Delineation of Porphyry Deposit by 3D Airborne Time Domain Electromagnetic Inversion

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Summary

The Mt. Milligan Cu-Au porphyry deposit has a complicated 3D geometry that consists of a high resistivity central stock surrounded by a low resistivity alteration halo. Airborne time domain electromagnetic (ATEM) methods have the capability to image this. Traditionally results from 1D inversions are stitched together to form an image used for geologic interpretation. Unfortunately, for Mt. Milligan, this procedure results in artefacts that contradict the known geology. The true conductivity can be revealed only by inverting the data using a full 3D inversion algorithm. In this poster we show:

- The results obtained from a 1D inversion algorithm
- How the geometry and basic physics conspire to generate the artefacts
- 1D and 3D inversion results from a synthetic model that emulates Mt. Milligan
- 3D inversion of VTEM data and comparison with known geology

Geology of Mt. Milligan

Mt. Milligan is a Cu-Au porphyry deposit situated in north central British Columbia. It consists of several mineralization zones (Figure 1a). The typical model of a porphyry deposit is that a monzonite stock intrudes into a volcanic host and the alteration halo is formed symmetrically around the stock (Figure 1 b and c). At Mt. Milligan the intrusive system was also distorted by subsequent geologic activity so now the MBX stock is dipping west and is cut by a fault (Figure 1d). The monzonite stock is expected to be electrically resistive and the mineral-bearing alteration relatively conductive.

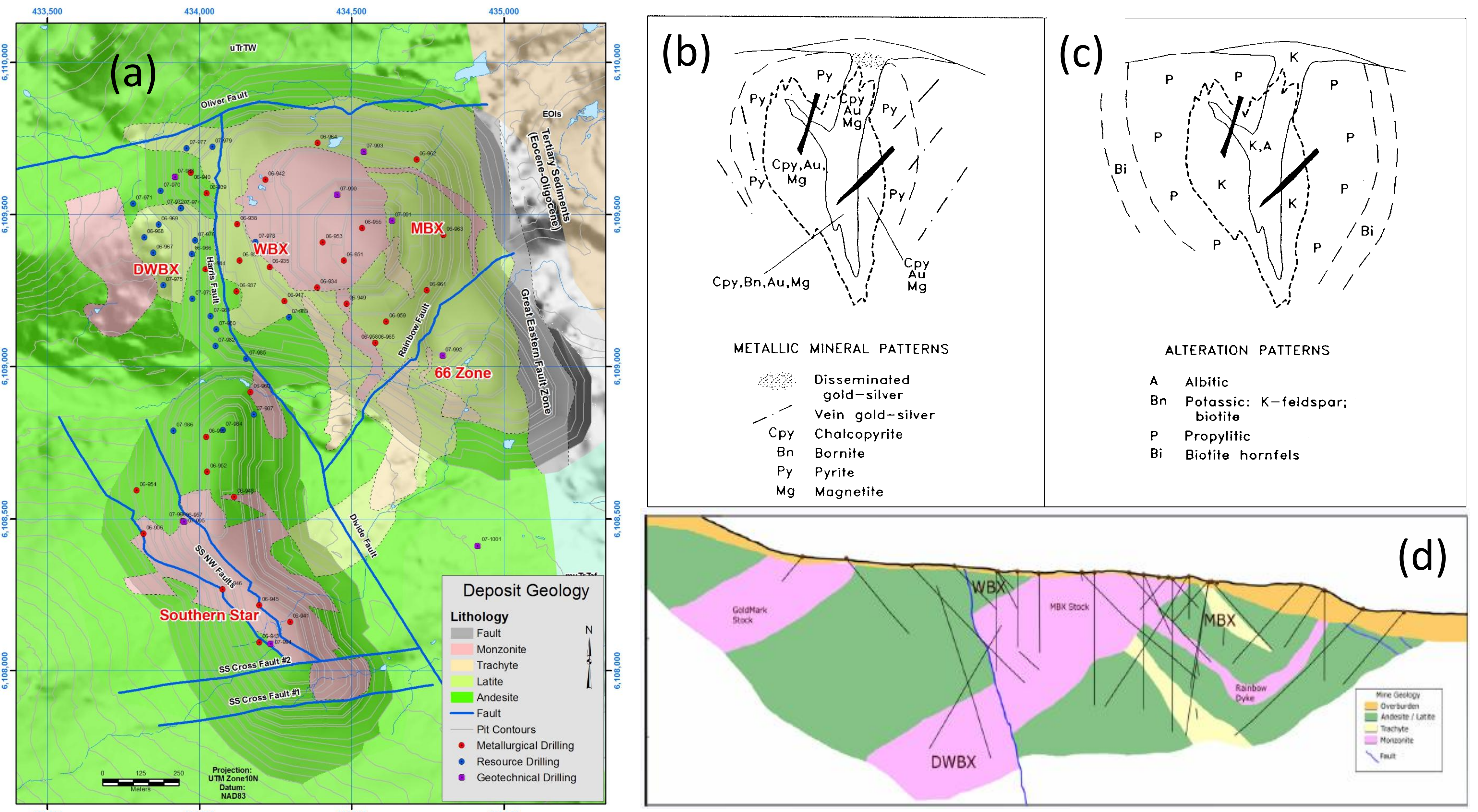

Figure 1. Geology of Mt. Milligan: (a) deposits; (b) metallic mineral distribution and (c) alterations of a typical intrusive Cu-Au porphyry system from McMillian (1991); (d) cross section at Y = 6109350;

