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Magmatism of the Earth and related strategic metal deposits

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The mineral deposits of strategic metals are vulnerable to political and economic changes, and their availability is essential for high-technology, green energy, and other applications. The most of they are related to the deep-seated alkaline magmas. This book offers a collection of papers presented at the 36th International Conference on "Magmatism of the Earth and Related Strategic Metal Deposits" held from May 23th to 26th 2019 in Saint Petersburg State University, Saint Petersburg, Russia. The conference articles are focused on the understanding of the geological processes that produce high concentrations of critical metals in geological systems such as the metal transport in the mantle and crust and enrichment processes, hydrothermal and metasomatic processes leading to the formation of such significant deposits. Papers in this book give a representative overview including mineralogy, geochemistry and origin of strategic metals deposits.

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The cover pictures – View down the Neva to the river between the Winter house of its Imperial Majesty and Academy of Sciences. G.A. Kachalov's engraving according to M.I. Makhayev's drawing (approx. 1750-1752).

GEOCHEMICAL CHARACTERISTICS OF ALKALINE PICRITES OF RARE-METAL-RARE-EARTH ORE FIELDS (MIDDLE TIMAN, RUSSIA)

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Intrusive structures, composing Chetlassky complex of subalkaline ultrabasic rocks, carbonatites, phenites and vein rocks, are developed within the Chetlassky Kamen in Middle Timan. Generally, the ultrabasites compose dike bodies marking faults with NE strike. The dikes break metaterrigenous structures of Late Riphean Chetlasskaya (Svetlinskaya, Novobobrovskaya, Vizingskaya formations) and Bystrinskaya (Rochugskaya, Paunskaya, Pavyugskaya formations) series. The absolute age of the rocks is Late Riphean ~ 600±15(30) Ma. Here in Middle Timan in the upper reaches of the Mezen, Svetlaya, Kosyu rivers we know complex rare metal–rare earth occurrences Kosyu, Oktyabrskoye, Novobobrovskoye, Mezenskoye, Shchugorskoe and others. Rare metal–rare earth mineralization is confined to vein Chetlassky complex and developed in albite-aegirine phenites on quartz sandstones and the dike rocks proper, as well as in veins (quartz-feldspar-goethite, quartz-feldspar-carbonate with hematite). Ore minerals: columbite, rarer pyrochlore, rare-earth carbonates, monazite, xenotime, Nb-rich rutile and wide range of other rare-metal and REE minerals.

Many published and archive papers were devoted to the study of ultrabasic rocks of Chetlassky Kamen in connection with the search for Timan primary diamond sources: Yu.P. Ivensen (1964), V.G. Cherny (1972), I.P. Ilupin (1990), E.V. Francesson (1983), V.I. Stepanenko (1979–1982, 1987), I.A. Malakhov (1985) and many others authors. Recently they were the subject of papers by A.B. Makeev et al. (2008, 2009), I.V. Nedosekova et al. (2011, 2013, 2017), O.V. Udoratina (2014). However, only few works are devoted to the geochemical characteristics of the rocks, only ultrabasic rocks of the Kosyu ore field are well characterized (Nedosekova et al., 2011).

Below we present new geochemical data on the dike bodies within the ore fields: Kosyu (A/15, KO3/15, 3052/3, MT16-41ц), Novobobrovskoye (A14-1), Oktyabrskoe (836), Nizhne-Mezenskoe (AH-4M). The data on the content of rare earth elements are obtained by ICP MS at the VSEGEI Central Laboratory (St. Petersburg). The chemical composition of the minerals was studied at the Geonauka Common Use Center (Syktyvkar). The minerals were studied at IEM RAS (Chernogolovka) on digital scanning electron microscope Tescan VEGA-II XMU with energy-dispersive spectrometer (EDS) INCA Energy 450.

The features of the mineral, petrographic and petrochemical composition of ultrabasic rocks within the studied ore fields reflect a complex and non-permanent composition of magma, and the rocks are also often saturated with various xenoliths of enclosing rocks, altered by alkaline processes and disintegrated in the oxidation zone. The terms of these ultrabasic rocks vary – lamprophyres, alkaline picrites, kimpicrites, elicites – indicate that the rocks are derived from mantle carbonate-rich magma.

These are olivine-pyroxene rocks with biotite (phlogopite) with amphiboles, chlorite, carbonate (dolomite, siderite), potassium feldspar, plagioclase, epidote and zoisite, zeolites, ore magnetite, pyrite, and accessory apatite and zircon. Pyroxene is represented by augite, in altered varieties – by aegirine; and amphibole (hastingsite, tremolite). But often the rocks are completely altered by subsequent fenitization processes and located in the oxidation zone, turning into a friable, lumpy mass that is hard to classify.

