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An exploration of AEM inversion methods for defining sub-basin geometries in the McArthur Basin, Northern Territory, Australia

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SUMMARY

Arguably AEM data are a critical technology in better understanding the geometry and extent of sub-basins and associated structures which may host SEDEX mineralisation in the Batten Fault Zone of the MacArthur Basin, Northern Australia. However there is a need to understanding of how best to interpret available AEM data, particularly in areas where the sediment packages are folded and faulted. Different inversion techniques, including a 1, 2.5 and 3D inversion methods, over a structurally complex area, are compared.

All inversion methods contribute to our understanding of geological variability and structural complexity. Results from the 1D smooth model LEI's (whether IP effects are accounted for or not) appear to map geological variability and structural complexity in the near surface in greater detail compared to those from the 2.5D and 3D inversions, even though the geology recognisably 3D in character. When employing numerically complex inversion methods in the interpretation of AEM data sets, there may be significant value in asking a contractor/consultant for both 1D as well as higher order inversion results. In the resulting interpretations if conductors appear in one but not the other, then a reason should be sought.

Key words: 1, 2.5D and 3D AEM inversion, Sub-basin geometries, McArthur River.

INTRODUCTION

The McArthur and neighbouring basins of northern Australia (Figure 1) host numerous Stratiform SEDEX ('sedimentary exhalative') ore deposits (Ahmad et al. 2013). These are a major source of base metals such as Zn–Pb–Ag ± Cu–N–Mo–Ba, and the primary source of Zn and Pb. In the McArthur Basin their main characteristics, as summarised by Large et al. (1998, 2005), are that they consist of laminated sphalerite and galena-bearing dolomitic siltstones; stacked ore lenses separated by carbonaceous mudstones, with ore deposition occurring adjacent to major faults.

Airborne electromagnetic (AEM) data sets have been employed as a key exploration technology in the search for these mineral systems particularly in the Batten Fault Zone, a major north-trending structural domain within the southern McArthur Basin, (Shalley and Harvey 1992, and Munday et al. 2017). Understanding the development of Palaeoproterozoic sub-basins in this Fault Zone, the host of these large scale sediment-hosted base metals deposits including Myrtle, Teena and McArthur River, is therefore critical, and an interpretation of available AEM data sets to complement the analysis and modelling of the gravity and magnetics to resolve the major structures, their kinematics, and the spatial distribution of depositional packages in 3D (Blaikie and Kunzmann 2017) is important. This is particularly relevant to the definition of sub-basin geometries (see Blaikie et al. 2018), and in this context there is a need to understanding of how best to interpret available AEM data, particularly in areas where the sediment packages are folded and faulted.

Here we give consideration to the geological information content of different inversion techniques, including a 1, 2.5 and 3D inversion methods, over a structurally complex area, within the Batten Fault Zone north of the McArthur River Mine. From a mapping perspective the AEM data are employed to target parts of the Barney Creek Formation, which contain conductive, mineralised units (HYC pyritic shale member). This study builds on that explored by Munday et al. (2018), and develops the discussion on when and how to employ higher order inversion codes as aids to subsurface geological characterisation and interpretation.

METHOD

AEM systems and survey

A total of ~900 line kms of VTEM helicopter TDEM data were examined along with two lines of coincident SkyTEM^{312} data in the central part of the Caranbirini study area (Figure 1). Lines were orientated in an E-W direction perpendicular to the strike of the main structures. Line spacing was 200m.

Inversion approaches

Three inversion approaches were examined, and consideration was also given to inverting for airborne induced polarisation (AIP) and resistivity.

1D Inversion

The 1D inversion scheme AarhusInv (Auken et al., 2015) was used in the Aarhus Workbench to process and invert both the the SkyTEM and VTEM data sets. The data were processed manually to remove noise. The AarhusInv algorithm inverts soundings for a set of 1D models connected through constraints. For the purposes of this study, a 30 layer model was used for the inversion employing Z component data. The first layer thickness was chosen to be 10m with logarithmically increasing thicknesses.

