

FIELD EXCURSION

# Geochemistry in Khibiny mountains and Monchegorsk, Kola Peninsula, Russia





# **Geochemistry in Khibiny mountains and Monchegorsk, Kola Peninsula, Russia**

Excursion guide, 27 - 31 August 2011

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Yuri Voytekhovsky and Jouni Pihlaja

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## Geochemistry in Khibiny mountains and Monchegorsk, Kola Peninsula, Russia

Yuri Voytekhovskiy<sup>1</sup> and Jouni Pihlaja<sup>2</sup>

<sup>1</sup> Russian Academy of Sciences, Kola Science Centre, Geological Institute, 14 Fersman Street, Apatity, 184209 Russia, e-mail woyt(at)geoksc.apatity.ru

<sup>2</sup> Geological Survey of Finland, P.O. Box 77, 96101 Rovaniemi, Finland, e-mail jouni.pihlaja(at)gtk.fi

### Abstract

This excursion gives a short introduction to the Khibiny alkaline massif and isotope geochemistry and geochronology of the Kola Peninsula focusing on the Monchegorsk intrusions. Different types of mine activity relating to apatite and Cu-Ni with PGE deposits with the environmental issues are to be seen during the excursion.

The Khibiny massif situates in the central part of the Kola Peninsula, 66°33' - 67°55'N, 33°13' - 37°16'E. It is a dome-shaped mountain massif with the highest point of 1200 m above the sea level. The Khibiny pluton is located in the contact of the Archaean gneisses and Proterozoic Pechenga-Imandra-Varzuga palaeoriftogenic volcanic-sedimentary complexes, which form the Lapland-Kola-Belomorian collisional structure. The Khibiny massif is a concentrically zoned multiphase intrusion composed of agpaitic nepheline syenites, and in minor amount of ultrabasic alkaline rocks. On the eastern slope of Mt. Takhtarvumchorr albitites are widespread.

The Monchegorsk pluton belongs to the Kola Province of PGE-bearing layered intrusions. The U-Pb age of the pluton is 2509-2487 Ma. It occurs in gneisses of the Kola-Belomorian complex and diorites with the age of 2932-2630 Ma. The horseshoe-shaped exposed area of the Monchepluton rocks is more than 60 km<sup>2</sup>. The general structure is affected by the south-east part of the pluton, the Vurechuaivench Foothills, lying monoclinally and joining through the bottom fold with the trough-like branch near the Nyud and Poaz. It gently dips south-eastwards under the supra-crustal complex of the Imandra-Varzuga zone. The rocks of Fm. Purnacha lie on the weathered surface of the Vurechuaivench gabbro-norites, and its basal conglomerates contain gabbro-norite pebbles.

The lowest zone of the pluton is in its SW part within the contact with the Monchetundra massif. The western part of the pluton consists mainly of bronsitites and harzburgites, while the eastern part includes plagioclase-bearing rocks generally represented by mesocratic norites and gabbro-norites. The rocks of the pluton show insignificant cryptic layering. The layered rocks of the pluton are cut by numerous gabbro-pegmatite veins, gabbro-norite dykes, later dolerites and lamprophyres. There are about 36 ore deposits and occurrences of Cu-Ni, PGE-bearing and chromite mineralization in Monchegorsk region. 21 of them are confined to the rocks of the Monchegorsk pluton.

Extracting Cu, Ni, Co and PGE from sulphide ores cause harm to the environment. Every ore producer faces this problem. Russia is no exception and the towns Nikel, Zapolyarny and Monchegorsk ecology testifies to the fact. Several years ago JSC "Severonikel" started investing in the recultivation of soils about Mts. Nittis, Kumuzhiya and Travyanaya. The Greenpeace-friendly organizations of the Kola Peninsula become all the more active. The administration of the region has been financially maintaining the ecological tourism.

## Excursion program and route

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### Saturday, 27th August

Leave from Rovaniemi at 9 am, arrive evening in Kirovsk, Russia. Overnight in Kirovsk (Hotel Severnaya).

### Sunday, 28th August

Workshop

1. Petrology and geochemistry of the Khibiny alkaline massif
2. Isotope geochemistry and geochronology of the Kola Peninsula

Overnight in Kirovsk (Hotel Severnaya)

### Monday, 29th August

Excursion to the Mt. Khibiny

Stop 1. Koashva open pit

The major excursion focus of the Koashva open pit is a member of the Eastern Group of apatitenepheline Khibiny deposits. The apatite-nepheline rocks are spatially related to urtite and juvite. The Rasvumchorr, Kukisvumchorr, Yukspor, Koashva, Niorkpahk are the biggest deposits of apatite ores located within a narrow zone in the southern part of the Khibiny massif.

Stop 2. Mt. Takhtarvumchorr

Depending on weather conditions and time rested after the excursion to the Koashva open pit, excursionists are to be taken to the bottom of Mt. Takhtarvumchorr. Phonolite dykes in foyaites of Mt. Takhtarvumchorr (about 500 m from the vehicle, elevation 100 m). There are a lot of vertical phonolite dykes (up to 1 m thick) at the slopes of this mountain. 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. Tinguaites are also found in the axial zones of the largest phonolite dykes and are distinguished from other varieties of phonolite by their 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 "ruin" texture, imparting a rather attractive appearance. Abundant bladed crystals of troilite are located in the central parts of cells.

Overnight in Kirovsk (Hotel Severnaya)

### Tuesday, 30th August

Excursion to the Monchegorsk area

Stop 3. "Terrace" deposit

The excursionists are to visit the Cu-Ni "Terrace" deposit in the Monchegorsk area with an extremely various rock composition, giant breccia textures and mafic pegmatites and dumps of sulphide ore at the "Fersman's adit". The access to the outcrops is within 300 m distance. The outcrop of the "Terrace" traces the horizon of giant blocks of thinly-bedded rocks known as "sadberites", or hypothetical units of the pluton roof.

The “Terrace” deposit is also confined to the norite and olivine norite complex and the “Crytical Horizon” rocks of the Nyud massif. The structure of the deposit is mainly bedded. The ore does crop out. The disseminated ore bodies occur in layers. In the lower part of the “Crytical horizon”, at the “Terrace” deposit, Academician A.E. Fersman discovered a large (2.0 x 3.5 x 6.75 m) sulphide nest with magnetite. It was mined out in 1930s, but the massive sulphide ore samples, though oxidized, are present in the dumps of the old adit.

#### Stop 4. Vurechuaivench deposit

The Vurechuaivench deposit is a nicely outcropped area with numerous exposures of gabbronorite, where the excursionists may examine the typical section of the ore-bearing reef. The detailed sector demonstrates the main rock mass represented by fine- and medium-grained mesocratic massive, partially metamorphosed gabbronorite of yellow-greenish colour. The rock is intercalated with leucocratic metagabbro and is cut by a metagabbrodolerite dyke. In the northern part of the area there are outcrops of gabbronorite with sulphide impregnation containing PGEs.

The Vurechuaivench prospect is confined to the zone of alternating meso-leucocratic massive and taxitic gabbronorite and anorthosite-plagioclase. The PGE mineralization is related to the extensive zone of lens-like and tabular sulphide bodies. The mineralized zone is conformable to the layering, and contains about 20 sulphide horizons.

