Electric Bipole Antenna Model Study of a Basin Scale Fault System

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SUMMARY

The generation of electric fields with electric bipole transmitters are applicable at a wide range physical scales and for many subsurface exploration endeavors. Increase in transmitter power for a wide range of waveforms combined with receiver sensitivity has led to deeper exploration with electromagnetic methods. We investigate the optimal design of grounded bipole EM system for generation of electromagnetic fields over a basin-scale fault in Perth, W.A. The technical objective is to recover detailed electrical conductivity distribution proximal to and within a large fault system to depths of as much as 1000m below the surface. The ultimate geological imperative for the exercise is reveal possible change in solute concentration or hydraulic across these large fault systems. For example, imaging of the difference composition of fault core zone would be a valuable outcome. We investigate various combinations of receiving and transmitting antenna geometries in preparation for a field campaign intended to resolve electrical parameters and structures of this large fault system.

INTRODUCTION

The Long-Offset Transient Electro-Magnetics, LOTEM, is a deep exploration, Time-Domain electromagnetic method. Modern examples of LOTEM application, range from hydrocarbon exploration (Strack et al. 1989) to analysis of the internal structure volcanoes (Haroon et al. 2015, Hördt and Müller 2000) and even crustal studies (Strack, Lueschen, and Koetz 1990). The Long-Offset concept is gaining renewed interest, with successful application of similarly constructed frequency domain systems becoming also commonplace in today's exploration markets. As LOTEM is sensitive to deep, resistive targets, the methodology is well placed for hydrocarbon, CO2, and freshwater aquifer identification. It is also relatively inexpensive can be high complementary to seismic reflection data.

Recently, the controlled source electromagnetic (CSEM) method have been applied in off-shore environments, where oil and gas reservoirs presented suitable higher resistivity targets. Land Based, long-offset CSEM and controlled source audio magneto-telluric (CSAMT) methods, both use a frequency domain signal to generate a far-offset plane-wave, and are believed to recover information to depths of 1 Km (Zonge 1992). Typical land-based CSEM applications involve the definition of deep, high resistivity targets, such as geologically sequestered CO2, and hydrocarbon deposits (Wirianto, Mulder, and Slob 2010b, Grayver, Streich, and Ritter 2014, Lovatini et al. 2013, Wirianto, Mulder, and Slob 2010a).

The Badaminna fault is a basin-scale extensional fault system, running roughly North/South across the entire Vlaming sub-basin (Marshal et al. 1993, Nicholas et al. 2013). Figure 1 indicates the extent of the fault through the basin. This fault intersects both the Leederville, and Yarragadee aquifers. This presents an opportunity to investigate the feasibility of long-offset electromagnetic methods applied to deep groundwater exploration and fault system characterisation. This fault system is suitable for our investigation as both deep wells and detailed seismic transects cross the fault. Airborne EM data is also available, allowing near-surface constraint on electrical conductivity distribution to approximately 300m.

Basin hydrodynamics is often intimately connected to large scale solution concentration distribution. So building a large scale picture of solution concentration across basin scale fault systems can be a key input to understanding the influence of large fault systems on basin hydraulics (e.g. groundwater flow). These are key considerations in building realistic groundwater models and such issues are currently being addressed by the Department of Water in Western Australia (Water 2016). The long-offset or deep sounding electromagnetic methods could prove effective in recovering detailed information about solute concentration of the Yarragadee and Leederville aquifers which exist on each side and are displaced by Badaminna fault system (Davidson 1995, Glasson 2011)

