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DETERMINATION OF HYDROTHERMAL ALTERATION STAGES OF AGHYOKHUSH GROUP AND MEREH DEPOSITS (LESSER CAUCASUS)

(Представлено членом редакційної колегії д-ром геол. наук, проф. В.А. Михайловим)

Background. ***Aghyokhush Group deposits are located on a morphogenetic junction of the volcano-tectonic-related fault systems of the Lesser Caucasus. The referred fault systems mostly consist of fault groups, sub-meridional faults, and north-sloping syn-volcanic, tectonic fault systems and thrusts directed from northwest to southeast. The geological structure of the Chovdar ore area is where, the Aghyokhush group and Mereh deposits are located on complex Middle and Upper Jurassic magmatic, metamorphic, and sedimentary rocks. The mineral assemblages and alteration zones observed in the Aghyokhush group and Mereh ore deposits are considered indicators for explaining the formation mechanism of mineralization.***

Methods. ***To be able to understand structural controls on ore mineralization, geological mapping, and chip sampling was done by AzerGold CJS's geologists. As a result, predictions were made on the location, lithological compound, alteration characteristics, size, and grade of potential ore bodies. Consequently, to examine the form and shape, the grade of potential orebody diamond drilling was carried out on a site, and core material from each drill hole was logged and sampled during the explanatory process.***

Results. ***The mineral assemblages and alteration zones observed in the Aghyokhush group and Mereh ore deposits are considered indicators for explaining the formation mechanism of mineralization. Tectonic discontinuities resulted in crushing and brecciation, which led to hydrothermally altered joints, planes, and ore mineralization over the discontinuities, which also, infrequently resulted in fault planes along the faults. Widespread rhyolite and rhyolite-dacite rocks in the ore field are mainly volcanogenic-sedimentary and volcanic, also, in some interval's subvolcanic facies. Mineralization phases caused alteration of the rock facies within deposits. Hydrothermal zoning was observed within altered rocks, that gradually changed from the margins to the center. The minerals identified are pyrite, chalcopyrite, pyrrhotite (rarely), marcasite, siderite, barite, quartz (vein and veinlets), vuggy silica, chalcedony, malachite, azurite, hematite, limonite, goethite, kaolinite, alunite, chlorite, epidote, calcite 2M mica, and sericite in Aghyohkhush group and Mereh deposits. As a result of the research, it is thought that the mentioned deposits are formed by the hydrothermal alteration of medium to felsic composed volcanic and subvolcanic rock facies, as a satellite deposits that are associated with Chovdar epithermal gold deposit.***

Conclusions. ***Discovered deposits are formed by the hydrothermal alteration of medium to felsic-composed volcanic and subvolcanic rock facies, as satellite deposits that are spatially and temporally associated with the Chovdar epithermal gold deposit. Deposits are formed by hydrothermal processes which lead to intermediate to high-sulfidation alteration characteristics on lithological units within the ore area. The mentioned alteration styles and structural controls that led to the discovery of deposits will be implemented in future exploration works that are going to be carried out on a Chovdar ore area.***

Keywords: ***Aghyokhush group and Mereh ore deposits, Lesser Caucasus, hydrothermal alteration, intermediate to high-sulfidation porphyry-related epithermal deposits.***

Background

By the end of the 20th and the beginning of the 21st centuries, ideas on ore-controlling processes, metallogenic settings and the genesis of epithermal gold deposits of the Southern Caucasus have dramatically altered. Firstly, ideas that suggested illustrated somehow simultaneously, only controlled by faults, also, separate products of various ore-forming processes. Today ideas support that, the deposits are related by a common origin and separated from the magmatic bodies through faults and represent some unique factors such as alteration halos, mineral paragenesis and tectonic controlled by faults.

Exploration for low, intermediate, and high sulfidation epithermal gold deposits, detecting their general features, and developing contemporary methodology for their prospecting and exploration in the Lesser Caucasus were extremely important for improving the resources and discovery of new epithermal Au deposits such as Aghyokhush-1, 2, 3, and Mereh deposit (Arribas, 1995; Hedenquist, 2000; Goldfarb, Groves, & Gardoll, 2001; Payot et al., 2005; John et al., 2018; Wang et al., 2019, etc.).

All the deposits are controlled by faults. Only Au grades reach economically significant grades. Ag only can be mined within Au orebody, as gold mineralization is weakly associated with Ag. Ore mineralization that occurs within unaltered parts of deposits is strongly followed by disseminated and veinlet pyrite mineralization, also, chalcopyrite is abundant within the orebody. The economical cutoff grade for Au mineralization is considered to be 0.3 ppm and the ore material planned to be carried to the main Chovdar plant for processing.

