

# **Understanding real time processes behind the development of surface geochemical expressions from ore bodies beneath cover: source to surface and detection by means of collector devices**

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## **ABSTRACT**

*Ongoing research at the University of Chile has dedicated over three years of experimental analogue laboratory work in an attempt to emulate real time processes that occur in a sulphide deposit beneath different types of unconsolidated overburden. Onset of oxidation and natural bacterial activity on primary sulphide mineralization occurs within a short period of time once sulphides are exposed to oxidising and water unsaturated conditions. Generation of free ions and hydrocarbon gaseous compounds were demonstrated by direct time integrated collection to adsorbent materials in specially designed collector devices, both within column and in-vitro experiments. Different column experimental designs allowed testing of the effects of various types of overburden, different conditions of water saturation and of air and argon flow, to better understand the mechanisms governing migration to surface. Results indicate that gaseous flows, together with development of electrochemical cells, are among the most important mechanisms governing migration to surface. Real time processes were also studied in the field. Profiles for porphyry copper deposits of the Toki district, Gaby, Spence, and the Chug Chug Pampa, II Region, and the El Teniente porphyry copper deposit, VI Region, were carried out, as well as a final full grid survey of the El Toki district, to test applicability of collector devices to mineral exploration in areas of transported overburden in northern Chile. Results show clear evidence of response to real time processes and good and robust contrast anomalies that effectively detect the presence of sulphide deposits beneath cover.*

## **INTRODUCTION**

As the discovery rate of world-class mineral deposits continues to decline in the world, increased attention is being focused on geochemical exploration methods designed for covered terrains. For companies that manage their exploration from a risk-based perspective, the development of methods for confident detection of ore bodies covered by transported overburden is critical to their future success (Kelley *et al.*, 2003). The application of geochemical techniques that focus on the detection of surface soil geochemical contrast anomalies related to potential buried mineralization have been used to try to detect subtle surface expressions, albeit with limited success. If definitive, low cost surface or near-surface detection of geochemical processes can be conducted in areas of shallow cover (<200m), large areas can be tested and expensive drilling can be optimized to higher probability targets. However, not all known buried mineralized systems including many with shallow cover appear to have surface geochemical expressions in soils. A serious impediment

to the adoption of such methods by the exploration industry is that the scientific basis for most of these methods is largely empirical. It is therefore difficult to distinguish between negative results (no mineralization) and null results. In order to apply geochemical exploration methods confidently in any given area, or to determine that any specific technique is inappropriate, it is necessary to understand the mechanisms by which surface expressions may form and determine the most cost/ effective ways to detect these.

For the past four years research in applied geochemistry focusing on exploration of undercover ore deposits has been conducted at the Department of Geology, University of Chile, in collaboration with Codelco, as part of a government funded applied research project, FONDEF D02I 1083. Extensive experimental and field work have been carried out, experimental work done at the University, field work case studies focused on five known porphyry copper deposits, four in northern Chile, one in central Chile, and one case study on an exploration target, also in northern Chile, bringing total case studies to six. In addition a final full grid test was carried out over the Toki porphyry copper district, II Region of Chile, to evaluate

applicability of a time integrated collector device developed and designed to detect geochemical and organochemical expressions of sulphide mineralization beneath cover and aid in more confident target drilling definition.

## EXPERIMENTAL RESEARCH

The construction of an Analogue Supergene Geochemical Processes Laboratory (ASGPL) is among one of the most interesting aspects of the project. Through analogue one metre columns, scaled proportionally, under different cover and environmental conditions, processes from source to surface are being studied.

