Application of forward model studies to highlight the case for massive data volumes in 3D data acquisition for DCIP surveys

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Abstract

There is growing evidence on the need for electrical methods to follow the seismic industry into the world of 3D geophysics. Like seismic, electrical methods having a strong vectoral component, may be affected by anisotropy and carry a profusion of characteristic information about the subsurface in general and a target in particular. While specialized subset arrays can provide a respectably plausible target model, high-contrast information tends to be cherry-picked yet smoothed so that characterization (vs. target extraction) is poorly managed, and target accuracy itself may be poorly resolved. To separate or better discern specific characteristics, universalized, dense, tensor arrays provide more information to remove ambiguity and better resolve a model space. Dense and large datasets are a result of these tensor(3D) arrays.

The development of 3D measurement systems for electrical methods dates to the early 1990's. In the 2000's and early 2010's, lower computer hardware costs and GPS availability resulted in the capability to field a multiplicity of channels. Inversion methodology advanced in the late 90's for 2D methods and 3D began in the 2000's, but it wasn't until the mid-2010's that 64-bit computing power made proper management of large data volumes viable. Cost, economic conditions and general lack of understanding to date have hampered the broad scale application of 3D surveys. However, more and more 3D surveys have been acquired in the last five years, and the data sets, although considered overwhelming by some and redundant by others, are clearly demonstrating effectiveness in exploration.

A forward model study was completed to compare the resolving capability of 2D, longitudinal 2D, incremental 3D and high volume 'complete', 'true' or tensor 3D. The primary model is a shallow, thin, strike-directed dike with breaks along strike (perhaps geologically termed a boudinage).

The modeling shows respectable capability of the incremental methods including longitudinal 2D, but there is distinct model refinement when a tensor 3D acquisition consisting of a high data volume is considered.

Geological Model

Figure 1 shows the primary model discussed is a shallow, thin, strike-directed dike with breaks along strike (perhaps geologically termed a boudinage). Four offset lenses are modeled. Each has a depth extent of 1 km. The northern and southern lenses have a strike-length of 400 m and the central lenses have strikes of 200 m and 300 m. The gap between the northern lenses is 200 m and the southern lens is separated along strike by 600 m. Lenses are buried 100 m below surface and are 100 m thick. The target (10 ohm-m) has a factor of 100 resistivity contrast lower than the host (1000 ohm-m). An intrinsic IP of .25 is assigned to each target and the host is held at 0 (intrinsic IP is defined between 0 and 1). For the inversion, the IP response is rescaled using an ad hoc factor of 210.

