GEOCHEMICAL CHARACTERISTICS AND METALOGENY OF HERCYNIAN GRANITOID COMPLEXES (EASTERN KAZAKHSTAN)

Purpose. To find out regularities of formation and spatial distribution of new non-conventional types of rare metal mineralization, to develop forecasting and search criteria and to evaluate perspectives as an additional reserve for strengthening and developing East Kazakhstan region mineral resources base.

Methodology. Using ICP MS methods at D. Serikbayev EKSTU Advanced Development Center, there are studied conventional and unconventional plays and occurrences of rare-metal mineralization within the Western Kalba and Rudny Altai, magmatites of Kalba–Narymsky rare-metal granitoid belt. Study on chemical composition of magmatites of a number of intrusive complexes was carried out, the relation of the granitoids with rare metals deposits and manifestations was established. A comparative characteristics of ore mineralization in studied deposits was carried out by scanning electron microscopy (JSM 6390LV).

Findings. Magmatic complexes of potential various rare-metal mineralization within the Kalba–Narym granitoid belt (East Kazakhstan) were identified; conclusions about the relation of potential ore content with granites of certain formation types were made.

Originality. It is established that along with the conventional rare-metal type within the Kalba–Narym metallogenic belt there are found non-pegmatitic unconventional manifestations of rare-metal mineralization of Nb, Li, Sn. Rare-metal pegmatitic ores with the increased content of Li, Ta, Nb, as well as greisen-silica-veined manifestations of Sn, W and gold ore sites with with the increased content of rare elements are to be prospective. The high content of rare metals and rare earth in ores of gold ore deposits at the approach to studying deposits. The development of analytical base, appearance of some new modern highly-precise methods for studying chemical and mineral composition of ores and enclosing rocks created prerequisites for changing research methodology and economic-geological evaluation of deposits [1, 2].

The given paper is devoted to analyzing the problem of Hercynian magmatism in the East Kazakhstan and to finding out regularities of complex conventional and unconventional deposits of rare metal formation.

Unconventional sources of rare metals have come under scrutiny of many scientists (Korobeinik, 1999, 2004; Bykhovsky and others, 1999; Potseluev, 2014). Under conditions of price and demand rise, this objects can become sources of concurrent recovery of precious components, due to development of rational technologies for recovery of valuable elements [3]. For example, high concentrations of rare metals have been found at many proper gold ore and pyrite-polymetallic deposits of Africa (Witwatersrand, the Republic of South Africa), Australia (Olimpia, Dem), Uzbekistan (Muruntau), Kazakhstan (Yubileinoe, Vasilkovka, Ridder-Sokolnuye) and others. On the other hand, high concentrations of precious metals are found in many large rare metals deposits of the world (Kosachinnoe, Chaglinka, North Kazakhstan), Oyu Tolgoi (Mongolia) and others. Factors of similar complex deposits, finding out criteria for their prospecting and evaluation are the basic tasks of modern prognostic-prospecting technologies development [4]. The territory of East Kazakhstan is a part of Great Altai that comprises Hercynian structures of the Rudny Altai, Kalba (the Kalba-Narym belt, the West-Kalba belt) and Zharma Saura. Line (belt) distribution of precious, non-ferrous and rare metals deposits was find out within these structures. The Rudny Altai mainly has gold-copper-polymetallic trend. Basic gold-ore deposits [5] are concentrated in the West-Kalba belt. Leading rare metal structure of the Great Al-
Ore bodies (average gold content is 9.4 g/t) were exposed at the depth of 1000–1500 m. Structures that localize mineralization are identified by geophysical methods at the depth of 3000 m. Ore bodies are lenticular, ribbon-, and lens-shaped subconcordant crushed veins, associated with intersection nodes of Kyzyl shear zone faults [1].

The basic valuable element is gold. Au content is dozens, more frequently hundreds g/t in pyrites. There is increased Ag content (up to 5 g/t). Ores contain up to 1.5 % of copper, molybdenum, tungsten, bismuth—a hundredth of a percent. Gold, tungsten and other elements distribution is characterized by vertical zonalit.

