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GEOLOGY

Specific Features of Picroilmenite Composition in Various Diamondiferous Fields of the Yakutian Province

S. I. Kostrovitsky[1], N. V. Alymova[1], D. A. Yakovlev[1], I. V. Serov[2], A. S. Ivanov[2], and V. P. Serov[2]

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Picroilmenite of kimberlitic rocks is among the major typomorphic minerals widely used in geological prospecting. Therefore, the elucidation of compositional differences between ilmenites from various fields of the Yakutian province is an important issue. Sobolev [1] was among the first researchers to note the necessity of using picroilmenite in prospecting for kimberlite fields. However, the attempts of several researchers [2–4] to decipher specific features of the ilmenite composition in various diamondiferous fields were unsuccessful. They were only able to establish that ilmenites from the Malobotuobinsk field are characterized by the presence of a unique ferromagnetic variety (the hematite end member is >20%). According to [5], ilmenites from the northern kimberlite fields of the Yakutian province are depleted in Mg and Cr relative to their southern counterparts. Our unpublished data refute this conclusion and indicate that ilmenites from these two areas have similar compositional variations. We believe that previous researchers were unable to detect the compositional specifics of picroilmenites from different fields of the Yakutian province because they focused their attention on comparing the statistical parameters of composition distribution. The present communication is devoted to a discussion of the more informative variation trend of ilmenite composition.

The study is based on representative microprobe analyses of ilmenites from the majority of kimberlite pipes in the Malobotuobinsk, Daldyn, Alakit-Markhinsk, and Verkhne-Munsk fields of the Yakutian province. These data were mainly obtained in the course of joint investigations carried out by the Vinogradov Institute of Geochemistry and the ALROSA Joint-Stock Co. Microprobe analyses were performed in the Central analytical laboratory of the Botuobinskaya Geological Prospecting Expedition (AK ALROSA) on a Superprobe JXA 8800R (JEOL). Results presented in the table indicate that ilmenites from different kimberlite fields are characterized by a sufficiently consistent homogeneous composition. Despite the wide variation ranges of major oxides, the average composition of ilmenites is similar for many kimberlite fields (excluding the Malobotuobinsk field). In general, kimberlites of the Malobotuobinsk field contain Fe-rich ilmenite (the Fe_2O_3 content is as much

Average interval of composition variation in picroilmenites from various diamondiferous fields of the Yakutian province

Oxide	Malobotuobinsk (1600)	Daldyn (4213)	Alakit-Markhinsk (707)	Verkhne-Munsk (409)
TiO_2	45.8 / 28.5–36.5	48.0 / 38.4–55.2	47.7 / 41.5–53.1	48 / 37.7–59.5
Al_2O_3	0.6 / 0–4	0.53 / 0–1.9	0.43 / 0–1.3	0.55 / 0–3.8
Cr_2O_3	1.0 / 0.1–9	1.0 / 0.2–14.5	1.3 / 0–6.1	1.5 / 0.1–12.6
Fe_2O_3	18.8 / 0–43.4	14.5 / 1.8–29.2	13.6 / 1.4–23.9	13.9 / 0–28.3
FeO	24.7 / 8–44.5	25.6 / 14.1–30.9	25.7 / 17.4–39.8	25.8 / 9–30.2
MnO	0.16 / 0.1–2.4	0.25 / 0.1–1.1	0.25 / 0.2–0.5	0.22 / 0.1–1.0
MgO	8.8 / 0–15.6	9.8 / 4.9–16.2	9.5 / 3–15.6	9.7 / 6.5–18.1

[1] *Vinogradov Institute of Geochemistry, Siberian Division, Russian Academy of Sciences, ul. Favorskogo 1a, Yakutsk, 664033 Russia; e-mail: serkost@igc.irk.ru*

[2] *Botuobinskaya Geological Prospecting Expedition, AK ALROSA, Mirnyi, Sakha, 678170 Russia*

[3] *Amakinskaya Geological Prospecting Expedition, AK ALROSA, Aikhal, Sakha, 678174 Russia*

