

THE EFFECTIVE USE OF FORWARD MODELLING AND PETROPHYSICAL ANALYSES IN THE APPLICATION OF INDUCED POLARISATION SURVEYS TO EXPLORE FOR DISSEMINATED SULPHIDE SYSTEMS IN THE PATERSON PROVINCE, WESTERN AUSTRALIA

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SUMMARY

The Citadel Project is a JV between Rio Tinto Exploration (RTX) and Antipa Minerals extending over 400 km² in North West WA. The project is targeting disseminated and massive copper sulphide systems beneath 40 to 120 m of transported Permian cover overlain by intermittent Cenozoic sand dunes. Dipole-Dipole (DD) and Pole-Dipole (PD) Induced Polarisation survey configurations were chosen as a cost effective method to prioritise 16 target areas. Induced Polarisation (IP) survey traverses over the known gold-copper-silver±tungsten Calibre and Magnum deposits illustrated the effectiveness of the IP method for detecting mineralisation and led to a 127 line km D-D and P-D Induced Polarisation survey being undertaken during the 2016 field season. The IP surveys highlighted multiple chargeability anomalies along the Calibre structural corridor of which 8 were selected for drill testing. On completion of drilling, forward modelling of chargeability and resistivity data, combined with petrophysical analysis of selected core samples provided a platform for testing geological concepts. In addition, it allowed the correlation of the chargeability data with drilling results, and the validation of inversion modelling results. In 2017 a new IP survey to further delineate the Blue Steel target and evaluate the Calibre structural corridor was proposed. As part of the planning process, forward modelling, along with information from regional AEM surveys illustrated that a Gradient Array IP survey would be a cost effective solution for exploring the Calibre structural corridor.

Key words: Induced Polarisation, Sulphides, Paterson.

INTRODUCTION

The Citadel Project is located in the northeast of the Proterozoic Paterson Orogen. Due to limited outcrop in this area, mineral exploration is dependent on interpretation of various geophysical datasets. Basement geology is interpreted to be dominated by the late Proterozoic Yeneena Basin stratigraphy which unconformably overlies the earlier Proterozoic Rudall Metamorphic Complex and the Archaean Pilbara Craton. Permian fluvio-glacial Paterson Formation sediments, up to 100m thick in the project area, unconformably overly the Proterozoic stratigraphy. Overlying the Permian Paterson Formation sediments are thin Cenozoic sand plains. At the Magnum and Calibre deposits, coarse sulphides of pyrrhotite, pyrite and chalcopyrite within steeply dipping NS trending buck quartz veins are hosted by either a gabbro or metasediments of the Malu Formation. The sulphide rich zones of these deposits have previously been explored by ground and airborne electromagnetic surveys (AEM). The Citadel JV project started exploration in 2016 for large disseminated sulphide systems associated with the targets generated from multiple datasets including Aeromagnetics and AEM. A “proof of concept” IP survey line (200 m DDIP) was completed over the known deposits in the area. Successful detection of the known deposits led to the completion of IP surveys over 16 other targets. This highlighted multiple chargeability anomalies which were followed up by drilling and subsequent forward modelling of results using petrophysical data.

IP SURVEY RESULTS

The target area is covered by 40-120 m of transported Permian cover overlain by intermittent Cenozoic sand dunes. High contact resistance experienced in the vicinity of the sand dunes proved problematic for injecting current into the ground. In other instances, a thin conductive layer below the resistive sand proved an even greater challenge to acquiring good quality data. The survey initially utilised a 200 m DDIP array, but subsequently changed to a PDIP array to increase signal levels. In total 127 line km of IP data was collected as detailed in Figure 1. Quality of the data was generally good to n=4 and was considered largely sufficient to test basement for any shallow chargeable sources.

The “proof of concept” IP survey at Magnum and Calibre was successful in mapping a discrete chargeable response with amplitude around two times greater than background. Figure 2 shows the observed data and unconstrained inversion model over Magnum. The new IP surveys highlighted Blue Steel as one of the best targets along the Calibre structural corridor. The survey in this area was designed to evaluate Trigger and the region east of Trigger in the Calibre corridor. This new IP chargeability anomaly was defined with similar magnitude to the Magnum deposit but without the coincident magnetic or conductivity responses. Figure 3 shows a perspective view of the Blue Steel anomaly along the Calibre structural corridor.