Exploration work that is carried out through the Chovdar ore area, is firstly based on only geochemical sampling of the hydrothermally altered prospects. Also, during the time and energy-consuming sampling process, all the lithological units were representatively sampled to detect mineralization prospects. By obtaining some Au grades, we considered creating a geochemical anomaly map for the area. Investigation of all of the hydrothermal alteration styles that occur within and as halos corresponding to the anomalies that illustrate higher-grade Au mineralization was done during the exploration process. Such exploration process for

Au mineralization actively applied on exploratory work done within last years. As a result, collected data such as alteration styles and their correspondence to the Au mineralization, also using characteristics of alteration stages as an indicative factor throughout the exploration work carried in the region, resulted in detecting of new Au mineralization prospects such as Peyedere, Chaikend, Nerimanli and so on.

Methods

Geological setting. Lokh-Kharabakh zone Middle Jurassic-Cretaceous Island zone of global extent. This metallogenic belt covers territories of Armenia, Azerbaijan, Georgia, and it is covered by Cenozoic (Early Quaternary) andesite-basaltic nappes, and continues to Turkey and beyond. The modern metallogenic model of above mentioned zone is investigated by an international team of Swiss, Georgian, Armenian, and Azeri geologists (Mederer et al., 2013; Richards, 2015; Moritz et al., 2016).

Dashkasan ore district located in Lokh-Kharabakh metallogenic belt, is situated nearly 54 km southwest of Ganja, the second-largest city in Azerbaijan. Dashkasan region is known as one of the oldest mining industry cities of Azerbaijan and houses different geological processes representing epithermal, magmatic-sulfide, skarn, and other distinctive types of mineralization. The magmatism of the region occurred in two main phases, Lower Cretaceous and Upper Jurassic (Fig. 1). The rocks that formed during the mentioned periods such as Lower Bajocian were composed of basaltic-andesites and andesites, in contrast, rocks that were generated by Upper Bajocian aged volcanism were composed as dacite-rhyolitic or rhyolitic formations. Also, mentioned formations are sometimes cross-cut, covered, or dislocated by andesitic lava, tuffs, tuff-breccias, subvolcanic diabase dykes and bodies, tuff-conglomerates, tuff-breccias, tuff-sandstones and diorite to granodiorite porphyries produced during The Bathonian volcanism. The Upper Jurassic aged formations are mostly andesite lavas and tuff-sedimentary formations, tuff-breccias, tuff-sandstones, tuff-conglomerates, and fresh or marbled limestones. Intrusions that took most of the ore-forming processes that occurred during the Upper Jurassic – Lower Cretaceous are composed of aphanitic gabbros, gabbro-diorites, and diorite to granite intrusive or subvolcanic bodies.

