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PETROLOGICAL INVESTIGATIONS IN THE POLAR URALS (RUSSIA) AS CERTIFICATE OF PROSPECTS OF ORE DEPOSITS

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ABSTRACT. The Polar Urals Mountain has a large number of small deposits of various minerals – Fe, Cr, Mo, Au, Pt, Ta, Nb, REE and many others. Petrological investigations with analysis of common tectonic situation indicate the possible presence of large deposits here. As a result of the research two conclusions can be made: 1. All listed rocks are magmatic cumulate and belong to an uniform intrusive ophiolite massif of unique size according to gravimetric data (more then 400x120 km) of a Late Ordovician age (nearly 450 Ma). These rocks are very exhausted in Ti and V. However in some gabbro rocks there are ore concentrations of Ti-magnetite. It is possible to assume the existence of huge ore deposits in the differentiated part of the massif under the thin MZ-KZ sedimentary cover. 2. Large gravitational anomaly settles down over the area of PR(?) amphibolites with a large number of granite bodies. Parts of the rocks are diagnosed as A-type and are accompanied with small Ta, Nb and Mo ore deposits. Amphibolites are considered to compose a thin nappe. It is possible to assume the presence of the large stratified Triassic massif as a product of the Siberian Siberian Large Igneous Province (LIP) and the existing of large ore deposits on an economically expedient depth.

ПЕТРОЛОГИЧНИ ИЗСЛЕДВАНИЯ В ПОЛЯРНИЯ УРАЛ (РУСИЯ) КАТО СЕРТИФИКАТ ЗА ПРОУЧВАНЕ НА РУДНИ НАХОДИЩА

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РЕЗЮМЕ. В Полярния Урал има голям брой от малки находища на различни минерали съдържащи Fe, Cr, Mo, Au, Pt, Ta, Nb, REE и много други. Петрологичните изследвания с анализа на общата тектонска ситуация е индикиратор за наличие тук на големи находища. Като резултат от изследването могат да се направят два извода. 1. Всички изброени скали са магмени кумулати и принадлежат към единен интрузивен офиолитов масив с огромни размери по гравиметрични данни (повече от 400x120 km) с късноордовишка възраст (близо 450 Ma). Тези скали са обеднени по отношение на елементи като Ti и V. Обаче в някои габрови скали има концентрации на титаномагнетит. Възможно е да се предположи наличието на огромни рудни находища в диференцираната част на масива под мезозой-кайнозойската седиментна покривка. 2. Една голяма гравитационна аномалия се намира в областта на протерозойските (?) амфиболити с голям брой на гранитни тела. Част от скалите са определени като А-тип и са придружени от малки Ta, Nb и Mo рудни находища. Предполага се, че амфиболитите изграждат една тънка клипа. Възможно е да се предположи наличието на голям стратифициран триаски масив като продукт на Сибирската Гигантска Магмена Провинция (ГМП), както и огромни рудни находища на изгодна за добив дълбочина.

Introduction

In the Polar Urals Mountain are located a large number of small deposits of various minerals – Fe, Cr, Mo, Au, Pt, Ta, Nb, REE and many others. Petrological investigations, geophysical data with analysis of common tectonic situation indicate the possible presence of large deposits here. There is the largest ophiolite belt at the East Zone of the Polar Ural Mountains. It is napped from the east over Paleozoic formations of the passive margin of the Baltica paleocontinent. This belt consists the ultramafic Voikar, Rai-Iz and Syumkeu massifs, which from the east are framed with a continuous belt of gabbro. These gabbro rocks concerne a considerable number of different in age magmatic complexes (Kershor, Trubayu, Sob, Malyko, Maslo, Kharampe and others). Gabbronorite, Ol-gabbro, Pl-websterite, pyroxenite, wehrlite and dunite take place in their structure (Savelieva, 1987; Remizov, 2004; and others). Their age was defined in a range from Paleoproterozoic to Devonian. The Kershor gabbro complex to the east of the Voikar massif is now one of the most well studied (Remizov et al., 2013).

