MINERALOGY OF OXIDES FROM KIMBERLITE GROUNDMASS: GENETIC AND APPLIED ASPECTS (AN EXAMPLE FROM THE YAKUTIAN DIAMOND PROVINCE)

ANGELIKA VALERIANOVNA BOVKUN¹, VICTOR KONSTANTINOVICH GARANIN¹ & GALINA PRITROVNA KUDRYAVTSEVA¹

ABSTRACT Microcrystalline oxides (spinel, ilmenite, and perovskite) in the groundmass of kimberlite and related rocks were analyzed from mine kimberlite fields of the Yakutian Diamond Province. Modal abundances and chemical compositions of the oxide phases are useful parameters for kimberlite prospecting and to evaluate kimberlite generation and evolution. There are four different oxide parageneses in the groundmass of the studied rocks, which correspond to high-Mg kimberlites with chromium spinel, magnesian-ferrous kimberlites with chromespinel-picroilmenite, magnesian-ferrous-titanium kimberlites with picroilmenite-titanomagnetite and related rocks (picrites and alnoites) with titanomagnetite-perovskite. The differences in microcrystalline oxides are a sensitive indicator of kimberlite diamond grade.

Keywords: kimberlite, diamond, groundmass, oxides, diamond potential, prospecting

INTRODUCTION Mineralogical criteria are recognized as very useful for diamond potential evaluation in kimberlites. For example, the widely known $\text{CaO-Cr}_2\text{O}_3$ diagrams for garnets, the $\text{TiO}_2\text{-Cr}_2\text{O}_3$ and $\text{Al}_2\text{O}_3\text{-Cr}_2\text{O}_3$ diagrams for chromespinels with respective discriminant fields for pyrope and chromite inclusions in diamond from rocks with dunite-harzburgite paragenesis (Sobolev 1974, Gurney, 1984). The modern classifications were designed on the basis of a garnet composition database from different types of mantle rocks and kimberlites (Dawson & Stephens 1975) with discrimination of a high-chromium low calcium group of garnets (known as G 10) from diamond bearing associations and also (Garanin *et al.*, 1991) on the basis of chemical-genetic classifications of garnet, olivine, clinopyroxene, chromespinel and ilmenite inclusions in diamond, diamond bearing rocks and other basic and ultra-basic rocks, with individualized groups of such minerals in association with diamond.

It is now known that among diamond bearing kimberlites there are also rocks which contain very low amounts of heavy minerals (for example, the kimberlites of the Arkhangelsk province (Bogatikov *et al.* 1999). On the other hand, investigation of kimberlites for diamond potential produces both minerals derived from mantle rocks and minerals derived from the kimberlite groundmass, but the latter have not received a great deal of attention so far.

The diamond deposit problems laboratory of the Geological Faculty at Moscow State University have paid much attention to the analysis of groundmass oxide minerals from kimberlite bodies with variable diamond grade over many years. Special emphasis was given to determination of oxide minerals ratio, their composition, and correlation of these data with the diamond potential of investigated bodies.

As a result, it was established, that oxides from the kimberlite groundmass (Bovkun 2000, Bogatikov *et al.* 1999, Garanin *et al.* 1986, 1987, 1991) can carry very relevant information on

the depth of kimberlite magma generation, including diamond bearing kimberlites, and about preservation of diamonds, since the dynamics of kimberlite melt rise influences the evolution of diamond as well as of other minerals from kimberlites.

RESULTS The oxide studies and their application for evaluation of kimberlite diamond potential Spinel, ilmenite and perovskite, their mutual relations, and their relations with other rock-forming groundmass minerals, play a key role as sensitive criteria of diamond potential in kimberlite bodies of Yakutian Diamond Province (YDP).

We studied minerals from the groundmass of 30 kimberlite pipes with different diamond grade in nine kimberlite fields from the central and northern portions of the YDP. Within the limits of the province, four basic types of kimberlite rocks were recognized, on the basis of oxide mineralization:

HIGH-MAGNESIAN KIMBERLITES WITH GROUNDMASS CHROMESPINEL This group corresponds extremely high-grade diamond bearing kimberlite pipes (Botuobinskaya, Nyurbinskaya, Aikhal, Internatsionalnaya), one medium-grade pipe (Yubileinaya), several low-grade pipes of the Kharamaiskoye field and one non-diamond bearing pipe Obnazhennaya. In these pipes, the most common heavy minerals are pyrope and chromespinel, while picroilmenite is practically absent. The groundmass oxide minerals content is low (< 3 vol.%). The most abundant oxide phase corresponds to chromespinel, which can reach up to 95 vol.% in high grade diamond bearing kimberlite pipes. Manganic and ferrous ilmenite ranges from 10 to 60 vol.%, and perovskite from 0 to 70 vol.%. High contents of ilmenite and perovskite are typical of both low-diamond and non-diamond bearing kimberlites.

