

Adularia-sericite type wallrock alteration at the María Josefa gold mine: An example of low sulfidation epithermal ore deposit, within the volcanic Rodalquilar Caldera (SE, Spain).

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ABSTRACT

The mineralogy of wallrock alteration in María Josefa mine was investigated in order to establish the paragenetic mineral association and their origin in the framework of the gold-alunite Rodalquilar mining district (SE Spain).

Microprobe analyses exhibit two types of adularia existing in the aureoles of the María Josefa vein system reflecting the evidence of both replacement and neof ormation during the alteration process. Three paragenetic associations have been recognized: quartz-adularia, quartz-adularia-sericite and quartz-sericite. X-ray diffraction analyses were performed in order to identify and quantify the existing minerals. The data obtained indicate the presence of minor amounts of kaolinite, goethite, hematites, calcite, gypsum and jarosite. Pyrite was identified as the principal base metal-containing mineral.

The mineral paragenetic assemblages found in wallrock alteration at the María Josefa mine present a good example of low sulfidation type of epithermal gold deposit located peripherally to the Rodalquilar caldera structure, contrasting with the high-sulfidation type existing in the core.

Keywords: Adularia. Low sulfidation. Hydrothermal alteration. Rodalquilar mining district

INTRODUCTION AND PREVIOUS WORK

The Cabo de Gata volcanic field (Almería, SE Spain) is the only large area of Miocene volcanic rocks on the Iberian Peninsula. Gold-bearing silicified ore de-

posits are widely spread in the volcanic complex around the town of Rodalquilar. These deposits were formed by hydrothermal alteration related to volcanic activity during the Miocene.

The regional geological setting of the Rodalquilar gold deposits has been described by Bordet (1985), Pohl (1987), Arribas *et al.*, (1989), Rytuba *et al.* (1990) and Arribas (1992). The main type of gold mineralization is related to ring and radial faults associated with the Lomilla caldera (Cunningham *et al.*, 1990). The María Josefa mine is located West of the Lomilla caldera, along a N-S structural direction in the peripheral part of the main collapse structure. The mineralized zones at the Rodalquilar caldera complex are characterized by a suite of intensive alteration of the volcanic host rocks (Arribas *et al.*, 1988; Friedrich, 1960; Lodder, 1966; Martin-Vivaldi *et al.*, 1971; Friedrich *et al.*, 1984; Kross, 1986; Sanger-von Oepen *et al.*, 1989).

Gold-deposits in the eastern part of the Lomilla caldera (Transaction mine) are associated with large areas of advanced argillic alteration, containing alunite, pyrophyllite and kaolinite. These deposits have been classified as acid-sulfate or high sulfidation deposits (Arribas *et al.*, 1988). The major alteration types existing in the Rodalquilar Caldera zone are schematically shown in Fig. 1. Many kinds of mineral assemblages occur as a

