Groundmass of unaltered kimberlites of the Udachnaya-East pipe (Yakutia, Russia): a sample of the kimberlite melt

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Introduction. The majority of the Siberian kimberlites (>90%), alike other kimberlites in the world, are variably affected by syn- and postmagmatic alteration. The alteration has mostly affected the mineral and chemical compositions of the kimberlite groundmass, so it is characterised by low-Si, high-Ca and high-Si, high-Mg endmembers, represented by calcite and serpentine, respectively. Although some studies claim findings of unaltered and macrocryst-poor kimberlite varieties (le Roex et al., 2003; Price et al., 2000), the groundmass of such kimberlites still remains dominated by abundant calcite and serpentine. The compositional effects, if any, of other groundmass phases are scarcely reported. Contrary to previous studies of group-I kimberlites worldwide, we record at least twenty magmatic minerals in the groundmass of the uniquely fresh kimberlites of the Udachnaya-East pipe. These phases are primarily responsible for so far unknown compositional features of kimberlites, such as low H_2O contents, and highly elevated CO_2, alkalies and chlorine (Kamenetsky et al., 2004; Kamenetsky et al., 2007b; Maas et al., 2005).

Groundmass mineralogy. Unaltered Udachnaya-East kimberlite rocks are located within a central subvertical stock at depths below 370 m (Marshintsev et al., 1976). These massive hypabyssal kimberlites are exclusive in having abundant fresh olivine and small quantities of xenoliths of sedimentary origin (1-6% cf 25-30% in the Udachnaya-East kimberlite breccias). The porphyritic texture of the rocks is defined by large olivine grains (up to 1 cm, 20-30 vol%; Fig. 1), and to a lesser extent by minor (<5%) macroocrysts of garnet, picroilmenite, clinopyroxene and phlogopite. The fine-grained (<0.5-0.7 mm) groundmass is dominated by olivine (up to 50 vol%, Fig. 1). Other silicates (phlogopite, monticellite, humite, sodalite), oxides (Na-bearing perovskite, chromite, Ti-magnetite, magnetite, rutile and picroilmenite), phosphates (apatite), alkali sulphate – aphtitalite $NaK_3(SO_4)_2$ and sulphides (pyrrhotite, pentlandite, rasvumite KFe_2S_3 and djerfisherite $K_6(Fe,Cu,Ni)_{25}S_{26}Cl$ are minor (~ 10 vol% in total) (Fig. 2). Carbonates and chlorides are very significant in the groundmass reaching up to 30 and 10 vol%, respectively (Figs. 3, 4). They are represented by calcite, dolomite, shortite $Na_2Ca_2(CO_3)$, zemkorite $(Na,K)_2Ca(CO_3)_2$, and chlorides - halite and sylvite. The early crystallising minerals (olivine, phlogopite, perovskite and Cr-Ti-Fe spinel) are characterised by compositional zoning (Fig. 2), especially complex zoning is shown by olivine

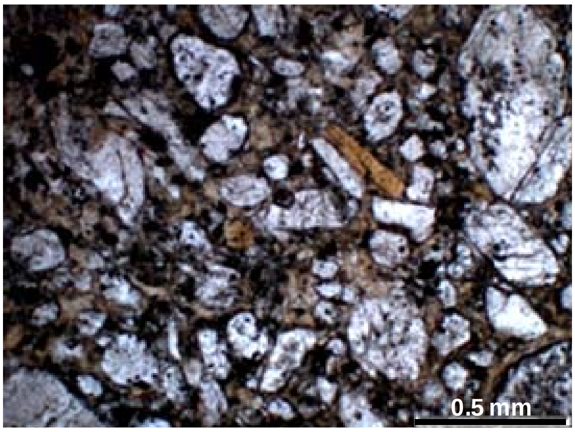

Fig. 1. Typical appearence of fresh Udachnaya-East kimberlite (thin section, transmitted light)

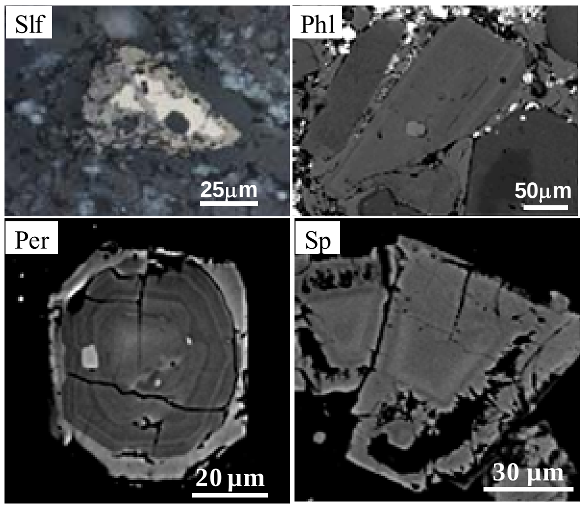

Fig. 2. Examples of the groundmass minerals with compositional zoning: sulphides (pyrrhotite - djerfisherite), phlogopite, perovskite and spinel (chromite - magnetite)

