

AEM, Seismic and Power-lines: A hydrogeological case study in Peel, Western Australia

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SUMMARY

Airborne time domain electromagnetic and high resolution 2D seismic data were acquired in 2018 to map structures of hydrogeological significance in the Peel region; Western Australia. Interpretation of the airborne electromagnetic (AEM) survey was complicated by the presence of major utilities including power lines. We consider methods for removing the impact of these sources of EM noise within processing prior to interpretation. Generally, we found this to be counterproductive as information was unnecessary lost. Imaging from high resolution seismic reflection data is unaffected by EM noise. We show how a strategically located high quality seismic imaging was instrumental in providing an interpretational framework that could be extended to the full AEM survey area. We provide examples of AEM interpretation for many hydrogeological features including: major faults, 3D hydrostratigraphic surfaces, geological dip, saline water interfaces and zones with potential hydraulic connection between shallow and deeper aquifer systems. This work facilitated significant revision of groundwater systems conceptualisation in the Peel region.

Key words: Airborne EM, AEM, Seismic, case study, powerlines, hydrogeology

INTRODUCTION

A 25Hz repetition frequency time domain airborne electromagnetic survey (i.e., SkyTEM) was flown over the Peel region in February 2018, for the Department of Water and Environmental Regulation (DWER) and CSIRO to assist with hydrogeological investigations. 48 predominantly E-W lines (644 line kilometres) of AEM data were acquired. The survey area spanned 550 km². Both X and Z components were collected in both high and low moment acquisition modes (SkyTEM, 2018). The survey area is located south of metropolitan Perth, within the Perth Basin (See Figure 1).

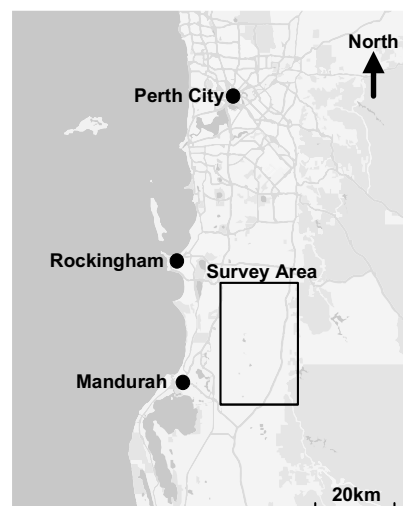


Figure 1. Approximate location of the Peel study area

In addition to the AEM, a strategically located 8 km long high resolution 2D reflection seismic survey was collected by Curtin University, Exploration Geophysics.

These surveys were completed to characterise: (i) the main confining hydrogeological units, (ii) regions with possible hydraulic connection between the superficial and older Leederville aquifer systems, (iii) zones of high solute concentration groundwater associated with the Serpentine and Murray River systems and (iv) major faulting. The survey was mostly completed above agricultural land and a leucoxene mineral sands mining operation (Rockwater Pty Ltd, 2006)

The AEM survey was conducted over major utility corridors—including powerlines, water pipelines and the Dampier-to-Bunbury gas pipeline. We explore the interpretation of the AEM and seismic data to provide insights into the hydrogeological framework of the Peel region in this highly challenging setting.

METHOD AND RESULTS

The AEM dataset was processed and interpreted using the following workflow.

1. **Data Cleaning:** Including the removal of decays badly contaminated by sferics and or late-time channels below a noise floor.
2. **Data-File creation:** Split the cleaned data by line and write to the inversion algorithm data file format. The inversion code used was the AMIRA P223, Airbeo

- 1D inversion algorithm (See Raiche et al., 1999 and Raiche et al., 1985). This algorithm uses an SVD non-linear least-squares inversion (Gauss-Newton-Marquardt) (Jupp & Vozoff, 1975).
3. **Seed model generation:** The workflow included the creation of 1500 seed models to investigate the range and variability of the inverted layer based electrical conductivity distribution. Within the 1500 seed models there were 1200 seed models based on random variations in resistivity based on the existing well logs, including the Keysbrook (KL) wells (Keysbrook, 2013) and the DWER AM bores plus 300 “anti-models”. These anti-models were unlikely to represent the true geo-electrical distribution. This is based off a similar approach to Johansen et al. (2008).
 4. **Small-scale inversion:** inversion of all 1500 seed models for both low moment and high-moment datasets along the AEM line proximal to the 2D reflection seismic transect.
 5. **RMS misfit analysis:** all models were ranked by RMS misfit and the top 5% of the models (typically less than 2% RMS misfit) were chosen for manual interrogation. These models were then compared against well logs and the 2D reflection seismic to determine the “best-case” model.
 6. **Full-Scale inversion:** A full inversion containing all cleaned soundings was performed. This was parallelized for each line to speed up computation as outlined by Pethick and Harris (2016).
 7. **Volume creation:** Inversion workflow 335 or 1500 was chosen for initial analysis. SEG-Y volumes of electrical conductivity and inversion sensitivity were created and imported into the Petrel interpretation suite.
 8. **Interpretation:** Interpretation was conducted using the aid of well logs, water chemistry, environmental traces, barometric sensor data, water table surfaces, 2D reflection seismic, AEM datasets, SLIP maps (SLIP, 2019), SRTM/LiDAR (ELVIS, 2019), geological reports (Leyland, 2012), PRAMS regional model surfaces (Davidson, 1995) and interpreted well tops (Davidson, 1995 and Keysbrook 2013).

