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Stratiform copper deposits in the San Jeronimo group, Cusco area, Peru: petromineralogical and genetic case study of the Tambomachay deposit

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(**) Este trabajo de investigación incluye la participación, como autora, de la Dra. Silvia Rosas Lizárraga, profesora del Departamento de Ingeniería de la PUCP, quien a su vez fue la *docente orientadora* del proyecto desarrollado por el grupo en el marco del PAIN 2016. Este grupo originalmente incluía a la estudiante Grecia Mescua Soriano, quien se retiró a inicios del proyecto. Por otro lado, el estudiante Misael Robles Ancajima, trabajó con el grupo desde el inicio del mismo.
(***) Año de finalización de la investigación.

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Stratiform copper deposits in the San Jeronimo Group, Cusco area, Peru: Petromineralogical and genetic case study of the Tambomachay deposit

Peru is currently the second largest copper producer in the world with a production of 2.3Mt mainly contributed by porphyry systems. Exploration for and research on the porphyry ores are considerable, but there is a lack of study of copper-bearing clastic sedimentary rocks as possible sources for sedimentary rock-hosted stratiform copper deposits (SRHSCD).

Near Cusco, in the southeast of Peru, copper oxide ores were extracted in nine small-scale historic mines. These deposits host stratiform copper orebodies within the Eocene-Oligocene San Jeronimo Group. One of these deposits, developed by the Tambomachay mine, was chosen for detailed study. The objective was to determine whether this could be classified as a SRHSCD. The methodology included bibliographic research, field work, and petromineralogical and geochemical analyses.

A feldspathic greywacke of the San Jeronimo Group, varying from 10 to 90 cm in thickness, hosts ore that is either disseminated predominantly along laminations or within veinlets. The primary minerals are chalcopyrite and bornite, there is also abundant chalcocite, and covellite-digenite replaces chalcocite. The presence of oxide minerals (malachite, brochantite, goethite) intergrown with the ores, particularly with covellite, chalcocite, and digenite, suggests a supergene enrichment event. Nevertheless, it is also possible that these oxides are of primary origin. The presence of calcite and chlorite has been observed in veinlets, with the chlorite suggesting some involvement of hydrothermal fluids. Six samples of the ore were analyzed for 50 elements analysis (ICP-MS) with digestion by four acids. The results show enrichment in metals that include Ag, Pb, and Zn, as well as in large ion lithophile elements that suggests the sedimentary rocks of the San Jeronimo Group were derived from a source with calc-alkaline composition.

We preliminarily suggest that Tambomachay is a SRHSCD, based mainly on petromineralogical and geochemical analyses. The basin architecture of the studied area is similar to the general basin model that characterizes most SRHSCDs and this work suggests that the source of the sulfur could be the evaporites of the Maras Formation. The texture, as well as the presence of chlorite and ore in veinlets, rules against a previously hypothesized syngenetic ore model. To confirm the existence of widespread SRHSCD occurrences, detailed geological and structural mapping, and fluid inclusion and isotope geochemistry will be carried out on the nine known occurrences in the Cusco region.

STRATIFORM COPPER DEPOSITS IN THE SAN JERONIMO GROUP, CUSCO AREA, PERU: PETROMINERALOGICAL AND GENETIC CASE STUDY OF THE TAMBOMACHAY DEPOSIT

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1. INTRODUCTION AND LOCATION

Peru is currently the second largest copper producer in the world with a production of 2.3Mt (USGS, 2016) mainly contributed by porphyry systems. The study and exploration of the latter is considerable, but there is a lack of studies of clastic sedimentary formations as possible hosts for Sedimentary Rock-Hosted Stratiform Copper Deposits (SRHSCD).

In the past, in the Cusco Region (southeast of Peru), copper oxides ores were extracted in small scaled mines (4 in the province of Cusco and 5 in Canchis). These mines present stratiform copper ore bodies hosted by the San Jeronimo Group (Eocene-Oligocene). Based on accessibility the Tambomachay Mine (about 6 km to the north of Cusco city, Fig. 1) was chosen as the main site for this research. This project was set with the objective to test the following hypothesis: ***The ore deposit of Tambomachay Mine could be a SRHSCD in the way of Hitzman et al. (2005).*** The methodology used included: bibliographic research, field work, petromineralogical and geochemical analysis.

2. REGIONAL GEOLOGY

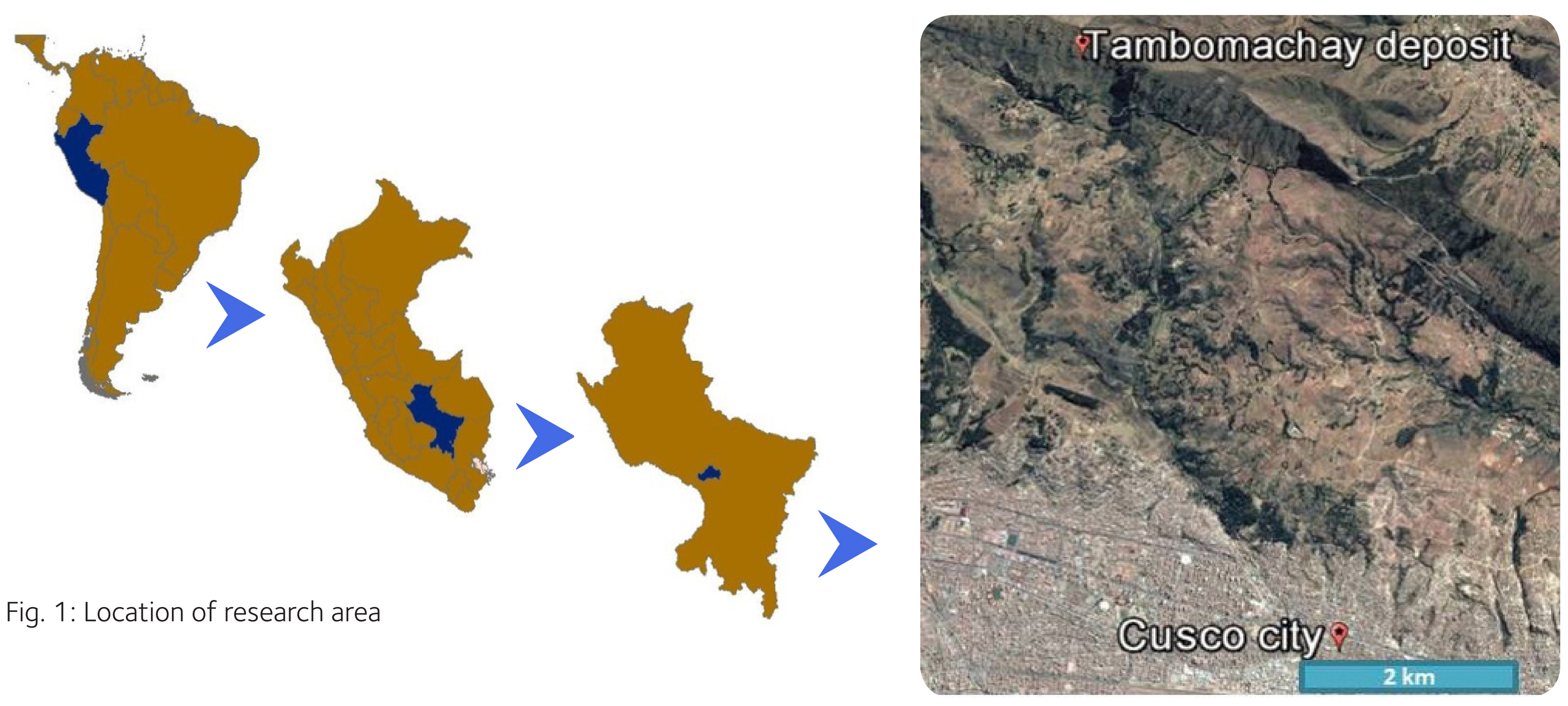

Fig. 1: Location of research area

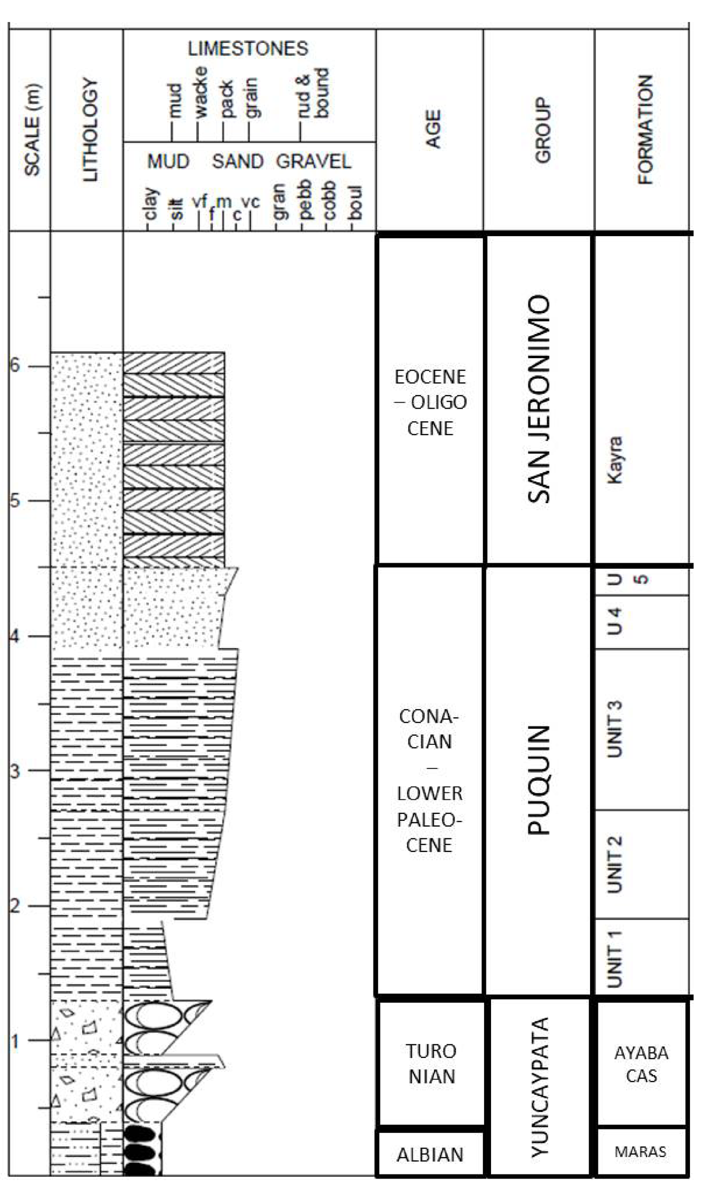

Fig. 2: Composite stratigraphic column for the Chincheros locality (10 km west of Tambomachay deposit)

A regional stratigraphic column can be observed in figure 2.
Maras Fm., consists of intercalation of claystones and red siltstones with evaporites (gypsum) and mudstones.

Ayabacas Fm., presents mudstone breccia with sandy matrix.
Puquín Gr., is in general represented by red and green claystone at the base and well sorted sandstone at the top.
Kayra Formation of the San Jeronimo Gr., consists of red sandstone of medium size grain, moderately sorted.

The mineralized horizon is located in the Kayra Formation, which was formed in the Eocene-Oligocene, in the foreland basin of the Western Cordillera of Central Andes, in a fluvial environment.

3. DESCRIPTION

3.1. OUTCROP

The mineralized horizon is a feldspathic greywacke (fig. 3B), displaying a thickness that varies from 10 to 90 cm, where the ore (chalcocite, covelite digenite, malachite, brocantite, chrysocolla) is disseminated (predominantly along laminations) or occurs filling veinlets. This horizon is hosted by arkosic sandstone of the San Jeronimo Group.

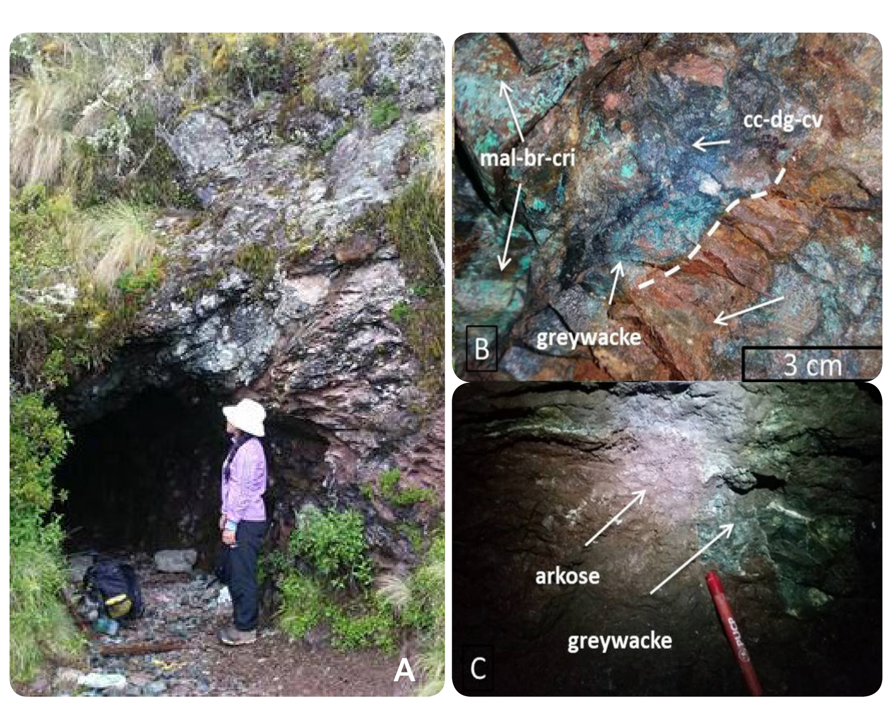

Fig. 3: Outcrop description:

Abbreviations: (br, brocantite; cc, calcosite; cri, chrysocolla; cv, covelite; dg, digenite; mal, malachite).

A) Section of undergraund Tambomachay Mine (1.85 x 1.85m).
B) Mineralization of secondary sulfides (chalcocite, covelite, digenite), disseminated in this minerals there are crystals and crystalline aggregates of primary sulfides (0.1-1 cm).
C) Deformed contact between the ore level (greywacke) and the host rock (arkose).

3.2. MINERALOGY AND PETROLOGY

The primary minerals are chalcopyrite and bornite, there is a predominance of digenite and covelite in coated texture as replacement (Fig. 4 A). The presence of oxidized minerals (malachite, brocantite, goethite) make evident a supergenic alteration (Fig. 4B). However digenite, chalcocite and covelite could be both product of a supergenic enrichment or evidence of primary hypogene textures, as it is common in SRHSCD.
Calcite bearing veinlets (Fig. 4C) and chloritized feldspars (Fig. 4D) suggest hydrothermal fluids circulation. Finally there is a presence of carbonaceous substance in the interstitial zone of primary sulfides.

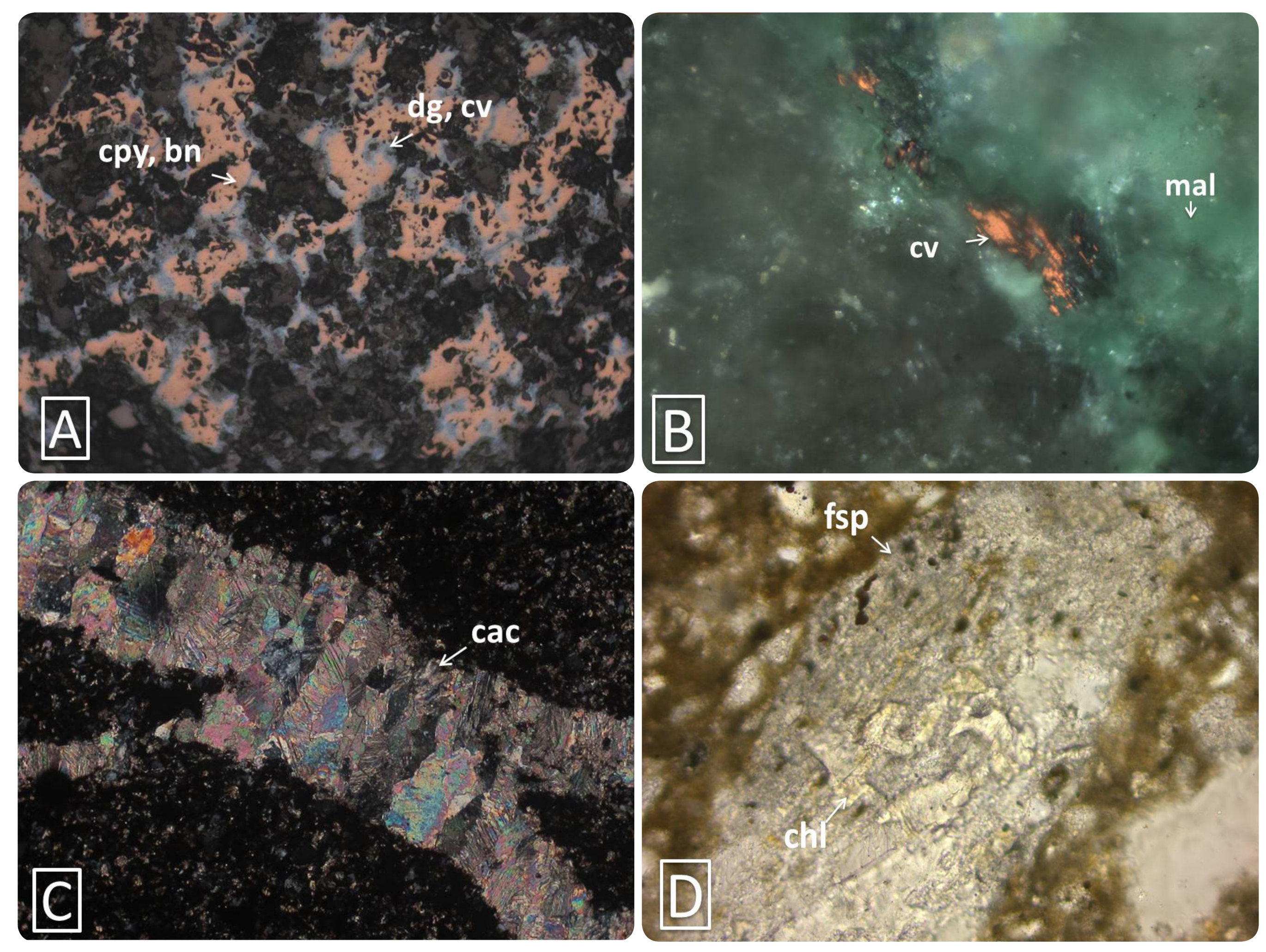

Fig. 4: Photomicrographs of samples of Tambomachay deposit (same abbreviations of fig. 3, other: bn, bornite; cac, calcite; chl, chlorite; cpy, chalcopyrite; fsp, feldspar; PW, Photo width; XPP, Crossed Polarized Nicholes). A) PW: 600 um; chalcopyrite and bornite with replacement of digenite and covelite in coated texture. B) XPP-PW: 300 um; covelite intergrown with malachite. C) XPP – PW: 600 um; calcite bearing veinlets. D) XPP – PW: 600 um; chloritized feldspars.

3.3. GEOCHEMISTRY

ICP-MS has been applied to the determination of 50 elements from 6 ore samples (four acids digestion). The results show enrichment in economic metals like Ag, Pb, and Zn (Fig. 5). The enrichment in these elements is characteristic of SRHSCD (Hitzman et al., 2005). The copper enrichmemment and the associated cobalt empoverishment (Fig. 5) could be a supergenic effect as it is suggested by Torremans et al. (2012), in a case study of Zambia.

Criteria/Elements	Cu	Ag	Pb	Zn	Co
Average concentration (ppm)	925.5	1.98	1247.13	195.75	11.03
Background (ppm)	11	0.25	17	65	16
Enrichment factor	84.14	7.94	73.36	3.01	0.689375

Fig. 5: Geochemical data table analysis done in SGS lab (Callao, Peru)

4. COMMON FEATURES WITH THE SRHSCD MODEL OF HITZMAN ET AL. (2005, 2010)

» **Source of metal and sulfur:** metal sources are considered to be red-bed sedimentary rocks, Kayra Formation. Sulfur sources are inferred to be evaporites, Maras Formation (should be probed by isotopic geochemistry).

» **Source of metal transporting fluid:** basinal fluid (should be probed through a fluid inclusion study, this could be in calcite veinlets of the ore level).

» **Transport paths of fluids:** related to the basin architecture (foreland basin). Tambomachay Mine's architecture is very similar to the one proposed in the model of Hitzman et al (2005, 2010).

» **Thermal or hydraulic pump to collect and drive the metal and sulfur transporting fluids:** Additional works needed to determine the nature of the pump

» **Chemical and physical processes which resulted in precipitation of the sulfides:** mainly reduction reactions caused by carbonaceous matter (see figure 4F).

5. ADDITIONAL WORKS

More detailed studies are required to confirm if the Tambomachay deposit and the related occurrences studied belong to the SRHSCD class including:

» Detailed geological and structural mapping in order to define the geometry of the basin.
» Fluid inclusion studies to determine temperature and salinities of ore fluids.
» Isotopic geochemistry to investigate the relation between the sulfur in the mineralized horizon sulfides and the one in the evaporites of Maras Formation.

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