Geochemical features of the compositions of the Mesozoic igneous rocks of the Khokhoi ore field (Upper Amga gold-mining district, Aldan shield, North Asian Craton)

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Abstract. The article considers features of geochemical composition of the Mesozoic igneous rocks of the Khokhoi ore field, spatially located in the Upper-Amga gold-mining district of the north-western part of the Aldan-Stanovoy shield, at the junction of two large structural units - the Olekma granite-greenstone region and the Aldan granulite-gneiss area, in the zone of meridional deep Amga fault. Magmatic formations are represented by the Northern Boskho, Western Boskho and Upper Khokhoi massifs of the Lebedinsky monzonite-syenite-granite complex, intruding rocks of the crystalline basement and terrigenous-carbonate complex of the Siberian platform cover, and by rare tephrite dikes. Due to the accessibility of the study area, little attention was focused on the mentioned igneous rocks until recently. The study showed that magmatic formations of the ore field are geochemically specialized in lithophile and siderophile elements, and they belong to derivatives of trachy-andesite and andesi-basalt magma. All studied rocks have sufficiently close spectra of rare-earth element distribution, in particular, the rocks are poor in heavy rare-earth elements relative to light rare-earth elements. Presence of low negative Eu-anomaly for the Northern Boskho and Upper Boskho massifs may indicate the fact that they were formed from residual differentiates during fraction crystallization of rock-forming minerals with the involvement of plagioclases. Low Eu/Eu* values also indicate the fact that these rocks were formed during the late stage of the area evolution. Negative niobium anomaly, identified for all igneous rocks of the ore field, indicates magma contamination with continental crust. Considering interpretation of rare-earth elements and their ratio, it was supposed that igneous rocks of the ore field were formed in intracontinental conditions. It was generally concluded that there was an intensive mantle-crust interaction throughout the magmatism evolution of the Khokhoi ore field, beginning from intrusion of tephrite dikes bodies to intrusion of syenite rocks. The presence of long-lived mantle source, as well as contamination with crust material, was responsible for heat and fluid inflow that supplied circulation of thermal spring in the system. Heat and fluids caused additional mobilization of ore material from surrounding rocks, with further formation of gold-sulfide mineralization close to tephrite dikes and the Northern Boskho massif.
1. Introduction
The Upper Amga gold mining district is located in the north-western part of the Aldan-Stanovoy shield, at the junction of two large structures - the Okekma granite-greenstone region and the Aldan granulite-gneiss area, in the zone of meridional deep Amga fault [1]. Numerous alkaline and subalkaline magmatic formations of the Lebedinsky monzonite-syenite-granite complex of this area are associated with the Mesozoic tectono-magmatic activation of the Aldan shield [1]. The greater part of intrusions is confined to the periphery of the Yamalakh horst, to the contact of the crystalline basement and terrigenous-carbonate deposits. Magmatic formations have different forms (laccoliths, laccolith-like deposits, stock-like, stratal bodies and dikes) and are localized in a relatively narrow zone of the north-eastern submeridional strike, and are isolated as separate Upper Amga magmatic cluster, which records the Khokhoy ore field.

Mineralization of the Khokhoy field of the kuranakh type is localized in linear karst zones on the contact of the Early Cambrian carbonate and the early Jurassic terrigenous strata of sedimentary cover of the platform, confined to submeridional high-angle faults [2]. Ores consist of sandy-loam material, saturated with disseminated goethite-hydrogoethite, with fragments of oxidized primary ores – pyrite-adularia-quartz metasomatites. Geochemical associations of the elements in these ores - Au, Ag, Sb, Tl. Typomorphic minerals – quartz, adularia, calcite, fluorite, barite, goethite, hematite, pyrite, native gold, galena, berthierite, hollandite, tellurites and antimonates. Native gold has a high fineness, porous structure. Two stages of mineralization origin are identified: primary ores were formed in the Early Cretaceous as a result of silicon-potassium metasomatism of the Cambrian carbonate rocks, occurred due to the Mesozoic tectono-magmatic activation; at the second stage – oxidation and disintegration of primary ores with the formation of karst zones took place in the Neogene and Quaternary.

