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THE ORIGIN OF THE EPITHERMAL GOLD-SILVER (Au-Ag) DEPOSITS IN THE AGDUZDAG ORE FIELD (LESSER CAUCASUS)

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Abstract

The Agduzdag epithermal gold-silver (Au-Ag) mineralization is spatially and genetically related to the Miocene-Pliocene (N1-N2) lavas and tuffs of rhyolites, dacites and andesites, and their subvolcanic analogues. In the zone of faults, these rocks are subject to hydrothermal alterations with formation of successively facies of low-temperature propylites and quartzites. Analyzing the behavior of these elements in the crystallization differentiation process and in subsequent secondary alterations changes, it is possible to determine the cause of the deposition of these elements by hydrothermal activity. Au, Ag and Hg, and possibly Cu, Zn, Pb do not accumulate in rock-forming minerals (K distribution - Kd <1), remain in excess and accumulate in the residual. As a result of subsequent metasomatic and post-magmatic hydrothermal processes, these elements are catched by hydrothermal processes and can form their own ore deposits and occurrences.

Therefore, we can argue that the existing deposits and manifestations of Au, Ag, and Hg, and possibly Cu-Zn-Pb, Mo, Li, As, Sb, U-Th, associated with medium and acid rocks were formed due to the accumulation of these elements in the residual melt at low values of the combined distribution coefficients of these elements between crystals and melts.

Thus, formation of Low-temperature gold-silver (Au-Ag), mercury (Hg), possibly mercury-arsenic-antimony (Hg-As-Sb), copper-lead-zinc (Cu-Pb-Zn) deposits and occurencies of the Lesser Caucasus are closely related to the Neogene (N) Hi-K volcanic and subvolcanic calc-alkaline andesites and different acid rocks and also intense block movements along the deep faults during the period of formation and development of graben-like structures. These structures were made by Cenozoic (KZ) volcanogenic and volcano-sedimentary rocks.

Keywords: Lesser Caucasus, Neogene (N) volcanism, epithermal Agduzdag gold-silver (Au-Ag) deposit, post-magmatic hydrothermal processes

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1.Introduction

With the Late Cenozoic volcanic series of the Lesser Caucasus is associated epithermal gold-silver deposit (Agduzdag ore field), as well as deposits and ore occurrences of the vein quartz-copper formation of the hydrothermal-plutonogenic type (Kalaki, Danakert, Ayridag, Shakar-dara), mercury-antimony-arsenic formation hydrothermal-volcanogenic type (Agyatag, Darrydag, Salvarts, Orta-kend, Nagajir, etc.), as well as the manganese formation (Bichenag, Alyachi), native copper formations (Khalkhal, Asadkaf, Kyzylca, etc.) exaggeration-sediment genesis. Similar deposits are available in the metallogenic zone of Iran, Turkey [5].

The revealed correlations between Late Cenozoic volcanic associations, petrogeochemical types of volcanic formations and mineralization clearly reflect the leading role of volcanism of this period in the formation of the above-named minerals.

Within the investigated area, a considerable part of the epithermal gold-silver deposits is developed within the Agduzdag ore field. It is confined to the western part of the Kalbajar superimposed trough and is controlled by a joint junction near the latitudinal Kazykhanly-Agduzdag and near the meridianal Komurdag fault zones. According to V.M. Baba-zadeh et al., V.G. Ramazanov [2, 12, 15], the ore field is confined to a large volcano tectonic structure, such as the settling caldera, complicated in the central part by the Ketidag extrusion. According to their data, a significant role in the structure of the ore field belongs to the NE faults (Terter, Shirvan), which controls the placement of both intrusive and subvolcanic bodies and ore occurrences. And disruptive violations of the north-western direction are poorly developed and practically non-ore-bearing.

2.Geology of the Neogene volcanic complex of the Lesser Caucasus

The Late Miocene – Quaternary volcanic rocks in the Turkey – Iran Plateau and the Lesser Caucasus are calc-alkalic, moderately alkaline, and alkaline, with their total alkalinity increasing from NW to SE [1, 4, 6, 9, 13, 14].

