Resource Potentials

www.respot.com.au info@respot.com.au

Passive seismic horizontal to vertical spectral ratio (HVSR) surveying to help define bedrock depth, structure and layering in shallow coal basins

by

Tom Dronfield, Jayson Meyers and David Stannard

3rd September, 2019

AEGC2019

Data to Discovery

Australasian Exploration Geoscience Conference

2-5 September 2019 • Perth, Western Australia

Incorporating the AIG, ASEG, PESA, and WABS

Introduction

Resource Potentials

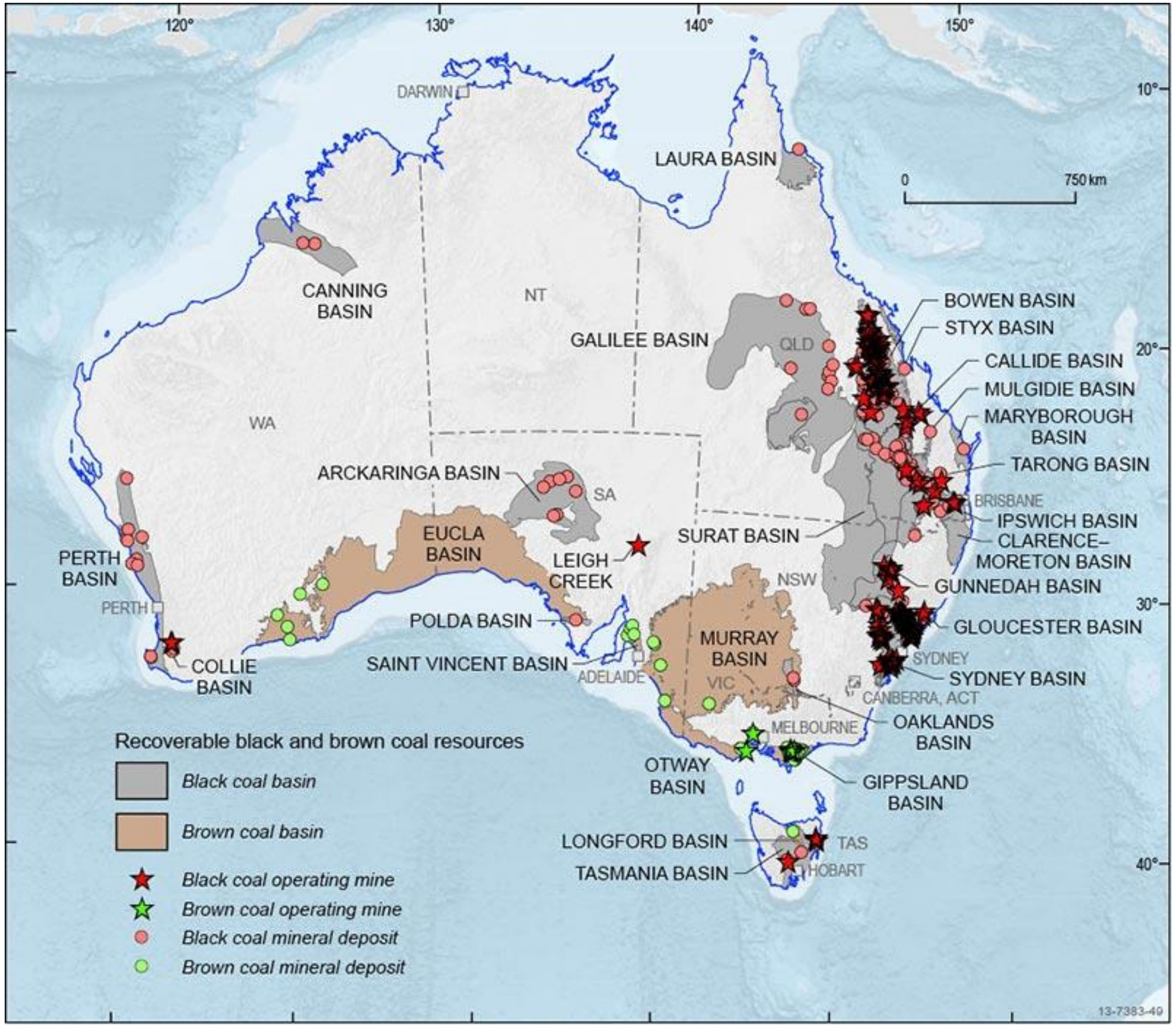
- Trial HVSR passive seismic survey to detect acoustic bedrock below shallow (<1,000m) and weakly lithified sedimentary deposits containing coal seams.
- Possibly detect layering within the basin deposits, especially coal layers, and structural offsets of these layers and the basement layer if detected.
- The HVSR method may compliment gravity and magnetic (potential field) geophysical survey information which are useful for outlining basin boundaries and structural trends, as long as there are magnetic and density contrasts between crystalline bedrock, intrusive dykes and stocks, and sedimentary basin fill deposits. But not useful for direct detection of coal seams and other sedimentary deposit layers.
- Electrical geophysical survey techniques (resistivity, induced polarisation and electromagnetics) can also be used to map conductive sedimentary and resistive coal deposit layering in the shallow parts of sedimentary basins (<300m).
- Seismic reflection surveying can then be planned and carried out based on potential field results, as seismic reflection is the most effective geophysical survey method for detecting subsurface sedimentary layering, unconformities and structural features within a coal basin to assist with exploration, resource definition and development, but is very costly, requires cleared access tracks, is labour intensive and slow, and then requires intensive data processing and interpretation that is also slow and expensive; but still cheaper than close spaced drilling…
- **Today's presentation introduces the HVSR passive seismic survey method as an effective and rapid technique to map major sedimentary basin architecture in the subsurface and resolve some stratigraphic layering.**

HVSR passive seismic surveying in the Wilga Basin

Australian Coal Basins

Resource Potentials

- Australian coal was first discovered in 1791 near Newcastle in NSW with economical black coal typically ranging in age from 150 million years to 280 million years.
- Significant coal deposits are all located on the east coast of Australia, where there are large volumes of high quality coking and thermal coal deposits, as well as coal seam gas deposits.
- WA coal occurrences are mainly Permian aged deposits in the Perth, Canning and Collie basins, with significant mining historically occurring within the Collie Basin, which is located 175km south of Perth.
- This study focusses on the Wilga Basin, which is 14km south of the Collie Basin, where access was permitted and existing tracks allowed for easy access to acquire 4 passive seismic survey lines in a 1 day period.

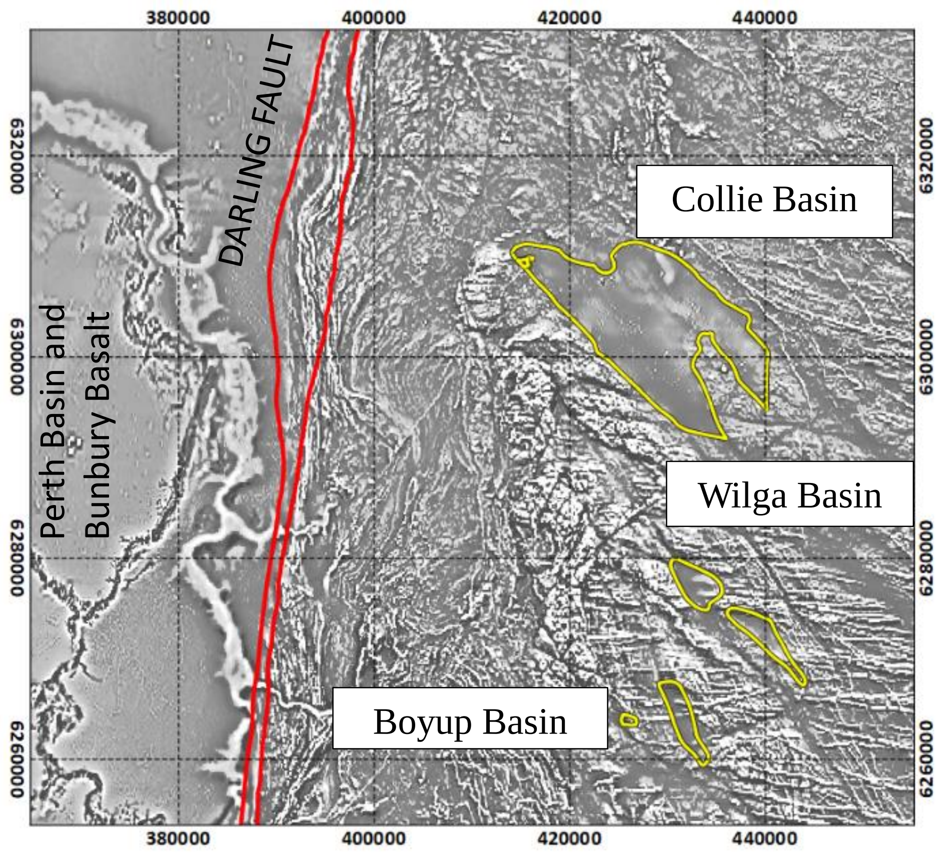


Major coal basins of Australia (from Geoscience Australia, 2012).

