
MINERALS AND PARAGENESES OF MINERALS

Behoite and Mimetite from the Saharjok Alkaline Intrusion, Kola Peninsula

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Abstract—The detailed study of the mineral composition of the nepheline syenite pegmatite from the Saharjok Intrusion has resulted in the finding of behoite and mimetite, a mineral species identified in the Kola region for the first time. The pegmatite body at the contact between nepheline syenite and essexite is unusual in textural and structural features and combination of mineral assemblages including unique beryllium mineralization. Behoite $\text{Be}(\text{OH})_2$ is an extremely rare beryllium mineral. It occurs as powderlike aggregates in the leaching cavities between euhedral pyroxene crystals. Behoite was identified by comparison of X-ray powder diffraction data of the studied mineral phase and behoite from the Be-bearing tuff in the type locality of this mineral (Utah, United States). Mimetite was found in the same pegmatite of the Saharjok intrusion. It forms unusual parallel-fibrous aggregates with individual fibers as long as ~1 mm and only ~1 μm across. X-ray powder diffraction data and the chemical composition characterize the mineral as hexagonal phase $\text{Pb}_3[\text{AsO}_4]_3\text{Cl}$. Both behoite and mimetite are the products of late hydrothermal alteration of primary minerals (meliphanite, galena, arsenopyrite, and loellingite). The secondary phases freely crystallized in the cavities remaining after the leached nepheline.

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INTRODUCTION

The Saharjok alkaline intrusion, mostly composed of nepheline syenite, alkali syenite, and essexite, is located in the central part of the Kola Peninsula and was first described by I.D. Batieva and I.V. Bel'kov in 1957 (Fig. 1). The intrusion was fissure-type intrusion emplaced as steeply dipping dike-shaped bodies extending for more than 7 km along the vertical faults between alkali granite of the West Keivy intrusion and gneissic diorite. The intrusion has a maximal width of 1.5–2 km in its northern part. Alkali syenite is localized in the western and southwestern parts of the intrusion. Nepheline syenite occurs in the eastern part of the intrusion together with large outcrops of essexite. Nepheline syenite affects the country alkali granite, alkali syenite, and essexite with the formation of fenite halos and pegmatite veins.

Syngenetic pegmatoid aggregates and veins, which are close in composition to nepheline syenite but enriched in accessory minerals, are also related to nepheline syenite. As follows from isotopic zircon dating, the intrusion is Archean in age: 2682 ± 10 Ma for alkali syenite and 2613 ± 35 Ma for nepheline syenite (Zozulya et al., 2007). High Zr, Nb, Ta, Y, and REE contents and the complex REE–Zr deposit with zircon and britholite-group minerals are the main geochemical and metallogenic distinguishing features of alkali and nepheline syenites of the Saharjok intrusion

that differentiate it from other Archean alkaline rocks. To date, the intrusion is one of the most promising and competitive primary sources of Zr and Y in Russia (Vinogradov et al., 2000).

In addition to Zr, Y, and REE, some other minor elements also form separate mineral species: Ti (titanite), Pb (galena), Mo (molybdenite), Be (meliphanite), and P (members of the apatite and britholite groups).

Taking into account the composition of recently found behoite and mimetite, the geochemistry of Be, Pb, and As in the rocks of the Saharjok alkaline complex is briefly described below.

GEOCHEMISTRY

Beryllium. The Be content in nepheline syenite is 20–40 ppm (our data) and up to 290 ppm in essexite (Batieva and Bel'kov, 1984); these values are many times higher than the global mean Be content in the crust. Beryllium mostly occurs as an isomorphic admixture in the rock-forming nepheline and as meliphanite $(\text{Ca}, \text{Na})_2\text{Be}(\text{Si}, \text{Al})_2\text{O}_6(\text{OH}, \text{F})$ in the contact zone between essexite and nepheline syenite. Beryllium is a light element inherent to crustal granitic and alkaline rocks enriched in active volatile components, primarily fluorine. The high F concentrations ensure geochemical migration of beryllium in the form of volatile fluorine–beryllate complexes. Geochemical barriers play an important role in beryllium deposition (Pekov, 1994). The rocks of the Saharjok alkaline

