The Khibina massif

The Khibina massif is situated in the central part of the Kola Peninsula, 66°33′-67°55′N, 33°13′-37°16′E. Topographically, it is a dome-shaped mountain massif with the highest point 1200 m above sea level. The massif is intersected by deep canyons and wide river valleys. Some of the mountains are cupped with extensive plateaus, and encircled with cirques and steep slopes. Topographic features bear evidence of glacial activity; moraine ridges are present in the river valleys. The Khibina pluton is located in the contact of Archaean gneisses and Proterozoic Pechenga-Imandra-Varzuga palaeoriftogenic volcanic-sedimentary complexes, which form the Lapland-Kola-Belomorian collisional structure.

Main rock complexes forming the Khibina massif.

The Khibina massif is a concentrically zoned multiphase intrusion composed of agpaitic nepheline syenites, and in minor amount of ultrabasic alkaline rocks (Galakhov, 1975; Zak et al., 1972; Kostyleva-Labuntsova et al., 1978) (Fig. 1). From the oldest to the youngest the components are as follows:

1. Remnants of the alkaline volcanic complex: peridotites, pyroxenites, melilite-bearing rocks
2. Melteigite-ijolite-urtite layered complex.
3. Nepheline syenites of the peripheral zone ("khibinites").
4. Nepheline syenites of the central part of the massif (foyaites) and pulaskites.
5. K-nepheline syenites ("rischorrites"), juvites, urtites and related apatite-nepheline rocks.
6. Pegmatites and late hydrothermal veins/
7. Dykes of essexite, alkaline picrite, nephelinite, phonolite, trachyte.
8. Carbonatites.

Despite the huge size of the Khibina massif, it is surrounded by just a narrow halo of metasomatic alteration. Fenitization of host gneisses rarely exceeds 50 m and the metavolcanic rocks of the Imandra-Varzuga complex have been metamorphosed to hornfels near to the contact without any overall change in composition. In the foyaite, immediately adjacent to the Central Ring, there are many xenoliths of hornfels richest in alumina and their fenitized equivalents, containing sillimanite, andalusite, corundum, hercynite, fayalite, quartz, topaz, cordierite, sekaninaite and pyrrhotite. The size of the xenoliths ranges from several metres up to 3 km, and reaches 600 m wide; their long axes are practically always parallel to the Central Ring.

The Khibina complex is somewhat a Mecca for mineralogists and mineral collectors due to numerous pegmatites comprising unique assemblages of rare minerals. About 80 new minerals were first discovered in the Khibina and most of them occur in pegmatites and late hydrothermal veins (Yakovenchuk et al., 2005). The bulk of the veins is related to rocks of the Central Ring and to adjacent foyaite localities. The most characteristic shapes of veins are equant and stockwork-shaped; their common size is 30–50 m long and 0.5–1 m wide (Tikhonenkov, 1963). The contacts of the host rocks can be gradual or sharp but also in the latter case an exocontact alteration is usually observed (decomposition of nepheline, sodalite and cancrinite to an entangled mass of fibrous natrolite and hydrous micas, and also eudialytization, aegirinization etc.).