VTEM Survey at Mt. Milligan

In 2007, Geotech Ltd. carried out a versatile time domain electromagnetic (VTEM) survey over the Mt. Milligan deposit area using a 200 meter line spacing (Figure 2). The VTEM system transmits quasi-square waveform at a base frequency of 30Hz and measures the off-time z-component of dB/dt at 27 time channels ranging from 99μs to 13645μs. The VTEM receiver is at the center of transmitter loop. There is considerable topography in the survey area.

Time Constant Analysis of VTEM Data

We calculate the time constants using channels 7-15 and plot the map in a logarithmic color scale (Figure 3). Large time constants indicate a good conductor; low time constants indicate resistive regions. The Southern Star stock area shows a low time constant but the MBX and DWBX stocks do not. The large time constants to the east reflect conductive sediments.

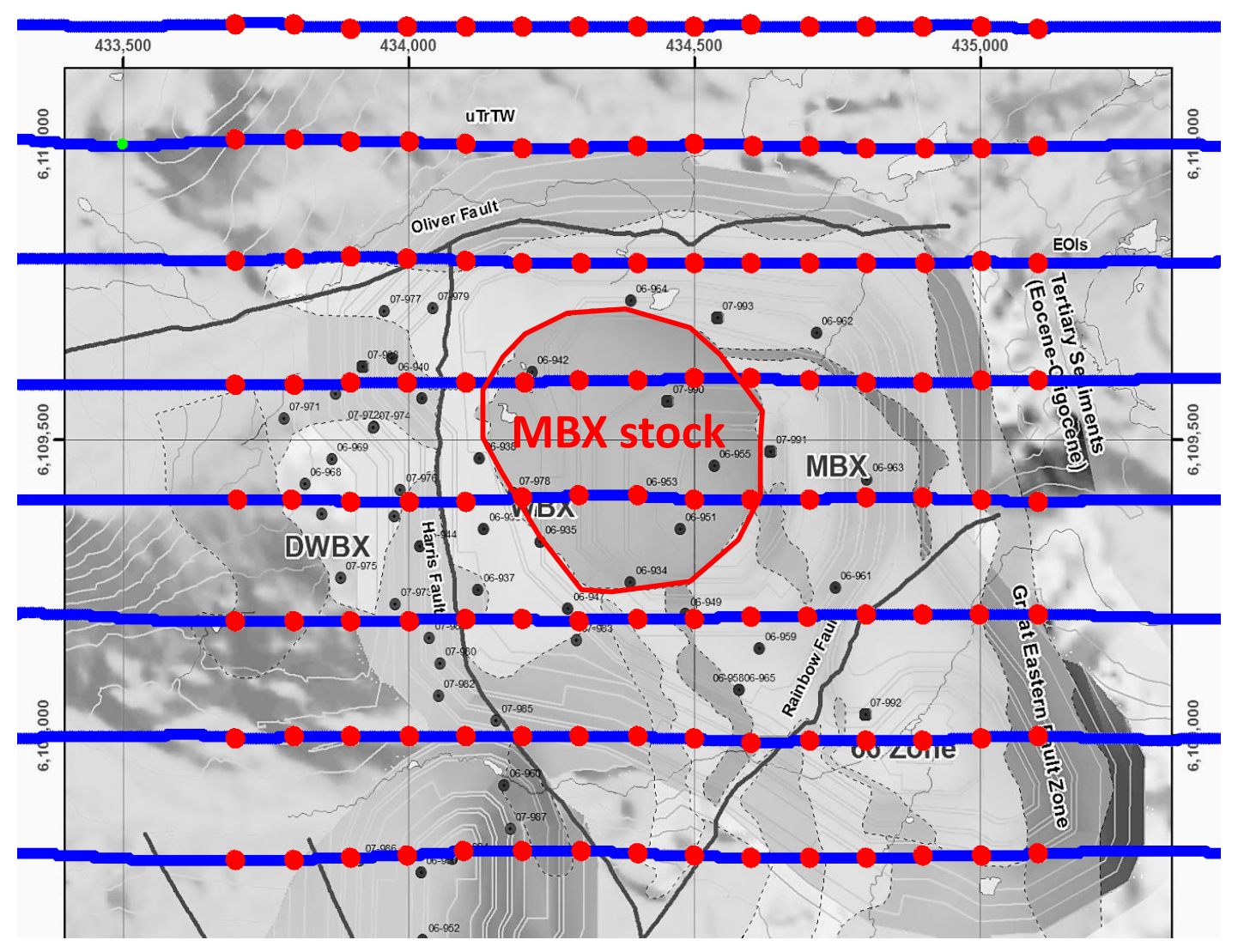

Figure 2. VTEM survey lines near the MBX stock (red dots indicating 3D inversion data grid)

