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Review Article

# The Ore-Bearing Potential of Amphibolic Gabbro Rocks of Koghov Mountain (Southern Armenia)

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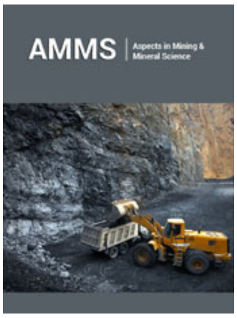


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## Abstract

The well-known copper-molybdenum porphyry deposits of the Zangezur ore district are spatially associated with the uneven-aged intrusive rocks of the Meghri pluton. Less well known are studies on the distribution of rare earth elements in intrusive rocks. This article discusses the prospects for rare earth mineralization of iron-magnesian metamorphogenic-metasomatic rocks associated with the gabbro-monzonite complex of the Upper Oligocene. The new type of amphibolization of rocks of Meghri Pluton singled out by us, which results in the formation of amphibolic gabbro rocks, is interesting primarily because of the enrichment of the latter with rare-earth elements. Correlation with the zone of amphibolic gabbro rocks of heterogeneous metasomatites allows to consider the zone of amphibolic gabbro rocks as perspective for rare earth mineralization.

**Keywords:** Southern Armenia; Meghri pluton; Amphibolic gabbro; Rare earth mineralization

## Introduction

Studies of the isotopic-material composition of individual intrusive phases of the largest in the Lesser Caucasus poly-formational Meghri Pluton [1] that continue to this day, allow clarifying their place in the chronology of magmatic events, and, no less important, determining the place of metasomatic and metamorphic changes, which accompany the formation of a number of magmatic bodies, introducing significant changes in the mineral composition of the original rocks. The spectrum of various types of changes accompanying the formation of individual intrusive phases of Meghri Pluton is an integral part of the magmatogenic system, not to mention the ore burden that the fluids carry with them, and the isotopic and petrochemical characteristics of changed rocks are no less informative than the intrusive ones. The well-known copper-molybdenum porphyry deposits of the Zangezur ore district are spatially associated with the uneven-aged intrusive rocks of the Meghri pluton, the characteristic features of which are described in a number of publications (Tayan, 1998; [2-6]). Less well known are studies on the distribution of rare earth elements in intrusive rocks [7]. This article discusses the prospects for rare earth mineralization of iron-magnesium metamorphogenic-metasomatic rocks associated with the gabbro-monzonite complex of the Upper Oligocene. This article provides data related to the complex of intrusive, metamorphosed and metasomatic rocks of the central part of Meghri Pluton, which have developed in the eastern frame of the Oligocene monzonite intrusion.

Involvement of metamorphic [8] and metasomatic [9-11] processes in the formation of rocks of Meghri Pluton and small intrusions of Bargushat have been repeatedly mentioned by researchers. Among these, the greatest part was assigned to the processes of iron-magnesium metasomatism, manifested by the amphibolization of rocks. Wide development of metasomatic rocks of plutonic appearance associated with the Upper Eocene intrusions of granitoid series

(Geghi, Lernashen, Kavjut, Akhlatyan and Surbkar) was proved for the first time within the limits of Western Bargushat by Melanocratic rocks with dominant amphibole, formed as a result of metasomatic change of andesite-basalts of the exocontact of intrusions, occupy about 20% of the surface of the intrusive metasomatic complex. According to the mineral composition Pl+Amph+(K-spar+qtz), stand for Plagioclase+ amphibole+ potassium feldspar+quartz, they correspond to hornblendites, hornblends gabbro, much less often to diorites, granodiorites, etc. (metahornblendites-metagabbro - hornblendss metadiorites-metagranodiorites, etc). Enrichment of metasomatites with accessory minerals was observed: apatite-up to 2%, sphen-0.5%, magnetite-up to 4%. Formation of melanocratic metasomatites was considered by Ghuyumjyan (1970), [9] as a manifestation of iron-magnesium metasomatism, caused by transmagmatic fluids.