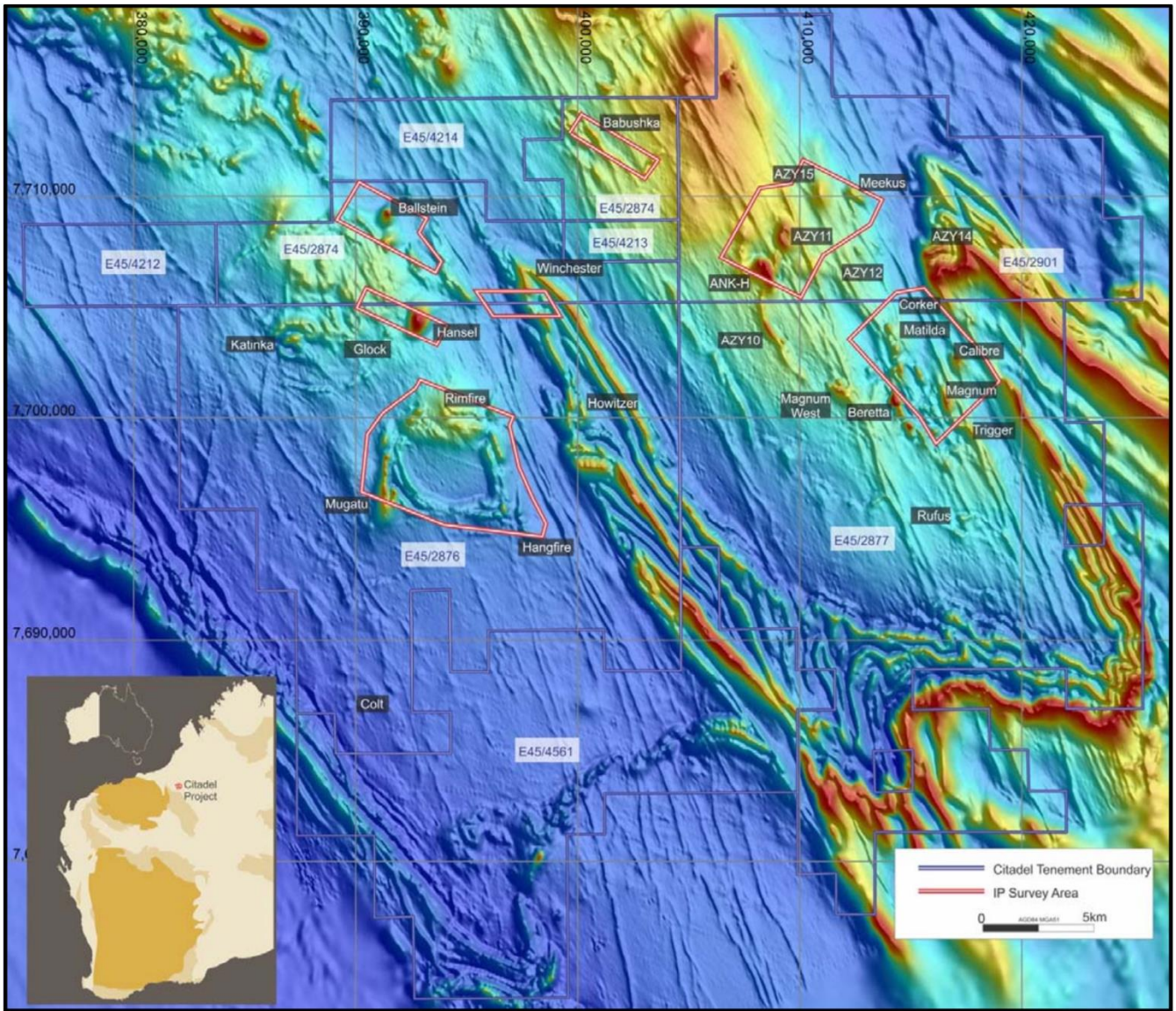


Figure 1: Citadel project showing deposits, targets, 2016 IP survey regions and tenements over Airborne magnetic image (source: Antipa Minerals ASX report).

