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Jurassic epithermal Au–Ag deposits of Patagonia, Argentina

I.B. Schalamuk [a,b,*], M. Zubia [c], A. Genini [c], R.R. Fernandez [a,d]

[a] *Instituto de Recursos Minerales, Universidad Nacional de la Plata, Calle 47 # 522, 1900 La Plata, Argentina*
[b] *CONICET, Buenos Aires, Argentina*
[c] *Subsecretaria de Mineria (Comodoro Rivadavia), U. Nac. de la Patagonia, Patagonia, Argentina*
[d] *CICBA, Buenos Aires, Argentina*

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Abstract

Important precious metal deposits have been discovered during the last 10 years in the Deseado Massif region of Patagonia, Argentina. This region is a plateau consisting of Middle to Upper Jurassic volcanic rocks that host fracture-controlled epithermal Au–Ag mineralization. These mineral deposits represent low sulfidation type hydrothermal systems and formed following the main period of volcanism, probably during the Late Jurassic period. The presence of silica sinters and veins interpreted to be feeder structures indicates that the tops of some deposits have been preserved, with erosion of younger sedimentary and volcanic rocks now exposing these systems. These deposits represent diverse erosional levels ranging from sinter formed at the paleosurface, to intermediate Au–Ag-rich quartz veins, to base metal-bearing Au–Ag veins that represent deeper levels of the epithermal systems. The best known deposits are in the Cerro Vanguardia district where vein systems occur over a 350 km^2 area and veins can be traced for more than 14 km. Geological mapping of the district has resulted in the definition of over 140 km of veins. Current reserves are over 3.2 million ounces Au equivalent with grades of 10 g/t Au and 120 g/t Ag. The geologic characteristics of the region and the presence of major Au–Ag deposits provide targets for continuing exploration in the Deseado Massif. © 1997 Elsevier Science B.V.

Keywords: Au-Ag deposits; epithermal; Jurassic; Patagonia

1. Introduction

The objective of this paper is to describe the general geologic characteristics of a number of precious-metal mineral deposits and occurrences that have been recently discovered in the southern part of Argentinian Patagonia, a part of Santa Cruz province known as the Deseado Massif. Genini (1988) first described the discovery of epithermal-type gold–silver mineralization in the Deseado Massif, referred to as the Cerro Vanguardia area. As a result of regional mapping carried out by the National Mining Secretariat, mineralized areas at Laguna Guadalosa (Panza and de Barrio, 1988) and Bajo Pobre (Nullo and Panza, 1991) were discovered. Exploration efforts in the Deseado Massif since the early 1990's have yielded additional structurally controlled precious metal discoveries. This paper summarizes research to date regarding the economic potential and metallogenic significance of the region.

2. Geological setting

The Deseado Massif is a region of about 60,000 km^2 having a generally subdued topography. The

* Corresponding author. Tel.: +54-21-225648; e-mail: rfernand@isis.unlp.edu.ar.

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Massif comprises the center of Santa Cruz Province and forms the southernmost region of Extra-Andean Patagonia (Fig. 1). One of the most important features of this area is an extensive plateau consisting of Middle to Upper Jurassic volcanic rocks that cover more than half (about 35,000 km^2) of this physiographic area.

Volcanic rocks of this region belong to the Bahia Laura Group, termed the Chon Aike Complex by Pankhurst et al. (1993b). This group consists of a sequence of ignimbrites of the Chon Aike Formation and of Callovian-age fossiliferous and tuffaceous volcaniclastic rocks of the La Matilde Formation, which unconformably overlies andesitic and basaltic rocks of the Bajo Pobre Formation.

Significant igneous activity in the Deseado Massif started at numerous volcanic centers at about 200 Ma (Varela et al., 1991) within an extensional environment (Gust et al., 1985) that followed an episode of rifting. Isotopic dates from the Chon Aike Formation (Table 1) show ages between about 150 and 170 Ma, although some uncertain younger ages occur in the southernmost Deseado Massif outcrops (tuffs of the Gran Bajo de San Julian area).

The Middle to Upper Jurassic volcanic units unconformably overlie a variety of older rocks, including Lower Cambrian (Pezzuchi, 1978) and Upper Silurian metamorphic rocks (Chebli et al., 1976), an areally restricted sedimentary sequence of Early Permian–Late Triassic age (Arrondo, 1972; Godeas, 1985) and Triassic–Lower Jurassic granitoid intrusions (Varela et al., 1991; Pankhurst et al., 1993a). Upper Jurassic tuffs and tuffites, Cretaceous to Quaternary sedimentary rocks and Upper Cretaceous to Plio-Pleistocene plateau basalts locally overlie the Chon Aike Formation.

The Deseado Massif represents a horst-and-graben setting developed in the Paleozoic basement. In the Patagonian region located to the north (Somuncura or North-Patagonian Massif), Coira et al. (1975) defined two structural systems, both having fractures that strike northwest and northeast, with the latter

