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A systematic approach to surface-to-downhole induced polarisation

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This article reports on Jarrad Trunfull's Honours project, which was sponsored by the ASEG Research Foundation in 2011. Jarrad's project was supervised by Mike Dentith at The University of Western Australia and Yvonne Wallace and Lee Sampson at Barrick (Australia Pacific) Limited.

A study was undertaken to investigate the potential use of induced polarisation surveys featuring combined surface-to-downhole electrodes. Two electrode array configurations were investigated, the Axial Gradient Directional Array and the Radial Array. Both were found to provide an advantage over surface IP in close proximity to the target. The Radial Array, however, produced data that allowed for simpler and less ambiguous interpretation. Further research needs to be conducted into the merits of combining both methods, as well as performing successful inversion of acquired data.

Introduction

The purpose of this study is to investigate the feasibility of surface-to-downhole induced polarisation (DHIP) for effective application in the field. This was initiated by identifying DHIP arrays that have a reasonable expectation of returning useful data, which include the Axial Gradient Directional Array and the Radial Array (Sumner, 1976; Mudge, 2004; A. Scott, pers. comm. 2009). These arrays have been investigated via systematically forward modelling different parameters in a static model in order to define the best possible set-up for a given geologic environment. This project used the UBC (University of British Columbia) forward-modelling code DCIPF3D, and also served to assess its ability to forward model DHIP data.

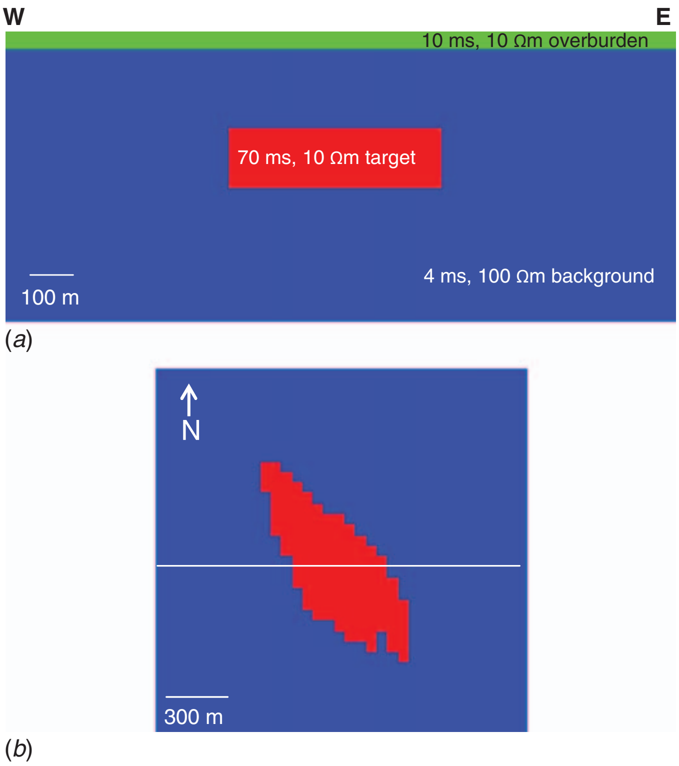

Fig. 1. *Three-dimensional synthetic model of the Centenary gold deposit. (a) A west–east section through the orebody labelled with respective properties of each component. (b) Depth slice at 300 m depicting the shape of the orebody. The white line on the depth slice represents the position of the section.*

The model was based on the Centenary gold deposit, Western Australia, owned by Barrick (Australia Pacific) Limited (Barrick), and consisted of a 250-m-thick chargeable/conductive rectangular body in a neutral/resistive background, with a 50-m-thick conductive overburden (Figure 1). The depth to the top of the target was 250 m. The target was assigned a chargeability of 70 ms and resistivity of 10 Ωm, with the overburden and background assigned values of 10 ms/10 Ωm and 4 ms/100 Ωm respectively.

The study looked at the optimisation of parameters such as target offset (distance between the drill hole and the target body), transmitter distance/depth (distance from and depth of the transmitters with respect to the drill hole), potential dipole size and extent (size and distance covered by the potential dipoles), target depth (depth to top of target body) and whether a target could be detected if not directly intersected by the line of sight between the transmitting and receiving electrodes.

The Axial Gradient Directional Array

The Axial Gradient Directional Array (AGDA) consists of four polar current electrodes located on the surface and transmitting in sequence, and a downhole dipolar array comprising potential electrodes (Figure 2). It measures vertical variations in IP and resistivity, making it ideal for delineating the depth and width of a target.