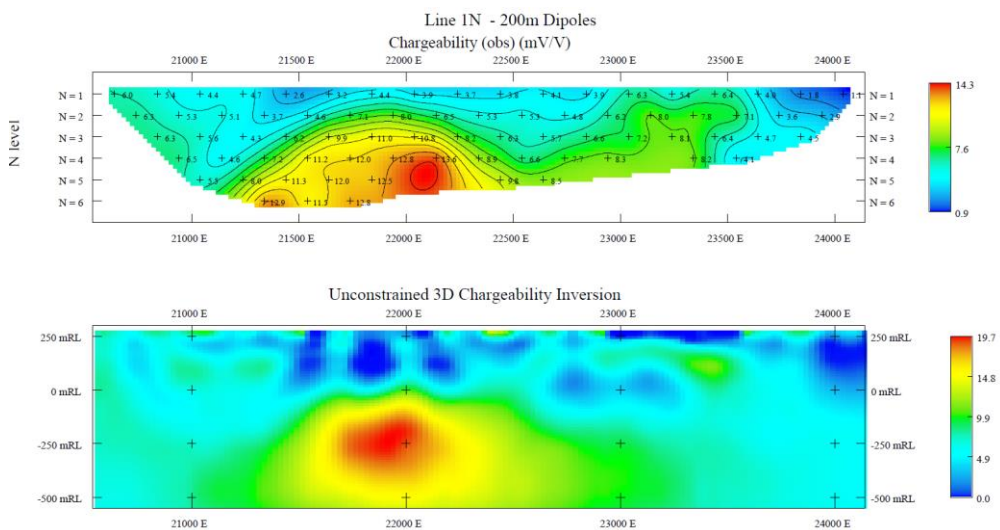


Figure 2: Observed and inverted model from DDIP data over Magnum deposit.