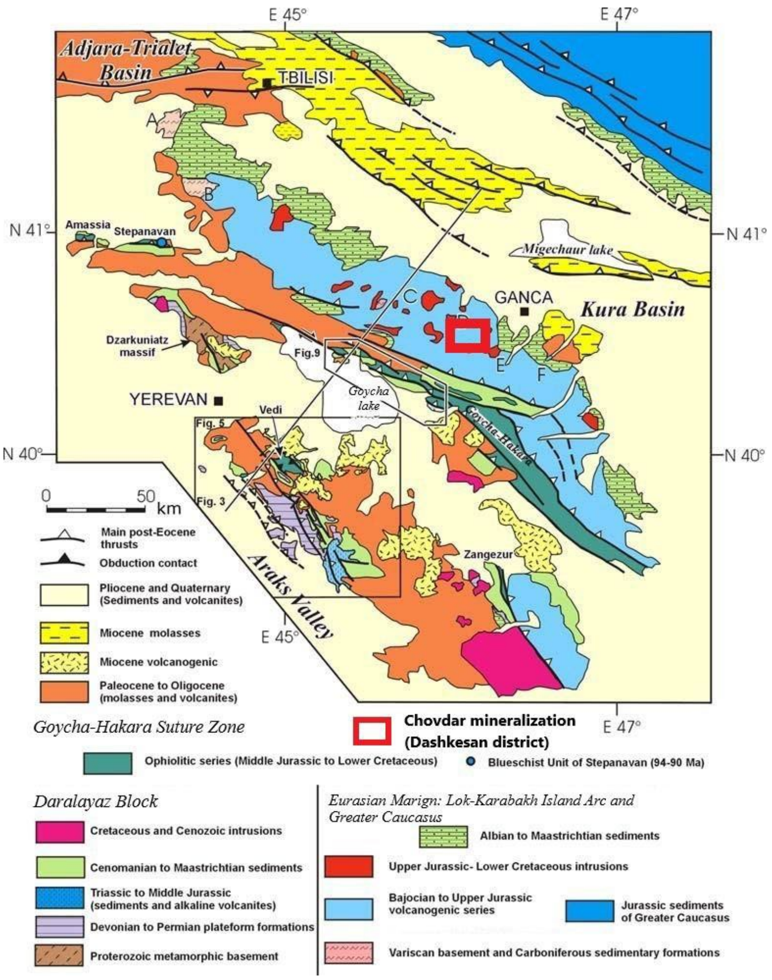

Fig. 1. Structural map of the Lesser Caucasus

The geology of the region is strongly complex due to the different characterized morphogenetic volcano-tectonic structures and fault systems. Faults, that are parallel directed such as Dashaltı, and Chovdar deposits, are located upstream of the Danayeri River with vertical strike angles that are characterized by brecciations due to the slickensided surfaces and narrow hydrothermal alterations. Barite veinlets are mainly connected to the mentioned fault systems. Geological and geotectonic investigation of the northern sides of the Chovdar mineralization area showed that the borderline for the local hydrothermal alteration zones is faults with lesser amplitudes.The above mentioned parallel directed faults are characterized by coulisse-shaped close occurrence and 75–85-degree dip angles.

Aghyokhush group and Mereh deposits are situated in the Dashkesan district of Azerbaijan, within a Caucasian segment of the Tethyan metallogenic belt, one of the world's major metallic provinces, that consists of many sectors. The geodynamic evolution of the Caucasian segment of the Tethys metallogenic belt was observed with the subduction and collision of Arabia and Gondwana-derived microplates with the Eurasia plate (Moritz, & Baker, 2019, Sosson, Rolland, & Müller, 2019). The mentioned deposits are located in the Lok-Karabakh belt of the Lesser Caucasus metallogenic province. From the Jurassic to the approximately end of the Cretaceous the Lok-Karabagh belt of the Lesser Caucasus belonged to a relatively continuous magmatic arc. Ore deposition formed during the Jurassic to Cretaceous subduction-related magmatism occurs mainly in porphyry Cu-Mo, epithermal Au-Cu, skarn deposit, also discretely spread in polymetallic (Pb, Zn) mineralization areas. They are typically distributed in discrete areas and ore districts along the magmatic belt and deposited spatially and temporally connected to the gabbro-diorite to granodiorite compounded intrusive and subvolcanic bodies.

The main ore-controlled structure known as Sadax-Narchala-Pirinyal started from the Cobalt mine and continued towards the east-northern direction of Aghyokhush group deposits until crossed with the Hachagaya-Peyedere-Nuzgar fault system (Fig. 2). The mentioned structure lies parallel to the Chovdar deposit and restricts the deposit's volcanic structures in the east-southern direction. Right in this part mentioned fault system branches out are likely in swarm-bundle form, by crossing the Narchala deposit and covering the Aghyokhush group deposits.

