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PRCAC Collaborative Agreement between Curtin University and Department of Water W.A.:

Hydrogeophysics Summary Report

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Executive Summary

The Perth Region Confined Aquifer Capacity (PRCAC) study is being completed by the Department of Water, Western Australia. It aims to improve long-term management of Perth's high value deep aquifer systems. Part of the PRCAC study is a research agreement between Curtin University and the Department of Water in which hydrogeophysical methods are being developed to build and/or verify basin scale groundwater models that will ultimately be used to predict the impact of various groundwater management strategies. These models require the correct distribution of hydrogeological properties to depths of over 1000 m and across areas of many thousand square kilometres. Outcomes from the hydrogeophyiscs project feed into the innovative, world class, groundwater science being completed in Western Australia.

More specifically, the research has included the acquisition and processing of many new datasets and reprocessing of existing data. These activities have resulted in new subsurface images. The project includes integration of reflection seismic, airborne electromagnetic, magnetotelluric, ground penetrating radar and electrical resistivity imaging data within a single interpretation environment that includes existing drill hole and monitoring data. A full range of hydrogeological depths and scales are being investigated. These range from the surface to more than 3 kms depth. The team's research focuses on scales ranging from the definition of the saline water interface to large scale hydrogeology across major fault systems of the Perth basin.

Ongoing collaboration with Department of Water scientists has focused research in hydrogeologically consequential areas. In the first 18 months of the project all planned field activities are complete and many key outcomes have been realised. Research activities will continue until 2018 and the below document is set out as a live document to be added to as each research activity is completed. The report is composed of two distinct parts. The first is a concise point form summary of all activities, data/data formats, and initial key outcomes. The second part consist of a set of appendices. This contains detailed descriptions or representations of research activities and outcomes (e.g., research papers, presentations, student thesis etc). In most cases preliminary representations of the research are in the process of being developed into manuscripts to be submitted to peer reviewed research papers.

Top 10 project highlights 2015 to 2016 (first 18 months)

1. **From the new Silver Rd Seismic Transect (2015)**: The new North South oriented high-resolution Silver Rd Seismic reflection images show clear conformable layers with a gentle gradient to the South within the cretaceous sediment . There is no indication of faulting through the Cretaceous sediment as was previously considered possible from sparse drill-hole information.
2. **Reprocessing of Gnangara Mound TEM data (2015)**: Reprocessing of existing AEM data with the aid of the Magnus Supercomputer (i.e. https://www.pawsey.org.au/) facilitated development of a 3D conductivity volume spanning more than 1000 square kilometres. This 3D image accurately delineated the 3D geometry of the large high conductivity hydrostratigraphy significant Kardinya Shale unit. The positon of the expansive shale unit showed excellent correlation with sparse drill-hole data.
3. **New Bindiar Rd Seismic Transect (2016)**: Imaging of the new Bindiar Rd seismic transect indicates that the Wanneroo sediments, although clearly displaced, may still be in hydraulic communication across the Badaminna fault zone. The results have directed follow-up geophysical work specifically targeted as resolving distribution hydrogeologically significant clays and sand dominately unit proximal and within the fault. This includes performing a long ERI transect across the fault zone.
4. **Yanchep Magnetotelluric (MT) Transect (2015)**: The top 300 m of the inverted MT conductivity distribution shows excelled consistency with AEM data, wire line logs (AM05 and AM23) and nearby seismic transects. The MT data a representation of deep electrical conductivity distribution. Additional cooperative inversion and iterative reprocessing of the data will be performed within the framework of the new detailed model of formations across the Badaminna fault zone which will provide a better understanding of both the solute concentration and the deep clay dominated and sand dominated (i.e. the confined aquifers) units.
5. **The new Clarkson Rd seismic transect (2015)**: The Clarkson Rd seismic transect was collected in an extreme high noise setting, 20m from a busy rail system along a sometime twisting narrow sand track. Despite the difficult high noise conditions, key horizons in the depth converted seismic image, matched exceedingly well to formation tops identified in wells AM23 and Q37. The image revealed hydrostratigraphic units that clearly thicken to the North; but provide no clear evidence of large scale faulting in the Cretaceous sediment as was previously suggested (i.e. the inferred Wanneroo Fault).

6. **Reprocessed Airborne Electromagnetic (AEM) data:** New 3D AEM derived conductivity images clearly resolved the geometry of the "recharge window" that appears to connect the Yarragadee aquifer to shallower aquifers at the "centre" of the Gnangara mound.
7. **Electrical Resistivity Imaging (ERI) data**: The hydrogeophysics team have tailored the Electrical Resistivity Imaging method to resolve the geometry of the saline water interface along the coastal margin of Perth. They have used these workflows to resolve the interface at several locations along a 50 km length of coast to generated excellent baseline information.
8. **3D Printed Model**: The first physical 3D printed scale model of the PRAMS v3.5 model was created, enabling both tactile and visual representations of the 3D hydrogeology of the North Perth Basin. The parameters for a new larger printed 3D model are being established.
9. **Hydrogeological Modelling Reconceptualization proximal to the Badaminna Fault:** The offshore and onshore Badaminna fault has been linked with existing, seismic, new seismic data and airborne TEM for the first time. The geometry and significance of the fault can now be assessed.
10. **Post-doctoral staff and PhD/Honours students choose hydrogeophysics**. Young high quality researchers are starting to work in groundwater research and in particular hydrogeophysics. This is perhaps one of the most important outcomes of the collaborative agreement between DoW and Curtin University. Honours students enter the workforce with a solid background in groundwater. Post-doctoral and PhD students are necessary for sustained high quality research and development in hydrogeophysics that will make Western Australia a global leader in this increasingly important area of research.

Top 10 Highlights 2016 to 2017

To come in the Future

Top 10 Highlights 2017 to 2018

To come in the future

Introduction:

This document provides baseline documentation for the Curtin University, Department of Water collaborative hydrogeophysics project spanning the first 18 months of activity. The first phase of activity was dominated by field experimentation, data acquisition, processing/reprocessing, base level interpretation and data integration. The new data sets created form the basis for many ongoing research activities. The report provides a high-level summary of each activity and in particular, details new data acquired, new processing completed along with the necessary instruction required to open, view and use the many images and data sets created by the hydrogeophysics team. It is, accompanied by a set of appendices that address detailed aspects of the research program. The summaries of each major activity have the approximate structure below (i.e., major headings):

- Purpose:
- Research objective:
- Location:
- Special acquisition parameters:
- Processing:
- Interpretation:
- Integration:

Research activities and intermediate products will be progressively translated to peer reviewed Journal papers. These will move through a stage of internal review at Curtin University and the Department of Water after which each manuscript will be submitted for independent peer review at the selected relevant Journal. Each research paper will focus on the geophysical technology and will identify the PRCAC hydrogeological outcomes stemming from research.

Towards the project's end, the team intend to compile a book out of published papers related to hydrogeophysics for groundwater management in the Perth Basin. Completion is expected towards the end of 2019.

PRCRC Hydrogeophysics Activity Summaries:

WP1- RA1 - Silver Rd Seismic Transect.

- Commenced 6th February 2015
- **Purpose:** The hydrogeological objectives for completing the Silver Rd seismic transect was to locate suspected relatively large displacement fault (i.e., the Wanneroo Fault). A secondary objective was to define hydrostratigraphy in a key location in the Perth basin.
- **Example of a research objective:** The survey was designed long linear Vibrated sweeps (6-150Hz) and used very long offsets such that deep refraction tomography and specialised processing could be completed. The refraction tomography generated velocity distribution to depths of over 300. This permitted accurate time to depth conversion and improved imaging of Perth key aquifers. The Silver Rd transect is in a key location and has immediately answered long-standing questions about distribution of Perth confined aquifers. The deep refraction tomography results also provided rock property distributions (velocity) from surface into the Cretaceous sediments. Initial work is being converted to a research paper (see Appendix ?).
- **Location:** The Silver Rd transect was located along Silver Rd to the South of the Gnangara mound. It extended for approximately 7500m South of Neaves Rd.
- **Special acquisition parameters:** The team laid out a long static seismic spread. This meant that 750 geophones were located at 10 metre intervals and all geophones were active during surveying. That is approximately 750 geophones were active for approximately 750 source records (Vibrator locations). Survey parameters are given in the table below.

Parameter	Survey Details
Date completed	6th February 2015
Line Start Coordinate	1st live CDP: 1001, 395338.6 X:, 6486690.0 Y: Rx: 395334.9 X:, 6486697.0 Y
Line End Coordinate	Last live CDP: 1750, 395113.1 X:, 6494141.0 Y: Rx: 395118.0 X:, 6494144.5 Y
Sweep Specification	24 second linear sweep with frequency range 6 Hz to 150 Hz (Univib)
Sample Rate	1 ms
Geophone Spacing	10 m
Source Spacing	10 m
Uncorrelated Trace length	24 seconds
Trace length	3 seconds
Number of Shot Points	750
Number of Live Geophones Per Source Point	750 750 (Static spread) Average elevation 25-39

Table 1: Basic table of Silver Rd seismic acquisition parameters

- **Processing:** Multiple processing refinements were completed. Long offset refraction was used to recover high quality velocities to approximately 400m below ground level. This accurate velocity data was then integrated into the processing workflow to improve imaging and time to depth conversion. The end result was a high quality image of the subsurface to approximately 2000 m beneath Silver Rd.
- **Interpretation:** Data quality for the Sliver Rd Seismic Transect was excellent. The final high quality image provided no indication of significant faulting in the east-west direction. Broadly conformable reflectors (i.e. layers) with a gentle north to south gradient of the order 1:50 were observed in the Cretaceous sediments along the full seismic transect (see Figure 1). The reflectors in the Jurassic are perhaps slightly more discontinuous but again there is no indication of significant displacement from faulting in an east west direction immediately below the this transect.
- Figure 1 shows an image of the Silver Rd seismic transect with key stratigraphic units overlain. The Figure is produced in the Petrel E&P software platform (2015). It shows all key hydrostratigraphic units. No significant displacement is observed on this transect.
- Figure 2 shows the velocity distribution recovered from long offset refractions tomography. Depths of up to 400 m of high resolution velocity distribution were recovered. The velocity model was consistent with detailed in-hole velocity measurements from the Water Corporation M345 site to the North (see Almalki, Harris and Dupuis 2014).

  Interpretation / The Wanneroo Fault: The Wanneroo Fault was postulated to pass below the Silver Rd transect, however no significant faulting is evident within the resulting seismic reflectivity images. That is, there is no evidence from seismic indicating for the existence of a large displacement faulting in the Cretaceous sediments below the Silver Rd transect. The North South gradient along reflectors observed in the Seismic image are shallow and consistent with expected dips of units like the South Perth Shale further to the North where AEM, drill hole and Seismic data exist.

- **Integration:** The Silver Rd transect is available as an industry standard SEGY file.

Final SEGY file Details	Remark
Datum Elevation	40 m
Segy file name(s)	20151005_SilverRd_MIG_COSPERIGRAM_depth_2k5@2m_datum_40m.sgy 20151005_SilverRd_MIG_COSPHS_depth_2k5@2m_datum_40m.sgy 20151005_SilverRd_MIG_depth_2k5@2m_datum_40m.sgy
SEGY Version:	Rev 1.
Import instructions	Output format: IBM Trace coordinates are on standard locations: - Trace header bytes: 73 and 77 (INTEGER*40)

Table 2: Silver Rd Seismic Post Stack SEGY file – Table of parameters

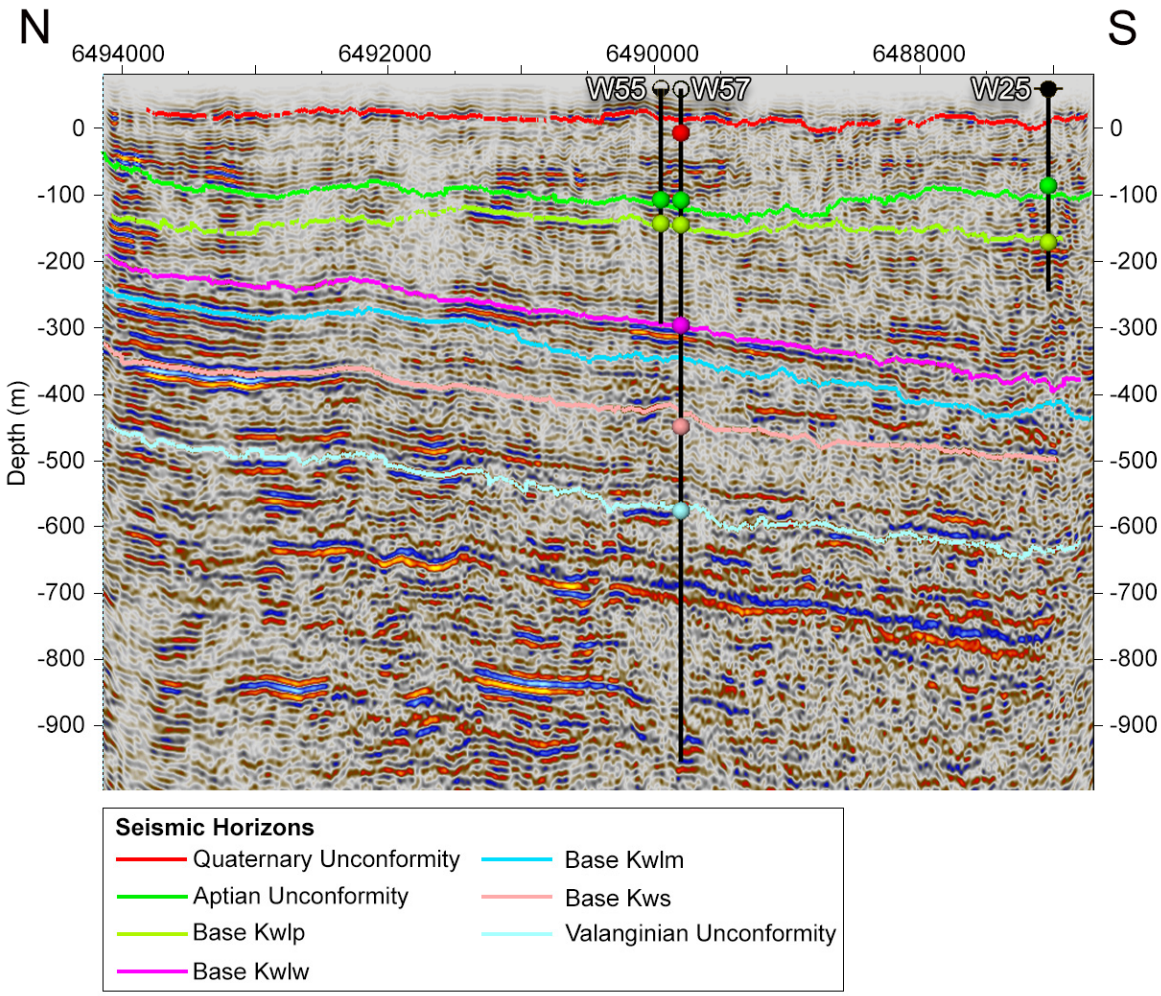


Figure 1: Image of the Silver Rd seismic transect with key stratigraphic units overlain. A vertical exaggeration of 5 was applied. Wireline logs and formation tops are provided. The figure is produced in the Petrel E&P software platform. Note the strong reflectors marking key formation boundaries.

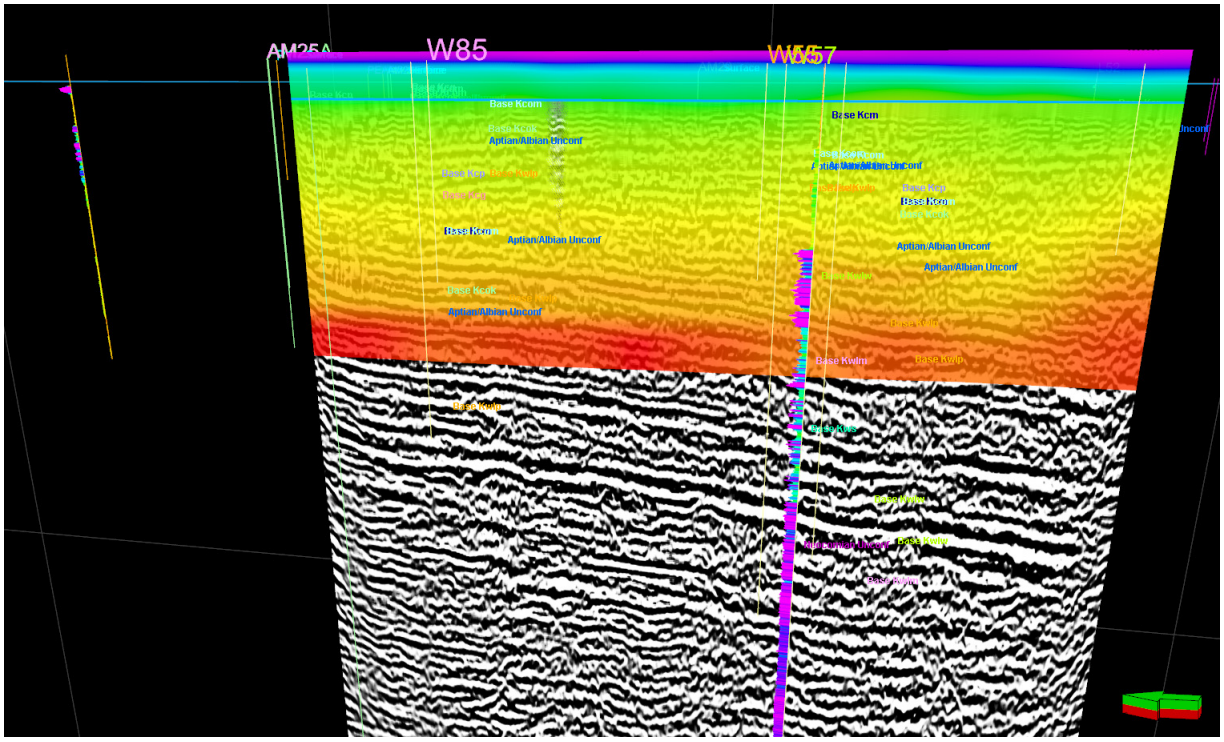


Figure 2: The tomographic inversion resolved interval velocity field overlying the cosine of phase seismic depth section.