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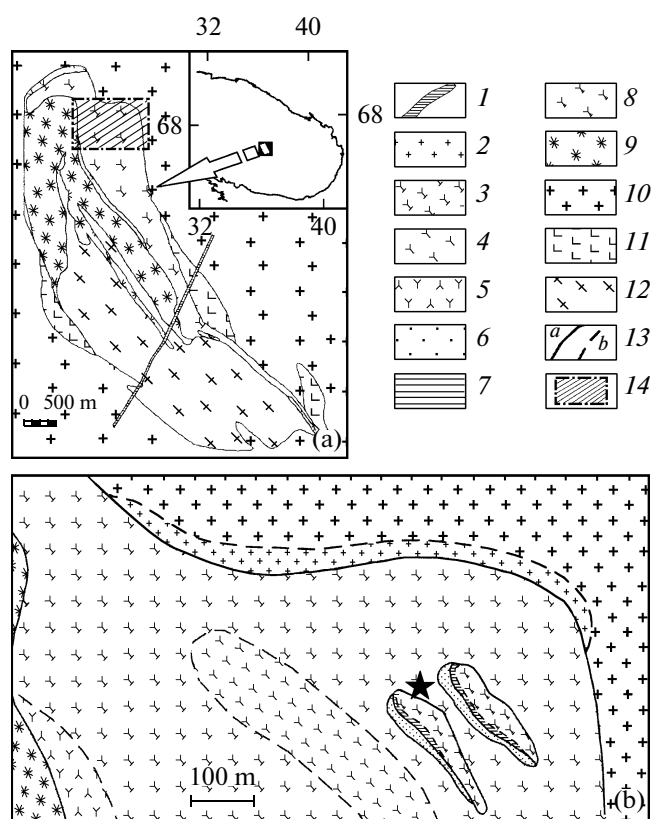


Fig. 1. Geological schemes of (a) the Saharjok alkaline pluton after Batieva and Bel'kov (1984) and (b) its north-eastern part. The pegmatite outcrop (not to scale) in the contact zone between nepheline syenite and essexite is marked by asterisk. (1) Dolerite, (2) fenitized alkali granite, (3) leucocratic nepheline syenite, (4) melanocratic nepheline syenite, (5) porphyroblastic nepheline syenite, (6) albitite, (7) glimmerite, (8) alkali gabbroid (essexite), (9) alkali syenite, (10) alkali granite (the West Keivy pluton), (11) gabbroanortosite, (12) gneissic diorite; (13) boundaries of (a) geological bodies and (b) facies varieties; (14) northeastern part of the pluton with essexite outcrops.

line intrusion are extremely rich in fluorine (0.30–1.30 wt % in essexite and 0.20–1.20 wt % in nepheline syenite). The geochemical barrier at the nepheline syenite–essexite contact facilitated the mass crystallization of meliphanite not only in the nepheline syenite itself but also in related pegmatites occurring in the contact zone and in glimmerite as a product of metasomatic alteration of essexite.

Lead. The maximal Pb content (507 ppm) was detected in melanocratic nepheline syenite (Batieva and Bel'kov, 1984); the other nepheline syenite varieties, except porphyritic, contain up to 300 ppm Pb. Galena—the major lead mineral—occurs as fine disseminations in interstices and rock-forming nepheline. Only in pegmatoid segregations of nepheline syenite does galena occur as sufficiently large (up to 3–5 mm) grains. Galena is commonly replaced by cerussite.

Arsenic. There are no data on the As content in the rocks. We can only note the occurrence of loellingite in essexite and arsenopyrite, in pegmatoid nepheline syenite.

