Passive Seismic for Mineral Exploration Under Cover

An independent method for determining depth to basement and cover sequence geometry

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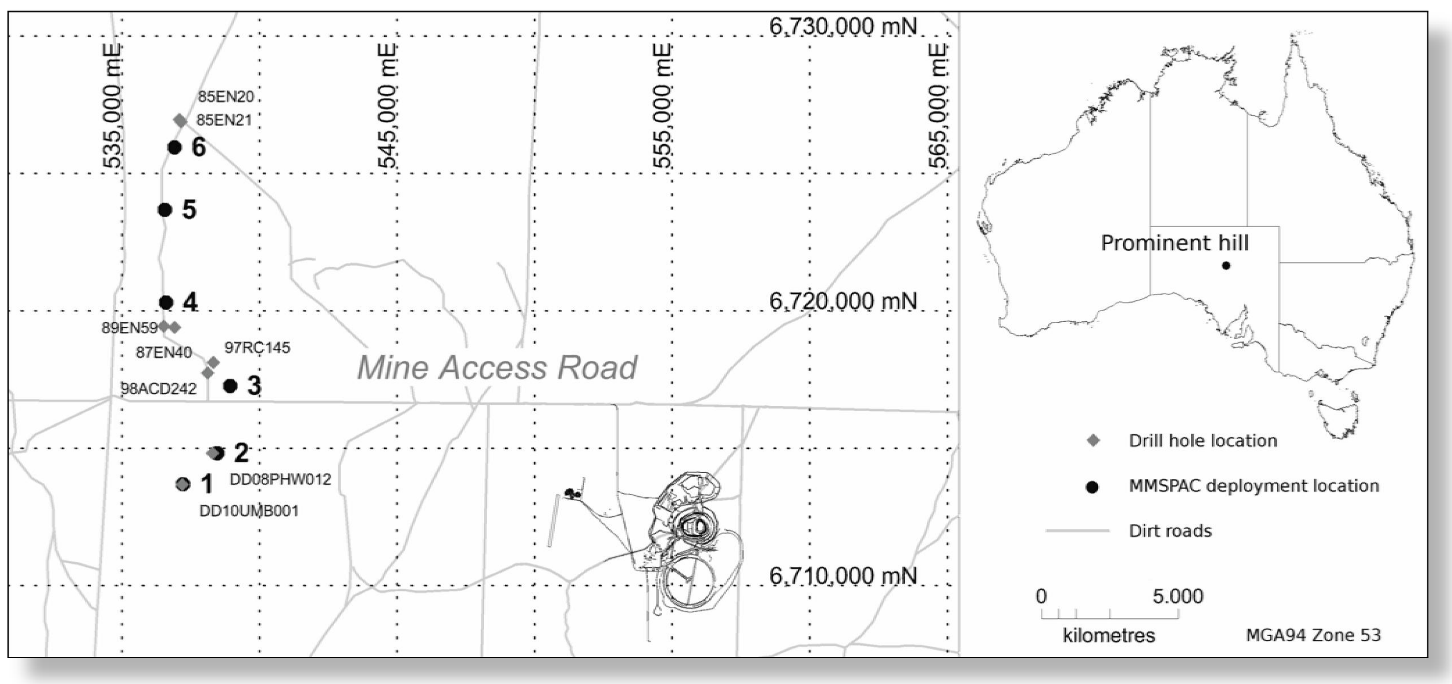
ABSTRACT

Thick sedimentary cover poses a major challenge to mineral exploration in Australia, significantly affecting the full spectrum of exploration activities: geoscience, logistics and economics. Acquisition and availability of government pre-competitive datasets and the development of adaptable technologies which define and constrain the geometry and physical properties of the cover are invaluable tools for the exploration industry.

