

GOLD MINERALIZATION DISTRIBUTIONS WITHIN ROCK UNITS AT THE HAJR GOLD MINE, SOUTHWEST SAUDI ARABIA

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الخلاصة:

يقع منجم حجر للذهب والأعمال القديمة فيه في الجزء الجنوبي من الدرع العربي، وهو يمتاز بكثرة الأعمال القديمة التي تتركز على طول خط التماس بين صخور السربنتينيت الكربونية وصخور الشيست الهورنبلندي وقواطع الألبيت. وتظهر الأعمال القديمة على شكل حفر قديمة وخنادق طولية، مائلة وعمودية لا تتعدى أعماقها عشرين متراً. كما دللت نتائج التحليلات لقطع العينات الصخرية السطحية التي جمعت عبر نطاقات التماس على طول الخنادق والفتحات القديمة أن الصخر المضيف لشوائب الذهب المحتمل هو وحدة صخر السربنتينيت الكربونية المتمزقة وصخور الشيست والقواطع القريبة من خط التماس. وقد أثبتت هذه الملاحظة من خلال النماذج الإحصائية التي بُنيت لـ (108) عينة حيث قُسمت العينات إلى أربع مجموعات: الصخور فوق الغامقة القريبة من خط التماس، الصخور فوق الغامقة البعيدة عن خط التماس، صخور الشيست والقواطع القريبة من خط التماس، صخور الشيست والقواطع البعيدة عن خط التماس. وأظهرت الدراسة أن قيم الذهب والتليريم عالية في صخور فوق غامقة وصخور الشيست والقواطع القريبة من خط التماس مقارنة بتلك البعيدة عنه. كما أن ارتفاع قيمة معامل التغير في قيم الذهب والتليريم في هذه الوحدات الصخرية قد يُدلل على أن شوائب الذهب ربما تتواجد على هيئة جيوب متفرقة فيها.

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ABSTRACT

The Hajr gold mine within its ancient workings is located in the southern part of the Arabian Shield. It is characterized by intensive ancient workings that are concentrated along the contact zones between the carbonatized-serpentinite and the hornblende schist and the aplite dikes. The ancient workings are in the form of open pits, linear trenches, and inclined and vertical shafts not exceeding 20 meters depth. The analytical results for the surface chip samples, collected across the contact zones, and along the ancient shafts, trenches, and pit, indicate that the probable host rock for the gold mineralization is the sheared carbonatized-serpentinite unit at its close contact with the schist and dike rock units. This observation is also proved through the statistical evaluation based on the analysis of 108 samples. The samples were divided into four categories: ultramafic rocks away from contact (UAC), ultramafic rocks close to contact (UCC), schist and dike rocks close to contact (SCC), and schist rock units away from contact (SAC). The Au and Te values are higher within the UCC and SCC rock units compared to the UAC and SAC units. The high coefficient of variation for gold and tellurium values in the former two rock units may also indicate that gold mineralization might be present in several separated pockets in both zones.

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INTRODUCTION

The ancient Hajr gold mine is located south of Bishah city at about 20 km southeast of the village of Hamdah at latitude $18^{\circ} 52'$ to $18^{\circ} 57'$ N; longitude $43^{\circ} 34'$ to $43^{\circ} 53'$ E (Figure 1). This mine is one of four mines named as the Hajrah–Hamdah group of ancient mines [1]. The area is known at present as Hamdah gold deposit [2].

