

2-D and 3-D IP/resistivity inversion for the interpretation of Isa-style targets

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ABSTRACT

A total of twenty line kilometres of IP, DC resistivity and MT data have been acquired using MIMDAS, (MIM's Distributed Acquisition System), over the Cluny prospect, south of Mt Isa. The utilisation of two-dimensional and three-dimensional inversion programmes has provided a significant advantage in the interpretation of these data.

The integration of geology and geophysics through the use of inversion, particularly three-dimensional inversions, has greatly improved the geological understanding of the Cluny region. It has enabled the identification of variations along linear conductors, and anomalous chargeable zones. This has implications for the ability of geophysics to provide discrimination for mineralisation along linearly extensive stratigraphy.

INTRODUCTION

A wide variety of geophysical techniques have been applied to exploration for Isa-style copper targets over the Mt Isa lease, since 1953. Historically, gravity surveys and aeromagnetic surveys were used as primary methods of exploration. The early application of geophysical techniques is discussed by Shalley, 1997. Electromagnetic (EM) and induced polarisation (IP) methods were initially disregarded due to the complexity of the geology and the strongly conductive nature of the stratigraphy. Following trials of downhole EM, it was shown that EM techniques were able to provide suitable discrimination between conductive host stratigraphy and economic mineralisation (Fallon and Busuttill, 1992), forming the basis for the successful introduction of EM methods into exploration over the Mt Isa lease.

Since 1997, and particularly within the last 18 months, geophysical techniques have driven the exploration effort. The dominant technique used is combined IP, resistivity (controlled source) and magnetotelluric (MT) methods, using MIMDAS. Through the use of MIMDAS, these techniques are able to penetrate more deeply, with increased resolution and confidence, than early IP methods. This approach has produced substantial quantities of high quality geophysical data to be interpreted and integrated with known detailed geology and geochemistry.

The use of inversion programmes and data integration is an integral part of geophysical interpretation. The following steps represent the method undertaken for this interpretation:

1. Two-dimensional inversion;
2. Geological and geochemical integration;

3. Partial reconciliation;
4. Three-dimensional inversion;
5. Target identification and drilling;
6. Reconciliation.

The two-dimensional inversions of the IP and resistivity data were completed using the Zonge inversion code, TS2DIP, (McInnes, 1999), and University of British Columbia (UBC) DCIP2D code, with three-dimensional inversions undertaken using the UBC DCIP3D inversion code (Li and Oldenburg, 2000).

This case history details a MIMDAS survey and subsequent interpretation over the Cluny prospect during 1999. Cluny is an historical copper prospect located at the southern end of the Mt Isa lease, as indicated in Figure 1. A total of 20 line kilometres of 100 m pole-dipole, dipole-dipole IP/resistivity and MT data were collected over ten survey lines, with a line spacing of 500 m.

GEOLOGICAL BACKGROUND

The geology of the Cluny region and the southern extent of the Mt Isa lease is dominated by fault-repeated, steeply dipping stratigraphy of Native Bee Siltstone, Breakaway Shale, Moondarra Siltstone, incorporating Mt Novit Horizon, Surprise Creek Formation and Eastern Creek Volcanics. The Mt Novit Horizon consists of a sequence of mica schists, phyllites and metasilstones



Fig. 1. Location of the 1999 MIMDAS survey over the Cluny target zone. The grid on the figure is 5 km x 5 km.

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Geological Unit	Resistivity (Ohm.m)
Native Bee Siltstone	12.5
Breakaway Shale	1.6
Moondarra Siltstone	15
Mineralisation (av. 4.8% Cu)	0.7

Table 1. Electrical properties of the stratigraphy within the Cluny survey region (Fallon and Busuttil, 1992).

containing gossanous material of coarse grained pyrite, pyrrhotite, and magnetite, with variable sphalerite, galena, marcasite, chalcopyrite, arsenopyrite and accessories (Russell, 1978). Exploration along this horizon has occurred over a 40 year period. The best drilling intersection recorded is from a 4 m interval containing 100 g/T Ag, 7.6% Pb and 11.6% Zn (Poole, 1981). Table 1 highlights the electrical properties of the conductive geological units, and the expected bulk copper mineralisation as measured throughout the Mt Isa region.

Generally, the mineralisation has a strong conductivity contrast with the host stratigraphy, except for the graphitic and weakly pyrrhotitic Breakaway Shale. At Mt Isa, copper mineralisation is frequently expected with lead/zinc mineralisation. This is also the case within the Cluny region. Native Bee Siltstone and Moondarra Siltstone are considered to be favourable host stratigraphy for mineralisation.

