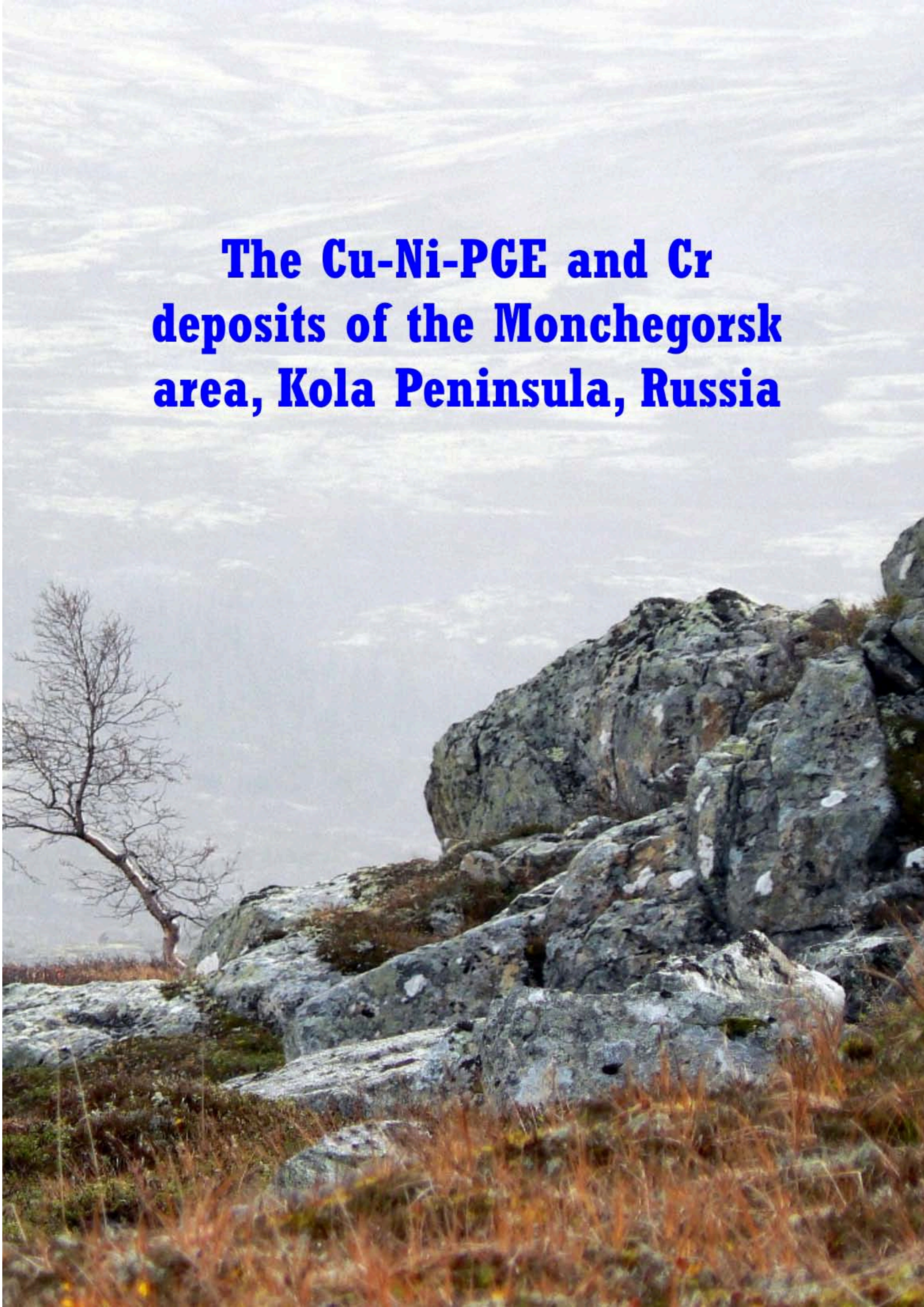
The Cu-Ni-PGE and Cr deposits of the Monchegorsk area, Kola Peninsula, Russia



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ROCK-FORMING AND ORE PROCESSES
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The Cu-Ni-PGE and Cr deposits of the Monchegorsk area, Kola Peninsula, Russia

Guidebook for geological excursions

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The geology, tectonics and stratigraphy of the Monchegorsk region (Kola Peninsula, Russia) is briefly described in the guidebook. The geological structure, ore localization and mineralogy of Cu-Ni-PGE and Cr occurrences in the major layered intrusions (Monchepluton, Imandra lopolith, Monchetundra intrusion) are presented in more detail.

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INTRODUCTION

The geological excursion to the deposits of the Monchegorsk ore field (the Kola Peninsula) is intended for geologists of broad interests, but mainly for mining geologists. The excursion aims at examining the genesis settings of Cu-Ni, Cr and PGE ore related to the layered mafic-ultramafic massifs intruded into the supracrustal Archean complexes at the 2500-2400 Ma boundary and marked the productive phase of mantle plume activity at the Archean-Proterozoic boundary (Fig. 1). The Monchegorsk pluton and the Imandra lopolith are the typical representatives of the Paleoproterozoic ore-bearing layered

Fig. 1. Generalized geological map of the north-eastern part of the Fennoscandian Shield showing the location of the early Palaeoproterozoic ca. 2440 Ma old layered intrusions. Modified after [1, 15].

intrusions on the Fennoscandian Shield, and due to the nice exposures and availability they are also unique sites for investigation.

Geology of the Monchegorsk area

The Monchegorsk ore region is located between the Kola and Belomorian Archean domains (Fig. 2). 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 Paleoproterozoic Imandra-Varzuga rift belt. Intrusive facies is represented by the three layered complexes, which are the Monchepluton, Mochetundra massif and Imandra intrusion, and a number of small mafic-ultramafic intrusions. Mafic dykes occupy about 5% of the Archean basement.

Geological map of the Monchegorsk ore gistrict

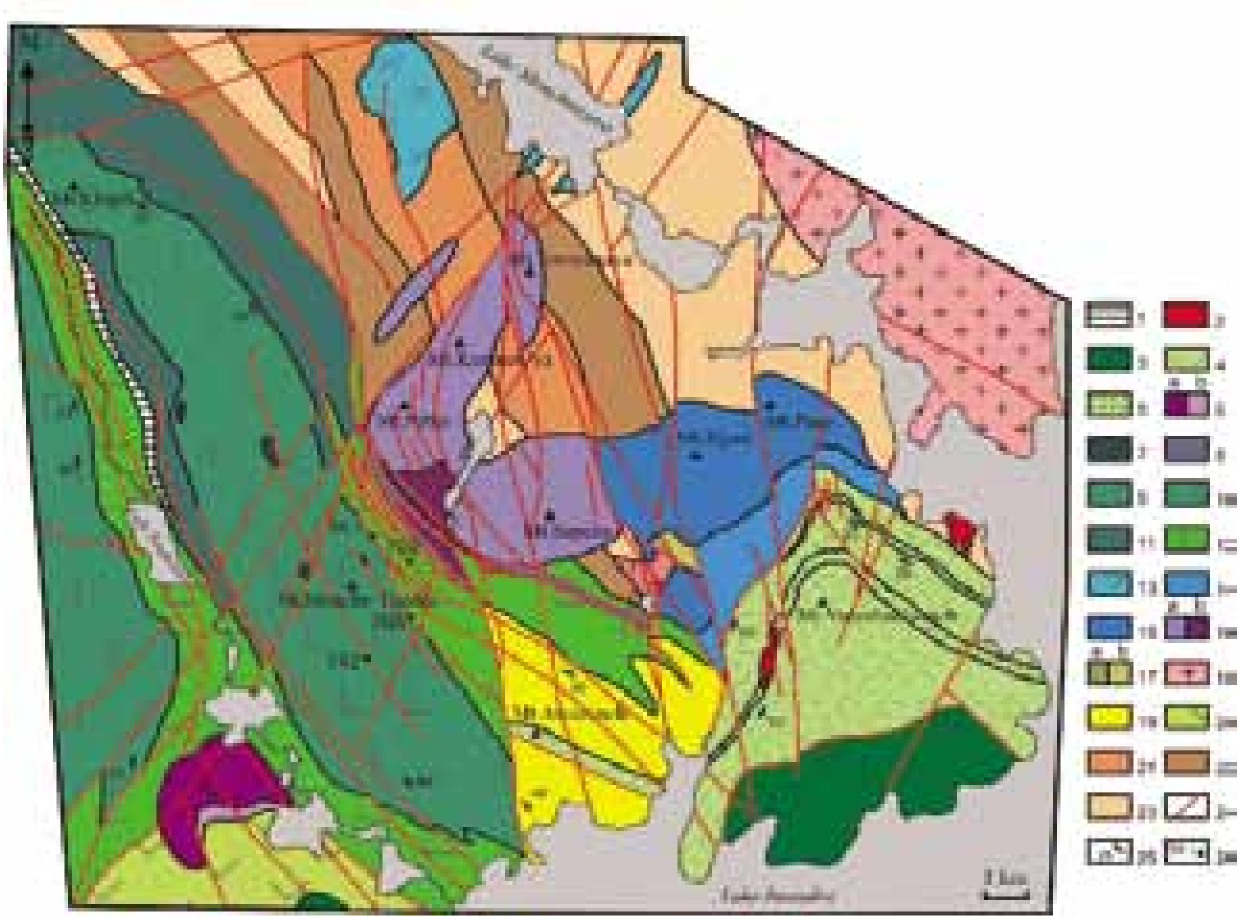


Fig. 2. The geological map of the Monchegorsk ore field. Compiled by V.G. Zagorodny (Geological Institute KSC RAS) with the use of the materials provided by the industrial organizations, [20].

Legend: 1 – large gabbro-dolerite dykes; 2 – anatectite-granite and trondhjemite; 3 – metagabbroids of the Imandra lopolith; 4-5 – metavolcanics (4), quarzites 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 Archean complex; 13 – Yarva-Varaka norite, diorite and granophyre quarzt diorite; 14 – Vurechuaivench Foothills metagabbro, gabbronorite and anorthosite; 15 – Monchepluton olivine norite, norite, gabbronorite (Nud-Poaz); 16 – Monchepluton peridotite, pyroxenite (a) and dunite (б) (NKT); 17 – diorite (a) and metagabbro (б) of the 10th anomaly; 18-23 – Archean complex: 18 – diorite, granodiorite, 19 – Archean acid volcanics and metasediments of Arvarench Mt., 20 – schistose amphibolite of the 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.

The Imandra-Varzuga structure is the part of the Paleoproterozoic 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 up to 7 km deep. Asymmetric structure is a result of the position between the hard Kola and remobilized Belomorian Archean domains. In the north-east limb of the trough, the Proterozoic units overlay the Archean basement in the same direction with angular unconformity, weathering crust and basal conglomerates. In contrast, in the south-west limb, a contact between the Proterozoic and Archean rocks, appears to be obscure because of the strong dislocation and metamorphic alteration.

The Early Proterozoic Pechenga-Varzuga volcano-sedimentary complex as a whole represents the Pechenga Supergroup comprising the five groups: Sumi, Sariola, Jatuli, Ludia, and Kaleva [36], which stratotypes occur mostly in Karelia [32].

Sumi includes the three Formations: Purnacha, Kuksha and Seidorechka, that are abundant only within the Imandra-Varzuga structure.

The Purnacha Fm has tectonic contact with the Archean basement rocks and extends for 135 km along the north border of the trough in the eastern part of the zone. The thickness reaches 1500 m. It consists mainly of tholeitic metabasalts with lenses of shallow cross-bedded carboniferous psammites up to 100-200 m thick.

The Kuksha Fm transgressively overlaps the Purnacha Fm in the eastern part of the zone, and lies on the Archean basement rocks in the west. Polymict conglomerates, intercalating with arkoses and gritstones and covered by arkosic sandstones with carbonaceous cement, are represented in the base of the section. Overlaying metabasalts composed of slightly differentiated low-Ca tholeites and compositionally closed to the metabasalts of the Purnacha Fm, dominate within the section. In the Monchegorsk area, metabasalts of the Kuksha Fm directly occur on the weathering surface of the Archean rocks or are separated from them by a thin layer of deluvial breccia and conglomerates with the residues of redeposited weathering crust. The total thickness of the formation is 1200-1300 m.

The Seidorechka Fm occurrs conformably on the weathered surface (caused by halmyrolysis) of the Kuksha Fm volcanites. The lower terrigenous part of the section up to 500 m thick is composed of sericitic schists (hydromicaceous pelites), feldspar quartzites, chlorite-quartz (montmorillonitic pelites), and tuffites. Volcanogenic units of the section are subdivided into the three zones: Lower – high-Mg basalts and basaltic andesites up to 800 m thick, Middle – basaltic andesites (1500 m), and Upper zone – rhyodacites (up to 1000 m).

Sariola in contrast to Sumi spreads along the whole Pechenga-Varzuga belt. It is represented by the Polisarka Fm within the Imandra-Varzuga zone. Its volcanic rocks directly overlie the eroded surface of the felsic volcanites of the Seidorechka Fm or are separated from them by a sedimentary horizon of polymict conglomerates, fine-rhythmical metaaleuropsammites including fragments of the Seidorechka volcanites, and sericitic schists (hydromicaceous pelites). Westwards, the psephytic facies changes into the pelitic one. The volcanogenic unit of the Polisarka Fm has a thickness of up to 300-1000 m. Lavas prevail within the section. Pyroclastic material comprises less than 5% of the rock sequence. Thickly bedded lithoclastic psephitic tuffs are established in the basement. High-Mg basalts make up most of the section; basaltic andesites lie above. Lavas show typical ball textures, indicating submarine volcanic eruption.

Jatuli is represented by the Umba Fm of basalts and basaltic andesites of subalkaline series with a carboniferous-terrigenous horizon in the basement of the Imandra-Varzuga section. It conformably overlies the rocks of the Polisarka Fm, but is not widespread due to pinching out in the Khibina area and completely absent in the Monchegorsk region. The total thickness of the Umba Fm is 1500 m.

Ludia is composed of the rocks of black shale formation, tholeitic basalts and rarely of ferropicrobasalts, which form the core of the Imandra-Varzuga graben-syncline in its western part. Stratigraphic sequence is not clear, as the thickness and relationships between the rocks of the Il'mozero, Mitrijarvi and Solenoozero Fms are still not ascertained. Westwards, the rocks conformably overlay the Polisarka Fm volcanites. The lower part of the section includes mottled volcanogenic-terrigenous rocks: pelites, aleurolites, black schists, dolomites, and quartzites with rare layers of tholeitic basalts (the Solenoozero Fm) up to 2 km thick. The volcanogenic series of tholeitic basalts and ferropicrobasalts with chlorite, sulphide-carboniferous schists and sandstones between the volcanic layers occur up the section.

Kaleva includes the Panarechenka and Saminga Fms, which rocks form an oval caldera-like structure in the central part of the Imandra-Varzuga zone. According to the rock composition and sequences, the Panarechenka Fm resembles that of Ludia. The Saminga Fm is represented by felsic volcanites mostly.

All the rocks of the Pechenga Supergroup have undergone zonal regional metamorphism of greenschist facies in the central parts of the Imandra-Varzuga zone and of epidote-amphibolitic and amphibolitic facies in the flanks.

The age of the Pechenga Supergroup is 2453-1765 Ma [3].