The Late Cenozoic volcanism was manifested in the central area of the Lesser Caucasus in two stages: Late Miocene – Early Pliocene and Late Pliocene – Quaternary. Differentiated andesite-dacite-rhyolite association formed at the first stage, and bimodal rhyolite and weakly differentiated trachybasalt–trachyandesite associations, at the second stage (Imamverdiyev, 2000). Products of the Late Cenozoic volcanism are found in the upper reaches of the Terter and Akera rivers in the Azerbaijan area; these are erupted lavas and pyro clasts of different compositions (Fig. 1).

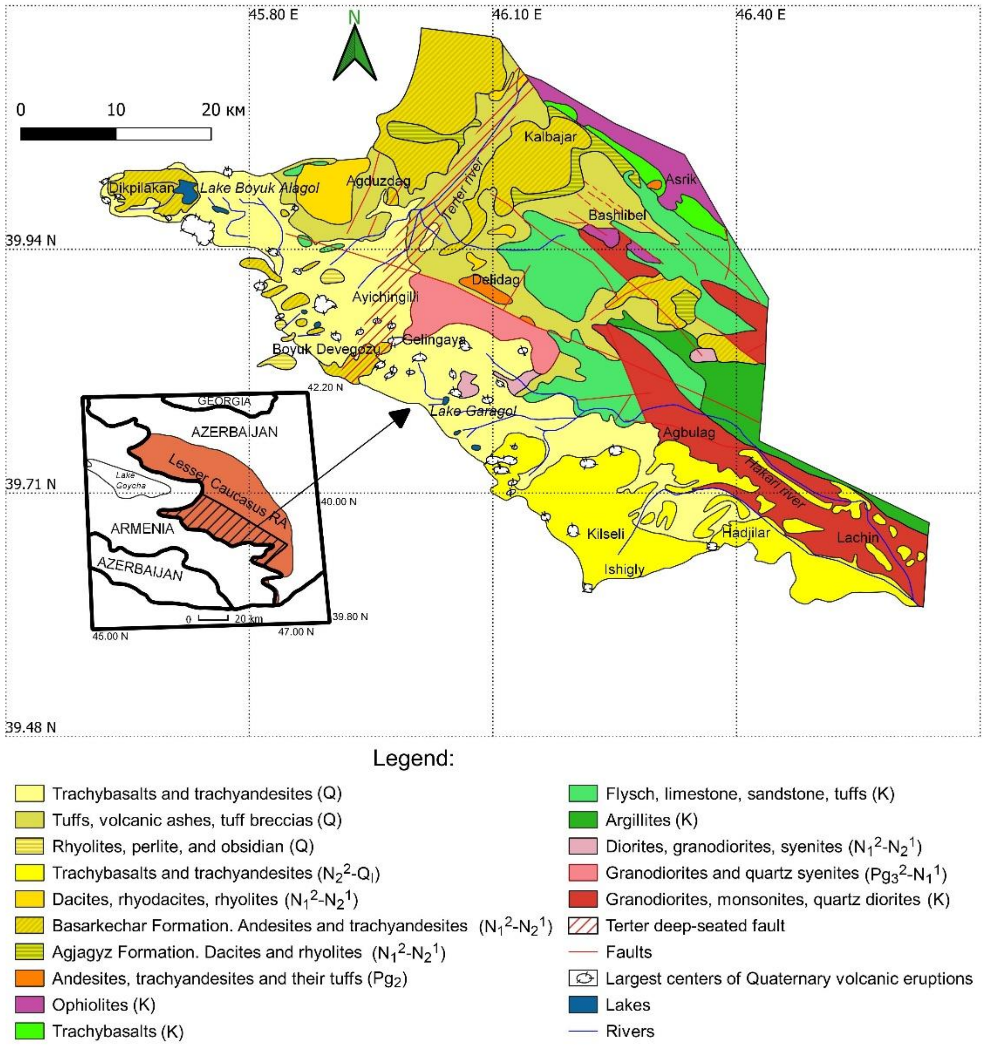

Fig. 1. *Geological map of Late Cenozoic volcanic associations in the central part of the Lesser Caucasus (Azerbaijan), scale 1:100,000. Compiled by N.A.Imamverdiyev (2000)*