WP1 – RA2 Clarkson Rd Seismic Transect.

- **Purpose:** The hydrogeological objective of completing the Clarkson Rd seismic transect was to recover detailed hydrostratigraphy between AM23 and Q37. The wells are separated by approximately 2000 m and there appears to be a vertical displacement of the order 200 to 400 m for the major hydrostratigraphic unit (i.e., between the wells).
- **Example of a research objective:** A particular challenge addressed by this survey is acquiring and processing data in an extreme high noise setting (i.e., parallel to a railway and in proximity to two high traffic roads). The Clarkson seismic transect needed to be acquired before commencement of earthworks required to extend the Michael Freeway. During the peak hour period, trains passed every 7 minutes. Passive data was acquired during the survey to directly compare the signal produced by trains with that produced by the Vibrator trucks. An assessment of the signal produced by the Train (and possible cars) may indicate if this type of passive noise can be used to create sub-surface images (i.e. given an optimally designed receiver spread were used).
- Figure 3**:** Image shows the NGL UniVib in front and the Clarkson rail system behind along with passing train. The survey had to work around daily train schedules and high traffic periods at the start and end of each day during acquisition. This combined with dry winding sandy tracks made the survey logistically challenging.
- **Location:** The approximately 6500m long transect was completed parallel to and typically within 20m of the Clarkson rail system (see Figure 3)
- **Special Acquisition Layout:** The team deployed a long approx. 6500 m static spread. This means that all approx. 650 geophones were laid out and data captured for the full spread during all 650-source points (UniVib source locations). The survey design provided high fold between the two wells. That is, highest quality seismic imaging would be expected between the two wells AM23 and Q37. Basic acquisition parameters for the Clarkson survey are outlined in Table 3.

Figure 3: An image of the UniVib in front of the Clarkson rail system. At peak times trains were passing the transect every seven minutes.

Parameter	Survey Details
Date completed	02/05/2015
Line Start Coordinate	1st live CDP: 3001, X:381597.1, Y: 6489706.1
Line End Coordinate	Last live CDP: 4218, X:379781.7, Y: 6495362.0.1
Sweep Specification	24 second linear sweep with frequency range 6 Hz to 160 Hz (Univib)
Samples Per Trace	5000
Geophone Spacing	10 m
Source Spacing	10 m
Uncorrelated Trace length	24 seconds
Correlated Trace Length	5 seconds
Number of Shot Points	625
Number of Live Geophones Per	661
Source Point	661 (Static spread)

Table 3: Basic table of Clarkson seismic acquisition parameters

- **Processing:** Several processing workflows were tested. Multiple cycles of densely spaced velocity analysis were undertaken as a key part of the processing work flow. This necessary step was carried out to improve the image quality between wells AM23 and Q37.
- **Interpretation:** High quality seismic imaging was achieved between the two wells AM23 and Q37. Several continuous reflectors could be observed between these wells. Of particular note is the strong reflector that seems to correlate with the interface between Wanneroo Sandstone and Mariginiup members of the Leederville formation in both wells (see Figure 4). The gradient along the Clarkson seismic transect for all major reflectors is from North to South. This North south gradient tended to increase with depth to a maximum at the interpreted Neocomian

unconformity. The highest gradients along the major reflectors tended to located between Q37 and AM23.

- **Interpretation / Wanneroo Fault:** A strong motivation for completing the Clarkson transect was to verify the existence of the postulated Wanneroo Fault. There are no indications from the seismic transect of a clear large displacement East West fault within Cretaceous sediments between well AM23 and Q37 (i.e. as was previously been postulated). Compared to other location such as over the Gnangara mound the reflectors in the Cretaceous sediments do have a relatively sharp gradient to the South. Higher gradients along the seismic transect appear to be between of the order 1:20 for shallower formations and 1:5 at the top of the interpreted Yarragadee. Faulting during the Jurassic is possible and line orientation is designed to detect E-W oriented structures. There appears to be a general thickening of each major stratigraphy unit to the South of the Transect, which is consistent with drill-hole data. Note that a large vertical exaggeration of five have been used to accentuate vertical features.
- **Integration:** The Clarkson transect has been created to be consistent with industry standard SEGY formatted files.

Final SEGY file Details	Remark
Datum Elevation	55 m
Segy file name(s)	20150602_2D_Clarkson_MIG_3km@2m.sgy 20150602_2D_Clarkson_MIG_CSP_3km@2m.sgy
SEGY Version:	Rev 1.
Import instructions	Output format: IBM Trace coordinates are on standard locations: - Trace header bytes: 73 and 77 (INTEGER*40)

Table 4: Clarkson Seismic Post Stack SEGY file – Table of parameters

- Figure 4 shows an image of the Clarkson Rd seismic transect with key stratigraphic units overlain. Wireline logs and interpreted formation tops are provided. The figure is produced within the Schlumberger Petrel software. Note the strong reflector marking in Magenta appears to correlate with the interface between Wanneroo Sandstone and Mariginiup Members of the Leederville formation (see AM23 and Q37).

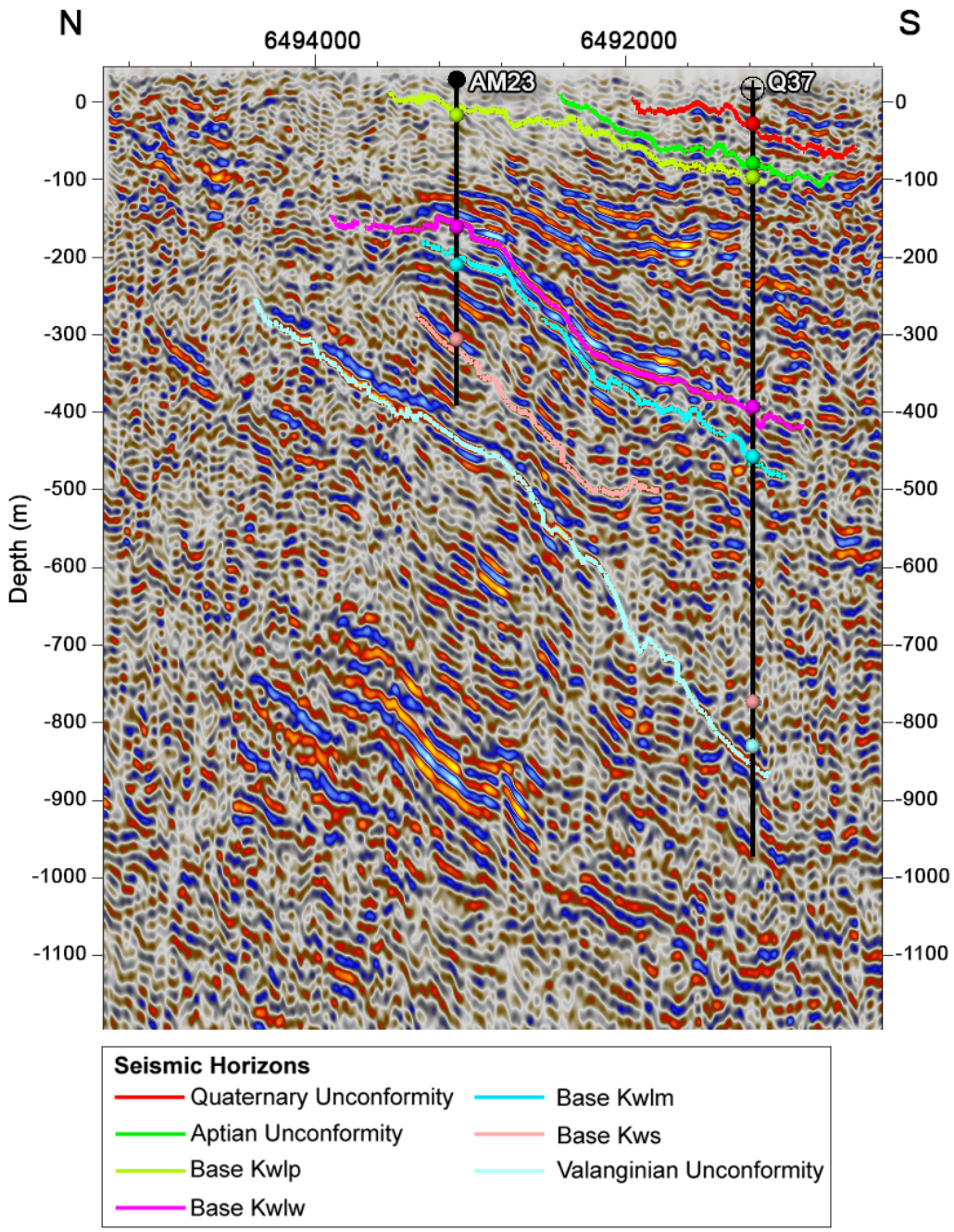


Figure 4: Image of the Clarkson Rd seismic transect with key stratigraphic units overlain. Wireline logs and formation tops are provided. The figure is produced in the Petrel software. Note the strong reflector-marking along key formations. A large vertical exaggeration of 5 have been used.

WP1- RA3 – Two Rocks (Bindiar Road) Seismic Transect.

- **Date** completed: 18th March 2016
- **Purpose:** The main hydrogeological objectives for completing the Two Rocks seismic transect was to better define the Badaminna Fault and hydrostratigraphy on the West of the Fault towards the Ocean. A secondary objective was to define hydrostratigraphy in a key location in the Perth basin. Of particular interest is possible hydraulic connection between the Wanneroo Sandstone Member of the Leederville formation and the Yarragadee formation. This transect is ideally located to be directly linked with conductivity distributions derived from airborne TEM data.
- **Example of a research objective:** The survey was designed such that long offset refraction tomography and specialised processing could be completed. The transect was "crooked" which enables a type of pseudo 3D seismic processing to be completed. This work forms part of on a 2016 honours research project. Information from the Bindiar Rd seismic transect will be combined with AEM derived conductivity, detail dipole-dipole ERI derived electrical conductivity and novel new ground based EM technologies that use a high powered electrical bipole antenna. The combination of these surveys will provide field scale data to commence analysis of connections between acoustic, electrical and hydraulic anisotropy for the key basin scale sedimentary unit of the Perth basin. This work forms part of a three year PhD research program being undertaken by Mr Alex Costal. The ERI data has been collected (June 2016) by the hydrogeophysics team and is being analysis. Follow electrical surveys will be completed to assess conductivity distribution across the fault. These data will combine to better define deep electrical conductivity distribution and any associated large scale solute concentration distributions.
- **Location:** The Bindiar Rd transect was located South of Two Rock town Site. It runs east west along Bindiar Rd for approximately 6500m from Indian Ocean Drive toward to Ocean.
- **Special acquisition parameters:** The team have laid out a long static spread. This meant that all approx. 690 geophones were laid out and the full spread of data was captured for each of the approx. 750 source points. Such a spread gives considerable flexibility in processing. The seismic survey acquisition parameters for the Bindiar Rd transect are provided in the table below. Survey parameters are shown in the table below.

Parameter	Survey Details
Date survey commenced	18th March 2015
Line Start Coordinate	1st live CDP:4, X:368973.9, Y:6513774.1 Rx:1, X:368973.9, Y:6513774.0
Line End Coordinate	Last live CDP:1370, X:375244.4, Y:6514341.3 Rx: 694, X:375301.2, Y:6514408.5
Sweep Specification	24 second linear sweep with frequency range 6 Hz to 150 Hz (Univib)
Sample Rate	1 ms
Geophone Spacing	10 m
Source Spacing	10 m
Uncorrelated Trace length	24 seconds
Trace length	3 seconds
Number of Shot Points	690
Number of Live Geophones Per Source Point	694
Number of active channels	694 (Static spread) Average elevation 25-39

Table 5: Two Rocks Survey - Bindiar Road - seismic acquisition parameters

- **Processing:** Multiple processing refinements were completed. Multiple rounds of first break picking and velocity analysis were required because of complex shallow velocity structure. The transect was process with both conventions 2D method and as a pseudo 3D data set. Results a being assess and improved as part of a 2016 honours project.

- **Interpretation:** The key observations from the Bindiar Rd seismic transect were:
    - The juxtaposition of the interpreted Wanneroo Member of the Leederville formation on the east and west of the Badaminna Fault was a key consideration for both seismic reflectivity imaging and reprocessing of Airborne TEM data. The seismic data strongly suggest that some part of the Wanneroo Sandstone Member overlap from one side to the other. There is clearly considerable displacement across the fault, however the bottom section of the Wanneroo to the East of the Fault appears to be opposite the upper section of the Wanneroo Sandstone on the West of the Fault. This is supported by the AEM data.
    - The Wanneroo Sandstone is considerably thicker on the West of the Badaminna fault. That is the Wanneroo Sandstone appears to thicken well over 250m at the

West of the Bindiar Rd Transect (more than 250m thick), although transition from Wanneroo Sandstone to Mariginiup Members of the Leederville formation is at this stage not clear. The nearest well AM74 several kilometres to the North, did not penetrate the interface between Mariginiup and South Perth Shale. Certainly, other wells to the west of the Badaminna fault (e.g. AM1, AM8 and AM12) all pass through relatively thick intervals of Wanneroo Sandstone consistent with what is seen in the Bindiar Rd seismic seismic image below.

- The Aptian Unconformity is clear from seismic data. The clay dominated Kardinya Shale is expressed by relatively simple continuous reflectors typical of a low energy clay dominated settings. This zone matches well with a high conductivity layer expected to be the Kardinya Shale observed in the AEM data as shown in the figure below.
- The Kardinya shale may sub-crop below the superficial formation just to the West of the fault. This is yet to be verified. The seismic reflections identified with the Kardinyashale appear to form the shape of a wedge either against the Badaminna Fault or against superficial formation. The termination of this shallow wedge below the superficial and or against the Badaminna fault is not clear in the AEM derived or seismic data. A shallow high-resolution ERI survey is likely to be able to the nature of the termination of the Kardinya shale. This survey has recently be completed and is now being analysed. Outcomes may have implications for hydraulics along the Southern extend of the onshore Badaminna fault.
- The package of rocks including Mariginiup, South Perth Shale, and Gage, are collectively represented as a set of reflectors dipping to the West on the West of the Badaminna fault. While this collective package is reasonably clear, the division between these stratigraphic units is difficult to establish. To the east of the Badaminna fault the reflections indicative of the angular unconformity between South Perth Shale/Gage and Yarragadee Fm can be seen towards the eastern most part of the Bindiar Seismic transect.
- Figure 5, presents the Bindiar Rd seismic reflection data with an AEM derived conductivity distribution overlay. Interpreted stratigraphic units are overlain. Figure 6 show a cosine of phase attribute representation of the Bindiar Rd seismic reflection data.

- **Integration:** The Bindiar Rd seismic images has been created and is available as an industry standard SEGY file (see table 6).

