

## The Trapiche Ni-Co prospect, Yauli Dome, Central Peru: formed by Miocene magmatic-hydrothermal activity

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### Abstract

The Trapiche Ni-Co prospect, province of Yauli, is located in the SE tip of the Yauli Dome, 2 km SE of the Andaychagua Ag-Zn-Pb mine. At Trapiche, discontinuous Ni-Co-Zn-Pb-Cu manto bodies are hosted by weakly metamorphic carbonate and basaltic rocks of the Devonian Excelsior Group. Despite its Ni-Co rich mineral association, Trapiche shares main characteristics with Miocene Cordilleran polymetallic deposits in the area.

### Resumen

El prospecto Trapiche está ubicado en el extremo SE del Domo de Yauli, a 2 km al SE de la mina de Ag-Zn-Pb de Andaychagua. En Trapiche mantos discontinuos con mineralización principal de Co-Ni-Zn-Pb-Cu están hospedados en calizas y basaltos del Grupo Excelsior que muestran un leve metamorfismo. A pesar de su mineralogía rica en Ni y Co, Trapiche comparte las características principales de yacimientos polimetálicos cordilleranos miocenos en el área.

### Introduction and geological background

The Trapiche Ni-Co prospect (11.755532°S, 76.000321°W, 4400 masl), is located 2 km SE of the Andaychagua Mine, Yauli Province, in the western Andean Cordillera of Peru, about 110 km east of Lima. The prospect is located in the SE tip of the Yauli Dome, a NNW-SSE elongated anticlinorium core consisting of Paleozoic rocks that outcrop between Mesozoic and younger rocks. The Yauli Dome is crosscut by Eocene and mainly late Miocene intrusive rocks. Porphyry Cu-Mo and porphyry-related epithermal polymetallic "Cordilleran" (Bendezú and Fontboté, 2009, Fontboté 2020) mineralization including, from south to north, the deposits of Andaychagua, San Cristobal, Toromocho, and Morococha (Beuchat, 2003, Beuchat et al., 2004, Catchpole et al., 2015 a,b) are genetically related to the late Miocene

magmatic activity. Main intrusions are aligned in NNW-SSE direction and main faults strike NE-SW and NNW-SSE.

The Trapiche area is affected by Pre-Andean tight overturned folds with steep axes dipping to the SW. The host sequence is inverted. The ore is mainly hosted by hydrothermally altered encrinitic limestone (Rosas et al., 2010) located on top (i.e., stratigraphically underlying) basalts that in places contain also minor Ni-Co mineralization (Fig. 1). Both, encrinitic limestones and basalts are intercalated Excelsior organic-rich shales attributed to the Devonian (McLaughlin, 1924, Harrison, 1943, Saintilan et al. 2021) and that may be correlated to lithologically similar Early to Middle Devonian units in southern Peru including the Cabanillas Group (Newell 1949, Boucot et al, 1980). Volcanic rocks at Trapiche are MORB within plate tholeiite alkaline basalts. Excelsior pillow lavas occurring 1 km to the east are within plate sub-alkaline basalts. The sequence is affected by weak metamorphism related to the Carboniferous Gondwanian (formerly, eo-Hercynian) Orogeny (Chew et al. 2016).

The presence of nickel and cobalt at Trapiche and other occurrences had been reported by Kobe (1982). In 2007, Volcan Compañía Minera performed an exploration program including 700 m underground workings and 22 short diamond drill holes defining an in average 1.10 m thick and 1050 long discontinuous "manto", with 0.60% Ni and 0.11% Co (Oldham et al., 2008). Zinc contents are in general below 2000 ppm, those of Cu and Pb largely below 1000 ppm, those of Bi, As, Sb lie mostly below 100 ppm, and those of Ag below 10 ppm. Gold contents are low, below 10 ppb whereas those of Pt higher, around 100 ppb in Ni-rich intersections; Pt/Pd ratios around 30.

Previous works on Trapiche and similar nearby occurrences suggested, mainly based on the

stratiform character of the ore showings and their correlation with basaltic rocks, a syngenetic volcanic-exhalative origin (Kobe 1990; Oldham et al. 2008; Acuña et al., 2008). The present study focused on the Trapiche main manto challenges this interpretation.

