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Understanding problems in old MT data using modern methods

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SUMMARY

Although the natural-source magnetotelluric method is relatively simple compared to controlled-source EM methods, the MT impedance estimates sometimes pose difficulties for modelling/inversion. Here we focus on two well-known legacy datasets that have never been completely understood. The first of these is the BC87 dataset, which exhibits Phase Roll Out of Quadrant (PROQ) for low frequency PhaYX data at all sites on the Nelson batholith, but none of the sites off the batholith. The second is Okak Bay, with very unusual dropping RhoA values at some sites close to an imaged and drilled conductor at some 500 m. Using a modern 3D MT inversion code that incorporates galvanic distortion, we can fit the PROQ effects in the BC87 data, but the model may not be geologically meaningful. The Okak Bay data remain enigmatic. An updated version of the code that inverts log(Z) and phaZ instead of Real(Z) and Imag(Z) does come close to having the steep RhoA curves, but not completely.

Keywords: 3D MT inversion, BC87, Okak Bay

INTRODUCTION

The natural-source magnetotelluric method (MT) is one that is seeing increasing usage across the globe, particularly commercially for imaging mineral deposits and geothermal systems. Although modelling and inversion tools are well advanced, there remains some data that still present significant challenges.

We examine two legacy datasets here, BC87 and Okak Bay using modern 3-D inversion. Both of these datasets have aspects that were perplexing at the time.

We conclude that fundamentally more data are needed at both locations in order to really understand the subsurfaces beneath them.

BC87

The BC87 dataset was acquired by Phoenix Geophysics in 1987 as the first test of contracting MT data for Lithoprobe through a Lithoprobe grant to Doug Oldenburgh. Data were acquired at a total of 27 locations from the Purcell Anticlinorium over the Kootenay Arc and the Nelson batholith onto the Omineca Belt (Fig. 1). The data were acquired in site-pairs, with approximately 2 km spacing between them, because in those days timing for remote-referencing was accomplished through a cable connection between the two sites. A description of the data can be found in Jones (1993).

One distinctive feature of the BC87 data is that the low frequency phases for the E-W electric field, i.e., PhaYX, at sites ON the batholith all go out of their quadrant, whereas at sites OFF the batholith this Phase Roll-Out of Quadrant (PROQ) doesn't happen.

An example is site 02 in the middle of the batholith, and the data are plotted in Fig. 2. Note the PhaYX data (blue symbols) leaves the 3rd quadrant by 2 s period and rotates into the 4th quadrant.

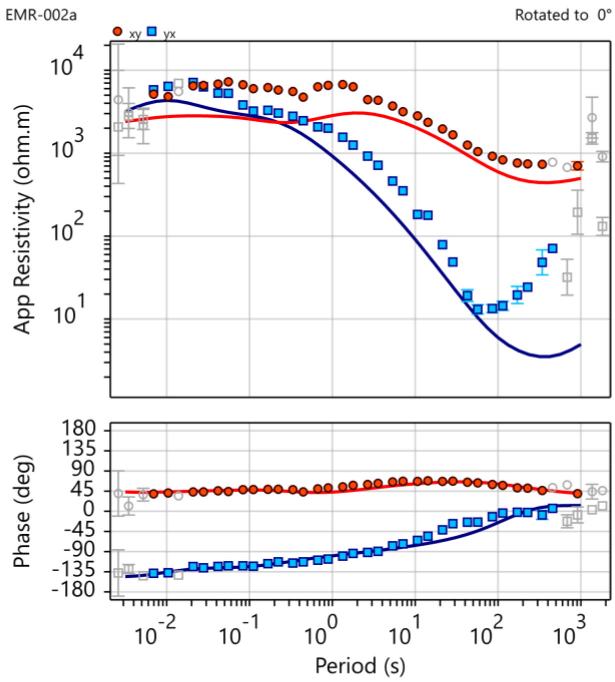

Figure 2: MT data at site 02. Solid lines are the model fit. Red = XY; Blue = YX.

A contour plot of the out-of-quadrant phases shows the PROQ effect limited to the extent of the batholith.