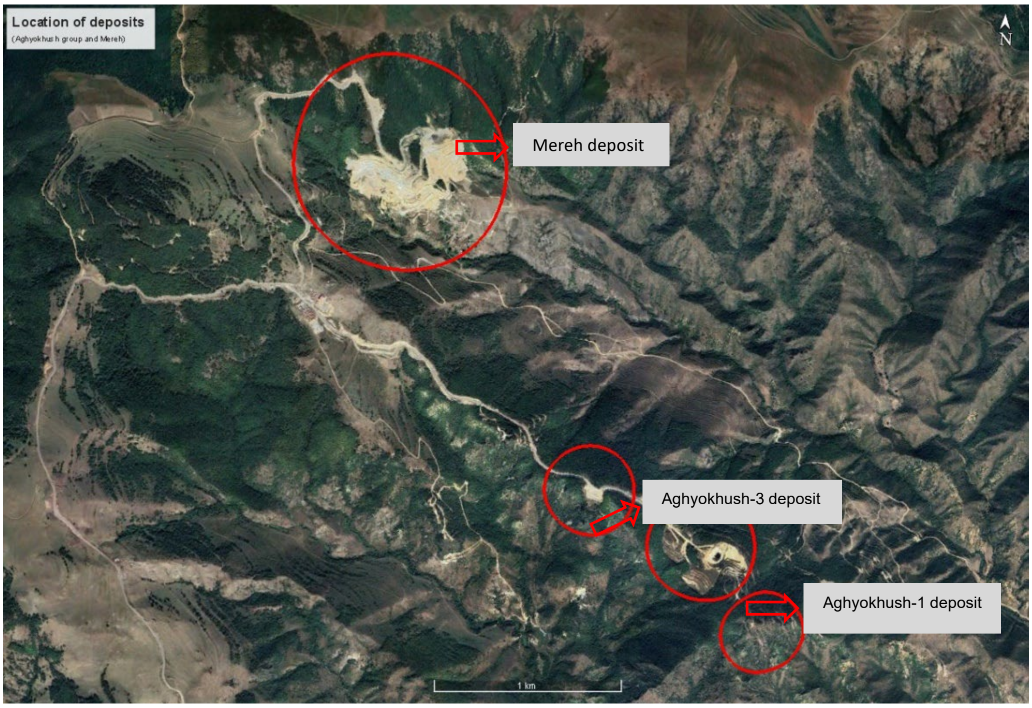

Fig. 2. Location of Aghyokhush group and Mereh deposit

Mineralization. Petrological and mineralogical determinations were made from drill core and surface samples to identify mineral paragenesis and lithological characteristics of ore bodies and wall rock. The mineralization area generally consists of the Bajocian and the Bathonian aged intermediate to felsic volcanic rocks that typically occur as andesitic, dacitic, and rhyolitic composition. The composition of Middle Jurassic rocks is typically Lower Bajocian aged and composed from basaltic-andesites, also, the Upper Bajocian aged dacite-rhyolite rocks. Due to the intensive metasomatic processes, sometimes we are unable to differentiate rocks that are composed differently. Mentioned behavior mainly occurs between dacitic and rhyolitic rocks. Sometimes relict structures of rocks are used to detect lithofacies of volcanics. In some areas, rock units are cross-cut and complicated by various dykes and subvolcanic bodies (Musayev, Huseynov, & Naghiyev, 2020). Unlike the Aghyokhush deposits, the subvolcanic body of the quartz-diorite porphyries bounds the northern to north-western part of the Mereh deposit. Quartz-diorite-composed rock is typically unaltered and does not constrain any ore-containing mineralization. Some intervals of the diorite porphyries are cross-cut by quartz-carbonate veinlets and rarely contain visible disseminated marcasite also infrequently (rarely) pyrite mineralization. On rock wall contact quartz-diorites are slightly altered by the propylitic alteration, with the presence of chlorite mineralization. All the deposits constrain Au mineralization within the orebody which is mainly composed of hydrothermally altered rhyolite, rhyolite-dacitic, and slightly dacitic volcanic and subvolcanic series.

Mineralisation Aghyokhush-1 deposit mainly argillic to advanced argillic from surface to deeper horizons with the presence of kaolinite, alunite (infrequent), dickite (rarely), and pyrophyllite within the residual and vuggy silica, also strong silicification of rhyodacite and rhyolitic volcanic (Musayev, Huseynov, & Naghiyev, 2020). Due to weathering, sulfide minerals are not common and overprinted by Fe oxide and hydroxides in the ore body. Ore mineral assemblages follow Au mineralization within alteration compounded limonite, and infrequent hematite. Gangue minerals such as calcite and gypsum are uncommon within the orebody. Barite mineralization is common and increases respectively with Au mineralization. Barite mineralization shows up as veinlets that fill cracks and fissures and also form mineral aggregates within the cavities of vuggy silica (Naghiyev et al., 2021).

Aghyokhush-2 deposit is mostly known for its advanced argillic to the argillic alteration from deeper horizons to surface with the presence of kaolinite, alunite, within the residual and vuggy silica, also strong silicification of rhyodacite and rhyolitic volcanic. Secondary quartzites (residual, vuggy silica) take up a significant part of the ore body. Due to the weathering, sulfide minerals are not common and are overprinted by mostly Fe oxides in the ore body. In contrast ore mineral assemblages that follow Au mineralization in the Aghyokhush-2 mostly hematite, are compared to limonite in the Aghyokhush-1. Also, gangue minerals such as calcite, and gypsum are not common within the orebody. However, barite is common and increases respectively to Au mineralization. Barite mineralization in Aghyokhush-2 is logged more frequently than in Aghyokhush-1 and shows as veinlets that fill cracks and fissures and also form mineral aggregates within the cavities of silicic alteration.

Mineral assemblages of the Aghyokhush-3 deposit showing the silicic (mostly) character of the ore body must be noticed, and alteration changes respectively from the surface to the middle of the orebody, with the presence of halloysite and kaolinite, sericite (rare). The ore body was made up by strongly silicified rhyodacitic and rhyolitic volcanic rocks. Compared to the Aghyokhush-2 deposit, In Aghyokhush-3 vuggy silica is uncommon, silicification mostly occurs as residual silica, chalcedony particles within the brecciated rock mass, and silicified intervals. Sulfide minerals such as disseminated pyrite are detected within ore mass. Also, ore mineral assemblages that follow Au mineralization are mostly limonite and hematite approximately in ~3/1 ratio. Gangue minerals such as calcite, and gypsum are detected rarely and not common within the orebody. Barite mineralization was noticed logged only in a few intervals.