In connection with the systematization of metasomatic formations, i.e., chemical alteration of Zangezur ore district linking them in time and space with producing magmatism, in monzonites of Kadjaran ore field, as a manifestation of iron-magnesium metasomatism, besides the areal amphibolization, amphibole-biotite-magnetite-apatite mineral association was singled out within Meghri Pluton by Karamyan with co-authors (1963, [11]). Metasomatic veinlets up to 5-6cm in thickness are traced for 2-3m, spotted and nested amphibolic segregations are observed not only in monzonites, but also in hornfels of the northern endocontact of monzonite intrusion, as well as in pegmatites, micromonzonites and medium-grained granodiorites. Areal amphibolization occupies small areas, however it occurs everywhere with the transformation of non-ferrous minerals into hornblende with significant enrichment of the rock with it, as a result of which the latter acquires more basic composition. Amphibolization and biotitization, as a result of manifestation of iron-magnesium metasomatism, as a characteristic feature of monzonite intrusion, were also observed by Meliksetyan [12].

Areal amphibolization of rocks was detected by us in the watershed area of Meghri range not in the monzonites, but in clinopyroxene-amphibolic and clinopyroxene gabbro rocks of the eastern frame of monzonite intrusion. The unusual texture and structure appearance of gabbroids along with the dominant development of amphibole, allowed to question the magmatic nature of amphibolic gabbro rocks.

## Meghri pluton

Meghri Pluton, with the magmatism of which are connected the deposits of copper-molybdenum-porphyritic and gold ore formations of Zangezur ore district, is characterized by discrete-pulsation character of formation. Its formation is associated with collision processes upon activation of the main magma-concentration zones (Figure 1) - Giratagh and Ordubad-Salvard, forming the Eocene-Oligocene magmatism (Meliksetyan, 1976), as well as Tashtun, controlling the Lower Miocene granitoid-porphyritic magmatism ([13]; Tayan, 1998).

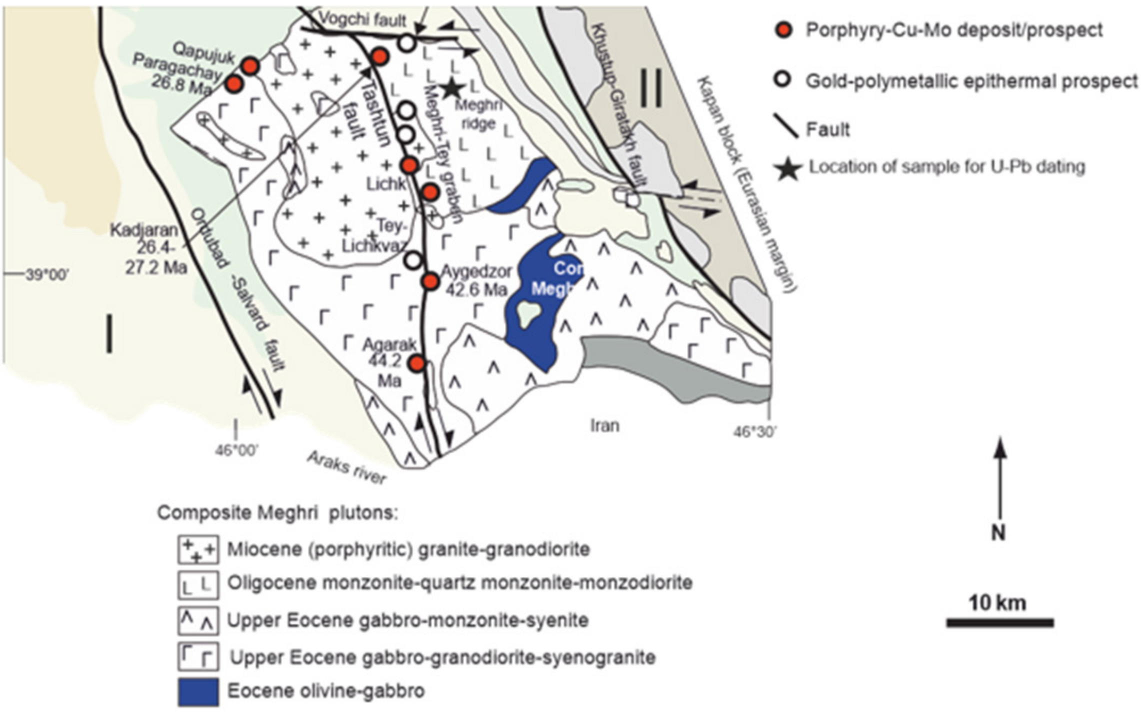


**Figure 1:** The structure of Meghri Pluton according to the latest data [22]. I - Zone of Nakhichevan Late Alpine folding; II - Zone of Kapan Early Alpine folding. The asterisk indicates the place of development of amphibolic gabbros.