The horizons are marked by a 1-3-m thick interval of rich ore, resembling a reef in a way. The length of the rhythmically layered series is 7-8 km along strike, the width is 1.5 km, and the thickness is up to 1 km. The content of ore minerals reaches 5-10 %. Ore minerals: chalcopyrite, pyrrhotite, millerite, and Ni and Co arsenides. PGE minerals: Pd and Pt telluro-bismuthides, sulphides, arsenides and sulphoarsenides. Among these are kotulskite, merenskite, maichenerite, moncheite, sperrhyllite, mayakite, arsenopalladinite, mertite, stibiopalladinite, stillwaterite, and gold and silver minerals, intermetallic phase of silver and gold and hessite with predominant Pt and Pd tellurides (55 %). The grain size varies from 10 to 70 µm. The total PGM content is 0.5-15 ppm.

Overnight in Kirovsk (Hotel Severnaya)

### **Wednesday, 31st August**

Drive back from Kirovsk to Rovaniemi, where at 4-5 pm.

#### **Weather and clothing:**

Weather in late August can vary considerably - the temperature range is in between 5 to 25°C, being typically around 15°C in daytime. It is recommended that one should have a weatherproof jacket in case of rain.

#### **SAFETY INSTRUCTIONS:**

**The instructions of your guides and hosts MUST be followed at all times.** Be aware of loose boulders and do not approach too close the open pits at the mines. Be aware of heavy machinery.

Mobile numbers of your guides:

Jouni Pihlaja: +358 40 824 3117



General map.

## The Khibina massif\*

Guide: Arkady K. Shpachenko, Cand. Sci.  
(Geol.-mineral.)

The Khibina massif is situated in the central part of the Kola Peninsula,  $66^{\circ}33' - 67^{\circ}55'N$ ,  $33^{\circ}13' - 37^{\circ}16'E$ . Topographically, it is a dome-shaped mountain massif with the highest point of 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 the 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.

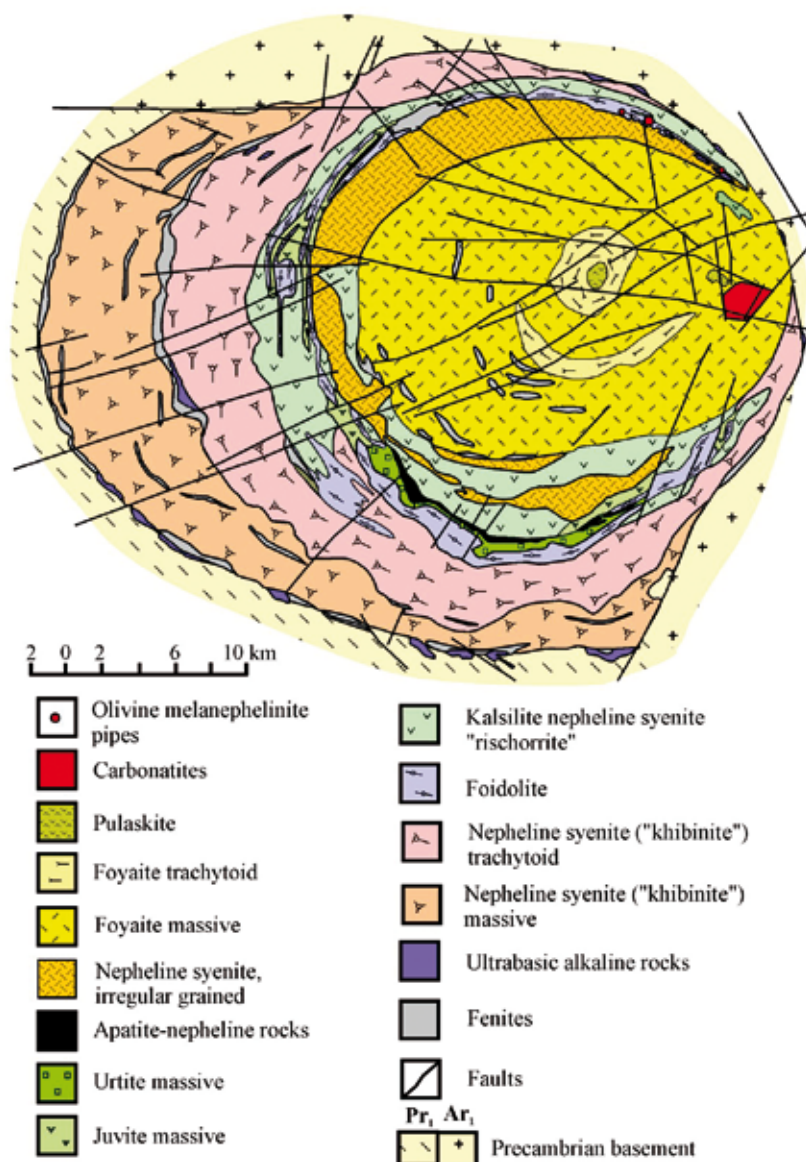
\* Based on Arzamastsev, A., Yakovenchuk, V., Pakhomovsky, Y. and Ivanyuk, G., 2008. The Khibina and Lovozero alkaline massifs: Geology and unique mineralization. Geological Institute, Kola Science Centre, Russian Academy of Sciences (Apatity, Russia). Published as the Guide 47 for the 33 IGS Congress in Oslo in 2008.

## 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 (“rischor-rites”), juvites, urtites and related apatite-nepheline rocks.
6. Pegmatites and late hydrothermal veins/
7. Dykes of essexite, alkaline picrite, nephelinite, phonolite, trachyte.
8. Carbonatites.

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



Despite the huge size of the Khibina massif, it is surrounded by just a narrow halo of metasomatic alteration. The 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 have been first discovered in the Khibina and most of them oc-

cur in pegmatites and late hydrothermal veins (Yakovenchuk et al., 2005). The bulk of the veins is related to rocks of the Central Ring and 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, aegiriniztion etc.).

### Mineral Deposits of the Khibina massif

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



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

### 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, Niorkpakhk 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.

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

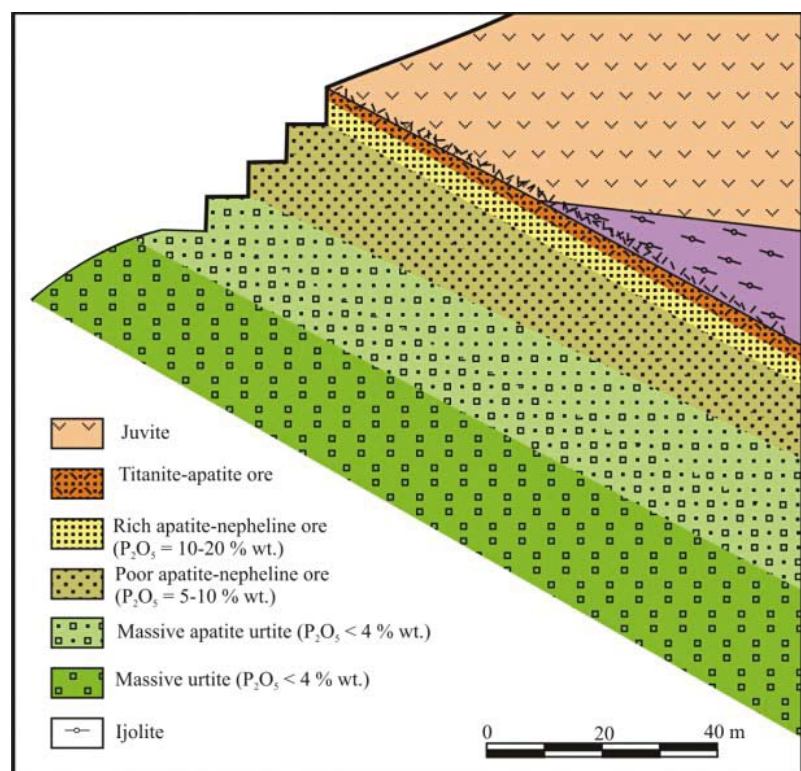


Table 1. Average modal composition of industrial types of apatite ores, vol. % (Kamenev, 1987).