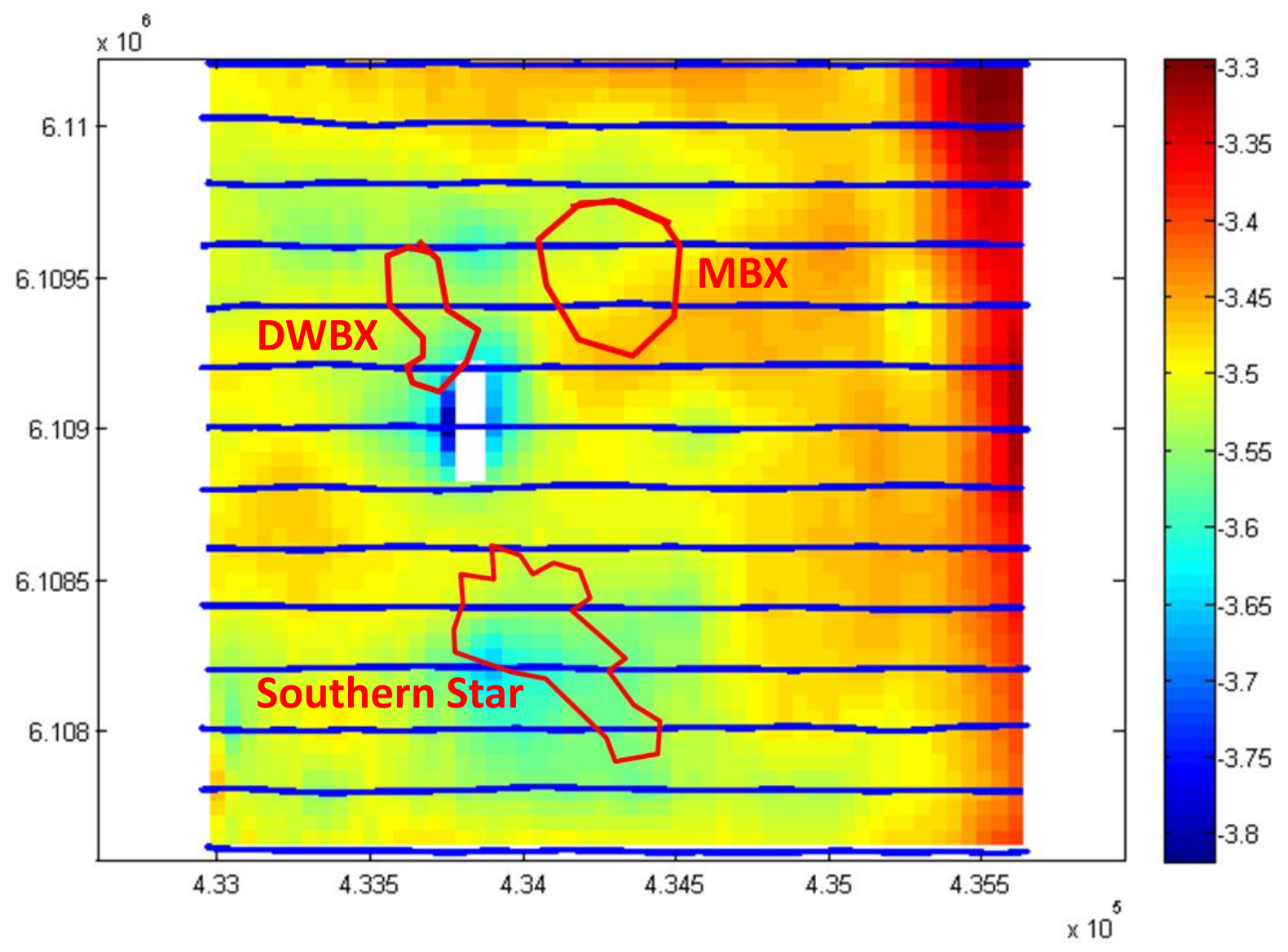

Figure 3. Time constant of Mt. Milligan Data (red wire frame indicating monzonites)

1D Layered Earth Model Inversion

In a 1D inversion we assume the earth is horizontally layered at each sounding location. The inversion models are stitched together to form a cross section and the geologic structure is overlaid (Figure 4). The MBX stock is imaged as a conductor rather than a resistor. This contradicts the geologic model.