INVERSION METHODS AND RESULTS

Two-dimensional inversion

Detailed surface geological mapping and drilling are available in the survey area, allowing considerable control to be incorporated into the two-dimensional inversions. Constraints for horizontal and vertical smoothness were applied to account for the steeply dipping stratigraphy. These inversions were completed using TS2DIP (Zonge software), as displayed in Figures 2(a) and 2(b), and also UBC DCIP2D. Figure 2(a) shows the series of sections resulting from the two-dimensional inversions of the resistivity data, and Figure 2(b) shows the IP inversion result. These sections are displayed to a depth of 800 m, and are considered reliable to at least this depth, as confirmed through drilling. MT data were also inverted, and although not discussed in this paper, the MT inversion results showed a close correlation with the controlled source resistivity inversion.

The resultant DC inversion sections show the dominance of the conductive Breakaway Shale and also highlight the Mt Novit Horizon. An exploration target was delineated in the interpretation, as a conductive and chargeable feature. This occurred within a region that the geological interpretation highlighted as favourable host stratigraphy (Native Bee Siltstone), and was not considered to be the conductive Breakaway Shale. The location of the anomaly with respect to the mapped geology is indicated in Figure 3.

Once the target was drilled, geological logging, geochemistry and downhole EM were completed. The integrated interpretation of these data identified the anomalous conductive and chargeable response as the result of an unexpected faulted repetition of Breakaway Shale, and not a target within the Native Bee Siltstone, as originally mapped. Minor pyrrhotite and chalcopyrite were intersected in veins throughout the hole.

The results from this drill hole were a major factor in increasing the level of confidence placed upon using geophysical inversions to map the subsurface geology. This reliance upon the geophysics necessitates the availability of the best possible inversion.

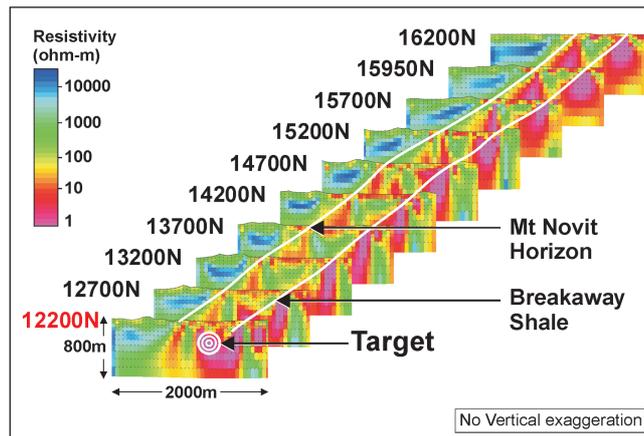


Fig. 2(a). Series of stacked resistivity inversions of the Cluny survey. Horizontal and vertical scaling are identical.

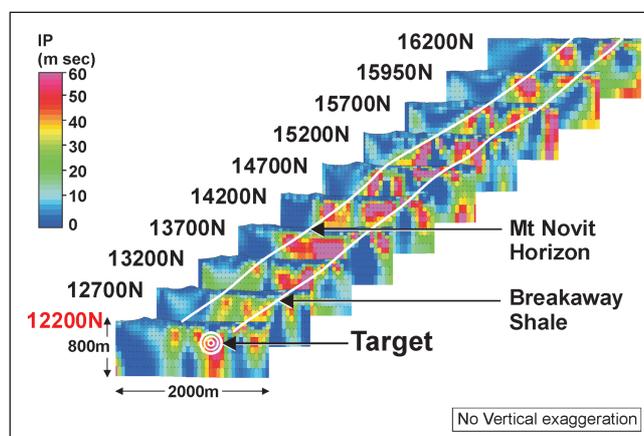


Fig. 2(b). Series of stacked IP inversions of the Cluny survey. Horizontal and vertical scaling are identical.

