N. Jb. Geol. Paläont. Abh.
2009, vol. 253/1, p. 25–40, Stuttgart, July 2009, published online 2009

Depositional age of Jurassic epithermal gold-silver ore in the Deseado Massif, Patagonia, Argentina, based on Manantial Espejo and La Josefina prospects

Pilar Moreira, Horacio Echeveste, Raúl Fernández, La Plata, **Léo A. Hartmann,** Porto Alegre, **João Orestes S. Santos,** Crawley, and **Isidoro Schalamuk,** La Plata

With 5 figures and 5 tables

MOREIRA, P., ECHEVESTE, H., FERNÁNDEZ, R., HARTMAN, LEO A., SANTOS, J. O. S. & SCHALAMUK, I. A. (2009): Depositional age of Jurassic epithermal gold-silver ore in the Deseado Massif, Patagonia, Argentina, based on Manantial Espejo and La Josefina prospects. – N. Jb. Geol. Paläont., Abh., **253**: 25-40, Stuttgart.

Abstract: Middle to Upper Jurassic bimodal volcanism developed during widespread extensional tectonism within the Deseado Massif in Argentinean Patagonia. This geologic environment led to the formation of numerous epithermal gold-silver deposits that are spatially and temporally related to the volcanic activity. The age constraints of the volcanic rocks that host the veins define Upper Jurassic ages for the volcanism. New U-Pb SHRIMP studies of zircons from ignimbrites from Manantial Espejo and La Josefina epithermal prospects are reported. The Manantial Espejo prospect dates (~ 167, ~ 163 and 158.9 ± 0.45 Ma) suggest that mineralization took place 6 My after the deposition of the host rock. The zircons of La Josefina prospect show a concordant age of 152.7 ± 2.3 Ma that suggests temporal overlapping between volcanism and mineralization.

Key words: Au-Ag epithermal veins, Jurassic volcanism, U-Pb SHRIMP ages, Deseado Massif.

Abstrait: Pendant le Jurassique Moyen et Supérieur un volcanisme de type bimodal s'est développé avec une tectonique amplement distribué sur le Massif du Deseado, Patagonie Argentine. Cette ambiance géologique favorise la formation de nombreux dépôts épithermaux en or-argent qui sont spatial et temporellement liés avec l'activité volcanique. Les limites d'âge des roches volcaniques qui sont les roches encaissantes définissent les âges Jurassiennes du volcanisme. Nouveaux études de SHRMP avec zircons provenant des ignimbrites des dépôts épithermaux Manantial Espejo et La Josefina sont présentées ici. Les données d'âge du prospect Manantial Espejo (~ 167, ~ 163 et 158.9 ± 0.45 Ma) suggèrent que la minéralisation a été placé 6 Ma après la formation de la roche encaissante. Les zircons du prospect La Josefina montrent un âge concordant de 152.7 ± 2.3 Ma qui suggère une juxtaposition entre le volcanisme et la minéralisation.

Mot-clés: Dépôts épithermaux en or-argent, Jurassique volcanisme, études de SHRIMP, Massif du Deseado.

DOI: 10.1127/0077-7749/2009/0253-0025 0077-7749/09/0253-0025 $ 4.00

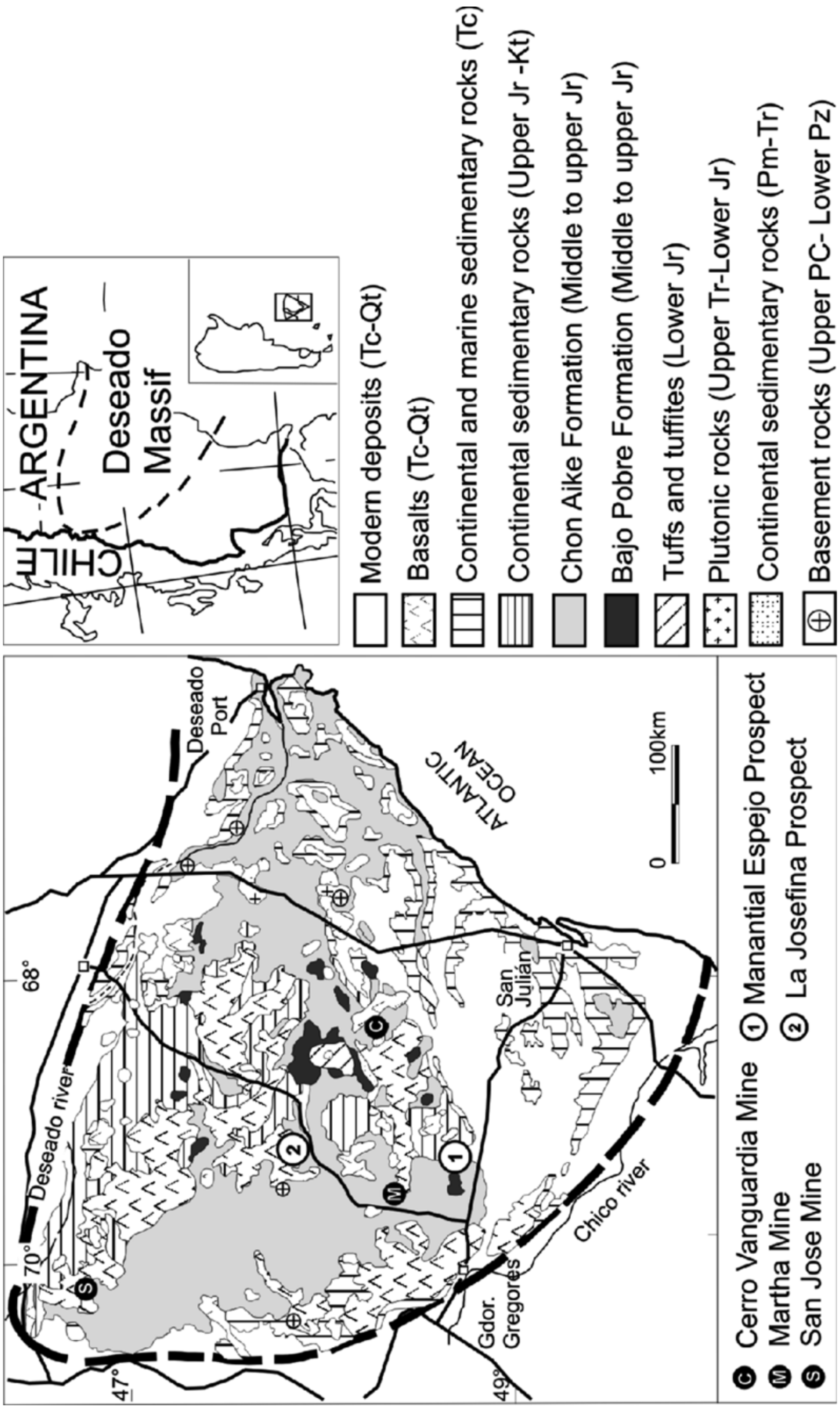

Fig. 1. Geological map of Deseado Massif, with the location of Manantial Espejo and La Josefina Prospects.

Introduction

The Deseado Massif is a geological province with an extension of about 60,000 km^2 located in the southern part of Argentinean Patagonia (Fig. 1). The most important units are silicic and mesosilicic volcanic rocks included in the Chon Aike and Bajo Pobre Formations of Jurassic age that cover more than half of the area of a wide plateau.

Several epithermal gold and silver deposits and occurrences in the Deseado Massif, named Deseado Auroargentiferous Province by Schalamuk et al. (1999), are spatially and genetically related to the Jurassic volcanic rocks (Arribas et al. 1996; Schalamuk et al. 1997). At present, there are three ore deposits under exploitation for gold and silver: Cerro Vanguardia, Martha and San José Mines (Fig. 1). Cerro Vanguardia is a world-class deposit composed of a quartz-vein filled with proved and probable reserves (status end of the year 2006) over 0.9 and 6.9 Mt with an average grade of 7.09 gr/ton and 6.22 gr/ton of gold respectively (www.anglogoldashanti.com). Martha Mine is a small, high-grade "bonanza" Ag vein deposit with proved reserves (status end of year 2006) of 33,000 t containing ~ 2 Kgr/ton of silver and 3.1 gr/ton of gold (http://www.coeur.com/reserves). San Jose Mine hosts a number of epithermal high-grade Ag-Au quartz veins with the Huevos Verdes and Frea vein systems currently under development with a current resource of 700,000 ounces of gold equivalent (www.minandes.com). The Manantial Espejo District was under feasibility studies that ended in 2007. Another 30 gold-silver projects are in different stages of exploration. Their most advanced are: La Josefina, Cerro León, Martinetas-Microondas and Cerro Moro with the last two situated in the eastern part of the Deseado Massif.

