

geofísica
internacional

Geofísica Internacional

ISSN: 0016-7169

silvia@geofisica.unam.mx

Universidad Nacional Autónoma de México
México

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Geofísica Internacional, vol. 36, núm. 2, april-june, 1997, p. 0

Universidad Nacional Autónoma de México

Distrito Federal, México

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A genetic model for the Los Uvares gold deposit, Baja California Sur, Mexico

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RESUMEN

El yacimiento de oro de Los Uvares es un yacimiento relativamente pequeño (~500,000 toneladas con un promedio de 3 gramos de oro por tonelada) localizado en el complejo cristalino de Cabo San Lucas, al sur de la península de Baja California. Los modelos genéticos previamente sugeridos para este depósito son: pórfiro-aurífero y dique-falla tonalítico (Escandón, 1983; Romero, 1986). Sin embargo, la evidencia petrográfica sugiere que Los Uvares es un yacimiento de oro diseminado relacionado con una falla (Carrillo, 1990; Carrillo y Huyck, 1990). Una comparación del depósito de Los Uvares con yacimientos pórfiro cupro-auríferos, de falla de bajo ángulo (detachment), tipo Carlin y epitermales indica que Los Uvares presenta similitudes con los yacimientos epitermales de oro. El modelo presentado en este trabajo puede ser usado como una guía para la exploración de más yacimientos de este tipo en la península de Baja California.

Palabras clave: Yacimiento de oro Los Uvares, península de Baja California, yacimientos epitermales de oro, exploración de oro.

ABSTRACT

Los Uvares gold deposit is a relatively small ore deposit (~500,000 tons of ore averaging 3 grams of gold per ton), located in the crystalline complex of the Cabo San Lucas block in southern Baja California peninsula. Previous proposed genetic models for Los Uvares gold deposit are: porphyry gold, and tonalite dike-fault

(Escand-n, 1983, Romero, 1986). However, the petrographic evidence suggests that Los Uvares is a fault-related disseminated gold deposit (Carrillo, 1990; Carrillo and Huyck, 1990). A comparison between the Los Uvares deposit with porphyry gold-copper, detachment-fault, Carlin type and epithermal deposits suggests that the Uvares is most similar to epithermal gold deposits. The model presented here could be applied as an exploration tool for other deposits in the Baja California peninsula.

Key words: Los Uvares gold deposit, Baja California peninsula, epithermal gold deposits, gold exploration.

INTRODUCTION

The Los Uvares gold deposit, 50 km southeast of La Paz, Baja California Sur, occurs in a fault zone within a tonalitic-granodioritic pluton of the Cabo San Lucas Block (CSLB). Recently Romero (1986) completed a geologic study and mineral evaluation, estimating 484,237 tons of ore with 3.0 grams of gold per ton; and Carrillo (1990), Carrillo and Huyck (1990), and Carrillo and others (1991) have described the mineralization, alteration assemblages, and radiometric ages based on fission tracks on apatite.

Other gold, silver and lead ore deposits occur in the area. These deposits are found in epithermal veins containing high concentrations of sulfide associated with gold and silver; fault-related disseminated gold deposits in igneous rocks; and one disseminated gold deposit in metamorphic rock (biotite-sillimanite schist). A similar genetic model is suggested for Los Uvares based on mineralization and alteration assemblages. The model is compared with genetic models of worldwide gold deposits.

Geologic setting

The Cabo San Lucas Block (CSLB) consists dominantly of granitoids ranging in composition from monzogranite to tonalite (Bates and Jackson, 1987) and is of Cretaceous age (Frizzell et al., 1984; Gastil et al., 1976). These plutonic rocks intrude Paleozoic(?) metasedimentary rocks and are partially covered by middle Tertiary volcanic rocks and upper Tertiary sedimentary sequences. The CSLB is bounded to northwest by the north-trending La Paz fault (Figure 1).

The setting of the Los Uvares gold deposit is dominated by an undeformed tonalite (regional country rock) and a cataclastically deformed tonalite (host rock for the mineralization). Other rock types include minor alaskite dikes and diorite dikes. The latter are related to a large diorite body that crops out east of the ore zone. The main structural features at Los Uvares are a major shear zone, which hosts the mineralization zone, and later east-trending strike-slip faults.