•

Final SEGY file Details	Remark
Datum Elevation	55 m
Segy file name(s)	20161428_Bindiar_Rd_PSTKMIG_depth_3km@2m_datum_55m.sgy 20160504_Bindiar_Rd_PSTKMIG_depth_3km@2m_datum_55m_NORM_2DFILT.sgy 20160504_Bindiar_Rd_PSTKMIG_depth_3km@2m_datum_55m_NORM_2DFILT_AGC250.sgy 20160504_Bindiar_Rd_PSTKMIG_depth_3km@2m_datum_55m_NORM_2DFILT_COSPHS.sgy 20160504_Bindiar_Rd_PSTKMIG_depth_3km@2m_datum_55m_NORM_2DFILT_PERCOSPHS.sgy
SEGY Version:	Rev 1.
Import instructions	Output format: IBM Trace coordinates are on standard locations: - Trace header bytes: 73 and 77 (INTEGER*40)

Table 6: Two Rocks Seismic Survey - Post Stack SEGY file – Table of parameters

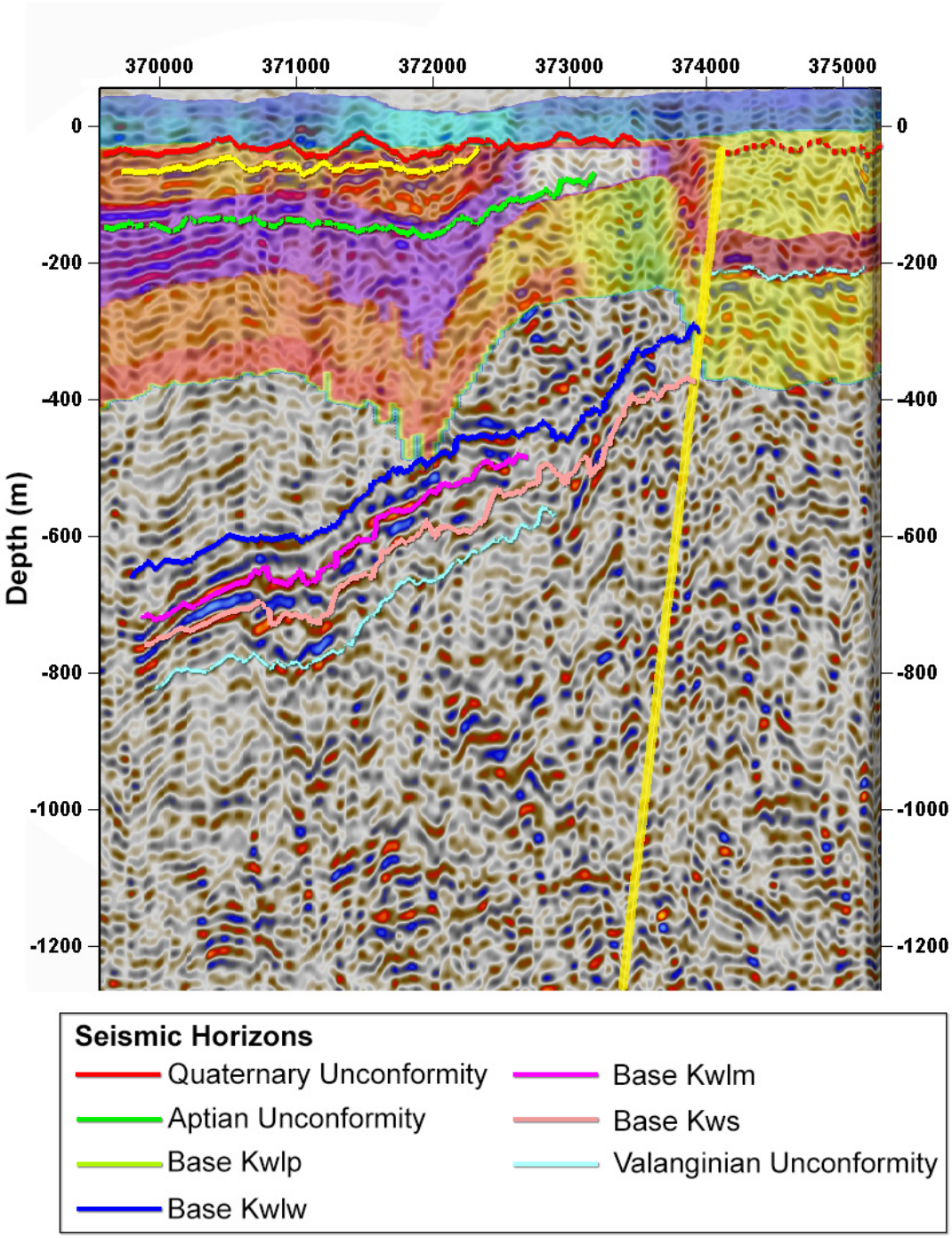


Figure 5: Figure 5 shows an image of the Bindiar Rd seismic transect with key stratigraphic units overlain. The Figure is produced in the Petrel E&P software platform (2015).

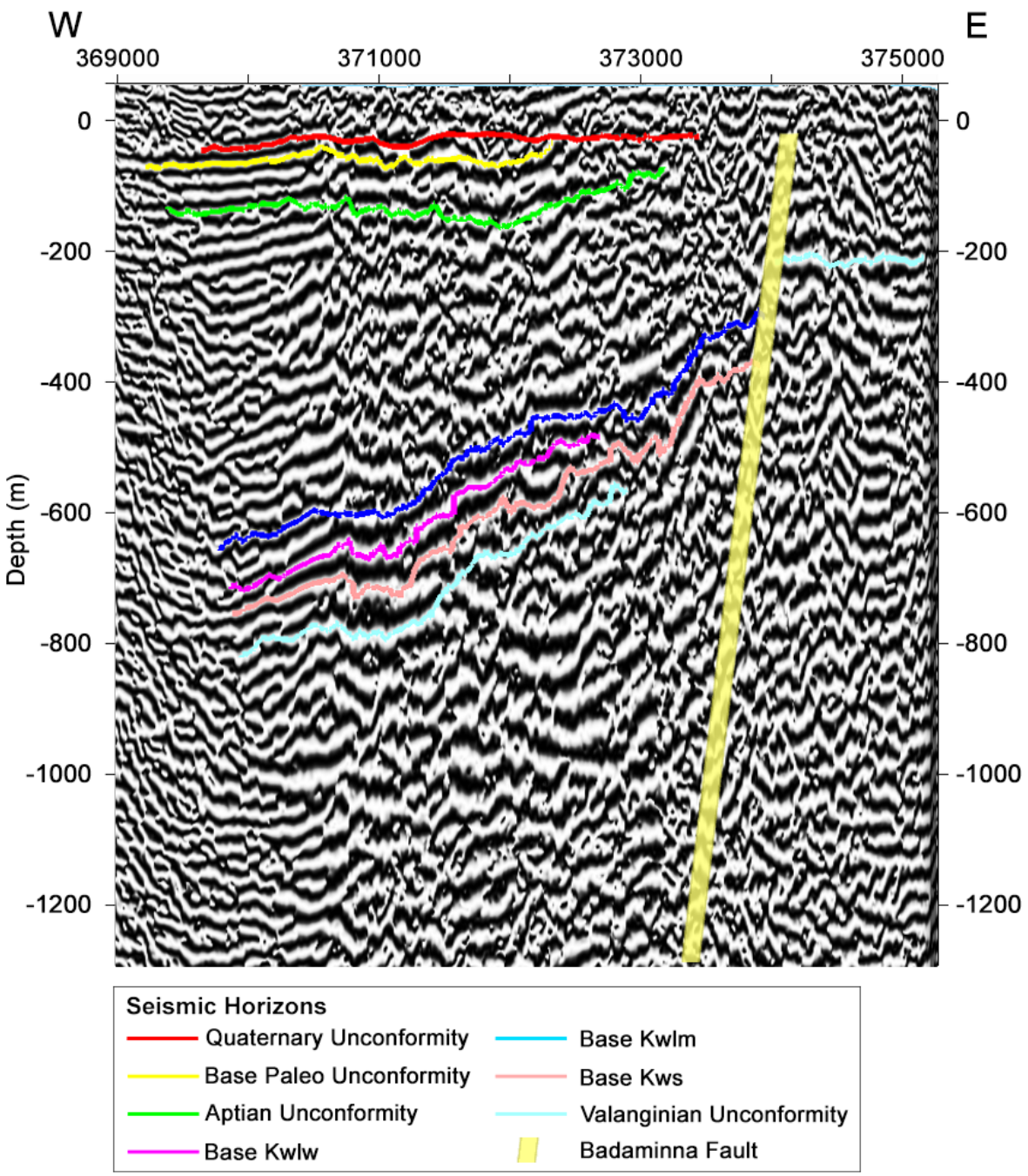


Figure 6: Image showing Cosine of phase attribute on the Bindiar road seismic section. A Vertical exaggeration of 5 was used. A basic interpretation of key hydro-stratigraphic interfaces is provided.

WP2 RA2 – Reprocessing of Airborne Electromagnetic Data

AEM Locations / Acquisition: Two airborne electromagnetic (AEM) surveys were completed over the northern part of the Gnangara groundwater mound in 2013. Some 4078 line kilometres of fixed-wing TEMPEST airborne electromagnetic data were acquired (Fugro 2013) and 2407 line kilometres of XTEM airborne electromagnetic data (Pennington Scott, 2013) was collected. A map showing the extent of these AEM surveys is included in Figure 7.

Key Acquisition details are:

The airborne TEM survey consists of:

Parameter	Survey Details
Survey / Reprocessing	Survey completed 2013 Reprocessing completed Nov 2015
East-west trending survey lines	101
Individual soundings	337,514
Rx components	13 channels (x and y)
Repetition frequency	75Hz
Approximate data points	9 million
Approximate station spacing	10-13 m
Approximate line spacing	400 m
Maximum east-west survey length	57 km
Maximum north south survey extent	40 km

Table 7: Tempest Airborne EM Basic Survey parameters

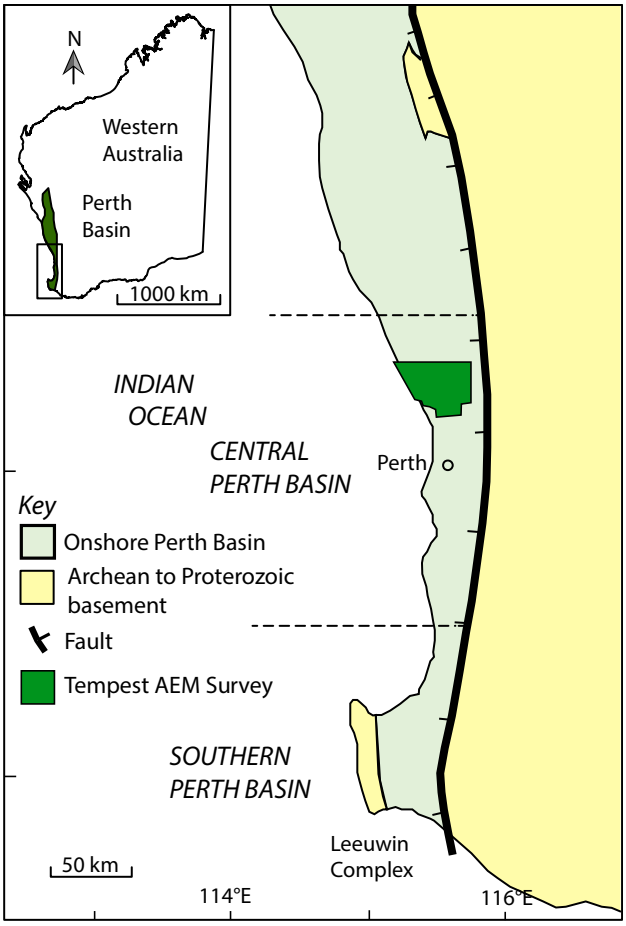


Figure 7: Location map (modified from Leyland) showing the location of the Tempest Airborne Electromagnetic Survey in perspective of the Perth Basin.

Purpose/Reprocessing: The Airborne TEM survey (TEMPEST data) was reprocessed in 2015. The purpose of the reprocessing was to generate a high quality consolidated 3D electrical conductivity distribution spanning the entire survey area. Reprocessing was completed on both the Curtin computing system and the Magnus Cray Cascade Supercomputer (https://www.pawsey.org.au/)

Research objective: Challenges that needed to be addressed in reprocessing the AEM data were: (i) isolation and elimination of cultural noise from the 3D image and (ii) refinement of the processing workflow such that conductivity distributions were reasonably matched to wireline log and seismic imaging where available. Other research objective that are being address by the hydro-geophysics research team are (i) automatic recognitions and removal of cultural noise (ii) computations of electrical conductivity distribution across complex 3D structures, automatic calibrations to wireline log data and estimation of solute concentration in the major confined aquifers.

Processing: The bulk of processing was completed on the Pawsey Centre Cray Cascade Supercomputer. Pethick and Harris 2015 have showed that processing time can be reduced by up to

three orders of magnitude by using the Magnus Cray Cascade Supercomputer when compared to a time required for processing on a conventional stand-alone PC. For the Gnangara mound TEMPEST data set the Cray Cascade Magnus system allowed over 200 processing workflows to be rapidly and semi-automatically assessed. Analysis of inversion errors and comparisons with wireline logs allowed the optimum workflows to be selected. Custom software code was developed to enable parallelization of Airbeo (Raiche et al., 1999 and Raiche 1985) on the IVEC Pawsey Supercomputer. This code enabled the inversion time for all 337, 000 soundings to be reduced from approximately 4 days to less than 1 hour. Several of the optimised workflows were applied to the full data set (337,514 individual AEM soundings). Output electrical conductivity were then converted to a 3D conductivity volume and output in petroleum industry standard SEGY format. This format allowed the data set to be integrated within all other data and interpretations in the Schlumberger Petrel Software package.

Interpretation: The product resulting from of the AEM reprocessing was a high resolution 3D conductivity volume spanning a maximum east-west survey extent of 57 km and maximum north-south survey extent of 40 km. Inline (X), crossline (Y), elevation (Z) and oblique cross sections were extracted from the 3D electrical conductivity volume to assist interpretation along seismic lines and along zones of interest. Specific hydrogeological outcomes facilitated by new electrical conductivity volumes include:

- **Imaging shows the extents of shallow superficial formations**: The shallow conductivity distribution provides a confirmation of the extents of shallow 'superficial' formations (e.g., Tamala Limestone, Bassendean Sand, Guilford Clay). Figure 8 shows a depth slice at 10 m above sea level overlain on mapped geology for the survey area.
- **Depth slice movies**: Several movies showing AEM derived electrical conductivity depth slices every 10 mbgl has been developed and is being analysed (this are provided in the Digital Appendix).
- **Imaging provides an indication of the Mariginiup/South Perth Shale**: In the survey area to the east of the Badaminna fault the Mariginiup/South Perth Shale package of siltstone/shale dominated rocks are modestly well mapped by the AEM to depths of approximately 300 m. The caveat on this statement is that where high conductivity sediments overly (i.e., Kardinya Shale or Guilford Clay) the Mariginiup/South Perth Shale package the resolution is compromised. If highly conductive sediment overly the Mariginiup/South Perth shale package then this seal cannot be accurately mapped. Extracted Long North-South transects towards the centre of the Gnangara mound show the south Perth shale as a continuous conductive unit dipping gentle to the South.
- **Definition of a "hydraulic window" through the Leederville Formation:** In the central zone of the Gnangara mound the Yarragadee Formation appears to be in direct contact with

superficial sediments. This "window" through the Leederville formation is well mapped by the newly processed AEM derived 3D conductivity volume (see Figure 9).

- **Large low elongated low conductivity zone down the mid of the Gnangara Mound**: More broadly there is a large north south elongated zone approximately along the centre of the Gnangara mound where more conductivity South Perth shale appears to have thinned or possibly disappeared. Note that in this zone down the centre of the Gnangara mound the relatively thin or absent of shallower conductive units tends to allow the AEM to have greater depth of penetration. This is evident along PRCAC section 6 as shown in Figure 13. The thinning or absence of South Perth shale down this zone is consistent with drill-hole data along this PRCAC section 6.
- **Mapping of the top of the conductivity Kardinya Shale to the West of the Badaminna fault**: Auto picking of the top of Kardinya shale, west of the Badaminna Fault system was completed from the 3D AEM derived conductivity volume within the Petrel software. The location of this surface was wholly computed based on the inverted 3D AEM electrical conductivity volume directed from the derived wireline well electrical conductivity data. The detailed 3D surface representing the top of the Kardinya shale was shown to match to the top of the shale in many wire-line logs (see Figure 10), the well logs shown were not used to condition the initial seed model. Auto picking based on the first large geo-electrical contrast (top of the Kardinya Shale) will fail along the coastline as the saline water interface is approached. That is, the saline water interface becomes the first high contrast geo-electrical boundary.
- **Mapping of the high conductivity salt water interface**: The extent of shallow saline water at the coastal margin could be broadly mapped as a high conductivity narrow strip following the coast (See Figure 9).
- **The Badaminna Fault Zone**: The trace of the Badaminna fault zone is well defined in the AEM-derived 3D conductivity distribution (see Figure 9). Care needs to be taken in separating the termination of the Kardinya shale which has a shallow dip to the West against the Badaminna fault zone and the trace of the fault itself which dips steeply to the west. The Kardinya shale is clearly terminated by the Badaminna fault.
- **Extraction of AEM data along DoW hydrogeological transects:** DoW have generated a number of hydrogeological transects based on the location of deeper wells. The trace of these hydrogeological transects was supplied and profiles of TEM data were extracted from the 3D electrical conductivity volume (see Figure 13).
- **Shallow high conductivity zones tend mask deeper conductivity distributions.** One important caveat required when considering AEM derived electrical conductivity is that high

conductive zones tend to mask or decrease certainty of conductivity distributions at greater depths.

- **A basic set of image representing the AEM data are provided below (figures 8 to 13).**
- **More details hydrostratigraphic interpretations for the AEM conductivity distributions are being developed in two forms.** The first is a comprehensive powerpoint slide package and the second is a Journal paper titled "3D interpretation of Airborne Electromagnetic data for Hydrogeology: Perth Basin WA" (Pethick, et al., 2016). It is intended that these additional research outcomes be completed in the next six months.

Integration: The 3D Airborne EM data set has been converted to standard E&P 3D SEGY format,which will import to any modern 3D seismic interpretation software package. The import parameters are provided in the table below.

