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Au-bearing skarns associated with Miocene volcanism of the modern non-volcanic region of shallow subduction in the central Andes, Argentina

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INTRODUCTION

The Miocene is one of the most prolific metallogenic epochs for gold mineralization in the central Andes. The current non-volcanic zone (28°S - 33°S) is within this metallogenic province.

Two skarn deposits associated with back-arc Miocene magmatism in the Precordillera thrustbelt (Argentina) are compared in this paper (Fig. 1): the Gualcamayo (Hualcamayo) district (29° 47' 3" S and 68° 49' 36" W) – a proximal Au-bearing magnesian Fe-skarn (Fe, Mo, Zn, Pb, Au, Ag, Bi, Te), and the Gualilán (Hualilán) district (30° 44' S and 68° 57' W) – a distal Au-bearing calcic Zn-skarn (Zn, Pb, Ag, Au, Te).

Reserves in the Gualilán district are estimated at 0.3 Mt with average grades of 10 g/t Au, 80 g/t Ag and 8% Zn. The Gualcamayo district estimated resources total 76 Mt with an average grade of 1 to 1.5 g/t Au, 0.6 Mt at 21.9% Fe, and 0.09 Mt at 0.19-0.27% Mo. Inferred resources include 17 Mt at 1.3 g/t Au. Yamana Gold Inc. expected Gualcamayo to start producing more than 200,000 ounces of Au per year from open pit and underground mining operations by the end of 2008.

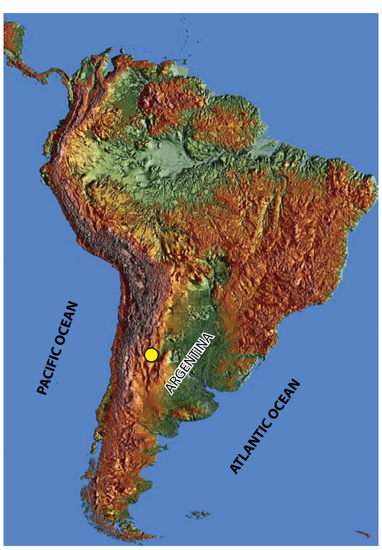

Figure 1. Location of the Gualcamayo and Gualilán districts in the Central Andes of Argentina (yellow dot).

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TECTONIC SETTING

The subduction zone in the non-volcanic zone has shallowed during the last 18 Ma, with the major change in the subduction angle occurring between 11 and 8 Ma. Back-arc magmatism spread to the east in the Precordillera between 18 and 7 Ma and has a unique signature that is consistent with a thickened crust (Kay et al., 1988). K-Ar dates for subvolcanic intrusions of the Precordillera indicate two volcanic events, one in the mid Miocene (17-19 Ma) and the other in the Late Miocene (8 Ma) (Kay et al., 1988; Fig. 2). The interaction of this magmatism and the Ordovician limestones (San Juan Formation) resulted in the development of complex Au-bearing skarn systems (Logan, 2000).

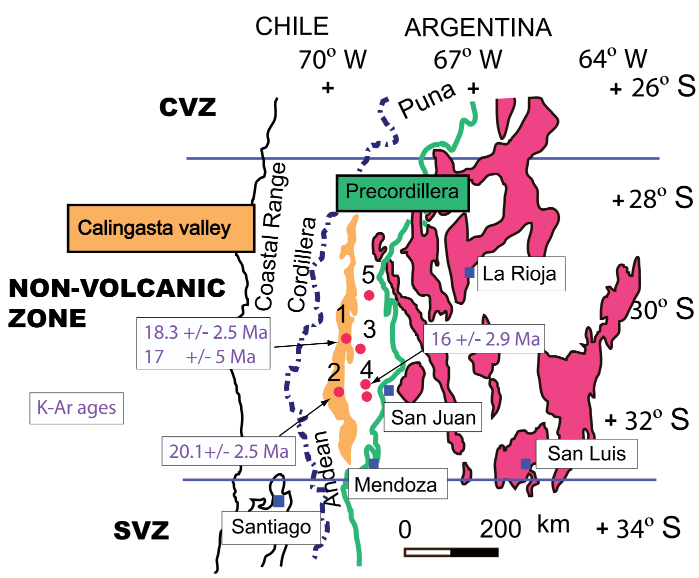

Figure 2. Map of the modern non-volcanic region between 28° and 33° S showing the sites of Tertiary volcanism after Kay et al. (1988) and the central volcanic zone (CVZ), non-volcanic zone and south volcanic zone (SVZ) according to Barazangi and Isacks (1976), Bevis and Isacks (1984), and Cahill and Isacks (1985). The dots are subvolcanic intrusions of Middle Miocene age in the Calingasta Valley (1: Iglesia; 2: Barreal) and the Precordillera thrustbelt (3: Gualilán; 4: Ullún-Zonda; 5: Gualcamayo).