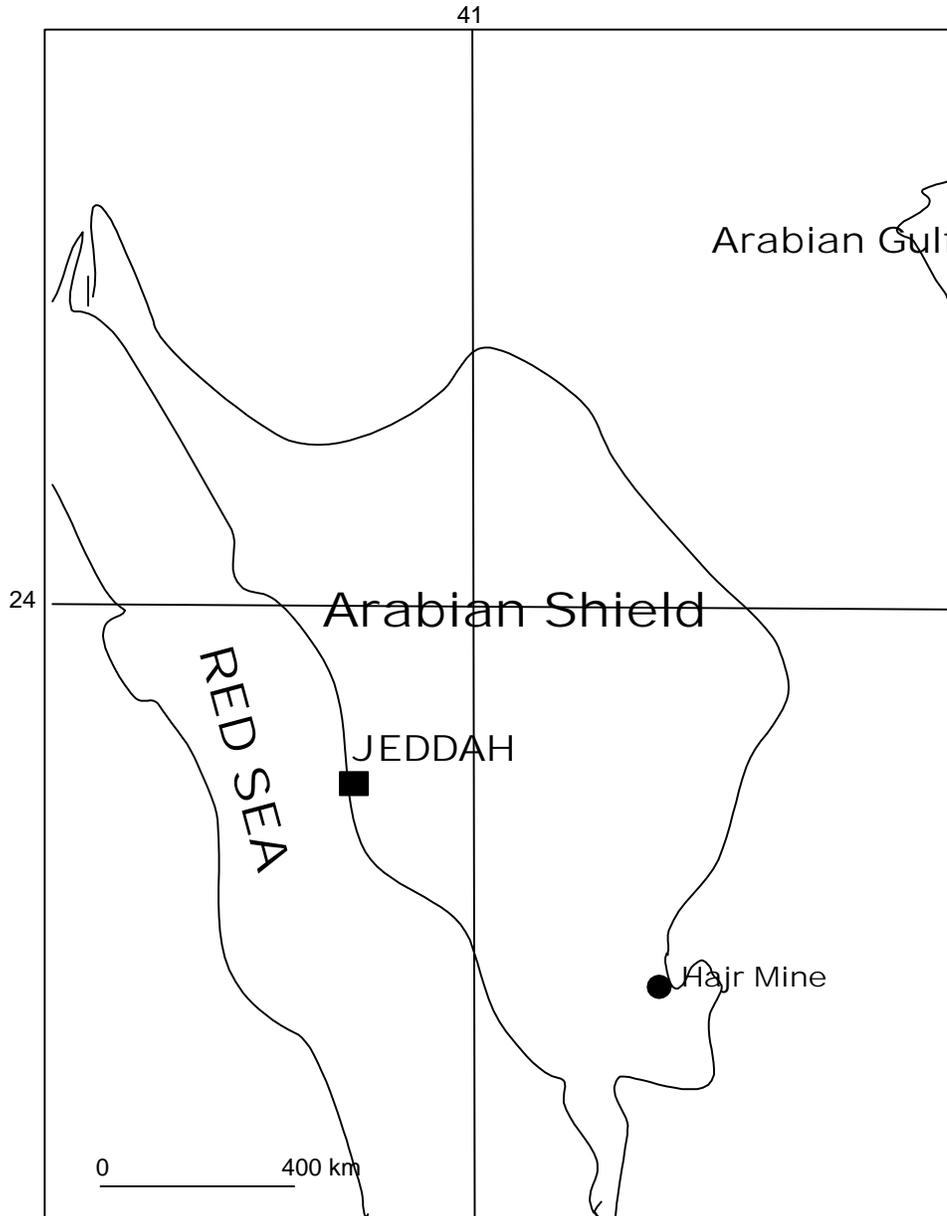


Figure 1. Location map of Hajr mine (Modified after Collenette and Grainger [6]).

Part of this study was conducted as part of the gold exploration project of the DMMR (Deputy Ministry for Mineral Resources). The objective of this study is to evaluate the potential of gold mineralization in the Hajr mine and to determine the possible host rocks for gold. The field study included geological mapping and description of old mining

works and rock-chip sampling for possible host rock units. Following chemical analyses of the rock samples, statistical models for gold and tellurium distribution in the different rock units were constructed.

GEOLOGICAL SETTING

The rock units at Hajrah–Hamdah area have been classified into layered metamorphic rock units, serpentinite, and intrusive rocks [1,3]. The layered metamorphic rock units consist of quartz–biotite schist, a hornblende schist, a carbonaceous schist, and a chlorite–epidote schist of metavolcanic and metasedimentary origin. These rock units represent Malahah subgroup of the Halaban greenstone belt [2]. A slab of deformed serpentinite overlies the hornblende schist, quartz–biotite schist, and carbonaceous schist and underlies the chlorite–epidote schists [3,2]. The layered metamorphic rocks and serpentinite were intruded by diorite to granite, and mafic to felsic dikes and sills. At the Hajr mine area, rock units present are mainly hornblende schist, serpentinite, and felsic dike and sills [1] (Figure 2). The hornblende schist is fine- to medium grained and composed mainly of hornblende and plagioclase with minor epidote, actinolite, and chlorite. This schist unit is probably the metamorphosed equivalent of crystal lithic tuffs [1]. Intercalation of quartz–biotite schist and dark gray marble is also common.