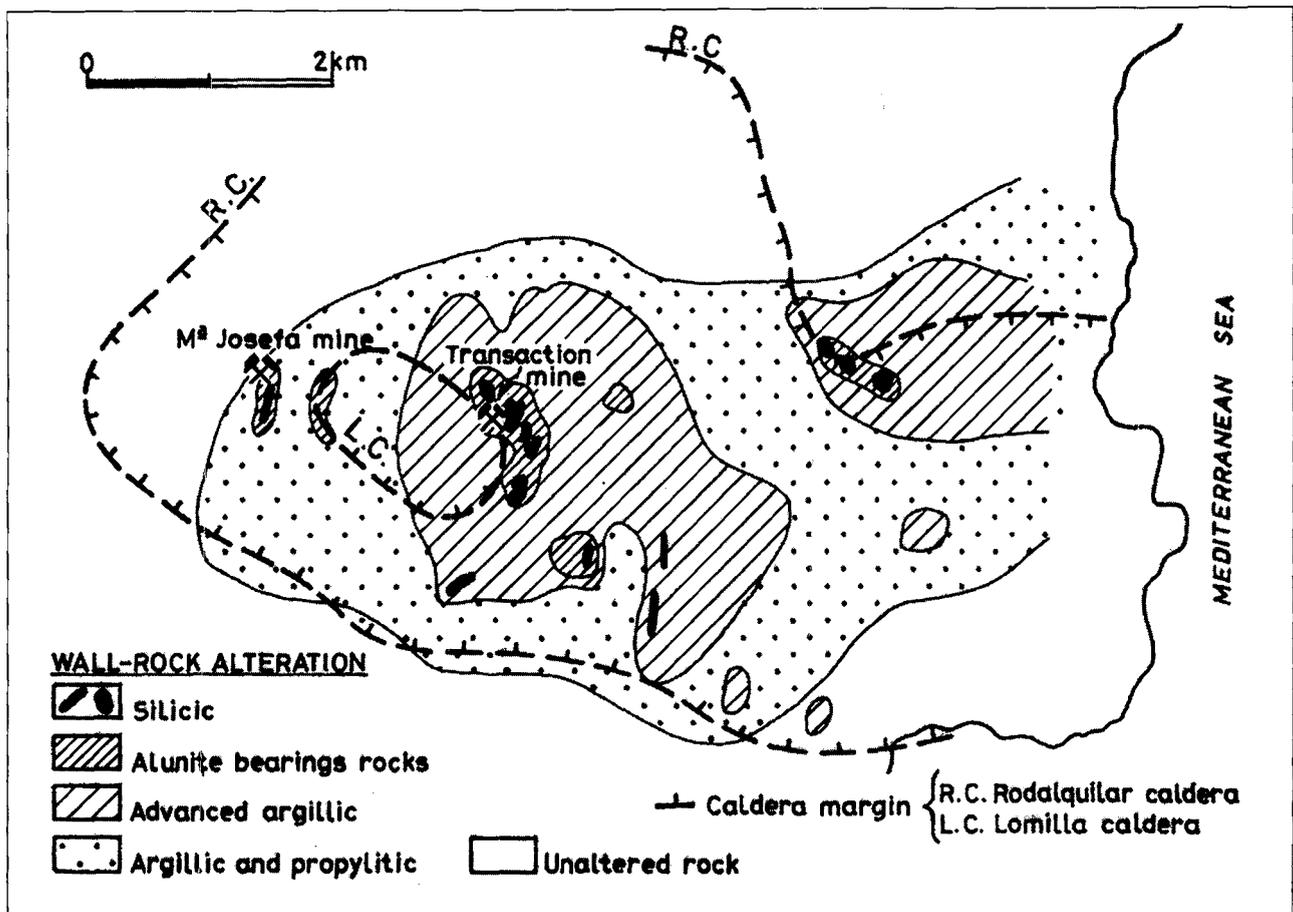


Fig. 1. Major alteration zones within the Rodalquilar caldera complex (from Arribas *et al.*, 1989).

major alteration products in the hydrothermal alteration aureoles around the silicified rocks. The main goal of this work is to study hydrothermal alteration and mode of mineralization associated with the silicified veins systems at the Maria Josefa gold mine

THE MARIA JOSEFA GOLD MINE

The information concerning geological setting and the general framework of the mineralized bodies in the Rodalquilar caldera is briefly compiled by Arribas *et al.* (1989) including some data on the Maria Josefa Mine. According to these authors, Maria Josefa exhibit similarities with the advanced argillic type of alteration, located peripherally to the core of altered rocks of Rodalquilar Caldera, where silicic, advanced argillic, argillic and propylitic types of alteration are observed. They consider the mineralized vertical structure cuts across hornblende andesites and has a length of hundred meters and an average thickness of the ore zone of 0.6 meters. According

to Arribas *et al.* (1989) the wallrock alteration around the vein is narrow (no more than 10 m.) and the rocks contain silica, kaolinite, illite, I/Sm interlayers, jarosite, hematite and traces of alunite. Plagioclase is replaced by K-feldspar in the propylitized host-rocks. Different gold-bearing silica lithologies are found.

Rytuba *et al.* (1990) have pointed out that Maria Josefa Mine consists off two black chalcedony veins with a total width of 2 m. localized in hornblende andesite flows. Based on fluid inclusion data, Sanger-von Oepen *et al.* (1990) compare Maria Josefa and Transaction deposits concluding Maria Josefa is a vein system hosted by rhyolitic ignimbrites, altered to an argillic alteration assemblage (illite-sericite abundant and subordinate kaolinite), that grades outwards into propylitic alteration. Homogenization temperatures of liquid-rich fluid inclusions in secondary quartz-phenocrysts range between 180° and 220°C with frequency distribution of salinities showing a maximum between 2 and 3% NaCl equivalent.