Geological setting

In a history of the Polar Ural Mountains it is possible to allocate two largest structural complexes of rocks. The ancient complex is presented by intensively metamorphosed formations of the Timan orogenic belt of Neoproterozoic – Early Cambrian age. There are the Marun-Keu, Kharbei, Haramatalou, Khord'yus and Dzela tectonic plates from the North to the South (Fig. 1). They are presented, mainly, by ocean formations of various origin. For our discussion the existence of large volume of granites and granite migmatites as a part of the Marun-Keu and Kharbei plates is important. Even more important is the fact that in the region of the maximum development of granites in Kharbei there is a positive gravitational anomaly established. The intensity of this anomaly is comparable to that over the ophiolite belt of the Polar Ural Mountains. It is possible to believe that Harbey and Marun-Keu represent thin tectonic plates (no more than 600-1500 m in different places), pulled over formations of the Paleozoic passive margin of Baltica.

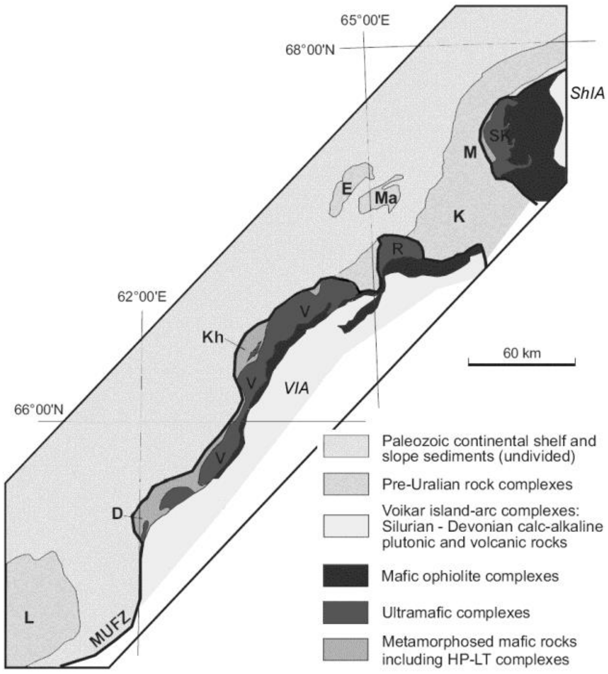

Fig. 1. Tectonic scheme of the Polar Urals (after Estrada et al., 2012): D – Dzela metamorphic complex; E – Enganepe; Kh – Khord'yus metamorphic complex; K – Kharbei metamorphic complex; L – Lyapin metamorphic complex; M – Marun-Keu, Ma – Manytanyrd; MUFZ – Main Uralian Fault zone; R – Rai-Iz; SK – Syumkeu; V – Voikar; VIA – Voikar island arc; ShIA – Shchuch'ya island arc

The second largest complex of rocks is presented by the ophiolite and island arch formations of an Ordovician – Late Devonian age. These are formations of the Paleozoic Ural paleoocean.

The Syumkeu and Rai-Iz-Voikar ultramafic complexes in geophysical fields are distinguished by intense positive gravity anomalies (25-40 mGal). The intensity of the anomaly increases in an eastern direction, which implies an increase in capacity of the ultramafic bodies in this area. According to geophysical data, the bottom of the array is a shallow (10-20, rarely up to 40°) drop to the east, and its capacity is increased from 0.5-1.0 km to the west of 8-10 km to the east (Savelieva, 1987).

The structure of the megacomplex consists of the banded Kershor dunite-wehrlite-clinopyroxenite-gabbro (DWCG) complex with alternating dunite, wehrlite, clinopyroxenite, plagioclase clinopyroxenite, gabbro, olivine gabbro, troctolite, anortozite and homogeneous gabbro, often metamorphosed under epidote-amphibolite facies. These structures are located east of the field of development of the ultramafic complex. Contact is a north-east strike, with subvertical or steep fall in the south-east and it is characterized by directness, lack of lateral displacements and apophysis or intrusive formations. In the contact zone are developed schistose rocks – cataclasites, milonites and ultramilonities, indicating its mainly tectonic character. However, in the Left Payer River are observed dikes and small bodies of metagabbroids in ultramafic rocks, with uneven contact. The uniformity of the gabbro of Kershor is confirmed by U-Pb method on single grains of zircon (SHRIMP II, VSEGEI). For three samples from different parts of the massif are received ages 446,8±4,3, 446±2 and 453±7 Ma (Remizov et al., 2010).