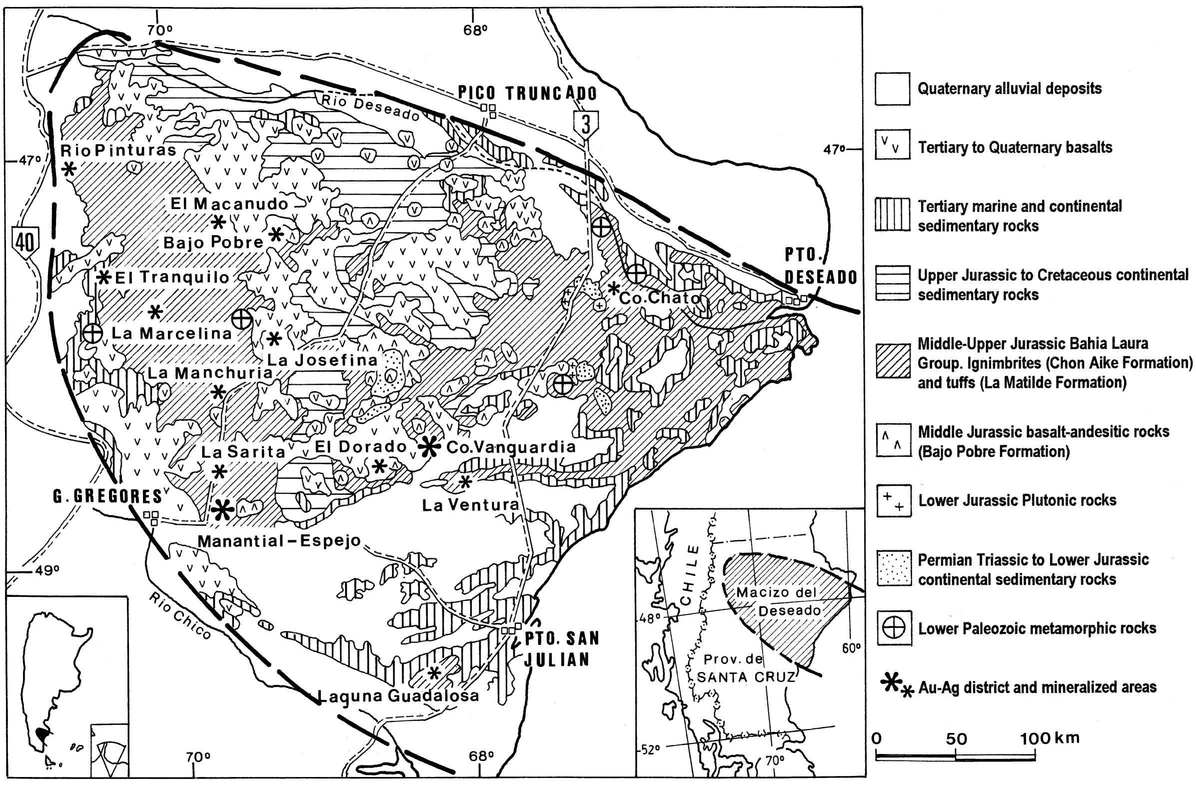


Fig. 1. Main epithermal districts and occurrences of the Macizo del Deseado, Patagonia, Argentina.

Table 1
Rb–Sr and K/Ar ages of Chon Aike Formation and associated mineralization

Location	Rock/mineral	Method	Age (Ma)	Ref.
Roca Blanca	ignimbrite	K/Ar (whole rock)	160 ± 7	Cazeneuve (1965)
Rio Pinturas	ignimbrite	K/Ar (whole rock)	155 ± 15	Baker et al. (1981)
Gran Bajo de San Julian	ignimbrite and tuffs	K/Ar (whole rock)	123? to 161 ± 10	Spalletti et al. (1982)
Bajo Grande	ignimbrite	K/Ar (whole rock)	153 to 157 ± 5	Hechem and Homovc (1985)
Rio Pinturas	ignimbrite	Rb–Sr	161 ± 5	de Barrio (1993)
Rio Deseado	ignimbrite	Rb–Sr	168 ± 2	Pankhurst et al. (1993b)
Josefina	ignimbrite (biotite)	K/Ar	148.8 to 153.2 ± 3.6	Arribas et al. (1996)
Cerro Vanguardia Veins	illite	K/Ar	142.3 to 152.4 ± 3.6	Arribas et al. (1996)
Cerro Vanguardia Veins	adularia	K/Ar	138.5 ± 3.3	Arribas et al. (1996)
Manantial Espejo Veins	adularia	K/Ar	124.8 to 142.6 ± 3.5	Arribas et al. (1996)

system reactived as shear-fractures in a northwest direction and as extensional ones with a northeast orientation. These fracture systems, the result of west-directed stresses, also influenced the development of the Deseado Massif area to the south. Gust et al. (1985) noted that the Middle to Upper Jurassic volcanism was preceded and accompanied by an extensional deformation with subsequent half-graben formation outlined by NW- and N-trending fault systems. Nullo (1991) proposed a mechanism of transpression and later extension in order to explain the development of these half-grabens. Panza (1982) defined the Tranquilo System (N20°W and N60°E) and the Bajo Grande System (N50°W and N35°E) for the primary and secondary stress directions, respectively. These two stress systems have generated most fracturing since the Jurassic within the Deseado Massif.

3. Precious metal occurrences

The Jurassic volcanic rocks host numerous, widely-distributed clusters of Au- and Ag-bearing quartz veins that locally contain base metals. Most of the reported occurrences correspond to low sulfidation type epithermal systems as defined by Hedenquist (1987). The locations of known mineral deposits, prospects and occurrences are shown in Fig. 1 and listed in Table 2.

The most important mineral deposits and occurrences, in general, are vein-shaped bodies composed of multiple fracture-fillings. Stockworks are generally present, either parallel to the veins or as along-strike continuations.

Silica, as quartz, chalcedony and to a lesser extent, opal, is the principal fracture-filling material. Recrystallization textures are commonly observed in opal and chalcedony, yielding zoned quartz crystals with bands of inclusions. Most vein structures are banded, crustiform (with gray quartz) and colloform, with the former vein type apparently the most important in relation to Au content in the Cerro Vanguardia and Manantial Espejo districts. Other common textures are: (1) saccharoidal (massive), typically formed by fine-grained quartz and/or chalcedony; (2) vuggy druse-lined cavities or comb quartz (sometimes with amethyst); (3) replacements of gangue minerals, especially barite; and calcite; and (4) breccias of country rock fragments and locally of vein quartz, with siliceous cement. Barite is another typical gangue mineral, as are volumetrically minor amounts of montmorillonite, kaolinite, calcite and rhodochrosite. Adularia is generally not abundant, but it has been observed in many districts; it is commonly altered to kaolinite. Hypogene hematite and pyrite occur as minor components.

Ore minerals consist of native gold, electrum, native silver and argentite. Tetrahedrite, Ag sulfosalts, galena, sphalerite and chalcopyrite are volumetrically minor components; uytenbogaardtite and petzite are rare. High fineness gold (976–984 fineness at Cerro Vanguardia) occurs along grain contacts, disseminated in quartz (generally but not exclusively in band-textured quartz) and in weathering-derived goethite. The average grain size of Au is between 10 and 50 μm; visible gold is rare. Individual gold grains, with diameters of 40–70 mm, group together in some vein occurrences. Electrum with variable silver content (47 to 68% Ag in Cerro Vanguardia and 20% Ag in Manantial Espejo and La Josefina) occurs along the rims of quartz crystals, or as fracture-fill. Argentite typically occurs in quartz and in goethitic Fe-oxides.

The most volumetrically widespread hydrothermal alteration type is silicification, although argillization (kaolinite, montmorillonite and illite), sericitization and propylitization are also present; the latter is the most common alteration type in basaltic and andesitic host rocks of the Bajo Pobre Formation. Alteration zones extend typically from a few meters to a few tens of meters adjacent to quartz veins.

