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Amphiboles from chromitites of the Yengaiskoye-1 ore occurence, Rai-Iz massif (Polar Urals)

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Abstract

The relevance of the work is associated with the poor degree of knowledge of the influence of solid-phase crustal transformations of ultramafic rocks on the processes of localization of chromium mineralization.
The purpose of the work is to study amphibole microinclusions in ore-forming chrome-spinels of medium-chromium composition and compare them with those from high-chromium chrome-spinels.
Research methods. The chemical composition of minerals was determined using a CAMECA SX 100 electron probe microanalyzer (IGG Ural Branch of RAS, Ekaterinburg).
Results. The chemical composition of amphiboles from medium-chromium chromium ores of the Yengaiskoye-1 occurrence of the Rai-Iz massif has been studied. Amphiboles form inclusions in chrome spinel grains and long prismatic euhedral grains in the silicate part of the ore. It has been established that amphibole from inclusions in chrome spinel corresponds in composition to chrome pargasite with a Cr_2O_3 content of 3.39–3.68 wt. %. In the silicate part of chromitite, that is, in cement, amphibole is represented by tremolite with Cr_2O_3 – 0.80–0.90 wt. %. Comparison with the compositions of amphiboles from high-chromium chromitites of the Tsentralnoye deposit showed that tremolites and pargasites of both objects are in equilibrium in the content of Al_2O_3 and Na_2O, which indicates the isochemical nature of their formation.
Conclusions. The studied tremolites from chromitite cement and chromium pargasites from inclusions in the ore-forming chrome spinel are equilibrium in chemical composition and are of metamorphic origin (both in medium-chromium and high-chromium ores). Their capture occurred at the stage of crystallization or recrystallization of the ore-forming mineral. In medium-chromium chrome spinels, inclusions of silicates with a higher content of Cr_2O_3 and Na_2O than in high-chromium spinels are observed. This may indicate the role of amphibole as a chromium concentrator during ore formation.

***Keywords*:** amphiboles, chromitites, Yengaiskoye ore occurrence, Rai-Iz massif, Polar Urals.

Introduction

The study of silicate inclusions in chrome spinel grains from ultramafic rocks and chromitites is the topic of many modern studies [1–5]. Such inclusions usually contain both minerals typical of host ultramafic rocks: olivine, ortho- and clinopyroxene, amphibole, chlorite, and micas – phlogopite, aspidolite.

In our works, the chemical composition of minerals from inclusions in grains of ore-forming chromium spinel and the silicate part of high-chromium chromium ores of the Tsentralnoye deposit of the Rai-Iz massif was studied [6, 7]. It was found that the composition of amphibole from the silicate part and inclusions in grains of ore-forming spinels varies noticeably within one sample, corresponding to edenite and tremolite according to the modern classification of calcium amphiboles. In individual grains of the mineral, an increased content of Cr_2O_3 was determined – 0.12–1.80 wt. % [6]. Amphibole microinclusions in the ore-forming chrome spinels of the Tsentralnoye deposit are very rare, and the inclusions are mainly represented by chlorite, olivine and serpentine.

Research methods

Chemical analysis of minerals was performed on a CAMECA SX 100 electron probe microanalyzer at the Institute of Geology and Geochemistry, Ural Branch of the Russian Academy of Sciences, analysts D. A. Zamyatin, A. V. Mikheeva.

Research results and discussion

In this work, the composition of amphibole microinclusions from medium-chromium chromium ores of the Yengaiskoye-1 occurrence was studied. The ores have a disseminated-banded texture, a poorly-sparsely disseminated structure [8, 9]. The silicate part is represented by an aggregate of olivine grains 0.8–1.2 mm in size, among which there are individual long-prismatic euhedral amphibole crystals up to 2.5 mm in elongation. The long axes of the crystals are oriented according to the banding of the ore.