Within the territory of ore field, the Mesozoic alkaline massifs Northern Boskho, Western Boskho and Upper Khokhoy are exposed (figure 1), which until now has not been given attention. Obtained data, in general, will help to form a clear picture of specific features of compositions of igneous rocks of the Khokhoy ore field, formation conditions, and their metallogenic specialization.

2. Methods
In the construction of the rare-earth element distribution diagram, chondrite normalization was performed. Normalized values are shown as ratios of element concentration in the studied samples to concentrations in chondrite standard [3]. Eu/Eu* = EuN/[SmN x GdN]1/2 ratio was for characteristics of europium anomalies, i.e. ratio of the measured value to the expected value, where EuN, SmN and GdN – normalized values of these elements to chondrite [4]. Geochemical composition and rare-earth element content in igneous rocks are given in g/t. Analyses of rocks, studied in the article, are given as tables and are compatible with real contents.
Figure 1A. Tectonic diagram of the Aldan shield [1]. Legend: 1 – granite-greenstone terrains (WA – Weast-Aldan, BT – Batomgsky); 2 – granulite-orthogneiss terrains (NM – Nimnyrsky, CG – Chogarsky); 3 – granulite-paragneiss terrains (AST – Sutamsky, Uch – Uchursky); 4 – Tonalite-trondhjemite-gneiss terrains (TN – Tyndinsky); 5 – Zones of tectonic mélange (am – Amga, kl – Kalar, tr – Tyrkandin); 6 – linking Early Proterozoic granites; 7 – Siberian platform cover; 8 – faults (dj – Dzheltula, ts – Taksakandin). Figure 1B. Geologic map of the central part of the Khokhoy ore field. Legend: 1 – alluvial deposits. 2 – Monzonite-syenite-granite Lebedinsky plutonic complex. Laccoliths, laccolith-like zones, stocks, stratal bodies of aegirine-augite, hornblende-pyroxene, hornblende syenites, syenite-porphry, biotite-augite syenites. Laccolith-like zones and stocks of syeno-diorites, monzonites, microsyenites. 3 – formation. Sandstones inequigranular, oligomictic, lenses and intercalations of gritstones, conglomerates, siltstones. 4 – Ungelinskaya formation undissected. Light-grey and yellowish-grey dolomites with intercalations of variegated marlstones and marlaceous dolomites. 5 – Tumuldurskaya formation. Upper subformation. Grey and light-grey dolomites with nodules and lenses of cherts, with rare intercalations of marlaceous dolomites. 6 – Tumuldurskaya formation. Lower subformation. Light-grey, cream-colored and grey dolomites. At the top – stromatolite dolomite limestone bed. 7 – Pestrotsvetnaya formation. Reddish-brown and greenish-grey marlstones and marlaceous dolomites. 8 – Ust-yudomskaya formation. Upper subformation. Grey, dark-grey bituminous dolomites with thin intercalations of marlaceous dolomites. 9 – Kurumkanskaya formation. Quartzites with bands of gneisses and crystalline schists. 10 – Principal faults, 11 – Second-order faults.
3. Features of geochemical composition of igneous rocks of the Khokhoy ore field

Syenite-porphry of the Northern Boskho massif[5] are geochemically specialized in B, Ba, Ca, Cr, Mg, Mn, Na, Nb, Rh, Sc, Sr, Ti, V, Zr (table 1), i.e. in lithophile elements, which contain significantly less chalcophile Cu, Ga, Sn, Zn Pb as well as siderophile Fe, Ni, Co elements. Considering content of Rb (105.3-115.2 g/t), Sr (640-1200 g/t), Sn (<5 g/t), Zn (<100 g/t), Co (up to 3 g/t), the massif rocks are close to derivatives of trachy-andesite (latite) magma [6]. Abnormally high concentrations of Ba (1900-2800 g/t), Cr (up to 380 g/t) in them may indicate limited fractionation of the latter. [7]. K/Rb=421.2-481.4, Rb/Sr=0.10-0.12 ratios and K/Rb-Rb, Sr-Rb/Sr ratios [8] (figure 2A,B) in the massif syenites are typical for rocks, formed from mantle source [4], [9].

