Groundmass Chromospinellides from Kimberlites of Khompu-May Kimberlite Field

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Abstract. The current paper presents the results of studying chromites of kimberlite mesostasis forming the Manchary, Aprelskaya, Erel, Turakhskaya, and Artemova pipes within the Khompu-May kimberlite field (central Yakutia). Despite shared texture and structural characteristics and mineral composition of the kimberlites, chromospinellide composition is distinctive in each pipe. Groundmass chromium spinel of the Aprelskaya and Erel kimberlite pipes is characterized by the highest aluminum oxide content (>10 wt. %). Chromites from the Erel and Turakhskaya pipes as well as a fraction of grains from the Manchary pipe with titanium oxide (<4 wt. %) form a field of common composition by Cr₂O₃ and TiO₂ content. The Aprelskaya and Artemova pipes show up to 17 wt. % TiO₂ in chromites. Such a difference in titanium content correlates with perovskite content in kimberlite groundmass of the Khompu-May field. The results of the study revealed two trends in evolution of chromospinellide microcrystals (R. Mitchell, 1986) – ulvöspinel associated with typical kimberlites and titanomagnetite characteristic of micaceous kimberlites. Chromospinellides of the Aprelskaya pipe demonstrate the ulvöspinel trend only, suggesting earlier spinel crystallization relative to groundmass mica. Spinellides from the Erel and Artemova pipes follow the titanomagnetite trend only, being crystallized after formation of mesostasis mica. Spinellides from the Manchary and Turakhskaya pipes meet the ulvöspinel and titanomagnetite trend, indicating two stages of mineral crystallization relative to phlogopite.

1. Introduction

To date, the Erel, Turakhskaya, Artemova, Manchary, and Aprelskaya pipes have been discovered within the middle Paleozoic Khompu-May kimberlite field. Petrographic characteristics of their composition are provided in [1], phlogopite is studied in [2], chromospinellide macrocrystals in [3], picroilmenite macro- and megacrystals in [4], and apatite in [5]. The current paper presents the results of studying chromium spinel microcrystals in polished sections of least altered kimberlites forming the pipes under investigation.
2. Geological background and petrography

The kimberlite pipes Erel, Turakhskaya, Artemova, Manchary, and Aprelskaya break through carbonate deposits of the Upper Cambrian and are overlapped by Jurassic terrigenous-sedimentary rocks up to 150 m thick. All bodies under investigation are single-phase, composed of porphyritic kimberlite and kimberlite breccia with gradual transitions as xenoliths of sedimentary, metamorphic rocks and serpentinite inclusions decrease. The rocks of upper horizons are intensively carbonized and hypergenetically modified up to 30 m deep [6], excluding the Artemova pipe. Unaltered minerals in the studied bodies are available in deeper horizons. Major components of kimberlites in all pipes are xenoliths of sedimentary, altered metamorphic rocks and micaites (the Manchary pipe). Oval and irregular serpentinite xenoliths (up to 13 sm) are also observed. All pipes show chromospinellide macrocrysts [3], picroilmenite macro- and megacrysts [4]. Phlogopite macro- and megacrysts were also found in the Manchary pipe [2]. Most least altered kimberlites are mainly composed of fine lamellar phlogopite, xenomorphic segregations of serpentine and carbonate. Also, perovskite, apatite, and minerals of the magnetite-chromospinellide series were identified in the mesostasis (Figure 2). In
in general, the petrographic composition of kimberlites in all bodies under investigation is similar, with some differences being caused by different intensity of late- and post-magmatic as well as hypergenetic processes within each body.

3. Methods and samples

Groundmass chromospinellides from kimberlites and associated minerals in polished sections were studied using a scanning electron microscope JSM6480LV with the energy dispersive spectrometer INCA-Energy 350 at the cathode voltage 20 kV and the electron current 1 nA. The surface of the polished blocks was sprayed by a layer of conductive carbon (until blue). Images were made using the following line standards: Al Kα – garnet O-145, Mg Kα – garnet O-145, Mn Kα – manganese garnet IGEM, Ti Kα and Fe Kα – picroilmenite GF-55, Cr Kα – chromite 531-M8.