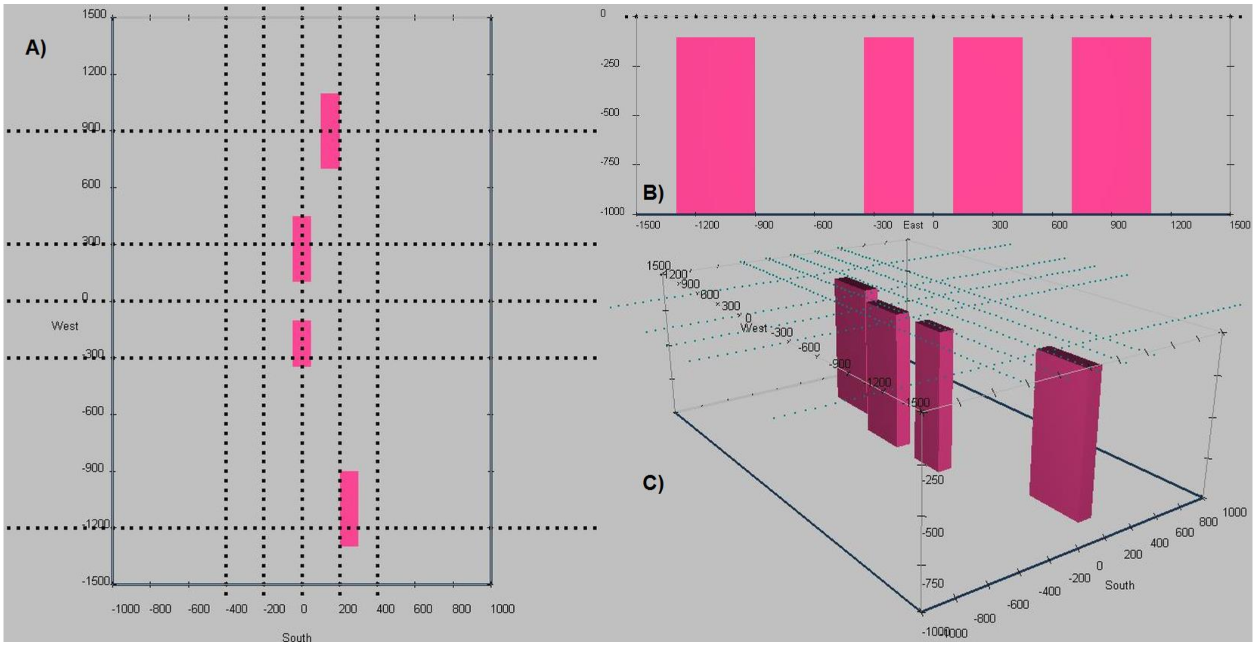

Figure 1: Model views a) plan, b) section south to north, c) 3D oblique view from south-west

Modeling software

The UBC GIF forward and inversion software for modeling DCIP were used for this work. The forward model was calculated using the 3D forward engine. Inversions were performed in 2D and 3D as discussed in the results. The 3D model uses 25 m cells in the core area and vertical cells expand with depth as shown in Table 1.

Table 1: 3D vertical mesh

Cell count	Thickness (m)	Model depth (from-to m)
10	15	0 - 150
5	20	150 - 250
4	25	250 - 350
5	30	350 - 500
4	50	500 - 700
4	75	700 - 1000
4	100	1000 - 1400
8	200	1400 - 3000

Calculated data

Forward data were calculated for a series of ten 2D lines as shown by dots that represent the electrode locations in Figure 1. Electrodes for the 100 m sized dipoles occur on the even '100's' while transmit locations occur on the '50's'. Transmit poles are shown because the configuration is ostensibly pole-dipole. The infinite is not shown since the modeling software understands an ideal infinite location for the remote pole. Five longitudinal (strike parallel) and five orthogonal (strike perpendicular) survey lines were modeled.

Results

2d Modeling

Figure 2 shows longitudinal survey line 0E that overlies the central targets and is offset from the south and north targets by 200 and 100 m respectively.

The 2D modeling of the longitudinal section shows that anomaly detection and lateral location are good, but depth extent is poorly resolved, and targets offset from the line appear deeper than they are.

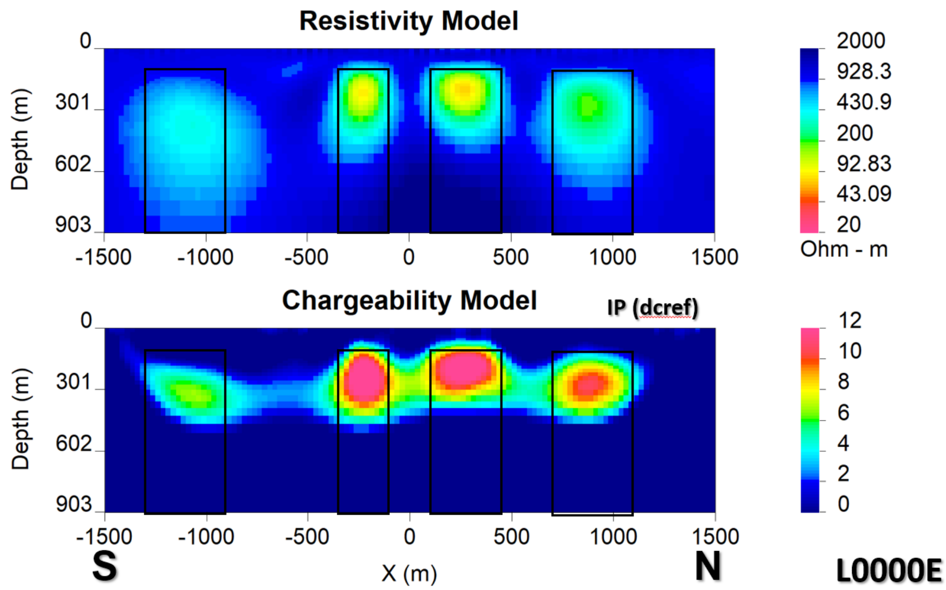

Figure 2: 2D inversion of longitudinal line 0E

Figure 3 shows orthogonal survey line 0N that does not directly overly any target and bisects the region between the central targets.

