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Salts in southern Yakutian kimberlites and the problem of primary alkali kimberlite melts

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ABSTRACT

Alkali carbonates, sodalite, gypsum, anhydrite, halite and sylvite are present in the groundmass and matrix of many kimberlites in the southern part of the Yakutian kimberlite province. The kimberlites were emplaced through 2 km-thick evaporite-bearing carbonate sediments saturated with brines. In the global context, southern Yakutian kimberlites are unprecedented in the amount of the crustal carbonate and evaporite material included in the pipes, as evidenced by the bulk major element chemistry and isotopic compositions of Sr, C, O, Cl and S. We present geological and hydrogeological data on country rocks and kimberlites of the Udachnaya, Mir and International'naya pipes. The secondary, crustal origin of Na, K, Cl and S-rich minerals is supported by the following: 1. A regional correlation between the geology and hydrogeology of the local country rocks and the kimberlite mineralogy, in particular the difference between southern and northern Yakutian kimberlites; 2. A restriction of halite or gypsum mineralization in the Mir and International'naya pipes to depths where pipes intersect country rock strata with similar mineralogy; 3. The localization of the highest abundances of Na–K–Cl–S-bearing minerals in the Udachnaya East kimberlite at a depth interval that correlates across three magmatic phases of kimberlites and coincides with the roof of the halite-bearing country rock and an aquifer carrying anomalously Na-rich brines; 4. The presence of evaporite xenoliths and veins of halite, gypsum and carbonate cutting through the kimberlite and xenoliths; 5. A secondary origin of halite and alkali carbonates as observed in their textural relationships to serpentine and other groundmass minerals; 6. The geochemical and isotopic evidence for crustal contamination. Addition of crustal salts to kimberlite melt began prior to the volcanic fragmentation as a result of preferential melting and assimilation of evaporite xenoliths and may have continued in-situ after the pipe emplacement via reactions with external saline fluids. The hybrid, alkali-, S- and Cl-rich compositions of residual melts and fluids were trapped in secondary inclusions in olivine. The crustal origin of salts in the Udachnaya East kimberlite demonstrated here is incompatible with a model of alkali-rich primary kimberlite melt. It is significantly more Ca-, Na-, B-, and S-rich than the deep-seated mantle K- and Ba-rich fluid inclusions in fibrous diamonds. Our analysis suggests that the Udachnaya East kimberlite is not "exceptional" and "uniquely fresh", but rather typical of the other crust-contaminated southern Yakutian kimberlites.

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1. Introduction

The presence of alkali carbonates, halite, sylvite, gypsum and other salts in the Udachnaya East kimberlite has received a lot of attention in recent years (Golovin et al., 2003; Kamenetsky et al., 2004; Maas et al., 2005; Veksler and Lentz, 2006; Golovin et al., 2007; Kamenetsky et al., 2007; Kamenetsky et al., 2009a, 2009b). There is a notion that this kimberlite is "exceptional" and "uniquely fresh", and the most publicized model on the origin of salts in the Udachnaya East kimberlite advocates their mantle origin. The model assigns low H_2O and high K and Na contents observed in the Udachnaya East pipe to the primary kimberlite melt (e.g. Kamenetsky et al., 2004; Maas et al., 2005). The authors further claim that all hypabyssal kimberlites with interstitial groundmass serpentine, comprising almost all hypabyssal kimberlites in the world except those at Udachnaya East, are altered. The model of the alkali-rich kimberlite melt has provided a new standard for mantle chlorine isotopes (Sharp et al., 2007) and has inspired numerous experimental studies of mantle melting (see, for example the Proceedings of the 10th International Kimberlite Conference).

Papers that proposed an alkali-rich affinity for the melt focused on geochemical evidence and did not report petrography or geology of the rocks. The goal of this work is to fill these gaps and describe the geology of the Udachnaya pipe and other Yakutian kimberlites, which is critically important for the geochemical interpretation. Many of the relevant data have been published in Russian and are unknown to a western reader. This necessitates the review format of the present paper that summarizes decades of research on Yakutian kimberlites. We demonstrate that the Udachnaya East kimberlite is not "unique", but is quite typical of other southern Yakutian kimberlites. Most of them carry abundant xenoliths of evaporites and are cut by veins and cavities with halite, sylvite, gypsum and carbonate (Fig. 1). Our paper investigates the origin of these minerals, which are uncharacteristic of other kimberlites worldwide, and provides abundant geological, petrographic and geochemical evidence that the kimberlites' alkali-rich affinity relates to crustal contamination. This term is used in our review very broadly, to collectively describe several processes such as physical incorporation of crustal xenoliths into volcaniclastic kimberlites during eruptive processes, high-T assimilation of crustal xenoliths by kimberlite melt, metasomatic reactions with wallrocks in skarn zones, or alteration by external hydrothermal waters or buried ancient brines.

