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GEOCHEMISTRY

Polyphase Inclusions in Chromium Spinels from Upper Triassic Gravelites from the Northeastern Part of the Siberian Platform

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Abstract—A comparative study of the chemical compositions of chromium spinel and polyphase inclusions has been carried out. Chromium spinels were separated from the concentrate of the Carnian Stage (T_3) rock sample collected at the northeastern fringe of the Siberian platform. The chromium spinels show a wide variety of compositions, most of which are of the "Kurung" type, which is considered to be a deceptive indicator of a kimberlite. They contain inclusions in the size range of 10–100 μm and contain several mineral phases. The most frequent inclusions are olivine and clinopyroxene; additional phases are nepheline, K–Fsp, Ti–Mg–Ca–amphibole, Ti–biotite (phlogopite), apatite and perovskite. Ilmenite and iron sulfides are less common. The data obtained on the composition of these inclusions indicate differences in the conditions of their formation and possibly different types of parental sources. A possible type of provenance source could be potassium alkali basites.

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The basal horizon of the Carnian Stage (Upper Triassic), which is a known diamond collector at the northeastern margin of the Siberian Platform, occurs widely from the lower reaches of the Lena River to Tsvetkov Cape in Eastern Taimyr. Its thickness varies from 0.1 to 1 m. The greatest amount of diamonds was found near the mouth of the Bulkur River (left tributary of the Lena River) and reaches 10 Ct/m^3 [1].

The peculiarity of this collector is the wide variety of diamond types recovered from it, including diamonds of types V and VII, which are not characteristic of a kimberlite source [2]. This raises the problem of identification of possible parental diamond source types, including non-kimberlitic ones.

Along with diamonds, the Carnian deposits contain typical kimberlite indicator minerals: garnets from peridotite and eclogite paragenesis, including sub-calcium garnets of dunite–harzburgite paragenesis, chromites, picroilmenites, and, in the Bulkur area, phlogopite, chrome diopside, and olivine. The results of comparison of the chemical compositions of garnet along the horizon's strike revealed the differences and, as a consequence, the likely diversity of the parental sources of the diamonds [3].

A separate problem is related to chromium spinels. For this study chromium spinels were extracted from a concentrate of the Carnian Stage samples (T_3). They were collected on the coast of the Laptev Sea and in the lower reaches of the Lena River during a joint expedition of the Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences and the Siberian Institute of Geology, Geophysics, and Mineral Resources in 2010 (Fig. 1).

Morphologically, the chromium spinels are highly euhedral. Grains up to 2 mm in size are divided into two morphological groups. The first one does not contain inclusions; it is of an octahedral shape with rounded ribs and tips, on which vicinal surfaces are developed, with frequent signs of magmatogenic matting. These chromium spinels are typical of kimberlite and diamondiferous lamproite and in the population of the Carnian Stage chromium spinels make up an insignificant fraction (a few percent). The second group spinels contain multiple polyphase inclusions and have the morphology of a plane-faced octahedron with sharp edges and tips. The faces often have a lay-

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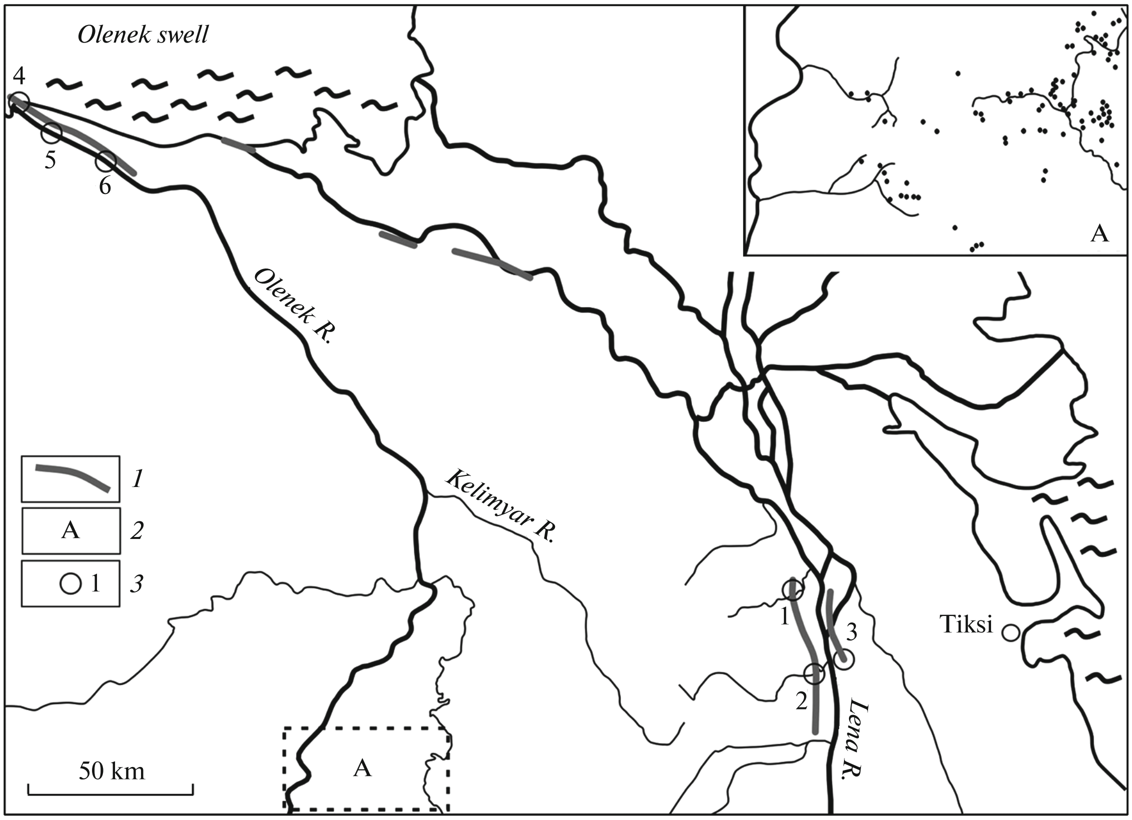

