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GEOLOGICAL CHARACTERISTICS AND HYDROTHERMAL ALTERATION FEATURES OF AGHYOKHUSH GROUP DEPOSITS

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Abstract

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. The geological structure of the Chovdar ore area where is Aghyokhush group and Mereh deposits are located made of 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.

Keywords: Dashkasan, mineralization, Chovdar, Aghyokhush, Mereh

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Introduction:

The Dashkasan region, located approximately 54 km southwest of Ganja, the second-largest city in Azerbaijan, represents one of the most historically significant mining districts in the country. It features a diverse array of geological processes and metallogenic systems, including epithermal, magmatic-sulfide, and skarn-type mineralization. The area's complex geodynamic evolution and lithological diversity make it a valuable site for studying ore-forming processes within volcanic-tectonic environments (Imamverdiyev, Jafarov, 2025).

This study presents the geological framework, lithological characteristics, and hydrothermal alteration-mineralization patterns of the Aghyokhush-1, Aghyokhush-2, Aghyokhush-3, and Mereh deposits in the Dashkasan ore district. These deposits are hosted in volcanic and subvolcanic rocks of Middle Jurassic to Lower Cretaceous age and exhibit distinct alteration styles and mineral assemblages typical of high-sulfidation (HS) epithermal environments. The purpose of this work is to clarify the relationship between host lithologies, structural controls, hydrothermal alterations, and the distribution of gold-bearing mineralization.

Geological setting

The geology of the Dashkasan district is shaped by multiple magmatic and tectonic episodes that occurred predominantly during the Upper Jurassic and Lower Cretaceous periods. Two principal magmatic phases are recognized (figure 1):

1. **Lower Cretaceous Volcanism** – characterized mainly by basaltic-andesitic and andesitic flows.
2. **Upper Jurassic Volcanism** – comprising dacitic to rhyolitic lava and pyroclastic formations.

The Middle Jurassic volcanic rocks are dominantly represented by:

- **Lower Bajocian**: basaltic-andesites and andesites.
- **Upper Bajocian**: dacitic and rhyolitic lava flows and pyroclastics.

These sequences are often intruded, covered, or offset by andesitic lavas, tuffs, tuff-breccias, subvolcanic diabase dykes, tuff-conglomerates, and porphyritic rocks of diorite to granodiorite composition, associated with Bathonian-aged volcanism. The Upper Jurassic sequences also include andesitic lavas interbedded with tuff-sedimentary units, marbled limestones, and tuff-breccias (Imamverdiyev et al., 2015).

The intrusive bodies related to ore-forming processes—most active from the Upper Jurassic to Lower Cretaceous—include aphanitic gabbros, gabbro-diorites, and diorite to granite intrusions and subvolcanic stocks.

Structurally, the region is marked by a complex network of volcano-tectonic fault systems, including the Dashaltı and Chovdar structures. These faults are oriented roughly parallel and exhibit brecciation, slickenside surfaces, and hydrothermal alteration halos. Many vein-type barite mineralizations are spatially associated with these faults. Detailed investigations near the Chovdar area show that local alteration boundaries are also defined by lesser-amplitude faults. These are generally coulisse-shaped, with steep dips of 75–85°, and show significant control over mineralization trends.

The principal ore-controlling structure, known as the **Sadax–Narchala–Pirinyal Fault System**, extends from the historic Cobalt mine eastward, intersecting with the Hachagaya–Peyedere–Nuzgar system. This structural corridor parallels the Chovdar deposit and marks the eastern boundary of the volcanic complex hosting the Aghyokhush group of deposits. Toward the northeast, it branches into a swarm-like configuration, encompassing the Narchala and Aghyokhush deposits.