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MODEL OF SKARN FORMATION

This study compares two skarn deposits formed under a compressive tectonic regime associated with the middle Miocene magmatism but formed under different pressures. Geobarometry in sphalerite indicates that the Gualcamayo district formed at 2 kb, whereas the Gualilán district, a shallower system, formed at 0.55 kb (Logan, 1999, 2000). Based on geological, structural, and geochemical studies, Logan (1999, 2000) proposed the model of skarn formation summarized in Figure 3 (a-d), correlating the different stages of skarn formation with the intrusion of subvolcanic rocks of monzodioritic to tonalitic to dacitic composition and the involvement of magmatic and meteoric water. Depths in Figure 3 (a-d) are estimates from geological reconstructions.

The Gualcamayo deposit formed in five mineralizing stages: (1) metamorphic skarn, (2) prograde skarn and magnetite deposits, (3) retrograde alteration of the skarn and Mo mineralization, (4) Cu-Zn-Pb mineralization, and (5) Au-Ag (Te-Bi) mineralization (Fig. 3).

The Gualilán deposit formed in three main stages: (1) prograde skarn, (2) retrograde alteration of the skarn and Zn mineralization, and (3) Au-Pb-(Te) mineralization (Fig. 3).

Table 1 summarizes the main structural, mineralogical and chemical aspects and Figs. 4 and 5 summarize the paragenetic sequences of each system.

GOLD OCCURRENCE

The gold occurrence in these two Miocene skarns is very different. Whereas gold in the shallower and distal skarn occurs as discrete electrum grains of up to 10 µm in size (Fig. 6), in the proximal skarn it occurs as submicroscopic grains associated with calcite and schapbachite-matildite (Fig. 7).

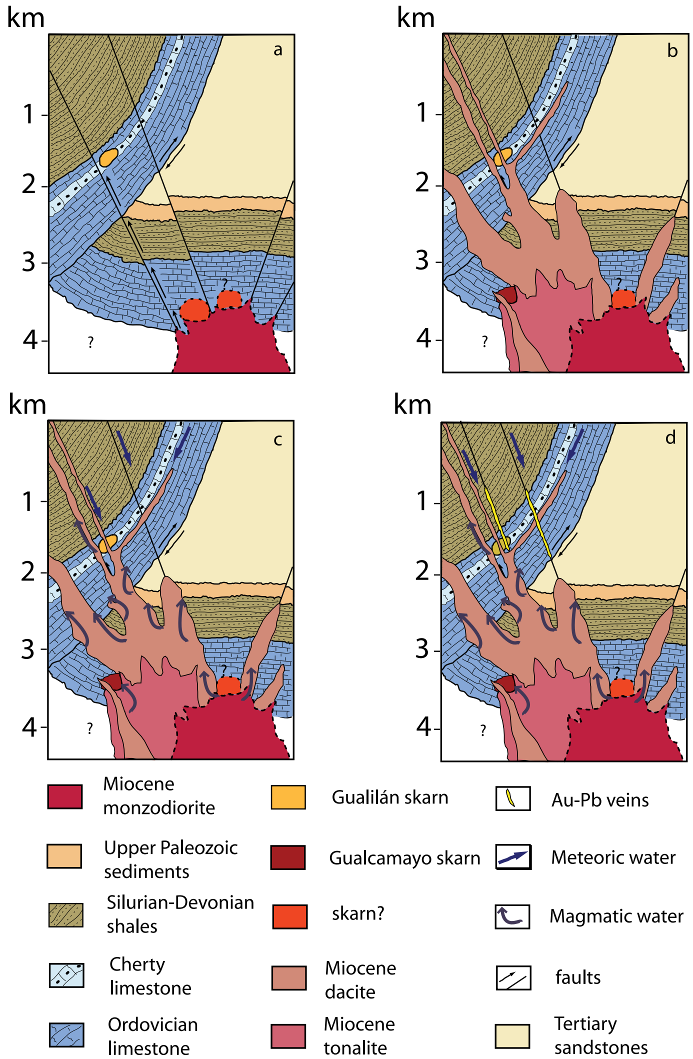

Figure 3 (above). Generalized model for skarn formation in the Gualcamayo and Gualilán districts (Logan, 1999, 2000).

