Postorogenic Granitoids of the Polousny Range (North-East of the Verkhoyansk-Kolyma Orogenic Region)

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Abstract. The article considers the petrology of postorogenic Albian subvolcanic granites of the North-Elikchan and Upper-Elikchan massifs of the South-eastern part of the Polousny synclinorium, which involved Au-Ag and Sn-W mineralization. Structural and textural features of magmatic rocks indicate a multievent pulsation intrusion of a granite melt. Typomorphic features of minerals of the rocks: the presence in rhyolite and granite porphyry of restites of pyroxenes, identical to pyroxenes of derivatives of basite - hyperbasite associations, chromium-containing native iron, zircons of crust-mantle morphotypes D and J, and the presence of globules of rhyolite composition in the matrix of dikes of trachidolerites formed after subvolcanic granites, indicate the interaction of crustal granite melt and alkaline-basic mantle melt in the process of evolution of magmatism. Crystallization of the granite melt at the early magmatic stage under conditions of high activity of oxygen, water and chlorine caused the formation of Au-Ag ore occurrences. During the late-magmatic stage, the crystallization proceeded from water-saturated melt under conditions favorable for the formation of rare-metal mineralization with the leading part of the borum. Subvolcanic and host rocks are transformed into quartz-tourmaline greisen with topaz and fluorite, tourmaline-containing exogreisens and tourmalinites, and are penetrated by quartz veins with cassiterite, wolframite, and arsenopyrite. The sharp increase of the borum content is presumably related to the supply of volatiles from an external mantle source.

1. Introduction
Granitoid magmatism in the North-east of the Verkhoyansk-Kolyma Mesozoids occurred throughout the Phanerozoic. The most common and most studied are the Early Cretaceous collision granitoids that form belts of large plutons, bordering the Kolyma-Omolon microcontinent. Late-and postorogenic Aptian-Albian granitoids were studied in detail just in recent decades [1, 2]. Meanwhile, according to geological surveys and exploratory work, these formations are associated with ore occurrences of rare and dispersed elements. Therefore, understanding their specific features and crystallization conditions leading to the generation of mineralization is not only of theoretical but also practical interest. The objects of research, which results are presented in this paper, were subvolcanic massifs of granitoids of the Elikchan ore-magmatic field, localized within the North-eastern branch of the Northern batholith belt.
2. Research methodology
The research was based on the principle of complexity, that is, the study of multifaceted features of specific objects. Petrography of rocks was studied and on this basis, the conclusion about the conditions of crystallization and ways of evolution of melts was made. Complete silicate and spectral quantitative analyses of rocks were performed. The compositions of rock-forming and accessory minerals were determined using the Camebax-micro x-ray microanalyzer. The results of the analyses were processed with the use of modern methods (CGDkit, Igpet, etc.), which allowed us to obtain genetic information and identify the potential ore content of the studied granitoids.

3. Research results
3.1. Geological structure of the territory
A large area Elikchan ore-magmatic field consists of the same name granodiorite-granite massif (Figure 1). Rb-Sr isochronous age of massif granodiorites – 134+/−2 Ma, biotite granites – 122+/−1.4 Ma, pegmatite– 116+/−2 Ma. The host rocks are represented by the Jurassic terrigenous formations with a total thickness of up to 5 km.