In addition to elevated background concentrations of minor elements in the rocks of the Saharjok Complex, local areas of anomalously high Zr, Y, Be, and REE concentrations, particularly, at the syenite–essexite contact, are noteworthy. Essexite crops out as large (about 80 × 200 m) circular bodies in the north-eastern part of the nepheline syenite field (Fig. 1). Essexite is a massive medium-grained rock composed of aegirine–diopside (30–60%), phlogopite (10–50%), plagioclase (up to 30%), nepheline (up to 5%), and calcite (1–3%). At the contact with nepheline syenite, essexite is replaced with amphibole and biotite and crosscut by feldspar–nepheline and sodalite veinlets. High Li (to 0.8%) and Be (up to 1%) contents were established in the contact zone in addition to high background REE–Zr mineralization in nepheline syenite. These geochemical features reflect the mineral composition of rocks. The pegmatite body studied in the contact zone is especially indicative in this respect.

The pegmatite body has complex internal structure and is hosted in fractured essexite, filling the fissures and swells therein. Giant-grained nepheline–feldspar aggregate with aegirine, aegirine–hedenbergite, aegirine–augite, and phlogopite crystallized in the fissures. Fluorapatite, fluorite, britholite-group minerals, zircon, and meliphanite are accessory minerals.

The occurrence of contrasting rocks at the contact led to the complex and unusual combination (superposition) of mineral assemblages and textural and structural features of the pegmatite body. Distribution of mineral assemblages in pegmatite is extremely heterogeneous: there are almost monomineralic melanocratic zones mostly composed of aegirine–augite and phlogopite with a small amount of analcime, fluorine, and meliphanite and leucocratic zones made up of analcime and nepheline with subordinate amounts of mica, pyroxenes, and meliphanite. The newly formed behoite and mimetite appeared at the late hydrothermal stage.

MINERALOGY

Behoite $\text{Be}(\text{OH})_2$ is an extremely rare mineral so far described only from granite pegmatites in Texas (Ehlmann and Mitchell, 1970) and Be-bearing tuffs in Utah, where it was found for the first time (Montoya et al., 1964). Behoite mentioned in syenite pegmatite of the Oslo region in Norway (Raade and Mladeck, 1983; Larsen et al., 1992) remains undescribed, and its distinguishing features are unknown. Behoite without complete description has also been included by Pekov (1994) into a list of Be-minerals from the occurrences of the northeastern Ladoga region (Pitkäranta ore

field). A monoclinic natural modification of $\text{Be}(\text{OH})_2$ —clinobehoite—was found only in desilicated pegmatites of the Izumrudny Kopi (Emerald Mine district) in the Urals (Voloshin et al., 1989).

In the Saharjok intrusion, behoite was found in melanocratic parts of the pegmatite body, where it occurs in leaching cavities up to 1.5–2 mm in size between euhedral aegirine–augite crystals. The mineral forms brownish powderlike aggregates (Fig. 2) and closely associates with prehnite.

Identification of behoite is based on coincidence of its X-ray powder diffraction pattern with that of behoite from Texas. Reflections were displayed by analogy with synthetic phase $\beta\text{-Be}(\text{OH})_2$ (39-1411 JCPDS) (Table 1). The chemical composition of behoite was not determined because of insufficient material. Only oxygen was detected with a LEO 1450 SEM equipped with a ROENTEC EDS.

Natural beryllium hydroxides are closely related to hydrothermal alteration of primary Be-minerals (Voloshin et al., 1989) or to weathering of such unstable Be-bearing minerals as epididymite and gadolinite (Ehlmann and Mitchell, 1970). In the Saharjok intrusion, meliphanite is a primary Be-mineral. Its tabular crystals are altered from the rims up to the complete replacement of entire grains. Meliphanite in the glimmerite zones developing after essexite is altered to the highest degree. It can be suggested that behoite is a product of hydrothermal alteration of meliphanite and precipitation of beryllium hydroxide from solution. The natural solutions are depleted in beryllium, which is rapidly removed therefrom as insoluble hydroxide (Ehlmann and Mitchell, 1970).