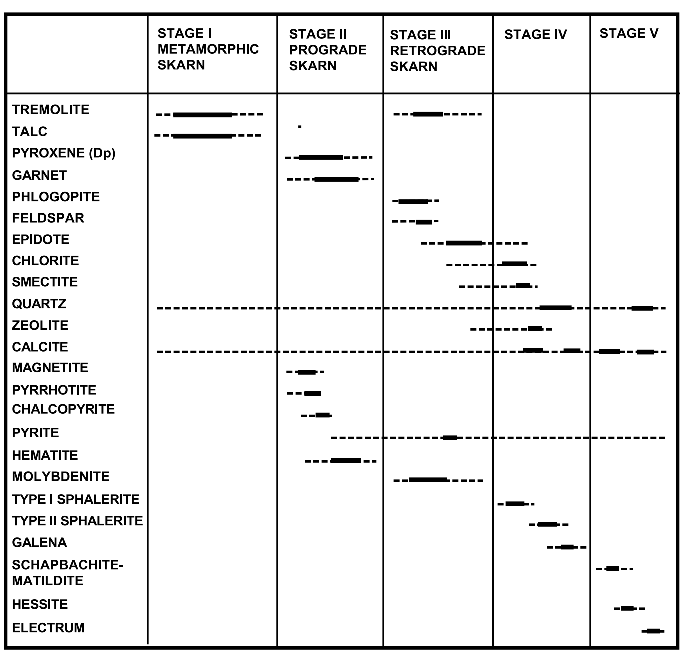

Figure 4. Paragenetic sequence of Gualcamayo district mineralization.

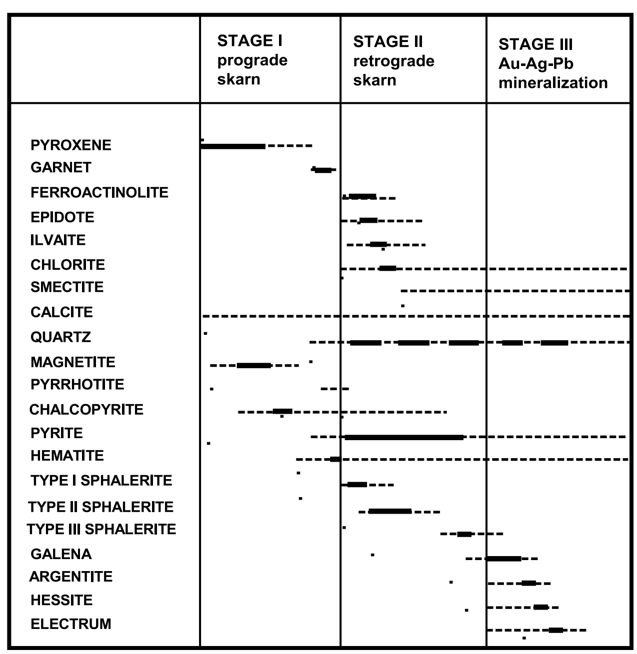

Figure 5. Paragenetic sequence of the Gualilán district mineralization.

Table 1. Principal structural, mineralogical and chemical aspects of the Gualcamayo and Gualilán skarn deposits.