Fig. 1. Scheme of sampling localities from the diamondiferous basal horizon of the Carnian Stage (Upper Triassic) in the northeastern part of the Siberian Platform; *1*, exposures of the basal horizon of the Carnian Stage [1]; *2*, sketch (inset) of the location of potassium alkali rocks, points denote single bodies and clusters of explosion pipes [4]; *3*, localities of sampling of the basal horizon of the Carnian Stage: 1, Bulkur River; 2, Khatystakh River; 3, Ulakhan–Aldzhyrkhay River; 4, Tumul Cape; 5, Tuora–Khaya outcrop; 6, Stan–Khaya–Juryage outcrop.

ered structure or distorted curvilinear surfaces, and the tips are often broken. The second type sharply dominates: by morphology it belongs to the so-called "Kurung" chromium spinel, which we attribute to deceptive indicators of kimberlite [5]. The source of the second group crystals, as a rule, is unknown. The search for the source of the "Kurung" chromium spinels from the Carnian deposits is the main task of this study.

The chromium spinels from the Carnian deposits have a wide variety of compositions, some of which may relate to the kimberlite source. But the second group of dominance of chromium spinels suggests that this is their inherent distribution, in which the kimberlite chromium spinels are not prominent.

Figure 2a displays the Cr_2O_3/Al_2O_3 ratio in chromium spinels from the Carnian deposits. Two groups can be distinguished, differing in the proportions of Cr, Al, and Ti. The group of chromium spinels with a low TiO_2 content (<1 wt %), and inverse correlation of Cr_2O_3 and Al_2O_3, corresponds to a chromium spinel of various ultrabasic rocks, such as xenoliths in kimberlites or lamproite and hyperbasite of the Kempirsai Massif type [5]: this group includes the "Kurung" chromium spinel. The contents of Al_2O_3 and Cr_2O_3 for this group vary from 5.7 to 48.1 and 2.5 to 61.9 wt %, respectively.

Another type is represented by crystals with a higher TiO_2 (1.2–9.0 wt %) content and a low Al_2O_3 content (2.9–27.2 wt %). In these grains, zoning is observed with a decrease in MgO and an increase in the FeO content from the center towards the edge, which is characteristic of a spinel of igneous genesis. In Fig. 2b a region with a concentration of figurative points in the Cr_2O_3 range of 40–50 wt % can be identified. It is this region of Cr_2O_3 where most of the chromium spinel containing polyphase inclusions is located.