1D Inversion for Airborne IP Effects and Resistivity

Induced polarization (IP) effects were evident in the VTEM data acquired over Caranbirini and are manifest as negative receiver voltage values, which in some cases is easy to detect. AIP modelling starts from thorough visual analysis of the data, and different metrics are used to assist in the assessment of the AIP effects spatially and against known geology. The data were then processed, deleting noisy gates, while retaining undistorted IP effects. The 1D inversion with IP modelling was carried out with AarhusInv, with Laterally Constrained Inversion (LCI). All four Cole Cole parameters (“IP corrected” resistivity σ, chargeability m, frequency parameter c, time constant π) are solved for, at once, with spatial constraints of varying strengths.

Although the 2.5D and 3D inversion codes employed here now model AIP, at the time of this submission results from the inversion of the VTEM/SkyTEM data sets examined here are not presented. Consideration of these outputs is currently underway. We note that its presence can lead to significant artefacts in the resulting model if they are not first identified and removed. Therefore, for these two methods, and for the results presented here, soundings affected by IP were manually identified and removed from the data set prior to inversion where possible.

2.5D Inversion

A 2.5D inversion of the VTEM data used the Intrepid Geophysics Moksha code. The algorithm has been described by Paterson et al., (2016), and Silic et al., (2015), and comprises a significantly re-engineered version of ArjunAir (Wilson et al., 2006). It includes a new forward model algorithm and a new 2.5D inversion solver with adaptive regularisation, allowing the incorporation of a misfit to the reference model and the model smoothness function. The regularisation parameter is chosen automatically and adaptively adjusted at each iteration, as the model, the sensitivity and the roughness matrices change (Silic et al., 2015). Initial estimation of regularisation parameter requires calculation of only one forward model and sensitivity matrix at each iteration, controlled by an easily understood parameter - the Relative Singular Value Truncation (RSVT) parameter. In this study, Z component data were inverted with 10m stations, a 30-40m (lateral dimension) mesh, and a 5m mesh at surface increasing with depth down to 750 m.

3D Inversion

The 3D inversion of the Caranbarini VTEM dataset was undertaken by Computational Geosciences Inc., using an adaptive OcTree mesh refinement, where the mesh spans the full computational domain but uses smaller mesh cells around the selected transmitters and receivers. This methodology results in a forward modelling mesh that has far fewer cells than the full inversion mesh. The approach yields a highly parallel 3D inversion algorithm that can handle large datasets, and is discussed by Haber et al., (2012), Schwarzbach et al., 2013, and Yang et al., (2014). For this project, the OcTree mesh's smallest cells were 25m x 25m x 25m. These fine cells were used to mesh the topography, the air surrounding the transmitter and receiver locations and the top 300m of the subsurface. Below 300m the cells expand by a factor of two with each 300m of depth. This discretization scheme resulted in an inversion mesh consisting of approximately 9.25 million cells (5,406,552 cells discretising the earth, 3,846,372 cells discretising the air). Only Z component data were inverted.

RESULTS

Limited, deep (~1000m) drilling is available in the study area, permitting the geological interpretation of the results generated from the inversions. Results for one line of VTEM data (Line 10440) shown in Figure 2 are presented as a set of conductivity depth sections in Figure 3. The McArthur Group of Sediments, which are prospective for SEDEX style mineralisation are located to the left of the section, west of the Emu Fault (Figure 2). Here the sediment package is folded and faulted, with sub-horizontal conductors present. We attribute these features to folded and faulted section of the McArthur Group of sediments, including the Barney Creek Formation. The presence of small conductive units are more apparent in the 1D results for top 300m in the SkyTEM data (not shown) for the same line. The presence of a dipping conductive unit at the western end of the line (at around -400mAHD, between 3000 and 4500m in Figure 3) in the 1D results, is also reflected in the 2.5 and 3D inversion results, confirms its likely presence, although the suggested geometry and extent differs between the results.

In the study area, all inversion methods contribute to our understanding of geological variability and structural complexity. However, all approaches generate smoothed versions of geological reality. Results from the 1D smooth model LEI’s (whether IP effects are accounted for or not) appear to map geological variability and structural complexity in the near surface in greater detail compared to those from the 2.5D and 3D inversions, even though the geology is recognisably 3D in character. Similar observations have been made elsewhere (e.g. Costelloe *et al*., 2013, and more recently Lawrie et. al. 2018).