The undeformed tonalite belongs to the granodiorite-tonalite intrusions of the

CSLB. This rock was classified by Romero (1986) as a granodiorite, based on modal analysis. We classify it as hornblende-tremolite-biotite tonalite, with minor deformation. In general, the texture is undeformed away from the ore zone (shear zone), but deformation increases towards the ore zone. Locally, this country rock contains as much as 5% of pyrite, but no gold was detected within this rock (Romero, 1986).

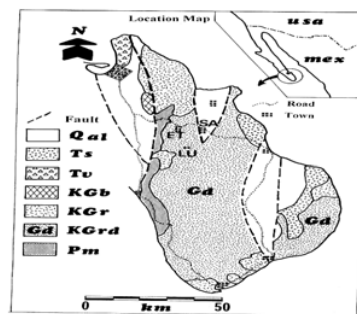


Fig. 1. Geologic map of the Cabo San Lucas block (CSLB) and location of Los Uvares gold deposit (LU) and the San Antonio (SA) and El Triunfo (ET) areas. Qal = quaternary deposits; Tv = volcanic; Ts = sedimentary; KGb = gabbroic; KGr = granitic; KGrd = granodioritic; Pm = metamorphic rocks.

The mineralized host rock (cataclastically deformed tonalite) occurs along a shear zone within the country rock. This shear zone forms a tabular body striking north 55° west, and dipping 50° to 60° northeast. The thickness of the shear zone ranges between 7 and 25 m and averages 12 m. It can be mapped on the surface for 1.5 km. A secondary set of east-northeast trending, left lateral strike-slip faults displaces the shear zone. Deformation in the host rock is randomly distributed. Mylonitic (foliated) and cataclastic (unfoliated) textures exhibit a similar random distribution (Carrillo, 1990). The modal sulfide mineralization in the host rock ranges between 2% and 10% and averages 5%. The main sulfide mineral is pyrite; minor amounts of chalcopyrite also occur. Pyrite to chalcopyrite ratio is 10 to 1. The sulfides exhibit mostly undeformed, euhedral to subhedral textures, and locally deformed and broken crystals are present. These minerals are disseminated throughout the rock (forming small 1 to 2 cm clusters), and occur also in thin vein (0.1 to 1 mm) veins with quartz and/or sericite. Despite the cataclastic deformation, this rock is similar to the country rock. The remanent mineralogy within the host rock also resembles the primary mineralogy of the country rock. Thus, we interpret the host rock as a cataclastically deformed equivalent of the country rock (Carrillo, 1990). Romero (1986) had proposed that the host rock is a separate intrusion into the country rock.

Alaskite dikes represent a minor rock type (less than 3%) at the Los Uvares deposit. At the surface, this rock intrudes both the country rock and the host rock. Locally the alaskite exhibits as much as 30% of cataclastic deformation. Diorite dikes intrude the regional tonalite, the cataclastically deformed and the alaskite. These dikes occur throughout the ore zone and can be observed on the surface and

in drill cores.

Ore deposition

Three major and two minor hypogene mineral alteration assemblages occur at the Los Uvares deposit: (1) chlorite + carbonate + epidote (first major alteration); (2) biotite (minor alteration); (3) sericite + quartz (second major alteration); (3a) chlorite + quartz (minor alteration); and (4) calcite + zeolite / zoisite (third and last major alteration). Gold mineralization is related in time to the sericite + quartz and chlorite + quartz alterations. Figure 2 shows the time relationships among the alteration mineral assemblages, mineralization, and intrusion of alaskite and diorite dikes. A detailed description of these mineral alteration assemblages can be found in Carrillo (1990).

Ore mineralogy at Los Uvares consists of minor amounts of chalcopyrite and micron-sized gold inclusions in pyrite. Pyrite and chalcopyrite grains (~3% of the host rock) crosscut the chlorite + carbonate + epidote alteration, but are crosscut by the calcite + zeolite / zoisite alterations. Locally, chlorite + quartz, and sericite + quartz veins are spatially related with the pyrite + chalcopyrite. Sulfides minerals distribution is irregular throughout the host rock. They locally occur within veins and form small clusters of 0.5 to 3 cm diameter. Pyrite exhibits dominantly euhedral textures; however, in microshear zones, it locally shows partially cataclastic textures. Euhedral and slightly cataclastic sulfides may occur only few millimeters apart. These sulfide textures suggest that the pyrite + chalcopyrite were deposited after a major cataclastic event, but before a minor structural event. Romero (1986) noted the sporadic presence of individual 1 to 5 mm gold crystals associated with "augen-quartz" structures; however, no free gold was observed in the petrographic analysis (Carrillo, 1990). Gold inclusions within the pyrite are found mainly within the host rock, but minor amounts are locally reported from the diorite dikes (Romero, 1986). Fluid inclusions in the quartz-pyrite veins, related to sericite + quartz alteration, suggest that the temperature of hydrothermal fluids responsible for the alteration (and mineralization) ranged between 230° and 250°C.

