Ferropericlase inclusions in a diamond microcrystal from the Udachnaya kimberlite pipe, Yakutia

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GEOCHEMISTRY

Ferropericlase Inclusions in a Diamond Microcrystal from the Udachnaya Kimberlite Pipe, Yakutia

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Inclusions in diamonds represent samples of minerals from mantle-related mineral assemblages, which characterize the silicate environment of diamond formation at depths of more than 120–150 km. Previous investigations revealed that most diamonds form under upper mantle conditions. Two principal types of diamond parageneses were distinguished: the ultramafic (U) type and the eclogitic (E) type [1, 2]. The possibility of diamond formation under superdeep conditions of the lower mantle was first supposed based on a find of ferropericlase, (Mg,Fe)O, in a diamond from the Orroroo kimberlite pipe, Australia [3]. More reliable evidence for the existence of diamond generation under lower mantle conditions was later provided by inclusions found in diamonds from the San Luis alluvial deposit in Brazil. These inclusions were represented by ferropericlase associated with MgSi- and CaSi-perovskites and with a tetragonal pyrope–almandine phase [4]. Ferropericlase inclusions in diamond are very rare. Up to the present, only about 15 diamond deposits are known in which diamonds containing ferropericlase inclusions have been registered [3–9]. About a half of this findings were made in alluvial diamond deposits. In the present work, we supplement this list by the first find of ferropericlase in a diamond microcrystal from the Udachnaya kimberlite pipe. We present characteristics of the microdiamond and of the inclusions it contains.

Morphological features of the microdiamond and inclusions were studied using a Zeiss-Axiolab polarization microscope. Characteristics of the defect and admixture composition of the microdiamond were obtained spectroscopically. The chemical compositions of the inclusions were determined according to standard procedure on a Camebax-Micro electron microprobe at the United Institute of Geology, Geophysics, and Mineralogy, Siberian Division of the RAS.

The microdiamond with ferropericlase inclusions was selected from a collection of small crystals ranging in size from –1.0 to +0.5 mm from the Udachnaya kimberlite. The average weight of crystals in this set was about 0.5 mg, which is equal to 0.0025 carats. The host microdiamond represented a rounded crystal with relics of flat octahedral faces. This crystal shape suggests that it was subjected to partial dissolution. Based on the schematic succession of dissolution of natural octahedral diamonds [10], the degree of microdiamond dissolution did not exceed 50%. Absorption spectra of the microdiamond (Fig. 1) allow us to assign it to type IIa (N-free) diamonds. No other lines related to admixture defects in diamond are registered in the absorption spectra (Fig. 1). According to [4], most diamonds containing ferropericlase inclusions were also N-free.

In the microdiamond, several prismatic inclusions of yellow-brown ferropericlase were found. A characteristic morphological feature of the inclusions studied is the inheritance of crystallographic peculiarities of the host mineral (Fig. 2). This is one of the basic indicators suggesting the syngenetic character of these inclusions [11]. In spite of the extremely small size of the inclusions (less than 50 μm), we managed to extract and analyze two discrete grains of ferropericlase. One of these grains was extracted by in situ grinding in the diamond, and another grain was extracted through combustion of the host diamond. The chemical composition of the ferropericlase is presented in the table. The two inclusions are practically identical in composition. The Mg mole fraction of the ferropericlase inclusions amounts to approximately 85%. They are also characterized by elevated contents of Cr_2O_3 and NiO (table). We should emphasize a higher Na_2O content in the microdiamond-

Chemical composition of ferropericlase inclusions in microdiamond

Oxide	UDV-3/1	UDV-3/2
SiO_2	0.15	<0.02
TiO_2	<0.02	<0.02
Al_2O_3	0.19	0.15
Cr_2O_3	1.04	1.02
MnO	0.21	0.23
FeO	23.6	21.0
MgO	72.7	74.3
NiO	1.44	1.39
Na_2O	0.73	0.76
Total	100.06	98.85
Mg/(Mg + Fe), %	84.6	86.3