	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 <sub>2</sub>	48.48	52.55	48.98	46.45	43.09	40.28	12.23	30.33
TiO <sub>2</sub>	2.64	0.52	0.64	2.33	3.07	2.09	1.10	10.63
Al <sub>2</sub> O <sub>3</sub>	19.99	21.53	22.84	20.15	23.46	27.16	6.45	9.52
Fe <sub>2</sub> O <sub>3</sub>	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 <sub>2</sub> O	6.55	7.30	9.83	0.01	12.40	15.10	3.36	5.42
K <sub>2</sub> O	12.08	11.72	9.98	6.88	5.74	4.98	1.35	2.14
P <sub>2</sub> O <sub>5</sub>	0.27	0.07	0.20	0.50	0.60	1.65	29.81	9.03
CO <sub>2</sub>	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 <sub>2</sub> O+	0.78	0.69	0.62	0.26	0.47	0.76	0.19	0.28
H <sub>2</sub> O-	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. With the decrease in the amount of apatite the ore grades into urtite. This structure of ore bodies is typical of the western group of deposits, whereas in the south-eastern part of the massif the ore zone is brecciated.

Apatite Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>F, being the main component of the ore, contains 40–41 wt.% P<sub>2</sub>O<sub>5</sub>, 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 a by-product, consists of 33 wt. % Al<sub>2</sub>O<sub>3</sub>, 15 wt.% Na<sub>2</sub>O, 7 wt.% K<sub>2</sub>O, 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.

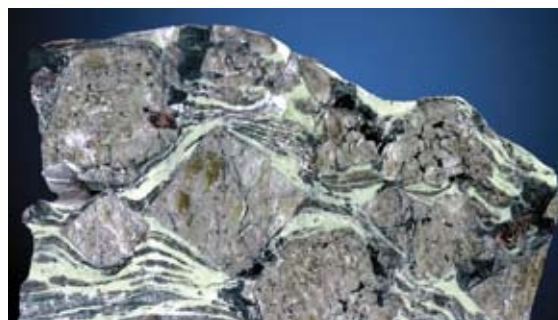


Fig. 4. 4-cm-size nepheline crystals in the apatite-nepheline ore.

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 Ruchej River and Vuonnemiok River. All of them are located along the Central Ring of the massif. A company, fittingly called “APATIT”, was set up in 1929/ In the 1930s the 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 to the world market. In the mid 1950s, the “APATIT” company began producing the apatite ore using underground mines at Mts Yuksporr and Rasvumchorr/ 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 Ruchej 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,  $330-340^\circ$ , and the dip is  $30-40^\circ$ . 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.

### **Mt. Takhtarvumchorr - Phonolite dykes, alkaline pegmatites and albitites**

Phonolite dykes in foyaite of Mt. Takhtarvumchorr (about 500 m from the vehicle, elevation 100 m) (Fig. 5).

There are a lot of vertical phonolite dykes (up to 1 m thick) at the slopes of this mountain (Fig. 6). Phonolite is a fine-grained green rock consisting of euhedral crystals of nepheline, thin-bladed ortho-

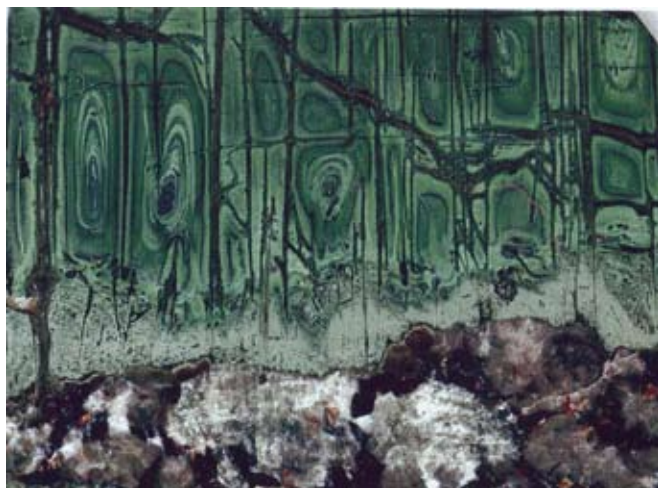
clase, entangled-fibrous and radiating aegirine, lamellae of phlogopite and grains of sodalite, analcime, natrolite, cancrinite and fluorite. Tinguaitite is also found in the axial zones of the largest phonolite dykes. It differs from other varieties of phonolite by its microstructure with large impregnations of nepheline and orthoclase in 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. 7), 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.

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

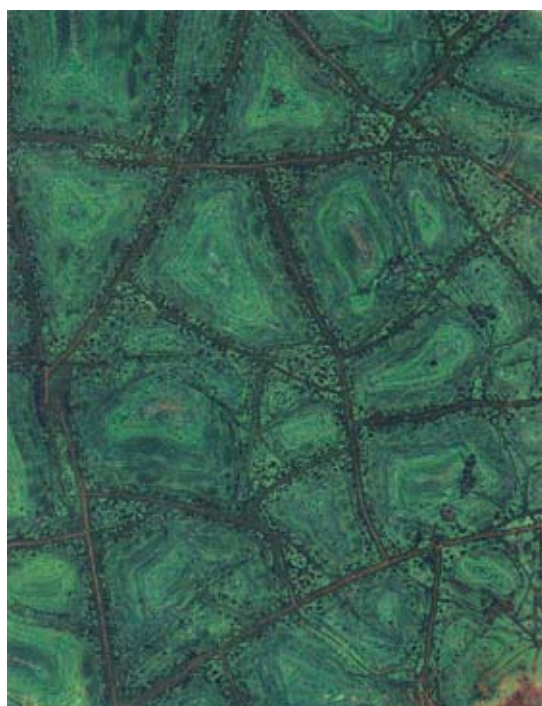


Fig. 7. A) cellular-zoned and b) brecciate texture of phonolite.