The inclusions studied have a size of 10–100 μm and contain a few minerals and a gas bubble. They, as a rule, have an oval shape. Often inclusions form multiple clusters in one sector of a crystal or are arranged in a circle (along the crystal growth zone) around the grain center: this indicates their primary magmatic genesis (Fig. 3). The most frequent inclusion minerals are olivine and clinopyroxene, while nepheline, K–Fsp,

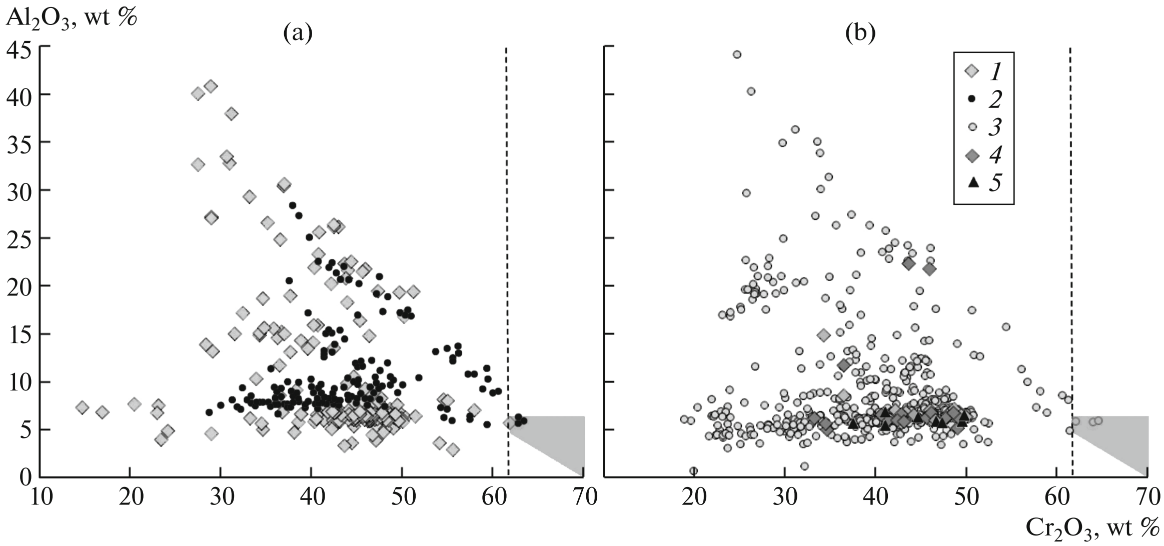

Fig. 2. The Cr_2O_3/Al_2O_3 ratio in of chromium spinels: a, from the basal horizon of the Carnian Stage (*1*) and potassium alkali volcanics of the Olenek Swell (*2*) from [4]; b, from alluvial sediments of the Kelimar River basin (*3*); chromium spinels with inclusions from the basal horizon of the Carnian Stage (*4*); from the paragenesis of phenocrysts of the Guli pluton meimechite (*5*) from [6].

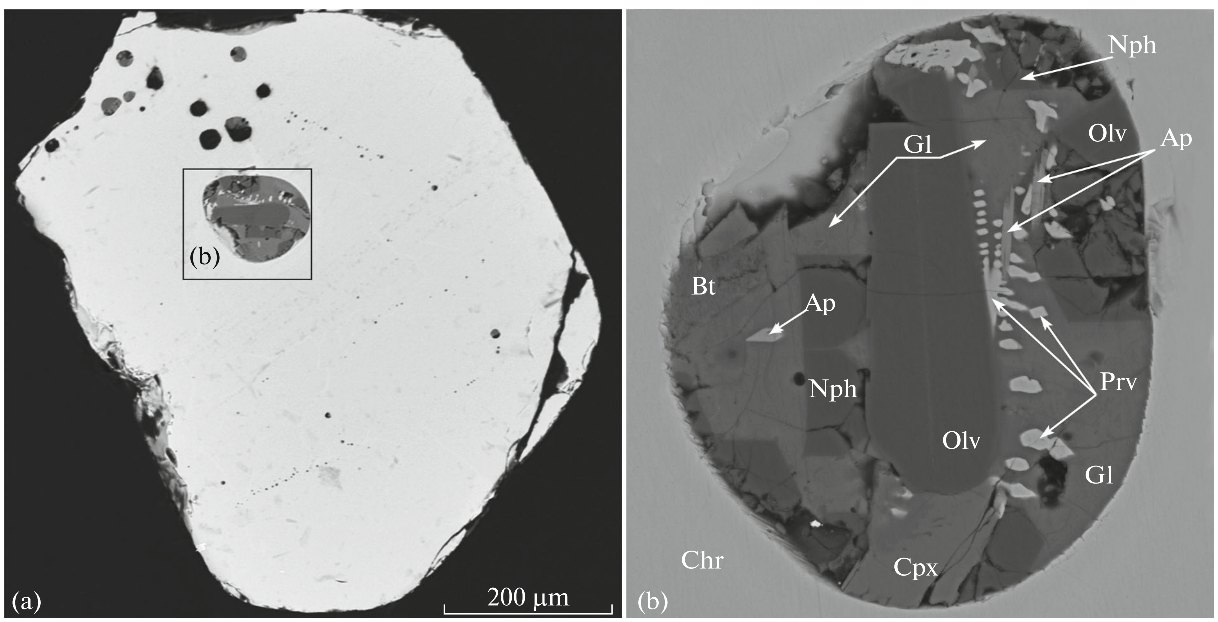

Fig. 3. Polyphase inclusions in chromium spinel from the basal horizon of the Carnian Stage. Back scattered electron images. (a) inclusion; (b) enlarged fragment. Gl, glass; Ap, apatite; Bt, biotite; Cpx, monoclinic pyroxene; Chr, chromium spinel; Olv, olivine; Nph, nepheline; Prv, perovskite.

