Full 3D geophysical analysis of a massive sulphide Cu discovery – Las Cruces, Southern Spain.

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Summary

Analysis of geophysical mineral exploration data can now be investigated with 3D numerical modelling. However full integrated 3D presentation of geophysical and geological data has been slow to develop, even though computer technology can now provide low cost interactive solutions.

At Rio Tinto a visualization system has been developed to take advantage of full 3D analysis for use in field operations. The software was developed using AVS Express, Advanced Visual Systems visualization software. The resultant object orientated package provides both rapid 3D data integration and identification of geological relationships normally difficult to observe with other presentation methods.

A massive sulphide deposit was one of the first projects to benefit from this approach. This was the Las Cruces deposit discovered in May 1994, 15km northwest of Seville, southern Spain by Riomin Exploraciones, a subsidiary of Rio Tinto. The conceptual understanding of the Las Cruces mineralization was greatly enhanced by the 3D presentation. Gravity models identified depth extents of the mineralization. Combining 2D IP model sections with geological surfaces immediately identified the effectiveness of the IP surveys. 3D volume visualization of TEM soundings subsequently identified an extension to the supergene ore zone.

Introduction

Las Cruces is a volcanogenic massive sulphide deposit located in the Iberian Pyrite Belt. Folded Carboniferous volcanic and sedimentary units form the host sequences of a number of such deposits. At the eastern end of the outcropping Pyrite Belt occur deposits such as Rio Tinto Mine, Aquas Tenidas and Aznalcollar. East of these deposits the Carboniferous sequences are covered by Tertiary marls and compacted sands of the Guadalquvir Basin. Although this basin is associated with the formation of a graben, the exploration group felt that there may be shallow extensions of the mineralized Carboniferous along strike under the Tertiary. So to investigate this concept a gravity survey was undertaken along roads in the region with station intervals of approximately 300 meters.

After completing 100 meter infill over anomalous areas a discrete +3.0 mgal residual anomaly was identified at Las Cruces (figure 1). Access to the anomaly was difficult because of crops, so the flank of the anomaly was drilled in late 1994. This produced an intersection of 43m @ 3.8% Cu in secondary mineralisation, followed later by another hole with 5.1m @ 4.1% Cu in primary mineralisation. Delineation of the mineralisation beneath the 100 to 150 meter thick Tertiary sediments was now a requirement. Of particular interest was the extent of a supergene enriched Cu zone, identified in mid 1995 from an intersection of 16.6m @ 19.5% Cu in the middle of the gravity high.

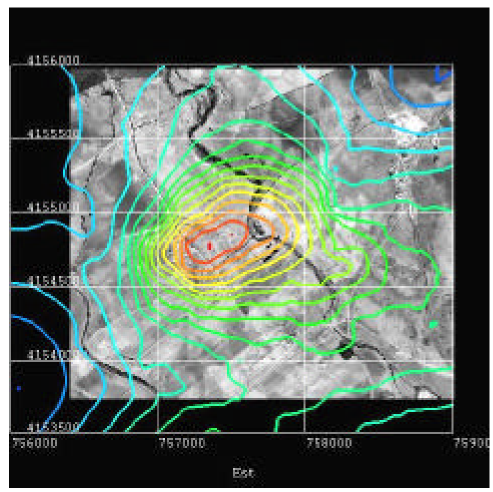

Figure 1: Local air photograph with contours of the residual bouguer gravity anomaly. Anomaly range from 0.5 to 3.5 mgal. The Las Cruces mineralisation is located at the centre of the gravity anomaly. Co-ordinates are UTM, in meters. (All figures are taken from the 3D visualization system).

Methods

By the end of 1997 as the 3D software was being developed, 65,000 meters of core had been drilled and a large number of geophysical surveys completed. The two principal geophysical methods were the gravity surveys and TEM in-loop soundings. Approximately 320 were surveyed using a Zonge GDP32 with a TEM3 antenna (10000m^2). These soundings were clustered over the gravity high and along profiles radiating out from the gravity high.