	Gualcamayo	**Gualilán**
Skarn type **Associated metals**	Au-bearing **magnesian Fe-skarn**. Fe, Mo, Zn, Pb, Au, (Ag, Bi, Te)	Au-bearing **calcic Zn-skarn**. Zn, Pb, Ag, Au, (Te)
Pressure of formation	2 kb	0.55 kb
Associated igneous rock	Monzodiorite. Middle Miocene magmatism of the Precordillera	Unknown. Probably diorite-monzodiorite. Middle Miocene magmatism of the Precordillera
Tectonic Setting **Associated igneous rocks** **Distance to the igneous source** **Cogenetic volcanic rocks**	Continental margin, back-arc basin. Transitional post-subduction Tonalite Middle Miocene magmatism Proximal Dacite porphyries and dikes.	Continental margin, back-arc basin. Transitional post-subduction Unknown, Monzodiorite? Middle Miocene magmatism Distal Dacite porphyries and dikes.
Control	Structural. Tonalite-limestone contact.	Lithologic and structural.
Sedimentary protolith	Lower member of the San Juan Formation. Dolomitic limestone Magnesian exoskarn	Upper member of the San Juan Formation. Cherty limestone Calcic exoskarn
Igneous protolith **Exoskarn** **Zoning** **Pyroxene: garnet ratio** **Pyroxene** **Garnet** **Early opaque minerals**	Endoskarn Well defined zones from endoskarn to the marble: garnet skarn, garnet-pyroxene skarn and pyroxene skarn. Variable according to zoning (increasing towards the marble) $Di_{73-97}Hd_{2-20}Jo_{0-2}$ $Ad_{45-100}Sp_{0-1}Gr_{0-54}$ Magnetite, pyrrhotite, chalcopyrite, bornite and pyrite	No endoskarn Disturbed. Drastic compositional variation in pyroxene within 5 µm. High $Di_{0-18}Hd_{52-46}Jo_{6-54}$ $Ad_{90-98}Sp_{0-3}Gr_{0-7}$ Magnetite, pyrrhotite, chalcopyrite and pyrite
Retrograde alteration **Hydrothermal alteration of co-genetic igneous rocks** **Alteration and replacement of the prograde skarn minerals** **Main deposition of sulfides and precious metals**	 Advanced potassic, sericitic, argillic and propylitic Ferroactinolite, epidote, phlogopite, K-feldspar, scholecite, smectite, calcite Molybdenite, pyrite, sphalerite, schapbachite-matildite, hessite, electrum.	 Sericitic, argillic and propylitic Ferroactinolite, epidote, ilvaite, chlorite, Mn-rich calcite, nontronite Pyrite, sphalerite, galena, argentite, hessite, electrum.

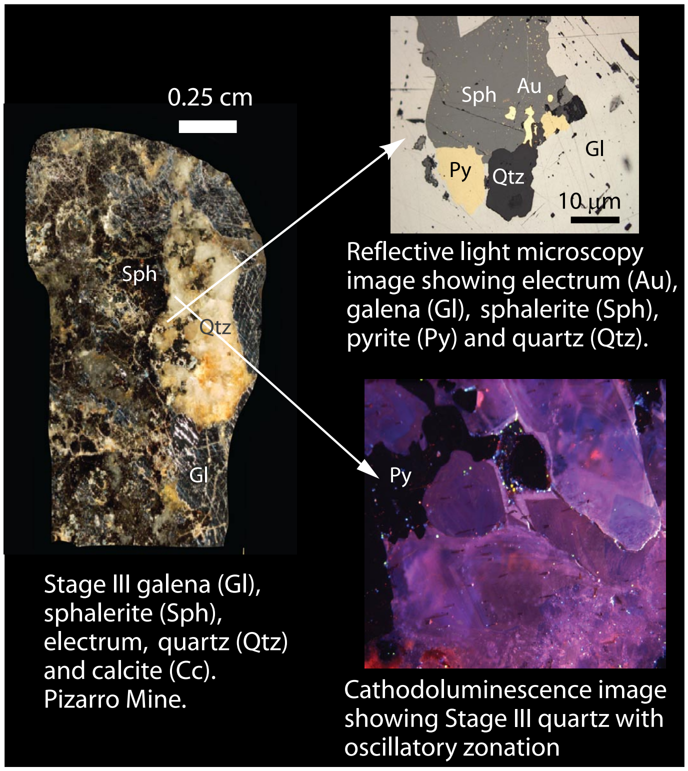

Figure 6. Stage III assemblage in the Gualilán district.

