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GEOCHEMISTRY

The First Find of Kimberlitic Accessory Minerals in Mafic–Ultramafic Dikes in Spitsbergen

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Since the discovery of diamond in kimberlites, the interest of geologists in these specific rocks has not faded away. The term "kimberlite" was proposed at the end of XIX century by H. Luis for diamondiferous rocks (volcanic peridotite with the porphyritic basaltic texture) from the Kimberley district in South Africa. The majority of researchers believe that kimberlite is a hypabyssal porphyritic rock. According to V.A. Milashev, one of the leading specialists in diamond geology, ultramafic and alkaline-ultramafic igneous rocks of the kimberlite facies must include barophile minerals, i.e., diamond and (or) pyrope garnet [6]. Therefore, finds of pyrope and other kimberlitic accessory minerals in ultramafic and lamproite-type mafic magmatites are very important for the discovery of new kimberlite fields.

The kimberlites are located on West Spitsbergen Island (Norway) in the Devonian graben filled with redrocks [3]. The kimberlites are represented by five extended dikes of altered picrites in the northern area of the graben (eastern part of Andre Land) and by one serpentinized dike (Fig. 1) in the southern area of the graben (coast of the Ekman fjord, James I Land). Based on the low silica content and presence of mica, such rocks were previously referred to the lamprophyre association of the archipelago [4, 5].

The nearly vertical dikes (average thickness 0.5 m) crosscut Devonian terrigenous rocks of the Gray Hook Formation and extend in the NNW direction. They are composed of rocks with porphyritic texture and massive structure. In picrites, the porphyritic phenocrysts are mainly composed of olivine, clinopyroxene, and biotite. Olivine phenocrysts are almost completely replaced by talc, serpentine, and carbonate. The groundmass is composed of chloritized and carbonatized glass with microlites of primarily pyroxene and biotite compositions. Phenocrysts in the carbonatized basalt dike are composed of partly albitized calcic plagioclase. Phenocrysts of pyroxene and completely carbonatized olivine are also found. The groundmass is composed of up to 0.5-mm-long plagioclase laths, between which one can see xenomorphic segregations of pyroxene (near the dike center) or glass (near the contact).

Specific features of the composition of dikes are shown in Table 1. They are characterized by low contents of SiO_2 and MgO. However, contents of Al_2O_3, CaO, and TiO_2 are high. They can be referred to the group of alkaline rocks based on the sum of alkali metals [7]. With respect to alkalinity, picrites in Andre Land belong to the K–Na and K types, whereas carbonatized basalt of James I Land belong to the Na type. Identification of these rocks is based on texture, miner-

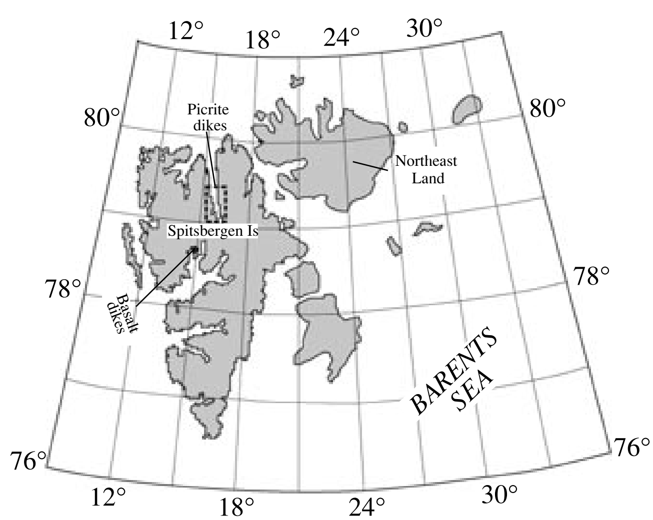

Fig. 1. Schematic location of dikes on the Spitsbergen Archipelago.