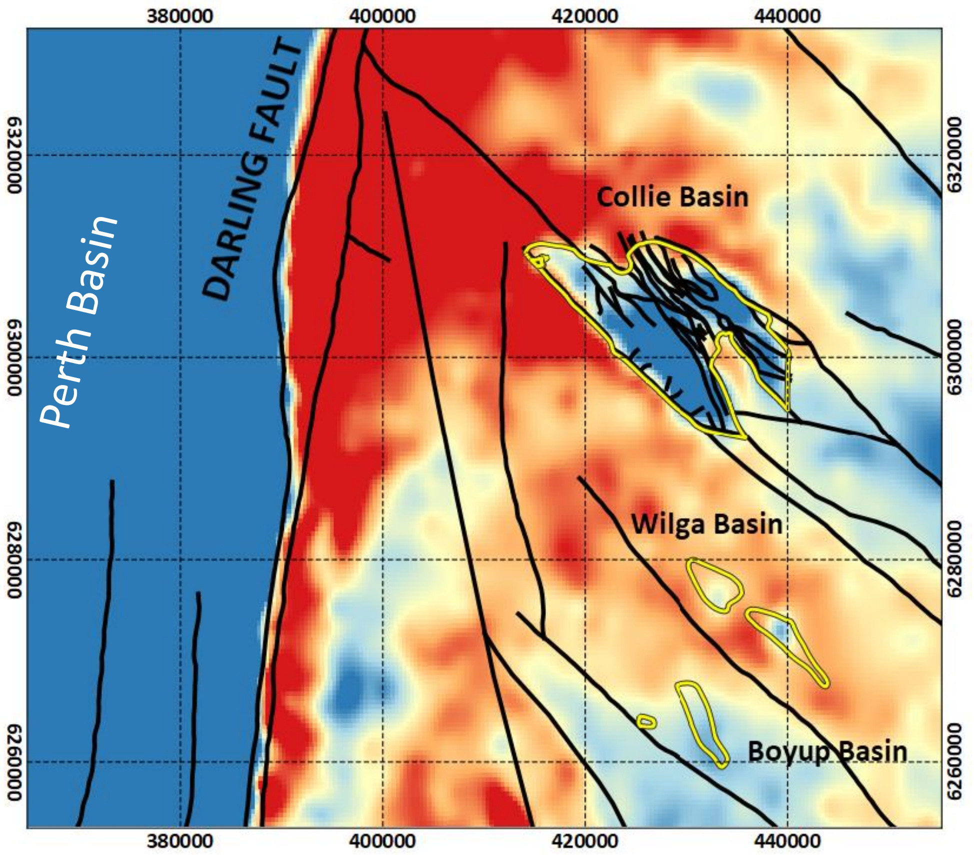
Gravity and Magnetic Expression of Sedimentary Basins

Resource Potentials

- Early stage exploration to delineate sedimentary basins typically employ aeromagnetic and gravity surveying.
- Magnetic data show long wavelength anomaly patterns associated with deep burial depth of magnetic crystalline bedrock under non-magnetic sedimentary deposits. Sedimentary basins are usually displayed in filtered magnetic images as "blurry zones" in the magnetic anomaly texture, where sedimentary cover subdues the bedrock response.
- Gravity data highlights low density zones caused by thick sedimentary deposits as well as low density crystalline bedrock.
- Both methods are ambiguous for defining true thickness of sedimentary basin fill and providing internal stratigraphic information.



1st vertical derivative filtered aeromagnetic image highlighting Collie, Wilga and Boyup sub-basins (yellow), with Darling fault in red.

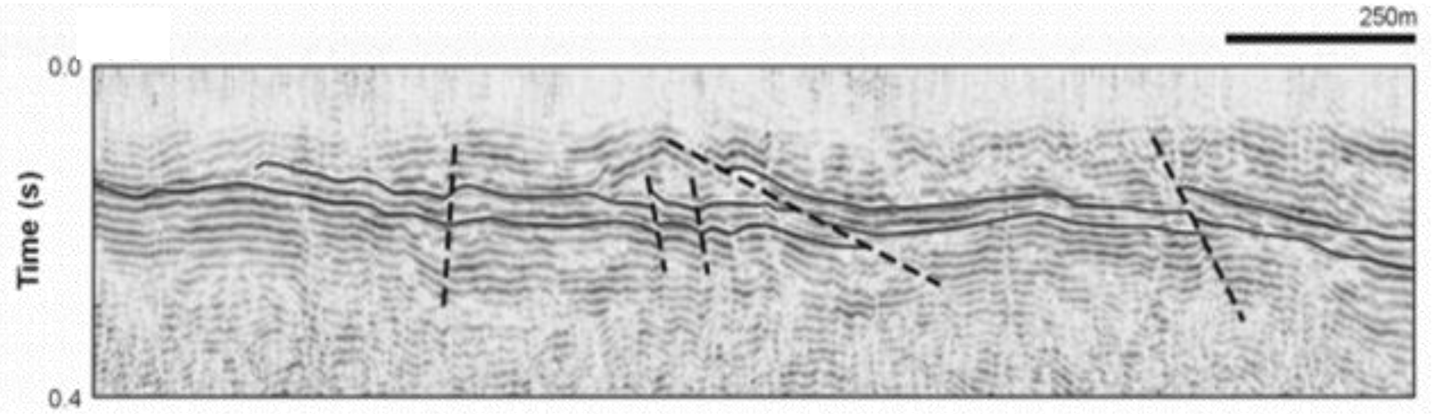


Gravity data, 0.5 vertical derivative filtered image highlighting Collie, Wilga and Boyup sub-basins (yellow), GSWA 1:500,000 scale regional interpreted structures in black.

Active 2D/3D Multichannel Seismic Reflection

Resource Potentials

- 2D seismic reflection surveying used for defining basin thickness, stratigraphic information and major structures at early stages of exploration.
- Detailed 2D and 3D seismic surveying at more advanced stages for direct imaging of coal seams and surrounding stratigraphy, unconformities, structures, intrusive bodies (dykes, sills and stocks) and potentially gas pockets.
- Seismic reflection surveying is by far the best geophysical survey method for defining sedimentary basin architecture and imaging stratigraphy.
- However, surveying is labour intensive, requires a large amount of survey equipment, and a significant amount of land clearing, resulting in high survey costs and time. Post surveying requires specialised data processing, which is also time consuming and expensive.



2D multi-component migrated seismic reflection time section from the Bowen Basin, Queensland. Coal seams shown as solid black lines, with dashed black lines showing interpreted faults (reproduced from Peters and Hendrick, 2006).