4. Geology of mineral deposits

4.1. Cerro Vanguardia district

Cerro Vanguardia currently is the best studied district within the Deseado Massif and has the greatest potential economic importance. This district (Fig. 2) occupies over 350 km^2 near the center of the Massif (Fig. 1), suggesting that it is one of the most extensive epithermal districts in the world. Geological mapping of the district, including detailed mapping of all surface veins, rock chip sampling and exploration sampling by trenching and drilling have

Table 2
Principal Au–Ag occurrences in the Macizo del Deseado

Name	Location (Long./Lat.)	Mineralization style	Vein attitude	Host rock	Area (km^2)
Cerro Vanguardia	68°17′W/48°18′S	veins	WNW/ > 70°–NW/ > 70°	felsic ignimbrites (Chon Aike Fm.)	350
Manatial Espejo	69°30′W/48°48′S	veins	WNW/ > 70°	felsic ignimbrites (Chon Aike Fm.)	70
		stockwork	WNW	minor Bajo Pobre Fm	
		sinter	subhorizontal relicts	tuffs (La Matilde Fm)	> 0.5
La Josefina	69°23′W/47°52′S	veinlets ≫ veins	NW to NS/55° to > 70°	felsic ignimbrites (Chon Aike Fm)	12
	69°20′W/47°50′S	sinter	subhorizontal	tuffs (La Matilde Fm.)	1
El Dorado-Monserrat	68°33′W/48°25′S	veins	N–S to NW/ > 70°	andesites (Bajo Pobre Fm.)	3
Laguna Guadalosa	68°23′W/49°29′S	veins	NE to WNW/ > 70°	felsic ignimbrites (Chon Aike Fm)	12
Bajo Pobre	69°14′W/47°15′S	veins	N–S to NNE/ > 70°	andesites (Bajo Pobre Fm.)	5
El Macanudo	69°35′W/47°16′S	sinter/ silicification	subhorizontal	tuffs (La Matilde Fm.)	4
Rio Pinturas	70°46′W/47°03′	veinlets/ dissemination	N–S/ > 60°	rhyolitic porphyry and tuffs (Chon Aike Fm.)	0.5 Has
Cerro Chato	67°11′W/47°41′S	veins	NE and WNW	Permian sediments (La Golondrina Fm.) and felsic ignimbrites (Chon Aike Fm.)	1
La Manchuria	69°52′W/48°16′S	veins (Ag)	NW/vert.	felsic ignimbrites (Chon Aike Fm.)	20 Has
		silicification	irregular	felsic ignimbrites (Chon Aike Fm.)	2 Has
Maria Esther	69°20′W/48°02′S	silicification	irregular	felsic ignimbrites (Chon Aike Fm.)	50 Has
La Sarita	69°47′W/48°37′S	vein (Pb–Zn)	NW/ > 70°	felsic ignimbrites (Chon Aike Fm.)	2 Has
La Leona	69°19′W/48°05′S	veins	WNW/ > 70°	lower Jurassic granite (La Leona Fm.)	4

resulted in the identification of precious metal veins with a total strike length of over 140 km. Current reserves are over 3.2 million ounces Au equivalent with grades of 10 g/t Au and 120 g/t Ag. Resources at Cerro Vanguardia are expected to increase through further systematic exploration.

Individual veins have strike lengths between 500 and 14,000 m in discontinuous vein outcrops. Vein systems strike WNW in the northern part of the Cerro Vanguardia district and NW to N in the southern part and dip steeply, mainly to the NE and E. Vein widths range from a few tens of centimeters to