Intrusive complexes

Layered intrusions of the Monchegorsk region occupy the same structural position as the supracrustal units, being located between the Archean 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 [22, 23]. The U-Pb age of the pluton is 2509-2487 Ma [33]. It occurs in gneisses of the Kola-Belomorian complex and diorites with the age of 2932-2630 Ma [34]. The exposed area of the Monchepluton rocks is more than 60 km^2. 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 lattitudinal branch up to 9 km long

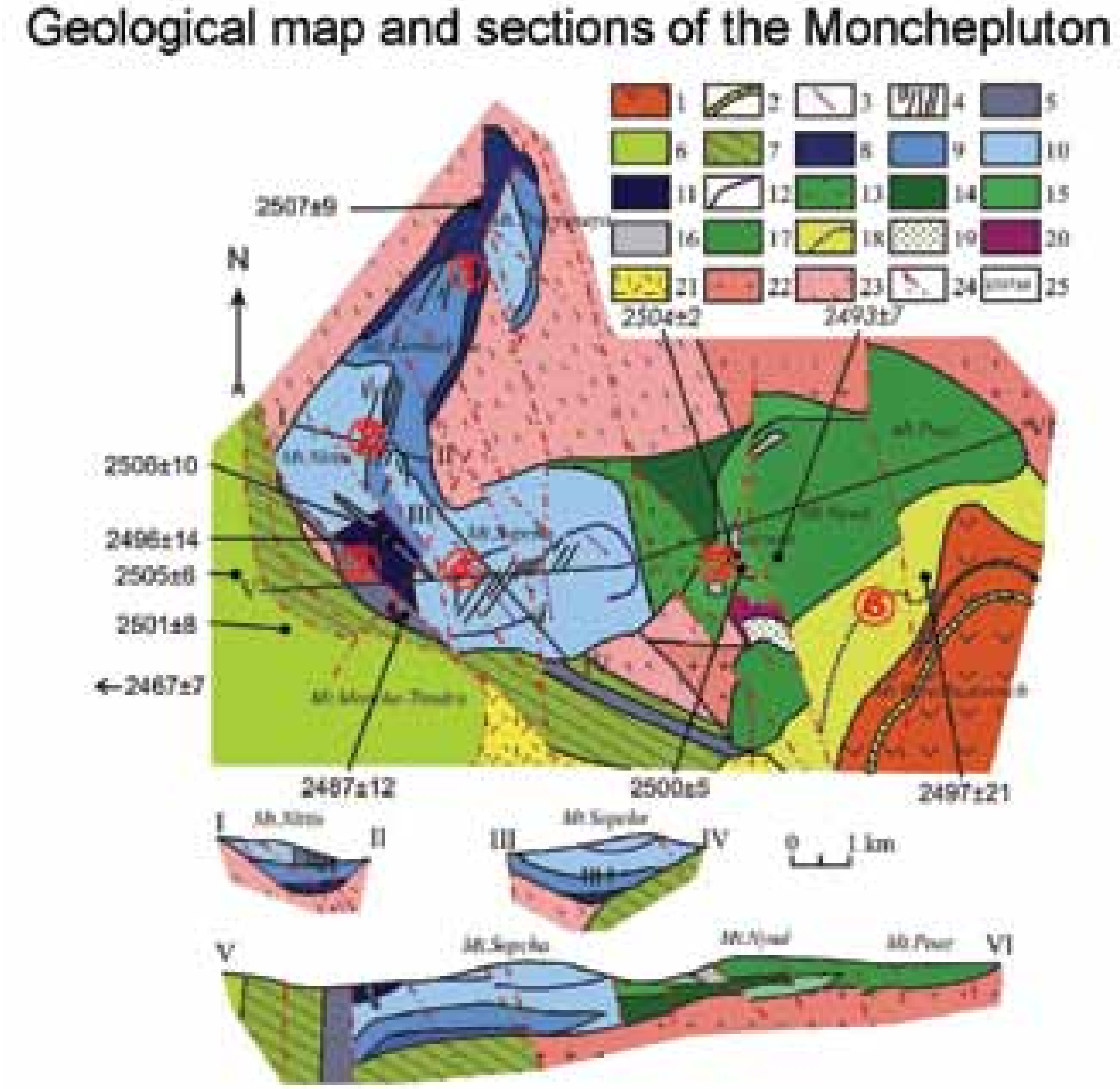


Fig. 3 Geological sketch map and cross-sections of the Monchepluton with isotope U-Pb data of the intrusive and dyke rocks [20].

Legend: 1-2 – metavolcanics (1), quarzite and schists (2) of the 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 – gabbronorite 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 – plagioorhopyroxenite; 14 – melanonorite; 15 – olivine norite, harzburgite; 16 - the “critical horizon” rocks of Nud Mt.; 17 – norite; 18 – metagabbronite, 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 Archean complexes; 24 – tectonic dislocations; 25 – isotope zircone and baddeleyite U-Pb age. The location layout of the excursion stops6 1 – bottom Cu-Ni ores of travyanaya Mt., 2 – vein field of the NKT Cu-Ni ores, 3 – the Sopcheozero 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.

– 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. 3). 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 Nud and Poaz. It gently dips south-eastwards under the supracrustal complex of the Imandra-Varzuga zone. The rocks of the Purnacha Fm lie on the weathered surface of the Vurechuaivench gabbronorites, and its basal conglomerates contain gabbronorite pebbles.

The lowest zone of the Monchepluton is situated in its south-western 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 Archean gneisses representing palingenic restites.

The western part of the pluton consists mainly of bronsitites and harzburgites, while the eastern part includes plagioclase-bearing rocks, which are generally represented by mesocratic norites and gabbronorites. 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 gabbronorites only in the very south-eastern part of the Vuruchuaivench Foothills. The rocks of the pluton show insignificant cryptic layering. The composition of the same rocks varies laterally from the west to the east to a greater extent than vertically. So, in rocks where orthopyroxene appears to be cumulus phase, $A1_2O_3$ content increases from 2.5 to 8%, and relative ferruginousity – from 15 to 21%. Such variations suggest that the composition of the melt, from which the rocks crystallized, became more leucocratic and ferriferous during the fractionation, while tracing eastwards. This phenomenon is known as a gravitational-cinematic differentiation [17]. It suggests filling of the magmatic chamber during the crystallization.

The layered rocks of the pluton are cut by numerous veins of gabbropegmatites, dykes of gabbronorites 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 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 established in the Monchepluton mineralization. Most of them are PGE-bearing [7, 12, 13, 27]. 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, melnikcrvite, marcasite, bravoite, polydymite, nickeline, leucoxene, bornite, chalcosine, covellite, kotulskite, merenskite, maichenerite, hollingworthite, sperrylite, platarsite, irarsite, laurite, Pt-gersdorffite, electrum, naumannite, moncheite, maslovite, frudite, braggite, cooperite, vysotskite, niggliite, iridosmine, stannopalladinite, sopcheite, and unnamed phases: Pd_3Ag, (Pd, Hg, $Au)_3As$, $PdBi_3$, Pd,Bi,Te_2, (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.

The ore prospects of the contact zone (Fig. 4)

The ore occurrences confined directly to the contact of the intrusion are grouped in the eastern part of the pluton and structurally associated with shear-zones along the contact between norites and diorites. They are not great in size. The typical occurrence, the «Moroshkovoe ozero» deposit, is confined to the north-west-striking tectonic zone at the border of norites of the Nyud-Poaz massif and host metadiorites. The Cu-Ni mineralization is located within the shear zone composed of actinolite-chlorite, actinolite and quartz-chlorite schists, which are the products of dynamic metamorphism of contact norites.

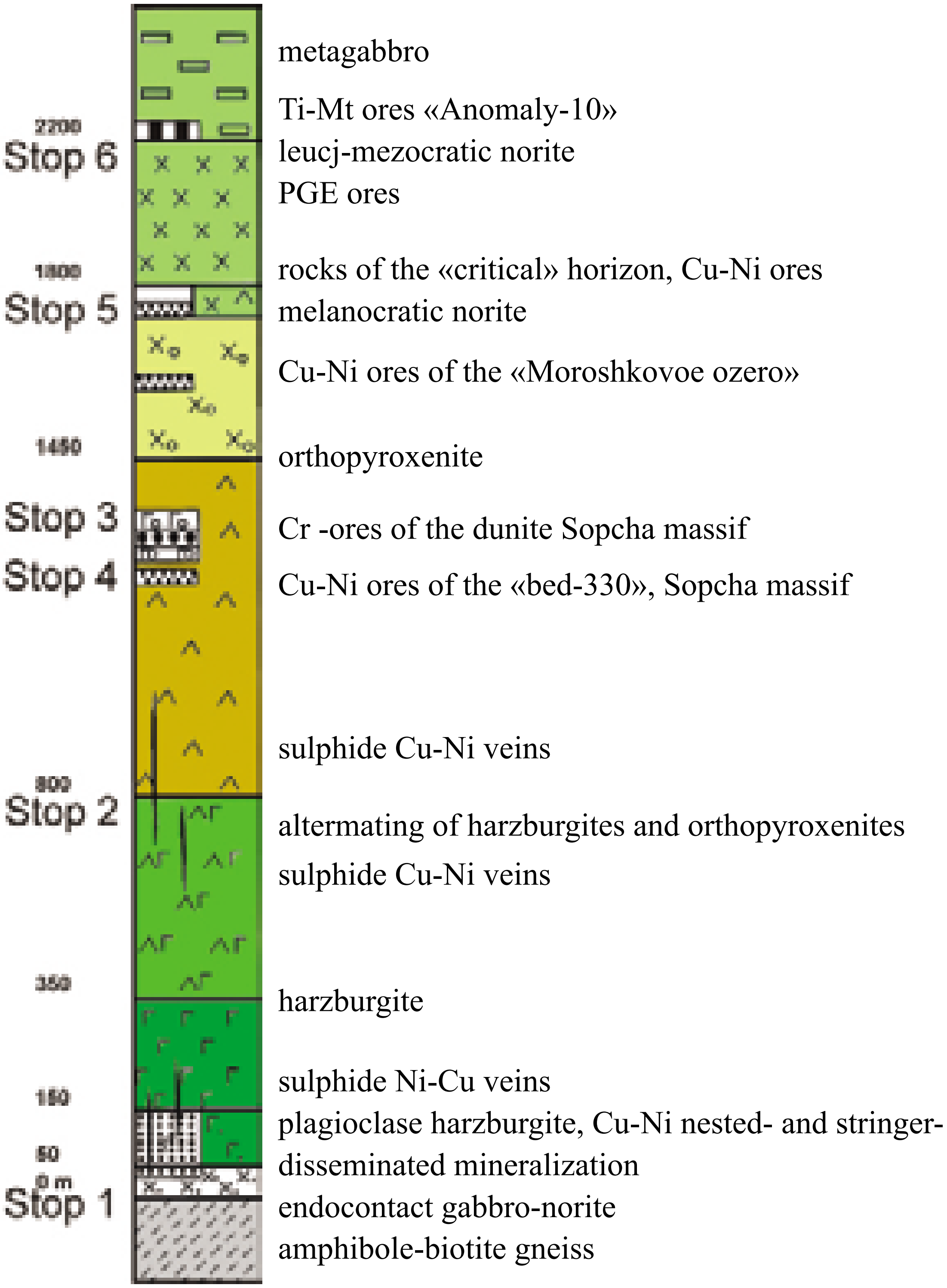


Fig. 4. Schematic geological cross-section of The Monchegorsk Pluton and location of Cu-Ni, Cr, Ti and PGE mineralizations.

The mineralized body takes the shape of a large lens striking in the nort-west at 325-330°, and dipping in the north-east at 30-70°. The ore lens pitches 30° in the south-east in the plane of occurrence. The ore is mainly disseminated, and occurrs in lenses, veinlets and rarely in pockets up to 20 cm in size. High Ni content is typical of the ore composition. Nickel-bearing pyrite with pentlandite admixture predominates in the mineral composition.

The ore deposits and ore prospects of the endocontact zone (Fig. 4)

The zone of endocontact rocks is of high ore potential. It is widespread through the base of the Monchepluton, but consists of different rock types. The ore is mainly poor-Ni-Cu disseminated and nest-disseminated, but also there are essentially Ni and Cu-bearing varieties with high PGE content. So, they are considered as complex ores. The typical example of such deposit is the NKT near-bottom horizon. The ore body inherits the contour of the massif bottom, but virtually does not directly overlay it; it is separated by quartz gabbronorites. Its thickness ranges from 5 to 50 m, and the length along the strike exceeds 3 km. There is direct correlation between the thickness of the ore body and endocontact rocks, such as between Ni and sulphide contents. The thickness of the ore body and the Ni content increase towards the axial part of the trough. The near-bottom rocks consist of plagioclase-bearing varieties, such as olivine pyroxenites, melanocratic olivine norites and gabbronorites, olivine-free feldspar pyroxenites, melanocratic norites, leucocratic norites and gabbronorites, and quartz-biotite gabbronorite [17]. The mineralization generally includes disseminated ores of variable scale and grade, pockets and vein-like bodies (so-called injections). The impregnations range from 0.5-3 to 4-8 mm in size, the pockets – from 1-5 cm to 1,5 m, and the injective nest-like isolations - up to few meters along the strike. The sulphide disseminated ore is confined to the horizon of near-bottom feldspar rocks representing the transitional zone between peridotites and gabbro-norites. The sulphide mineralization occurs 5-10 m above the massif bottom. The chemical composition of the ore is as follow: Ni – 0.29 *%,* Cu – 0.14 %, Co – 0.02 %, S – 1.0 %, total PGE (100 % sulphide concentrate) = 18 g/t, Pt/Pd = 0.11-1.0.

The ore deposits and ore prospects in plagioclase-bearing harzburgite and harzburgite (Fig. 4)

Harzburgites make up the lower western part of the pluton above the zone of endocontact rocks. The best-studied mineralization is in the NKT. Presently, the whole complex is being investigated to evaluate the economic potential of the PGE-bearing ore. Preliminary works have outlined a Cu-PGE-bearing deposit characterized by the development of vein-like, thickly disseminated and nest-disseminated ores in harzburgites. The host fissured structures are principally confined to the central over-trough part dislocated towards the western side of the massif, are also steeply-dipping and strike 20-40° in the north-east. The zone spreads up to 120-150 m wide in plane, and is traced along the dip up to 150 m. The mineralization is sporadical owing to the discontinuity of structural and morphological features of ore-enclosing cavities in the lower part of the Monchepluton. The Cu mineralization is closely associated with diorite-pegmatites, that is expressed in co-occurrence within the same structures and gradual transitions between each other. The Cu mineralization is traced up to the zone of endocontact rocks, and in couple with near-bottom ores is best examined in the outcrops of Mt. Travyanaya.

The ore deposits of the zone of alternating pyroxenite and peridotite (Fig. 4)

The complex of alternating pyroxenites and peridotites is the main host for Cu-Ni veined deposits, which locate in the NKT and Sopcha massifs. The typical veined deposit is the NKT ore field. It is represented by a series of steeply dipping (85-90°) sulphide veins within the massif. Their length is up to 100-1400 m, and thickness reaches 5-50 cm, even 2-3 m in pinches. The veins are composed of essentially massive ores with impregnations of silicates and other material. The vertical length of the veins is more than 150 m. The upper parts of the veins occur in pyroxenites, and the lower - within the zone of alternating pyroxenites and plagioharzburgites 300-350 m above the massif bottom. The strike of the ore field coincides with the axis of the NKT massif. In the east, the veins dip to the west, and *vice versa,* i.e. to the axis of the massif. 51 veins are counted there. Ore-controlling faults agree partly with the primary fissuring but are generally associated with superimposed disturbances. Shear zones are locally developed along the faults; single veins are entirely placed in the sheared rocks. Wallrock alterations close to the veins are insignificant and expressed in the presence of amphibole (anthophyllite) and strings of talc-breunnerite. The ore composition within the veins varies from essential pyrrhotite through mixed pentlandite-chalcopyrite-pyrrhotite to chalcopyrite. Some parts of the veins consist of essentially magnetite ores. The sulphide ores often grade into gabbro-pegmatites changed with gabbro-norites along the strike. Moreover, along the strike of ore veins such transitions appear to be multiple. The genesis of the ore veins is still obscure. They are clearly epigenetic as they cut the rocks of the massif, but contact alterations are weak, and the internal structure corresponds to the *in situ* crystallization of sulphides. At the same time, valid source of the melts parental to the veins is not presently established since the veins are “hanging” within the massif and do not reach the contact of the massif.

The chemical composition of the ore strongly varies: Ni 2-6 %, Cu 1-12 %, Co 0.15-0.30 %, S 9-26 % [17], total PGE (100 % sulphide concentrate) = 7 ppm, Pt/Pd = 0.11.

The ore deposits and ore prospects in pyroxenite (Fig. 4)

The complex of pyroxenites comprises layers of peridotite with disseminated Cu-Ni ores and dunites with chromite beds.

«Horizon 330» Cu-Ni deposit occurкs in the Sopcha massif. The sulphide Cu-Ni mineralization makes up «hanging» bodies of disseminated ore in the layers of olivine-bearing rocks within the orthopyroxenites. In the western part sulphides are concentrated in peridotite layers (the highest concentrations tend to the upper part of the layer) and in olivine pyroxenites. The abundance of peridotite decreases eastwards. Thus, sulphides are accumulated in olivine pyroxenites and monomineral pyroxenites. There is no strict petrographic control of sulphide distribution.

The sulphide mineralization of «Horizon 330» is fine-grained and characterized by higher PGE content comparatively with the other ore types in the Monchegorsk pluton [35]. The chemical composition of the ore is as follow: Ni 0.35-0.55 %, Cu 0.17-0.25 %, Co 0.015-0.04 %, S 0.9-2.39 %, total PGE (100 % sulphide concentrate) = 35 ppm, about 1.5 ppm in ore; Pt/Pd = 0.13.

The Sopcheozero chromite deposit is confined to dunites of the south-west Monchepluton. Dunite fields cover an area of 1.5×2.0 km at the vertical thickness up to 700 m. Dunites are restricted by the Monchepluton pyroxenites from the south-west to the south-east, and schistose gabbro of the Monchetundra massif from the south-west. According to the available data, dunites overlie pyroxenites, but some researchers suggest, that they grade into the zone of intercalating peridotites and pyroxenites. The chromite deposit represents a lenticular-sheet body up to 1100 m long and 160 to 260-280 m wide. The ore body pitches to the south-east, and dips to the south. In the north-west it outcrops, being overlapped by the moraine. The ore body is vertically traced up to 315 m. The thickness ranges from 1.0 to 32.5 m, averaging in 7.8 m. The thickness rises south-eastwards. The Cr_2O_3 content is 23% in the ore. The contacts of the ore body and country rocks are generally gradational, but the chromite content abruptly increases (within 0.5-1.0 m). The average mineral composition of the ore is as follows: olivine – 41 %, chromite –

50%, pyroxenes – 6%, total content of secondary minerals (serpentine, chlorite, talc, amphiboles) – 6%, plagioclase is extremely rare.

The ore deposits and ore prospects in norite (Fig. 4)

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 Nud-2 deposit. It is situated in the south-west of the Nud-Poaz massif to the upper section of it, and occurrs in melanocratic norites underlain by plagioclase pyroxenites, olivine norites, and plagioclase peridotites [10]. 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. Schlierens of massive ore are 5-7 m in size. They are framed by the complicated apophyses, veins and dissemination.

