

Combined C-isotope and Geochemical Evidence for a Recycled Origin for Diamondiferous Eclogite Xenoliths from Kimberlites of Yakutia

Z. V. Spetsius¹, de Vries D.F.Wiggers² and G.R.Davies²

¹*YaNIGP CNIGRI, ALROSA Co. Ltd, Mirny, Yakutia, Russia;*

²*Vrije University, Amsterdam, Netherlands*

Introduction

More than 5000 carbon isotope compositions have been reported from diamonds from kimberlites (Cartigny, 2005) but only a few crystals from xenoliths (Stepanov et al., 2007; Thomassot et al., 2007). Here we make a contribution to redressing this imbalance through an integrated petrographic-geochemistry and radiogenic and stable isotope study of diamondiferous eclogite xenoliths from the Udachnaya pipe, Russia.

Samples and Analytical techniques

Carbon isotope compositions were determined in diamonds from 15 xenoliths that are representing predominantly by eclogites mostly from the Udachnaya pipe. The small size crystals of cubic and octahedral forms were used (Tabl. 1).

Carbon isotope determinations were performed using a Finnigan-MAT Delta at Vrije University, Amsterdam and SIMS ion probe in Edinburg while in situ mineral major and trace element concentrations were determined using LA-ICP-MS and microprobe. The diameter for a typical 30 min SIMS analysis was 20-30 µm and a depth of 1-6 µm, and this represent a good resolution. The analyzed points were located on CL-topograms. The accuracy of determination of C isotope compositions is within 1‰. The trace elements (TRE) have been measured in garnets and clinopyroxenes of eclogites by laser Ablation ICP-MS (LAM) at the Utrecht University, Netherlands, with NIST 610 glass as external standard and Ca as internal standard; pit

diameters were 40 –50mm. Garnet-clinopyroxene Nd-Hf-Sr isotope determinations are currently underway.

Table 1. Description of diamonds combusted for $\delta^{13}\text{C}$ analysis.

| Sample | Weight (mg) | Number of crystals for analysis |
|----------|-------------|--|
| BN1 | 0.019 | 3 octahedral crystals |
| U47 | 0.84 | 1 cubic crystal |
| S14 | 0.018 | 1 cubic crystal |
| U60 | 0.052 | 3 cubic crystals |
| U59 | 0.113 | 1 cubic crystal |
| U260 | 0.29 | 1 crystal, yellow |
| U260-2 | 0.086 | chip of crystal, yellow |
| U213 | 0.068 | 2 cubic crystals |
| U388-1 | 0.053 | 1 cubic crystal & little piece of crystal |
| U388-2 | 0.138 | cubic crystal complicated form, graphitized |
| U656-1 | 0.05 | gray cubic intergrowth graphitized |
| U656-2 | 0.06 | white cubic intergrowth partly graphitized |
| U820-1 | 0.102 | complicated form cubic crystal, yellowish\ |
| U820-2 | 0.06 | chip of octahedral crystal, complicated form, yellowish |
| U820-3 | 0.044 | complicated form octahedral crystal, yellowish |
| Ud200 | 0.026 | 2 chips of white octahedral crystal |
| Ud200-2 | 0.013 | piece of white octahedral crystal |
| Ud201-1 | 0.063 | transparent octahedral crystal of polycentric growth, slightly graphitized |
| Ud-201-2 | 0.118 | transparent octahedral crystal similar to previous |
| Ud218 | 0.01 | chip of octahedral crystal |
| A923 | 0.08 | irregular octahedral crystal yellowish & graphitized |
| U759 (1) | 0.04 | 5 gray octahedral crystals |
| U759 (2) | 0.032 | 6 transparent octahedral crystals (3 slightly pink) |
| U759 (3) | 0.06 | 11 octahedral crystals, transparent |
| U759 (4) | 0.04 | 10 octahedral crystals, mostly gray |

Results

Isotope compositions of carbon of combusted diamonds vary between different eclogite xenoliths but are similar in different runs of crystals entire samples (Tabl. 2).

Table 2. Representative data of $\delta^{13}\text{C}$ analyses of diamonds from xenoliths.

| Sample | Weight, mg | $\delta^{13}\text{C}/12\text{C}$ | Calculated |
|---------|------------|----------------------------------|------------|
| BN-1 | 0,019 | -10,013 | -8,68 |
| S14 | 0,018 | -7,903 | -6,54 |
| BN3 | 0,005 | -14,294 | -13,02 |
| U60 | 0,052 | -7,305 | -5,93 |
| U59 | 0,113 | -6,52 | -5,14 |
| U260-2 | 0,086 | -7,28 | -5,91 |
| U215 | 0,068 | -6,604 | -5,22 |
| U388-1 | 0,053 | -7,058 | -5,68 |
| U388-2 | 0,138 | -6,864 | -5,49 |
| U656-1 | 0,05 | -6,36 | -4,98 |
| U-656-2 | 0,06 | -6,79 | -5,41 |
| U820-1 | 0,102 | -6,442 | -5,06 |
| U8202 | 0,06 | -6,246 | -4,86 |
| U820-3 | 0,044 | -6,917 | -5,54 |
| Ud200 | 0,026 | -8,01 | -6,65 |

The main findings of the C isotope study are:

- Carbon isotope composition of diamonds from the 15 xenoliths varies significantly from -15.9 to -2.78‰. Although this range is less than reported from all diamonds from kimberlites (from -38.5 to +5.0‰, Cartigny, 2005), the large variation in a small sample suite establishes that the C source in the eclogite parental rocks was extremely variable;

- Carbon isotope composition of diamonds from a single sample record little variation, with $\delta^{13}\text{C}$ variations usually close to $\pm 1\text{‰}$;

- Core-rim zonations in individual crystals are in the order of 1 per mil.