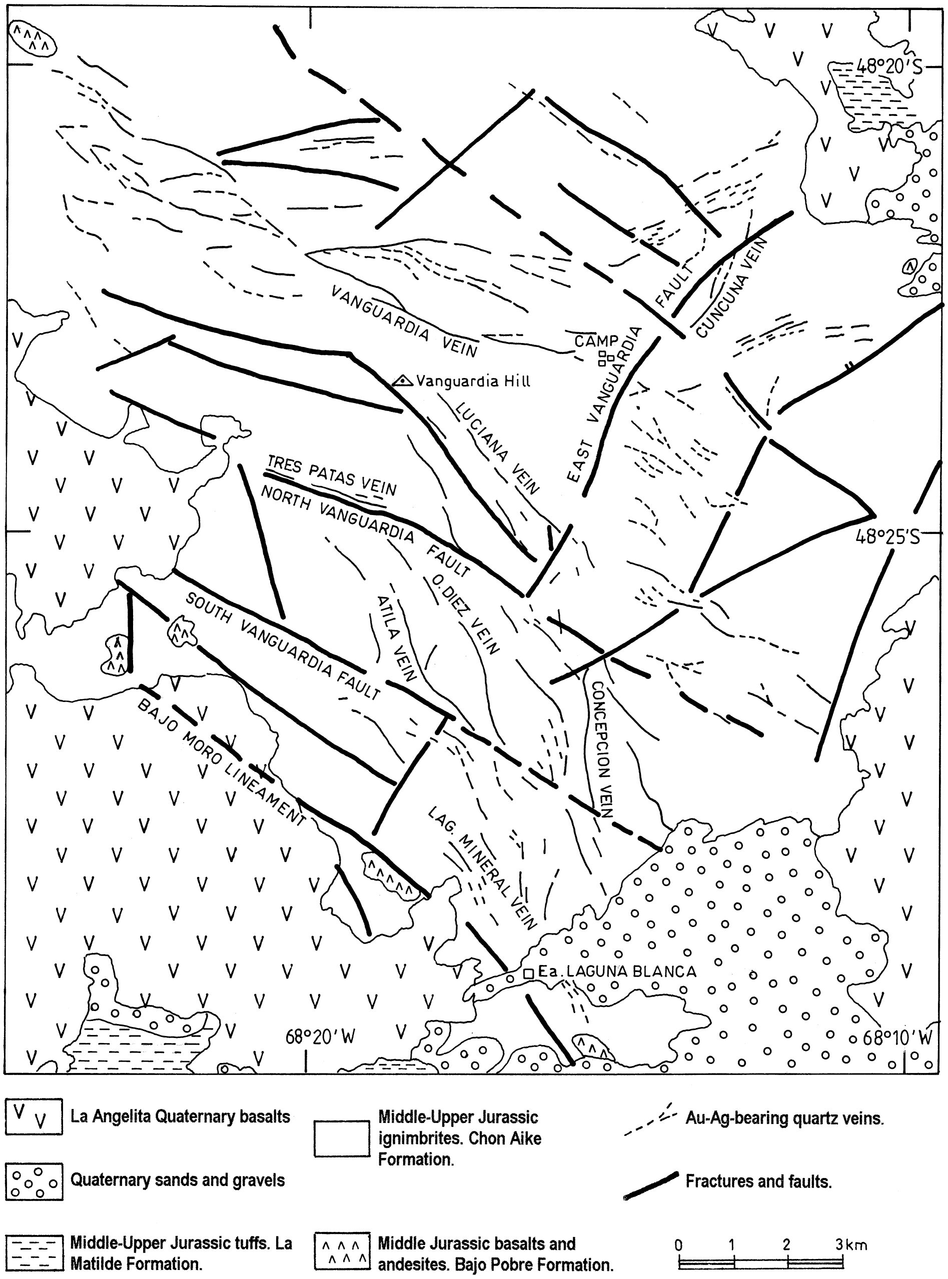


Fig. 2. Geology of the Cerro Vanguardia district (modified from Panza et al., 1996).

14 m. Some oxidation phenomena are observed up to 100 m below outcrops. The lithology enclosing the veins is a monotonous ignimbrite sequence of the Chon Aike Formation. Minor tuff of the La Matilde Formation and andesitic–basaltic volcanic rocks of the Bajo Pobre Formation crops out on the periphery of the main body of ignimbrites. Panza et al. (1996) described circular features from the TM satellite image that covered part of the area of the Cerro Vanguardia veins (Fig. 3), suggesting a relationship to caldera-bounding structures.

Gold–silver mineralization in the district is relatively homogeneous, an unusual feature for epithermal vein deposits. However, there are bonanza-type ore shoots that extend along strike from 200 to 700 m and vertically from 40 m (Vanguardia Vein) to 120 m (Luciana Vein) to more than 160 m (Osvaldo Diez Vein). Generally, Ag increases with depth and the Au content and vein thickness remains constant. At least three episodes of quartz and minor chalcedony deposition have been identified, although it has not been determined how many of them are associated with the economic mineralization.

The southwest part of the Cerro Vanguardia area displays some differences relative to the rest of its mineral occurrences, having local concentrations of Fe and Mn oxides that contain galena and sphalerite. These oxides apparently result from the oxidation of sulfides and carbonates, including pyrite, arsenopyrite, rhodochrosite and siderite. The carbonate minerals were microscopically defined on the basis of relict and pseudomorphic replacement textures.

4.2. Manantial Espejo district

The Manantial Espejo District is located in the WSW part of the Deseado Massif, about 50 km ENE of the village of Gobernador Gregores (Fig. 1).

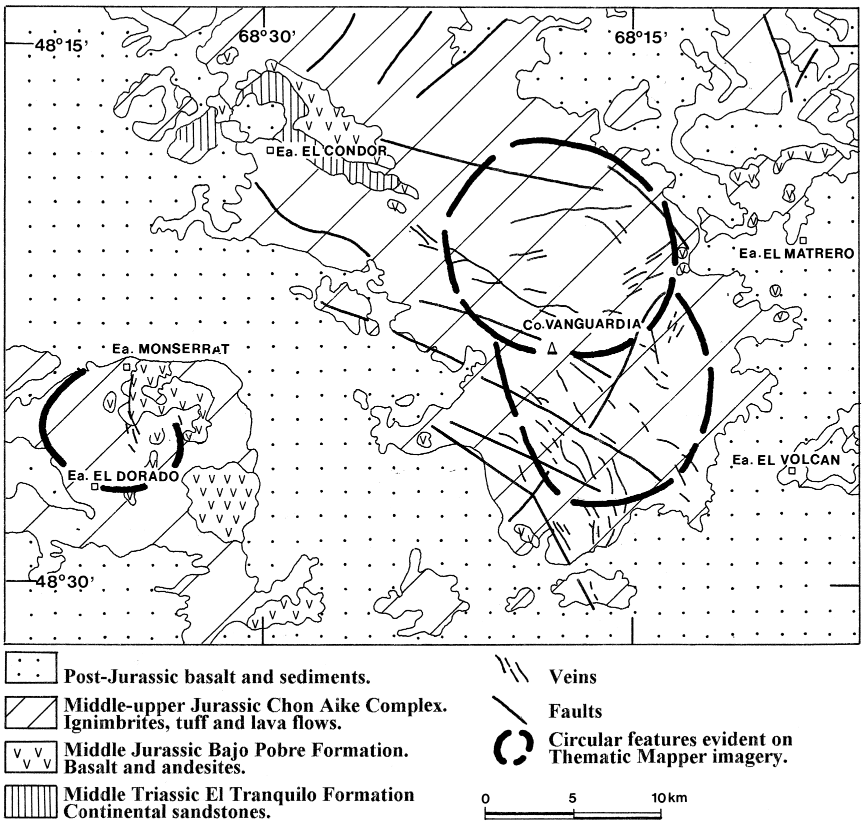


Fig. 3. Circular features in the Cerro Vanguardia and El Dorado-Monserrat districts visible on Thematic Mapper (Modified from Panza et al., 1996).

Mineralization styles comprise quartz veins with free gold or electrum and scarce sulfides; quartz stockworks also bearing Au and sinter and silicified bodies associated with hydrothermal breccias. Veins and stockworks, over an area of 100 km^2, are localized in the rhyolites of the Chon Aike Formation; siliceous bodies and breccias preferentially occur in tuffs and volcanic agglomerates of the La Matilde Formation.

Vein structures occur along a trend having a strike length of more than 27 km. To date, the most economically important structure is the E-trending Maria Vein that has a strike length of about 1,500 m and widths up to 20 m (Schalamuk et al., 1994). A stockwork zone of meter-scale veins extends eastward for about 4 km away from the main Maria Vein structure. The 'Maria Stockwork' zone of subparallel veins is well developed in the northern part of the district.

