Mineralogical features and formation conditions of the Zafar copper-gold deposit (Lesser Caucasus, Azerbaijan)

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Abstract. The Zafar copper-gold deposit is located in Gadabay ore district, 3.5 km northwest of the Gadabay gold mine and 2 km southwest of the Ugur mine. This newly discovered copper-gold deposit contains 6.8 million tonnes of measured resource (0.5% Cu, 0.4 ppm Au and 0.6 % Zn, according to Zafar JORC Mineral Resource Estimate Update Report 2022). SEM analyses were carried out via «JSM-6610LV Scanning Electron Microscope» manufactured by JEOL USA. Petrographic studies were carried out using a ZEISS microscope with ZEN 2.3 imaging software. In this stage of the research we defined mineralogical properties of rocks and gold bearing mineralization type. According to the SEM analysis, gold mineralization formed in the pyrite, chalcopyrite (their derivatives too) stages. Based on the mineralogical study, the main ore minerals consist of pyrite, chalcopyrite, enargite, sphalerite, arsenopyrite, galena, baryte, pyrrhotite and stembergite (silver mineral) based on polished section results. The main gangue minerals are quartz, baryte and carbonate. Quartz crystals in bands are euhedral to anhedral, vary in size from microcrystalline to coarse grained. The Zafar deposit was formed by two events. The first event is the formation of the «massive pyrite» related to small Later Bajocian sub-volcanic rhyolite-dacite bodies. The second event is assumed to be «copper-pyrite» and «copper-zinc» mineralization and is reported to be formed by the post-magmatic activity of the Gadabay diorite intrusive. This study has demonstrated new ideas about the formation and genesis of the Zafar deposit. The K-rich calc-alkaline composition of various rocks indicates that subduction-related magmatism occurring along Lok-Karabakh belt had a crucial role in forming this deposit. The information given in the article is of practical importance for regional predictive metallogenic constructions, prospecting and evaluation of epithermal Au–Cu deposits.

Key words: Zafar, copper-gold deposit, ore minerals, gold, copper, ore formation conditions

Мінералогічні властивості та умови формування Зафарського мідно-золотого родовища (Малый Кавказ, Азербайджан)

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Анотація. Зафарське мідно-золоторудне родовище розташоване в Гедабайському рудному районі, в 3,5 км на північний захід від Гедабайського золоторудного рудника і в 2 км на південний захід від Угурського рудника. Це нещодавно відкрите мідно-золоте родовище містить 6,8 мільйона тонн вимірюваних ресурсів (0,5% Cu, 0,4 ppm Au та 0,6% Zn, згідно з оновленим звітом про оцінку мінеральних ресурсів Zafar JORC за 2022 рік). SEM-аналіз проводив за допомогою скануючого електронного мікроскопу JSM-6610LV виробництва JEOL USA.Петрографічні дослідження проводили за допомогою мікроскопа ZEISS із програмним забезпеченням ZEN 2.3. На даному етапі досліджень ми визначили мінералогічні властивості пород і тип золотовмісної мінералізації. За даними SEM-аналізу, мінералізація золота утворилася на стадіях піриту, халькопіриту (та його похідних). Виходячи з мінералогічних досліджень, основні рудні мінерали складаються з піриту, халькопіриту, енаргіту, сфалериту, арсенопіриту, галеніту, баріту, ітіурібергиту (мінерал зрошення) за результатами полірованого розрізу. Основними корисними мінералами є кварц, баріт і карбонат. Кристали кварцу в смугах від ідіоморфних до ксеноморфних.
Introduction

The Zafar Cu-Au±(Zn-Ag) deposit is a new discovery in Gadabay ore district in the Lesser Caucasus region of Azerbaijan. The Gadabay ore district is one of the main producing mining districts of Western Azerbaijan, and is the largest porphyry-epithermal ore field of the country. The ore district belongs to the Lok-Karabakh island of the Jurassic–Cretaceous age, formed by subduction of the Tethys Ocean to the Eurasian Caucasus in the Tethys metallogenic belt. The Lesser Caucasus is located in the central part of the Tethys metallogenic belt. It is located within the Jurassic-Cretaceous Lok-Karabakh magmatic arc, resulting from the subduction of the Tethys Ocean along the Eurasian margin.