The Neogene volcanism in the Lesser Caucasus was manifested mainly in the period from Late Sarmatian and Meotian – Pontian to Late Pliocene. A 200 m thick Upper Sarmatian volcanic complex in the central area of the Lesser Caucasus is described in literature as the *Agjagyz Formation*. It is composed of dacites, rhyolites, rhyodacites, and their pyroclastic derivates, namely, vitroclastic dacite and rhyolite tuffs. The volcanic rocks alternate with beds of normal sedimentary rocks (carbonaceous shales and lignite's).

In many sections, the base of the *Agjagyz Formation* has a thin andesite, dacite and trachyandesite nappe of irregular strike. Its thickness increases near Mt. Ketidag. Effusive rocks of the dacite – rhyolite complex correspond to the lava, pyroclastic, and root (subvolcanic, extrusive, and vent) facies. Lava facies rocks occur mostly within the Kelbajar–Istisu syncline. The lava flows are 5 to 15-20 m, seldom, up to 35 m in thickness. In vertical direction they are repeatedly changed by volcaniclastic flows or tuff horizons 3 to 20 m in thickness. The lava facies rocks are andesite dacites, dacites, rhyodacites, and rhyolites.

A 1150 m thick volcanic complex of Meotian – Pontian age was first recognized (Kashkai et al., 1952) as the *Basarkechar Formation*. It comprises dacite – trachydacites, andesite-trachyandesites, and quartz latites. The complex rests with angular and azimuthal unconformities upon the *Agjagyz Formation* and locally, Eocene and Cretaceous rocks.

The rocks of the *Basarkechar Formation* on volcanic highlands are considerably overlapped by Upper Pliocene – Quaternary volcanics. These are coarse-grained feldspathic (plagioclase or orthoclase) rocks as well as abundant acicular and prismatic amphiboles and foliated biotite's. Volcanic domes in these areas are composed mostly of andesites, trachyandesites, quartz latites, black and gray dacites, and rhyodacites. The section base is formed by lilac-gray biotite-hornblende andesites and trachyandesites.

Above, there is an exposed member of clumpy agglomerate tuffs consisting of poorly sorted andesite pebble. The tuffs are overlain by coarse-grained feldspathic trachyandesites and quartz latites reaching 300 m in thickness. Up section, they locally pass into welded tuff. The rocks of the andesite-dacite complex are often intruded by subvolcanic dacite–trachydacite bodies.

The volcanics of this complex are fresh as compared with the rocks of the lower complex. The regional paleo volcanic reconstructions suggest that the volcanism was related to the dome uplifting of the regional heterogeneous structure. Subaerial eruption of central-type volcanoes took place in residual and superposed depressions, in uplift zones, and in faults conjugate to deep-fault zones.

The effusive rocks of the *Basarkechar Formation* correspond to the lava, volcaniclastic, and root facies. The effusive-lava flows and nappies cover vast areas in the central area of the Lesser Caucasus. These flows reach 0.5-8 km in length, 400-800 m in width, and 20-60 m in thickness.

The lava facies rocks of the trachyandesite–trachydacite complex are dacite–trachydacites, andesite dacites, and andesite-trachyandesite-quartz latites.

We united these volcanic complexes into a differentiated *andesite-dacite-rhyolite association* [5-9]. According to geological data, the association is of Late Miocene-Early Pliocene age [11].

3.Epithermal gold-silver deposits of the Agduzdag ore field

The Agduzdag ore field is an integral part of the Ketidag synclinal structure, which in turn is complicated by the Komurdag synclinal and Zeylik anticline structures near the meridian direction.

The Zeylik anticline, encompassing the central part of the ore field, is complicated by numerous feathering structures of the Komurdag, Kazykhanly-Agduzdag fault zones and subvolcanic dikes, intrusive stems and Ketidag extrusion.