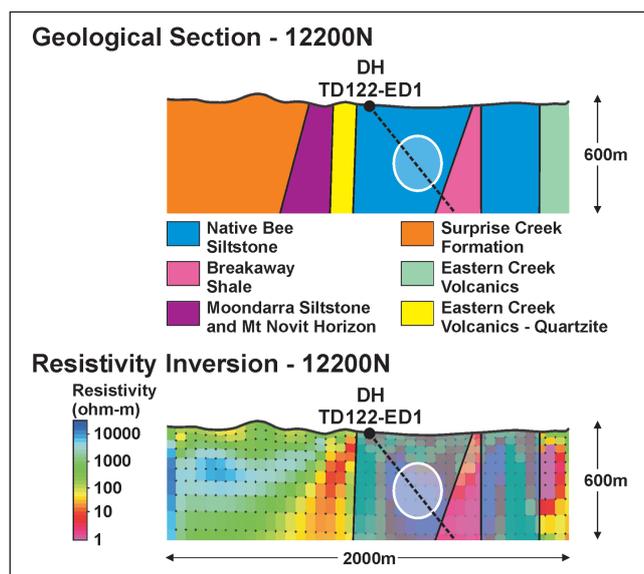


Fig. 3. Interpreted geology section and resistivity inversion for line 12200N of the Cluny survey. The exploration target is identified by the shaded circle, and the drill hole (TD122-ED1) by the dotted line.

Three-dimensional inversion

To optimise the available information from the geophysical data collected over the Mt Isa lease, a three-dimensional geophysical inversion, using the UBC DCIP3D software, was completed.

The complete set of pole-dipole, dipole-pole data is comprised of 3678 observations. As the true noise of these data were not known, each datum was assigned a first pass standard error of $5\% + 0.0001$ volts. The three-dimensional earth model was divided into $(100 \times 42 \times 33)$ cells for a total of 138600 cells. The horizontal dimensions of the cells in the survey area were 25×125 m; the thickness of the cells was 12.5 m at the surface, increasing with depth. The inversion algorithm was designed to produce uniform smoothness in all three spatial directions and the length scale parameter was 250 m. The DC inversion was run using a misfit criterion. A misfit of 4689 (corresponding to a chi-squared factor of 1.27) was achieved after 16 iterations. The result, which took 278 hours on a 500 Mhz single processor machine, is shown in Figure 4(a). The Breakaway Shale unit, with resistivities as low as 0.01 ohm-m is the dominant feature, with a weaker conductive region visible to the west. This weaker conductor is coincident with the Mt Novit Horizon.

The sensitivities from the resistivity model were computed (CPU time was 11 hours) and the IP data were then inverted. For the initial inversion an error of $5\% + 2$ ms was assigned to each IP datum. The mesh and model objective function minimised were the same as those used for the DC inversion, and the inversion was carried out using a misfit criterion. The initial IP inversion was unsuccessful. Difficulties arose in reproducing the very large negative chargeabilities for long offset data obtained when the current electrode was on the east (32 values were less than -100 ms). Those data could not be inverted with the two-dimensional inversion algorithm either and so data with an n-spacing of greater than 10 were discarded for the electrode configuration with the current electrode to the east. This left 3243 observations. Even after removing these, the specified error level could not be fitted. After several inversion runs, a model misfit to a chi-factor of 4 was accepted. This results in underestimating the noise by a factor of two. Because the geological structure is clearly striking north-south, this extra geological information was incorporated into the final inversion by increasing the smoothness in the north-south direction. The length scales were $(L_e, L_n, L_z) = (250, 750, 250)$. The final chargeability image, achieved after 8 iterations and 4 hours of CPU time, is shown in Figure 4(b). The western IP zone coincides with the Mt Novit Horizon, which is the weak linear conductor in Figure 4(a). The eastern IP anomaly lies on the western flank of the Breakaway Shale unit. Both units exhibit considerable variation along strike. In the Mt Novit Horizon, these variations reflect changes in the grade of mineralisation.

The pixel images in Figures 4(a) and 4(b) convey quantitative information about the values of the physical properties in each cell. Complementary information is obtained by viewing the models in an iso-surface format. Figures 5(a) and 5(b) show the resistivity and IP models plotted with iso-surface values of 2 ohm.m and 37 ms respectively.

The use of the three-dimensional inversions can be extended to characterise the along strike variations in linearly extensive chargeable or conductive zones. Within the Cluny region, the Mt Novit Horizon is such a zone of interest. As indicated in the geological discussion, numerous holes have been drilled into this horizon, with varying intersections obtained. Figure 6 is a slice through the 3D chargeability model with the Mt Novit Horizon highlighted. Drillholes, containing significant lead intersection results, are superimposed on this figure. Table 2 is a summary of the drill results for the intersected Mt Novit Horizon. As can be seen from the comparison of Figure 6 and Table 2, areas of increased chargeability correlate with areas of increased lead mineralisation.