To be aware of the Jurassic volcanic evolution it is imperative to understand the geological controls of the mineral deposits in Patagonia. Constraining the age of the volcanic rocks that host the mineralized veins is a fundamental step in this direction. The geochronological studies by different methods (De Barrio 1989, 1993; Pankhurst et al. 1993, 2000; Pankhurst & Rapela 1995; Aldric et al. 1996; Arribas et al. 1996; Zubia et al. 1999; Tessone et al. 1999; Feraud et al. 1999; Dube et al. 2003; Guido 2002; Guido et al. 2006) have contributed to the knowledge of the Jurassic volcanism of the Deseado Massif. These studies are restricted to the volcanism in Bajocian to Tithonian (Middle to Late Jurassic) times and support the idea that it represents a calc-alkaline bimodal (andesite and rhyolite) volcanic complex. The objective of the present contribution is to present a geochronological study involving U-Pb SHRIMP analyses of zircons in samples of ignimbrites from the Chon Aike Formation of the central part of the Deseado Massif (Fig. 1), specifically those from the Manantial Espejo and La Josefina prospects. We present the results and their relevance to the ore geology of the province.

Geology and mineralizations of the Deseado Massif

Geology and stratigraphy of the Deseado Massif are summarized in Figure 1 and Table 1. The oldest rocks belong to the Río Deseado Complex and the La Modesta Formation. The Rio Deseado Complex is represented by isolated outcrops of Upper Proterozoic to Lower Paleozoic metamorphic and igneous rocks around the eastern sector of the Deseado Massif (Guido et al. 2004). The presumed lower Paleozoic La Modesta Formation is composed of low-grade metamorphic muscovite schists, metavolcanic and calk-silicate rocks with minor contents of magnetite and tourmaline occurring in the central-western part of the Deseado Massif (Moreira et al. 2005).

A Permian to Triassic Gondwana sedimentary sequence (La Golondrina, La Juanita and El Tranquilo Formations) overlies these basement rocks. The sequence was deposited in a rift basin during an initial extensional phase, which was followed by block faulting and the development of half-grabens containing lakes and deltas. The rocks are fluvio-lacustrine sandstone, siltstone and conglomerate, with the sequence evolving upward to tuffaceous sandstone and laminated tuff.

In the last years, the Jurassic volcanic complex has been studied particularly to detect possible genetic links to epithermal deposits. The first magmatic evidence of Jurassic volcanism in the study area includes the Lower Jurassic granitoid rocks of La Leona Formation, followed by Lower Jurassic tuffs and tuffites of the Roca Blanca Formation and the intrusive basic rocks of the Cerro León Formation. The bimodal volcanic rocks of the Chon Aike Formation and Bajo Pobre Formation represent more than 60% of the surface exposures of the Deseado Massif, with a dominance of Chon Aike Formation rocks. The Chon Aike Formation is composed of volcaniclastic rocks (ignimbrites, tuffs, volcanic breccias and tuffites) as well as magmatic units (domes, lava flows, subvolcanic bodies and dykes). They are mainly represented by calc-alkaline and peraluminous rhyolites with few dacites. Most of the Bajo Pobre Formation is composed of lava flows and minor volcaniclastic rocks (tuffs, agglomerates and tuffites). They are mainly calc-alkaline andesites to dacites with few basaltic andesites.

Jurassic volcanism is found in grabens in an extensional tectonic setting. Echavarría et al. (2005) pro-

Table 1. Geology and stratigraphy of the Deseado Massif.

<table>
<tr><th>Era</th><th colspan="2">Period</th><th>Age (Ma)</th><th colspan="4">Stratigraphy and lithology</th></tr>
<tr><td rowspan="3">Cenozoic</td><td colspan="2">Quaternary</td><td>Present-1.75</td><td colspan="2">Modern deposits</td><td rowspan="3">Olivine Basalt flows</td><td rowspan="2">Gravel deposits (Rodados Patagónicos)</td></tr>
<tr><td colspan="2">Neogene</td><td>1.75-23.5</td><td rowspan="2">Monte León and San Julian Formations (marine sedimentites)</td><td>Santa Cruz Formation (continental sedimentary rocks)</td></tr>
<tr><td colspan="2">Paleogene</td><td>23.5-65</td><td></td><td></td></tr>
<tr><td rowspan="5">Mesozoic</td><td colspan="2">Cretaceous</td><td>65-145</td><td colspan="2" rowspan="2">Bajo Grande Formation (sandstones and tuffs)</td><td colspan="2">Baqueró Formation (tuffs and sandstones)</td></tr>
<tr><td rowspan="3">Jurassic</td><td>Upper</td><td>145-161</td><td colspan="2"></td></tr>
<tr><td>Middle</td><td>161-175</td><td colspan="2">Chon Aike Formation (volcaniclastic to magmatic felsic rocks)</td><td colspan="2">Bajo Pobre Formation (mesosilicic lava flows and minor volcaniclastic rocks)</td></tr>
<tr><td>Lower</td><td>175-200</td><td>La Leona Formation (granitoid rocks)</td><td>Roca Blanca Formation (tuffs and tuffites)</td><td colspan="2">Cerro León Formation (intrusive mafic rocks)</td></tr>
<tr><td colspan="2">Triassic</td><td>200-251</td><td colspan="4">El Tranquilo Formation (shales and sandstones)</td></tr>
<tr><td rowspan="7">Paleozoic</td><td colspan="2" rowspan="2">Permian</td><td rowspan="2">251-299</td><td colspan="4">La Juanita Formation (sandstones)</td></tr>
<tr><td colspan="4">La Golondrina Formation (arkoses and shales)</td></tr>
<tr><td colspan="2">Carboniferous</td><td>299-359</td><td colspan="4"></td></tr>
<tr><td colspan="2">Devonian</td><td>359-416</td><td></td><td colspan="3" rowspan="3">La Modesta Formation (low grade metamorphic rocks)</td></tr>
<tr><td colspan="2">Silurian</td><td>416-443</td><td rowspan="2">Rio Deseado Complex (igneous rocks)</td></tr>
<tr><td colspan="2">Ordovician</td><td>443-488</td></tr>
<tr><td colspan="2">Cambrian</td><td>488-542</td><td colspan="4"></td></tr>
<tr><td>Neoproterozoic</td><td colspan="2"></td><td>542-1000</td><td colspan="4">Rio Deseado Complex (metamorphic rocks)</td></tr>
</table>

posed that the extension occurred simultaneously with the eruption of the Jurassic volcanic rocks and ended at the climax of volcanism or shortly thereafter. As yet it was not possible to map each volcanic center within the Jurassic volcanic province of the Deseado Massif. Locally, small calderas were reported (Fernandez et al. 1996; Echavarría 1999; Chernicoff & Salani 2002), but they do not account for the great volume of effusive rocks found in the area. The eruptions of large volumes of ignimbrite may be fault-related fissure eruptions and not central volcanoes (e. g. Gust et al. 1985).

During Jurassic times, the geotectonic environment of Patagonia was characterized by a very slow subduction at the Pacific margin of Gondwana (Ramos 1988) causing extension and rifting in the Deseado Massif with NW-SE grabens and hemigrabens being generated. In combination with the possible existence of a mantle plume (Karoo-Antartic-Tasmania; Riley et al. 2000) this resulted in a high thermal gradient and an important magmatic activity in the back-arc. This rifting process provides evidence for the beginning break-up of Gondwana.

Later, in Upper Jurassic to Cretaceous times, continental pyroclastic and sedimentary rocks (Bajo Grande and Baqueró Formations) were deposited in small extensional basins. The Tertiary period is mainly represented by marine (Monte León and San Julian Formations) and continental sedimentary rocks (Santa Cruz Formations). Tertiary and Quaternary are also characterized by several olivinic basaltic flows and gravel deposits (Rodados Patagónicos) that overlie most of the Deseado Massif region and produce typical tableland landscapes.

Deseado Massif epithermal deposits are represented mainly by Au- and Ag-rich silica veins composed of multistage fracture fillings that are characterized by a gangue mineral assemblage comprising quartz, adularia, calcite, and illite. Economic gold/silver mineralization is normally hosted in ore shoots that are related to structural openings within regional shear zones (Echavarria et al. 2005). Schalamuk et al. (1997, 1999) proposed that the general characteristics of the Deseado Massif epithermal deposits (ore and gangue mineralogy, quartz textures, alteration minerals, geochemistry and hydrothermal fluid signature) are very similar to the low sulfidation type deposits studied by White & Hedenquist (1990, 1995) or the adularia-sericite type deposits of Heald et al. (1987).

Features of shallow epithermal deposits like siliceous sinter and travertines characterize the western occurrences of the Deseado Massif (Guido & Schalamuk 2003).

In recent years, some distinct epithermal occurrences have been found in the Deseado Massif. The Martha mine is the best known example. It is an Ag-rich deposit with an Ag : Au ratio of 1000 : 1 and high contents of base metals. These characteristics were the reason for Gonzales Guillot et al. (2004) to include it in the intermediate sulfidation type deposit of Hedenquist et al. (2000). Jovic et al. (2004) described a new metallogenetic association in Cerro León characterized by the anomalous presence of Sn, Cd and In together with anomalies of Zn and Ag, and also high contents of Cu, Mn, Pb, W and Bi, in a complex sulphur-rich mineralogy.

The Manantial Espejo Prospect

Manantial Espejo Prospect (MEP), currently under feasibility studies, is the property of a joint venture between Silver Standard Resources and Pan American Silver Corporation companies. It is located in the central part of the Deseado Massif, approximately 44 km east of Gobernador Gregores (Fig. 1).