The least altered rocks are from the Kosyu site. Thin dike bodies (outcrop A/15, central part of the ore field), exposed by surface mine workings (ditch, KO3/15, 3 km down the Kosyu River from central part of the ore field) are petrographically medium-grained black and dark green alkaline picrites often saturated with a large volume of xenoliths of enclosing rocks (quartzitic sandstones). In thin sections, there is an irregular granular hypidiomorphic structure with elements of poikilite. Composition: phlogopite, olivine, clinopyroxene, hornblende, titanomagnetite, apatite, glass. Large (3-

4 mm) flakes of phlogopite and amphibole grains are either in intergrowths with olivine (0.5-1 mm) and clinopyroxene (0.5-0.8 mm), or contain their poikilite inclusions. Olivine is pseudomorphically substituted by talc. Devitrified glass is developed between crystalline phases.

Sample 3052/3 was taken from the outcrops on the left bank of the Kosyu River in the central part of the ore zone. Pycrite-like rocks with a brecciated structure with xenoliths of quartzite-sandstones (Figure 1) – black and green rocks, saturated by a large volume of strongly modified fragments of enclosing rocks of various sizes from fine-grained to gravel. Interclastic cement is represented by albite with abundant needle apatite, single zonal clinopyroxenes (Aeg-Aug) with amphiboles rims and «druzite» clinopyroxene shells, sulphides (chalcopyrite and pyrite), magnetite, and titanite. Debris have predominantly albite cores (often with quartz and calcite) and pyroxene-amphibole shells. The mineral composition of the shells – aggregate of lamellar aegirine-augite, alkaline amphiboles, calcite, zonal apatites, titanites (sometimes niobium-enriched up to 3.5% Nb_2O_5), sulfides, single relict chrome-spinellides. Allanite-epidote aggregates were detected in the shells of altered xenoliths, the microprobe analysis of which showed the presence of central allanite zones significantly enriched in chromium (up to 13 wt % Cr_2O_3 – Varlamov et.al.(2019)).

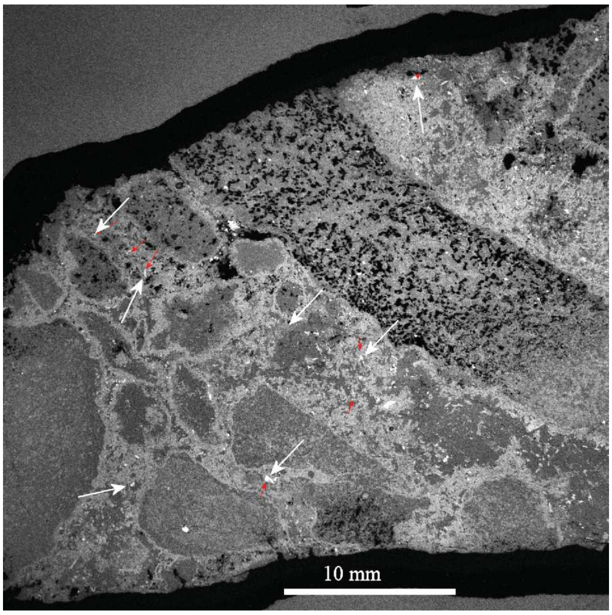

Figure 1. Altered xenoliths in picrite-like breccias, sample 3052/3. White arrows – extremely high-Cr allanites.

Sample MT16-41ц from central part of the ore field drilled by a borehole near puff-up A (carbonatite bunch), the rock contain abyssal xenolite (MT16-41). The rocks are represented by friable material with preserved fragments of gravel size of light green color. In the plates (bulk material), microprobe studies record the following minerals – pyroxene, phlogopite, epidote, and abundant amount of chlorite. In preserved lumps, albite-aegirine rocks with Th monazite are observed.

The dike rocks of the Novobobrovsky ore field (borehole material A14, sample A14/1), black porphyritic, phenocrysts of phlogopite are distinguished. The rock is composed of porphyritic phenocrysts of potassium feldspar (2-4 mm) and a fine-grained mass of quartz- potassium feldspar grains (80-100 microns), with dispersed abundant ore mineralization.

Dike within the Oktyabrskoe ore field, sample 836 (collection by V.I. Stepanenko). The rock is composed of a uniformly-grained (0.8-1 mm) mass of hypidiomorphic potassium feldspar grains and biotite flakes.

The dike rocks of the Nizhne-Mezensky site from the ditch-opened area of Anomaly 4, sample AH4-M – full crystalline, ferriferous ultrabasic green rocks. The rock has a clastic texture, a newly formed lepidoblast structure, and relics of the poikilite structure are preserved in the areas. Composition: talc, serpentine, chlorite, amphibole, magnetite, pikotit. The pseudomorphically talc-substituted small (0.5-0.6 mm) grains of olivine are found in large serpentinite secretions.

Table 1. Chemical composition of rocks.