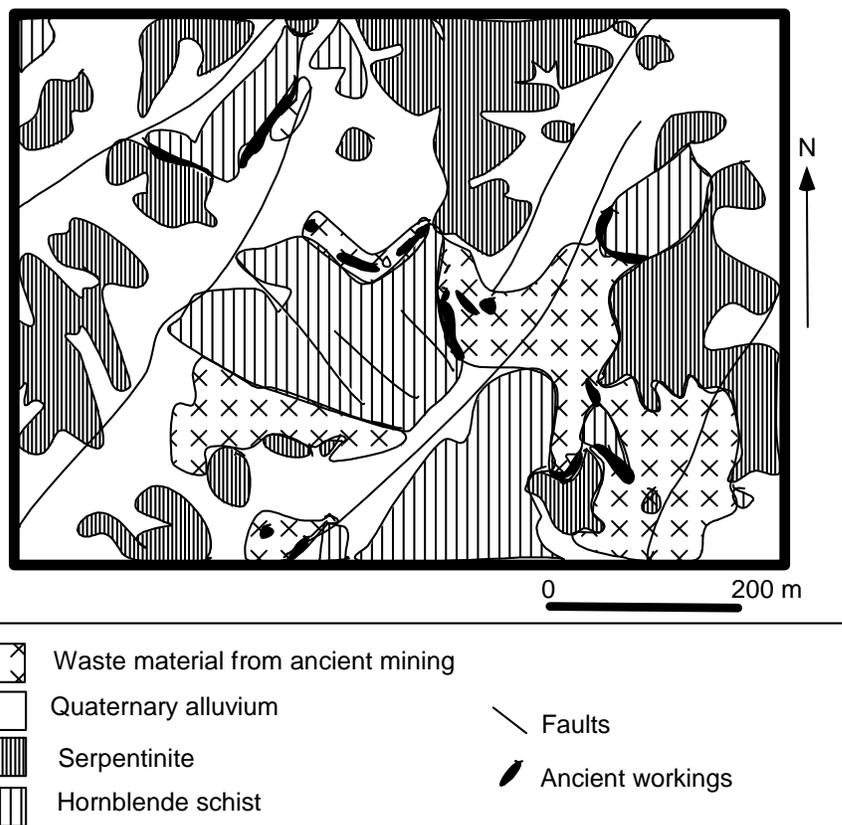


Figure 2. Simplified geologic map of Hajr mine (modified after Helaby and Worl [1])

Serpentinite conformably overlies the hornblende schist and the lower contact of the serpentinite parallels the schistosity. Helaby and Worl [1] reported that in many places the contact between the serpentinite and the hornblende schist is gradational. However field observation and detailed mapping along and across the contact proved that sharp contact is present all over the study area between the serpentinite and schist and aplite dike rock units (Figures 2 and 3). This contact, for most part, is gently dipping, and is intruded in many places by aplite and quartz vein and stringers. Worl [3] suggested that the serpentinite may have originated as a cumulate complex of peridotite with minor pyroxenite. Bookstrom and others [2] indicated that the serpentinite may represent the erosional remnants of folded slab of Hamdah serpentinite that was thrust along the Hamdah thrust over the layered metamorphic rocks. Johnson [4] suggested that the serpentinite and pyroxenite within Asir terrane intruded in the period between about 810 and 740 Ma. The serpentinite is sheared and altered to asbestiform minerals, magnesite, calcite, and magnetite, and commonly

carbonatized and silicified along fractures and contacts. The serpentinite rock unit is altered to listwaenite in the upper part of the thrust zone and phyllonite in the lower part [2].

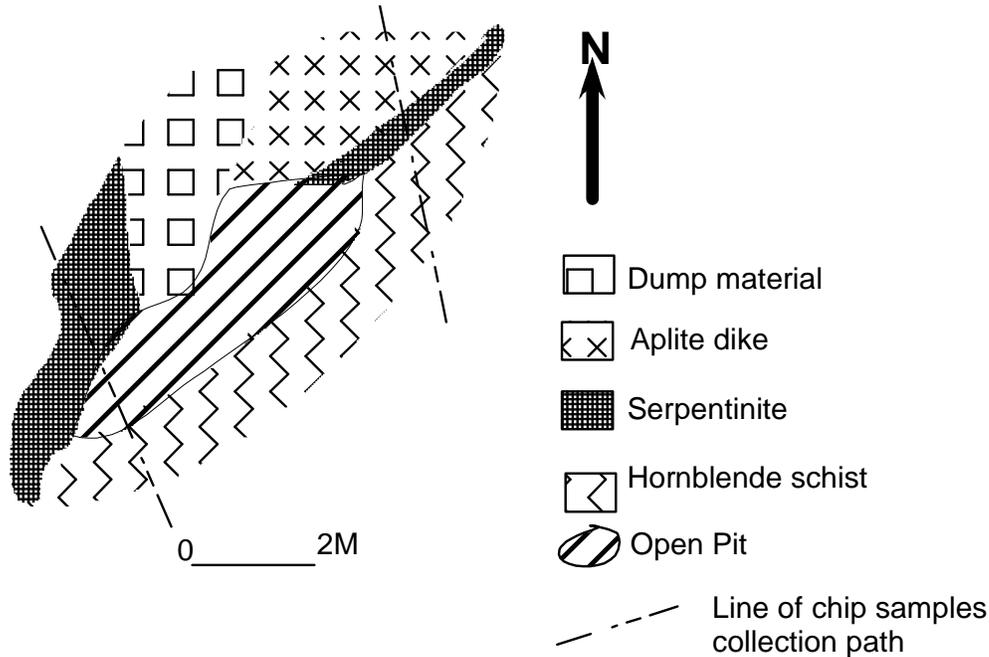


Figure 3. Sketch of plan view of an ancient pit in Hajr mine area, showing the different rock units at the contact zone and the sampling trace (modified after Hariri [5]).

Aplite bodies occur as sills and dikes mainly along the contacts between the serpentinite and hornblende schist. In places these rocks cut the hornblende schist. The aplite rocks are fine-grained, pinkish to yellowish, and composed mainly of quartz and feldspar with abundant garnet. They are similar in mineralogy to the plutons existing in the region [1].