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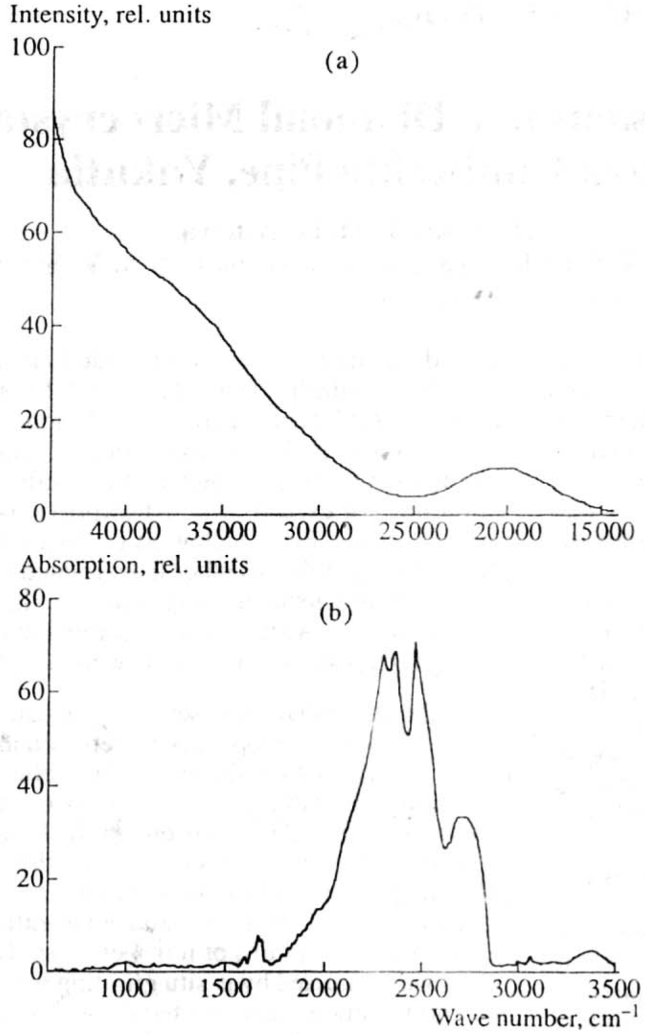

Fig. 1. Absorption spectra of microdiamond with ferropericlase inclusions within the (a) UV to visible light and (b) IR ranges.

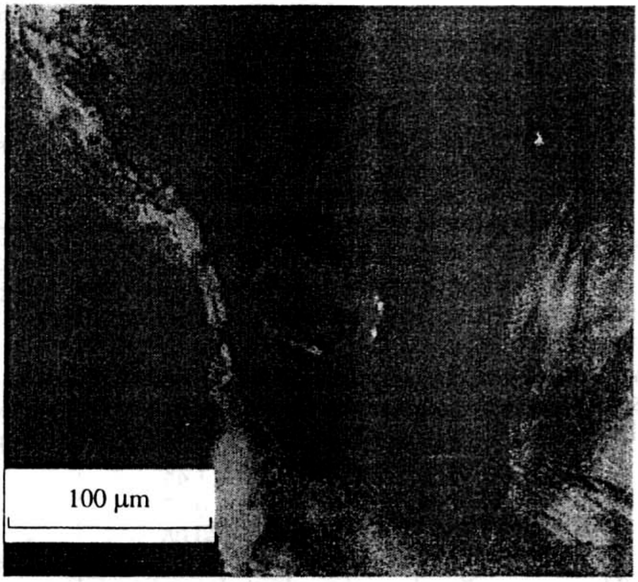

Fig. 2. Ferropericlase inclusion in microdiamond.

hosted ferropericlase (table). Based on experimental data [14], the Na_2O-rich ferropericlase is formed at pressures exceeding 22 GPa. Therefore, it is assumed [12], that ferropericlase is probably formed in deep sections of the upper/lower mantle transitional zone. The chemical composition of these ferropericlase inclusions strongly resembles the composition of most ferropericlases in diamonds, except for ferropericlases from the San Luis and Juina (Brazil) [4, 5] deposits in which most of them have a more ferrous composition and a decreased content of the Cr_2O_3 and NiO admixtures (Fig. 3). Figure 3b, based on almost all of the well-known data on the world, shows a distinct correlation between the Mg index and the NiO admixture content in the diamond-hosted 81 ferropericlase inclusions from different deposits. The correlation coefficient is equal to 0.69. This trend observed in [7] is supported by our results and new data [5].

The close compositional similarity between most ferropericlases from diamonds may be evidence for the similar conditions of their formation in a U-type silicate substrate, which is suggested by the elevated Cr_2O_3 and NiO admixture content (Fig. 3). At the same time, in one of the diamonds extracted from the D'yanga kimberlite pipe situated in the northern Siberian Platform [6], ferropericlase practically devoid of the Cr_2O_3 and NiO admixtures (Fig. 3) is associated with garnet of the eclogite–pyroxenite type, suggesting that ferropericlase is assigned to the E-type paragenesis.