Geo-Electrical Interpretation Guide

An interpretation guide was created, highlighting the generalised distribution of AEM derived electrical conductivity for major hydrostratigraphic units (See Figure 2). In this Figure an electrical resistivity histogram was generated from the volume derived from the AEM inversion workflow 335 of 1500. Volumetric interpretation was completed to determine, the range of inverted electrical conductivities for each geological/hydrological unit. The histogram in Figure 2 highlights challenge of interpreting of hydrogeological units that have overlapping or similar electrical conductivity ranges. One example is differentiating between the sandier Members of the Leederville Fm in the Peel area such as the Wanneroo Mb and the Mariginiup Mb. Several well logs were selected to validate the layer-based AEM derived electrical conductivity distributions. A good agreement between the well logs and the inversed AEM conductivity volume was observed. Interpretation yielded surfaces for the unconfined Superficial aquifer, expansive sheet like aquitards, fault planes, plus high-solute concentration zones proximal the Serpentine and Murray Rivers.

Cultural Artefacts

Figure 3 compares a 2D cross-section containing inverted AEM electrical conductivity, 2D seismic reflection imaging and a power line noise intensity dataset (i.e., provided with the SkyTEM data). According to SkyTEM (2018) the values of power line noise indicators (PLNI) are “derived from a frequency analysis of the raw Z-component EM data” determined for each low-moment EM data block via a Fourier transformation. This is an estimate of the amplitude spectral density at 50 Hz.

A major interpretation challenge was to establish the impact of utilities on the AEM inversion outcome. A network of high-voltage electrical powerlines, gas pipelines and water pipelines cross the AEM survey area. Zones of anomalously high electrical conductivity were identified over utility lines. However, the depth at which the utility impacted on inverted electrical conductivity varied considerably. Not all cultural features produced significant artefacts and no strict relationship between the power line noise indicator at 50 Hz and resulting artefacts in the inversion outcome could be made. This is because the AEM transmitter, the utility and the earth’s conductivity distribution exist as a coupled EM system. For this reason, attempts at removal of the impact of utilities prior to inversion tends to be highly problematic. A theoretical alternative is to include the utility within the modelling, however this would require specific knowledge of the EM characteristics of the utility.

A brutal approach would be to surgically remove data below utilities prior to inversion then simply interpolate electrical conductivity across the resulting space. However, the near surface (i.e. very early time data) can be unaffected by the presents of utility lines. To avoid removal of shallow information a mute-filter could be designed to be dependent on a “depth” parameters and laterally distance from each utility. (i.e. a custom designed filter for each cultural feature). Our experience was that such methods tended to remove shallow conductivity information. Due to the high variability for each cultural EM signature, it was decided to simply interpret AEM inversion data with the effects of utilities present. Interpretation was performed with all relevant SLIP datasets (SLIP, 2019), showing the location of powerlines and pipelines.

In Figure 3, the dashed black line shows the top of the interpreted South Perth Shale Mb of the Leederville Fm horizon. Fortunately, the South Perth Shale horizon is remarkably flat within this area enabling the influence of the high-voltage powerline to be clearly identified. The powerline produced an anomalous 70 m “pull-up” at a depth of 200 m below ground level. The width of this anomaly extends at least 1 km either side of the powerline. However almost no artefacts were obvious at depths less than 60 m.

The north-south running Dampier-to-Bunbury gas pipeline and Hopeland Rd power line also add challenges to AEM interpretation. These two features run parallel within a major North South fault zone. This fault zone is hydrogeologically significant, as it extends into cretaceous Leederville aquifer. It has a displacement of approximately 50 m within the. Because the utilities and the fault zone run in parallel, the AEM could not be interpreted with confidence. This is particularly true when interpreting horizons and faults away from the seismic transect. A “pull-up” effect at depth was also observed in this zone. Interpretation of the AEM data was in part resolved by

high resolution seismic data which provided precise definition of the faulting.