The predominant structures in Hajr mine area are broad open folds, where the whole rock sequence has been folded into northeast- and northwest-trending folds that form generally domes and troughs [1]. However, complex folds occur locally within the schist unit and near the contact zones. Thrust faults are parallel to the contact between the hornblende schist and the serpentinite. These faults may be related to the emplacement of the serpentinite rock unit [3].

GOLD MINERALIZATION

Gold mineralization in Hajr mine is in the form of sparse disseminations within rock units [5]. Earlier workers like Bookstrom and others [2] and Helaby and Worl [1] related the gold mineralization to the felsic sills or dikes [1,2]. Hariri [5] reported that the gold may have been mobilized from the ultramafic rocks by the aplite magma intrusion and concentrated along the lower serpentinite boundary, which acted as an impervious and reactive cap to the ascending aplitic magma and hydrothermal solutions. This conclusion was also adopted by Bookstrom and others [2], who reported that the gold concentrations are most common in altered phyllonite forming the footwall of the aplite sills, in the listwaenite above the sills and in the sills themselves. They also stated that the serpentinite may also have acted as impermeable cap rock for the gold mineralization. Although the earlier studies focused on the Au concentration in the rock units, no statistical analyses were performed to define the host rocks through Au distribution. Moreover, none of the earlier studies examined the spatial distribution of Au concentrations away from and close to the contact.

The average gold values, at Hajr mine, for channel samples taken across contacts, grab samples from the ancient workings, and traverse samples are 1.25 g/t, 3.31 g/t, and 1.67 g/t respectively, and the gold values in the drill-holes ranged between 1.1g/t and 4.84 g/t. [1] Hariri [5] reported a maximum gold value of 18 g/t in the sheared carbonatized serpentinite around the inclined shafts and the minimum detected value of less than 0.01 g/t in the hornblende schist.

ANCIENT MINING WORKS

The ancient workings at Hajr mine were classified into three types: linear trenches, inclined shafts, and vertical shafts [1] (Figures 3 and 4). The trenches vary in width one to three meters and in length between ten and hundred meters

[5]. The vertical shafts have an average cross sectional area of one meter square and reach the depths of ten to fifteen meters [5]. The average cross sectional area of the inclined shafts is about one meter square and reaches a maximum depth of 25 meters. In many places the shafts are located in the serpentinite and extend to the contact with the hornblende schist. Trenches, on the other hand, are always sited along the contact zone within the sheared and carbonatized serpentinite [5]. The concentration of the ancient workings on the contact zone proves that the ancient miners were targeting the carbonatized serpentinite.