In 2006, proved reserves were 3.79 Mt with an average grade of 151 gr/ton of silver and 2.05 gr/ton of gold. The estimated reserves are 3.7 Mt with an average grade of 181 gr/ton of silver and 2.66 gr/ton of gold (http://www.panamericansilver.com).

The Middle to Upper Jurassic volcanic and volcaniclastic rocks from the Bajo Pobre and Chon Aike Formation are the representative units in the MEP (Fig. 2) with a strong predominance of syneruptive over epiclastic deposits. Fourteen volcanic units were identified, mostly represented by ignimbrites with a dacitic and rhyolitic composition (Echeveste 2005b).

The quartz-gold-silver vein and veinlet assemblages are arranged in fractures predominantly running in WNW direction with nearly vertical inclinations and their mineralized structures totaling 13.6 km in length. Characteristic of the mineralization is that it is filling open spaces. These structures are found in a strip of about 16 km length running in WNW-ESE direction and covering an area of 50 km^2. Maria vein is the most important mineralized structure, because of its dimensions and because it has been the target of most of the exploration efforts. The ore veins present typical replacement textures: those where crustiform texture is replaced by a colloform one as well as those where platy calcite is replaced by silica. Main ore minerals are argentite, electrum and native gold, associated minerals include pyrite, marcasite, sphalerite, galena, chalcopyrite, bornite and tetrahedrite. Sphalerite contains trace contents of Ag. The Au/Ag ratio is in the order of 1 : 55.

The hydrothermal alteration most extensively found is the silicification of fractures by quartz and chalcedony and silica replacement of rocks with travertine, and fragmental volcanic units rich in ash (ash flow tuffs). Phyllic argillic alteration forms halos around the veins, while the propylitic alteration affects mainly rocks with dacitic and andesitic composition.

The La Josefina Prospect

La Josefina Prospect (LJP), currently under exploration, is a property of the state company FOMICRUZ S. E. and is located in the central part of the Deseado Massif, approximately 130 km northwest of Cerro Vanguardia Mine (Fig. 1). FOMICRUZ S. E. offered the prospect to public sale in 2006; a junior company (Minera Cerro Cazador S. A.) has started a four year project of new exploration.

The Jurassic pyroclastic rocks of Bajo Pobre and Chon Aike Formations are the most representative units in the La Josefina Prospect (Fig. 3). The Bajo Pobre Formation, mainly andesitic-dacitic rocks, includes porphyritic and aphanitic flows partially self-brecciated as well as porphyries, sills and ring-dykes surrounding rhyolitic domes. The Chon Aike Formation covers ap-

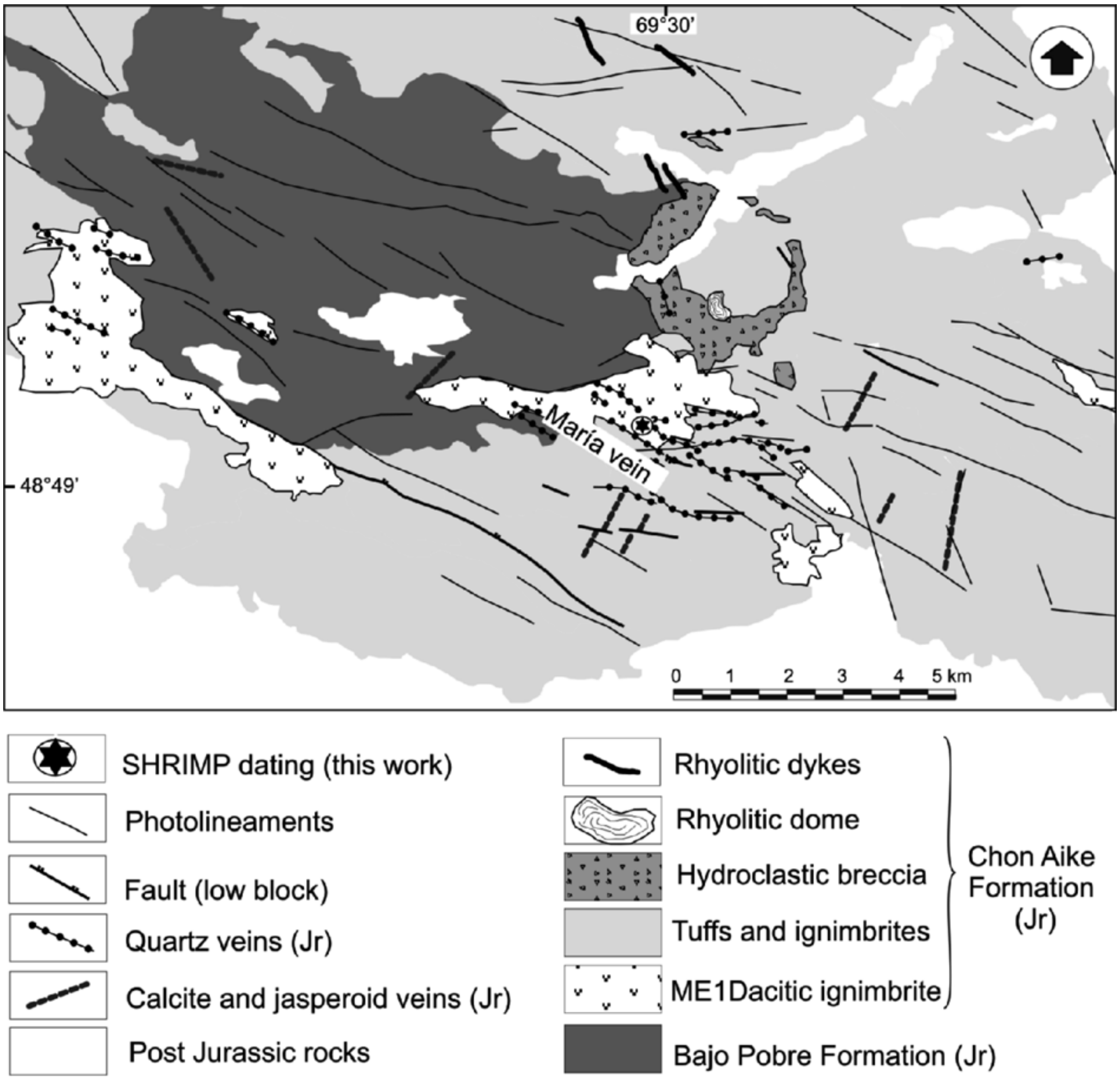

Fig. 2. Simplified geological map of the Manantial Espejo Prospect. Modified from Echeveste (2005 b).

proximately 60% of the LJP area. Moreira (2005) defined six members with lithofacial criteria which include magmatic facies (lava flows and domes) and volcaniclastic facies (principally ignimbrites and minor tuffs, tuffites, volcanic breccias and surge pyroclastic flows). They are mainly calc-alkaline and peraluminous rhyolites, with some rhyodacitic rocks. Also Early Paleozoic low-grade metamorphic rocks (Moreira et al. 2005) of La Modesta Formation and Cenozoic basaltic flows occur in the region.

The mineral occurrences in LJP are represented by Au-bearing (minor Ag) structurally controlled veins and veinlets that extend over a strip about 12 km long and between 500 and 1200 m wide. The veins are filled with multiple generations of banded and brecciated quartz, with late carbonate-replacement texture accompanied by scarce adularia, illite and later barite. The hypogene mineral assemblage comprises native gold, electrum, Ag-bearing sulphosalts, pyrite, specular hematite, minor arsenopyrite with base metal sulfides represented mainly by sphalerite and galena, along with smaller amounts of