![Figure 2A](image1.png)

**Figure 2A.** K/Rb-Rb ratio in igneous rocks of the Khokhoy ore field: diagram fields [8]: formations I - mantle, III – mantle-crust. Rock symbols: 1. – Northern Boskho; 2 – Western Boskho; 3 – Upper Khokhoy; 4 – Tephrite dikes. **Figure 2B.** Sr-Rb/Sr ratio in igneous rocks of the Khokhoy ore field: diagram fields [8]: formations I - mantle, II – crust, III – mantle-crust

Monzonites of the Western Boskho massif[5] in comparison with syenites of the Northern Boskho massif are characterized by lower values of lithophile and insignificantly higher contents of siderophile elements (table 1). Considering content of Rb (84.6-90 g/t), Zr (94-120 g/t), Nb (<8 g/t), syenites of the massif are close as possible to derivatives of andesi-basalt magma, and considering content of Ba (1400-2100 g/t), Sr (880-960 g/t), Pb (38-57 g/t), Zn (<100 g/t), Co (3.2-3.7 g/t), Sn (<5 g/t) are close to derivatives of trachy-andesite magma [6]. K/Rb=404.7-432.7, Rb/Sr up to 0.11 [9] ratios and K/Rb-Rb, Sr-Rb/Sr ratios [8] (figure 2A,B) in the massif monzonites have mantle signatures, and Cr (100-150 g/t) values may indicate crust component of the latter.

Geochemical specialization of monzonites of the Upper Khokhoy massif[5] significantly differs from above mentioned massifs, which results in increased content of chalcophile Ga, Cu, Pb, decreased lithophile Mg, V, Sc, Ca, Rb and siderophile Fe, Co elements (table 1).

Rocks of the massif, considering Rb (73.8-77.4 g/t), Zr (88-120 g/t), Nb (<8 g/t) content as well as monzonites of the Western Boskho massif are close to derivatives of andesi-basalt magma, and considering Ba (1500-2100 g/t), Sr (740-1000 g/t), Pb (31-67 g/t), Zn (<100 g/t), Co (3.2 g/t), Sn (<5 g/t) content, are derivatives of latite magma [6]. K/Rb=404.7-432.7, Rb/Sr ratio values up to 0.10 [9] and K/Rb-Rb, Sr-Rb/Sr [8] ratios (figure 2A,B), and high concentrations of Cr (up to 340 g/t) in the massif monzonites correspond to mantle formations [7].
Table 1. Geochemical composition (g/t) of igneous tocks of the Khokhoy ore field