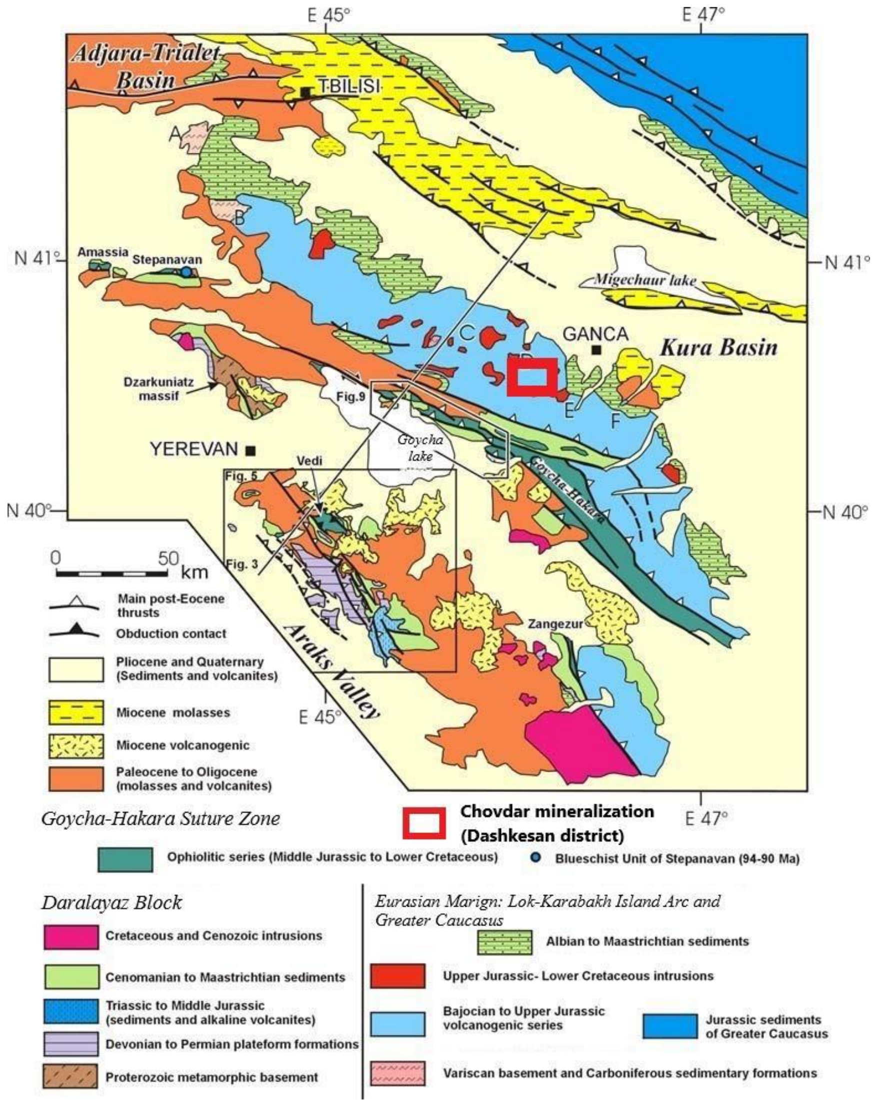

Figure 1. Structural map of the Lesser-Caucasus

Mineralisation

Petrological and mineralogical analyses were conducted on drill core and surface samples to determine the mineral paragenesis and lithological characteristics of both the ore bodies and the surrounding wall rocks. The mineralized zone is generally hosted within intermediate to felsic volcanic rocks of Bajocian to Bathonian age, predominantly andesitic, dacitic, and rhyolitic in composition (Sosson et al., 2010).

Middle Jurassic formations are typically Lower Bajocian in age and consist mainly of basaltic-andesites, while Upper Bajocian units are characterized by dacitic to rhyolitic compositions. Due to intense metasomatic alteration, it is sometimes challenging to distinguish between rocks of differing original compositions—this is especially true between dacitic and rhyolitic units. In such cases, relic structures within the rocks may be used to infer the original volcanic lithofacies (Robert Moritz, Timothy Baker, 2019).