### Mineralization and alteration styles

Figure 2 shows a paragenetic sequence of the Trapiche manto. Nickel- and cobalt bearing recognized sulfides are millerite (Figs. 3, 4, 5, 6) siegenite-violarite (Figs. 4, 5, 6, 7), gersdorffite, cobaltite, and ullmannite. They occur with pyrite, Fe-poor sphalerite (~4-1% mol FeS), galena, chalcocopyrite, and tetrahedrite. Sulfides appear as euhedral to subhedral fine-grained crystals within small aggregates up to 4 mm in length, mainly filling spaces between the fragments of crinoids (Fig. 3).

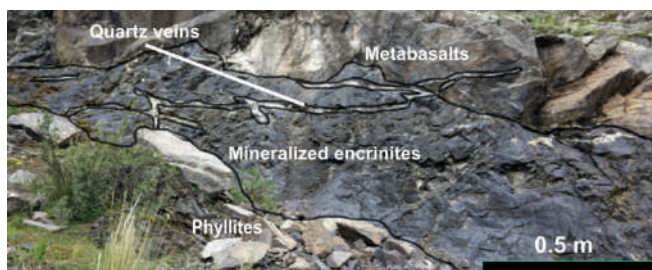


Fig. 1. Outcrop of the Trapiche manto. It mainly replaces encrinitic limestone and subordinately metabasalt layers intercalated in phyllites of the Excelsior Group with pre-ore quartz veins produced by metamorphic segregation.



Fig. 2 Paragenetic sequence at the Trapiche manto.

Manganese-rich carbonates are the main alteration minerals in Trapiche. A first generation of Mn>Fe>>Ca-Mg carbonates replaces pervasively the limestone and partly the basalt. Less abundant Mn-Ca-Mg-Fe carbonates (with distinctly lower Mn and Fe contents) occur in late veins and crosscut metamorphic segregation quartz veins (Fig. 8.) Quartz and minor sericite are intergrown with both

generations of carbonates. Black alteration crusts of Mn-Fe oxides resulting from the oxidation of the Mn-bearing carbonates are observed in the manto outcrops, both in basaltic and carbonate host rocks. (Fig. 1.)

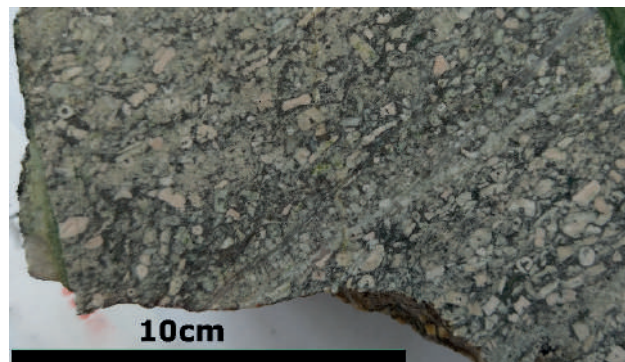


Fig. 3. Hand sample of mineralized encrinite. Dark parts between the fragments host sulfide mineralization, mainly millerite. Bioclasts are altered to Mn-Fe-Ca-Mg carbonates.

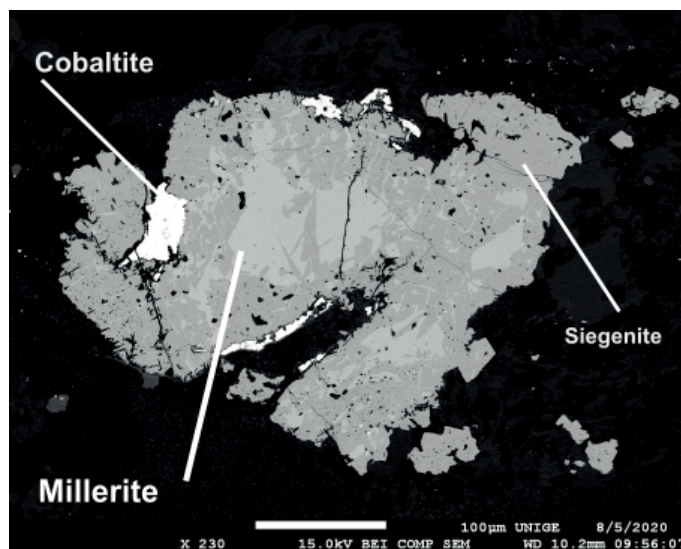


Fig 4. Sulfide grain, with millerite, siegenite, and cobaltite. Millerite is apparently replaced by siegenite in Mn-Fe-Ca-Mg carbonate (dark parts). Backscattered electron SEM image, width 10.2 mm.