The ore deposits and ore prospects in gabbronorite (Fig. 4)

Gabbronorites are located in the eastern part of the Monchepluton. These rocks are characterized by the presence of low-sulphide PGE mineralization that is being explored. According to the preliminary data, the Vuruchuaivench ore occurrence is represented by low sulphide PGE mineralization associated with the 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 was revealed.

The Vurechuaivench intrusion entirely consist of gabbronorites that exposes at the day surface north-eastwards for a distance of 7-8 km, and disappears in the Lake Imandra. The width of the expose is 1.5-2 km. The rocks dip south-estward at angels varing from 5-10^{o} to 20-30^{o} beneath the effusive rocks of the Imandra-Varzuga Belt. The vertical thickness of the gabbronorite sequence is 600-700 m. A few deep boreholes have penetrated the gabbbronorites down to a depth of 3 km. The gabbronorite overlay metamorphosed diorite of the basement with the contact between them having tectonic genesis.

THE MONCHETUNDRA MASSIF

The Monchetundra massif occurs in the central part of the Kola Peninsula. It is the eastern elongation of the largest mafic intrusive body of the Kola Peninsula – the Main Ridge intrusion (Fig. 2). In terms of tectonic position, the intrusion is confined to the junction zone of the Belomorian and Central-Kola megablocks with the intracontinental Pechenga-Imandra-Varzuga paleorift. The emplacement and evolution of the intrusion took place under the influence of the geodynamic setting formed at the Sumi stage of the Early Proterozoic tectonic activity resulted in the formation of the Kola PGE province [22, 23, 26]. The Province accommodates the Fedorovo-Pansky PGE Complex affiliated to the northern flank of the Pechenga-Imandra-Varzuga paleorift. The development of the PGE concentrations of the Complex has been proved economically eligible.

The Monchetundra massif belongs to the great gabbro-anorthosite complex of the Chuna-Monche-Volch'ya tundra with total area of 500 km^2. It is situated south-west of the Monchepluton within the zone of the north-west rift-forming faults. It has a lenticular shape in plane and extends to the north-west for up to 20 km (Fig 2). In the cross-section it is a trough complicated by flank faults.

The Monchetundra massif has a northwestwardly elongated oval shape with a total area of ca. 120 sq. km. The length of the intrusion is ca. 30 km, and the width varies from 2 to 6 km. From east and southeast, the Monchetundra intrusion is separated from the Monchepluton intrusion by a thick mass of blastocataclasites and blastomilonites, and from west by the Viteguba-Seidozero fault (Fig. 2). The shape of the intrusion is also compared with a lopolith. The massif generally plunges south-westwards, but in its central part the layering and trachytoid elements occur near-horizontally, dipping towards the axial part of the intrusion. The maximum vertical thickness of the Monchetundra massif cross-section exceeds 2 km.

The age of the massif was determined by U-Pb technique on zircon and baddeleyite. Gabbronorites from Mt. Monchetundra yielded 2453 ± 4 Ma [21] and from Hebbruchorr -2467±16 Ma, and gabbronorites of the Monchetundra massif gave the age of 2488±3 Ma [33]. The age scatter could reflect the duration of the intrusion emplacement caused by irregular metamorphic alteration of the rocks. The oldest age was obtained on the non-altered rock. For more information about geological structure – see description of the stops and Figure 5.

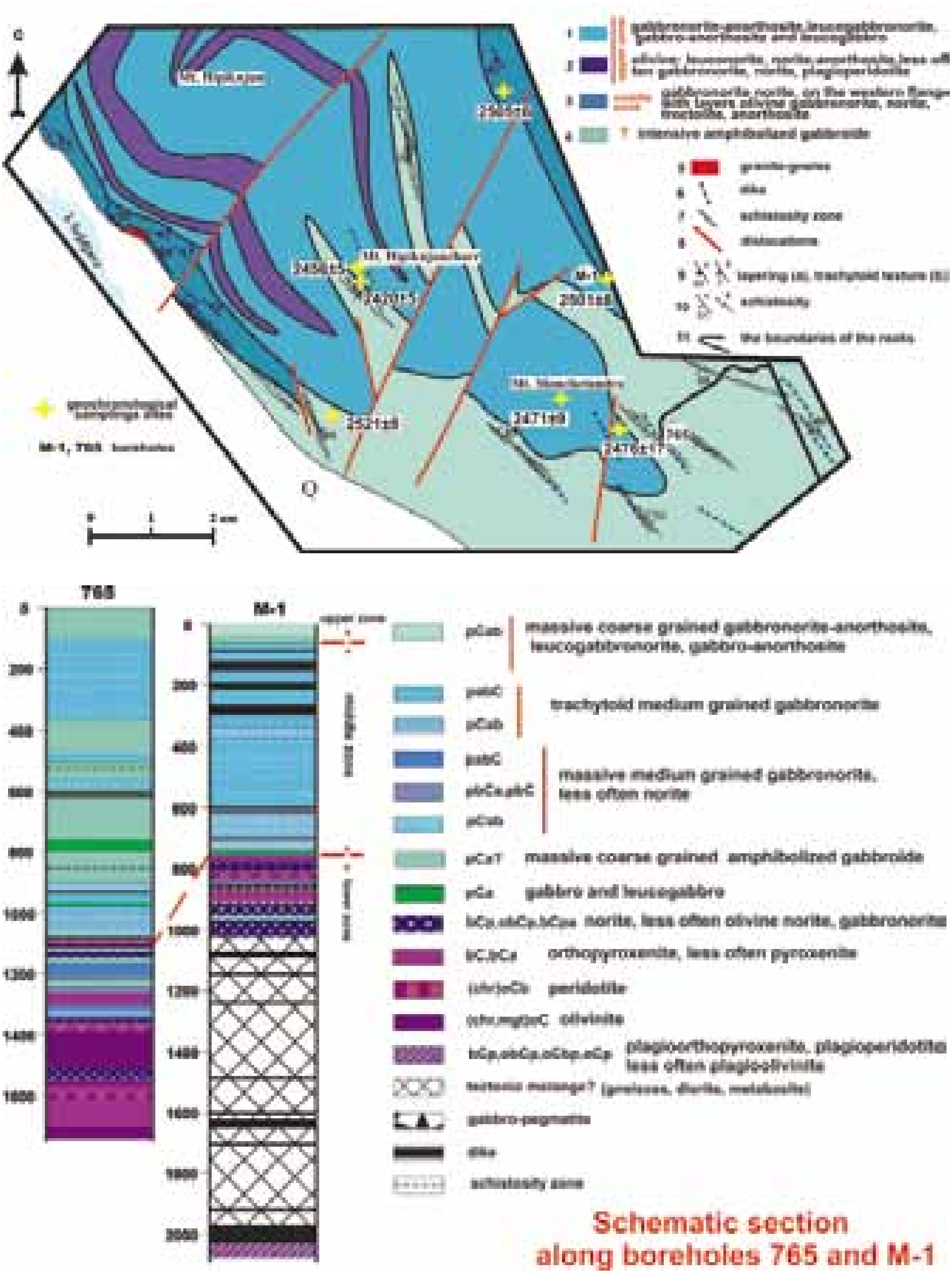


Fig. 5. Schematic geological map of the central and southeast parts of the Monchetundra massif.

THE IMANDRA LOPOLITH

The Imandra layered intrusion was intruded in the upper part of the Sumi section within the north-western Imandra-Varzuga zone of the geological age of the intrusion much younger than that of the Monchepluton. It is represented by the four outwardly isolated massifs. Thus, the Imbarechensky and Severny underlie conformably the felsic volcanites of the Seidorechka Fm, the Majyavr-Devich'ya and Yagel'ny intrudes gneisses and amphibolites of the Upper Archean Tundra series (Fig. 6).

The latter three intrusions make up a group of northern limb with bottom-roof direction oriented to the south. The most extensive Umbarechensky massif occurrs in the south limb of graben-syncline and dips to the north.

Close rock compositions, similar rock sequences, conformable occurrence below the felsic volcanites, assembling of all the tectonic blocks into a sole contour allow to assume that these massifs belong to a single intrusion [9], although it is more difficult to make such suggestion for western flank massifs occurring in the Upper Archean rocks. There is a gravitational anomaly between massifs of Mts. Majyavr-Devich'ya and Yagel'naya and western flank of Umbarechensky massif, caused by flat body plunging to a depth of 4 km, which unites the western flank massifs [29]. The exposed area of the Imandra intrusion is 225 km^2, and probable area together with the plunged part is assumed to be 1300 km^2.

The section of the Imandra intrusion is represented by:

1) Lower chilled zone (5-10 m) of fine-grained gabbronorites;
2) Lower layered zone (<120 m) of melanorites with chromite interlayers (0.1-0.6 m), and porphyry gabbronorites;
3) Main zone of mesocratic gabbronorites (<2 km);
4) Upper layered zone (300 m) of rhythmical alternating leuco- and mesocratic gabbro with a gabroanorthosite horizon (<60 m) right upper;
5) Near-roof zone of ferrigabbroids (<500 m) with a horizon of disseminated Ti-magnetite ore (10 m) in the bottom;
6) Granophyric zone (600 m) resulted from melting of felsic volcanites in the roof of Imandra intrusion.

The Upper chilled zone is absent. The transition from the layered rocks to granophyres is gradual, and between them there is an interlayer of the quartz ferrodiorites (35 m) probably originated by crystallization of the end residual melt.

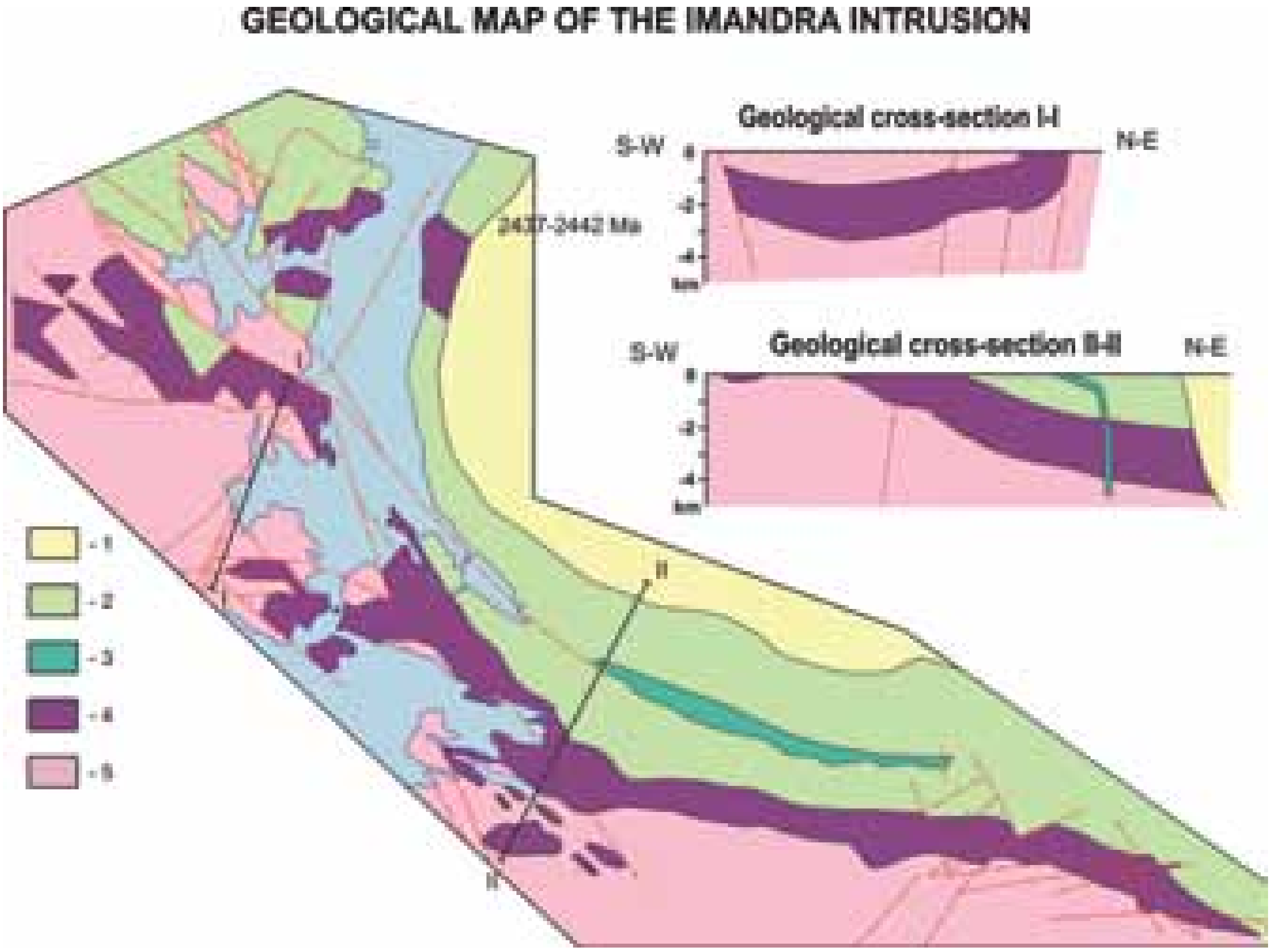


Fig. 6. Schematic geological map and cross-sections of the Imandra intrusion.

Legend: 1 – Nepheline syenites of the Khibina massif; 2 – Imandra-Varzuga rocks; 3 – Syenites of the Soustov massif; 4 – Imandra intrusion; 5 – Archean gneisses.

In contrast to the other massifs discussed above, the Imandra intrusion shows great cryptic layering. Ferruginosity increases upwards from 23 to 80%, and anorthite content in normative plagioclase reduces from 60 to 25%.

The timing of the Imandra complex formation was established with U-Pb technique on zircon and baddeleyite from the rocks of the Lower layered zone, the Umbarechensky massif (2441±1,6 [2], 2437±7, 2440±4, 2446±39 Ma), and from plagioclasites of the upper layered zone, the Severny massif (2437111 Ma [5]). These ages fall into the time span defined by the ages of volcanites, that belong to the Seidorechka Fm enclosing the Severny massif (2448+8 Ma) and granophyres from the roof of the Severny massif (2434+15 Ma [5]), although all the ages set close to 2440 Ma within the error of determination. Close ages of the Imandra intrusion and host volcanites indicate its emplacement under the thin cover of felsic volcanites of the Seidorechka Fm. The rocks overlying the Polisara Fm deposited after the formation of the intrusion.

Cr and Fe-Ti-V ore occurrences are related to the rocks of the Imandra intrusion, but are presently not of economic significance.

PETROLOGY OF THE INTRUSIVE ROCKS

Petrochemical study has demonstrated that magmas of the above-discussed layered intrusions and high-Mg volcanites of the Seidorechka and Polisarka Fms were derived from a single mantle source, but evolution of parental melt in both cases was individual. Primary melts of the Imandra intrusion, the Monchegorsk pluton and high-Mg volcanites of the 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 was 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 thegravitational separation of pyroxene and plagioclase that caused poor-developed cryptic layering. The rocks of the Imandra intrusion crystallized under the conditions of convective melt mixing, and thus resulted

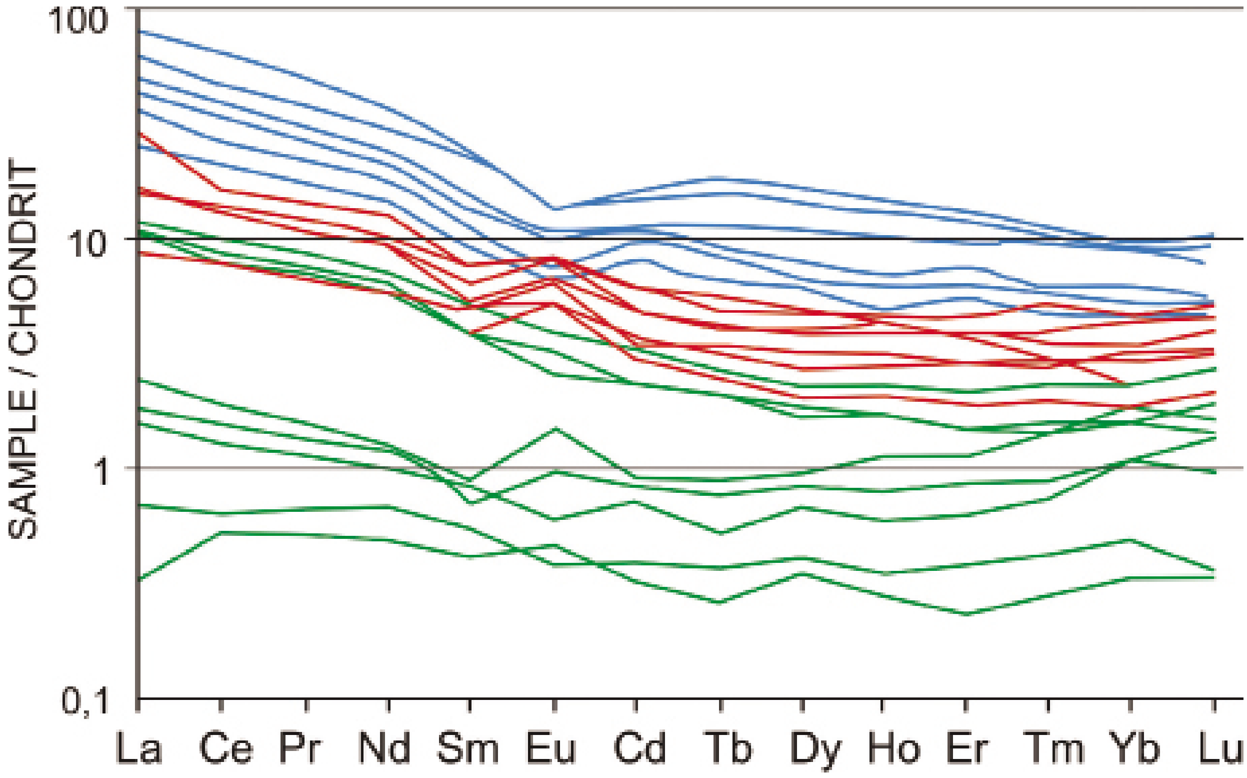


Fig. 7. Chondrite-normalized plots of the REE distribution in layered rocks of the Monchegorsk region and high-Mg volcanites of the Polisarka and Seidorechka Fms. Red lines indicate basic layered rocks,green lines – ultrabasic layered rocks, and blue lines – volcanites.