In several areas, these volcanic units are intruded and disrupted by numerous dykes and subvolcanic bodies. Unlike the Aghyokhush deposit, a prominent subvolcanic quartz-diorite porphyry body marks the northern to northwestern boundary of the Mereh deposit. This quartz-diorite is generally unaltered and does not host significant ore-related mineralization. However, in some intervals, it is cut by quartz-carbonate veinlets and may rarely contain disseminated marcasite or, less commonly, pyrite. At the contact with host rocks, the quartz-diorite shows signs of weak propylitic alteration, notably with chlorite development. Gold mineralization across the deposits is primarily hosted in hydrothermally altered rhyolite, rhyodacite, and slightly dacitic volcanic and subvolcanic sequences.

At the Aghyokhush-1 deposit, alteration transitions from argillic to advanced argillic from surface down to deeper levels. This is marked by the presence of kaolinite, occasional alunite, rare dickite, and pyrophyllite, all within residual and vuggy silica zones, along with strong silicification of rhyodacitic and rhyolitic rocks. Due to surface weathering, sulfide minerals are rare and largely replaced by iron oxides and hydroxides. The ore-related mineral assemblage associated with gold includes limonite and, less frequently, hematite. Gangue minerals such as calcite and gypsum are uncommon within the ore zones. Barite mineralization is widespread and correlates positively with gold enrichment. It typically occurs as veinlets filling fractures and fissures, and as mineral aggregates within vuggy silica cavities.

The Aghyokhush-2 deposit is primarily characterized by a vertical zonation of hydrothermal alteration, transitioning from advanced argillic at depth to argillic alteration toward the surface. This alteration assemblage includes kaolinite and alunite associated with zones of residual and vuggy silica, accompanied by pervasive silicification of rhyodacitic and rhyolitic volcanic rocks. Secondary quartzites, particularly residual and vuggy silica varieties, form a substantial portion of the ore body. Due to the effects of surface weathering, sulfide minerals are largely absent and are typically overprinted by iron oxides. In contrast to the Aghyokhush-1 deposit—where limonite is the predominant weathering product—hematite is more commonly associated with gold mineralization at Aghyokhush-2. Gangue minerals such as calcite and gypsum are rare, while barite is a frequent accessory mineral. Its abundance appears to correlate with zones of higher gold concentration. Barite typically occurs as veinlets filling fractures and fissures, as well as aggregates within cavities formed by silicic alteration.

The Aghyokhush-3 deposit exhibits a distinctly silicic character, with alteration intensity and mineral composition varying with depth. The upper levels of the ore body transition into middle-depth zones featuring a mineral assemblage that includes halloysite, kaolinite, and, to a lesser extent, sericite. The host rocks consist mainly of strongly silicified rhyodacitic and rhyolitic volcanics. Unlike Aghyokhush-2, vuggy silica is not a dominant feature in Aghyokhush-3; instead, silicification is primarily manifested as residual silica and scattered chalcedony fragments within brecciated volcanic rocks and silicified intervals. Disseminated pyrite is present within the ore mass. Gold mineralization is accompanied predominantly by limonite and hematite, typically in a 3:1 ratio. Gangue minerals such as calcite and gypsum are seldom encountered, and barite mineralization is limited to a few sporadic intervals.

The Mereh deposit is distinguished by a phyllic to silicic alteration assemblage, progressing from the surface toward the core of the ore body. Alteration minerals include kaolinite and sericite, along with rare occurrences of 2M mica, all set within a matrix of strongly silicified rhyodacitic and rhyolitic volcanic rocks. Compared to the Aghyokhush-2 and -3 deposits, silicification in Mereh displays a broader range of textural varieties, including partial vuggy silica, residual silica, pervasive silicification, and chalcedony breccias, particularly within zones affected by hydrothermal brecciation. Sulfide minerals are present as disseminated and veinlet pyrite, with occasional chalcopyrite observed in mineralized intervals. The ore assemblage associated with gold includes disseminated pyrite, infrequent veinlets of pyrite, and subordinate limonite and hematite, especially in weathered zones. Gangue minerals such as calcite and gypsum are rarely detected, and barite mineralization is notably absent in this deposit.