The near-axis part of the Zeylik anticline is prone to intensive fragmentation, changes with the development of numerous pre-ore tectonic discontinuities, to which gold-bearing ore bodies of near-meridian strike are confined.

In the zones of faults and in the jaws, the primary rocks were intensively altered and converted into quartzites and propylites. Hydrothermal metasomatic rocks in terms of material composition and spatial confinement to certain facies are divided into types of rocks, the relationships of which are very difficult to establish. Among the facies the most recent is the quartz-sericite type, especially the powerful process was the process of low-temperature silicification.

With the fields of hydrothermally altered rocks, a gold-silver mineralization is associated with the marginal part of the sub volcanoes. A significant part of the Au-Ag mineralization is concentrated in the chalcedony quartz and sulphidized hydrothermally altered zones near the meridional and northeastern directions. Mineralized zones are more developed in the region of subvolcanic dikes of rhyolites and dacites, and geochemical kinship is noted between them, which indicates a paragenetic relationship between gold-ore mineralization and late Miocene volcanism.

More than 60 quartz veins and hydrothermally altered zones have been identified in the ore field, which are concentrated on the Agduzdag, Vagif, Fizuli, Ketidag, Shirvan, and Zeylik ore occurrences (Fig. 2). In addition, along the r. Terter also knows numerous ore occurrences (Mishni, Ayrum, Kelbajar, Keshtek, Lower Isti-su, etc.), controlled by the Terter deep fault.

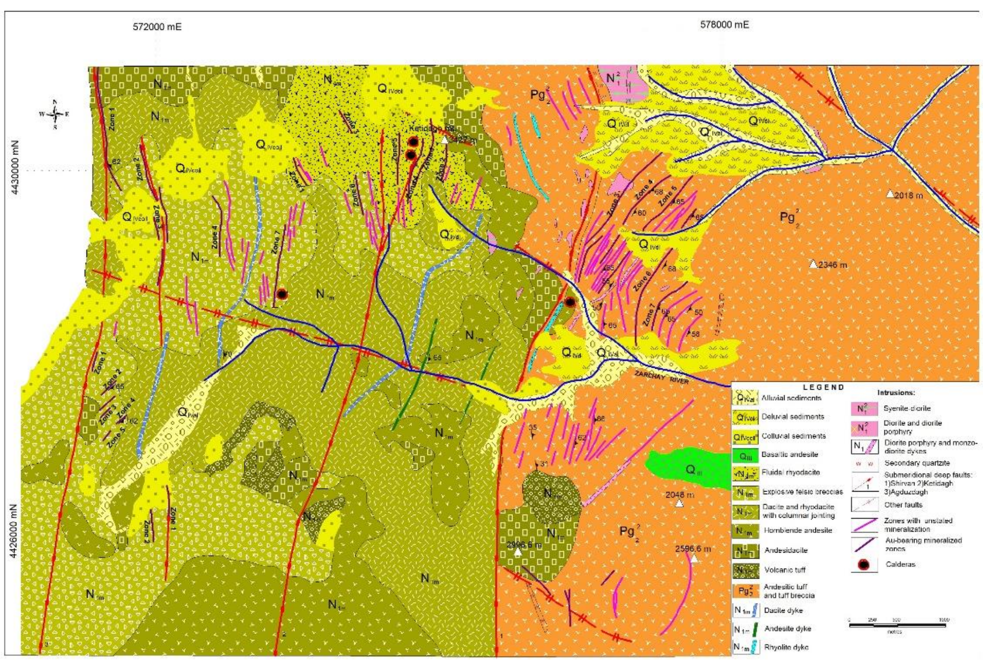

***Fig.2**. Schematic geological map of the Agdudzag ore area. Scale 1:10 000.*

In these manifestations, mineralization is developed in quartz veins, weakly sulfidized zones of hydrothermally altered rocks, stockwork and complex metasomatic deposits. In the ore occurrences, gold-bearing zones have been identified, the thickness and content of gold, in which it varies in different scales.

For example, in the Shirvan ore occurrence, a high gold content (over 5 ppm) is confined to a strong (40-60 m) zone, traced along the strike to 500 m. In Agdudzag ore occurrence, up to 16 ppm gold was detected.

