Picroilmenite from Kimberlite Pipes of Central Yakutia

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Abstract. Picroilmenite is one of the most important indicator minerals of kimberlite rocks, which can be used in solving petrological problems and in the search for diamond deposits. The present study shows the results of studying picroilmenite grains from the Manchary and Aprelskaya pipes within the Khompu-May kimberlite field (Central Yakutia). The rocks composing the pipes are represented by porphyritic kimberlite and kimberlite breccia, between which there are gradual transitions. Rocks forming the upper pipe horizons are highly carbonatized and supergenetically altered. Porphyritic segregations are represented by carbonatized serpentine pseudomorphs from macro-, megacrysts and olivine phenocrysts. Pyrope, picroilmenite mega-, macrocrysts and chromospinelide macrocrysts are found in both pipes. Most weakly altered parts of mesostasis are microgranular and formed mostly by phlogopite, with xenomorphic segregations of calcite and serpentine. Picroilmenite in both kimberlite bodies occurs as irregular and rounded macrorysts ranging from 0.7 to 10 mm and megacrysts ranging from 10 to 25 mm. Micrograins of this mineral were not diagnosed in the mesostasis. Individual grains of picroilmenite from the Manchary pipe are surrounded by a polymineral rim composed of either ferrospinel and magnetite, or perovskite and magnetite. High-and low-chromium varieties which correspond to two parageneses are identified among the picroilmenite grains from the Manchary pipe. Crystallization trend of high-chromium ilmenites from the Manchary pipe is clearly seen in the diagram in the coordinates Fe₂O₃-FeTiO₃-MgTiO₃ and associated with the presence of Cr-rich phlogopite from lherzolites xenoliths. Picroilmenite grains from the Aprelskaya kimberlite pipe are more magnesian in comparison with similar grains from the Manchary pipe. Picroilmenite from both pipes in the coordinates Fe₂O₃-FeTiO₃-MgTiO₃ is characterized by a magmatic kimberlite trend of the mineral composition evolution. The distribution of mineral composition points from the studied pipes in the diagram in the coordinates MgO - Cr₂O₃ has form of the “Haggerty parabola” (Haggerty, 1975) - typical for picroilmenites from kimberlites of industrial diamond-bearing middle Paleozoic pipes of Yakutia (Aikhal, Mir, Udachnaya). In general, picroilmenite of Central Yakutia pipes differs from picroilmenite of the Aikhal, Mir and Udachnaya pipes by the presence of the parabola right branch in the Haggerty diagram and an indistinct left branch. The Aikhal, Mir, and Udachnaya pipes are characterized by a clear demonstration of the left branch and a weak right. At the same time, the composition points of the high-chromium picroilmenite variety from the Manchary pipe in the Haggerty diagram coincide with the high-chromium picroilmenite from the Grib kimberlite pipe (Arkhangelsk diamondiferous province). Thus, the study showed the genetic polygeny of picroilmenite from the Manchary and Aprelskaya kimberlite pipes, and also the correlation with mineralogical diamond potential of both pipes traced by comparison with the known industrial ilmenite diamondiferous pipes of Yakutia and Arkhangelsk region.
1. Introduction
The mid-Paleozoic [1] Khompu-May kimberlite field is located in the Northern Aldan Antecline (Central Yakutia) (Figure 1). At present, 6 kimberlite pipes were found within this field, with the first one being the Manchary pipe [2] followed by the Aprelskaya pipe 40 km to the South.

![Figure 1. Location of the Khompu-May kimberlite pipe.](image)

So far petrographic characteristics of rocks of these bodies [3, 4], the results of phlogopite [5] and chromospinellide [6] identification have been reported. Picroilmenite is one of the most important indicator minerals of kimberlite rocks, which can be used in solving petrological problems and in the search for diamond deposits. The present study provides the results of studying picroilmenite mega- and macrocrysts identified in polished sections and crushed samples of the least altered kimberlite varieties that form the largest pipes of the Khompu-May kimberlite field – Manchary and Aprelskaya.

