Petrology of the White River Diamondiferous Paleoproterozoic Intrusive Rocks

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Introduction

Diamond-bearing kimberlitic rocks have recently been identified within the Oskabukuta property owned by Rio Tinto Exploration Canada Inc. (RTECI), 15km west of the town of White River, Northwestern Ontario (Figure 1). The property is located in the Abitibi-Wawa island-arc terrane within the Archean Superior Province. The rocks are predominantly hosted within post tectonic granites of the Pukaskwa Complex (2.719-2.688 Ga). The diamond-bearing intrusion has been mapped at surface for over a 900 m, and is referred to as the Rabbit Foot intrusion. We present a description of the mineralogy, mineral chemistry, age dates and geothermobarometry for this occurrence. These data are used to constrain the timing of the destruction of Southern Superior Province's cratonic roots.

Figure 1: Location of the Oskabukuta Project

Petrography and Mineral Chemistry

The Rabbit Foot rocks are divided into several phases based on distinctive textural characteristics, and generally described as an intrusion, 2 to 30 meters in width, containing abundant xenocrysts of serpentinized-olivine (2 mm to 2 cm), garnet, ilmenite, chromite, chrome diopside and diamond. These phases are set in a crystalline matrix consisting of a phenocryst assemblage of olivine-phlogopite-clinopyroxene-carbonate-apatite-oxide (spinel-magnetite-perovskite) with a variably serpentinized carbonate bearing groundmass (Figure 2). The rock contains mantle derived micro-xenoliths of garnet lherzolite and can contain up to 50 percent of a diverse suite of altered country rock xenoliths.

Phenocrystic olivine range in modal abundance from 0 – 25 %, are <0.5 mm, typically anhedral, and variably serpentinised/carbonatised. Forsterite content ranges between 0.85-0.87 and contains variable NiO (0-0.38 wt. %). Mica ranges in size and shape from 1 mm hexagonal oscillatory laths, to anhedral groundmass grains <0.5mm with orange/red mantles. The modal abundance of mica ranges between 10 – 45 %. Mica ranges in composition from Ba-phlogopite to tetraferriphlogopite; the barium content is not high enough (0-4.4 wt. % BaO) to identify the mica as kinoshitalite. Groundmass spinel are subhedral to euhedral, <0.5mm, represents 10-30 percent of the groundmass phases and can display oscillatory zoning and atoll textures. Cores are typically chromite in composition with titanomagnetite rims. The trend features spinel whose compositions range from aluminous magnesian chromite, to titanian chromite to ulvöspinel-magnetite series. Perovskite are <200µm, subhedral, are relatively pure $CaTiO_3$, and lack substantive REE concentrations. Clinopyroxene is present, and is typically related to the rims of altered crustal xenoliths (Metteer, 2016). The xenocryst assemblage consists of olivine, pyrope and eclogitic garnet, chrome diopside, orthopyroxene, chromite, ilmenite and diamond. A dominant proportion of chromite contains high Cr_2O_3 and low TiO_2 contents, consistent with chromite inclusions in diamonds worldwide. Garnet compositions are typically harzburgitic and lherzolitic and contain a minor eclogitic garnet component based on mineral chemistry. Macrocrystic olivine compositions average Fo_{93} and contains Ni contents of ~3300 ppm.

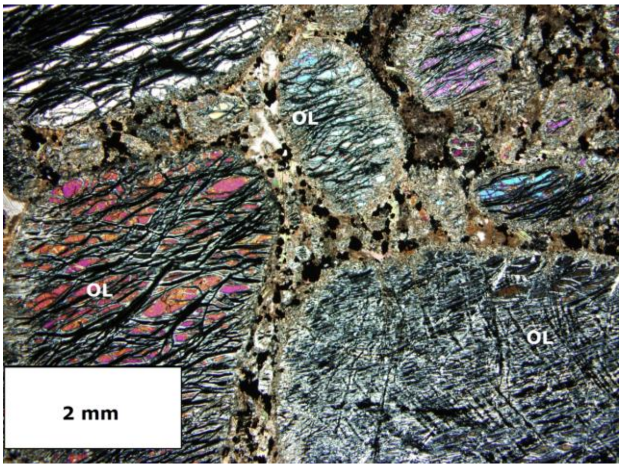

Figure 2: Photomicrograph showing coarse serpentinised olivine in an olivine-phlogopite-calcite-oxide

Geochronology and Age of Emplacement

$^{206}Pb/^{238}U$ geochronology by ICP-MS was completed on 250 groundmass perovskite grains at the University of Alberta. Results from 250 grains returned a model age of 1945.3 ± 1.9 Ma. Textural evidence suggests the perovskite to be a relatively late stage crystallisation product from the melt as shown by its inter-grown relationship with other phenocrystic phases such as oxides and in olivine rims. For this reason we interpret the 1945.3 Ma date to closely represent the emplacement age.

Geothermobarometery and Paleoheat flow

Clinopyroxene (cpx) and garnet were extracted from heavy mineral concentrates. Major and trace element mineral chemistry was analysed at Rio Tinto's Bundoora Analytical Facility, Australia. We use cpx and garnet mineral chemistry to assess the paleoheat flow of the Southern Superior Province by obtaining P-T estimates from a combination of the single crystal enstatite-in-cpx thermometer, Cr-in-cpx barometer of Nimis and Taylor (2000), garnet geobarometer of Grutter et al. (2006) and Ni-in-Garnet geothermometer of Canil (1999).