Image of 2 Velseis vibroseis seismic source trucks, sourced from www.velseis.com

HVSR Passive Seismic Method

Resource Potentials

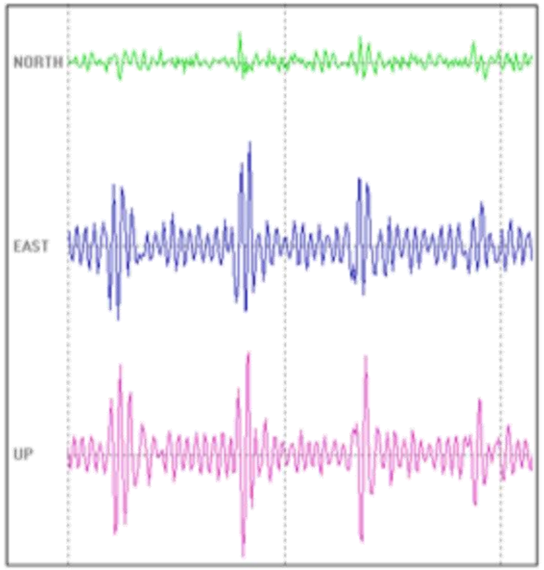
- HVSR passive seismic is a geophysical surveying technique designed to quickly and easily measure the depth to fresh bedrock beneath unconsolidated to poorly lithified cover sediments and weathered crystalline bedrock.
- The HVSR passive seismic survey tool used in this case study was the Tromino® ENGY seismometer.
- Rapid HVSR passive seismic surveying has several advantages over active seismic reflection surveying in early exploration stages:
  - No active source required, uses ambient seismic energy from all directions, mainly coastal wave energy, micro seismicity, distant winds, and distant anthropogenic signal.
  - Small and lightweight, self contained 3 component seismometers with no need for a link between seismometers.
  - Fast data acquisition and processing turn around to generate cross sections.
  - Anyone can acquire and download data, and Trominos come with easy to use Grilla software.

HVSR passive seismic data acquisition using a Tromino® seismometer

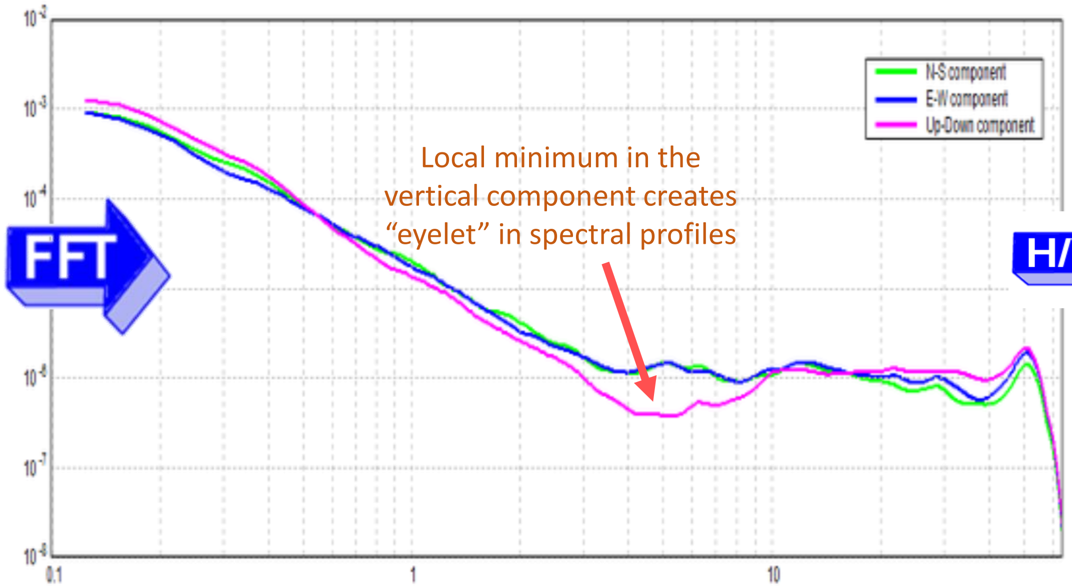
HVSR Passive Seismic Method

Resource Potentials

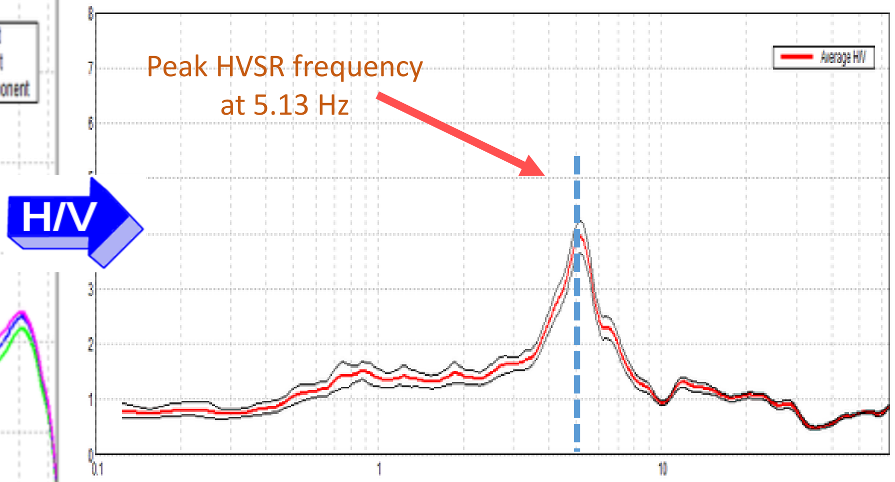
- Based on vertically travelling ambient shear waves (SH) becoming trapped in softer and slow velocity regolith cover, poorly consolidated sediments and weathered bedrock sitting over harder and higher velocity fresh bedrock.
- Passive seismic surveying involves recording ambient or naturally occurring seismic vibrations over a broad range of frequencies and a specific time period (e.g. 10-30 min). The Tromino® seismometer records 3 axial components of vibration: two horizontal (relative X and Y axes) and one vertical (Z axis).
- SH wave resonance is developed within low velocity layers sitting over a higher velocity layer to produce a local minimum in the vertical vibration component frequency power spectrum, thereby creating an ‘eyelet’ shaped separation between the horizontal and vertical vibration frequency components. Calculating the averaged X and Y horizontal (H) to vertical (V) spectral ratio (HVSR) will produce a peak HVSR frequency representing the resonant frequency of the cover deposit layers.



