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Research Paper

Lithogeochemical Exploration, Alteration and Gold Mineralogy in the Sonajil-Heris Low-Sulfide Epithermal Deposit, East Azerbaijan

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Abstract: The epithermal part of copper-gold porphyry deposits are important due to their high grade, low exploitation costs and the presence of precious elements. The main rock outcrops in the area from old to new include Eocene volcanoclastic deposits, Oligo-Miocene intrusive bodies and Quaternary deposits. The Sonajil area is known as a site of porphyry deposit and copper mining, but the characteristics, style and origin of the mineralization of its epithermal part has not been described in the scientific literature. On the basis of results achieved from studying satellite images and field and laboratory controls, the presence of kaolinite, quartz, alunite and hydroxyl minerals, has been confirmed, which are the indicator of phyllic, propylitic, argillic, siliceous and tourmalinization in the epithermal part. The Interpretation of the stream sediments geochemistry, data analysis and lithology along with classical statistical methods, grade-number and grade-area fractal models showed that the grade-number fractal method with a high reliability coefficient is the most effective for separating the epithermal part from the porphyry mineralization in the region, which has been used as the basis for the interpretation of the maps. The maximum values of Au element anomaly are consistent with epithermal-related siliceous veins in the western part of the area and the lowest anomaly is related to the northeast of the deposit. According to the results of geometallurgical studies in Canada's ActLab laboratory, the occurrence of gold mineral is accompanied by quartz less than ten microns in size. Therefore, the origin of gold mineralization in the Sonajil deposit belongs to epithermal deposits. The presence of colloform texture, hydrothermal breccia's along with the geochemical correlation of elements and principle component statistical analysis results are all consistent with features of low sulfidation epithermal deposits.

Keywords: Epithermal Gold, Lithogeochemistry, Fractal, Sonajil, Geometallurgy.

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INTRODUCTION

The epithermal gold deposits of Arasbaran zone are mostly in the form of siliceous-sulfide veins and veinlets in calc-alkaline volcanic and pyroclastic host rocks with an acidic to intermediate composition [1]. Gold deposition occurs in hydrothermal environments under the control of boiling, sulfidation, oxidation, cooling and fluid mixing phenomena and bisulfide (HS^-) and chloride (Cl^-) ligands are very effective in transferring this precious metal. In this article, classical and fractal statistical indices were used to prepare geochemical anomaly maps under the cover of lithogeochemical discoveries on a scale of 1:5000, and its purpose is to identify the areas of high potential with the possibility of epithermal gold mineralization in the western part of Sonajil deposit, which is located in the northwest of Iran.

MATERIALS AND METHODS

In order to be acquainted with the geochemical abundance of gold and associated elements in rock outcrops and associated alterations in the region, the results of lithogeochemical sampling and stream sediments from the west of the Sonajil area were used. In order to identify the rock type and mineralogy of the ore, thin and polished sections have been prepared and studied. 59 samples from copper mineralized outcrops (porphyry and epithermal) and gold-bearing epithermal systems have been sent to the laboratory for gold and ICP analysis. Geometallurgical studies have also been conducted at an accredited laboratory (Act Lab) in Canada. In order to evaluate mineralization, a number of samples were taken from outcrops with different alterations and analyzed for XRD mineralogical studies. A total of 1248 surface and deep samples were analyzed for geochemical analysis of major, minor, and trace elements (44 elements) using the ICP-AU method at the AMDEL laboratory in Australia. In preparing geochemical anomaly maps of the area in ArcGIS, only 10 important geochemical and pathfinder elements in epithermal gold (Ag, As, Au, Bi, Mo, Hg, Fe, Cu, Pb, Sb) were selected from 44 elements.