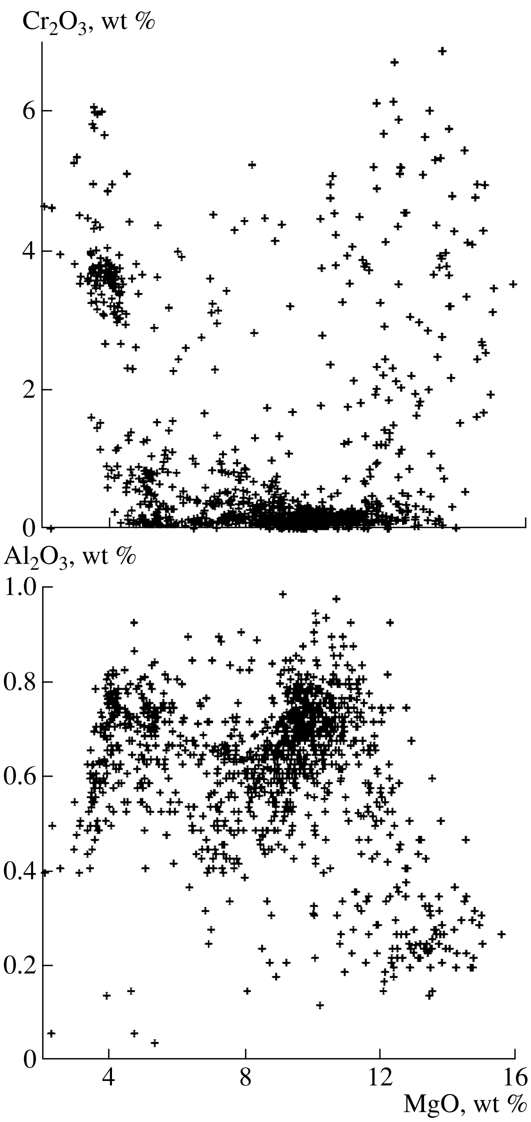

Fig. 1. Correlation of picroilmenite composition in kimberlites of the Malobotuobinsk field.

as 43.4 wt %). Data presented in the table suggest that the majority of kimberlite fields do not differ in terms of statistical parameters of the chemistry of ilmenites. Let us consider compositional trends of picroilmenites from various kimberlite fields.

Despite the small number of kimberlite pipes (only eight pipes are known to date), the Malobotuobinsk field is among the most productive fields of the Yakutian province, because they are located in operating mines. The database characterizes the compositions of ilmenites from the Mir, Internatsional'naya, XXIII S"ezd KPSS, Dachnaya, Taezhnaya, Amakinskaya, and Anomaliya-21 pipes. According to [6, 7], Cr_2O_3 and Al_2O_3 are the most informative oxides for the analysis of the chemistry of ilmenite. The distribution of data points of ilmenite composition in the MgO–Cr_2O_3 plot (Fig. 1) resembles the "Haggerty parabola" [8]. The most prominent and populous group of data points is composed of low-Cr (Cr_2O_3 up to 0.5 wt %) ilmenites with a wide variation range of MgO contents. The low- and high-Mg groups of data points of ilmenites with different Cr_2O_3 contents make up two branches of the parabola with a scattered type of distribution. In the MgO–Al_2O_3 plot, the data points are clustered into two distinct groups with different MgO contents and one less distinct group with a scattered (contrast) type of MgO and Al_2O_3 distribution. The first and second groups show a direct correlation between MgO and Al_2O_3 contents, while the third group is characterized by the highest MgO content and the lowest Al_2O_3 content.

The Daldyn kimberlite field incorporates more than 60 pipes and dikes, including the Udachnaya Pipe (the largest diamond deposit in Russia) and the Zarnitsa Pipe (one of the largest diamondiferous bodies in the Yakutian province). Our database (4213 analyses) characterizes the ilmenite composition of the majority of diamondiferous pipes in the Daldyn field (51 pipes). The MgO–Cr_2O_3 plot (Fig. 2) compiled for this field shows three distinct groups of data points with or without a correlation between oxides. The MgO variation range is relatively wide. However, the Cr_2O_3 content remains constant in the first and second groups. In the third (Cr-depleted) group, the Cr_2O_3 content is weakly correlated with MgO. The existence of three ilmenite groups with different Cr_2O_3 contents was first reported from the Zarnitsa Pipe by researchers from Novosibirsk [9]. It is worth mentioning that a detailed study of the spatial distribution of ilmenite composition in the Daldyn field [7, 10] revealed that the average composition of ilmenites is similar for pipes of a single kimberlite cluster, while ilmenites from different clusters demonstrate stable compositional distinctions with respect to Cr_2O_3 and MgO contents. The existence of three ilmenite groups is characteristic of the majority of (but not all) kimberlite pipes in the Daldyn field. For example, ilmenites from kimberlite pipes of the Dal'nyaya cluster show a unimodal distribution of Cr_2O_3. Therefore, we suggested the existence of block-shaped heterogeneity in the lithospheric mantle beneath the Daldyn field [7].