Time-based Tromino reading
Natural vibrations



Frequency power spectrum of ambient vibrations



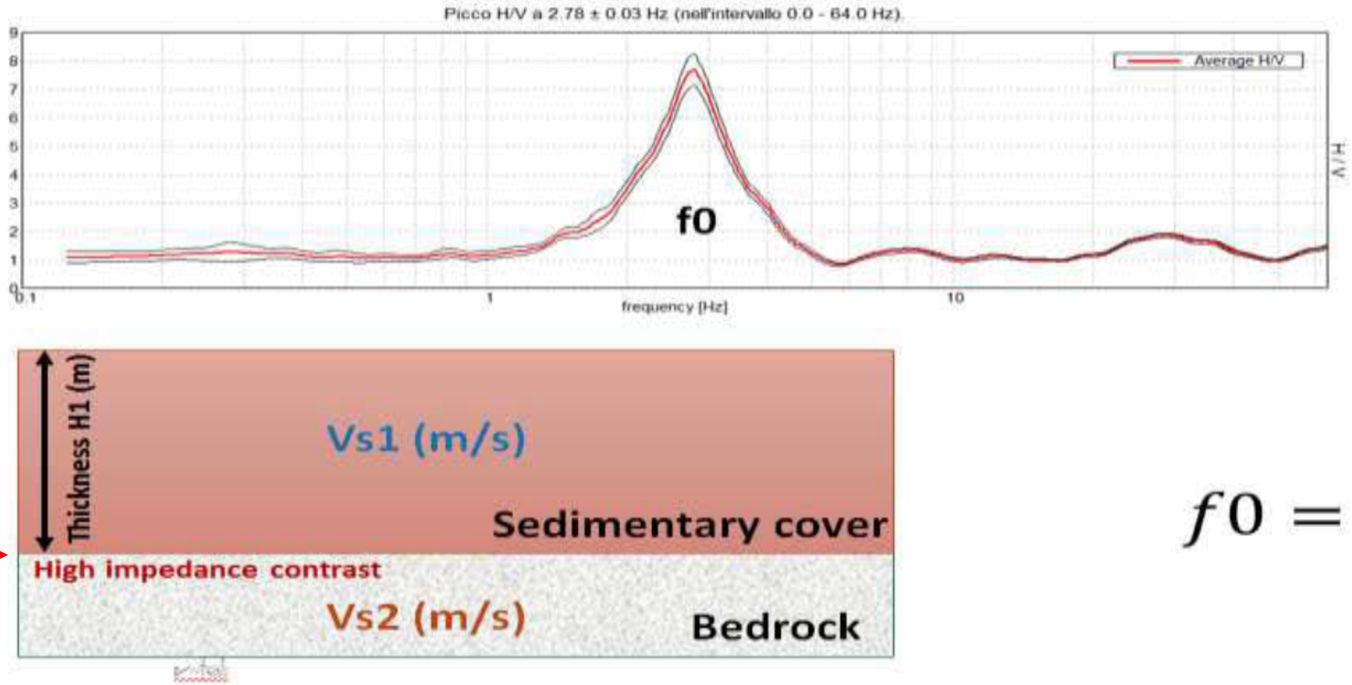
HVSR profile

HVSR Passive Seismic Method

- The peak resonant frequency (f_0 in Hz) is related to thickness (h in metres) and average shear wave velocity (V_s in m/s) of the low velocity cover layer by the following equation:

$$f_0 = \frac{V_s}{4h} \quad \text{(Equation 1)}$$

- The image below shows a visual representation of Equation 1 and an HVSR power spectrum plot with a single well defined, high amplitude resonant frequency peak:



High acoustic impedance contrast boundary between layers (AI = Vs x density)

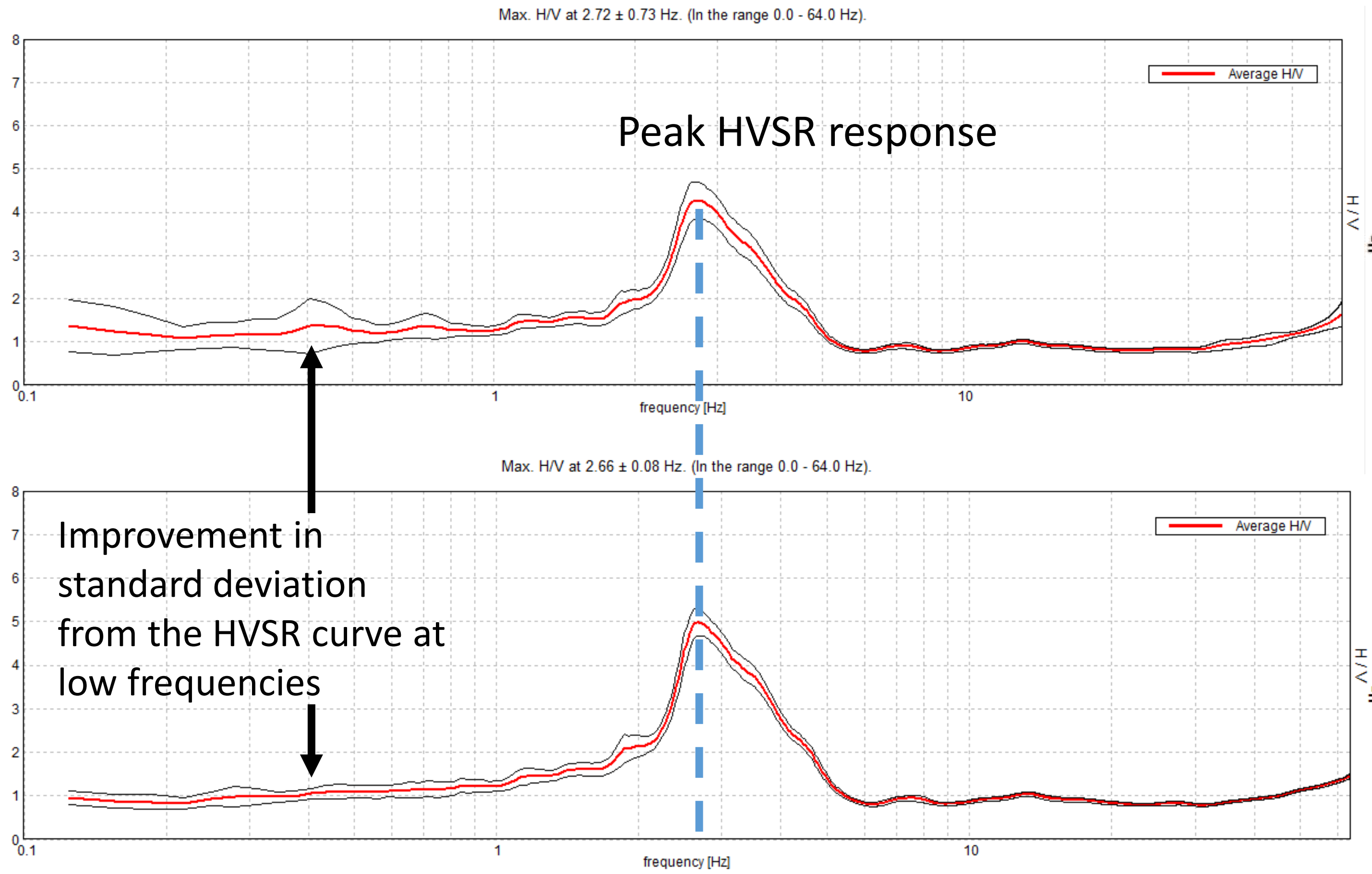
Need to define Vs to calculate depth

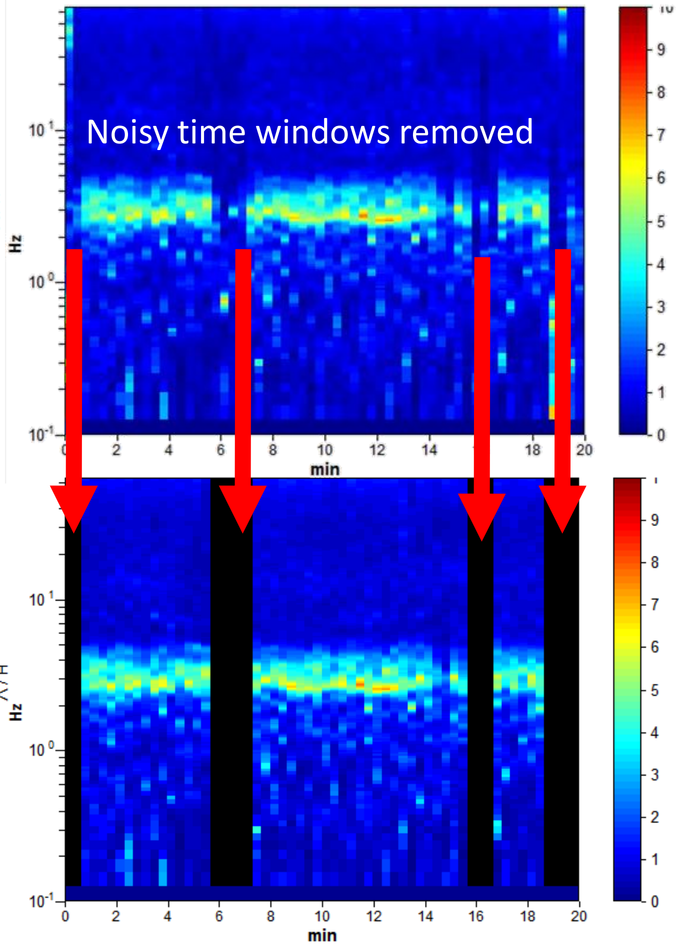
$$f0 = \frac{Vs1}{4.H1}$$

HVSR Passive Seismic Data Editing

Resource Potentials

HVSR passive seismic data are edited by the removal of noisy time windows to reduce the standard deviation away from the calculated HVSR curve. The example HVSR profile below highlights how removing anomalous recording time windows can improve the final stacked quality of the HVSR curve, especially at lower frequencies.