Geological units in the Sonajil region based on the 1:5000 geological-mining map, the Cenozoic deposits mainly include 1) Eocene volcanic-sedimentary deposits, 2) Oligo-Miocene intrusive masses, and 3) Quaternary volcanic rocks. Shoshonitic intrusive bodies in the Arasbaran region are associated with various mineralization in the region, including porphyry and epithermal, and these bodies usually have high Au content [2]. The Sonajil porphyry was the oldest intrusive body during Tertiary magmatism in the region, At the same time, the main epithermal mineralization factor is located in the western part of the deposit.

FINDINGS AND DISCUSSION

Based on the results of conducted studies and all available evidences, the accumulation of gold in the Sonajil deposit have occurred in relation to key factors. Faults, the nature of the host rock, hydrothermal alteration, and the composition and type of fluids were among the factors that played a role in the deposition of metal ores.

In order to determine the characteristics of fluids controlling mineralization, micro thermometric studies of fluid intercalations on Sonajil silica veins were used. Based on the petrography of the studied samples, five types of fluid interlayers can be distinguished, which in the order of frequency, include, three-phase fluid media (L+V+S), two-phase liquid-rich (L+V), two-phase gas-rich (V+L), single-phase gas (V), and single-phase liquid (L) media. According to the results of thermometry of fluid intermediate loads, salinity values range from 4% by weight of sodium chloride equivalent to more than 55% by weight of sodium chloride equivalent, and homogenization temperatures range from 180°C to 540°C. The Inclusions without the salt-daughter phase exhibit low salinity in the range of 4 to 12% weight equivalent of sodium chloride. These values are in complete agreement with those reported from many of the world's major porphyry copper deposits.

The epithermal mineralization system occurred in a silicic vein aligned with a northwest-southeast trending fault in the western part of the Sonajil range. Based on the results of analyses conducted on 32 taken samples, the gold content ranged from "below the detection limit of the device" to about "4.7 ppm." The highest copper and silver grades are 1.2 percent and 12 grams per ton, respectively. No specific enrichment is seen in the analyses for the elements lead, molybdenum, and antimony. Based on the gold assay results of taken samples, the vein can be divided into three zones: 1, 2, and 3.

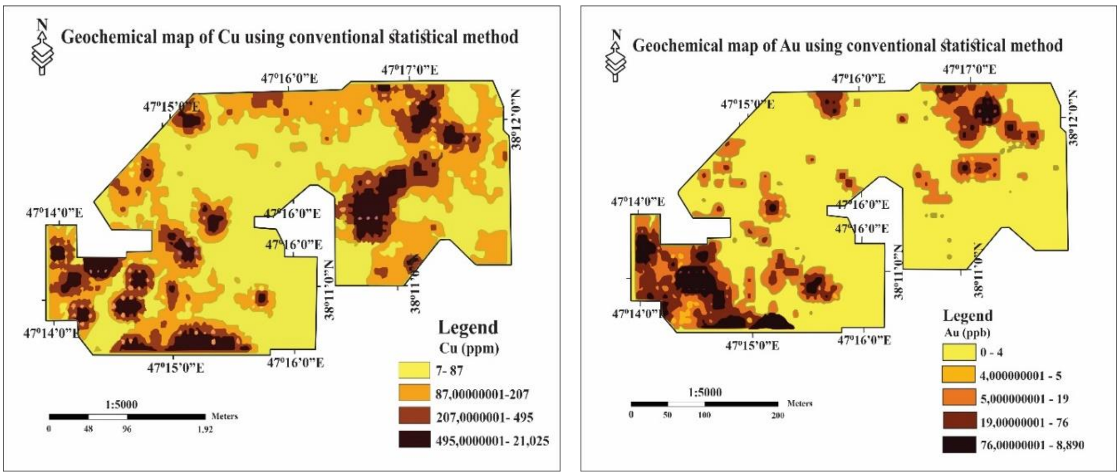
The silica vein was formed as a result of fluid circulation processes within the fracture system with a northwest-southeast trend. The presence of various types of shear, colloform, and cauliflower textures are the characteristic of low-sulfide environments in epithermal gold deposits [3,4]. The structure and textures related to the boiling stage (sponge texture and lattice texture) as well as the mineralogical and geochemical paragenesis indicate that the mineralization system is epithermal. The existence of correlation between copper and gold in this vein confirms this interpretation.

