High Resolution Controlled Source Magneto-Telluric Surveys on Massive Sulphide Deposits in Europe.

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Introduction

This paper presents the preliminary field results of data collected from a recent survey over a massive sulphide deposit in southern Spain. The survey was undertaken during the field testing phase of the CSEMM (**C**ontrolled **S**ource **E**lectro-**M**agnetic **M**apping) Project, which is being undertaken by a partnership of Metronix and CSA Ltd, Geological Consultants, Dublin, Ireland, and is financially supported by the Brite-Euram Industrial Research and Development Programme of the European Community.

CSEMM System

The purpose of the Brite-Euram Project was to develop and field test a high-resolution CSAMT system for application to mineral exploration of concealed targets at depths of between 50 to 1000 m.

The technical limitations of TEM and VLF constrain depth penetration to a maximum of several hundred meters, and data can generally only be displayed in one dimension. The practical limitations of standard MT are the long measuring time and the low energy of higher natural frequencies.

The CSEMM transmitter generates a source field in a frequency range of 0.5 Hz to 8192 Hz and is located about 12 km from the multichannel receiver, which measures 5 electric fields and 3 orthogonal magnetic fields for the full impedance tensor. In this field test, the electrode spacing at the receiver site was 30 m. Transmitter and receiver are synchronized by highly stable GPS-clocks. In the frequency domain robust processing reduces the error to a minimum and decreases the measurement time. Online calibration of the complete system (magnetometers, cables, analog filters) yields a precision of less than 2 degrees in phase. The signal to noise ratio can be improved by initial stacking of the time series.

Field productivity is dependent on electrode spacing, terrain and access, but using two electrode arrays at the receiver site, it is possible to cover up to 1000 profile-m per day.

Geology of the Test Site

The selected test area is located at Aguas Tenidas in the Spanish sector of the Iberian Pyrite Belt (IPB). The geology of the IPB consists of a succession of volcanics and sediments of Devonian to Carboniferous age. The pyrite-rich massive sulphide deposits are hosted within a sequence of rhyolites, rhyolitic and chloritic tuffs and black shales. Near surface mineralisation was mined earlier this century, and recent exploration at Aguas Tenidas Este has identified a semi-continuous massive sulphide zone about 1200 m long at depths of about 200 m in the east to 850 m in the west. The deposit is bound to the north by a distinctive, east-west striking, normal fault. The subsurface geology is controlled by a series of exploration drill holes. Previous geophysical surveys in the area include TEM and gravity (Hopgood & Hungerford, 1994).