Similar data are given for the Vagif, Sabir, and Zeylik ore occurrences. Thus, around development of hydrothermal altered rocks associated with subvolcanic formations of the Miocene-Pliocene age along the northeastern and near the meridional deep faults, gold ore zones are revealed. In the localization and placement of gold mineralization, the main role is played by the magma supply channels, deep faults and local discontinuous disturbances. It should be noted that, like the Miocene-Pliocene volcanic associations, gold ore occurrences are localized at the junction points of disruptive disturbances in the north-western and north-eastern directions. Apparently, along the faults, ore-bearing solutions move in different zones, and they are the most weakened, permeable and favorable for ore deposition. On the other hand, the fault zones, regionally controlling gold mineralization, are zones of ancient location and long-term development.

The material composition of the ore of the Agduzdag ore field is characterized by a simple mineral composition. The main mineral of veins is quartz (95-98%), and ore minerals represented by pyrite, chalcopyrite, sphalerite, galena, magnetite, native gold, altaite, aikinite, rutile, etc. account for 2-3% of the total mass of the ore. Most minerals are characterized by several generations. Quartz is represented by the largest number of generations; pyrite is present in quartz and in host rocks in the form of well-delineated crystals of the early stages of isolation and later irregular allotriomorphic grains, etc. Gold is established in two generations: 1) early dark gold in the form of minute (up to 0.052 mm) allotriomorphic inclusions in dense sugar-like quartz; 2) later light gold with a significant admixture of silver (electrum), which is characterized by a pronounced xenomorphism of grains performing the interstices between quartz.

Formation of gold ore zones of the Agduzdag ore field occurred by penetration of hydrothermal solutions through the systems of close fracture cracks and deposition of ore matter in intensively crushed, highly fractured tuffaceous rocks of the lava facies favorable for the development of metasomatic processes and ore formation. In the localization of mineralization, a significant role is played by the physic-mechanical properties of the enclosing rocks. The most favorable for its localization are the substantially porous tuffaceous rocks.

We associate gold mineralization with the post magmatic activity of the subvolcanic formations of the Miocene-Pliocene. In favor of this, the following arguments are presented: a close spatial relationship of hydrothermally altered zones with subvolcanic formations; relative one-age, the presence of similar minerals and elements-impurities in the composition of ores and rocks; and, finally, high gold content of subvolcanic rocks, where it varies within the range of 1.3-10.0 ppb, on average, 5.03 ppb.

Mineralization is multi-stage. We distinguish three stages of ore formation: 1) quartz-gold ore; 2) quartz-gold-sulfide; 3) quartz-carbonate. The bulk of gold (about 70%) was released into the second productive stage of the hydrothermal process. The quartz-carbonate stage is practically not gold-bearing.

Si, S, Fe, Ca, Ti, Cu, Pb, Zn, As, Sr, Mo, Ag, Au, Hg, Sb, Bi, Co, V, Ni, Cr, Ga, Se, Te, of which the most characteristic are Au, Ag, Cu, Zn, Mo, Pb, Hg, Sb, As, Ni, Co.

Formation of the first quartz-gold ore stage according to the decrepitation data occurred in the temperature range 240-340^0 C. According to the homogenization data, this interval ranges from 220 to 2450° C. Crystallization of minerals of the quartz-gold-sulfide stage, according to decrepitation, occurred in the temperature range 180-240^0 C. The homogenization temperature fluctuates in the interval 180-200^0 C. The temperature of formation of the quartz-carbonate stage occurred in the range 180-190^0 C.

According to the data of thermometric studies of gas-liquid inclusions in the minerals of the Agduzdag ore field, the formation of the deposit occurred at a temperature of 340-180^0 C, at a relatively shallow depth (0-500 m), where the lithostatic pressure did not exceed 200 atm (Baba-zadeh et al., 2000).