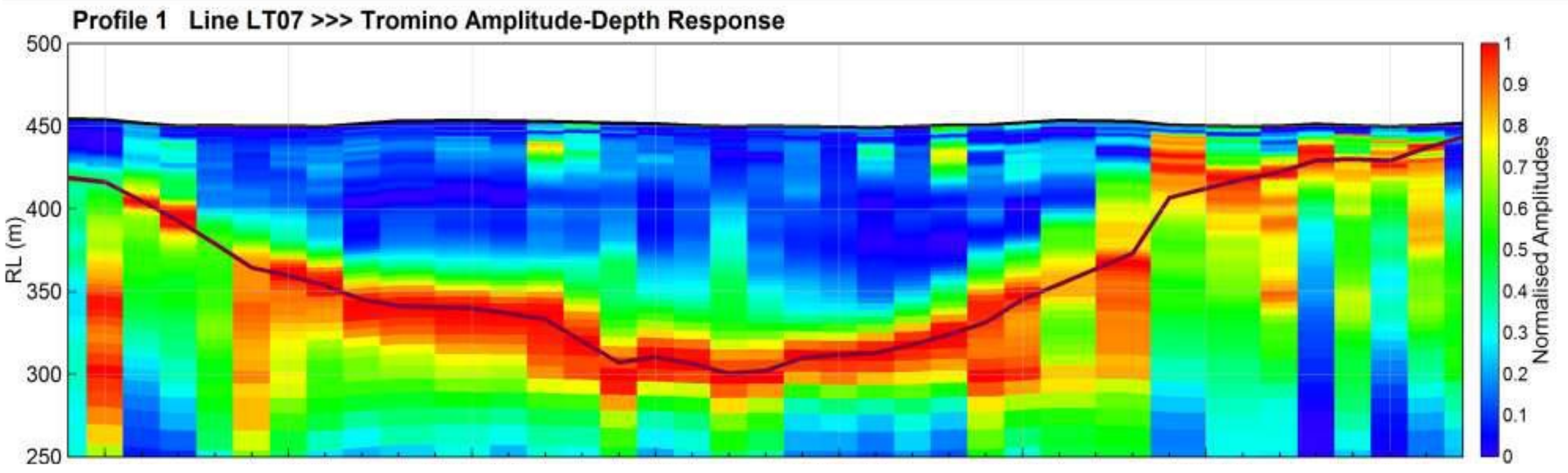


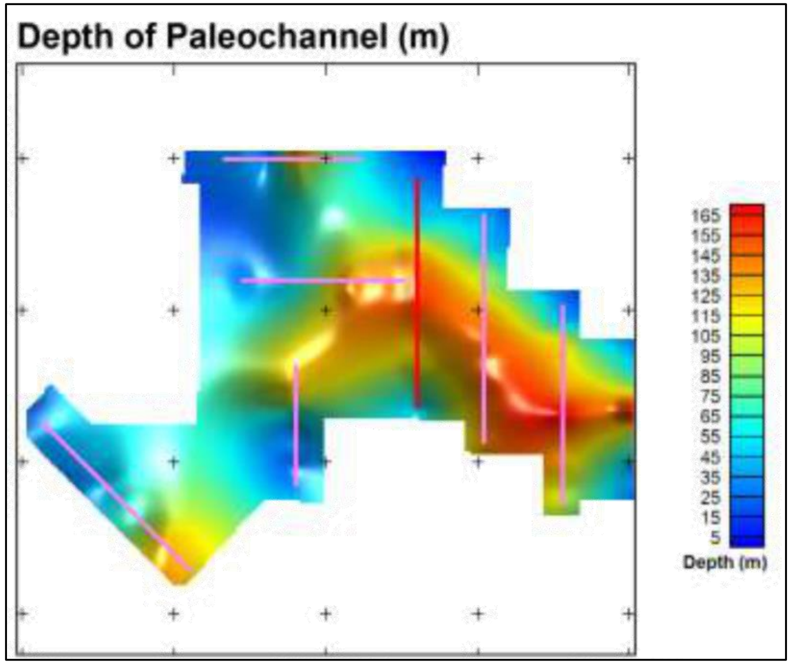
Example HVSR Passive Seismic Survey Results

Resource Potentials

1) Normalised amplitude HSVR depth cross sections enhance layer continuity by amplifying adjacent peak frequency responses. This processing technique enhances layer continuity of high impedance contrast lithological boundaries when displayed as depth converted cross sections, such as the paleochannel example below.

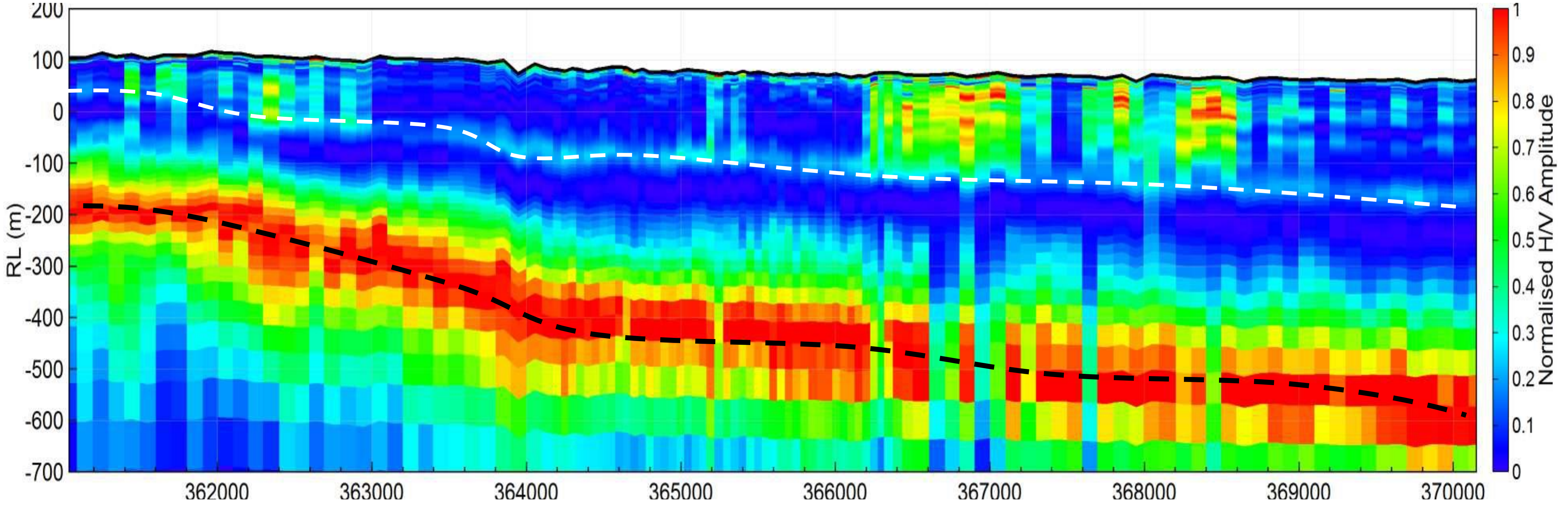
2) Depth to fresh bedrock can be gridded, imaged and contoured to map paleochannel or shallow sedimentary basin architecture from multiple passive seismic survey lines.





