Geology of the Monchegorsk area

The Monchegorsk ore region is located between the Kola and Belomorian Archean domains (Fig. 1). 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.

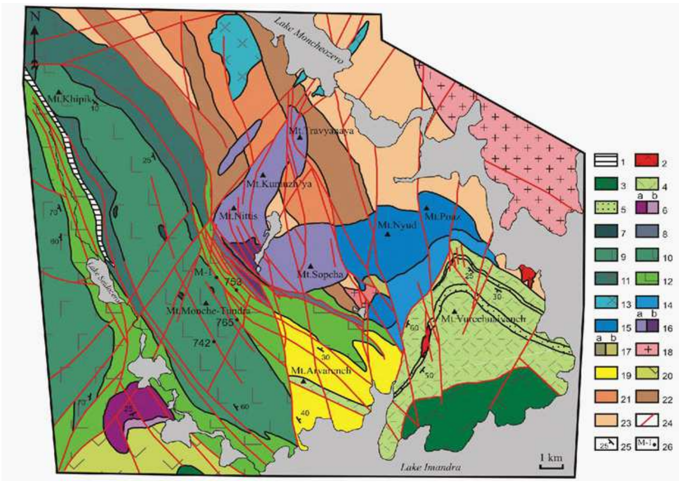

Fig. 1 Geological map of the Monchegorsk ore district

Legend: 1 – large gabbro-dolerite dykes; 2 – anatectite-granite and trondhjemite; 3 – metagabbroids of the Imandra lopolith; 4-5 – metavolcanics (4), 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 (Nyud-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 NE 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 SW limb, a contact between the Proterozoic and Archean rocks, appears to be obscure because of 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 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 (Mitrofanov et al., 1994 1993-?). The U-Pb age of the pluton is 2509-2487 Ma (Smolkin et al., 2001). It occurrs 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^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 - 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. 2). 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 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 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 Archean gneisses representing palingenic restites.

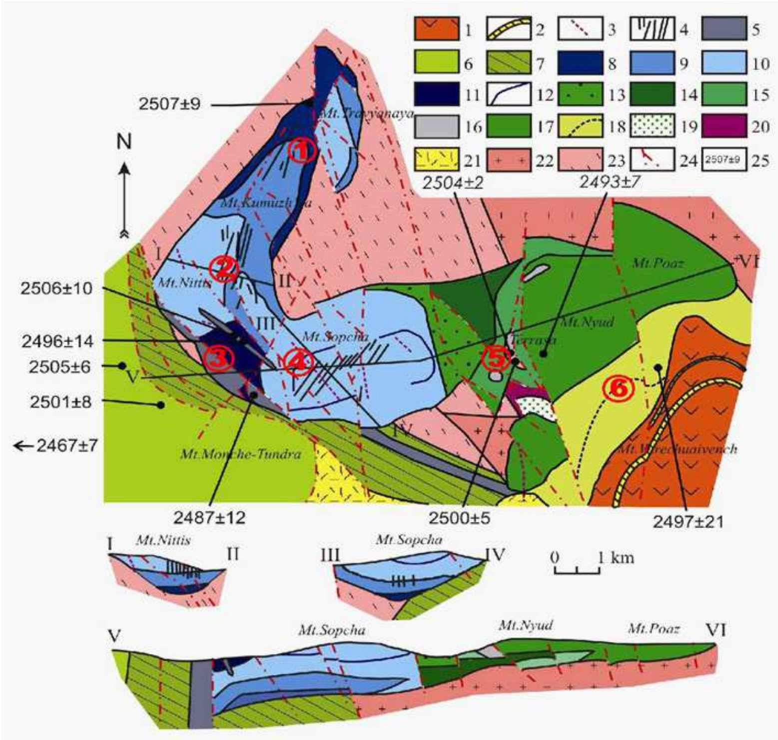

Fig. 2 Geological sketch map and cross-sections of the Monchepluton with isotope U-Pb data of the intrusive and dykes rocks. "Layered intrusions...,2003".

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 Nyud 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 stops: 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 ores6 – the Vurechuaivench deposit of Pt-Pd ores. 1-6 exposures are to visit during the excursion.