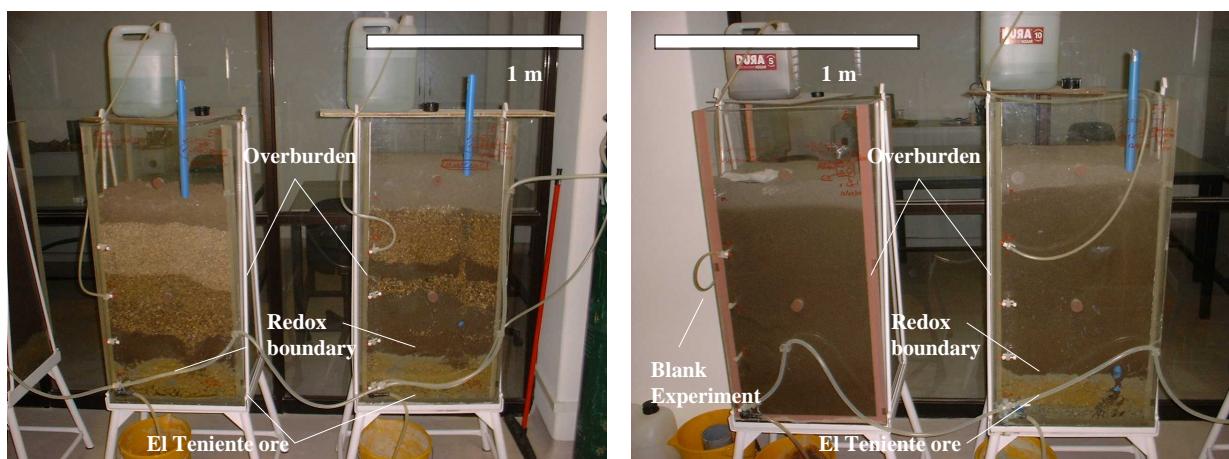
A total of six experimental columns (Fig. 1) were built, five having started with El Teniente porphyry copper  $\frac{1}{4}$ " inch primary ore (1.2% Cu) at the bottom, with a ~70–80 cm cover of gravel, sand and clays. Two experimental columns are housed within incubators for temperature/humidity control, emulating different environmental conditions, typical of desert climate, including a day/night cycle and surface temperature control during the day cycle. Sulphide degradation processes at the source have been monitored for over two years, including pH, Eh,  $\text{Cu}^{2+}$ ,  $\text{Cl}^-$ , bacterial activity and count, and mineralogical transformations. These processes were initially activated by simple exposure of ore rock to tap water and air (air injected at the base of the column, water inserted above the ore and drained, keeping ore rock unsaturated).

Within two weeks of exposure, analysis of drainage water after equilibration, from all five experiments with ore, respect to original tap water and experiment 6 (blank), demonstrated rapid pH decrease, slight Eh increase, appearance of  $\text{Cu}^{2+}$  at detectable levels, up to 3 ppm, and increase of above 100 ppm  $\text{Cl}^-$ . Results after over three years of monitoring have shown that sulphide degradation processes associated with water unsaturated oxidizing conditions of primary ore observe onset of chemical and biological oxidation and hydrolysis. Liberation of  $\text{Cu}^{2+}$  (cationic Cu) and  $\text{Cl}^-$ , pH decrease, Eh increase, mineral transformations with development of marked reduction –

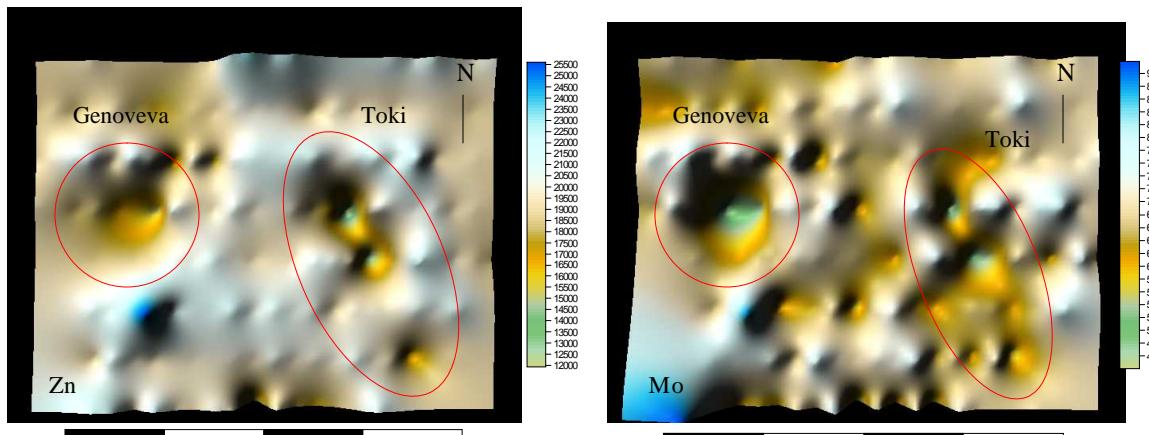
oxidation (redox) boundaries, and activation of bacterial activity have been documented. Increase in time of bacterial activity forms a biomass anomaly (bacterial community) associated directly with their source of energy, sulphides. The source, upon oxidation and hydrolysis, becomes a bio-organic feast, with generation of abundant free cations and associated inorganic and organic gases product of mineral degradation and biologic activity. Gases and free elements may then rise by means of different mechanisms to surface. In blunt terms, ore rock degradation processes smell, the smell rises, and may be detected at surface. Having identified and better comprehended processes that generate free ions and gaseous compounds at the source, understanding migration to surface and detection techniques was the following step of research.