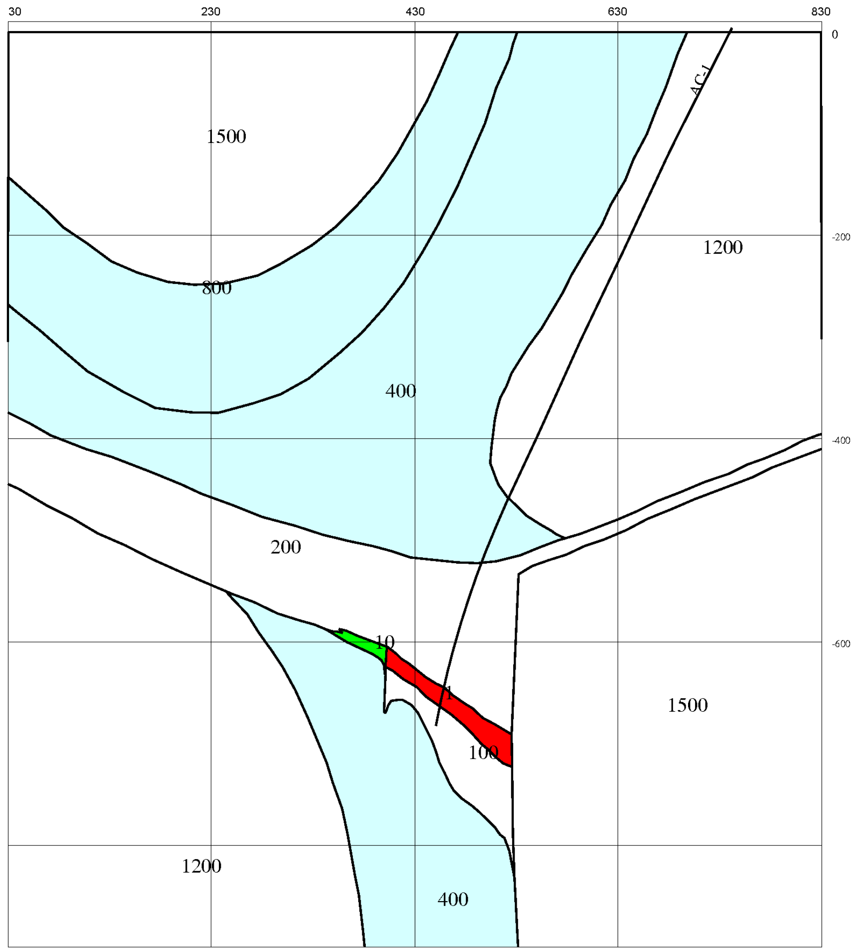

Figure 1: Cross-section along one profile, Aguas Tenidas Este, compiled by CSA showing location from drilling of the massive sulphide body (red) and laterally adjacent oxide mineralisation (green). Rock resistivities for different lithological units from Hopwood & Hungerford (1994) and company data in ohm*m.

Geophysical Interpretation

The raw data was decomposed using Eggers eigenstates in order to describe the 2-dimensional components of the data (Eggers 1982). The Smith & Booker (1991) programme RRI (rapid relaxation inverse) was used for the 2D inversion. The results from a profile are displayed as a resistivity cross section in Figure 2, and data from 9 profiles have been compiled as a resistivity plane view for a depth of 658 m in Figure 3.

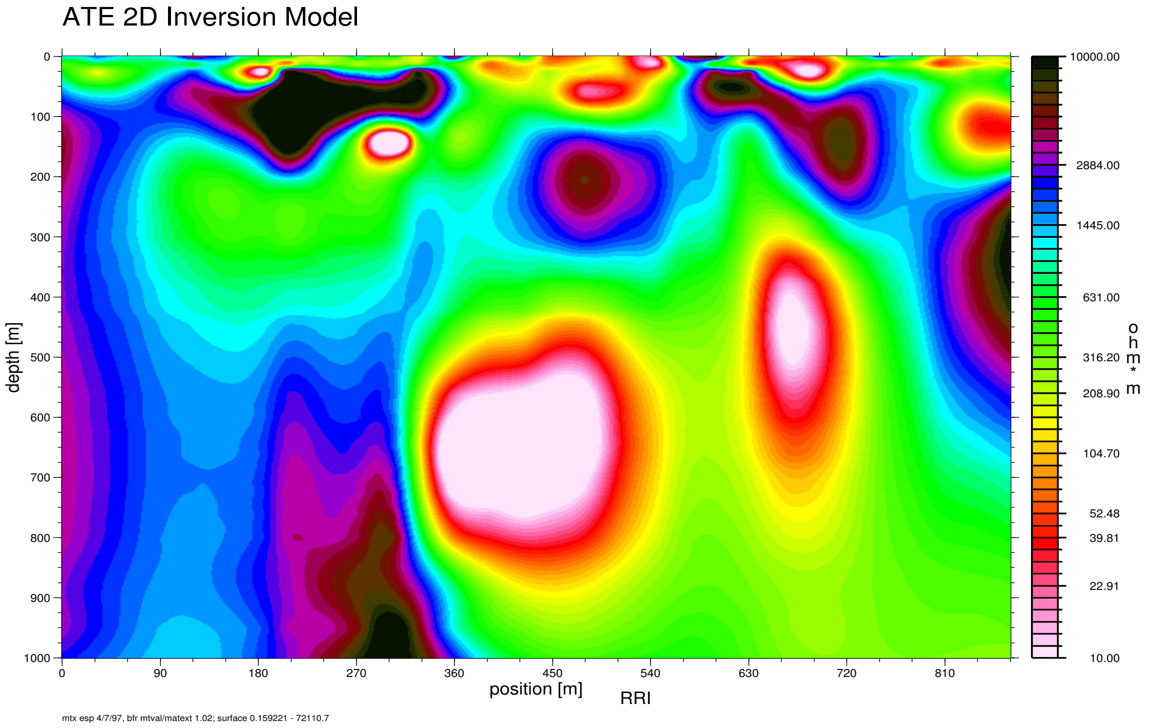

Figure 2: Resistivity-depth interpretation for one line, Aguas Tenidas Este

The good conductors near the top of the section are probably reflecting the shallow massive sulphide mineralisation that was mined previously. In addition there is a near surface conductive layer that persists across the whole section, and may be due to weathered rock. High level, near surface conductors represent a serious problem for the interpretation of other EM data, however the CSEMM can identify structures beneath this layer.