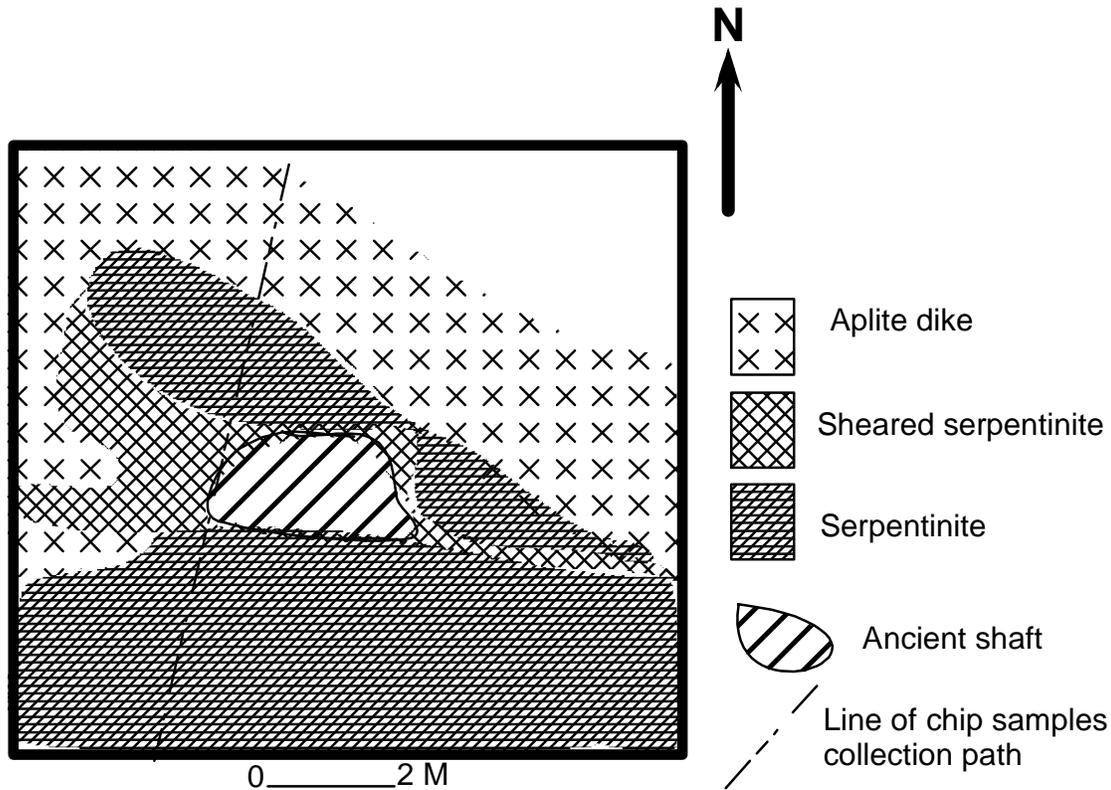


Figure 4. Cross section sketch of an inclined ancient shaft in Hajr mine area, showing the different rock units at the contact zone and the sampling trace (modified after Hariri [5]).

The estimated extensive waste dumps, associated with the ancient workings, contain 200#000 tons of rocks with an average grade of 3.8 g/t gold [1].

SAMPLING AND ANALYTICAL METHODS

Although the previous studies and the distribution of the old workings indicated that the gold mineralization is closer to the contact zones of the serpentinite with the schist and aplite dikes. However, the earlier workers did not consider determining accurately the host rock for gold mineralization. The reason for the was probably that earlier workers did not attempt to examine gold concentrations in rocks with respect to the contact zone proximity. In this study the samples' spatial distribution in relation to the contact zone was considered and the statistical analysis procedures were performed to precisely define the host rock for gold mineralization.

For the purpose of this study 108 rock chip samples were collected across the ancient trenches, and open pits and across the contact in un-mined locations from serpentinite, schist and aplite dikes (Figures 3 and 4). With respect to the contact zone, the samples were classified into four categories: ultramafic rocks away from the contact (UAC), ultramafic rocks close to the contact (UCC), schist and aplite dike close to the contact (SCC), and schists away from the contact (SAC). The samples were analyzed by atomic absorption in the DGMR/USGS chemical laboratory in Jeddah for Au, Te, Ag, Cu, Pb, Zn, As, Sb, Bi, and Mo. Only the analyses for Au, Te, and As are used in this study as the concentrations of the other elements are below or close to the detection limit. In addition, Cr and Ni element values were determined using the spectrographic method, in the same laboratory.

RESULTS AND DISCUSSION

In order to obtain meaningful interpretation and further confirm the type of rocks hosting the gold mineralization at Hajr mine, statistical studies were conducted using data from 108 samples. Computing certain statistical parameters that represent a variable is a common practice in geological data analysis [7]. These parameters provide valuable information about the association of elements with different rocks types. They may also support certain hypothesis about the origin, extension and quality of economic ores [7]. The univariate statistics of each element were examined to delineate their abundance and distribution in each rock unit.

Analyses of rock chip samples in this study indicate that maximum Au, Te, and As values are 18 000 ppb, 1100 ppb, and 560 ppm, respectively, detected in the sheared carbonatized serpentinite around the inclined shafts. The minimum values of the same elements, with 6 ppb Au, 0.01 ppb Te, and 3 ppm As, respectively, are detected in the schist rock units away from the contact zone. The high anomalies that reach up to 2000 ppm of Cr, and Ni are associated with the ultramafic rock unit both close and away from the contact.

Table 1 shows the average values of Au, Te, As, Cr and Ni for the different rock units. The highest average gold and tellurium values are within rock units close to the contact namely the carbonatized serpentinite (UCC) and the schist and aplite dike (SCC) as displayed in Figure 5. However, the average values of both elements are much higher within the carbonatized serpentinite than that within the schist and dike. This may emphasize the idea that UCC unit is the host rock for gold mineralization. This finding is also compatible with the earlier conclusion of Hariri [5]. In many old workings the pink-to-red and carbonatized serpentinite was mined because of its higher gold content [5].

Table 1: Average values for Au, Te, As, Cr, and Ni, According to Rock Units.

Rock Unit	No. of Samples	Au (ppb)	Te (ppb)	As (ppm)	Cr (ppm)	Ni (ppm)
UAC	36	32.4	43.3	63.5	866.6	511.1
UCC	45	6955.6	476.6	60.8	1122.2	700.4
SCC	9	292.7	55.9	27.7	180.1	36.2
SAC	18	23.7	42.7	32.8	200.3	63.9

(UAC) ultramafic rocks (serpintinite) away from the contact; (UCC) ultramafic rocks (serpintinite) close to the contact; (SCC) schist and aplite dike rocks close to the contact; and (SAC) schist rock units away from the contact.

