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Using Scandinavian Smart Technology in Brownfield Exploration of Polymetallic Sulphide Deposits in the Andes

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1. Abstract

This contribution provides an update on current exploration methods applicable to the exploration of base metal-rich sulphide deposits, driven by the need to increase the success rate by making use of exploration technology more effectively. Geochemical footprint and protolith determination are crucial components when assessing the fertility and preservation of the ore stratigraphy in districts hosting stratabound deposits. In near mine exploration, especially when tectonic disturbance is significant it becomes important to extend the search radius of exploratory drillholes, by using for example down-borehole electromagnetic and gravity techniques. A comprehensive selection of techniques based on an understanding of the style of ore formation, petrophysical properties of ores and related alteration coupled with borehole structural observations will make integrated 3D modelling a precise targeting tool in routine brownfield exploration of semi-massive and massive sulphide ores such the ones occurring in VMS, cordilleran style replacement, skarns and MVT systems.

2. Introduction

Exploration technologies in the Nordic area have been driven by the search for massive sulphide deposits (VMS and Ni sulphide deposits) in depth ranges exceeding 1,5km in near mine environments. The similarity in petrophysical properties of ores containing large quantities of Fe-sulphides suggests that these developments could also be applied to a variety of base metal systems in the Andes. This is of major significance when exploration is conducted from deep underground mine locations where conventional geophysical methods lose resolution.

Common challenges in the exploration for volcanic and sediment hosted base metal ore deposits in the Nordic countries arise when primary depositional geometries and alteration footprints are obliterated by metamorphism and deformation. In the Andean context these challenges can be different, dealing mainly with the problem of identifying continuity of ores and correlation of altered stratigraphy. The assumptions made in and extrapolation of surface geological mapping into deeper portions can be misleading if 3D structural and kinematic interpretations have not been gained from oriented drillcore data.

3. District scale prospectivity

The style and composition of volcanism and metallic ores can be highly variable in juvenile arcs developing at continental margins. Good understanding of the compositional and size variations among the deposits should always take into consideration assessment of arc development, sedimentary rock interactions and preservation potential e.g. paleobathymetry or paleoerosion levels.

It is widely accepted (Franklin et al., 2005 and references therein, Piercey et. al., 2008) that submarine hydrothermal cells develop efficiently in extensional settings with anomalous thermal gradients, this being a primary formational control for VMS deposits on a district scale. The understanding of the thermal regime of the arc can be indirectly recognized by looking at the chemistry of volcanic products. Even in areas where alteration has completely obliterated the primary texture, protolith recognition and fertility signatures can be determined.

In initial district scale exploration, choosing the right analytical protocols to investigate rock and soil compositions are fundamental to the effort to assessing arc fertility, as well as locating ore horizons within the altered stratigraphy (Barrett et al., 2005; Barrett and Imaña, 2008). This can include the selection of a varied range of methods including a multiacid digest with almost total dissolution, to complete fusion of the sample with whole extraction of elements; to non-destructive techniques involving laser ablation techniques and XRF determinations, the latter can be routinely implemented with a portable handheld instrument.

Metamorphism and syn- and post depositional remobilization and deformation can cause detachment and tectonic transposition of the systems, obscuring traditional vector indicators in geochemical and geological mapping. Although this phenomenon is more common in Proterozoic and Archean arcs, metamorphic modification of altered rocks related to contact metamorphism can also occur in younger settings.

4. Downhole exploration techniques

One of the major opportunities of getting closer to a discovery is when drilling, and at this stage it becomes important to gain the maximum search radius in every drillhole, especially when long exploration holes are planned. VMS deposits usually contain massive mineralization bounded by iron sulphides which make them susceptible to detection if an artificial electromagnetic field is induced. Time domain electromagnetic techniques (TEM) can be applied by airborne or surface surveys, but most effectively down-borehole (BHEM). EM can detect conductive material up to a few hundred metres away from the hole, meaning that the search distance between drillholes is expanded. Combining BHEM with down-borehole structural measurements (taken in oriented drillcore) increases the chances of discovery especially in areas of structural complexity.