Numerous research by Paffenholz, Grushevoy, Arapov, Mkrtchyan, Movsesyan, Litvin, Adamian, Tadevosyan, Meliksetyan, Mezhlumyan, Karamyan, Tayan, Guyumjyan, Khodzhabaghyan and many others, dedicated to the magmatism of Zangezur ore district, allowed to give petrographic, mineralogical and petro-geochemical features to the intrusive rocks of Meghri Pluton, to determine the general diagram of sequence of introduction of plutonic bodies. By isotopic dating by K-Ar method gabbro-monzonite-granosyenite - 37- 38 million years and porphyric granite-granodiorite formations - 22- 24 million years were singled out [14]. The isotopic-geochronological research of magmatic rocks of Meghri Pluton carried out over the last decade [15-22] showed that later classification schemes of magmatism with combination of intrusive phases into complexes (gabbro-olivinite, gabbro-monzonite-syenitic, gabbro-diorite-granosyenite-granodiorite, porphyric granitoid [23] and regionally magmatic formations (gabbro-tonalite-granite, gabbro-syenitic, monzodiorite-granosyenite, gabbro-monzonite-syenitic, syenite-granosyenite-granite, granite-granodiorite [7] need to be corrected and refined. Isotopic research made it possible to accurately determine the place of monzonites, syenogranites and granitoid rocks of Meghri Pluton in the evolutionary scheme of magmatism (Figure 1). Gabbroid rocks of pluton turned out to be out of geochronological research, with the exception of amphibolic gabbro rocks of near the watershed area of Meghri range, which were also dated to Early Oligocene [18,19,21,22].

## Geological position of amphibolic gabbro rocks

Complex relations of different types of gabbroid rocks and monzonites of the northern intrusion were traced by us in the watershed and near the watershed areas of the southern slope of Meghri range. The age of monzonites of Kadjaran intrusion by K-Ar was evaluated by definitions at 28-32Ma [14]. This contradicted the facts of the intersection of monzonites of the southern part of pluton by apophyses of earlier granodiorite-granosyenite intrusion and it was explained by rejuvenation of monzonites of the north due to the loss of argon during the introduction of porphyric granitoids of Early Miocene (Baghdasaryan et al. 1968). Isotopic research of monzonites by Rb-Sr method gave 28.2-31.0 ±0.9Ma [15], TIMS U-Pb isotopic dating of zircons - 31.83±0.02Ma [16-21]. This clearly determined the Lower Oligocene age of monzonites.

Monzonite intrusion is characterized by extremely heterogeneous structure; among the actual monzonites the outcrops of quartz monzonites, diorites and quartz diorites, monzo-gabbro, quartz and orthoclase gabbro rocks single out [10,11,23]. In the western part monzonites are broken through by porphyric granitoids of Lower Miocene and their derivatives. In the east monzonites break through the terrigenous-flyschoid formations of Piramsar strata of Middle Eocene [24] and aleurolites, conventionally related to Danian-Paleocene (Tayan, 1998), in the near watershed area of Meghri range monzonites break through clinopyroxene-amphibolic gabbro rocks, in the south granodiorite-granosyenites of the Upper Eocene [15]. The remnants of olivine gabbro rocks are traced in gabbroids from the watershed area of Meghri range to the village Taghamir in the south. They are referred to as the most ancient intrusive formations of late Eocene magmatism ([7,23], Tayan, 1998) and represent the earliest manifestations of collision magmatism [7].