Testing was initially conducted to determine the operable distance of the array from a target. Forward-modelling results

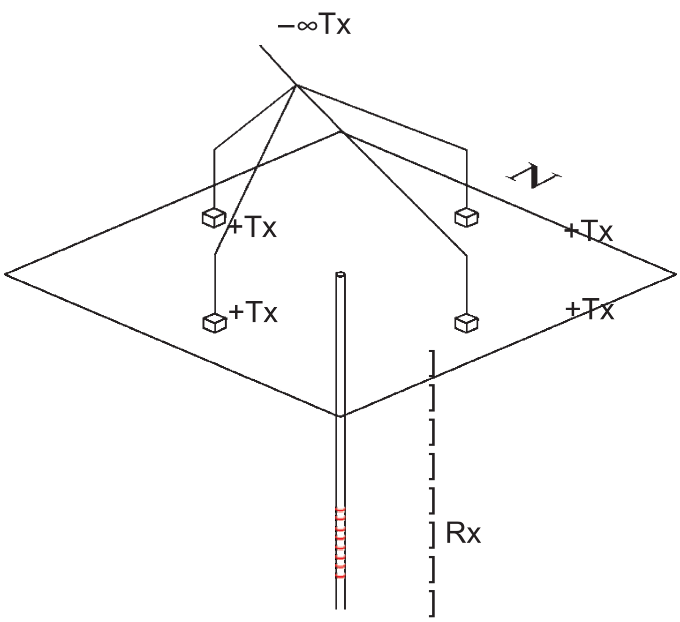

Fig. 2. *Schematic diagram of the Axial Gradient Directional Array.*

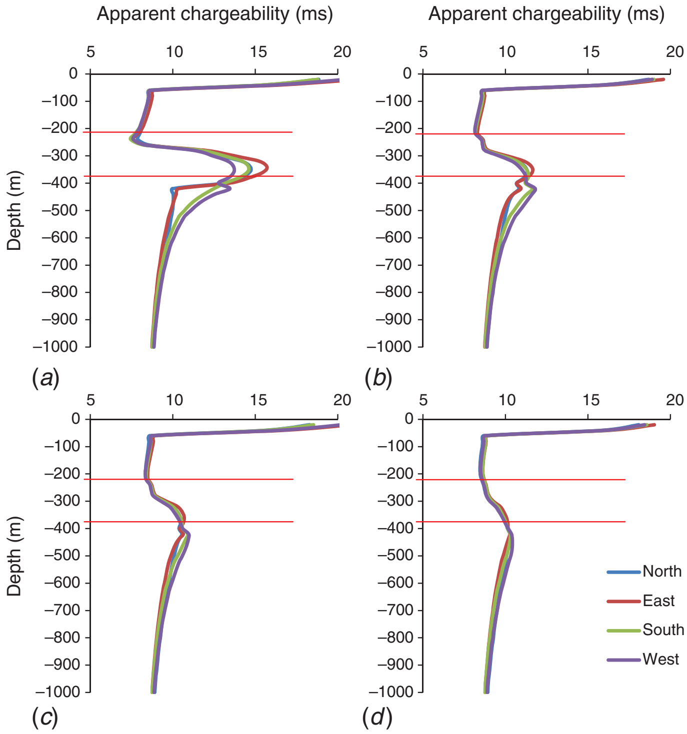

Fig. 3. *Vertical profiles of apparent chargeability from drillholes with (a) 25, (b) 50, (c) 75, and (d) 100 m displacement between the deployed Axial Gradient Directional Array and the target. Red horizon lines denote the vertical position of the target.*

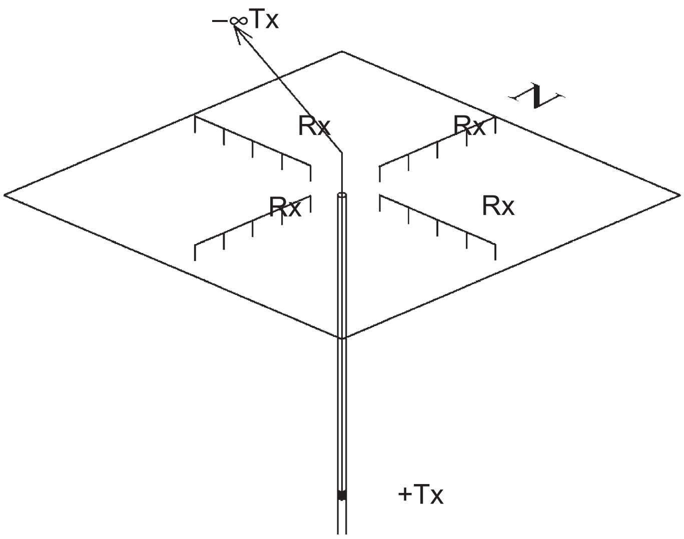

Fig. 4. *Schematic diagram of the Radial Array. Note that only four potential arrays (Rx) are pictured, but the array may include many more at a specified angular interval.*

show the AGDA is able to define a large and clear anomaly at a short (e.g. 25 m) drill hole offset from a target, which weakens approximately linearly as this offset is increased; a maximum offset being considered approximately 50 m. The amplitudes of the anomaly vary at the different current electrodes, allowing the data to be used to approximate the spatial location of the target (Figure 3). At a larger drill hole offset (e.g. 100 m) this difference can be masked or overprinted by noise.