In the middle of the section between 330 - 510 N there is a strong conductive zone at a depth range from 550 to 730 m. This corresponds to the main zone of mineralisation shown in

Figure 1. The distinct vertical break in the resistivity pattern at 630 N coincides with the ore-controlling, east-west trending, normal fault shown as marking the northern limit to the mineralisation on Figure 1. The conductor at 690 m and 450 m depth has not been drilled.

To the south (left hand) of the known mineralisation, the broad resistivity pattern reflects the lithological distribution shown in Figure 1.

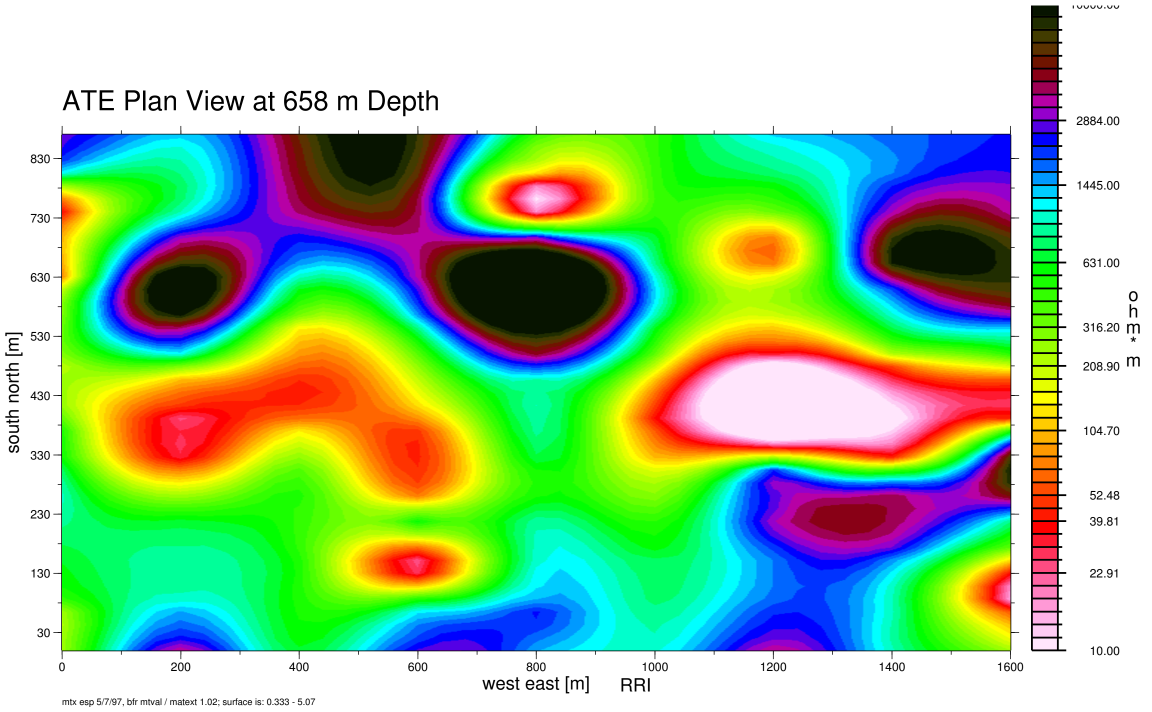

Figure 3: Resistivity-plane view of the survey area at a depth of 658 m.

The distribution of the highly conductive zone on Figure 3 (1000E to 1500E) corresponds to the plane view of the massive sulphide mineralisation at 660 m as interpreted from drilling. The W-E trending normal fault to the north of the massive sulphide mineralisation appears to extend further to the west of the known mineralisation.