A

B



### Mt. Takhtarvumchorr - Albitites

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 some 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 eudialyte (up to 1 cm in diameter), microcline laths up to 3 cm long and nodules and stream-like aggregates of black fine-crystalline aegirine. Sometimes the 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 in diameter) of light green sugar-like fluorapatite and molybdenite (Fig. 8) are found in the axial zones of these veins. Molybdenite occurs as groups (up to 2 cm in diameter) and spherulites (up to 5 mm in 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 in diameter) occur in association with the molybdenite. Titanite is

widespread as lemon-yellow prismatic crystals (up to 1.5 cm long) and spherulites of thin-acicular crystals (up to 4 cm in diameter). Graphite is characteristic of the aegirine-rich parts of the veins. It forms parallel-fibrous (areas up to 100 cm<sup>2</sup>) or radiating (up to 5 cm in diameter) aggregates when intergrown with aegirine and occurs 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 livenite (up to 3 mm long) is common. Bladed grains of pyrrhotite, up to 1 cm, are always, more or less, 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, l avenite, marcasite, microcline, molybdenite, parakeldyshite, pyrite, pyrrhotite, sodalite, sphalerite, titanite, zircon, loparite-(Ce). Chalcopyrite grains (1.5 cm in diameter) surrounded by a wide rim of blueish-green brochantite are found in the thin-fibrous aegirine spherulites.

Fig. 8. Molybdenite rosettes (up to 2.5 mm) in an apatite-albite rock, Mt. Takhtarvumchorr.



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## Geology of the Monchegorsk area\*

Guide: Pavel V. Pripachkin, Cand. Sci.  
(Geol.-mineral.)

The Monchegorsk ore region is located between the Kola and Belomorian Archaean domains (Fig. 9). The area is characterized by the voluminous Early Proterozoic mafic-ultramafic magmatism. Its effusive species comprise more than 90 % of the total volcanic-sedimentary rocks of the Palaeoproterozoic

Imandra-Varzuga rift belt. Intrusive facies is represented by the three layered complexes to follow: the Monchepluton, Mochetundra massif and Imandra intrusion, and a number of small mafic-ultramafic intrusions. Mafic dykes occupy about 5 % of the Archaean basement.

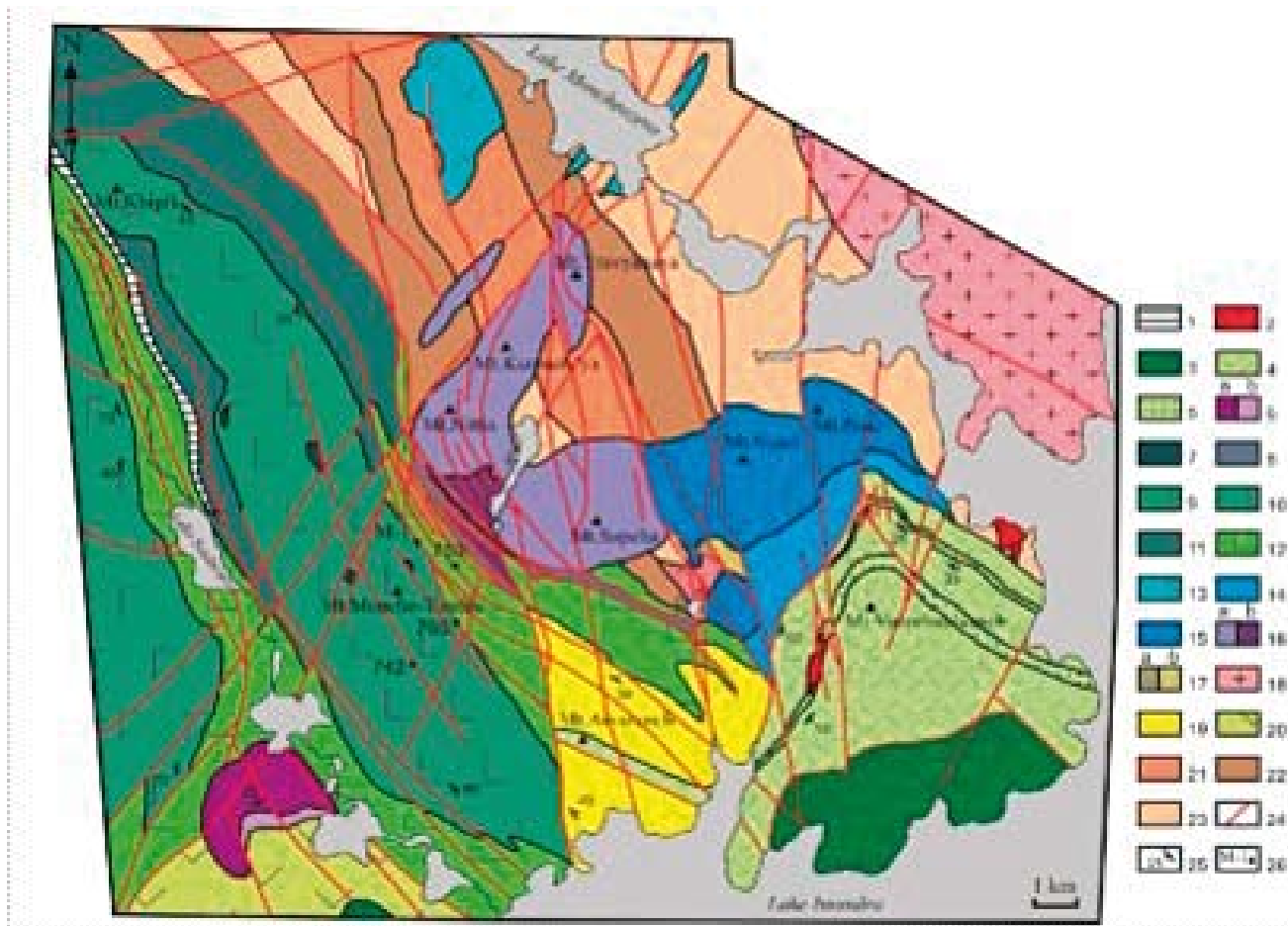


Fig. 9. Geological map of the Monchegorsk ore district.

Legend: 1 – large gabbro-dolerite dykes; 2 – anatectite-granite and trondhjemite; 3 – metagabbroids of the Imandra lopolith; 4-5 – metavolcanics (4), quartzites and shists (5) of the Kuksha and Seidorehcka Fms of the Imandra-Varzuga zone; 6 – lherzolite, websterite, orthopyroxenite (a) and gabbronorite of the Ostrovsky Lake massif; 7 – troctolite; 8 – large norite, orthopyroxenite and gabbro dykes; 9 – gabbro-anorthosite of the Chuna-tundra massif; 10-11 – metagabbro, gabbronorite (10) and alternating orthopyroxenite and norite (11) of the Monche-tundra massif; 12 – blastocataclasite mainly after Chuna- and Monche-tundra gabbroids, and after amphibolite, gneiss and diorite of the Archaean complex; 13 – Yarva-Varaka norite, diorite and

granophyre quartz diorite; 14 – Vurechuaivench Foothills metagabbro, gabbronorite and anorthosite; 15 – Monchepluton olivine norite, norite, gabbronorite (Nyud-Poaz); 16 – Monchepluton peridotite, pyroxenite (a) and dunite (a) (NKT); 17 – diorite (a) and metagabbro (a) of the 10th anomaly; 18-23 – Archaean complex: 18 – diorite, granodiorite, 19 – Archaean acid volcanics and metasediments of Arvarench Mt., 20 – schistose amphibolite of Vite-guba Fm, 21-23 – high-alumina (21), garnet-biotite (22) and biotite-amphibole (23) gneiss; 24 – tectonic dislocations; 25 – strike and fault; 26 – deep record borehole.