The deposits of the Agduzdag ore field belong to the wretched sulfide gold-quartz formation, closely related to the areas of development of the Moicene-Pliocene, mainly andesite-dacite volcanism. The sedimentary-tuffaceous strata of the middle Eocene, extrusive-subvolcanic bodies of andesite-dacites and rhyodacites of the andesite-dacite-rhyolite formation of Moicene-Pliocene are host rocks. Ore bodies are represented by hard-built, often secant veins, impregnation zones and stockworks, and localized in shallow discontinuities and zones of fracturing of various directions, which are fragments of annular and radial disturbances associated with the formation of volcanic-tectonic structures of various types and orders.

Gold manifestations are localized in the areas of distribution of subvolcanic formations (dikes, extrusions, etc.) of andesite-dacite, rhyodacite composition, with the largest role being played by the Ketidag extrusive, confined to the central part of the same volcanic-tectonic structure. The gold-bearing zones arc arced in zones of intense fracturing, framing smaller extrusions (Shirvan, Agduzdag, Sabir, etc.), or confined to cracks in the separation of the Ketidag extrusion itself.

On the Shirvan and Zeylik gold occurrences, the ore bodies are clearly controlled by the rhyodacite dykes, located in their hanging sides. These dikes are shattered by subsequent tectonic movements, hydrothermally transformed and converted into secondary quartzites and other metasomatites.

4.Origine of the epithermal gold-silver depozits of the Agduzdag ore field

Summarizing the above data, it can be concluded that epithermal gold-silver mineralization is spatially and paragenetically related to lavas, tuffs of rhyolites, dacites and andesites, and their subvolcanic formations of the Miocene-Pliocene age. In the zone of faults, these rocks are subject to hydrothermal changes with the formation of successively alternating facies of low-temperature type propylites and quartzites.

Within the investigated area, unlike the rocks of the Upper Sarmatian (Agjagiz formation), the volcanogenic rocks of the Meotic Pont-Lower Pliocene (Basarkechar formation) do not contain ore bodies and are not subject to hydrothermal changes; they differ from the underlying rocks by their freshness, subvolcanic dikes, hydrothermal-changed zone. In other words, metasomatic changes are mainly associated with acidic (dacite-rhyolite) complexes of the association and the hydrothermal activity that led to the formation of ores corresponded to the interval between the formation of Upper Sarmatian acidic subvolcanic bodies and the post-ore complex of tuffs and lavas of Meotic-Pont-Lower Pliocene andesites. This feature is sharply expressed within the Agduzdag ore field. In addition to gold, silver and mercury, a high content of Cu, Pb, Zn, Mo, As, Bi was found here [5, 6, 9]. In the altered acid rocks of the andesite-dacite-rhyolite association, other high concentrations of Cu, Pb, Zn, and Mo were also noted at other points. Therefore, analyzing the behavior of these elements in the crystallization differentiation process and in subsequent secondary changes, it is possible to determine the cause of the deposition of these elements in the process of hydrothermal activity. These elements do not accumulate in rock-forming minerals (K_d <1), remain in excess and accumulate in the residual mass. As a result of subsequent metasomatic and post magmatic hydrothermal processes, these elements are introduced by hydrothermal formations and can form their own deposits and ore occurrences.

Therefore, it can be argued that the existing deposits and manifestations of Au, Ag and Hg, and possibly Cu, Zn, Pb, Mo, Li, As, Sb, U, Th, associated with medium and acid rocks of the andesite-dacite-rhyolite association were formed due to the accumulation of these elements in the residual melt at low values of the combined distribution coefficients of these elements between crystals and melts. In the formation of deposits and ore manifestations of the above-mentioned elements, and possibly also of several other elements (W, Sn, Zr, REE, etc.), the role of magmatic processes, based on the behavior in magma of the above-named elements typical for hydrothermal deposits [3], where it is indicated that the coefficient of distribution of ore elements depends on temperature. Analyzing these studies, we can conclude that the crystallization of leucocratic minerals (quartz, feldspar) leads to a decrease in the combined distribution coefficient of these elements and their accumulation in residual magma. In our opinion, gold and silver, and possibly mercury, arsenic, antimony, behave similarly, which contributes to the accumulation of their residual melts.