In the south-east, granitoids of the Kokpela complex are border of the Kershor gabbro complex. The contact is tectonic everywhere. In the contact zone milonites upon gabbroides and granitoids are widespread. On the north of the Voikar region superimposed plagiomigmatization developed along this contact, both on gabbroids and on granitoids. This is the Sob plagiogranite complex.

Further to the East volcanic rocks of an early to middle Devonian age covered the Kokpela granitoid complex. Granitoids, basalts, and andesites form an uniform volcano-plutonic association. This is unambiguously proved by geochemical and isotope data (Remizov *et. al., in print.)*.

The Kershor DWCG complex

The Kershor gabbro is characteristic by a lower content of SiO_2 fluctuating from 39 up to 49%, low contents of the sum of alkalis, seldom exceeding 2%, the lowest contents of TiO_2 (less than 1 and usually less than 0,5%), and the contents of MgO are 10-18%, CaO – 5-13%. Quantities of K_2O never exceed 0,5% and, usually are about values of 0,1%, and as a rule – less than 2% Na_2O. The degree of $Fe^{3+}/(Fe^{3+} + Fe^{2+})$ does not exceed 0.3. It testifies to crystallization of melts in recovery conditions and does not promote magnetite crystallization.

The gabbro has the lowest (below, than MORB, sometimes much and more) content of rare-earth elements with rather wide variations. The nature of distribution and concentration of rare-earth elements of the rocks are similar to the komatiites and picrites In some cases a positive Eu anomaly is noted (Fig. 2). Kershor's melt could be formed by partial melting of a more depleted source – similar is the boninitic composition.

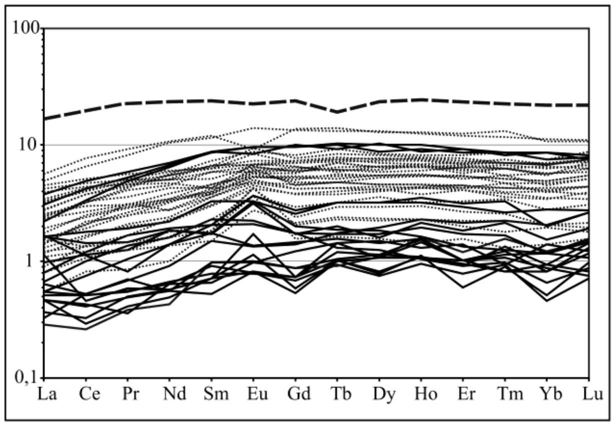

Fig. 2. The spectrum of REE to the rocks of Kershor DWCG complex, normalized by hondrite C1 (Boynton, 1984); dashed line – NMORB

Many researchers believe that the rest after melting the Kershor's gabbro are ultramafic rocks of the Ray-Iz-Voykar complex. However, the content of rare-earth elements, especially LREE, in gabbroids is too low for such assumption.

In Fig. 3 is shown the distribution of rare-earth elements in the Kershor rocks, rated to harzburgites at the Ray-Iz-Voykar complex.

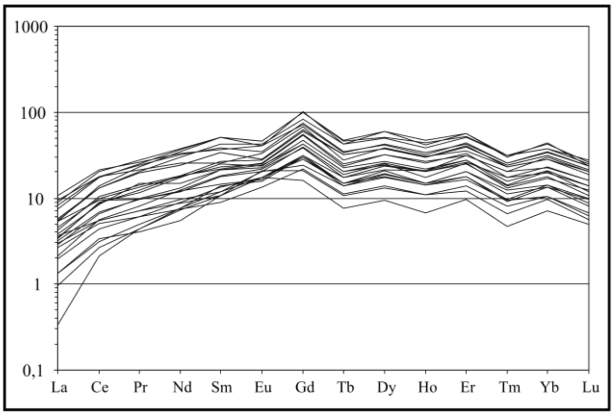

Fig. 3. The spectrum of REE for the rocks of Kershor DWCG complex, normalized by average harzburgite

It is visible that only concentration of rare-earth elements of the middle of the row reach 100-fold values for harzburgites whereas the maintenance of easy and heavy REE exceeds concentration of these elements in harzburgites at least 30-40 times, and lanthanum – only 10 times (sometimes similar to that in harzburgites). Gabbro rocks are characterized by a wide variation of contents of rare and rare-earth elements whereas products of partial melting have a minimum of this parameter. According to D. Shou's equation, only at extent of partial melting less than 10% of a variation in the concentration of REE can exceed tenfold level whereas at big extents of melting these distinctions will be smaller even at gross coefficient of division 0,01 for olivine. If extent of partial melting was less than 10%, distinctions in the concentrations of REE between the gabbro melt and restitic harzburgites would be considerably large.