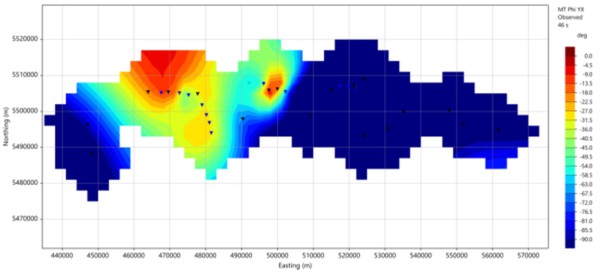

Figure 3: Out-of-quadrant PhaYX phases at 46 s period.

Despite these data being one of the datasets examined in the first MT Data Inversion Workshops (MT-DIW2), held in Cambridge, UK, in 1992, and quite a few authors looking at them, a satisfactory explanation has never been proffered. 3D galvanic distortion of a regional 2D Earth was unsatisfactory (Jones et al., 1993), as were other suggestions.

Additional data are available for this area and were acquired in 1988 by Advanced Energy Technology (AET) using their newly-developed EMAP system. The bipoles were 1000 feet in length, and the remarkable PROQ effect was seen in all of the data on the batholith. The change occurred over one dipole length, from off-batholith to on-batholith.

We undertook extensive 3D inversion of these data using the RLM-3D code of Randy Mackie (Mackie et al, 2020), which allows for galvanic distortion (Soyer et al, 2018).

The current best model is shown in Fig. 4. Weird 3D geometries of near-surface conductors in the area of the Nelson batholith combined with very large crustal conductors to the south are imaged. The geological interpretation is that there is a conducting sequence at the base of the batholith, and the conductor to the south is known from regional data in SE BC and NW Montana on the Purcell Anticlinorium (Gupta & Jones, 1995).

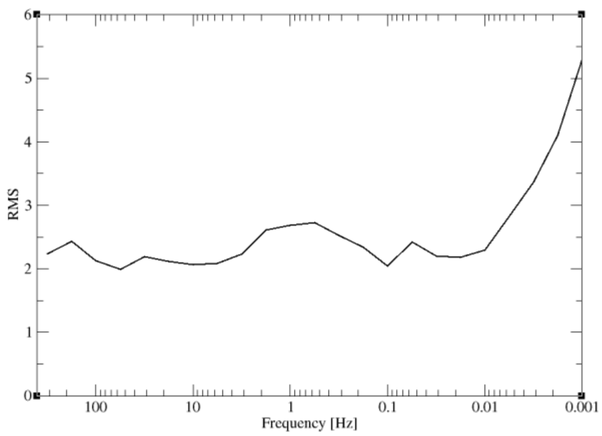

Figure 5: BC87 Average misfit by frequency.

The misfits to this model show a bias, with high misfits at low frequencies (Fig. 5).

OKAK BAY

The second puzzling dataset comes from Okak Bay in northern Labrador. This 46-site dataset (locations shown in Fig. 6) was acquired for a commercial client (Gallery Resources) by Phoenix Geophysics in 1997. The survey area was chosen based on a magnetic high, with the hope that another Voisey's Bay was there.

Initial RRI inversions by Phoenix suggested a shallow anomaly, and a deeper very extensive one. Drilling (OK1-M1, OK-M2/OK-M3 locations in Fig. 6) found the shallow anomaly, but not the deeper one.

One aspect of the dataset is the very steeply-declining RhoA curves at low frequencies <10 Hz, exemplified by site *gal005* (Fig. 7). The decline is greater than 45° (solid line on the RhoA plots), and is inconsistent with the phase responses (dashed lines on the RhoA plots).

2D analyses by Jones and Garcia (2003) showed this RhoA-Pha inconsistency, which possibly led to the erroneous deep highly conducting body. Jones and Garcia (2003) inverted data along the various transects down to only 10 Hz in 2D, and a pseudo-3D model was constructed from the 2D models.

Trials were made of all sites, the core of sites, and of site *gal005* on its own, allowing extreme rapid variations in conductivity by turning the smoothing off, and allowing extreme galvanic distortion.

