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The origin of high-MgO diamond eclogites from the Jericho Kimberlite, Canada

Katie A. Smart [a,*], Larry M. Heaman [a], Thomas Chacko [a], Antonio Simonetti [a,1], Maya Kopylova [b], Dale Mah [c,2], Delene Daniels [c]

[a] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada T6G 2E3
[b] Department of Earth and Ocean Sciences, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4
[c] Tahera Diamond Corporation, Canada

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ABSTRACT

A unique suite of diamond-rich eclogites from the Jericho kimberlite, Nunavut, Canada, has a uniform but unusual geochemical and isotopic composition that is unlike any other eclogite suite worldwide. Compared to other eclogite suites, garnets from Jericho diamond-bearing eclogites have high MgO (19.6–21.2 wt.%), Cr_2O_3 (0.28–0.60 wt.%), Sc (88–113 ppm), and Zr (32–36 ppm) contents and are characterized by consistent highly fractionated chondrite-normalized HREE patterns ($[Lu/Gd]_N = 4.0–6.6$). Na-poor clinopyroxene has a uniform LREE-enriched pattern and radiogenic $^{87}Sr/^{86}Sr$ values between 0.7057 and 0.7061, higher than other eclogite groups at Jericho and the Jericho kimberlite itself. The distinct geochemical and isotopic compositions of the Jericho diamond eclogites are not directly compatible with either the subducted oceanic crust or high-pressure mantle melt models commonly invoked for the origin of mantle eclogites. We propose a multi-stage origin that involves multiple metasomatic events coupled with hybridization between basaltic eclogite and mantle peridotite. Emplacement of basaltic eclogites in the diamond stability field was followed by metasomatism by a carbon-bearing, LREE-enriched metasomatic fluid or melt as recorded by clinopyroxene and diamond inclusions in garnet. Subsequent or concurrent partial melting of eclogite produced melts that facilitated diffusional elemental exchange between residual eclogite and ambient peridotite. This process enabled the eclogites to attain their distinct high-Mg and Cr composition. Finally, carbonatite-like modal metasomatism grew phlogopite, carbonate and apatite and potentially also facilitated additional diamond growth, producing the extreme diamond enrichments found in these eclogites.

1. Introduction

Although the proportion of eclogite within the cratonic lithospheric mantle is inferred to be small (<2%, Schulze, 1989), the proportion of eclogite xenoliths and eclogitic diamonds recovered from some kimberlites, including the Jericho kimberlite, is surprisingly large (e.g. Stachel and Harris, 2008). Despite the worldwide abundance of eclogitic diamonds, there are comparatively fewer diamondiferous eclogite xenoliths available for study, limiting our understanding of the origin of eclogitic diamonds and their host rocks. Additionally, mantle eclogites can provide insight on the composition and evolution of the continental lithospheric mantle. Two main hypotheses have been proposed for the origin of eclogite xenoliths: 1) remnants of subducted and metamorphosed oceanic crust (e.g. Helmstaedt and Doig, 1975; Jagoutz et al., 1984; MacGregor and Manton, 1986; Jacob et al., 1994; Jacob 2004) and 2) cumulates of basaltic magmas crystallized at high pressure (e.g. O'Hara and Yoder, 1967; Smyth et al., 1989). In this study, we evaluate these hypotheses in light of the major-, trace-element and Sr and Pb isotope compositions of minerals in a suite of high-MgO eclogite xenoliths recently recovered from the Jericho kimberlite, including thirteen spectacularly fresh, diamond-rich eclogites.