Final SEGY file Details	Remark
Datum Elevation	375 m above sea level
Segy file name(s)	20160331_AEM_S87Ch_Cond_mSm_Datum375m_Dz2_5.segy - Units in Electrical Conductivity: milli Siemens per metre (mS/m) - Vertical resolution 2.5 m - East/North Resolution 40 m
SEGY Version:	Rev 1
Import instructions	Output format: IBM Trace coordinates are on standard locations: Trace header bytes: 73 and 77 (Note: to double check elevation after import, check if the top of the non-null extreme western conductivities align with zero as this corresponds with the ocean level.)

Table 8: TEM Airborne TEM SEGY file – table of parameters

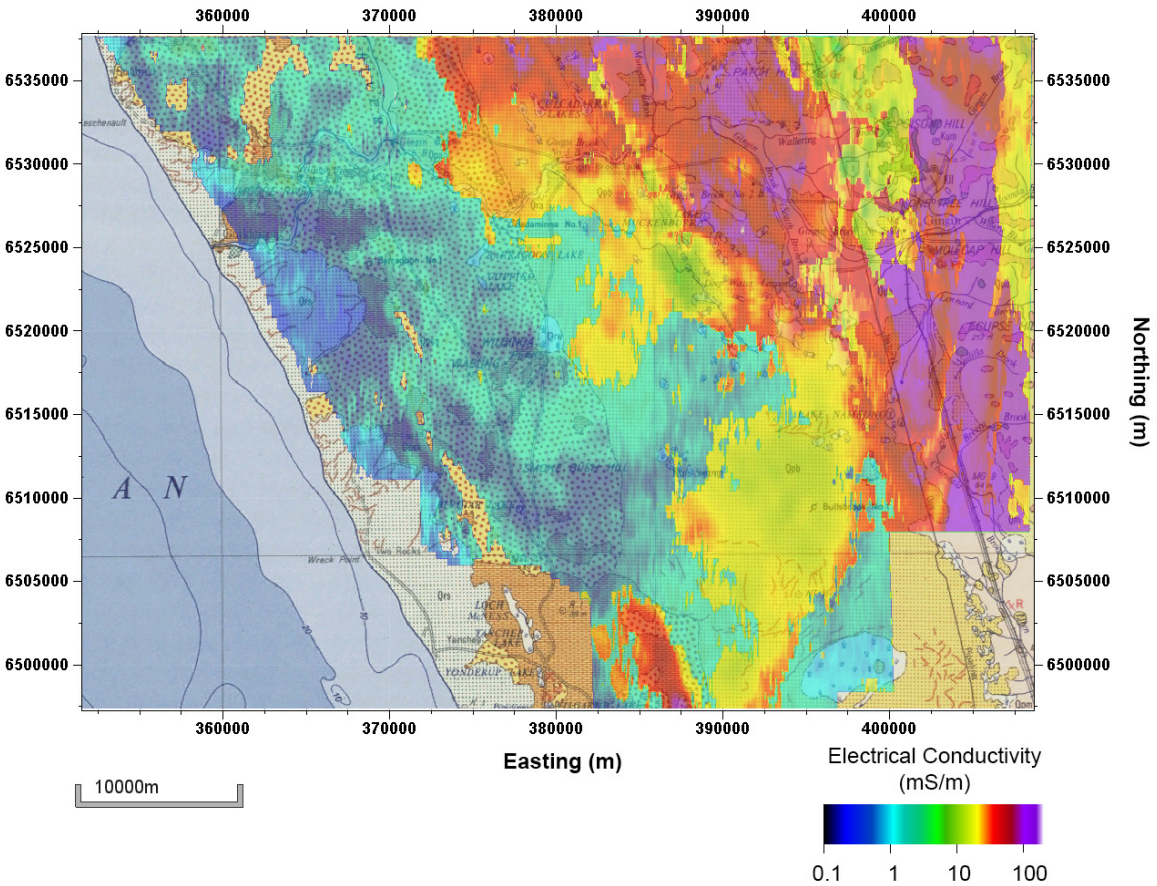


Figure 8: A plan slice of AEM electrical conductivity in (mS/m) at 10m above sea level overlying the survey geology. Several units can be identified, coastal limestone (e.g., Tamala Limestone), Bassendean sands and Guilford Clay. The surface geology map is taken from the scanned 1:250:000 geology map, Geoscience Australia, Sheet "SH 50–14 AND PART OF SHEET SH 50–13" .

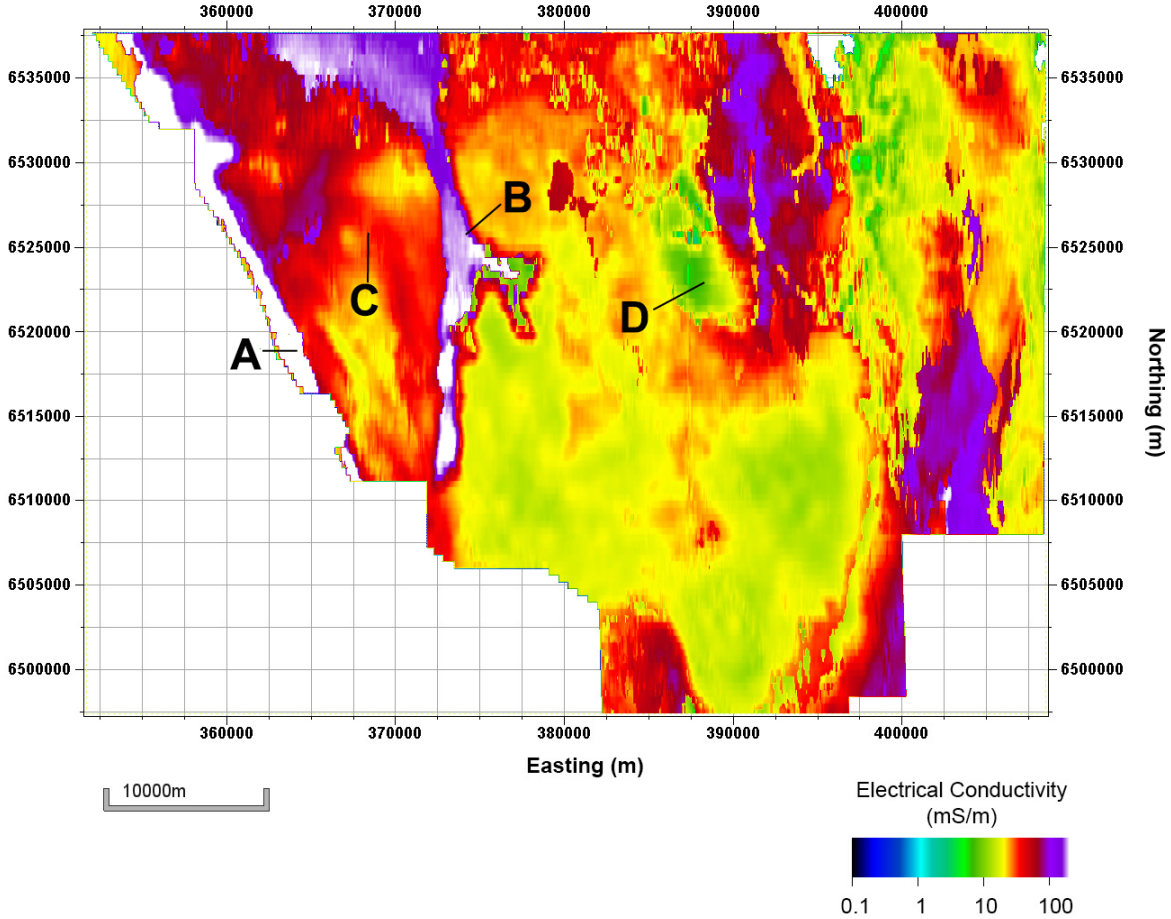


Figure 9: Plan slice of electrical conductivity at 50 m below sea level. Several key features can be identified. (A) The salt water intrusion zone, (B) Badaminna fault zone, (C) Kardinya Shale and (D) Yarragadee recharge window.

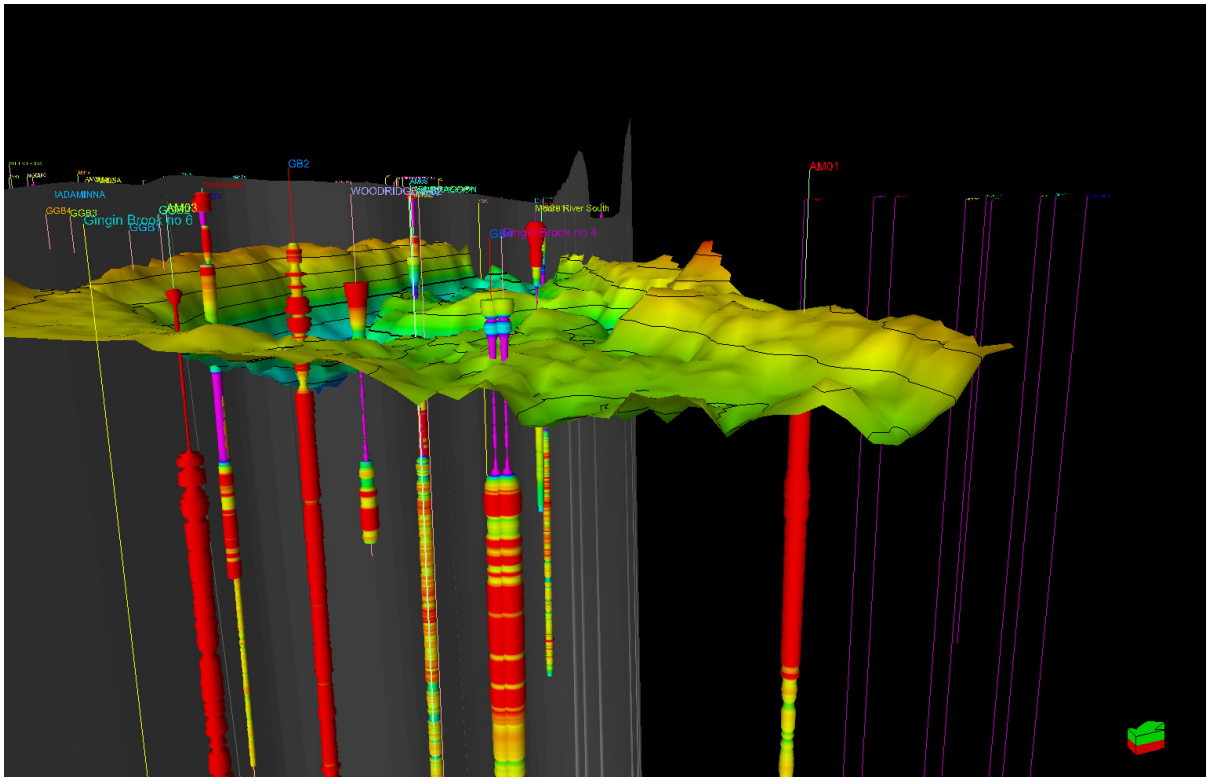


Figure 10: Kardinya Shale Top surface, 25x exaggeration, with Badaminna Fault plane location (grey) and well logs showing electrical resistivity derived from 64in wireline tool. The transition from the overlying resistive sedimentary layer to the conductive Kardinya shale unit seen in the wireline logs reasonable coincides with the surface derived from the AEM electrical conductivity volume.

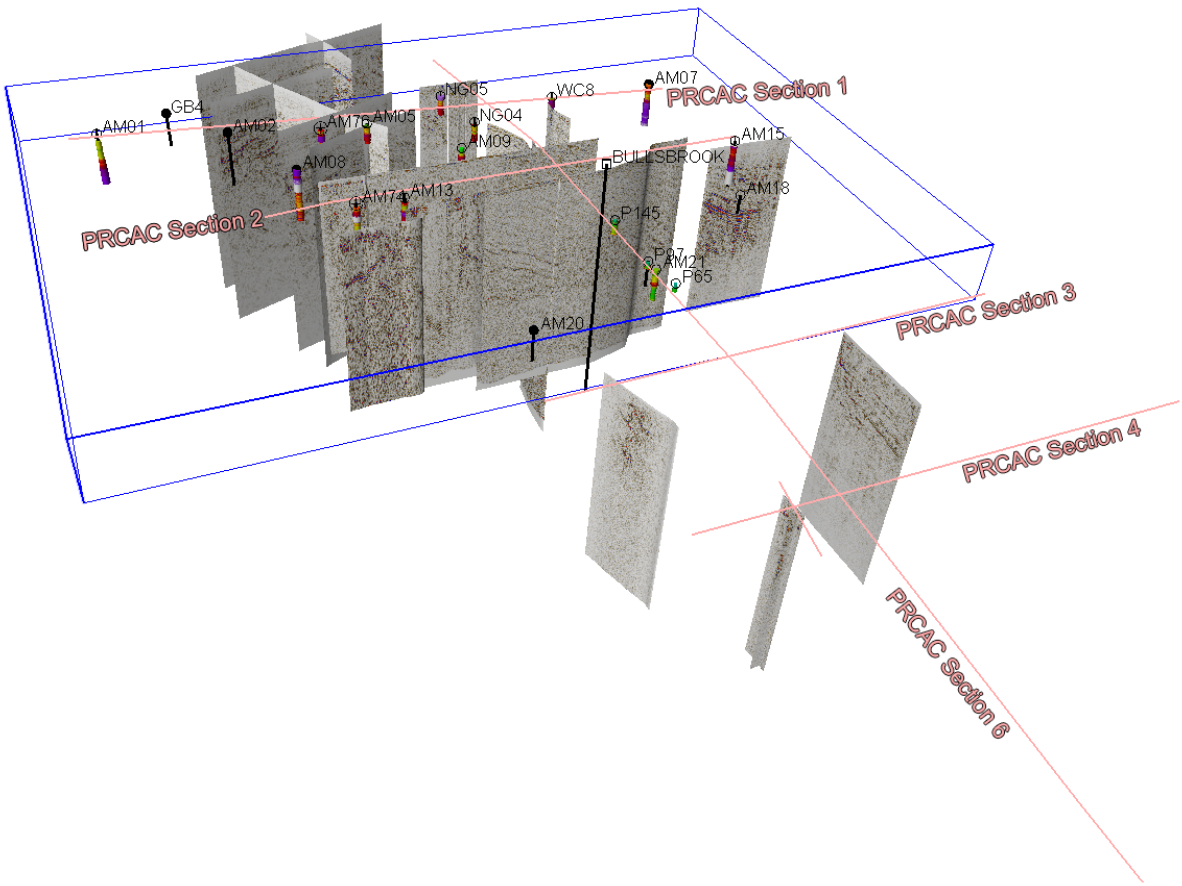


Figure 11: Extent of Geophysical Surveys. The image shows locations of MT transect, extent of TEM coverage and seismic transects. Key drill hole locations are provided for reference.