From the aforesaid follows that the Kershor gabbroids could be formed as a result of partial melting of a strongly depleted source, or they have a cumulative nature. In favor of the cumulative nature of the gabbro ois the distribution in them of rare-earth elements and positive Eu anomaly. The inclination of curves of distribution REE towards LREE in gabbro corresponds to a curve of coefficients of their distribution for CPx, and the existence of positive Eu anomaly correspond to positive Eu anomaly in a plagioclase (Arth, 1976). It is possible to believe that gabbroides are CPx-Pl cumulates, and dunites, wehrlites and clinopyroxenites are olivine, Ol-CPx and CPx cumulates respectively.

Striate interstratifying rocks possibly were created by numerous intrusions in "crack" zones. Thus rising primary fusions experienced fractionation with continuous division cumulates and residual melt. Sharply nonequilibrium crystallization displaced melt composition (from cotectic) towards this or that crystal phase in which fractionation led to melt returning on cotectic.

But, if cumulates construct the main body of Kershor massif where are the differentiates? It is supposed the melts will be enriched by water during differentiation that will lead to crystallization of hornblende and the Ti-magnetite during the last phases. The small fields of hornblende pegmatites are observed in a field of striated gabbroides. In the eastern parts of the massif they form fields, some of big size, also forming sometimes zones enriched with Ti-magnetite up to ore concentration. These fields are blocked by a cover of Voikar island arch volcanic-sedimentary rocks, but it's capacity doesn't exceed 200-400 m (Litovchenko, Romanenkov, 1964; unpublished data).

Kharbei metamorphic complex

The Kharbei complex is build by different metamorphic rocks: amphibolites after basalts, gneisses formed on rocks of different origin, serpentine ultramafic rocks and granitogneisses. In this structure there are many granite bodies of different origin. Analyzed are some of the geochemical data available now. On Fig. 4 is shown the content of microelements, normalized by NMORB (McDonough, Sun, 1995).

It is possible to see that all rocks are characterized by the high maintenance of practically all incompatible elements concerning NMORB. Nb-Ta anomaly as the certificate of a subduction origin of the rocks is absent. Concentrations of compatible elements (Ni and Cr) are sharply lowered. Such features in distribution of microelements are characteristic for rocks of hot spots. For comparison schedules of average concentration are provided in the rocks of the Kerguelen plateau (Fig. 5).

A large number of granite bodies are present in the Kharbei (and Marun-Keu) complex. Most part of the granite bodies agree with structures containing amphibolites and crystal slates and are connected with them by gradual transition migmatization zones. Amphibolites and granite gneisses originally possibly represent bimodal basalt-rhyolite series.

According to numerous determinations of isotope age, the granites have a most probable age about 540-560 Ma that corresponds to time of Timan accretion events. Other large stage of a metamorphism and granite's forming is fixed at the level of Late Carboniferrous – Permian age and corresponds to the Uralian collision.

From the given comparison, the presented structure of the Kharbei complex with numerous ultramafic bodies and other data a conclusion can be drawn, that this complex initially was the Neoproterozoic oceanic plateau, which as a fragment was included into the Baltica structure by the Timan accretion events during the Late Vendian – Cambrian time. All the granites have similar geochemical parameters (Fig. 6).

The negative anomaly of europium which is present in samples from different granitic complexes can be coordinated with low anomaly Eu^- in gneisses and amphibolites. However in case of partial melting the origin of granites has to be opposite – more differentiation of easy and heavy REE and intensive anomaly of Eu has to be observed. Some granites distinctly display this feature (Fig. 7).