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 happen because of high temperature difference between the main melt within the chamber and the felsic liquid in its upper part.

Independent petrological data were gathered from the analysis of REE distribution. Figure 7 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 a 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 e_{Nd} -2± 1 in rocks [4].

THE DESCRIPTION OF THE STOPS AND OUTCROPS

The Monchepluton

Stop 1 (Fig. 3, 8, 9). Cu-Ni disseminated ore of the NKT near-bottom zone

The excursionists will visit the dumps of the old mine (Fig. 10), where the near-bottom NKT ores were mined. The dumps contain samples of the country gneiss of the Kola series, contact gabbronorite, disseminated and nest-disseminated ores in peridotite, pyroxenite, norite, mafic pegmatite, and the PGE copper veins.

The mineralization characterizes the deposit of the nest-disseminated ore “Bottom seam” (NKT) located in the endocontact zone of the pluton.

The near-bottom disseminated ore is traced along the whole bottom part of the NKT for the distance of 3 km (Fig. 11).

The sulphide dissemination is confined to the horizon of near-botoom feldspar rocks that represent the transition zone from periudotitie to

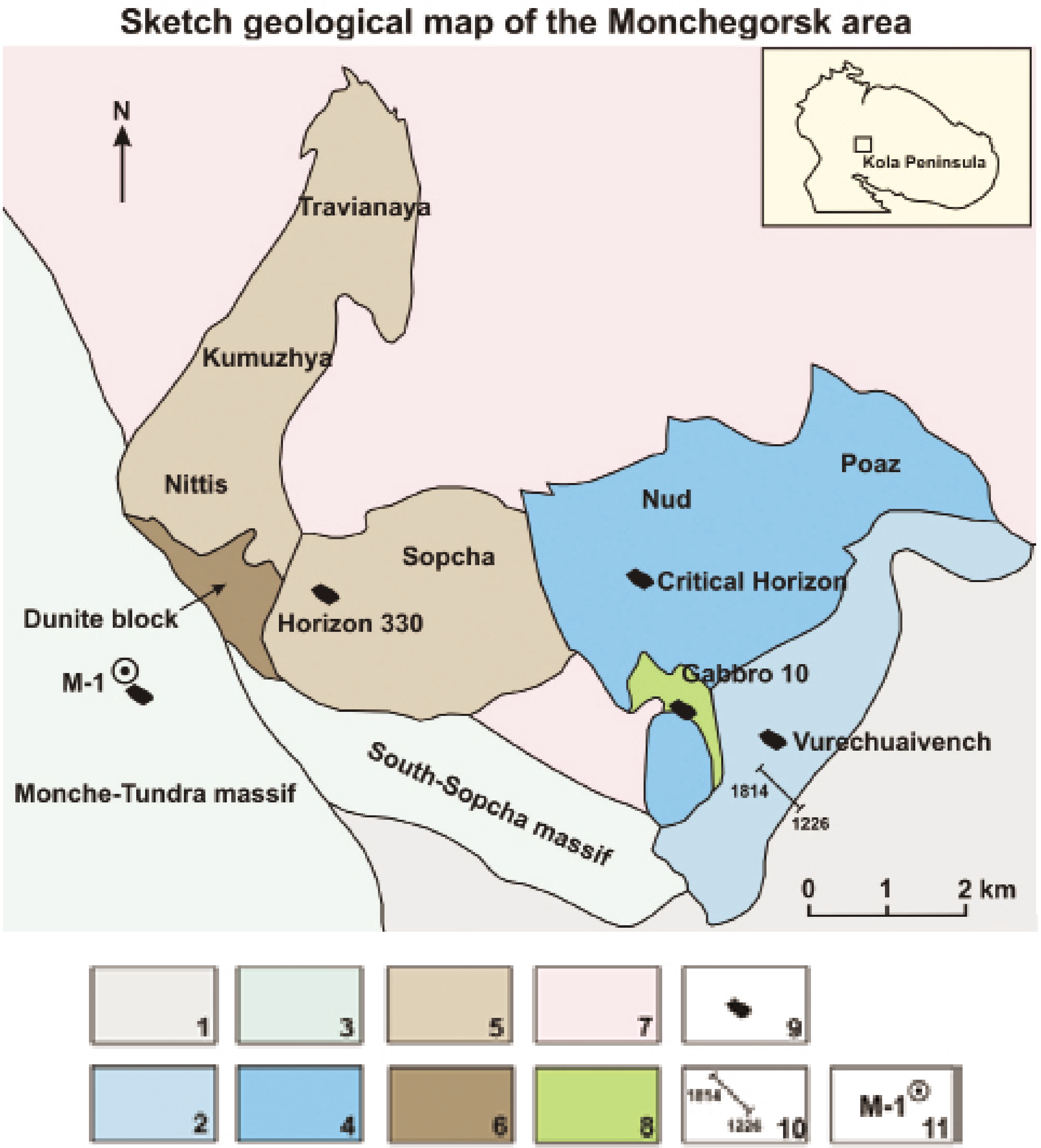


Fig. 8. Sketch geological map of the Monchegorsk area.

Legend: 1 – Imandra-Varzuga volcanic-sedimentary rocks; 2 – metagabbroic rocks of the Vurechuaivench massif; 3 – gabbroic rocks of the Monche-Tundra and South-Sopcha massifs; 4 – norites of the Nud and Poaz massifs; 5 – pyroxenites and peridotites of the Nittis-Kumuzhya-Travianaya and Sopcha massifs; 6 – dunites; 7 – Archean gneisses; 8 – gabbroic rocks of the Gabbro-10 massif; 9 – detailed areas; 10 – the line of cross-section across the Vurechuaivench massif (drill holes 1814-1226); 11 – drill hole M-1.

metagabbro

Ti-Mt ores «Anomaly-10»

leucj-mezocratic norite

PGE ores

rocks of the «critical» horizon, Cu-Ni ores

melanocratic norite

Cu-Ni ores of the «Moroshkovoe ozero»

orthopyroxenite

Cr -ores of the dunite Sopcha massif

Cu-Ni ores of the «bed-330», Sopcha massif

sulphide Cu-Ni veins

altermating of harzburgites and orthopyroxenites

sulphide Cu-Ni veins

harzburgite

sulphide Ni-Cu veins

plagioclase harzburgite, Cu-Ni nested- and stringer-disseminated mineralization

endocontact gabbro-norite

amphibole-biotite gneiss

Fig. 9. Schematic geological cross-section of The Monchegorsk Pluton and location of Cu-Ni, Cr, Ti and PGE mineralizations.

Fig. 10. Ore dumps of mine №5 at Travyanaya Mt.

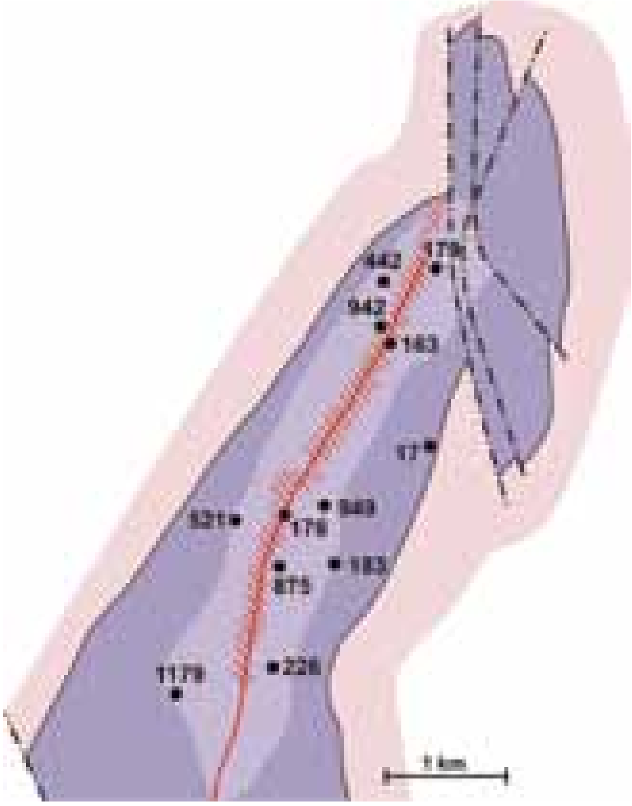


Fig. 11. The location of the bottom nest-disseminated ore bed in the NKT. The distribution of bottom ores is shown with specks, boreholes are numbered, and the contours of the massifs and tectonic dislocations are shown.

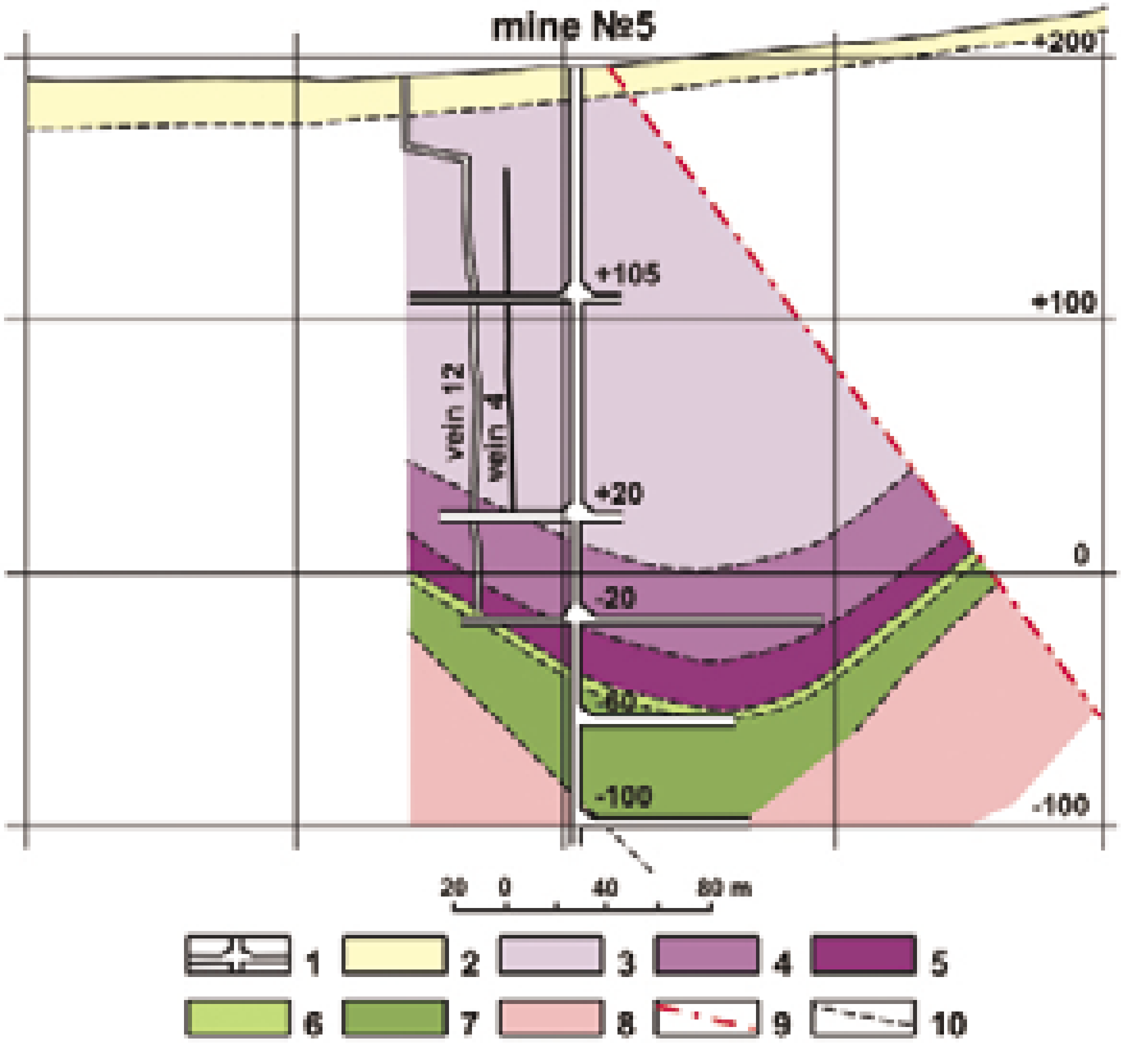


Fig. 12. The structure of the NKT northern bottom zone.

Legend: 1 – excavations; 2 – mo-raine, 3 – peridotite (harzburgite) with interlayrs of pyroxenite and olivine pyroxenite; 4 – feldspar peridotite with interlayers of feldspar pyroxenite and olivine pyroxenite; 5 – olivine norite with interlayers of feldspar pyroxenite and melanocratic norite; 6 – norite; 7 – ophitic gabbronorite; 8 – diorite-gneiss; 9 – tectonic dislocations; 10 – sulphide veins, sulphide disse-mination, rock boundaries.

gabbronorite. The near-bottom minerlization is best-studied in the northern end of the NKT at the Travyanaya area, where the ore comes close to the surface at the depth of 200 m and is opened by underground workings (Fig. 12). Here, all the above-listed features of the near-bottom ore are represented, and the presence of «copper ores» has been revealed. The latter indicates the spatial relationship of epigenetic mineralization richest in PGE with poor syngenetic Ni ore of near-bottom seams.

Stop 2 (Fig. 3, 8, 9). Cu-Ni veined ores of the NKT massif

The excursionists are to hike to the slope of Mt. Nittis and examine the outcrop of ore veins of the main ore field NKT in the northern part of Mt.

Nittis. One can observe the outcrops of tectonic zones in pyroxenite, where oxidized sulphide veins occur (Fig. 13, 14). It is also possible to see in detail the structure of the dislocations, cutting the ultramafic rocks and sample oxidized pentlandite-pyrrhotite ore. A nice view of the city of Monchegorsk opens from the slope of Mt. Nittis.

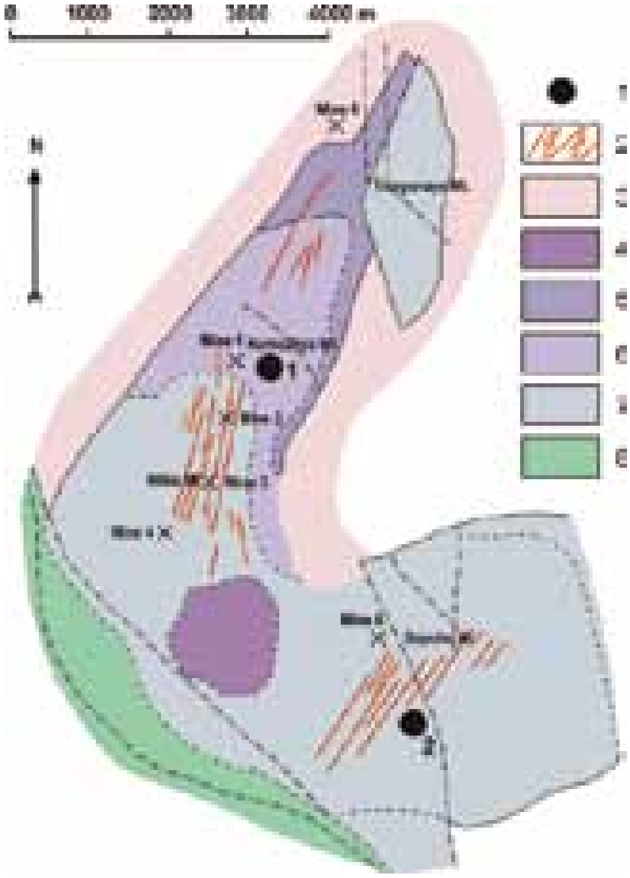
The ore field NKT was the main source of ore for the industrial complex «Severonickel» from 1936 to 1975. 51 veins has been explored at the NKT area, and 13 – at the Sopcha area. The direction of the veins at these two areas does not coincide (Fig. 15).

The sulphide veins locate vertically within the massif (Fig. 16), mainly in the pyroxenite zone and in the zone of thin peridotite and pyroxenite alternation (Fig. 9).

The morphology of the veins is rather complicated with geniculate bends, abrupt thickness variations, lack of visible alteration at the contacts of the veins and country pyroxenite (Fig. 17). It is noted that the tectonic treatemnt of the rocks along veins is strongly manifested at Mt. Sopcha.