Figure 4 shows orthogonal survey line 900N that directly overlies the northern target. The 2D modeling of the orthogonal sections shows that anomaly detection and lateral location are good. The modeling code cannot discern between depth extend and anomaly width at depth. The response at line 0N is very similar to the response at line 900N indicating poor certainty in respect of knowing whether the target is under the survey line.

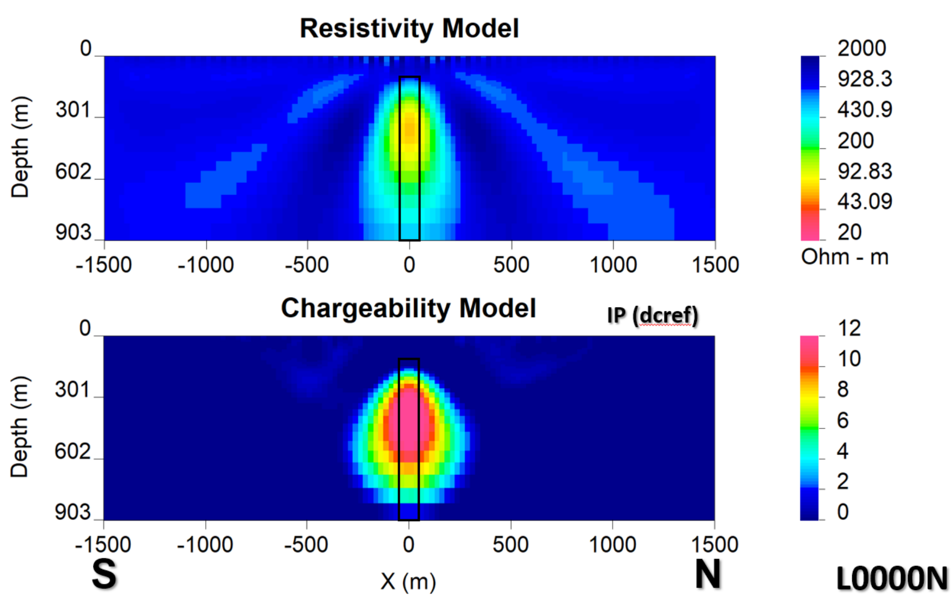

Figure 3: 2D inversion of orthogonal line 0N

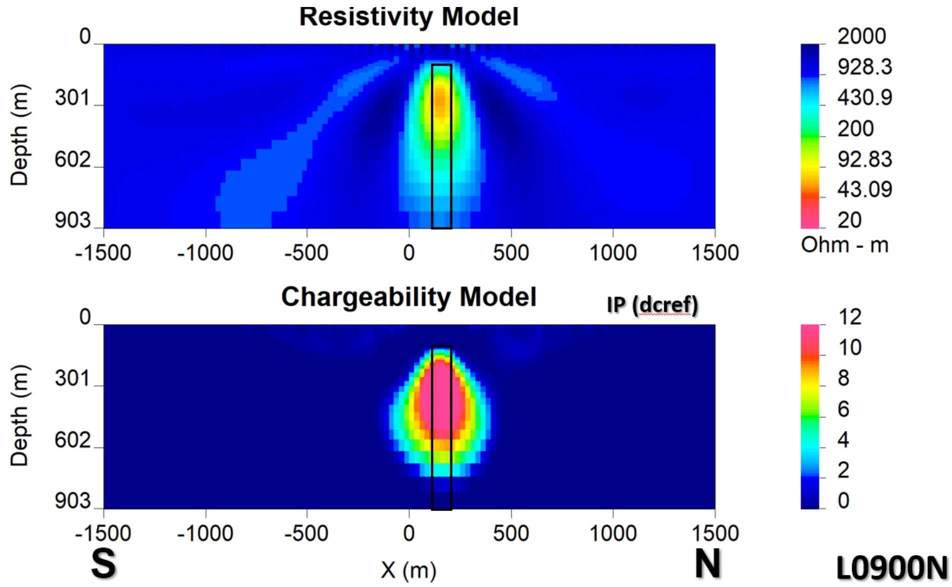

Figure 4: 2D inversion of orthogonal line 900N

3D Modeling

3D modeling was performed for five cases. In the first case, only the five NS lines were modeled. Data collection was 2D, i.e. no offset transmits were used. In the second case the five EW lines were modeled with the central NS line. Data