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 SE 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 (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 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 (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, 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.

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 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 5 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

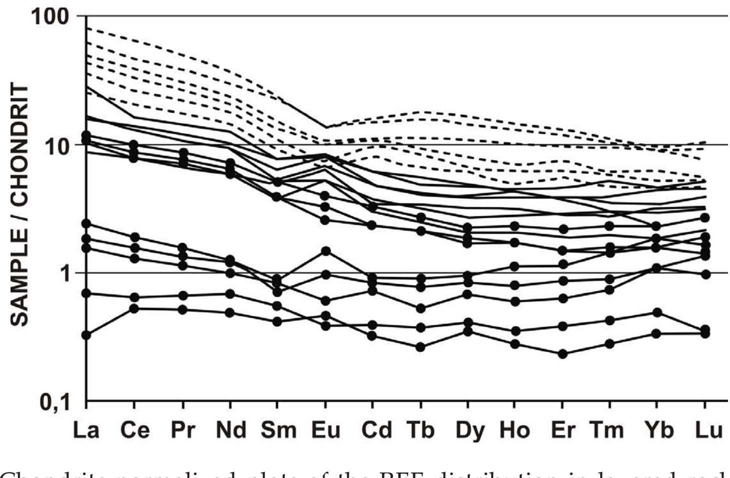

Fig. 3. Chondrite-normalized plots of the REE distribution in layered rocks of the Monchegorsk region and high-Mg volcanites of the Polisarka and Seidorechka Fms. Firm lines indicate basic layered rocks, lines with circles - ultrabasic layered rocks, and dotted line - volcanites.

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 (Balashov et al., 1993).

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 occurrs 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. 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

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

The description of the stops and outcrops

Stop 5 (Fig. 2) Cu-Ni ore of the "Crytical horizon"

Visit to the mine at the Nyud-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 (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 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 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 Nyud-2 deposit is also related to this element of the Monchepluton structure (Fig. 4).

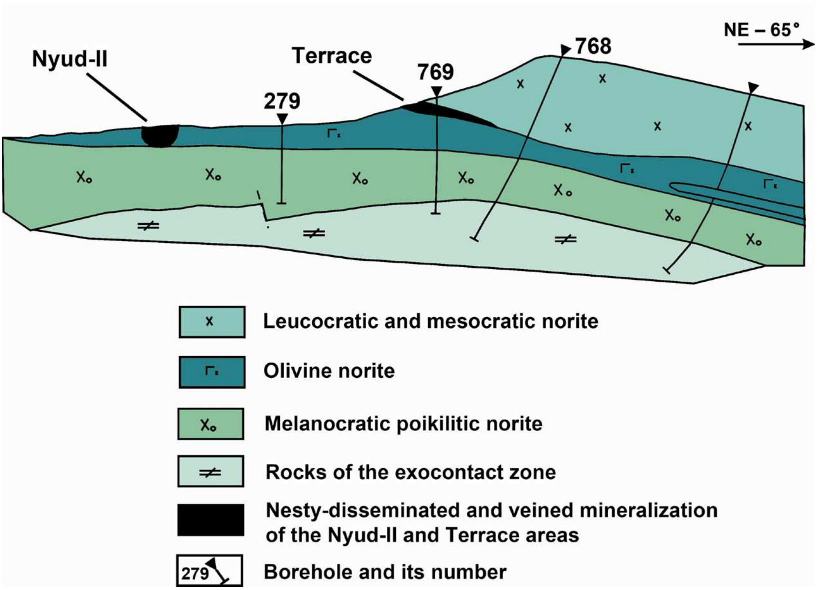

Fig. 4. The sketch cross-section of the eastern part of the Monchepluton through the Nyud-II and Terrace deposits complied by P.V. Pripachkin on the basis of CKE data.

Stop 5-a (Fig. 3) Cu-Ni ore of the "Terrace" deposit

Fig.5. Outcrops of Terrace deposit micrograined layered rocks; at the bottom of the picture one may see dumps of the Fersman adit.

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. 5). 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 «sadberites», or hypotethical 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, 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 6 (Fig. 3) 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. 6) 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. 7) with sulphide impregnation containing PGEs.