Fig. 13. Outcrops of oxidized sulphide Cu-Ni veins at Nittis Mt.

Fig. 14. Yu.N.Neradovsky near the Cu-Ni vein (left) and the detailed fragment of the vein (right).



Deposits:
1 – Nittus – Kumuzhya – Travyanaya
2 – Sopcha

Cu-Ni ores

Amphibole-biotite gneiss

Dunite

Peridotite

Alternating peridotute and pyroxenite

Pyroxenite

Gabbro

Fig. 15. The sketch of the Monchepluton ore fields.

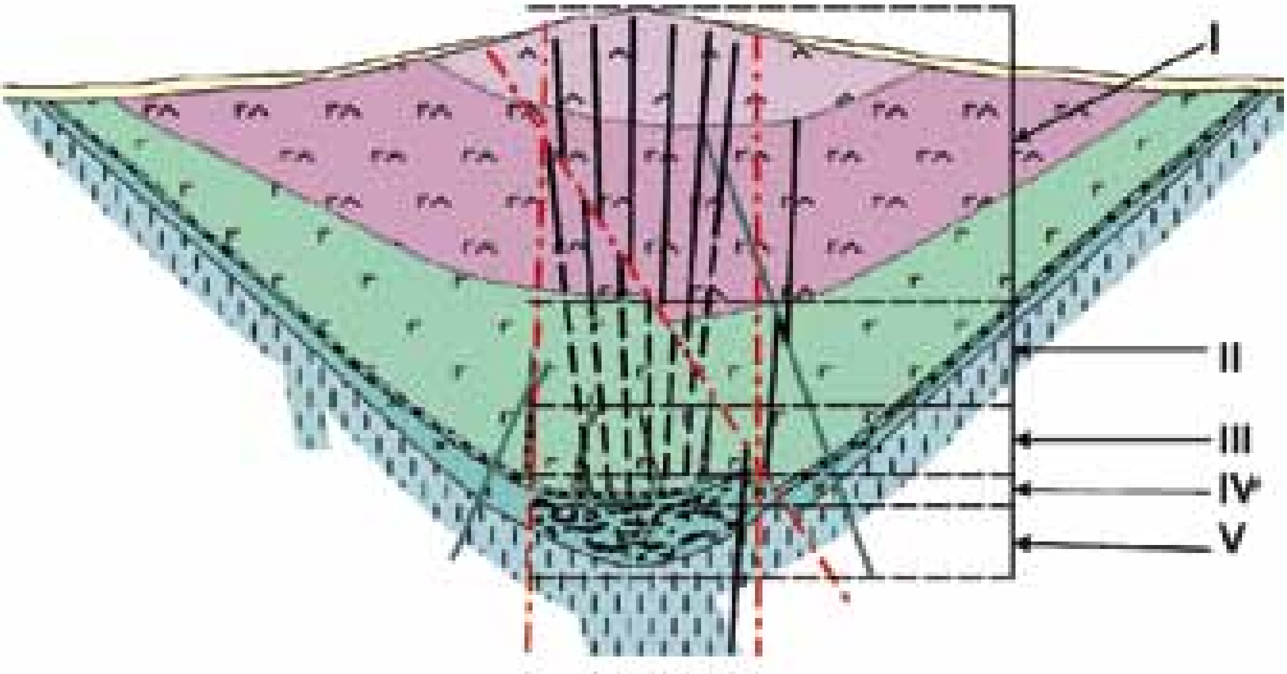


Fig. 16. One of the models of the NKT cross-section.

Legend: I – upper zone of pyrrhotite veins in pyroxenite; II – zone of pinching-out pyrrhotite veins; III – zone of «copper» ores; IV – zone of vein roots; V – nest-disseminated bottom ores. Legend is the same as in Fig. 9 (symbols, but not color).

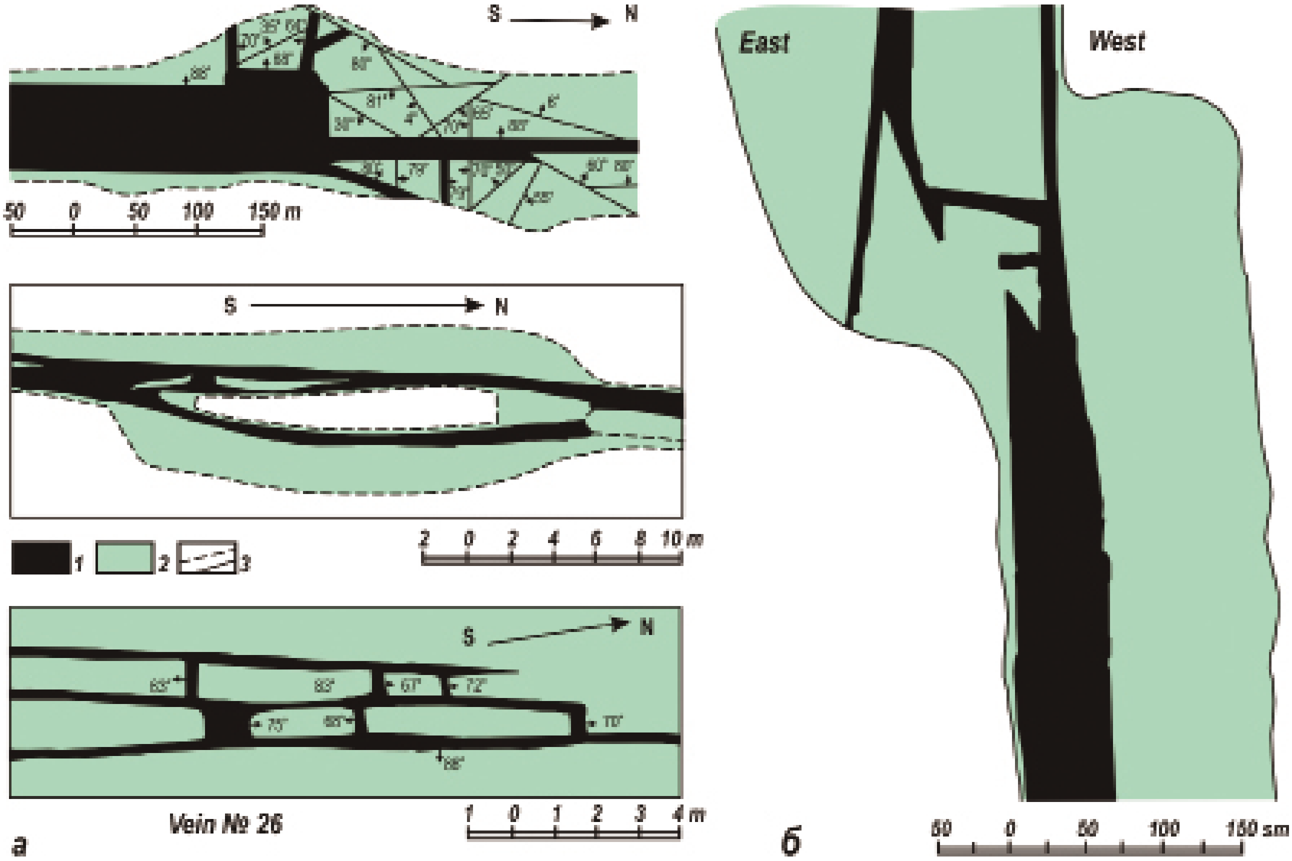


Fig. 17. The morphology of NKT sulphide veins: along strike – a, along rise – б.

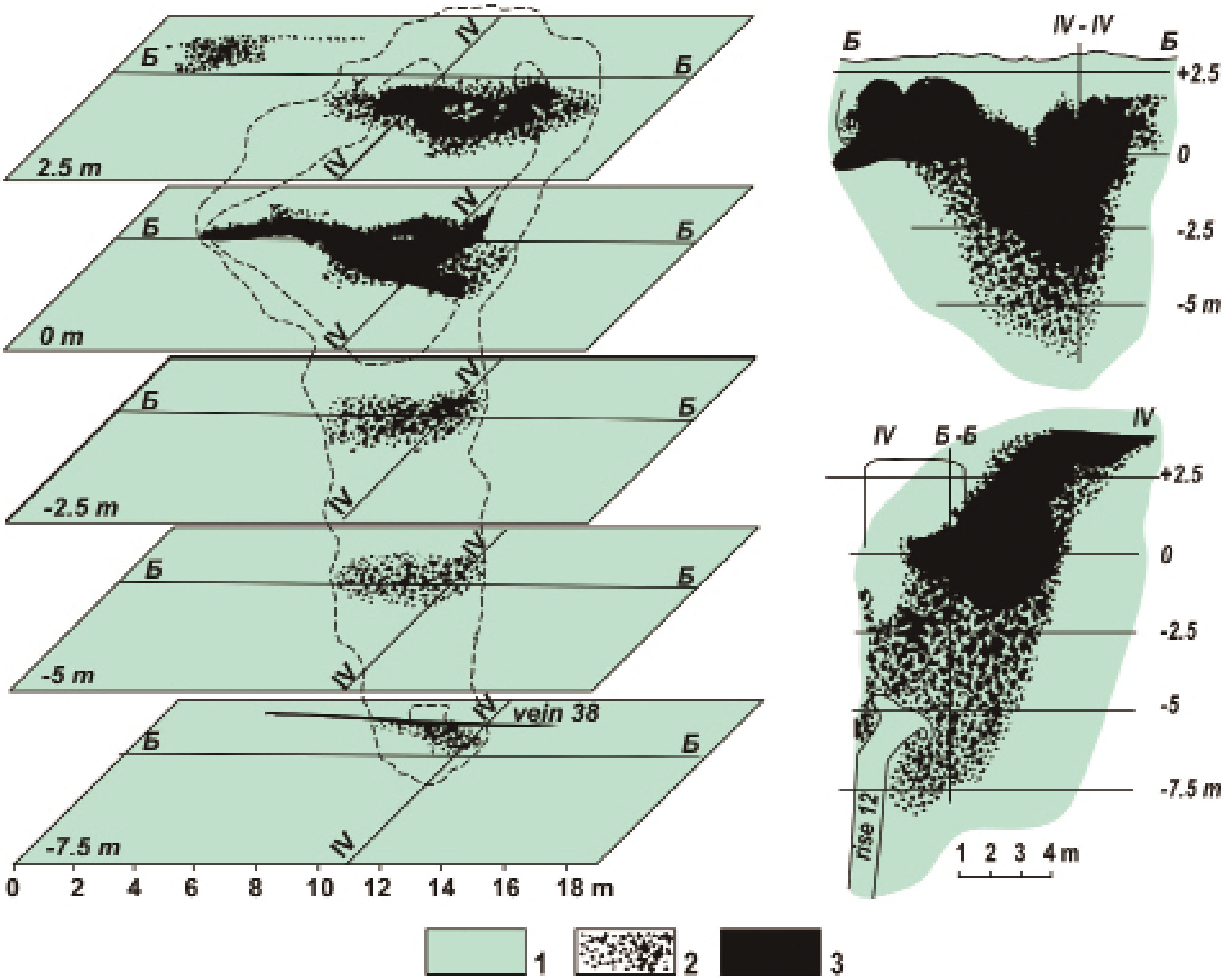


Fig. 18. The relationship of vein № 38 with the giant nest of pegmatite and sulphides at Nittis Mt.

Legend: 1 – pyroxenite; 2 – gabbropegmatite with sulphide nests; 3 – sulphides.

The veins are characterized by combination of gabbronorite dykes and sulphide vein and gabbro-pegmatite nests (Fig. 18).

Most veins at the NKT area have been mined out, while at the Sopcha area only the richest ones have been worked. Presently, excavations at the NKT are drowned.

The excursionists have the possibility to examine the structure of the upper part of the NKT sulphide veins undergone to intensive oxidation. Close to the old pit, the ore dumps representing all the ore types of the NKT vein field. Together with the sulphide veins, the NKT ore field contains dikes originated before and after the ore-forming process.

Stop 3 (Fig. 3, 8, 9). Cr ore of the Sopcheozero deposit

Visit to the mine in the western part of the Sopcheozero chromite deposit (Fig. 19). The mine opens the north-western part of the deposit where the *chromitite locate in the peridotite and plagioclase peridotite. The chromite impregnation in various concentrations is nicely visible as clear layers and lenses.*

The Sopcheozero chro-mite deposit occurrs in the ultramafic rocks of the south-eastern part of the Monchepluton (Fig. 20). The deposit is interested since it is confined to the so-called «Dunite Block», occuring in pyroxenites. The dunite is restricted from the north-west, north-east, and south-east by the Monchepluton pyroxenites, and from the south-west by the schistose Monchetundra gabbro. The south-western and south-eastern contracts are cut by tectonic dislocations. The south-western contact of the complex is referred to as the junction zone between the Monchepluton and Monchetundra massifs, while the south-eastern contact of the complex with pyroxenite goes along the tectonic north-east-trending zone locally marked by the depression of the Sopcha lakes. A fault that pulls down the lalitudinal branch of the Monchepluton relative to the meridional one for 300 m [17] passes along the depression.

Fig. 19. The Sopcheozero chromite deposit mine, upper banks opened moraine (light colour), lower banks opened chromitite (black).

The dunite near the contact with the Monchetundra massif is broken by tectonic dislocations parallel to the junction zone into small vertical plates. The dislocations are marked by the mafic dykes. Some dykes contain PGE mineralization. The chromite ore body is located in one of vertical tectonic

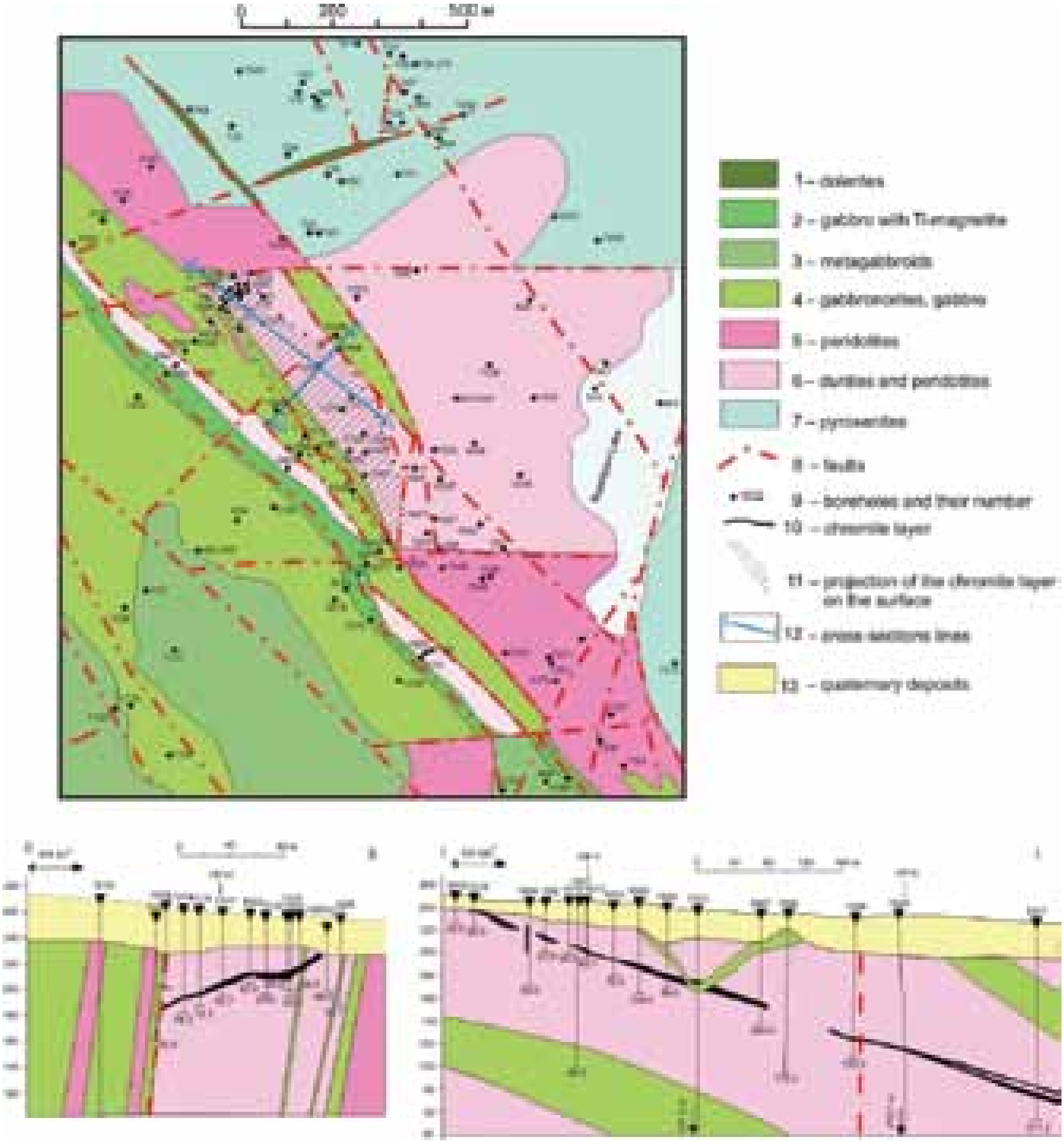


Fig. 20. The geological sketch map and cross-sections of the Sopcheozero chromite deposit.

plates, which is tilted in the north-east and is restricted from the north-east and south-west by tectonic dislocations. The faults bound the distribution of the chromite ore. The fault bounding the chromite body from the north-east is fixed by the injected complicated microgabbro-microgranite dyke, which actually forms the border of the ore body. The fault parallel to the complicated dyke bounds the ore body from the south-west.