The general feature for all gold deposits in black-shale rock mass (Muruntai, Kumtor and others) is high content of tungsten and other rare metals due to late gold-quartz-carbonate-scheelite-chalcopyrite-molybdenum mineralization. Volframite share in ores of Kumtor deposit is from 0 to 30.4 %, impurities content in calcium tungstate in g/t is Sc 20–300; La 500–1000; Sr 30 000; Mo 10–1000; Y 100–6000; Yb 400. The content of rare and rare-earth metals in Muruntai scheelites in g/t is Y 100–6000; Nd 250; Ce 190–350; Eu 2–130; Sr 400–1100; Lu 0.5–4.0; Sm 20–90. Gold and rare metals para-genesis at Bakyrchik deposit has not been studied well enough. However, rare metals and rare earths have been found in the ores of the deposit by L.G. Marchenko (W, Mo, Sn, Y, Ce, Ga, In, Ta, Yb, Er, La, etc.). Scheelite concentrate can be considered as a source of tungsten and rare earth, molybdenum, bismuth. Medium and upper levels of Bakyrchik deposit are prophase pluton gold, and tungsten content increases with depth. Tungsten mineralization at such deposits is of great interest as it can be the source for recovering numerous valuable elements (rare metals and rare earth). These elements increase margins of their mining. Processing products (gravity concentrates of gold-sulphide ores) are also supposed to be the source of tungsten [1].

The Permian granitoid formations of the Kalba-Narym belt vary in age, material composition, type of rare-metal mineralization [10]. The chemical composition, concentration of the main and dispersed elements of the main igneous complexes were determined by ICP-MS methods. An almost constant Al2O3 content (mass %) on average 15.6 (up to 13.7 in leucogranites) was established for the entire range of granitoids. The sum of K2O and Na2O is different for all complexes with a predominance of potassium oxide in most complexes (K2O and Na2O from 6.4 to 8.4), except for the plagiogranites of the Kunush complex, which fall into the field of normal series. K2O/Na2O in g/t is Y 100–6000; Nd 250; Ce 190–350; Eu 2–130; Sr 400–1100; Lu 0.5–4.0; Sm 20–90. Gold and rare metals para-genesis at Bakyrchik deposit has not been studied well enough. However, rare metals and rare earths have been found in the ores of the deposit by L.G. Marchenko (W, Mo, Sn, Y, Ce, Ga, In, Ta, Yb, Er, La, etc.). Scheelite concentrate can be considered as a source of tungsten and rare earth, molybdenum, bismuth. Medium and upper levels of Bakyrchik deposit are prophase pluton gold, and tungsten content increases with depth. Tungsten mineralization at such deposits is of great interest as it can be the source for recovering numerous valuable elements (rare metals and rare earth). These elements increase margins of their mining. Processing products (gravity concentrates of gold-sulphide ores) are also supposed to be the source of tungsten [1].

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the trace elements has a general trend, which indicates a similar enrichment — depletion pattern of the elements.

The spidergram of scattered elements (Fig. 2, a) of all magmatite complexes shows clearly pronounced negative anomalies of Pr, Ce, La, Nb, Ba; to a lesser extent of Ti. The leucogranites curve of the Monastyrsky complex indicates that depletion of Ce, La is much lower compared to other complexes, yet significant (10 times) for Ti, P, Sr. A negative anomaly of Ti is also characteristic of Kalbinsky complex muscovitized granites of phase II. A significant Cs, Pb concentration in rocks of all magmatic complexes is observed: K, Th, U, Ba concentration and other large lithophile elements to a lesser degree. Positive Nd anomalies are observed in leucogranites of the Monastyrsky complex except for those listed above. The presence of positive Cs, U, Pb and negative Nb, P, Ti, Yb anomalies is characteristic of Kunush plagiogranites.

The pattern of rare-earth elements distribution in Kalbinsky complex granites of I and II phases (Fig. 3, b) has a similar element distribution trend being practically in a single field; the overall negative slope of the curves with a significant predominance of light elements over heavy ones. A weakly pronounced negative Ce anomaly and a pronounced negative Eu anomaly are observed. The Monastyrsky leucogranites have a general trend for the rare-earth elements curve slope similar to the Kalbinsky granites which contain the rare-earth elements; they have a distinct Eu anomaly. The spider plot of the Kunush granodiorites shows a significant predominance of light rare-earth elements over heavy ones, which is expressed by a sharply negative field of the distribution curves; there are almost no negative or positive anomalies.