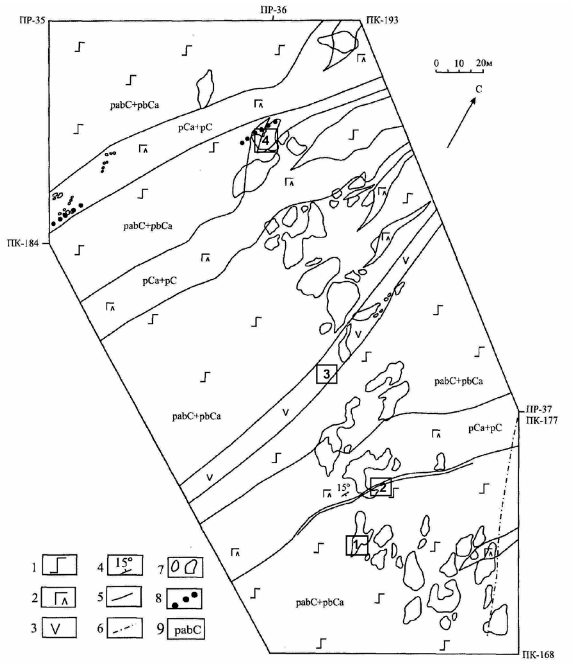

Fig. 6. The geological sketch map of the Vurechuaivench layered horizon (by P.V. Pripachkin, T.V. Rundkvist).
1 – mesocratic metagabbronorite; 2 – leucocratic metagabbro and anorthosite; 3 – metagabbrodolerite dike; 4 – layering strike and dip; 5 – geological boundaries; 6 – tectonic dislocations; 7 – autochthonous outcrop and alluvial fragment contours; 8 – levels of sulphide mineralization; 9 – cumulus minerals. Squares denote metagabbronorite observation points, contact of mategabbronorite and leucocratic metagabbro, dikes of metagabbronorite, and low-sulphide PGE mineralization.

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 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%. The ore minerals are chalcopyrite, pyrrhotite, millerite, and Ni and Co arsenides. The PGE minerals are represented by Pd and Pt telluro-bismuthides, sulphides, arsenides and sulphoarsenides. Among them are kotulskite, merenskite, maichenerite, moncheite, sperrhy-

Fig. 7. Autochthonous outcrops of meso-leucocratic anorthosite with low-sulphide PGE mineralization at the Vurechuaivench deposit.

lite, mayakite, arsenopalladinite, 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 μm. The total PGM content is 0.5-15 ppm.

References

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, №2, pp. 147-161.

Grokhovskaya T.L., Bakaev G.F., Lapina M.I., Sholokhnev V.V. PGE mineralization of the Monchetundra. Proceedings of the All-Russian symposium «Geology, genesis and problems of developing complex deposits of noble metals» - M.:LLC «Svyaz-print», 2002, pp. 136-140.

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. Edited by Louis J.Cabri. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume. 54, p. 569-577, 2002 .

Dokuchaeva V.S., Sholokhnev V.V. New data on the geological structure of the Nyud-Poaz massif. Regional geology, metallogeny and geophysics. Apatity: publ. of Kola branch of USSR Academy of Sci., 1974, pp. 88-95.

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

Layered intrusions of the Monchegorsk ore field: petrology, isotopy, mineralization, and deep structure. Authors: Smolkin V.F., Fedotov Zh.,A, Neradovsky Yu.N., Bayanova T.B., Borisova V.V., Glaznev V.N., Dedyukhin A.N., Orsoev D.A., Ohnenstetter D., Raevsky A.B., Tolstikhin I.N., Chaschin V.V., Mokrushin A.V., Novikov D.D., Ikorsky S.V., Kamensky I.L., Delenitsyn A.A., Mitrofanov F.P. Ed. by Smolkin V.F. Apatity: publ. of KSC RAS, 2003. 33 p.s.

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

Smolkin V.F., Bayanova T.B., Mitrofanov F.P. et al. 2001: Paleoproterozoic mantle plume magmatism (2.5 Ga), Kola Region. *In*: XVI Symphosium on the isotope geochemy abstracts, Moskow