collection was 2D, i.e. no offset transmits were used. In the third case, the five EW lines were modeled with the five NS lines. Data collection was 2D, i.e. no offset transmits were used. In the fourth case, a strike-directed 3D pattern was modeled. In this case, the six-channel loggers are deployed with 4 channels that are oriented NS and 2 channels that are oriented EW. Transmits are along the receiver lines (Figure 5a). In the fifth case, an omnidirectional 3D pattern was modeled. In this case, the six-channel loggers are deployed with 3 channels that are oriented NS and 3 channels that are oriented EW. Transmits are along the survey lines and an additional center-spot transmit is recorded (Figure 5b).

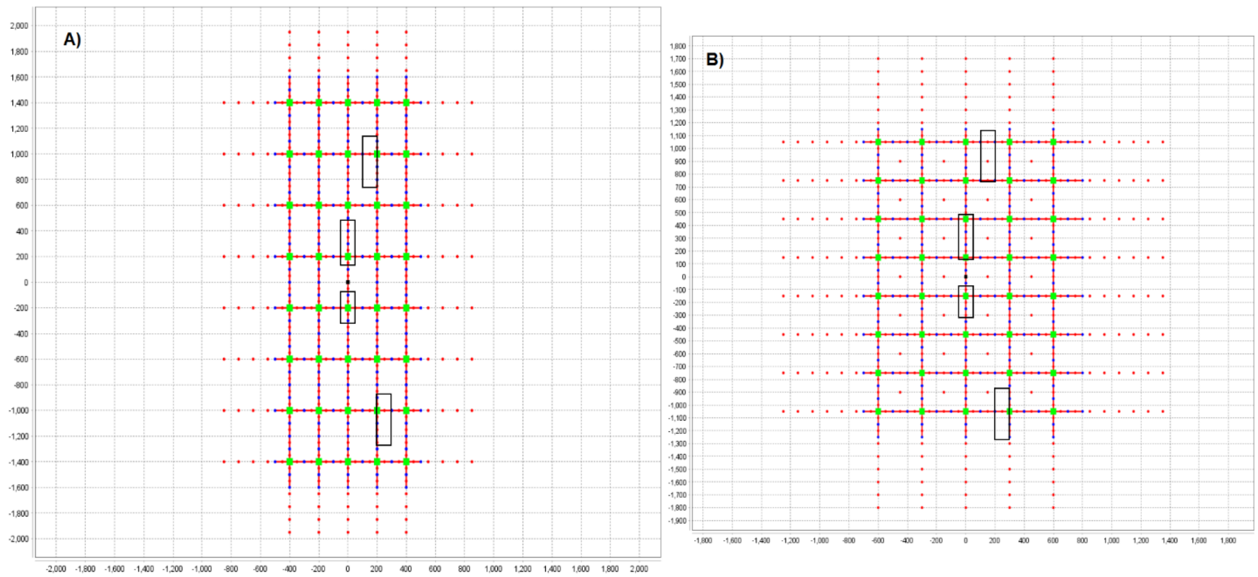

Figure 5: ORION 3D deployments showing a) strike-directed layout and b) omnidirectional layout

