

Mantle Xenoliths from the Obnazhennaya Kimberlite, Yakutia

Keller, Randall A.¹, Remley, David A.¹, Snyder, Gregory A.¹, Taylor, Lawrence A.¹, and Sobolev, Nikolai V.²

¹Planetary Geosciences Institute, University of Tennessee, Knoxville, TN, 37996, USA; rkeller@utk.edu

²Institute of Mineralogy and Petrography, Russian Academy of Sciences, Novosibirsk 630090, Russia

Introduction

The Obnazhennaya kimberlite erupted near the edge of the Siberian platform and is diamond-free; are these two facts related? By studying eclogite and peridotite xenoliths from the Obnazhennaya kimberlite, we hope to determine why the mantle conditions beneath the northeastern edge of the Siberian platform are not conducive to diamond growth, or that diamonds could exist in the mantle beneath Obnazhennaya, but were destroyed enroute to the surface.

Petrography

Eclogites from Obnazhennaya are composed of dark-to-bright green clinopyroxene up to 3 cm, pale orangish-pink garnet up to 1.2 cm, and trace amounts of orthopyroxene less than 3 mm. The xenoliths are highly fractured, with moderate secondary alteration occurring along these fractures. Typical secondary minerals include serpentine, chlorite, and carbonate. Thin kelyphytic rims are found on many of the garnets. The garnets also show evidence of serpentinization and amphibolization along internal fractures. Kimberlite penetrates fractures in most of the samples to various degrees. Orthopyroxene exsolution in the clinopyroxene, and rutile exsolution in the garnet, also occur. Trace amounts of sulfide occur in some of the samples.

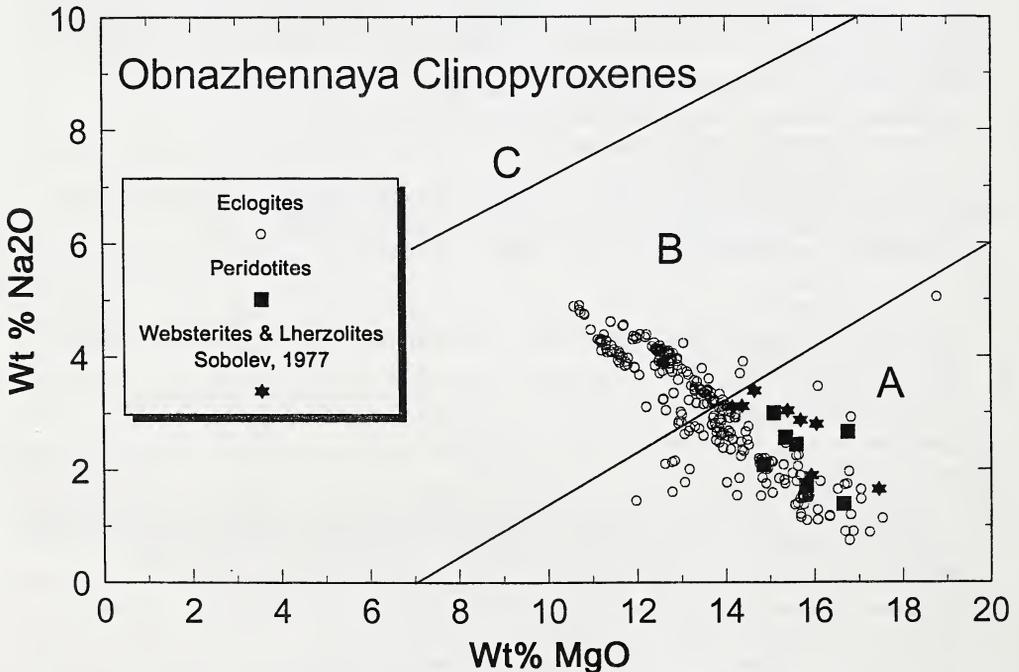


Figure 1. MgO vs. Na₂O in clinopyroxene. Cores of clinopyroxenes from the Obnazhennaya eclogites plot within the field for Group B eclogites, while some rims plot within the Group A field. As expected, clinopyroxene from the Obnazhennaya peridotites plot entirely within the Group A field. Group boundaries are from Taylor and Neal (1989).

