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PARTIAL EXTRACTION GEOCHEMICAL TECHNIQUES IN SOILS: A CASE HISTORY IN THE GABY POPHYRY COPPER, II REGION, ANTOFAGASTA, CHILE

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INTRODUCTION

The greatest dream of an explorer is to be able to "see" under a cover of post-mineralization rocks. Geochemical exploration encompasses the use of partial extraction techniques in soil samples that allow the detection of deep-seated mineralization. This paper presents the methodology used for sampling, analysis and interpretation of the geochemical responses of aqua regia ICP-MS analysis, partial extraction provided by the Mobile Metal Ion (MMI) technique, and Enzyme Leach, which were applied to soil samples taken from unconsolidated alluvial and colluvial gravel wich cover all the Gaby Sur orebody of CODELCO-Chile. We assume that there is a source of unstable (i.e. in oxidization stage) sulphides liberating emanations of different elements; a means of transportation by which these emanations migrate towards the surface, conditioned by the geologic-structural and physic-chemical features related to humidity and water layers; and a reservoir or environment for the deposition of these emanations (Fig. 4). The formation of pseudo-horizon "B" (i.e. poorly developed horizon) corresponds to an equitemporal process of the ground's exposure to the surface for a prolonged length of time, and is independent of the age of the unit that it affects. In addition, it is a horizon chemically rich in oxidized Fe and Mn amorphous species, so that the capturing processes are more active and therefore it corresponds to a reservoir for elements migrating through the substratum. The source-transportation-depositing models that explain the migration of elements are still controversial. Nevertheless, the example presented here shows that the data somehow reflect the hydrothermal Gaby Sur system independent from data treatment.

FEATURES OF GABY SUR

LOCATION, SOIL DEVELOPMENT AND VEGETATION

The Gaby Sur orebody is located in the northern part of the endorreic basin of Salar Elvira, some 15 km northeast of this salt-flat (Fig. 1). The orebody occur within the Atacama Desert of Northern Chile. It is an dry area of gentle hills formed by vast unconsolidated gravel deposits, possibly of Miocene age, cut by younger gullies with alluvial soils. Alluvial plains occur towards the north and south such as Llano Mariposa and Pampa Elvira respectively. The ground presents great development of pedogenic carbonates and sulphates formed by evaporation-transpiration and deposition of Ca-rich components. The climate is desertic extremely dry, with no rainfall and scarce formation of vegetation species.

GEOLOGICAL DESCRIPTION

Gaby Sur is a Paleocene porphyry copper deposit formed of copper oxides (chrisocolla), product of the *in situ* oxidation of disseminated and veinlets of primary copper sulphides (chalcopyrite) hosted by a biotitized granodiorite, under a cover of polymictic gravels from 40 to 60 m thick. The 0.3% Cu grade envelope extends 2.5 km N-S and 1.5 km E-W. In the area there are island-hills formed by outcrops of felsic Paleozoic volcanic rocks of the La Tabla Formation and Cenozoic fine dioritic intrusions (Fig. 2). The main structural lineament have a NE-SW orientation (Pampa Elvira and Gaby faults), associated to the Domeyko Fault System.

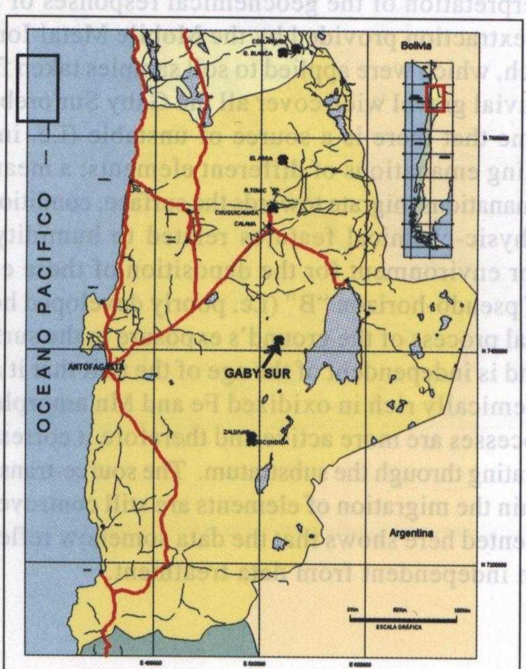


Fig. 1. Location map, Gaby Sur copper deposit in II Region, Antofagasta.