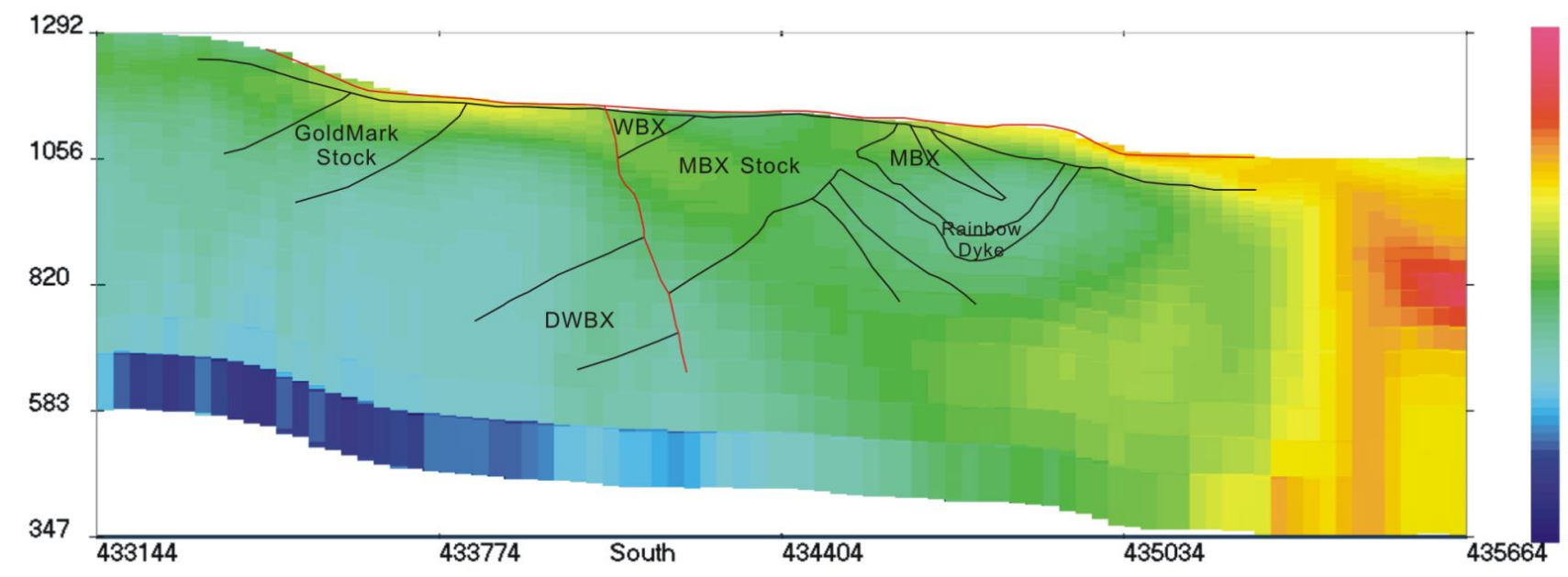

Figure 4. 1D inversion model of conductivity (cross section at Y = 6109400)

Synthetic Model Inversions

A synthetic model is designed to simulate a typical intrusive structure of the porphyry system as described in Figure 1. The model consists of: overburden, stock, alteration and the host. Reasonable conductivities are assigned (Figure 5). We use a 3D forward modelling code to generate simulated data at locations indicated by the red dots in Figure 5.