The current best 3D model (Fig. 8) shows a conductive anomaly exactly where the pseudo-3D model, created from 2D inversions, placed it.

Although the final model from 3D inversion was able to fit reasonably well (Fig. 9), it was not able to match the steep RhoA drop at site gal005 (Fig. 10).

Also the average RMS at each frequency shows a very strong bias, with high and low frequencies being poorly fit, and mid-band frequencies being very well fit (Fig. 11). This plot is an exemplar that a single number does not well describe how close a model is to the data, and higher level statistics need to be considered (Jones, 2018).

To address this problem of misfitting RhoA at *gal005* at low frequencies, the code was modified to invert for log(|Z|)-phaZ instead of Real(Z)-Imag(Z), and emphasis was placed on fitting the impedance amplitudes. This was somewhat more successful, although not entirely. The fit when inverting only site gal005 in shown in Fig. 12.

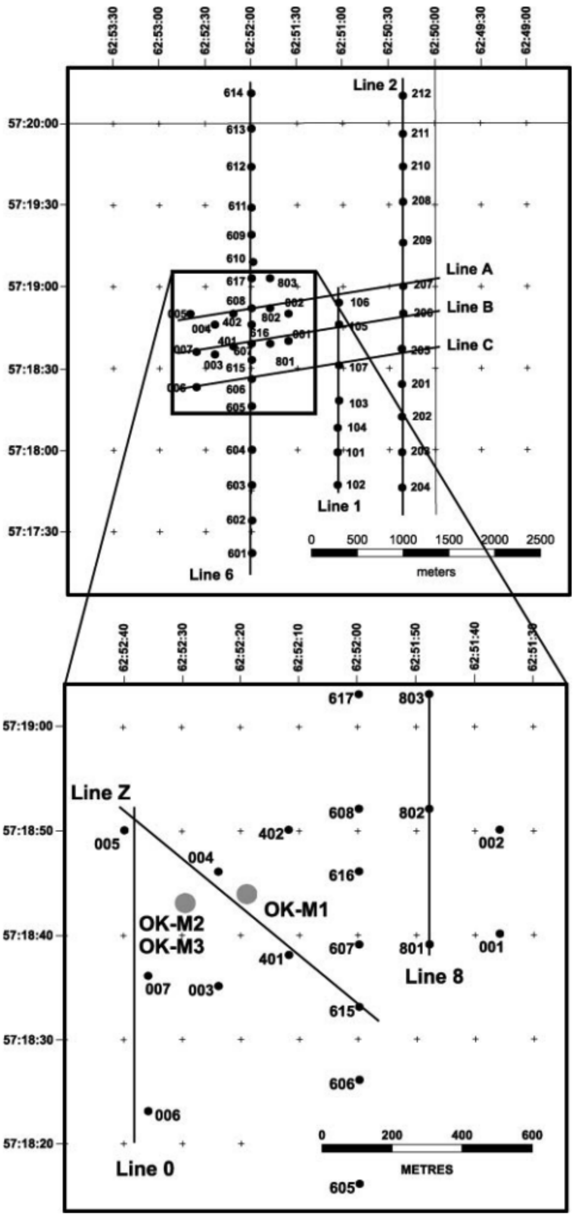

Figure 6: Map of AMT site locations in the Okak Bay deposit area. The AMT sites were assigned to the nine profiles shown (0, 1, 2, 6, 8, A, B, C, Z). Also shown are the locations of the drillholes OK-M1 and OK-M2/OK-M3.

CONCLUSIONS

Although we have come a long way since the Dark Ages of the 1970s when one of us (AGJ) first started making MT measurements, and MT has become a very viable geological tool, there are still challenges. These two datasets show us some of the modelling and statistical challenges.

Unfortunately, with both of them we are data poor – we need far more data in order to fully understand them.

Also, there is the question as to the veracity of the low frequency RhoA data for site *gal005* of the Okak Bay dataset.