Figure 1. Geologic map of the Elikchan and Istekh ore fields [3]
1 – Quaternary deposits (Q); 2-4 – Cretaceous system: 2 – upper series: volcanic formations of the medium middle composition; 3 – upper series: rhyolites, their tuffs and tuff lavas (K2); 4 – lower series: dacites, indesidacites, andesites and their tuffs, tuffstones and tuff siltstones K2; 5–7 – Jurassic system: 5 – upper series: polymictic sandstones, siltstones and claystones (J3); 6 – middle series: polymictic sandstones, siltstones and claystones (J3); 7 – lower series: calcareous sandstones, claystones and siltstones); 8–9 – Late Cretaceous dikes: 8 – trachyandesites, and trachydolerites (βµK2); 9 – rhyolite porphyry (λπK3); 10 – dikes of aplite and pegmatites (ιK1) and stocks of leucogranites (ιγK1); 11 – granites (γK1); 12 – granite porphyry (γπK1); 13 – granodiorites (γδK1); 14 – dikes of quartz diorites (qδK1); 15 – of Late Jurassic dikes of gabbro – diabases (νβJ3) and stocks and small bodies of gabbro (νJ3); 16 – stratigraphic and intrusive contacts; 17 – tectonic contact and faults; 18–21 – ore occurrences: 18 – gold; 19 – tin; 20 – tungsten; 21 – tin deposits. The massifs of granitoids: E – Elikchan, NE – North Elikchan massif, UE – Upper Elikchan massif.
At the beginning of the Early Cretaceous, the formation of the massif was preceded by subaerial flows of lavas of variegated composition with parameters of volcanic rocks of active continental margins [4]. Lava flows and crack intrusions continued after the formation of granitoids. During this magmatic stage, the Upper-Elikchan and North-Elikchan subvolcanic massifs of alkaline-feldspar leucogranites were formed, which are associated with Au-Ag and tin ore-occurrences of the cassiterite-tourmaline type and a series of dykes of rhyolite and granite porphyry with Rb-Sr isotopic age of 102-104 Ma. Magmatic activity within the territory is completed by the intrusion of trachidolerite dikes with an isotopic Rb-Sr age of 92-79 Ma. Thus, the conditions of increased permeability in the studied territory were preserved at least throughout the Cretaceous.

In subvolcanic massifs of the installed stations areas and fractured granite greysenization with tourmaline, topaz, fluorite, cassiterite and tantalum-niobates. Subvolcanic endocontact zones of massifs acquired breccia-taxite structure as a result of superimposed tectonic processes and experienced repeated metasomatic transformation into fine-grained greisens and kaolinite-muscovite-quartz metasomatites. Dikes of granite and rhyolite porphyry are almost completely transformed into muscovite-quartz or tourmaline-muscovite-quartz greisens and contain nest-veinlet inclusions of tin-bearing sulfides.

3.2. Petrography and mineralogy of granitoids.

The North-Elikchan massif is a fractured body with an outcrop area of about 10 km², extended in a North-eastern direction. The Upper Elikchan massif has an unusual form of outcrop with an area of about 10 km² with bays and apophyses into the host rocks. It contains large blocks of granodiorites and granites of the Elikchan massif. In the Northern extremity of the upper Elikchansky massif, two shtokverkovy quartz zones (30-50 m across) are marked, in which leucogranites and rhyolite porphyry are permeated by a dense network of veins and lenses of quartz up to 2 m thick. quartz includes large blocks of feldspar and small nests of tourmaline with cassiterite. The main facies of subvolcanic massifs are presented by pegmatoid and leucocratic granites. Heterogranular fabric with hypidiomorphic-granular and xenomorphic-granular structure prevails. The closer to the contact, the structure is replaced by a serial-porphyry structure with the transition to granite-and rhyolite-porphyry. Among the porphyry inclusions, along with quartz, mica and feldspar, there are comparable grains of topaz, apatite, zonal zircon and rare grains of amphibole. The groundmass is microxenomorphic-granular, micropoikilitic, spherulitic, felsitic, and occasionally granophyric. The contact areas often record eruptive breccias. They, in turn, are significantly cataclasized and are intruded by dikes of rhyolite porphyry with felsitic and granophyric groundmass. The character of porphyry phenocrysts in them is identical to that in subvolcanic massifs.

Plagioclase of the rocks is represented by non-zonal oligoclase and albite, and in the porphyritic differences – indistinctly zoned oligoclase and albite (26–5% an) and contains rare inclusions of high orthoclase. K-feldspar – high and intermediate orthoclase (2V Np=32–68°). In the phenocrysts it is zonal and contains inclusions of oligoclase (12-16% an) and the magnesian augite. The latter is characterized by an increased content of alkalis (up to 7.3% of the aegirine molecule) and low mafic index f = 13-21%. It is close in composition to clinopyroxenes of derivatives of basite-hyperbasite associations of increased alkalinity [5]. Amphibole of porphyry phenocrysts has a composition of magnesian hornblende with f = 33-40%. It is characterized by a high content of alkalis (1.2–2.4%), low content of halogens (0.2–0.5%) and crystallized at high oxygen activity and water content in the melt up to 7.7%, decreasing to 3.3 % with pressure drop (calculations based on [6]). Its high content of alkalis is comparable to amphiboles of syenites and alkaline-basic rocks [7].