The Gadabay Contract Area (GCA) is approximately 300 km² in size and is the site of the Gadabay Open Pit Mine, Gadabay Underground Mine, the Ugur Open Pit Mine (now mined out) and the Gadir Underground mine. Zafar is located approximately 1.5 km northwest of the Gadabay mine processing plant and is accessed by the road that linked the Gadabay and Ugur mines (Fig.1). It lies within the Gadabay Contract Area. Mineralization in the area was discovered by AIMP geologists based on complex data interpretation in 2020 (Anglo Asian Mining JORC Mineral Resource Estimate Report for Zafar July 2021). Nearly 3.5 million tons of mineable reserve with an average grade of 0.7% Cu, 0.8% Zn, and 0.6 ppm Au, is on the agenda for Anglo Asian Mining Plc in 2022.

Geological settings, nature of mineralization, ore mineralogy and hydrothermal alteration forms indicate intermediate sulphidation epithermal deposit type for the Zafar copper-gold deposit.

Methods of research

SEM analyses were carried out using a «JSM-6610LV Scanning Electron Microscope» manufactured by JEOL USA in the laboratory of the Institute of Geology and Geophysics under Azerbaijan National Academy of Science. Petrographic studies were carried out using a ZEISS microscope with ZEN 2.3 imaging software.

Firstly, petrographic observations of samples were made under reflected light. After the microscop-
ic study of the polished sections, a total of 5 samples with details of ore grains were analyzed on the Scanning Electron Microscope.

Sample preparation was realized according to standard procedures: cutting or trimming, grinding, polishing etc. First, the samples were cleaned and then a small piece was put on the sample holder with carbon double adhesive tape on it. Before the observations under the reflected light microscope, surfaces of the polished section were cleaned with alumina polishing abrasives to prevent any extrinsic oxidation. During the preparation of the article, maps were drawn based on the data of the company, and results of chemical and geochemical analyses were used. Macro and micronutrient analysis (over 500 micronutrients, including Au, Ag, Cu) was performed by X-ray fluorescence (XRF) laboratory at SGS Mineral Services UK LTD in Ontario.

Geological setting

The Lesser Caucasus is part of the Tethys metallogenic belt, which is one of the world’s major metal producing belts. The Lesser Caucasus is located in a continental collision zone between the Eurasian and the Africa-Arabian plates (Fig.2.). The formation of various types of ore deposit in the Lesser Caucasus is related to three major tectonic settings associated with the closure of the Tethys Ocean: 1) the subduction of the Tethys during the Middle-Jurassic-Early Cretaceous; 2) the collision stage associated with the closure of the Tethys during the Upper-Cretaceous, and 3) different post-collisional processes occurring during the Cenozoic. However, ore deposits located in the Lesser Caucasus are poorly reported in the occidental literature. The geological history of the Gadabay area and metallogenic processes associated with the Zafar deposit can be related to the Late Paleozoic intensive magmatic activity which occurred throughout the Lesser Caucasus. During the Middle-Jurassic to Early-Cretaceous period, volcanism peaked in the Caucasus and thus the geology is dominated by prominent volcanism and intrusion bodies (Baba-zadeh, Valiyev, Abdullayeva et al., 2015; Geology of Azerbaijan, Tektonika, 2005).

The surface geology of the Zafar copper-gold deposit is dominated by Upper Bajocian strata age rocks. The Upper Bajocian strata lava facies are quartz-plagioporphyryte (rhyolite-dacite porphyry), dacite and rhyolite lavas and tuffs, some of which are obscured by argillic and phyllic alteration, which makes definitive classification of the original lithology difficult (Fig. 3). Volcanic rocks are andesitic to rhyolitic in composition, and mainly dated from the Bajocian to Bathonian (Mineralno-sireviye resurs; Azerbaydzhana, 2005; Geology of Azerbaijan Maqmatism, 2003). The sub-surface geology is only known from the drill cores retrieved from the current drilling programme.