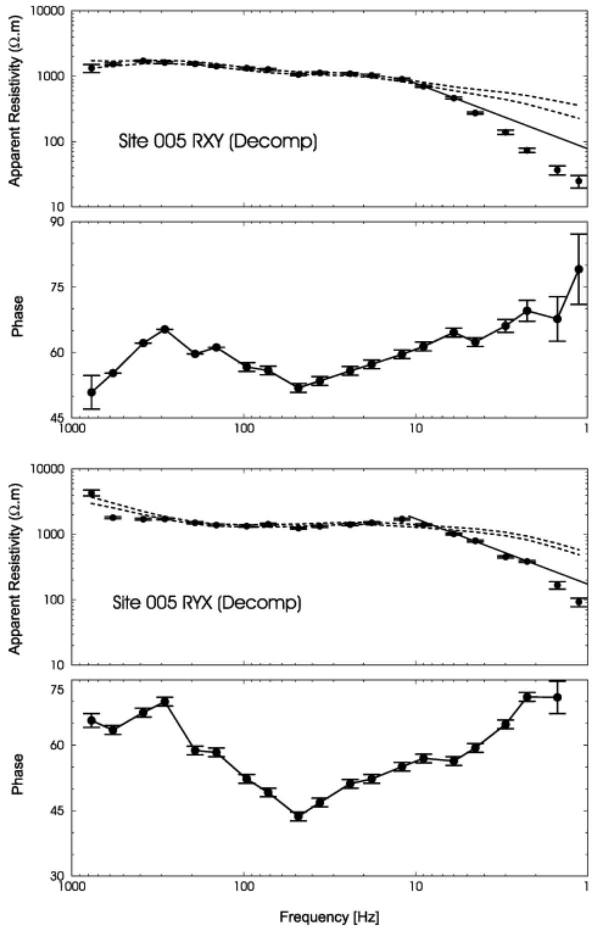

Figure 7: Derived low-frequency tensor decomposed apparent-resistivity data for site 005 together with their prediction (dashed lines show ± one standard error) from the phase data using Parker and Booker’s (1996) Rho$^+$ algorithm. The solid lines in the apparent resistivity plots show the decay for an infinitely conducting substratum. Also shown are the decomposed phase data.

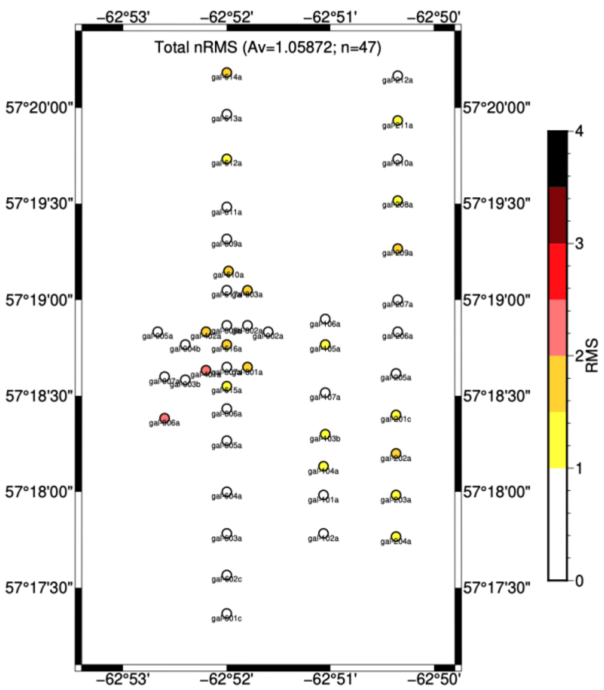

Figure 9: Total RMS for all sites.