4. Mineral chemistry

Chromospinellides of the kimberlite mesostasis in the Erel pipe are detected as sub-square crystals (up to 100 μm) and grains (up to 30 μm) (Figure 2a), in rare instances surrounded by lamellar crystals (up to 120 μm) of magnetite. Such atoll-like aggregates of these minerals are rarely found in kimberlites of the Erel pipe. In the least carbonized residuals of the Turakhskaya pipe there are accumulations of fine (up to 40 μm) atoll-like aggregates (Figure 2b), the core of which is formed by chromospinellide and the rim by lamellar magnetite segregations. Kimberlites of the Artemova pipe are characterized by the lack of atoll-like aggregates of chromospinellides, which suggests another process of post-magmatic modifications. In this case, chromospinellides are present in groundmass as single xenomorphic isometric grains that are rarely crystallographically formed. Their common size is up to 15 μm, with individual grain reaching 90 μm (Figure 2c). Chromium spinel of the kimberlite mesostasis in the Manchary and Aprelskaya pipes was detected as cores (up to 25 μm) of atoll-like aggregates (Figure 2d) formed by spongy or lamellar magnetite crystals (up to 100 μm). In addition, magnetite is found in groundmass as xenomorphic grains (up to 30 μm) and spongy aggregates (up to 50 μm). The transition zone of atoll-like mesostasis formations of all bodies under investigation is made of dolomite, ferromagnesian calcite, rarely andradite. Representative analyses of magnetite and chromospinellides are given in Tables 1 and 2 respectively.

Table 1. Representative analysis of atoll magnetite from pipes of Khompu-May field (wt. %)

| Pipe       | №  | TiO₂ | Cr₂O₃ | FeO | MnO | MgO | Total |
|------------|----|------|-------|-----|-----|-----|-------|
| Erel       | 1  | 2.63 | 0.00  | 88.73 | 0.00 | 3.21 | 94.57 |
| Turakhskaya| 2  | 1.79 | 0.00  | 88.26 | 0.00 | 3.13 | 93.18 |
| Artemova   | 3  | 4.26 | 0.28  | 85.75 | 0.04 | 3.38 | 93.71 |
|            | 4  | 3.71 | 0.00  | 86.51 | 0.00 | 2.76 | 92.98 |
| Manchary   | 5  | 0.00 | 0.87  | 88.37 | 0.00 | 3.59 | 92.83 |
|            | 6  | 0.00 | 0.00  | 89.5  | 1.18 | 1.96 | 92.64 |
| Aprelskaya | 7  | 0.00 | 0.00  | 91.24 | 0.00 | 6.54 | 91.24 |
|            | 8  | 0.00 | 0.00  | 85.54 | 0.00 | 6.54 | 92.08 |
Figure 2. Groundmass from kimberlite pipes of the Khompu-May field: a – Erel, b – Turakhskaya, c – Artemova, d – Manchary. Minerals: 1 – chromospinellide, 2 – calcite, 3 – serpentine, 4 – magnetite, 5 – apatite, 6 – phlogopite. BES.

Table 2. Representative analysis of groundmass chromospinellides from pipes of Khompu-May field (wt. %)

| Pipe         | №  | Cr₂O₃ | TiO₂ | Al₂O₃ | FeO  | MgO  | Total |
|--------------|----|-------|------|-------|------|------|-------|
| Erel         | 1  | 35.98 | 3.15 | 13.08 | 33.48| 12.08| 97.77 |
|              | 2  | 51.14 | 2.05 | 12.49 | 21.87| 12.21| 99.76 |
| Turakhskaya  | 3  | 32.76 | 9.52 | 3.34  | 34.98| 16.36| 96.96 |
| Artemova     | 4  | 52.35 | 3.48 | 1.8   | 30.51| 8.93 | 97.07 |
|              | 5  | 24.48 | 13.43| 3.51  | 43.71| 12.57| 97.70 |
| Manchary     | 6  | 38.56 | 7.65 | 3.58  | 29.7 | 18.63| 98.12 |
|              | 7  | 50.59 | 1.24 | 11.72 | 22.19| 12.63| 98.37 |
| Aprelskaya   | 8  | 31.51 | 7.63 | 13.74 | 28.89| 14.82| 96.59 |
|              | 9  | 37.94 | 6.17 | 13.11 | 28.25| 15.13| 100.60|
Figure 3. $\text{Al}_2\text{O}_3$ vs $\text{Cr}_2\text{O}_3$ for chromian spinel microcrystals in kimberlites [7, 8] from kimberlite pipes of Khompu-May field: 1 – Erel, 2 – Turakhskaya, 3 – Artemova, 4 – Manchary, 5 - Aprelskaya, 6 - Udachnaya 7 - Yubileynaya, 8 – Snap Lake, 9 – picrite trend, 10 – peridotite trend, 11 – inclusions in diamonds, 12 – chromospinellides associated with diamonds.

If $\text{Cr}_2\text{O}_3$ content is more than 12 wt. %, concentration of $\text{Al}_2\text{O}_3$ in microcrystalline spinellides of the Turakhskaya, Artemova, and Manchary pipes is lower than in those of the Erel and Aprelskaya pipes (Table 2, Figure 3).