Mimetite $\text{Pb}_5[\text{AsO}_4]_3\text{Cl}$ is a mineral from supergene zones of sulfide Pb–Zn deposits, where it is less abundant than pyromorphite $\text{Pb}_5[\text{PO}_4]_3\text{Cl}$, its phosphate analogue. Exceptional cases of primary mimetite formation at hydrothermal low-temperature

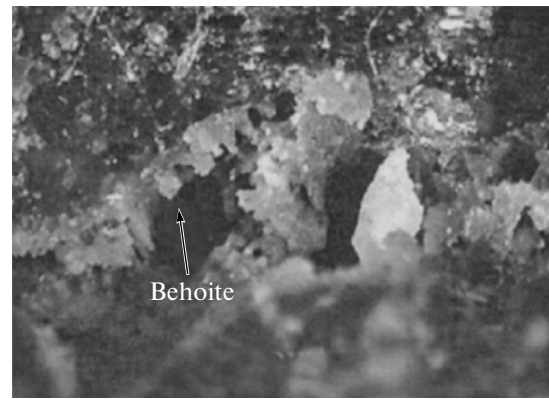


Fig. 2. Behoite in the leaching cavity between aegirine–augite crystals. Magn. $\times 35$.

deposits of Bolivia were described in the literature. Russian occurrences of mimetite are known from descriptions of this mineral in Pb–Zn ores at the Spassk, Klichka, Kadaya, and other deposits in the eastern Transbaikalia (Betekhtin, 1950). The finding of mimetite in the Saharjok intrusion is the first in the Kola Peninsula.

Mimetite from the pegmatite body of the Saharjok intrusion is unusual in crystal morphology. Mineral occurs as parallel-fibrous aggregates of individual fibers; their length (up to 1 mm) is much greater than their thickness ($\sim 1 \mu\text{m}$) (Figs. 3, 4). The mineral is light yellow in color and silky lustrous in aggregates. The dissolution cavities between euhedral aegirine–augite crystals, where mimetite was found, are composed of analcime crystals and powderlike aggregates of unidentified lead silicate (Fig. 4).

The X-ray powder diffraction pattern of mimetite from the Saharjok intrusion is shown in Table 2. Mimetite of the Pingtoulung deposit from the Guang-

Table 1. X-ray powder diffraction patterns of behoites from pegmatite of the Saharjok intrusion (I) and granite pegmatite in Texas, USA (II)

I		II		<i>hkl</i>	I		II		<i>hkl</i>
<i>I</i>	<i>d</i> , Å	<i>I</i>	<i>d</i> , Å		<i>I</i>	<i>d</i> , Å	<i>I</i>	<i>d</i> , Å	
8	3.84	vs	3.88	110	2	2.171	vw	2.17	012
		vs	3.83	011	1	2.098	vw+	2.10	130, 031
5	2.95	m	2.95	111	1	2.027	w	2.04	102
5	2.79	m	2.79	021	4	1.979	m	1.99	211
10	2.39	vs+	2.39	121	4	1.958	m	1.96	112
		vw	2.32	200	4	1.906	mw	1.91	022, 131
1	2.27	w	2.28	002	3b	1.779	vw	1.78	221
5	2.206	mw	2.20	210			vw	1.77	122, 040

Note: Behoite (I) was examined on a 57.3 mm RKD camera ($\text{Fe}_{K\alpha}$ radiation); data on behoite (II) are given after Ehlmann and Mitchell (1970). Lines: (vs+) strongest, (vs) very strong, (m) medium, (mw) medium–weak, (w) weak, (vw) very weak, and (vw+) weakest.

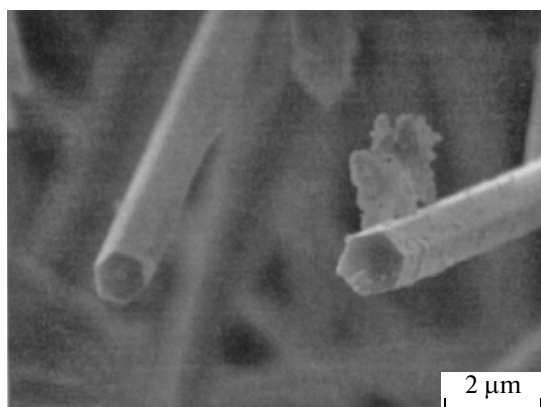


Fig. 3. Long-prismatic crystals of mimetite.