\* Based on Voytekhovskiy, Y. and Neradovskiy, Y., 2008. The Cu-Ni-PGE and Cr deposits of the Monchegorsk area, the Kola Peninsula, Russia. Geological Institute, Kola Science Centre, Russian Academy of Sciences (Apatity, Russia). Published as the Guide 47 for the 33 IGS Congress in Oslo in 2008.

The Imandra-Varzuga structure is the part of the Palaeoproterozoic Pechenga-Varzuga rift belt, extending through the whole Kola Peninsula from the White Sea Throat to the Norwegian Caledonides. Supracrustal volcano-sedimentary rocks form graben-like asymmetric troughs up to 40 m wide and 7 km deep. Asymmetric structure is a result of the position between the hard Kola and remobilized Belomorian Archaean domains. In the NE limb of the trough, the Proterozoic units overlay the Archaean basement in the same direction with angular unconformity, weathering crust and basal conglomerates. In contrast, in the SW limb, a contact between the Proterozoic and Archaean rocks, appears to be obscure due to the strong dislocation and metamorphic alteration.

Layered intrusions of the Monchegorsk region occupy the same structural position as the supracrustal units, being located between the Archaean domains and tracing this boundary even outside the Imandra-Varzuga zone. They are confined to the submeridional transform fault dislocating the Pechenga and Imandra-Varzuga parts of the Pechenga-Imandra-Varzuga volcanic belt.

### The Monchepluton and associated deposits

The Monchegorsk pluton, or Monchepluton, belongs to the Kola Province of PGE-bearing layered intrusions (Mitrofanov et al., 1993). The U-Pb age of the pluton is 2509-2487 Ma (Smolkin et al., 2001). It occurs in gneisses of the Kola-Belomorian complex and diorites with the age of 2932-2630 Ma (Balashov et al., 1993). The exposed area of the Monchepluton rocks is more than 60 km<sup>2</sup>. It takes a horseshoe shape in plane. The meridional branch up to 7 km long is marked out by Mts. Nittis, Kumuzh'ya and Travyanaya (NKT) and latitudinal branch up to 9 km long – by Mts. Sopcha, Nyud and Poaz. The bottom of the both branches has a shape of symmetric trough and plunges westwards, where the branches of the Monchepluton are jointed (Fig. 10). The general structure is affected by the south-east part of the pluton, the Vurechuaivench Foothills, lying monoclinally and joining through the bottom fold with the trough-like branch near the Nyud and Poaz. It gently dips south-eastwards under the supracrustal complex of the Imandra-Varzuga zone. The Purnacha Fm rocks lie on the weathered surface of the Vurechuaivench gabbro-norites and its basal conglomerates contain gabbro-norite pebbles.

The lowest zone of the Monchepluton is situated in its SW part within the contact with the Monchetundra massif, which is evident from: 1) increasing thickness and volume of the ultramafic rocks; 2) deepening of the pluton bottom when closing to this zone; 3) abundance of the local complex

dykes and dunites considered as residues of the magmatic feeder; 4) strong alteration of the Archaean gneisses representing paligenic restites.

The western part of the pluton consists mainly of bronstites and harzburgites, while the eastern part includes plagioclase-bearing rocks, which are generally represented by mesocratic norites and gabbro-norites. The section transgressively thickened; in other words, directional variation in the rock composition takes place both vertically and laterally. It is demonstrated by the outlined compositional difference between the western and eastern parts of the Monchepluton and by the presence of gabbro-norites only in the very SE part of the Vuruchuaivench Foothills. The pluton rocks show insignificant cryptic layering. The composition of the same rocks varies laterally from west to the east to a greater extent than vertically. So, in rocks where orthopyroxene appears to be cumulus phase, Al<sub>2</sub>O<sub>3</sub> content increases from 2.5 to 8 %, relative ferruginosity – from 15 to 21 %. Such variations suggest that the composition of the melt, from which the rocks crystallized, became more leucocratic and feriferous during the fractionation, while tracing eastwards. This phenomenon is known as a gravitational-cinematic differentiation (Kozlov, 1973). It suggests filling of the magmatic chamber during the crystallization.

The layered rocks of the pluton are cut by numerous veins of gabbro-pegmatites, dykes of gabbro-norites that belong to the local regional complex, and later dolerites and lamprophyres.

The pluton is broken by shear-faults into blocks displaced for long distances. Thus, the latitudinal branch is lower than submeridional up to 300 m downward.

There are about 36 ore deposits and occurrences of Cu-Ni, PGE-bearing and chromite mineralization in the Monchegorsk region. 21 of them are confined to the rocks of the Monchepluton. Ore types are intimately related to the rock types.

### Mineral composition of the ores

More than 60 opaque minerals are determined in the Monchepluton mineralization. Most of them are PGE-bearing (Grokhovskaja et al., 2000; 2002; Dedeev et al., 2002). The main minerals are pyrrhotite, magnetite, pentlandite, chalcopyrite, Ti-magnetite, pyrite. Minor and rare minerals are ilmenite, chromite, cubanite, violarite, molybdenite, mackinawite, sphalerite, millerite, galena, tellurobismuthine, altaite, sylvanite, kalaverite, hessite, melonite, native Au, hematite, melnikervite, marcasite, bravoite, polydymite, nickeline, leucoxene, bornite, chalcocite, covellite, kotulskite, merenskite, maichenerite, hollingworthite, sperrylite, platarsite, irarsite, laurite, Pt-gersdorffite, electrum, nauman