Microinclusions in chrome spinel grains are represented by chrome pargasite according to classifications [10, 11]. The mineral was found in the form of grains of irregular, angular shape, 20–30 microns in size (Fig. 1). Its chemical composition (Table 1, an. 1–5) is characterized by an extremely high chromium content for pargasite, 3.41–3.68 wt. %. This

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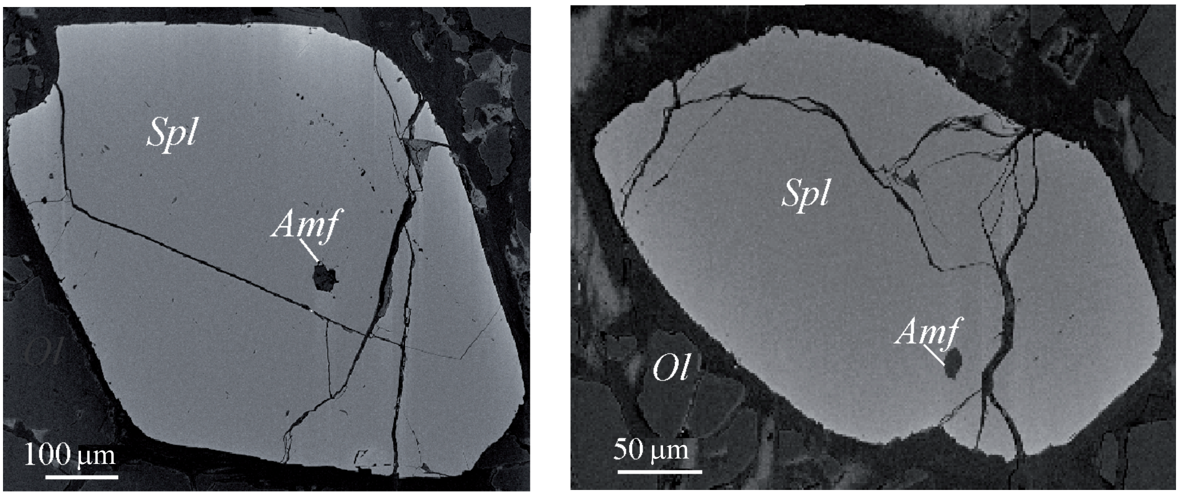

Figure 1. Spinel grains (*Spl*) with amphibole inclusions (*Amf*) in an olivine-serpentine matrix. BSE image, CAMECA SX-100
Рисунок 1. Зерна шпинели (*Spl*) с включениями амфибола (*Amf*) в оливин-серпентиновом матриксе. BSE-изображение, CAMECA SX-100

Table 1. Chemical composition of amphibole from medium-chromium chrome ore of the Yengaiskoye ore occurrence, wt. %
Таблица 1. Химический состав амфибола из среднехромистой хромовой руды рудопроявления Енгайское, мас. %

Oxides and elements	Analyses							
	1к	2ц	3к	4	5ц	6	7	8
SiO_2	43,02	42,38	43,79	43,81	43,56	58,15	57,10	57,28
TiO_2	0,67	0,60	0,68	0,51	0,51	0,07	0,07	0,02
Al_2O_3	11,70	11,29	11,11	11,20	11,16	0,36	0,43	0,33
Cr_2O_3	3,58	3,39	3,41	3,54	3,68	0,20	0,71	0,12
FeO	1,93	1,91	2,56	2,13	2,42	0,86	0,90	0,80
MgO	18,92	20,57	18,76	18,74	19,09	23,90	23,38	23,77
MnO	0,05	–	0,03	0,05	0,05	–	0,03	–
CaO	12,58	11,28	11,97	11,96	12,91	13,03	12,45	12,05
Na_2O	3,52	3,07	3,33	3,13	3,49	0,31	0,64	0,54
K_2O	0,22	0,22	0,26	0,26	0,26	0,02	0,03	0,03
F	0,29	–	0,16	0,06	–	–	0,09	–
Cl	0,01	0,01	0,01	0,02	0,01	0,01	0,03	–
Total	96,49	94,72	96,07	95,41	97,14	96,91	95,86	94,92
Formula coefficients (calculation for 23 oxygen atoms)								
Si	6,23	6,20	6,35	6,37	6,27	7,97	7,93	7,99
Ti	0,07	0,07	0,07	0,06	0,06	0,01	0,01	–
Al	2,00	1,95	1,90	1,92	1,89	0,06	0,07	0,05
Al^{IV}	1,29	1,34	1,19	1,17	1,26	0,03	0,07	0,01
Al^{VI}	0,71	0,61	0,71	0,75	0,63	0,02	–	0,05
Cr	0,41	0,39	0,39	0,41	0,42	0,02	0,08	0,01
Fe	0,23	0,23	0,31	0,26	0,29	0,10	0,10	0,09
Mg	4,08	4,49	4,05	4,06	4,09	4,88	4,84	4,94
Mn	0,01	–	–	0,01	0,01	–	–	–
Ca	1,95	1,77	1,86	1,86	1,99	1,91	1,85	1,80
Na	0,99	0,87	0,94	0,88	0,97	0,08	0,17	0,15
K	0,04	0,04	0,05	0,05	0,05	–	0,01	0,01