| № sample | Ga | Cu | Sn | Zn | Pb | Mg | Cr | V | Sc | Sr | Nb | Zr | Mn | Ca | Ti | B | Rb | Fe | Ni | Co | K/Rb | Rb/Sr |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|-------|
| A17-1     | 20 | 10 | <5 | <100 | 43 | <3.3 | 0.26 | 230 | 49 | 4 | 4 | 2400 | 980 | <8 | 130 | 0.06 | 1.8 | 0.22 | 9.2 | 100.8 | 2 | 8.8 | <3.2 | 464.5 | 0.1 |
| A17-2     | 20 | 8.4 | <5 | <100 | 38 | <3.3 | 0.22 | 160 | 45 | 4.3 | 2500 | 1200 | <8 | 150 | 0.07 | 1.5 | 0.2 | 7.4 | 115.2 | 2.2 | 13 | <3.2 | 460.54 | 0.1 |
| A17-4     | 21 | 10 | <5 | <100 | 40 | <3.3 | 0.24 | <14 | 44 | 5 | 2200 | 1100 | <8 | 150 | 0.07 | 1.4 | 0.2 | 10.9 | 117 | 2.1 | <7 | <3 | 481.49 | 0.11 |
| A17-5     | 19 | 11 | <5 | <100 | 63 | <3.3 | 0.24 | 260 | 47 | 3.8 | 2800 | 1100 | <8 | 130 | 0.07 | 2 | 0.2 | 8.5 | 107.1 | 2.1 | 12 | <3.2 | 421.87 | 0.1 |
| A17-7     | 19 | 11 | <5 | <100 | 46 | <3.3 | 0.3 | 230 | 49 | 4.7 | 2100 | 910 | <8 | 140 | 0.07 | 2.2 | 0.2 | 10 | 105.3 | 2 | 14 | <3.2 | 421.29 | 0.12 |
| A17-8     | 18 | 13 | <5 | <100 | 51 | <3.3 | 0.25 | 380 | 47 | 3.4 | 2000 | 1000 | <8 | 140 | 0.07 | 1.9 | 0.2 | 14 | 106.2 | 2 | 12 | <3.2 | 422.35 | 0.11 |
| A17-9     | 20 | 11 | <5 | <100 | 47 | <3.3 | 0.27 | 340 | 43 | 4.4 | 2600 | 900 | <8 | 110 | 0.06 | 2.4 | 0.19 | 16 | 108.9 | 1.9 | 9 | <3.2 | 430.71 | 0.11 |
| A17-11    | 19 | 11 | <5 | <100 | 43 | <3.3 | 0.27 | 160 | 46 | 4.8 | 1900 | 640 | 9.5 | 130 | 0.07 | 1.4 | 0.26 | 25 | 115.2 | 2 | 11 | <3.2 | 425.66 | 0.18 |
| A17-14    | 18 | 9.2 | <5 | <100 | 43 | <3.3 | 0.33 | 100 | 32 | 3.7 | 1400 | 890 | <8 | 120 | 0.08 | 1.8 | 0.14 | 8.3 | 90 | 2 | 11 | 3.7 | 399.98 | 0.1 |
| A17-15    | 21 | 8.3 | <5 | <100 | 57 | <3.3 | 0.34 | 110 | 38 | 3.7 | 1500 | 900 | <8 | 120 | 0.07 | 2 | 0.16 | 9.6 | 84.6 | 2.1 | 8.1 | 3.2 | 410.97 | 0.09 |
| A17-16    | 23 | 11 | <5 | <100 | 40 | <3.3 | 0.38 | 140 | 34 | 3 | 1800 | 880 | <8 | 94 | 0.07 | 2.5 | 0.14 | 7.3 | 85.5 | 2.1 | 9.1 | 3.5 | 404.73 | 0.1 |
| A17-17    | 21 | 7.4 | <5 | <100 | 38 | <3.3 | 0.38 | 150 | 33 | 3.4 | 1700 | 960 | <8 | 110 | 0.07 | 2.6 | 0.15 | 8.1 | 84.6 | 2.3 | 8.5 | <3.2 | 405.15 | 0.09 |
| A17-18    | 20 | 8.7 | <5 | <100 | 42 | <3.3 | 0.34 | 110 | 36 | 4.1 | 1900 | 910 | <8 | 110 | 0.06 | 2.1 | 0.16 | 10.1 | 86.4 | 1.9 | 10 | <3.2 | 432.78 | 0.09 |
| A17-23    | 21 | 14 | <5 | <100 | 67 | <3.3 | 0.16 | 330 | 26 | <3.1 | 1500 | 740 | <8 | 100 | 0.08 | 1.4 | 0.11 | 6.9 | 77.4 | 1.6 | 14 | <3.2 | 476.74 | 0.1 |
| A17-24    | 21 | 7 | <5 | <100 | 34 | <3.3 | 0.2 | 340 | 26 | <3.1 | 1600 | 740 | <8 | 120 | 0.02 | 1.1 | 0.12 | 8 | 77.4 | 1.6 | 11 | <3.2 | 488.4 | 0.1 |
| A17-25    | 22 | 13 | <5 | <100 | 31 | <3.3 | 0.17 | 240 | 24 | <3.1 | 2000 | 830 | <8 | 88 | 0.05 | 1.4 | 0.12 | <10 | 75.6 | 1.6 | 10 | <3.2 | 498.94 | 0.09 |
| A17-26    | 24 | 12 | <5 | <100 | 44 | <3.3 | 0.23 | 250 | 27 | <3.1 | 2100 | 1000 | <8 | 110 | 0.07 | 2 | 0.13 | <10 | 73.8 | 1.6 | 18 | <3.2 | 515.56 | 0.07 |
| A17-12    | 17 | 100 | <5 | <100 | 34 | <3.3 | 1.83 | 170 | 160 | 20 | 3500 | 1300 | <8 | 160 | 0.1 | >7.8 | 0.45 | 130 | 146.7 | 5.9 | 77 | 32 | 514.81 | 0.11 |
| A17-12/I1 | 16 | 110 | <5 | <93 | 25 | <3.3 | 1.8 | 140 | 140 | 21 | 2400 | 1800 | 11 | 230 | 0.12 | 6.4 | 0.39 | 140 | 137.7 | 5.5 | 81 | 29 | 565.13 | 0.08 |