2. Geological background and petrography
The kimberlite pipes Manchary and Aprelskaya reach 250 and 300 m in diameter respectively. The pipes breach the Upper Cambrian carbonate sediments and are overlapped by terrigenous strata of the Jurassic up to 150 m thick. Both kimberlite bodies are formed by porphyritic kimberlite and kimberlite breccia, between which there are gradual transitions as the amount of xenoliths in sedimentary rock decreases. The upper horizons of the Manchary pipe are highly carbonatized, silicified, and supergenetically altered up to about 20 m deep. The secondary processes in the Aprelskaya pipe reach as deep as 30 m. Within these upper horizons, the rocks are characterized by heterogeneous structure due to the presence of different mineral assemblages composed of carbonate minerals of variable composition (dolomite, magnesite, siderite, ankerite, and calcite), quartz, and montmorillonite [4]. In deeper horizons, the rock partially conserved unaltered minerals. The major components of kimberlite rock in both pipes are xenoliths of sedimentary, altered metamorphic rocks and glimmerites (the Manchary pipe). Both bodies also show serpentinite xenoliths (up to 13 cm) of oval and irregular shape, chromospinellide macrocrysts [6], picroilmenite macro- and megaerysts [7]; with phlogopite...
mega- and macrocrysts being found in the Manchary pipe [5]. The main body of the least altered kimberlites is predominately composed of microlamellar phlogopite, xenomorphic segregations of serpentine and carbonate. Besides, perovskite, apatite, and magnetite-chromospinelilide group minerals were diagnosed in the mesostasis. Overall, the petrographic composition of kimberlites in the pipes is homogenous.

3. Methods and samples
Picroilmenite grains were selected from crushed samples of the least altered kimberlites, mounted in epoxy and polished (the Aprelskaya pipe n=300 grains, the Manchary pipe n=84). Single macrocrysts were studied in polished sections. Picroilmenite composition from crushed samples was studied using the conventional method on a Camebax micro-probe. Picroilmenite and associate minerals in polished sections were identified in a scanning electron microscope JSM6480LV with an INCA-Energy 350 energy dispersive spectrometer using a 20 kV accelerating voltage and 1 nA beam current. Imaging on both devices was made using the following standards for lines: Al Kα – garnet O-145, Mg Kα – garnet O-145, Mn Kα – manganese garnet IGEM RAS, Ti Kα and Fe Kα – picroilmenite GF-55, Cr Kα – chromite 531-M8.

4. Mineral chemistry
Picroilmenite is found in kimberlites of the Manchary and Aprelskaya pipes as irregular fragments (Figure 2a) or rounded grains (Figure 2b). In terms of size, its segregations are macrosrysts (0.7 to 10 mm) and megacrysts (10 to 25 mm) [8].

Picroilmenite grains with signs of resorption related to substitution of macrocrysts by ferrospinel, magnetite and perovskite are found in polished sections of the Manchary pipe (Figure 2b). The developed polyminal rim is composed of either ferrospinels and magnetite (Figure 2d) or perovskite and magnetite (Figure 2e). The inner part of the rim is composed of magnetite, the outer part of ferrospinel and perovskite. Discrete ferrospinel grains (FeO up to 56.68 wt. %, Cr2O3 up to 9.51 wt. %, and TiO2 up to 20.52 wt. %) of rounded shape with elements of octahedral configuration are 10 to 50 μm large (Figure 2d). Magnetite (FeO up to 89.65 wt. %, MgO up to 3.32 wt. %, and TiO2 up to 1.48 wt. %) forms spongy aggregates (50 to 120 μm). Some ferrospinel and magnetite grains contain MnO. Perovskite (CaO up to 39.05 wt. %, TiO2 up to 59.31 wt. %, and FeO up to 3.05 wt. %) is observed as subsisometric xenomorphic grains (Figure 2c) from 20 to 80 μm large, often forming a 50 μm wide fragmented rim. Some perovskite grains demonstrate SrO and Na2O impurities. The presence of these minerals at the rim of macrocrysts suggests chemical imbalance between earlier formed picroilmenite grains and the kimberlite matrix [9]. The representative analyses of ferrospinels, magnetite and perovskite are provided in Table 1.