The weakly conductive zone at 200E to 600E is a response from the mineralisation in the overlying Aguas Tenidas mine. This mineralisation extended to a depth of about 300 m, and the mining operations were abandoned in the 1930´s.

Acknowledgements

Permission from Navan Resources plc, holder of the Aguas Tenidas Este property, to present this data in this abstract is gratefully acknowledged. It is also a pleasure to thank Navan for their support and cooperation during the fieldwork. The financial support of the European Community Brite-Euram Industrial Research and Development Programme is also gratefully acknowledged.

References

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Appendix

The two following images provide additional details for geophysicists, and emphasise the capabilities of CSEMM.

In Figure 4 high phase angles (dark blue colors) indicate zones that are *overlying* good conductors. It can easily be seen that even the raw data provides a first impression of the resistivity structure - although without precise depth information.

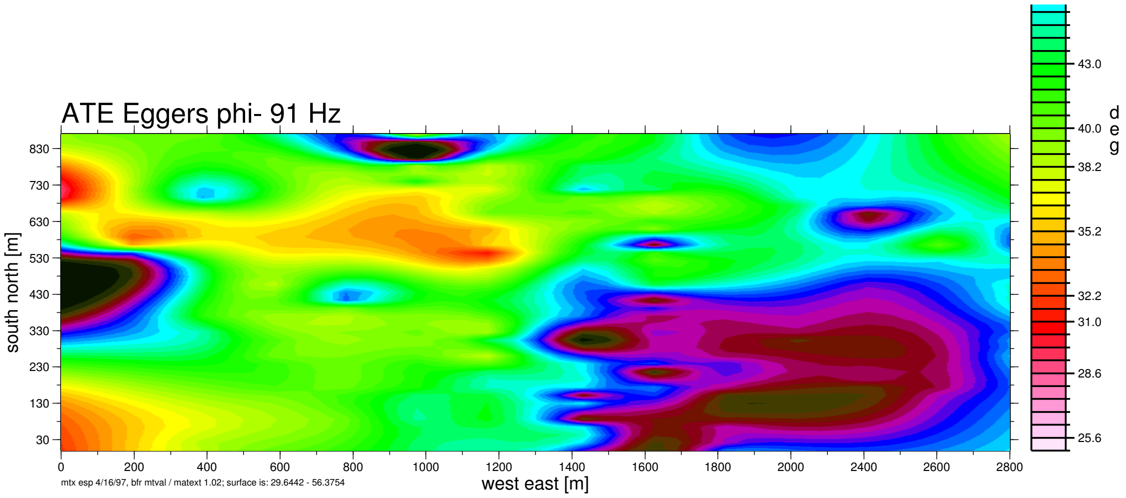

Figure 4: Phases plan view of the survey area at 91 Hz (approx. depth 500 - 700 m)

