Application of passive seismic and AEM to 3D paleochannel imaging: Capricorn Orogen

Sara Jakica  
Geological Survey of Western Australia  
100 Plain St, East Perth, WA  
sara.jakica@dmirs.wa.gov.au

Lucy Brisbout  
Geological Survey of Western Australia  
100 Plain St, East Perth, WA  
lucy.brisbout@dmirs.wa.gov.au

SUMMARY

This study uses shallow passive seismic HVSR (horizontal-to-vertical spectral ratio) technique to determine the depth and extent of a Cenozoic paleochannel composed dominantly of sand and clay incised into the Proterozoic granitic basement of the Capricorn Orogen. The paleochannel contains sand-dominated intervals that host water that is presently being explored by Hastings Metals. There is some drilling data available but only a few drill cores intersect the basement. Improved understanding of the paleochannel geometry will assist with water exploration.

The measured resonant frequency is related to shear wave velocity (Vs) and layer thickness. Passive seismic measurements at drill hole SWMB007 allow us to define a Vs for the regolith package overlying the basement. This Vs value is applied to 53 passive seismic measurements along Traverse 7 and the thickness of the paleochannel has been imaged in normalised H/V amplitude images.

Along Traverse 7, HVSR data image a symmetrical paleochannel with a maximum depth of ~115 m. The geometry of the paleochannel is broadly similar to the geometry obtained from 2.5D AEM inversion. However, the paleochannel has a greater maximum depth in AEM and some internal features of the paleochannel also differ.

Key words: passive seismic, AEM, paleochannel, HVSR, depth to basement

INTRODUCTION

The aim of this study is to use multiple geophysical methods in conjunction with drilling information to produce a 3D model of the Yangibana paleochannel, located in the Paleoproterozoic Gascoyne Province of the Capricorn Orogen, Western Australia (Figure 1a).

Most of the surface of the study area is covered by Cenozoic alluvial units deposited by the Edmund River system. The surface is composed of sand and gravel with ferruginous cement (Figure 1a,b). The thick regolith cover masks the basement, making it difficult to interpret beneath the cover.

The basement is exposed in the eastern part of the study area and is dominated by granitic rocks of the Paleoproterozoic Durlacher Supersuite. Minor sandstone, siltsilt and dolostone of the Paleoproterozoic Yilgatharra Formation, of the Edmund Basin, are also present.

Drilling information from Hastings Metals has indicated that there is an aquifer within the Yangibana paleochannel, but the geometry and the depth of the channel are unknown.

Where available, drilling information were used to ground truth geophysical measurements and to obtain velocities for seismic measurements that lacked drill core control. Drill core data were provided by Hastings Technology Metals Limited.

The AEM method has been used extensively in the past to explore under thick sedimentary cover (Paterson et al., 2017; Munday et al., 2018; Roach, 2018). The passive seismic method is also becoming a routine method in exploring the thickness of the cover (Ibs-von Seht et al., 1999; Smith et al., 2013; Scheib, 2014; Kumar et al., 2018; Jakica, 2018). Owens et al. (2016) demonstrated that the Tromino HVSR passive seismic method has been successful in mapping paleovalley geometry.

This study uses Tromino HVSR (horizontal-to-vertical spectral ratio) passive seismic method and the regional airborne electromagnetics (AEM) inversion to determine the depth of a paleochannel which, in this study, is equivalent to the depth to the granitic basement. The study also compares the AEM and passive seismic results along one traverse. The 3D model of the depth of the paleochannel will inform ground water exploration and landscape evolution studies.

ACQUISITION

In August 2018 the Geological Survey of Western Australia acquired shallow passive seismic data over the Yangibana paleochannel. The survey was designed using regional aeromagnetic and AEM data. The acquisition was carried out using the single station HVSR method with Tromino® instruments (Figure 1b) (MOHO, 2015). Data were acquired over nine traverses, with seven traverses crossing the paleochannel, as interpreted from the aeromagnetic data (Figure 1c). The two remaining traverses follow sections of two AEM lines from the Capricorn regional survey (CGG, 2013). The results presented in this paper illustrate the outcome from measurements taken from drill hole SWMB007 and Traverse 7 that lie along the AEM survey section 1002601.