In other words, the deep differentiation of calc-alkaline magmas (extended andesite-dacite-rhyodacite-rhyolite series) with an elevated content of alkalis, fluids lead to the formation of magmatic rocks rich in these elements. In subsequent post magmatic and hydrothermal processes, the circulation of hydrothermal solutions leads to leaching of ore elements from rocks and subsequent deposition under favorable conditions. In the Upper Miocene time, the general uplift was accompanied by the activation of all the faults that served as channels for the formation of medium and acid volcanogenic formations, penetration of hydrothermal solutions. These faults carry to the mercury zone deposits of Au, Ag, Pb, Zn, Cu, Li, As, Sb and other elements. Highly heated volatiles extracted from the melt, together with ore components, rising in an environment of stretching up the fault zones, could possibly remove such elements as Au, Ag, etc. from the host rocks of the continental crust and deposited in near surface conditions. In other words, in the formation of such deposits, the dominant role was played by the fluids of the magmatic deposit.

Thus, the formation of low-temperature gold-silver, mercury, possibly mercury-arsenic-antimony, copper-lead-zinc deposits and manifestations of the Lesser Caucasus in time are closely related to the Neogene medium-acid rocks of high potassium calc-alkaline magmatism and intense block movements along the deep faults in the period of the formation and development of grabens or graben troughs, which are made by Cenozoic volcanogenic, volcanogenic-sedimentary rocks.

5.Conclusions

A distinctive feature of the investigated Late Miocene- Early Pliocene rocks of the Lesser Caucasus is that they are generally medium and acid. Volcanites composition meets mainly andesites and trachyandesites, dacites and trachydacites and also rhyolites. The volcanism was very powerful in relation to the attic tectonic activity of Late Miocene-Early Pliocene. During this period there occurs Pre-Mesozoic base uplift and volcanism is mainly manifested in the central parts of the anticlinal zones of the Lesser Caucasus. The andesites and andesidacites with acid pyroclasts dominate in the products' composition at the beginning of the volcanic phase and at its end - andesite lavas. Magmatism of the main composition of high alkalinity has locally been manifested in the extreme parts of the anticlinal zones. Subvolcanic appearings of formation invaded after volcanogenic strata (Basarkechar suite) formation and have more acid composition. After active effusive-explosive activity of Meotian-Pontian-Early Pliocene volcanoes, more acid and viscous magma, cooling at a depth, rising along fractures at shallow depths hardened in the form of dikes and other subvolcanic bodies.

Gold ore fields in the investigated area are confined to systems of long-term faults of the north-western, northeastern near latitudinal and near-meridional directions with an external framing of ring structures, and mainly, by the junction of their intersections. These include the ore-controlled longitudinal Lachin-Bashlybel and transverse Terter faults and Kazykhanly-Agduzdag, Dalidag, Seutly and Agduzdag-Zods faults, and annular structures that support them.

The established spatial and genetic relationship of Au-Ag manifestations and deposits with the late Sarmatian dacite-rhyolite complex allows us to recommend them as magmatic and age-related search features. Here, the areas of development of hydrothermally altered volcanogenic formations of medium and acidic composition exposed in the zones of large faults can serve as the main search criterion.

Such, we conclude that the Neogene magmatism of the Lesser Caucasus and attendant mineralization & epitermal silver-gold deposits formation were results of postcollisional, slab breakoff-related mantle–crust dynamics.

Very promising areas include the development zones of hydrothermal-metasomatically altered rocks that preceded ore deposition and are expressed in propylitization, argillization, silicification, pyritisation and clarification. Promising targets can serve as areas of development of ring and linear structures in the areas of development of the Pliocene – Quaternary volcanogenic rocks, where, possibly, the ore occurrences are covered by these volcanogenic strata. In these places it is necessary to conduct detailed geophysical, geochemical work.

In general, the area of work can be considered promising for the detection of new Au, Ag, Hg, As, Sb ore, Au-Cu-Mo, Au-polymetallic, copper-polymetallic, polymetallic manifestations and deposits.

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