1.1. Background

The 173 Ma Jericho kimberlite (Heaman et al., 2006) is located in the northern Slave craton in Nunavut, Canada approximately 400 km NNE of Yellowknife. Our new data and previous studies on Jericho eclogites (Cookenboo et al., 1998; Kopylova et al., 1999a; Heaman et al., 2002; Schmidberger et al., 2005; Heaman et al., 2006) reveal that in addition to garnet and clinopyroxene, Jericho eclogites may also contain diamond, kyanite, corundum, rutile, phlogopite, apatite or zircon. The Jericho eclogites can be subdivided into three broad geochemical groups based on garnet composition; 1) Mg-rich (19.6–21.2 wt.% MgO), 2) Ca-rich (up to 17.5 wt.% CaO), including kyanite-bearing eclogites, and 3) Fe-rich (up to 26.5 wt.% FeO), including zircon-bearing xenoliths. This grouping broadly correlates geochemically with the Group A–B–C eclogite classification originally proposed

* Corresponding author. Tel.: +1 780 271 3452; fax: +1 780 492 2030.
E-mail address: kasmart@ualberta.ca (K.A. Smart).
[1] Dept. Civil Engineering & Geological Sciences, University of Notre Dame, Notre Dame, IN, USA, 46556.
[2] Olivut Resources Ltd.

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by Coleman et al. (1965), and will be used to describe the three groups hereafter. The diamond-bearing eclogites at Jericho are predominantly Mg-rich Group A eclogites and have homogeneous mineral compositions (Cookenboo et al., 1998; Heaman et al., 2006). A few intermediate-MgO, Group B (~14.0 wt.% MgO) diamond eclogite xenoliths have recently been reported from Jericho by De Stefano et al. (2009). Garnet-clinopyroxene thermometry of the high-MgO diamond eclogites using the calibrations of Ellis and Green (1979) and Krogh Ravna (2000) indicates a restricted temperature range of 1000–1015 °C (calculated at 5.0 GPa) for the last equilibration (Cookenboo et al., 1998; Heaman et al., 2006). This differs from diamond-bearing eclogites from the Diavik kimberlites, just 100 km south of Jericho, which have Group B and C compositions and record much higher temperatures (1127–1299 °C, Schmidberger et al., 2007). The uniform mineral compositions and limited range of equilibration temperatures of the Jericho diamond eclogites led Cookenboo et al. (1998) to propose that these rocks represent high-pressure cumulates from primary mantle melts. This origin is distinct from all other Group B and C eclogites at Jericho, which have been interpreted to be remnants of Paleoproterozoic subducted oceanic crust (Heaman et al., 2002; Schmidberger et al., 2005; Heaman et al., 2006). Although Paleoproterozoic to Mesoproterozoic formation and modification ages have been reported for other suites of Jericho eclogites (Heaman et al., 2002; Schmidberger et al., 2005; Heaman et al., 2006), there is no age information available for the high-MgO, Jericho diamond eclogites.

1.2. Petrography of the Jericho diamond eclogites

The Jericho diamond eclogites (abbreviated JDE hereafter) investigated in this study are dominantly garnet–clinopyroxene–diamond ± phlogopite (1–2%) rocks, where diamond and phlogopite can comprise up to 20% and 2% of the mode, respectively (Fig. 1a). Reddish-orange garnet and vibrant green clinopyroxene occur as 1–3 mm, generally fresh inclusion-free crystals with a granoblastic texture. These rocks are not layered or deformed and garnet and clinopyroxene are fresh. Diamonds are 0.5–2 mm colorless and transparent octahedra, twinned-octahedra and irregularly shaped aggregates that occur at the grain boundaries of garnet and clinopyroxene, where commonly the morphology of diamond is controlled by the morphology of these minerals. The diamonds are variably surrounded by a fine-grained black material, consisting of fine phlogopite, apatite, carbonate and a Mg- and Al-rich silicate phase. This assemblage also occurs as thin vein networks throughout the eclogites, locally transecting both garnet and clinopyroxene crystals. Diamonds in the Jericho eclogites are also commonly mantled by phlogopite and these diamonds invariably have resorbed grain boundaries (Fig. 1b). However, a small population of diamond is in direct contact with neighboring garnet and clinopyroxene and a few sharp-edged, <0.5 mm diamonds occur as inclusions in garnet (Fig. 1c). Inter-connected networks of Ni-rich sulfide globules rimmed by phlogopite and carbonate are also present in the JDE (Fig. 1d). An additional discovery of this study is the occurrence of a tiny (~20 μm) garnet inclusion in diamond in eclogite JDE 03 (Fig. 1b), which is compositionally different from garnet in the host eclogite.