In the Caranbirini VTEM data there are apparent conundrums/coincidences that can confuse geological interpretation. The presence of “pants legs” or “off end” conductors defined in the 1D inversion results adjacent to the Emu Fault appear to coincide with a conductive part of the HYC shale unit as defined in drilling. However the 2.5D suggests the conductor is not present. This is most likely a more accurate result, but the presence of a slightly more conductive response in the 3D model confuses the interpretation. Elsewhere the 2.5 nor the 3D inversion methods have not always identified what are interpreted as thin conductive sequences within the Barney creek formation where it has been mapped in drilling across the study area. This shale unit is known to be variably mineralised, laterally extensive, and in this area has been mapped through geophysical logs as being very conductive where intersected by drilling. Whilst present at depth, there is no evidence, at present, to suggest that parts of it cannot be resolved by an airborne EM system.

CONCLUSIONS

The geological suitability of inversion results requires that their assessment be made against available geological information, rather than by the mathematical suitability of the inversion algorithm alone. Whilst the significance of the geological setting, its complexity, and the nature of the targets will have a bearing on how well different codes define a target, results from this investigation suggest that the 1D results can be interpreted with some confidence and can be used effectively in further exploration for sediment hosted base metal accumulations in the Batten Fault Zone in the southern McArthur Basin, although caution is required when interpreting such results in certain settings as artefacts can occur. The outcomes of this study also indicate that when employing numerically complex inversion methods in the interpretation of an AEM data set, it is useful to examine both 1D as well as higher order inversion results. In the resulting interpretations if conductors appear in one but not the other, then it is worth asking the question why and exploring the settings deployed in the processing and inversion of the data. Arguments about whether codes are "superior" (cf. Paterson *et al.* 2017) without qualification can be misleading to the uninitiated and should be avoided where possible.

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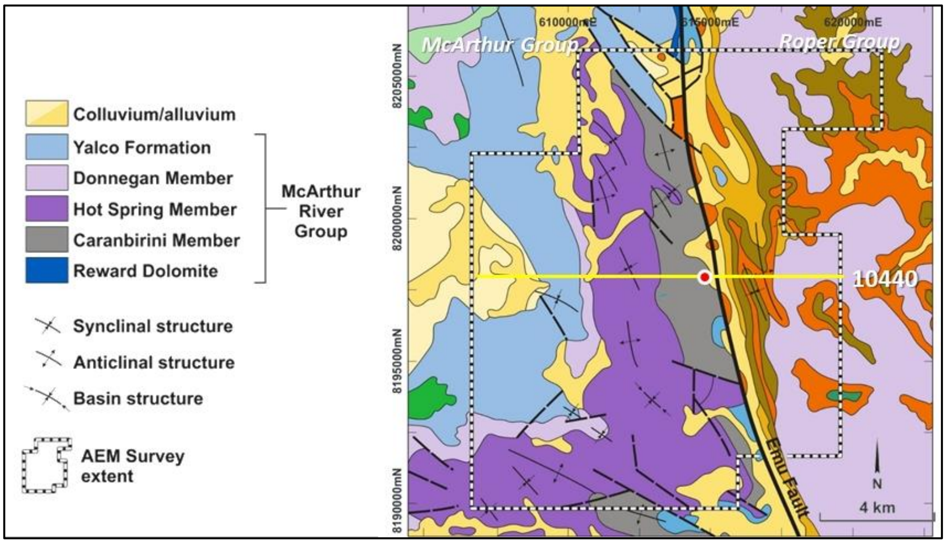

Figure 1: Simplified Geological map of the Caranbirni area in the McArthur Basin, Northern Territory. Sediments of the McArthur Group are the target sequences. The position of line 10440 is shown in yellow.