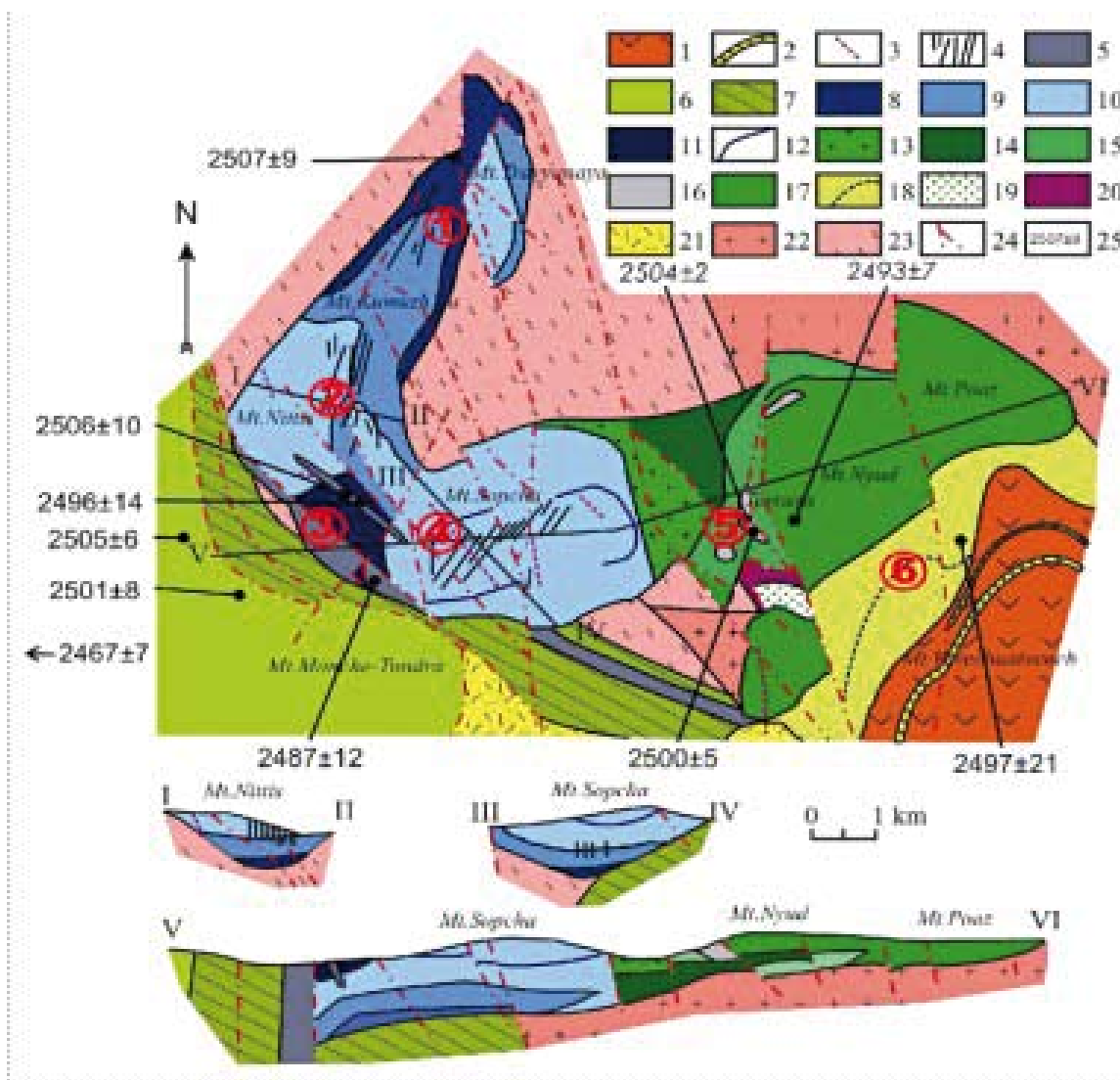


Fig. 10. Geological sketch map and cross-sections of the Monchepluton with isotope U-Pb data of the intrusive and dykes rocks. "Layered intrusions...", 2003.

Legend: 1-2 – metavolcanics (1), quartzite and schists (2) of Kuksha and Seidorechka Fms of the Imandra-Varzuga zone; 3 – metadolerite and lamprophyre dykes; 4 – sulphide veins of the NKT and Sopcha ore fields; 5 – gabbro, melanonorite, and orthopyroxenite dykes; 6 – gabbro and anorthosite of the Monche-tundra massif; 7 – blastocataclasites after gabbroids; 8 – harzburgite and the near-bottom NKT rocks; 9 – alternating harzburgite, olivine orthopyroxenite and orthopyroxenite; 10 – orthopyroxenite; 11 – Dunite Block dunite, plagiodunite, and chromitite; 12 – the "330" ore horizon of Sopcha Mt.; 13 – plagiorthopyroxenite; 14 – melanonorite; 15 – olivine norite, harzburgite; 16 – the "Critical horizon" rocks of Nyud Mt.; 17

– norite; 18 – metagabbro, gabbro and anorthosite of the Vurechuaivench Foothills and PGE-bearing horizon; 19 – amphibolized gabbro and 20 – diorite of the 10th anomaly; 21-23 – acid volcanics of Arvarench Mt. (21), diorite, granodiorite (22), biotite, garnet-biotite, amphibole and the gneisses richest in alumina, magmatites (23) of the Archaean complexes; 24 – tectonic dislocations; 25 – isotope zircon and baddeleyite U-Pb age. The location layout of the excursion stops: 1 – bottom Cu-Ni ores of Travyanaya Mt., 2 – vein field of the NKT Cu-Ni ores, 3 – the Sopchezero Cr deposit, 4 - "horizon 330" of Cu-Ni ores, 5 – the Nyud-2 deposit of Cu-Ni ores 6 – the Vurechuaivench deposit of Pt-Pd ores. 1-6 exposures are to visit during the excursion.

nite, moncheite, maslovite, frudite, braggite, cooperite, vysotskite, niggliite, iridosmine, stannopalladinite, sopcheite, and unnamed phases: Pd<sub>3</sub>Ag, (Pd, Hg, Au)<sub>3</sub>As, PdBi<sub>3</sub>, Pd,Bi,Te<sub>2</sub>, (Pd, Pb), (Pd, Rh, Cu), and hydrous ferric oxides.

The oxidation zone is represented by various ferric oxides, such as limonite and hydrogoethite, which are widespread on the hills' surface.

### Petrology of the intrusive rocks

The petrochemical study has demonstrated that magmas of the above-discussed layered intrusions and high-Mg volcanites of Seidorechka and Polisarka Fms had derived from a single mantle source, but evolution of parental melt in both cases had been individual. Primary melts of the Imandra intrusion, Monchegorsk pluton and high-Mg volcanites of Seidorechka and Polisarka Fms are the products of ultrabasic melt differentiation derived during the high degree partial melting of the mantle. The primary mafic melt of the Monchetundra massif and the whole complex of the Main Ridge were derived from the same mantle source during the low-degree partial melting.

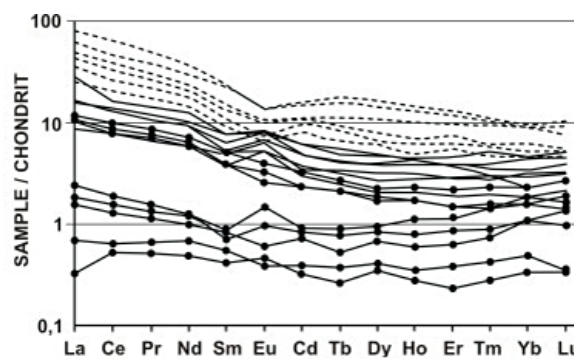
Melt fractionation within the chamber in the Monchegorsk and Monchetundra massifs took place at the stagnant environment and was related only to the gravitational separation of pyroxene and plagioclase that caused poor-developed cryptic layering. The rocks of the Imandra intrusion crystallized under convective melt mixing, thus resulted in a high degree fractionation, obvious cryptic layering and presence of magnetite ferrogabbrodiorites in the upper part of the section. The convection in the melt could presumably happened due to high temperature difference between the main melt within the chamber and the felsic liquid in its upper part.

Independent petrological data have been gathered from the analysis of REE distribution. Fig. 11 shows diagrams of the REE distribution normalized to chondrite in rocks. The mafic rocks of the layered intrusions and high-Mg volcanites lie parallel at the REE distribution diagrams. The volcanites are characterized by higher level of the REE concentration, showing distinct negative Eu anomaly, although, the layered rocks define a clear positive Eu anomaly. Such difference is most likely, because the volcanites represent quenched rocks, while the layered rocks are cumulative.