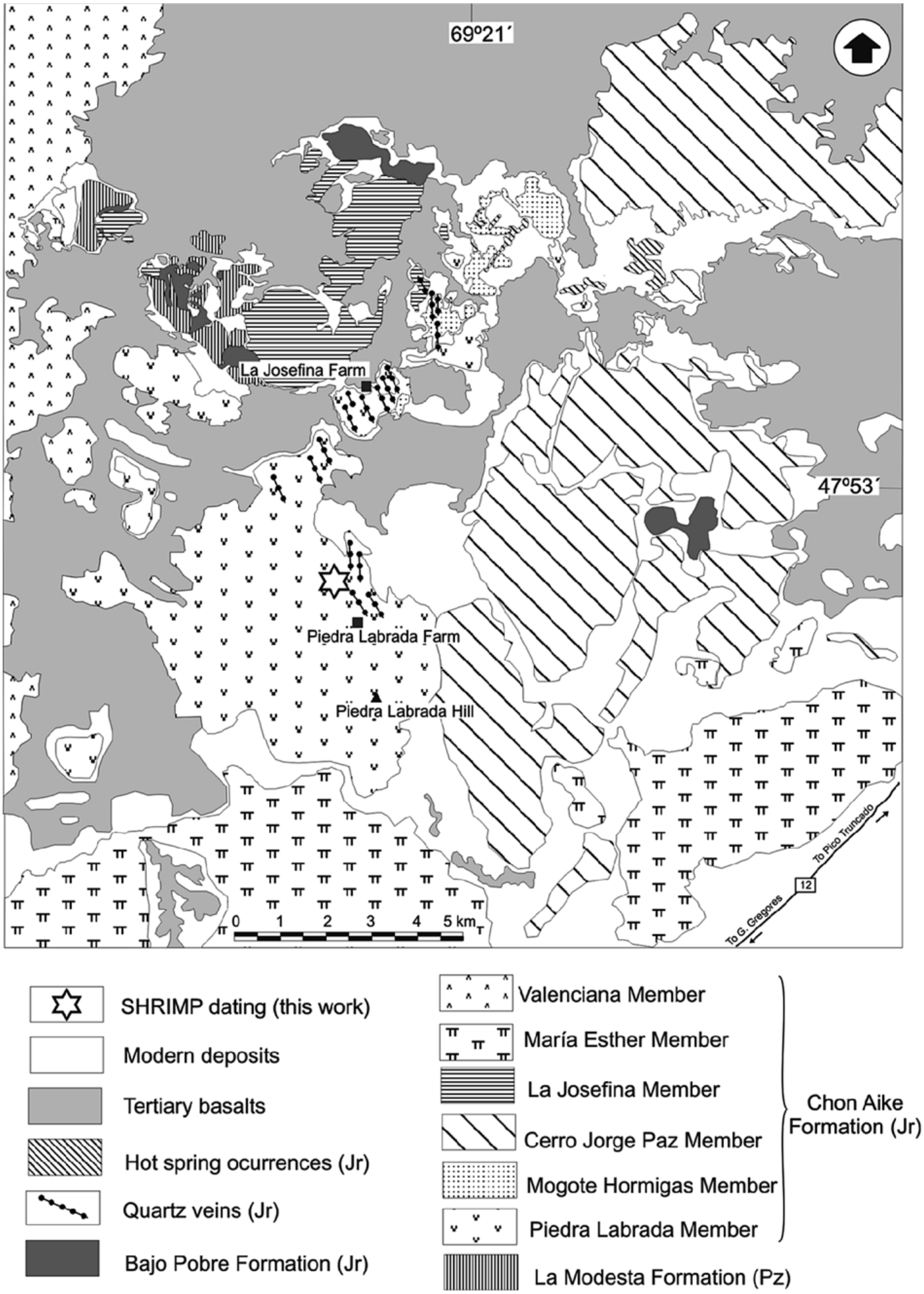

Fig. 3. Simplified geological map of the La Josefina Prospect. Modified from Moreira (2005).

Table 2. Summary of the published ages for the Chon Aike Formation. **DM =** Deseado Massif.

Age (Ma)	Unit	DM location	Material	Method	Reference
160 ± 7	tuff	Roca Blanca Farm	whole rock	K-Ar	Cazeneuve (1965)
166 ± 5	unknown	Bahía Camarones	whole rock	K-Ar	Creer et al. (1972)
155 ± 15	ignimbrite	Río Pinturas	whole rock	unknown	Baker et al. (1981)
162 ± 10	rhyolitic dyke	Bajo La Leona	whole rock	unknown	Marquez (1981)
160 ± 10	ignimbrite	Bajo de San Julián	whole rock	K-Ar	Spalletti et al. (1982)
157 ± 10	ignimbrite	Bajo de San Julián	whole rock	K-Ar	
138 ± 10	rhyolitic dyke	Bajo de San Julián	whole rock	K-Ar	
149 ± 10	Lava	Bajo de San Julián	whole rock	K-Ar	
161 ± 10	ignimbrite	Bajo de San Julián	whole rock	K-Ar	
123 ± 10	ignimbrite	Bajo de San Julián	whole rock	K-Ar	
157 ± 5	ignimbrite	Bajo Grande	whole rock	K-Ar	Hechen & Homovc (1985)
153 ± 5	ignimbrite	Bajo Grande	whole rock	K-Ar	
123 ± 5	ignimbrite	El Tranquilo	whole rock	K-Ar	De Barrio (1989)
161 ± 11	ignimbrite	Bajo Pellegrini	whole rock	Rb-Sr	
161 ± 5	ignimbrite	Bajo Pelegrini Farm	whole rock	Rb-Sr	De Barrio (1993)
168 ± 2	ignimbrite	Puerto Deseado	whole rock	Rb-Sr	Pankhurst et al. (1993)
177.6 ± 0.7	ignimbrite	Puerto Deseado	Sanidine	Ar-Ar	Alric et al. (1996)
151.5 ± 0.5	ignimbrite	El Recreo	Sanidine	Ar-Ar	
153.2 ± 3.6	ignimbrite	La Josefina prospect	Biotite	K-Ar	Arribas et al. (1996)
151.5 ± 3.6	ignimbrite	La Josefina prospect	Biotite	K-Ar	
149.6 ± 3.5	ignimbrite	La Josefina prospect	Biotite	K-Ar	
148.8 ± 3.6	lava	La Josefina prospect	Biotite	K-Ar	
171.0 ± 1	ignimbrite	Vanguardia	Zircon	U-Pb	Zubia et al. (1999)
148 ± 2	ignimbrite	central sector	whole rock	Rb-Sr	Tessone et al. (1999)
168.6 ± 0.4	ignimbrite	north central sector	Sanidine	Ar-Ar	Feraud et al. (1999)
153.4 ± 0.3	ignimbrite	northwestern sector	Sanidine	Ar-Ar	
177.7 ± 0.4	ignimbrite	Puerto Deseado	Sanidine	Ar-Ar	
177.8 ± 0.4	ignimbrite	Puerto Deseado	Sanidine	Ar-Ar	
154.6 ± 0.5	ignimbrite	Zona noroccidental	Sanidine	Ar-Ar	
151.5 ± 0.5	ignimbrite	Zona noroccidental	Sanidine	Ar-Ar	
158.4 ± 0.3	ignimbrite	near Manantial Espejo	Sanidine	Ar-Ar	
157.9 ± 0.5	ignimbrite	near Manantial Espejo	Sanidine	Ar-Ar	
168.4 ± 1.6	Unknown	Cabo Dañoso	Zircon	U-Pb	Pankhurst et al. (2000)
162.7 ± 1.1	Unknown	San Julian	Zircon	U-Pb	
156.2 ± 1.8	Unknown	Río Pinturas	Zircon	U-Pb	
169.1 ± 1.6	Unknown	Puerto Deseado	Feldspar	Ar-Ar	
156.4 ± 2.4	Unknown	Río Pinturas	Feldspar	Ar-Ar	
177.8 ± 0.8	Unknown	Cabo Dañoso	Feldspar	Ar-Ar	

chalcopyrite and bornite. The supergene association consists of remobilized gold, argentite, chalcocite-covellite, cerusite-anglesite and malachite-azurite. The average Au : Ag ratio is ~ 1 : 12.

The attributes of the veins in LJP are consistent with the model of an epithermal gold-rich deposit associated with quartz ± calcite ± adularia ± illite gangue mineral assemblages (Simmons et al. 2005).

Spatially, the veins are associated with hydrothermal eruption breccias, silica sinter terraces, geyserites, carbonate stromatolitic deposits, and blankets of steam-heated acid alteration, mainly to the north of the prospect.

Previous geochronology

Geochronological data on the Jurassic volcanic rocks (Chon Aike and Bajo Pobre Formation) of the Deseado Massif (Table 1 and Table 2) show a spread of ages between 177 and 150 Ma. The volcanic activity spanned more than 25 My, but each eruptive event was fairly short-lived lasting about 1 – 2 My (Pankhurst & Rapela 1995). Geochronological dates were obtained with different methodologies (most of them K-Ar and Ar-Ar methods in total rock samples). There are only three published U-Pb SHRIMP dates reported by Pankhurst et al. (2000) for Jurassic volcanic rocks from the eastern (168.4 ± 1.6 and 162.7 ± 1.1 Ma) and western (156.2 ± 1.8 Ma) portions of the Deseado Massif.

A published geochronological age on Chon Aike Formation from Manantial Espejo is 159.9 ± 0.5 Ma (SIMS U-Pb on zircon; Dube et al. 2003). This absolute age is close to the ages obtained by Feraud et al. (1999) in ignimbrites near the MEP sector (Table 1) and indicates that the MEP volcanism occurred between 158.4 ± 0.3 and 159.9 ± 0.5 Ma.

Moreira (2005) proposed that this volcanic activity in LJP was developed in the Upper Jurassic (Oxfordian) and spanned ~ 4 My. The lower member consists of crystal-rich, welded ignimbrite dated at 153 ± 3,6 Ma (K-Ar on biotite; Arribas et al. 1996) with the youngest units composed of rhyolitic lavas and ignimbrites dated at 148.8 ± 3.6 Ma (K-Ar on biotite).

Geochronological data on epithermal adularia and illite from veins and hydrothermal alteration halos at different locations support the genetic relationship between Jurassic volcanism and the epithermal mineralization in the Deseado Massif (Table 3). The age of the

Table 3. Summary of the published ages for the Bajo Pobre Formation. **DM =** Deseado Massif.