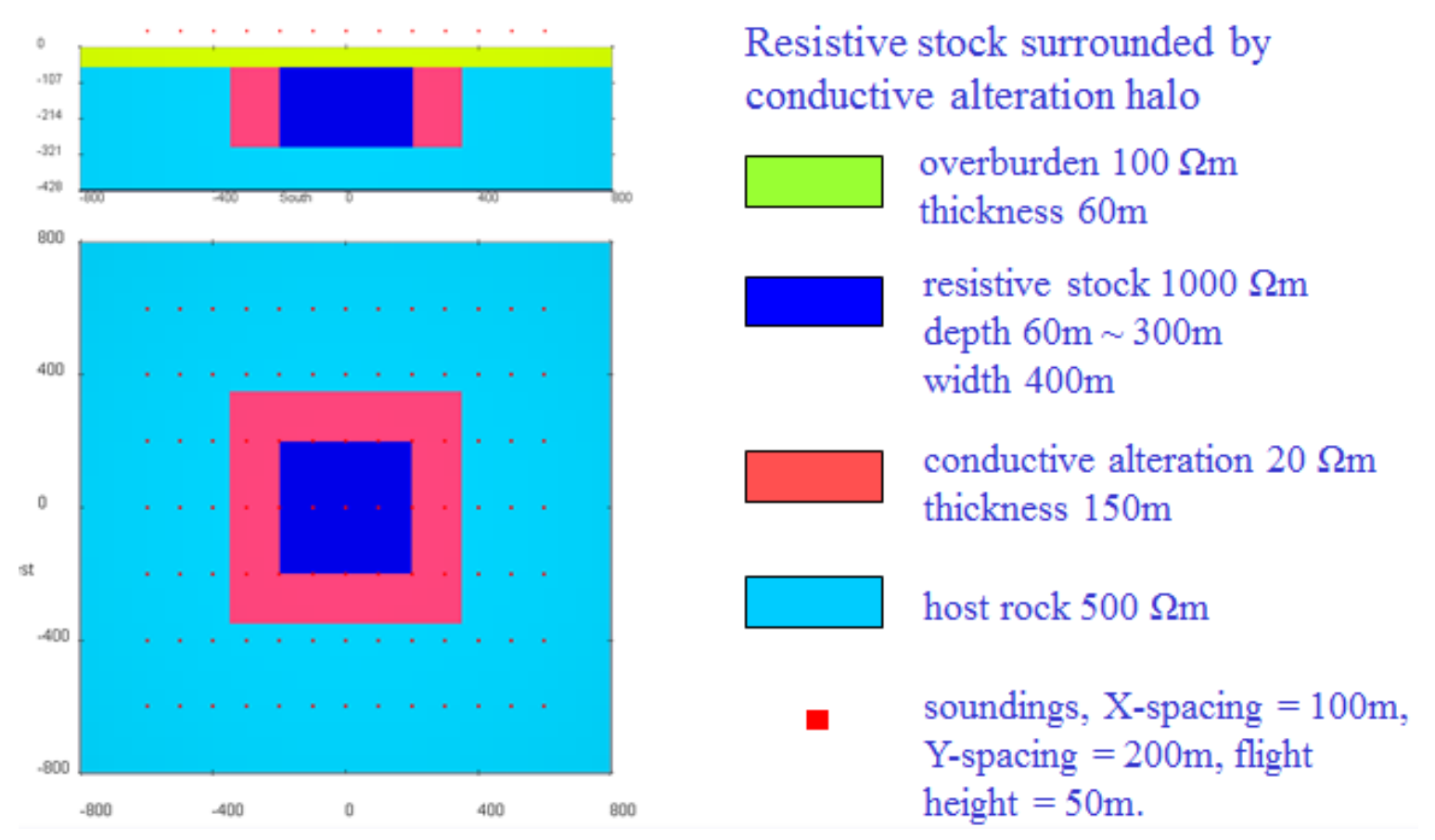

Figure 5. Synthetic model of intrusive porphyry system (top: cross section; bottom: plan view)

A 1D inversion of data along the survey line across the center of the stock is shown in Figure 6. The overburden and shallow parts of the model are well recovered. However the conductive layer at the base of the stock is an artefact.

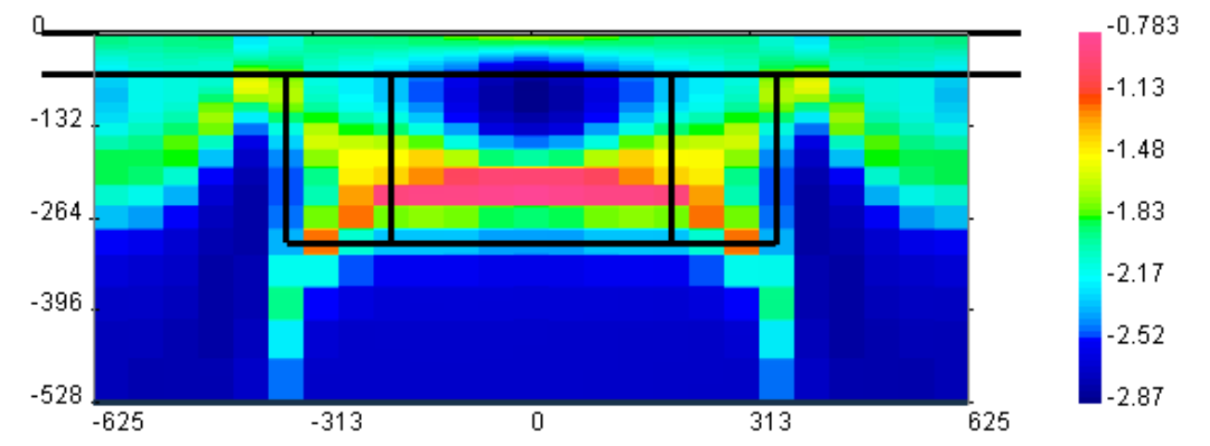

Figure 6. 1D inversion of the synthetic data (wire frame indicating the true model)

Next we invert the synthetic data set in 3D using the inversion code h3dtdinv (Oldenburg et al., 2008). The 3D inversion produces a more realistic model that delineates all the units with correct geometries and reasonable conductivities (Figure 7).