IP dipole-dipole profiles were placed across the gravity anomaly north to south, with a dipole spacing of 100 meters from n=1 to n=6, and a profile separation of 100 meters. Other techniques that were used but are not reviewed in this paper, included CSAMT, mise-a-la-masse, down hole TEM and reprocessing of a wide line spaced airborne magnetic survey.

Down hole data provided valuable controls for the 3D geophysical models. The drill core assays were integrated with core density measurements, and some PIMA hyperspectral measurements. Vulcan mine model software was used to generate ore and geological models from the drill logs.

3D visualization software.

Development of a 3D data analysis, integration and visualization system commenced in late 1996. Some of the principal objectives were:

- A field based system for Windows/NT PCs.
- Reasonably easy to use and customize.
- Quick to adapt to on going project needs.
- Flexible data input so that any data type is easily incorporated, including databases.
- Provide quantitative information as well as interactive visual assessment.
- Avoid duplicating existing software tools.
- Moderate cost so that it is accessible to all the operations.
- Well-supported industrial software that keeps up to date with changes in graphics hardware and standards.
- Provide an integrated solution for all 3D geophysical and geological modelling software.
- Provision of data displays and file control for the Joint and Cooperative Inversion (JACI) software developed at the University of British Columbia.

Having examined a wide range of specialist commercial software, developed for mine modelling, seismic and well field analysis, geological modelling and general voxel rendering it was realized that many of the above requirements were not met by these systems. In particular many packages start with the supposition that a detailed geological model was available. This is generally not the case in exploration projects. It was decided that the AVS visualization software could be developed to provide some basic 3D functionality, as it satisfied most of the graphics and portability requirements.

The development produced macros that can read, integrate and simultaneously display in a 3D view many data types. These include satellite and geophysical images, geological vector maps and sections, Vulcan 3D models, geophysical vertical sections, multi parameter down hole surveys and assays, geochemistry databases, vector fields, survey line profiles, and both geometric and 3D volume geophysical models.

Besides the normal visualization tools other important applications have been developed. Interactive 3D magnetic and gravity modelling using another data type for definition of the model. For example IP sections, such as in figure 2 can be automatically converted to a susceptibility distribution in a 3D mesh. This mesh is then used for calculating the induced magnetic response of the IP anomalies. Multiple viewers provide interactive 3D and 2D data displays, a useful procedure for examining down hole data and multi channel data such as TEM.

Some 3D results from Las Cruces

It is not possible to review all the Las Cruces data and results in this paper, so three important features of the study have been reviewed.

During the exploration program it was soon recognized that the Tertiary cover was very conductive due to saline ground water, typical values from the TEM soundings were between 2 and 10 ohm meter. This limited the effectiveness of the electrical and electromagnetic surveys. Despite this an IP phase response was recorded and modeled using the JACI program, DCIP2D (Oldenburg and Li, 1994) The modelled sections compared well with the horizontal supergene enriched Cu zone and gossan bearing Au zone, figure 2.

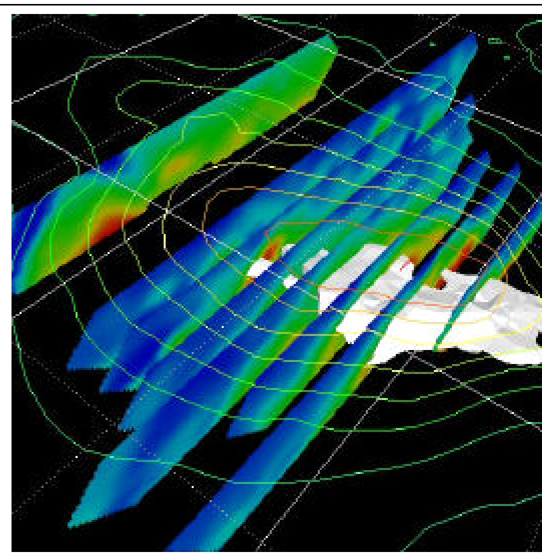

Figure 2: Oblique view of 2D inverted IP sections (blue low phase, red high phase) and intersecting white lense of high copper grades (>10%) interpolated from drill assays. Contours are the residual gravity contours shown in figure 1. Grid lines are 1km square and at ground level.