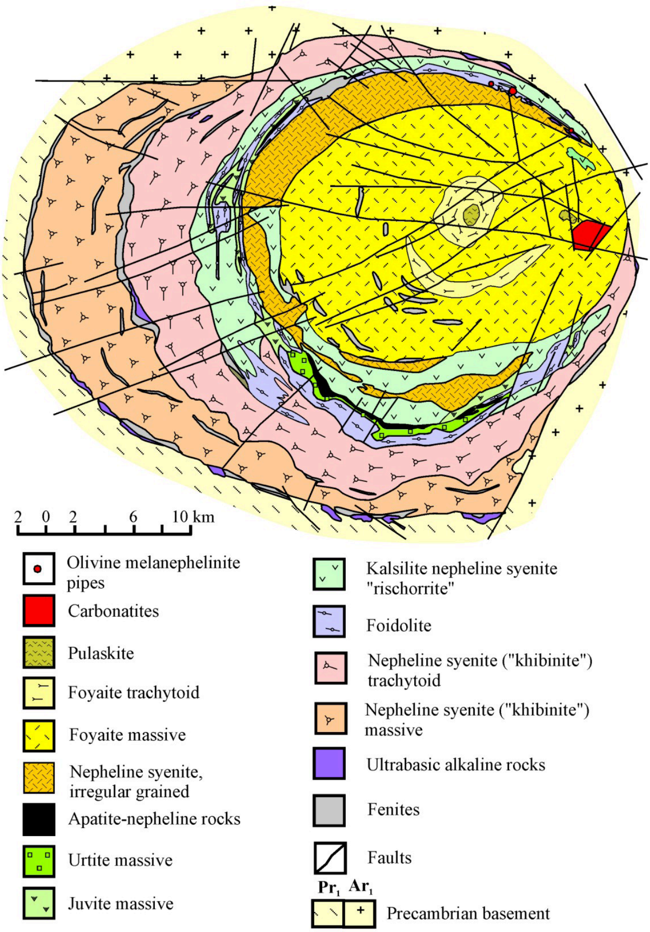

Fig. 1. Geological map of the Khibina massif generalized from the map of MGRE PGO "Sevzapgeologiya" (V.P.Pavlov).

Fig. 2. Open cast mines, the Niorkpakhk (at the front) and Koashva (in the background) deposits.

Mineral Deposits of the Khibina massif

Visit to the Eastern group of apatite-nepheline deposits (Vostochny mine (Fig.2) (8 hours, 50 km of the Apatity town).

Stop 1. Koashva open pit

Main types of apatite-nepheline ores, titanite-apatite ore, magmatic apatite breccia, massive juvite, pegmatite zones.

Apatite-nepheline rocks are spatially related to urtite and juvite. Rasvumchorr, Kukisvumchorr, Yukspor, Koashva, Niorkpahk are the biggest deposits of apatite ores located within a narrow zone in the southern part of the massif. A typical cross section of the ore body from top to bottom is as follows (Fig. 3):

a) Titanite-apatite uppermost contact zone. Titanite mineralization is spread in the upper zone of juvites and ijolites.

b) Breccia of apatite ores. Xenoliths of different ore types are settled fine-grained apatite, apatite-titanite or apatite-nepheline matrix.

c) A rich mottled and banded apatite ore (10 - 20 % wt. P_2O_5),

c) A poor lenticular, taxitic, and block apatite ore types (5 - 10 % wt. P_2O_5),

d) Apatite-bearing massive coarse-grained urtite,

e) Apatite-free massive coarse-grained urtite.

Table 1. Average modal composition of industrial types of apatite ores, vol. % (After Kamenev, 1987).

	Apatite	Nepheline	Pyroxene	Titanite	Titano-magnetite	Ilmenite	Feldspar	Others
Titanite-apatite	21.9	30.92	17.73	18.21	4.23	1.19	2.20	3.62
Mottled	74.62	14.85	5.89	1.35	0.39	0.20	1.55	1.15
«Blocked»	44.04	39.75	8.68	3.00	1.21	0.35	1.22	1.74

Lens-banded	43.33	42.09	7.69	2.21	2.02	0.28	0.68	1.70
Massive	40.11	38.74	11.11	3.12	1.12	0.38	3.26	2.16
Net-like	31.71	51.84	9.25	2.64	2.55	0.65	0.45	1.51
Urtite with apatite	10.10	63.50	16.18	4.16	0.75	0.37	2.30	2.64

Table 2. Selected analyses of K-nepheline syenite, juvite, urtite and apatite-nepheline rocks.