Massif and sample numbers: Northern Boskho A17-1 – A17-11; Western Boskho A17-14 – A17-18; Upper BoskhoKhokhoy A17-23 – A17-26; Dikes A17-12, A17-12/1. Elements: Ga-Ge – lithophile, Mg-Rb – chalcophile, Fe-Co – siderophile

Tephrites of the dikes bodies[5] differ from the massif rocks by low content of chalcophile Ga, Sn, Zn Pb, and increased content of lithophile B, Ba, Ca, Mg, Mn, Na, Nb, Rb, Sc, Sr, Ti, V, Zr, and siderophile Fe, Ni, elements (table 1). Cr (140-170 g/t) and Co (29-32 g/t) values are typical for the rocks of alkaline-basalt series[4]. Considering Rb (137.7-146.7 g/t) content and Rb/Sr ratio below 11, the latter are correspond to lalites of shoshonite series. Considering abnormally high Ba (2400-3500 g/t), Sr (1300-1800 g/t) contents, tephrite dikes, in general, have signs of the rocks of the latite series[4]. K/Rb-Rb, Sr-Rb/Sr[8] (figure 2A,B) ratios in them indicate mantle genesis of these rocks.
4. Rare-earth element distribution in igneous tocks of the Khokhoy ore field

Rocks of the Northern Boskho massif have smooth negative [4] incline in rare-earth element distribution, i.e. they are depleted with yttrium (Y, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) and enriched with cerium (La, Ce, Pr, Nd, Sm) elements, excluding Eu (figure 3, table 2). Nb/La ratios with the limits 0.45-0.52 reflect the degree of magma contamination with continental crust [10], Nb/La<1 value means negative niobium anomaly – a clear sign of continental crust[11]. Values of La/Yb=11.67-13.63, Ce/Yb=23.06-23.66 ratios in syenite-porphyry of the massif are close to parameters of rocks of the latite series. These rocks are widely distributed in intracontinental settings [9], for which mantle-crust interaction while magma generation, is proved in many regions [6]. As it was mentioned, weak negative Eu-anomaly (Eu/Eu* =0.79-0.89) is typical for the massif rocks, it may indicate the formation of primary mantle magma during fractional crystallization of rock-forming minerals with the involvement of feldspars (Balashov).

Rare-earth element distribution in monzonites of the Western Boskho is close to rocks of the previous massif, but differs from it by rather decreased concentrations of light and heavy rare-earth elements (figure 3, table 2), which contents have more negative anomaly [4]. Nb/La=0.38-0.50 ratio in monzonites of the massif may indicate contamination of primary mantle magma with crust substance[10], [11]. Values of La/Yb=13.75-18.15, Ce/Yb=27.24-30.48 ratios are slightly higher, than in tocks of the Northern Boskho massif and considering these parameters, they are closest to rocks of intracontinental setting.

![Figure 3. Rare-earth element distribution diagrams. Symbols of rocks: 1. – Northern Boskho; 2 – Western Boskho; 3 – Upper Khokhoy; 4 – Tephrite dikes](image)

Remarkable increase of the growth of Eu/Eu* ratio at 0.88-0.99, is close or identical with chondrite and indicates the formation of melts during fractional crystallization only of dark-colored rock-forming minerals, and also indicates deep differentiation [12].
Table 2. Rare-earth element content (g/t) and their principal ratios in igneous rocks of the Khokhoy ore field