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Table 1. Representative X-ray spectral data on rocks and microprobe data on barophile minerals in dikes of the Spitsbergen Archipelago (wt %)

Component	Composition of rocks						Composition of clinopyroxenes					Composition of chrome spinels			Composition of pyropes		
	picrites			basalt			picrites			basalt		picrites		basalt	picrites	basalt	
	No. 41-3	No. 41-13	No. 7	No. 1455-3	No. 1455-7	No. 1456-2	No. 7-24	No. 7-25	No. 7-34	No. 1455-6	No. 1455-7	No. 7-26	No. 7-29	No. 1455-13	No. 7-1	No. 1455-10	No. 1455-11
SiO_2	35.55	32.44	34.71	37.53	42.45	38.37	52.03	52.89	52.25	54.82	54.18	n. a.	0.43	0.00	41.76	40.47	41.11
TiO_2	2.09	2.52	1.36	3.42	3.07	3.62	0.5	n. a.	0.33	0.00	0.00	0.33	0.33	0.83	0.67	0.33	0.33
Al_2O_3	8.45	9.55	7.56	11.31	12.45	11.53	6.43	4.16	4.54	0.00	0.00	14.74	16.64	6.05	20.23	18.71	17.2
Cr_2O_3*	n. a.						1.61	1.61	1.61	0.73	0.73	51.46	52.49	53.95	3.22	5.7	6.14
FeO	n. a.						1.64	1.89	2.00	0.00	1.00	12.66	12.84	12.83	5.92	4.73	6.65
Fe_2O_3	10.89	10.72	13.44	12.2	12.53	13.42	1.9	1.05	0.00	1.16	0.00	4.23	4.89	13.67	2.14	2.69	0.83
MnO	0.16	0.17	0.21	0.21	0.21	0.19	n. a.	n. a.	0.00	0.00	0.00	n. a.	n. a.	0.00	0.39	0.00	0.52
MgO	15.11	9.39	15.71	5.05	4.6	5.35	17.58	16.75	15.42	19.07	20.07	13.76	15.42	13.1	21.56	22.06	24.54
CaO	12.41	18.13	14.44	16.82	14.98	15.34	16.78	20.14	22.24	23.64	23.08	n. a.	n. a.	0.00	4.48	5.17	3.36
Na_2O	1.97	2.45	1.31	2.02	2.34	2.04	1.75	1.21	2.02	0.00	0.00	n. a.	n. a.	0.00	n. a.	0.00	0.00
K_2O	1.14	0.95	0.44	0.44	0.3	0.13	n. a.	n. a.	0.00	0.00	0.00	n. a.	n. a.	0.00	n. a.	0.00	0.00
P_2O_5	0.49	0.44	0.54	0.22	0.22	0.28	n. a.										
L. O. I.	10	11.3	9.6	9.1	5.1	7.9	n. a.										
S	0.19	0.36	0.24	0.08	0.14	0.06	n. a.										
Total	99.66	99.61	99.56	99.76	99.78	99.72	100.22	99.7	100.41	99.42	99.06	97.18	103.03	100.43	100.4	99.86	100.68

Note: X-ray spectral analyses of rocks were carried out in the YaFM Team, Polar Marine Geological Exploration Expedition (V.I. Pogrebnoi, analyst); microprobe analyses of barophile minerals were performed in the Moekhanobr-Analit Laboratory, St. Petersburg (Yu. L. Kretser, analyst). Refractive index (*N*): 1.740 (Sample 7-1), 1.755 (Sample 1455-10), and 1.753 (Sample 1455-11). (n.a.) Not analyzed; (n.d.) not detected.

alogy, and chemistry, with the consideration of secondary alterations [13].

Some picrite dikes demonstrate a noticeable differentiation of elements across the section. From the center to margins, the dikes are enriched in CaO, Al_2O_3, TiO_2, K_2O, S, and volatiles. At the same time, they are depleted in SiO_2, MgO, Fe_2O_3, Na_2O, and P_2O_5. This trend is consistent with the intensification of rock alteration from the dike center to its margins. The deep origin of picrites is indicated by the small amount of xenoliths of dunites, spinel lherzolites, and wehrlites up to 3 cm in size.

The geological age of the carbonatized basalt of James I Land was determined at the exposure. Lower Devonian redrocks are crosscut by the dike, which, in turn, is overlain by Middle Devonian carbonate rocks. Results of Rb–Sr and K–Ar datings in the laboratory of the Institute of Precambrian Geology and Geochronology (St. Petersburg) indicate that the picrites have an Early–Middle Carboniferous age (Table 2). Panning mineralogical sample 7 (15.3 kg) taken from a picrite dike in the Purpur Dallen Valley yielded 102.3 g of the heavy fraction that contained 24 pyrope grains together with chrome diopside and chrome spinels. Nuggets of kimberlitic accessory minerals (chrome spinels, chrome diopside, and moissanite) were found in two picrite dikes. In the feldspar-containing basalt sample (weight 9.9 kg, heavy concentrate 0.77 g), we found six nuggets of pyrope, nine grains of chrome diopside, and a few grains of chrome spinels.