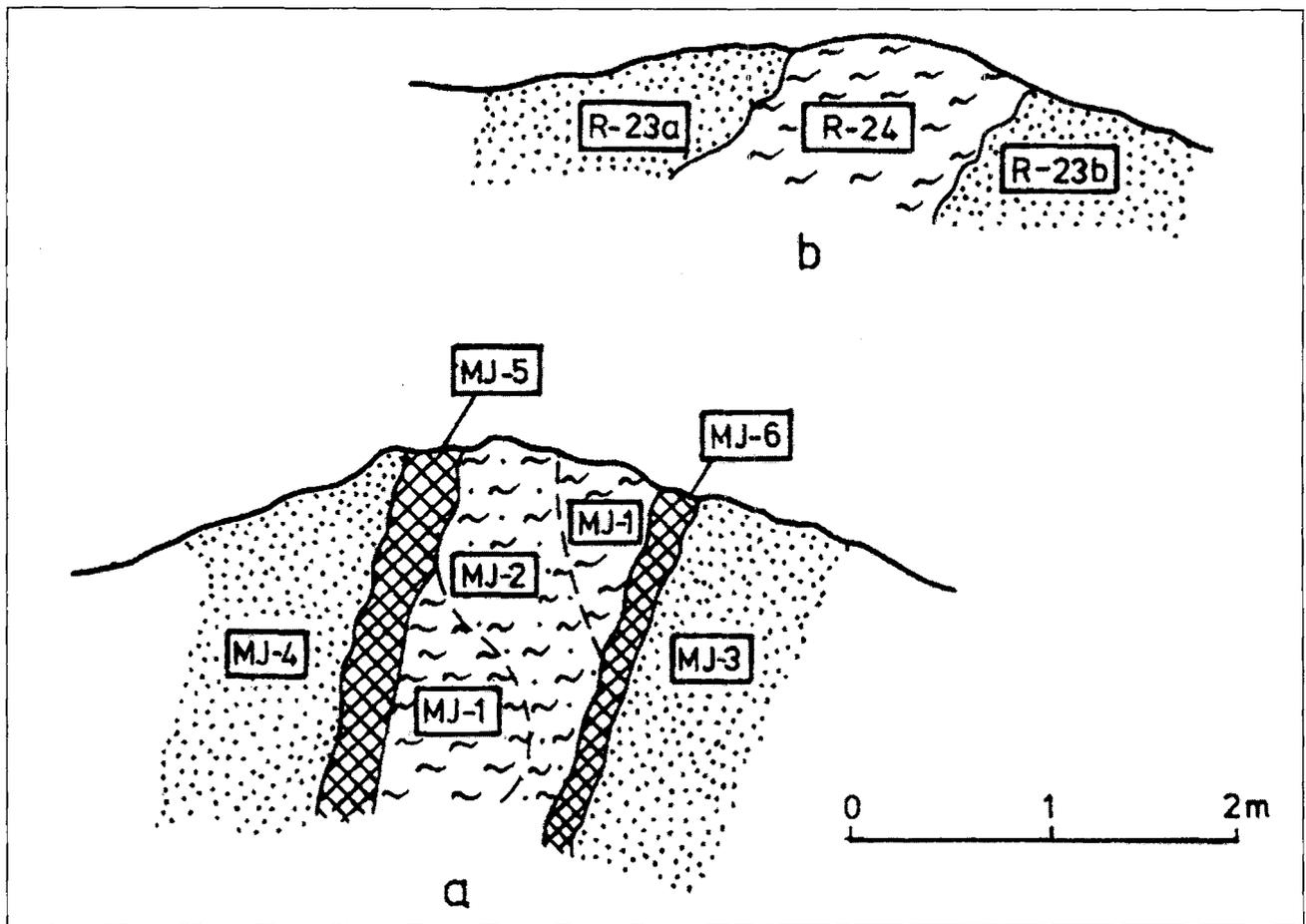


Fig. 2. Sampling points and sample location at Maria Josefa gold mine.

- a) Open pit structure. MJ-1. Black chalcedony. MJ-2. Withish chalcedony. MJ-3 and MJ-4. Quartz-sericitic rocks. MJ-5 and MJ-6. Quartz-iron oxides rocks.
- b) Outcrop near the top of the Cerro de la Cruz. R23a and R23b. Quartz-sericitic host-rocks. R24. Opaline silica with disseminated sulfides.

On the basis of Heald *et al.* (1987) classification, Sanger-von Oepen *et al.* (1990) considered that the core of Rodalquilar deposits may be attributed to the acid-sulfate type of volcanic hosted epithermal gold-mineralization, whereas Mara Josefa Mine reveal some unclear affinities to the adularia-sericite type.

SAMPLING AND METHODS

Selected samples from open pits and from outcrops exposed in the area of the abandoned Maria Josefa mine were taken gradually outwards from the lode, in order to obtain a representative specimens to study the mineral assemblages and the zonal pattern along the vein system.