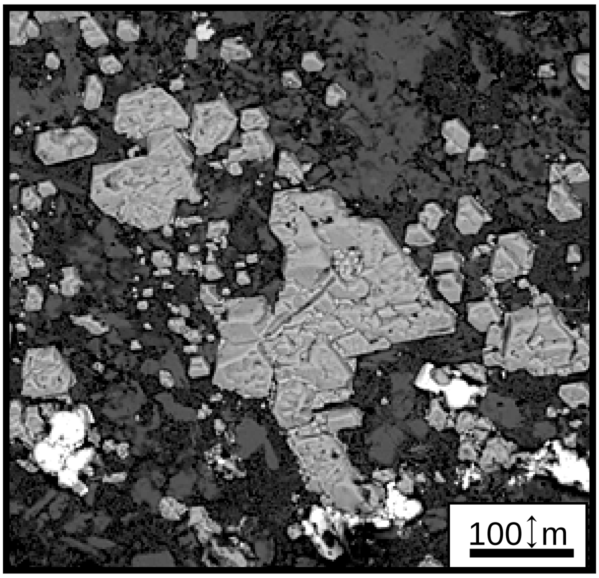

Fig. 3. Abundant chloride segregations in the kimberlite groundmass.

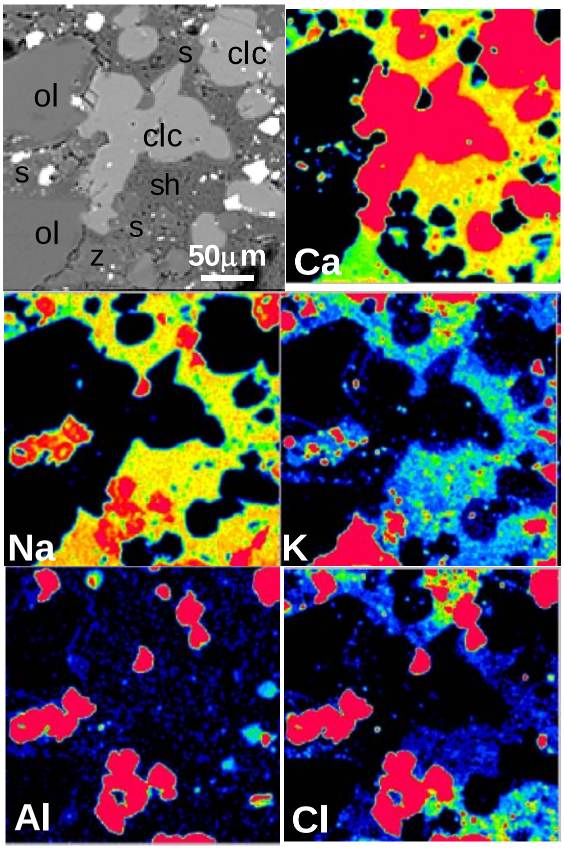

Fig. 4. BSE image and X-ray elemental maps showing groundmass olivine (ol), calcite (clc), shortite (sh), zemkorite (z) and sodalite (s).

phenocrysts (Kamenetsky et al., 2008a). The late groundmass minerals are more homogeneous in composition. In some samples we recorded magmatic veinlets and round mineral segregations that can be also attributed to the groundmass assemblage (Fig. 5). They are composed of olivine, monticellite, phlogopite, sodalite, perovskite, chromite, T-magnetite, rutile, picroilmenite, djerfisherite, calcite, halite and sylvite. It is worth noting that carbonates are minor in this assemblage (3.2 wt% CO_2), and sodalite is one of the latest phases, cementing other phases.