Biotite rarely forms porphyry phenocrysts, it often occurs in the fine-grained matrix of rocks. Early generation is moderately ferruginous (f = 47-59. 1%), it crystallized from the water-unsaturated melt at a temperature of 750-800°C with relatively high oxygen activity and high water and chlorine
activity, that is, under conditions similar to those of gold-bearing ore-magmatic systems [8] (Table 1). Considering the parameters of the composition the late generation corresponds to biotites of derivatives of the crust-mantle melts (Figure 2). As the temperature decreased, the mafic index of biotite rapidly increased with the transition to lepidomelane and siderophyllite, along with a drop in the activity of oxygen and chlorine. According to the composition parameters, it corresponds to the biotites of the shoshonite series or A-type granites and crystallized already from a volatile-saturated derivatives of the crust-mantle melts (Figure 2). As the temperature decreased, the mafic index of biotite rapidly increased with the transition to lepidomelane and siderophyllite, along with a drop in the activity of oxygen and chlorine. According to the composition parameters, it corresponds to the biotites of the shoshonite series or A-type granites and crystallized already from a volatile-saturated melt. Biotite is intensively replaced by chlorite, in which fine-scale accumulations are confined to small crystals of cassiterite and nests of sulfides.

### Table 1. The representative compositions of biotite magmatic rocks

| Oxides, % | T731/4 | T721/1 | T720/5 | O267/4 | T728/1 | T725/1 |
|-----------|--------|--------|--------|--------|--------|--------|
| SiO₂      | 35.48  | 35.41  | 36.22  | 35.33  | 36.91  | 36.61  |
| TiO₂      | 3.71   | 2.99   | 5.44   | 3.40   | 3.86   | 4.17   |
| Al₂O₃     | 14.34  | 13.72  | 13.28  | 14.73  | 12.66  | 13.14  |
| Cr₂O₃     | 0.05   | 0.08   | 0.03   | 0.00   | 0.02   | 0.02   |
| Fe₂O₃     | 2.48   | 3.05   | 1.88   | 2.52   | 2.61   | 2.26   |
| FeO       | 23.14  | 23.41  | 20.33  | 22.67  | 20.48  | 20.05  |
| MnO       | 0.36   | 0.39   | 0.44   | 0.47   | 0.60   | 0.68   |
| MgO       | 6.38   | 6.22   | 8.33   | 6.35   | 9.21   | 8.58   |
| CaO       | 0.21   | 0.08   | 0.03   | 0.11   | 0.16   | 0.10   |
| Na₂O      | 0.11   | 0.04   | 0.31   | 0.14   | 0.11   | 0.16   |
| K₂O       | 9.76   | 9.71   | 9.39   | 9.57   | 9.51   | 9.42   |
| Cl        | 0.77   | 0.39   | 0.91   | 0.75   | 1.62   | 0.41   |
| F         | 0.43   | 0.35   | 0.31   | 0.46   | 0.63   | 1.23   |
| H₂O⁺      | 2.85   | 3.47   | 2.64   | 3.35   | 3.34   | 3.91   |
| Total     | 100.07 | 99.74  | 99.59  | 99.88  | 101.73 | 100.74 |
| F         | 69.1   | 70.2   | 59.7   | 68.8   | 57.9   | 59.1   |
| T°C       | 695    | 663    | 754    | 685    | 709    | 700    |
| P, kbar   | 135    | 108    | 15.75  | 0.77   | 1.56   | 1.29   |
| log fO₂   | -166   | -166   | -16   | -0.5   | -1.57  | -1.66  |
| log fH₂O  | -2.5   | 2.28   | 2.75   | 2.78   | 2.36   | 3.00   |
| log fHCl  | -1.26  | -1.3   | -0.91  | -1.35  | -0.89  | -0.58  |
| log fH₂O² | 195    | 206    | 299    | 1.84   | 291    | 23     |
| H₂O*, %   | 6      | 7      | 3.5    | 6      | 5      | 6      |
| mineral   | Fe-biotite | siderophyllite | Fe-biotite | siderophyllite | Mg-biotite | Fe-biotite |

**Notes:** T731/4 – pegmatite, T721/1 – leucogranite, T720/5 – granite-porphyry, O267/4 – leucogranite, T728/1 – granite-porphyry, T725/1 – rhyolite-porphyry. Calculations by: T°C [9], by P [10]; log fO₂ [11]; log fH₂O, log fHCl and log fH₂O² – water content in the melt [13].