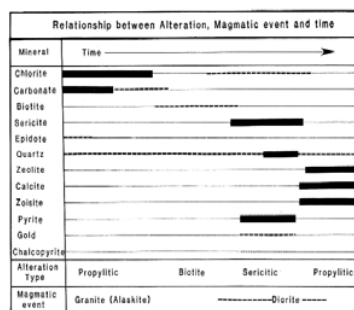


Fig. 2. Mineral alteration assemblages, mineralization paragenesis and their relation to intrusion events.

In general, the less deformed the rock, the higher is the gold grade, except for rocks with biotite and calcite + zeolite / zoisite alterations. Gold is very low in the chlorite + carbonate + epidote and in the biotite alterations. Gold increases in the sericite + quartz and chlorite + quartz alterations samples. This suggests a temporal relationship between mineralization and sericite + quartz and chlorite + quartz alterations. Gold values decrease within the calcite + zeolite / zoisite alteration, which could be explained by remobilization, by non-deposition or by dilution of the gold during this last alteration. These results are based on an analysis of eleven samples of altered host rock.

Based on Carrillo (1990) we suggest that, at least, three structural events are recorded at the Los Uvares deposit: (a) cataclastic deformation before any alteration and mineralization in the shear zone; (b) minor cataclastic deformation after the first alteration (chlorite + carbonate + epidote), but before mineralization affecting the country rock, the host rock and the alaskite dikes; and (c) minor local faulting after mineralization and intrusion of diorite dikes.

ORE GENESIS

Few attempts to classify the Los Uvares gold deposit have been made. Escandón (1983) classified the Los Uvares gold deposit as a "porphyry gold deposit". He did not explain the formation and distribution of the gold, and suggested that the gold was an igneous by product of the tonalite intrusion. Romero (1986) proposed a tonalite dike-fault model. The present paper suggests a fault-related epithermal model, in which the hypogene mineralization and related alteration occurred throughout a shear zone within the host rock (Carrillo, 1990, Carrillo et al. 1990, 1991). Romero's model and the present model differ in the interpretation of the genesis of the host rock. Romero's model considers the host rock as a separate intrusion in the country rock, whereas our model suggests that the host rock was derived from the country rock by cataclastic deformation along a shear zone.

The sequence of events for the dike-fault model by Romero (1986) is: (a) intrusion of the "granodiorite" (hornblende tonalite or country rock); (b) shearing; (c) mineralization (first event); (d) intrusion of the tonalite dike, (e) cataclastic deformation of the tonalite dike; (f) mineralization (second event); (g) intrusion of alaskite; (h) minor faulting; (i) intrusion of diorite dikes, and; (j) minor faulting. Our proposed sequence of events is: (1) intrusion of the hornblende tonalite (country rock); (2) major faulting and cataclasis of the tonalite along shear zones; (3) intrusion of the alaskite dikes, and formation of chlorite + carbonate + epidote and biotite alterations; (4) faulting and local cataclasis; (5) intrusion of the diorite dikes, sericite + quartz alteration and pyrite + gold + chalcopyrite mineralization; (6) chlorite + quartz alteration; (7) late alteration (calcite + zeolite + zoisite); and, (8) minor local faulting. In the model proposed here, pyrite and chalcopyrite are genetically associated (same hydrothermal fluids), and mineralization is

temporally related to the sericite + quartz and chlorite + quartz alterations.