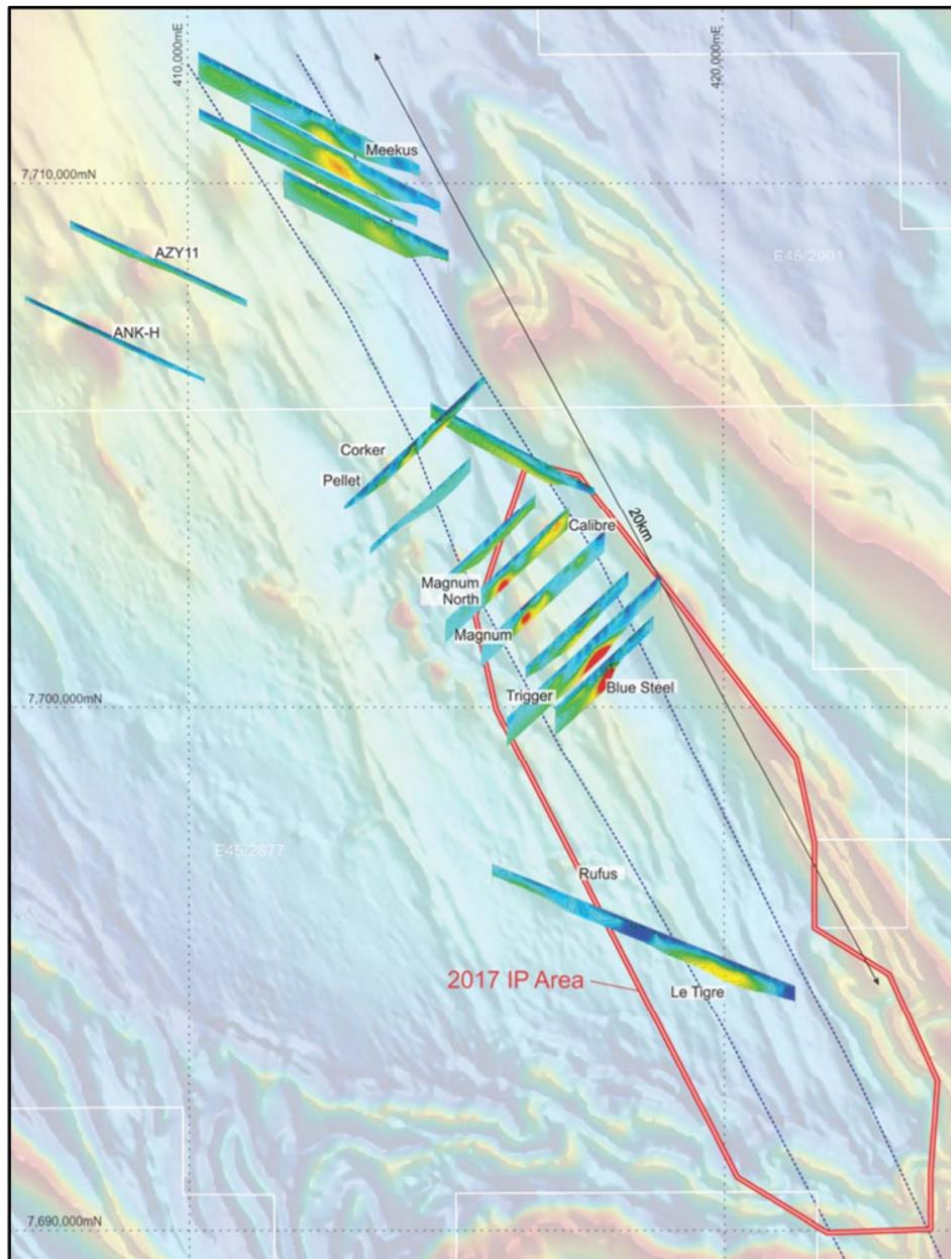


Figure 3 : Eastern region of the Citadel Project showing the Calibre and Magnum deposits, 2016 IP survey Chargeability inversion sections highlighting multiple IP anomalies along 20 km NNW-SSE trending corridor and the planned 2017 IP survey region over Airborne magnetic image (source: Antipa Minerals ASX report).

DRILLING RESULTS AND PETROPHYSICAL ANALYSIS

In 2016, five RC drill holes for 1004m and one diamond drill hole for 661m tested the chargeability anomaly. There were no significant sulphides observed in the RC drilling. At 517m, at the expected depth of the chargeable source, the drillhole intersected a 19m interval of pyrrhotite bearing magnetic gabbro with a true width of just 11m. The gabbro contained slightly anomalous Cu, Pb, Zn and W.

On completion of drilling, selected samples from Magnum and Blue Steel were sent for petrophysical analysis. Terra Petrophysics performed petrophysical analysis of 16 samples from Citadel project. The main objective of the analysis was to obtain information that could be used for further modelling and understand the relationship of sulphide content with chargeability values measured in the laboratory. Figure 4 shows the plot of Sulphur assays vs Chargeability values on a log linear scale. The general trend suggests the chargeability of the samples increases with increased sulphur assays. This agrees with previous studies that have shown that sulphide concentration and electric chargeability exhibit a direct nonlinear proportionality (Sebastian et al, 2016). As shown in Figure 5, the

anomalous sulphur intersected in various drill-holes at Blue Steel is significantly less than Magnum and Calibre and was considered inadequate to explain the ground IP response. While the presence of clays (Telford et al, 1976) or iron oxide mineralisation can exhibit significantly high polarisation effects (Hart and Freeman, 2003), none of the drill holes in this area intersected any iron oxide or clay alterations. Other possible explanations were tested using forward modelling of observed IP response.