This demonstrates an upper layer of approximately 200 m to 300 m, which is dominated by dacite (DAC) with sub-ordinate andesite (AD) and porphyritic andesite (AP). Below this depth a sharp contact is made with what has been logged as quartz porphyry (QP). There are also zones of hydrothermal breccias (BC) as well as numerous dykes and faults (FAU) throughout the sequence (Valiyev, Bayramov, Ibrahimov et al., 2018).

Upper Bajocian strata age rocks. The rocks of this substage in the investigated area are widely developed and traced from the northeast and northwest directions to the centre. In tectonic condition they are confined to a block of Arykhdam anticline bounded from the northeast and southwest by the Gadabay-Bittibulag and Gadabay-Shekarbek faults respectively, which are composed of magma-incurrent and ore-incurrent canals of Upper Bajocian volcanism. The rocks of the effusive facies are represented by various fragmental tuffs (from ash to agglomerate) and mantles of rhyolite and rhyolite-dacite porphyrites. They have light-grey with pinkish, sometimes yellowish
grey colour. The rocks under a microscope have a felsite structure and contain fragmentary examples of quartz and plagioclase. In rare cases mica is observed. Cement is represented by an argillaceous-siliceous bulk coating the fragments. The rocks of the effusive facies of Upper Bajocian Substage are not outcropped within the bounds of the deposit (Geology of Azerbaijan Maqmatism, 2003).

Lower Bajocian volcanic rocks are represented by alternation of andesite-basalts, andesite-porphyrites with thin-bedded interlayers of fragmental crystalline-lithoclastic andesite tuffs. They are also characterised by alternation of andesite and andesite-basalt lava porphyrites with sets of medium- to thick-layered fine- to medium-grained clastic tuffs with diabase sill at the bottom.

Andesites are macroscopically represented by taupe (dark grey), greenish-grey thick rocks. Under a microscope they have a porphyritic structure. Porphyry exhalations are represented by plagioclase. Plagioclase is also observed in the main bulk as fine, medium and coarse grains. In the main bulk, chlorite, epidote and sometimes zeolite are quite often observed.

Andesite-basalts are represented by taupe, almost black, massive rock of porphyry structure. Under a microscope, a porphyry structure is observed in the rock. Porphyry exhalations are represented by quite large, tabular individuals which are substantially pelletized and sericitized. The main bulk has a microlitic structure and extensively chloritized and sericitized.

Bathonian volcanogenic rocks. The renewal of volcanic activity began in the Bathonian Stage, however there were some shifts both in their composition towards mafic species and in the spatial location of their flow centers. Volcanic formations of Bathonian Age within the bounds of the mapping area are observed in the upper layer of Eastern sector and some area of Western sector of the Qizilcadag Mountain. On sediments of Upper Bajocian Substage there are transgressively occurring formations of Bathonian Stage represented by an alternation of fine- and thin-layered, ashy and agglomerated tuffs with rare interlayers of andesitic-porphyritic breccia and andesitic-dacitic lavas (Geology of Azerbaijan Maqmatism, 2003).

Metamorphic rocks. Within the bounds of the prospecting area there are widely developed different facies of contact-metamorphic and hydrothermal-metasomatic rocks. Contact-metamorphic rocks are represented by hornfelses and silicified andesite rocks.

Copper, gold, zinc and silver mineralization appears to be mostly associated with the underlying quartz porphyry.

There are also several local and regional scale faults such as Zafar and Shimal faults, which may pass through the Zafar mineralisation if these faults persist and are vertical.