The issue of the age of the Kalba–Narym granitoids is adequately covered in the literature; correlation schemes and the sequence of formation of magmatic complexes were compiled in different years. The basis of the correlation is general geological data and isotope datings for zircons (U–Pb), biotite (K–Ar), amphibole (Ar$_{40}$/Ar$_{39}$) [12]. It was found that the total time of formation of magmatites is about 100 million years.

### Table

| Era, age | Granitoid complex | Age, mln (PD Kotler et al., 2015) | Mineralization |
|---------|------------------|---------------------------------|----------------|
| $C_1$   | Kunushsky        | $295 \pm 2.0 – 306 \pm 9.0$    | Au, Ag, As     |
| $P_1$   | Kalbinsky I phase | $290 \pm 3.0 – 300 \pm 3.0$  | Sn, W (Li, Be, Ta) |
| $P_1$–$P_2$ | Kalbinsky II phase | $289 \pm 3.0 – 275 \pm 3.0$ | W, Sn (Ta, Li) |
| $P_2$   | Monastyrsky      | $285 \pm 3.0 – 271 \pm 3.0$  | W, (Sn, TR)    |

The age of the Kalba–Narym igneous complexes [13]
according to the data from space images interpretation. They are located inside the north-west part of Sekisovka ring structure.

Ore mineralization is associated with gabbro-diorite-granodiorite-granite Sekisovka multiphase massif of Zmeinyogorsk complex (C). Massif area is about 100 km². Magmatites are localized in igneous-sedimentary rocks (D, fm-C). Igneous rocks of Sekisovka massif can be divided into 2 series (gabbro-diorite and plagiogranite), main and acidic postgrain dykes control basic ore mineralization (Figs. 3, a, b) [14].

Both series have similar indicators of concentration and depletion of rare elements (they are rich in K, Zn, Pb, and depleted in Nb, P and Ti) (Fig. 4, a). Cabbro-diorite series demonstrate a planar structure of rare earth elements with weak Eu anomaly and low concentration of light rare earth elements in comparison with heavy rare earth elements. Peaks from granite porphyrites illustrate various behavior of rare earth elements with strong concentration in light rare earth elements in comparison with heavy rare earth elements and small negative or even positive Eu anomalies (Fig. 3, b).

There are zones of multiphase explosive-hydrothermal breccia in the north-east part of the massif. The deposit ore bodies are concentrated within complicated hydrothermal breccia. They are pipe-shaped, tapered towards the bottom; their size is from 40 to 120 m in diameter. Their tracked depth is from 100 to 900 m [15]. According to mineral composition, there are four types of ore-bearing breccia (mixed, main and acidic). Mixed breccia is most of all rich in gold ore.

Gold is contained in sulphides (mainly pyrite, galenite, sphalerite). Gold and silver tellurides, as well as bismuth minerals are widely developed [1, 15]. Free chalcopyrite, galenite, sphalerite). Gold and silver tellurides, association are gold II, native silver, lead and gold tellurides, quartz, different carbonates, pyrite of several generations, carbonates, pyrite, marcasite, bismuthine, molybdenite, scheelite (Fig. 4).

The late stage of deposit formation and mixed breccia emersion is characterized by gold-silver-bismuth-tellur – polymetallic association. The characteristic minerals of this association are gold II, native silver, lead and gold tellurides, quartz, different carbonates, pyrite of several generations, bismuth minerals, galenite, sphalerite and others. Late mineral association is controlled by dykes of quartz albitophyres, granite- and felsite-porphryites [1]. Free gold, and gold contained in tellurides and in the form of fine-dispersed impurities in sulphides predominate. The average content of metals in pyrites is the following: Au 30–1000 g/t; Bi 300–400 up to 1000 g/t; Mo up to 1 g/t. There are increased contents of rare and rare-earth elements in the changed enclosing rocks and ore breccia, g/t: (W up to l; Te 0.3–0.4; Sn 13.5; Rb 26.1–59.64; Nb 1.9–5.7; Cs 2.5; Nd 5.2–18.7; Y 5.4–35.7; Sr 65.0–200.0; Sm 1.7–3.13; Th 0.4–0.9) (Fig. 4).