corresponds to 0.39–0.42 formula units of Cr in terms of 23 oxygen atoms with the upper limit for the inclusion of cations of the element in the mineral structure of 0.43±0.06 f. u. [12]. From the center to the edge of the mineral grains, the amount of Cr_2O_3 and Al_2O_3 increases by 0.2 and 0.4 wt.%, respectively, and the content of Na_2O increases by 0.5 wt. %.

In the silicate part of the studied chromitite, i. e. in the cement, individual prismatic tremolite grains are observed, up

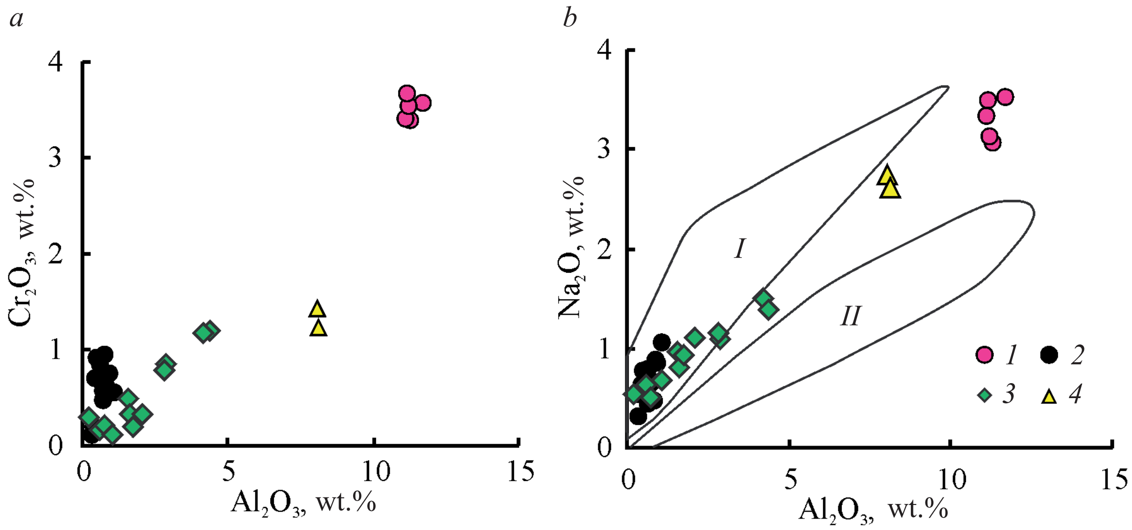

Figure 2. Dependences of the contents of Cr_2O_3 on Al_2O_3 and Na_2O on Al_2O_3 in amphiboles from chromitites and plagioclasites of the Rai-Iz massif: *1* – chromium pargasite from an inclusion in the ore-forming spinel of chromitite of the Yengaiskoe-1 ore occurrence; *2* – tremolite from the silicate part of chromitite of the Yengaiskoe-1 ore occurrence; *3*, *4* – amphiboles from chromitites of the Tsentralnoye deposit: *3* – silicate part, *4* – inclusions in chrome spinel. Composition fields of amphiboles from ultramafic rocks hosting mineralization: *I* – high-chromium type; *II* – aluminous type (according to [13])

Рисунок 2. Зависимости содержаний Cr_2O_3 от Al_2O_3 и Na_2O от Al_2O_3 в амфиболах из хромититов и плагиоклазитов массива Рай-Из: *1* – хромовый паргасит из включения в рудообразующей шпинели хромитита рудопроявления Енгайское-1; *2* – тремолит из силикатной части хромитита рудопроявления Енгайское-1; *3*, *4* – амфиболы из хромититов месторождения Центральное: *3* – силикатная часть, *4* – включения в хромшпинелиде. Поля составов амфиболов из ультрамафитов, вмещающих оруденение: *I* – высокохромистого типа; *II* – глиноземистого типа (по [13])

to 0.5–0.7 mm in diameter. The mineral contains 0.5–1 wt. % Cr_2O_3, Al_2O_3, Na_2O, and is also depleted in TiO_2 to 0.07 wt. % (Table 1, an. 6–8).