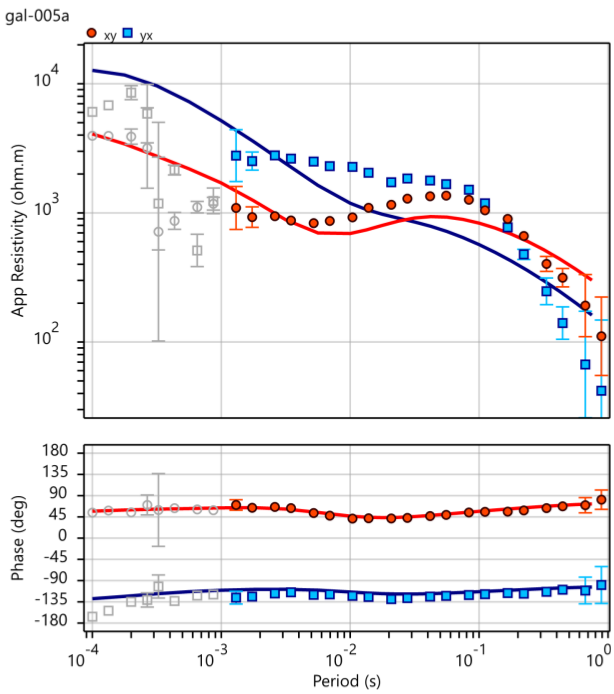

Figure 10: Best fitting model to site gal005.

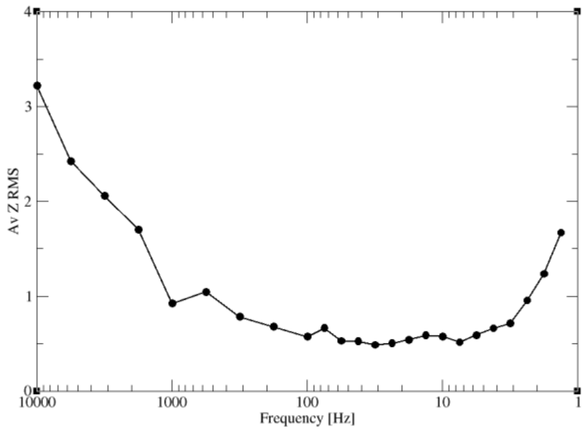

Figure 11: Average Z RMS at each frequency.

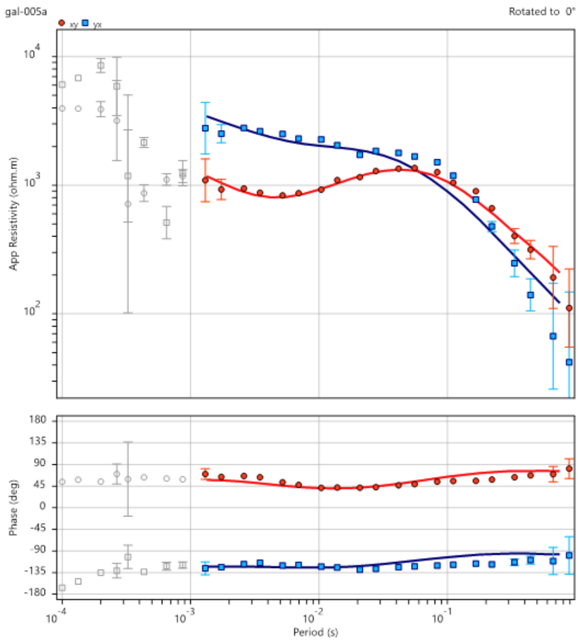

Figure 12: Fit of the 3D model to gal005 using the code inverting for log(|Z|)-PhaZ.

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The Okak Bay dataset was also acquired by Phoenix Geophysics for Gallery Resources.