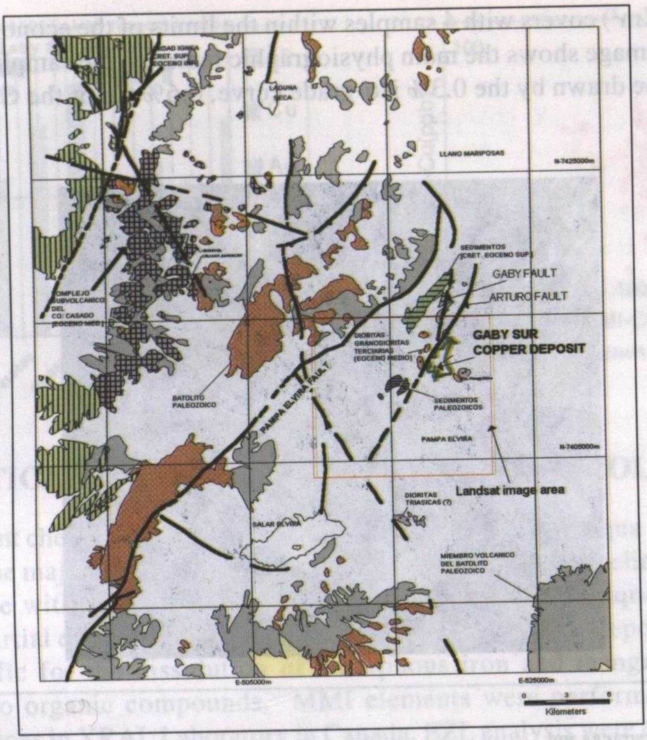


Fig. 2 Gaby Sur area, property geology and copper deposit (from Sernageomin, 1996 and Berg, K., 1996).

METHODS

Soil: There is no significant soil development in these latitudes of the Atacama Desert. Distinct morphologic units are observed, just as: brown to reddish alluvial terraces and recent gullies with alluvial deposits with main NE to SW-trending drainage; colluvial and colluvial to alluvial fan terraces at elevated zone limits; and older raised terraces with colluvial to regolithic deposits on outcrops (Fig. 3).

The best condition for soil formation are alluvial and regolithic terraces due to stability for being in contact with the scarce atmospherical humidity The B-horizon is the maximum illuviation level where particles and water move downward from a less alkaline and more oxidizing to alkaline and less oxidizing environment with pedogenic carbonates and sulphates (Fig. 4).

Soil Sampling: 189 soil samples were collected regularly each 500 m from the B pseudo-horizon along E-W lines with 1 Km separation. Samples were sifted through <80 mesh (Tyler) by hand, homogenized and put into plastic bags on site. These sample are formed of a composite of different increments throughout an area of 20-30 m in diameter at the sampling point, for the best selection of the soil horizon development and area representation. The sampling density

($2.5\ sample/Km^2$) covers with 4 samples within the limits of the economic orebody. The satellite image shows the main physiographic features, the sampling locations and the outline drawn by the 0.3% iso-grade curve, 0.6% Cu of the Gaby orebody (Fig. 3)

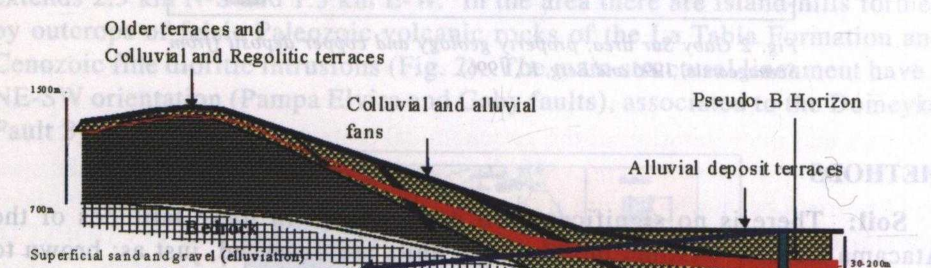
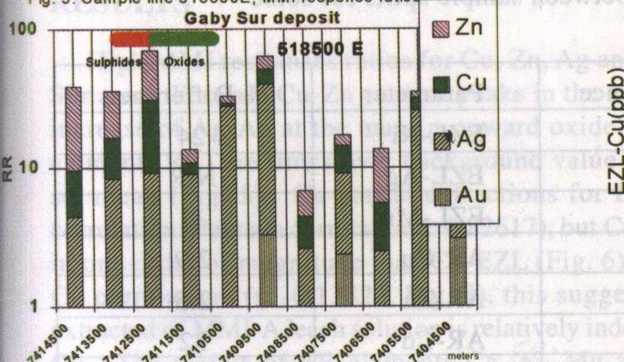


Fig. 4. Schematic field model.

The soil samples were collected from *pseudo* B horizon at a depth approximately 5-30 centimeters and 5-15 centimeters in thickness. A distinct yellow to reddish colour, an scarce increase of limonites, clays and brown to yellowish limonite surface clasts, occur at *pseudo* B-horizon. Sometimes this layer was at the top of an carbonate crust or caliche. Soil immediately above this layer was the selected sampling medium.