Manantial Espejo veins typically display banded textures (Fig. 4a) with parallel quartz bands of diverse colors and grain sizes. Silica also occurs as local chalcedony and opal, with and without adularia. Development of kaolinization and/or incipient sericitic alteration is common. Quartz locally replaced barite of tabular habit (Fig. 4b). Some minor veins in the Manantial Espejo area contain barite, either fresh or partially replaced by silica and calcite. Open spaces, forming comb textures, are common.

In the ENE part of the district, an outcrop containing silica sinter and siliceous replacement of volcanic rocks and hydrothermal breccias occurs over an area 3 km long and 50 to 100 m wide. These siliceous outcrops are anomalous in Hg, Sb, As and Au content and appear to represent the near-surface expression of a shallow epithermal vein system.

Exploration in the Manantial Espejo District indicates current resources and reserves of about 950,000 ounces in the Maria and Maria East veins with average grades of 7.6 g/t Au equivalent.

4.3. La Josefina prospect

Del Blanco et al. (1994a) and INREMI (1996) described the geological setting of veins and host rocks in the La Josefina area (Fig. 5). Veins are hosted by 151–153 ± 3.4 Ma ignimbrites (Arribas et al., 1996) of the Chon Aike Formation that overlie Paleozoic metamorphic rocks. Within the Chon Aike Formation, 148.8 ± 3.6 rhyolitic domes intrude the volcanic sequence; these domes grade into lavas in their upper parts and indicate resurgence occurred 1 to 3 m.y. after the ash flow tuffs. The lava flows and breccias are best developed in the southern part of the prospect area, where they occur with small vitrophiric bodies. A megabreccia has been mapped, possibly representing a caldera rim slide, in the central part of the area.

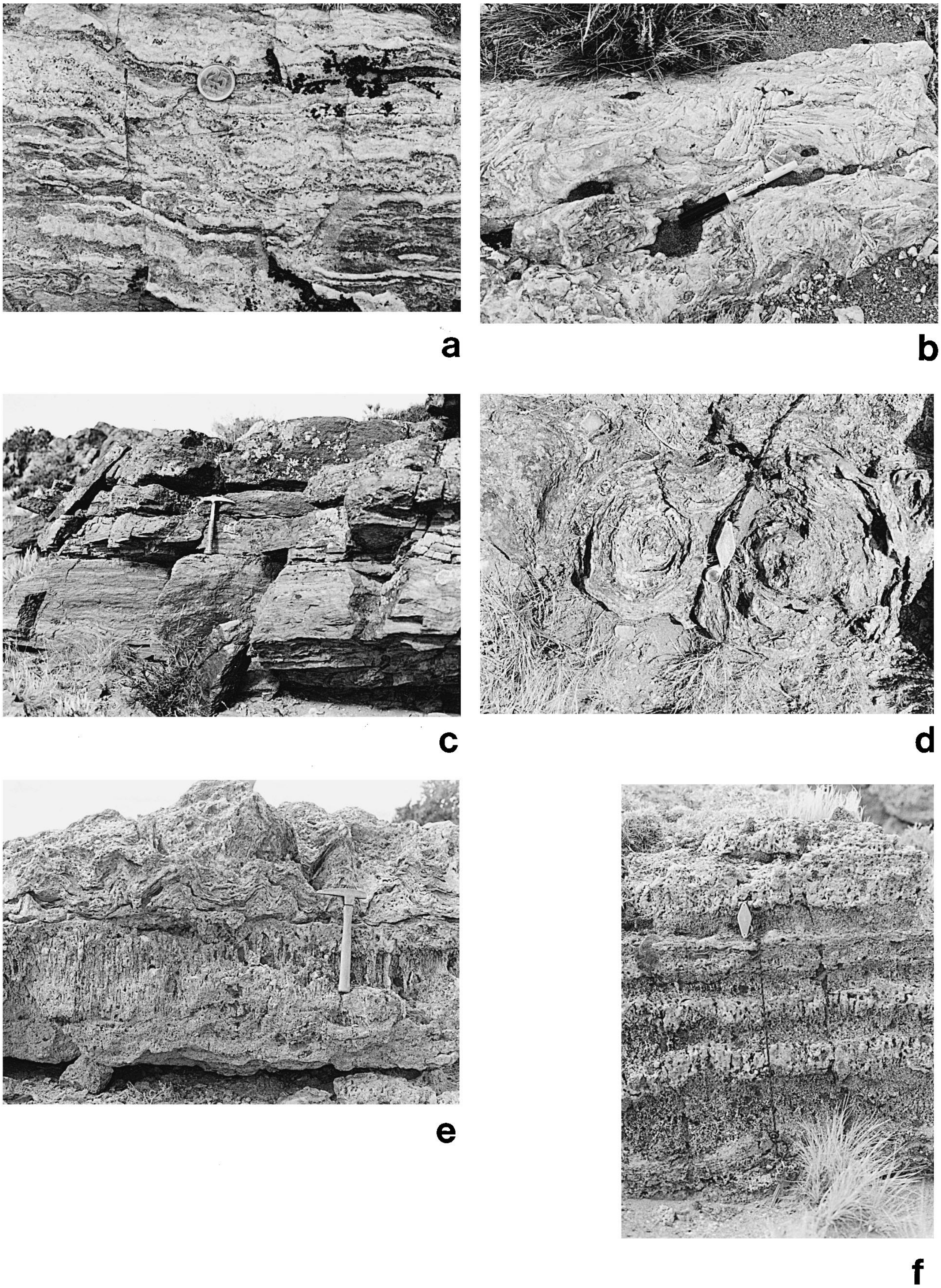
An arcuate belt of altered ignimbrites, about 10 km long and 800 to 1,000 m wide, hosts most N and NNW-striking of veinlet and less than decimeter-wide vein systems. Veinlet 'swarms' are 1 to 18 m wide and have discontinuous strike lengths ranging from tens of meters to 1,500 m. The main vein fill consists of massive and comb quartz, chalcedony, and opal; some veins contain barite. Small outcrops of silica-cemented hydrothermal breccias occur locally.

Sampling has demonstrated that most structures in the vein systems are anomalous in gold, with some of them yielding 1–3 g/t Au over a sampling interval of 1 m. Small portions of the vein are enriched in Au (up to 93 g/t) and are accompanied by abundant hematite. Base-metal values are geochemically anomalous in relation to other districts in the region.

