High Cu-Au Grade Filo del Sol Porphyry Deposit, Argentina-Chile

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1. Introduction

The Filo del Sol porphyry deposit on the Argentina-Chile border contains **unusually high grades of Cu and Au** (filocorp.com). The mineralogy is complex; the deposit contains typical porphyry Cu alteration and sulphides plus an overprint of alunite-pyrite and high sulphidation-state (HS) minerals (Perelló et al., 2023).

The objectives of this BSc. Honours project are to (1), characterize the mineralogy and paragenetic sequence including that of the high-grade mineralization (2), determine temperature of each stage from $\delta^{34}S$ values of coexisting sulphide-sulphate pairs (3), and investigate evidence for mineral zonation that may indicate hydrothermal (intrusive) centres.

2. Geology and Alteration

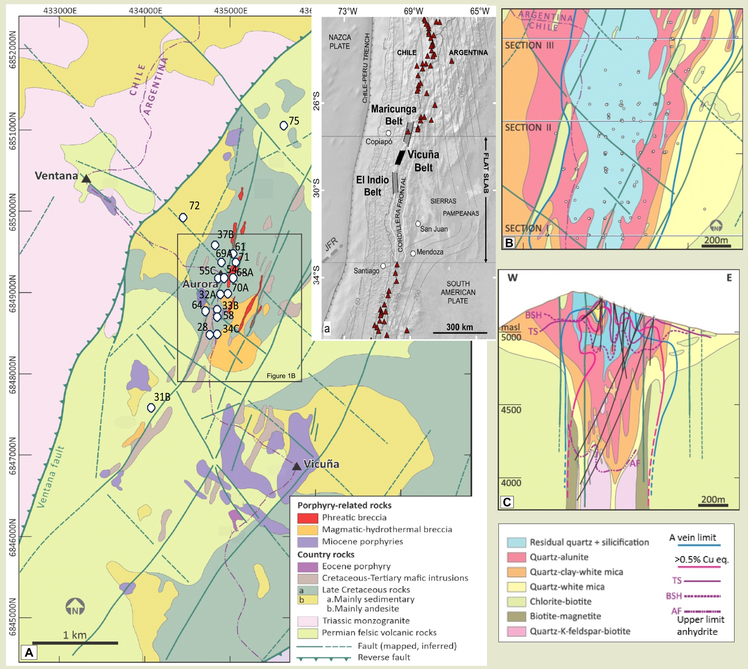


Fig. 1: (A): Geology map of Filo del Sol, with locations of sampled drillholes; inset, regional setting. (B): Aurora zone alteration map and (C) :alteration cross section, latter showing the quartz-alunite overprint. From Perelló et al. (2023).

- Located within the Vicuña metallogenic belt of porphyry Cu-Mo, Cu-Au, Au, and high-sulphidation epithermal Cu-Au-Ag deposits and prospects, along Argentina-Chile border at elevations up to 5500 m (Fig. 1A; Perelló et al., 2023)
- Hosted by Permian felsic volcanic rocks and Late Cretaceous volcano-sedimentary rocks, intruded by middle Miocene diorite porphyry dikes, cut by a series of N to NE trending reverse faults
- Typical porphyry-style alteration at depth of biotite + K-feldspar but overprinted at surface (Fig. 1B) and to >500 m depth by quartz-alunite (Fig. 1C), latter associated with HS Cu-Au mineralization

3. Samples

- 32 samples from 18 drill holes along 6 km N-S trend (Fig. 1A), from 150 to 1600 m depth, mainly from Aurora zone, ~2 km N-S at 400 to 1600 m depth
- 22 polished thin sections examined (Fig 7), mainly from Aurora zone, plus scanning electron microscopy (SEM) (Fig. 4)
- Coexisting sulphide (chalcopyrite, pyrite or enargite) – sulphate (anhydrite or alunite) pairs carefully separated and ~1 mg analyzed for $\delta^{34}S$ isotopes