Study techniques

5 polished sections under the microscope and 15 SEM analyses of these 5 polished sections were realized for the Zafar deposit. Firstly, petrographic observations (ZEISS microscope with ZEN 2.3 imaging software) of samples under the reflected light were realized.
After the microscopic study of the polished sections, a total of 5 samples with details of ore grains were analyzed on the Scanning Electron Microscope in the laboratory of the Institute of Geology and Geophysics under Azerbaijan National Academy of Sciences. SEM analyses were carried out using a «JSM-6610LV Scanning Electron Microscope» manufactured by JEOL USA.

The selection of the individual details that were dealt with for SEM analysis was based on the variety of ore minerals, their compactness, their representative morphological forms and of course their position, which enables reliable diagnostics under SEM. Analyses have shown that the analyzed ore minerals confirm the positive identification under the optical microscope and gave the mineral compositions with some influence on the associated trace minerals standard for minerals of this type.

Within the current ore minerals study (petrographic and SEM analysis), samples were analyzed taken from cores of 5 exploration drill holes drilled at different parts of the Zafar deposit. 21GED21 (ZF21-319.2) West, 21GED22 (ZF22-322) North, 21GED37 (ZF37-322) South and 21GED25, 45 (ZF25-248.7, ZF45-225.4) located East parts of the Zafar deposit. Of the total obtained and shortened specimens, a total of 5 samples from 5 drill holes were evenly selected for the needs of the mineralogical study so that different levels could be enclosed and studied within the drilled area (Fig.7). From those 5 samples, 5 polished sections were made and investigated under optical microscopes and 15 SEM (Scanning Electron Microscope) analysis of these polished sections.

Sample preparation was realized according to standard procedures: cutting or trimming, grinding, polishing etc. First, the samples were cleaned and then a small piece was put on the sample holder with carbon double adhesive tape on it. Before the observations under the reflected light microscope, surfaces of the polished section were cleaned with alumina polishing abrasives to prevent any extrinsic oxidation. During the preparation of the article, maps were drawn based on the data of the company, and results of chemical and geochemical analyses were used. Macro and micronutrient analysis (over 500 micronutrients, including Au, Ag, Cu) was performed by X-ray fluorescence (XRF) laboratory at SGS Mineral Services UK LTD in Ontario.

During the observations the SEM analyses, ore minerals and gold inclusions were determined. Copper and gold grade are not uniform in the deposit. Gold inclusion mainly was observed in chalcopyrite. Small gold inclusion was observed with SEM analysis in chalcopyrite in samples ZF21-319.2, ZF25-248.7, ZF37-322, ZF45-225. Gold was found inside arsenopyrite in the baryte part of the polished section on SEM analysis in sample ZF22-322.

The calculated mineral formulas of the samples were described in tables beside photos of the SEM (Fig. 4,5,6).

![Polished section: ZF37-322 (Total Measuring)](image)

**Fig. 4.** ZF37-322 sample SEM (Scanning Electron Microscopy) analysis results
Mineralogical features of the deposit

Based on petrographic study the main ore minerals consist of pyrite, chalcopyrite, enargite, sphalerite, arsenopyrite, galena, baryte, pyrrhotite and sternbergite (silver mineral) based on polished section results (Fig.8).

**Pyrite** is the most dominant substance of most of the samples. The amount of massive pyrite ranges from 40 v% to 80 v% of samples. Some parts of massive pyrite are silicified and there are numerous quartz and barite veinlets that cut massive pyrite. In most cases, pyrites are very fine-grained (50-120 microns), and sometimes lengths of pyrite crystals reach up to 200 microns.

**Chalcopyrite** is the main ore mineral and sometimes the only copper-bearing ore, crystals are subhedral or massive.
The size of chalcopyrite crystals ranges between 100 to 700 microns (with an average of 200 microns) and aggregates of chalcopyrite crystals reach 4 mm in length.