### Sulfur isotopes

Seven samples of sulfides from the Trapiche manto were selected for sulfur isotope analysis. All the measured  $\delta^{34}\text{S}$  values are close to zero (Table 1), pointing to a deep/magmatic sulfur source.

### Discussion and conclusion

Most primary nickel and cobalt deposits occur in mafic and ultramafic rocks as the result of magmatic fractionation. However, other hypogene types of Ni-Co deposits including "five element veins" are

known. Also, relatively high amounts of Ni and/or Co are occasionally found in mineral assemblages of Cordilleran deposits in several parts of the Andean Cordillera, as for example in Mina Ragra, Perú (Haggan and Parnel, 2000) and in Capillitas and Famatina, Argentina (Paar et al., 2016)

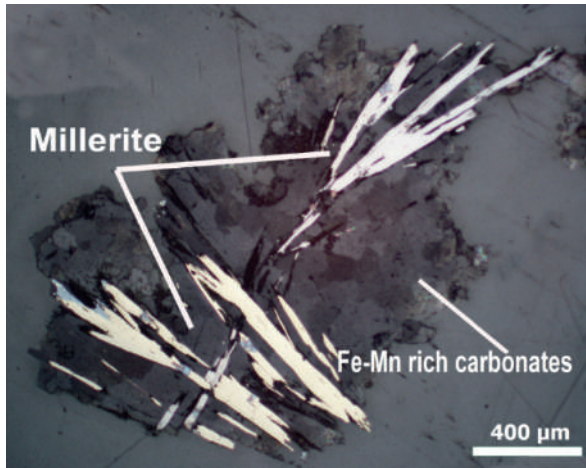


Fig 5. Small euhedral needle like crystals of millerite, in Fe-Mn-Ca-Mg carbonate. Reflected light, NX.

Table 1. Values of  $\delta^{34}\text{S}$  for sulfide samples from Trapiche. Analysis carried out at the University of Lausanne, Switzerland.

Sample	Mineral	Total S (mg)	$\delta^{34}\text{S}$ ‰ VCDT
TAM-15	Millerite <sub>1</sub>	28.6	-1.6
TAM-15	Millerite <sub>1</sub>	30.3	-0.8
TAM-15	Grey sulfide <sub>2</sub>	0.04	-2.6
TAM-15	Grey sulfide <sub>2</sub>	21.7	-1.4
TAM-15	Millerite <sub>3</sub>	26.3	-1.3
TAM-1	Ni concentrate <sub>4</sub>	27.2	2.1
TAM-1	Ni concentrate <sub>4</sub>	32.1	1.9

1. Millerite, traces of violarite-siegenite. Sulfides concentration included treatment with 15% HCl for 24 h. 2. Likely siegenite -violarite. Concentration without HCl treatment. 3. Millerite with traces of violarite-siegenite. Concentration included treatment with 15% HCl for 24 h. 4. The concentrate, according to microscopic observation and portable XRF analysis, contained approximately 31% millerite, 5% siegenite, 21% sphalerite, 26% pyrite, 7% galena, 5% chalcocopyrite, 2% arsenopyrite, and 1% fahlore. TS: total sulfur.

Several observations, including that the hydrothermal alteration and ore mineral assemblages crosscut Carboniferous metamorphic quartz veins (Fig. 8), are not compatible with volcanic-exhalative interpretations as previously suggested (Kobe 1990; Oldham et al. 2008; Acuña et al., 2008). Rather, the Trapiche intermediate sulfidation mineral assemblages can be compared with “Stage C” assemblages in Zn-Pb-Ag veins in the Domo de Yauli characterized by the presence of complex Mn-Fe-dominated carbonates, fahlore and Fe-poor sphalerite (stage nomenclature according to Rottier et al., 2018 and Fontboté, 2020).



Fig 6. Crystals of siegenite-violarite over millerite needles in a veinlet of Mn-Fe-Ca-Mg carbonate. The carbonate has been attacked with  $\text{H}_3\text{PO}_4$  to reveal the crystal shapes. Image width: 1 mm.