Products resulting from picroilmenite substitution are not observed in the Aprelskaya pipe. In terms of composition, a part of picroilmenite grains from the Aprelskaya pipe is more magnesian (MgO from 8.28 to 15.36 wt. %) in relation to grains from the Manchary pipe (MgO from 7.49 to 13.54 wt. %) (Table 2, Figure 3).
Figure 2. Picroilmenite from kimberlites of the Khompu-May field: a – unaltered macrocrystal (the Aprelskaya pipe), b – rounded macrocrystal resorbed at the lower edge (the Manchary pipe), c – resorbed macrocrystal with the outer rim of perovskite and magnetite (the Manchary pipe), d – the edge of a resorbed macrocrystal with the outer rim of ferrospinel and magnetite (the Manchary pipe): 1 – picroilmenite, 2 – ferrospinel, 3 – magnetite, 4 – perovskite, 5 – apatite, 6 – serpentine, SEI.

Table 1. Representative analyses of minerals associate with picroilmenite from the Manchary pipe (wt. %)

|        | TiO₂ | Al₂O₃ | Cr₂O₃ | FeO₄ | MgO | MnO | CaO | Na₂O | SrO | Total |
|--------|------|-------|-------|------|-----|-----|-----|------|-----|-------|
| Ferrospinel |      |       |       |      |     |     |     |      |     |       |
| 20.52  | 2.51 | 5.81  | 47.71 | 19.94| 0.36|     |     |      |     | 96.85 |
| 16.43  |       | 2.77  | 9.51  | 56.68| 11.11|     |     |      |     | 96.50 |
| 15.73  | 4.95  | 3.63  | 54.61 | 18.57|     |     |     |      |     | 97.49 |
|        | 0.87  |       | 88.37 | 3.59 |     |     |     |      |     | 92.83 |
|        | 1.15  |       | 89.65 | 2.23 | 1.16|     |     |      |     | 94.19 |
|        | 1.48  | 0.44  | 86.03 | 3.32 | 0.58|     |     |      |     | 91.85 |
| Magnetite |      |       |       |      |     |     |     |      |     |       |
| 59.31  | 2.19  |       | 39.02 |     |     |     |     |      |     | 100.52 |
| 58.23  | 1.13  |       | 37.54 |     |     |     |     |      |     | 98.37 |
| 57.38  | 3.05  |       | 38.35 |     |     |     |     |      |     | 98.78 |
| 56.99  | 1.66  |       | 39.05 | 0.43 |     |     |     |      |     | 98.13 |
| Perovskite |      |       |       |      |     |     |     |      |     |       |
|        |      |       |       |      |     |     |     |      |     |       |
Table 2. Representative analyses of picroilmenite grains from Khompu-May field kimberlites (wt. %)

|   | TiO$_2$ | Al$_2$O$_3$ | Cr$_2$O$_3$ | FeO | MgO | MnO | CaO | Total |
|---|---------|-------------|-------------|-----|-----|-----|-----|-------|
| Manchary |         |             |             |     |     |     |     |       |
| 1 | 48.39   | 1.03        | 2.25        | 37.92 | 11.18 | 0.17 | 0.01 | 100.95 |
| 2 | 49.02   | 0.18        | 0.29        | 43.86 | 7.49  | 0.13 | 0.00 | 100.97 |
| 3 | 57.68   | 0.25        | 0.54        | 31.24 | 11.93 | 0.06 | 0.03 | 101.74 |
| 4 | 53.12   | 0.24        | 0.02        | 37.35 | 9.34  | 0.10 | 0.02 | 100.19 |
| 5 | 51.36   | 1.50        | 4.47        | 30.59 | 13.01 | 0.10 | 0.03 | 101.05 |
| 6 | 52.54   | 1.08        | 2.04        | 30.78 | 13.54 | 0.25 | 0.03 | 100.26 |
| Aprelskaya |      |           |             |     |     |     |     |       |
| 7 | 49.72   | 0.21        | 1.39        | 40.99 | 8.28  | 0.26 | 0.00 | 100.85 |
| 8 | 53.59   | 0.90        | 2.85        | 27.78 | 14.64 | 0.35 | 0.15 | 100.26 |
| 9 | 53.31   | 0.63        | 0.43        | 34.59 | 12.20 | 0.23 | 0.03 | 101.42 |
| 10| 53.31   | 0.88        | 3.27        | 27.75 | 14.74 | 0.39 | 0.20 | 100.54 |
| 11| 55.31   | 0.89        | 0.67        | 28.07 | 15.36 | 0.41 | 0.10 | 100.82 |

Note: 1–2 – peridotite trend, 3–11 – kimberlite trend.