Rock	K-nepheline syenite		Juvite		Urtite		Apatite-nepheline rocks	
Drillhole	979	1113	818	360	20	522	1152	466
Depth, m	946	357	786	670	100	500	80	645
SiO_2	48.48	52.55	48.98	46.45	43.09	40.28	12.23	30.33
TiO_2	2.64	0.52	0.64	2.33	3.07	2.09	1.10	10.63
Al_2O_3	19.99	21.53	22.84	20.15	23.46	27.16	6.45	9.52
Fe_2O_3	2.84	2.87	2.98	3.31	2.86	1.96	2.11	4.41
FeO	2.15	1.65	1.57	2.16	2.67	1.37	1.08	3.87
MnO	0.16	0.08	0.12	0.16	0.13	0.04	0.08	0.22
MgO	0.60	0.12	0.92	2.51	1.22	0.20	0.31	1.88
CaO	3.06	0.92	1.26	4.63	4.61	4.52	38.18	20.54
Na_2O	6.55	7.30	9.83	0.01	12.40	15.10	3.36	5.42
K_2O	12.08	11.72	9.98	6.88	5.74	4.98	1.35	2.14
P_2O_5	0.27	0.07	0.20	0.50	0.60	1.65	29.81	9.03
CO_2	0.18	0.21	0.05	0.14	0.09	-	0.10	0.10
Cl	0.04	-	-	-	0.04	-	-	-
F	0.10	0.04	0.13	0.12	0.16	0.23	2.35	0.95
H_2O^+	0.78	0.69	0.62	0.26	0.47	0.76	0.19	0.28
H_2O^-	0.04	0.26	0.08	0.38	0.11	0.01	0.07	0.05
Total	99.92	100.53	100.20	99.99	100.68	100.37	100.62	100.73
Nb	168	98	28	35	43	24	42	412
Sr	1520	1690	1450	1776	846	2114	15559	10993
Rb	357	347	485	219	119	11	18	46
Li	9	20	19	13	11	15	5	9
Cs	17	4	6	3	2	3	1	1

There is no distinct boundary between the ore zone and the underlying urtite, and with the decrease in the amount of apatite the ore grades into urtite. This structure of ore bodies is typical of western group of deposits, whereas in south-eastern part of the massif the ore zone is brecciated.

Apatite $Ca_5(PO_4)_3F$, being the main component of the ore, contains 40-41 wt.% P_2O_5, 1.8-3.5 wt.% SrO, 9000-11000 ppm REE, and 500-900 ppm Y. It is represented by several generations of different shape and colour. Light green fine-grained varieties dominate, needle-like light yellow crystals and recrystallized smoky-coloured coarse-grained aggregates are also abundant. Nepheline (Fig. 4), the second main rock component used now as by-product, consists of 33 wt.% Al_2O_3, 15 wt.% Na_2O, 7 wt.% K_2O, 150 ppm Rb and 40 ppm Ga. High content of Fe and presence of numerous microneedles of aegirine is a factor which limits the use of nepheline as a crude ore for ceramics. Chemical analyses of apatite-nepheline ores are listed in Table 2, modal composition of commercial ore types are presented in Table 1.

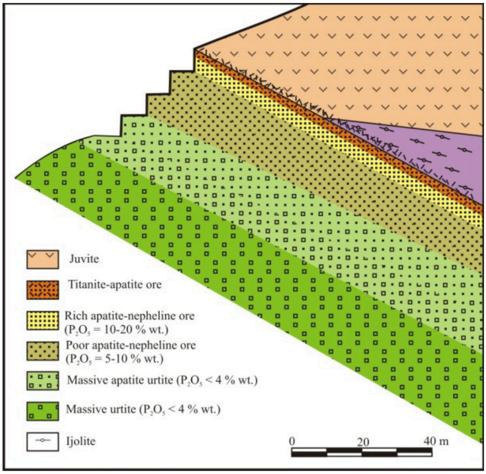

Fig. 3. Schematic cross section of the apatite-nepheline ore zone in the northwestern part of the massif.

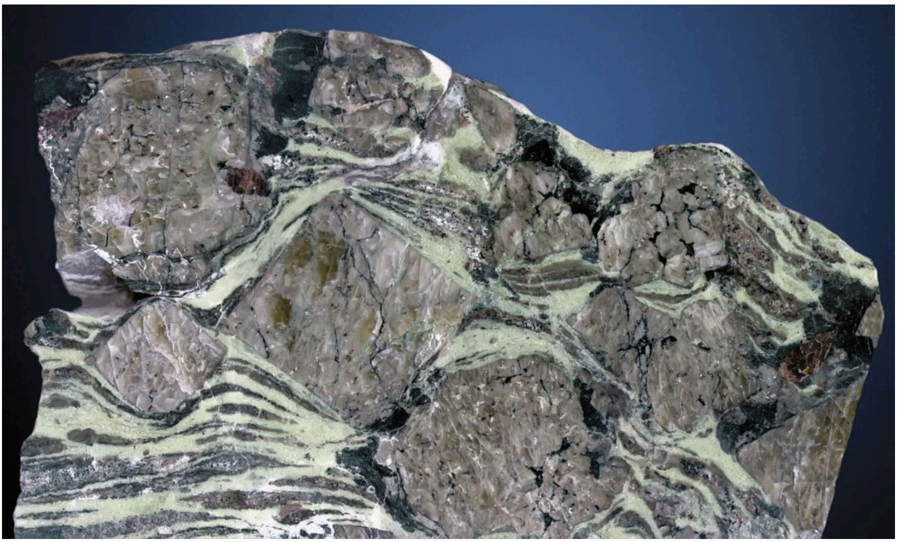

Fig. 4. 4-cm size nepheline crystals in apatite-nepheline ore.