	A/15	**3052/3**	**KO3/15**	**MT16-41ц-1**	**A14/1**	**836**	**AH4-M**
SiO_2	40.2	54.9	39.0	35.3	51.3	46.3	38.64
TiO_2	1.6	1.0	1.3	1.9	1.4	2.4	1.2
Al_2O_3	11.5	9.2	10.5	9.6	11.0	16.0	13.89
Fe_2O_3	3.0	4.0	4.7	9.2	18.8	7.1	10.73
FeO	6.3	2.1	4.0	0.8	0	6.1	2.98
MnO	0.2	0.1	0.2	0.2	1.3	0.1	0.19
CaO	13.3	10.5	16.5	10.6	**1.9**	**0.3**	**4.42**
MgO	13.7	1.2	14.2	18.0	**0.5**	**6.2**	**16.43**
K_2O	2.5	0.4	3.3	1.2	**8.1**	**5.4**	**0.54**
Na_2O	1.4	4.7	0.5	0.2	0.6	0.5	0.25
P_2O_5	0.5	0.4	0.6	0.6	0.8	0.2	0.28
LOI	4.4	1.7	4.1	11.1	4.2	9.5	10.62
Total	99.2	98.1	99.3	98.9	100.0	100.1	100.01
H_2O	0.4	0.3	0.6	5.4	0.7	0.5	0.34
CO_2	2.1	0.6	1.3	0.8	0.1	0.7	0.54
Be	1.5	1.8	1.6	1.7	4.6	3.3	1.8
V	203.0	191.0	241.0	212.0	148.0	295.0	224.0
Cr	661.0	446.0	617.0	713.0	648.0	**1010.0**	**2510.0**
Co	52.7	31.3	47.8	54.0	40.4	68.7	81.3
Ni	228.0	99.7	171.0	382.0	99.6	319.0	**658.0**
Cu	36.2	93.2	38.6	63.8	46.3	201.0	45.7
Zn	56.8	49.5	58.3	73.2	**634.0**	**3010.0**	**146.0**
Ga	13.4	13.5	12.5	15.2	87.3	20.8	18.0
Rb	113.0	6.3	128.0	62.0	156.0	140.0	20.5
Sr	994.0	286.0	943.0	173.0	271.0	31.1	153.0
Y	21.1	18.5	16.3	24.5	94.0	39.7	28.0
Zr	120.0	163.0	113.0	257.0	178.0	151.0	145.0
Nb	92.8	66.7	113.0	124.0	**1160.0**	98.1	93.7
Ba	991.0	508.0	1600.0	1160.0	976.0	592.0	348.0
La	103	69.3	96.8	107.0	**947.0**	81.6	111.0
Ce	171.0	123.0	170.0	178.0	**1820.0**	158.0	182.0
Pr	18.2	13.4	17.8	19.1	259.0	18.9	19.8
Nd	60.1	47.1	60.7	67.7	**1190.0**	74.0	70.1
Sm	8.3	7.3	8.3	10.5	230.0	13.8	11.0
Eu	2.4	1.8	2.6	3.2	46.7	3.9	2.9
Gd	8.0	5.4	7.1	8.2	97.5	13.2	8.6
Tb	1.0	0.7	0.9	1.1	7.5	1.7	1.1
Dy	4.4	3.6	3.9	5.3	24.3	8.3	5.7
Ho	0.9	0.7	0.7	0.9	3.6	1.4	1.0
Er	2.0	1.8	1.5	2.3	9.3	3.6	2.6
Tm	0.3	0.3	0.2	0.3	1.2	0.5	0.4
Yb	1.6	1.5	1.2	1.8	8.4	3.4	2.0
Lu	0.3	0.3	0.2	0.3	1.4	0.5	0.3
Hf	2.5	4.2	2.3	6.6	5.8	4.0	3.5
Ta	4.2	3.8	5.4	6.0	16.5	5.7	6.3
Pb	5.3	9.8	17.7	8.7	**3570.0**	**2590.0**	6.9
Th	15.9	11.8	13.7	18.2	**960.0**	15.8	14.6
U	2.6	2.0	2.9	1.6	22.9	7.8	2.7

The chemical composition strongly depends on the secondary alterations of the rocks. Petrochemically, the rocks are divided into groups according to the chemical composition in ore fields, as a rule, these are potassium rocks. The K_2O content in the ultrabasic rocks in the ore fields varies (wt %, Table 1) Kosyu 0.4–3.0, Novobobrovskoye 8.0, Nizhne-Mezenskoe 1.0, Oktyabrskoe 5.0. Generally, more high potassium rocks are less magnesian. Total concentrations of REE in the studied rocks vary (table): Kosyu 276-405 ppm, Novobobrovsk 4646 ppm, Nizhne Mezensky 419 ppm, Oktyabrskoe 383 ppm. Geochemically, the differences are very large and the content of Nb, La, Ce, Nd Th, and Zn, Pb increases by an order of magnitude in the most phenitized dike rocks, which is associated with the development of mineralization - columbite, Th-monazite, zinc and lead sulfides/carbonates.

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