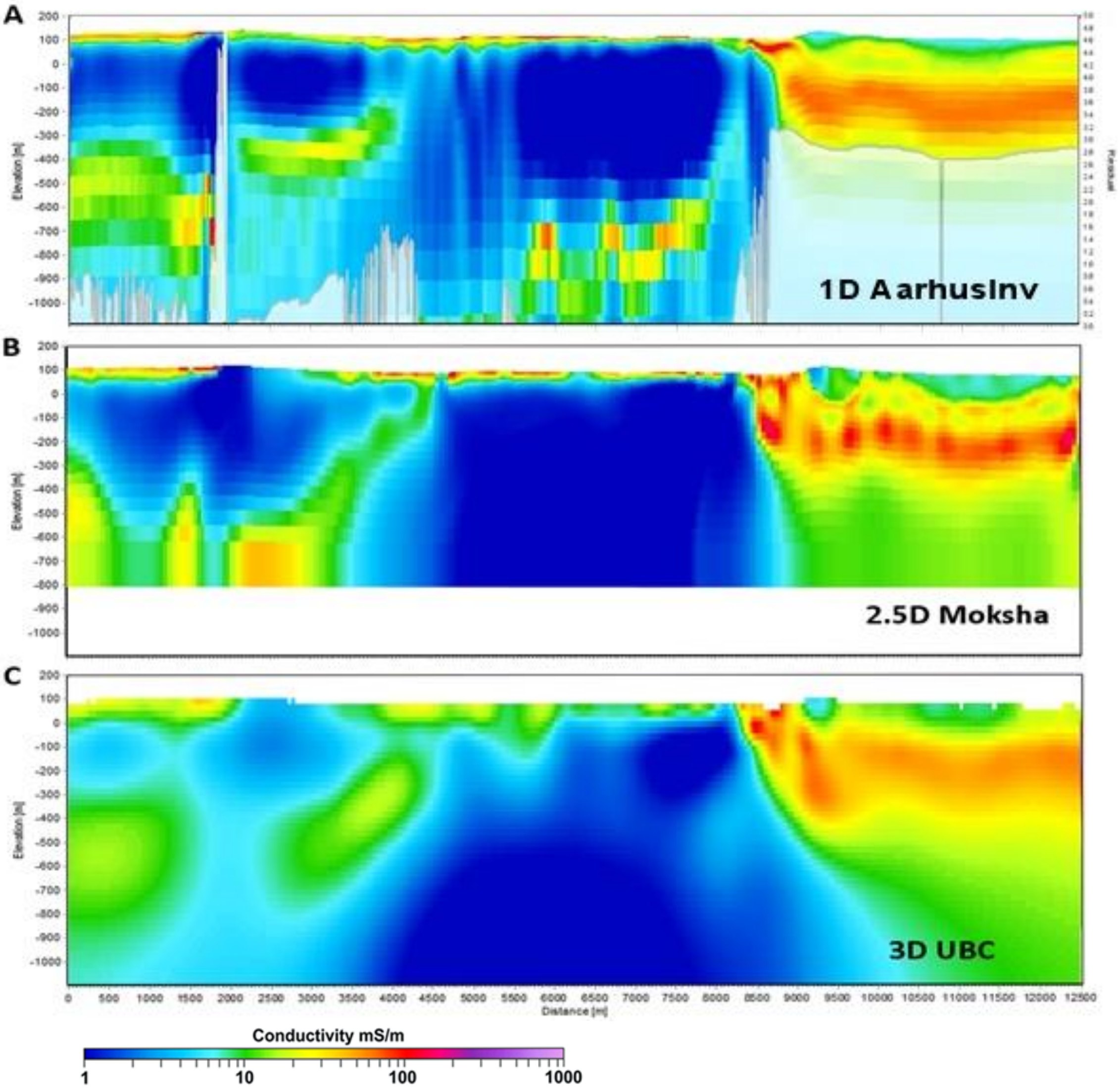

Figure 2: Conductivity-depth sections for line 10440, with results for three inversion approaches shown in the three panels. The top panel (A) is derived from the 1D smooth model inversion using AarhusInv; the middle (B) generated by Intrepid Geophysics using their 2.5D code; and the lower panel (C) using results from CGI's 3D inversion. The higher order inversion results produce smoother models with both suggesting the conductor at or just above the DOI (white line in Panel A) fitted in the 1D code is likely an artefact. The dipping conductor representing Barney Creek Formation sediments intersected by drillhole DD83CA3 in Line 10460 to the north is also defined in the 3D results (albeit smoothed - between 8000 and 9000m).