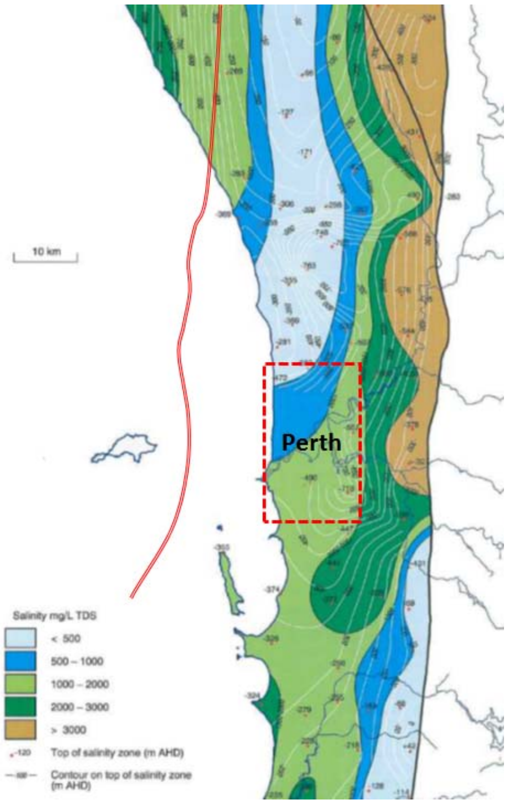

Figure 1: Salinity distribution of the Yarragadee aquifer, modified after (Davidson 1995). The estimated spatial distribution of the Badaminna fault system is shown in Red, trending North/South.

METHOD AND RESULTS

The relative offset of receivers, and transmitted waveform contribute to the depth of investigation and resolving capability of the EM system. The software to support 1D, 2D and 3D forward and inverse modeling of frequency domain systems has existed in various forms for considerable time. (Barnett 1984, Farquharson and Oldenburg 1993, Farquharson, Oldenburg, and Li 1999, Haber, Oldenburg, and Shekhtman 2007, Nekut 1987, Scholl 2005). Full three dimensional Inversion of time domain EM data in complex setting is still evolving and generally required the initial model to be close to the final inverted outcome. Full 3D inversion of deep penetrating time domain CSEM data is one challenge not quite fully resolved by today's computational geophysics.

Identifying which combination and orientation of transmitter and receiver antennas will be most effective require forward modeling. A poor choice of receiver orientation may result in negligible amplitudes, effectively wasting time deploying and collecting the data. To plan for the deep penetrating EM survey we created a number of geo-electrical models based around information from existing seismic and well-logs. We compare outcome from are range of field configurations and for a range of possible geo-electrical models.

Modeling is completed with Marco which is from the P223 AMIRA software suite (http://p223suite.sourceforge.net/). We show one example here that uses a low frequency (i.e. 0.37 Hz), 50 % duty cycle bipolar square waveform to assess various configurations of transmitter and receiver orientation. The earth model used for Marco is simplified, representing the Badaminna fault system as a conductivity vertical "fault zone" and alternating shale dominated and sandstone dominated layers – indicated by Figure 2. Units are given in mV/Amp. For the modeling the transmitter current is always 1 Ampere.

Transmitter receiver geometries are shown in Figure 3. Each transmitter is modeled with receivers in Ex, and Ey orientations. Results depicted in Figure 4 onwards show the effect of the fault on signal amplitudes. These are seen to be quite prominently in the far-offset, North-South driving bipole in the Ex component. Initially, in very early times, the footprint presented by the fault zone is approximately 600 m wide – three times greater than the physical width of the fault body (indicated by dotted white lines).

The fault appear to have less impact on in-line transmitter-receiver geometries as shown in Figure 5 and Figure 6 (Long and near offsets). Analysis of the target percentage effect indicates the long-offset transmitters show largest differences across the fault zone. We have computed many model and present one simple model in here.

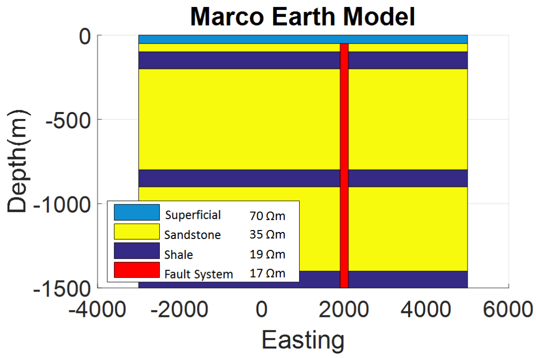

Figure 2: An example of an simplified geo-electrical earth model use for testing a range of survey parameters. Several geo-electrical models were developed to assess the signal strength and distribution in various geo-electrical settings.

