

CHEMICAL EVOLUTION OF MICAS FROM THE UDACHNAYA-EASTERN PIPE KIMBERLITES, YAKUTIA: DATA FROM INCLUSIONS IN OLIVINE

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Introduction

The Udachnaya pipe (Middle Paleozoic) is situated in the Daldyn-Alakit field of the Yakutian kimberlite province. It consists of two bodies (western and eastern), which are connected on the surface forming eight in plan. Upper-middle Cambrian and Lower Ordovician dolomites, dolomitic limestones, mudstones, sandstones, and calcareous conglomerates are the country sedimentary rocks of the Udachnaya pipe. The eastern diatreme was comprised at least by four intrusive phases: the three phases are different types of kimberlite breccias, the fourth phase is veined and dyke kimberlites (Khar'kiv et al., 1998). The studied unaltered kimberlite breccias are related to the main third stage. These rocks were exposed on the 350-650 m depth.

Mineralogy and petrography of studied rocks

Kimberlite breccias of the main third stage of the Udachnaya-Eastern diatreme contain abundant mantle-derived xenocrysts and xenoliths as well as the crustal xenogenic material. Olivine-1 and phlogopite are the main macrocrysts and phenocrysts in these rocks. Fine-grained groundmass consists of olivine-2, calcite, phlogopite, perovskite, zoned spinel (chromite-Ti-magnetite-magnetite), ilmenite, djferfisherite and other sulfides, and possibly Ca-Na-carbonates. The secondary alterations are normally absent in all studied kimberlites. According to X-ray powder diffraction, the rocks contain also Na-K-chlorides, but their nature is unclear. Possibly they have post/late magmatic origin due to infiltration of Na-K-solutions or melts in kimberlites.

Occurrence of micas in kimberlite breccias

Besides of phenocrystal and groundmass mineral, phlogopite also occurs as single crystallites (up to 100 μm) together with Cr-spinel and rutile in olivine-2 and the outer zones of olivine-1. Moreover, tetraferriphlogopite was observed as a phase in secondary melt and polycrystalline inclusions, which form trails and are confined to healed microfractures in the host olivine.

Secondary melt inclusions are rounded, drop-like, irregular or semifaceted in shape. Their size ranges from 2 to 80 μm . The phase composition is as follows: fine-crystallized aggregate (carbonates + sulfates + chlorides) + gas \pm transparent crystalline phases \pm ore phases (Fig. 1). Silicates (tetraferriphlogopite, olivine, humite-clinohumite, and diopside), carbonates (calcite, dolomite, siderite, and Na-Ca-carbonates), Na-K-chlorides, Na-K-sulfates and Mg-phosphate have been identified among transparent phases. Magnetite, djferfisherite, and Ni-pyrrhotite occur as ore phases (magnetite and sulfides are often intergrown). Inclusions with a variable phase composition are observed within one chain. As was established from the cryometric studies, the fluid phase of inclusions is composed of a low-density carbon dioxide (triple point lies at -57.0 to -57.5°C). Thermometric experiments revealed that the inclusions completely homogenize in the range of 700-800°C. Tetraferriphlogopite is the main daughter silicate phase of melt inclusions and seems to be a first mineral which crystallize within inclusions (Golovin et al., 2003).

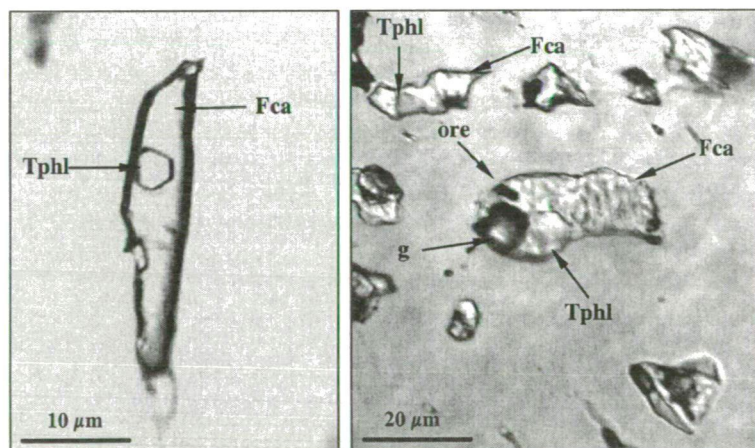


Figure 1. Tetraferriphlogopite (Tphl) from secondary melt inclusions in olivine.

Fca - fine-crystallized aggregate; ore - ore mineral; g - gas bubble.

Polycrystalline inclusions contain the following associations: calcite + magnetite + djferfisherite and phlogopite + magnetite.

Chemistry of micas

The chemical composition of micas was determined on a CAMEBAX microprobe at UIGGM SD RAS, Novosibirsk. Phenocrystal micas slightly vary in composition from core to rim (in wt. %): SiO_2 - 37.4-37.2; TiO_2 - 4-4.4; Cr_2O_3 - 0-0.4; Al_2O_3 - 16.4-15.9; FeO - 8.9-6.5; MgO - 19.2-21.3; BaO - 0.3-0.5; Na_2O - up to 0.4; K_2O - 9.5; F - up to 0.24. In contrast to phenocrysts, groundmass micas broadly range in composition (in wt. %): SiO_2 - 36.5-41.5; TiO_2 - 0.6-4.2; Cr_2O_3 - 0-0.6; Al_2O_3 - 12.1-15.1; FeO - 5.1-6.9; MgO - 22.1-25.7; CaO - up to 0.15; BaO - 0.1-0.6; Na_2O - up to 0.2; K_2O - 9.2-10.4; F - 0.3-0.6. However, the core-to-rim variations are insignificant.