4. Mineralogy and Paragenesis

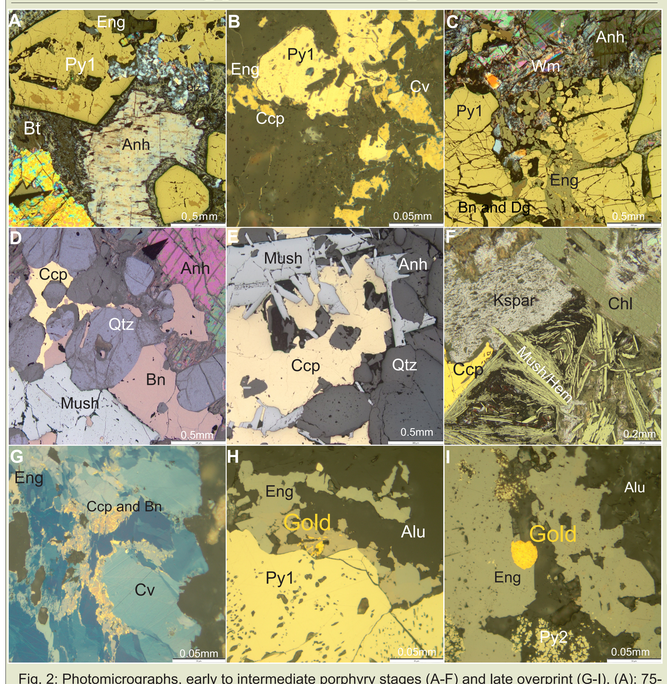


Fig. 2: Photomicrographs, early to intermediate porphyry stages (A-F) and late overprint (G-I). (A): 75-1-959.9, euhedral Py1 with Anh, Bt, Qtz and Wm. (B): 37B-558.1, subhedral Py1 rimmed by later Ccp, overprinted by Eng, Cv and Alu. (C): 75-1-946.5, brecciated Py1 infilled by later Ccp/Bn, cemented by late Eng. (D): 54-1178, Ccp-Bn intergrown with Anh, Qtz and Mush. (E): 55C-1058.7, Ccp intergrown with Mush, Qtz and Anh. (F): 55C-1177, Ccp intergrown with, Anh, Kspar, Chl, Mush and Wm. (G): 58-736.8, Ccp-Bn overprinted by Eng, Cv and Alu. (H): 64-788.3, Py1 overprinted by Eng and Alu. Free gold common with coarse Eng. (I): 64-788.3, Eng with free gold, intergrown with blebby Py2. Abbreviations listed in Fig. 2.

Mineral (Abbreviation)	Porphyry Stage Early and Intermediate	High-Sulphidation Overprint
K-Feldspar (Kspar)	→	
Biotite (Bt)	→	
Mushketovite (Mush)	→	
Quartz (Qtz)	→	
Anhydrite (Anh)	→	
Illite (Wm)	→	→
Chlorite (Chl)	→	→
Hematite (Hem)	→	→
K-Alunite (Alu)		→
Pyrite (Py1/Py2)	→	→
Chalcopyrite (Ccp)	→	
Bornite (Bn)	→	
Sphalerite (Sph)	Incl. minor Fe	→
Galena (Gl)		→
Molybdenite (Mol)		→
Tenn-Tetra (Tnt-Trt)		→
Enargite (Eng)		→
Chalcocite (Cct)		→
Digenite (Dg)		→
Covellite (Cv)		→
Free Gold (Au)		→

Fig. 3: Paragenetic sequence from polished thin section petrography, SEM and δ34S results

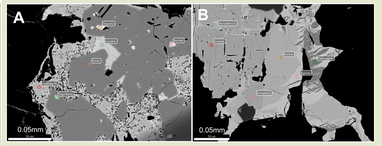


Fig. 4: EDS images of HS overprint (A): 37B-558.1, subhedral Py1, later Ccp, Cv, and Dg with Alu. (B): 75-1-946.5, Bn-Ccp intergrown with Dg exsolved from Ccp. Overprinted by Tnt (Zn-Rich) and later Eng and Alu