*Enargite* is the dominant sulfide mineral precipitating at the beginning of this stage. It forms polycrystalline masses filling fractures and intergranular voids within pyrite and chalcopyrite from the previous stages. The low-temperature polymorph of Cu₃AsS₄, luzonite, has not been observed in Zafar. The composition of enargite is close to being stoichiometric. Its most significant feature is the presence of small amounts of Sb (0.09–1.52 wt.%).

*Sphalerite* is observed in association with chalcopyrite, but in comparison with the latter, it doesn’t contain the inclusions. The minerals being in growths with sphalerite might be set in the following by sulfide minerals: chalcopyrite, tetrahedrite and arsenopyrite.

*Arsenopyrite* is quite widely developed and practically detected in all polished sections, containing chalcopyrite. The graphic structure of growth with chalcopyrite, probably arising in decay consequence of solid solution, is interesting. Besides, it forms growths with sphalerite, tetrahedrite and gold.

*Galena* comprises the second most abundant sulfide mineral, which occurs as euhedral crystals, and in most cases was co-precipitated with sphalerite and with chalcopyrite on fractures. Sphalerite and galena occur in grain size up to a couple of centimeters in massive veins or as small as 10mm when they occur disseminated in quartz and calcite or included in pyrite.

*Pyrrhotite* is found in irregular grains (0.01-0.2 mm), plates in non-metal bulk in association with pyrite, chalcopyrite. Pyrrhotite is generally fine-grained and occurs more commonly as inclusions in iron-rich cores of zoned sphalerite.

*Sternbergite* was found in pyrrhotite as rounded 5–10-μm grains or their intergrowths and flattened zoned spherulites developing along fractures. The chemical compositions of the Ag sulfides are very variable with respect to Ag and Fe contents; zoning was observed in sternbergite rims after pyrrhotite with an increase in Fe content toward the center of the rims. The analyses of sternbergite indicate the persistent presence of Co (up to 0.2 wt %) and Au (up to 0.1 wt %).

The main gangue minerals are quartz, baryte and carbonate. Quartz crystals in bands are euhedral to anhedral, vary in size from microcrystalline to coarse grained. Colloform and chalcedonic bands of quartz show interlocked grains of irregular shape or spherulites with radial extinction or the typical feathery textures of chalcedony. Carbonate crystals vary in grain-size from fine to coarse and the bands commonly contain microcrystalline quartz in the interstices. Other common gangue minerals associated with quartz and calcite that may form bands are chlorite, dolomite–ankerite, adularia, hematite and undifferentiated phyllosilicates (illite and/or interlayered illite/smectite). Bands of quartz-hematite and epidote have been observed alternating with bands of black and white chalcedony (Novruzov, Valiyev, Bayramov, Mammadov, Ibrahimov, 2019).

Results of the study and discussion

**Mineralogical categorizing of samples**

Based on the studies and considering the results of the chemical analyses, samples are categorized main-
ly into 3 different groups: 1) chalcopyrite group; 2) sphalerite group; 3) chalcopyrite – sphalerite group.

**Chalcopyrite group.** Chalcopyrite is the main ore mineral and sometimes the only copper-bearing ore. Chalcopyrite crystals are subhedral or massive. The size of chalcopyrite crystals ranges between 100 to 700 microns (with an average of 200 microns) and aggregates of chalcopyrite crystals reach 4 mm in length. Most of these samples contain magnetite. The presence of a high amount of magnetite is a distinctive feature in samples of this group. In addition to chalcopyrite, magnetite, and hematite, massive pyrite (silicified in some parts), quartz veinlets, pyrrhotite, baryte veinlets, sometimes bornite, rarely jasper, sternbergite and possibly epidote also occur in these samples. The important point is the abundance of chalcopyrite at the depths of more than 340 meters. The host rock is detectable only in a few samples which belong to the chalcopyrite group, and all magnetite-bearing samples to some extent have chalcopyrite. Whereas all magnetite-bearing samples belong to deep levels, all deep samples do not have magnetite.