Age (Ma)	Unit	DM location	Material	Method	Reference
175	andesite	eastern sector	whole rock	Rb-Sr	Pankhurst & Rapela (1995)
156.7 ± 2.3	andesite	Bajo Pobre	plagioclase	Ar-Ar	Alric et al. (1996)
164 ± 2	basaltic andesite	unknown	plagioclase	Ar-Ar	Mertz et al. (1996)
173 ± 8	andesite	eastern sector	whole rock	Rb-Sr	Tessone et al. (1999)
164.1 ± 0.3	basaltic andesite	Bajo Pobre	whole rock	Ar-Ar	Feraud et al. (1999)
160.5 ± 0.5	basaltic andesite	Bajo Pobre	whole rock	Ar-Ar	
152.8 ± 2.6	andesite	central sector	plagioclase	Ar-Ar	
152.7 ± 1.2	andesite	central sector	plagioclase	Ar-Ar	
150.6 ± 2.0	basaltic andesite	Bajo Pobre	biotite	Ar-Ar	Pankhurst et al. (2000)
150.6 ± 4.1	agglomerate	San Jose prospect	biotite	Ar-Ar	Dietrich et al. (2005)
151.3 ± 0.7	andesite	San Jose prospect	plagioclase	Ar-Ar	
144.4 ± 1	andesite	San Jose prospect	plagioclase	Ar-Ar	
177 ± 4	basaltic andesite	eastern sector	plagioclase	Ar-Ar	Guido et al. (2006)
151.3 ± 3.4	basaltic andesite	eastern sector	whole rock	K-Ar	

MEP mineralization was determined as 142.6 ± 3.2 and 124.8 ± 3 Ma (K-Ar on adularia; Arribas et al., 1996) and 134 ± 5 Ma (adularia; Dube et al. 2003). The differences in ages between adularia and volcanic rock samples are attributed by Echeveste (2005b) to radiogenic Ar loss during alteration. The age of the mineralization in LJP is not well constrained; the Rb-Sr errorchron is 156 ± 2 Ma (Fernandez et al. 1999).

SHRIMP geochronology

Samples and methodology

Samples in MEP and LJP were collected to determine the connection between the mineralization age and the local volcanic processes. In the MEP, the sample collected for the isotopic study consists of an ignimbrite from the Chon Aike Formation called "ME1 Dacitic ignimbrite" by Echeveste (2005b, Fig. 2). This unit hosts the northern part of the María vein, has a strong hydrothermal alteration (pyritization and phyllic alteration) and is the oldest Jurassic unit in the area. In the LJP, the sample collected consists of an ignimbrite from the Chon Aike Formation equivalent to the "Piedra Labrada Member" defined by Moreira (2005, Fig. 3). This unit hosts the greater part of the Au-Ag epithermal quartz vein and veinlet systems. It is considered the oldest unit in LJP based on its stratigraphic position.

Zircons were separated from the rock at Universidade Federal do Rio Grande do Sul (Porto Alegre, Brazil). For each sample, about 3 kg of rock were collected for zircon separation. Samples were crushed, milled, sieved and washed to remove very fine material (clay and silt sizes). The 60 - 250 mesh fractions were treated with heavy liquids to remove light minerals and with magnetic separator to concentrate the less magnetic minerals such as zircon. Zircon was hand-picked and mounted in epoxy resin together with the zircon standard CZ3 (564 Ma; $^{206}Pb/^{238}U$ = 0.0914). The mount was polished and carbon-coated for SEM (Scanning Electron Microscope) study.

Back-scattered electron images (BSE) were obtained with a JEOL6400 SEM at the Center for Microscopy and Microanalyses at University of Western Australia. Images of zircon (Fig. 4) are critical for identifying internal features such as core and rims and to help avoid areas with high common lead content (inclusions, fractures, and metamict areas). These images also provide important information on zircon morphology and internal structure which cannot be obtained from conventional optical microscopy.

Zircon U-Th-Pb isotopic analyses were carried out on the U-Pb SHRIMP (**S**ensitive **H**igh **R**esolution **I**on **Mi**cro**p**robe) at the Curtin University of Technology in Perth (Western Australia). Smith et al. (1998) describe the analytical methods, and the decay constants used are those recommended by Steiger & Jager (1977). The uncertainties of individual ages are quoted at 1 σ whereas the ages at the plots are calculated at 2 σ level (about 95% confidence). SHRIMP data were reduced using SQUID software (Ludwig 2003) and plots are prepared using ISOPLOT/Ex (Ludwig 2001).

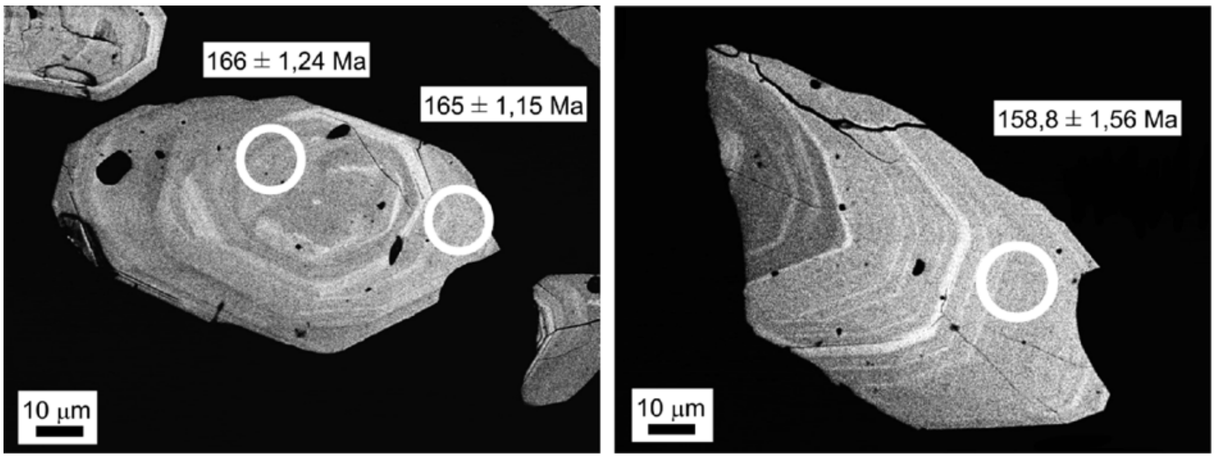

Fig. 4. Back-scattered electron images of zircon crystals from the Manantial Espejo Prospect showing euhedral zoning. The white circles show the analyzed areas.

Table 4. Geochronological data for several mineralized epithermal rocks of the Deseado Massif. **DM =** Deseado Massif.

Age (Ma)	Material	DM location	Unit	Method	Reference
149.5 ± 3.5 152.4 ± 3.6	illite	Co Vanguardia	hydrothermally altered Vanguardia vein	K-Ar	Arribas et al. (1996)
142.3 ± 3.4 151.0 ± 3.5	illite	Co Vanguardia	hydrothermally altered Osvaldo Diez vein	K-Ar	
138.5 ± 3.3	adularia	Co Vanguardia	Natalia vein	K-Ar	
124.8 ± 3.0 142.6 ±3.5	adularia	Manantial Espejo	Maria vein	K-Ar	
171.9 ± 1	zircon?	Co Vanguardia	hydrothermally altered ignimbrite	U-Pb	Zubia et al. (1999)
150 ± 4	total rock	La Josefina	hydrothermally altered ignimbrite	Rb-Sr	Fernandez et al. (1999)
153.4 ± 1.46 152.9 ± 2.75 155.1 ± 3.0	adularia	Co Vanguardia	Osvaldo Diez vein	Ar-Ar	Sharpe et al. (2002)
157 ± 1.5	adularia	Co Vanguardia	Osvaldo Diez vein	Unknown	Dube et al. (2003)
134 ± 5	adularia	Manantial Espejo	Maria vein	Unknown	
159.9 ± 0.5	zircon?	Manantial Espejo	hydrothermally altered ignimbrite	U-Pb	
167.9 ± 1.71	adularia	Martinetas	Coyote vein	Unknown	
151.1 ± 1.2	adularia	San José	vein	Ar-Ar	Dietrich et al. (2005)
151.2 ± 0.5	adularia	San José	vein	Ar-Ar	
152.1 ± 0.5	adularia	San José	vein	Ar-Ar	

Results

Zircon crystals are euhedral, have a 2 : 1 aspect ratio, and display euhedral internal zoning commonly considered typical of crystals precipitated from a melt. Crystal sizes analyzed in this investigation are 80 – 150 µm.

The SHRIMP zircon U-Pb isotopic results are shown in Table 4. The MEP dates obtained a range from ~ 156 to 168 Ma (ten spots), but two groups of data are recognized (Fig. 5A). The oldest one is from the central portion of the crystals with determination values between ~ 167 and 163 Ma. The younger ones are from the edge of the crystals and the date obtained from five spots is 158.9 ± 0.5 Ma (c^2: 93.8%, MSWD: 1.7 and probability of concordance of 0.19).

The $^{206}Pb/^{238}U$ analyses in LJP zircons yield dates between ~ 156.4 and 150.5 Ma (eight spots with an irregular distribution). The Concordia diagram of figure 5B shows a concordant age at 152.7 ± 2.3 Ma from five spots (c^2: 95%, MSWD: 8.6 and probability of concordance: 0.003).