Epithermal Environments of the Aghyokhush Group and Mereh Deposits

Deposits exhibiting a range of textures and mineral assemblages correspond to various stages within epithermal environments. These mineral associations, along with the fluid inclusions that capture temperature and pressure conditions, provide key insights. The maximum temperature within an epithermal setting typically reaches approximately 300°C, though most deposits form within a temperature range of 160°C to 270°C (Hedenquist et al., 2000). Hydrostatic pressure constrains the maximum temperature by the vapor pressure of boiling water at specific depths. Given the strong evidence of boiling within epithermal systems, the aforementioned temperature range is typically associated with depths between 50 and 700 meters beneath the paleowater table (Hedenquist et al., 1996; Sillitoe, 1999). The deposition of minerals in these environments is driven by fluid composition variations, which result from rapid shifts in thermobaric conditions from deeper levels to the surface. These fluctuations in temperature and pressure also induce boiling, which facilitates the precipitation of bisulfite-complexed metals like gold. Additionally, the rapid temperature drop associated with boiling leads to the deposition of gangue minerals such as calcite, barite, adularia, gypsum veinlets, kaolinite, alunite, and sericite, along with the mineralization of quartz exhibiting various textures and structures. The formation of steam-heated waters and hot springs further generates alteration halos and lithological formations, including chalcedony or opaline blankets, alunite-kaolinite zones, and silica sinter (Lindgren, 1933).

The primary alteration style observed in the Aghyokhush-1 and 2 deposits is predominantly argillitic to advanced argillitic, characterized by the presence of kaolinite, alunite, vuggy silica, and pyrophyllite. Barite aggregates are notably abundant within the ore bodies, typically associated with vuggy silica. These deposits are separated by andesitic to andesite-dacitic volcanic rocks. The ore bodies in the Aghyokhush-1 deposit are extensively oxidized, with sulfide minerals having been primarily altered to iron hydroxides such as limonite (with goethite present) and faint hematite. In contrast, the Aghyokhush-2 deposit shows complete oxidation, with hematite being the dominant iron oxide and only rare occurrences of limonitization. There is a weak correlation between gold (Au) and arsenic (As), antimony (Sb), and mercury (Hg) in the oxide zones of both deposits, indicating some secondary mobility of these elements. Barite, an insoluble gangue mineral, frequently accompanies high-sulfidation sulfide mineralization and persists even after the sulfides are fully oxidized. The presence of vuggy quartz, kaolinite, and alunite, often in association with barite, allows the epithermal environment of both deposits to be classified as high-temperature, acid-sulfate, high-sulfidation epithermal deposits (Figure 2. A, B).

The primary alteration style of the Aghyokhush-3 deposit is predominantly silicic and phyllic, with the presence of kaolinite, sericite (rarely), and halloysite. Barite aggregates are not commonly observed and have not been logged in the drill cores. This deposit is situated on the north-western side of the same morphogenetic volcano-tectonic fault system that hosts the Aghyokhush-1 and 2 deposits, though it is intersected by cross-cutting faults of lesser amplitude. The ore body is nearly fully oxidized, with sulfide minerals primarily altered to iron hydroxides, such as limonite and hematite, although hematite is less abundant than limonite. Pyrite minerals were identified within unaltered chalcedony particles, which are found in hydrothermally brecciated intervals, cemented by clay minerals or late-stage silicification. The presence of kaolinite, halloysite, sericite (infrequently), and silicic alteration allows for the characterization of the epithermal environment at this deposit as shallow, intermediate to late-stage high-sulfidation. The presence of sericite, coupled with the absence of alunite and barite, suggests that the mineralization at Aghyokhush-3 occurred in a relatively lower-pH and lower-temperature environment compared to the Aghyokhush-1 and 2 deposits (Figure 2 C).