**Sphalerite group.** Sphalerite is the only zinc-bearing mineral in Zn-rich samples. Samples contain 5-15 v% sphalerite and most of them in all studied samples are Fe-rich, so those are dark-coloured, and sometimes those display red internal reflection. Baryte veinlets which form 10-30 v% of samples are
the most important ore-bearing components. Quartz veinlets consist of 1-10 v% of samples that could host ore-minerals, too. In addition to fine-grained pyrite as the most prominent phase in samples of this group (60-80 v%), which are termed massive pyrite in the current report, some coarse-grained pyrite crystals are also present in some samples (Volkov, Savva, Kolova, et. al., 2018).

Sphalerite crystals (70-1500 microns) and aggregates (up to 5 millimeters) occur in baryte veinlets or are associated with baryte, quartz veinlets, massive pyrite, galena and silicified parts of massive pyrite. Minor phases are chalcopyrite, bornite, rarely secondary copper minerals, jasper and galena.

So, it can be summarized that sphalerite crystal/aggregates occur: 1) in baryte; 2) in veins; 3) in quartz veinlets; 4) in massive pyrite; 5) in silicified parts of the massive pyrite; 6) rarely in host rock.

**Chalcopyrite – Sphalerite group.** More than 10% of samples belong to the chalcopyrite + sphalerite group. Massive pyrite (50-800 microns) is the most abundant component of most samples of this group. It is obvious that chalcopyrite and sphalerite are the main ore-bearing minerals of these samples. Chalcopyrite and sphalerite have been observed in both baryte and quartz veinlets which cut through massive pyrite. The size of chalcopyrite crystals ranges from 100 to 700 microns and the length of chalcopyrite aggregates reaches up to 13 millimeters. Sphalerite crystals and aggregates are between 100 – 1500 microns and 6 millimeters, respectively. Some baryte veinlets cut through previously formed mineralization such as sphalerite + chalcopyrite, sphalerite and chalcopyrite. Minor phases in samples of this group consist of sulphosalts secondary copper minerals, Fe hydroxide and galena.

**Formation condition**

Observations made in the Gadabay mining district are in agreement with its description as a porphyry-epithermal district. The alteration model, proposed by Baba-zade et al. (1990), suggests that the Kharadagh, Kharkhar and Djaygir deposits represent the upper part of the porphyry system (see alteration model by Sillitoe, 2010), which is more or less consistent with the uplift of the Shamkir estimated at ~2km by Tvalchrelidze (2009). Volcanoclastic rocks, dated from the Bajocian to Bathonian (Baba-zade et al., 1990) are intruded by two main intrusive events. All the intrusions spatially associated with ore deposits (Gadabay, Dashkasan, Djaygir) indicate similar ages belonging to the second intrusive event. This is consistent with the Kimmeridgian mineralizing event observed in the Lok-Karabakh volcanic arc by Sossen et al. (2010).

The tectonic regime and related stress field are one of the most influential elements controlling the hydrothermal deposits types in volcanic arcs. On a regional-scale, translithospheric, arc-parallel, strike-slip structures and faults act as a primary control on magma emplacement in many volcanic arcs. Low sulphidation deposits generally formed in extensional environments related to arc or post-collisional rifts. Intermediate sulphidation deposits formed under neutral to weak extensional stress condition similar to high sulphidation deposits, with andesite-dacite-rhyolite composition caused by subduction-related magmatism (Sillitoe and Hedenquist, 2003).

Magmatic fluid is a primary source of many components in the hydrothermal deposits formed in a volcanic arc. Metals enter magmas through a variety of pathways, including mantle melting, mass transfer from the subduction slab and melt of the crust.

Despite the general alteration in the area, geochemical data from Gadabay district are consistent with a subduction related magmatism, generally with a basaltic to andesitic composition.

Earlier, the Zafar Cu–Au hydrothermal deposit was interpreted as an intermediate epithermal deposit genetically linked to porphyry-Cu deposits in Gada¬bay district.