The MgO–Al_2O_3 plot, in which data points of ilmenites from the Daldyn field make up a single trend, is informative for understanding the genesis (this issue is scrutinized below in the discussion of results). The trend includes two segments. The high-Mg (MgO 9–13 wt %) segment indicates the absence of a correlation between oxides. In contrast, the low-Mg (MgO 6–9 wt %) segment shows the presence of such a correlation. In [7], we demonstrated that the specific feature mentioned above is characteristic of all kimberlite pipes in the Daldyn field.

The Alakit-Markhinsk kimberlite field also incorporates more than 60 pipes and dikes, including the Aikhal, Komsomol'skaya, Sytykanskaya, and Yubilei-

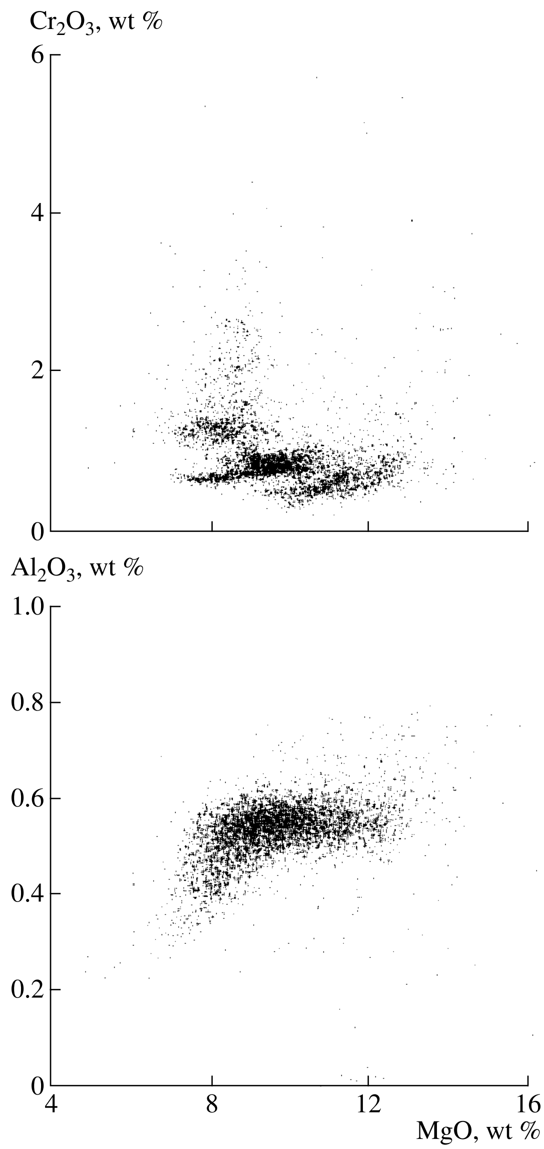

Fig. 2. Correlation of picroilmenite composition in kimberlites of the Daldyn field.