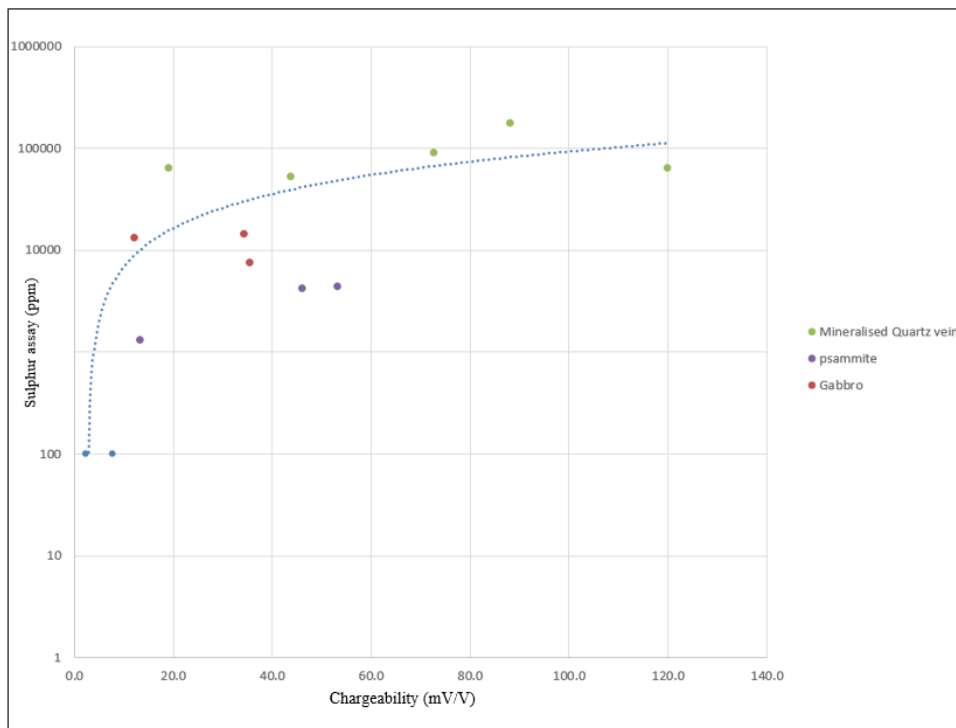


Figure 4: Graph showing the relationship between sulphur assays and Chargeability values from laboratory measurements.

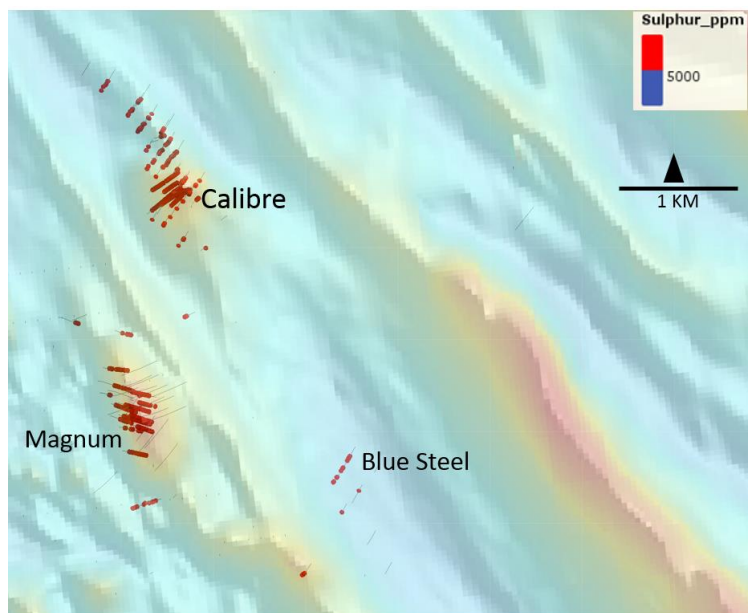


Figure 5: Sulphur assay plot as a proxy to anomalous sulphides on the drillhole traces over Magnum, Calibre and Blue steel. Image: Airborne magnetic image.

IP FORWARD MODELLING

Results from drilling and the petrophysical analysis were used to test geological concepts with forward modelling. UBC DCIP3D codes were used to compute the forward model responses. Since the only major intersection of sulphides with anomalous chargeability values were recorded in a steeply dipping gabbro unit, drilling data was used to construct a simple geological model. The geological model of thin steeply dipping gabbro and other possible geological scenarios were further used to forward model the chargeability response. Figure 6a and b shows the inversion model and pseudo section plot of observed chargeability data on one of the lines at Blue Steel. Past studies (Telford et al, 1976) have shown that quantitative modelling of chargeability response is challenging and the apparent chargeability measured is dependent on multiple factors which includes sulphide mineralisation, clays, pore-water salinity and tortuosity. Since there are no indications of discrete saline water patches or clay alteration, this case study assumes that the majority of the response is indicative of anomalous sulphides in the rocks. It is also important to note that only the shape and relative values of the anomalies generated from forward modelling has been compared to the observed data. Figure 6 presents various possible geological scenarios that were compared to the observed chargeability response.