The inclination and dip of the ore body is to the south-east. In the north-west the ore body is overlain by the moraine. In the vertical direction the ore body is traced for 315 m. The thickness of the ore body varies from 1.0 to 32.5 m, being 7.8 m on average. The thickness increases south-eastwards. The ore body is characterized by the layering of different level (Fig. 21).

Fig. 21. Banded texture of the Sopcheozero deposit chromite ore.

The thickness of chromite layers varies from millimetres to first decimetres [6]. The chromite concentration in the layers is unevenly distributed, usually increasing top-down. According to the data on testing the thickness of marco-layers with a short range, the variations in micro-layers range from centimetres to 3-5 m. The Cr_2O_3 content in the ore body is ca. 23 % with the highest concentrations in the middle part of the ore body. The contacts of the ore body with the country rocks are gradual. The composition of the rock-forming part of the ore body mainly responds to the composition of the country rocks.

Thus, the location of the chromite body does not comply with any element of the Monchepluton layering. According to [17], around the «Dunite block» the pyroxenite shows the trachytoid structure «obducing the Dunite block», giving the right to consider the dunite body as a huge early-phase xenolith incorporated by magma during the pyroxenite crystallization.

Stop 4 (Fig. 3, 8, 9). Cu-Ni ore of “Horizon 330”

The excursionists are to climb Mt. Sopcha up and examine the deposit of the disseminated ore «Horizon 330», represented by the outcrops of mineralized peridotites and olivine pyroxenites within the monotonous orthoptyroxenite layer. The bottom of «Horizon 330» is well-exposed at the slope and represented by eruptive peridotite breccia in piroxenite (Fig. 22). The peridotite is intercalated with the olivine pyroxenite and has brown colour and thin banding (Fig. 23). There are a lot of exposures of pyroxenites, peridotites, olivine pyroxenite cutting diabase dykes.

Fig. 22. The participants of the excursions at the foot of the «Horizon 330» at Sopcha Mt. At the background there are the lake Sopch-Yavr and the Monchetundra massif. It is possible to see the south-eastern dip of the massif foot.

This area gives the impression of the structure of the unique element of the Monchepluton, “Horizon 330”. The “Horizon 330” represents a large deposit of disseminated sulphide ore in the upper part of the Monchepluton section. The average thickness of the ore body is about 4-5 m, the diameter is about 2 km, and the total reserves of Cu, Ni, Co are about 260 thousands of tons. Historically, the exploration of “Horizon-330” in 1930s gave grounds to build the mining complex “Severonickel”, but the deposit itself has not been mined because of the poor ore quality. Poor quality of the ore is accounted for

Fig. 23. Fragments of thinly layered pyroxenite and peridotite of the «Horizon 330» at Sopcha Mt.

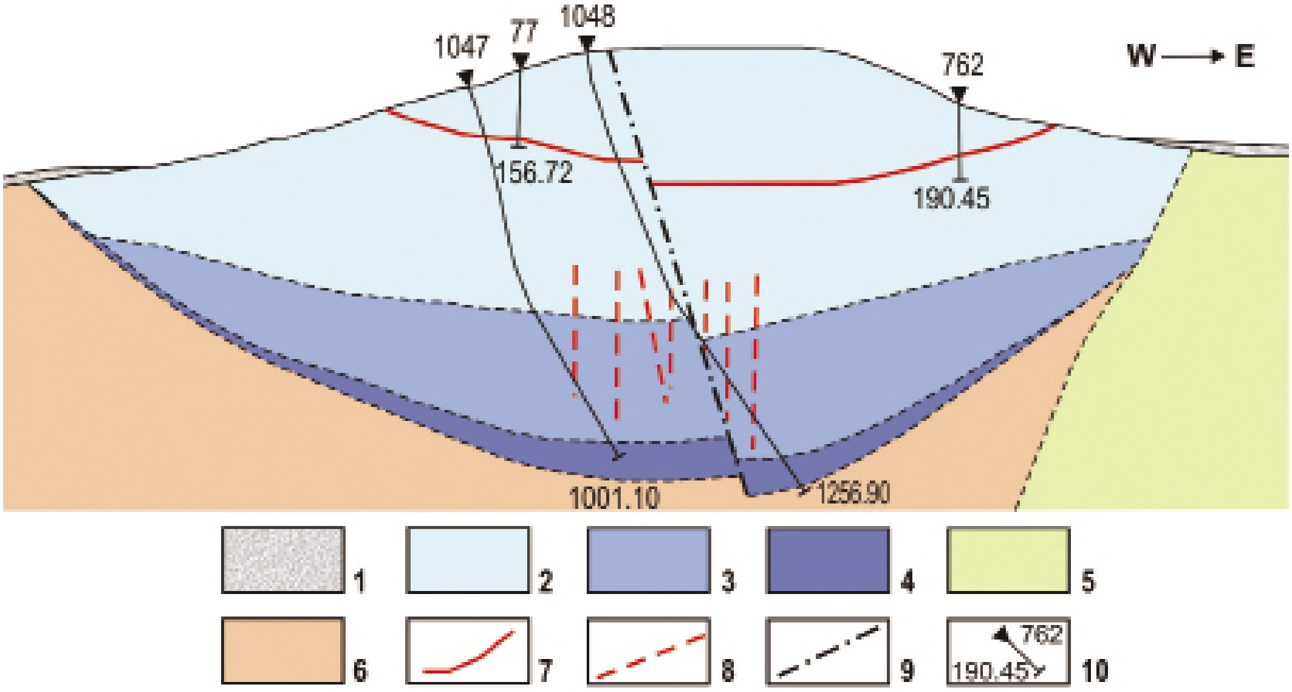


Fig. 24. The schematic geological cross-section of the Sopcha massif on W-E direction. Compiled by P.V.Pripachkin on the basis of CKE JSC data.

Legend: 1 – quaternary cover; 2 – pyroxenite; 3 – alternation of pyroxenite, olivine pyroxenite and peridotite; 4 – peridotite; 5 – metagabbro; 6 – gneisses; 7 – ore horizon 330; 8 – sulfide veins; 9 –geological boundaries; 10 – borehole and its number.

by the high content of silicate nickel linked with olivine. The problem of the deposit genesis is one of the most exiting puzzles related to the Monchepluton. The deposit is confined to discontinuous flow layers of olivine-bearing rocks: olivinites, peridotites (harzburgites), olivine pyroxenites, feldspar olivine pyroxenites occurring within the pyroxenite (bronzitite) sequence in the upper part of the Mt. Sopcha section. The olivine-bearing rocks and associated sulphides are, so to say, hanging at a height of about 800 m from the pluton bottom (Fig. 24) and are bounded by bronzitites from the top and below. The sulphide-bearing rocks composing separate lens-like bodies at several levels make up a relatively pesistent "horizon", outcropping along the whole perimeter at the slopes of Mt. Sopcha at a height of 330 m (Fig. 24). The most spectacular and complete sections of the ore horizon with peridotites and all peculiar genetic fragments can be observed at the western slope of Mt. Sopcha (excursion stop). At the eastern slope the exposure of «Horizon 330» lacks peridotites, and only olivine pyroxenite and feldspar olivine pyroxenite crop out.

The «Horizon 330» sulphide ore is fine-grained, and possesses high PGE concentrations in the sulphide mass in comparison with other types of the Monchepluton ores. The highest PGE concentrations are confined to the lower part of the horizon, i.e. to pegmatoid pyroxenites.

Stop 5 (Fig. 3, 8, 9). Cu-Ni ore of the "Crytical horizon" (Nud-II open pit)

Visit to the mine at the Nud-2 deposit and the «Terrace» deposit. The attention of the excursionists will be devoted to examining of the outcrop of the «Crytical horizon» of the Monchepluton within the mined-out deposit (Nud-II) of disseminated and nest-disseminated ores (Fig. 25).

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 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 suplhide 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

Fig. 25. Mine of the Nud-II deposit. The walls of the mine and dumps contain numerous deebris of sulphide nests and disseminated ores.

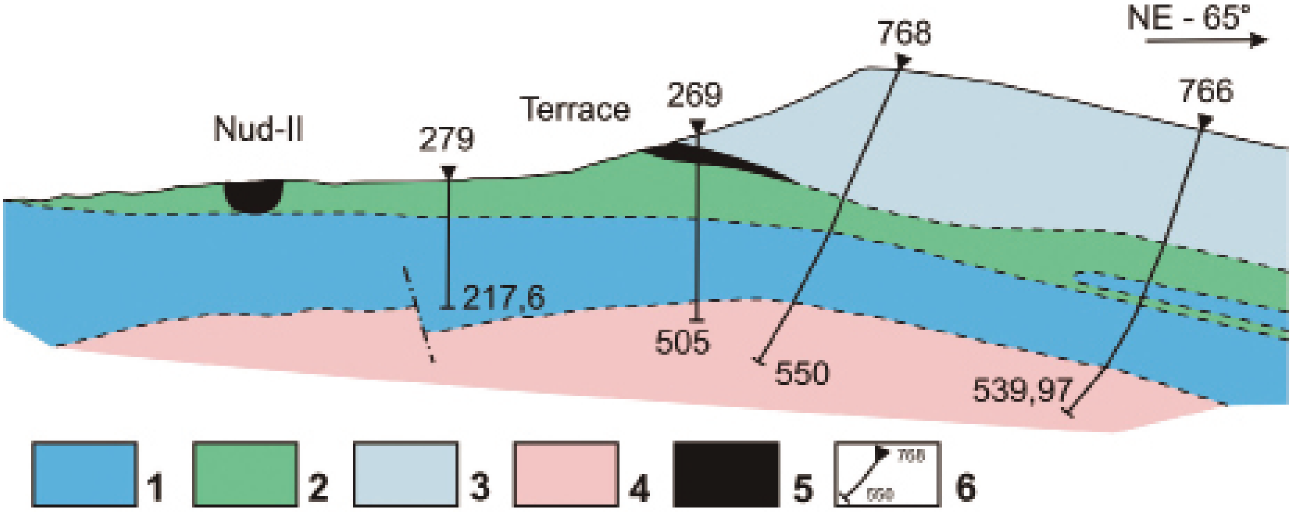


Fig. 26. The sketch cross-section of the eastern part of the Monchepluton through the Nud-II and the “Terrace” deposits complied by P.V. Pripachkin on the basis of CKE data. Legenda: 1 – melanocratic poikilitic norite; 2 – olivine norite; 3 – leucocratic and mesocratic norite; 4 – rocks of the exocontact zone; 5 – nesty-disseminated and veined sulfide mineralization; 6 – borehole and its number.

in the ore. The combination of syngenetic and epigenetic ore types with predominating Cu-Ni metallogeny is common. The geological boundary is marked by the borders of the «Crytical horizon» rock distribution. The «Terrace» deposit, that occurs east of the Nud-2 deposit is also related to this element of the Monchepluton structure (Fig. 26).

Stop 5-a (Fig. 3, 8, 9). 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 «Fersman's adit» (Fig. 27). The access to the outcrops is within 300 m distance (Fig. 28). The outcrop of the «Terrace» traces the horizon of giant blocks of fine-grained and thinly-bedded rocks, or hypotethical units of the pluton roof (Fig. 29, 30).


Fig. 27. Outcrops of the "Terrace" deposit micrograined layered rocks; at the bottom of the picture one may see dumps of the Fersman adit.

The «Terrace» deposit is also confined to the norite and olivine norite complex and the «Crytical horizon» rocks of the Nud massif. The structure of the deposit is mainly bedded. The ore does crop out. The disseminated ore bodies occur in layers. According to modern concepts «Crytical horizon» is the result of additional portion of magma with brecciation. In the olivine norites and pyroxenites there is chalcopyrite-pyrrhotite dessimination from 1-2 to 3-5% with RGE+Au content 1.5-3 ppm. In the lower part of the «Crytical horizon», at the "Terrace" deposit, Fersman discovered a large (2.0 × 3.5 × 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.

Fig. 28. View from the «Terraca» deposit at the quarry «Nud-II».

Fig. 29. The micronorites body in the «Critical horison» strucrure.

Fig. 30. The flow structure in the «Critical horizon» thinly-bedded rocks.

Stop 6 (Fig. 3, 8, 9). 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 demonstrates the main rock mass represented by fine- and medium-grained mesocratic massive, partially metamorphosed gabbronorite. 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. 31) with sulphide impregnation containing PGEs.

The «Vurechuaivench» prospect is confined to the zone of alternating meso-leucocratic massive and taxitic gabbronorite and anorthosite-plagioclasite. 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 subdivision of the VM into two zones (Fig. 32) is highlighted by the fact that the upper zone is mineralized whereas the lower zone is almost barren. In the upper zone sulfide mineralization has been established at 10 levels of the stratigraphic section (boreholes 1801-1803 and 1811-1813).

Two of these levels (upper and lower) display elevated concentrations of the PGE and have been traced down dip (Fig. 32). The Upper Level has been intersected in boreholes 1811 and 1812, and is underlain by anorthosites (pC) and overlain by irregular-grained mesocratic gabbronorites (pCabq). The sulfide and related PGE mineralization occur along the upper contact of the anorthosite layer. The Lower Level (intersected in boreholes 1226, 1811, 1812, 1803 and 1801) is located within medium-grained gabbronorites and norites (pabC and pbC) with numerous (1-10m) thick lenses of anorthosite (plagioclase cumulates). The PGE and Au content reaches here 3-4 ppm. The Lower Level crops out at surface (Fig. 8, 31, 32) along a strike of up to 150m [30, 31]. Mineralized zones are up to 1-3m thick (rarely – 6-9 m and more). Both these levels dip gently (10-20°) south eastwards concordant to the country rocks.

The sulfide mineralization (0.5-1%, rarely up to 3-5%) is disseminated, heterogeneous in abundance and grain size, and irregularly distributed. The most common grains size is less than 0,1 mm. Sulphide-bearing veins and nests (2-3 mm in size) are less common. The grains boundaries are xenomorphic. The sulfide grains are located mostly between secondary silicate aggregates. Sulfide mineralization of the VM is represented by several paragenetic associations [11-13]. The millerite + chalcopyrite + (pentlandite ± pyrrhotite ± pyrite) association is favourable for PGE which occurs as both mineral phases and solid solution within sulfides and sulfoarsenides of Fe, Ni and Co. Minerals of Pt metals are represented by arsenides and bismuttellurides of Pd, and less commonly by sperrylite, hollingworthite, irarsite, menshykovite and isomertieite. Noble metals mineralization is in direct proportion to sulfide content. It follows from this that the origin of PGE and Cu-Ni sulfides are closely related.

It should be noted that the PGE mineralization in the VM belongs to the so-called Stillwater type [8]. This type is characterized by disseminated sulphide mineralization and long spread PGE reefs. In the VM the levels with PGE mineralization were traced along a strike up to 2.7 km [16].

Some analogy of the VM with the neighboring well-studied West-Pana Massif (WPM) [18, 24, 25] can be noted. Both massifs are sheet-like bodies of gabbronorite composition. The WPM contains the South PGE reef in its upper part [34] and the North PGM-reef in its lower part [19]. Both PGE reefs are traced for approximately 10 km along the strike and closely associated with sections that are composed of alternating gabbronorite and norite with leucogabbro and anorthosite [19]. Although the layered upper zone of the VM shows less pronounced variations in composition of alternating layers, the VM may also represent a promising target for PGE deposits. Much more work is needed to provide deeper understanding of the geology, petrology and ore genesis of the VM.