Additional intrusions of micromonzonites and microsyenites characteristic of monzonites, stock-shaped bodies of medium-grained granites and granodiorites are particularly often observed in the southern part of the intrusion [23]. Their outcrops are stretched out in the meridional and northeastern directions. The largest in terms of area - up to 1.5km$^2$, the body of medium-grained granites is observed in the watershed area of the Meghri range to the west of the mountain of Koghov (Sabat-Kechmas), where the medium-grained granites break through both monzonites and clinopyroxene-amphibolic gabbro rocks (Figure 2). Amphibolic gabbro rocks are observed along the northern exocontact of medium-grained granites. Their age according to isotopic dating of zircons by TIMS U-Pb method [18-22] is defined as Lower Oligocene - 33.49±0.02Ma.

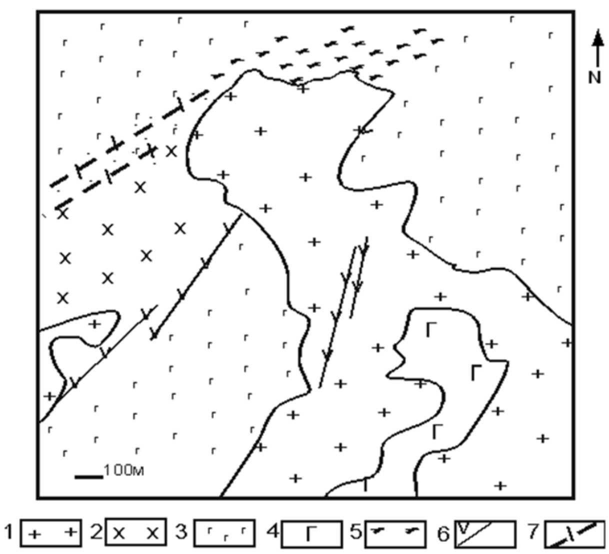


**Figure 2:** Geological position of amphibolic gabbro rocks [27]. 1. Medium-grained granites; 2. Monzonites; 3. Clinopyroxene-amphibolic gabbro rocks; 4. Olivine gabbro rocks; 5. Amphibolic gabbro rocks; 6. Dykes of diorite-orphyrites; 7. Hydrothermal changes.

Amphibolic gabbro rocks of the indicated zone are characterized by variability of the texture-structure pattern over a short interval, the phenomena of collective recrystallization are observed; nested and vein-like clusters of amphibole 2-5cm in thickness are unevenly developed along the rock. Vein-like bodies, composed of amphibole, coarse lamellar biotite and magnetite cementing them are also observed. Under the microscope, it turns out that they are all equally impregnated by apatite. In the eastern part of the zone of amphibolic gabbro rocks the outcrops of pegmatites, potassium feldspar- pyroxene, amphibole-albite, quartz-feldspar metasomatites are observed, which are superimposed by epidote-actinolite and epidote-chlorite-albitic mineral associations in the form of veinlets and nested segregations. The latter are characterized by a significant frequency of development of accessory minerals up to 1-2mm in size - sphen, apatite, zircon.

## Petrographic description of rocks

Clinopyroxene-amphibolic gabbro, On which amphibolization is imposed, have the following quantitative-mineral composition: plagioclase - 35-60%, clinopyroxene - 20-30%, amphibole - 0-10%, biotite - 0-5%, ore mineral - up to 1%, apatite - up to 0.5%, sphen. The texture is coarse-grained, panidio-morpho-granular with porphyric segregations up to 6-7mm. The composition of plagioclase varies from basic andesine to bitovnite -$An_{50-70}$, the content of anorthite molecules in plagioclase, which indicates its basic composition. Clinopyroxene - diopside [8] is colorless-light greenish, forms short-prismatic crystals: Ng=1.724-1.728; Np=1.706-1.708; cNg=47-50$^0$; +2v=58-60$^0$. Biotite is brownish brown, pleochroates to straw-yellow. Hornblende is represented by a greenish-brown difference of ordinary hornblendes, it forms prismatic crystals: cNg=18$^0$; 2v=74-76$^0$, absorption scheme is ordinary.