Mineralization of the Mereh deposit is characterized as phyllic to silicic (mostly) from surface to center of the orebody with presence of 2M mica (rare), kaolinite, and sericite, with strong silicification of rhyodacite, rhyolitic volcanic rocks. Compared to Aghyokhush-2–3 deposits, In Mereh silicification mostly occurs partly vuggy silica, residual silica, strongly silicification of the rock mass, and chalcedony breccias within hydrothermally brecciated intervals of the ore body. Sulfide minerals such as disseminated and veinlet pyrite, rarely chalcopyrite are detected within ore mass. Also, ore mineral assemblages that follow Au mineralization are mostly disseminated, veinlets (infrequent) pyrite, limonite, and hematite within the weathered zone. Gangue minerals such as calcite, and gypsum are detected rarely and not common within the orebody. Barite mineralization is uncommon and not logged.

Ephithermal enviroments of Aghyokhush group and Mereh deposits. It is obvious that deposits with various textures and mineral assemblages refer to different stages of epithermal environments, also, mineral associations, and fluid inclusions that record temperature and pressure. The maximum temperature recorded in an epithermal environment is about 300°C, although most of the deposits form in a temperature interval from 160° to 270 °C (Hedenquist, Arribas, & Gonzalez-Urien, 2000). Hydrostatic pressure limits the maximum temperature by the vapor pressure of boiling water at a given depth. As there is the strongest evidence that boiling is common within epithermal deposits, the temperature interval mentioned above corresponds to a depth range of about 50 to 700 m below the paleowater table, respectively (Sillitoe, 1999). The reason for mineral deposition in the epithermal environment is variation in the composition of fluids due to the fast change of thermobaric parameters within the epithermal environment, from deeper horizons to the surface. Also, intensive changes in temperature and pressure parameters cause boiling, which is the reason for the precipitation of bisulfite-complexed metals such as gold. Boiling and the immediate rapid temperature drop also result in numerous related features, such as gangue mineral deposition such as calcite, barite, adularia, gypsum veinlets, kaolinite, alunite, sericite, also, mineralization of quartz with various structures and textures, and so on. Formation of steam-heated waters and hot springs that create alteration halos and lithographs such as chalcedony and/or opaline blankets, alunite-kaolinite, silica sinter, and so on (Hedenquist, Arribas, & Gonzalez-Urien, 2000).

As mentioned above main alteration style of the Aghyokhush-1 and 2 deposits is strongly argillitic to advanced argillitic, with the presence of kaolinite, alunite, vuggy silica, and pyrophyllite. Barit aggregates are abundant within the ore body and are associated mainly with vuggy silica. Deposits separated each other with andesitic to andesite-dacitic volcanics. Ore bodies were completely oxidized and sulfide minerals in the Aghyokhush-1 deposit changed mostly iron hydroxides as limonite (with the presence of goethite) and weakly distinguishable hematite. Whereas, in the Aghyokhush-2 deposit complete oxidization occurs with abundant presence of hematite with rare limonitisation. There is a weak correlation of Au with As, Sb, and Hg in deposits that are all oxide, suggesting some secondary mobility of this suite of elements. Barite is an insoluble gangue mineral that commonly accompanies high-sulfidation sulfide mineralization, and it remains even after the complete oxidation of sulfides. The presence of vuggy quartz, kaolinite, and alunite, and their occasional association with barite enable us to characterize the epithermal environment of both deposits as high-temperature acid-sulfate composition, high-sulfidation epithermal deposits (Fig. 3 A, B).

The main alteration style of the Aghyokhush-3 deposit is mostly silicic and phyllic with the presence of kaolinite, sericite (rarely), and halloysite. Barit aggregates are not common and not logged in drill cores. Deposits are located in north-western side of the same morphogenetic volcano-tectonic fault system of the Aghyokhush-1 and 2 deposits and cross-cut faults with lesser amplitude. Ore body almost oxidized and sulfide minerals in the Aghyokhush-3 deposit changed mostly iron hydroxides as limonite and hematite. Hematite mineralization is less abundant than limonite. Pyrite minerals were detected within unchanged chalcedony particles that were observed in hydrothermally brecciated intervals that were cemented with clay minerals or late silicification. The presence of kaolinite, halloysite sericite (rarely) and silicic alteration enable us to characterize the epithermal environment of the deposit as shallow depth intermediate to late high-sulfidation epithermal deposit. The presence of sericite and absence of alunite and barite enable us to predict that the mineralization on the Aghyokhush-3 deposit results in a relatively less pH and lower temperature environment than Aghyokhush-1 and 2 deposits (Fig. 3 C).