| Sample   | La   | Ce   | Pr  | Nd  | Sm  | Eu  | Y   | Gd  | Tb  | Dy  | Ho  | Er  | Tm  | Yb  | Lu  | Nb/La | La/Yb | Ce/Yb | Eu/Eu* |
|----------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|-------|--------|
| A 17-2   | 23   | 39   | 4.8 | 19.3| 3.6 | 0.91| 18.7| 3.2 | 0.49| 2.7 | 0.58| 1.77| 0.27| 1.66| 0.25 | 0.45 | 13.63 | 23.66 | 0.83  |
| A 17-7   | 20   | 40   | 4.8 | 18.9| 3.5 | 0.96| 17.4| 3.3 | 0.47| 2.9 | 0.60| 1.66| 0.25| 1.70| 0.26 | 0.48 | 12.04 | 23.30 | 0.87  |
| A 17-8   | 18.7 | 37   | 4.4 | 17.0| 3.5 | 0.94| 16.1| 3.0 | 0.44| 2.5 | 0.54| 1.57| 0.24| 1.60| 0.24 | 0.52 | 11.67 | 23.14 | 0.89  |
| A 17-11  | 20   | 39   | 4.7 | 18.3| 3.7 | 0.91| 17.2| 3.3 | 0.47| 2.7 | 0.57| 1.75| 0.27| 1.69| 0.27 | 0.47 | 12.12 | 23.06 | 0.79  |
| A 17-15  | 20.0 | 34   | 4.5 | 16.8| 3.1 | 0.86| 12.2| 2.9 | 0.39| 2.0 | 0.39| 1.12| 1.10| 1.07| 0.17 | 0.38 | 18.15 | 30.48 | 0.88  |
| A 17-16  | 15.6 | 31   | 3.6 | 14.5| 3.1 | 0.86| 12.3| 2.6 | 0.33| 1.98| 0.39| 1.12| 1.13| 1.18| 0.13 | 0.18 | 13.75 | 27.24 | 0.92  |
| A 17-17  | 17.0 | 34   | 4.1 | 15.9| 3.2 | 0.96| 13.0| 2.8 | 0.39| 2.1 | 0.44| 1.18| 0.19| 1.22| 0.18 | 0.50 | 13.94 | 27.68 | 0.99  |
| A 17-23  | 13.4 | 24   | 2.8 | 10.8| 2.1 | 0.59| 14.1| 2.2 | 0.30| 1.90| 0.42| 1.20| 0.20| 1.44| 0.22 | 0.80 | 9.31  | 16.93 | 0.85  |
| A 17-25  | 16.2 | 25   | 3.4 | 12.6| 2.6 | 0.72| 15.4| 2.3 | 0.36| 2.2 | 0.45| 1.48| 0.25| 1.60| 0.24 | 0.65 | 10.10 | 15.79 | 0.89  |
| A 17-26  | 14.4 | 25   | 3.0 | 11.4| 2.3 | 0.63| 14.6| 2.2 | 0.33| 1.92| 0.42| 1.33| 0.22| 1.61| 0.24 | 0.73 | 8.95  | 15.76 | 0.85  |
| A 17-12/1| 25   | 51   | 6.4 | 26  | 5.3 | 1.50| 14.9| 4.3 | 0.55| 2.6 | 0.51| 1.30| 0.18| 1.14| 0.17 | 0.32 | 22.05 | 44.99 | 0.96  |

Massifs and numbers of the samples: Northern Boskho А17-1 – А17-11; Western Boskho А17-15 – А17-17; Upper Khokhoy А17-23 – А17-26; Dikes А17-12/1.

Rare-earth element distribution in monzonites of the Upper Khokhoy massif is identical to the distribution of the massif rocks of the Khokhoy group, i.e. considerable decrease of concentration of heavy lantanoids is observed with increased content of light rare-earth elements (figure 3, table 2). Parameters of rocks of the Upper Khokhoy massif are similar to such parameters of the Western Boskho massif, but differ by slightly decreased concentrations of light rare-earth elements and increased concentrations of heavy ones, and they have a smooth negative incline. Nb/La ratio within 0.65 to 0.80 indicates contamination of magma with continental crust[10], and values of La/Yb=8.95-10.1, Ce/Yb=15.76-16.93 ratios are significantly lower than in above-mentioned massifs and are typical for the rocks of intracontinental settings[9]. Eu/Eu*=0.85-0.89 ratio is close to 1 that indicates deep differentiation[12].