The difference between our sequence and the model proposed by Romero (1986) is based on two key observations. First, detailed petrographic observations show the predominance of euhedral and subhedral pyrite and chalcopyrite crystals in the host rock. Pyrite and chalcopyrite are locally broken and slightly brecciated. The morphology of the pyrite and chalcopyrite suggests a single mineralization event, not two as proposed by Romero (1986). Second, important petrologic similarities between the country rock and the host rock suggest that they are part of the same intrusion. Both have similar plagioclase composition (An₂₀₋₃₀). Hornblende and tremolite (abundant in the country rock) form residual minerals in the altered host rock. Both have similar modal percentages of sphene and zircon; and the less deformed part of the host rock exhibits textures similar to the country rock. These similarities suggest that the cataclastically deformed tonalite was derived from the country rock (tonalite) by faulting and cataclastic deformation.

COMPARISON WITH OTHER GOLD DEPOSITS

The nearby location and structural similarity of the Los Uvares deposit with epithermal vein deposits in the CSLB requires that these deposits be compared. The geochemistry of the epithermal veins does show some minor differences with the Los Uvares geochemistry (higher lead content and silver-gold ratios in the epithermal veins), but no alteration mineral assemblage studies have been completed in the epithermal veins. Furthermore, the Los Uvares gold deposit exhibits features characteristic of several other types of gold deposits. The cataclastic textures are typical of detachment-fault gold deposits in southwest Arizona and southeastern California (Liebler, 1986; Willis, 1986). The country rock resembles that of gold-copper porphyry deposits (Titley, 1981; Sillitoe, 1979). The micron-size gold and gold grade resemble disseminated Carlin-type deposits in volcanic rock (Tooker, 1985) and the overall structure and the general alteration patterns resemble those in epithermal vein precious metal deposits (Buchanan, 1981). Table 1 compares some features of the detachment-fault, porphyry gold-copper, epithermal vein deposits and Los Uvares deposit. A brief description of these types of deposits will be followed by a comparison with the Los Uvares gold deposit.

Detachment-fault gold deposits

The occurrence of detachment-fault gold deposits has been known for a number of years, but only recently has interest arisen in the existence of detachment faults and their spatial and temporal relationship to mineralization (Guthrie et al., 1987; Liebler, 1988; Lehman et al., 1987; Manske et al., 1987; Willis, 1988). These deposits commonly occur in southwest Arizona and southeast California. They average about 9 million tons of ore, with an average grade of 1.4 grams per ton (Willis, 1988).

Mineralization occurs within breccias and cataclastic zones along a main low-

angle detachment. The detachment fault puts in contact two different sequences of rocks, known as the lower plate sequence and the upper plate sequence. In some detachment deposits, the upper plate sequence consists of Middle Tertiary volcanic and clastic rocks, and the lower plate consists of Precambrian to pre-Cretaceous intrusive and metamorphic rocks (Willis, 1988). Detachment faulting is due to extensional tectonics that affected southwest North America during the Middle and Upper Tertiary. Continued faulting along major detachments faults has produced a complex low-angle faulting system that favored gold and pyrite precipitation during the upper Tertiary (Drobeck et al., 1986).

The ore-bearing assemblages of detachment deposits include gold, hematite, chalcopyrite, pyrite, minor bornite, barite and fluorite (Drobeck et al. 1986; Cox and Singer, 1986). Drobeck et al. (1986) suggested that part of the hematite is the product of pyrite oxidation, but hematite locally occurs as a hypogene mineral in equilibrium with pyrite. Hematite, quartz and chlorite are the most conspicuous hydrothermal alteration in these deposits. Drobeck et al. (1986) suggested the following sequence of alteration and mineralization: (a) brecciation; (b) gold and pyrite mineralization with minor silicification and hematite veining; (c) hematite replacement of pyrite; (d) carbonate veining; and (e) supergene redistribution of gold. They also considered the main mineralization controls to be structural and assumed flow of oxidizing water. The geochemical signature of detachment deposits is gold, copper, iron, fluorine, barium, and very low anomalies in silver, arsenic, mercury and tungsten (Cox and Singer, 1986).

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The Los Uvares deposit exhibits similar cataclastic textures within the host rock as the detachment gold deposits but the Los Uvares fault zone is not likely to be a detachment-fault because it is a high-angle fault. It features no difference between the "upper plate" and "lower plate" sequences. Rotation can occur in the detachment-fault to yield a high-angle fault, but no evidence of rotation was found at Los Uvares. Mineralization at Los Uvares resembles, in some aspects, detachment-fault type mineralization (pyrite-gold, with minor chalcopyrite); but hematite in equilibrium with pyrite is not observed at Los Uvares. On the other hand, sericite + quartz and chlorite + quartz alterations, synchronous with mineralization at Los Uvares, are not present in detachment-fault deposits.