The rare earths elements (REE) and other trace elements have been obtained for the garnets and clinopyroxene most of the samples where diamonds were studied (Figs. 2, 3). About 80% of analysed on trace elements garnets and clinopyroxenes from investigated samples show a positive Eu-anomaly that suggests of possible formation of eclogitic xenoliths through the recycling of the crust.

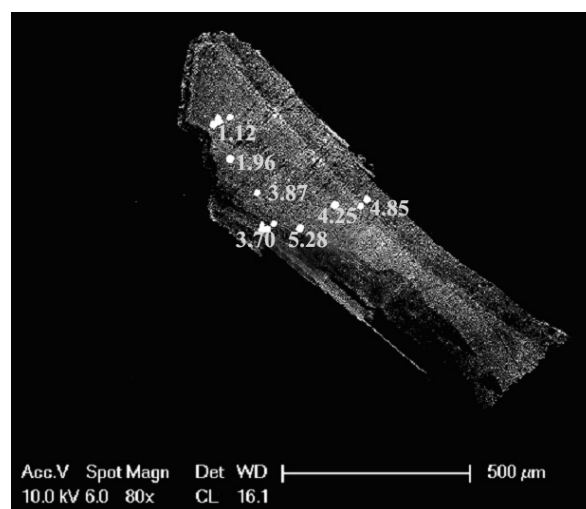


Fig. 1 SIMS data of carbon isotope compositions in entire diamond in situ in eclogite xenolith (sample Ud-28). Results are superposed on CL topogram.

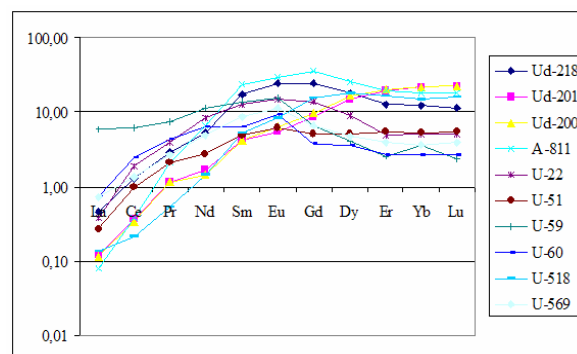


Fig. 2 Chondrite normalized REE distribution in garnets of diamondiferous eclogitic xenoliths from the Udachnaya pipe.

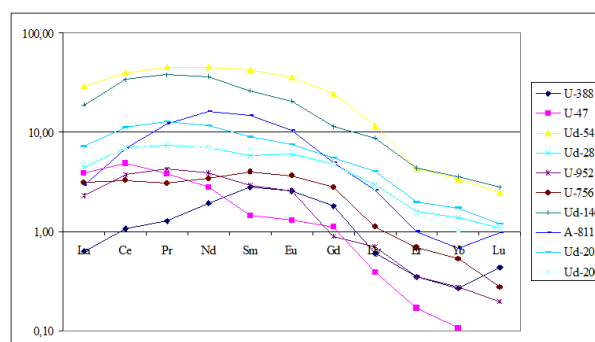


Fig. 3 Chondrite normalized REE distribution in clinopyroxenes of diamondiferous eclogitic xenoliths from the Udachnaya pipe.

Discussion

The minor C isotope variations recorded within individual crystals and individual xenoliths places

important constraints upon the diamond formation process. Individual samples are formed from a large enough C-bearing reservoir that it is not significantly depleted in C and diamond formation is not associated with marked C isotope fractionation. This contrasts markedly with the large but coherent variations in N and C isotopes and N aggregation state reported by Thomassot et al. (2007) for 59 diamonds extracted from a single peridotite xenolith from the Cullinan Mine, South Africa. These authors ascribed precipitation of the diamond population by a Rayleigh distillation process from a methane-bearing fluid. The extreme heterogeneity recorded in the both trace element and C-(N) isotope data for the Udachnaya eclogitic diamonds does not conform to a Rayleigh distillation model. In contrast we favour a recycling model to account for the extreme chemical heterogeneity.

Presence of diamonds with decreasing $\delta^{13}\text{C}$ is fixed in kimberlites of the different provinces (Cartigny, 2005). The study of inclusions being present in them shows that diamonds with the lightened isotopic composition belongs to the eclogitic paragenesis. There are performed determinations of carbon isotopic compositions of diamonds in several xenoliths from the Udachnaya pipe, amongst them are fixed crystals with low $\delta^{13}\text{C}$ values. Carbon isotope composition of diamonds from different xenoliths varies significantly but variations of $\delta^{13}\text{C}$ in different crystals of any individual xenolith are insignificant as a rule. Variations of carbon isotopic compositions inside the entire crystals are within the range of $\delta^{13}\text{C}$ values less than 4 ‰. The distribution of $\delta^{18}\text{O}$ values of diamonds from different eclogitic and ultramafic mantle xenoliths from the Udachnaya kimberlite pipe is distinctly close to those of world-wide occurrences. In combination with literary information (Stepanov et al., 2007), got

results allow to confirm that eclogitic substratum being parent environment for the forming a number of diamonds in some cases have contained crustal carbon recycled into the mantle by subduction or was metasomatised by percolating fluids with crustal marks. Some other evidence as the presence of coesite and separate oxygen isotope determination of high $\delta^{18}\text{O}$ values of garnets (Spetsius and Taylor, 2003) allowed concluding that at least part diamondiferous eclogitic xenoliths are formed in the result of subduction of ancient oceanic crust. This proves the participation of crustal components in process of diamonds nucleation and possibility of the formation of some eclogites through the oceanic crust subduction.

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