The alteration style observed in the Mereh deposit is classified as silicic to phyllic, characterized by the presence of 2M mica (rarely), kaolinite, sericite, residual silica (with some intervals exhibiting vuggy quartz), and chalcedony fragments within hydrothermal breccia zones. Barite aggregates were not detected in either drill core or outcrop samples. This deposit is situated on the north-western side of the Quytul-Narimanli-Aghyokhush fault system. The north-western portion of the deposit is bordered by quartz-diorite subvolcanic rocks. The ore body itself is partially weathered and contains sulfide minerals such as pyrite and chalcopyrite (rarely). Weathering has altered the sulfide minerals to limonite and hematite. Marcasite is relatively uncommon, being observed only within slightly chloritized intervals of quartz-diorite rocks, and shows no correlation with gold (Au) mineralization. The deposit exhibits strong silicification, with kaolinite and sericite mineralization being common. These factors collectively allow for the characterization of the epithermal environment at Mereh as an intermediate to high-sulfidation epithermal deposit (Figure 2 D).

Figure 2. (A) Representative core samples from the Aghyokhush-1 deposit. The presence of vuggy silica and kaolinite within the orebody suggests high-pressure, highly acidic fluids responsible for the precipitation of gold, indicative of an argillic to advanced argillic alteration style typical of high-sulfidation (HS) epithermal deposits. (B) Typical core samples from the Aghyokhush-2 deposit. Hydrothermal alteration is characterized by vuggy and residual silica associated with kaolinite and alunite, indicating a low-pH, high-temperature environment, which corresponds to an advanced argillitic, strongly high-sulfidation (HS) epithermal deposit. (C) Core samples from the Aghyokhush-3 deposit, exhibiting weathered, crushed, and fractured volcanic rock with significant kaolinization, halloysite,

and residual silica, along with silicified breccias. These features are consistent with a high-sulfidation epithermal deposit, but at relatively shallow depths and lower temperatures. (D) Representative core samples from the Mereh deposit, showcasing silicification, chalcedony fragments, silicified breccias, sericite, and hydrothermal brecciation. These characteristics suggest high-pressure, high-temperature fluids at greater depths, indicating a high-sulfidation epithermal deposit.

Conclusion

The Aghyokhush-1, 2, 3, and Mereh gold deposits are situated within the Dashkesan ore district, part of the Lok-Karabakh metallogenic belt, and are tectonically located in the subduction-related zone of the Lesser Caucasus region. The area is characterized by multi-stage volcanic-plutonic activity, which has led to the formation of the Chovdar, Aghyokhush, Mereh epithermal, and other porphyry-epithermal and skarn deposits within the Lok-Karabakh metallogenic district.

The principal ore minerals identified in the research area include limonite, hematite, pyrite, and chalcopyrite. The regional deposits are surrounded by mineral assemblages exhibiting propylitic alteration, specifically chlorite-sericite-epidote. Barite, a common gangue mineral in high-sulfidation deposits, marks the terminal phase of epithermal processes in the region and frequently fills fault systems as veinlets. Its insolubility allows it to persist in the system after the oxidation and weathering of sulfide minerals. The hydrothermal alteration zones observed in the Aghyokhush-1 and 2 deposits are predominantly argillic to advanced argillic, while the Aghyokhush-3 and Mereh deposits are characterized by phyllic to silicic alterations.

Overall, the mineralization in this area is linked to calc-alkaline felsic magmatism. The rocks hosting the ore mineralization are predominantly altered rhyolites and secondary quartzites, with phyllic, advanced argillic, and argillitic alterations observed in secondary quartzites. A significant portion of the ore mineralization is concentrated within these altered zones. The hydrothermal alteration in the Aghyokhush-1 and 2 deposits is classified as high-sulfidation, moderate to acidic (≥2 pH), with the presence of alunite, and occurs beneath the paleowater table at depths of 150-300 meters, as indicated by the presence of residual silica and vuggy quartz (Hedenquist et al., 1996). In contrast, the Aghyokhush-3 deposit exhibits intermediate to high-sulfidation alteration, but with a lower level of acidity compared to the Aghyokhush-1 and 2 deposits. The presence of 2M mica (rarely), kaolinite, sericite, and pyrophyllite (rarely) suggests that the hydrothermal alteration at the Mereh deposit occurred at greater depths (approximately 500 meters), at higher temperatures, and within an intermediate to high-sulfidation epithermal environment.

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