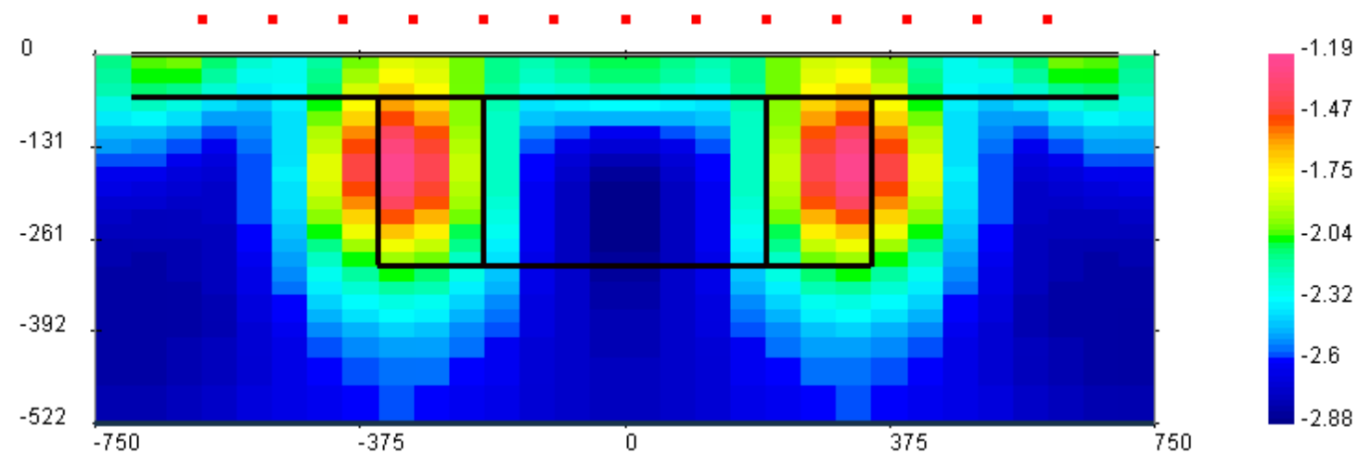

Figure 7. 3D inversion of the synthetic data (same cross section as Figure 6)

The artefacts in the 1D inversion can be explained by the "smoke ring" effect (Nabighian et al., 1991). The EM field excited by a horizontal transmitter loop propagates downwards and outwards. At late time the currents are trapped in the region of high conductivity around the stock. These currents produce a large dBz/dt at the receiver that is modelled as a conductor at depth when a 1D inversion is carried out.

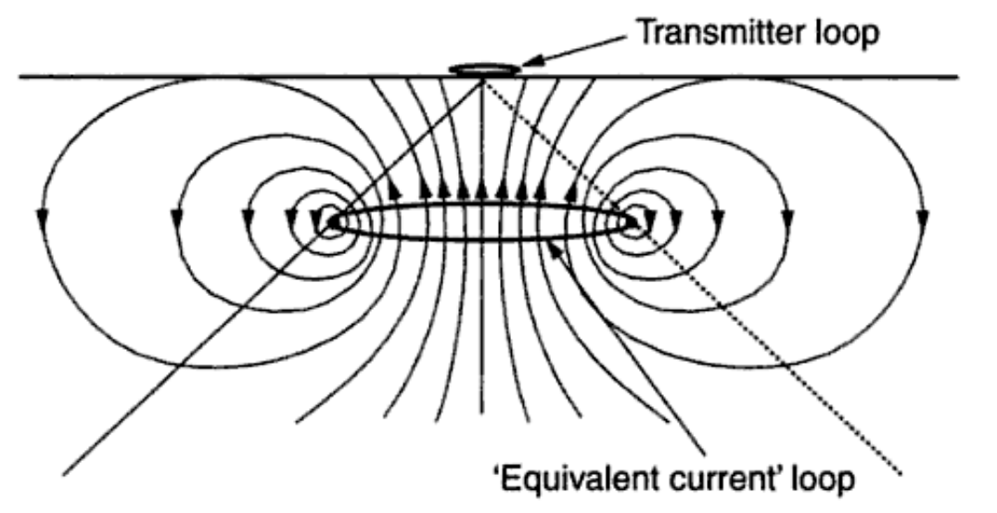

Figure 8. "Smoke ring" excited by a horizontal loop

3D Inversion of Mt. Milligan VTEM Data

The major challenge for inverting 3D VTEM data is the computation and memory requirements due to a large mesh and large number of transmitters. We take two approaches to reduce the computational cost to make the 3D inversion more tractable.

Decimation of the data set: We down-sample the soundings to form a rectangular data grid with 200m line spacing and 100m in-line spacing (red dots on Figure 2). In addition, we only use a subset of the decimated soundings at early iterations of the inversion.

Two-mesh strategy: We use a coarse mesh with fewer cells to do a fast large-scale inversion at the early stage of inversion when building up the first order structure; then we switch to a validated fine mesh to resolve the small features of the model. (Figure 9).

Those methods greatly speed up the 3D inversion. For example, the 3D synthetic inversion (Figure 7) using one fine mesh and 91 transmitters takes about 32.5 hours to achieve the target misfit on a computer cluster having 24 cores and 96GB RAM. If our smart strategies are used, the CPU time can be reduced to 11.5 hours.