The acquisition parameters for the passive seismic survey were:
- 20 minutes recording time,
- 100 m spacing between the stations and
- line lengths between 2000 and 5200 m

METHOD

Passive Seismic

The passive seismic method is a horizontal-to-vertical (HVSR) method that uses three-component measurements of ambient
seismic noise to determine and evaluate fundamental seismic resonance frequencies (Nakamura, 1989; Lane et al., 2008). Figure 2a shows an example of measured H/V spectra, with peaks indicating an acoustic impedance contrast at depth. To determine whether the peak is of stratigraphic or anthropic origin, the single component spectra graph is observed. Stratigraphic peaks occur at the local minimum of the vertical component, which is absent in the horizontal spectral component and forms an eyelet (Figure 2a). In a simple two-layer earth, the acoustic impedance contrast defines the boundary between two different geological units. Individual peaks indicate the resonance frequency of the site.

Shear wave velocities (Vs) are required to derive depth estimates from the frequencies of peaks. Shear wave velocities were estimated using the depth to basement from the drill core (Figure 2b) and the equation relating frequency (fz), shear wave velocity (Vs) and thickness (h) (Nakamura, 1989):

\[ f_z = \frac{V_s}{4h} \]  

AEM

The Yangibana paleochannel occurs within the limits of the 2013 Capricorn Tempest AEM (airborne electromagnetic) survey (CGG, 2013). This survey has a flight-line spacing of 10 km and in the study area, lines are oriented north-south (Figure 1a).

The AEM lines traversing the paleochannel have been inverted using Intrepid Geophysics 2.5D inversion code. The code is an updated version of ArjunAir code, a product of CSIRO/AMIRA project P223F (Wilson et al., 2006). Unlike common depth point inversion and 1D inversion, 2.5D inversion can use all the measured components in a joint inversion and forward models, using a 3D source, producing a more realistic prediction of geological structures that are poorly represented by 1D assumptions (Paterson et al., 2017). Paterson et al. (2017) demonstrated the improvement gained using 2.5D AEM inversion performs well when mapping water aquifers and paleochannels, where cleaner geometry of the channel is imaged compared to other inversion types.

RESULTS

Passive Seismic

Grilla software was used to import, process and forward model Tromino HVSR passive seismic data. The data was statistically analysed and unwanted noise was removed to enhance H/V peaks in the spectra.

The approach used in this project was to calculate shear wave velocity at drill core constrained models. These shear wave velocities have been applied to HVSR measurements without drill core constraints, to determine the depth to the basement.

Using Equation 1 and known h values from the drill core SWMB007 and the peak frequency (fz) measured at the drill hole, the shear wave velocity of 290 m/s has been calculated and used in subsequent calculations (Figure 2).

Along Traverse 7, the frequency obtained from the HVSR method has been used to calculate thickness using Equation 1 (h = 290/(4 x fz)). H/V has been normalised, using feature scaling, which transforms H/V amplitude to a range from 0-1, enhancing smaller amplitude peaks but also enhancing noise. For each station, 2048 normalised H/V values and corresponding elevations are obtained. Along Traverse 7, data from 53 stations have been plotted with points coloured by normalised H/V with higher values (in white) representing possible peaks (Figure 3a).

H/V vs frequency traces have been individually assessed to determine whether the highest amplitude H/V value represents the basement acoustic impedance contrast or not. Other sources of high amplitude H/V values include a shallower impedance contrast (e.g. clay/sand interface) and noise (e.g. wind, car). For 12 sites, the highest H/V amplitude plotted in Figure 3 do not represent the basement impedance contrast. This is due to either multi-frequency spectra or high frequency noise. Based on previous studies (Meyers, 2017; Jakica, 2018) in multiple frequency peak spectra, lower frequency peaks are interpreted to represent the bedrock. While higher frequency peaks are interpreted to represent shallow regolith interfaces. A line profile of interpreted depths to the basement of the manually selected peaks have been plotted in Figure 3.