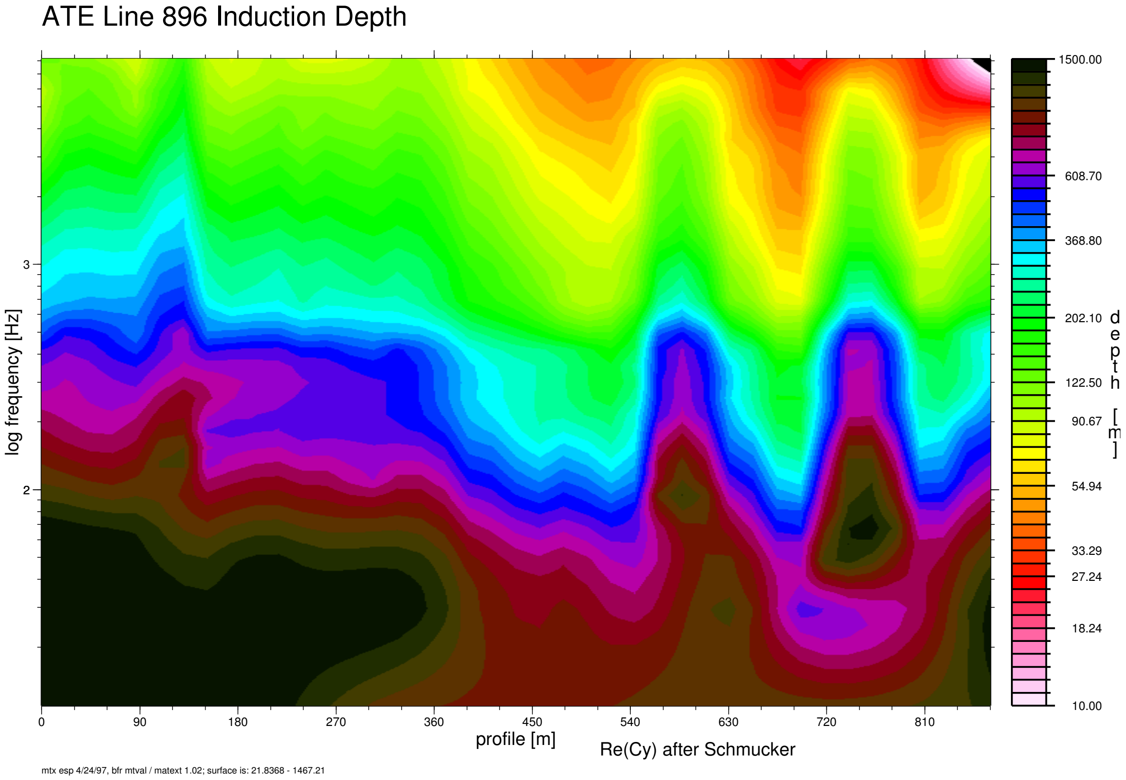

Figure 5: Induction depth

Figure 5 demonstrates that the lowest frequencies (11 Hz and 1 Hz are possible) induce currents that are definitely below the target depth.

This emphasises the depth penetration of the CSEMM system, even through a conductive near surface weathering zone.

The productivity and costs of a CSEMM survey can be illustrated as follows:

- 1 km2 can be covered with a profile spacing of 200 m in 5 days - this provides data that can be interpreted to depths of 1000 m;
- the costs for this would be less than 2 diamond drill holes to depths of about 500 m.

We consider the most useful and cost-effective situations for CSEMM surveys include drill-target definition in exploration projects with initial intersections of massive sulphides. CSEMM will provide information regarding the size, extension, location and depth of conductors related to these intersections.

A 2D model has been calculated from the data acquired on each of the profiles across the ATE massive sulphide mineralisation in southern Spain (see Figure 2 for an example).

Figure 7 shows a 3D view derived from 2D models calculated from eight N-S profiles spaced 200 m apart.

The 3D view shows the conductivity characteristics of a cubic kilometre, and is displayed as a cut-out shown in Figure 6.

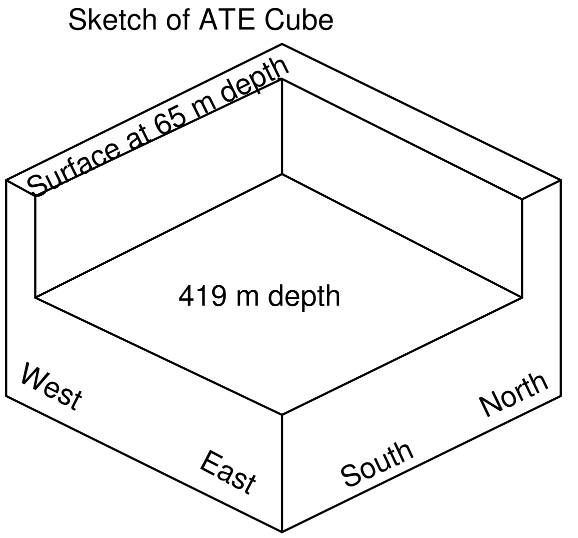

Figure 6: 3D Sketch for Figure 7

The colour scheme on the Figure 7 is related to the scales shown in Figures 2 and 3, but due to the different software used it has not been possible to use exactly the same colour spectra. In order to obtain a better 3D impression of the cube, the resistivities that show as green in Figures 2 and 3 (mid-range resistivities) are rendered transparent in Figure 7.