When mixed type breccia was formed at the late stage, gold-silver-bismuth-tellurium-polymetallic association was deposited (with gold II, native silver, telluride, quartz, carbonates, pyrite, chalcopyrite, altaite, aikinite, tentannite, galenite, sphalerite, greencokite, tellurobismuthite, pettezite, hessite, crennerite, calaverite, sylvanite) at the upper levels of breccia bodies. This association is controlled by dykes of quartz albitophyres, granite-porphryites, and felsites. Quartz-carbonate and quartz-sulphide veins predominate. Gold is in free form as tellurides and fine-dispersed impurities in sulphides. Pyrites contain Au 30–1000 g/t; Bi 300–400 up to 1000 g/t; Mo up to 1 g/t [1, 14].

It can be seen that besides gold, rare metal mineralization predominate at gold-sulphide stockwork deposits. It should be taken into account in further assessment works and in ore concentration technology. Baladzhal deposit is referred to gold-sulphide stockwork deposits in the West Kalba. It is necessary to continue to study ores of this deposit.

Discussion. The ore-bearing granitoid magmatism of Kalba and adjacent areas was estimated based on the system analysis of geotectonic, geological, structural, petrological, mineralogical and geochemical characteristics and criteria that are indicators of the metallogenic specialization of certain geochemical environments and ore-magmatic systems. The cyclically-directed evolution of the Late Paleozoic magmatism is emphasized, which is fixed by a consistent series of specific magmatic complexes and phases with different ore-bearing properties.

The collision ore-magmatic system uniting the near-fault belts of the hypabyssal minor intrusions and dikes of granodi-
orge and rare metals. It is evident that the Monastyrsky leucogranite (TR, W, chambered crystal-bearing pegmatites, Sn, W) deserves attention. Defined potential ore content of metal-pegmatite ores (Li, Ta, Nb, Sn) and greisen-quartz-veined ore (Ti, Zr) and the Miryukovsky dike gabbro-diorite-granite-porphyritic P2 (Ta, Li, Sn) complexes.

At the same time, the Kalbinsk complex granitoids of phase I have a pronounced increased basicity and are productive for the leading type (tantalum-tin-lithium-cesium rare metal-pegmatite) mineralization (Bukhonenko, Yubileynoye, Belaya Gora deposits, etc.).

Quartz-albite-muscovite pegmatites and albite-greisen metasomatites (Sn, Ta, Li) (Quartz), as well as greisen-quartz-vein deposits (Leninskoe, Karash, and others) are associated with granites of phase II of this complex. Wolframite hydrothermalites and monazite placers are characteristic for the Monastyrsky leucogranites. The Buran granitoids are productive for zircon-ilmenite mineralization in residual weathering crusts and alluvial deposits (Satpayevskoe, and so on).

Conclusions. The studies have shown that a lot of deposits can be considered as complex ones, due to peculiarities of ore formation processes and different mineralization types. Gold and rare metal mineralization of different stages have been found within large ore control structures of ore fields at the known deposits. It has been found out that complex mineralization is within long-lived ore control structures (shear zones, zones of crossing differently directed deep-level tectonic faults, ring-type structures, deep-level intrusions, and others). There are perspectives of recovering rare and rare earth elements together with gold from gold-containing ores (Sn, Be); the Buran monzonite-syenite-alkaline-granite P2 (Sn, Be), the Buran monzonite-syenite-alkaline-granite P2 (Ti, Zr) and the Miryukovsky dike gabbro-diorite-granite-porphyritic P2 (Ta, Li, Sn) complexes.

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Геохімічна характеристика та металогенія герцинських гранітідних комплексів (Східний Казахстан)

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Мета. З'ясування закономірностей формування та просторового розподілу нових негерцинських видів мінералізації рідкісних металів, розробка критеріїв прогнозування та пошуку, оцінка перспектив в якості додаткового резерву для зміцнення й розвитку мінерально-сировинної бази Східного Казахстану.