In this research, after collecting all geochemical data of the Sonajil region, non-structural (statistical) and structural (fractal) methods were used to separate the anomaly from the background.

Geological modeling of deposits, especially gold deposits, where even very small changes in grade can be significant, play a very important role in evaluating resources and reserves and creating a suitable estimation environment for geostatistical surveys [5]. The unusual distribution of the geochemical population of target elements is consistent with epithermal mineralization. Since the data distribution was not normal in the multivariate statistical study, factor analysis was used to interpret the variability of the data and the factors affecting them. Based on the Principal Components Analysis (Principal Components) research using SPSS software in the Sonajil deposit, factor 1, with special eigenvalues of 2.08, explains more than 46% of the variability of the data. Since the elements gold, silver, arsenic, antimony, bismuth, and copper are present in this factor, it is attributed to epithermal type mineralization. Factor 2 accounts for about 1.5% of the especial eigenvalues and explains 25% of the variability in the data. Since the elements arsenic, bismuth, and copper are present in this factor, this factor is attributed to the presence of sulfosalt minerals, including tetrahedrite, etc. (sulfide with arsenic-like metals and copper-bearing minerals).

For producing a geochemical map, first, logarithmic data were estimated using the IDW method in ArcMap software; after ranking the element data, a map of the anomalous areas of Cu and Au elements was drawn using the classical statistical method in the Sonajil deposit (Figures 1A and 1B).

In the fractal model, which shows the anomalous regions resulting from the concentration-area and concentration-number methods of the elements Au Cu, in (Figures 2A and 2B), the highest Au anomaly corresponds to the silica veins attributed to epithermal in the western part of the Sonajil deposit, and the lowest anomaly is related to the northeast of the study area. Accordingly, the anomalies obtained in these methods are also consistent with the anomalies obtained in the classical statistical method and the only difference between them is that in the concentration-number method, one rank (Class) is further separated. Due to the high accuracy of the maps drawn in separating mineralization communities and separating various anomalies from the background, fractal maps have been used to introduce promising mineral areas in Sonajil.



(A) **(B)**

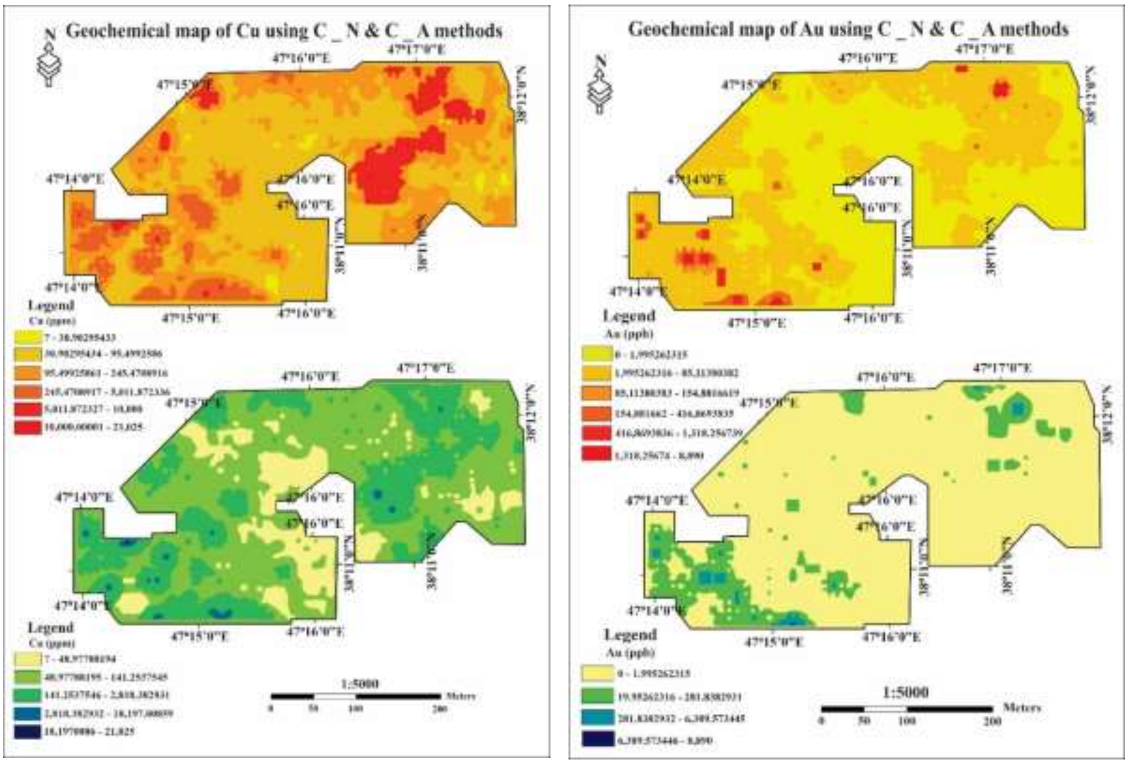
Figure 1. A: Geochemical map of Cu, **B:** Au using classical statistics method in Sonajil