Example HVSR Passive Seismic Survey Results

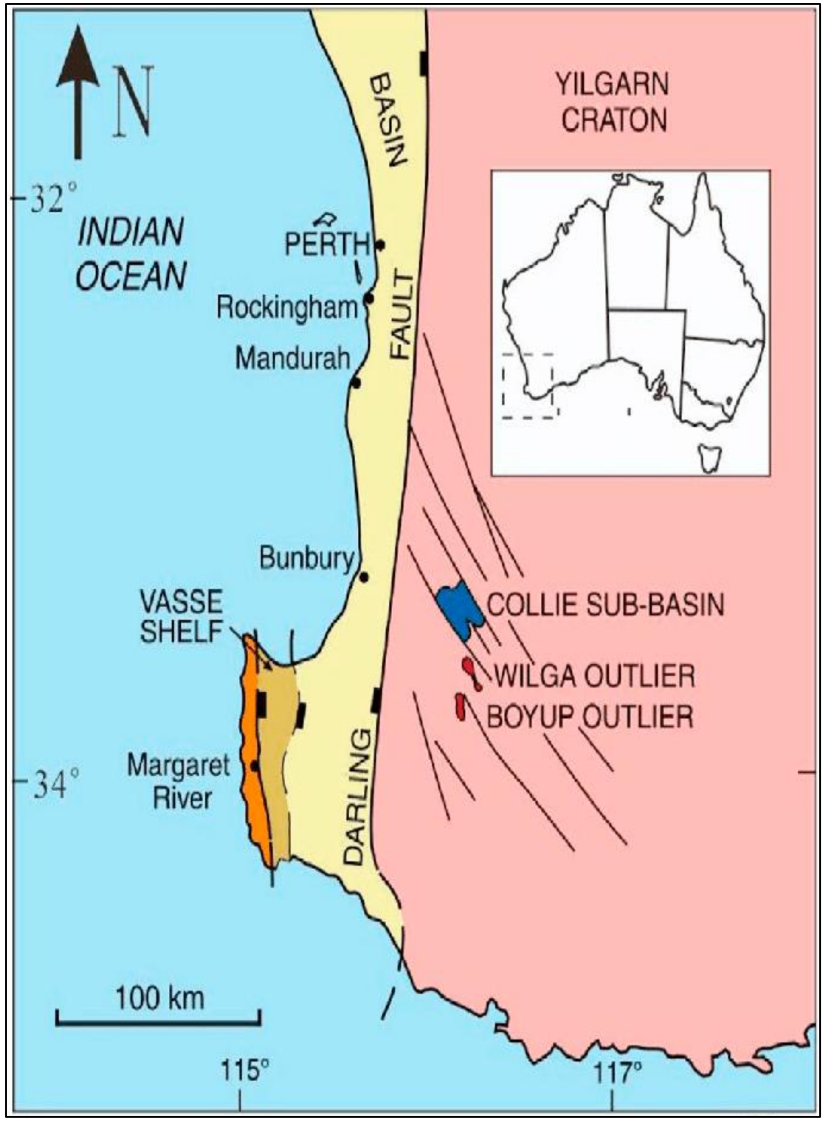
- HVSR passive seismic cross section shown below was acquired in a sedimentary basin environment within Central Australia, where the primary objective of the survey was the detecting fresh bedrock to a depth of 700m below weakly lithified Mesozoic and Cainozoic sedimentary deposits.
- An acoustic impedance contrast was detected (dashed black line) and correlates to known crystalline bedrock based on deep drillholes and multiple channel seismic reflection surveying. The dashed white line indicates a major unconformity also imaged by 2D seismic reflection surveying and logged in drillholes.



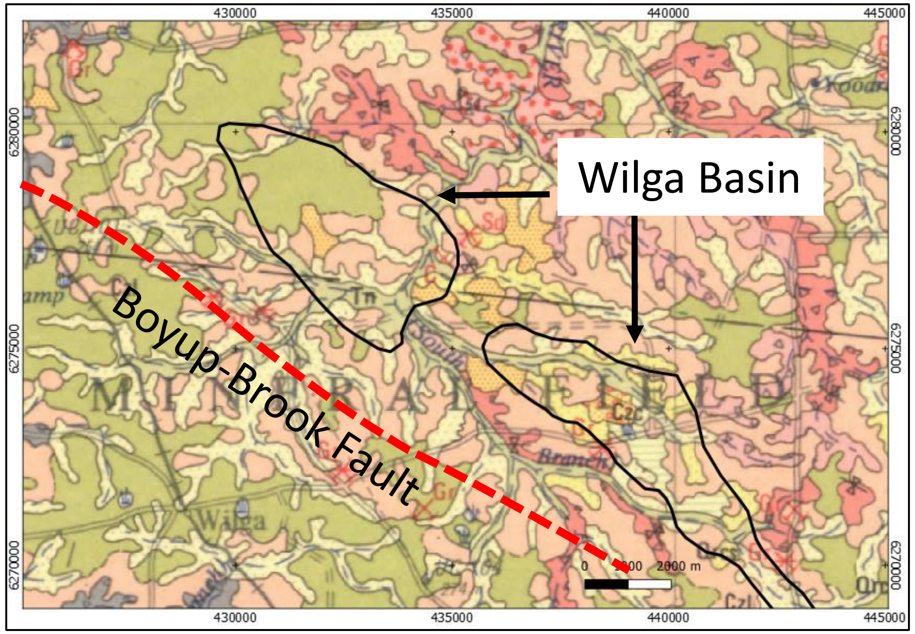
Wilga Basin Case Study - General Geology and Location

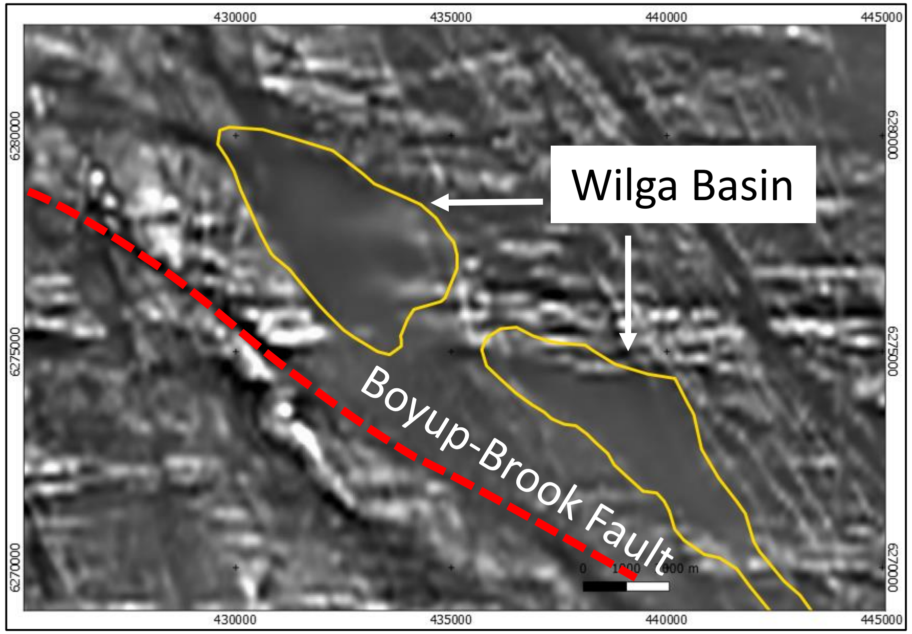
Resource Potentials

- The Wilga Basin is a small, shallow and isolated sedimentary basin containing Permian coal seams. It is located approximately 190km to the south of Perth, WA. It is regarded as a sub-basin of the larger Collie Coal Basin, 14km to the north, and both basins are outliers of the larger Perth Basin located along the western side of the Darling Fault.
- The basin is interpreted to be located within a northwest trending fault bounded graben. It was first discovered in 1918 with the general shape identified in 1960 by a regional ground gravity survey.
- The 1:100K scale geology map to the right shows Cretaceous to Cainozoic laterite and alluvial deposits covering most of the interpreted basin, with Archean granite-gneiss outcrop shown in dark pink surrounding the northern and southern extents of the basin. The NW-SE trending Boyup-Brook Fault is shown on both a geology map image and first vertical derivative filtered magnetic image as a dashed red line.



Location of the Collie, Wilga and Boyup Basins (reproduced from Yu et al., 2018). Basins are located in the Western Gneiss Terrane of the Archaean Yilgarn Craton (pink area).