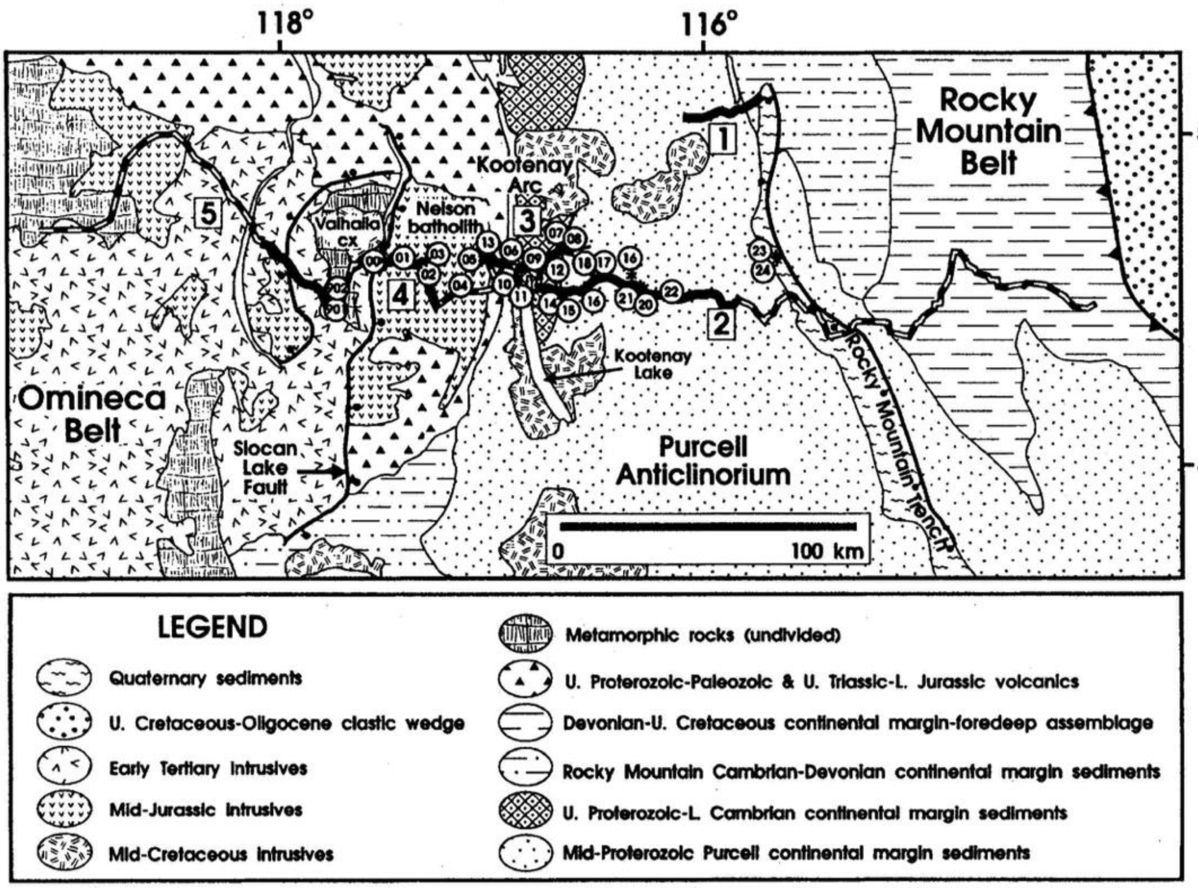

Figure 1: Simplified geology map of the region (based on COOK et al., 1988) showing the locations of the MT sites (numbers in circles), the seismic reflection lines (solid lines with associated numbers in squares) and seismic refraction receiver points (dashed line). Overlapping circles indicate local/remote 10-channel pairs.