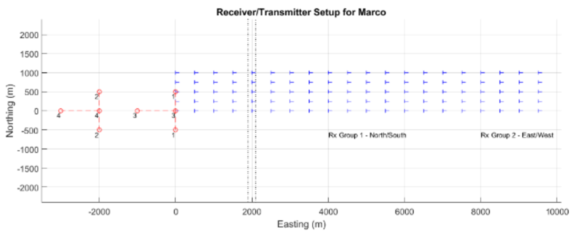

Figure 3: Plan view of the modeled receiver and transmitter setup. The vertical dotted lines indicate the location of the fault zone, from 1900 - 2100 m Easting. Note the 0,0 coordinate is relative to first receiver, rather than UTM coordinates.

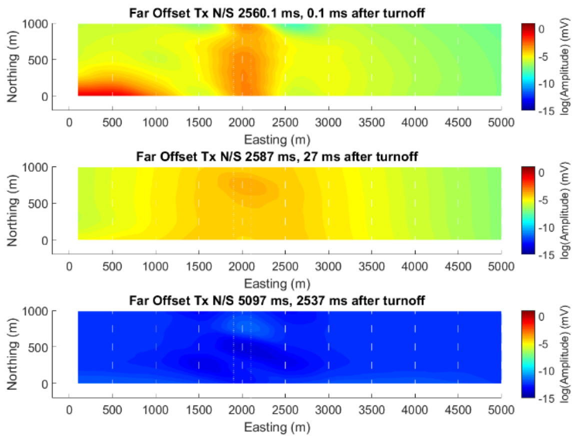

Figure 4: Receiver responses from the "Near" offset, Ex Component of a North/South Bipole (i.e. Transmitter position 1, Figure 3.) These responses demonstrate the effect of the fault zone prominently, and a strong anomaly over the top of the fault zone prism is immediately obvious in early time responses.

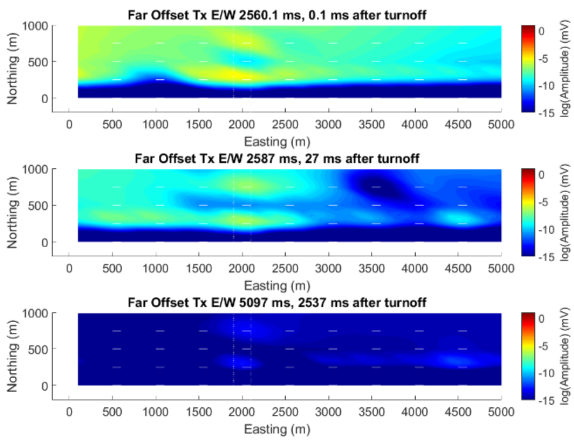

Figure 5: Receiver responses from the "Far" offset, Ex component of an East/West bipole (i.e. Transmitter position 4, Figure 3.) with East/West oriented receivers. The impact of the fault zone is considerably less here, however an interesting response exists at 2100 m E, 500 m N, possibly a result of the faults presence.

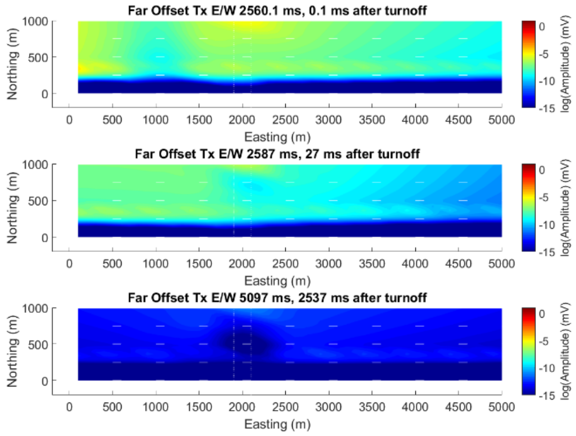

Figure 6: Receiver responses from the "Near"offset, Ex component from East/West bipole (i.e. Transmitter position 3 in Figure 3.) with East/West oriented receivers.

CONCLUSIONS

In this paper we present initial modeled results from simplified large scale geo-electrical structures as they may appear from various grounded bipole antennae configurations used in the field. We aim to identify the best orientation and transmitter/ receiver combinations in order to resolve electrical parameters of this deep large scale fault system. The investigation of these structures is important for groundwater considerations, and antennae design including transmitter waveform are critical element in the successful planning and design of deep penetrating land based EM surveys. Initial models show the longer offset geometries which drive current along the fault potentially has a greater impact on the received signal amplitudes. We are in the process of investigating the effects of different waveforms and possible field configurations prior to collecting data in the field.

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