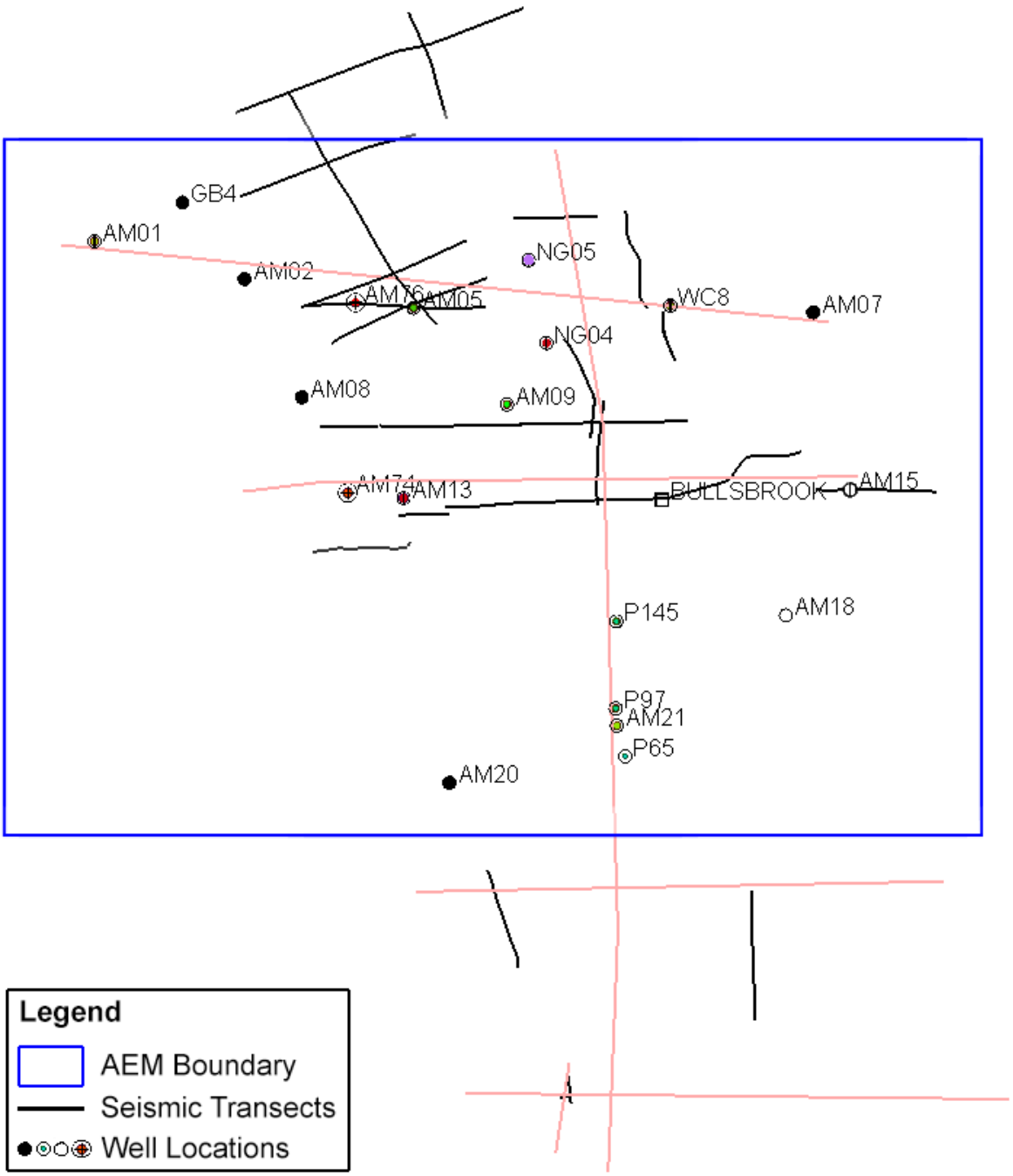
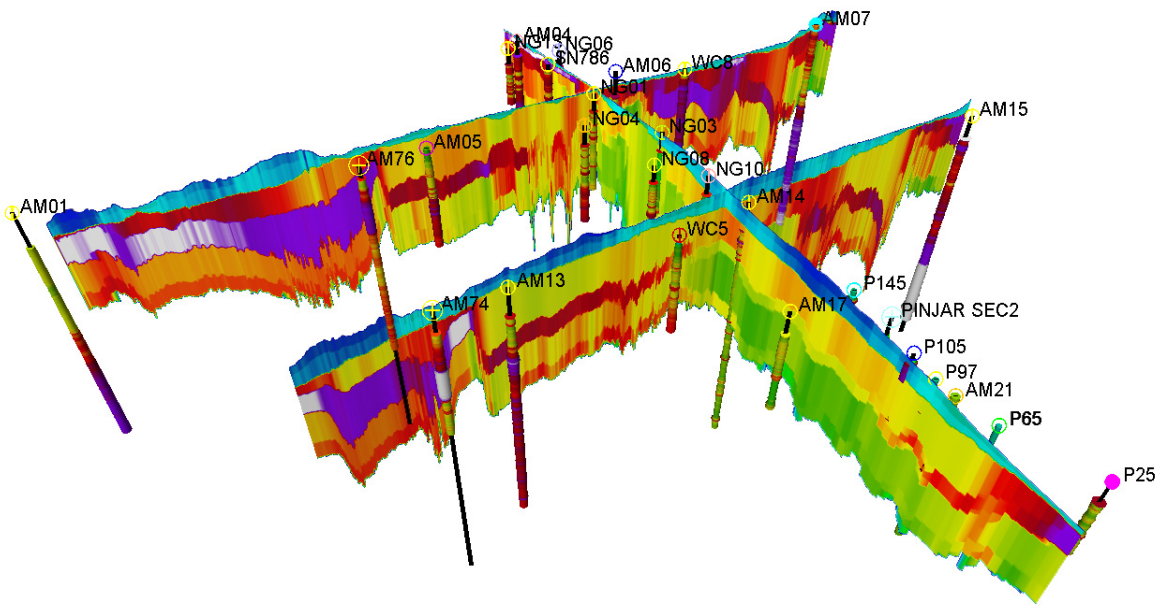
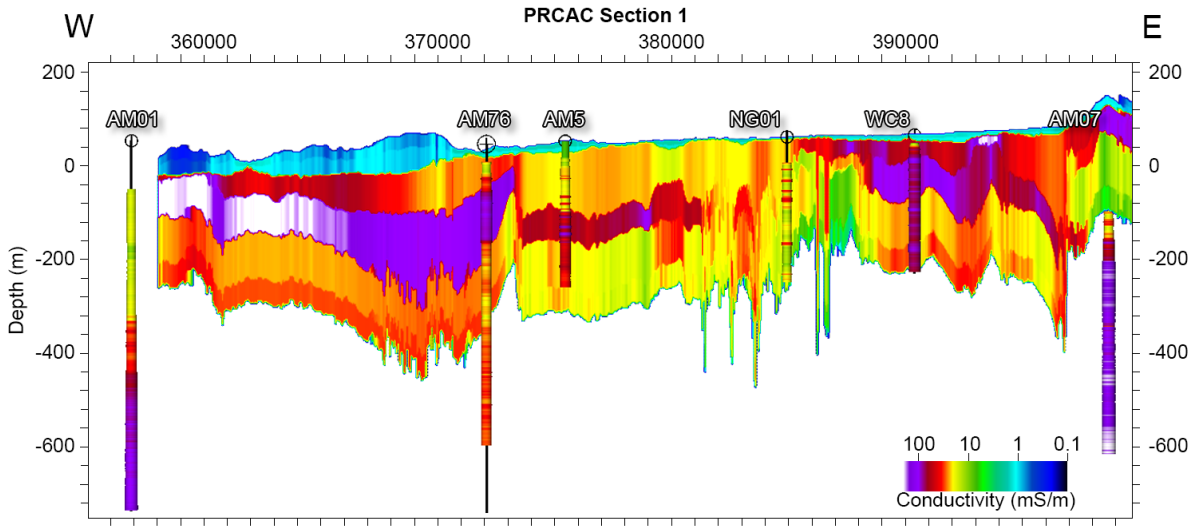
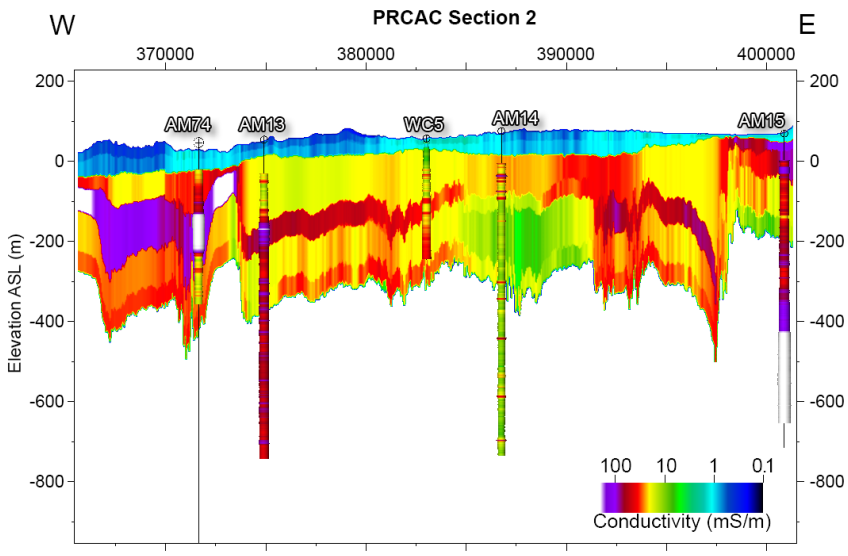


Figure 12: Extent of Geophysical Surveys. The image shows locations of MT transect, extent of TEM coverage and seismic transects. Key drill hole locations are provided for reference.


AM07
AM04
NG13
NG06
SN786
AM06
WC8
NG01
AM15
NG04
NG03
AM05
AM76
NG08
NG10
AM01
AM14
WC5
AM13
P145
AM74
AM17
PINJAR SEC2
P105
P97
AM21
P65
P25


PRCAC Section 1
W
E
360000
370000
380000
390000
200
0
-200
-400
-600
Depth (m)
AM01
AM76
AM5
NG01
WC8
AM07
100
10
1
0.1
Conductivity (mS/m)


PRCAC Section 2
W
E
370000
380000
390000
400000
200
0
-200
-400
-600
-800
Elevation ASL (m)
AM74
AM13
WC5
AM14
AM15
100
10
1
0.1
Conductivity (mS/m)

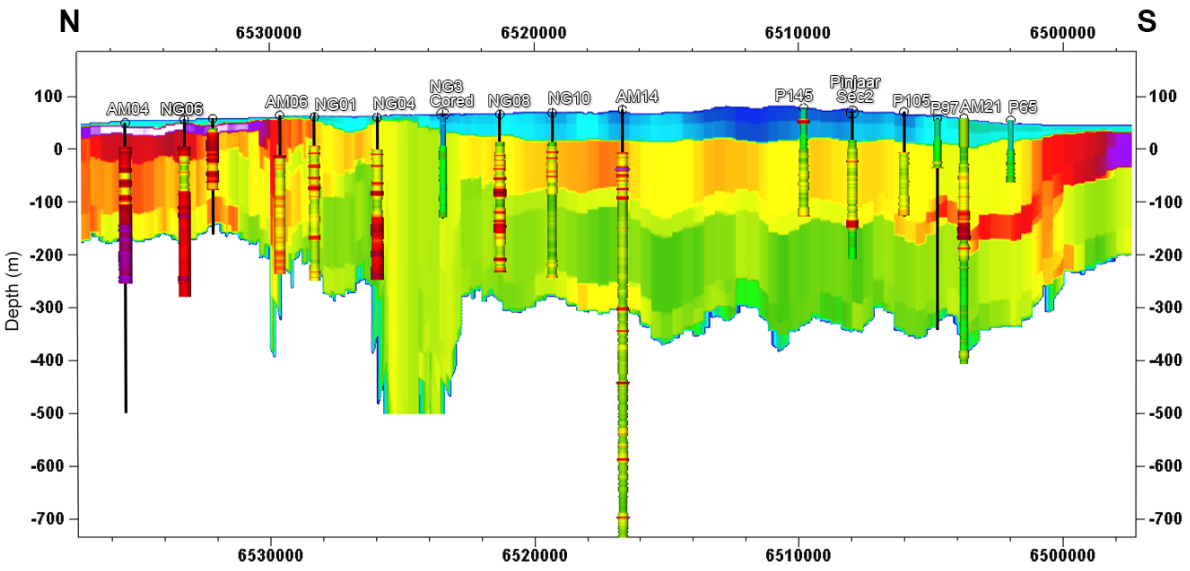


Figure 13: a, b, c, and d, The Figures show a 3D views key PRCAC transects (Figure 13a) and location of TEM derived conductivities for PRCAC Sections 1 (Figure 13b), PRCAC sections 2 (Figure 13c), and PRCAC Section 6 (Figure 13d).

WP3 RA1 – Magnetotellurics for Groundwater

- **Date completed**: June 2015 (ongoing)
- **Purpose:** The hydrogeological objectives for completing the Yanchep MT transect was to better define the electrical properties surrounding the Badaminna Fault zone and hydrostratigraphy on both the eastern and western sides. A secondary objective was to define the hydrostratigraphy in a key location in the Perth basin. The near surface inverted MT electrical conductivities correlate well with the airborne TEM surveying. The existing AEM survey successfully recovered the shallow (less than approximately 350m) 3D conductivity distribution whereas the MT data were collected to recover the deeper electrical conductivity distribution (surface to > 1.5 km depth) perpendicular to the Badaminna fault zone**.**

- **Example of a research objective:** The intent of acquiring the MT data is to test the method's ability to constrain the solute distribution and lithological changes across large fault systems that are often consequential for developing large scale hydrogeological models (e.g., the PRAMS model). The MT transect roughly overlapped with well positions AM05 and AM76 on the east and west of the Badaminna fault respectively. The depth of penetration for the MT methods is beyond that of any drill holes in the area. Estimating solute distributions is subject to ongoing interpretation.
- **Location:** The Dundas Rd transect is approximately 8 km long and extends through Wilbinga and Yeal. The line is approximately located 12 km north of Two Rocks and its most western receiver location is approximately 10 km from the Indian Ocean.
- **Special acquisition parameters:** In February, April, May and June 2015, magnetotelluric data were collected across the Badaminna fault zone. A total of 20 sites along an east-west orientated line covering a length of approximately 10 km. The average MT station interval ranged from 300-500 m, reducing to 150-180 m for sites located on the expected fault zone. The recording time for the AMT data ranged from 1 hour to 3-4 hours, while the MT data were recorded overnight when possible (approximately 12 to 14 hours). A Phoenix v8 system was used for data acquisition, recording two magnetic and two electric channels. Table 9 lists the acquisition parameters.

Key Acquisition details

Parameter	Survey Details
	Processing completed Nov 2015
Acquisition period	February, April, May and June 2015
Acquisition Data Type	Audio Magnetotelluric (AMT) and Magnetotelluric (MT)
AMT Frequency range	0.43 Hz – 10400 Hz
AMT Recording Time	1-3h
MT Frequency range	0.00034 Hz – 320 Hz
MT Recording Time	Mostly overnight from 12-13 h
North Reference	Magnetic North
Line Orientation	EW
Line length	8345 m
Number of stations	20
Station Interval	300-500 m
Station Interval at fault zone	150-180 m
Electrode Spacing	100 m
Number of Electrodes (pots)	4
Components measured	Ex, Ey and Hx, Hy
Instrument used	Phoenix V8

Table 9: MT Survey parameters

Integration

The conductivity distribution derived from unconstrained inversion of AMT and MT data has been converted to Petroleum standard SEGY format.

Final SEGY file Details	Remark
Datum Elevation	40 m
Segy file name(s)	MT_ITER06.iter_cond.segy_corr.sgy
SEGY Version:	Rev 1
Import instructions	Byte Swapped Trace coordinates are on standard locations: Trace header bytes: 73 and 77

Table 10: Magnetotelluric SEGY file – table of parameters

Basic Processing of MT Data

The raw time-series from MT and AMT acquisition was converted to frequency domain impedance tensors using the Phoenix *SSMT2000* software. The MT and AMT data were merged and the result stored as industry standard ASCII EDI format using the Phoenix *MTEditor* software. Prior to inversion, the impedance tensors were rotated based on estimated geo-electrical strike. Later, the impedance data was converted to MT apparent resistivity and phase and stored in the Occam2D input date file format. A first pass unconstrained inversion using the Occam2D software was used to generate a 2D conductivity distribution perpendicular to the Badaminna fault.

Interpretation

The Dundas Rd MT derived electrical conductivity distribution is shown in Figure 14. The MT recovered conductivity ranges from ~10 mS/m to ~140 mS/m with a general agreement in conductivity values at the well locations (i.e., AM76 and AM05). The average resistivity in the Wanneroo formation in AM76 and AM05 are approximately 35 Ohm.m (19 mS/m) and 50 Ohm.m (29 mS/m) respectively, which would lead to a broad conclusion that the salinity of the Wanneroo at AM05 is slightly lower than in the deeper Wanneroo in AM76 provided the formation properties are similar. While the unconstrained MT inversion has provided a good representation of shallow conductivity (e.g., top 600 m) the deeper conductivities are smeared and will require constraints to be imposed on the inversion to better reflect the known geology.

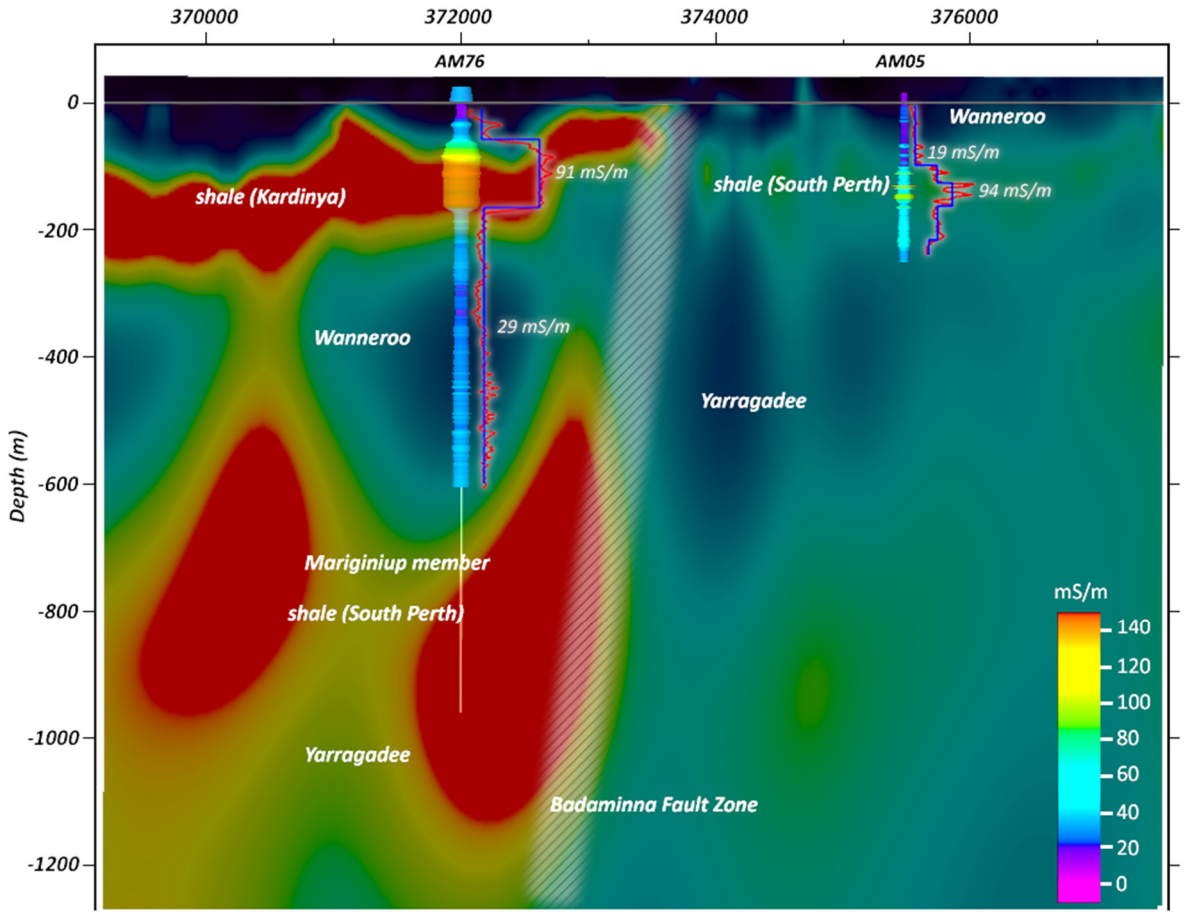


Figure 14: Section through the unconstrained MT inversion model showing the derived electrical conductivity distribution along the Dundas transect. Resistivity logs with approximate hydrostratigraphic layers are superimposed. A vertical exaggeration of 5 was applied. The images are produced in Petrel.