Fluid and melt inclusions in the Udachnaya East kimberlite and fibrous diamonds have also been used to argue for an alkali and chloride-rich primary kimberlite melt (Kamenetsky et al., 2004, 2009a). The second part of this review critically assesses the fluid inclusion data and demonstrates that studied secondary inclusions in olivine and K–Ba-rich inclusions in diamonds cannot be evidence for the mantle origin of alkalis in kimberlites. Even though petrologists still have to search for the composition of the primary kimberlite melt (Kopylova et al., 2007; Kjarsgaard et al., 2009; Russell et al., 2012), the future search should steer away from the heavily contaminated Udachnaya East kimberlite.

2. Geology and hydrogeology of the Yakutian kimberlite province

The Yakutian kimberlite province on the Siberian craton is comprised of 20 kimberlite fields (Fig. 2). The fifteen northern fields do not host economic pipes, whereas some of the 5 southern fields contain kimberlites that have been mined (i.e. the Mir, Aykhal, Jubilee, Nyurba Udachnaya and International'naya pipes). Erosion of most kimberlite pipes is estimated to be ~500 m (Khar'kiv et al., 1991). Southern Yakutian kimberlites differ from northern Yakutian pipes in the stronger crustal contamination, evident, for example, in the shift of stable isotopes from mantle to crustal values (Fig. 3). It is therefore necessary to outline the crustal geology of the kimberlite fields and to search for potential sources and processes of crustal contamination.

The fields of the Yakutian province span a large expanse of the craton, from the Anabar Shield with exposed basement in the north to a platform region with thick sediments in the south. Northern kimberlites erupt through 0–1 km of sediments, whereas southern pipes cut through 1–3 km of Vendian, Cambrian and Ordovician carbonate sediments with local evaporite beds (Brakhfogel, 1984). There were at least three epochs of evaporite formation on present sites of southern Yakutian kimberlites. During the latest Neoproterozoic (Vendian), the central part of the Siberian platform was the site of deposition of carbonate and evaporite facies sediments (Fig. 2 and Pelechaty et al., 1996). The belt is characterized by bedded carbonates and sabkha-related evaporites (Kuznetsov and Suchy, 1992). In the Lower Cambrian, evaporites formed in the south of the Yakutian province (Fig. 2) around the Mir and International'naya pipe sites and around other kimberlite sites of the Malobotuobuya field. In the Middle Cambrian, evaporites were deposited to the north, in the so-called Daldyn–Markha bank, 60–85 by 250 km in extent (Fig. 2). The bank represented an isolated inter-reef shallow basin with higher water salinity where intrashelf lagoon sediments were deposited (Drozdov and Sukhov, 2008). This Middle Cambrian basin now encloses sites of the Udachnaya pipe and other Daldyn kimberlites.

Nowhere in the world except in Yakutia do kimberlites erupt through thick carbonate sediments that contain so much highly mineralized groundwater, with salinity >0.2–0.4 g/cm^3, representing ancient parental brines buried together with syngenetic sediments (Alekseev et al., 2007). The kimberlites erupt through several cryohydrogeological basins, the Olenek, Yakutian (Alekseev et al., 2007) and the Daldyn-Markha basin (Drozdov and Sukhov, 2008) (Fig. 2). The Lower–Middle Cambrian Olenek basin, which hosts the majority of Yakutian kimberlite fields, differs significantly in hydrogeological characteristics from the Lower to Upper Cambrian Daldyn-Markha basin that encloses the Udachnaya pipe. The latter basin shows 5 times higher porosity (10.3% vs. 1.7%), 4 times higher transmissivity (12 vs 2.8 m^2/day), 100 times higher discharge rates in wells (0.32 vs 0.00054 l/(s∗m)), a ten times higher permeability coefficient (11.0 vs 0.9 mD) and ten times higher total effective thickness (129 vs 13 m) (Tables 1 and 2 in Drozdov and Sukhov, 2008) than the former basin. Brines and waters are sealed by a continuous, 1200 m-thick unit of gypsum- and halite-bearing Cambrian

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