The passive seismic technique has recently been adapted to a mineral exploration context in remote South Australia[1], from its traditional application in geotechnical engineering and environmental studies. Using arrays of portable broadband seismometers coupled with the Multimode Spatially Averaged Coherency (MMSPAC) and Horizontal to Vertical Spectral Ratio (HVSR) processing methods for Data from arrays of portable seismometers, deployed for as little as 30 minutes, were used to map the thickness and seismic velocity structure of sedimentary cover overlying a prospective basement terrane. Field work protocols which ensured consistent acquisition of high quality wavefield data for a range of ground conditions were developed. A forward modelling approach which addressed the challenges posed by the seismic properties of the cover sequence and the mineral exploration context was developed. Application of this approach was used to recover shear-wave velocity profiles with sensitivity to layer thickness of ± 5 %, and accurate depth to basement as confirmed by geological information from nearby drill holes.

[1] Smith, N., Reading, A., Asten, M., and Funk, C. (2013). "Constraining depth to basement for mineral exploration using microtremor: A demonstration study from remote inland Australia." *GEOPHYSICS*, 78(5), B227–B242. doi: 10.1190/geo2012-0449.1

LOCATION



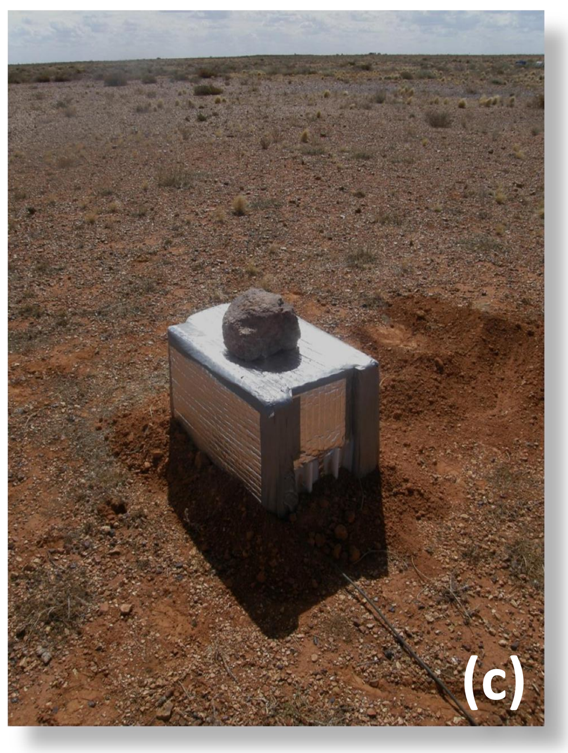
Above: Location of MMSPAC study site, near Prominent Hill mine in northern South Australia.

DATA ACQUISITION

As part of this study, field protocols were developed to optimise the efficiency and consistency of data acquisition for the variety of field conditions commonly encountered in northern South Australia.

Guralp CMG-6TD broadband seismometers with integrated data recorders were deployed in arrays of 7 sensors arranges into a hexagon + central station geometry, with 50m array radius. The site for each sensor was prepared by digging a small trench, lining the trench with "quick-dry" cement and levelling a ceramic tile upon the drying layer of cement. The seismometer was then placed onto the tile, aligned with north and levelled. A GPS antenna, used for timing purposes, was connected to the seismometer and placed into the ground several metres from the deployment site. Remaining equipment including a 12-volt marine battery and surplus antenna cabling were placed into the seismometer trench and the trench was covered with by a thermally insulated plastic box (roofing insulation sheets work well) and secured with a rock.

A Toyota Landcruiser tray-back field vehicle was driven around the array several times, maintaining a separation of ~100m from the closest sensor of the array, to supplement ambient seismic noise and generate energetic surface waves with a source azimuth distribution approaching 360 degrees. Data were recorded for approximately 30 minutes and the sensors were uplifted and moved to the next deployment site.



Above: Photographs of a typical field deployment site showing **(a)** trench for seismometer, **(b)** deployed seismometer, battery and GPS cables, **(c)** deployed and covered seismometer, **(d)** fully loaded field vehicle ready to head out, and **(e)** field vehicle with deployed seismometers at a deployment site.