Figure 3 shows mineral compositions used in this study and comprise cpx compositions consistent with garnet peridotite (220 grains; Figure 3a), and lherzolitic and harzburgitic compositions for garnet (693 grains; Figure 3b). Figure 3c shows P-T estimates for cpx (closed black circles), and garnet (open purple circles). Model conductive geotherms are shown for 35, 40 and 45 mW/m^2 for reference. Although significant scatter exist with respect to the cpx data, our best estimate for a conductive heat flow is 38-

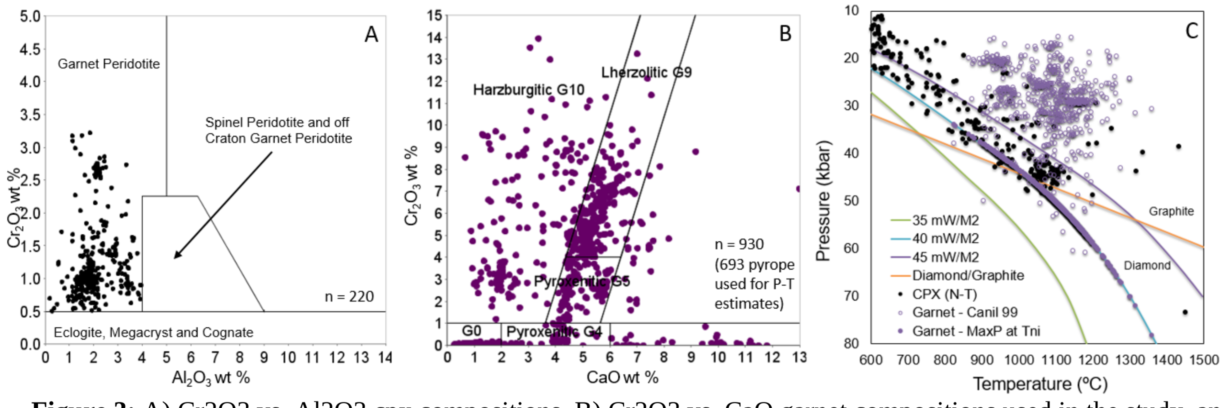

Figure 3: A) Cr2O3 vs. Al2O3 cpx compositions, B) Cr2O3 vs. CaO garnet compositions used in the study, and C) P-T estimates with reference conductive geothermal gradients.

41 mW·m^{-2}. Systematics of the Cr-in-garnet geobarometer and Ni-in-garnet geothermometer (Canil, 1999) are such that maximum pressures at a given temperature defines the geotherm assuming coexisting chromite and orthopyroxene equilibration (Ryan and Griffin, 1996). Garnet P-T estimates have been projected onto the 40 mW/m^2 geotherm (closed purple circles) for reference, however maximum pressures are consistent with an interpolated model conductive geotherm of ~39 mW/m^2, comparable with our cpx P-T estimates.

Discussion

There are many problems related to the classification of alkaline ultramafic rocks under volatile-rich conditions, and it is out of the scope here to definitively classify the Rabbit Foot rocks; however, the abundance of olivine macrocyrsts, the macrocrystal suite (i.e. harzburgitic garnet, diamond), the phenocryst mineral suite and compositions (forsterite - Ba-phlogopite - trend-2-spinel- Sr-rich REE-poor apatite and perovskite) and presence of groundmass calcite are all characteristics which are undoubtedly of kimberlitic affinity. In addition to the melt fraction, the system transported diamond-bearing harzburgitic and lherzolitic lithosphere to crustal levels during the Paleo-Proterozoic, approximately 1945 Ma.

Geothermobarometry of the Proterozoic (2.7 Ga) aged diamondiferous metaconglomerate in Wawa (90 km SE) reported a maximum geothermal gradient range between 39 and 41 mW/m^2 corresponding to a minimum lithospheric thickness of the Superior Craton of 190-220 km (Miller et al., 2012). In contrast, these authors highlight that younger kimberlite (e.g. ~1.1 Ga Wawa kimberlite) within the Southern Superior record a substantially warmer conductive geotherm (46 mW/m^2; Kaminsky et al., 2002) and maximum depth of garnet sampled of 150 km. Miller et al. (2012) interpret the apparent heating of the mantle is likely to have resulted from the Midcontinent Rift, which is broadly coeval with the Wawa kimberlite age.

Our data support the interpretation of Miller et al. (2012) and further constrain the presence of a cool and thick Southern Superior keel was still present 1945 Ma. In fact, several of our garnet compositions support a minimum lithosphere-asthenosphere boundary (LAB) of 250 km in depth and suggest (along with the presence of diamond) that the Rabbit Foot intrusion transected and sampled a significant portion of depleted and diamond stable lithospheric mantle at ~1945 Ma. A later thermal event, likely related to the Mid-continental rift, has subsequently heated and thinned the Southern Superior Craton, thereby constraining timing of the cessation of diamond fertile sublithospheric mantle in the region.

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