



Combined C isotope and geochemical evidence for a recycled origin for diamondiferous eclogite xenoliths from kimberlites of Yakutia

Z.V. Spetsius^{a,*}, D.F. Wiggers de Vries^b, G.R. Davies^b

^a *YaNIGP CNIGRI, ALROSA Co. Ltd, Mirny, Yakutia, Russia*

^b *Faculty of Earth and Life Sciences, Vrije University, Amsterdam, The Netherlands*

ARTICLE INFO

Article history:

Received 12 October 2008

Accepted 27 April 2009

Available online 13 June 2009

Keywords:

Eclogite xenoliths

Diamonds

Carbon isotopes

Trace elements

Siberia

ABSTRACT

An integrated petrographic-geochemistry and stable isotope study of 15 diamondiferous eclogite xenoliths is presented from the Udachnaya pipe, Russia. Carbon isotope determinations were performed by combustion and SIMS while in situ mineral major and trace element concentrations were determined using LA-ICP-MS and microprobe. Carbon isotope compositions of diamonds range from -13.7 to -2.8% . Although this range is less than that reported from all diamonds from kimberlites (-38.5 to $+5.0\%$), the large variation in a small sample suite establishes that the C sources in the eclogite parental rocks were extremely variable. The carbon isotope composition of diamonds from a single sample records little variation, with $\delta^{13}\text{C}$ variations usually close to $\pm 1\%$ excluding samples where two generations of diamonds are present. Core-rim zonation in individual crystals are in the order of 1 per mil.

Major and trace elements have been obtained for garnet and clinopyroxene from most of the samples studied for diamonds. About 60% of garnets and clinopyroxenes show Eu anomalies that suggest possible formation from recycled oceanic lithosphere. Additional evidence in support of an origin from subduction of ancient oceanic crust includes the presence of coesite and high $\delta^{18}\text{O}$ values of garnets.

The minor C isotope variations recorded within individual crystals and individual xenoliths imply that diamond was formed from a C-bearing reservoir that was large enough not to undergo marked C isotope fractionation during diamond formation. This contrasts markedly with the large but coherent variations in N and C isotopes and N aggregation state reported for 59 diamonds extracted from a single peridotite xenolith from the Cullinan Mine, South Africa. The extreme heterogeneity recorded in trace elements of the Udachnaya eclogitic suite, coupled with the homogeneity of C isotopes in individual diamonds, does not conform to a Rayleigh distillation model.

Mineralogy and geochemistry suggest that most of these eclogite xenoliths were formed from rocks produced by crystallization of gabbroic rocks in abyssal conditions that underwent subsequent subduction. The wide variation in carbon isotope compositions possibly implies the involvement of both carbonate and carbonaceous sources in the petrogenesis of the eclogitic xenoliths. Notably, however, there is clear evidence that a limited number of eclogites record multiple diamond forming events.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

The genetic association of diamond with eclogitic rocks is substantiated by the presence of diamondiferous xenoliths in many diatremes (e.g., Viljoen et al., 1996; Kirkley et al., 1992; Jerde et al., 1993; Sobolev et al., 1994; Spetsius, 1995; Spetsius and Taylor, 2008). These studies of mantle xenoliths containing diamonds have provided many constraints on the nature of the processes that lead to diamond genesis in the mantle but the exact process of diamond formation remains a matter of debate (e.g., Sobolev, 1977; Boyd and Gurney,

1986; Kirkley et al., 1992; Bulanova, 1995; Anand et al., 2004; Cartigny, 2005; Stachel and Harris, 2008; Thomassot et al., 2007).

Eclogites are coarse-grained rocks composed mainly of almandine-grossular-pyropite garnet and omphacitic clinopyroxene. They are mostly interpreted to be the result of subduction of ancient oceanic crust that has been de-volatilized and possibly partially melted during subduction (e.g., Helmstaedt and Schulze, 1989; Neal et al., 1990; Snyder et al., 1995; Taylor et al., 2003; Spetsius et al., 2008). The mineral chemistry of diamondiferous eclogite xenoliths indicates that they have been subjected to upper-mantle P - T conditions, consistent with the environment necessary for the formation of diamond (e.g., Dawson, 1980; Boyd and Gurney, 1986). In addition, in excess of 30% of mineral inclusions in diamonds have identical chemical specificity with the mineralogy of eclogitic xenoliths (e.g., Taylor et al., 1996; Sobolev et al., 1998; Stachel and Harris, 2008).