Ultramafic rocks also demonstrate two patterns of REE distribution. Cumulative layered ultramafic rocks are related to the chondrite type. The enrichment in LREE is defined for the lower ultramafic bodies, which can indicate LREE enrichment of the mantle source. A single enriched mantle source of primary melts of the Proterozoic layered intrusions,

dykes of gabbronorite and high-Mg volcanites, is supported by a narrow range of  $\epsilon_{Nd} -2 \pm 1$  in rocks (Balashov et al., 1993).

Fig. 11. Chondrite-normalized plots of the REE distribution in layered rocks of the Monchegorsk region and high-Mg volcanites of the Polisarka and Seidorechka Fms. Firm lines indicate basic layered rocks, lines with circles - ultrabasic layered rocks, and dotted line - volcanites.



### The ore deposits and ore prospects in norite

Two sulphide Cu-Ni deposits and one ore occurrence are confined to norites. Great variability of ore types marked by discontinuous beds and stock-like bodies, which are associated to the rocks of critical horizon, development of irregular sulphide dissemination, veinlets, large pockets and schlierens of 0.5-0.7 m are the most remarkable features of these deposits. The lack of structural control in the ore-type distribution within the deposits and metals in the ore is typical there. A distinctive example is the Nyud-2 deposit. It is situated in the south-west of the Nuyd-Poaz massif to the upper section of it and occurs in melanocratic norites underlain by plagioclase pyroxenites, olivine norites and plagioclase peridotites (Dokuchaeva & Sholokhnev, 1974). The ore body represents an up to 40 m thick cyathiform stock. The geological contact of the ore body is defined by the boundaries of "critical horizon" rocks' distribution. The ore types are massive schlierens and flying reefs, streaky-disseminated and disseminated. The size of schlierens of massive ore is 5-7 m. They are framed by the complicated apophyses, veins and dissemination.

### The ore deposits and ore prospects in gabbronorite

Gabbronorites are located in the eastern part of the Monchepluton. They contain a low-sulphide PGE mineralization that is being explored. According to

preliminary data, the Vuruchuaivench ore occurrence manifests a low sulphide PGE mineralization associated with a zone of lenticular and sheet-like bodies. The mineralized zone is conformable to the layering and includes up to 20 sulphide horizons, where the reef-like interval of high-grade ore up to 1-3 m thick has been revealed.

The exposed rhythmical layering is traced for 7-8 km along the strike. It is 1.5 km wide and up to 1 km thick.

#### Cu-Ni ore of the "Critical horizon"

Visit to the mine at the Nyud-2 deposit and the "Terrace" deposit. The attention of the excursionists will be devoted to examining the "Critical horizon" outcrop of the Monchepluton within the mined-out deposit (Nyud-2) of disseminated and nest-disseminated ores.

The dumps and wall debris of the mine contain samples of various nest-disseminated ores

in norites, gabbronorites, pyroxenites and other rock types. The rocks are often represented by fine-grained varieties with taxitic textures. The deposit is characterized by a high variability of ore types exhibited in inpersistent layers and stock-like bodies associating with the rocks of the «Crytical horizon», development of uneven sulphide impregnation, streaks and large nests and schlierens varying from 0.5 to 7.0 m in size. The massive sulphide schlierens are framed by complicated systems of apophyses, veins and impregnation. The lack of structural control in the distribution of dissemination is typical both of the ore within the deposit and metals in the ore. The combination of syngenetic and epigenetic ore types with dominating Cu-Ni metallogeny is common. The geological boundary is marked by the borders of the "Crytical horizon" rock distribution. The "Terrace" deposit occurring eastwards from the Nyud-2 deposit is also related to this element of the Monchepluton structure (Fig. 12).

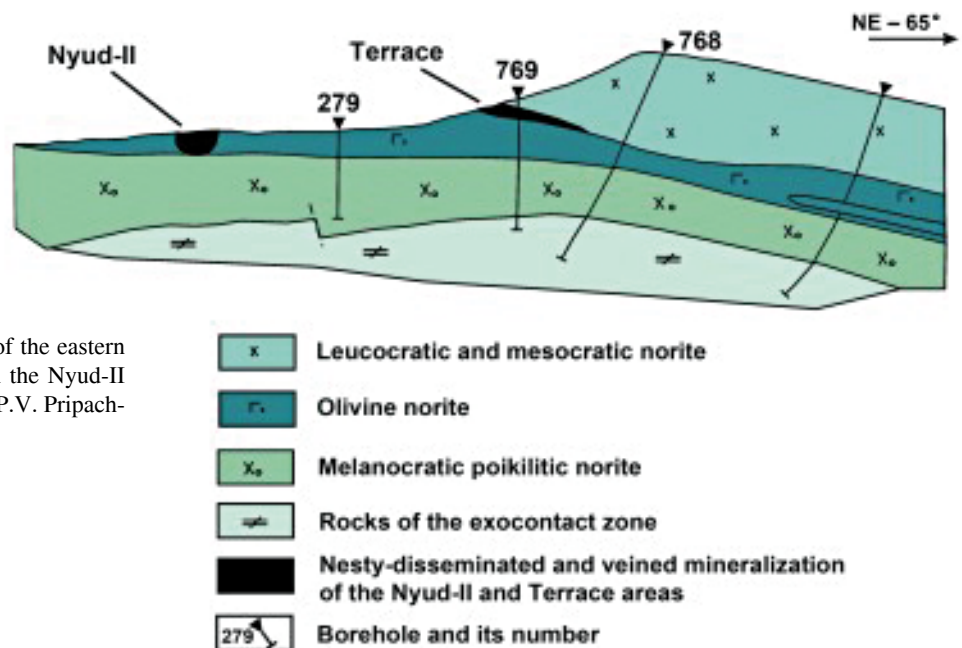
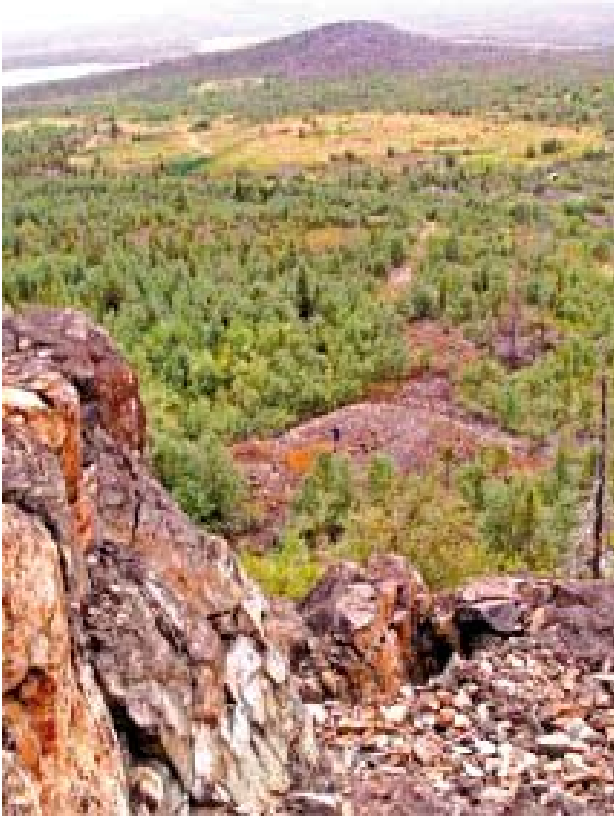


Fig. 12. The sketch cross-section of the eastern part of the Monchepluton through the Nyud-II and Terrace deposits compiled by P.V. Pripachkin on the basis of CKE data.