Mechanisms through which free ions and gases may rise to surface have been studied experimentally and empirically in the field. These have been tested by a collector device approach. Different types of in-house built collector devices have been tested, the basic concept, the use of pure adsorbent materials of known source, characteristics and composition. The objectives of collector devices is to detect real time migration of ions and gases from the source to surface, with the advantage of having an approximately homogeneous sample (adsorbent materials) of known baseline composition through which gains or losses may be compared to the original after being exposed to the environment at top of experimental columns, either buried at 3–5 cm depth, or at top of a PVC tube connected directly to the degrading ore at the base of the column (Fig. 1), or in the field, buried at a depth of 30 to 40 cm. Time of exposure has been from 70 to 120 days.

To test different processes of migration to surface many experiments were carried out, with variations of overburden (and permeability conditions), depth of cover, influx of air and/or argon at base of columns, raised water input to improve water capillarity to surface, among other tests. Two parameters have been noticed as important, gaseous flow to surface and onset of redox boundaries and cells. If injection of air (and argon) is



**Figure 1:** From left to right, experiments 4, 3, 6 and 5. Note development of a marked reduction – oxidation boundary at ore – overburden interface for experiments with ore (3–5). Different types of overburden have and are being tested.



**Figure 2:** Collector device concentration distribution map for Zn and Mo (colour scale in ppb), Toki cluster. Raw data linear kriging interpolation. Contrast anomalies show locations of the Genoveva and Toki porphyry copper deposits. Scale bar in metres.

suppressed, no detectable anomalies occur among collectors within 90 days. Collector materials were also tested directly within the top of the PVC tubes, only possible transfer from base to top either by gaseous streaming and/or aerosols. Samples from the PVC tubes showed over 7 ppm increases of copper concentrations within 90 days, together with an increase of heavy hydrocarbon gaseous compounds to adsorbent materials. This approach was also tested in the field, in the Toki ore deposit (Calama). Adsorbent materials were placed at the top of drill hole tube casings (surface), well protected from particulate contamination, over 400 m above the ore deposit and 80 m above the water table, for over 120 days. Increments of about 12 ppm Cu were detected, among other ions added to the original material. Exactly how metal cations are transferred by gaseous means is yet unclear and requires detailed study. Generation of redox boundaries and cells have been documented in the experimental columns, cells with observable boundaries from source to near surface. Collector devices of different design and materials were tested in the columns, from which an original prototype was developed for field application.

Testing of collector materials for hydrocarbon gases have demonstrated that heavy hydrocarbon gaseous compounds are generated from degrading sulphides, the source linked and correlated to bacterial activity. This has been detected among the experimental columns, in the field, and most recently from *in vitro* experiments. Sulphides within an oxidizing environment attract chemotrophic iron oxidizing bacteria and an increment of chemotrophic bacteria activity attracts heterotrophic bacteria which feed on chemotrophs, breaking down their organic composition to hydrocarbon gases. An anomalous biomass (bacterial community) is the primary source of hydrocarbon gaseous compounds. Experimentally the relation between bacteria and hydrocarbon gases have been tested and demonstrated, but much work is still under way, including additional *in vitro* experiments to relate combinations of bacteria types and sulphides, in an attempt to determine exactly which compounds relate directly to the presence of sulphide associated

bacteria. These tests have also been conducted in the field, demonstrating a very good link between the presence at depth of an ore body and increments of heavy hydrocarbon compounds to collectors at surface.

Field case studies were conducted at Codelco's Toki ore deposit, Calama, the Gaby ore deposit, south of Calama, the Inca de Oro ore deposit, just north of Copiapó, and El Teniente, central Chile. BHP Billiton's Spence deposit and Teck Cominco's Rever property in Pampa Chug Chug were also tested. A large grid study at the Toki ore deposit was conducted (at over 180 samples), as well as a 3 line grid at the Inca de Oro porphyry copper deposit, north of Copiapo (Codelco). Details on results are not yet disclosed but some profiles and grid distribution maps are included (Fig. 2) for different elements from the Toki case study. Distribution maps present raw data linear kriging interpolations. No statistical processing of data was incurred in order to visualize the process of elemental and hydrocarbon gaseous compounds arrival at surface in its pure form. Most elements of the 72 element sweep have a similar distribution, a multivariable statistical test was carried out (factor analysis) to test robustness of distribution. Over 80% grouped in two factors, showing that elemental response to presence of an ore body beneath overburden is consistent. An increase in concentrations of these elements on adsorbent materials integrated in time indicates these are real time processes that can be detected with good contrast respect to background.

## REFERENCES

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