Ti–Mg–Ca–amphibole, Ti–biotite (phlogopite), apatite, and perovskite are subordinate. Ilmenite and iron sulfides are less common.

A paragenesis of magnesian olivine (Fo 90.3–92.5 mol %, NiO 0.27–0.32 wt %) and chrome diopside (F 5.0–17.6%, Ca/(Ca + Mg) 41–54.7) is typical for the high–Cr chromium spinels (Cr_2O_3 43–49 wt %). In chromium spinels with Cr_2O_3 = 33–41 wt %, inclusions are clinopyroxene or paragenesis of a low–Mg olivine (Fo 85.9–88.9 mol %, NiO 0.13–0.21 wt %) and clinopyroxene (F 14.8–23.1%; Ca/(Ca + Mg) 41–55.9).

Olivine in the inclusions forms relatively large crystals. It has a high CaO content (0.21–0.7 wt %, Table 1), which is not typical of kimberlite [7], but is more typical for meimechite and potassium alkali volcanites [4, 7].

Table 1. Representative analyses (wt %) of olivines and clinopyroxenes from inclusions in chromium spinels from the basal horizon of the Carnian Stage

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	Total	Mg#		Sample no.
							Olivine*							
40.31				8.41	0.38		50.10	0.21			99.41	91.4		1-7
40.76	0.06			8.06	0.29	0.15	49.60	0.63			99.55	91.7		3-1
40.06	0.07			12.93	0.13	0.20	46.18	0.46			100.03	86.4		6-3
39.60	0.07			13.21	0.12	0.22	45.74	0.55			99.51	86.1		6-7
40.31				10.58	0.21	0.21	47.76	0.54			99.61	88.9		9-7
						Clinopyroxene*						F	Ca#	
49.87	2.84	2.58	1.61	3.64		0.12	16.82	21.89	0.85	0.05	100.27	10.9	48.3	1-7
46.90	4.25	4.22	1.69	5.62		0.06	14.80	22.15	0.65	0.05	100.39	17.8	51.8	3-1
50.54	2.31	2.27	2.16	4.48		0.07	16.37	21.65	0.74	0.05	100.64	13.4	48.7	6-3
45.85	3.72	6.25	0.61	7.33		0.13	13.74	21.60	0.91	0.02	100.16	23.4	53.1	6-7
48.48	2.46	4.45	0.99	5.60		0.11	14.26	22.38	1.05	0.09	99.87	18.3	53.0	6-7
48.16	2.84	2.47	1.03	4.95		0.08	16.07	22.87	0.55	0.02	99.04	14.9	50.6	9-7
45.55	5.26	4.94	0.41	6.94		0.12	13.81	22.15	0.98	0.04	100.20	22.4	53.6	9-7
							Amfibole*							
47.50	2.81	7.63	1.20	4.14		0.05	20.25	11.17	4.09	0.33	99.17			
45.42	3.1	8.41	1.29	4.10			19.65	10.49	3.69	0.31	96.47			

* The chemical composition was obtained by electron microprobe analysis; Mg# = 100 × Mg/(Mg + Fe); F = 100 × Fe_t/(Fe_t + Mg); Ca# = 100 × Ca/(Ca + Mg).

The small (20–30 μm) inclusions comprise rims of monticellite and titanite around olivine, which indicates a high calcium content of the parental melt.

Clinopyroxenes occur as euhedral crystals of titanium augite (Fs 2.6–13.3%, Wo 36.9–50.9%, En 40.15–56.7%, Table 1). They typically have reduced SiO_2 contents and high Al_2O_3 and TiO_2 (up to 6.3 and 7.5 wt %, respectively). The inverse dependence of Si on Ti, as well as the value of Al (IV) = 2–Si, which is often greater than the total Al, indicate the occurrence of titanium in the tetrahedral positions or substitution of the Fe^{2+}+ Ti^{4+}+ 2Al type instead of 2Mg + 2Si [8, 9].