A uniform trend evolves from picrochromite (>56-59 wt.% Cr_2O_3 and 2 wt. % TiO_2) for extremely rich pipes; to Ti-bearing picroferroferrochromites (41 wt.% Cr_2O_3 and 7-8 wt.%

¹ Geological Faculty, 119899, Moscow, Vorobyevy Hills, Moscow State University, Russia, vgaranin@mail.ru

TiO₂) for the non-diamond bearing Obnazhennaya kimberlite.

MAGNESIAN-FERROUS KIMBERLITES WITH GROUNDMASS CHROMESPINEL-PICROILMENITE Pipes of this type are widespread in the YDP. It comprises high-grade pipes (Mir, Udachnaya), medium-grade pipes (Sytykanskaya, Zarnitsa), low-grade pipes (Djanga, Universitetskaya) and others. The high picroilmenite, pyrope and pyrope-almandine contents are characteristic, as well as the clearly subordinate character of the at the chromespinels. Oxide minerals comprise 5-20 vol.% of the kimberlite groundmass. Spinels (35-55 vol.%) and ilmenite (35-50 vol.%) dominate, and perovskite (10-15 vol.%) is subordinate in the diamond bearing bodies. In low-grade bodies, the perovskite content increases (from 20 up to 80 vol.%), and ilmenite content noticeably decreases (5-30 vol.%).

Two similar evolutionary trends are recognized for spinel and ilmenite, respectively. The spinel trend begins with medium-chromium picroferrochromites (49-52 wt.% Cr₂O₃ and 2.5-5.5 wt.% TiO₂) for diamond bearing pipes, progresses with medium-chromium picroferrochromites (42-44 wt.% Cr₂O₃ and 5-7 wt.% TiO₂) for low-diamond bearing pipes, and with magnesian Cr-bearing ulvospinel (37-38 wt.% Cr₂O₃ and 9-10 wt.% TiO₂) for non-diamond bearing pipes, being completed in all cases by the crystallization of titanomagnetite. The ilmenite trend begins with picroilmenite for diamond bearing pipes. For non-diamond bearing bodies the Mn-bearing ilmenite is characteristic only.

MAGNESIAN-FERROUS-TITANIUM KIMBERLITES WITH GROUNDMASS PICROILMENITE-TITANOMAGNETITE SPECIALIZATION OF OXIDES These rocks correspond to low-diamond bearing and non-diamond bearing pipes (Leningradskaya, Morkoka). Among the heavy minerals picroilmenite is abundant, pyrope is subordinate, and chromespinels are extremely rare. The oxide contents are 4-5 vol.%. Chromespinels are not found in the kimberlite groundmass, while titanomagnetite and magnetite are widespread (up to 40 %), picroilmenite and Mn-ilmenite are abundant (40-90 %) and perovskite varies from 5 up to 20 %. Only one picroilmenite-ilmenite trend with preferential distribution of Mn-ilmenite is established.

KIMBERLITE-RELATED ROCKS (PICRITES AND ALNOITES) WITH GROUNDMASS TITANOMAGNETITE-PEROVSKITE This group comprises non-diamond bearing rocks such as the carbonatites of the Velikan dyke and the montichellite alnoites of the Montichellitovy stock.

The low abundance of heavy minerals (pyrope, chromespinel and picroilmenite), and the high contents of groundmass oxide minerals (10-20 vol.%, equally distributed between titanomagnetite and perovskite) are characteristic. The composition trend evolves from Cr-bearing ulvospinels (21-24 wt.% Cr₂O₃ and 10-13 wt.% TiO₂) to magnetite.