Fig. 3. (A) Representative core samples from the orebody of the Aghyokhush-1 deposit. The presence of vuggy silica kaolinite within the orebody indicates high pressure and highly acidic fluids that precipitated gold grades as argillic to advanced argillic alteration HS deposit. (B) Typical core samples from the orebody of the Aghyokhush-2 deposit. Hydrothermal alteration dominated by vuggy and residual silica that is associated with kaolinite and alunite indicates low pH, and high temperature advanced argillitic (strongly) HS epithermal deposit. (C) Core samples from the Aghyokhush-3 deposit that illustrate weathered, crushed and fractured, strongly altered, kaolinized volcanic rock with the presence of halloysite and residual silica also silicified breccias specify deposit as HS epithermal deposit (relatively shallow deep, low temperature). (D) Representative core samples from the Mereh deposit with the presence of silicification, chalcedony fragments, silicified breccias, sericite, and hydrothermal brecciation within the orebody indicate high-pressure and high-temperature fluids that show characteristics of greater deep high-sulfidation epithermal deposit

Alteration style on the Mereh deposit is characterized as silicic to phillic altered, with the presence of 2M mica (rarely), kaolinite, sericite, residual silica (some intervals with vuggy quartz), chalcedony fragments within hydrothermal brecciated intervals. Barit aggregates were not detected on the drill core and outcrop samples. The deposit is located in north-western side of the Quytul-Narimanli-Aghyokhush fault system. The north-western part of the deposit is bordered with quartz-diorite subvolcanic rocks. The ore body itself is partly weathered and contains sulfide minerals such as pyrite, and chalcopyrite (rarely). Weathering changed sulfide minerals to limonite and hematite. Marcasite is not common and only observed on quartz-diorite rocks, within slightly chloritized intervals and without any correlation with Au mineralization. Silicification is strong within orebody, kaolinite, and sericite mineralization is common. All above mentioned factors enable us to characterize the epithermal environment of the deposit intermediate to high-sulfidation epithermal deposit (Fig. 3 D).

Discussion and conclusions

The Aghyokhush-1, 2, 3, and Mereh gold deposit located in the Dashkesan ore district belongs to the Lok-Karabakh metallogenic belt and is tectonically situated in the subduction-related zone in the Lesser Caucasus region. Region characterized it is multi-stage volcano-plutonic activity periods that caused the formation of Chovdar, Aghyokhush, Mereh epithermal, and other porphyry-epithermal, skarn deposits in the Lok-Karabakh metallogenic district.

The main ore minerals observed in the research area are limonite, hematite, pyrite, and chalcopyrite. In a region scale deposit is surrounded by mineral assemblages of propylitic alteration (chlorite-sericite-epidote). Barite, which is a gangue mineral in high sulfidation deposits, indicates an end member of the epithermal processes in the region and commonly fills up the fault systems as veinlets. Also, it is insoluble and remains in the system, when all sulfides are weathered and oxidized. The hydrothermal alteration zones identified in Aghyokhush-1, 2 deposits are argillic to advanced argillic, and in the Aghyokhush-3 and Mereh deposits phyllic to silicic.

In general, as a result of the given data above, in the region rocks that contain ore mineralization are called the altered rhyolites and secondary quartzites. Phyllic, advanced argillic, and argillitic alterations are observed in secondary quartzites and a significant part of the ore mineralization is observed within mentioned zones. Hydrothermal alteration is considered as high-sulfidation moderate to acidic ≥2 pH (presence of alunite) below the paleosurface water table to 150–300 meters (presence of residual silica, vuggy quartz) in Aghyokhush-2 and 1 deposit (Hedenquist et al., 1996). In the Aghyokhush-3 deposit hydrothermal alteration is considered as intermediate to high-sulfidation, but less acidic compared to Aghyokhush-1 and 2. Logged 2M mica (rarely), kaolinite, sericite, and pyrophyllite (rarely), enables us to consider the hydrothermal alteration of Mereh deposit at greater depth (approximately ~500 meters), high temperature, intermediate to high-sulfidation epithermal deposit.

By using the mentioned factors such as alteration halos and rock facies that are strongly related to mineralization, and ore-controlled fault systems new Au mineralization prospects were detected and are currently under investigation stage. Formerly in the region, the main factors for exploration processes considered even or both faults and alteration characteristics, while, exploration work that was done by our team considered taking into account firstly alteration characteristics as a vector, faults as a ore controlling factors, and lithofacial characteristics of the rocks. For instance, by taking into account all the mentioned factors, exploration work that was done in the region, Narimanli, and Peyedere mineralization areas were discovered. Alteration style of the Narimanly Au area is strongly similar to the Mereh deposit and characterized as silicic to phillic altered, kaolinite, sericite, residual silica (some intervals with vuggy quartz), chalcedony fragments within hydrothermal brecciated intervals. Relict fragments of unaltered rocks illustrate rhyolitic to rhyolitic volcanics. The alteration style of the Chaikend Au area is silicic and phyllic with the presence of kaolinite, sericite (rarely), and halloysite. Due to the alteration of the rocks facial belonging of the rocks was identified by unaltered parts and fragments, and again, Au containing altered orebody mostly belong to either rhyolitic or rhyodacitic compounded volcanic.