Six different samples (MJ-1 to MJ-6) are from the main vein (Fig. 2), three samples (R23a, R23b and R24)

from the outcrop located near the top of the Cerro de la Cruz. Samples R25 and R26 belong to host rocks out of the aureole of the main vein structure (approximately 100 m. to east of the main lode vein). All the samples were X-ray analyzed, using powder diffraction methods. In order to obtain a comprehensive knowledge of the existing clay minerals, oriented aggregates were prepared and subsequent ethylen-glycol treatments were carried out. A semiquantitative estimation of the amount of different minerals distinguished by X-ray procedures using the method developed by Chung (1974), was done. The results of the mineralogical analyses is shown in Table 1.

RESULTS

The inner part of the vein structure (MJ-1 and MJ-2 samples) is characterized by a open space filling consist-

Table 1. Mineralogical semiquantitative analysis. X-Ray diffraction.

Sample	Q	Fd	Mc	K	Go	Hm	Gy	Jr	Py	Ca
<u>Main vein system</u>										
MJ-4	54		43					1	2	
MJ-5(ex)	85		5	2	1	2	1	5		
MJ-5(in)	86		3		1	2	4	1	3	
MJ-1	95				2				3	
MJ-2	92		7					tr		
MJ-6	85				5	1		1	8	
MJ-3	52		48							tr
<u>Upper outcrop</u>										
R23a	77		23							tr
R24	98							1		
R23b	91		6			2	2			
<u>Rocks surrounding mine</u>										
R25	71	29								
R26	44	16	22	8					11	

Q.- Quartz; Fd.- K-feldspar; Mc.- Mica-"sericite" (10 Å basal spacing); K.- Kaolinite; Go.- Goethite; Hm.- Hematite; Gy.- Gypsum; Jr.- Jarosite; Py.- Pyrite; Ca.- Calcite; tr.- traces.

ting of dark cryptocrystalline quartz. Narrow cross-cutting quartz-veinlets with a coarser grain size (around 0.1 mm) that likewise overlap the wall pores can be also found at this part. Large (aprox. 3 mm) corroded quartz crystals occur within the matrix. This fact indicates different steps in quartz precipitation according to the criteria of Cuevas *et al.* (1987). Mafic phenocrysts replaced by jarosite, carbonate minerals and a 2-3% of metallic minerals complete the observed mineral composition. Some parts of the vein are lighter on color (MJ-2, Fig. 2) due to the white mica and fine grained quartz contents and the minor amounts of metallic minerals and traces of jarosite.

Samples MJ-5e, MJ-5i and MJ-6 taken from the direct contact area with the vein structure, are intensively silicified containing rounded and fractured quartz crystals (1 to 2 mm in size). Dissolution of previous minerals resulted the development of skeletal structures and holes. Secondary quartz and small amounts of carbonates can be found in the wall holes. Some metallic minerals (sulfides) and iron oxides can be optically observed.

In the external parts (samples MJ-3, MJ-4) of the vein system, the prevailing rocks have porphyritic textures. Many phenocrysts, suggesting an original plagioclase composition, are totally replaced by clay minerals. Quartz phenocrysts are rounded and corroded, having the corrosion pores filled by clay minerals. Some corrosion figures suggest replacement of quartz phenocrysts by sericite. Titanite, pyrite and jarosite can be distinguished.

The rocks of the higher part of the outcrop, near the top of the Cerro La Cruz (sample R24) consist of cryptocrystalline quartz, quartz, and finely disseminated metallic minerals (up to 8%). The host rocks in this outcrop (samples R23a and R23b) are strongly altered having porphyritic texture (20% of phenocrysts) with fine grained quartz matrix. Phenocrysts are internally replaced by clay minerals and minor amounts of metallic minerals and carbonates can be observed.

Both R25 and R26 samples present good examples of adularization of feldspars. Plagioclase phenocrysts are completely altered and replaced by sericite and adularia.