Laminated silica sinter horizons in the northern part of the mineralized zone (Fig. 4c) contain as much as 1.3 ppm Au, 7.5 ppm Ag, 1.26 ppm Hg, 332 ppm As, 8 ppm Sb and 0.96 ppm Tl; the sinter is hydrothermally brecciated and cemented by chalcedony and Fe oxides (Echeveste et al., 1995; INREMI, 1996). A highly silicified and kaolinized zone, oriented E–W, occurs 1.5 km east of the sinter.

4.4. El Dorado-Monserrat prospect

Barite and quartz-after-barite veins (Genini, 1976) occur in the El Dorado-Monserrat area. These veins, some of which have a radial orientation, are hosted by the Bajo Pobre Fm (Echavarría, 1995). N- and NW-trending quartz veins have higher Au/Ag ratios than the quartz-after-barite veins, and the latter have lower precious metal contents. Veins occur over a total strike length of about 10 km; quartz, barite, or quartz + barite veins have been identified. The most interesting results from sampling, with values over 10 g Au/t, are found in the N-trending veins in the northern area.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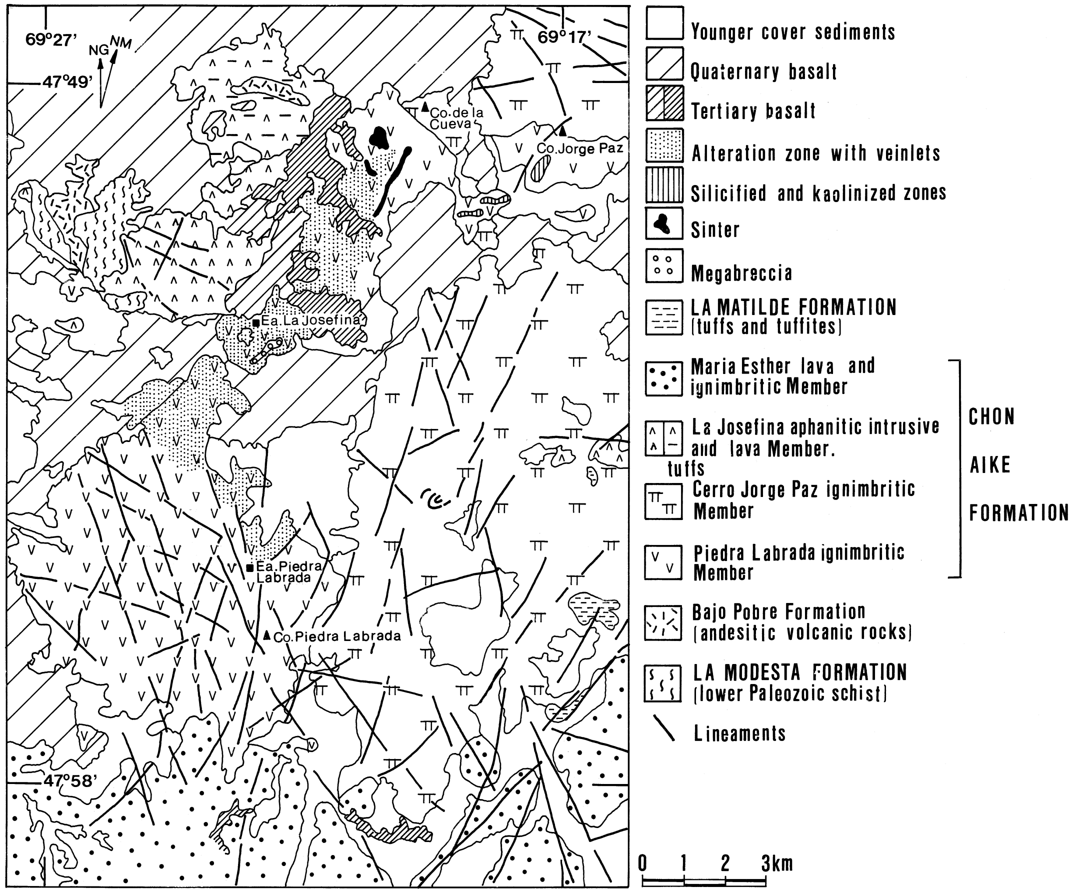

Fig. 5. Simplified geologic map of the La Josefina prospect.

4.5. Laguna Guadalosa prospect

The Laguna Guadalosa prospect is the southernmost vein system known in the Deseado Massif. It consists of a NE-trending major vein of variable width that is almost 5 km long, along with several generally E-striking subsidiary veins with anomalous Au values. All veins occur in the Chon Aike Formation ignimbrites (de Barrio et al., 1994). Wallrocks display silicification in the form of veins, veinlets and irregular impregnations. This prospect has not been well studied; however, preliminary sampling shows Au values ranging from 0.6 to 1.0 g/t with minor Ag and traces of As and Hg.

4.6. Rio Pinturas prospect

The only precious metal mineral deposit in the northwestern end of the Massif is associated with a subvolcanic rhyolitic intrusion (Genini, 1994) that forms an outcrop 500 m long and 50 m wide within comagmatic tuffaceous rocks of the Chon Aike Formation. Pyrite, which is volumetrically dominant, occurs with free gold (5–30 μm), electrum, native

Fig. 4. Field photographs of selected geologic features of epithermal deposits of the Deseado Massif. (a) Typical quartz banded texture of Maria Vein, Manantial Espejo district (the coin is 2.3 cm in diameter). (b) Pseudomorphic replacement of quartz after barite in the Maria Vein, Manantial Espejo district (the pen is 13 cm long). (c) Laminated silica sinter at the La Josefina prospect. (d) Cylindrical, coalescent pipe-shaped feature in the sinter of El Macanudo. (e) Layer of vertical thin tubular silica beneath the cylindrical pipe-shape in the sinter of El Macanudo. (f) Lower level of undulated, laminated silica interlayered with porous silica in the sinter of El Macanudo.

silver, marcasite, galena, sphalerite and tetrahedrite as disseminated grains and in veinlets. Gold values between 0.1 and 3 g/t, accompanied by 0.6 and 91 g/t Ag, have been obtained by trench sampling.

4.7. Bajo Pobre occurrence

Quartz veins occur with a dominant ENE strike and in a sub-radial pattern, within a zone of approximately 30 km^2 in the Bajo Pobre area. The largest vein is approximately 1,000 m long and has widths ranging from 1 to 10 m, mostly averaging about 2 m. Most host rocks are the Bajo Pobre Formation and veins have mineralogic and textural characteristics similar to those of other prospects in the Deseado Massif. One of the Bajo Pobre subordinate veins has a strike length of 1,000 m and also contains fresh barite and calcite. All surface samples in the area show weak but consistent gold and silver anomalies (up to 3 g/t Au). A linear stockwork more than 2,000 m long and with widths ranging from 20 to 50 m occurs in the eastern sector of the area, but has not yet been explored in detail.