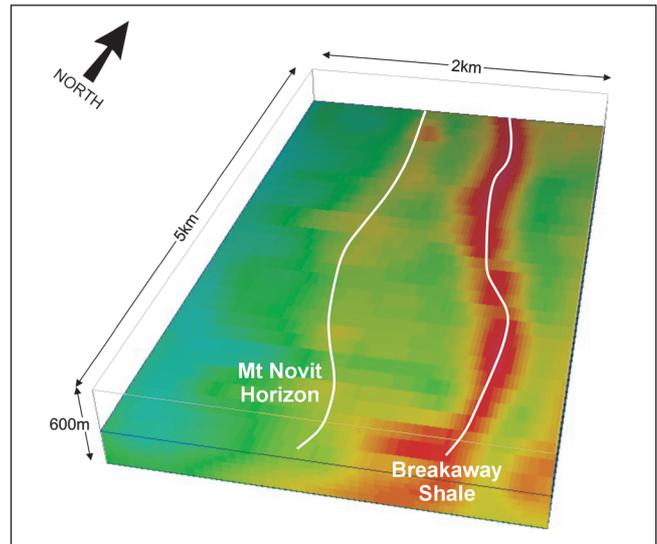


Fig. 4(a). Three-dimensional block view of the resistivity inversion of the Cluny survey at a depth of 281.25 m from the highest point in the survey region. Colour stretch from 0 -10000 Ohm.m

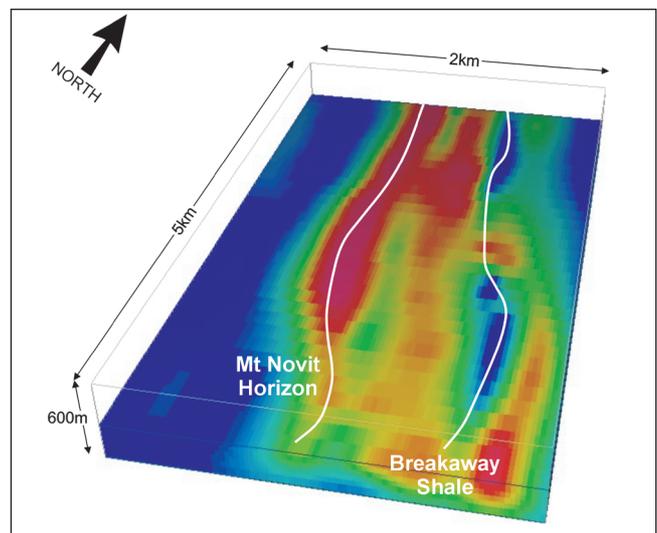


Fig. 4(b). Three-dimensional block view of the IP inversion of the Cluny survey at a depth of 281.25 m from the highest point in the survey region. Colour stretch from 0 - 45 ms.

Comparison

The results from the two-dimensional (both TS2DIP and DCIP2D) and three-dimensional inversion methods compare favourably. Given the relatively uncomplicated geological setting, this is not an unexpected outcome. The two-dimensional inversions, when used in conjunction with known geological constraints, provide a close approximation to the subsurface geology. This two-dimensional inversion process is relatively straightforward, requiring minimal data manipulation and short computing run-times. Higher quality inversion results are obtained when geological constraints can be applied to the inversions.

The three-dimensional inversions show exceptional closeness to the revised geology, and are able to provide an understanding of the lateral variations in the physical characteristics of the conductive and chargeable units. These variations become increasingly important when stratigraphy, such as the Mt Novit Horizon, are of high exploration potential. Identifying variations in the conductivity and chargeability along linear conductive units,

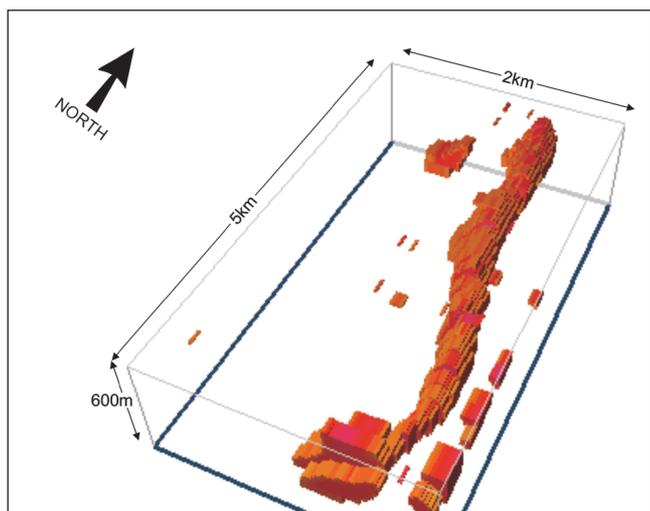


Fig. 5(a). Three-dimensional resistivity model is plotted as an isosurface with a cutoff of 2 ohm-m.