Given the high content of P, Sr, REE, Y, Ti, Al, Na, K, Li, Rb and Ga, the Khibina apatite-nepheline ores are of great commercial importance. However, apatite deposits are now the only object of commercial importance for phosphorus.

There are eleven apatite-nepheline ore deposits in the Khibina massif: Partomchorr, Kuelporr, Kukisvumchorr, Yuksporr, Apatite Circus, Rasvumchorr, Koashva, Niorkpakhk, the Oleny Ruchei River and Vuonnemiok River. All are located along the Central Ring of the massif. A company, fittingly called "APATIT", was set up in 1929 and in the 1930s industrial production of the Khibina apatite from the Kukisvumchorr Deposit enabled Russia to stop importing Moroccan phosphorites and become the largest supplier of apatite concentrate in the international market. In the mid 1950s, the "APATIT" company began production of apatite ore using underground mines at Mts Yuksporr and Rasvumchorr, and then, in 1964, the "Tsentralny" (Central) Open Cast Mine on the Rasvumchorr Plateau was put into operation.

Later, in 1981, the "Vostochny" (East) Open Cast Mine was set up to work the Koashva and Niorkpakhk Deposits. In 2007, a new open cast mine was opened to work the Oleny Ruchei River Deposit. Today the "APATIT" company is unique, it is one of the world's biggest manufacturers of phosphate raw material. Total reserves of apatite at the Khibina are estimated at 3 billion tons. Production reached a maximum of 20.04 million tons per year in 1981 but has now fallen and levelled off at 9 million tons per year in 2000.The total registered reserves of apatite-nepheline ores of the Khibina deposits are estimated as almost 4 bln.t., which corresponds to 600 mln.t. of P_2O_5, i.e. the enterprise is provided with prospected reserves for 50 years.

The Koashva Deposit, richest in the Khibina massif, was discovered in 1959. The ore zone of the deposit is made of a series of closely related lens-shaped bodies, spread over more than 3 km. Its strike is north-east, 330–340°, and the dip is 30–40°. The thickness of the ore zone as a whole decreases as the depth increases, from 200–300 m up to several metres. The host rocks are orthoclase-bearing ijolite-urtite. Typical characteristics of the deep part of the ore zone are the compact arrangement of the ore bodies and consistent layered form. The ore body is practically uniform up to 200 m thick and for the purposes of mining, the structure is very similar to the Kukisvumchorr or Rasvumchorr Deposits. In the top part of the ore zone the ore body is divided into series of separate lenses. Brecciated rocks are most common and all the rest textural types are of secondary importance. Within the overlying rocks, lens-shaped bodies of apatite-titanite rock, up to 20 m thick, are predominant. The deposit has been mined since 1978 by means of an open cast mine (the "Vostochny" Mine): Fig. 2.

Fig. 5. Mt. Takhtarvumchorr. It shows positions of the numbered mineral localities

The Khibina massif. Phonolite dykes, alkaline pegmatites and albitites of Mt. Takhtarvumchorr

Stop 2. Mt. Takhtarvumchorr

Phonolite dykes in foyaite of Mt. Takhtarvumchorr (about 500 m from the vechicle, elevation 100 m).

There are a lot of vertical phonolite dykes (up to 1 m thick) at the slopes of this mountain (Fig. 5). Phonolite is a fine-grained green rock consisting of euhedral crystals of nepheline, thin-bladed orthoclase, entangled-fibrous and radiating aegirine, lamellae of phlogopite and grains of sodalite, analcime, natrolite, cancrinite and fluorite. Tinguaite is also found in the axial zones of the largest phonolite dykes and is distinguished from other varieties of phonolite by its microstructure, in which there are large impregnations of nepheline and orthoclase into the trachytic structure of the main orthoclase-aegirine-nepheline mass. The marginal parts of the phonolite dykes frequently display an unusual cellular-zoned, rhythmically-banded, dendrite-like, breccia or “orbicul” texture (Fig. 6), imparting a rather attractive appearance. Abundant bladed crystals of troilite are located in the central parts of cells. Minerals: aegirine, analcime, cancrinite, fluorite, natrolite, nepheline, orthoclase, phlogopite, sodalite, troilite.