Discussion and conclusions

In the MEP, the oldest ages (~ 167 and 163 Ma) are interpreted as the crystallization age of the zircons from the "ME1 Dacitic ignimbrite". The age of 158.9 ± 0.5 Ma found is interpreted as a later thermal event, related to strong hydrothermal alteration. This alteration af-

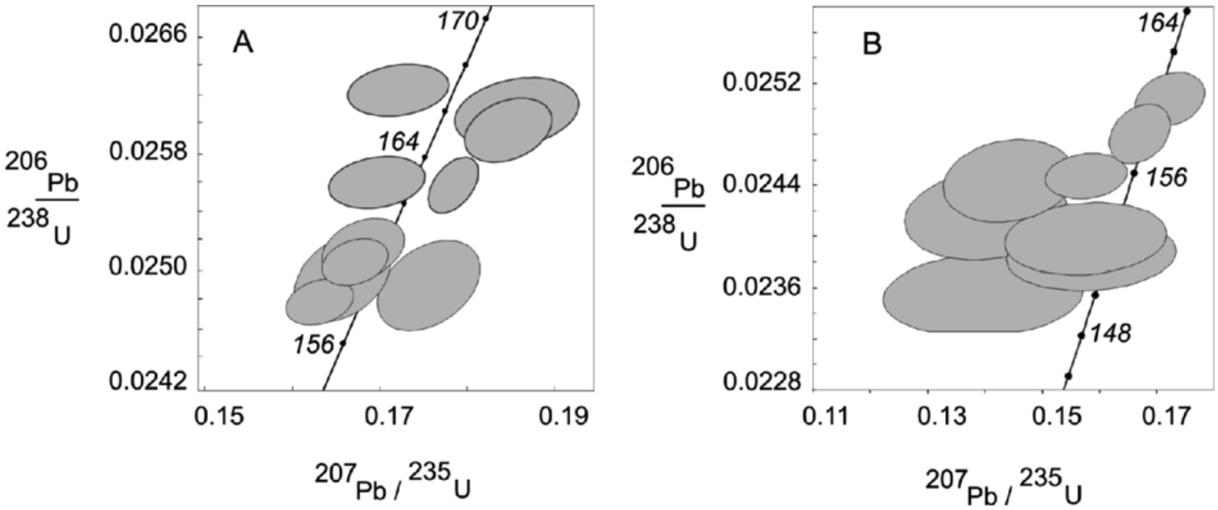

Fig. 5. Concordia diagram **A**. of the Manantial Espejo Prospect, **B**. of the La Josefina Prospect. Ellipses drawn with 2σ error.

fected the analyzed sample and destroyed most of its minerals. Although not clear from the zircon images, we interpret the youngest age as caused by partial resetting of the zircon crystals with Pb loss through diffusion or recrystallization processes in the edge of grains. This suggests that mineralization in the MEP took place 6 My after the host rock solidification.

This interpretation of the MEP zircons being reset is supported by some authors. For example, Geisler et al. (2002) showed experimentally that chemically attacking zircon crystals results in loss of some elements on some sectors of these crystals. Resetting of zircon ages were indicated also by the studies of Ross et al. (2004) in the Kanowna Belle Gold Mine vein system in Western Australia and by Hogdhal et al. (2001) in Paleoproterozoic zircons of the Fennoscandic shield in Sweden.

We interpret the age of MEP adularia crystals studied by Arribas et al. (1996) and Dube et al. (2003) – 124.8 ± 3.0 Ma, 142.6 ± 3.5 Ma and 134 ± 5 Ma – as minimum ages indicative of a post-mineralization thermal event that led to the partial Ar radiogenic loss in the adularia crystals.

In the LJP, U-Pb zircon age was determined from the "Piedra Labrada" member. This date is interpreted as zircon crystallization age (152 ± 2.8 Ma) and is broadly consistent with its position in the stratigraphic succession studied by Moreira (2005). The studied unit is older than the lavas effusion of 150 Ma (Arribas et al. 1996) and is concordant with the K-Ar date (153.2 ± 3.6 Ma) obtained by these authors. Moreira (2005) proposed that this volcanic activity in LJP was developed in the Upper Jurassic (Oxfordian) and lasted ~ 4 My It is possible that volcanism and mineralization overlapped in the LJP, because of the presence of mineralization in the oldest volcanic rocks and age delimitation by Fernandez et al. (1999).

Feraud et al. (1999) indicated a regular decrease of ages ($^{40}Ar/^{39}Ar$ method) in the Deseado Massif from the ENE (187 Ma) to the WSW (144 Ma) along a distance of about 650 km and apparently related to the tectonic structure in half-grabens oriented in NNW - SSE direction. Pankhurst et al. (2000) proposed that the Jurassic volcanism in Patagonia and Antarctic Peninsula spanned more than 30 My, but defined three episodes on the basis on peak activity: V1 (188 – 178 Ma), V2 (172 – 162 Ma) and V3 (157 – 153).

Alric et al. (1996), Feraud et al. (1999) and Pankhurst et al. (2000) assumed that volcanic activity migrated from east to west and from north to south with time. However, Panza & Haller (2002) noted that such migration should be analysed with caution due to the complexity of the sample location within the stratigraphic column of Jurassic volcanism and that more data were needed to better constrain such an interpretation. In the same way, Guido et al. (2004) interpreted the tendency to yield younger ages to the west in the Deseado Massif as a consequence of a deeper structural level of exposure in the eastern part of this geological province.

The U-Pb SHRIMP dates of zircon from Jurassic ignimbrites that we report delimit the ages of the oldest felsic volcanism in MEP and LJP. The U-Pb crystallization ages obtained in the MEP are older than ex-

Table 5. U-Pb SHRIMP data for zircon from the Manantial Espejo (MEP) and La Josefina Prospects (LJP).

Spot	U [ppm]	Th [ppm]	Th/U	^{206}Pb [ppm]	f206 [%]	Isotopic ratios $\frac{^{206}Pb}{^{238}U}$	Isotopic ratios $\frac{^{207}Pb}{^{235}U}$	Isotopic ratios $\frac{^{207}Pb}{^{206}Pb}$	Ages [Ma] $\frac{^{206}Pb}{^{238}U}$	Ages [Ma] $\frac{^{207}Pb}{^{206}Pb}$	Conc. [%]
MEP sample											
1	280	169	0.62	6.0	0.00	0.0251 ± 0.95	0.1775 ± 2.74	0.0513 ± 2.6	159.8 ± 1.5	253 ± 59	37
2	468	142	0.31	10.4	0.00	0.0258 ± 0.48	0.1803 ± 2.29	0.0507 ± 1.2	164.3 ± 0.8	226 ± 27	27
3	332	178	0.56	7.2	0.12	0.0254 ± 0.58	0.1698 ± 1.26	0.0486 ± 2.2	161.5 ± 0.9	127 ± 52	-28
c.32-2	338	128	0.39	7.3	0.13	0.0250 ± 0.36	0.1647 ± 1.93	0.0478 ± 1.9	159.1 ± 0.6	89 ± 45	-78
c.29-1	320	167	0.54	7.3	0.28	0.0265 ± 0.41	0.1739 ± 2.76	0.0476 ± 2.7	168.5 ± 0.7	81 ± 65	-107
c.28-1	241	70	0.30	5.2	0.12	0.0252 ± 0.91	0.1674 ± 2.72	0.0482 ± 2.6	160.2 ± 1.4	111 ± 61	-44
c.28-2	140	36	0.27	3.1	0.00	0.0262 ± 0.59	0.1867 ± 2.20	0.0517 ± 2.1	166.7 ± 1.0	272 ± 49	39
c.24-1	226	89	0.41	5.1	0.00	0.0263 ± 0.65	0.1877 ± 3.13	0.0517 ± 3.1	167.5 ± 1.1	273 ± 70	39
c.37-1	355	168	0.49	7.7	0.09	0.0253 ± 0.34	0.1688 ± 1.81	0.0484 ± 1.8	160.9 ± 0.5	121 ± 42	-33
LJP sample											
d.2-2	132	52	0.44	2.7	0.52	0.0245 ± 1.01	0.1446 ± 6.47	0.0428 ± 6.39	156.2 ± 1.6	-181 ± 60	186
d.2-1	80	31	0.58	1.7	0.01	0.2963 ± 0.48	4.5700 ± 0.70	0.1119 ± 0.51	1673.0 ± 7.0	1830 ± 173	9
d.2b-1	68	25	0.38	1.4	0.00	0.0241 ± 0.85	0.1581 ± 7.34	0.0477 ± 7.29	153.3 ± 1.3	83 ± 9	-85
d.3-1	124	48	0.40	2.6	0.21	0.0239 ± 0.88	0.1591 ± 7.64	0.0482 ± 7.59	152.5 ± 1.3	110 ± 179	-39
d.4-1	136	57	0.89	2.9	0.03	0.0249 ± 0.66	0.1675 ± 2.57	0.0488 ± 2.49	158.5 ± 1.0	139 ± 58	-14
d.4b-1	244	113	0.48	5.2	0.37	0.0246 ± 0.45	0.1581 ± 3.71	0.0467 ± 3.68	156.4 ± 0.7	35 ± 88	-352
d.4c-1	363	315	0.57	7.8	0.00	0.0252 ± 0.57	0.1729 ± 2.86	0.0498 ± 2.81	160.1 ± 0.9	188 ± 65	15
d.7-1	158	88	0.40	3.4	0.96	0.0242 ± 1.13	0.1407 ± 8.26	0.0421 ± 8.18	154.5 ± 1.7	-222 ± 206	170
d.6-1	101	35	0.36	4.3	0.14	0.0496 ± 0.58	0.3589 ± 2.89	0.0524 ± 2.83	312.4 ± 1.8	304 ± 65	-3
d.8-1	117	65	0.41	29.8	0.86	0.0236 ± 1.05	0.1401 ± 10.21	0.0430 ± 10.15	150.5 ± 1.6	-167 ± 253	190

Uncertainties are 1σ. Isotopic ratios errors are %

All Pb in ratios are radiogenic component.