A work document with a more complete summary of the ongoing interpretation of the MT data is in Word file: "PRCAC_MT_(Dundas)_DraftSummaryReport_2016-02-22_RS(2).docx", in folder "u:\EGP_Data\Projects\Research\WATER Projects\DoW_Hydrogeophysics_2015_2018\Reports for DoW\PRCAC - Summary Report for DoW\"

Comparison of Conductivity values *(subject to ongoing investigation)*

Conductivity values from EC measurements are shown below in Table 9*.

(The EC values are possibly contaminated by drill mud – this is subject to further examination)*

	W	*E*	*W*	*E*	*S*	*N*	*S*	*N*
Well ID	*AM76*	*AM5C*	*AM74*	*AM13C*	*AM13B*	*AM5B*	*AM74*	*AM76*
Easting (m)	*372048*	*375480*	*371646*	*374909*	*374909*	*375480*	*371646*	*372048*
Northing (m)	*6528292*	*6527971*	*6517257*	*6516946*	*6516946*	*6527971*	*6517257*	*6528292*
Distance from Fault (m)	*~1500*	*~1800*	*~2600*	*~650*	*~650*	*~1800*	*~2600*	*~1500*
Screen (Top) (m bgl / m elev)	*271 / 239*	*133 / 81*	*343 / 309*	*150 / 96*	*464 / 410*	*291 / 239*	*343 / 309*	*271 / 239*
Screen (Base) (m bgl / m elev)	*277 / 245*	*144 / 92*	*349 / 315*	*156 / 102*	*473 / 419*	*310 / 258*	*349 / 315*	*277 / 245*
Aquifer	*L*	*L*	*L*	*L*	*Y*	*Y*	*Y*	*Y*
Log conductivity (mS/m)	*29*	*19*	*20*	*20*	*n/a*	*19*	*20*	*29*
EC (mS/m)	*204*	*60*	*75*	*39*	*176*	*215*	*75*	*204*
TDS (mg/L)	*1240*	*318*	*398*	*235*	*1180*	*1340*	*398*	*1240*
	L = Leederville, Y = Yarragadee							

Table 11 Electrical Conductivity (EC) and Total Dissolved Solids (TDS) from well bore measurements within the screened interval (note possible contamination of EC/TDS values from drill mud, subject to further examination). The left-hand side of the table compares values from West and East of the Badaminna Fault at available boreholes; the right-hand side shows the South-North variations. (Note that AM76 and AM74 are displayed in both panels for better comparison). Screen intervals are given in metre below ground level (m bgl) and in elevation with respect to the Australian Height Datum (m elev). Also shown are the averaged conductivity values from logging.

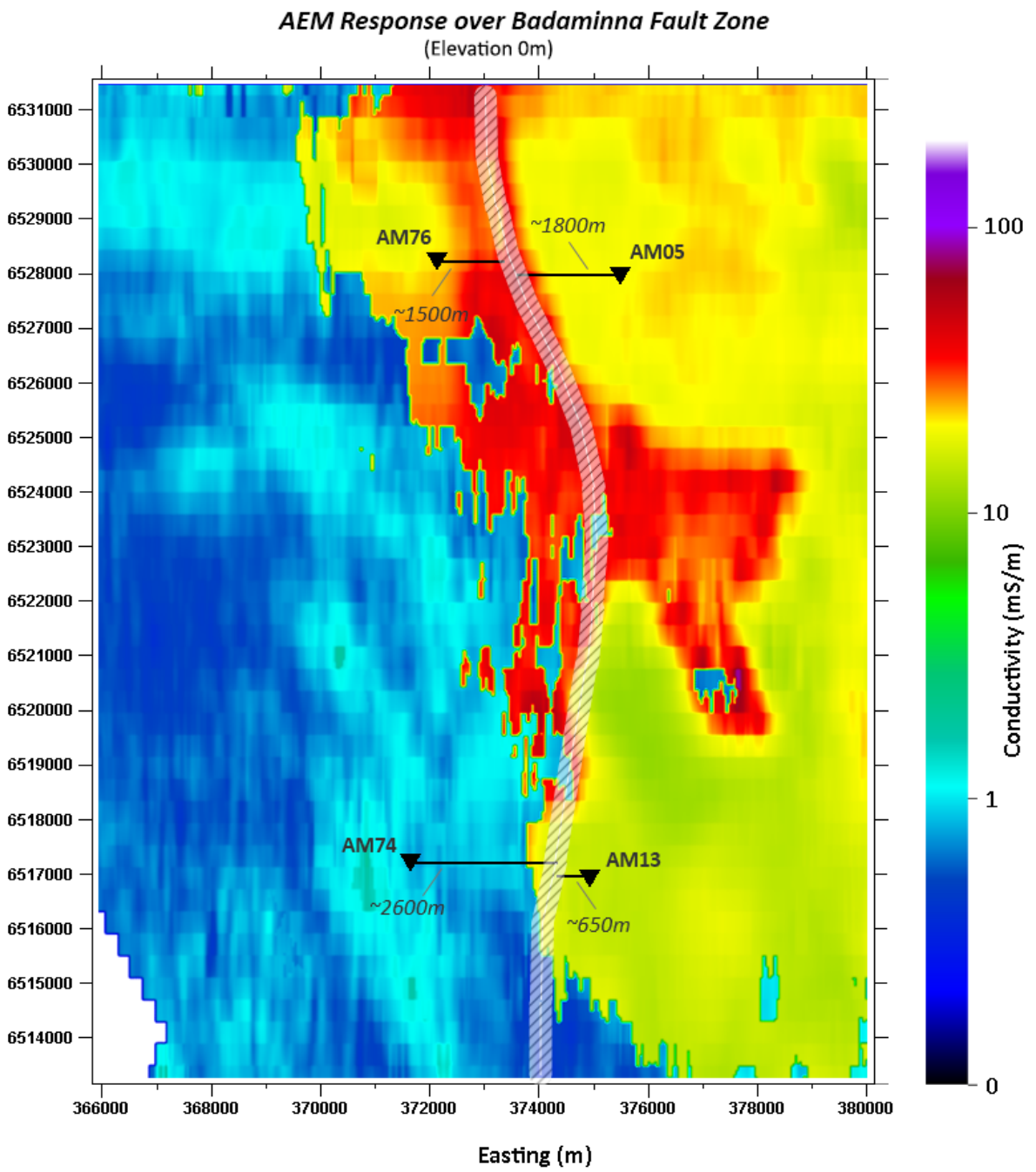


Figure 15 AEM section at 0m elevation with superimposed borehole locations. The approximate Badaminna fault zone is indicated by the white curved zone.

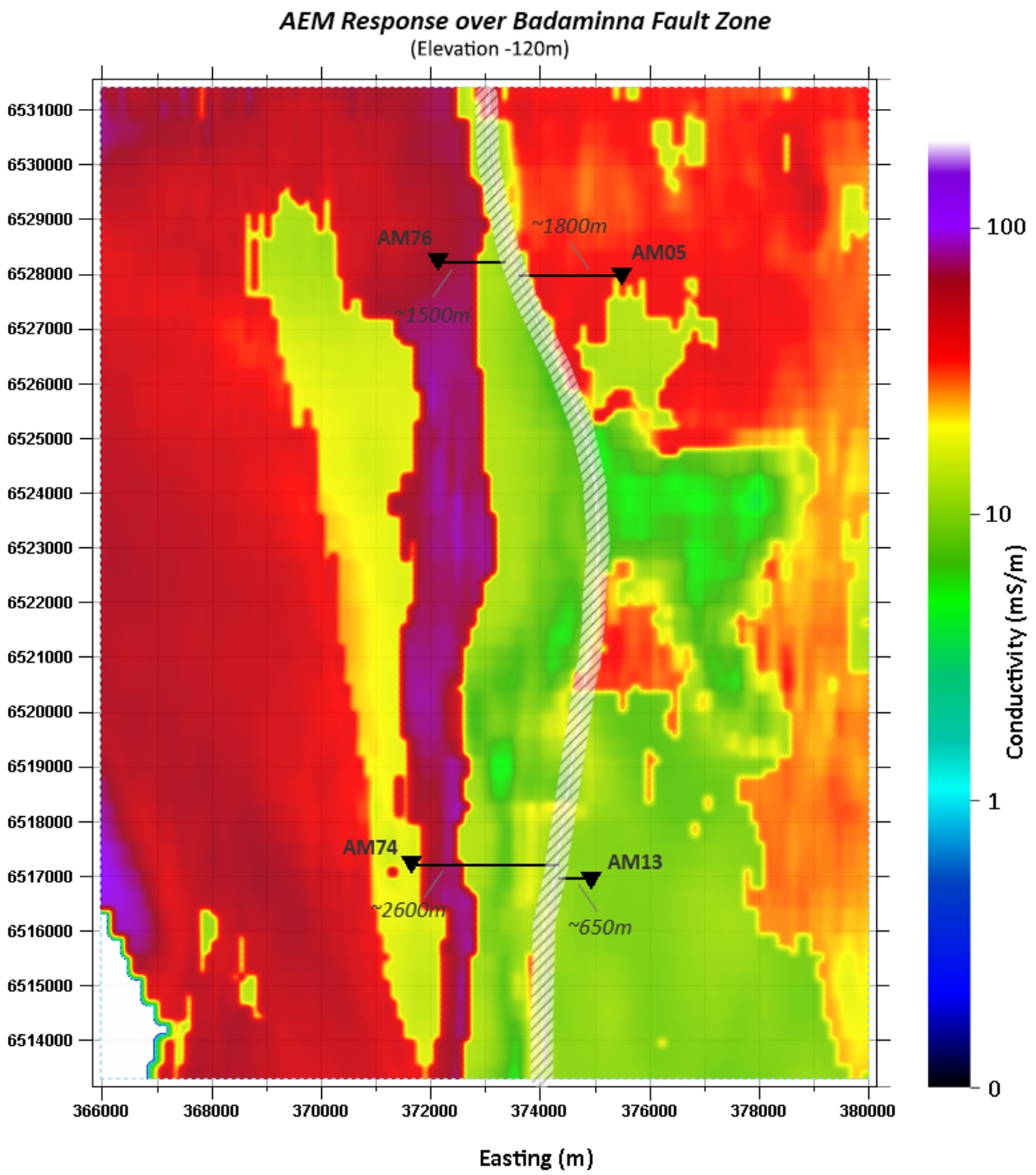


Figure 16 AEM section at -120m elevation with superimposed boreholes locations. The approximate Badaminna fault zone is indicated by the white curved zone. Clearly visible in the region west of the fault is the conductive Kardinya Shale trending South-North somewhat parallel to the fault zone. On the eastern part the South Perth Shale are showing.

WP4 RA –3D Hydrostratigraphy and 3D Printed Model

- Date: 26 February 2016
- **Purpose:** The principle objective of building a simplified version of the hydrostratigraphy was to compare the PRAMS model with a simplified 3D version of the solid geology based on new information from drilling, geophysics and new conceptualization. Part of this process is to represent the PRAMS model as a 3D printed model. Of particular interest are the geometries across the Badaminna Fault and the possible existence of the Wanneroo Fault.
- **Example of a research objective:** Updating the hydrostratigraphy of the PRAMS model with detailed geometry across the Badaminna fault. This is to facilitate other hydrogeological research activities. The solid geology is used as a baseline geometric constraint on various geophysical modelling. For example, it is expected that baseline MT inversion can be improved with assistance of such constraints. This would be intended to more accurately recover deep conductivity distributions from which distribution of solute concentration should be better estimated. Various forms of the modern cooperative inversion strategies (e.g. seismic and MT) required a broad geological framework within which detailed rock property distributions may be revealed.
- **Method:** The method used for building the 3D solid geology was to integrate all new data (e.g. new seismic, well completions and airborne TEM data) and compare at a existing conceptualization with possible modifications resulting from additional geophysical data. In the early stages the purpose is only to identify possible large-scale features that may require modification in the PRAMS model. Detailed models connected to deep seismic sections are also being created for specific subvolumes (e.g. the zone proximal to the onshore and offshore Badaminna fault).
- **Interpretation:** The work completed suggest several updates to the current PRAMs conceptualization. The four possible areas that may be considered are:

    1. **Trace of the Badaminna fault:** The trace to the upper most expression of the Badaminna fault is well defined in the AEM DATA.
    2. **Existence of the Wanneroo Fault:** The Wanneroo fault (i.e. a large displacement fault) is not located in Cretaceous sediments below the Silver Rd or Clarkson seismic Transects. Rather than a clear fault existing between Q37 and AM23 the formations appear to be relatively continues and dip between the wells.

3. **Window through the Leederville formation:** The AEM data clearly shows an absence of any clear confining layer in the centre of the Gnangara mound.
4. **Displacement on the Badaminna fault**: Large displacement extending through the Kardinya Shale is clear on MT, AEM and Seismic transects. Reprocessing of Seismic transect 3B clearly reveals characteristic and significant changes in geometry from East of Wanneroo Highway to West of Wanneroo highway (see Figure 12 below).
5. **Detailed geometry of the Badaminna faults**:

Integration: New interim surfaces generated from a scattered 3D point ASCII file and imported within Petrel's model database. Key hydrostratigraphic horizons and faults are included within the master Petrel project. A first pass 3D printed model of the existing PRAMS model has been printed. This 3D printed model provides a physical representation of major hydrostratigraphic units. It is intended that larger 3D printed models be created as the new conceptualization is complete. The printed model will serve to improve understanding of the complex relationships between the system of confined aquifers and aquitards in the central Perth Basin.