Identification of pyropes was based on their color, refractive index, and chemical composition (Table 1). They occur as clasts (0.2–0.8 mm) of pink and red colors with lilac tints in the picrites and of violet-red color in the carbonatized basalt. Specific features of the Cr_2O_3–CaO relationship in the pyropes are shown in the Sobolev diagram (Fig. 2). One data point from the basalt dike falls into the pyrope domain of the diamondiferous assemblage, while other data points are typical of pyropes of the lherzolite assemblage in kimberlites.

The emerald-green chrome diopside is found as rare xenomorphic grains (0.1–0.5 mm) with the maximal Cr_2O_3 content of 1.6 wt % (Table 1). In terms of the contents of MgO, CaO, Al_2O_3, and Cr_2O_3, chrome diopside grains from picrites of Spitsbergen are similar to pyroxenes from lamproites [2], while chrome diopside grains from the basalt dike are similar to those from the diamondiferous nodules in kimberlites (Fig. 3).

Chrome spinels occur as black or brownish black clastic and euhedral grains (0.2–0.8 mm), with the Cr_2O_3 content varying from 10.2 to 54.0 wt % (Table 1). In the summary diagnostic diagram (Fig. 4), data points of chrome spinels from Spitsbergen fall into the domain of chrome spinels from the diamondiferous kimberlites and lamproites.

Taking into consideration the findings of kimberlitic accessory minerals (pyrope, chrome diopside, and chrome spinel) in porphyritic ultramafic rocks of Spitsbergen, as well as the absolute age of Paleozoic dikes in the archipelago, which coincides with the Carboniferous kimberlitic magmatism on the Zimnii coast (Arkhangelsk district) and Kola Peninsula, the picrite dikes in Spitsbergen (primarily, the best-studied dike 7) can be assigned to the pyrope facies of kimberlitic magmatism. The association of kimberlites, porphyritic picrites, and alkaline basaltic rocks is known in kimberlite fields of the Yakutian kimberlite province and in Greenland. Therefore, the spatial association of kimberlites of Spitsbergen with the carbonatized basalt dikes is quite natural.

According to [11], the Spitsbergen Archipelago was detached from Greenland during the opening of the North Atlantic Ocean. Therefore, kimberlites of Spitsbergen can represent the Paleozoic member of the Greenland kimberlite province that existed in the Early Proterozoic–Mesozoic [12].

Table 2. Absolute age of picrites in Andre Land, Spitsbergen Archipelago (Ma)

Sample	Rb–Sr method	K–Ar method
41-23 (Dike 2)	334.8 ± 3.8	357 ± 28.6
41-24 (Dike 3)	315.0 ± 3.0	297 ± 23.8
222-7 (Dike 5)	326.8 ± 2.6	422 ± 33.8*

Note: Analyses were carried out at the Institute of Precambrian Geology and Geochronology, St. Petersburg (E.S. Bogomolov and I.V. Tokarev, analysts). (*) Error in this determination can be significantly higher.

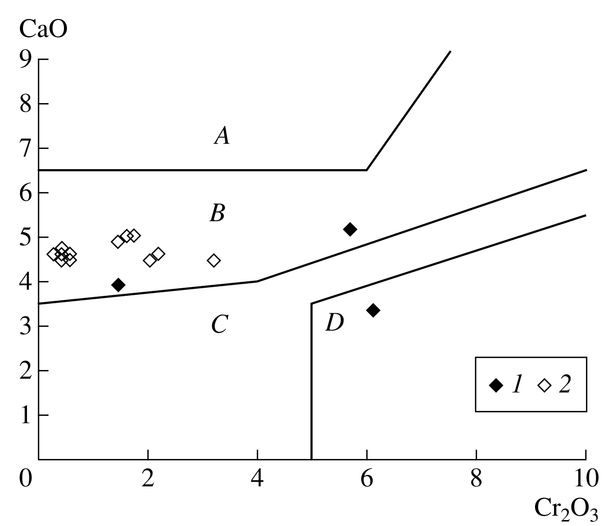

Fig. 2. The Cr_2O_3–CaO relationship in Cr-bearing garnets and pyropes from dikes on the Spitsbergen Archipelago. Compositional fields of garnets [10] from: (*A*) wehrlites, (*B*) lherzolites, (*C*) dunite–harzburgites, and (*D*) pyropes included in diamond. (*1, 2*) Pyropes from dikes on the Spitsbergen Archipelago: (*1*) carbonatized basalt dike, (*2*) picrite dike.