Chromospinellide microcrystals from the Erel and Turakhskaya pipes as well as a small part of those from the Manchary pipe with titanium oxide less than 4 wt. % make up a field of common composition by $\text{Cr}_2\text{O}_3$ vs. $\text{TiO}_2$ content (Figure 4). Such difference in titanium content correlates with perovskite content in groundmass of kimberlites of the Khompu-May field. In the Aprelskaya and Artemova pipes, perovskite is present as rare grains, with $\text{TiO}_2$ content in chromites reaching up to 17 wt. %. (Figure 4) in this case. Mesostasis spinel of the pipes within the Khompu-May field is characterized by two major trends of mineral crystallization typical for kimberlites – peridotite and picrite [7, 8]. The former is defined by $\text{Cr}^{3+}$ and $\text{Al}^{3+}$ isomorphism with low titanium content, the latter is related to decrease in chromium content and increase in total iron with moderate titanium oxide content and low aluminum oxide concentration. A larger part of spinel from the Manchary and Turakhskaya pipes belongs to the picrite trend, a smaller one to the peridotite trend. Chromospinellides from the Aprelskaya and Artemova pipes are characterized only by the picrite trend, while the Erel pipe demonstrates only the peridotite trend of crystallization.
The undertaken comparison of micro-segregations of chromian spinel from the pipes within the Khompu-May field with those from industrial diamondiferous pipes Udachnaya [9], Yubileynaya [9], and Snap Lake dyke [10] showed that the studied chromospinelides generally contain less \( \text{Cr}_2\text{O}_3 \) and similar amount of titanium (Figure 4). Mesostasis spinellides of the Manchary pipe have the same aluminum content as those from groundmass of the industrial diamondiferous dyke Snap Lake (Figure 3).

Chromospinellide microcrystals from kimberlites of the pipes under investigation fall into two separate groups on a diagram introduced by R. Mitchell. One belongs to the ulvöspinel and the other to the titanomagnetite trend. The ulvöspinel trend is consistent with typical kimberlites, with the titanomagnetite one being characteristic for micaceous kimberlites. According to R. Mitchell the titanomagnetite trend is related to early crystallization of phlogopite which decreases the aluminum and magnesium content in melt [11]. Chromospinelides from the Aprelskaya pipe are characterized only by the ulvöspinel trend which suggests earlier crystallization of spinel relative to groundmass mica. Spinellides from the Erel and Artemova pipes meet only the titanomagnetite trend. Spinellides from the Manchary and Turakhskaya pipes show both ulvöspinel and titanomagnetite trend, which could indicate two stages of mineral crystallization. The presence of the titanomagnetite trend is related to early crystallization of phlogopite in kimberlite groundmass of the Khompu-May field. Chromospinelides from the industrial diamondiferous dyke Snap Lake are also characterized by two trends of evolution (Figure 5), suggesting similar conditions of crystallization.

**Figure 4.** TiO\(_2\) vs Cr\(_2\)O\(_3\) for microcrystals of chromian spinel in kimberlites [7, 8] from kimberlite pipes of Khompu-May field: 1 – Erel, 2 – Turakhskaya, 3 – Artemova, 4 – Manchary, 5 - Aprelskaya, 6 - Udachnaya 7 - Yubileynaya, 8 – Snap Lake, 9 – picrite trend, 10 – peridotite trend, 11 – inclusions in diamonds, 12 – chromospinelides associated with diamonds.

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Figure 5. \( \frac{\text{Ti}/(\text{Ti}+\text{Cr}+\text{Al})}{\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Mg})} \) for spinel from kimberlites [11]: 1 – Erel, 2 – Turakhskaya, 3 – Artemova, 4 – Manchary, 5 - Aprelskaya, 6 - Snap Lake, 7 - ulvöspinel trend, 8 - titanomagnetite trend

5. Conclusions
The study of chromospinellide micro-segregations from the pipes within the Middle Paleozoic Khompu-May kimberlite field revealed differences in mineral composition. Chromospinellides of kimberlite groundmass of the Manchary and Turakhskaya pipes formed in two stages – grains with higher \( \text{Al}_2\text{O}_3 \) content before crystallization of groundmass phlogopite and those with lower \( \text{Al}_2\text{O}_3 \) content during and after mica crystallization taking aluminum and magnesium from the melt [11]. Chromian spinel with high aluminum content from the Aprelskaya pipe crystallized before mesostasis phlogopide. Spinnellides of the Erel and Artemova pipes are characterized by the titanomagnetite trend of evolution that suggests mineral crystallization during or after mica of groundmass. Thus, despite similar texture and structural features of rocks and same mineral composition of kimberlites, chromospinellide composition of each pipe of the Khompu-May kimberlite field is unique.

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