- Three main assemblages were observed at Filo del Sol
- 1: Early-stage porphyry: Py1, Anh, Bt, Kspar, Mag/Mush, Qtz (Fig. 2A, B, C)
- 2: Intermediate- stage porphyry: Ccp/Bn, Anh, Mush, Qtz, Bt, Kspar (Fig. 2D, E, F) with uncommon Tnt-Trt, Gl, Mol
- 3: High-sulphidation (HS) overprint: Eng, Alu, Py2, Cv, Cct, Dg, and gold (Fig. 2G-I; Fig 6)
- Two generations of Py observed in the Aurora zone: Early Py1 - Brecciated, coarse, subhedral, cemented by later overprint; later Py2 - Fine, irregular, blebby, rims on Eng or Py1

5. Zonation from $\delta^{34}S$ Results

- $\Delta^{34}S$ of Anh-Ccp pairs from Aurora samples returned temperatures of 520 ± 60ºC, most at ~1000 m depth, whereas ~2 km north of Aurora at similar depths, Anh-Py pairs indicate temperatures of 335-365ºC (Fig. 5)
- Three late mineral pairs (1 Alu-Eng, 2 Alu-Py2; Fig. 6B) indicate temperatures of 235-260ºC, associated with the high-grade overprint in the Aurora zone .
- Py1 $\delta^{34}S$, -1.9 to -3.4‰ and lighter Py2 $\delta^{34}S$, -5.3 to -6.9‰, indicating evolution to more oxidized conditions

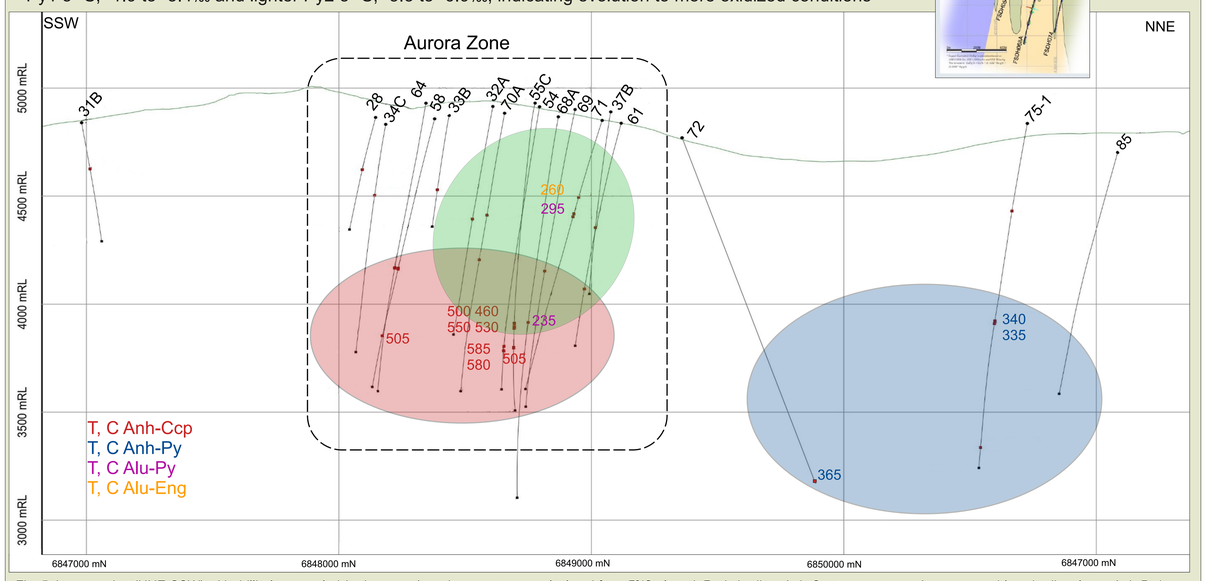
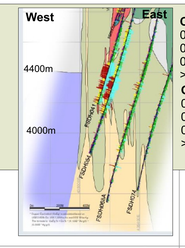


Fig. 5: Long section (NNE-SSW) with drillholes sampled (red squares), and temperatures calculated from $\delta^{34}S$ plotted. Red shading, Anh-Ccp temperatures Aurora zone; blue shading, lower Anh-Py1 temperatures, north of Aurora. Green shading, quartz-alunite and enargite (HS) overprint of the Aurora zone. Inset: High-grade drillhole results, section 9200 N, Aurora zone (filocorp.com).