Conc. = concordance, as 100 {t [$^{206}Pb/^{238}U$] / t [$^{207}Pb/^{206}Pb$]}

f206 = (common ^{206}Pb) / (total measured ^{206}Pb) based on measured ^{204}Pb or ^{208}Pb.

pected following the volcanic migration proposed by Feraud et al. (1999) and Pankhurst et al. (2000) but in LJP the age is concordant.

The apparent difference in the ages determined in the MEP is interpreted in two ways. First, the $^{40}Ar/^{39}Ar$ ages obtained by Feraud et al. (1999) may be minimum ages because the dated rocks may be hydrothermally altered. In this way, Pankhurst et al. (2000) proposed that the $^{40}Ar/^{39}Ar$ method in feldspar of the Deseado Massif is not reliable because of two reasons, the radiogenic Ar loss by hydrothermal alteration and the initial ^{40}Ar excess.

Another interpretation is that Feraud et al. (1999) dated one of the younger ignimbrites that are predominant in the MEP area whereas in this work we studied the oldest Jurassic unit that has an areal distribution smaller than the other Jurassic acid volcanism manifestations. The precise location of the samples dated by Feraud et al. (1999) is not known so we are unable to make more precise interpretations. Considering all evidence, we now know that the acid volcanic activity in the MEP started between ~167 and 163 Ma (this work) and continued up to ~157.9 ± 0.5 Ma (Feraud et al. 1999), with a main hydrothermal event at 158.9 ± 0.5 Ma (this work).

The MEP and LJP Jurassic volcanic and hydrothermal evolution corresponds to the V3 episode defined by Pankhurst et al. (2000). The MEP period is in agreement with the older limit of this episode while the LJP is near the youngest one.

Different explosive volcanic events were registered in the Chon Aike Formation of the Deseado Massif. The detailed geological studies allow the qualified interpretation of the geochronological ages in the considered areas and their relationship with the gold-silver mineralization.

Acknowledgements

This study is part of the "Deseado Massif epithermal ore deposits" project sponsored by the Agencia Nacional de Promoción Científica y Tecnológica (FONCyT), Argentina. The authors appreciate the constructive comments of Prof. Dr. Dietrich D. Klemm, Munich, and Prof. Dr. Stuart Simmons, Auckland.

References

Alric, V., Haller, M. J., Feraud, G., Bertrand, H. & Zubia, M. (1996): Cronología 40 Ar/39 Ar del volcanismo jurásico de la Patagonia extrandina. – XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, **V**: 243-250.

Arribas, J. R. A., Schalamuk I. A., De Barrio, R., Fernandez, R. & Itaya, T. (1996): Edades radimétricas de mineralizaciones epitermales auríferas del Macizo del Deseado, provincia de Santa Cruz, Argentina. IGCP Project 342: Age and isotopes of South American Ores. – XXXIX Congresso Brasileiro de Geología: 254-257.

Baker, P. E., Rea, W. J., Skarmeta, J., Caminos, R. & Rex, D. C. (1981): Igneous history of the Andean Cordillera and Patagonia Plateau around latitude 46º S. – Philosophical Transactions of the Royal Society London, **A 303**: 105-149.

Cazeneuve, H. (1965): Datación de una toba de la Formación Chon Aike (provincia de Santa Cruz) por el método Potasio - Argón. – Ameghiniana, Revista Asociación Paleontológica Argentina, **4** (5): 156-158.

Creer K., Mitchel, J. & Aboudeer, J. (1972): Paleomagnetism and radiometric ages of the Jurassic Chon Aike Formation from Santa Cruz province, Argentine: Implications for the opening of the South Atlantic Ocean. – Earth and Planetary Science Letters, **15**: 131-138.

Chernicoff, C. J. & Salani, F. M. (2002): Identificación de calderas asociadas a las volcanitas de la Formación Chon Aike en la región del Río Seco, provincia de Santa Cruz. – XV Congreso Geológico Argentino, El Calafate, **II**: 23-28.

De Barrio, R. (1989): Aspectos geológicos y geoquímicos de la Formación Chon Aike (Grupo Bahía Laura) en el noroeste de la provincia de Santa Cruz. – 175 pp.; unpubl. doct. thesis (Facultad de Ciencias Naturales y Museo, La Plata University).

– (1993): El vulcanismo ácido jurásico en el noroeste de Santa Cruz, Argentina. – XII Congreso Geológico Argentino, **III**: 289-298.

Dietrich, A., Nelson, E., Gutierrez, R. & Layer, P. (2005): Structural control of vein formation and mineralization at the epithermal Huevos Verdes Ag-Au vein system, San Jose District, Deseado Massif, Argentina. – Geological Society of America, Annual Meeting Salt Lake City, abstract, 39: 7.

Dube, B., Zubia, M. A., Dunning, G. & Villeneuve, M. (2003): Estudio geocronológico de los campos filonianos de baja sulfuración hospedados en la Formación Chon Aike en el Macizo del Deseado, provincia de Santa Cruz. – In: Zubia, M. & Genini, A. (Eds.): Yacimientos auroargeníferos epitermales del Macizo del Deseado, Provincia de Santa Cruz. – SEGEMAR Serie Contribuciones Técnicas Recursos Minerales, **13/D**: 17-24.

Echavarría, L. (1999): Evolución geológica y su relación con la mineralización epitermal en el área Dorado-Monserrat, Macizo del Deseado, Argentina. – Studia Geologica Salmanticensia (España), **35**: 21-39.

Echavarría, L., Schalamuk, I. A. & Etcheverry, R. (2005): Geologic and tectonic setting of Deseado Massif epithermal deposits, Argentina, based on El Dorado-Monserrat. – Journal of South American Earth Sciences, **19**: 415-432.

Echeveste, H. (2005a): Travertines and jasperoids of the Manantial Espejo, a Jurassic hot spring environment. Macizo del Deseado, Santa Cruz province, Argentina. – Latin American Journal of Sedimentology and Basin Analysis, **12** (1): 23-39.

– (2005b): Metalogénesis del Distrito Argento-Aurífero Manantial Espejo, Macizo del Deseado, provincia de Santa Cruz. – 251 pp.; unpubl. doct. thesis (Facultad de Ciencias Naturales y Museo, La Plata University).

Feraud, G., Alric, B., Fornari, M., Bertrand, H. & Haller, M. (1999): 40Ar/39Ar dating of the Jurassic volcanic province of Patagonia: migrating magmatism related to Gondwana break-up and subduction. – Earth and Planetary Science Letter, **172**: 83-96.

Fernandez, R., Echeveste, H., Echavarría, L. & Schalamuk, I. A. (1996): Control volcánico y tectónico de la mineralización epitermal del Area La Josefina, Macizo del Deseado, Santa Cruz. Argentina. – XII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, **III**: 41-54.

Fernandez, R., Echeveste, H., Tassinari, C. & Schalamuk, I. A. (1999): Rb-Sr age of the La Josefina epithermal mineralization and its relation with host volcanic rocks, Deseado Massif, Santa Cruz Province. Argentina. – 2º Simposio Sudamericano de Geología Isotópica: 462-465.

Geisler, T., Pidgeon, R. T., Van Bronswijk, W. & Kurtz, R. (2002): Transport of uranium, thorium, and lead in metamict zircon under low-temperature hydrothermal conditions. – Chemical Geology, **191**: 141-154.

Gonzalez Guillot, M., De Barrio, R. & Ganem, F. (2004): Mina Martha, un yacimiento epitermal en el Macizo del Deseado, provincia de Santa Cruz. – VII Congreso de Mineralogía y Metalogenia: 199-204.

Guido, D. M. (2002): Geología y metalogénesis del sector oriental del Macizo del Deseado, provincia de Santa Cruz. – 244 pp.; unpubl. doct. thesis (Facultad de Ciencias Naturales y Museo, La Plata University).

Guido, D. & Schalamuk, I. A. (2003): Genesis and exploration potential for low sulfidation epithermal deposits in the Deseado Massif, Argentinean Patagonia. – In: Eliopoulos, D. G. et al. (45 Eds.): Mineral exploration and sustainable development, **I**: 493-496; Rotterdam (Millpress).