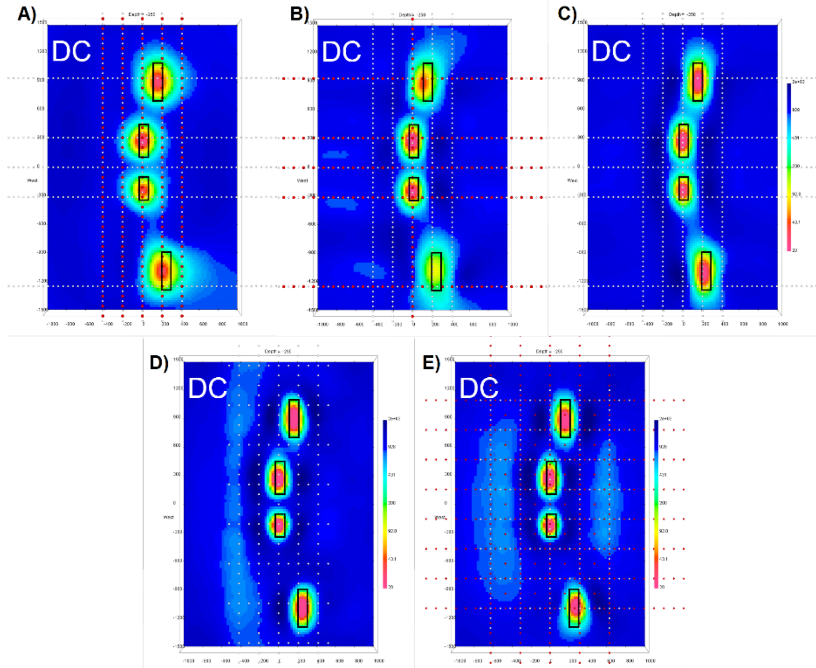

Figure 6: Plan view at 250 m depth of 3D inversion of DC showing a) 5 NS 2D lines, b) 5 EW 2D lines and one NS line, c) 5 NS 2D lines and 5 EW 2D line, d) strike-oriented ORION 3D, e) omnidirectional ORION 3D

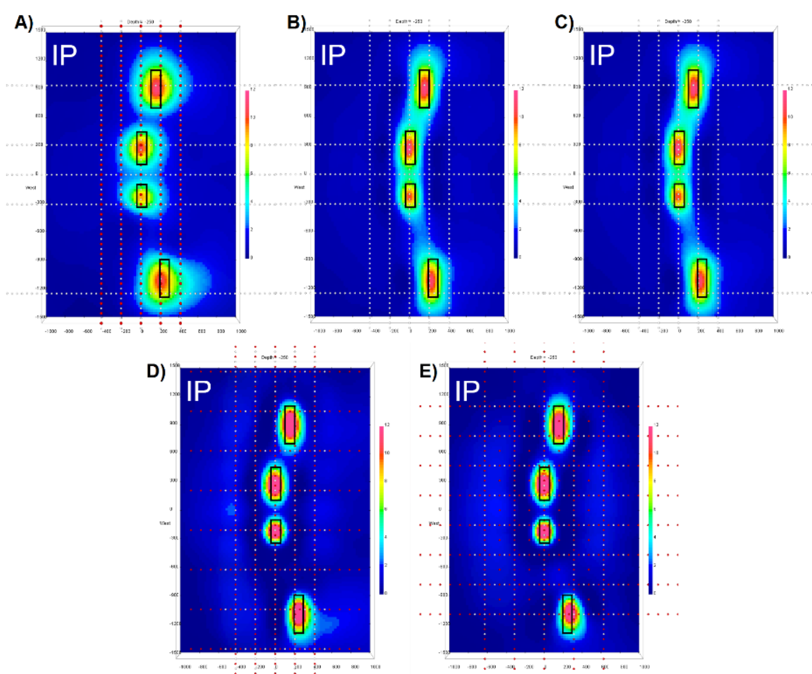

Figure 7: Plan view at 250 m depth of 3D inversion of IP resistivity showing a) 5 NS 2D lines, b) 5 EW 2D lines and one NS line, c) 5 NS 2D lines and 5 EW 2D lines, d) strike-oriented Orion 3D, e) omnidirectional ORION 3D