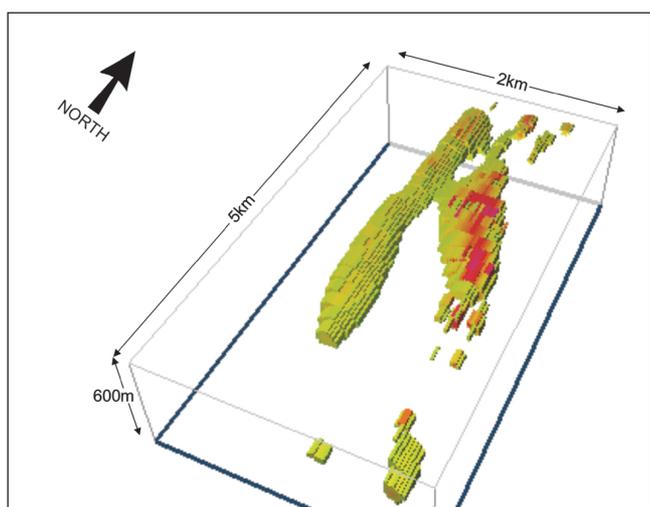


Fig. 5(b). Three-dimensional chargeability model is plotted as an isosurface with a cutoff of 37 ms.

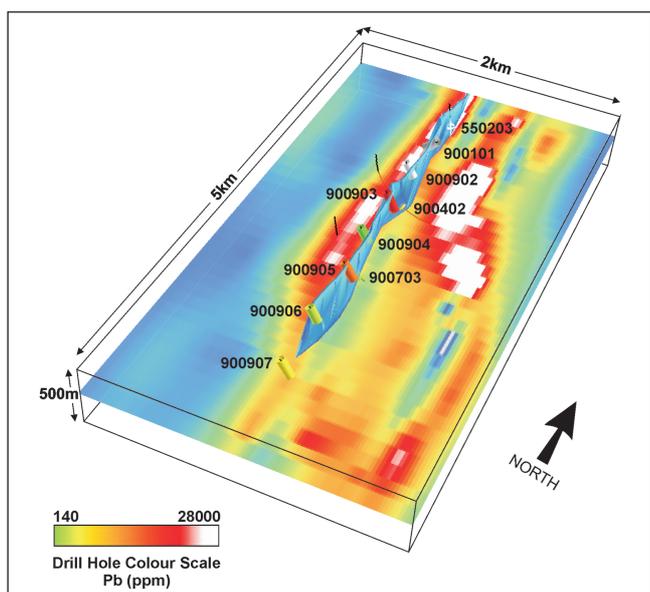


Figure 6. View of the three-dimensional chargeability block model. The blue unit on the western side of the image is the Mt Novit Horizon, with the significant drillholes

Drill Hole Name	Pb Intersections	From	To
550203	28000 ppm	214.6	215.3
900402	17400 ppm	527.7	528.4
900703	220 ppm	403.6	404.4
900901	11000 ppm	60.0	62.0
900902	8500 ppm	131.0	132.0
900903	710 ppm	124.0	125.0
900904	140 ppm	96.0	98.0
900905	540 ppm	150.7	152.5
900906	210 ppm	106.0	107.0
900907	270ppm	126.0	127.0

Table 2. Best drilling intersections along the Mt Novit Horizon, within the Cluny area, as highlighted in Figure 6.

which correlate with increases in economic grade, has significant exploration implications. The disadvantage in the application of the technique occurs in the necessity for heavy data manipulation and long computing run-times.

CONCLUSIONS

In areas of relatively simple geology, generally conventional two-dimensional inversion techniques are able to provide an adequate understanding of the region. Where the geology becomes more complex, for example, rapid changes in strike between adjacent survey lines caused by folding and faulting, or where the level of geological control is low, the dependency upon the use of three-dimensional inversions increases. The results from the Cluny survey have demonstrated the importance of understanding inversion results and the ability to form integrated geophysical, geological and geochemical interpretations. They have provided an appreciation for the variation in linearly extensive stratigraphy as a function of mineralisation.

This survey has been the first step towards undertaking a full three-dimensional survey, from acquisition to interpretation, thereby providing a more realistic appreciation of the three-dimensional nature of exploration. The use of the full three-dimensional inversion capabilities has provided an additional level of understanding in the geophysical and geological interpretation within the Mt Isa lease.

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