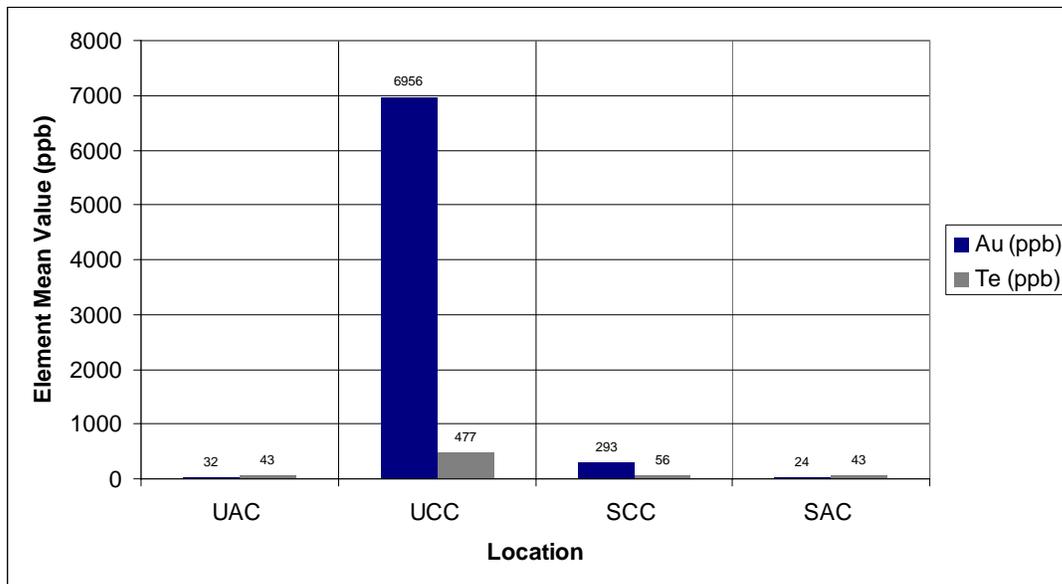


Figure 5. Mean Au and Te values within rock units.

Figure 6 indicates that gold concentration is higher within the UCC compared to the other rock units. Also, the median for gold values within the same rock unit suggests that about 50% of samples have values of 500 ppb and above. This statistical observation may indicate that this rock unit should be the main target for further exploration and exploitation activities. On the other hand, the same statistical parameter shows that the SCC rock unit could be the second target with 50% of Au values equal to or exceed 300 ppb.

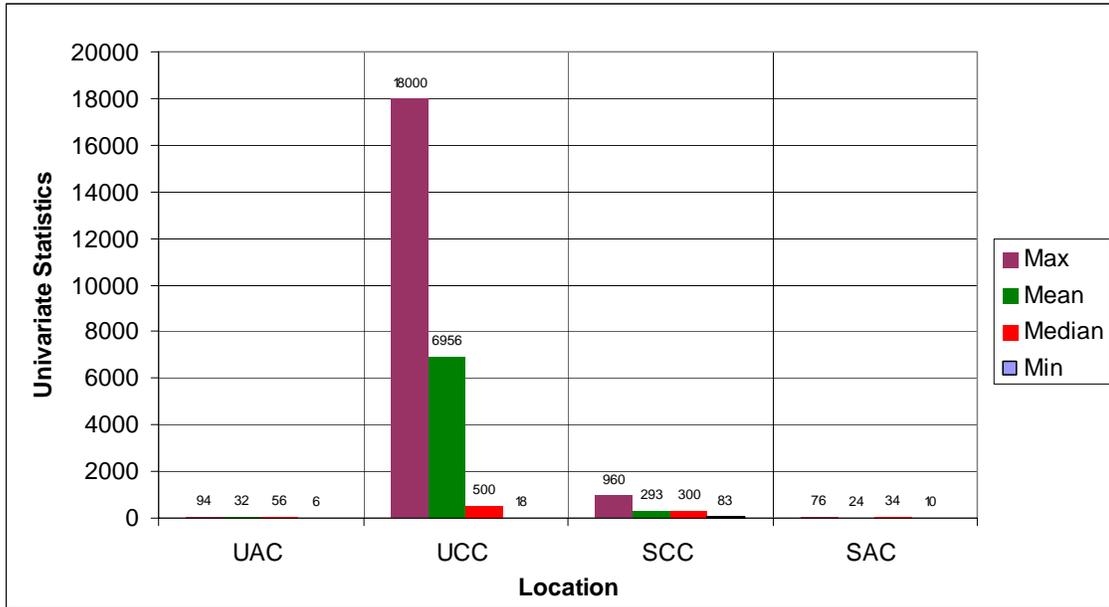


Figure 6. Univariate statistics of Au within rock units.

Higher positive skewness for both UCC and SCC units indicate the presence of extremely high gold values (Figure 7). Moreover, coefficients of variation (CV) values indicate the random nature of gold distribution in both rock types. This feature may be related to the heterogeneous nature of the ore.