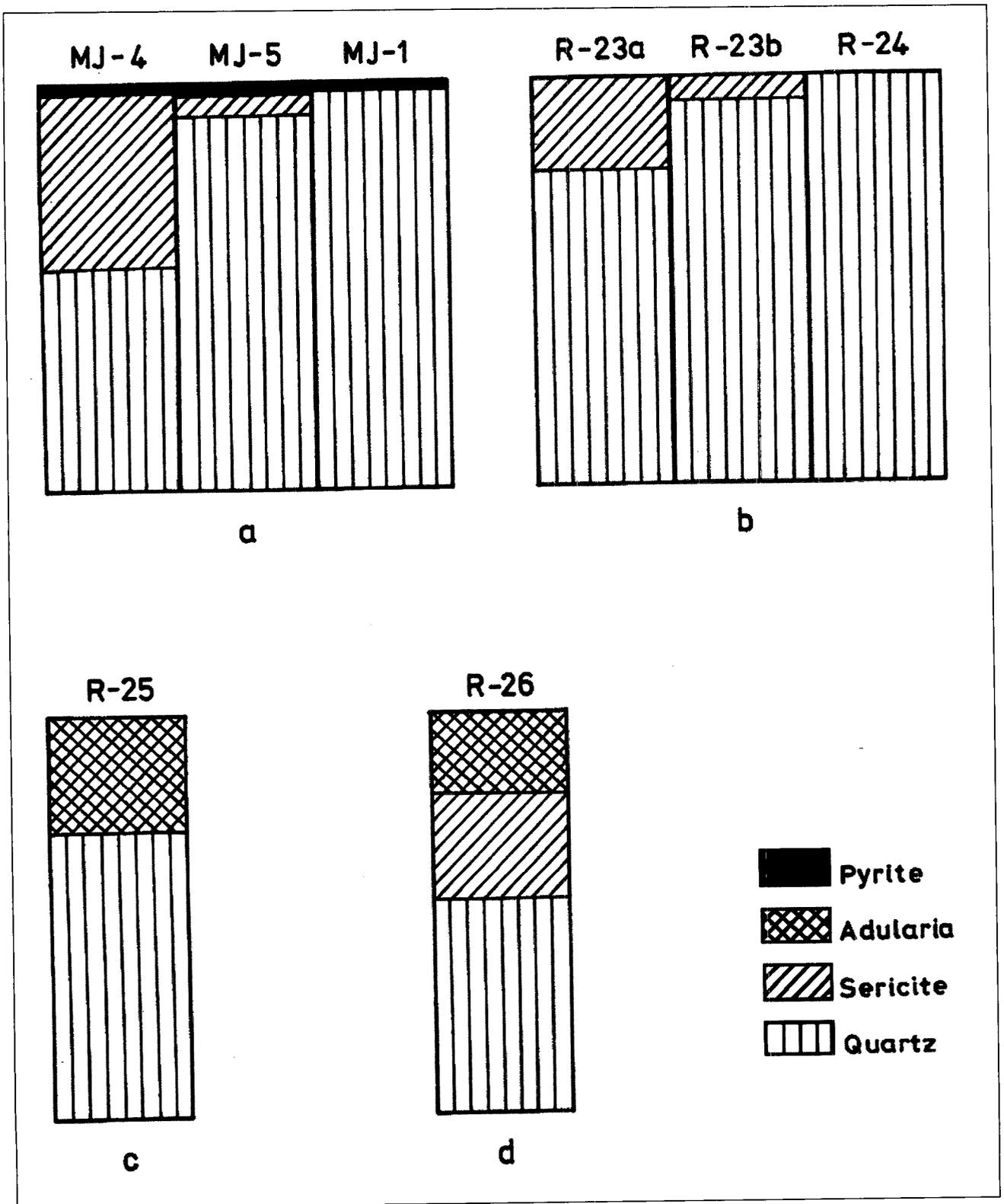


Fig. 3. Typology of wallrock alteration in Maria Josefa gold mine.
 a) and b) Sericite type. Vein system structure.
 c) and d) External aureole. Adularia and Adularia-sericite types

Table 2. Microprobe analyses, structural formulas and feldspar composition of adularia.

Sample R-25										Sample R-26												
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
SiO ₂	65.80	65.46	65.98	66.34	67.05	64.78	66.20	65.29	63.45	64.63												
TiO ₂	0.10	0.05																				
Al ₂ O ₃	18.41	18.89	17.93	19.23	18.53	18.08	18.76	18.69	19.04	18.55												
FeO				0.11	0.24				0.06													
MnO									0.14													
MgO				0.22					0.44													
Na ₂ O	2.14				0.84					0.17												
K ₂ O	13.14	15.40	15.74	13.52	13.30	16.09	15.03	15.44	14.97	15.78												
BaO			0.19	0.23	0.20	0.31	0.10	0.37	1.23	0.55												
Total	99.59	99.80	99.84	99.65	100.16	99.26	100.09	99.79	99.33	100.30												
Si	3.01	3.01	3.04	3.02	3.04	3.02	3.02	3.01	2.96	2.99												
Ti	0.00	0.01																				
Al	0.99	1.02	0.97	1.03	0.99	0.99	1.01	1.02	1.05	1.01												
Fe ⁺²				0.00	0.01				0.00													
Mn									0.01													
Mg				0.02					0.03													
Na		0.19							0.07													
K	0.77	0.90	0.92	0.79	0.77	0.96	0.91	0.91	0.89	0.93												
Ba			0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.01												
Ab	19.8			8.7																		
Or	80.2	100.0	99.7	99.5	90.9	99.4	99.3	99.3	97.5	93.4												
Cn			0.3	0.5	0.4	0.6	0.7	0.7	2.5	1.0												