Методика. Методами ICP MS у Центрі опережаючого розвитку ВКГУТІ імені Д. Серікбаева вивчено традиційні та нетрадиційні руди та рудові об’єкти з рідкіснометального орудення в межах Західної Калби та Рудного Алтая, магматит рідкіснометального Калба-Наримського гранітоїдного поясу. Проведене вивчення хімічного складу магматитів ряду інтурузивних комплексів, встановлено зв’язок гранітідів із рудовіми та рудними об’єктами. Методами аналізу електронної мікроскопії (JSM 6390LV) проведена порівняльна характеристика рудної мінералізації досліджуваних рудових об’єктів.

Результати. У межах пермського гранітоїдного Калба-Наримського поясу (Східний Казахстан) виявлені магматичні комплекси, перспективні на різні типи рідкіснометального зрудення, зроблені висновки щодо зв’язку потенційної рудоносності з певними формационними типами гранітів.

Наукова новизна. Встановлено, що поряд із традиційним рідкіснометальним типом у межах Калба-Наримського гранітоїдного поясу виявлені внepегматові негерцинські прояви рідкіснометальної мінералізації Nb, Li, Sn. Перспективними є також рідкіснометально-легматитові руди з підвищеним вмістом Li, Ta, Nb, а також грейзеново-кварцеві прояви Nb, W, а також золоторудні об’єкти з підвищеним вмістом рідкісних елементів. Встановлено зв’язок гранітідів з мінералізацією рідкісних металів з рудними об’єктами.

Практична значимість. Отримані дані можуть бути використані при проведенні прогнозу та пошуку рудових об’єктів з рідкісними металами.

Ключові слова: магматизм, рудові об’єкти, рідкісні метали, Калба-Наримський гранітоїдний пояс, Казахстан, ресурси

Геохимическая характеристика и металлогения герцинских гранитоидных комплексов (Восточный Казахстан)

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Цель. Выведение закономерностей формирования и пространственного распределения новых нетрадиционных видов минерализации редких металлов, разработка критериев прогнозирования и поиска, оценка перспектив в качестве дополнительного резерва для укрепления и развития минерально-сырьевой базы Восточного Казахстана.

Методика. Методами ICP MS в Центре опережающего развития ВКГУТ имени Д. Серикбаева изучены традиционные и нетрадиционные месторождения и проявления редкометального оруденения в пределах За-падной Калбы и Рудного Алтая, магматит редкометального Калба-Нарымского гранитоидного пояса. Проведено изучение химического состава магматитов ряда интрузивных комплексов, установлена связь гранитов с месторождениями и проявлениями редких металлов. Методами сканирующей электронной микроскопии (JSM 6390LV) проведена сравнительная характеристика рудной минерализации изучаемых месторождений.

Результаты. В пределах пермского гранитоидного Калба-Нарымского пояса (Восточный Казахстан) выделены магматические комплексы, перспективные на различные типы редкометального оруденения, сделаны выводы о связи потенциальной рудоносности с определенными формационными типами гранитов.

Научная новизна. Установлено, что наряду с традиционным редкометальным типом в пределах Калбы-Нарымского гранитоидного пояса обнаружены внепегматовые нетрадиционные проявления редкометальной минерализации Nb, Li, Sn. Перспективными являются также редкометально-легматитовые руды с повышенным содержанием Li, Ta, Nb, а также грейзеново-кварцевые проявления Sn, W, а также золоторудные объекты с повышенным содержанием редких элементов. Установлены повышенные содержания редких металлов и редких элементов в рудах золоторудных месторождений За-падной Калбы и Рудного Алтая.

Практическая значимость. Полученные данные могут быть использованы при проведении прогноза и поисков месторождений редких металлов и комплексных золоторудных объектов.

Ключевые слова: герцинский магматизм, месторождения, редкие металлы, Калба-Нарымский редкометальный пояс, Казахстан, ресурсы

Recommended for publication by Ye. M. Saparaliev, Doctor of Geological and Mineralogical Sciences. The manuscript was submitted 12.04.19.