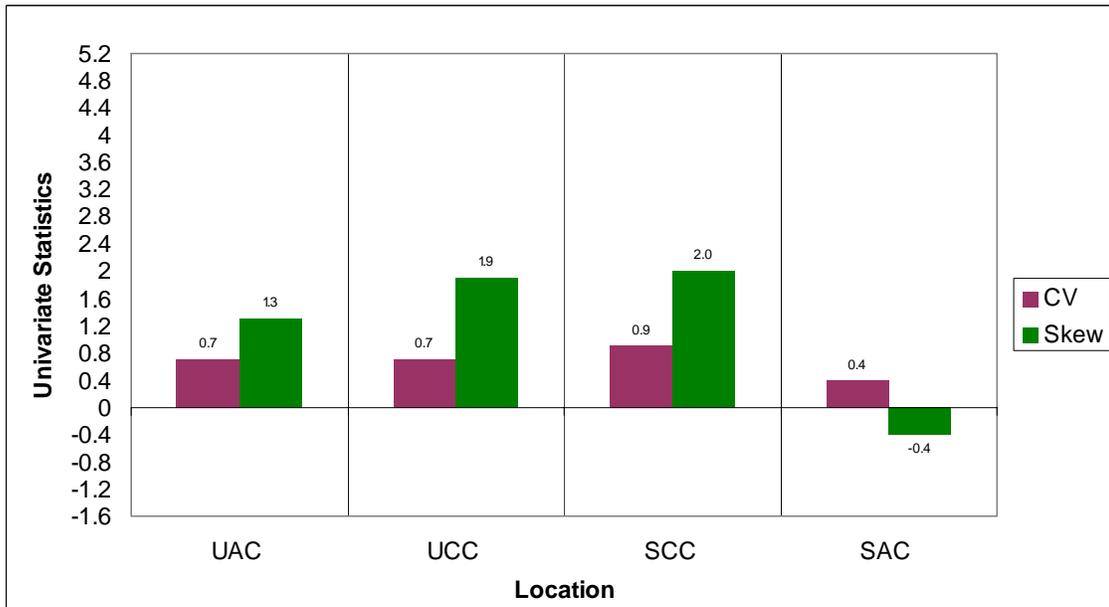


Figure 7. Shape and dispersion statistics of Au within rock units.

The heterogeneous nature of gold mineralization may be due to either one or more of the following reasons: different ore sources; limited number of samples used in analysis; and uncertainty associated with chemical analysis [8].

Cr and Ni concentrations are high within the carbonatized serpentinite rock unit close to the contact compared to the serpentinite rocks away from the contact (Figure 8).

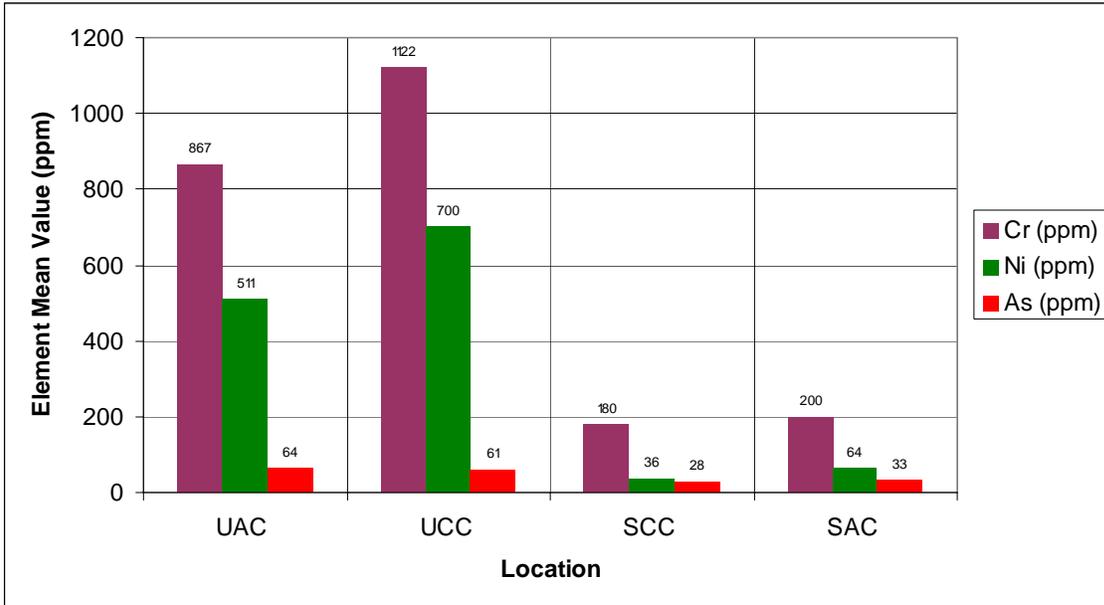


Figure 8. Mean Cr, Ni, and As values within rock units.

This might be related to the concentration of these elements in the carbonatized rock unit by the weathering and alteration processes rather than their depletion in the un-carbonatized rocks.

The correlation coefficients between Au and other elements are, generally, low (Figure 9). This might be due to the gold dispersion and mobilization through the country rock as a result of the thermal conductivity that had been associated with the intrusion of aplite dikes and quartz veins.