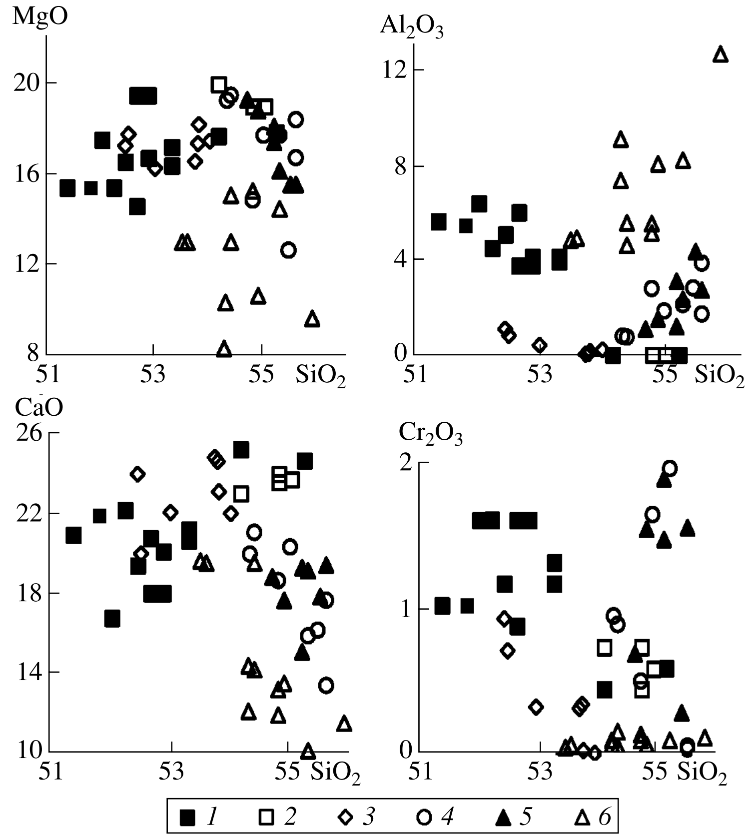

Fig. 3. Comparison of pyroxene compositions in dikes (Spitsbergen) vs. kimberlites and lamproites (adopted from [2]). (*1, 2*) Dikes in Spitsbergen: (*1*) picrites in Andre Land, (*2*) carbonatized basalt dike in James I Land; (*3*) lamproites (Australia); (*4–6*) kimberlites (Yakutia): (*4*) diamondiferous nodules, (*5, 6*) hosted in diamond of the ultramafic and eclogitic assemblages, respectively.

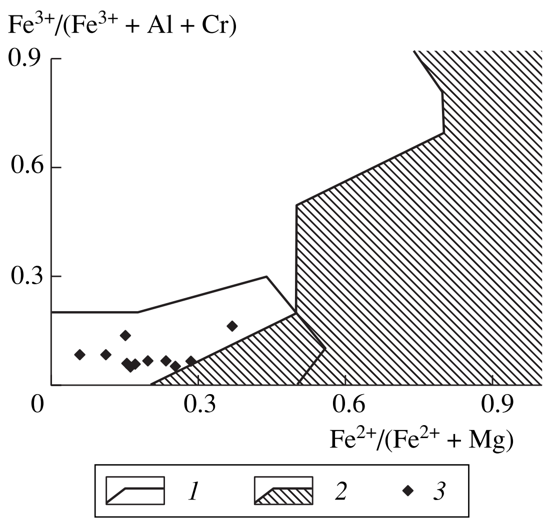

Fig. 4. The $Fe^{2+}/(Fe^{2+}+Mg)$–$Fe^{3+}/(Fe^{3+}+Al + Cr)$ relationship in chrome spinels from dikes on the Spitsbergen Archipelago. (*1, 2*) Compositional fields of chrome spinels [1] from (*1*) diamondiferous kimberlites and lamproites and (*2*) diamond-free nonkimberlitic rocks; (*3*) chrome spinels from Paleozoic dikes in Spitsbergen.

The second neighbor of the Spitsbergen kimberlite province is represented by diamondiferous diatremes on the Zimnii coast (Arkhangelsk district). They make up a single continent with Spitsbergen in the field of Proterozoic metamorphic basement.

Their absolute dates fall into the interval of 340–360 Ma [8, 9], which fits the Late Devonian–Early Carboniferous age. Thus, one cannot rule out the existence of a northwestern (Spitsbergen) branch of the Russian kimberlite province.

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