

Yakutian Diamond-forming fluids - the evolution of carbonatitic high density fluids

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Introduction

Sub-micrometer inclusions in fibrous diamonds carry high-density fluids (HDF) from which the diamonds have precipitated. The trapped material remains shielded from the changing conditions and its analysis is a major tool for direct study of mantle fluids.

The composition of the trapped HDFs varies between three end-members: (a) a silicic end-member rich in water, Si, Al, K and water; (b) a carbonatitic end-member rich in carbonate, Mg, Ca K and carbonate and (c) a saline end-member rich in Cl, K and water.

Evolutionary models for the observed fluid range suggests progression from a parental HDF towards the composition of the other end-members through mineral fractionation and fluid immiscibility (e.g. Klein-BenDavid et al., 2007; Safonov et al. 2007a, b). However, carbon isotopic composition of the diamond matrix (Shiryayev et al., 2005), radial profiles (Weiss et al., 2008) and radiogenic isotope signature of the HDFs (Klein-BenDavid et al., 2008) indicate that HDF evolution, even during the growth of single diamonds involves mixing between various components.

A genetic connection between the HDFs and kimberlitic melts was suggested based on their major and trace element data patterns and their high volatile concentration. Various mechanisms, such as metasomatic interaction with mantle rocks, melting of carbonated peridotite or eclogite or fractional crystallization and immiscible separation of kimberlitic melts have been proposed as mechanisms for the evolution of the parental fluids.

Here we present a comprehensive study of the major element composition (EPMA), the volatile content (FTIR), and the carbon isotopic composition (SIMS) of

a suit of diamonds from various mines in Yakutia, Siberia. Most of the diamonds carry carbonatitic HDFs and allow a close look on the primary stages of evolution of HDFs and the relations between them and kimberlites.

Results

High-Mg Carbonatitic HDFs (MgO>15 wt%)

The high-Mg carbonatitic group is unique to Yakutian diamond. On a CO₂ and water-free basis, the composition of the average high-Mg carbonatitic HDF is: SiO₂=8.9 wt%, TiO₂=1.1%, Al₂O₃=0.9%, FeO=8.4%, MgO=22.5% CaO=19.5%, BaO=1.2%, Na₂O=8.4%, K₂O=21.7%, P₂O₅=2.7%, Cl=4.1% and Cr₂O₃=1.2%.

The high-Mg HDFs are more primitive than the previously defined carbonatitic end-members (e.g. Schrauder and Navon 1994), exhibiting higher Mg# and MgO content. Figure 1 shows continuous evolution of the compositions between 28 and 17 wt% MgO, a gap between 17 and 12% and different trends in the low-Mg suite. The decrease in MgO content from 28 wt% to 17 wt% is accompanied by similar decrease in the CaO content. The SiO₂, Al₂O₃, TiO₂ and P₂O₅ contents remains constant, Na₂O and Cl concentrations increase and K₂O content first increases and then decreases (at ~20% MgO). All the arrays in Fig. 1 may be explained by fractionation of an assemblage consisting of ~85 wt% of Ca-Mg carbonates, 12 wt% silicates (CPX and garnet) and 3 wt % of apatite and rutile. At around 20% MgO, K₂O concentration starts falling. The most probable explanations are the fractionation of K-bearing carbonate phase and/or the loss of K₂O and water to the wall-rock.

The gap between 17 and 12 wt% MgO marks a change in the evolution of the HDF. CaO concentration stop



falling and even increases and TiO₂ content starts rising. The fall in K₂O is now accompanied by fall in Na₂O and Cl. SiO₂ and Al₂O₃ retain their constant values down to ~10% MgO. Thereafter, their concentration rises while those of all other elements decrease. Fractionation is not the only possible mechanism; as discussed in more detail in Navon et al., (2008) it may form as a result of penetration of saline HDF into a carbonate-peridotite (Safonov et al., 2007), or during melting of peridotite in the presence of fluids and accessory phases such as mica, carbonate and apatite.

Low-Mg HDFs

Diamond forming fluids with compositions that range between carbonatitic and silicic HDFs were previously reported in fibrous diamonds from worldwide locations. The Yakutian low-Mg HDFs reported here also falls in that range. Close examination reveals a number of differences between HDFs from different localities. For example, Botswanan and Yakutian suites form parallel arrays, but at the same silica content, Botswanan HDFs have higher TiO₂, FeO and MgO and lower Al₂O₃ concentrations. Such differences in major element chemistry between the various suites may be used for tracing the source locality of suites of HDF-bearing diamonds.