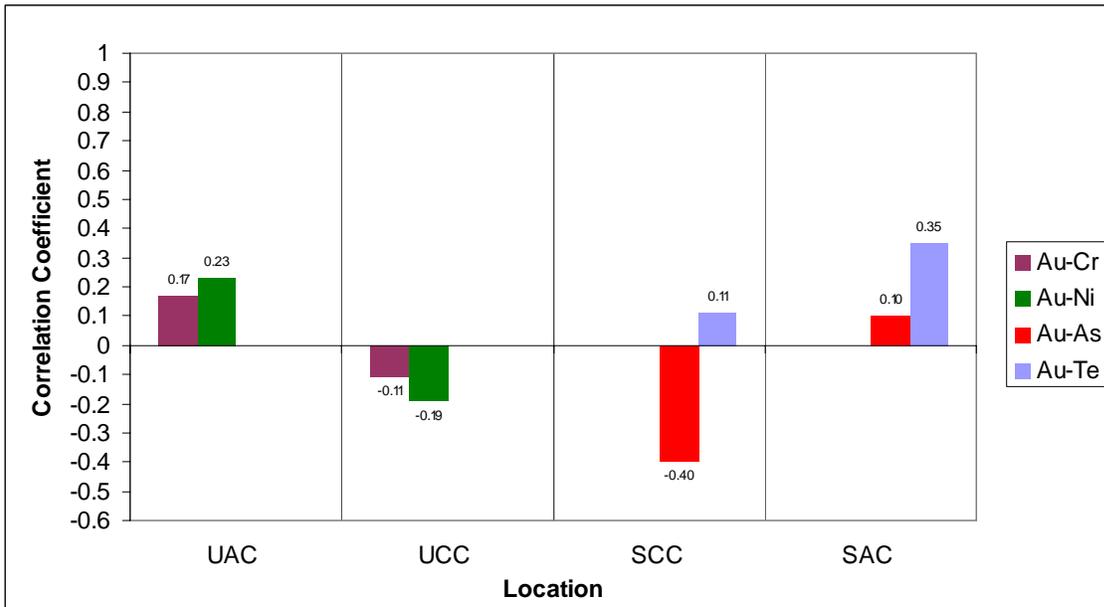


Figure 9. Correlation coefficients between Au and other elements.

This is also supported by the observation that the gold is mainly hosted by the high temperature formation rock unit, serpentinite close to the contact zone. Moreover, gold values decrease within low temperature formation rocks, (*i.e.* schist). This can be explained by the fact that the elevation of the contact zone temperature due to the emplacement of

aplite dikes resulted in the gold mineralization mobilization toward the serpentinite and the schist rock units away from the intruded aplite dikes. As the serpentinite has a higher formation temperature than that of the aplite and schist, this rock unit was not affected by the heat produced by the emplacement of aplite dikes as much as the schist rock unit. This process might have stopped the gold mineralization from mobilization through the serpentinite and caused its concentration within serpentinite rather than within schists. The low gold concentration within the schist might be attributed to the fact that the schist rock units might be heated due to the aplite dikes emplacement, as both have closer formation temperatures, which allows the gold to mobilize further and disperse through the schist. Part of the gold mineralization might also be originated from the serpentinite rock unit itself.

SUMMARY AND CONCLUSIONS

The geological settings of the Hajr ancient gold mine is made up of hornblende schist overlain in serpentinite, with aplite dikes intruded in to the contact zone in between the two rock units. The serpentinite is sheared and carbonatized along the contact zone. Gold mineralization in the form of disseminations is present within the three rock types. However, gold values decrease further from the contact. Field observation, location of ancient workings, chemical analyses, and statistical studies indicate that the sheared carbonatized serpentinite rock unit is the predominant mineralized rock type in the area. Gold mineralization may have been mobilized from the aplite rocks, to the contact zone as result of the thermal effect of the aplite dike emplacement. Moreover, the formation temperature difference between the aplite dikes, schist rocks and serpentinite rock units might have caused the gold mineralization to concentrate within serpentinite and get dispersed through the schist. In addition, the lower serpentinite rock unit at the contact zone may also act as an impervious cap to the ascending aplitic magma and hydrothermal solution. Cr and Ni concentrations are also high within the carbonatized serpentinite rock unit close to the contact compared to the serpentinite rocks, due to weathering and alteration processes rather than depletion in the un-carbonatized rocks.

The coefficients of variation for the gold and tellurium values indicated random distribution of these elements in rock units at the contact. Mineralization in the Hajr area may be contemporaneous with the shearing in the serpentinite. Shearing was possibly the result of competency difference between the serpentinite and schist rock types and occurred during a period of gentle folding.

This study emphasizes that the host rock for gold mineralization is the ultramafic carbonatized serpentinite at the contact zone. The ancient workings in the area were also concentrated at the contact zone. However, none of the old workings go deeper than 20 meters. This finding and observation may encourage further exploration in the carbonatized serpentinite at the contact zone, and down to depths greater than 20 meters, using the current technology.

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