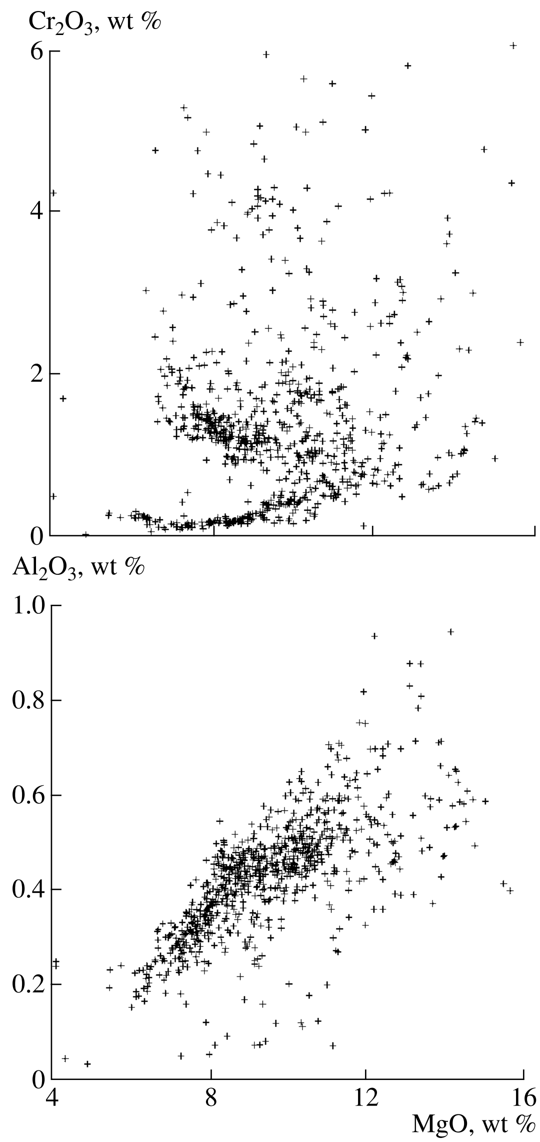

Fig. 3. Correlation of picroilmenite composition in kimberlites of the Alakit–Markhinsk field.

naya diamond deposits. The database (707 analyses) characterizes the compositions of ilmenites from 12 pipes of the Alakit-Markhinsk field (Iskorka, Kollektivnaya, Moskvichka, Neva, NIIGA, Radiogeodezicheskaya, Svetlaya, Slavutich, Snezhnaya, Talisman, Fainshteinovskaya, and Yunost pipes). Despite the limited number of data, we believe that the main regularities in the distribution of ilmenite composition are reflected in the respective trend plots. The summary MgO–Al_2O_3 plot for the entire Alakit-Markhinsk field (Fig. 3) shows a superposition of different types of distribution. The composition of ilmenites from the Iskorka, Kollektivnaya, and Svetlaya pipes is likely to fit the Haggerty parabola type that lacks the low-Mg branch. The second distribution pattern, typical of the northernmost cluster in the Alakit field (NIIGA, Radiogeodezicheskaya, and Talisman pipes), demonstrates a negative correlation between oxides. The scattered type of distribution without any distinct correlation between the oxides is characteristic of ilmenites from the Neva, Slavutich, and Fainshteinovskaya pipes. On the whole, the distribution of data points of the Alakit-Markhinsk field in the MgO–Cr_2O_3 plot radically differs from the pattern for other diamondiferous fields.

In the MgO–Al_2O_3 plot, ilmenites from both the Alakit-Markhinsk and Daldyn fields make up a single compositional trend. However, in contrast to the Daldyn plot, the Alakit-Markhinsk version shows a direct correlation between oxides over the entire variation range of the MgO content. However, the concentration of data points into a narrow horizontal band with an MgO content of 8–11 wt % indicates that the Alakit-