#### Cu-Ni ore of the "Terrace" deposit

The excursionists are to visit the eastern part of the "Crytical horizon" with an extremely various rock composition, giant breccia textures and mafic pegmatites and dumps of sulphide ore at the "Fersman's adit" (Fig. 13). The access to the outcrops is within 300 m distance. The outcrop of the «Terrace» traces the horizon of giant blocks of thinly-bedded rocks referred to as «sadberrites», or hypothetical units of the pluton roof. The "Terrace" deposit is also confined to the norite

and olivine-norite complex and the "Critical horizon" rocks of the Nyud massif. The structure of the deposit is mainly bedded. The ore does crop out. The disseminated ore bodies occur in layers. In the lower part of the "Critical horizon», at the "Terrace" deposit, Fersman discovered a large (2.0x3.5x6.75 m) sulphide nest with magnetite. It was mined out in 1930s, but the massive sulphide ore samples, though oxidized, are present in the dumps of the old adit.



Pt-Pd ore of the "Vurechuaivench" deposit

The excursionists are transported by a truck to the stop. A nicely outcropped area shows numerous exposures of gabbronorite, where the excursionists may examine the typical section of the ore-bearing reef. The detailed sector (Fig. 14) demonstrates the main rock mass represented by fine- and medium-grained mesocratic massive, partially metamorphosed gabbronorite of yellow-greenish colour. The rock is intercalated with leucocratic metagabbro and is cut by a metagabbrodolerite dyke. In the northern part of the area there are outcrops of gabbronorite (Fig. 15) with sulphide impregnation containing PGEs.

Fig. 13. Outcrops of Terrace deposit micrograined layered rocks; at the bottom of the picture one may see dumps of the Fersman adit.

Fig. 14. The geological sketch map of the Vurechuaivench layered horizon (by P.V. Pripachkin, T.V. Rundkvist).

1 – mesocratic metagabbronorite;  
 2 – leucocratic metagabbro and anorthosite;  
 3 – metagabbrodolerite dike; 4 – layering strike and dip;  
 5 – geological boundaries;  
 6 – tectonic dislocations;  
 7 – autochthonous outcrop and alluvial fragment contours;  
 8 – levels of sulphide mineralization;  
 9 – cumulus minerals. Squares denote metagabbronorite observation points, contact of metagabbronorite and leucocratic metagabbro, dikes of metagabbronorite, and low-sulphide PGE mineralization.

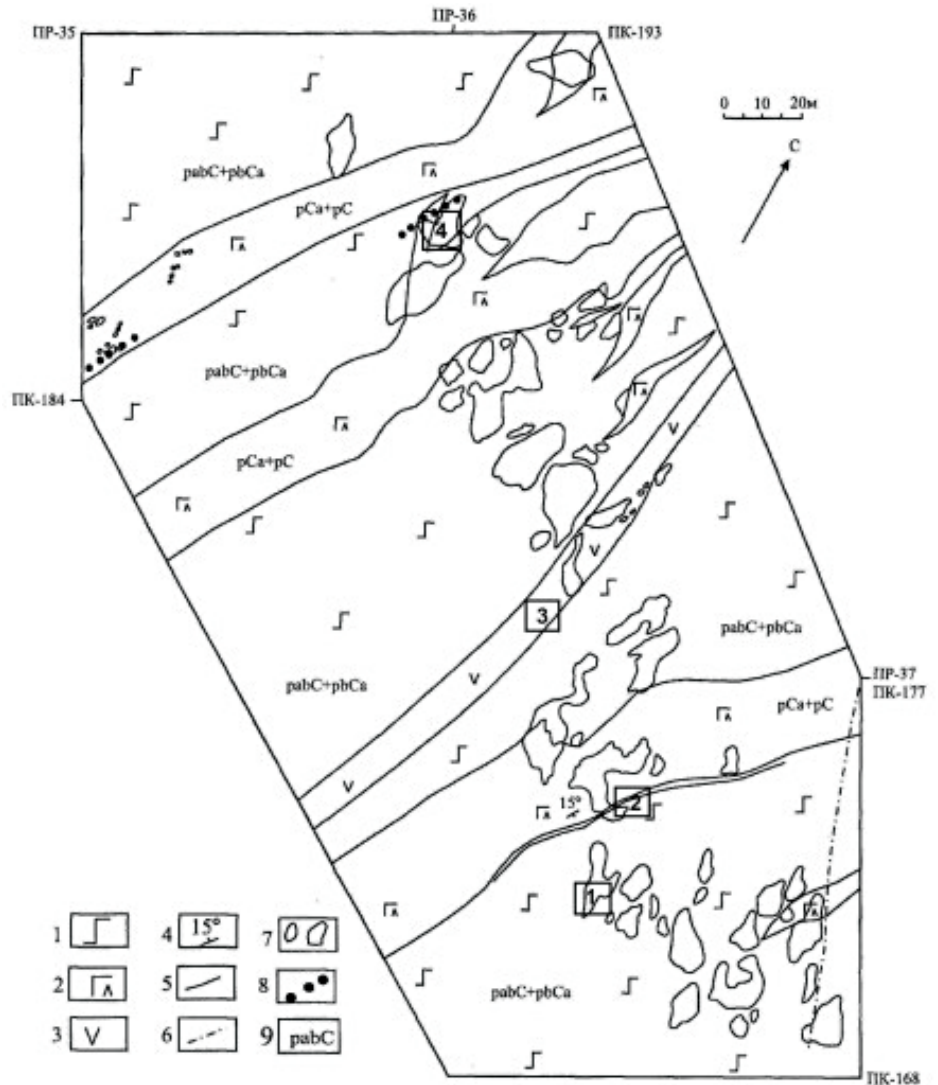




Fig. 15. Autochthonous outcrops of meso-leucocratic anorthosite with low-sulphide PGE mineralization at the Vurechuaivench deposit.

The “Vurechuaivench” prospect is confined to the zone of alternating meso-leucocratic massive and taxitic gabbro-norite and anorthosite-plagioclase. The PGE mineralization is related to the extensive zone of lens-like and tabular sulphide bodies. The mineralized zone is conformable to the layering, and contains about 20 sulphide horizons. They are marked by a 1-3-m-thick interval of rich ore, resembling a reef in a way. The length of the rhythmically layered series is 7-8 km along strike, the width is 1.5 km and thickness is up to 1 km. The content of ore minerals reaches 5-10 %. The ore minerals are chalcopyrite, pyrrhotite, millerite, Ni and Co arsenides. The PGE minerals are represented by Pd and Pt telluro-bismuthides, sulphides, arsenides and sulphoarsenides. Among them are kotulskite, merenskite, maichen-erite, moncheite, sperrhylite, mayakite, arsenopal-ladinite, mertiite, stibiopalladinite, stillwaterite, and gold and silver minerals, intermetallic phase of silver and gold and hessite with predominant Pt and Pd tellurides (55 %). The grain size varies from 10 to 70  $\mu\text{m}$ . The total PGM content is 0.5-15 ppm.

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