4.8. El Macanudo occurrence

In the area known as El Macanudo-Mirasol, west of the Bajo Pobre occurrence, a surface area of 4 km^2 contains extensive subhorizontal silica layers, possibly a silica cap, covering a sequence of stratified and partially laminated and argillized tuff of the La Matilde Formation. Individual silica layers are 1 to 3 m thick, reddish dark-gray to black, laminar, and fine-grained, with many vugs filled with botryoidal Fe and Mn oxides.

Curious pipe-shaped (Fig. 4d) cylindrical to ovoid vertical structures are observed within the El Macanudo-Mirasol area and occur in an outcrop area about 100 m long and 30 m wide. These structures, locally coalescent, consist of silica of different grain sizes in concentric bands with diameters from 0.3 to 0.6 m and up to 1 m high. There is a 0.5 m thick layer with abundant thin tubular silica structures underneath these structures (Fig. 4e). Horizontal interlayers of fine-grained, laminated silica and porous silica (Fig. 4f) are interpreted to be a silica sinter with algal type features. Argillized tuffs occur below this zone, probably representing acidic hydrothermal alteration below a silica-rich cap.

Extensive siliceous layers interpreted to be hot spring sinters (White et al., 1989) and the absence of outcropping vein structures, suggest that the El Macanudo area corresponds to a slightly eroded hot-springs type epithermal system. However, preliminary chip sampling has not shown significant Au–Ag values in these silica outcrops.

4.9. Cerro Chato occurrence

Cerro Chato area is a new prospect comprising 2 major veins in the initial stage of investigation. One vein is exposed over an area 1,200 m long and 1 to 5 m wide, whereas the other structure is 2,500 m long with widths up to 20 m; both contain breccia zones and stockworks. Surface sampling indicates many weak gold (0.5 g Au/t average) and silver anomalies (Giacosa and Genini, 1995). Textural, mineralogical, and structural characteristics are similar to those of other Deseado Massif vein deposits. Veins are hosted by Jurassic volcanic rocks, but they also extend into Permian sedimentary rocks and Lower Jurassic granites, a feature that distinguishes these structures from the exposed portions of other vein systems in this metallogenic region.

4.10. Other occurrences

Other zones of interest in the Deseado Massif region are the silica bodies of Maria Esther, 20 km south of the silicified and kaolinized NNE part of the La Josefina district, the La Manchuria area that contains anomalous Au, Ag, As and Sb values in silica bodies and silicified fracture zones and La Rosita, a base metal-bearing vein (Del Blanco et al., 1994b).

5. Fluid inclusion and isotope studies

Preliminary fluid inclusion studies document general differences among the diverse vein structures in the Deseado Massif. Primary inclusions occur along growth zones in quartz and barite. Single-phase, two-phase and rare three-phase primary inclusions have been recognized. Freezing studies suggest that the trapped fluids belong to the H_2O–NaCl–KCl system.

Fluid inclusion homogenization temperatures are

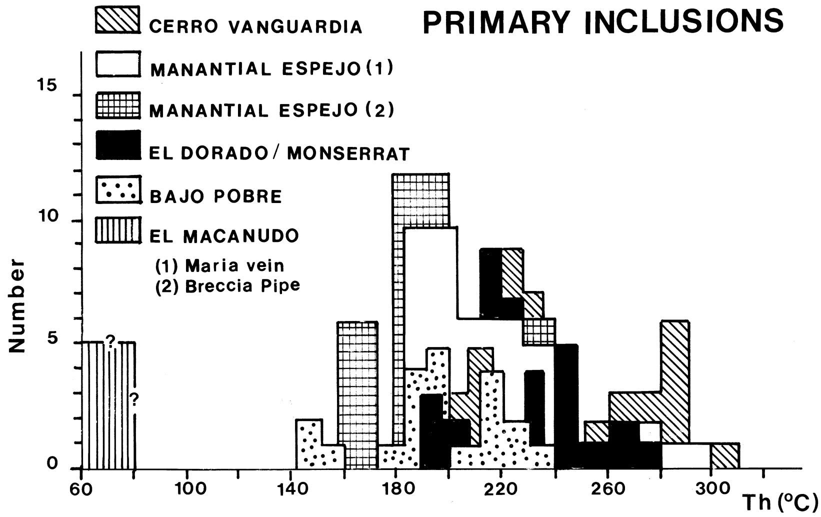

Fig. 6. Histograms of temperature of homogenization (Th in °C) of primary fluid inclusions from several epithermal deposits of the Deseado Massif.

generally less than 100°C in sinter and greater than 100°C in feeder veins (Fig. 6). Homogenization temperatures of primary fluid inclusions in gold-bearing quartz from the Atila Vein (Cerro Vanguardia) vary from 200 to 240°C, with a minor population showing temperatures between 250 and 310°C (Schalamuk et al., 1995b). Salinity data from lower temperature inclusions range from 1.6 to 4.8 wt% eq. NaCl with an average of 3.8 wt% eq. NaCl.

Quartz from the vein structures in the Manantial Espejo district, similar to those at Cerro Vanguardia, contain liquid- and vapor-rich primary inclusions characterized by low salinity solutions (1 to 4 wt% eq. NaCl) and homogenization temperatures between 164 and 240°C (Fig. 6). Quartz-hosted fluid inclusions from a siliceous breccia have homogenization temperatures from 165 to 232°C and salinities of 5 to 6.6 wt% eq. NaCl (Rios et al., 1994).

Homogenization temperatures of fluid inclusions in late barite from El Dorado Monserrat vary from 150 to 180°C and salinity ranges from 1 to 1.7 wt% eq. NaCl (Fig. 6). In mineralized quartz, salinities are similar to barite and homogenization temperatures of 190 to 280°C were obtained.

Primary fluid inclusions are abundant along the growth zones in quartz crystals from the Bajo Pobre occurrence. Single-phase inclusions dominate over the two-phase ones, suggesting trapping temperatures less than 100°C (Fig. 6). The aqueous fluid indicated is almost pure water (≤ 0.3 wt% eq. NaCl) with maximum Th V values of 230°C.