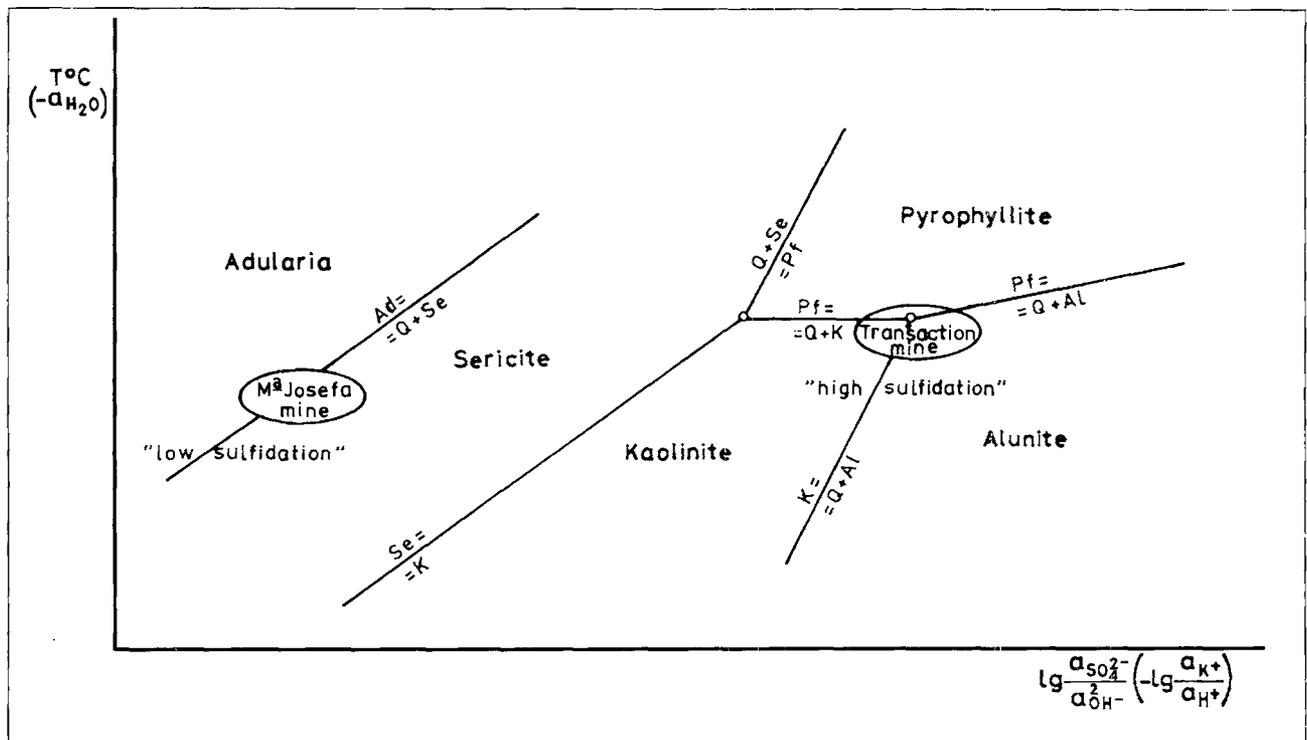


Fig. 4. Scheme of the relationships between the acid-sulphate and adularia-sericite types of alteration in basis of mineral equilibria (modified from Kazirski, 1992). Ad. Adularia. Al. Alunite. K. Kaolinite. Pf. Pyrophyllite. Q. Quartz. Se. Sericite.

In sample R25 plagioclase minerals are entirely replaced by adularia and partially by sericite. The quartz phenocrysts have intensive corrosion and the matrix is composed of K-feldspar, quartz and some plagioclase microcrystals. The R26 sample is brecciated and quartz cemented, containing clay minerals. Jarosite grains and metallic minerals are found. Sericite is not developed where fine quartz-veinlets cross plagioclase-adularia replaced crystals.