The complex of accessory minerals includes magnetite, ilmenite, sphene, orthite, zircon, garnet, F-apatite, rutile, pyrrhotite. Zonal zircon with a ZrO₂/HfO₂ value of 70-80, corresponding to that in the zircons of the basic rocks, up to 17-20 on the periphery. High-temperature (mantle-crustal by [14]) morphotypes D, J3-5 predominate. In rhyolite porphyry and granophyry, chromium-containing (up to 5% Cr) native iron is found. Intensely corroded restite grains of subcalcic magneizoaugite and calcicmagnesian pygeonite with calculated crystallization parameters: T = 1123oC and 1247oC, P = 16.1 and 15.5 kbar, typical for pyroxenes of derivatives of basite-hyperbasite associationa, and
ferruginous tschermakite - a typical mineral of lower-crustal amphibolites are found in crushed samples of granite-porphyry and rhyolite-porphyry [1].

![Figure 2](image)

**Figure 2.** The parameters of biotite composition in North-Elikchan (1) and the Upper-Elikchan (2) massifs

a) P–T-diagram of the granite-water system for independent P_{total} and PH_{2O} [13].

b) Ratios F/OH and Mg/Fe in biotites of magmatic rocks. Fields of biotite compositions [15] – biotite of derived melts: I – formed by contamination and assimilation of sub-sea meta sediments; II – mantle; III – cow-mantle; IV – mantle-crustal; V – crustal anatectic

c) The ratio of fluorinity (OH/F), aluminous (al) and ferruginous (f) biotites. Fields of the diagram-biotite of standard types of granitoids [16]: I- mantle-crustal island arcs, M-mantle, S-crustal and mantle-crustal collisional environments, SH- post-collisional shoshonite, A – anorogenic environments.

### 3.3. Petrochemistry and geochemistry of granitoids

Rocks of the subvolcanic massifs and dykes fractured bodies of rhyolite composition also belong to the most potassium granitoids of the territory and have high and extremely high aluminosity and mafic index. (Figure 3, Table 2). According to all petro- and geochemical parameters, the rocks correspond to postorogenic or riftogenic granites, near the granite of A-type (Figure 3, Table 2, 3). On the diagram of L.S. Borodin (Figure 3d) the points of their compositions indicate a trend that cuts through the trends of standard evolution, which is typical for granitoids of crust-mantle origin and, in particular, for A-type granites of the Upper-Kolyma Mesozooids [1]. In accordance with this, the estimated melt temperature is defined at 960–1030°C, and the maximum pressure during magmogeneration is 0.9–1.1 GPA.

According to the distribution of trace elements, the considered rocks occupy an intermediate position between the palingenic granitoids of the calcic-alkaline series and the granitoids of the latite series (Table 3). The content of Ba and Sr in them is closer to the first, and the of ore elements is closer to the second. The values of La/Yb (19–54) correspond to those in the granitoids of the latite series [17]. The studied rocks, as well as other magmatic formations of the ore field, are geochemically specialized in Bi, Sb, Ag, Mo, less- in Sn and W. they also have increased Cr and Ni contents. Au concentrations are low, but the crystallization parameters at the early magmatic stage are close to those prospective for gold of the ore-magmatic systems, what caused the formation of Au-Ag manifestations. At the late magmatic stage, the melt becomes fluid-saturated, which is good for the origin of rare metal occurrences. According to the (Li+Rb) – F – (Ba+Sr) ratios, they belong to highly ore-bearing formations (Figure 3e). Probably, the main role as a formation of complexes belonged to borum, as indicated by the transformation of dikes and host rocks into tourmaline-containing greisens and tourmalinites.
Figure 3. Parameters of the chemical composition of North-Elikchan (1) and the Upper-Elikchan (2) massifs

a) SiO₂ – (Na₂O+K₂O) ratio in granites. Diagram fields [18]: I – granites; II – alkaline granites, III – granosyenites and quartz syenites.