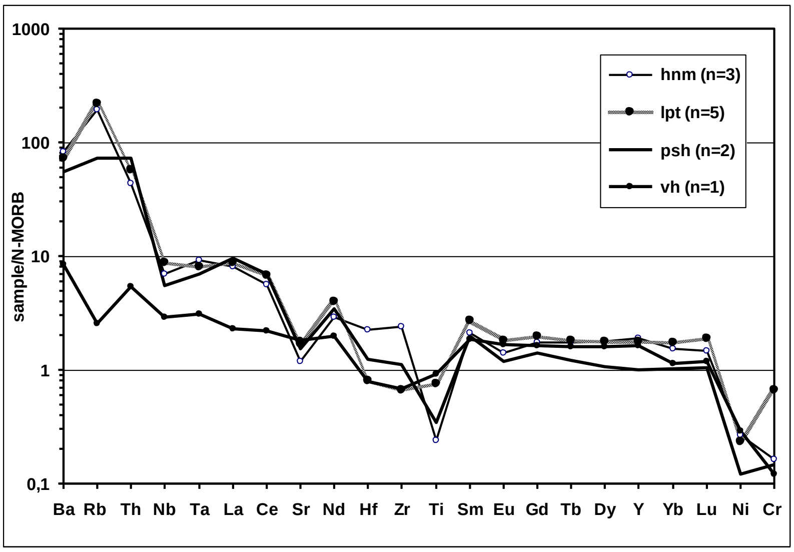

Fig. 4. Spider diagram of the basaltic amphibolites from different suites of the Kharbei complex

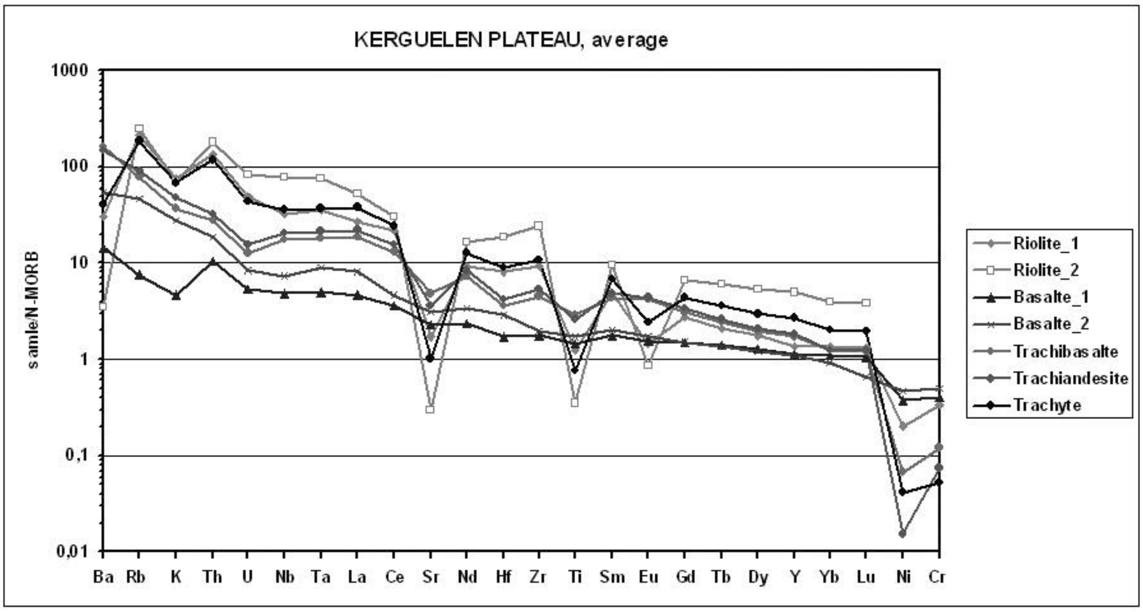

Fig. 5. Spider diagram of the average concentrations in the rocks of Kergelen Plateau (open database, Institute Max Planck, Mainz, Germany; http://georoc.mpch-mainz.gwdg.de/Start.asp)