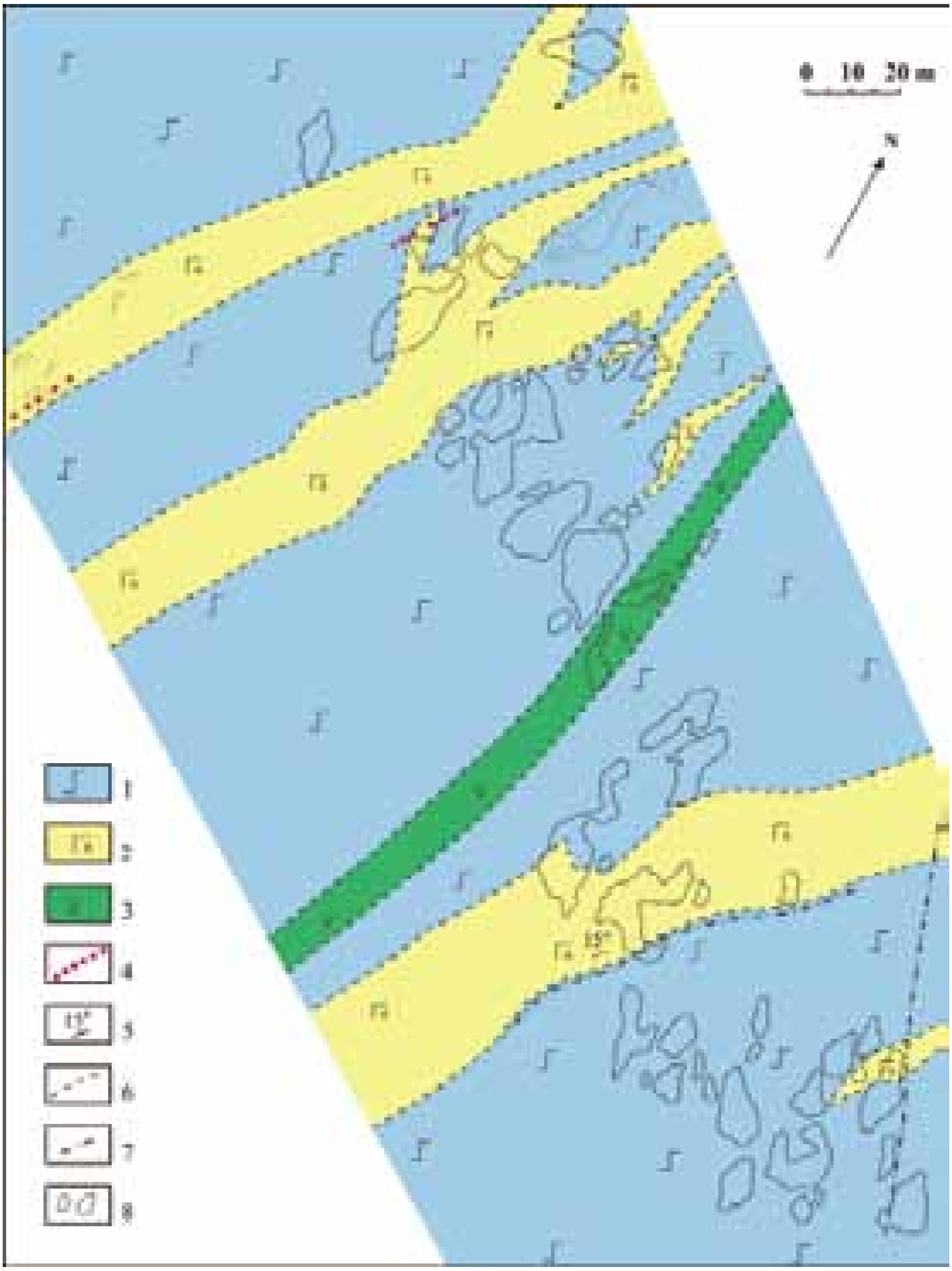


Fig. 31. The sketch geological map of the detailed target «Vurechuaivench». Complited by P.V.Pripachkin.

Legend: 1 – mesocratic metagabbronorites; 2 – leucocratic metagabbro and metaanorthosites; 3 – metagabbrodolerites; 4 – sulfide and PGE mineralization; 5 – dip and strike; 6 – geological boundaries; 7 – faulting; 8 – outcrops.

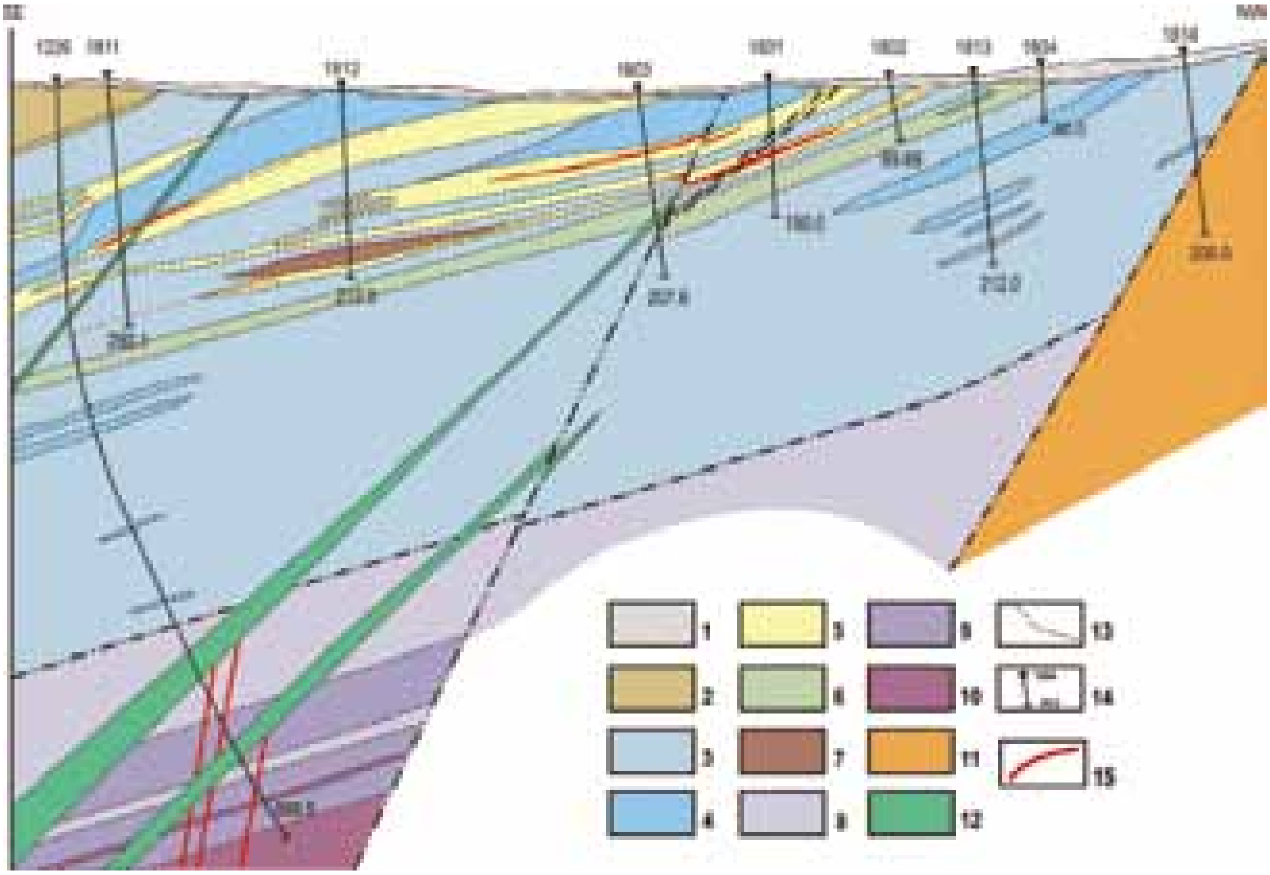


Fig. 32. The sketch geological cross-section of the Vurechuaivench massif along the DH 1226-1814 line (see Fig. 8). Complited by P.V. Pripachkin and T.V. Rundkvist on the base of CKE JSC data.

Legend: 1 – moraine; 2 – Imandra-Varzuga volcanic rocks; 3 – metagabbronorites; 4 – poikilitic metagabbronorites; 5 – metaleucogabbro, metaanorthosites; 6 – fine-grained metagabbro; 7 – metanorites; 8 – gabbronorites (Nud massif); 9 – norites (Nud massif); 10 – pyroxenites; 11 – diorites; 12 – gabbro-dolerites; 13 – fauting; 14 – drill hole with the depth (m); 15 – sulfide and PGE mineralization.

Fig. 33. Autochthonous outcrops of meso-leucocratic anorthosite (white color, lower foto) with the low-sulphide PGE mineralization at the Vurechuaivench deposit.

The Imandra lopolith

Stop 1 (Fig. 6). Cr ore of Mt. Majyavr-Devich'ya prospect

The excursionists may examine the structure of the gabbronorite layer and vertical chromite horizon in several outcrops (Fig. 34, 35). The exposures of the gabbronorite are traced by a ridge for over 300 m. In the lower part, they change into the endocontact zone of the Imandra lopolith with the Imandra-Varzuga belt. The contact is well-exposed.

The Devich'ya-Maryavr massif extends for 18 km north-westwards, has a shape of 2.5-m-thick vertical plate, and occurrs in amphibolite, presumably of the Archean age. The chromite prospect locates in the lower level of the Imandra lopolith main zone layering. It is easily accessible from the Murmansk-Saint-Petersburg highway, 10 km south of the city of Monchegorsk.

Geological structure of the lower marginal zone and lover layered chromite-bearing zone I in the northern limb of the Imandra intrusion (Fig. 6).
The basal part of the pluton cutting andesite-basalt metavolcanic rocks (Fig. 34) is exposed here in steep slopes of canyon and small outcrops over an area of 100×800 m^2. The visible thickness of the exposed zone is 70-100 m, and it can be traced over a distance of 800 m along the strike. The SE-

NW trending (320-330°) rocks of the pluton dip to the southwest at 75° and more; reverse dips are also found. There is an exposure of contact between the intrusion and host volcanic rocks. 15 mup the section from the contact, there is a zone of mesocratic gabbronorite containing schlieren (varying in size from a few mm to tens of cm in diameter) and pegmatoid veins of leuco-mesocratic amphibole-plagioclase composition. The size and the number of schliren increase from bottom to top of the section, and their morphology changes from small rounded and oval schlieren in the bottom to large irregular nests, lenses and vein-like bodies, commonly connected by thin "conductors". These bodies in the upper part of the zone contain disseminated chromite mineralization, which in places wakes up the bulk of the "schliren" reaching several tens of cm across. These bodies constitute the lower marginal zone of the pluton designated as schliren or taxitic horizon. This zone has been previously found in the Umbarechensky massif. In the area of borehole 639 these and overlying rocks of the chromite-bearing zone are more weakly tectonized and metamorphosed than the rocks in other parts of the intrusion, and this favours to the examination of original features of the intrusion structure in that area.

These rocks are directly overlain by the first bed of chromitite. The bed thickness varies from 0.6 to 1.7 m. Its base is uneven, and the contact with

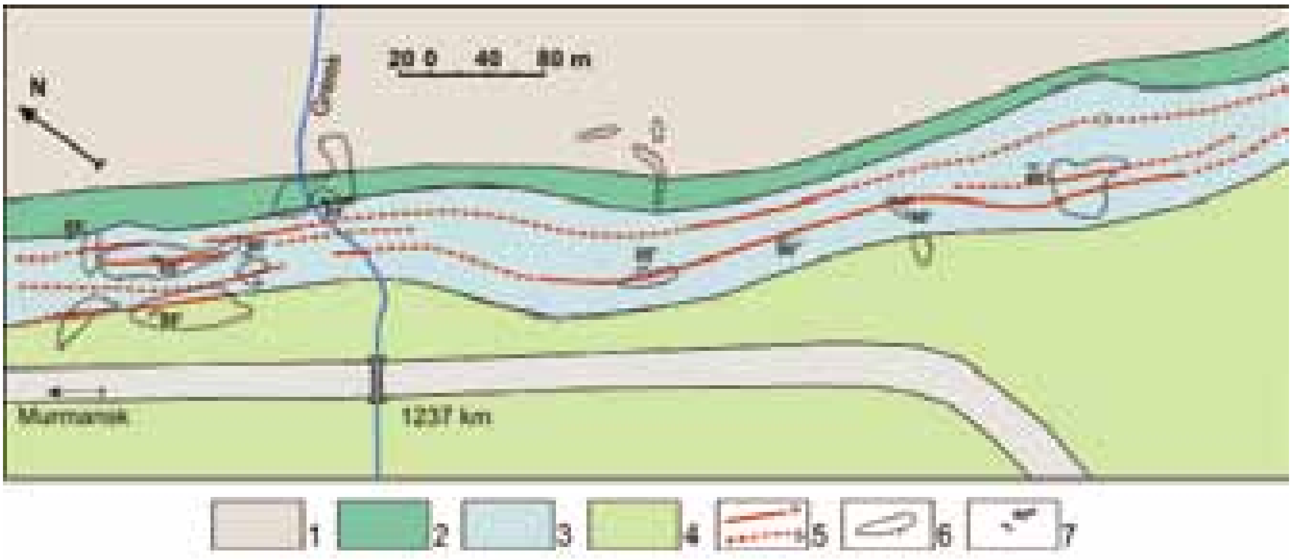


Fig. 34. The sketch geological map of the chromite-bearing zone of the Imandra layered intrusion in the area of Mt.Devichja. Compiled by V.Sholokhnev (1992th).

Legend: 1 – meta-andesite-basalt and Lopian schist after them; 2-4 – Imandra layered intrusion: 2 – mesocratic gabbronorite with schliren the Lower marginal zone, 3 – melanocratic metanorite and metagabbronorite, 4 – mesocratic metagabbronorite; 5 – chromite beds (a – traced on the surface, b – inferred); 6 – contours of outcrops; 7 – dip and strike.

Fig. 35. The participants of excursion visit the chromitite layer in Mt. Mayavr-Devich'ya gabbronorite.

underlying taxitic rocks and ores is sharp. At the upper contact, there is a 10 cm thick transitional interval, where the ore bad grades into barren melanocratic norite. This bed starts the section through the chromite-bearing layered zone I, the lower half of which (about 65 m thick) is composed of melanocratic poikilitic in the base and alternating melanocratic norite and gabbronorite with minor mesocratic gabbronorite in the top. In addition to the first ore bed, the melanocratic rocks contain 3 other thin (0.1-0.3 m) beds of chromitite. All the chromite ore beds and chromite-bearing schliren are characterized by increased PGE and Au contents (1-1.5 ppm in some samples). The lower contacts of ore beds II-IV with underlying melanocratic norite are sharp and straight. The upper contacts exhibit gradual disappearance of chromite 5-15 cm away from the ore bed. In many places there are rhythmically bedded chromite-bearing and chromite-free 5-15 mm thick laminae. This transitional zone locally contains poor dissemination of sulfides. The upper half of the section through zone I is composed of porphyraceous mesocratic gabbronorite with accessory chromite-magnetite mineralization.

Stop 2 (Fig. 6). Cr ore of the Bol'shaya Varaka deposit

The excursionists will visit a series of outcrops of chromitite body in the plagiopyroxenite extending for over 100 m (Fig. 36, 37).

The Bol'shaya Varaka chromite deposit is situated 11 km south of the city of Apatity. The ascertained reserves of the chromite ore exceed 7 mln. tons at the average Cr_2O_3 content of 22.5%. The deposit is trenched and easily accessible for observing the chromite layer in the outcrop, occurring here laterally, as is opposed to the Majyavr-Devich'ya deposit.

The Bol'shaya Varaka massif, occurring among the gneiss of the Archean complex, represents an erosion remainder of the Umbarechensky massif, which structure is complicated by cross-cut tectonic dislocations. The massif shows well-preserved fragments of the lower layered zone and incorporated chromitite ore, that are partially exposed at the surface (Fig. 36) and penetrated by boreholes at depth. The lower zone and chromitite in the cross-section represent a lens-like body extending eastwards. The lens is thickest in the central part of the massif. The content of cumulative orthopyroxene

Fig. 36. Outcrops of the chromitite layer in the Bolshaya Varaka deposit trench.

Fig. 37. Outcrop of the chromitite layer; the upper boundary (dark colour) with gradual transition into the country rocks is clearly visible.

in the plagiopyroxenite and melanocratic norite ranges within 60-80 %; that of intercumulative plagioclase and clinopyroxene is 10-30% and 5-10 %, respectively. The early generation of chrome-spinelid is also referred to as a cumulative phase.

The rocks and ores of the near-contact part are metamorphosed, but the relics of the primary minerals are preserved. The lower marginal zone has a thickness of 90 m at Mt. Bol'shaya Varaka, and is composed of taxitic microgabbronorite.

The Monchetundra massif

Stop 1 (Fig. 5, 8). The target near the M-1 borehole

The excursionists will visit a series of outcrops near the wellhead of M-1 borehole in the transitional interval between the Middle and Upper zonez of the Monchetundra massif (Fig. 38-40).

According to the results of the geological and petrographic study carried out on the principles of cumulative stratigraphy the mafic and ultramafic rocks of the Monchetundra intrusion have been divided into three zones [5] (Fig. 5).

The rock sequence of the lower zone varies from olivinite to leucocratic norite. The lower zone is dominated by norites with quite a wide distribution of pyroxenites and olivinites, which are common in the south-eastern flank of the intrusion. Minor are harzburgites and gabbronorites. Orthopyroxene and olivine cumulates prevail in the cumulative stratigraphy of the lower zone.

The rocks of the middle zone represent northwestwardly elongated strings at the exposed surface of the eastern and western flanks of the intrusion and compose a significant part of the cross-section in the boreholes. The rock sequence of the middle zone ranges from troctolite and olivine gabbronorite to anorthosite. Contrast layering is more typical of the western flank of the intrusion. The middle zone is dominated by trachytoid medium-grained gabbronorite with plagioclase-pyroxene and minor plagioclase cumulates.

The rocks of the upper zone make up the central part of the intrusion. In terms of composition, the rocks of the upper zone range from plagioperidotites to gabbronorite-anorthosites and gabbro-anorthosites. The

Fig. 38. View from the top of the Monchetundra mountain at the Sopchjavr Lake and «Severonikel» plant.