b) alumina content of granitoids. Diagram fields, granitoids [19]: IAG – island – arc, CAG – continental arcs, CCG-continental collision, POG-postorogenic, CEUG-continental epeirogenic uplift, RRG-riftogenic.

c) The ratio of Sr – Rb/Sr in granites. Trends of differentiation of typical series [20]: I-tholeiitic series of island arcs, II-calcareous-alkaline series of island arcs, III- calcareous-alkaline series of active margins, IV-series of rift zones of continents; I, S, A-petrotypes of granitoids.

d) Magmatic series of granites. Symbols [21]: As-cation activity; trends of evolution: CAI-calcareous low-alkaline (island-arc), CA-calcareous-alkaline (crustal), HKO-high-potassium (orogenic), L-latite, T-trachite.

e) (Li+Rb) – F – (Ba+Sr) ratios in the rocks of North-Elikchan (1) and Upper-Elikchan (2) massifs. Diagram fields [22]: I – non-ore-bearing, II – limited ore-bearing, III – high-ore-bearing granitoids.
Table 2. Chemical composition of postorogenic granites

| Massif            | North Elikchan | Upper Elikchan | dykes |
|-------------------|----------------|----------------|-------|
|                    | O260 O258 T720 T730 T722 T720 T721 O260 T638 T638 T642 O195 T637 T725 T706 O214 | | |
| Oxides, %         | 7 7 7 3 5 1 5 3 7 5 1 5 | 7 3 19 | |
| SiO₂              | 71.48 73.48 73.62 73.90 70.74 74.68 75.72 77.30 | 71.18 74.37 74.36 74.36 75.04 75.52 | 73.26 75.52 |
| TiO₂              | 0.17 0.13 0.12 0.11 0.25 0.13 0.03 0.15 | 0.32 0.18 0.09 0.15 0.21 0.18 | 0.15 0.10 |
| Al₂O₃             | 13.79 13.54 13.18 12.93 13.99 13.53 13.33 12.60 | 15.71 13.74 11.93 13.18 13.62 13.53 | 14.19 12.94 |
| FeO               | 1.04 1.13 0.13 0.76 0.01 1.17 0.28 0.59 | 1.46 1.08 1.36 0.85 0.01 0.70 | 1.28 0.32 |
| MnO               | 0.04 0.02 0.05 0.02 0.06 0.04 0.02 0.03 | 0.03 0.02 0.16 0.08 0.06 0.05 | 0.07 0.08 |
| MgO               | 0.28 0.24 0.13 0.04 0.42 0.07 0.03 0.50 | 0.18 0.13 0.05 0.22 0.32 0.10 | 0.21 0.13 |
| CaO               | 0.70 0.35 0.70 0.77 1.54 0.31 0.27 0.50 | 0.06 0.17 0.28 0.47 0.01 0.01 | 0.28 0.30 |
| Na₂O              | 3.46 3.46 3.56 2.74 3.24 3.13 3.34 2.60 | 3.49 2.56 0.58 3.17 1.35 0.82 | 1.30 2.74 |
| K₂O               | 5.24 5.40 4.80 5.68 5.00 5.06 5.74 4.38 | 5.05 5.56 8.52 5.40 5.87 4.99 | 5.46 5.40 |
| H₂O               | 0.27 0.27 0.14 0.37 0.27 0.29 0.23 n/d | 0.30 0.30 0.12 0.10 n/d 0.24 | 0.09 0.16 |
| FeO+Mg            | 1.73 1.16 0.42 0.74 0.78 0.78 0.80 1.31 | 0.54 0.54 1.53 0.40 0.80 0.91 | 2.05 0.84 |
| P₂O₅              | 0.05 0.05 0.02 0.02 0.08 0.02 0.03 0.02 | 0.04 0.03 0.02 n/d 0.03 0.04 | 0.11 n/d |
| CO₂               | 0.27 0.27 0.15 0.81 0 0 0 | 0.27 0 0.66 0 0 0 | 0.15 0.27 |
| F                 | 0.06 0.03 0.20 0.01 0.04 0.10 0.13 0.04 | 0.08 0.08 0.03 0.10 0.14 0.15 | 0.04 0.03 |
| Li₂O              | 0.005 0.003 0.004 0.005 0.001 0.0035 0.014 0.004 | 0.001 0.001 0.003 0.005 0.006 0.0062 | 0.003 0.002 |
| Rb₂O              | 0.013 0.014 0.0221 0.02 0.026 0.0228 0.13 0.017 | 0.0216 0.0216 0.043 0.0139 0.0210 0.0187 | 0.016 0.0207 |
| S                 | n/d 0.10 0.02 0.10 0.10 n/d 0.01 0.10 | 0.01 0.01 0.10 0.03 0.18 0.01 | 0.05 0.01 |
| Total             | 99.77 100.4 98.74 98.89 99.57 99.83 100.16 101.0 | 98.51 99.34 99.93 99.58 99.68 99.02 | 98.91 99.84 |
| Fe/Fe+Mg          | 90.1 90.9 92.4 97.6 85.5 97.0 97.2 74.3 | 92.3 89.7 96.9 90.0 86.3 96.4 | 88.2 91.8 |
| T°C               | 975 971 944 936 1003 950 692 972 | 1011 980 921 967 993 981 | 960 925 |
| P, IIa             | 6.4 5.4 4.8 4.5 7 4.7 4.4 2.3 | 8.6 5.1 3.8 4.6 4.5 3.7 | 5.2 3.8 |