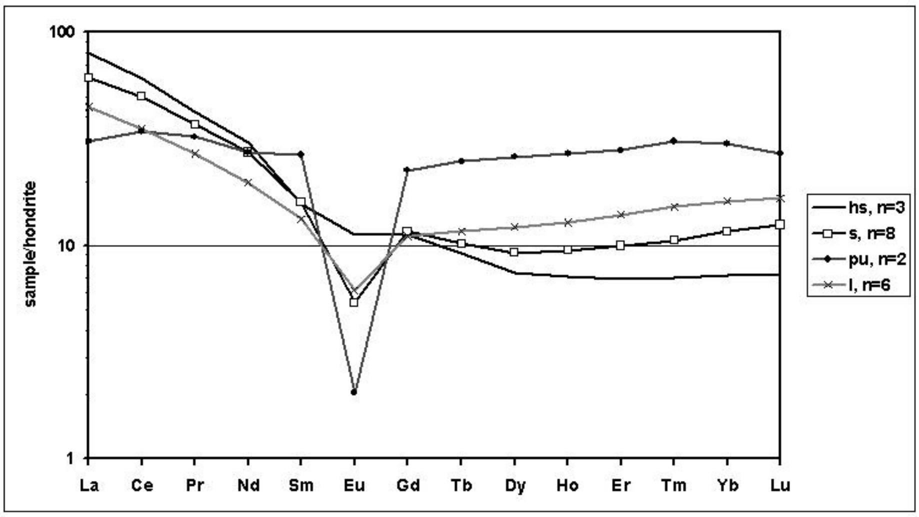

Fig. 6. The spectrum of REE of the granites of the Polar Ural

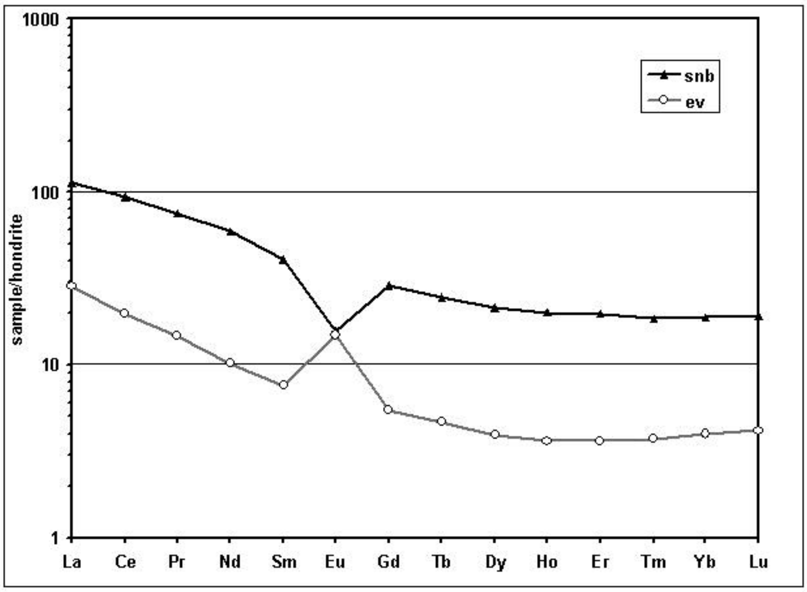

Fig. 7. The spectrum of REE of the different types of granites

Granites of Late Paleozoic or later age demonstrate negative anomaly of europium and correspond to A-type granites. The granites can be derivates from hot spot magmas. It can explain link to REE-related ore within the granite massifs.

Conclusions

As a result of researches during the last years and the analysis of the available information two following conclusions can be made:

● All listed rocks are magmatic cumulate and belong to an uniform intrusive massif of unique size according to gravimetric data (more then 400x120 km) of Late Ordovician age (close to 450 Ma). These rocks are much depleted to incoherent elements, and well as to Ti and V. However in some gabbro rocks are found ore concentrations of Ti-magnetite. It is possible to assume the existence of huge ore deposits in the differentiated part of the massif under thin MZ-KZ sedimentary cover.

● Large gravitational anomaly settles down over the area of PR(?) amphibolites with a large number of granite bodies. The parts of the rocks are diagnosed as A-type and are accompanied by small Ta, Nb and Mo ore deposits. We Amphibolites are considered to compose a thin nappe. It is possible to assume the presence of a large stratified Triassic massif as a product of the Siberian Large Igneous Province (LIP) and the existance of large ore deposits at an economically expedient depth.

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