Note:

A student report on the printed model and elements of the 3D model development has been generated by Tahlia Downs: *Tahlia's report is being updated and converted to a paper which will make explicit comparison with the existing PRAMS model. See Downes, T., Harris B., Squelch, A., Pethick A., 2016, Interactive visualisation of 3D hydrogeology model of the Perth Basin, Curtin University, Curtin HIVE (Hub for Immersive Visualisation and eResearch), Department of Exploration Geophysics. Considerable work has been completed since this document was compiled and an new far more detailed model (especially proximal offshore and Badaminna fault) is being finalized. The new work incorporated new seismic not previously available.*

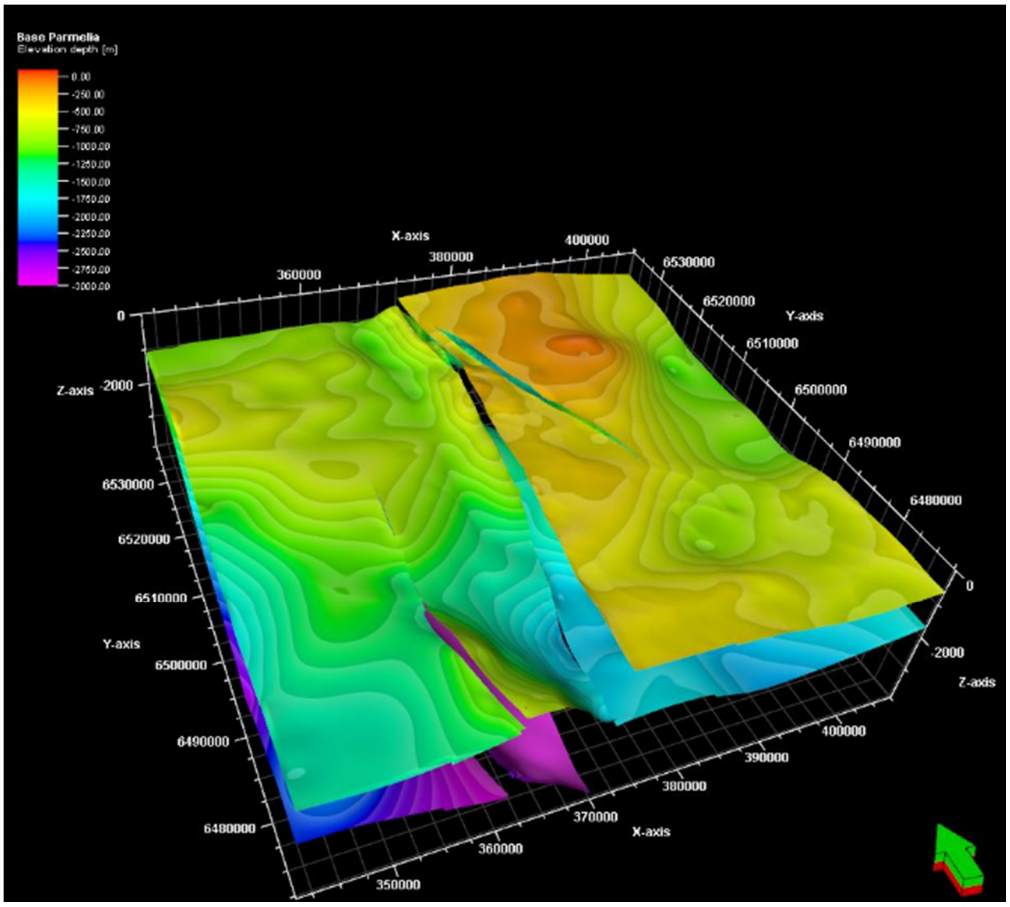


Figure 17: Top of the Yarragadee Formation including the Gage Sst. (Tahlia Downes)

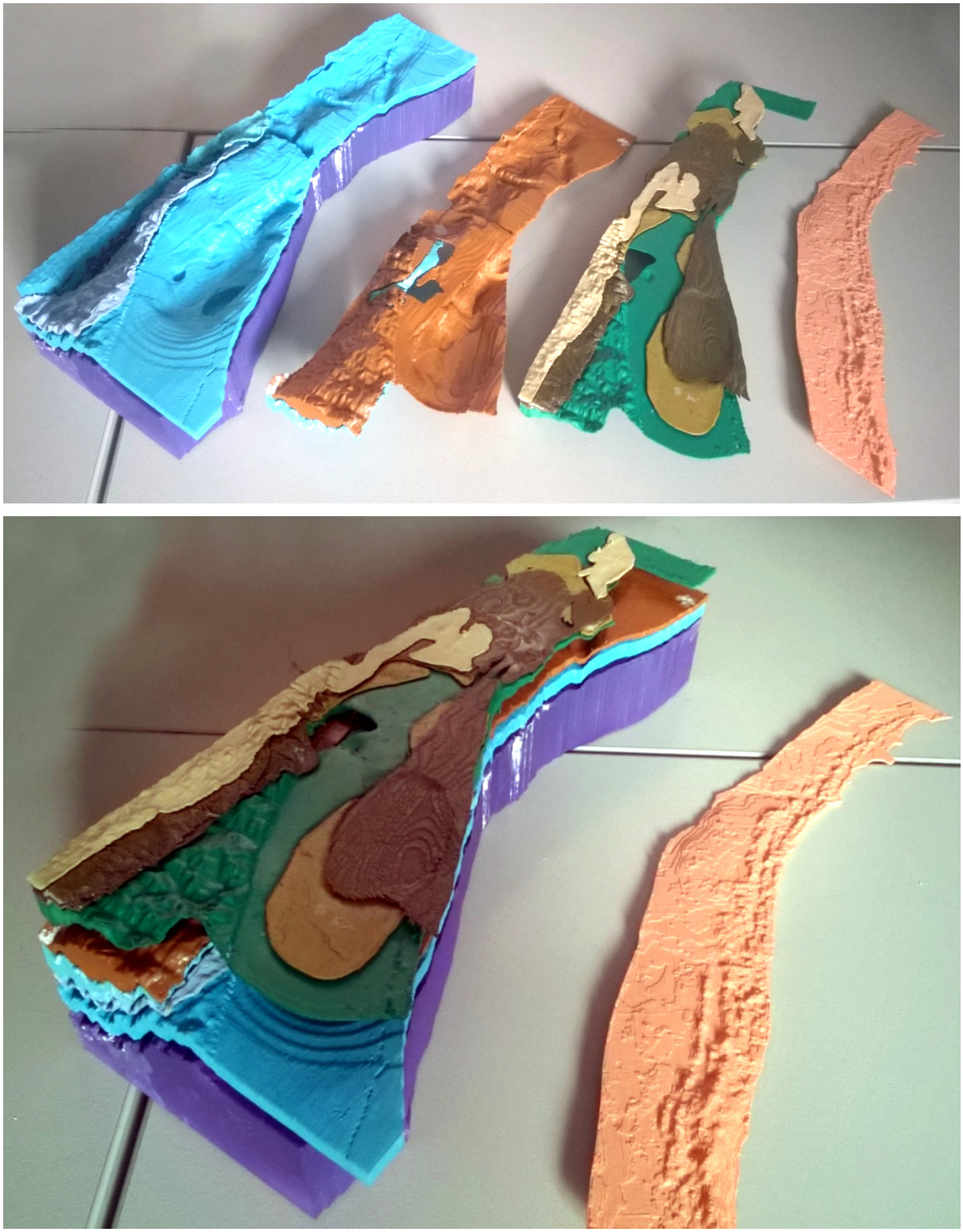


Figure 18: The Prams 3D printed model

References

Raiche, A., 1999, A flow□through Hankel transform technique for rapid, accurate Green's function formulation: Radio Science, 34, 549□555.

Raiche, A.P., Jupp, D.L.B., Rutter H. and Vozoff, K., 1985, The joint use of coincident loop transient electromagnetic and Schlumberger sounding to resolve layered structures: Geophysics, 50, 1618-1627.

Appendix

The provided digital deliverable storage device contains the digital appendix. The structure of the digital media is divided into the four main work projects (WP) and an Appendix directory. The appendix labelling corresponds to the following appendix headings in this report and a short description for each is provided. Each directory contains images, videos, reports and/or presentations related to the appendix topic.

```
├──Appendix
│   ├──Appendix A_Tempest Interpretation Guide
│   ├──Appendix B_Interactive Visualisation and 3D Printed Models
│   ├──Appendix C_Application of Long Offset Refraction Tomography
│   ├──Appendix D_Radar along Coastal Margin WA
│   ├──Appendix E_ERI Imaging and Defintion of Saline Water Interface
│   ├──Appendix F_MT and Seismic Across Badaminna
│   ├──Appendix G_PhD Candidacy Document_Alex
│   ├──Appendix H_Seismic Processing Reference
│   ├──Appendix I_Report and Miscellaneous Images
│   │   ├──No_Text
│   │   └──Text
│   └──Appendix J_AEM Movie
├──WP1 - Seismic
│   ├──WP1-RA1 - Seismic Silver Rd
│   ├──WP1-RA2 - Seismic Clarkson Station
│   ├──WP1-RA3 - Seismic New Line - Two Rocks
│   └──WP1-RA4 - Seismic Research
├──WP2 - Reprocessing
│   ├──WP2-RA1-re-processing-Seismic
│   ├──WP2-RA2-re-processing-Airborne TEM
│   └──WP2-RA3-Research
├──WP3 - MT and ERI
│   ├──WP3-RA1-MT
│   ├──WP3-RA2-ERI_Radar
│   └──WP3-RA3-Research
└──WP4 - Printed Model
    ├──WP4-RA1-printed 3D Model
    └──WP4-RA2-printed 3D Model Research
```

Figure 19: Directory tree structure of the appendix

Appendix A: An interpretation guide the TEMPEST AEM data collected over the Gnangara Mound.

Appendix is composed of two parts:

1. A PowerPoint interpretation Guide for AEM data over the North Perth Basin
2. A draft research paper looking at AEM data processing, inversion and interpretation.

Interpretation Guide

This is a PowerPoint presentation explaining key feathers observed within the AEM data collected over the Gnangara Mound. In consist of a series of annotated images. Key area addressed are:

- Expression of the Saline water interface along the coastal margin
- Transition between saline water interface and Kardinya shale along the coastal margin
- Expression of the Kardinya Shale
- Expression of the South Perth Shale
- Expression of the Badaminna fault
- North South Dip of the Mariginiup South Perth Shale Package
- Expression the distribution of superficial sediments (in particular across the Badaminna fault.
- The recharge window where Yarragadee come into hydraulic connection with Badaminna fault.

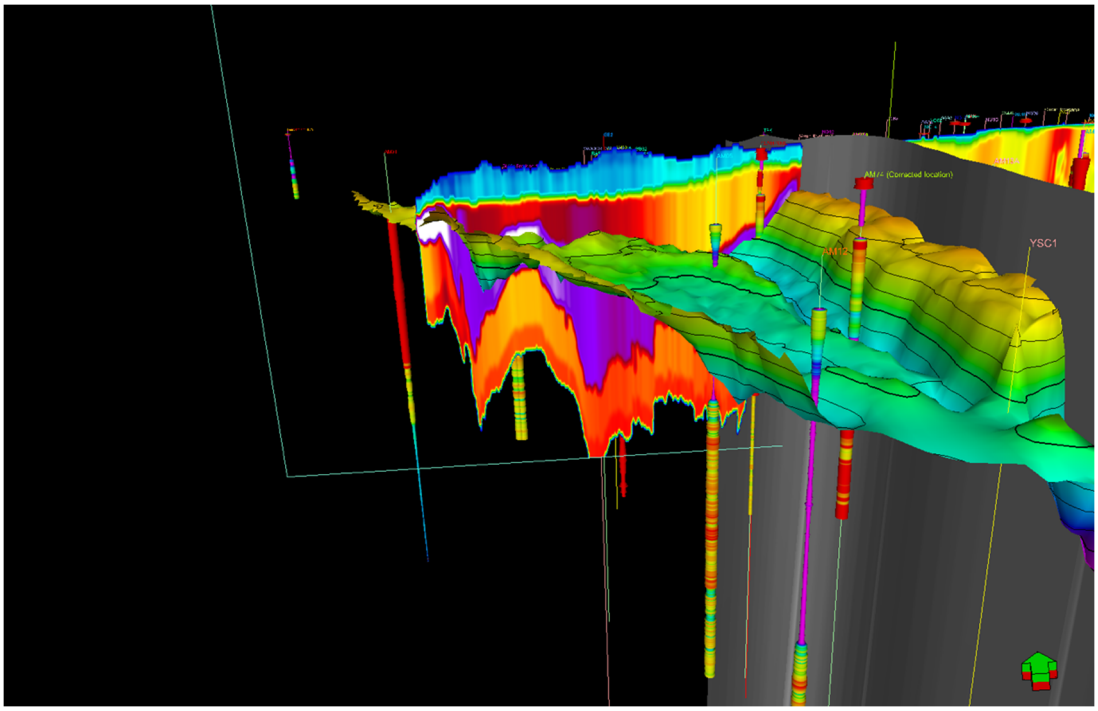


*Figure 20: Kardinya Shale Top surface, 25x exaggeration, with Badaminna Fault plane location (grey), well logs showing electrical resistivity derived from 64in wireline tool and an inline east-west cross section of AEM derived electrical conductivity. (Pethick, A., et al., 2016**)*

Research paper

Pethick, A., Harris, B., Schaa, R., Interpretation of Airborne TEM data; Gnangara Mound: Perth Basin WA. Currently provided in draft form with notes containing the potential future direction of the paper. This will be finalized over the next 6 to 12 months.

Appendix B - Interactive visualisation and 3D printed models of 3D hydrogeology model of the Perth Basin, Curtin University

The work conducted by Tahlia Downes focussed on two main areas. These are:

1. The 3D design and creation of a printed 3D model of the hydrostratigraphy of the Gnangara Mount.
2. Development of a preliminary updated 3D hydrostratigraphic model incorporating new information from newly acquired or reprocessed geophysical data.

Preliminary outcomes are provide in the Curtin HIVE student report and PowerPoint presentations below.

- Downes, T., Harris B., Squelch, A., Pethick A., 2016, Interactive visualisation of 3D hydrogeology model of the Perth Basin, Curtin University, Curtin HIVE (Hub for Immersive Visualisation and eResearch), Department of Exploration Geophysics. This work is current in a draft form.
- PowerPoint presentation showing preliminary results: Tahlia Downes 2015: Interactive visualisation of the 3D hydrogeology model of the Perth Basin: Department of Exploration Geophysics, Presented at the HIVE internship student forum and to DoW

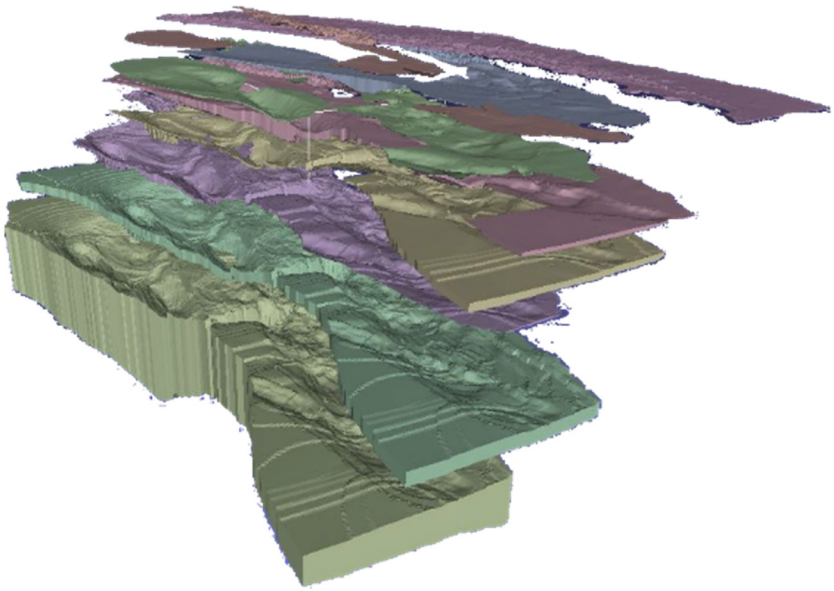


Figure 21: The PRAMS v3.5 printable model (Downes, T. et al., 2016)

The outcome of the above will be a research paper that includes a synthesis of work on the printed model and re-conceptualization based on new data of the Northern Gnangara Mound.

Research paper

The paper is being assembled into a paper, Downes, T., et al., 2016 “Interactive visualisation of the 3D hydrogeology model of the Perth Basin:” and will be finalized over the next 12 months.

Appendix C: Application of Long Offset Refraction Tomography

The undertaken work by Jacob Jackson culminated in the creation of a velocity model through long offset refraction tomography and formed a component of his honours research project. The Thesis and PowerPoint presentation are as below:

Jackson, J., 2015, The Application of Long Offset Refraction Tomography to Improve Seismic Reflection Imaging in the Perth Basin, Honours Thesis, Curtin University, Exploration Geophysics.

Jackson, J., 2015, The Application of Long Offset Refraction Tomography to Improve Seismic Reflection Imaging in the Perth Basin: ASEG student night presentation 2015. (Student was Winner of ASEG student night prise).

The next step in this project is to finalize a Research paper. A draft paper has been completed.

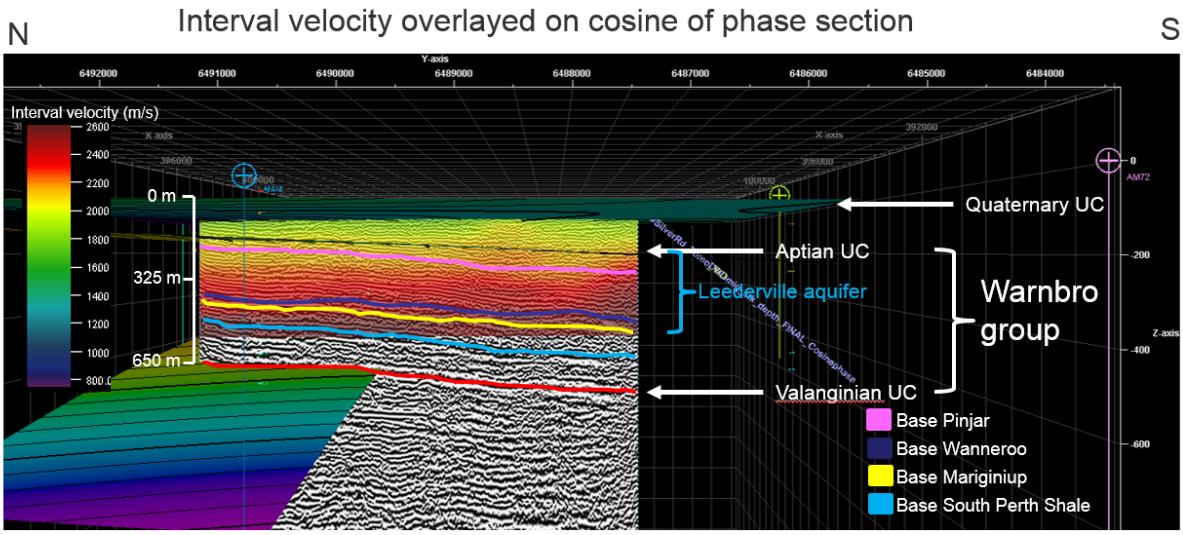


Figure 22: Interval velocity derived from long offset refraction tomography overlaying seismic cosine of phase. Image reproduced from Jackson, J., 2015, Presentation.

Appendix D: Case study Application of Radar along the coastal margin of Western Australia.

Ground Penetrating Radar (GPR) data was collected at several locations along the coastal margin of Western Australia by Alex Costall in 2014. This honours research work culminated in a written thesis and presentation:

Costall, A., 2014, Feasibility of Ground Penetrating Radar for Delineation of the Saline Water Interface Along Perth's Coastal Margin, Honours Thesis, Curtin University, Exploration Geophysics.