Mt. Takhtarvumchorr

Albitites, Mt. Takhtarvumchorr. Albitites are widespread on the eastern slope of Mt. Takhtarvumchorr, forming a stockwork of veins from 0.1 up to 4 m wide, between which the foyaite is variably albitised. Albitites are usually easy to distinguish because of their rusty-brown colouring caused by the widespread development of goethite after pyrrhotite. Contacts with the host rocks are usually indistinct; in places, the eudialyte content increases appreciably in foyaite up to 30 cm from the albite veins. The veins are composed of compact, fine-grained albite with relics of altered light-brown eu-

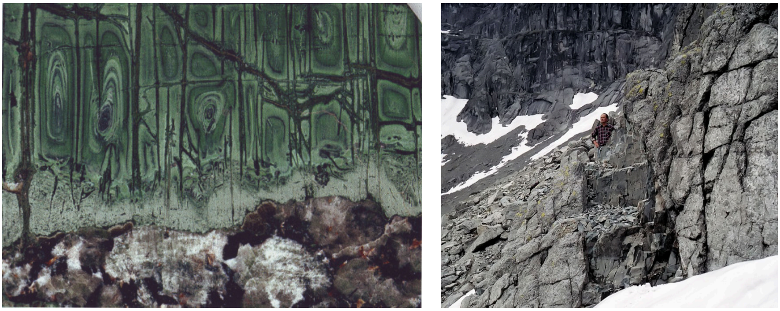

Fig. 6. Stop 2-1: phonolite dyke in foyaite, Mt. Takhtarvumchorr.

dialyte (up to 1 cm diameter), microcline laths up to 3 cm long and nodules and stream-like aggregates of black fine-crystalline aegirine. Sometimes albitization has developed within separate parts of the aenigmatite-eudialyte-aegirine-microcline veins widespread in this area. Lens-shaped clusters (up to 50 cm wide and up to 1 m diameter) of light green sugar-like fluorapatite and molybdenite are found in the axial zones of these veins. Molybdenite occurrs as groups (up to 2 cm diameter) and spherulites (up to 5 mm diameter) of lamellar crystals within the groundmass of albite and fluorapatite and can reach proportions as high as 20 vol.%. Bladed ilmenite crystals (up to 7 mm diameter) occur in association with the molybdenite. Titanite is widespread as lemon-yellow prismatic crystals (up to1.5 cm long) and spherulites of thin-acicular crystals (up to 4 cm diameter). Graphite is characteristic of the aegirine-rich parts of the veins. It forms parallel-fibrous (areas up to 100 cm^2) or radiating (up to 5 cm diameter) aggregates when intergrown with aegirine, and occurrs together with molybdenite impregnating albite and fluorapatite. In some of the albite veins there is an abundant impregnation of semi-transparent brown, prismatic zircon (up to 6 mm) surrounded by a 1–3 mm fringe of snow-white parakeldyshite (TL), keldyshite, sodalite and cancrinite. Parakeldyshite and keldyshite also often develop after eudialyte. Reddish-orange prismatic levenite (up to 3 mm long) is common. Bladed grains of pyrrhotite, up to 1 cm, are always, to a greater or lesser degree, replaced by pyrite, marcasite and goethite. Grains of galena (up to 5 mm) and black sphalerite (up to 1 cm) are also found.

Minerals: aegirine, aegirine-augite, aenigmatite, albite, astrophyllite, cancrinite, eudialyte, fluorapatite, galena, goethite, graphite, ilmenite, keldyshite, låvenite, marcasite, microcline, molybdenite, parakeldyshite, pyrite, pyrrhotite, sodalite, sphalerite, titanite, zircon, loparite-(Ce). Chalcopyrite grains (1.5 cm diameter) surrounded by a wide rim of blueish-green brochantite are found in the thin-fibrous aegirine spherulites.