[Oxygen isotopes of garnets in diamondiferous eclogites from the Udachnaya pipe, Yakutia: Evidence for their origin]

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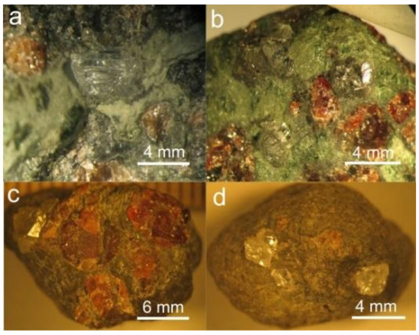
[Introduction]

[The Udachnaya pipe is one of the most unique primary deposits in the Siberian Platform and is characterized by a high content of diamonds and their high quality. It is the deepest open-pit mine in the world and well-known for it numerous eclogite xenoliths of different varieties (A, B & C Groups), including a wide selection of diamondiferous eclogites. At that moment from kimberlites of this pipe were recovered more than 300 xenoliths with diamonds. The relatively numerous diamondiferous eclogites from the Udachnaya have been well-characterized (e.g., Sobolev et al., 1994); however, oxygen isotope analyses of minerals from these samples are not abundant (Spetsius et al., 2009).
Mantle eclogites make up an important component in mantle xenolith suites and diamondiferous eclogites represent one of the main diamond reservoirs. Studies of eclogites are important for refining models of global crust-mantle evolution and provide constraints on the origin of diamondiferous mantle as eclogites represent significant diamond reservoirs in some portions of SCLM of Siberian Craton (e.g., Spetsius et al., 2008). Here, we present major- and trace-element data for eclogitic minerals along with oxygen-isotope data for garnets from 30 new samples and some xenoliths of old collection eclogites with diamonds.

Samples and Methods

Studied collection of 60 diamondiferous xenoliths from the Udachnaya pipe of Yakutia comprise by bimineralic eclogites, rare kyanite eclogites and some corundum eclogites. Most xenoliths contain two or more diamond crystals (0.2-1.0 mm) with predominantly octahedral or transient forms (Fig. 1). The amount of diamonds in separate samples could be up to 260 crystals with the predominating of small crystals (<1.0 mm). Cubic diamonds were found in six xenoliths. The distribution of crystals in xenoliths is irregular and does not coincide with the specimen surfaces. Mineral inclusions are rare and represented by sulfides, garnet, clinopyroxene and rare rutile. Fine-grained interstitial metasomatic mineral assemblages and partial melting phases have been identified in all xenoliths; this is a characteristic a specific feature of diamondiferous eclogites (Spetsius, Taylor, 2008).
Major element compositions of eclogite minerals were determined with a Superprobe JXA-8800R electron microprobe at the "ALROSA" OJS Company. Natural minerals and synthetic were used as standards. Analytical conditions included an accelerating voltage of 15 keV, a beam current of 20 nA, beam size of 5 µm, and 20 seconds counting time for all elements. All analyses underwent a full ZAF correction. The trace elements have been measured by laser Ablation ICP-MS (LAM) at the Macquarie University, with NIST 610 glass as external standard and Ca as internal standard; pit diameters were 40 –50 mm.
Oxygen-isotopes were measured on the garnet separates using a laser fluorination technique at the University of Wisconsin, Madison. Prior to analysis, the samples were cleaned with isopropanol and methylene chloride to remove any contaminants. The oxygen-isotope analyses were performed on garnet mineral separates, approximately 1-2 mg per run, using a 32 W CO_2 laser, BrF_5, and a dual-inlet Finnigan MAT 251 mass spectrometer (Valley et al., 1995). All $\delta^{18}O$ values are reported with respect to V-SMOW. Over the course of oxygen-isotope analysis, standard UWG-2 gave a mean of 5.77 ± 0.14 ‰ (2 sd). Replicate analyses were performed on several samples including those that had initial oxygen-isotope values outside of the normal mantle range of 4.7-5.9 ‰.



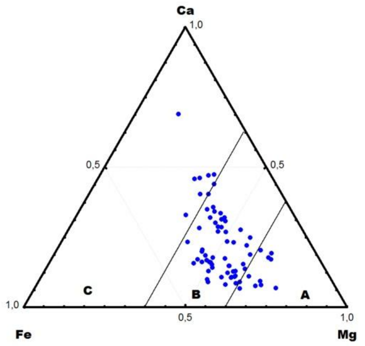


Figure 1: Diamondiferous eclogites from the Udachnaya pipe. (a - sample Ue-11 with the step-faced octahedron crystal, b - sample Ue-12 containing more than 10 octahedral crystals, c - sample Ue-28 containing octahedron with two inclusions of sulfides, d - sample Ue-33 corundum eclogite containing 6 octahedral crystals).
Figure 2: Compositions of diamondiferous eclogites garnets from the Udachnaya on Ca-Fe–Mg ternary plot.

[**Analytical Results**

Garnets from eclogitic xenoliths have a wide variation in Fe-, Mg- and Ca-content (Spetsius and Taylor, 2008). Studied garnets are relatively low in Cr_2O_3 (< 0.2 wt. %) and plot predominantly within the Group B eclogite field and six garnets from kyanite and corundum eclogites have occupied the field of C-group eclogites (Fig. 2). Garnets of two eclogites with corundum differ by higher Ca# (up to 17.2 wt. % CaO) and they have high Mg#. Twelve high-magnesian garnets with MgO content up to 20 wt.% answer the field of B-group eclogites. Minerals in eclogites from this study display no zonation in their chemistry; as such, the major-element compositions can be used to estimate the equilibration temperatures of these samples. Clinopyroxene-garnet thermobarometry which is based on Mg–Fe^{2+} exchange suggests equilibration at 1000–1325 °C at 4 GPa according the thermometer of Ellis and Green (1979).

The rare earths elements (REE) and other trace elements have been obtained for the garnets and clinopyroxenes. Eclogitic garnets form obvious two different groups of TRE profiles with low and high LREE (Fig. 3). Most clinopyroxenes and some garnets in xenoliths display LREE and MREE enrichments, consistent with minor amounts of cryptic metasomatism. The presence of Eu-anomalies suggests a plagioclase-rich cumulate protolith for some eclogites. The distribution of REE for Group C and partly B eclogites overlap with typical oceanic basalts; the presences of distinct Eu anomalies suggest that their protoliths had undergone significant plagioclase fractionation/accumulation. Most clinopyroxenes and about 40% of the garnets display LREE and MREE enrichments, consistent with possible cryptic metasomatism. The lack of obvious minerals zoning preserved in these samples suggests that any cryptic metasomatism must have occurred over relatively large time scales, likely predating entrainment into the host kimberlite.

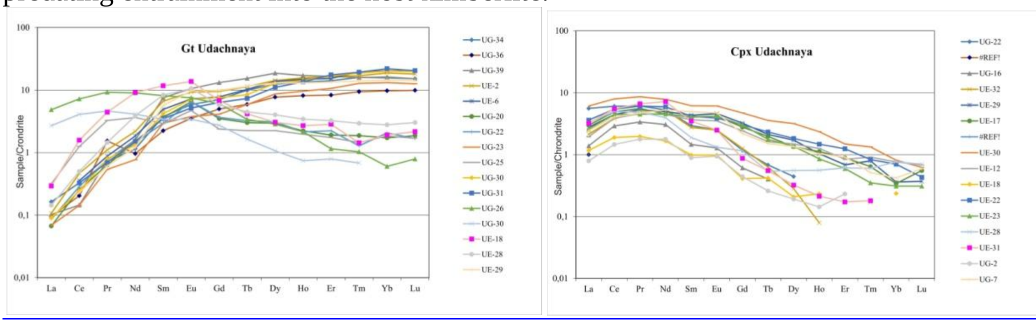


Figure 3: Chondrite-normalized REE abundances of Udachnaya eclogite garnets and clinopyroxenes. All normalization factors from McDonough and Sun (1995).

The garnet oxygen isotope data can be divided into two distinct groups of eclogites. The majority of the samples lie within the range of average mantle $\delta^{18}O$ values (5.5±0.45 ‰), and remaining group (≈40%) have $\delta^{18}O$ values above 6.0 ‰. This second group includes all garnets of Group C eclogites and part of the Group B garnets, with high contents of MgO (>14.0 wt. %) and low CaO <7.5 wt. %.

There is fixed not a very strong inverse relationship of $\delta^{18}O$ values with Mg# of garnets. It should be pointed that all high magnesium Group A garnets answer mantle range. We have presented on a diagram (Fig. 4) a comparison the results of oxygen isotope data for Udachnaya eclogitic garnets with analogous data for garnets of Nyurbinskaya diamondiferous xenoliths that show very obvious similarity. The unusual range of high $\delta^{18}O$ values for these xenolithic garnets is accompanied by evidence for strong late-stage metasomatism. Thereby, the possibility exists that mantle metasomatic fluids may also possess crustal signatures, as a result of ancient subduction. This wide range and abundance of high $\delta^{18}O$ values of garnets in diamondiferous xenoliths from Udachnaya and Nyurbinskaya pipes, outside of mantle values that combined with crustal evidences from several of the other Yakutian kimberlites (Spetsius et al., 2014; Pernet-Fisher et al., 2014), confirm the intense evolution of the lithospheric mantle beneath the Siberian Platform.

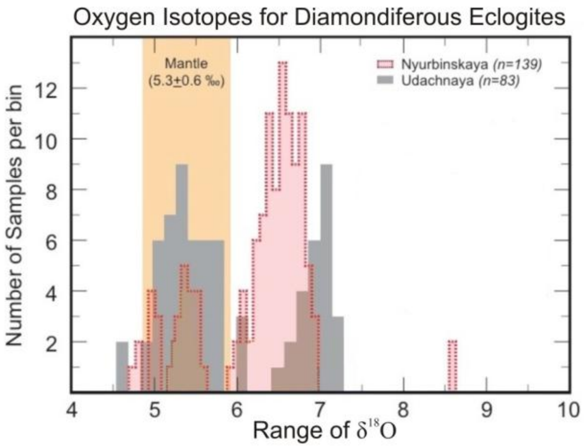


Figure 4: Distribution of $\delta^{18}O$ in garnets of diamondiferous eclogitic xenoliths from the Udachnaya pipe in comparison with $\delta^{18}O$ for garnets of Nyurbinskaya diamondiferous xenoliths (Spetsius et al., 2008).

Conclusions

In summary, we confirm that approximately half of diamondiferous eclogites from the Udachnaya pipe represent protoliths from subducted oceanic crust, with the possibility of a portion of the eclogites as mantle restites. The distribution of diamonds in the xenoliths, the presence of diamonds with different morphology in the same xenolith and other evidence suggest multistage diamond growth from metasomatic fluids that could be a generated during subduction.]

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