The optimal distance of the surficial current electrode from the drill hole was also investigated via forward modelling. Coloured pseudosections were plotted in an attempt to understand the behaviour of data and identify an optimal distance; however, this was not able to be discretely identified. Various receiver dipole sizes were also investigated as part of this study, with the conclusion being that the dipole size needs to be smaller than the target to allow detection (a smaller dipole size increases survey resolution but is not always necessary.)

The Radial Array

The Radial Array (Sumner, 1976; Mudge, 2004) is, in essence, the reverse configuration of the AGDA, consisting of a downhole polar current electrode and at least four dipolar receiving arrays located on the surface in each quadrant around the drill hole (Figure 4). Snyder and Merkel (1973), along with Asch and Morrison (1989), demonstrated that placing the current electrodes beneath conductive overburden enhances the current density arriving at targets. The Radial Array is best designed to measure horizontal variations in IP and resistivity. This study

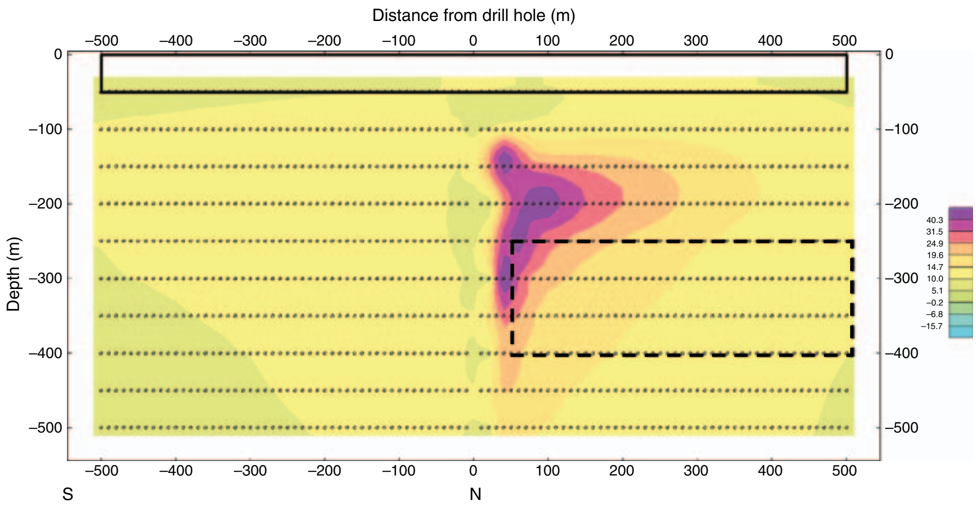

Fig. 5. *Coloured north–south pseudosection of apparent chargeability collected using the Radial Array with an indirect target located to the north-west. A reference colour bar shows apparent chargeability in milliseconds. The drill hole is located in the centre (at 0). Note the strong skewed 'pant-leg' shape; the target is located at the nadir. Black boxes on the diagram represent the position of the overburden and target; the dashed box indicates the relative location of the target where no direct intersection occurs.*

shows that it can also, to a certain degree, recognise vertical differences by using a current electrode at various depths.

Forward modelling was conducted with the Radial Array using the same systematic approach that was used for the AGDA. The optimal distance from the target for deployment of the array was determined to be similar to that of the AGDA, where less than 50 m was ideal. The optimal depth of the electrode was also tested, and in this study observed as coincident with the base of the target – in this case approximately 400 m. A pseudosection of chargeability data was constructed, as for the AGDA, which displayed a discrete anomaly approximately coincident with the location of the body (Figure 5). This means chargeability data can be directly and easily interpreted without relying on inversion.

Further modelling shows that the receiver dipole size has a strong influence on the quality of data, with a shorter dipole producing a stronger and more horizontally constrained anomaly, and a larger dipole producing a broader and weaker anomaly. Interestingly, the model showed an interim value of 50 m produced the largest amplitude anomaly. It was also tested whether more than four receiving arrays would be required on the surface, but a strong anomaly was generated even where the array did not pass directly over the source.

Summary

The results of this study show that DHIP is both feasible and useful (in the case of the AGDA and Radial Array) for a near-miss scenario (i.e. where a target has been missed by 50 m or less). Modelling also suggests that DHIP is useful in overcoming electrical effects associated with clay overburdens. The Radial Array produced the best results in terms of ease of interpretation, but a combination of both AGDA and Radial DHIP approaches ultimately decreases ambiguity. The Radial Array is also logistically harder to deploy due to the need to place the current electrodes downhole. Prior to undertaking field trials it is recommended that the results from this study should be verified and expanded using a second downhole induced polarisation modelling code. Further investigation into inversion of forward-modelling results also needs to be conducted.

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