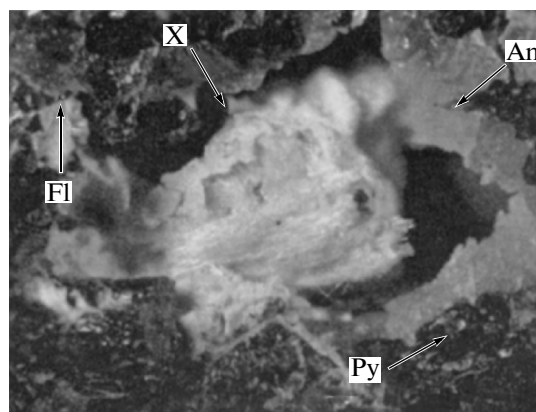


Fig. 4. Parallel-fibrous aggregate of mimetite crystals in the leaching cavity. Fl, fluorite; An, analcime; Py, pyroxene; X, unidentified phase (Pb silicate?). Magn. 40.

dong Province in China was studied under the same conditions for comparative purposes. The X-ray powder diffraction patterns of both samples are similar but some differences have been noted. Most d values of the Sahariok mimetite are slightly lower than in the Chinese sample but some values are similar (italicized in Table 2). The 211 and 112 lines of the Saharjok mimetite are drawn together so tightly that they are not detectable. Both X-ray powder diffraction patterns are satisfactorily displayed in the hexagonal system. The unit-cell parameters determined from 19 (for mimetite I) and 24 (for mimetite II) unambiguously displayed reflections are $a = 10.12(1)$, $c = 7.43(2)$ Å and $a = 10.24(1)$, $c = 7.44(1)$ Å, respectively. The latter

values almost completely coincide with the parameters of synthetic hexagonal mimetite: $a = 10.25$ Å and $c = 7.442$ Å (19-683 JCPDS).

Approval of clinomimetite (monoclinic modification of mimetite) (Dai and Hughes, 1991) by the Commission on New Minerals in 1991 caused some difficulties in mineral phase identification. The above authors emphasized that the structure of clinomimetite is strongly pseudohexagonal. The X-ray powder diffraction patterns do not discriminate between mimetite and clinomimetite because the deviation from the hexagonal system ($\beta = 119.88^\circ$) is comparable to the uncertainty of the powder method. Only high-precision monocrystal technique determines the

Table 2. X-ray powder diffraction patterns of mimetites from the Saharjok intrusion (I) and Pingtoulung ore deposit, China (II)

I			II			I			II		
I	$d_{\text{exp.}}, \text{\AA}$	$d_{\text{calc.}}, \text{\AA}$	I	$d_{\text{exp.}}, \text{\AA}$	hkl	I	$d_{\text{exp.}}, \text{\AA}$	$d_{\text{calc.}}, \text{\AA}$	I	$d_{\text{exp.}}, \text{\AA}$	hkl
1	4.423	4.384	1	4.441	200	2	2.032	2.035	3 (broad)	2.048	312
2	4.188	4.184	2	4.211	111	3	1.987	1.984	5	1.994	213
			4	3.72	002	3	1.947	1.942	5	1.963	321
2	<i>3.442</i>	<i>3.422</i>	3	<i>3.442</i>	<i>102</i>	3	1.916	1.913	5	1.933	410
6	3.319	3.314	6	3.348	210	3	1.888	1.888	5	1.905	402
10	3.027	3.027	10	3.058	211	<i>1</i>	<i>1.86</i>	<i>1.858</i>	<i>4</i>	<i>1.861</i>	<i>004</i>
		2.996	10	3.015	112				1	1.752	313
6	2.925	2.923	6	2.956	300	1	1.699	1.701	3	1.717	412
			1	2.854	202	2	1.658	1.657	3	1.68	420
			1	2.555	220	2	1.645	1.646	3	1.666	331
1	2.303	2.311	3	2.32	311	2	1.619	1.621	3	1.628	214
		2.297			302	2	1.584	1.586	3	1.598	502
<i>1</i>	<i>2.228</i>	<i>2.225</i>	2	<i>2.228</i>	<i>113</i>	3	1.564	1.562	5	1.575	323
1	2.188	2.192	2	2.210	400	3	1.534	1.536	5	1.553	332
4	2.094	2.092	7	2.111	222			1.540			511