Las Cruces 3D analysis.

As the mineralisation was associated with a gravity high it was important to establish which geological and mineralogical units contributed to the increased density. The drill core densities (Table 1) could then be used to identify the extent of the economic mineralization.

Tertiary cover	
Clays and marls	2.0
Carboniferous host rocks	
Felsic volcanics	2.4 to 2.7
Intermediate volcanics	2.6 to 2.9
Mineral and sulphide zones	
Gossan cap – Au bearing	2.96
Supergene horizon HCL	3.34
Cu bearing massive sulphide HCH	4.42
Zinc bearing zone	4.50

Table 1. Mean densities in gm/cm^3 for the respective geological and mineralized units.

The first approach was to calculate a plausible density distribution by inversion modelling of the residual gravity anomaly, using the JACI program GRAV3D (Li and Oldenburg, 1997). For the model a 25 meter regular 3D mesh was constructed beneath the area of data coverage, figure 4. The top of this mesh coincided with the base of the Tertiary. A stable and convergent inversion produced a model populated with a density distribution between 2.3 and 4.5 gm/cm^3. Figure 3 shows the volume containing densities greater than 3.0, the lower range of the sulphide densities. This is a single high density zone located directly beneath the drilled mineralization and approximates the NW 45 degree dip of the massive sulphides. If lower density zones are displayed, the resulting bodies are dispersed through out the mesh. The question that arises from this; is how realistic is the model and is there high density mineralisation at depths below the drilling?

To test this model the densities from the drill cores were assigned to the cells of an identical 25 meter regular mesh, figure 3. This is a simplistic approximation of the real geology, as there has been no allowance for material between the drill holes, and in many holes the density measurements are not continuous down the hole. As expected the forward gravity model from this mesh (produced by GRAV3D) fails to account for the observed gravity high.

A third density model was interpolated from the drill core densities using Vulcan modelling, figure 3. The resultant gravity field completely matches the central observed anomaly, with only a few small over estimates, figure 4. It therefore appears that if the Vulcan model is correct there is no depth extension of massive sulphide zone below the drilling. The answer is however not conclusive, as the Vulcan model does not include the stockwork and the closure of the NW dipping massive sulphide lens.

A successful result was achieved with the TEM in-loop soundings. The soundings were converted to conductivity soundings by Zonge Engineering 1D smooth modelling, and compared with 1D inversions using GRENDL, part of the Encom, EMVision software. These conductivity depth profiles were then displayed in the 3D viewer as drill holes for comparison with the other data sets. The best result was achieved by mapping the conductivities into the 25 meter regular 3D mesh. The base of the Tertiary was clearly mapped with an isosurface at 0.3 siemen. Values higher than 0.4 and reaching 3.0 produced isosurfaces that corresponded with the Cu zones in the drill core. The importance of this result was that the 3D TEM model identified an extension of the mineralization to the west of the known ore zone, figure 5.

