lake KIM are also dominated by peridotitic garnet (45 %), followed by chromite (22 %), chrome-diopside (21 %), olivine (10 %) and 1 % of both ilmenite and eclogitic garnet.

Analytical Results

A sub-sample of ~ 3100 (Horn Plateau) and ~ 570 (Trout Lake) KIM grains were analysed by electron microprobe. To this major and minor element data we applied traditional methods of estimating and understanding the diamond potential of the KIM from the two regions, based on the comparison to diamond inclusions from worldwide sources. The Cr-Ca contents of the peridotitic (> 1 wt. % Cr_2O_3) garnets analysed from the two regions suggest significantly different compositions of lithosphere sampled and transported to the surface by kimberlite. From the ~ 1600 Horn Plateau garnet grains collected, lherzolitic garnets (G9) dominate (67 %), followed by high-TiO_2 peridotitic garnets (G11, 17 %) and harzburgitic garnets (G10, 14 %) using the Grütter et al. (2004) classification. Additionally, a relatively large population of the garnets are Cr_2O_3-rich (up to 15 wt. %), suggesting derivation from deep and highly depleted lithosphere extending into the diamond stability field. Conversely, the Trout Lake garnet chemistry is dominated by lherzolitic garnets (G9, 83 %), followed by high-TiO_2 peridotitic garnets (G11, 8 %), wherlitic garnets (G12, 7 %) and no harzburgitic garnets (G10), suggesting kimberlite sampling of a relatively less depleted lithosphere (Grütter et al. 2004).

Paleo-geotherms for each of the two regions were determined using clinopyroxene thermobarometry (Nimis and Taylor 2000), assuming that the grains were locally derived and sampled pene-contemporaneously from their mantle sources. The geotherm constrains the depth of lithosphere being sampled and allows the placement of various geochemical groups (e.g. fertile and depleted peridotites) within a lithospheric mantle stratigraphic framework. The well-constrained Horn Plateau geotherm (57 grains) suggests that at the time of volcanic activity it was underlain by a 215 km thick lithosphere; the geothermal gradient is identical to the central Slave Craton, although the mode of sampling occurs at slightly shallower depths (125-175 km). The poorly-contrained Trout Lake geotherm (4 grains) indicates a paleo-geothermal gradient with a substantially shallower base of the lithosphere (175 km) and a mode of sampling between 80-120 km depth, outside the diamond stability field.

A sub-sample of 840 peridotitic garnets and 61 mantle olivine grains from the Horn Plateau were selected for trace element characterization by laser ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS). Similarly, a sub-sample of 168 peridotitic garnets and 42 mantle olivine grains from the Trout Lake region were analysed. The chondrite-normalized rare-earth element (REE_N) patterns of the majority of the peridotitic garnet grains are sinusoidal, typical of diamond inclusions, suggesting these garnet grains may have interacted with diamond forming fluids (Stachel and Harris 2008). Nickel concentrations were used to determine the temperature of equilibration of individual peridotitic (lherzolitic and harzburgitic) garnet grains; the majority of the garnets from the Horn Plateau indicate equilibration temperatures between 850-1150 °C, while those from the Trout Lake region have a smaller range, between 850-1000 °C (averages of Griffin et al. 1989 and Canil 1999). Extrapolation of these data to the two “regional” geotherms indicates significant sampling of garnet-peridotites in the diamond stability field for the Horn Plateau, whilst the small diamond window in the mantle beneath Trout Lake was sampled less extensively. These results are supported by temperature estimates based on the Al-in-olivine geothermometer (Bussweiler et al. 2017) for olivine derived from garnet-peridotite (Al analysed via LA-ICP-MS).

Horn Plateau kimberlitic ilmenite crystals from the 1.0-2.0 mm size fraction (n = 22) were selected for analysis of Hf isotope compositions to derive an age bracket for the emplacement of their source kimberlites. As there were only five kimberlitic ilmenites (0.25-0.5 mm size fraction) recovered from the Trout Lake region, an additional sixty-five rutile grains from this region were analysed by LA-ICP-MS for U-Pb isotopic ratios to help constrain source kimberlite emplacement age. From the Trout

Lake rutile analysed, seven grains (from five samples) had potential U-Pb kimberlitic ages, between ~ 415-110 Ma, consistent with eruption through the Cretaceous to Devonian aged sedimentary rocks found within this region; similar ages are reported for kimberlites elsewhere in the western North American Craton, but they are distinct from the kimberlite ages of the Central Slave Craton. Only five Trout Lake rutile grains have ages similar to the Central Slave (2.8-2.5 Ga), while the remainder (n = 53) have ages between 2.2-1.6 Ga, similar to the Wopmay Orogen. These first constraints on the eruption age(s) of the Central Mackenzie Valley kimberlites, based on rutile U-Pb dating and ilmenite Hf isotope compositions, indicate the potential for three KIM sources for the Horn Plateau region, while possibly two (or more) sources exist for the KIMs supplied to the Trout Lake region.

Discussion

The Horn Plateau KIM are derived from a source underpinned by a cold, deep (> 200 km) diamondiferous root. The geotherm and mantle sampling pattern along with the high proportion of G10 garnets for the Horn Plateau are similar to the Central Slave Craton. However, our initial geochronology results are not consistent with the Central Slave kimberlites representing the source of the KIM in this region but instead indicate the potential for new local kimberlite sources of previously undocumented ages. Our results provide a better understanding of where diamond exploration efforts should be focused in the Central Mackenzie Valley.

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