Porphyry gold-copper deposits

Porphyry gold-copper deposits have been extensively described in the geologic literature, since they represent an important copper source. Recently, gold has been considered an important by-product of copper production, but little is known about the gold mineralogy, zonation and genesis (Kesler, 1973; Cuddy and Kesler, 1982; Wilson and Kyser, 1988; Huyck, 1988).

The volume of porphyry gold-copper deposits averages 100 million tons, and gold grade averages 0.38 grams per ton (Cox and Singer, 1987). Host rocks are intrusive bodies, often of cylindrical shape and diameter ranging between 0.5 and 2 km, between tonalite and monzogranite, and showing porphyritic textures. Porphyry gold-copper deposits commonly contain breccia zones inside the intrusive body. The gold-copper systems exhibit a zoned alteration pattern: a inner potassic zone (quartz + magnetite + biotite + potassic feldspar); an outer propylitic zone (chlorite + carbonate + epidote); and, in some deposits, phyllic alterations (sericite + quartz + pyrite).

In the porphyry gold-copper deposits and in the Los Uvares deposit, both sericite + quartz and chlorite + carbonate + epidote alteration types are present. However, at Los Uvares, the sequence of alteration seems to differ from that of gold-copper porphyry systems. At Los Uvares the chlorite + carbonate + epidote (propylitic) alteration is pre-mineralization and, in general, is peripheral to the ore zone. Rebagliati and others (1990) and Fox and others (1990) described gold in propylitic altered rocks related to porphyry gold-copper systems. Sericite + quartz alteration is contemporaneous with the mineralization at Los Uvares. At the gold-copper porphyry systems, sericite + quartz alteration occurs after mineralization. Furthermore, the mineralization at the gold-copper porphyry deposits is mainly chalcopyrite + bornite + gold associated with K-feldspar; pyrite is a late-stage mineral. Mineralization at the Los Uvares deposit is pyrite + gold and minor amounts of chalcopyrite disseminated in cataclastically deformed host rock. In conclusion, the Los Uvares deposit is not a gold-copper porphyry system.

Epithermal vein deposits

Epithermal vein deposits generally occur with

Tertiary calc-alkalic andesite volcanic arc provinces, mainly in volcanic and sedimentary host rocks, although andesite is the most common host rock (Buchanan, 1982; Cox and Singer, 1987). Epithermal vein deposits have tonnages ranging between 0.1 and 1 million tons and gold grades ranging between 0.16 and 10 grams gold per ton.

The most characteristic features of the epithermal vein deposits, as proposed by Buchanan (1982) for an idealized composite system, are: (a) open space filling and banded texture of the veins, and (b) zoned distribution of ore mineralogy and alteration mineral assemblages. Vertical ore mineral zonation for a complete system grades from base metal (galena, sphalerite and chalcopyrite) near the bottom, to precious metals (gold in pyrite, silver in sulfosalts) near the top.

Vertical zonation of alteration minerals is, from bottom to top: quartz-fluorite-chlorite, quartz-adularia-sericite-minor chlorite, quartz-calcite-pyrite-barite-fluorite, and clay minerals-zeolite-calcite (Buchanan, 1982; Cox and Singer, 1986).

Heald and others (1987) made a comparative analysis of acid-sulfate and adularia-sericite epithermal vein deposits. This comparison shows different alteration assemblages for the two types of deposits: acid-sulfate features enargite, alunite, kaolinite, rare chlorite and no adularia, while adularia-sericite has sericite, adularia, chlorite and no enargite. The epithermal vein deposits of the CSLB and Los Uvares appear to be characteristic of acid-sulfate deposits.

A comparison between the Los Uvares deposit and epithermal vein deposits shows some similarities in shape (tabular), texture (open space filling) and tonnage. It is important to note that the epithermal vein deposit model presented by Buchanan (1982) is a recompilation of several epithermal systems all over the world. No single system features all the characteristics. Los Uvares contains sericite + quartz, chlorite and calcite + zeolite alterations. These alterations are also present in epithermal veins. The sericite-adularia epithermal system is most closely related to Los Uvares, yet no adularia is present at Los Uvares. Other differences between Los Uvares and epithermal veins are: lack of banded veins, lower base metal content and no evidence of boiling at Los Uvares. According to Buchanan (1981), a boiling area should be the transition from base metals to precious metals. In conclusion, Los Uvares is not a characteristic epithermal vein deposit. However, it exhibits certain features of shape, texture, and alteration patterns that resemble those in epithermal veins.