6. Discussion

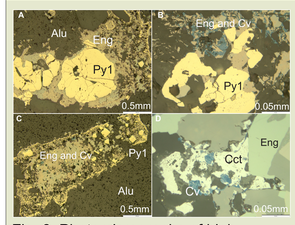


Fig. 6: Photomicrographs of high-sulphidation overprint. (A): 64-788.3, Eng rimming and replacing Py1 in Qtz-Alu matrix. (B): 64-788.3, Eng with Cv on margins, overprinting and cementing Py1, with Alu matrix. (C): 64-788.3, Py1 largely replaced by Eng during Alu-Eng overprint. (D): 64-790.5, Cct and Cv on margins of Eng.

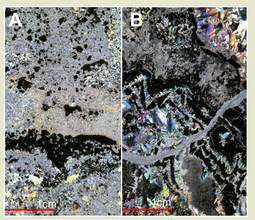


Fig. 7: Transmitted light (cross polar) scans of thin sections, Alu associated with Py (black). (A): 32A-555, brecciated Py1 cemented by later Alu (ΔS=2.04, not in equilibrium). (B): 68A-981.3, Alu intergrown with Py2 in laminations (ΔS=24.76, 235ºC).

- Anh-Ccp pairs consistent with early high-temperature porphyry stage, 520 ± 60ºC, (Fig. 8); Ccp-Bn later than Py1 at Aurora, and Anh does not form pairs with Py1; Py1 isotopically lighter than Ccp,indicating non-equilibrium (Fig. 9). Sph, Tnt, Gl later than Ccp-Bn (Fig. 4)
- North of Aurora, Anh-Py appears in equilibrium (Fig. 2A, C); indicates lower temperature of 335-365ºC at similar depth (Fig. 5)
- Overprint of Alu-Eng and Alu-Py2 (Fig. 6) at Aurora indicate temperatures of 235-295ºC, above the Anh-Ccp zone (Fig. 5).
- early Py1 brecciated and cemented by Alu (Fig. 6A), and overgrown by Eng and Cv (Fig. 6); Gold associated with Eng (Fig. 2H, I)
- Hydrothermal conditions shifted from reduced to oxidized

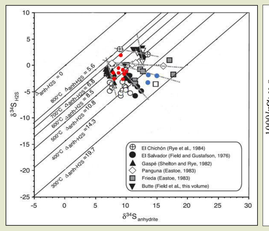


Fig 8: Filo del Sol S isotopic analyses compared to other porphyry deposits. Anh-Ccp (red) corresponds with previous analyses from other deposits. Anh-Py (blue) returned wider range of lower temperature results. (Rye, 2005)

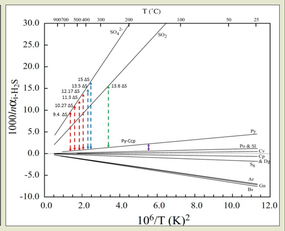


Fig.9: ΔS values of representative Anh-Ccp (red), Anh-Py (blue) and Alu-Py (green) values, highlighting correlation between ΔS fractionation and temperature. Py-Ccp dashed line (purple) notes that Py must be heavier than other sulphides if in equilibrium (Seal, 2006)

7. Conclusions

- The early Filo del Sol porphyry stage is characterized by pyrite or chalcopyrite and bornite, with anhydrite, biotite and K-feldspar. Lower temperature overprint by tennantite-tetrahedrite, enargite, chalcocite, covellite, and free gold with alunite
- Sulphur isotope data of equilibrium mineral pairs (with petrographic results confirming intergrowths) indicate early stage at ~520 ± 60ºC (typical of other porphyry Cu deposits; Fig. 8) followed by ~260ºC overprint with higher Cu-Au grades
- Up to ~2km NNE of the Aurora zone at similar depth, Anh-Py indicates lower temperature, i.e., this area is likely the margin of the hydrothermal system, consistent with suggestions by Perelló et al. (2023).

8. Acknowledgements

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