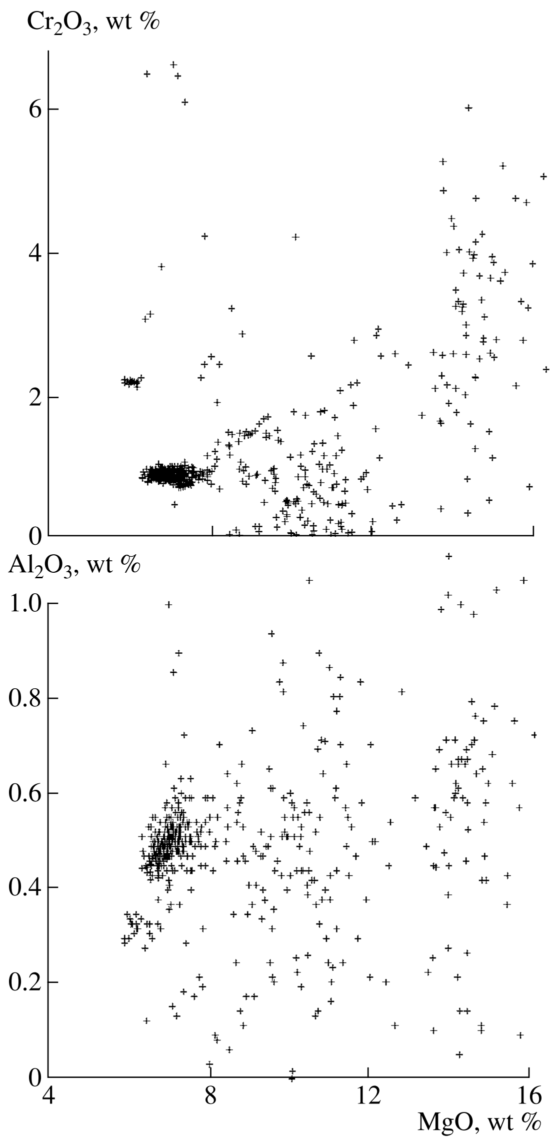

Fig. 4. Correlation of picroilmenite composition in kimberlites of the Verkhne-Munsk field.

Markhinsk field also incorporates kimberlite pipes without any correlation between the oxides.

The Verkhne-Munsk field includes 16 kimberlite pipes. The database (513 analyses) characterizes the compositions of ilmenites from the majority of kimberlite pipes in this field. Ilmenites from each kimberlite pipe of the Verkhne-Munsk field include a low-Mg (MgO 6.5–8 wt %) group with a distinct MgO–Al_2O_3 correlation and constant Cr_2O_3 content (Fig. 4). Ilmenites with an MgO content of more than 8 wt % are characterized by the scattered type of distribution in both MgO–Cr_2O_3 and MgO–Al_2O_3 plots. This distribution pattern reflects wide variation ranges of the mineral composition with respect to oxides.

The interpretation of the distribution pattern of ilmenite composition is open to debate. The compositional trend is usually attributed to fractional crystallization [11]. We believe that the trends of Cr_2O_3 and Al_2O_3 distribution discussed above are related to different genetic processes. It is worth mentioning that the MgO–Al_2O_3 and MgO–Cr_2O_3 plots have contrast configurations within a single kimberlite field. The MgO–Al_2O_3 plot shows a single compositional trend (except for the Malobotuobinsk field), whereas the MgO–Cr_2O_3 plot usually demonstrates separate clusters of data points. It is remarkable that one can always see a direct correlation between Al_2O_3 and MgO (although not along the entire MgO variation range). In contrast, Cr_2O_3 is not usually correlated with MgO. Moreover, the Cr_2O_3 content remains invariable, while the MgO content shows a wide variation range. Analysis of data on the Daldyn field revealed that the Cr distribution remains unaltered only within a single cluster of kimberlite pipes, while the Cr_2O_3 distribution in ilmenites is usually variable in different clusters. The Al_2O_3 distribution differs from the Cr_2O_3 pattern. The continuous trend of MgO–Al_2O_3 correlation is characteristic of all kimberlite pipes in the Daldyn field. Ilmenites from the Alakit-Markhinsk field are also characterized by different styles of Cr_2O_3 and Al_2O_3 distribution.

In interpreting the distribution of Cr_2O_3, one should take into consideration the following points. First, this oxide shows a dualistic behavior: as an independent component (relative to the major oxides in ilmenite) and as a component correlated with MgO (probably, depending on the *PT* conditions of crystallization and oxygen fugacity) [12]. Second, the Cr_2O_3 concentration in ilmenite depends on the oxide concentration in melt. Therefore, we assume that the formation of clusters of ilmenites with different Cr_2O_3 concentrations is a secondary process. Since kimberlite pipes in one cluster are characterized by a single type of Cr_2O_3 distribution, we believe that the latter parameter is governed by the evolution of the magma chamber that fostered the specified cluster of kimberlite bodies. Specific features of the formation of other magma chambers within the kimberlite field are reflected in the diversity of Cr_2O_3 distribution in ilmenites from various clusters of the field.