* Corresponding author. Chernyshevsky St 7, Mirny, Yakutia, 678170, Russia. Tel.: +7 41136 30982.

E-mail address: spetsius@cnigri.alrosa-mir.ru (Z.V. Spetsius).

Eclogitic xenoliths predominantly have lower equilibration P – T conditions than those of E-type diamond inclusions. This characteristic is thought to be a consequence of modification of eclogites by metasomatic fluid interaction (Switzer and Melson, 1969; Ireland et al., 1994; Spetsius and Taylor, 2002). In excess of 90% of known diamondiferous xenoliths from Yakutian kimberlites are eclogitic (Spetsius, 1995; Sobolev et al., 1984). Similar estimations are given for diamondiferous xenoliths from South Africa (Kirkley et al., 1992). These data suggest that the majority of diamonds may have originated in an eclogitic environment.

Mantle eclogites have been classified by Taylor and Neal (1989) using the ternary garnet chemistry originally introduced by Coleman et al. (1965). A three-fold classification is proposed based upon both the garnet and omphacite compositions: group A (high Mg# Gt, low-Jd Cpx); group B (lower Mg#, high-Fe Gt; moderate-Jd Cpx); and group C (low Mg#, high-Ca Gt; high-Jd Cpx). Subsequently in Russian literature these eclogite groups are often described as magnesian, ferrian and high-aluminian varieties (e.g., Spetsius and Serenko, 1990). Diamond-bearing eclogites have been reported to occur in all three groups. Previous work on eclogites from Siberia has shown that most diamondiferous eclogites are of group B and C eclogite affinity (e.g., Spetsius, 1995).

Group A (magnesian) eclogites are biminerally, coarse-grained rocks (2–8 mm) of mosaic or cataclastic (rarely poikilitic) texture composed of orange garnet (30–70 modal %), pale-green low-jadeite omphacite, with rare rutile grains. Group A eclogites are distinguished from other eclogites by their elevated contents of Cr_2O_3 (to 2.5 wt.%). As was shown by Spetsius and Taylor (2008) group A eclogites have elevated Mg# (53–74), contain 13–21 wt.% MgO, with low Na and K and low total ($\text{FeO} + \text{Fe}_2\text{O}_3$) of <12 wt.%. Rutile, sulfides, and rare ilmenite represent accessory minerals.

Group B (ferrian) eclogites are coarse-grained rocks of mosaic texture composed of orange-red garnet (30–60 modal %; 1–10 mm in size) and dark-green clinopyroxene, along with accessory minerals of rutile, sulfides, and ilmenite. These eclogites have low Mg# (40–60%), usually high contents of total ($\text{FeO} + \text{Fe}_2\text{O}_3$) from 10.07 to 14.42 wt.%, and elevated contents of titanium (on average >0.60 wt.% TiO_2).

Group C (high-aluminian) eclogites are coarse-grained rocks typically containing kyanite (up to 30%) as an additional phase to the high-Ca garnet and high-jadeite clinopyroxene (up to 11 wt.% Na_2O). Wide variations of garnet (20–80%) and clinopyroxene (20–60%) modes can be observed. Coesite and corundum are common, with rare rutile, sulfides, and ilmenite (Spetsius, 2004).

The presence of secondary products of melting in eclogites can be observed in many xenoliths (e.g., Spetsius and Taylor, 2008). Investigations of xenoliths from the Udachnaya and others pipes of the Daldyn–Alakitsky region of Yakutia have demonstrated that the process of partial melting has occurred in the majority of xenoliths, especially in eclogites, but also garnet pyroxenites (Spetsius and Serenko, 1990). Melting products include partially devitrified glass and other products of melting that are clearly observed between garnet and clinopyroxene grains, sometimes in the form of veinlets that transect these minerals. The degree of partial melting of garnet is usually less than that of clinopyroxene. Eclogites with evidence for extensive development of melting in Udachnaya pipe have been recently documented by Spetsius and Taylor (2002), as well as the chemistry of secondary minerals, effect of metasomatism and a source of the altering fluids. Melting is pronounced in both biminerally and kyanite eclogites, including diamondiferous varieties. Spetsius and Taylor (2002) recognise different stages of metasomatic-induced partial melting: 1) alteration of primary omphacite to clinopyroxene with lower jadeite content; 2) larger degrees of partial melting involving both primary omphacite and garnet, with fluids enriched in K_2O and water, and 3) extensive melting involving fluids containing appreciable K_2O and Na_2O , in addition to H_2O and CO_2 . In a single xenolith, it is possible to recognize two or three stages of melting and subsequent crystallization.