All the samples analyzed exhibit high quartz content and the external parts of the lode show the presence of mica clay (10Å basal d-spacing,) amounting up to 48 percent. The mica found at Maria Josefa mine exhibits dioctahedral type with d(060) value of 1.496, and its behaviour after glycol solvation is the same as that described by Kawano and Tomita (1991). Only 2M1 polytype have been identified and no different polytypes far away from the vein are found.

Kaolinite is found in minor quantities or traces at the halo of the vein system, associated with K-feldspar, 10Å micas and quartz. No other phyllosilicates were found and the glycol solvation allow us to discard the presence

of expandable clay minerals (I/Sm interlayers or smectites). Concerning the sulphate minerals, only gypsum and jarosite were identified and alunite was not detected in any sample.

The characteristics of the main diffraction peaks of the feldspar minerals (grading to 3.30 and 3.27 Å, and 201 plane diffracting around 4.22 Å) in the R25 and R26 samples are in correspondence with those of the orthoclase subgroup, following the criteria of Moore and Reynolds (1989), suggesting the high-potassium feldspar presence. Macroscopic observations allow us to recognize the presence of adularia in these samples.

Chemical analyses of adularia are reported in Table 2. Two types of adularia can be distinguished, both of them with traces of Ba. One type of adularia is sodium-rich (analyses 1, 5 and 10) and occurs replacing plagioclase. The other, is potassium-rich and occurs in the fine-grained quartz veinlets. Ca was not detected in any of the analyses.

Chemical composition data of mica group minerals are presented in Table 3, together with data for calcite

Table 3. Illite, calcite and jarosite microprobe analyses..

Sample	Illite		Calcite		Jarosite			
	MJ-3	R-23	MJ-3	R-23	MJ-1	MJ-1	MJ-6	R-25
SiO ₂	51.25	51.23	0.17	1.47	0.47			
TiO ₂		0.05						0.05
Al ₂ O ₃	35.98	36.05	0.25	0.45	1.20	2.31	0.76	2.50
FeO		0.17	0.07					
Fe ₂ O ₃					45.78	45.04	46.30	39.91
MnO	0.04			0.06				
MgO	0.58	0.22	1.55	0.48				
CaO			52.95	53.00				
Na ₂ O								
K ₂ O	7.35	8.81		0.06	1.00	3.13		
BaO	0.11		0.33		9.73	4.34	9.97	8.91
H ₂ O(*)	4.69	3.47			10.30	11.37	9.75	11.39
CO ₂ (*)			44.68	44.48				
SO ₃					31.99	33.81	33.22	36.77
Total	95.31	96.53	55.32	55.52	89.70	88.63	90.25	88.61
Si	3.28	3.27						0.02
Ti		0.00						0.00
Al	2.72	2.71			0.05	0.10	0.03	0.11
Al ⁺⁴	0.72	0.73						
Al ⁺⁶	2.00	1.98						
Fe ⁺²		0.01						
Fe ⁺³					1.30	1.24	1.29	1.08
Mn	0.00							
Mg	0.06	0.02						
Na					0.07	0.22		
K	0.60	0.72			0.47	0.20	0.47	0.41
Ba		0.00						
H	2.00	1.48						
H ₂ O					2.58	2.77	2.41	
SO ₂					0.90	0.93	0.93	
S								0.99

(*) H₂O content calculated from theoretical 100% by subtraction.

and jarosite. The chemical results for jarosite indicate the existence of intermediate compounds between jarosite and Na-jarosite.

DISCUSSION AND CONCLUSIONS

Adularia-sericite and acid-sulfate are the two main extreme types of wallrock alteration of volcanic rocks associated with epithermal gold deposits. Their characteristic mineral assemblages result from the interaction of hydrothermal fluids of different pH, near neutral for the former and acid for the later, and host rocks. The two types have been defined using different terminology.

Based on mineral or on acidity conditions, Heald *et al.* (1987), used the terms "adularia-sericite" and "acid-sulfate" alteration types. According to mineral criteria, Berger and Henley (1989) proposed "adularia-sericite" and "kaolinite-alunite". Bonham (1986) used respectively "low sulfur" and "high sulfur", reflecting the active sulfur content. Assuming the differences of the oxidation state of sulfur in the mineralizing fluids, Hedenquist (1987) proposed the terms "low sulfidation" and "high sulfidation". It is possible that fluids of intermediate composition between the two extreme types exist as suggested by Giggenbach (1988).