Guido, D., Escayola, M. P. & Schalamuk, I. A. (2004):

The basement of the Deseado Massif at Bahía Laura, Patagonia, Argentina: a proposal for its evolution. – Journal of South American Earth Sciences, **16**: 567-577.

Guido, D., Escayola, M., De Barrio, R., Schalamuk, I. A. & Franz, G. (2006): La Formación Bajo Pobre (Jurásico) en el este del Macizo del Deseado, Patagonia: Vinculación con el Grupo Bahía Laura. – Revista de la Asociación Geológica Argentina, **61** (2): 137-300.

Gust, D., Biddle, D., Phelps, H. & Uliana, M. (1985): Associated Middle to Late Jurassic volcanism and extention in southern South America. – Tectonophysics, **116**: 223-253.

Heald, P., Hayba, D. O. & Foley, N. K. (1987): Comparative anatomy of volcanic-hosted epithermal deposits: Acid sulfate and adularia-sericite types. – Economic Geology, **82**: 1-26.

Hechen, J. & Homovc, J. (1985): Modelo de facies volcaniclástico y consideraciones estratigráficas para la Formación Bajo Grande y el Grupo Bahía Laura, Jurásico superior-Cretácico inferior, provincia de Santa Cruz. – xx pp.; unpubl. report (Yacimientos Petrolíferos Fiscales Y. P. F.).

Hedenquist, J., Arribas A. & Gonzalez-Urien, E. (2000): Exploration for epithermal gold deposits. – Reviews in Economic Geology, **13**: 245-278.

Hogdahl, K., Gromet, L. P. & Broman, C. (2001): Low P-T Caledonian resetting of U-rich Paleoproterozoic zircons, central Sweden. – American Mineralogist, **86**: 534-546.

Jovic, S., Guido, D. M., Tiberi, P. & Schalamuk, I. A. (2004): Cerro León, una variación del modelo epitermal de baja sulfuración del Macizo del Deseado. – VII Congreso de Mineralogía y Metalogenia: 225-230.

Landrum, V. D. & Holtby, M. H. (2004): Manantial Espejo Property, Santa Cruz province, Argentina. – 52 pp.; unpubli. techn. report (Silver Standard Resources Inc.).

Ludwig, K. R. (2001): Squid 1.02: A user manual. – Berkeley Geochronological Center Special Publication, **2**: 19 pp.

– (2003): Isoplot/Ex version 3.00 - A geochronological toolkit for Microsoft Excel. – Berkeley Geochronological Center Special Publication, **4**: 70 pp.

Marquez, M. J. (1981): Geología preliminar de proyecto 19NA, La Leona, Santa Cruz. – 30 pp.; unpubl. report (SEGEMAR-Plan Patagonia Comahue).

Mertz, D., Bitschene, P., Renne, P. & Homovc, F. (1996): Age, source, and tectonic setting of Patagonian Bajo Pobre volcanic rocks. – Terra Nostra, **8**: 23 pp.

Moreira, P. (2005): Geología y metalogénesis del Prospecto La Josefina, Macizo del Deseado, provincia de Santa Cruz. – 360 pp.; unpubl. doct. thesis (Facultad de Ciencias Naturales y Museo, La Plata University).

Moreira, P., Gonzalez, P., Fernandez, R., Echeveste, H., Schalamuk, I. A. & Eycheverry, R. (2005): El basamento de bajo grado de las Estancias La Modesta y La Josefina, Macizo del Deseado, Provincia de Santa Cruz. – Revista de la Asociación Geológica Argentina, **60** (1): 49-63.

Pankhurst, R. S. & Rapela, C. W. (1995): Production of Jurassic rhyolite by anatexis of the lower crust of Patagonia. – Earth and Planetary Science Letters, **134**: 23-36.

Pankhurst, R., Sruoga, P. & Rapela, C. (1993): Estudio geocronológico Rb-Sr de los complejos Chon-Aike y El Quemado a los 47º30’ L.S. – XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos, **IV**: 171-178.

Pankhurst, R., Riley, T., Fanning, C. & Kelley, S. (2000): Episodic silicic volcanism in Patagonia and the Antarctic Peninsula: Chronology of magmatism associated with the break-up of Gondwana. – Journal of Petrology, **41** (5): 605-625.

Panza, J. L. & Haller, M. J. (2002): El volcanismo jurásico. – In: Haller, M.J. (Ed.): Geología y Recursos Naturales de Santa Cruz. – Relatorio del XV Congreso Geológico Argentino: 89-102.

Ramos, V. (1988): Late Proterozoic-Early Paleozoic of South America. A collisional history. – Episodes, **11**: 168-175.

Riley, T., Leat, P., Pankhurst, R. & Harris, C. (2000): Origin of large volume rhyolitic volcanism in Antarctic Peninsula and Patagonia by crustal melting. – Journal of Petrology, **42** (6): 1043-1065.

Ross, A. A., Barley, M. E., Brown, S. J., McNaughton, N. J., Ridley, J. R. & Fletcher, I. R. (2004): Young porphyries, old zircons: new constraints on the timing of deformation and gold mineralisation in the eastern goldfields from SHRIMP U-Pb zircon dating at the Kanowna Belle Gold Mine, Western Australia. – Precambrian Research, **128**: 105-142.

Sharpe, R., Riveros, C. & Scavuzzo, V. (2002): Stratigraphy of the Chon Aike Formation ignimbrite sequence in the Cerro Vanguardia Au-Ag epithermal vein district. – XV Congreso Geológico Argentino **II**: 370-375.

Schalamuk, I. A., Zubia, M., Genini, A. & Fernandez, R. (1997): Jurassic epithermal Au-Ag deposits of Patagonia, Argentina. – Ore Geology Reviews, **12** (3): 173-186.

Schalamuk, I. A., De Barrio, R., Zubia, M., Genini, A. & Echeveste, H. (1999): Provincia Auroargentífera del Deseado, Santa Cruz. – In: Zappettini, E. (Ed.): Recursos Minerales de la República Argentina. – Instituto de Geología y Recursos Minerales SEGEMAR, **35**: 1177-1188.

Schalamuk, I. A., De Barrio, R. E. & Guido, D. M. (2000): Jurassic sinter and stromatolite deposits related to Au-Ag mineralization, Deseado Massif, Patagonia, Argentina. – 31st International Geological Congress, Río de Janeiro: Abstracts (CD).

Smith, J. B., Barley, M. E., Groves, D. I., Krapez, B., Bickle, M. J. & Chapmann, H. J. (1998): The Sholl shear zone, west Pilbara: evidence for a terrane boundary from intergrated tectonic analysis, SHRIMP U-Pb age-dating and granitoid geochemistry. – Precambrian Research, **88**: 143-171.

Spalletti, L., Iñiguez Origuez, M. A. & Mazzoni, M. (1982): Edades radimétricas de piroclastitas y vulcanitas del Grupo Bahía Laura, Gran Bajo de San Julián, Santa Cruz. – Asociación Geológica Argentina, **37** (4): 483-485.

Steiger, R. H. & Jager, E. (1977): Subcommission on

geochronology: convention on the use of decay constants in geo- and cosmochronology. – Earth and Planetary Science Letters, **36**: 359-362.
Tessone, M., Del Blanco, M., Macambira M. & Rolando, A. P. (1999): New radiometric ages of the Chon Aike and Bajo Pobre Formations in the central zone of the Deseado Massif, Argentina. – II Simposio Sudamericano de Geología Isotópica: 132-135.
White, N.C. & Hedenquist, J. W. (1990): Epithermal environment and styles of mineralization: Variations and their causes, and guidelines for exploration. – Journal of Geochemical Exploration, **36**: 445-474.
– (1995): Epithermal gold deposits: Styles, characteristics and exploration. – Society of Economic Geologists Newsletter, **23**: 1-13.
Zubia, M. A., Genini, A. D. & Schalamuk, I. A. (1999): Yacimiento Cerro Vanguardia, Santa Cruz. – In: Zappettini, E. (Ed.): Recursos minerales de la República Argentina. – SEGEMAR, Anales, **35**: 1189-1202.

Manuscript received: September 09, 2007.
Modified manuscript received: February 22, 2008.
Accepted by the Munich editor: March 16, 2008.

Addresses of the authors:

Postdoc Dra. Pilar Moreira, Prof. Dr. Horacio Echeveste, Prof. Dr. Raul Fernandez and Prof. Dr. Isidoro A. Schalamuk, Instituto de Recursos Minerales, La Plata University, calle 64 entre 119 y 120, Argentina-1900-La Plata. E-Mail: pilimoreira@yahoo.es, hecheves@inremi.unlp.edu.ar, raul_fernandez@fibertel.com.ar, schala@inremi.unlp.edu.ar
Prof. Dr. Leo A. Hartmann, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Avenida Bento Gonçalves, 9500; Brazil-91501-970-Porto Alegre. E-Mail: leo.hartmann@ufrgs.br
Prof. Dr. João Orestes S. Santos, University of Western Australia, 35 Stirling Highway, Crawley 6009 Australia. E-Mail: orestes1@uol.com.br