Fig. 7. Twinned (spinel law twin) crystal of siegenite-violarite in a veinlet of Mn-Fe-Ca-Mg carbonate. The carbonate has been attacked with  $\text{H}_3\text{PO}_4$  in order to reveal the crystalline shape. Image width: 1.5 mm.

The  $\delta^{34}\text{S}$  values close to zero of Ni-Co sulfides in Trapiche are consistent with a predominant magmatic origin of the sulfur. The fact that the values are slightly below zero and also lighter than those of sulfides in Cordilleran polymetallic ore deposits in other parts of the Yauli Dome (Moritz et al., 2001; Beuchat, 2003; Catchpole 2011) suggests that a small contribution of a bacteriogenic source is possible, probably small amounts of sulfur leached from framboidal pyrite in the Excelsior shales.

In conclusion, available results suggest that the Trapiche mineralization is a Ni-Co rich variety of Stage C Cordilleran polymetallic mineralization. Cooling and neutralization are the main processes

favoring precipitation of Ni and Co minerals in the epithermal environment (e.g. Jansson and Liu (2020), i.e., the same parameters that favor precipitation of the other metals of the polymetallic ores in the district. The fact that Zn-Pb-Ag veins outcropping at Andaychagua contain also high amounts of Ni (i.e., up to 600 ppm Ni, pXRF measurements NE of the Andaychagua vein), supports this view. High Ni-Co contents are known of other Miocene polymetallic deposits of magmatic-hydrothermal affiliation, as for example in Capillitas and Famatina (Argentina).

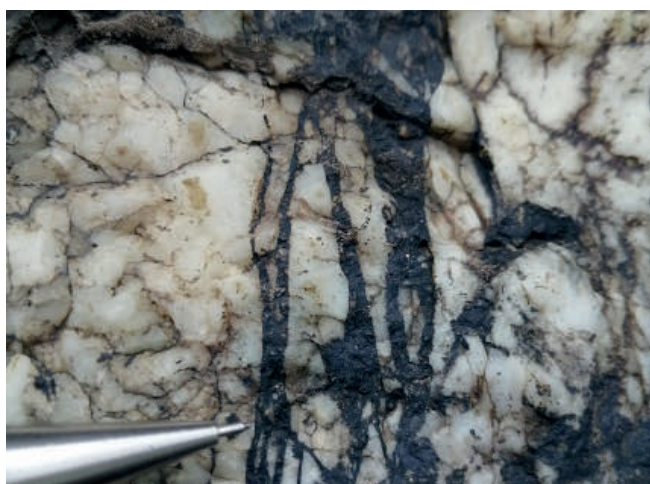


Fig 8. Veinlets of Mn-Ca-Mg-Fe carbonates and Ni-Co minerals crosscutting a metamorphic segregation vein of quartz.

The reason why the mineralization at Trapiche particularly Ni-Co rich is not known. As reviewed by Jansson and Liu (2020), saline oxidizing hydrothermal fluids have the potential of leaching Ni and Co of a variety of rocks. Leaching by Miocene hydrothermal fluids of Excelsior Devonian shales could be considered as Devonian reduced sediments with high Ni-Co contents have been described in Yukon and elsewhere (e.g., Peter et al., 2018, Gadd et al., 2020). However, the predominant magmatic sulfur isotope signature with  $\delta^{34}\text{S}$  values close to zero that allow only a minor, if any, biogenic reduced sulfur contribution does not support extensive leaching of Excelsior shales as it could be expected if Excelsior shales were important metal contributors (for instance, the Yukon Ni-Co hyper-enriched shales are characterized by strongly negative  $\delta^{34}\text{S}$  values, Gadd et al., 2019). Analyses of the Excelsior phyllites with Ni and Co values below 50 and 20 ppm, respectively, do not support this hypothesis either. Leaching of Excelsior mafic rocks or rather of other older mafic or ultramafic rocks by the Miocene

hydrothermal fluids is a more plausible explanation. Leaching by hydrothermal fluids or incorporation in the magmatic system of basement ultramafic rocks is supported by the existence of Neoproterozoic ultramafic rocks with Cr- and Ni-Co occurrences in central Peru (Tassinari et al. 2011) and by the relatively high Pt contents of the Trapiche ore.

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