Carlin-type gold deposits

Carlin-type gold deposits have been found in the southwestern United States of America (particularly Nevada and Utah). Tonnage ranges between 1.1 and 24 million tons, and the grades vary between 0.69 and 7.6 grams per ton of gold (Guilbert and Park, 1986; Sillitoe and Bonham, 1990). Their main host rocks are thinly bedded silty or argillaceous, carbonaceous limestones or shally carbonaceous dolomites. Carlin-type deposits are related to high-angle normal fault zones or thrust zones and to local intrusions. The mineralogy consists of native gold + pyrite + realgar + orpiment + arsenopyrite + cinnabar + fluorite + barite + stibinite. The main alteration is jasperoid + quartz + illite + kaolinite + calcite. The most common texture within these deposits is the silica replacement of carbonate, with generally less than 1% disseminated sulfides. An outstanding feature is the occurrence of very fine-grained gold particles, detectable only in the laboratory. The geochemical signature of Carlin-type deposits is gold, arsenic, mercury, tungsten, and molybdenum (Cox and Singer, 1987; Tooker, 1985).

Carlin-type deposits and Los Uvares deposit both have high angle faults and intrusions. The Los Uvares deposit locally exhibits low percentages of fine-grained disseminated sulfides and very fine-grained gold particles within the

sulfides. However, sulfide content increases locally to 15%. Also, visible gold particles can be observed in the pyrite in Los Uvares. Furthermore, the alteration assemblages differ in the Carlin-type and Los Uvares deposits. In conclusion, Los Uvares is not a Carlin-type gold deposit.

Suggested model for Los Uvares

Based on texture, on distribution of alteration assemblages (Carrillo, 1990) and on a comparison of the Los Uvares deposit with other gold deposits, we suggest an epithermal origin for the Los Uvares deposit. In epithermal systems, gold is mostly transported as a simple dihydrosulfide-gold (I) complex $\text{Au}(\text{HS})_2^-$ (Henley, 1985; Seward, 1989) in dilute solutions which may or not boil. Boiling is a common mechanism for deposition of gold. However, at Los Uvares, boiling has not been observed in a limited set of fluid inclusions.

We propose a fault-related model in which the host rock, a cataclastically deformed tonalite, has been directly derived from the tonalite country rock by pre-mineralization cataclastic deformation. The cataclastic deformation increased porosity and permeability in the host rock and favored the circulation of the epithermal mineralized fluids. Timing of mineralization suggests that the diorite may have triggered the circulation of fluids through the cataclastically deformed tonalite.

Mineralization seems to have taken place in response to chemical changes contemporaneous with the sericite + quartz alteration and the lesser chlorite + quartz alteration. A possible mechanism could be the release of iron during sericitization of chlorite, biotite and amphiboles, breaking down the simple dihydrosulfide gold(I) complex $\text{Au}(\text{HS})_2^-$. The zonation of the chlorite + carbonate + epidote, and sericite + quartz alteration assemblages supports this idea.

SUMMARY AND CONCLUSIONS

The two earlier models for this deposit are referred to as "porphyry gold" (Escand-n, 1983), and "diike-fault" (Romero, 1986). However, the host rock does not feature any porphyritic texture, and the petrographic evidence shows that the host rock was not a separate intrusion into the country rock; rather it was the result of an early major cataclastic deformation. Therefore, a "fault-related" model is a more likely explanation for the petrographic observations in the country rock and the host rock.

Comparisons between Los Uvares gold deposit and other gold deposits suggest a similarity with epithermal gold deposits. Circulation of dilute, hydrothermal fluids was enhanced by the cataclastic deformation within the host rock. Based on the morphology of fluid inclusions in quartz-pyrite veins related to the sericite + quartz alteration, the possible temperature of mineralization ranges between 230°C and 250°C. No evidence of boiling was observed in the fluid inclusions. Diorite

intrusion (including dikes and an adjacent large intrusive) was the most likely heat source that triggered the circulation of the epithermal fluids. The alteration mineral assemblages and local space-filling structures in Los Uvares show similarities with those of epi-thermal deposits.

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