Fig. 5. Sample line 518500E, MMI response ratios



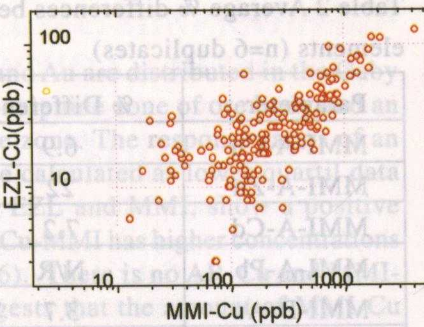


Fig. 6. Scatter diagram MMI-Cu v/s EZL-Cu.

ANALYTICAL METHODS AND QUALITY CONTROL

Different chemical attacks were tested in this study. A hot aqua regia extraction (AR) for the major and trace elements was used to produce a baseline concentration to compare with other extractions: Mobile metal ion techniques, MMI-A and MMI-B partial extractions and Enzyme Leach (EZL) that are reportedly selective and specific for the dissolution of amorphous iron and manganese oxides in addition to organic compounds. MMI elements were performed for A and B types routines in XRAL Laboratory in Canada, EZL analysis were done by ActLabs laboratory in Colorado, U.S.A., and AR analysis in ACME laboratories, Chile.

Table 1. Analytical methods used.

Aqua regia	32 elements	ICP-MS
MMI-A	Cu,Zn,Cd,Pb	ICP-MS
MMI-B	Au,Ag,Ni,Co,Pd	ICP-MS
Enzyme Leach	60 elements	ICP-MS

Six soil sample splits were collected in the field with a random selection. Sample splits are duplicates of the same sample, taken prior to sample preparation. These measure the combined variance due to sample preparation plus analytical error.

Table 2 Average % differences between sample splits for some elements (n=6 duplicates)

Parameter	% Difference	Parameter	% Difference
MMI-A-Cu	6.9	EZL-Ni	24
MMI-A-Zn	22	EZL-Ag	N/R
MMI-A-Cd	7.2	EZL-Mn	11
MMI-A-Pb	N/R	AR-Cu	2.9
MMI-B-Au	3.7	AR-Zn	2.5
MMI-B-Co	N/R	AR-Cd	32
MMI-B-Ni	9.4	AR-Pb	19
MMI-B-Pd	21.4	AR-Au	N/R
MMI-B-Ag	19	AR-Co	5.5
EZL-Cu	47	AR-Ni	24
EZL-Zn	8	AR-Fe	3.15
EZL-Cd	569	AR-Mn	1.7
EZL-Pb	205	AR-Ca	6.9
EZL-Co	13		

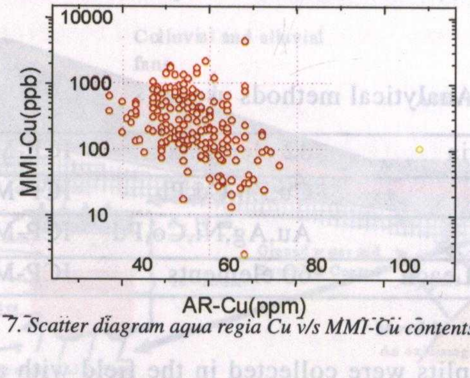


Fig. 7. Scatter diagram aqua regia Cu v/s MMI-Cu contents.

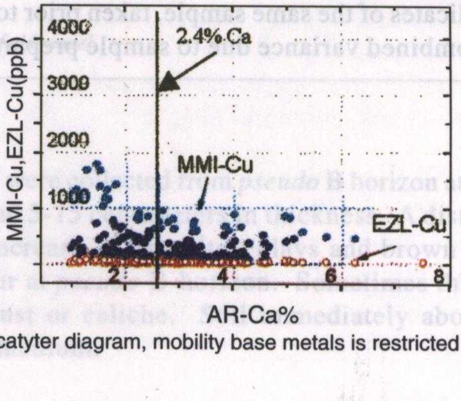


Fig. 8 Scatyter diagram, mobility base metals is restricted Ca contents.