## Amphibolic gabbros

Plagioclase - 45-60%, clinopyroxene - 0-10%, amphibole - 30-50%, biotite - 0-5%, ore mineral - 3-4%, apatite - up to 3%, sphen, rutile. Amphibole is brownish with transitions to brownish-green, it pleochroates to pale yellow: Np<Nm≈Ng; cNg=12-13$^0$ (the optical parameters of the crystals, angle of optical axes of crystals). In the crystals of amphibole the relicts of clinopyroxene are observed, as well as traces of dissolution of biotite. Uneven development of amphibole along the rock is often observed within the same thin section. The texture of the rock with pseudomorphic displacement of pyroxene by amphibole is hipidioblastic or blastogabbro, more often - cumuloblastic and glomeroblastic; with the development of amphibole along the xenoblastic substratum of plagioclase - poikiloblastic and poikilo-porphyry-blastic. The concentration of apatite prismlets in amphibolic borders around clinopyroxene allows to connect the development of amphibole with exposure to solutions that carry volatile elements.

## Petrochemistry of gabbroids

**Table 1:** Chemical composition of gabbroid rocks.

Note: 1 clinopyroxene-amphibolic gabbros - data by Meliksetyan [12] according to 7 samples; 2, 3 amphibolic gabbros - according to the results of microprobe scanning; 2 - № Kj-12-07 [22], 3 - № S-201 (the coordinates: 39 06.15 and 46 13.27) - the authors data.

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | K2O | $P_2O_5$ | LOI | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40,16 | 0,59 | 19,30 | 7,60 | 6,18 | 0,30 | 10,20 | 13,76 | 1,28 | 0,32 | 0,45 | - | 100.14 |
| 2 | 42,07 | 1,67 | 18,50 | 12,94 | - | 0,20 | 6,55 | 12,84 | 2,62 | 0,64 | 1,24 | 0.68 | 99,96 |
| 3 | 42,18 | 1,33 | 18,94 | 12,86 | - | 0,21 | 6,03 | 12,35 | 2,63 | 0,74 | 1,3 | 1.48 | 100.05 |

The average chemical composition of clinopyroxene-amphibolic (1) and amphibolic gabbro rocks (2 and 3) is given in Table 1. The main elements of the sample S-201 were analyzed by X-Ray Spectral Fluorescent (XRF) method (SARM in Nancy, France), the rare earth elements and a number of other impurity elements - by mass spectrometry using the inductively coupled plasma (ICP-MS). Isotopic features of Sr, Nd, Pb were received at the University of Montpellier-2 (France). Differences in chemistry between clinopyroxene-amphibolic and amphibolic gabbro rocks are reflected by the increased contents of $TiO_2$ and $P_2O_5$ in the latter and are completely uncharacteristic of intrusive rocks of Meghri Pluton [22]. Increase in $P_2O_5$ correlates with quite high development of apatite in amphibolic gabbro rocks; titanium is distributed between sphen, titanium-magnetite and it is partly contained in hornblende.

The increase in the index of ferruginousity or mafic index from 0.90 to 1.19, and the coefficient of titanium content from 8 to 25 in amphibolic gabbro rocks is accompanied by increase in the ratios of siderophile elements - Ti/Cr, V/Cr, Ni/Co (Table 2), which is undoubtedly due to the introduction into the system, besides Ti, of V and Co and carrying-out of Mg and Ni (Table 3). With the increase in features of total alkalinity - K+Na/∑Fe+Mg from 0.0007 to 0.17-0.18 and $Na_2O+K_2O/Al_2O_3$ from 0.14 to 0.27, change in the ratios is observed, respectively - K/Rb and Rb/Sr (calculated according to the data of Meliksetyan [12]). With relatively inert behavior of Rb the introduction of Sr correlates with the increase in the rock of the contents of apatite. The content of rare-earth elements and impurity elements in amphibolic gabbro rocks is given in Table 3.

**Table 2:** Petrochemical features of gabbroid rocks.

| | ∑Fe/Mg | 100Ti/ | $Al_2O_3$/ | $Na_2O+K_2O/Al_2O_3$ | K+ Na/ | Ti/Cr | V/Cr | Ni/Co | K/Rb | Rb/Sr |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ∑Fe | ∑FeO+MgO | | ∑Fe+Mg | | | | | |
| 1 | 0,90 | 8 | 0,80 | 0,14 | 0,0007 | 364 | 22 | 0,75 | 273 | 0,04 |
| 2 | 1,10 | 25 | 0,95 | 0,27 | 0,17 | 5142 | 244 | 0,20 | 750 | 0,01 |
| 3 | 1,19 | 18 | 1,00 | 0,26 | 0,18 | 8350 | 55 | 0,40 | 777 | 0,01 |