Clusters of porphyry copper deposits and epithermal deposits usually occur in zones which experienced prolonged history of plate subduction and/or collision (Sillitoe, 1997, 2008, Qin et al., 2002; Richards, 2015; Shen et al., 2015). Three global metallogenetic belts closely related to plates subduction and collision, i.e., Circum-Pacific (Pacific Rim) metallogenetic belt, Tethys-Himalayan metallogenetic belt and Central Asian metallogenetic belt, contain most porphyry copper deposits and all types of epithermal deposits.

Zafar deposit was formed by two events. The first event is the formation of the «massive pyrite» related to small Later Bajocian sub-volcanic rhyolite-dacite bodies. The second event is assumed as «copper-pyrite» and «copper-zinc» mineralization and is reported to have been formed by the post-magmatic activity of the Gadabay diorite intrusive.

Sulfide mineral assemblage in the majority of IS deposits can be relatively simple, including combinations of pyrite, Fe-poor sphalerite, galena, chalcopyrite, and tetrahedrite/tennantite (Einaudi et al., 2003; Sillitoe and Hedenquist, 2003). IS deposits show less intimate relations with magmatism than HS deposits do (e.g., Rye et al., 1992; Hedenquist and Lowenstern, 1994; Arribas, 1995;
Hedenquist et al., 1998; John, 2001), but still exhibit affinity to magma (e.g., Sillitoe and Hedenquist, 2003; Echavarria et al., 2006).

The occurrence of pyrrhotite indicates a reduced environment and is related to low content of the sulphur in the system at the beginning of evolution of the deposit. Then increase in sulphur caused formation of pyrite (Einaudi et al., 2003):

$$2\text{FeS} + \text{S}_2 \rightleftharpoons 2\text{FeS}_2$$

Pyrrhotite Pyrite

Electron microprobe analysis shows decrease in FeS content. According to the Einaudi et al. (2003) model, this decrease indicates general intermediate sulphidation state for the fluid (Fig. 9).

Magmatism acts not only as a metal and heat producer during the epithermal mineralization, the physicochemical property of which also determines the types of epithermal systems. Many IS deposits show close relations with calc-alkaline andesitic-dacitic or monzonitic magmatism.

This study has demonstrated new ideas about formation and genesis of the Zafar deposit. The K-rich calc-alkaline composition of various rocks indicating that subduction-related magmatism happened along the Lok-Karabakh belt has a crucial role in forming this deposit.

**Results**

1. Based on the geological studies, we can claim that ore mineralization emplaced in metasomatic analogues of rhyolite and rhyodacite, and their metasomatic tuffs while sphalerite and galena are sometimes emplaced in baryte veins.

2. Gold was not observed under the microscope. According to the SEM analysis, gold mineralization formed in pyrite, chalcopyrite (their derivatives too) stages. In the second or baryte stage, polymetal mineralization happened.

3. It is impossible to provide a polished section study due to the absence of high mineral content in these samples. It is recommended to send high concentrate mineral samples for providing monomineral as pyrite, chalcopyrite, covellite, digenite, baryte, sphalerite, galena investigation, which will be more helpful for polished section studies.

4. In order to identify gold, copper, silver, zinc and lead mineralization more precisely, analyses of high grades samples recommended.

5. For future studies, detailed fluid inclusion studies are recommended. Samples must be taken from every alteration zone in order to understand the fluid environment in every part of the deposit. Moreover, measurement on the baryte, pyrite, chalcopyrite and especially sphalerite minerals from high-grade mineralization zones will give net temperatures for mineralization.

6. According to the petrographic observation, two paragenetic sequences had been defined. The most precious metal copper formed at Stage II. Furthermore, petrographic observations revealed oxidation phenomena and some tectonism signature for the deposit.

7. All of the characteristics show epithermal deposits characteristic for the Zafar copper-gold deposit in the general classification. But the combination of all characteristics (geological settings, nature of mineralization, ore mineralogy and hydrothermal alteration forms) of the Zafar deposit which have been
realized in this study indicate an intermediate sulphidation deposit type.

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References


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