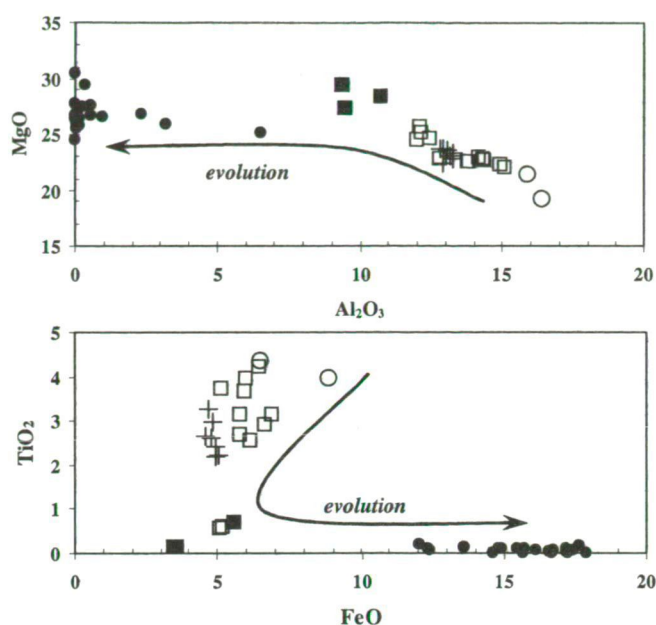


Figure 2. Compositional variations for micas from the Udachnaya pipe kimberlites.

Open circle – phenocrystal phlogopite; **open square** – groundmass phlogopite; **cross** – phlogopite crystallite in olivine; **solid square** – phlogopite from polycrystalline inclusions; **solid circle** – tetraferriphlogopite from melt inclusions.

Discussion

The data obtained allow tracing the chemical evolution of micas during crystallization of the Udachnaya-Eastern pipe kimberlites. In general, the following sequence of mica crystallization was revealed for the Udachnaya kimberlites: phenocrystal phlogopite → phlogopite crystallite in olivine → groundmass phlogopite, phlogopite from polycrystalline inclusions in olivine → tetraferriphlogopite from melt inclusions in olivine. Phenocrystal phlogopite and crystallites in olivine possibly started to crystallize under higher PT-parameters, while groundmass and inclusion micas were formed under shallow depths and 850-750°C. Micas during crystallization evolved towards increasing FeO and decreasing TiO₂, Cr₂O₃ and Al₂O₃ contents. This mica trend is very similar to one of compositional trends typical of the world kimberlites (Mitchell, 1986). The appearance of tetraferriphlogopite is the regular result of evolution of kimberlitic melt for the Udachnaya pipe. According to recent data (Golovin et al., 2003), the evolution of kimberlitic melt during crystallization was initially directed towards the enrichment in CaO, Na₂O, K₂O, FeO, and volatile components (CO₂, F, Cl, S) and the depletion in SiO₂, MgO, and Al₂O₃. After the crystallization of olivine-2, the melt acquired silicate-carbonate composition with a marked carbonatitic trend. The further crystallization of minerals in the groundmass (phlogopite, Ti-magnetite, perovskite, and carbonates) gave rise to the formation of alkaline-carbonatitic residual melt poor in Al₂O₃.

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Phlogopite crystallites in olivine-1-2 are similar in contents of some oxides to phenocrystal and groundmass micas, but in general are Cr-rich (in wt. %): SiO₂ – 39.4-40.6; TiO₂ – 2.2-3.3; Cr₂O₃ – 1.3-1.5; Al₂O₃ – 12.8-13.3; FeO – 4.6-5.1; MgO – 22.4-23.7; CaO – <0.05; BaO – up to 0.14; Na₂O – up to 0.3; K₂O – 9.9-10.3; F – 0.3-0.5. The equilibrium temperatures calculated for olivine-Cr-spinel pairs (Fabries, 1979) show that olivine-trapped phlogopites might be crystallized at temperatures more than 850-900°C.

Micas from secondary melt and polycrystalline inclusions in olivine are characterized by lower Al₂O₃ than early phlogopites. Thus, micas from polycrystalline inclusions are similar to some groundmass phlogopites, but in general have a higher MgO and F and lower TiO₂ than majority of phenocrystal and groundmass phlogopites (in wt. %): SiO₂ – 40.9-41.6; TiO₂ – 0.1-0.7; Cr₂O₃ – 0; Al₂O₃ – 9.4-10.7; FeO – 3.5-5.6; MgO – 27.4-29.4; CaO – <0.3; BaO – <0.1; Na₂O – <0.2; K₂O – 10.3-10.8; F – 1.2-1.5. They have compositions intermediate between phlogopite and tetraferriphlogopite. Micas from melt inclusions are tetraferriphlogopites with variable Al₂O₃ content (in wt. %): SiO₂ – 38.2-42.2; TiO₂ – 0-0.2; Cr₂O₃ – 0-0.2; Al₂O₃ – 0-6.5; FeO – 12.1-17.9; MgO – 24.5-30.5; CaO – 0-0.2; BaO – <0.1; Na₂O – 0-0.5; K₂O – 9.5-10.4; F – 0.1-0.7. In some inclusions the mineral is zoned: core rich in Al₂O₃ and rim free in Al₂O₃. It should be noted that the Al₂O₃-free tetraferriphlogopite is the first finding of this mineral in the Udachnaya pipe. It is very close to the ideal composition $K_2Mg_6[Si_3Fe^{3+}O_{10}]_2(OH)_4$. In general, tetraferriphlogopites are typical of carbonatites and related silicate rocks (Solovova et al., 1998; Guili et al., 2001) as well as of some world kimberlites (Mitchell, 1986).