The High-Mg suite and kimberlites

Kimberlites and HDFs are highly enriched in incompatible elements and carbon isotopic composition of kimberlites and the HDF-bearing diamonds is close. However, the major elements composition of the two is quite distinct. With MgO up to 28% the high-Mg suite comes close to kimberlitic composition, but still, with lower silica and alumina content and higher K₂O, Na₂O and CaO levels. Experimental work in peridotitic, carbonate bearing systems have shown that the composition of near solidus melt come close to that of the high-Mg carbonatitic HDFs (Fig 2). This resemblance indicates that it may be possible to produce the high-Mg HDFs by incipient melting of phlogopite-carbonate-peridotite or in the presence of saline HDF. It should also be possible to reach the composition of the HDFs by cooling and crystallization of kimberlitic-like melts produced by higher degrees of partial melt, or by mixing such melts with saline HDF.

The evolution of the low-Mg suite

Klein-BenDavid et al. (2007) have suggested that HDFs evolve from a parental carbonatitic-HDF through the precipitation of various minerals and the separation into two immiscible HDFs: silicic and saline. Recently Safonov et al. (2007a, b) performed experiments at 5 GPa and 1400-1600°C in anhydrous silicate-carbonate-chloride systems. They suggested that the evolution of cooling silicate-carbonate melts is from more silicic to more carbonatitic composition with a parallel evolution of the saline melt towards more carbonatitic composition. We suggest that the

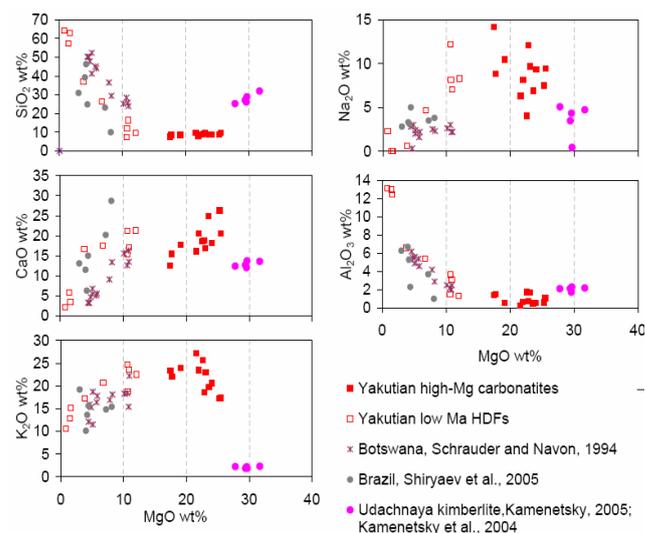


Figure 1. The co-variation between different oxides and MgO in HDF-bearing diamonds.

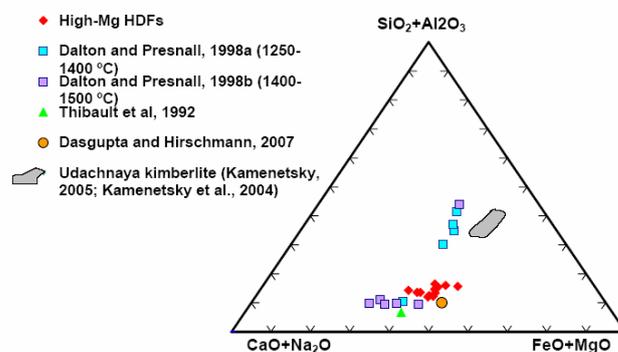


Figure 2. Yakutian HDF and kimberlite composition compared with experimental melt composition in peridotitic systems.

observations of Safonov et al., (2007) relate to interaction of saline HDFs with high-temperature melts with low water content along the carbonatitic-kimberlitic join, where the carbonatitic melts are the near solidus melts. The silicic HDFs are hydrous and very rich in silica. They resemble low temperature melts of eclogites (Yaxley et al. 2004; Kessel et al., 2005). We propose that these HDFs were trapped at lower temperatures, and that at these lower temperatures, the evolution of cooling HDFs is from carbonatitic towards water-rich silicic compositions.

Carbon Isotopic composition and the role of mixing

The $\delta^{13}\text{C}$ of four of the diamonds was measured. The internal variation is different for each diamond with tendency to evolve towards heavier compositions, yet most analyses fall within the common range of fibrous diamonds. If grown from a single fluid, the observed zoning calls for extensive isotopic fractionation (e.g. >50% for evolving from -7.3 to -5.2‰ in one diamond from Udachnaya). Such strong fractionation is not supported by the chemical composition of the fluid. Open systems CO₂ degassing or growth from methane-

rich fluids are not compatible as they lead to lighter isotopic composition. We conclude that that mixing must play a major role in the evolution of the HDFs and the diamonds. Additional evidence for mixing come from radiogenic isotopes (Klein-BenDavid et al., this volume) and radial evolution of HDFs in Guinean diamonds (Weiss et al., 2008).

Conclusions

We suggest that fractionation of carbonatitic HDFs, melting of a water+carbonate+K-bearing source and interactions of infiltrating fluids with the surrounding wall rocks are the fundamental processes that produce the range of HDF compositions. Mixing of newly arriving HDFs with pre-existing fluids, or metasomatic interaction between such fluids and the mantle rocks is important in the formation of individual diamonds.

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