RESULTS

High MMI responses ratios for Cu, Zn, Ag and Au are distributed in the Gaby Sur area, there are Cu-Zn content peaks in the sulphide zone of ore body and an increase of Ag-Au at the margin, toward oxide zone. The response ratios of an element (RR) are times over background value calculated as lower quartil data set mean (Fig. 5). Cu partial extractions for EZL and MMI, show a positive correlation (Pearson correlation r: 0.82617), but Cu-MMI has higher concentrations in one order of magnitude than Cu-EZL (Fig. 6). There is no AR-Cu and MMI-Cu correlation. (r: -0.13823, Fig. 7), this suggests that the amount of MMI-Cu extracted of MMI-A leach solution is relatively independent of aqua regia extractable Cu. The results of AR elements Ca, Al, Mg and K are negatively correlated with the MMI-Cu and appear to be influenced by the solubility of the MMI-A elements. (Fig. 8). Ca-rich soils are found in arid environments and may be controlling the efficiency of the weak MMI-A solution. The MMI element varimax factor analysis is shown in Table 3. The Factor 1 correlates Cu, Co, Zn, Cd, Pb and Ni, Factor 2, Au, Ag y Pd. Factors are strongly negatively correlated, probably because the MMI-A solution elements (similar factor 1) are affected by changes in Ca contents in soils. The MMI-Cu distribution may produce false anomalies, because the concentrations depend on Ca contents and soil alcalinity. The concentration of MMI Cu is controlled by the AR-Ca in the soil from 0.97-2.4%, above 2.4% the distribution shows a constant pattern (Fig. 8). An MMI-Cu anomaly variable was modeled related to the AR-Ca element. MMI-Cu data was ratio ed against background curve that relates MMI-Cu and AR-Ca. The Cu anomaly (MMI-Cu anomaly, Fig., 9) is an unbiased response ratio.

Fig. 9 MMI-Cu anomaly distribution
GABY SUR DEPOSIT

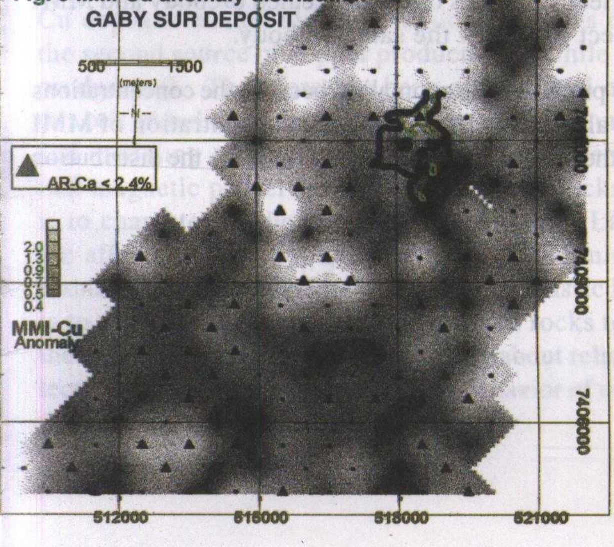


Table 3. Varimax factor loadings.

MMI-Element	Factors F1	F2
Cu	**0.94602**	-0.12988
Co	**0.91027**	-0.03713
Zn	**0.88879**	-0.19196
Cd	**0.79815**	-0.0259
Pb	**0.55826**	-0.07886
Ni	**0.5337**	0.20485
Pd	0.04358	**0.82748**
Ag	0.06039	**0.82558**
Au	-0.1927	**0.43244**
% Variance	42.108	18.4144

DISCUSSION

Any copper and iron sulphide-bearing body in contact with phreatic groundwater is chemically more unstable than an oxide zone. Therefore, this environment is more likely to release mobile elements upward. This fact explains that mobile base element concentrations are higher in a oxidizing sulphide ore than in an oxide deposit that could be the case for Gaby Sur orebody. On the other hand, the 0.3% Cu envelope is a parameter to define a possible economic deposit, but the hydrothermal Gaby Sur system is likely to be much larger. Therefore, the detected mobile element anomalies on surface by MMI or EZL analyses are not necessarily a vertical expression of a covered economic ore deposit. The partial extraction concentrations may be responses of the hydrothermal system and upward migration of chemical specimens that may be controlled by lithological, structural and groundwater factors (Fig.4). Finally, for the interpretation of total and partial extraction data and understanding of the nature and behavior of mobile elements, it is very important to consider the following aspects: sampling density (according to the target deposit), the physiographic features of the landscape, the zonation of element concentration, and the soil compounds.

CONCLUSSIONS

Gaby Sur is an oxidized porphyry copper deposit covered by 40 to 60 m of gravels within an extremely dry section of the Atacama Desert. Soil development in this environment is rather poor, but pseudo B soil horizon was sampled and partial extraction MMI and Enzime Leach geochemical techniques were tested and compared to aqua regia extraction. MMI base element anomalies from these partial extraction techniques reflect sulphides of the concealed orebody and MMI precious Ag-Au anomalies reflect oxides of the same orebody.

The MMI-Cu distribution may produce false anomalies, because the concentrations depend on Ca contents and soil alcalinity. In our case the concentration of MMI Cu is controlled by the AR-Ca in the soil from 0.97-2.4%, above 2.4% the distribution shows a constant pattern.