Scenario 1

In this scenario, the chargeable gabbro unit is modelled by extrapolating it to the unconformity surface. The modelling result in Figure 6c corresponding to geological model in Figure 6d manifests no resemblance to the observed data and suggests that for a 200 m PDIP survey, the chargeable body needs to be deeper to resemble the observed response.

Scenario 2

In this scenario shown in Figure 6f, the top of the gabbro unit is 300 m below the surface to better replicate the drilling results. The forward modelling result in Figure 6e shows a small response with an amplitude close to expected noise levels. It is expected that such a response will not be detected in an IP survey. This suggests that a deeper and thicker chargeable body is required to replicate the observed data.

Scenario 3

In this scenario shown in Figure 6h, a deeper chargeable body is added to the modelled gabbro unit. The forward modelling response shown in Figure 6g has comparative amplitude and shape to the observed data pseudo-section and so this scenario is considered one possible valid explanation of the observed data.

Scenario 4

In this scenario shown in Figure 6j, a shallower chargeable body is located 200 m to the south of the IP line. The forward modelling response shown in Figure 6i has comparative amplitude and shape to the observed data pseudo-section. Since the chargeable response is not closed off laterally to the south, this was also considered as one of the possibilities and economically more favourable for hosting a sulphide rich system.

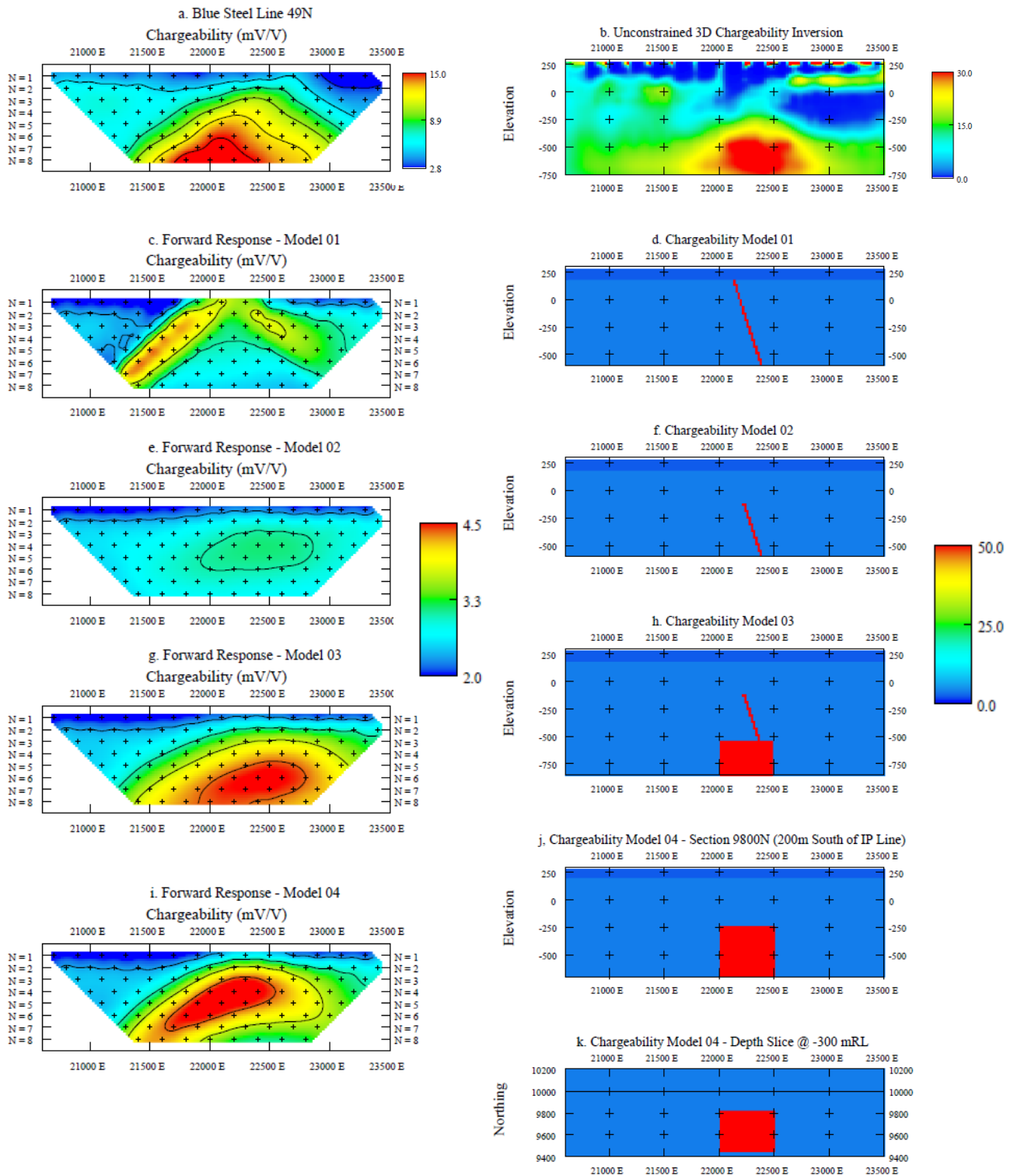


Figure 6: Forward modelling scenarios at Blue steel

FORWARD MODELLING FOR 2017 PLANNING

Analysis of IP data from 2016 concluded that the anomaly at Blue steel required closure to the SSE, and that the previously untested Calibre structural corridor south of Blue steel was prospective. The chargeability anomaly at Blue Steel was planned to be followed up by a PDIP survey, while forward modelling was undertaken to decide the optimum array type to test the large area to the south as shown in Figure 3.

Drilling and regional AEM data suggested that the cover thickness along the Calibre structural corridor south of the Blue Steel target is 70-100 m and both cover and basement are moderately resistive i.e. 300 ohm m and 600 ohm m respectively. Cover is significantly more conductive (40 ohm m) towards the east of the structural corridor. The presence of parallel/sub-parallel dunes every 5-6 kms makes IP surveying logistically challenging and requires the planning of pit locations away from the dunes, while still covering the entire area. Forward modelling was undertaken to understand the effectiveness of various survey designs in highlighting