CONCLUSIONS

Successful hydrogeological interpretation can be completed in areas where significant infrastructure is present. Despite electromagnetic coupling between the AEM system, utility lines and the earth, shallow conductivity distributions appear to exhibit surprisingly few artefacts.

Not all infrastructure could be accounted for or clearly identified during interpretation. The influence of the Dampier to Bunbury Gas pipeline running parallel to a major fault zone could not be easily characterized within the inverted AEM electrical conductivity volume. The high resolution 2D seismic reflection imaging was essential as it guided to interpretation of the AEM derived conductivity within this zone.

In summary we provide examples of AEM interpretation in the presents of major utilities for many hydrogeological features including major faults, 3D hydrostratigraphic surfaces, packages of rock with geological dip, saline water interfaces, along with zones with potential for hydraulic connection between key shallow and deeper aquifer systems.

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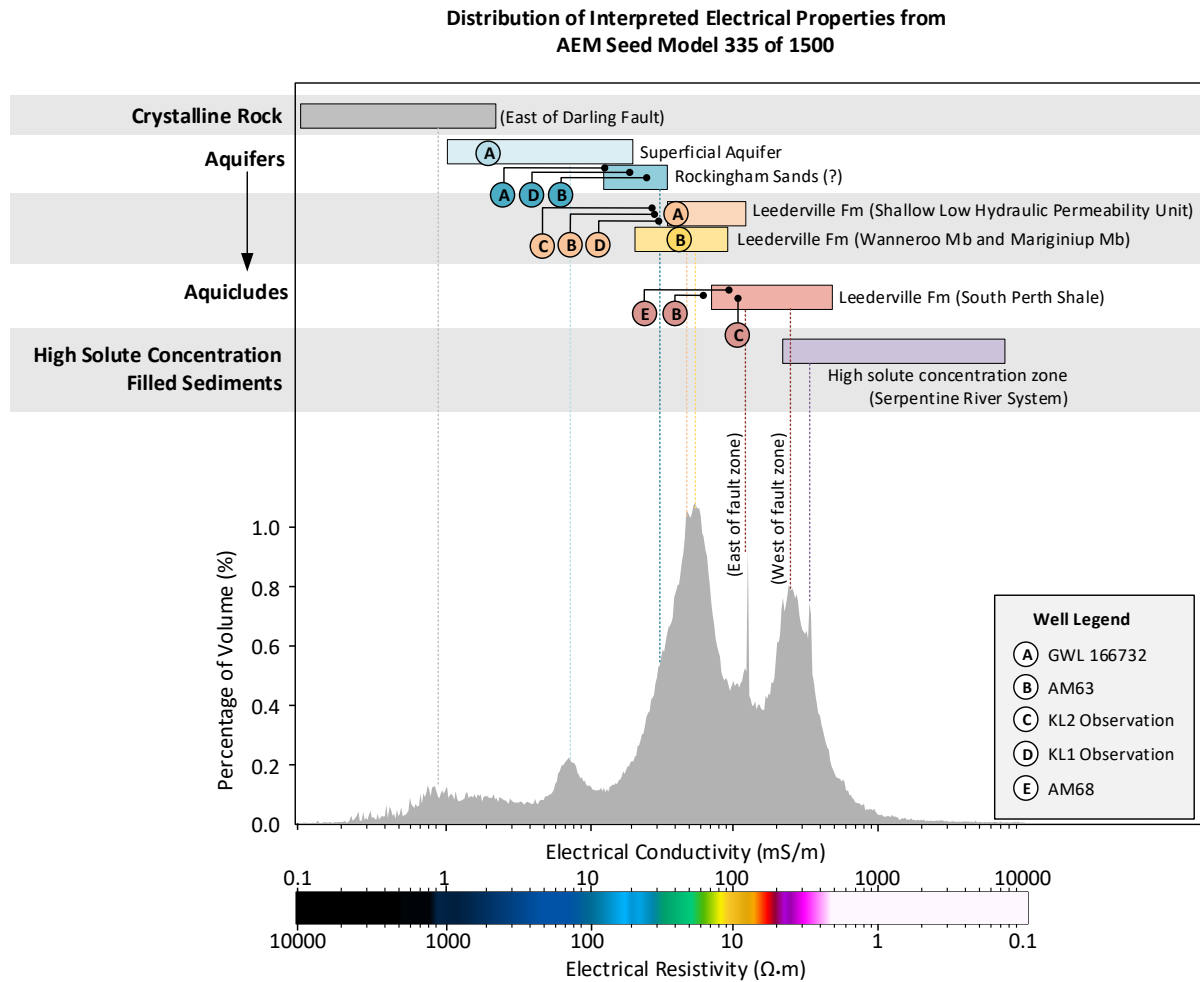


Figure 2. Geo-electrical interpretation guide of several of the major geo-electrical units within the AEM inverted electrical conductivity seed model 335 of 1500. The horizontal bars represent the interpreted electrical conductivity range, the circles show the average of well log derived electrical conductivity within the corresponding interval and the histogram shows the distribution of inverted electrical conductivity.