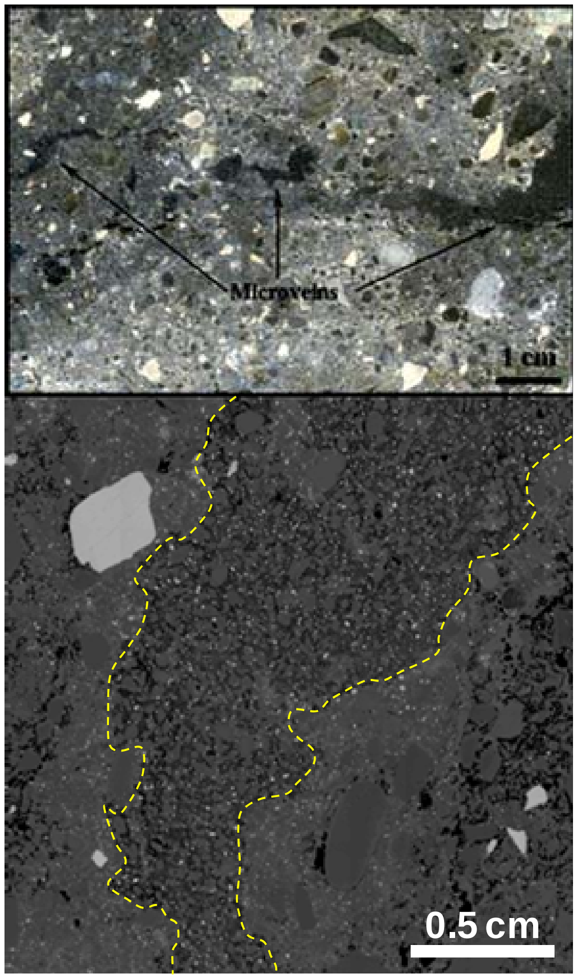

Fig. 5. Photo and BSE image of fresh kimberlite with olivine-monticellite-sodalite-perovskite veinlets.

Discussion. Most of the Udachnaya-East groundmass minerals have been previously described as magmatic in other kimberlites across the world (Mitchell, 1986; Mitchell, 1995). Reports of other minerals, such as djerfisherite and shortite are scarce (Clarke et al., 1994; Watkinson and Chao, 1973). Sodalite, rasvumite, zemkorite, aphtitalite and chlorides, found in our samples, are recorded for the first time. The origin of the latter is still debated in the Russian literature, however, magmatic crystallisation of these unusual minerals is well supported by compositions and trapping temperatures of the olivine-hosted melt inclusions (Golovin et al., 2007; Golovin et al., 2003; Kamenetsky et al., 2004; Kamenetsky et al., 2007a). The Udachnaya-East kimberlite contains at least ten alkali-bearing mineral phases, among which only phlogopite is commonly found in other kimberlites. Typical abundances of K_2O in kimberlites is 0.5-1.0 wt% (up to 2.5 wt%), whereas Na_2O is very low (0-0.2 wt%; not exceeding 1 wt%; Vasilenko et al., 2002). The presence of phlogopite is usually attributed to recorded K_2O contents, but Na-bearing minerals, except rare pectolite $NaCa_2Si_3O_8(OH)$, are virtually absent in kimberlites. On the other hand, a prolong evolution of the kimberlite melt (even initially Napoor) should result in Na enrichment towards the end of crystallisation, and this may result in formation of alkali carbonates, chlorides and sulphates. The presence of these minerals is kimberlites and other magmatic rocks, in general, is uncommon, because they are highly soluble in water. The active Oldoinyo Lengai volcano in Tanzania is the only example of magmatic crystallisation of such water-soluble minerals. However, their dissolution and decomposition (natrocarbonate into Ca-carbonate) is also well known (Zaitsev and Keller, 2006), and such transformations can be similarly envisaged for kimberlitic rocks.

The estimates of P-T parameters of crystallisation of all groundmass minerals in the kimberlite are difficult to make. The existing experiments on the kimberlite melt crystallisation do not take into account H_2O-poor and alkali-rich compositions that represent the Udachnaya-East kimberlite, and therefore, the assemblage of olivine, alkali carbonates and chlorides has been never reproduced experimentally. At present, even P-T conditions of crystallisation of the groundmass olivine are unclear (Kamenetsky et al., 2008a). The olivine was the first groundmass mineral to crystallise on the mantle-derived olivine “fragments”, so the olivine rims (~50 vol%), containing inclusions of Cr-spinel, phlogopite, perovskite, rutile and ilmenite, possibly formed close to the surface at 1100-750^{o}C. Calcite started to crystallise at 750^{o}C (Mal'kov and Bobolovich, 1977), followed by alkali carbonates. The residual kimberlite liquid was markedly enriched in the alkali carbonate and chloride that were likely immiscibly separated at <600^{o}C (Kamenetsky et al., 2007a).

In conclusion, the magmatic mineralogy of unaltered Udachnaya-East kimberlite is unlike that of all other kimberlites, because it lacks serpentine and features water-soluble carbonates, chlorides and sulphates. We cannot exclude discovery of other rare mineral species in future. Preservation of water-soluble alkali carbonates and chlorides in the groundmass of the “dry” Udachnaya-East kimberlites matches well their absence in all other kimberlites with high H_2O contents. Essentially anhydrous and carbonate- and chloride-rich compositions can be attributed to the parental magma of the Udachnaya-East kimberlite and its derivates, and thus the role of H_2O and significance of alkalies and chlorine in the kimberlite magmas worldwide requires further investigation (Kamenetsky et al., 2008b).

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