Comparison of Passive Seismic and AEM Results

Passive seismic data was acquired along two of the AEM lines and provided the opportunity to compare the results from these two methods. One of these lines, AEM flight-line 1002601 traversed the paleochannel and hence located seismic section 7 along the same location.

In an extract of the conductivity data along Traverse 7, the paleochannel is associated with a highly conductive anomaly (Figure 3b). Drill core data suggest that the source of this conductive anomaly is most likely to be clays and sandy clays of the paleochannel that overlie a non-conductive granitic basement.

Comparison of the passive seismic and AEM data along Traverse 7 shows that the depth to basement calculated from manually selected H/V peaks is broadly similar to the depth of the basement from AEM. For example, a smaller channel at the southern margin of the paleochannel is imaged in both passive seismic and AEM (labelled 1 in Figure 3).

One of the major differences is the maximum depth of the paleochannel. Passive seismic predicts a shallower maximum depth (~115 m) than AEM (~170 m) (labelled 2 in Figure 3). This might be a result of differences due to the inversion algorithm involved or requiring additional Vs constraints. At the northern margin of the paleochannel, passive seismic data images a separate smaller channel which is not imaged in the AEM (labelled 3 in Figure 3). One explanation is that this channel is sand-dominated and relatively dry. A sand/basement interface would be imaged in passive seismic but would not be imaged well in AEM, since sand is less conductive than clay.

CONCLUSIONS

This study shows that single station passive seismic HVSR method worked well in mapping the depth of the Yangibana paleochannel and hence the thickness of the cover sequence. The results coincide well with 2.5D AEM inversion providing further details on the depth and the geometry of the paleochannel:

- HVSR method was successful under low conductive ground conditions that are unsuitable for AEM methods.
[Paleochannel imaging using passive seismic] Jakica and Brisbout

- Modelled paleochannel depth using the passive seismic technique reached 115 m below the surface at the deepest part of the channel. The deepest part of the channel interpreted from AEM inversion is 170 m. This may be the result of differences in the inversion algorithm used for the AEM data, or the lack of broader drill hole constrain on Vs.
- Overall, integrating short station HVSR method with AEM inversions proves to be the future tool for mapping the basement-cover interface in the areas where suitable acoustic impedance and/or conductivity contrast exist between the cover sequence and underlying bedrock.
- Further confirmation of the usefulness of the technique will become apparent as the other eight traverses are processed and compared with drill hole data.

ACKNOWLEDGEMENTS

Hastings Technology Metals Limited are thanked for providing drill core information.

REFERENCES


Jakica, S., 2018, Using Passive seismic to estimate the thickness of the Leonora Breakaways, Western Australia: 5th Australian Regolith Geoscientists Association Conference, Wallaroo, South Australia, 17-20.


Figure 1. a) Surface geology in the study area (Martin et al., 2004) showing passive seismic traverses, AEM lines and drill holes, b) Field photograph showing the sandy, lag dominated cover and a Tromino, c) First vertical derivative of the aeromagnetic data, showing the interpreted map-view extent of the paleochannel.

Figure 2. a) Observed (red and black) and synthetic H/V spectra (blue) and amplitude spectra measured at drill hole SWMB007, b) logged geology at SWMB007, model parameters, including Vs used to produce synthetic H/V spectra in a).
Figure 3. a) Traverse 7 normalised H/V data showing the interpreted base of the paleochannel (black line), b) Conductivity section from 2.5D inversion of AEM data (line 1002601) along Traverse 7, showing the base of the paleochannel interpreted from passive seismic data.