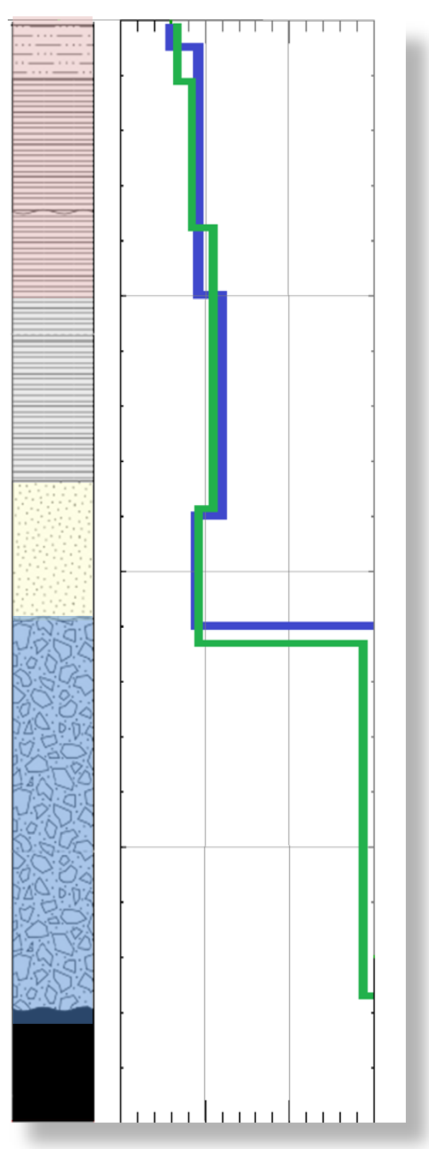
PROCESSING AND RESULTS

Spatially averaged coherency (SPAC) curves are extracted by calculating the coherency between sensor pairs in the array, and then averaging the coherency spectra for sensor pairs which share a common separation. A hexagonal array allows for the calculation of SPAC curves for 4 different separations, each of which is sensitive to the velocity structure at different depth ranges.

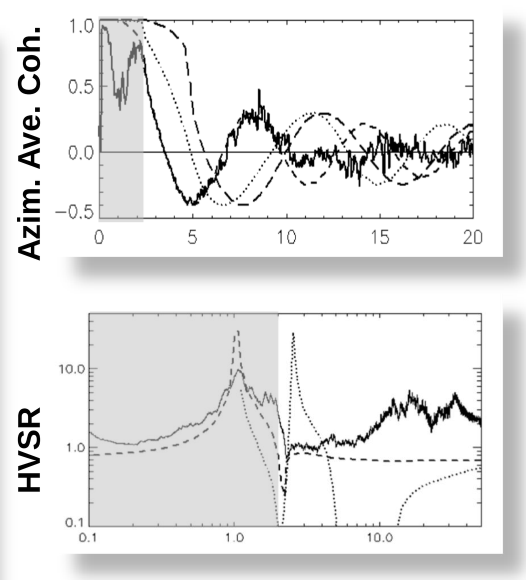
Horizontal to vertical spectral ratio (HVSR) curves are calculated from the magnitudes of horizontal and vertical ground motion of a 3-component sensor in the centre of the array. Peaks in the HVSR curve are generated by a large acoustic impedance contrast and give a representation of the resonant frequency of the sedimentary cover. The resonant frequency can be modelled in terms of the Rayleigh wave particle motion ellipticity, which is dependant on the total thickness and average velocity of the cover sequence.

SPAC and HVSR curves are modelled simultaneously using an iterative forward modelling approach and an initial model constrained by available petrophysical data. A standardised modelling approach is used whereby shallow structure is modelled by fitting modelled and observed SPAC spectra at high frequency and then deeper structure is modelled by fitting modelled and observed SPAC and HVSR spectra at lower frequencies. This procedure accounts for the effect of the shallow velocity structure on the fit of modelled and observed SPAC spectra at lower frequencies. After achieving a close visual fit between modelled and observed SPAC spectra the main peak of the modelled Rayleigh wave ellipticity curve is fit to the observed HVSR spectra by adjusting the overall thickness of the model. Finally, the fit with the observed SPAC spectra is fine-tuned by adjusting layer velocities within the available petrophysical constraints.