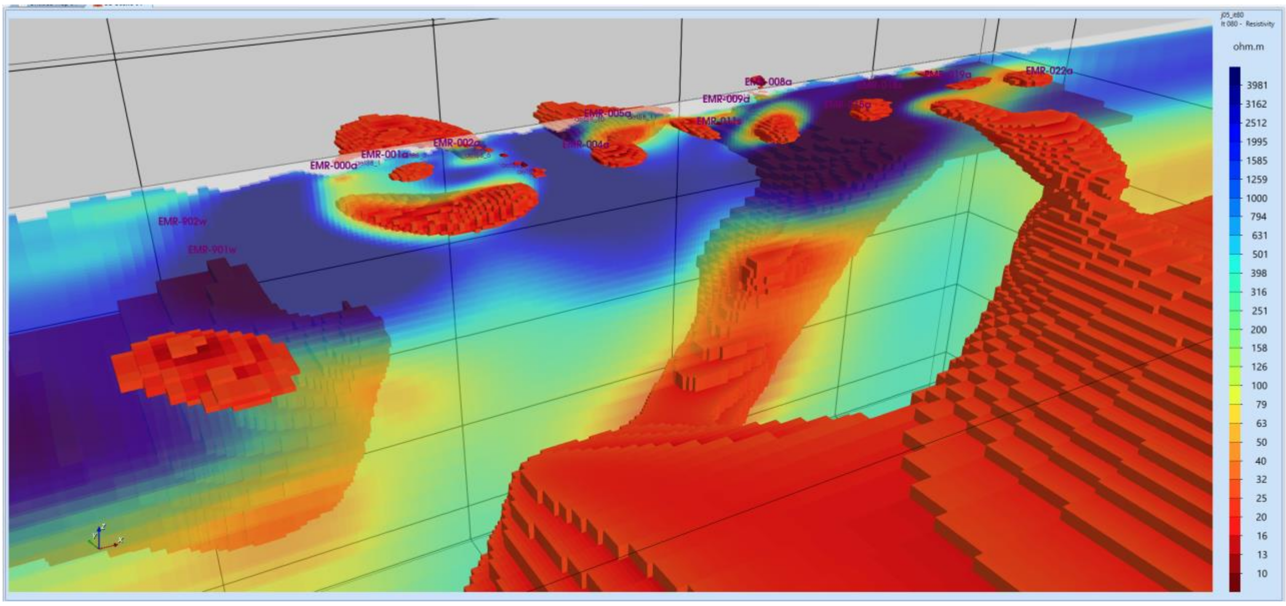

Figure 4: Current best 3D model to the BC87/EMAP88 data. The solid surface is 30 Ωm.

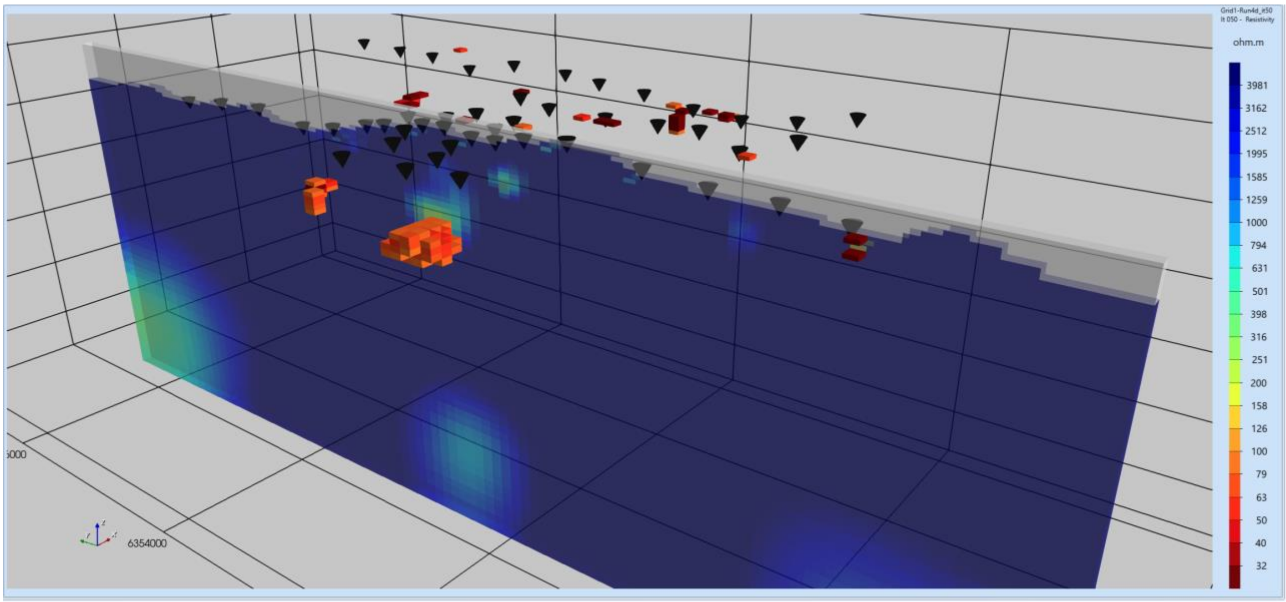

Figure 8: Current best 3D model of the Okak Bay dataset. The surface is at 100 Ωm, and the slice is along Line 6. View from the SW towards the NE.

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