Notes: The analyzes were performed at IGABM SB RAS – analysts of D. A. Kulagina, G. N. Okhlopkova, S.E. Diakonova: n/d – the content was not defined. Calculation T°C – [23], P kb – [24].

4. Discussion of results

The studied magmatic rocks are confined to the zones of the intersection of the regional fault. By most parameters of the composition, the rocks that compose them are close to the A-type granitoids. Rhyolite and granite porphyry contains pyroxene restites, identical to pyroxenes of derivatives of basite - hyperbasite associations, chromium-containing native iron, zircons of crust-mantle morphotypes. The matrix of trachydolerite contain rhyolite globules. These data indicate the interaction of crustal granite and alkaline-basic mantle melts during the in the process of magmageneration. The geochemical specialization in Bi, Sb, As, Ag, Mo, W, B was identified for all rocks of the ore-magmatic field with the maximum enrichment of the most silicic rocks with Cr and Ni. This geochemical specificity of magmatic rocks is also a direct sign of the interaction of multi-level melts at all stages of the formation of the Elikchan field magmatism.

Crystallization of the granite melt at the early magmatic stage took place with increased activity of oxygen, water, and chlorine, which could ensure the formation of Al-Ag occurrences within subvolcanic massifs and their exocontacts. Geochemical specialization in Bi, Sb, and As caused the complexity of these ore occurrences. At the late magmatic stage, rocks were crystallized from watersaturated melts. Due to intensive tectonic movements, fluid-saturated granite reservoirs were broken and eruptive, which is a sign of high ore content. They correspond to magmatic systems highly
prospective for rare metal mineralization. This is confirmed by the ratios in these rocks (Li+Rb) – F – (Ba+Sr) (Figure 3e).

Table 3. Average trace element content of magmatic rocks of Elikchan ore-magmatic field