The El Macanudo siliceous vents are tabular exposures of sinter crusts deposited on ash fall tuff. Samples from four different concentric pipes showed a dominance of chalcedony with some quartz. The few inclusions detected are primary, small and single phase, suggesting trapping at temperatures less than 70°C (Schalamuk et al., 1995b).

There are only a few isotopic studies for some of the mineral deposits, and consequently these results represent only a preliminary indication of the isotopic signatures of precious metal mineralization in Deseado Massif. Reconnaissance Pb isotope measurements on galena (Table 3) suggest relatively radiogenic crustal sources, an interpretation that is compatible with the lower crustal source proposed

Table 3
Pb-isotope composition of galena from mineral deposits in the Deseado Massif[a]

Deposit	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Cerro Vanguardia	18.490	15.770	39.000
Manantial Espejo-a	18.488	15.885	39.293
Manantial Espejo-b	18.722	15.953	39.527
La Josefina	18.482	15.828	39.126
La Sarita	18.538	15.728	38.701

[a]Analyses by C. Tassinari, Institut of Geochronology, Sao Paulo University, Brazil.

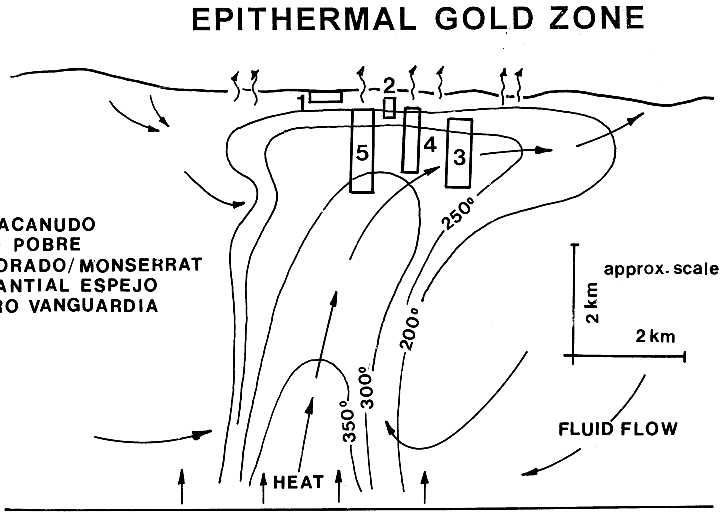

Fig. 7. Geologic model for some epithermal deposits of the Deseado Massif showing their ranges of temperature and hypothetical levels of mineralization.

for Jurassic volcanic rocks (Pankhurst and Rapela, 1995).

6. Conclusions

The Deseado Massif constitutes a metallogenic subprovince with excellent possibilities for economic occurrences of precious-metals deposits. The main targets for mineral exploration correspond to late fracture systems that transect Bajo Pobre Formation mafic rocks and, most importantly, the Chon Aike Formation felsic pyroclastic rocks. Mineralizing fluids apparently ascended through these structures in repeated pulses and deposited Au and Ag minerals by pressure loss and boiling. The relations between those structures and the earlier volcanic processes are not yet well understood; however, the occurrence of silica-replaced layers and sinters related to the La Matilde Formation suggest shallow, late hydrothermal activity associated with waning volcanic activity. Such sinters may not be economically important, but they are an outstanding metallogenic guide for initial exploration.

In agreement with Gust et al. (1985) and Nullo (1991), we interpret that the structural setting of the Deseado Massif veins indicates that Jurassic volcanism and the formation of a set of NW-oriented half-grabens in a continental back-arc environment were contemporaneous. Ignimbritic flows and volcanic rocks, sourced from coalescent calderas within those grabens, cover some horsts and are products of magmatism related to the melting of continental crust (de Barrio, 1993; Pankhurst and Rapela, 1995).

The volcanic landforms that originated with this Middle-Upper Jurassic ash flow tuff sequence were affected by early, coeval, and late (upper Tertiary) block tectonics and were covered by areally extensive Cretaceous and Tertiary sedimentary rocks and younger Tertiary and Quaternary basalt flows. Large circular features observed in several places on the Deseado Massif, such as Cerro Vanguardia, can be interpreted as expressions of buried calderas. The El Dorado-Montserrat prospect occurs near a circular setting and includes features as breccias and lava domes (Echavarria, 1996, personal communication). Detailed mapping (INREMI, 1996) in the La Josefina area has identified steep-wall megabreccias, a possible caldera rim, central resurgent silicic domes and rhyolitic lava domes that are possibly related to ring-fractures.

Known sinter occurrences (Manantial Espejo, La Josefina, El Macanudo) seem to be confined to the lowest part of volcanic landforms related to the La Matilde ash-fall tuff deposits, perhaps representing in a lake environment. The Manantial Espejo and La Josefina sinters have yielded anomalous concentrations of Au, As, Hg and Sb; at La Josefina, there are anomalous values of Cu, Pb and Zn in addition to precious metals. In the El Macanudo sinter, metal contents are not significant, and the deposit is interpreted as the uppermost level of a hot springs system that developed in the Deseado Massif.

In the Deseado Massifregion, there is no direct evidence of the relation between some volcanic features and mineralized structures. Hydrothermal fluids apparently flowed through fracture systems generated during Upper Jurassic extension subsequent to the shear-related fracturing. However, Jurassic volcanic centers which developed during a period of about 20 m.y. must have been important heat sources for the movement of the fluids and metals.

Gold deposits in this region are classified as the 'sericite–adularia' (Heald et al., 1987) or 'low sulfidation' (Hedenquist, 1987) type (Fernández and de Barrio, 1994). Recent field observations have recognized the tops of the hydrothermal systems and thus many occurrences fit a hot spring model (Schalamuk et al., 1995a). A hypothetical geologic model has been developed for the epithermal deposits of the Deseado Massif based on geologic characteristics and fluid inclusion data for selected deposits (Fig. 7). Considering the Deseado Massif as a whole, it is possible to recognize the diverse erosion levels of these epithermal deposits, from the Au–Ag minor base metal veins (La Sarita, Rio Pinturas), to the intermediate Au–Ag quartz veins (Cerro Vanguardia, Manantial Espejo, La Josefina, La Manchuria areas) and to the silica sinter formed at the paleosurface (El Macanudo-Mirasol, La Josefina, Manantial Espejo).

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