There are at least two possibilities to explain the presence of ferropericlases in diamonds. This mineral may be formed at the expense of olivine decomposition in the lower mantle and the formation of ferropericlase and MgSi-perovskite, or it represents a possible mineral of peridotites and eclogites formed under extremely reductive conditions. The lack of critical paragenesis does not allow us to assign with certainty the formation of ferropericlase in the microdiamond from the Udachnaya kimberlite to olivine decomposition in the lower mantle. However, the compositional resemblance of the ferropericlase grains to the known inclusions of this mineral associated with MgSi-perovskite and other minerals (produced due to the decomposition of peridotites in the lower mantle) is indirect evidence that the host microdiamond in our case crystallized and captured the ferropericlase grains in an altered peridotite substrate within the lower mantle. Theoretically, the periclase phase associated with forsterite in ultramafic rocks can appear in the system in the case of silica deficiency. Such a situation may be realized for extremely depleted dunites. However, this supposition is contradictory to the known facts of the coexistence of ferropericlase and garnet of eclogitic paragenesis within a common host diamond [6, 8]. Such ferropericlase is distinguished for a very low content of the Cr and Ni admixtures. If we assume the lower mantle-related genesis, this mineral assemblage is a nonequilibrium system. Another example of nonequilibrium mineral assemblages is the paragenesis of ferropericlase and olivine [7]. The authors of [7] believe that this assemblage could be produced by

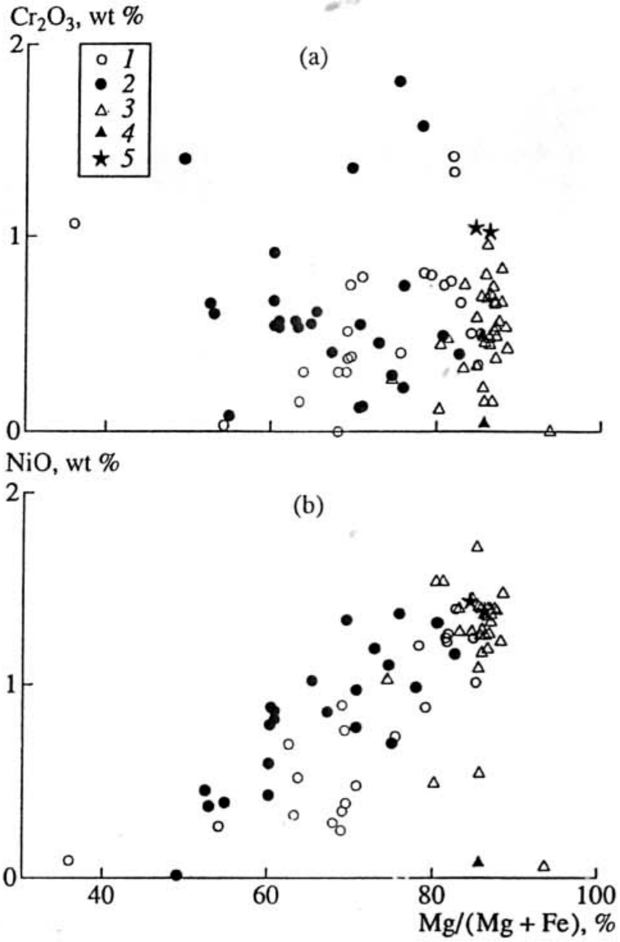

Fig. 3. Compositions of ferropericlase inclusions in (*1*) diamonds from the San Luis deposit, (*2*) Juina deposit, Brazil, (*3*) other deposits, (*4*) in association with E-type garnets, and (*5*) in microdiamond from the Udachnaya kimberlite.

reactions at the retrograde stage of diamond transport from the lower mantle. Hence, there is uncertainty as to the origin of ferropericlase. Therefore, the presence of only ferropericlase inclusions in diamonds is not sufficient evidence for diamond growth under lower mantle conditions. This may be only a reflection of the extremely reductive conditions of mineral formation.

The ferropericlase in the microdiamond from the Udachnaya kimberlite is the first find of this sort for kimberlite pipes of the central Yakutian diamond-bearing province and for diamond deposits worldwide. The weight of this microdiamond is two orders of magnitude lower than that of the smallest inclusion-bearing diamond found in alluvium in Brazil [4]. Most ferropericlase inclusions known from the global data, including those associated with minerals of presumably lower mantle paragenesis, are characterized by significant similarities of their chemical compositions. Ferropericlases in eclogite-type diamonds have the following geochemical features [6]. The defect and admixture signature of the diamonds with ferropericlase inclusions is also peculiar: practically all these diamonds are N-free (type IIa).

These features of ferropericlase paragenesis in di ferent mineral deposits cannot elucidate the problem (its formation at great depth. At the same time, takir into account finds of extraordinary inclusions (spine Ti-chromite, olivine with a forsterite content less tha 90% and anomalously high Ni admixture, and othe [13, 12]) in Yakutian microdiamonds, we can assum certain compositional differences of the silicate sul strate where microdiamonds are crystallized. Anoth feasible way to independently verify the hypothesis (a superdeep, lower mantle formation of ferropericlas in addition to the analogy with experimental results i a simplified system [15], is an independent measure ment of the internal pressure of coesite inclusions i some of the diamonds containing ferropericlase inclu sions [7]. The coesite in diamond barometer has bee substantiated by Raman spectroscopy and by X-ra microstructural investigations [15].

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