Figure 3. MgO distribution in picroilmenite grains from kimberlites, the Aprelskaya (a) and Manchary (b) pipes.

Grain distribution in the MgO content histogram for picroilmenite from kimberlites of the Aprelskaya pipe is bimodal. The maximum grain number is shown for 8-10 and 14-16 wt. % MgO. Grain distribution of picroilmenite from the Manchary pipe is unimodal, varying from 6 to 14 wt. % MgO, with the main contents ranging from 8 to 14 wt. % MgO (Figure 3). Grains with less than 6 wt. % MgO were not diagnosed in kimberlites of the Manchary pipe. Despite the similarities in the petrographic composition of the Manchary and Aprelskaya pipes, picroilmenite samples from the studied bodies differ in MgO and Cr$_2$O$_3$ content (Figure 4).
Picroilmenite from the Manchary and Aprelskaya pipes is characterized by wide variations in magnesium and chromium, with its imaging points in the MgO - Cr₂O₃ diagram forming the “Haggerty parabola” [10], which has the right part only. Picroilmenites from economic diamondiferous pipes in Yakutia [1] Aikhal, Mir and Udachnaya show only the left part of the parabola (Figure 4) unlike the pipes of the Khompu-May field. To construct a diagram for the mineral from the Aikhal, Mir and Udachnaya pipes we used literature data [11]. Picroilmenite of the Manchary pipe broadly shows two trends – low chromium (from 0.02 to 1.50 wt. % Cr₂O₃) and high chromium (from 0.54 to 4.47 wt. % Cr₂O₃) that might correspond to different parageneses (Figure 4). Between these two trends, there is the ilmenite trend from the Aprelskaya pipe (from 0.67 to 3.27 wt. % Cr₂O₃) which is significantly offset to the classic “Haggerty parabola”. The MgO - Cr₂O₃ shows agreement in plots of high-chromium ilmenite variety from the Manchary pipe and picroilmenite megacrystals from the highly diamondiferous pipe Grib (Arkhangelsk diamondiferous province) [12]. The plot of MgO - Cr₂O₃ for picroilmenite from the Manchary and Aprelskaya indicates mineral crystallization under reductive conditions [13], which corresponds with the presence of diamond microcrystals in both pipes. A 0.7 mm diluted fragment of an octahedral crystal of type I diamond was found in the Manchar pipe [14]. Three more crystals, 0.2, 0.6, and 0.7 mm, were diagnosed in the Aprelskaya pipe [15].

![Figure 4](image_url)

**Figure 4.** Evolution of picroilmenite from kimberlites on MgO-Cr₂O₃ diagram [10, 13].

On the ternary Fe₂O₃-FeTiO₃-MgTiO₃ diagram suggested by S.E. Haggerty et al. [10] and R.H. Mitchel et al. [16], the majority of points for picroilmenite content from both pipes follow the magmatic trend in the early evolution of kimberlite melting (Figure 5). The Fe₂O₃-FeTiO₃-MgTiO₃ diagram shows a special trend for the Manchary pipe, which is likely to result from the relationship between high-chromium picroilmenite variety and high-chromium phlogopites from lherzolite xenoliths [5].
5. Conclusions
1. Picroilmenite from the Manchary pipe corresponds to two different parageneses. Low-chromium picroilmenite from the Manchary pipe follows the magmatic trend of the early evolution of kimberlite melting [10, 16]. High-chromium variety shows its own trend associated with the relationship with high-chromium phlogopites from lherzolite xenoliths [5]. Its composition is close to that of the megacryst ilmenite association from the Grib industrial diamondiferous pipe. The received data suggest polygenetic nature of picroilmenite from the Manchary pipe, i.e. the rock shows mineral grains from xenoliths of deep-seated origin besides those of kimberlitic genesis proper [9].

2. Picroilmenite from the Aprelskaya pipe is more magnesian and also follows the magmatic trend of the early evolution of kimberlite melting [10, 16] (Figure 5).

3. Picroilmenites from the Manchary and Aprelskaya pipes on the Fe$_2$O$_3$-FeTiO$_3$-MgTiO$_3$ diagram [10, 16] follow the magmatic trend of the early evolution of kimberlite melting. However, despite the similar petrographic composition they differ from each other and the industrial diamondiferous pipes of the Yakutian kimberlite province (Figure 4) in MgO and Cr$_2$O$_3$ content.

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