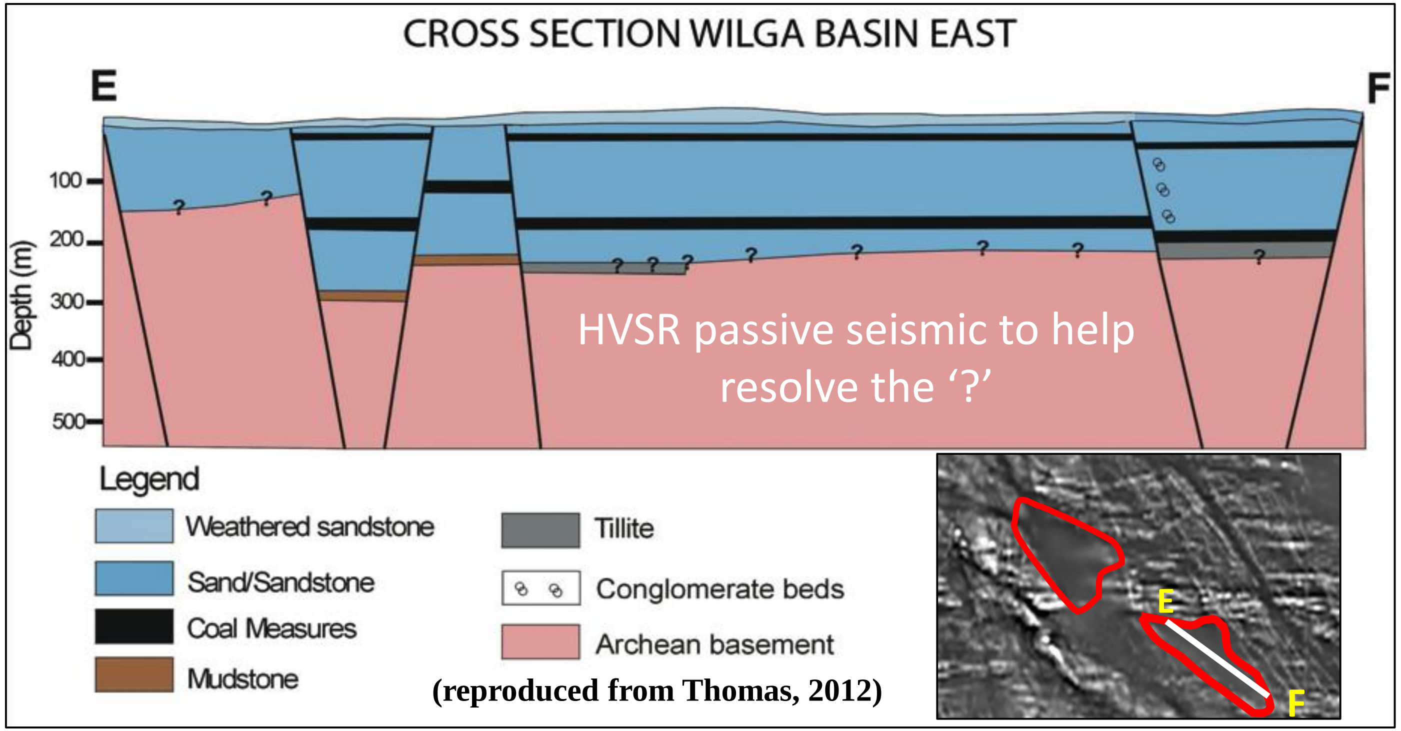




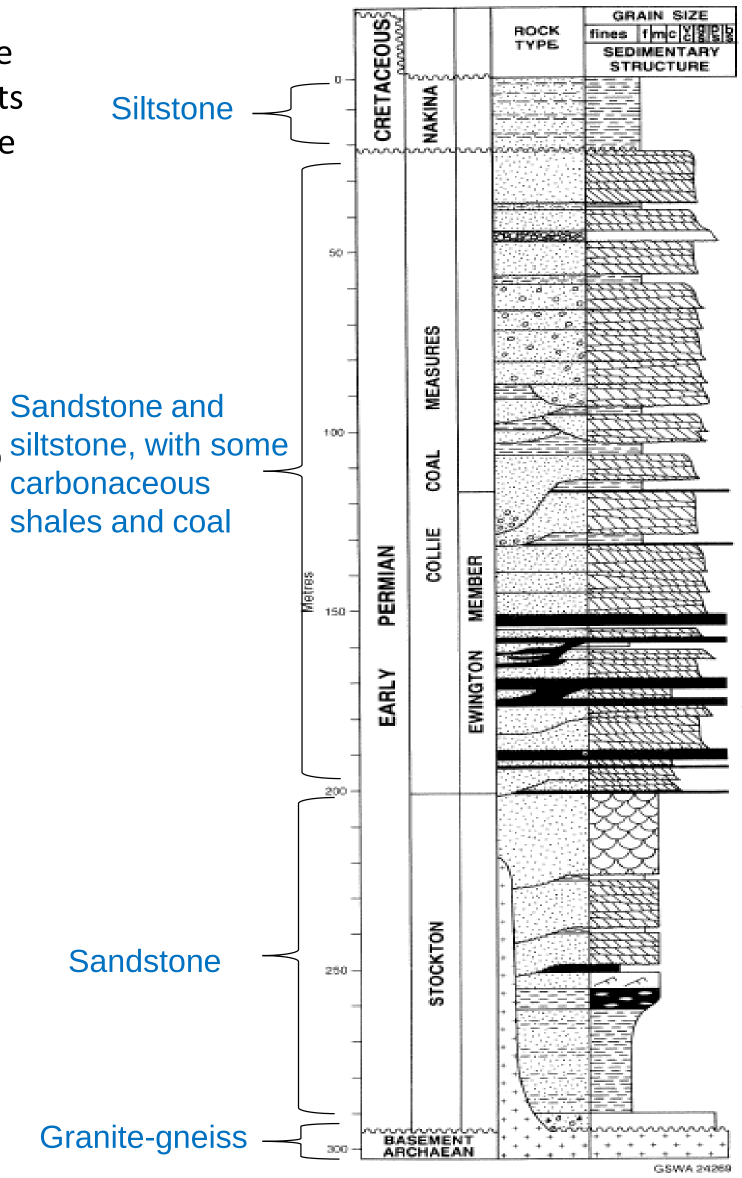
Wilga Basin – Geology

Resource Potentials

- The geology of the Wilga Basin is very similar to the Collie Basin, with Cretaceous sediments unconformably overlying Permian sandstone, siltstone, shale, and coal bearing measures. The coal is mainly present within the Ewington Member of early Permian age, with coal seams intersected over 10m thick. The Cretaceous sediments are similar to the Nakima Formation of the Collie Basin, and the Ewington Member potentially correlates to the Collie Coal Measures. The basement rock is known to be a crystalline granite-gneiss of Archean age, which is offset by younger faults, and outcrops on the edges of the basin.
- Recent (2012) drilling by Wesfarmers Premier Coal has intersected multiple layers of sandstone and siltstone down to over 180m depth in the Wilga Basin without intersecting the Archean bedrock. Historical drilling and shaft sinking dating back to 1921 have intersected granite at approximately 200m in the northern part of the basin, with the southern Wilga Basin considered to reach depths of 300m.
- The geological cross section of the southern Wilga Basin shown below, displays a faulted and variable depth to the Archean granite bedrock.