More than 5000 carbon isotope compositions have been reported from kimberlite-derived diamonds (Cartigny, 2005) but few crystals from xenoliths have been analyzed (Jacob et al., 1994; Stepanov et al., 2007; Thomassot et al., 2007). This is despite the fact that a full understanding of diamond genesis requires a detailed knowledge of the chemical and mineralogical variations in diamonds and their host rock. Here we make a contribution to redressing this imbalance by reporting initial results from an ongoing integrated petrographic-geochemistry and radiogenic and stable isotope study of diamondiferous eclogite xenoliths from the Udachnaya pipe, Russia.

2. Samples and analytical techniques

Major-element compositions of garnets and clinopyroxenes in the xenoliths are presented in Tables 2 and 3 and were determined with a CAMECA SX-50 electron microprobe at the Institute of Geology (Yakutsk) and with a Superprobe JXA-8800R electron microprobe at the ALROSA Co Ltd. (Mirny, Russia). A portion of the garnets and clinopyroxenes were also investigated by scanning electron microscope equipped with an energy dispersive spectrometer at the University of Western Australia (Perth). Analytical conditions included an accelerating voltage of 15 kV, a beam current of 20 nA, beam size of 5 μm , and 20 second-counting time for all elements. Wavelength determinations were calibrated against known mineral standards and all data underwent full ZAF corrections.

Carbon isotope compositions were determined in diamonds from 14 eclogite xenoliths and one garnet websterite, derived predominantly from the Udachnaya pipe. Analyses were performed on crystals with both cubic and octahedral forms. The analyses were made on entire crystals or group of crystals, usually <200 μm and only for three samples where chips from larger grains analyzed. Carbon isotope determinations were performed using a Finnigan-MAT Delta at the Vrije University, Amsterdam and by ion probe using a Cameca SIMS 1270 at the NERC Facility at the School of Geosciences, University of Edinburgh. Full details of the analytical technique are given by Harte et al. (1999) and Fitzsimons et al. (2000). The diameter for a typical 30 min secondary-ion mass spectrometry (SIMS) analysis was 20–30 μm with a depth of 1–6 μm .

Points on the diamond surfaces for SIMS analysis were chosen based on cathode luminescence-topograms. Diamonds were rough, poorly polished crystals remaining in xenoliths. Several analyses were obtained for some larger individual crystals and these data were averaged to overcome possible analytical induced isotopic fractionation due to surface irregularities. The reproducibility of C isotope compositions by a Finnigan-MAT Delta is within $\pm 0.5\%$ based on multiple analyses on the standard diamond powder and a comparable precision is obtained from SIMS data from polished diamond plates (Fitzsimons et al., 2000).

Garnet and clinopyroxene trace element concentrations were measured by laser ablation ICP-MS at the Utrecht University, Netherlands, using NIST 610 glass as an external standard. Concentrations are determined by comparison to Ca, which was previously determined by microprobe. Crater diameters were 40–50 μm . Accuracy and precision were monitored by using basalt standard BCR-2G with each batch of samples as an unknown (see Hin et al., this issue). Garnet-clinopyroxene Nd–Hf–Sr isotope determinations are currently underway.

3. Petrography and mineralogy of investigated samples of diamondiferous xenoliths

The majority of the studied diamondiferous eclogites are extensively altered with between 10 and 50% of the original primary mineralogy preserved. However, based on the alteration products it is possible to accurately estimate the original mineral modes and textures. Two diamondiferous eclogite groups can be distinguished on the basis of different mineralogy and chemistry: biminerally and kyanite eclogites (Table 1). Coesite, or pseudomorphs after coesite, are

Download English Version:

<https://daneshyari.com/en/article/4717216>

Download Persian Version:

<https://daneshyari.com/article/4717216>

[Daneshyari.com](https://daneshyari.com)