As a result, all the data given above, which illustrate the style of mineralization, alteration halos, and rock facies that are strongly related to mineralization can be complex methods for the exploration of new potential Au and Cu porphyry deposits. However, the unresolved part of the question is the investigation of the temperature, and pressure, and, detailed mineralogical, fluid inclusion, and petrographic analyses will provide more precise information about the deposits. As formerly stated, porphyry and epithermal deposits are reported separately, also, without any attention to the potential genetic relation between them (Ghaderi, Narges, & Mina, 2018; Kuşcu, Tosdal, & Gençalioğlu-Kuşcu, 2019, etc.). However, Sillitoe outlined a genetic unity of porphyry copper and epithermal gold mineralization (Sillitoe, 2000).

As mentioned above, the studying of the P/T conditions, investigation ore mineralogy, fluid inclusion, isotope and petrographic analyses must be done to establish comprehensive exploration strategy and methodology, that, can lead to discovery of several porphyry copper and high sulfidation epithermal gold deposits in region.

Authors' contribution: Sultan Heybet JAFAROV – writing, investigation, methodology, formal analysis, conceptualization, data curation, supervision; Nazim Ajdar IMAMVERDIYEV– investigation, writing, visualization, data curation, formal analysis, supervision.

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References

Arribas, A., Jr. (1995). Characteristics of high sulfidation epithermal deposits, and their relation to magmatic fluid. In J. F. H. Thompson (Ed.), *Magmas, Fluids, and Ore Deposits* (pp. 419–454). Mineralogical Association of Canada.

Ghaderi, M., Narges, Y., & Mina, B. K. (2018). *Porphyry copper deposits of Iran*. Tarbiat Modarres University Press.

Goldfarb, R. J., Groves, D. I., & Gardoll, S. (2001). Orogenic gold and geologic time: A global synthesis. *Ore Geology Reviews*, 18(1–2), 1–75.

Hedenquist, J. W., Arribas, A., Jr., & Gonzalez-Urien, E. (2000). Exploration for epithermal gold deposits. *Reviews in Economic Geology*, 13, 245–277.

John, D. A., Vikre, P. G., du Bray, E. A., Blakely, R. J., Fey, D. L., Rockwell, B. W., Mauk, J. L., Anderson, E. D., & Graybeal, F. T. (2018). *Descriptive models for epithermal gold-silver deposits* (Scientific Investigations Report 2010–5070–Q). U.S. Department of the Interior, U.S. Geological Survey.

Kuşcu, I., Tosdal, R. M., & Gençalioğlu-Kuşcu, G. (2019). Chapter 8. Porphyry-Cu Deposits of Turkey. In F. Pirajno, T. Ünlü, C. Dönmez, & B. M. Şahin (Eds.), *Mineral Resources of Turkey* (pp. 337–425). Springer Nature Switzerland AG.

Mederer, J., Moritz, R., Ulianov, A., & Chiaradia, M. (2013). Middle Jurassic to Cenozoic evolution of arc magmatism during Neotethys subduction and arc-continent collision in the Kapan Zone, southern Armenia. *Lithos*, 177, 61–78.

Moritz, R., & Baker, T. (2019). Metallogeny of the Tethyan Orogenic Belt: From Mesozoic Magmatic Arcs to Cenozoic Back-Arc and Postcollisional Settings in Southeast Europe, Anatolia, and the Lesser Caucasus: An Introduction. *Economic Geology*, 114(7), 1227–1235.

Moritz, R., Rezeau, H., Ovtcharova, M., Tayan, R., Melkonyan, R., Hovakimyan, S., Ramazanov, V., Selby, D., Ulianov, A., Chiaradia, M., & Putlitz, B. (2016). Long-lived, stationary magmatism and pulsed porphyry systems during Tethyan subduction to post-collision evolution in the southernmost Lesser Caucasus, Armenia and Nakhitchevan. *Gondwana Research*, 37, 465–503.

Musayev, Sh., Huseynov, F., & Naghiyev, M. (2020). *Report / notification on "Discovery and its commercial value" on Agyokhush gold deposit*.

Naghiyev, M., Gojayeva, N., Jafarov, S., et al. (2021). Determination of hydrothermal alteration zones containing mineralization in Chovdar gold deposit, Dashkesan region. In *3rd International European conference on interdisciplinary scientific researches* (pp. 536–542).

Payot, B. D., Maglambayan, V. B., Dimalanta, C. B., Yumul, G. P., Jr., Tamayo, R. A., Jr., Matsuda, T., Suzuki, S., & Bellon, H. (2005). Geology and hydrothermal alteration of the low sulfidation Pantingan Gold System, Mount Mariveles, Bataan (Luzon), Philippines. *Resource Geology*, 55(3), 155–162.

Richards, J. P. (2015). Tectonic, magmatic, and metallogenic evolution of the Tethyan orogen: From subduction to collision. *Ore Geology Reviews*, 70, 323–345.