The geology of Aguas Tenidas area is extremely complex, and at this stage it is not possible to make any direct correlations between specific lithologies and resisitivity patterns. However, the 3D view does show the following features that are known from drilling:

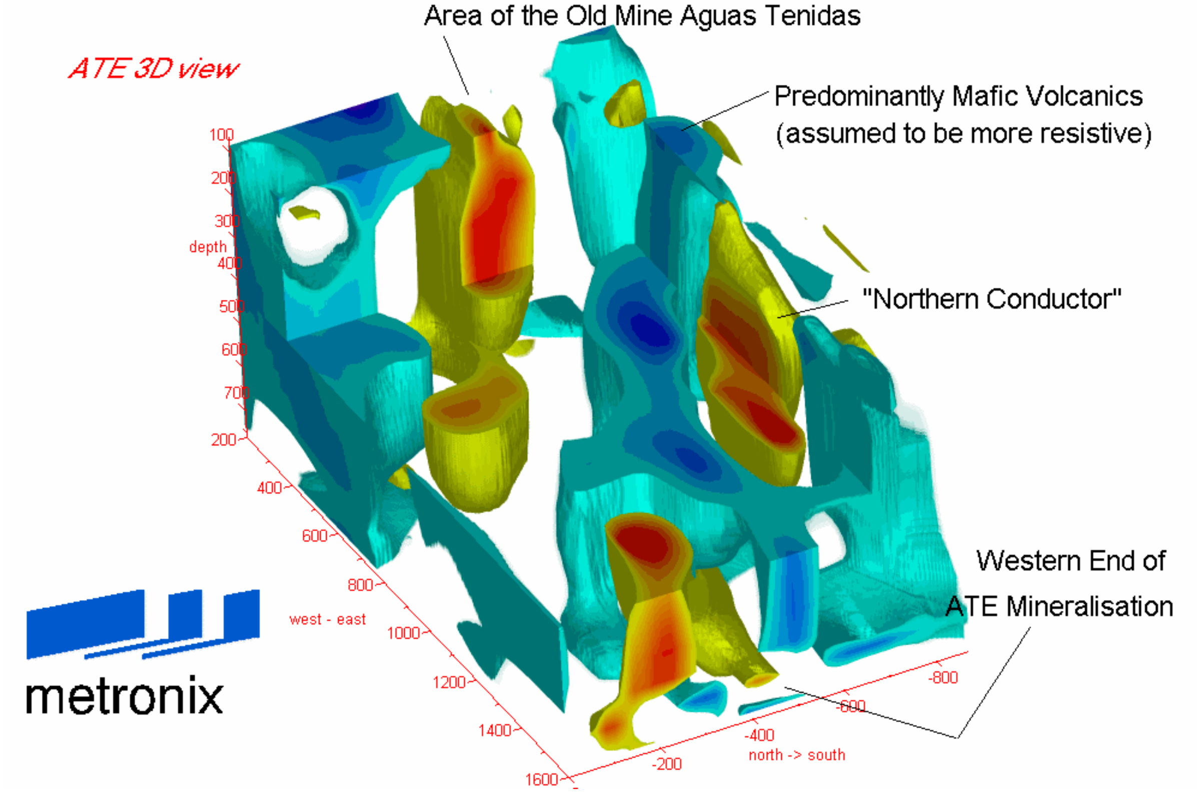

Figure 7: 3D Visualisation of 2D Models

- the western end of the main ATE mineralisation intersected in a drillhole at a depth of 650 m;
- the area of the old Aguas Tenidas Mine at shallow depths;
- an E-W striking zone of high resistivity, predominantly mafic volcanic rocks that form the northern boundary to the known mineralisation.

In addition to this, the following features are identified and interpreted as follows:

a possible extension to depth and the SE of the near-surface mineralisation at the old Aguas Tenidas Mine;

a conductor of unknown affiliation (the "northern conductor") at a depth of about 450 m north of the above-mentioned mafic volcanic unit. The 3D view suggests, however, that there is a possible break in the mafic volcanic unit and that there may be a structural connection between ATE and this "northern conductor" (compare also Figure 3).

The cut-out on the 3D perspective is at 419 m, which emphasises the "northern conductor" compared to the deeper conductors such as ATE, whereas at a greater depth such as that shown in the plan view for 658 m (Figure 3) the ATE conductor is clearly the dominant feature compared to the "northern conductor".