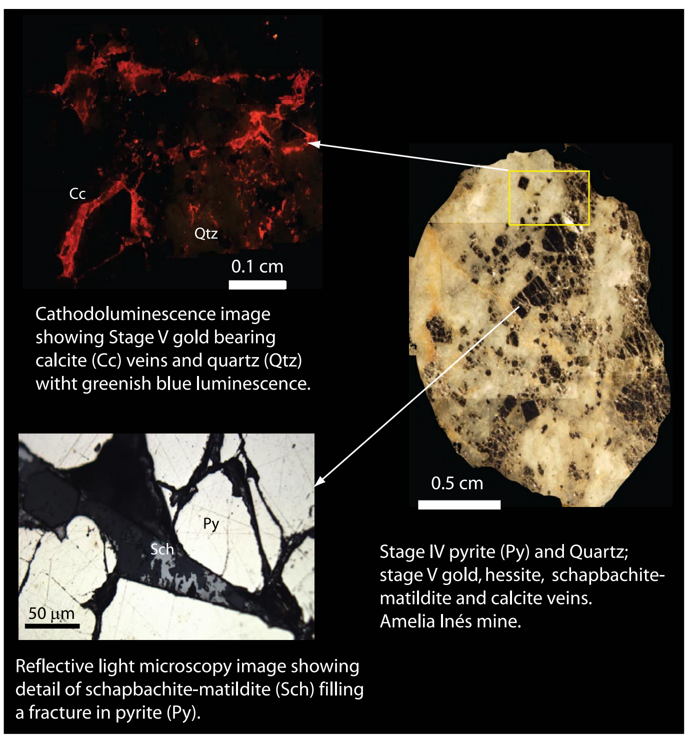

Figure 7. Gold bearing assemblage in the Gualcamayo district.

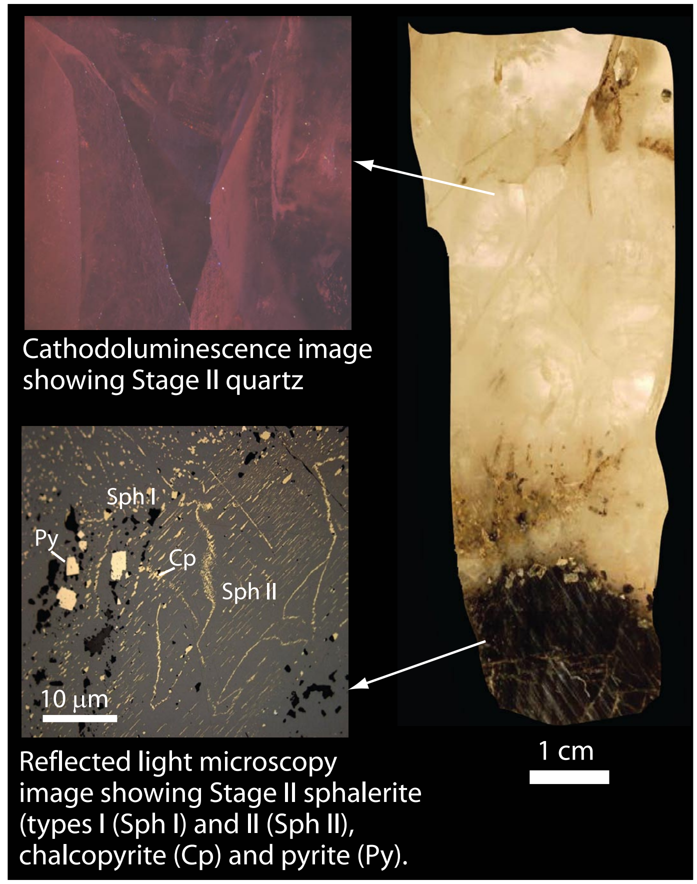

Figure 8. Stage II assemblage in the Gualilán district.

Preliminary cathodoluminescence analyses indicate that quartz luminescence varies with different mineralizing stages and mineral assemblages. In the Gualilán distal skarn, Stage II quartz associated with the Zn mineralization has a dark red luminescence (Fig. 8), whereas Stage III quartz associated with the Pb and Au mineralization has a purple-blue luminescence and displays oscillatory zonation (Fig. 6). The Stage V quartz, which is associated with gold, calcite, and Te-Bi-Ag minerals in Gualcamayo, displays a dark green luminescence (Fig. 7).

CONCLUDING REMARKS

The gold mineralization associated with the Middle Miocene magmatism of the Precordillera is part of a large metallogenic province in the Central Andes that is not well known. The magmatism and associated skarn systems are syntectonic. Gold occurs towards the final stages of mineralization and its occurrence is directly related to the depth of skarn formation. Deposit formation was complex and involved several mineralizing stages that occurred as the composition of the igneous rocks of the associated magmatism evolved from monzodioritic to dacitic. From the scientific and economic point of view, much remains to be understood regarding the processes involved in the gold deposition. Cathodoluminescence analyses performed in this study indicate that quartz from each mineralizing stage has a unique luminescence.

These results indicate that cathodoluminescence analysis has great potential for understanding the complexity of skarn-formation processes and of gold deposition at different depths in these Miocene systems. Thus, it could be a useful exploration tool, particularly in cases in which the gold is submicroscopic.

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