The compositions of the studied amphiboles from inclusions in chromitite are distinguished by the highest content of Al_2O_3, Cr_2O_3 and Na_2O among those common in the ophiolite massifs of the Polar Urals (Fig. 2, *a*, *b*). The diagram (Fig. 2, *b*) shows the compositional fields of amphiboles from ultramafic rocks of the Rai-Iz and Voykar-Syninsky massifs, which host mineralization of high-chromium (I) and aluminous (II) chemical types [13]. The compositions of amphiboles from the silicate part of chromitites fall into field I, and from inclusions in chrome spinel grains they are located between fields I and II. In Fig. 2, *b*, the compositions of amphiboles form a single linear sequence, which is associated with the peculiarity of the incorporation of Na^+ into the tremolite structure, which is accompanied by the replacement of Si^{4+} by Al^{3+} [14].

According to olivine-spinel thermometry data given in [3], the central parts of the largest grains of chrome spinel from chromitite containing inclusions of chrome pargasite of the Yengaiskoe-1 ore occurrence were formed at a temperature of 670–690 °C and an oxygen fugacity of 1.1–1. 4 log. units above the FMQ buffer.

Chromium pargasites, similar in composition to those studied in our work, are known in chromitites of the Cuba, Oman, and Luobus massifs [4, 6, 15]. Their origin has been interpreted in various ways: (1) as the result of crystallization from a volatile-rich melt; (2) during the formation of chromitites as a result of the interaction of harzburgite and magma rich in incompatible elements; (3) during metasomatic processes in the upper mantle [4, 6, 15]. The low temperature of olivine-spinel equilibrium established in our work calls into question the possibility of amphibole formation in the magmatic process.

Conclusions

The equilibrium change in the content of Na_2O and Al_2O_3 in the studied amphiboles indicates the constancy and unity of the conditions for their formation. Tremolite is typical of metamorphic parageneses. It follows that the capture of inclusions could occur at the stage of crystallization or recrystallization of the ore-forming mineral under metamorphic conditions. In medium-chromium chrome spinels, inclusions of silicates with a higher content of Cr_2O_3 and Na_2O than in high-chromium spinels are observed. This may indicate the role of amphibole as a chromium concentrator during ore formation.

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Амфиболы из хромититов рудопроявления Енгайское-1 массива Рай-Из (Полярный Урал)

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Аннотация

Актуальность работы связана со слабой степенью изученности влияния твердофазных коровых преобразований ультрамафитов на процессы локализации хромового оруденения.

Цель работы – исследование микровключений амфибола в рудообразующих хромшпинелидах среднехромистого состава и их сравнение с таковыми из высокохромистых хромшпинелидов.

Методы исследования. Химический состав минералов определен при помощи электронно-зондового микроанализатора CAMECA SX 100 (ИГГ УрО РАН, г. Екатеринбург).

Результаты. Исследован химический состав амфиболов из среднехромистых хромовых руд проявления Енгайское-1 массива Рай-Из. Амфиболы образуют включения в зернах хромшпинелида и длиннопризматические идиоморфные зерна в силикатной части руды. Установлено, что амфибол из включений в хромшпинелиде соответствует по составу хромовому паргаситу с содержанием Cr_2O_3 – 3,39–3,68 мас. %. В силикатной части хромитита, т. е. в цементе, амфибол представлен тремолитом с Cr_2O_3 – 0,80–0,90 мас. %. Сопоставление с составами амфиболов из высокохромистых хромититов месторождения Центральное показало, что тремолиты и паргаситы обоих объектов равновесны по содержанию Al_2O_3 и Na_2O, что свидетельствует об изохимизме их образования.

Выводы. Исследованные тремолиты из цемента хромитита и хромовые паргаситы из включений в рудообразующем хромшпинелиде равновесны по химическому составу и имеют метаморфическое происхождение (как в среднехромистых, так и в высокохромистых рудах). Их захват происходил на этапе кристаллизации или перекристаллизации рудообразующего минерала. В среднехромистых хромшпинелидах наблюдаются включения силикатов с более высоким содержанием Cr_2O_3 и Na_2O, чем в высокохромистых. Это может указывать на роль амфибола как концентратора хрома при рудообразовании.

Ключевые слова: амфиболы, хромититы, Енгайское рудопроявление, массив Рай-Из, Полярный Урал.

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