2. Analytical methods

We report the results on thirteen previously unstudied JDE from the Jericho kimberlite, and present new data on a suite of Group B and C eclogites, of which six (of fifteen total) were studied by Kopylova et al. (1999a). All JDE reported here are between 2–4 cm in diameter and were recovered during ore processing at the Jericho mine. Eclogite xenoliths were wrapped in multiple layers of plastic and coarsely crushed.

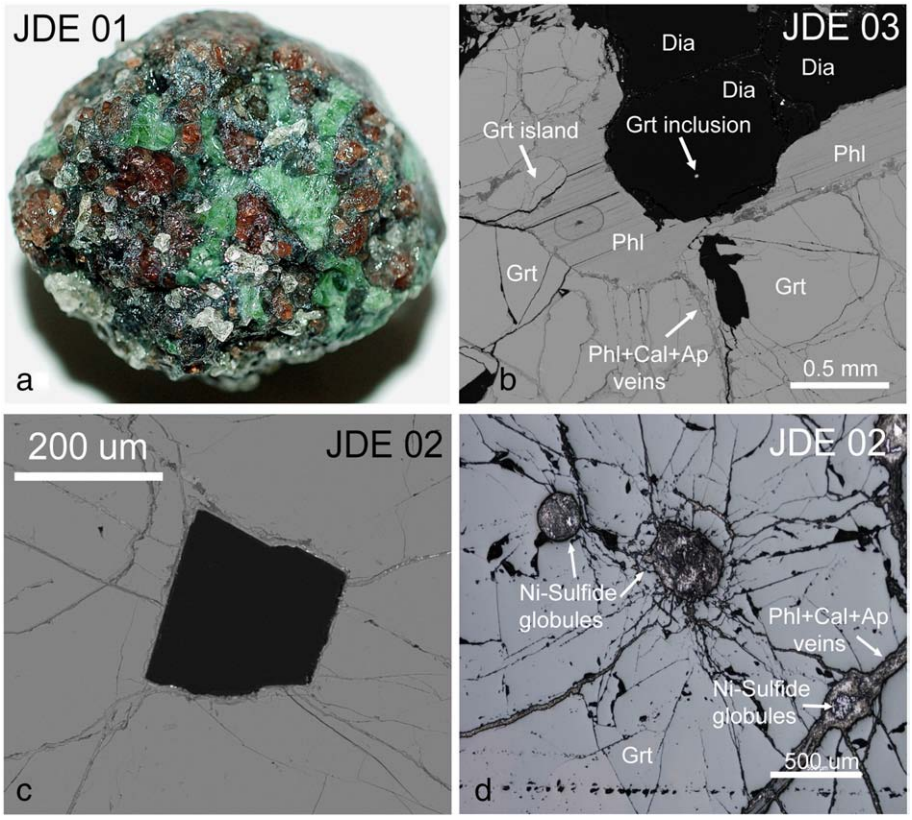

Fig. 1. (a) Photograph of Jericho diamond eclogite (JDE) 01. Xenolith is 4 cm wide. (b) Backscattered electron microprobe image of JDE 03 showing the textural relationship of diamond, pholgopite and garnet. The small light dot included in the central diamond is actually a garnet inclusion that was exposed during polishing of these sections, and is approximately 20 μm across. (c) Backscattered electron microprobe image of a diamond inclusion in garnet in JDE 02. (d) Reflected light photomicrograph showing pholgopite + apatite + calcite veins and associated Ni-sulfides. Grt = garnet, Phl = phlogopite, Cal = calcite, Ap = apatite, Di = diamond.