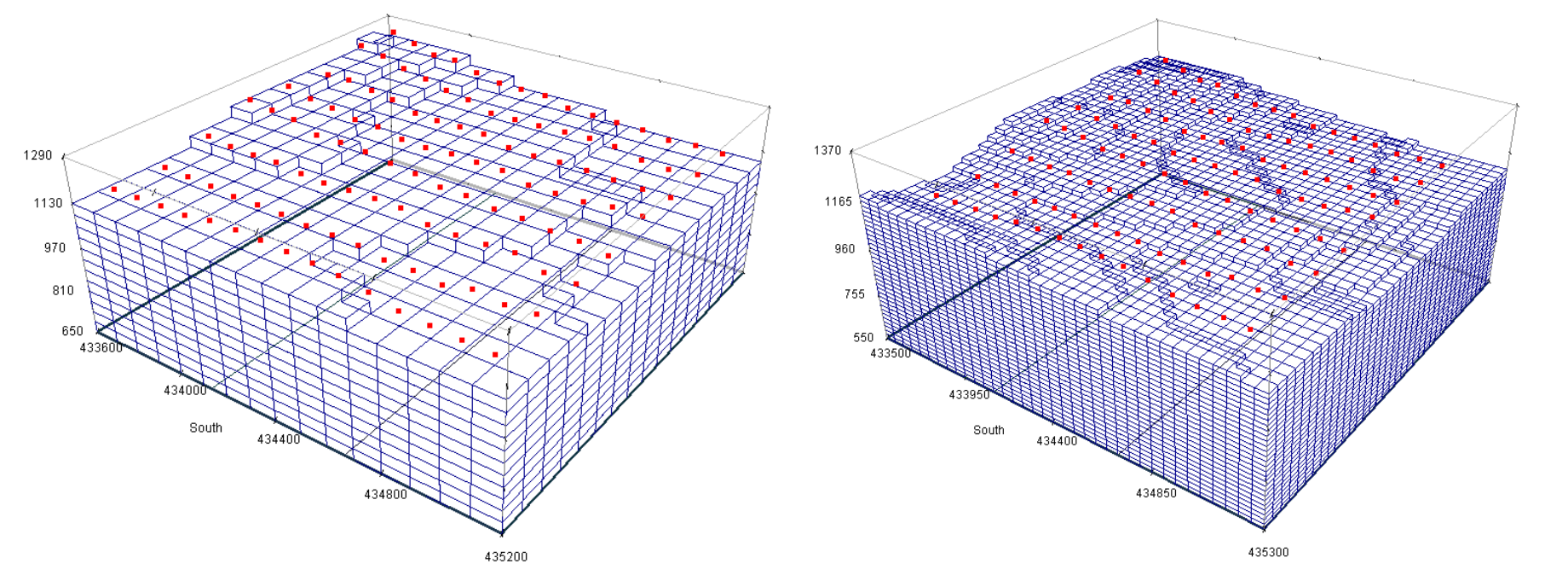

Figure 9. Coarse and fine meshes (coarse: 100x100x40m, 32400 cells; fine: 50x50x20m, 152500 cells)

At the coarse mesh stage, we invert the Mt. Milligan field data from 64 soundings on a uniform 8 x 8 grid with 200m sounding and line spacings. 7 iterations required 6 hours to achieve the target misfit on an Intel i7 960 Quad-core desktop PC with 16GB RAM. Despite the modeling error due to the coarse mesh a reasonably good 3D conductivity model is obtained. It clearly shows a resistive stock and the surrounding conductive alteration (Figure 10).

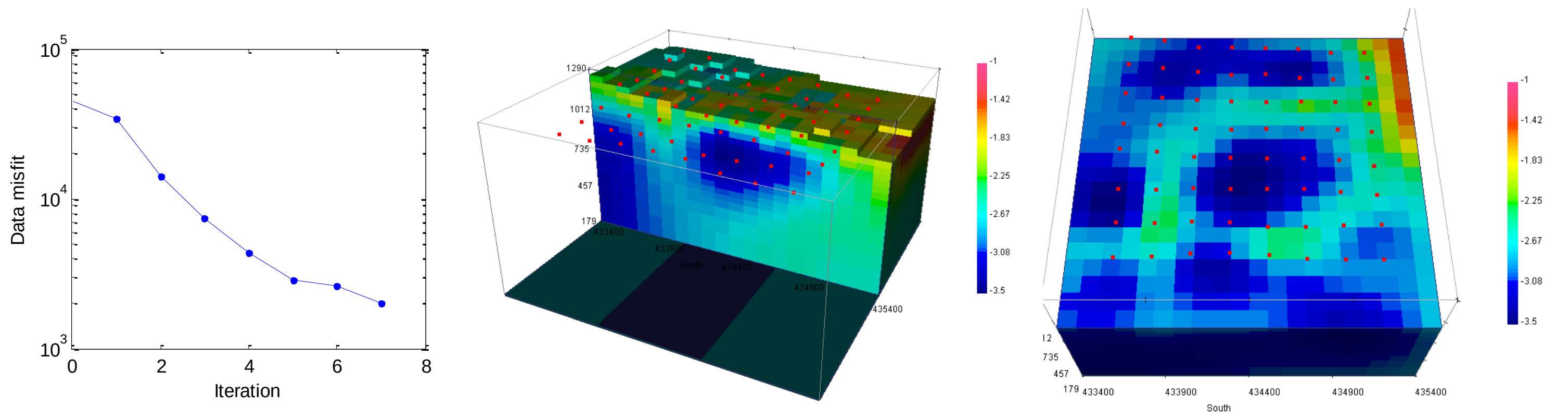

Figure 10. 3D coarse mesh inversion of Mt. Milligan Data (left: convergence of data misfit; middle: cross section of the MBX stock; right: depth slice of the MBX stock)

The 3D coarse mesh model is interpolated onto a fine mesh and forward modelled to produce data at all 120 soundings in the 8 x 15 initial grid of soundings. 58 soundings, chosen because of their high misfit, are selected as data for the next stage inversion. This takes another 6 hours on our cluster. The overall misfit for the 120 soundings is reduced from 5823 to an acceptable value of 3657 (target misfit = 2229).