We attribute the formation of Al_2O_3 trend to processes of fractional crystallization. Together with picroilmenite, other minerals of the megacryst Fe–Ti association (primarily, high-aluminous phases, such as garnets and clinopyroxenes) were also crystallized. We propose the following model of trend formation. The primary high-aluminous melt was fractionated into silicate and ilmenite liquids. First, the high-Mg ilmenite and garnet were crystallized. The level of alumina concentration in the ilmenite melt was maintained in the course of garnet crystallization due to contamination from the silicate melt. The alumina concentration in the ilmenite melt successively decreased after the garnet crystallization in response to the crystallization of ilmenite and, probably, clinopyroxene in the silicate restite. The scattered type of alumina distribution is caused by the heterogeneous composition of the respective melt.

We believe that the picroilmenites of all kimberlite fields in the Yakutian province are derived from a single melt source. This is evident from the similarity of their average compositions (table). However, the crystallization of ilmenites in each field proceeded under specific conditions, leading to the development of different crystallization trends. The MgO–Al_2O_3 plot shows two compositional trends in the Malobotuobinsk field. The low-Mg trend characterizes the compositional distribution of ferromagnetic ilmenites. The origin of this ilmenite group is related to the secondary crystallization of the normal paramagnetic ilmenite in an oxidizing environment rather than to the primary crystallization.

The next important genetic conclusion is based on specific features of compositional MgO–Al_2O_3 trends of the high-alumina ilmenite in kimberlite fields. We can consider the crystallization of ilmenites within one field as a single process that predated the intrusion of kimberlite pipes. As mentioned above, the distribution of Cr_2O_3 in ilmenites has a secondary origin related to the evolution of a magma chamber that produced the cluster of pipes within the specified kimberlite field.

Thus, each kimberlite field of the Yakutian province is characterized by the presence of picroilmenites with specific characteristics of crystallization trends. Therefore, the affiliation of any picroilmenite aureole with a specified field should be interpreted on the basis of a comparison of compositional trends rather than on the basis of the statistical analysis of data on certain oxides in the minerals.

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REFERENCES

1. N. V. Sobolev, Geol. Geofiz., No. 10, 149 (1980).
2. I. P. Ilupin, V. I. Vaganov, and B. I. Prokopchuk, *Kimberlites* (Nedra, Moscow, 1992) [in Russian].
3. Yu. S. Genshaft, I. P. Ilupin, *et al.,* in *Composition and Properties of Deep Rocks in the Earth's Crust and Upper Mantle of Platforms* (Nauka, Moscow, 1983), pp. 95–190 [in Russian].
4. V. K. Garanin, G. P. Kudryavtseva, and L. T. Soshkina, *Ilmenite from Kimberlites* (Mosk. Gos. Univ., Moscow, 1984) [in Russian].
5. S. M. Tabunov, in *Minerals and Mineral Assemblages of Rocks* (Nauka, Leningrad, 1979), pp. 76–84 [in Russian].
6. D. H. Green and N. V. Sobolev, Contr. Mineral. Petrol. **50**, 217 (1975).
7. N. V. Alymova, S. I. Kostrovitsky, A. S. Ivanov, and A. P. Serov, Dokl. Akad. Nauk **395**, 799 (2004) [Dokl. Earth Sci. **395**, 444 (2004)].
8. S. E. Haggerty, in *Physics and Chemistry of the Earth* (Pergamon, New York, 1975), pp. 295–308.
9. A. N. Amshinsky and N. P. Pokhilenko, Geol. Geofiz., No. 11, 116 (1983).
10. S. I. Kostrovitsky, N. V. Alymova, *et al.*, in *Problems of the Prognosis, Prospecting, and Investigation of Mineral Deposits at the Threshold of XXI Century* (Voronezh. Gos. Univ., Voronezh, 2003), pp. 300–306 [in Russian].
11. W. L. Griffin, R. O. Moore, K. J. Rayah, *et al.*, Geol. Geofiz., No. 38, 398 (1997).
12. N. V. Sobolev, *Deep-Seated Inclusions in Kimberlites and Problems of the Upper Mantle Composition* (Nauka, Novosibirsk, 1974) [in Russian].