chargeability anomalies. A simple physical property (resistivity and chargeability) model was created to simulate the response of these designs. Figure 7a shows the plan view of the model with dimensions of 400m x 400m x 250 m, a chargeability of 3x's background and located 250 m below the surface. In this scenario of moderately resistive conditions and consistent thin cover, Gradient array IP (GAIP) was array of the choice with Inline PDIP follow-up to get depth estimates for drill testing.

Figures 7b, c and d shows forward modelling results of GAIP design with 2, 3 and 5 km transmitter dipole lengths, 100m receiver dipoles and 200, 250 and 300 m line spacing respectively. Transmitter dipole length were limited to 5 km as anything larger would require placing one of the pits into the relatively thicker and more conductive cover sequence to the east. UBC DCIP3D codes were used to simulate the response. Chargeability, as modelled using this code, is defined by the ratio of the peak secondary voltage to the peak primary voltage. This ranges from zero for non-chargeable material, to one for highly chargeable material that would result in the secondary voltage being equal to the primary voltage. A standard deviation of 0.02 mV of white noise added to the primary and secondary voltages to simulate survey noise (UBC GIF v5.0 manual). Since all calculations are also scaled to 1A of current and signal/noise scales inversely, the noise is halved to simulate the twice the current. Modelling suggested that all 3 scenarios would map the chargeable feature unambiguously which could then followed up by PDIP. Since GAIP survey with a 5 km transmitter dipole would require less arrays, which equates to significantly less number of pits and cable laying as compared to the others, it was considered as the optimum design to test the area.

CONCLUSIONS

Unconstrained inversions act as a quick tool to plan drilling and to advance exploration at various stages. Although they provide a single best fit model, often this is regarded as the truth while discarding the intrinsic non uniqueness of geophysical datasets. We recommend that interpretation should be driven by realistic geological models by computing forward models on various plausible scenarios.

Petrophysical data from Magnum, Calibre and Blue Steel and forward modelling from Blue Steel showed that the sulphides intersected in the diamond drill core from Blue Steel are not sufficiently extensive to be responsible for the observed chargeability anomaly. Thus it was concluded that the chargeability target at Blue Steel had not been adequately tested. Additional IP surveys were recommended to investigate the possible extension of the Blue Steel chargeability anomaly towards the SSE.