Note: Both mimetites were examined on a 57.3 mm RKD camera (Fe radiation, without filter, NaCl standard).

Tables 3. Chemical composition of mimetites from the Saharjok intrusion (I) and Pingtoulung ore deposit, China (II)

Oxide	I		II	
	wt %	f.c.	wt %	f.c.
PbO	63.64	3.25	75.14	5.00
FeO			0.00	
V ₂ O ₅			0.00	
CaO	1.52	0.31	0.00	
Al ₂ O ₃			0.00	
As ₂ O ₃	27.85	2.76	21.49	2.78
SiO ₂	4.74	0.90	0.00	
P ₂ O ₅			0.07	0.01
SO ₃			0.12	0.02
Cl	2.25	0.72	2.27	0.95
Total	100.00		99.10	

Note: Calculation of formula coefficient (f.c.) is based on 13 oxygen + chlorine anions.

structure of the minerals unambiguously. In the case of the Saharjok sample, monocrystal study of mimetite is impossible because of its very fine fibrous morphology. The X-ray parameters and chemical composition (see below) identify the Saharjok mineral as a hexagonal modification of $\text{Pb}_5[\text{AsO}_4]_3\text{Cl}$.

Chemical composition was determined with a LEO-1450 SEM equipped with a ROENTEC EDS in a nonpolished section because of the morphological specificity of mimetite. Pb, As, O, and Cl are detected as major elements, whereas Ca and Si are noted as trace elements. The estimated oxide contents recalculated to 100% are given in Table 3 along with the mimetite composition from the Chinese deposit determined with a CAMECA MS-46 microprobe operating at an acceleration voltage of 22 kV and current intensity of 20–40 nA. The following standards were used: Fe—hematite ($\text{Fe}K_{\alpha_1}$), Si,Ca—diopside ($\text{Si}K_{\alpha}$, $\text{Ca}K_{\alpha}$), Al— $\text{Y}_3\text{Al}_5\text{O}_{12}$ ($\text{Al}K_{\alpha}$), V—metal ($\text{V}K_{\alpha_1}$), P—apatite ($\text{P}K_{\alpha_1}$), S,Pb—galena ($\text{S}K_{\alpha_1}$, $\text{Pb}M_{\alpha}$), As—GaAs ($\text{As}L_{\beta_1}$), and Cl—atacamite ($\text{Cl}K_{\alpha_1}$).

Isomorphism $\text{Si}^{4+} \rightarrow \text{As}^{5+}$ and $\text{Ca}^{2+} \rightarrow \text{Pb}^{2+}$ is typical of mimetite from various localities. The second scheme was even suggested as a criterion of mimetite and clinomimetite discrimination (Dai, 1993)¹.

¹ If the presence or absence of Ca in the chemical composition of $\text{Pb}_5[\text{AsO}_4]_3\text{Cl}$ is the only criterion for distinguishing mimetite and clinomimetite, the Chinese sample should be referred to as a monoclinic modification

Mimetite from the pegmatoid body of the Saharjok alkaline intrusion is probably a product of late hydrothermal alteration of the primary sulfides and their analogues. As was mentioned above, loellingite was found in essexite, and arsenopyrite was identified in the pegmatoid facies of nepheline syenite; both rocks contain galena. The morphology of mimetite testifies to its free crystallization in leaching cavities presumably left after nepheline. Ca and Si admixtures characteristic of mimetite decrease the unit-cell parameters in comparison with those of the synthetic phase.

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