| Massiv          | Elikchan | Upper Elikchan | North Elikchan | volcanic covers | dykes      | Clarse for granites [25] |
|-----------------|----------|----------------|---------------|-----------------|------------|-------------------------|
|                 | granodiotites | granites      | granite-porphry and rhyolite-porphry | rhyolites | trachyandesites | trachydolerites |
| N               | n=11     | n=8            | n=8           | n=8             | n=11       | n=3                     | n=3          |
| B               | 28       | 32             | 33            | 26              | 38         | 51                      | 42           | 12.5          |
| Li              | 38       | 51             | 28            | 17              | 40         | 38                      | 28           | 37            |
| Rb              | 178      | 153            | 298           | 198             | 180        | 120                     | 119          | 180           |
| Sn              | 5.3      | 5.1            | 8             | 10.6            | 18         | 4.8                     | 18.8         | 3             |
| W               | 15       | 11             | 8             | 6.6             | 8          | 2.3                     | 3            | 2.2           |
| Mo              | 6.2      | 7              | 4.4           | 5.4             | 5.6        | 3.3                     | 1.3          | 1.5           |
| Zn              | 100      | 104            | 100           | 105             | 42         | 110                     | 144          | 39            |
| As              | 43       | 27             | 48            | 58              | 35         | 36                      | 58           | 1.6           |
| Pb              | 33       | 30             | 30            | 40              | 16         | 45                      | 30           | 19            |
| Bi              | 0.8      | 0.6            | 0.9           | 1.1             | 0.9        | 0.45                    | 0.5          | 0.01          |
| Sb              | 4.8      | 8.2            | 9             | 9.2             | 9.2        | 2.6                     | 10           | 0.2           |
| Ag              | 0.35     | 0.1            | 0.11          | 0.22            | 0.11       | 0.27                    | 0.2          | 0.038         |
| Au              | 1.3      | 1              | 1.8           | 2.4             | 2          | 2                      | 10           | 2.7           |
| Cu              | 15       | 14.1           | 15            | 47              | 15         | 12                      | 36           | 10            |
| Zr              | 263      | 195            | 150           | 126             | 120        | 120                     | 180          |                |
| Th              | 23       | 29             | 14            | 10              | 17         | 17                      | 18           |                |
| U               | 5.6      | 4.4            | 3.1           | 2.8             | 5.6        | 3.9                     | 3.9          |                |
| Ba              | 1252     | 935            | 577           | 490             | 1500       | 700                     | 1800         | 750           |
| Sr              | 884      | 270            | 151           | 106             | 120        | 120                     | 700          | 150           |
| Co              | 12.5     | 5.5            | 3.2           | 4.7             | 0.8        | 8.4                     | 9            | 1             |
| Ni              | 29       | 20.3           | 14            | 9.4             | 10         | 12                      | 10           | 3.5           |
| V               | 92       | 41.3           | 9             | 10.1            | 88         | 210                     | 25           | 38            |
| Cr              | 24       | 24             | 51            | 97              | 16         | 92                      | 75           | 5.6           |

Notes: n – number of samples. * Calculations of average Au and Ag contents based on neutron activation analysis, Li based on silicate analysis, and other trace elements based on ISP-MS analysis.

These processes and subsequent metasomatism caused the formation of Sn-W ore occurrences. Subvolcanic and host rocks are intensively greisenized and penetrated with quartz veins with cassiterite, wolframite and arsenopyrite. At the same time, the leading role in a complex formation belonged to borum, as indicated by the transformation of host rocks into tourmaline-containing exogreisens and tourmalinites. The sharp increase in borum content can only be related to the supply of volatiles from an external source, since both the rocks of subvolcanic massifs and the granitoids preceding them contain only twice the amount of borum. The development of magmatism of the ore field is completed by dikes of trachidolerites of the shoshonite series of alkalinity and geochemical type of latites. Taking into account the maximum enrichment of these rocks with Li, Rb, B, F compared to other magmatic formations, it is logical to consider the magmatic melt (the rocks are derivatives of this melt), as an additional source of heat and volatiles in the formation of complex mineralization of the studied ore-magmatic systems.
5. Conclusions
Considering parameters of the content, postorogenic subvolcanic granites of the Polousny synclinorium are closest to the granites of A-type. Typomorphism of rock-forming, accessory, and restite minerals indicate mantle-crustal interaction in the process of generation of granite melt. Rocks are characterized by geochemical specialization in a wide range of ore elements, which is typical for granites of the latite series of mantle-crustal origin and involves Au-Ag and Sn-W mineralization. The sharp supply of boron at the late post-magmatic stage is presumably related to its income from an external mantle source.

Acknowledgements
The author is grateful to all the employees who participated in the analytical work, as well as to A. I. Ivanov and M. S. Ivanov for their help in the design of the graphics. The work was performed according to the state task of IGABM SB RAS.

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