Composition data for chromespinel from the kimberlite groundmass are presented in Table 1. Trends of chromespinel

Table 1 – Composition features of groundmass chromespinels (wt.%) from YDP kimberlites (these spinels correspond to the earliest stages of spinel crystallization in kimberlite pipes)

Diamond potential of rocks	Types of kimberlite rocks										
	High-magnesian kimberlites with groundmass chromespinel Comments: PK-porphry kimberlite, AKB-autholitic kimberlite breccia, KB-kimberlite breccia, VK-vein kimberlite			Magnesian-ferrous kimberlites with groundmass chromespinel-picroilmenite			Magnesian-ferrous-titanium kimberlites with groundmass picroilmenite-titanomagnetite		Kimberlites and related rocks with groundmass perovskite-titanomagnetite		
	Pipe	Cr ₂ O ₃	TiO ₂	Pipe	Cr ₂ O ₃	TiO ₂	Pipe		Pipe	Cr ₂ O ₃	TiO ₂
Extremely high-grade	Botuobinskaya	57.6–58.9	2.0–2.8	Mir	48.4–51.4 42.4	2.3–5.1 5.4					
	Nyurbinskaya	56.0–59.9	1.7–2.3	PK							
	Internationalnaya	53.2–53.5	2.1–3.7	AKB							
	Aikhal	57.0–59.3	2.0–2.3								
High-grade				Udachnaya-Zapadnaya	45.0–49.5	3.7–4.9					
				Udachnaya-Vostochnaya	46.6–48.1	4.3–5.6					
Medium-grade	Yubileinaya	50.0–52.9 52.7–53.9	4.4–5.2 2.8–3.2	Sytykanskaya:	39.4–41.3 38.5–40.2 51.2–54.0 50.0–50.8 42.8–44.1	4.6–4.78 4.15–4.94 4.0–5.6 4.3–5.9 5.2–5.7	Dal'naya PK AKB	Titanomagnetite only			
	PK			S-W body							
	AKB			N-E column							
				Central column							
				Malokuonapskaya							
Low-grade	Evenkiiskaya	53.0–56.0 44.2–44.6 42.2–47.5 43.7–45.8	2.4–2.7 6.4–6.6 3.5–5.2 5.8–6.4	Universitetskaya	36.9–40.1	7.87–9.14	Leningradskaya	Titanomagnetite only			
	PK										
	VK										
	Boloto-1										
	Boloto-2										
Non diamond-bearing	Obnazhennaya	38.0–41.3	7.1–7.9	Grenada PK	37.3–38.7	9.2–10.5	Morkoka	Titanomagnetite only	Montichel-litovaya	36–39	7.6–8.4
				KB	23.4–25.4	11.4–12.4			Velikan	30.5	11.2

Figure 1 - Compositions of groundmass chromespinel of the Aikhal (1), Udachnaya (2), Obnazhennaya (3) kimberlite pipes and the Montichellitovaya alnoitic stock, Yakutian Diamond Province.

Figure 2 - Compositions of groundmass chromespinel of the Botuobinskaya (1), Nyurbinskaya (2), Yubileinaya (3), Grenada (4) kimberlite pipes and the Velikan carbonatite dyke (5), Yakutian Diamond Province.

compositions from the groundmass of kimberlite with different diamond grade are illustrated on Fig. 1, 2.

Representative analysis of groundmass chromespinel and ilmenite (more than 1000 analyses for each mineral) from all studied kimberlite bodies and picrites were compounded in a database. Cluster analysis was carried out in order to establish the grouping of these minerals. A chemical-genetic classification is proposed, on the basis of composition ranges of the studied minerals (groups), comprising high-, medium-, and low-grade diamond bearing kimberlites, non-diamond bearing kimberlites and picrites. Based on oxide content and correlations, 15 groups were recognized for spinel and 11 for ilmenite. The proportion of these groups among pipes with different diamond potential varies. A new method for the evaluation of kimberlite diamond potential is proposed, based on the calculation of discriminant functions for all groups compositional features of groundmass spinels and ilmenite, and perovskite abundance.

The criteria for distinguishing diamond bearing kimberlites

on the first stages of explorations are: presence of chromespinel, containing more than 40 wt. % Cr_2O_3 (for extremely rich kimberlites, more than 53 wt.% Cr_2O_3) and less than 4 wt.% TiO_2 ; presence of high-chromium picroilmenite (more than 12 wt.% MgO and 2 wt. % Cr_2O_3) and absence or low content of perovskite (less than 5 vol. %).

The mineralogical criteria defined here on the basis of groundmass oxide mineralization, together with earlier designed chemical-genetic classifications of diamond mineral indicators (Garanin *et al.* 1991) are the basis of a multifunction automated control system of diamond-bearing kimberlite prospecting, their diamond potential and preliminary evaluation. These criteria and evolution trends were confirmed by results of groundmass oxide mineralization study for kimberlite pipes of Arkhangelsk diamond bearing province (Krotkov *et al.* 2001).

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