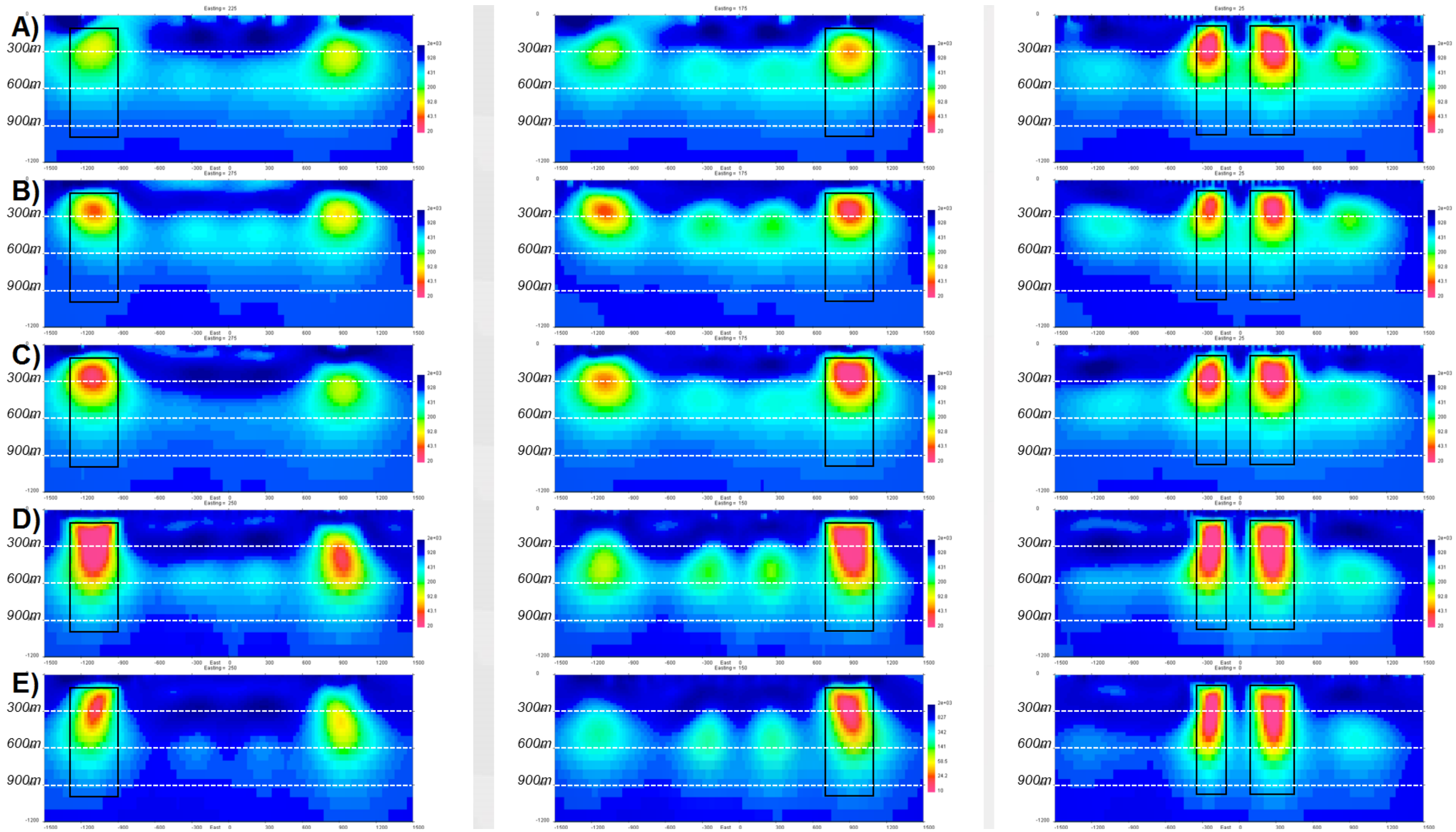

Figure 8: Section view of DC at 275-250E (left column), 175-150 E (center column) and, 25-0E (right column). Rows show a) 5 NS 2D lines, b) 5 EW 2D lines and one NS line, c) 5 NS 2D lines and 5 EW 2D line, d) strike-oriented ORION 3D, and e) omnidirectional ORION 3D