CONCLUSIONS

The host rock of gold mineralization in the west of the Sonajil deposit is often carbonate, sedimentary, or as a replacement in siliceous limestone. Gold mineralization occurs mainly in the form of silicic veinlets and veins on the margins of the massive and disseminated grains. Analysis of ore samples shows that the average gold grade in the silica vein is appropriate and around 2 ppm. Mineralization in the western part of the range has been mainly associated with the greater density of faulting as a conduit for mineralizing fluids in epithermal gold. Therefore, there is a genetic connection between fluids, magmatism, and tectonics in Sonajil. Reasons include: sedimentary, carbonate and volcanic host rock, strong structural control of mineralization (fault), phyllic, propylitic, argillic, silicic, and tourmalinization alterations with sulphidzation, elemental paragenesis of Au, Ag, As, and Sb, and the occurrence of gold mineralization (in the form of platinum-containing electrum compounds) and in the form of association with quartz less than ten microns in pyrite, causing the Sonajil deposit to have similarities with the Carlin type; However, the lack of observation of realgar and orpiment minerals, the presence of hydrothermal breccias, colloform, spongy and canine tooth textures, and other evidence from the current study indicate that gold mineralization in the Sonajil area is of the low- sulfidation epithermal type.

Reanalysis of the results of geochemical data using classical statistical methods, concentration-number and concentration-area fractal models showed that the concentration-number fractal method has the highest resolution in the region, and the interpretation of the maps is based on the results of this method. As observed, the highest Au anomaly corresponds to the silica vein attributed to epithermal in the western part of the Sonajil deposit, and the lowest anomaly is related to the northeast of the study area. Therefore, the results obtained from fractal methods are more reliable not only in surface but also in subsurface studies. Considering the alteration halos and mineralizations observed at the surface and the analysis of anomaly maps using the fractal method, confirms the presence and high potential of the West Sonajil region from a gold perspective.

Various types of vapor-rich, liquid-rich, halite-rich, and single-phase gas interlayers are found in mineralization zone samples in most porphyry deposits of the Sonajil region and they are considered as signs of the formation of hypersaline fluids due to boiling. In the upper levels of the epithermal system, gold mineralization has occurred as a result of the collapse of the ore-bearing structure, which has led to the production of gold-bearing hydrothermal breccias. Given the nature of gold mineralization in Sonajil, which is consistent with the low-sulfidation epithermal type. It was not possible to observe gold in polished sections, but for the first time, by using the MLA advanced analysis method while seeing gold, the shape, size, way of engagement and its composition were determined.



(A) (B)

Figure 2. A: Geochemical map of Cu, **B:** Au using concentration -area and concentration -number methods in Sonajil

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