We choose the terms "high sulfidation" and "low sulfidation" as they better represent the varying acidity of the rock-fluid system, which is the base of the two genetic classifications of wallrock alteration (Meyer and Hemley, 1967, Zharikov and Omelyanenko, 1978).

Aureole alterations of ore deposits reported in the literature are often considered to be formed by superimposed multistage processes affecting the original rock. In this sense, the Maria Josefa mine is a very useful and adequate example for the study of altered rocks in a vein system aureole related with a single-stage episode. Therefore the paragenetic assemblages seem to be related to only one hydrothermal alteration episode.

Following the classification criteria of Meyer and Hemley for the minerals remaining in equilibrium, we can analyze the zonal arrangement at the Maria Josefa mine. The lateral zones developed (Fig. 3a) grading outwards from the lode vein reflect the main features of the sericitic alteration type (Meyer & Hemley, 1967, Heald *et al.*, 1987). The mineralized and unmineralized veins exhibit the same zonal arrangement (Fig. 3a and 3b).

In the upper part of the Maria Josefa vein system (Fig. 3c) the altered rocks comprise only adularia, sugges-

ting a vertical zonality, due to the high potassium activity in the superficial part. A further detailed investigation may confirm an adularia-sericite transitional zone. Externally to the major vein system, the assemblage quartz-adularia-sericite can be found in the host rocks (Fig. 4d).

Adularization processes in Rodalquilar caldera have been so far reported. In the early study of Lodder (1967) adularia is described as an widespread occurrence in the lower part of the El Cinto ignimbrite-bearing complex, explaining that in most cases the plagioclase is completely replaced by adularia. This phenomenon has been cited also in the Neogene volcanic wallrocks by Pineda (1984). Usually, the altered rocks containing K-feldspars are accepted in the literature concerning Rodalquilar caldera as one by-product of the propilitic alteration. Besides the scarce presence of minerals belonging to the supergenic processes (jarosite, gypsum, hematites, goethite) all other minerals are thought to represent hypogene equilibrium state.

The results obtained from the wallrock at Maria Josefa mine indicate the presence of three paragenetic assemblages (quartz-sericite, quartz-adularia and quartz-adularia-sericite). The zonality, ore morphology and structure allow us to recognize the main features belonging to low sulfidation (adularia-sericite) deposits as detailed by White and Hedemquist (1990) and White (1991).

Hayba *et al.* (1985) conclude that the most common regional structural setting characteristic for adularia-sericite type deposits is along the margins of caldera and they emphasize that sericite alteration is prevailing in the borders of the silicified zone near the vein. This fact is also well evidenced at the Maria Josefa mine.

Our investigations do not confirm the presence of alunite, despite it seems exist in trace amount, in some sample. If we accept that this mineral is sporadic, undoubtedly it is not genetically related with the adularia-sericite type of alteration because adularia and alunite are antagonic minerals and can not appear in paragenetic assemblages (Kanazirski, 1992). Alunite is accepted as of supergene origin in the low sulfidation alteration type (Hayba *et al.*, 1985 ; Heald *et al.*, 1987). Recent studies (Rye *et al.*, 1992) reveal the possibility for alunite generation from oxidation of H₂S on the top of boiling part of low-sulfidation systems.

Kaolinite is found in small quantities (max. 2% in the vein and 8% at the aureole) and can be attributed to su-

pergenic origin. Jarosite, goethite and hematite can be considered as an end by-products of pyrite alteration. Gypsum, calcite and anatase are locally found. The low salinity of the solutions (Sänger-von Oepen *et al.*, 1990) support genetic relationship with the low sulfidation type of alteration. On the basis of the classifications reported by Hayba *et al.* (1985) and Heald *et al.* (1987) we can confirm the hypothesis of Säenger-von Oepen *et al.* (1990) about the relationship between the Maria Josefa mineralization and the low sulfidation type from the study of genetically related minerals.

CONCLUSIONS

Based on the study of paragenetic mineral assemblages we can recognize in the Rodalquilar mining district the two extreme alteration types associated with epithermal deposits according to the proposed scheme of Kanazirski (1992) summarized in the Fig.4. The Maria Josefa mine is a good example of epithermal gold-deposit of the "low sulfidation" type. In contrast, the Transaction mine, belongs to the "high-sulfidation" type as evidenced by the abundance of hypogene alunite within zones of advanced argillic alteration, containing also pyrophyllite, kaolinite and dickite. In this sense, the epithermal deposits of Rodalquilar mining district (Transaction mine and María Josefa mine) provide a good example of differential hydrothermal acid-alteration to contrasting paragenetic assemblages from the same type of parent rock.

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