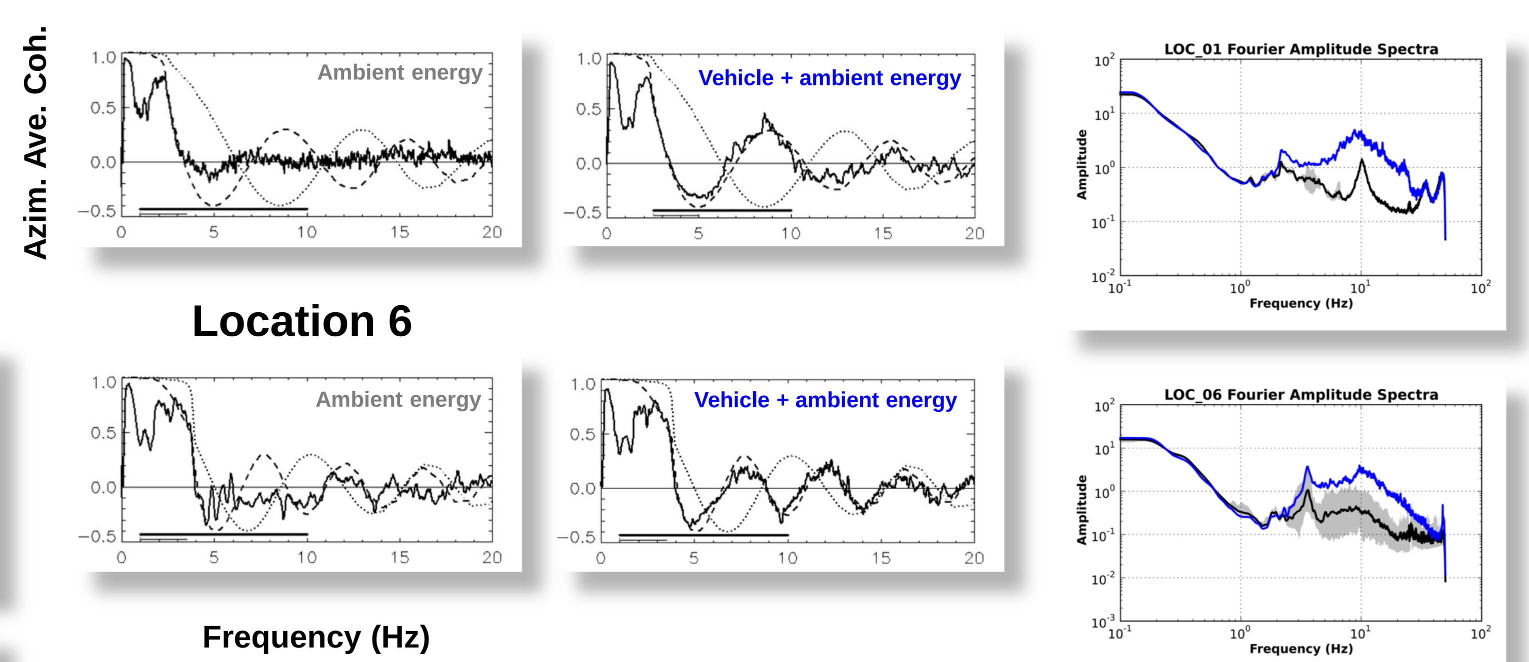
Using a hexagonal array with 50m radius, and energy from a light vehicle to supplement the ambient sources, high quality SPAC and HVSR curves were extracted and modelled to give accurate information on the depth to basement and velocity structure of a sedimentary cover sequence in northern South Australia.