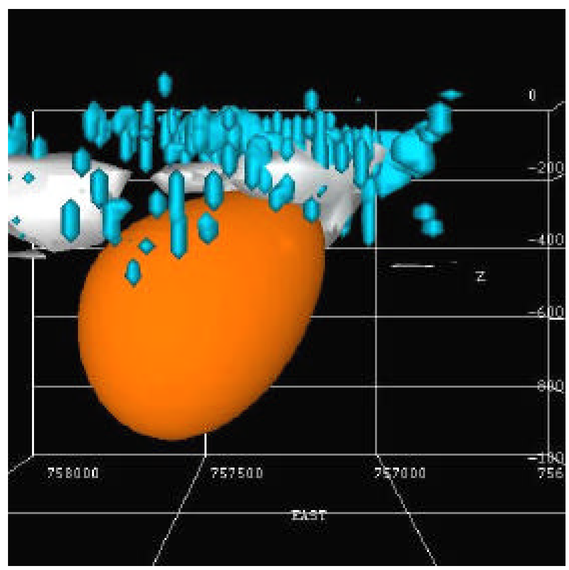

Figure 3: High density zones, derived from three different models. Blue: 50 meter cell representation of drill core densiries greater than 3.3 gm/cm^3. Grey: a Vulcan model interpolated from drill logs showing densities greater than 3.3 gm/cm^3. Orange: A 3D inversion model (25 meter mesh) calculated from the residual gravity; the orange zone encloses densities greater than 3.0 gm/cm^3. The depth range is 0 to 1000 meters, the origin starting at the base of the 100m thick tertiary cover.

Las Cruces 3D analysis.

Conclusions

The integration of mineral exploration data in 3D visualization and analytic systems provides for rapid analysis of complex multivariate data sets. At the Las Cruces deposit the 3D distribution of the mineralisation has been more conclusively established. At the same time anomalies and data errors not related to mineralization are identified with much greater certainty.

The functionality of the 3D-exploration system is now significantly advanced and a user can selectively choose macros and applications suitable for any project. Subsequent projects have included continental scale targeting, grass roots exploration and near mine detailed exploration. Environmental applications are also being considered.

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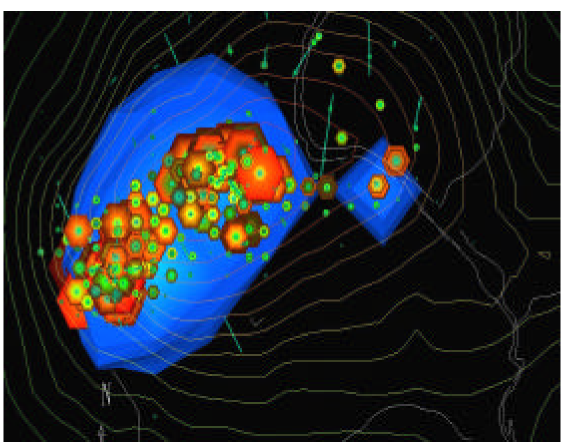

Figure 5: Plan view of 3D conductor interpolated from TEM soundings (blue isosurface encloses conductivities greater than 0.4 siemen). Drill hole traces show high copper grades as red and low green to blue. The diameter of each drill hole is linearly proportional to the measured core densities. Contours represent the residual gravity anomaly as shown in figure 1.

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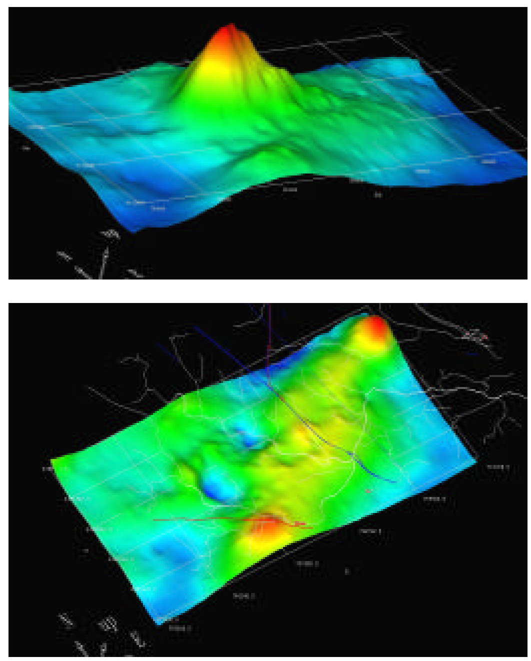

Figure 4: Top perspective surface is the observed residual gravity anomaly used for inversion modelling. (blue –0.5 to red 3.0 mgal). The lower perspective surface shows the difference between the gravity anomalies derived from forward modelling of the Vulcan density distribution (figure 3) and the observed anomalies. The SW-NE gravity ridge is the principal remaining anomaly.