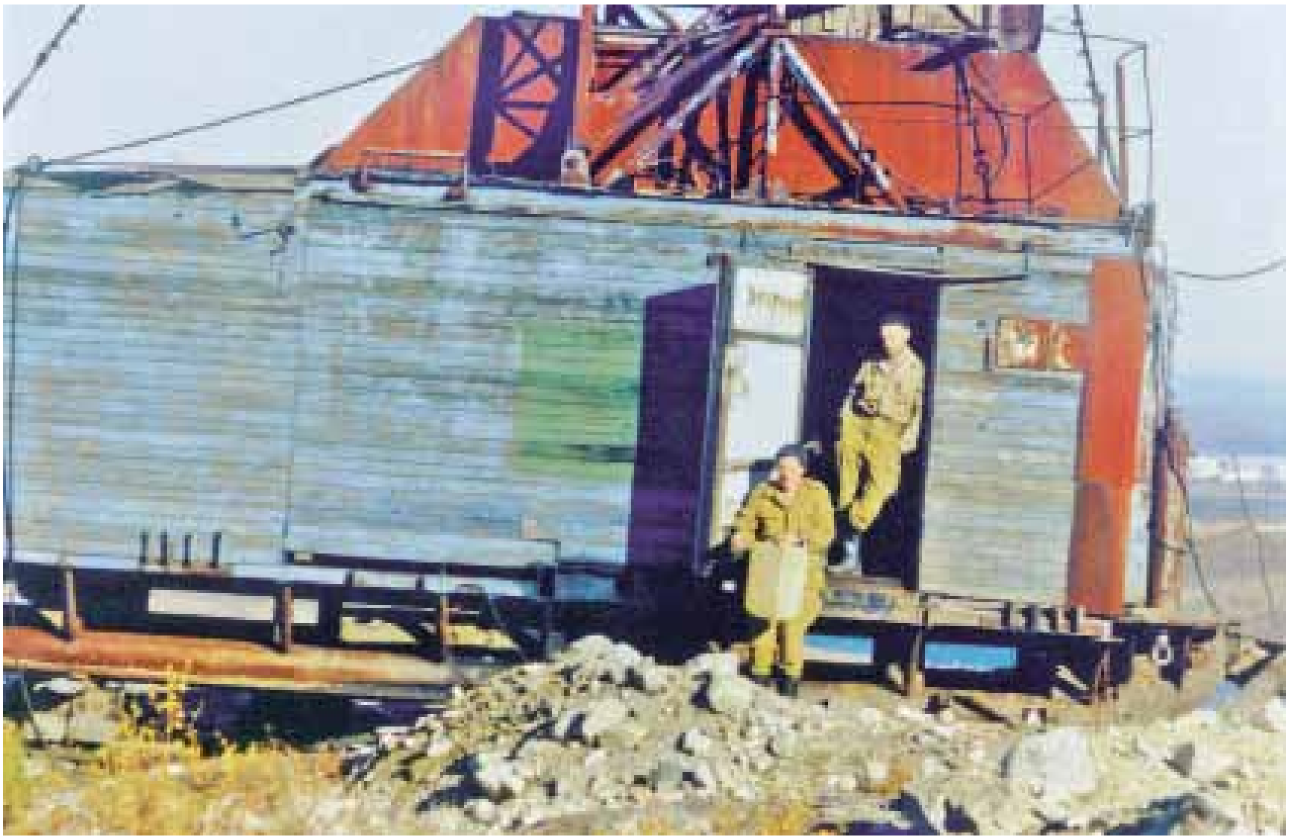


Fig. 39. The wellhead of the M-1 borehole.

Fig. 40. The layering in the Middle zone of the Monchetundra massif near the M-1 borehole.

contrast of the rocks increases northwestwards. Massive coarse-grained augite-pigeonite and augite-enstatite varieties of gabbronorite-anorthosites and leucogabbronorites, gabbro-anorthosite and leucogabbro prevail in the upper zone. The leucogabbro apparently represents an individual intrusive phase since there are xenoliths of leucocratic varieties of gabbronorites in the gabbro-anorthosites and leucogabbros of the upper and middle part of the Hipiknyunchorr Mt. slopes. The rocks of the upper zone correspond to plagioclase cumulates: poikilitic inclusions of plagioclase are typically observed in the pyroxenes and olivines. Minor are plagioclase-pyroxene and plagioclase-olivine cumulates. Poikilitic inclusions of cumulus plagioclase in pyroxenes and olivines are found even in such melanocratic rocks as plagioperidotites of the upper zone.

Thus, the lower zone of the Monchetundra intrusion consists of orthopyroxene and olivine cumulates, the middle zone of pyroxene-plagioclase and plagioclase cumulates, and the upper zone mainly of plagioclase cumulates.

Massive coarse-grained meso-leucocratic, mesocratic, and rarely melanocratic amphibole-plagioclase rocks are common in the southeastern and southwestern parts of the Monchetundra intrusion. These rocks are mainly thought to be altered varieties of leucogabbro, gabbro-anorthosite, and gabbro. Only relic clinopyroxene rarely shows well-preserved primary igneous features. The observed relic gabbro-ophytic and poikiloophytic structures indicate that the rocks are close to the leucogabbro and gabbro-anorthosite of the upper zone. However, secondary alteration of the rocks strongly hampers their investigation.

The internal structure of the Monchetundra intrusion displays significant lateral heterogeneity. The degree of differentiation tends to increase from the eastern flank of the intrusion southwards (for the lower zone) and westwards (for the middle and upper zones). This implies a possibility to find PGE mineralization not only at the junction of the Monchetundra and Monchepluton intrusions (eastern and southeastern flanks of the intrusion) that has mainly been investigated, but also in the rocks of the southwestern, western, and northwestern flanks of the intrusion.

The Monchetundra intrusion was earlier found to contain a level of noble metal mineralization confined to the norite and pyroxenite of the lower zone [14, 20]. In 2005-2008, the exposed central and southeastern parts of the Monchetundra intrusion that are mainly composed of the upper zone rocks and of the middle zone rocks in the eastern and western flanks, were sampled for a geochemical analysis.

The analysis of the geochemical data has shown that the local geochemical anomalies are mainly concentrated within the western slope of Mt. Monchetundra. The only exception is Mt. Hipiknyunchorr, where increased Pd content is observed along the whole intersection from east to west. On the whole, for the massive gabbroids of the upper zone, and for the dike and veins of the intrusion, oxide mineralization that is often accompanied by syngenetic chalcopyrite and epigenetic chalcosine-bornite-chalcopyrite masses, is more typical. It correlates with a slight increase in Pd and rarely Au content. A slight increase in Pd content is also registered in the chlorite-amphibole schists after gabbroids adjacent to the shear-fault displacement planes. No noble-metal minerals themselves have been found in the above-discussed cases.

Higher concentrations of valuable components and noble-metal minerals are established in the trachytoid gabbronorite of the middle zone at the western flank of the intrusion. The mineralization traced for over 10 km has been clearly associated with the top of the middle zone in terms of structure and lithology. It points out the stratiform character of mineralization. Due to the low sulphide content (1-1.5%) the ore can be referred to the low-sulphide type. The mineragraphic investigation of the Seid'yavr Lake rocks has revealed quite a diverse assemblage of noble-metal minerals. Braeggite [(Pt, Pd, Ni) S] is found as monomineral spherical grains among silicates and as intergrowths with vysotskite [(Pd, Ni) S], stillwaterite [Pd_8As_3], [(Pt, Pd, Co) S], chalcopyrite. Native gold and moncheite [$PtTe_2$] form intergrowths with chalcopyrite, oxides, and monomineral isolations. Electrum [Au, Ag] and merenskite-melonite minerals [$(Pd, Pt, Ni) (Te, Bi)_2$] are also present.

REFERENCES

1. Alapieti T.T., Filen B.A., Lahtinen J.J., Lavrov M.M., Smolkin V.F., Voitsekhovsky S.N. Proterozoic layered intrusions in the Northeastern part of the Fennoscandian Shield / Miner.Petrol. 1990. V 42. P 1-22.

2. Amelin Yu.V., Heaman L.M., Semenov V.S. U-Pb geochronology of layered mafic intrusions in the eastern Baltic Shield / Precambrian Res. 1995. V 75. P 31-46.

3. Balashov Yu.A. Geochronology of the Pechenga-Varzuga structure earlyproterozoic rocks of the Kola Peninsula / Petrology. 1996. T 4. N 1. P 3-25. (In Rus.).

4. Balashov Yu.A., Bayanova T.B., Mitrofanov F.P. Isotope data on the age and genesis of layered basic-ultrabasic intrusions in the Kola Peninsula and Northern Karelia, northeastern Baltic Shield / Precambrian Res. 1993. V 64. N 1-4. P 197-205.

5. Bayanova T.B., Galimzyanova R.M., Fedotov Zh.A. Evidence of the multifase complex history of the Imandra lopolith / Svekalapko 6th workshop, Lammi, Finland. 2001. Abstracts. P 7.

6. Chaschin V.V., Galkin A.S., Ozeryansky V.V. et al. The Sopcheozero chromite deposit and its PGE content. Monchepluton (Kola Peninsula, Russia) / Geology of ore deposits. 1999. V 41. N 6. P 507-515. (In Rus.).

7. Dedeev A.V., Khashkovskaya T.N., Galkin A.S. PGE Mineralization of the Monchegorsk Layered Mafic-Ultramafic Intrusion of the Kola Peninsula / The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum-Group Elements. Louis J. Cabri (Ed.). Canadian Institute of Mining, Metallurgy and Petroleum. Spec. Vol. 2002. N 54. P 569-577.

8. Dodin D.A., Chernyshov N.M., Polferov D.V. et al. PGE deposits in the world. M: “Geoinformmark”, 1994. V 1. 279 p (In Rus.).

9. Dokuchaeva V.S., Zhangurov A.A., Fedotov Zh.A. Imandra lopolith – a new major layered intrusive on the Kola Peninsula / Dokl. AN. 1982. V 265. N 5. P 1231-1234. (In Rus.).

10. Dokuchaeva V.S., Sholokhnev V.V. New data on the geological structure of the Nyud-Poaz massif / Regional geology, metallogeny and geophysics. Apatity: KSC RAS,1974. P 88-95. (In Rus.).

11. Grohovskaya T., Laputina I. Platinum mineralization of some layered intrusions of the Kola Peninsula / Nickel in mafic-ultramafic complexes of the Karelia-Kola region. Apatity: KSC RAS, 1988. P 69-73. (In Rus.)

12. Grokhovskaya T.L., Bakaev G.F., Shelepina E.P., Lapina M.I., Laputina I.P., Muravitskaya G.N. PGE mineralization in the gabbronorite of the Vurechuaivench massif, Monchepluton (Kola Peninsula, Russia) / Geology of ore deposits. 2000. V 42. N 2. P 147-161. (In Rus.).

13. Grokhovskaya T.L., Bakaev G.F., Lapina M.I., Sholokhnev V.V. PGE mineralization of the Monchetundra. Proc. of the All-Russian Symp. «Geology, genesis and problems of developing complex deposits of noble metals». M.: Svyaz Print, 2002. P 136-140. (In Rus.).

14. Grokhovskaya T.L., Bakaev G.F., Sholokhnev V.V. et al. PGE mineralization of the Monchegorsk layered igneous complex (Kola Peninsula, Russia) / Geology of ore deposits. 2003. V 45. N 4. P 329-352. (In Rus.).

15. Iljina M. The Portimo Layered Igneous Complex – with emphasis on diverse sulphide and platinum-group element deposits / Departament of Geology, University of Oulu, Finland. Acta Univ. Oulu. A 258. 1994. 158 p.

16. Ivanchenko V.N., Davydov P.S., Dedeev V.A. et al. Major features of the Vuruchuaivench (Vurechuaivench) deposit geological structure / The neighborhood cooperation and experience exchange of geological prospecting and survey of PGE deposits in the Northen Fennoscandia. Interim results of International Project KOLARCTIC INTERREG III A North – TACIS N KA-0197 entitled as "Strategic mineral resourses as a basis of sustainable development of the North" (Russia-Finland-Sweeden). Apatity: KSC RAS, 2008. P 82-87.

17. Kozlov E.K. Natural rock series of nickel-bearing intrusions and their metallogeny. Leningrad: Nauka, 1973. 288 p. (In Rus.).

18. Korchagin A., Mitrofanov F., Subbotin V. et al. Geology and comparison of PGE mineralization of the Northern and Southern Reefs of the West-Pana layered intrusion (Kola Peninsula, Russia) / Ext. abstracts of 10th Int. Platinum Symp. 2005, Aug. 7 –11, University of Oulu, Finland. T.O. Tormanen, T.T. Alapieti (Eds). ESPOO 2005. P 154-156.

19. Latypov R.M., Chistyakova S.Yu. Mechanism of differentiation of the west Pansky Tundra layered Intrusion. Apatity: KSC RAS, 2000. 315 p (In Rus.).

20. Layered intrusions of the Monchegorsk ore region: petrology, mineralization, isotopy, deep structure / F.P. Mitrofanov, V.F. Smolkin (Eds). Pt 2. Apatity: KSC RAS. 2004. 177 p. (In Rus.).

21.Mitrofanov F.P., Balagansky V.V., Balashov Yu.A. et al. U-Pb age of gabbro-anortosites of the Kola Peninsula / Dokl. AN. 1993. V 331. N 1. P 95-98. (In Rus.).

22. Mitrofanov F.P., Yakovlev Yu.N., Balabonin N.L. et al. The Kola platinum-bearing province / Platinum of Russia. M.: Geoinformmark, 1994. P 66-76. (In Rus.).

23. Mitrofanov F.P., Yakovlev Yu.N., Distler V.V. Kola region: a new PGE-bearing province / Geology and genesis of PGE-bearing deposits. M.: Nauka, 1994. P 65-79. (In Rus.).

24. Mitrofanov F.P., Korchagin A.U., Dudkin K.O. et al. Fedorov-Pana layered mafic intrusion (Kola Peninsula, Russia): approaches, methods, and criteria for prospecting PGEs / Mineral. Assoc. of Canada Short Course 35. Oulu, Finland. 2005. P 343-358.

25. Mitrofanov F.P., Neradovsky Yu.N., Subbotin V.V. et al. Ore-bearing rocks and species varieties of PGM minerals in intrusive complexes of the Kola region / Ext. abstracts of 10th Int. Platinum Symp. 2005, Aug. 7-11, University of Oulu, Finland. T.O. Tormanen, T.T. Alapieti (Eds). ESPOO 2005. P 480-483.

26. Mitrofanov F.P. Exploration indicators of new industrial deposits of Rh-Pt-Pd, Co-Cu-Ni and Cr ores on the Kola Peninsula / Geology of Russia. 2006. N 4. P 3-9. (In Rus.).

27. Neradovsky Y.N., Borisova V.V., Sholokhnev V.V. The Monchegorsk layered complex and related mineralization / Ore deposits of the Kola Peninsula, Northwestern Russia. Research and exploration – where do they meet? 4th Biennial SGA Meeting. Aug. 11-13, 1997. Turku, Finland. Excursion guidebook B4 Geol. Surv. of Finland. Guide 45. 1997. P. 27-31.

28. Nerovich L., Savchenko E., Serov P. Geological and petrographic characteristics of the Monchetundra intrusion and its new nobel-metal mineral deposit / Petrology and metallogeny of the Kola region. Apatity: KSC RAS, 2008. P 179-182. (In Rus.).

29. Pavlovsky V.I., Galichanina L.D., Ivanov G.A. et al. A new data on the south-east part Monchegorsk ore region composition / Geophisical researchs in the north-eastern region of the Baltic Shield. Apatity: KSC RAS, 1976. P 36-44. (In Rus.).

30. Pripachkin P.V., Kostenko L.S. PGE deposits in the layered zones in latitude brunch of Moncheplutone: geology and localization of PGE mineralization / New data on geology and mineral deposits of the Kola Peninsula. Apatity: KSC RAS, 2005. P 85-95 (In Rus.).

31. Pripachkin P., Kostenko L. Rundkvist T. The localization of PGE-mineralization in the Vurechuaivench Member of the 2.5 Ga Monchegorsk

Mafic Layered Complex (Kola Peninsula, Russia) based on cumulus stratigraphy / Ext. abstracts of 10th Int. Platinum Symp. 2005, Aug. 7 –11, University of Oulu, Finland. T.O. Tormanen, T.T. Alapieti (Eds). ESPOO 2005. P 537-539.

32. Semikhatov M.A., Shurkin K.A., Aksyenov E.M. et al. A new stratigraphic time-scale of the precambrian of the USSR / Izv. AN SSSR. Ser. Geol. 1991. N 4. P 3-14. (In Rus.).

33. Smolkin V.F., Bajanova T.B., Mitrovanov F.P. et al. Mantle plume magmatism in the Early Proterozoic (2.5 Ga), the Kola Peninsula. XVI symposium on isotope geochemistry of Academician A.P. Vernadsky. Abstracts. Moscow, 2001. P 230-231.(In Rus).

34. Vursiy G., Gabov D., Subbotin V. et al. PGE-mineralization in Olivine horizon in the West-Pana Layered Intrusion (Kola Peninsula, Russia) / Ext. abstracts of 10th Int. Platinum Symp. 2005, Aug. 7 –11, University of Oulu, Finland. T.O. Tormanen, T.T. Alapieti (Eds). ESPOO 2005. P 558-561.

35. Yakovlev Yu.N., Dokuchaeva V.C. PGE mineralization of the Monchepluton. Geology and genesis of PGM deposits. M.: Nauka, 1994. P 79-86. (In Rus.).

36. Zagorodny V.G., Radchenko A.T. Tectonics of the Karelides of the northeastern Baltic Shield. Leningrad: Nauka, 1988. 111 p. (In Rus.).