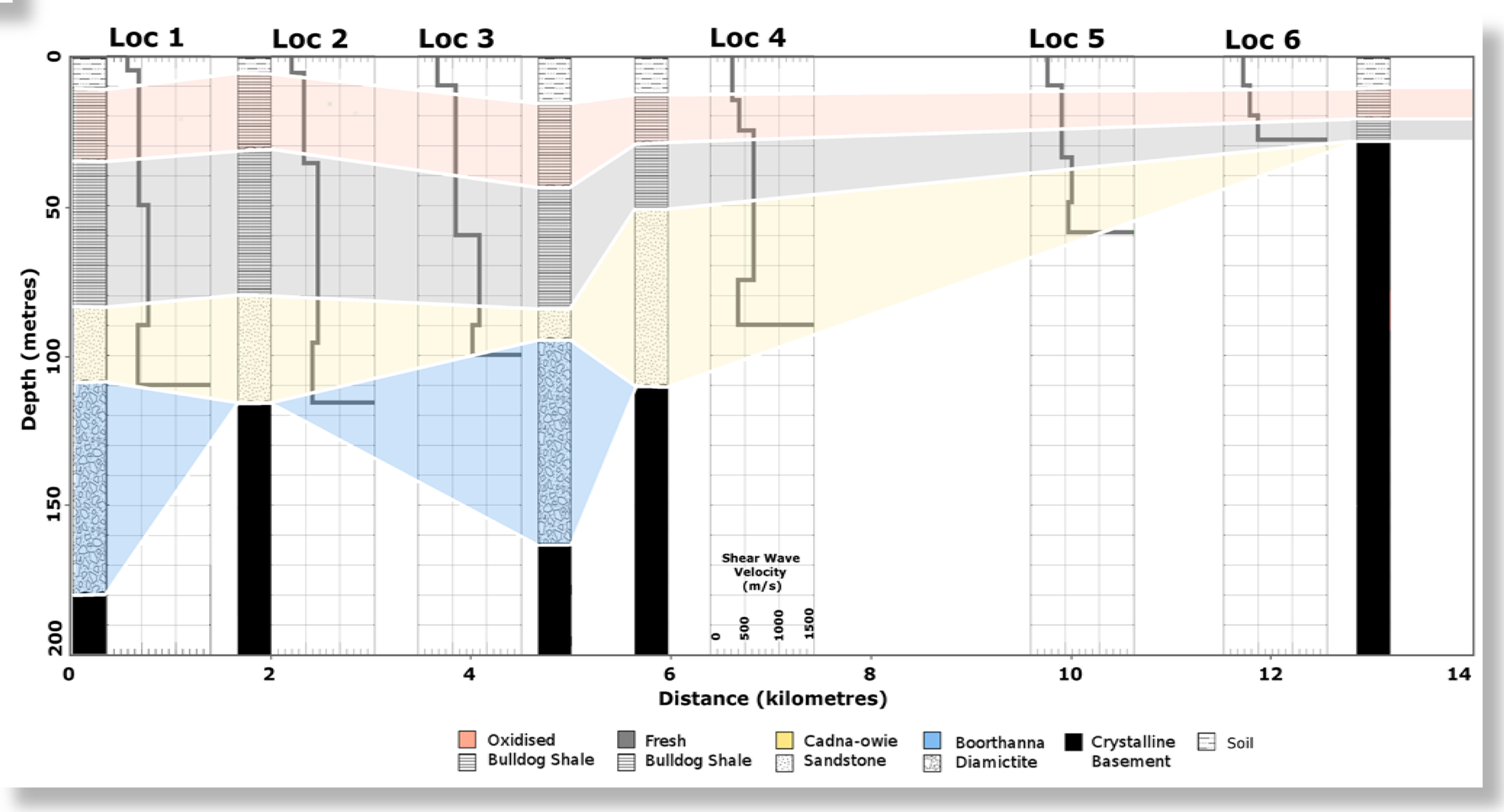
Above: Drill hole log for location 1 and modelled shear wave velocity profile for SPAC modelling (blue line) and SPAC + HVSR modelling (green line). The HVSR is sensitive to deeper structure, and as such, allows for modelling across several acoustic impedance contrasts (large impedance contrasts occur at top of diamictite, and top of basement).



Above: SPAC and HVSR curves for location 1. The shaded area shows where SPAC cannot be done due to degeneration of particle motion to the horizontal plane, although HVSR modelling can continue to lower frequencies.



Above: *1st column)* Observed SPAC curves (solid line) for "ambient only" wavefield, with modelled SPAC curve for the fundamental and 1st higher mode Rayleigh wave (dashed and dotted lines).
2nd column) Observed SPAC curves for a wavefield supplemented by vehicle energy, with modelled SPAC curve as for the top row.
3rd column) Wavefield amplitude spectra showing "ambient only" range and average (grey area and black line), and much more energetic ambient + vehicle spectra (blue line).



Right: Cover sequence cross-section showing drill hole stratigraphic logs with laterally extrapolated geology, and 1D shear wave velocity profiles.