Sillitoe, R. H. (1999). Styles of high-sulphidation gold, silver and copper mineralization in the porphyry and epithermal environments. In *Pacrim '99 Congress, Australasian Institute of Mining and Metallurgy, Bali, Indonesia, Proceedings* (pp. 29–44).

Sosson, M., Rolland, Y., & Müller, C. (2010). Subductions, obduction and collision in the Lesser Caucasus (Armenia, Azerbaijan, Georgia), new insights. *Geological Society, London, Special Publications*, 340, 329–352.

Alizade, A. *(Ed.). (2005). Geology of Azerbaijan. Vol. 6: Useful minerals (2nd ed.). Nafta-Press* [in Russian]. [Али-заде, А. (Гл. Ред.). (2005). *Геология Азербайджана. Т. 6: Полезные ископаемые* (2-е изд.). Nafta-Press.].

Wang, L., Qin, K., Song, G., & Li, G. (2019). A review of intermediate sulfidation epithermal deposits and subclassification. *Ore Geology Reviews*, 107, 434–456.

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ВИЗНАЧЕННЯ СТАДІЙ ГІДРОТЕРМАЛЬНОГО ЗМІНЕННЯ РОДОВИЩ АГЙОХУШСЬКОЇ ГРУПИ ТА МЕРЕХ (МАЛИЙ КАВКАЗ)

В с т у п . ***Родовища групи Агйохуш розташовані на морфогенетичному стику вулкано-тектонічних систем розломів Малого Кавказу. Згадані системи розломів переважно складаються з груп розломів, субмеридіональних розломів та систем сино-вулканічних, тектонічних розломів із північним нахилом і насувів, спрямованих із північного заходу на південний схід. Геологічна структура рудного району Човдар, де розташовані родовища групи Агйохуш та Мерех, складена складними магматичними, метаморфічними та осадовими породами середньої та верхньої юри. Мінеральні асоціації та зони зміни, що спостерігаються в рудних родовищах групи Агйохуш та Мерех, розглядаються як індикатори для пояснення механізму утворення мінералізації.***

М е т о д и . ***Для розуміння структурного контролю рудної мінералізації геологи AzerGold CJS виконали геологічне картування та шліхове опробування. В результаті зроблено прогнози щодо розташування, літологічного складу, характеристик зміни, розміру та вмісту потенційних рудних тіл. Відповідно, для вивчення форми та розміру, вмісту потенційних рудних тіл на ділянці проведено алмазне буріння, а керновий матеріал з кожної свердловини задокументовано та відібрано під час розвідувального процесу.***

Р е з у л ь т а т и . ***Мінеральні асоціації та зони зміни, що спостерігаються в рудних родовищах групи Агйохуш та Мерех, розглядаються як індикатори для пояснення механізму утворення мінералізації. Тектонічні розриви призвели до дроблення та брекчіації, що спричинило гідротермально змінені тріщини, площини та рудну мінералізацію над розривами, що також, нечасто, призводило до площин розломів уздовж розломів. Широко розповсюджені ріолітові та ріоліт-дацитові породи в рудному полі є переважно вулканогенно-осадовими та вулканічними, а також, в деяких інтервалах, субвулканічними фаціями. Фази мінералізації спричинили зміну гірських фацій усередині родовищ. Гідротермальна зональність спостерігалася в змінених породах, яка поступово змінювалася від країв до центру. Виявлені мінерали: пірит, халькопірит, піротин (рідко), марказит, сидерит, барит, кварц (жили та прожилки), пористий кремнезем, халцедон, малахіт, азурит, гематит, лімоніт, гьотит, каолініт, алуніт, хлорит, епідот, кальцит, слюда 2M та серицит у родовищах групи Агйохуш та Мерех. В результаті досліджень вважається, що згадані родовища утворені гідротермальною зміною вулканічних та субвулканічних гірських фацій середнього та кислого складу, як сателітні родовища, пов'язані з епітермальним золоторудним родовищем Човдар.***

В и с н о в к и . ***Виявлені родовища утворені гідротермальною зміною вулканічних та субвулканічних гірських фацій від середнього до кислого складу, як сателітні родовища, просторово та тимчасово пов'язані з епітермальним золоторудним родовищем Човдар. Родовища утворені гідротермальними процесами, що призводять до характеристик зміни від проміжного до високосульфідного типу на літологічних одиницях у межах рудного району. Згадані результати досліджень, що призвели до відкриття родовищ, будуть застосовані в майбутніх розвідувальних роботах, які проводитимуться в рудному районі Човдар.***

К л ю ч о в і с л о в а : ***родовища Агйохушської групи та Мерех, Малий Кавказ, гідротермальне змінення, проміжні до високосульфідних порфірові епітермальні родовища.***

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