**Table 3:** Content of rare-earth elements and impurity elements in amphibolic gabbro rocks (ppm).

Note: S-201 the author's data; Kj-12-07 [22].

| | S-201 | Kj-12-07 | | S-201 | Kj-12-07 | | S-201 | Kj-12-07 |
|---|---|---|---|---|---|---|---|---|
| Rb | 18,82 | 15 | Nd | 73,28 | 73 | Lu | 0,3 | 0,4 |
| Sr | 1718,21 | 1606 | Sm | 11,77 | 15 | Hf | 1,78 | 2,5 |
| Y | 27,32 | 40 | Eu | 3,36 | 3,5 | Ta | 0,42 | 0,5 |
| Zr | 69,49 | 81 | Gd | 9,43 | 12 | Th | 4,5 | 3,7 |
| Nb | 10,23 | 11 | Tb | 1,11 | 1,4 | U | 1,05 | 0,9 |
| Cs | 0,76 | 1,5 | Dy | 5,96 | 8,3 | Co | 34,41 | 43 |
| Ba | 458,64 | 449 | Ho | 1,02 | 1,5 | Cr | 6,978 | 2 |
| La | 69,85 | 63 | Er | 2,76 | 3,6 | Ni | 15,03 | 9 |
| Ce | 149,28 | 135 | Tm | 0,34 | 0,5 | V | 385,7 | 488 |
| Pr | 17,13 | 17 | Yb | 1,96 | 2,9 | Pb | 6,47 | 5 |
| | | | | | | Zn | 110,5 | 100 |

In the rare earth spectrum of intrusive rocks of Oligocene normalized for chondrites [22], the graph of amphibolic gabbro rocks occupies the top position, which testifies to enrichment of rocks with rare earth elements. This is also confirmed by our data, which is illustrated in Figure 3. According to the slope of the distribution curves (Figure 3a), as well as LREE/HREE $La/Yb_N$-25.6; $La/Sm_N$-3.83, amphibolic gabbro shows a higher degree of enrichment with light rare earth elements compared to intrusive rocks of Oligocene complex, well-known for rare earth-cerium specialization (Meliksetyan, 1984), [8]. On the chart of intrusive rocks of Oligocene, normalized to primitive mantle [22], enrichment of rocks with light rare-earth elements is also observed. Here, in addition to negative anomalies Ta-Nb and Ti-P, characteristic of the whole complex of volcano-plutonic rocks of Zangezur ore district from Middle Eocene to Early Miocene, Zr-Hf and less significant Rb and Pb minimums are observed, due to amphibolic gabbro of the sample Kj-12-07. Identity of geochemical spectra of the sample Kj-12-07 and S-201 (Figure 3b) allows us to assume that the indicated minimums characterize the metasomatic changes forming amphibolic gabbro rocks. Relations between isotopes of strontium and neodymium in the sample S-201 have low values: $^{87}Sr/^{86}Sr$ - 0.70388, $^{143}Nd/^{144}Nd_{(i)}$ - 0.51282; primary relation of isotopes of lead is moderately high $^{207}Pb/^{204}Pb_{(i)}$ - (15.57); $^{208}Pb/^{204}Pb_{(i)}$ - (38.70); $^{206}Pb/^{204}Pb_{(i)}$ - (18.69).