Measuring down borehole petrophysical properties (conductivity, magnetic susceptibility, density, and seismic velocities.) is a relatively inexpensive procedure that can be implemented at mine site. It gives the advantage of gaining fundamental information for the effective modelling and planning of down-borehole EM and seismic surveys (Heinonen et al., 2012) in new brownfield areas, and helps to assess the occurrence of possible anomalies associated with conductive non-sulphide rock types such as graphitic shales or saline bearing fractures.

Another intrinsic feature of massive sulphide mineralization is the higher density than surrounding rock, making sulphide rich deposits attractive for down-borehole gravity measurements in massive sulphides with low electrical conductivity e.g. near vertical Zn-rich baritic ores. Recent technical development has enabled the reduction of gravity tool to fit into the slim exploration boreholes providing a new tool for brownfield exploration, especially useful in areas where high conductivity graphitic shales are abundant and cause unwanted EM-anomalies. Nind et al (2007) estimate that 10 MT massive sulphide ore body in typical host rock environment (density 2.8 g/cm3) would be detected at least 300 m away from the borehole. In order to define the 3D spatial location of the anomaly source, gravity measurements should be made in several boreholes surrounding the volume of interest. Conducting gravity measurement in a single borehole provides information about density disturbances in the volume surrounding the borehole but the exact location of the anomaly cannot be determined. Combining density disturbances derived from a gravity survey with lithogeochemical data can be used to refine the stratigraphy, define new ore locations and the extension of the hydrothermal alteration in the rock volume (Schetselaar and Shamsipour, 2015).

5. Possible applications in Peruvian deposits

Pyritic and pyrrhotitic polymetallic ores are known in VMS and cordilleran style replacement deposits of Central Peru (Vidal, 1987, Fontboté and Bendezú, 2004); these styles of mineralization are typically conductive, with dimensions that span from few to several hundreds of meters. Conductive “manto” and sulphide breccia style of mineralization could therefore be a good EM target even if located at depth under thick piles of barren quartzite or limestone. This is an important advantage over electric methods that are less able to differentiate between massive and disseminated style of mineralization.

Pyrrhotite bodies are more conductive than pyrite bodies and therefore more susceptible to tracing at deeper levels using conventional surface EM surveys, providing an advantage over surface magnetic surveys. In deep underground exploration these techniques will enable conductive mineralization to be detected with more precision than conventional surface based surveys that have to deal with the interference provoked by mine infrastructure.

VMS deposits in the Coastal region can be composed of orebodies with different composition; although commonly contain dense and conductive pyritic zones amenable to detection by a variety of EM techniques. In some cases, pyrite poor, and Zn-rich barite ores occur which can only be detected by gravity surveys. Conductive anomalies in VMS systems can exist in different parts of the system such in the feeder zone, the main mound or sulphide blanket or in non-economic exhalites and distal parts of the system; the ranking of these anomalies will depend on the 3D geological understanding of the system.

Using lithogeochemical techniques to characterize the ore horizons at a district scale will enable mining companies to use the results to explore along these interfaces and consider EM investigation of ore horizons even in areas under unaltered cover previously not considered to be of exploration interest.

6. Conclusions

Selection of effective technologies in brownfield exploration depends on knowledge gained from known orebodies and the willingness to consider new ideas. In the deep underground mine environment 3D modelling for exploration involves the combination of geophysical parameters inherent to altered rocks and ore types (e.g. conductors, resistors, equipotential trends, seismic reflectors), chemostratigraphic units and quantifications of mass gain or loss of mobile hydrothermal components (Maki et al., 2015; Imaña et al., 2013). Thus 3D modelling for near mine exploration represents a multidisciplinary approach which is best workable if immersive 3D visualization or 3D printings are generated. Combining novel borehole geophysical methods with surface geophysics and mine geology, creates reliable 3D earth models to aid brownfield exploration.

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