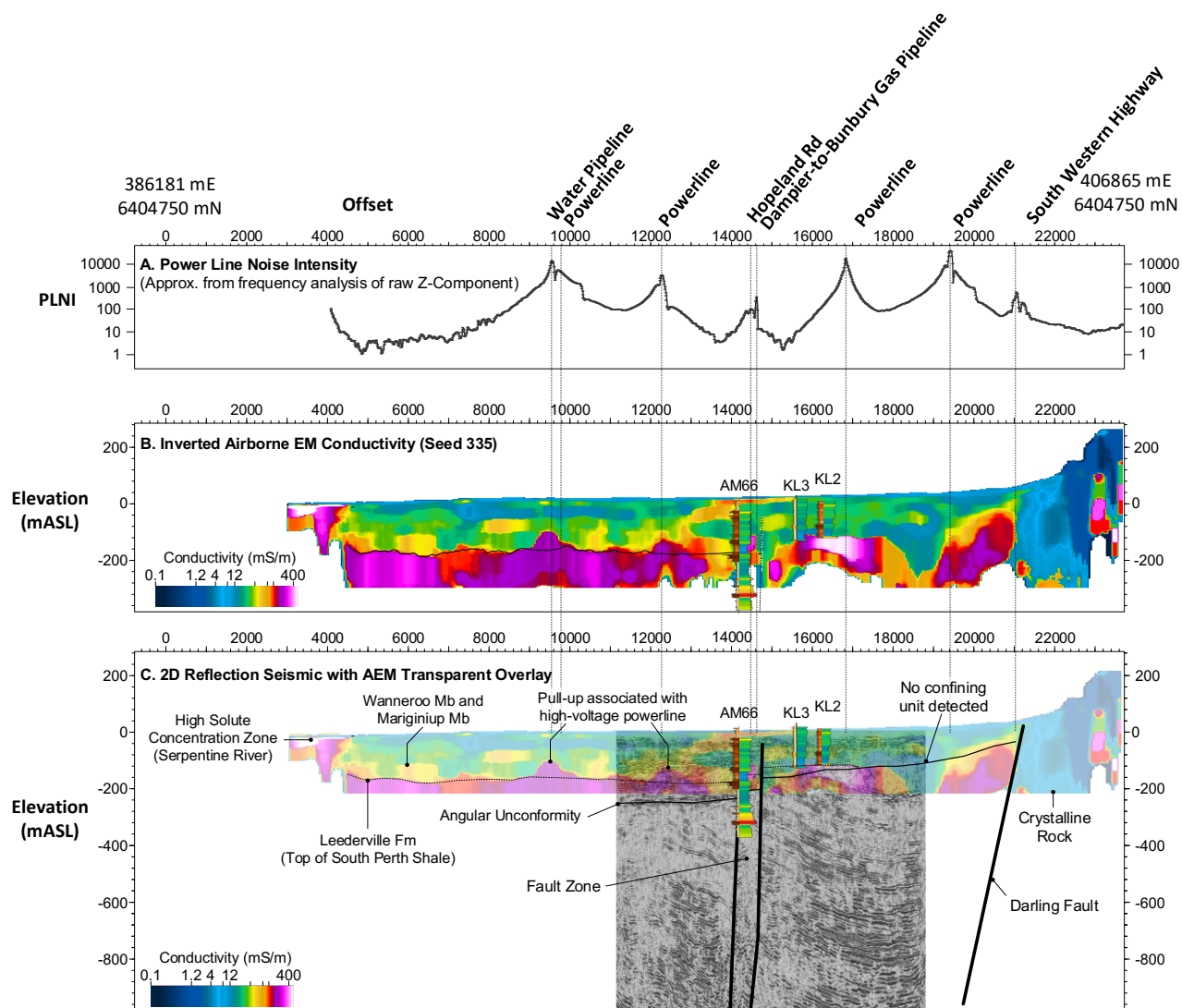


Figure 3. Comparison of (A) SkyTEM derived power line noise intensity (B) 2D inverted airborne electrical conductivity section proximal to the 2D high reflection seismic and (C) the 2D high reflection seismic down to 1 km depth co-rendered with inverted airborne electrical conductivity. The angular unconformity divides the Cretaceous and underlying Jurassic/Triassic sediments.