Forward modelling showed that GAIP with 5 km transmitter dipole is the most suitable array type to test the Calibre structural corridor south of the Blue Steel target.

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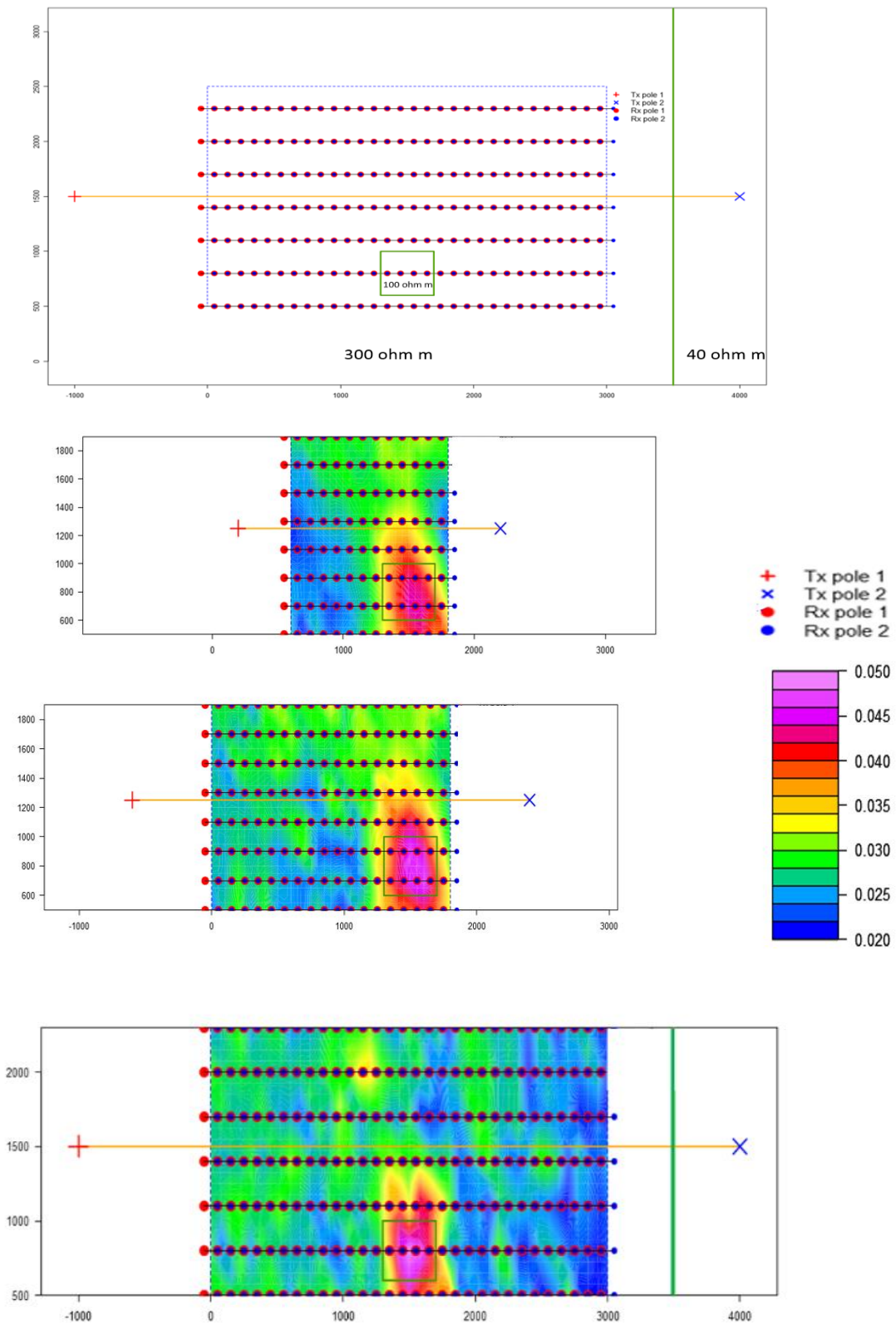


Figure 7: Forward modelling scenarios for GAIP