Petrology

Clinopyroxenes in the eclogites are diopsidic to augitic and have core-to-rim compositional variations that include decreasing Al_2O_3 , FeO , and Na_2O , and increasing MgO and CaO . These variations are such that the core compositions of many of the clinopyroxenes plot within the field for Group B eclogites worldwide (Taylor and Neal, 1989; Figure 1), whereas rim compositions of many of those same clinopyroxenes extend into the Group A eclogite field. The same general trend in clinopyroxene compositions is also observed in the garnets, although garnet compositions cover a narrower range. The garnets are pyropic and fall within the lherzolite trend on a plot of Cr_2O_3 vs. CaO (Figure 2).

The peridotite xenoliths include lherzolite, spinel lherzolite, garnet websterite, and garnet peridotite. Preliminary indications are that the clinopyroxene is mainly diopsidic with core-to-rim decreases in Al_2O_3 , MgO , FeO , and Na_2O , and increases in CaO concentrations. Garnet is pyropic and has core to rim variations that include increasing Al_2O_3 and MgO , and decreasing Cr_2O_3 , CaO , and FeO . Orthopyroxene is bronzite with slight increases in FeO and Al_2O_3 from core to rim. Olivine is homogeneous at approximately Fo_{92} .

Discussion

Garnets and clinopyroxenes in eclogites from kimberlites throughout the world have low Cr_2O_3 contents (Figures 2 and 3). Garnets and clinopyroxenes from Obnazhennaya eclogites, however, have wide ranges of Cr_2O_3 contents (up to 4.1 wt.% in garnet and 0.8 wt.% in clinopyroxene) and some of the garnets fall along a trend defined by lherzolites in Cr_2O_3 vs. CaO space (Figure 2). This may indicate that Obnazhennaya eclogites interacted with peridotite or kimberlite. Such interaction may have provided opportunities for minerals to re-equilibrate, and even for high-pressure phases such as diamond to dissolve completely. Preliminary geothermometry and geobarometry calculations (Ellis and Green, 1979; Finnerty and Boyd, 1987) place the peridotites at conditions just shallower than depths where diamonds are stable (1145–1280 °C and 24–37 kb), and the eclogites even shallower (1135–1170 °C and 20–32 kb).

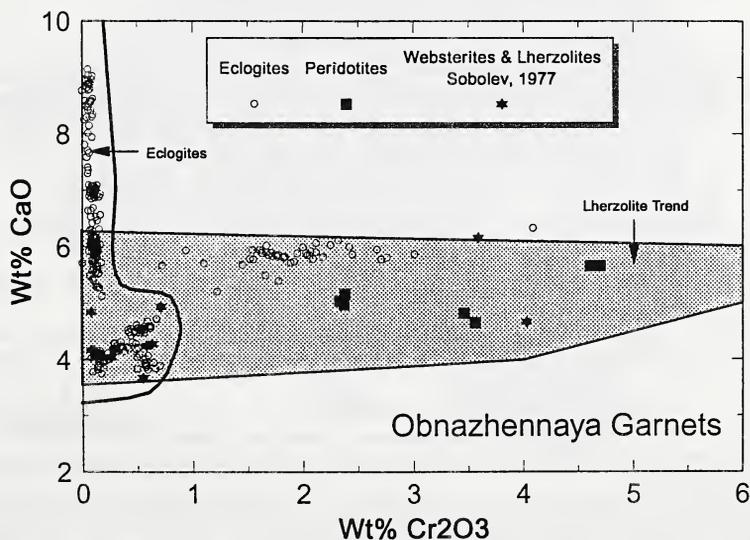


Figure 2. Cr_2O_3 vs. CaO in garnet. Garnets from eclogites worldwide are mostly low in Cr_2O_3 , but garnets from Obnazhennaya eclogites follow the lherzolite trend towards high Cr_2O_3 . Garnets from Obnazhennaya peridotites also follow the lherzolite trend of Sobolev et al. (1973). Data for eclogite field from numerous sources.

Garnet compositions, as well as clinopyroxene rim compositions, of eclogites from Obnazhennaya are similar to Group A eclogites (Coleman et al., 1965). This fits with the fact that Obnazhennaya eclogites, like most Group A eclogites, are diamond-free. Clinopyroxene rim compositions approach clinopyroxene compositions found in Obnazhennaya peridotites. However, core compositions of clinopyroxenes in Obnazhennaya eclogites are similar to Group B eclogites from other kimberlites in Siberia, including diamondiferous kimberlites. These variations in the mineral chemistry of the Obnazhennaya xenoliths, combined with complexities in the Sr-Nd isotopic systematics of Obnazhennaya eclogites (Snyder et al., this volume) suggest that the Obnazhennaya xenoliths had complex histories, perhaps including partial equilibration with peridotite or even kimberlite. Such complex histories could be fatal to diamonds.

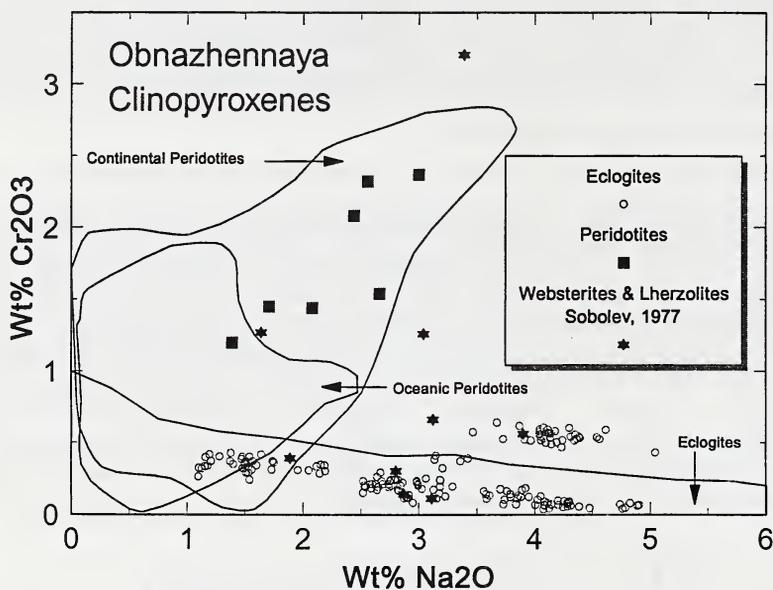


Figure 3. Na_2O vs. Cr_2O_3 in clinopyroxene. Clinopyroxenes from eclogites worldwide are mostly low in Cr_2O_3 , but clinopyroxenes from Obnazhennaya eclogites extend towards high Cr_2O_3 , similar to peridotites. Clinopyroxenes from Obnazhennaya peridotites plot at the high- Cr_2O_3 end of the peridotite field. Data for eclogite and peridotite fields from numerous sources.

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3-D Petrography of a Diamondiferous Eclogite from Udachnaya, Siberia

Keller, Randall A.¹, Taylor, Lawrence A.¹, Snyder, Gregory A.¹, Sobolev, Vladimir S.¹, Carlson, William D.², Sobolev, Nikolai V.³, and Pokhilenko, Nikolai P.³

¹Planetary Geosciences Institute, University of Tennessee, Knoxville, TN, 37996, USA; rkeller@utk.edu

²Department of Geological Sciences, University of Texas, Austin, TX, 78712, USA

³Institute of Mineralogy and Petrography, Russian Academy of Sciences, Novosibirsk 630090, Russia

Introduction

The environment in which diamonds form is preserved in diamondiferous xenoliths, but this environment has never been fully examined in three dimensions. We are conducting a detailed analysis of a diamond assemblage *in situ* in an eclogite xenolith to establish the timing and conditions of diamond crystallization. This addresses one of the fundamental questions of diamond genesis: Did these diamonds crystallize at the same time as their host rock (i.e., are they igneous), or are they associated with a later metasomatic fluid event (i.e., metamorphic)? Our approach is a complete characterization of the 3-D texture of a 4x5x6 cm eclogite xenolith from the Udachnaya kimberlite (Yakutia) using high-resolution X-ray computed tomography (HRXCT; Denison et al., 1997; Rowe et al., 1997), followed by dissection of the xenolith and detailed examination and chemical analyses of the diamonds, their inclusions, and the associated eclogite host minerals.

Tomography & 3-D Petrography

The entire volume of eclogite xenolith U51-3 was scanned in a series of 79 X-ray slices (Figure 1) at a slice thickness of 0.5 mm, using a microfocal X-ray source operating at 100 kV and 0.4 mA.

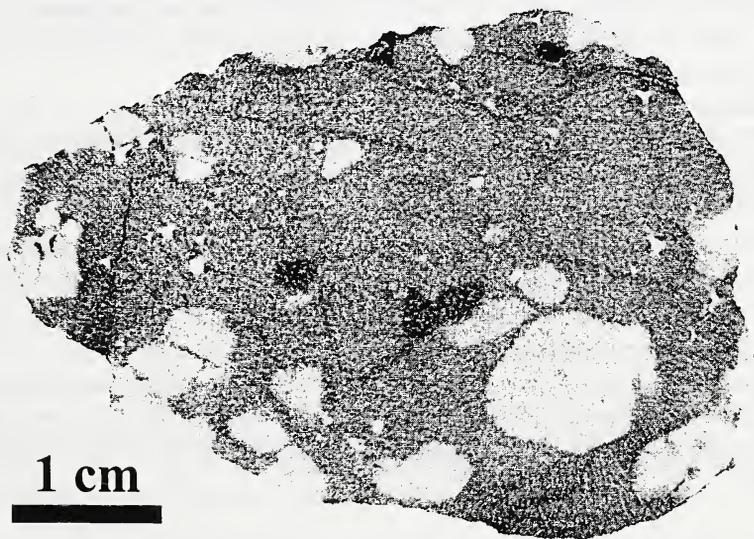


Figure 1. A tomographic "slice" through the diamondiferous eclogite shows diamonds (dark gray to black shapes near the center and top edge of the image), sulfides (small white spots), and garnets (light gray shapes) in a matrix of clinopyroxene (medium gray) with a linear alteration fabric (seen as slightly darker gray lines). The entire volume of the sample was scanned in a series of 79 of these X-ray slices. Darkness in this grayscale image inversely corresponds with a combination of density and mean atomic number. The diamonds are easily distinguished from the other minerals using this technique, whereas previous XCT experiments on a diamondiferous rock (Schulze et al., 1996) resolved diamonds only where they were surrounded by a high-density mineral (barite).

This provided optimum contrast between the minerals present, and in-plane resolution of approximately 0.25 mm. Beam-hardening artifacts were minimized by embedding the sample in powdered garnet, and correcting for absorption measured in a scan through the powder alone. The HRXCT clearly resolved the diamonds in this sample and the textural details of their surrounding mineral assemblages. Stacking the 79 HRXCT slices into a three-dimensional digital model of the xenolith allows us to view spatial relationships between the diamonds, textural relationships between the diamonds and the eclogite, and calculate volume percentages of minerals.

The sample is 0.5% macro-diamonds by volume, or approximately 25,000 carats/tonne. Eleven diamonds with maximum dimensions of up to 4 mm are visible on the exterior of the sample, and HRXCT revealed an additional 19 diamonds in the interior. Ten of the 30 diamonds abut kelyphytic rims of garnets, but the diamonds are never enclosed within a garnet or clinopyroxene crystal, consistent with the interpretation that the diamonds postdate the silicate minerals. Most of the diamonds are associated with the prominent fabric of alteration veins (visible in hand-sample and in the HRXCT data), which is also consistent with a secondary origin for the diamonds. An alternative explanation is that the rock was preferentially altered around the diamonds. This may be possible because of the large difference in compressibility between diamonds and silicate minerals. Differential expansion could have localized stress at the diamonds, causing the rock to preferentially fracture and more easily alter around the diamonds.