Costall, A 2014, Feasibility of Ground Penetrating Radar for Delineation of the Saline Water Interface Along Perth's Coastal Margin: power point presentation.

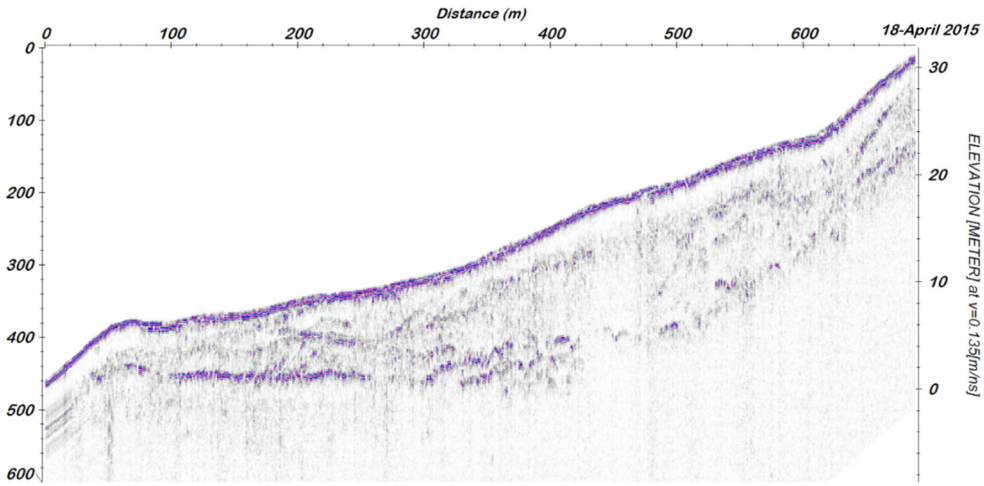


Figure 23: Example transect from Costall et al. (2016) showing processed Ground Penetrating Radar data from Swanbourne, Perth W.A

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Appendix E: Electrical Resistivity Imaging and Definition of the Saline Water Interface: Perth, Western Australia

This appendix contains the research conducted by Alex Costall looking at imaging the saline water interface using ERI methods. A finished draft journal article is ready for publication:

Costall, A., Harris, B. and Pigois., J.P., 2016, Electrical Resistivity Imaging and Definition of the Saline Water Interface: Perth, Western Australia, Department of Exploration Geophysics, May 2016.

This is a comprehensive analysis of the ERI methods and it application to defining the saline water interface along Perths Coastal margins. Selected sites along a 50 km length of mostly urban coast line are provided.

A PowerPoint presentation covering ERI test and trial sites collected along Perth Coast and River margins is also included.

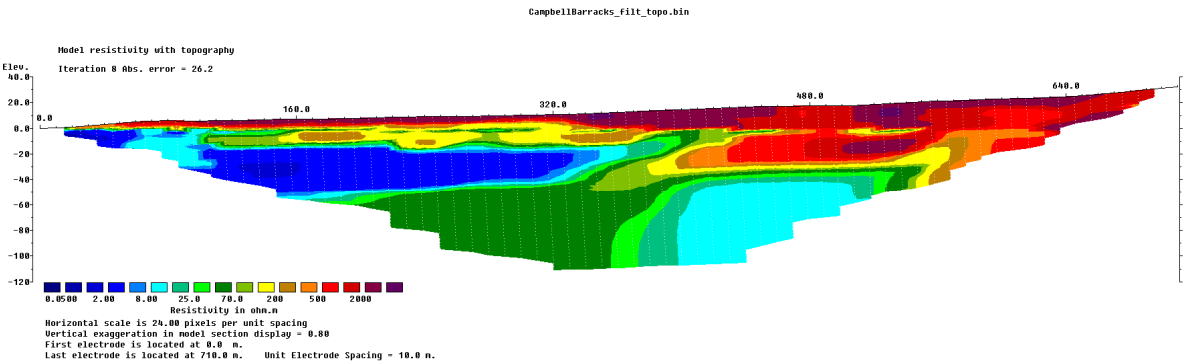

Figure 24: Example transect from Costall et al. (2016) showing an inverted electrical resistivity ERI transect from Swanbourne, Perth W.A.

Appendix F: MT and seismic across the Badaminna Fault zone

This Appendix consist of three parts:

1. Data and analysis of data: Short document describing methods used to acquire and invert data.
2. PowerPoint presentation describing initial unconstrained inversion of MT data.
3. Research paper describing constrained inversion of MT data across large faults.

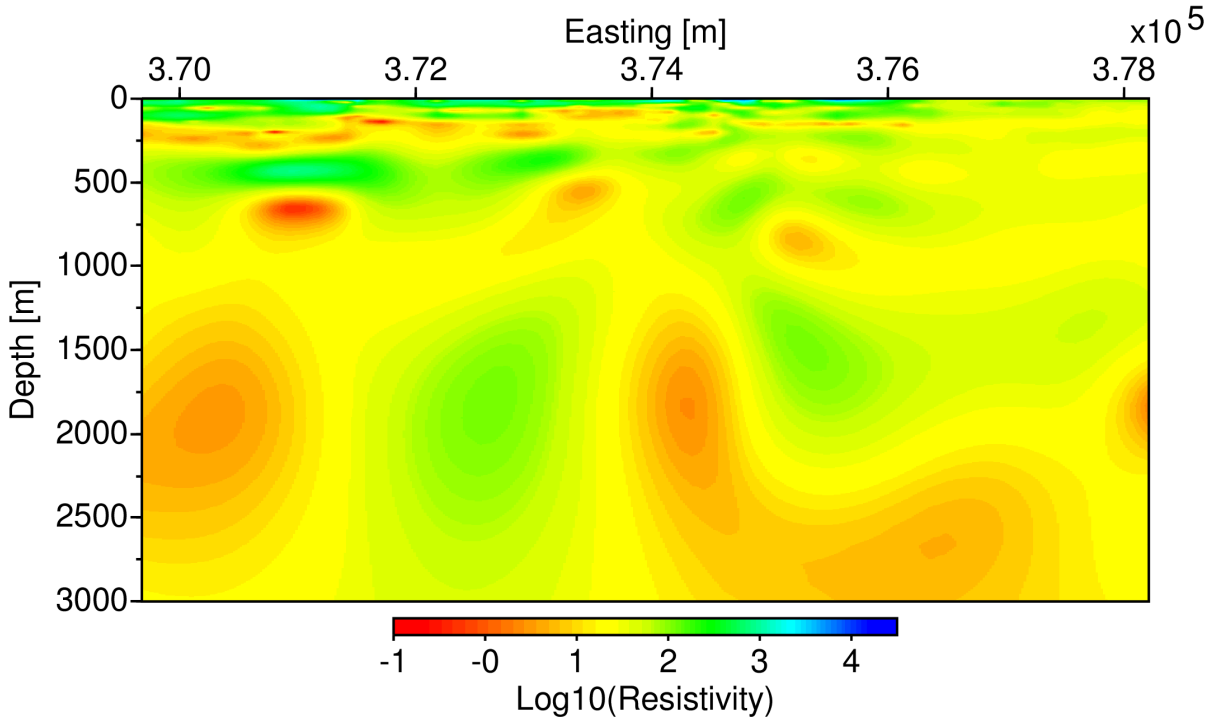

Figure 25: Inverted MT electrical resistivity distribution along the Dundas Rd transect. This image is

Appendix G: Alexander Costal – PhD Candidacy Document.

This Appendix documents the work program that will be completed by PhD Candidate Alexander Costal during his PhD (~2015 to 2018).

Alex will focus on combining electrical and seismic methods for defining large-scale hydrogeology of the Perth Basin with an emphasis on large fault systems. The research will have a focus on novel combination of geophysical methods in detecting the electrical properties of faults (i.e., new applications of LOTEM for hydrgeophysical property detection)

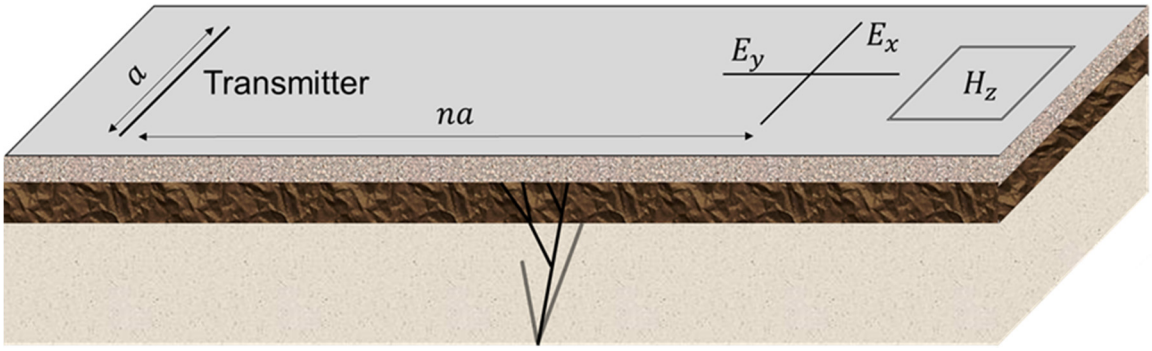

Figure 26: LOTEM survey layout. Image reproduced from Costall, A., 2016, Electromagnetic Characterisation of Regional-Scale Aquifers:Perth, Western Australia. Candidacy Presentation, Curtin University, Exploration Geophysics.

Appendix H: Seismic Processing Reference

This Appendix documents the steps taken to process the raw seismic time series data to migrated stacked seismic sections. The appendix documents the individual processing steps for currently the Silver Rd. seismic dataset. This document will be finalised in the next 6 to 12 months.

Individual statics, deconvolution filter, air blast attenuation, CVS and other parameters are explicitly stated.

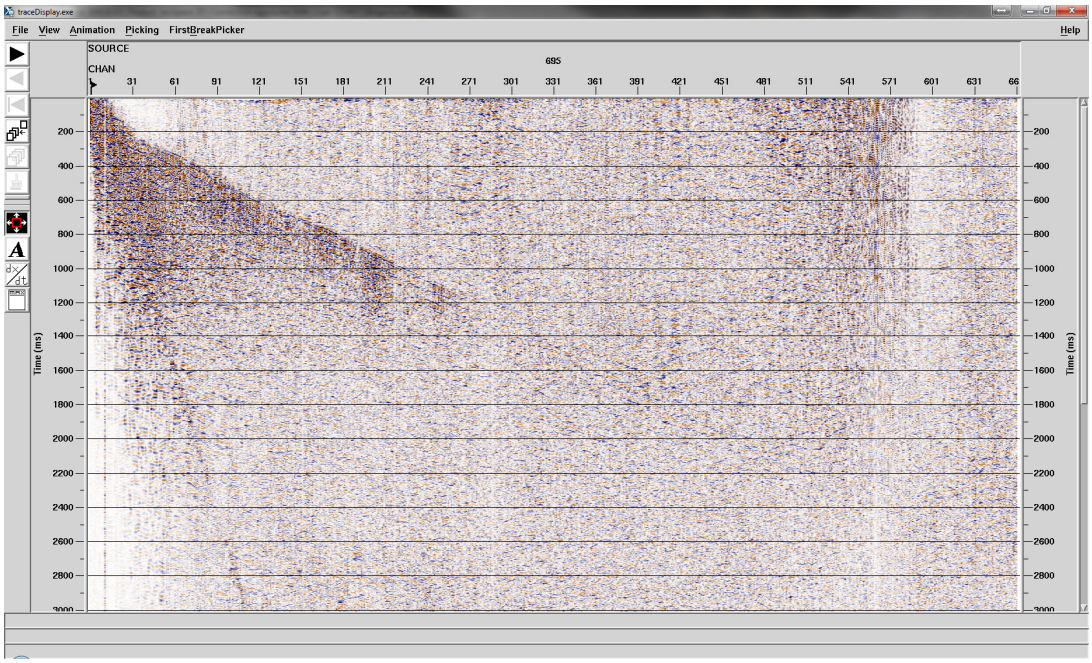

Figure 27: Example raw shot record from the Clarkson Rd seismic dataset. Image reproduced from Dzunic, A., (2016) processing report.

Appendix I: Report and Miscellaneous Images

The appendix includes several image galleries. These galleries contain images generated for report and presentations. Predominantly the focus is upon the AEM, seismic and MT methods. The images are also organised in a very basic structure:

- Report images
- Miscellaneous images

Please contact one of the authors for permission to reproduce or provision of an interpretation of the image.

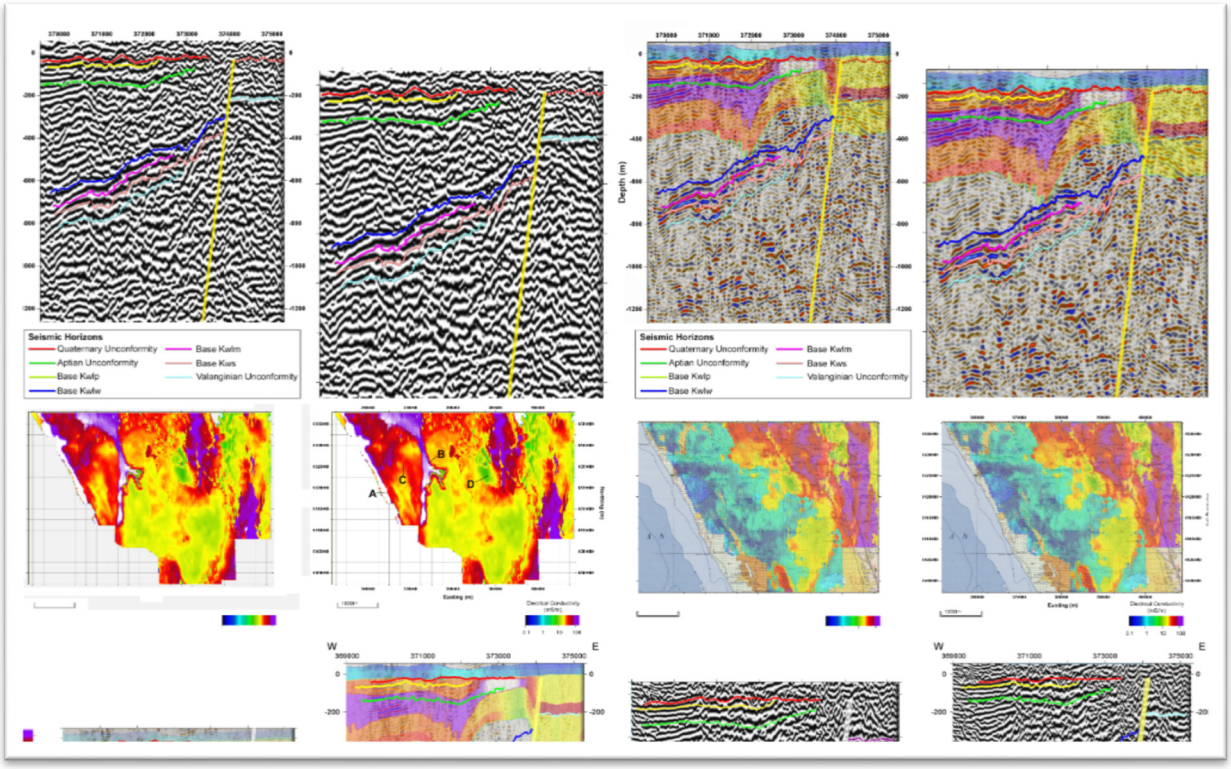

Figure 28: Example pictures contained within the gallery.

Appendix J: AEM Video, 10 m Elevations Slices

This movie slices through the reprocessed AEM derived conductivity volume at 10 m intervals. The movie also identified key wells and geographical features.

The mpeg4 (mp4) video file is provided in full HD 1080p at 3 speeds. 2x, 1x and 0.5x. At 1x speed the video is set to run for 30 seconds.

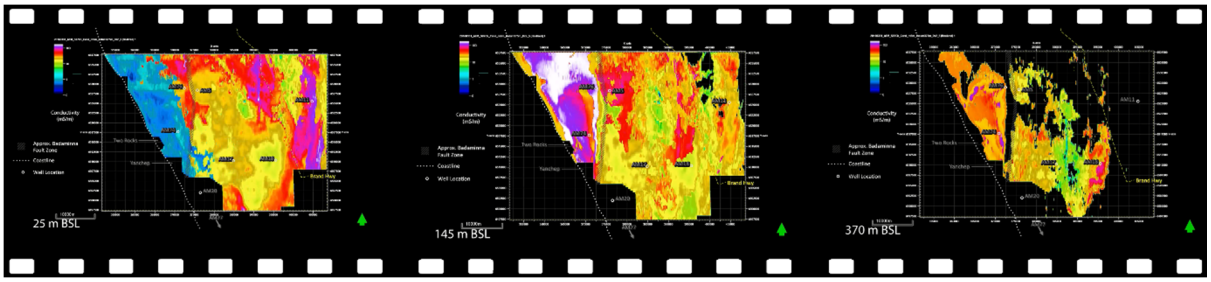

Figure 29: Three frames extracted from the video showing three AEM derived electrical conductivity depth slices.