The amphiboles of the Ca group in the inclusions are mainly a titaniferous variety (usually 2.5–4.9 TiO_2), Mg–gastingsite and edenite with K_2O = 0.3–0.6 wt %. A mica of biotite–phlogopite composition also contains high concentrations of TiO_2 (up to 12.6 wt %) and an admixture of BaO, SO_3, and P_2O_5 (0.8–2.7 wt %, up to 0.67 wt %, up to 0.66 wt %, respectively). Potassium feldspar contains a significant amount of Na_2O ($Ab_{37–47}$, $Or_{51–63}$), and it always contains an admixture of Cl (0.12–0.26 wt %), sometimes P_2O_5 up to 0.7 wt %. It should be noted that the FeO admixture (0.73–3.8 wt %) and low content or absence of Ca is typical for K–Fsp from lamprophyre [10]. Nepheline in the inclusions contains 3.9–10 wt % of K_2O and up to 1.4 wt % of CaO.

F-apatite is regularly found in the inclusions and has, apart from the high contents of trace elements (SrO 2.0–7.8 wt % Ce_2O_3 up to 1.2 wt % F to 3.9 wt %), a Cl content up to 0.84 and a SO_3 content up to 1.62 wt %. The admixture of SiO_2 (Table 2) is not characteristic of apatite from kimberlite [11] and suggests that the parent rocks are not related to any kimberlite. Perovskite in the inclusions occurs as skeletal or acicular crystals in glass or between Cpx crystals. It is characterized by an admixture of Na_2O and SrO up to 1.3 and 1.8 wt %, respectively. The glass is present in some polyphase inclusions and contains skeletal and needle crystals of perovskitean and apatite. The glass composition corresponds to mafic phonolite [12] and contains a high concentration of TiO_2 and admixtures of Cl and P_2O_5 (Table 2).

The results of study of the polyphase inclusions, as well as the features of the mineral and glass compositions, indicate the ultrabasic alkali high-potassium and high-titanium composition of the parental melt. The presence in the inclusions of skeletal crystals and glass indicates rapid cooling, probably as a result of the rapid transport of the chromium spinel phenocrysts to the surface.

The search for a possible primary source of the chromium spinels from the Carnian deposits allows us to establish their very probable relation to the numerous Late Vendian explosion pipes of potassium alkali basites known in the Olenek uplift of the Siberian

Table 2. Representative compositions (wt %) of minor minerals and glass from inclusions in chromium spinels from the basal horizon of the Carnian Stage

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5	SrO	F	Cl	Total
Nepheline*													
43.81	0.25	31.16	0.67	1.04	1.16		15.42	6.61					100.13
45.97	0.32	28.68	0.45	1.54	1.23		14.56	7.54					
K–Fsp*													
57.06	1.57	20.26	0.26	1.56			5.11	13.02	0.46			0.26	99.56
59.35	1.92	20.05	0.58	0.73		0.43	5.88	9.67	0.92			0.18	99.71
Apatite*													
3.94	4.74	1.47	0.54	0.37	0.36	46.16	0.69	0.87	33.09	2.81	3.8		98.48
2.29			0.31	0.86	1.69	47.31	0.38		39.32	4.85	3.86	0.08	100.94
Biotite*													
40.07	11.34	10.09	0.86	2.95	19.17		0.9	9.37			3.05		97.81
42.53	5.3	9.24	0.56	3.62	22.19	0.62	1.5	8.94			5.06		99.54
Glass*													
51.79	5.64	10.6	0.5	2.03	3	0.48	4.99	16.82	0.6			0.34	96.78
51.82	5.02	12	0.51	1.99	2.37	0.31	5.07	16.35	0.76			0.33	96.52

* Chemical compositions of minerals and glass were obtained with SEM EDS analysis.

Platform [4], which contain abundant chromium spinels, close in composition to those from the Carnian Stage deposits, as well as modern alluvial deposits of the Kelimyar, Nikabyt Khorbusuonka, Beenchime, and Kuoyka rivers along the northern and southern borders of the Olenek uplift (Figs. 1, 2). Chromium spinels from a meimechite of the Siberian Craton have a similar composition (Fig. 2b) [3, 13, 14].

Nevertheless, the issue related to the sources of the heavy fraction minerals in the Carnian Stage deposits is still debatable. The study of the gravelite composition revealed the presence of fragments of altered ultrabasic rocks and trachytes with phlogopite, K–Fsp, clinopyroxene, and chromium spinel [15]. The data on the composition of inclusions in the chromium spinel suggest differences in the conditions of their formation and possible diversity of their provenance source types. As indicated above, a contribution from potassium alkali basites is highly likely [4].

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