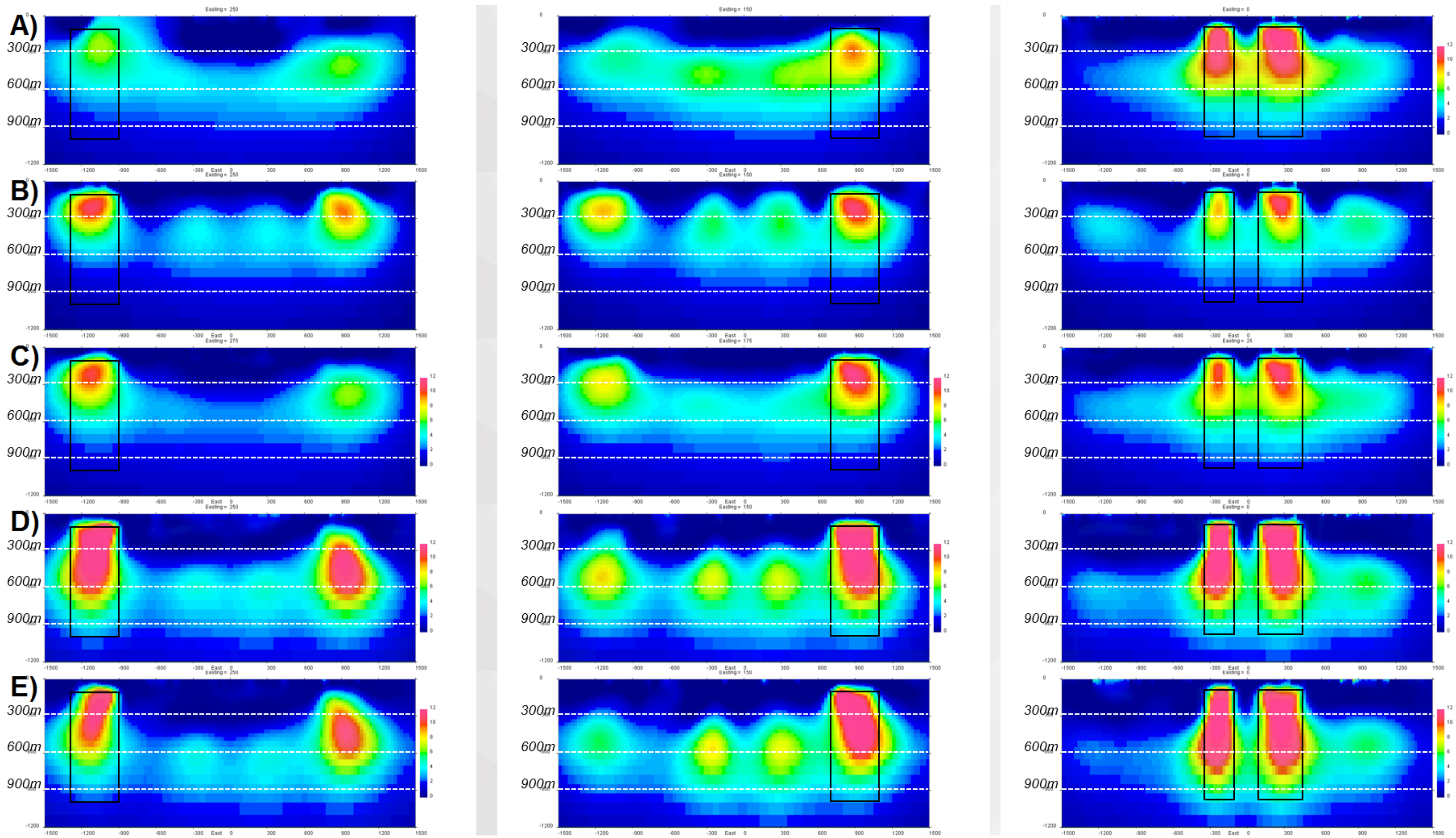

Figure 9: Section view of IP at 275-250E (left column0, 175-150 E (center column) and, 25-0E (right column). Rows show a) 5 NS 2D lines, b) 5 EW 2D lines and one NS line, c) 5 NS 2D lines and 5 EW 2D line, d) strike-oriented ORION 3D, and e) omnidirectional ORION 3D

Conclusions

- The 3D surveys show much better isolation, location and depth extent.
- The 2D surveys can lead to some ambiguity in interpretation and mis location, potentially resulting in missing the target.
- Strike parallel 2D may be OK for anomaly detection but it is not suitable for characterization and drill targeting.

Synthetic modelling is generally simple and abrupt and relies on high contrasts. Full 3D data acquisition demonstrates improved depiction of the target models. There is a strong argument for the broadscale adaptation and use of 3D data acquisition in industry. In addition, inversion in 3D is demonstrated as being better than inversion in 2D, even for 2D data.

In the real world, the subsurface is subtler and more complex. Large data volumes and data management issues are small obstacles if the result is better as demonstrated here. It is therefore a natural step to acquire data in a manner that will best depict the subsurface prior to drill testing. A full 3D approach to data acquisition provides the explorer with best practice approach to subsurface imaging.

References

DCIP2D; A Program Library for Forward Modelling and Inversion of DC Resistivity and Induced polarization Data over 2D Structures, version 3.x (2014). Developed under the consortium research project Joint/Cooperative Inversion of Geophysical and Geological Data, UBC-Geophysical Inversion Facility, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia.

DCIP3D; A Program Library for Forward Modelling and Inversion of DC Resistivity and Induced polarization Data over 3D Structures, version 5.x (2018). Developed under the consortium research project Joint/Cooperative Inversion of Geophysical and Geological Data, UBC-Geophysical Inversion Facility, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia.