

Hydromorphic dispersion of metals and geochemical signatures in transported overburden from a porphyry copper deposit: The Inca de Oro District, Northern Chile

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Introduction

In sulfide copper deposits it is a well-known fact that both ore and gangue minerals decompose when exposed to the supergene environment, this by means of oxidation and hydrolysis. The oxidation of copper-iron and iron sulfide minerals occurs upon contact with atmospheric oxygen, this by chemical and biological (microbial) processes. If in the presence of water, oxidation of copper-iron and iron sulfides will lead to acid drainage, this leading to hydrolysis of silicates and other gangue minerals. Evidence of these processes, past and present are observed in secondary enrichment profiles of porphyry copper deposits as well as in leach and bioleach pads and sulfide-containing waste rocks in active mines. Contact of a copper-iron and iron sulfide-rich rocks with groundwater and atmospheric oxygen will lead to water/rock interaction and equilibrium reactions, reactions which will control physico-chemical properties and chemical composition of water, as well as mineral transformations and total mass transfer. Upon chemical break-down of minerals, elements may enter solution, and when saturated, re-precipitate as new minerals, these processes much dependent on hydrological and hydro-geological conditions of interacting groundwater.

It is with no doubt then that a copper-sulfide mineralized body, such as a porphyry copper type deposit, upon uplift, erosion and exposure to surface will most commonly suffer mineral break-down and geochemical dispersion, such dispersion controlled by a myriad of conditions, hydrological, hydro-geological, lithological, alteration/mineralization, geomorphological, structural, and many other, making each case quite unique and by such, hard to interpret. To understand processes and mechanisms that control geochemical dispersion and therefore the footprints which may be generated from a porphyry copper deposit, an integral source to surface approach is necessary. Such an approach must link hydrological, hydro-geological, hydro-geochemical and landscape evolution processes with the geochemical footprints resulting from dispersion. In the case of the Inca de Oro district, Atacama region, Northern Chile (Fig. 1), such a study was carried out on the Inca de Oro porphyry copper deposit. This deposit lies beneath 80 to 230 m of transported overburden, Atacama gravels and more recent alluvial, eluvial and fluvial deposits of diverse origin.

Hydro-geochemistry

Groundwater samples, taken from exploration boreholes along hydrological flow direction, before, within and out of the deposit, demonstrated effective dissolution of primary minerals, solution of chemical elements, and saturation and precipitation, processes which vary depending on time of year. Results of these studies demonstrated that water/rock interaction processes control the physico-chemical parameters and geochemical composition of groundwater, therefore the geochemical dispersion along the flow direction of groundwater. Base metals, sulfur, semi-metals, and many other elements observe transfer, from one end to the other, along groundwater flow direction, demonstrating these processes occur on a present time scale (Fig. 2). In addition to groundwater samples, the exploration borehole cores of the unconsolidated gravel were mapped and sampled for

geochemical analysis. The results showed that the overburden matrix, mainly sand and silt, located above the deposit, contained almost a tenfold higher concentration in base metals respect to samples away from the vertical projection of the deposit, the highest concentrations occur directly above bedrock (deposit), increasingly lower up towards surface, contrast which is lost at surface, as evidenced by soil/cover material samples at surface. These surface samples showed a much closer relation with regolith and landscape evolution processes, geochemical dispersion contrast mostly unrelated to the underlying deposit, at least not evident.

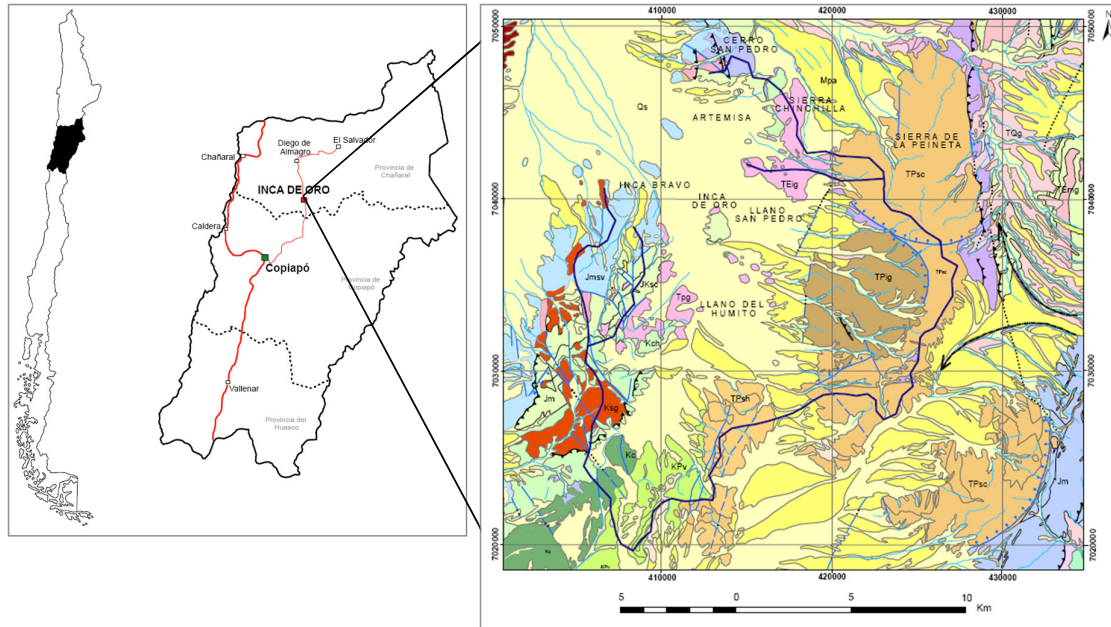


Figure 1. Location of the Inca de Oro District, Atacama region, northern Chile (left). Detail of regional geology and hydrological drainage basin (right), marked in black outline. Location of Inca de Oro porphyry copper deposit is indicated by red rectangle. Jurassic and Cretaceous (Jr and K) volcanic and sedimentary rocks in blue and green tones, La Negra and Punta del Cobre formations; Cretaceous (K) intrusives in red; Tertiary – Paleocene (TP) volcanic rocks, mostly ignimbrites, in brown tones; Tertiary – Paleocene (TP) intrusives in pink tones. Recent alluvial and fluvial deposits in yellow tones.

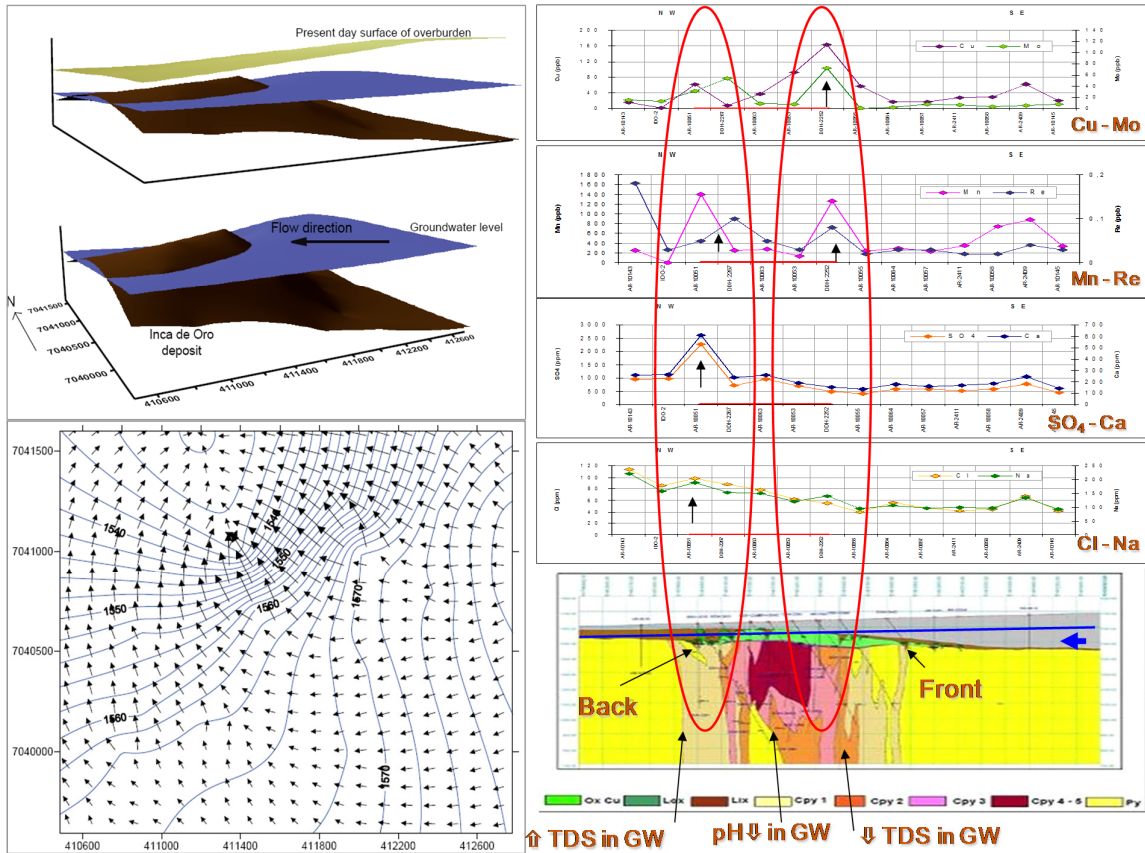


Figure 2. Idealized bedrock surface (black), present water table surface (blue) and present gravel surface (brown) at the Inca de Oro district (3D model), at top left. Hydrological flow model of present groundwater drainage basin (bottom left). Examples of element concentration behaviors in groundwater samples respect to position of ore deposit and groundwater flow direction (right). These behaviors were compared respect to TDS and pH, as well as modeled respect to saturation indexes according to described mineralogy.

Geochemical dispersion from groundwater to surface

To understand the geochemical break between the dispersion processes from depth from those resulting from surface mechanisms, detailed geochemical profiles were carried out within 2 meter deep pits, from surface, down to the “caliche” layer. The results show that geochemical dispersion from depth does not reach above the “caliche”, and if it does, the geochemical footprint is weak, barely discernable from the dominating surface landscape and regolith evolution contrast. In addition to all previous studies, rock, gravel and groundwater samples were taken for a copper isotope study. The results demonstrate that the break-down of copper-iron sulfide minerals from groundwater/rock interaction processes lead to an increase concentration of light copper isotopes at the source, while the heavy isotopes tend to concentrate in groundwater (Fig. 3). As groundwater ascending dispersion occurs, the heavier copper isotope fractions and the lighter isotope tend to concentrate at surface (Fig. 3). Such behavior suggests that the transport of copper from depth to surface occurs by means of hydromorphic processes such as capillary rise, evaporation/condensation, barometric pumping, as well as recurrent seismic pumping. Capillary rise is strong directly above the water table, as also evidenced by the geochemical composition of gravels from depth towards surface.

The Inca de Oro porphyry copper deposit is a unique case, a deposit which is crossed by the water table and presents evidence of on-going geochemical dispersion. The geochemical dispersion footprint is then unique as well; therefore, the interpretation of surface, “caliche” and overburden geochemistry must take into account hydrological, hydro-geological and hydro-geochemical conditions of groundwater. Not all ore deposits are at present in contact with groundwater, for example the Casualidad IOCG deposit, north-west of Inca de Oro, in which the deposit lies at least 300 m above the water table. The geochemical dispersion footprint in such case is very different from that at Inca de Oro.

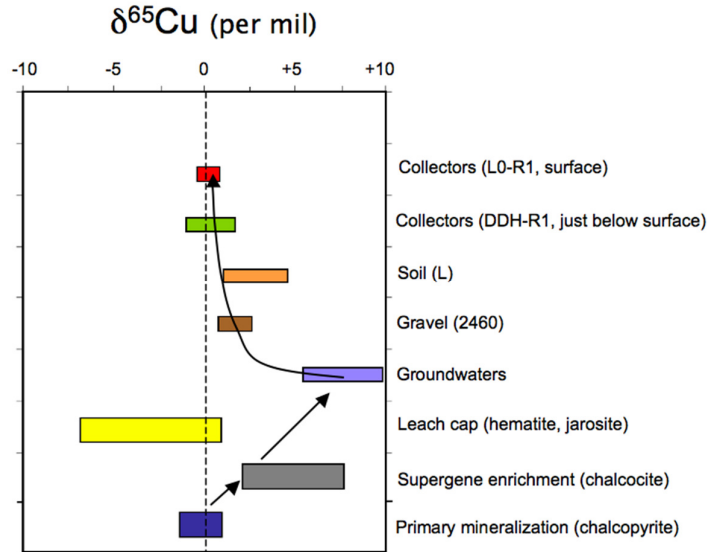


Figure 3. Copper isotope results for samples from primary mineralization (chalcopyrite), supergene enrichment (chalcocite), leach cap (hematite, jarosite), groundwater, gravel, soil and passive gas collectors. Heavy isotopes partition to the groundwater, light isotopes remaining in the leach cap. From groundwater up to surface, heavy isotopes remain at depth, lighter isotopes rise through cover (gravel), up to soil. Passive gas collectors reflect light isotopes potentially rising by means of combination of aqueous and gaseous mechanisms.

Conclusions

To fully understand and interpret the geochemical distribution of dispersion processes from a deposit lying beneath transported overburden, it is necessary to understand the local hydrological and hydro-geological conditions, as well as the landscape/regolith evolution footprints. As every exploration case will be set in specific environments, the particular conditions must be taken into account for proper interpretation. Geochemistry is an effective exploration tool and has the potential to detect deposits beneath transported overburden, but requires careful and reasonable processing and interpretation to make it effective, which can only be completed by means of an integral environment analysis.