The final 3D model looks very similar to the coarse mesh model, but more detail about the boundaries of geologic units are delineated (Figure 11). The model is very different from information conveyed from the time constant map and from the 1D inversion.

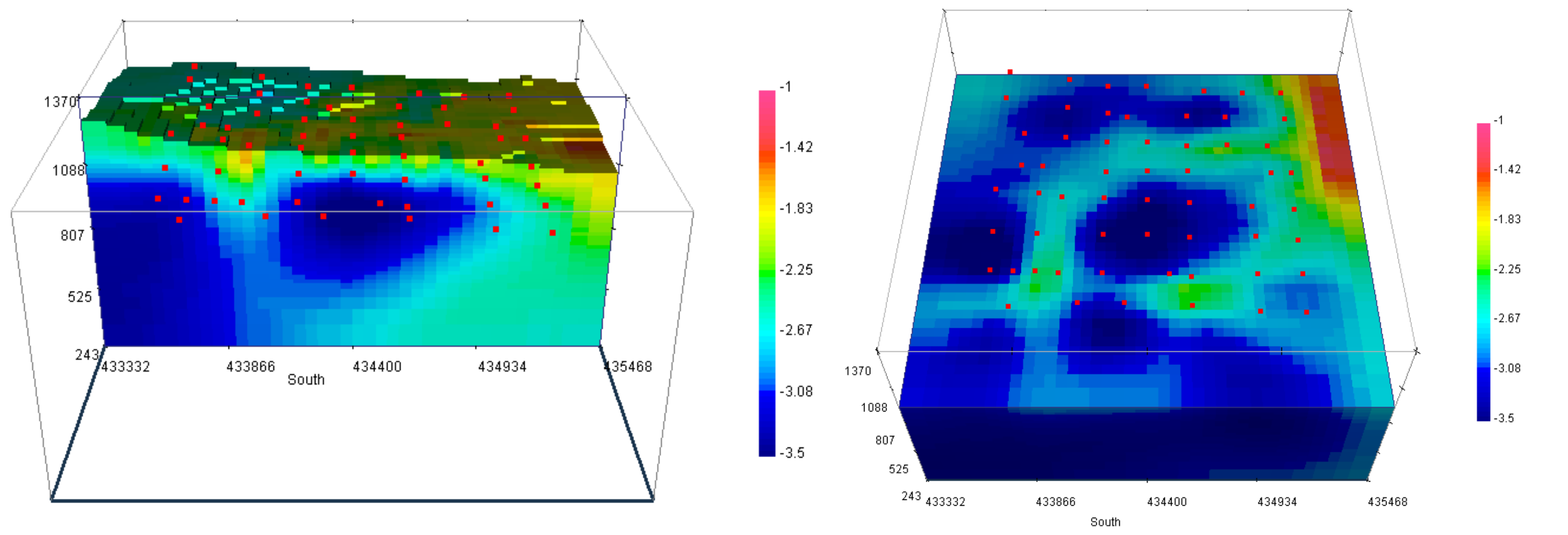

Figure 11. 3D fine mesh inversion of Mt. Milligan Data (left: cross section of the MBX stock; right: depth slice of the MBX stock; red dots indicating soundings)

The 3D inversion model nicely recovers the overburden and near-surface sediments as a thin and conductive layer. At depth, a typical porphyry system (a resistive rock stock surrounded by conductive alteration halo) is clearly delineated. In addition, the geometry of the MBX stock is well portrayed by the west dipping feature that is evident on the cross section of Figure 11. The alteration units of the porphyry system associated with the MBX stock can be better viewed on the depth slice of Figure 11. The location and boundary of the central resistor are consistent with the round-shaped MBX monzonite stock on the geology map (Figure 1a).

Conclusions

- In areas of complicated geology such as Mt. Milligan, analysis using time constants or 1D inversions can produce misleading results.
- A synthetic model of the porphyry system is studied to show that 1D inversion may produce conductive artefacts and hence 3D inversion is required.
- Two methods are employed to make the 3D inversion of the Mt. Milligan airborne EM data set computationally tractable: (1) data were down-sampled and (2) a two-mesh strategy using coarse and fine meshes was employed. The total computation time required to generate the final 3D conductivity model was 12 hours.
- The final 3D conductivity model showed considerable detail that was consistent with known geology. This bodes well for the use of this technique in the analysis of other data sets over porphyry deposits.

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