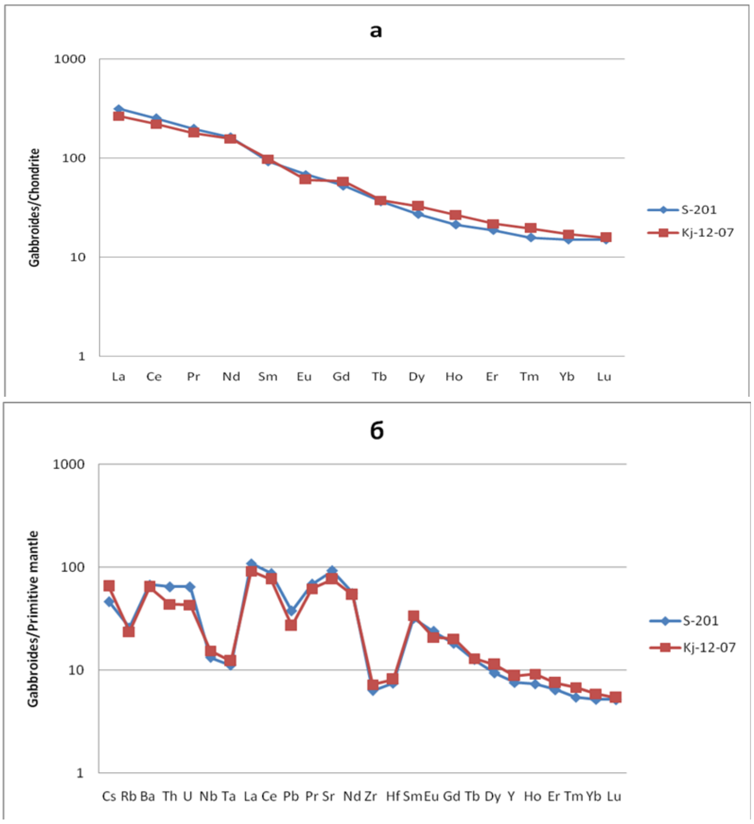


**Figure 3:** Distribution of normalized for chondrites (a) and normalized to primitive mantle of rare-earth elements and impurity elements (b) in amphibolic gabbro (Sun & McDonough,1989).

## Discussion of Results and Conclusions

Amphibolization as a characteristic feature of the northern monzonite intrusion of Meghri Pluton has been repeatedly observed by researchers of magmatism of Zangezur ore district and was perceived as a result of iron-magnesium metasomatism [10-12]. The amphibolization of gabbroids of the watershed area of Meghri range singled out by us along the northern exocontact of medium-grained granitoids has its own characteristics: it is defined by increasing alkalinity of mineral-forming environment, introduction of Ti, volatile, light rare-earth elements, with little bearing-out of strong bases - Mg, to a lesser extent, Ca и $Fe^{2+}$ from clinopyroxene-amphibolic gabbro rocks. Development of amphibole along clinopyroxene-amphibolic gabbro rocks does not cause the formation of rocks more basic than the original ones, and by the insignificance of changes of petrochemical features of primary rocks compared to amphibolic gabbros, amphibolization rather corresponds to metamorphic changes. At the same time, the development of veinlet and nested segregations of amphibole in the rock, their transitions to mineral associations of iron-magnesium metasomatism suggest that the development of amphibole along gabbroids marks the beginning of metasomatic changes.

The migration path of rock-forming elements carried out from clinopyroxene-amphibolic gabbro is short: it is recorded in the same amphibolic gabbro in the form of veinlets of amphibole-biotite-magnetite-apatite composition. Development in the zone of amphibolic gabbro, besides the mineral associations of iron-magnesium metasomatism, potassium feldspar-pyroxene, potassium feldspar, pyroxene-albitic, albite-amphibolic, epidote-hornblende, quartz-epidote, quartz-feldspar metasomatites testifies to the ongoing metasomatic processing of rocks. The complex of the listed facies of metasomatites is known in connection with rare metals-rare earth mineralization of Khalzan-Tsakhira zone in Mongolia [25] and the deposit Elozero in Russia [26].

Isotopic zirconium dating of amphibolic gabbro rocks by TIMS U-Pb method - 33.49Ma [22] can be correlated with time of formation of clinopyroxene-amphibolic gabbro. Thus, the formation of Oligocene rocks of quartz-monzonite, monzonite-monzodiorite [22] or monzonite-syenodiorite complex 28.2-31Ma [16] is preceded by the introduction of the intrusion of clinopyroxene-amphibolic gabbro, which have a significant development in the rocks of Meghri Pluton. The new type of amphibolization of rocks of Meghri Pluton singled out by us, which results in the formation of amphibolic gabbro, is interesting primarily because of the enrichment of the latter with rare-earth elements. Correlation with the zone of amphibolic gabbro of heterogeneous metasomatites that are formed during a single petrologic process, along with the tendency of accumulation and enlargement in them of accessory minerals, concentrating rare-earth elements, allows to consider the zone of amphibolic gabbro as perspective for rare earth mineralization [27,28].

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