The remainder of the xenolith consists of 31% red-orange garnets ($\text{Gr}_9\text{Py}_{58}\text{Al}_{32}$) up to 1 cm in diameter and 1% Fe-Ni sulfides up to 3 mm in diameter, all dispersed in a variably altered matrix of dark green (where unaltered) clinopyroxene ($\text{Wo}_{37}\text{En}_{49}\text{Fs}_{14}$; Na_2O - 5.5 wt.%) that makes up 68% of the sample. All of the garnets have kelyphytic rims, but are otherwise fresh. Clinopyroxene occurs as inclusions in garnet, and vice versa. Sulfides occur as inclusions in garnet and clinopyroxene. There are no systematic differences between garnets and clinopyroxenes that abut diamonds and those that do not.

Inclusions in Diamonds

Nearly all of the diamonds in this eclogite contain numerous mineral inclusions. Sulfide inclusions are ubiquitous, whereas clinopyroxene inclusions are far less abundant, and garnets are rare. Many inclusions less than 20 μm in size also occur, but have not been positively identified.

Two 50–100 μm clinopyroxene inclusions from crack-free regions of two separate diamonds have compositions similar to clinopyroxene in the host xenolith except that the inclusions have distinctly lower Na_2O (4.5 wt.% vs. 5.5 wt.%) and higher K_2O (0.2 wt.% vs. <0.1 wt.%) than the host (Figure 2). This same phenomenon was observed by Taylor et al. (1996) in other eclogitic diamond inclusions from Udachnaya. Higher K_2O in the clinopyroxene inclusions is consistent with crystallization at a higher pressure (Harlow and Veblen, 1991) and suggests that the clinopyroxenes in the host were partially melted or re-equilibrated at a lower pressure after the diamonds formed.

Conclusion

Apart from minor re-equilibration at lower pressure, clinopyroxene in this eclogite xenolith has changed little since the time that the diamonds crystallized. We take this as evidence that this xenolith is a well-preserved sample of the environment in which eclogitic diamonds form. That every single one of the 30 diamonds in this xenolith is associated with alteration is compelling evidence for the interpretation that the diamonds crystallized during a metasomatic event.

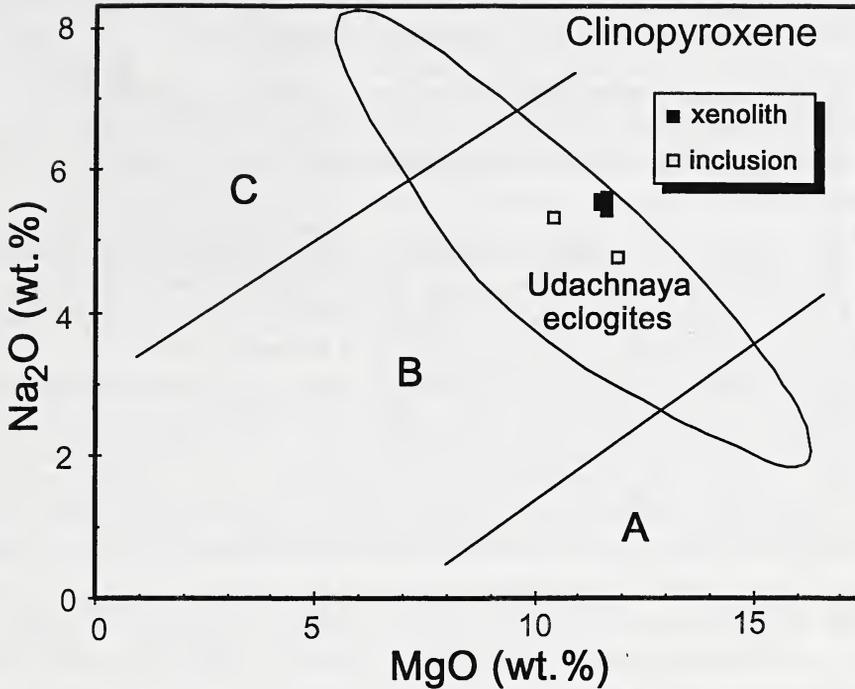


Figure 2. Clinopyroxene inclusions in diamonds from eclogite U51-3 have lower Na_2O contents and lower to slightly higher MgO contents than clinopyroxenes in the eclogite host. Both the host and the inclusions plot within the field for Group B eclogites, which is consistent with data for the majority of Udachnaya (field from Sobolev et al., 1994). Group boundaries are from Taylor and Neal (1989).

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