Tephrite dikes in comparison with rocks of the massifs of the Khokhoy group are mostly intensively enriched with light lantanoids and depleted with heavy rare-earth elements, in particular, Er, Tm, Yb, Lu (figure 3, table 2). Values of La/Yb=0.65-0.80 ratio, close to 1 and Ce/Yb at 22.05 and 44.99, may indicate contamination of parental magma with crust substance. Eu/Eu=0.96 ratio is identical to chondrite that indicates deep differentiation and belonging to early phases in intrusion[12].

5. Discussion
Geochemical features of igneous rocks of the Khokhoy ore field are not ambiguous and have dual nature. Syenite-porphry of the Northern Boskho massif is geochemically specialized on lithophile elements and belongs to derivatives of trachy-andesite (latite) magma. Monzonites of the Western Boskho massif in comparison with the Northern Northern massif are characterized by decreased
values of lithophile and slightly increased contents of siderophile elements. Considering the content of REE, the massif rocks belong to derivatives of trachy-andesite and andesite-basalt magma. Geochemical specialization of monzonites of the Upper Khokhoy massif significantly differs from the Northern Boskho massif rocks, and considering these parameters is relatively close to the Western Boskho massif. The duality of compositions is typical for rocks of the Upper Khoio massif, as well as for rocks of the Western Boskho massif that can be determined by the degree of partial melting of different mantle substrates: enriched and depleted mantle [13]. All studied rocks have close spectra of rare-earth element distribution, and diagrams have a negative incline, i.e. rocks are depleted with heavy rare-earth elements with respect to light rare-earth elements. Such distribution spectrum [4] is related to the presence of hornblende (up to 10%) and zircon in rocks [5]. Eu/Eu* ratio for rocks of the Western Boskho massif (0.88-0.99) and tephrite dikes (0.96) is close to chondrite (from the primary melt) i.e. rocks were formed during fractional crystallization mainly of dark-colored rock-forming minerals [12]. That is reflected in their petrographic composition [5], where the content of dark-colored minerals reaches 10% for the Western Boskho and 40% for tephrite dikes. In general, presence of slightly negative Eu-anomaly for the Northern Boskho (0.79-0.89) and Upper Khokhoy (0.85-0.89) massifs may indicate the fact that they were formed from residual differentiates during fractional crystallization of rock-forming minerals with the involvement of plagioclases. Also, decreased Eu/Eu* values indicate that these rocks were formed during the late stage of the territory evolution [12]. Negative niobium anomaly (Nb/La<1) for all igneous rocks of the ore field indicates contamination of magma with continental crust [10]. Values of La/Yb and Ce/Yb ratios in the massif rocks are typical for the formations of intracontinental conditions [9]. The identified duality of geochemical compositions of the rocks can be caused by the presence of mantle as well as crust sources. It is most probable that these rocks were formed as a result of melting of mixed mantle source or mantle source, contaminated with continental crust, followed by differentiation of the melts in intermediate crust chambers.

6. Conclusion

Thus, magmatic formations of the ore field are geochemically specialized in lithophile and siderophile elements, and close to derivatives of latite and andesi-basalt magma. All studied rocks have sufficiently close spectra of rare-earth element distribution; in particular, the rocks are poor in heavy rare-earth elements relative to the light rare-earth elements. Presence of low negative Eu-anomaly for the Northern Boskho and Upper Boskho massifs may indicate the fact that they were formed from residual differentiates during the fraction crystallization of rock-forming minerals with the involvement of plagioclases. Low Eu/Eu* values also indicate the fact that these rocks were formed during the late stage of the area evolution. Negative niobium anomaly, identified for all igneous rocks of the ore field, indicates contamination of magma with continental crust. Considering interpretation of rare-earth elements and their ratio, it was supposed that igneous rocks of the ore field were formed in intracontinental conditions. It was generally concluded that there was an intensive mantle-crust interaction throughout the magmatism evolution of the Khokhoy ore field, beginning from the intrusion of tephrite dikes bodies to the intrusion of syenite rocks. Presence of long-lived mantle source, as well as contamination with crust material, was responsible for heat and fluid inflow that supplied circulation of thermal spring in the system. Heat and fluids caused additional mobilization of ore material from surrounding rocks with further formation of gold-sulfide mineralization close to tephrite dikes and the Northern Boskho massif.

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