(reproduced from Thomas, 2012)

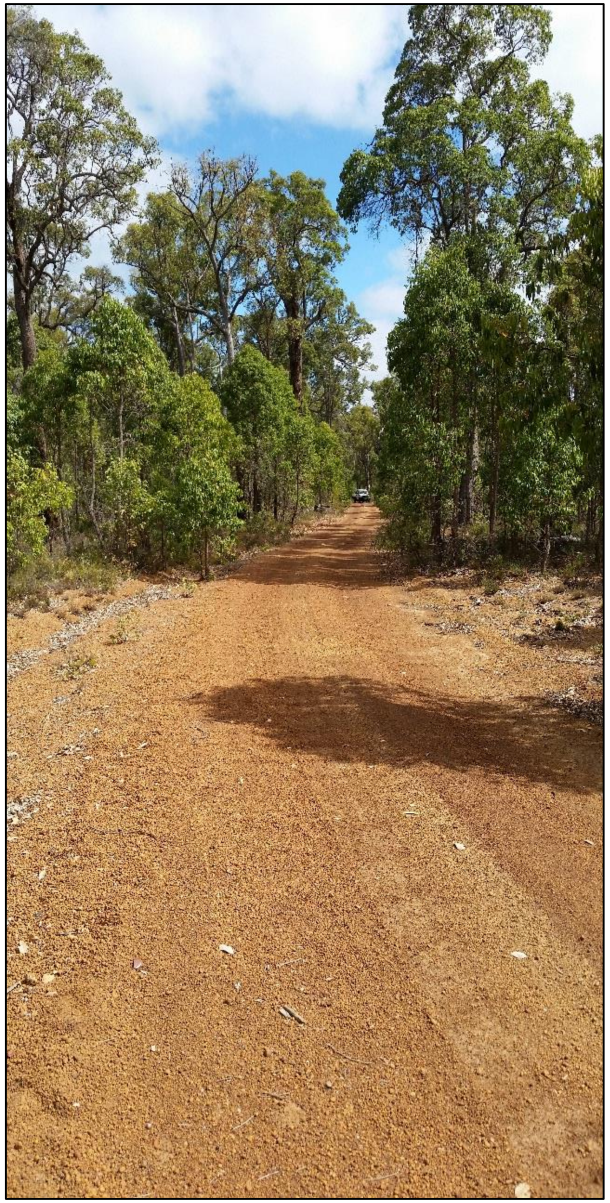


(reproduced from GSWA, 1990)

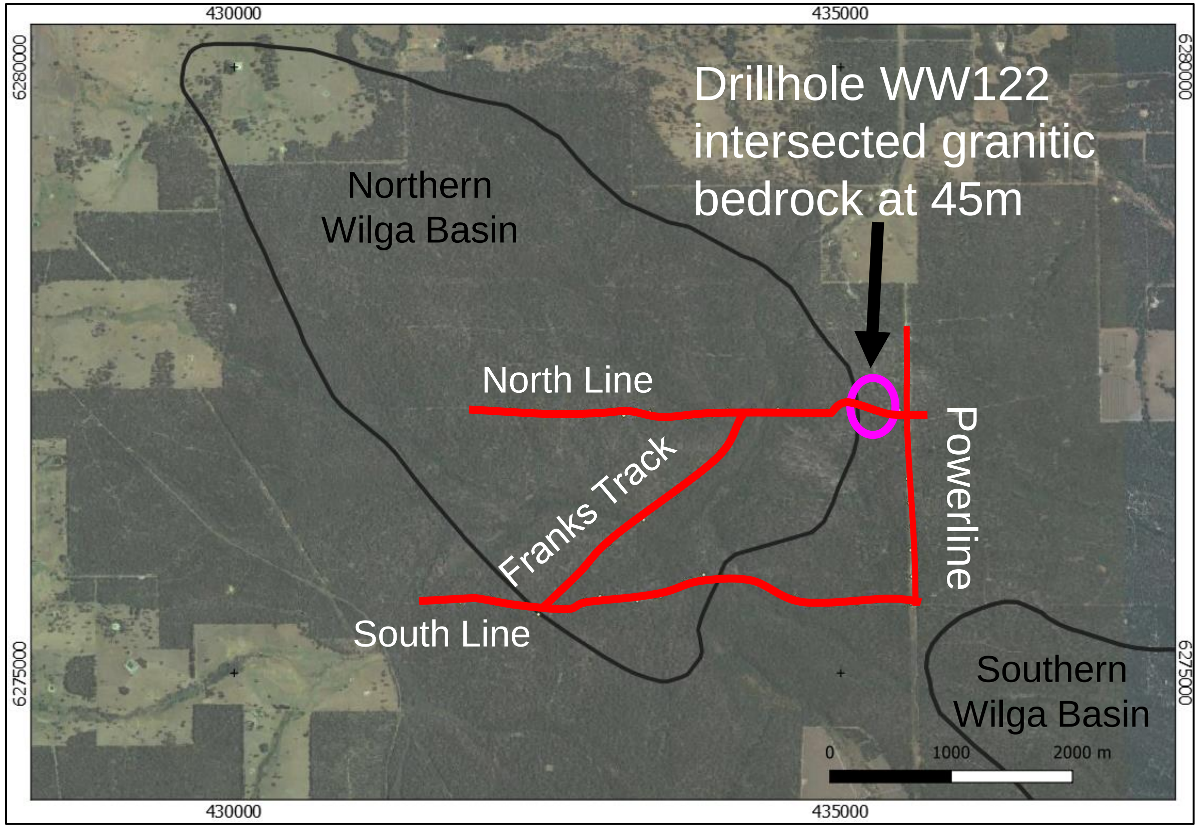
Passive Seismic Survey Specifications

Resource Potentials

- Passive seismic surveying carried on 4 public access tracks in forested area located towards the southern part of the northern Wilga Basin.
- Passive seismic station spacing was nominally **200m**. 4 Tromino® seismometers used to acquire a total of 65 stations. **20 minute** recording time for each station. Surveying completed within 1 day, and could be done by only 1 person, but 2 were used for safety reasons.
- Open-file diamond drilling was reviewed, with only 4 drillholes located close enough to passive seismic stations to be used for depth calibration. However, only 1 drillhole intersected fresh bedrock to be used for Vs calibration.
- The map on the right shows the HVSR passive seismic survey lines in red with the outline of the Wilga Basin in black. The photo shows an access track located along the southern survey line.



Survey Line	Number of Stations Acquired	Approximate Survey Time
North Line	21	3 hours
South Line	28	4 hours
Franks Track	4	25 minutes
Powerline	12	1.5 hours

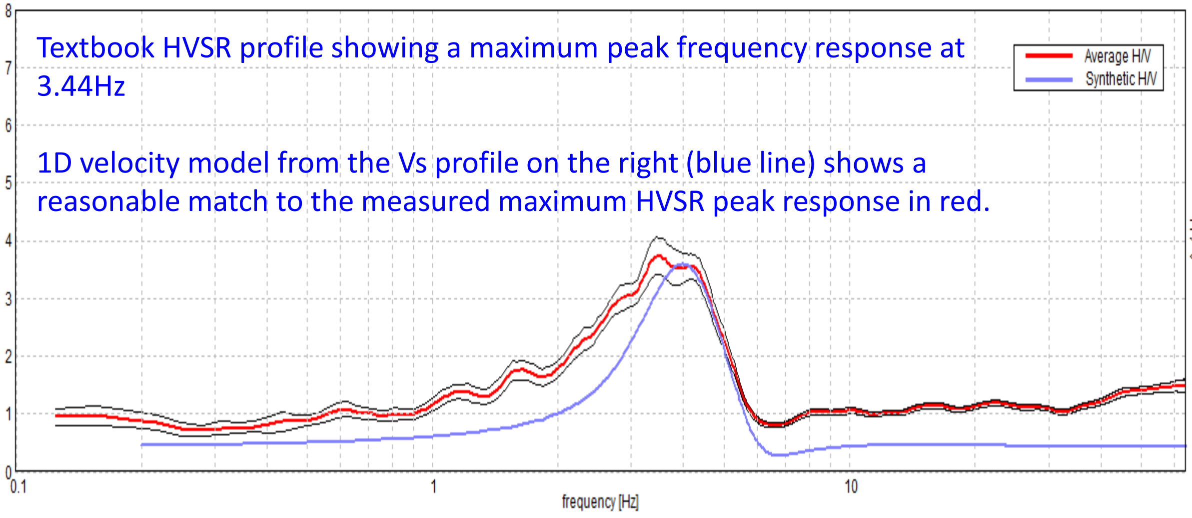


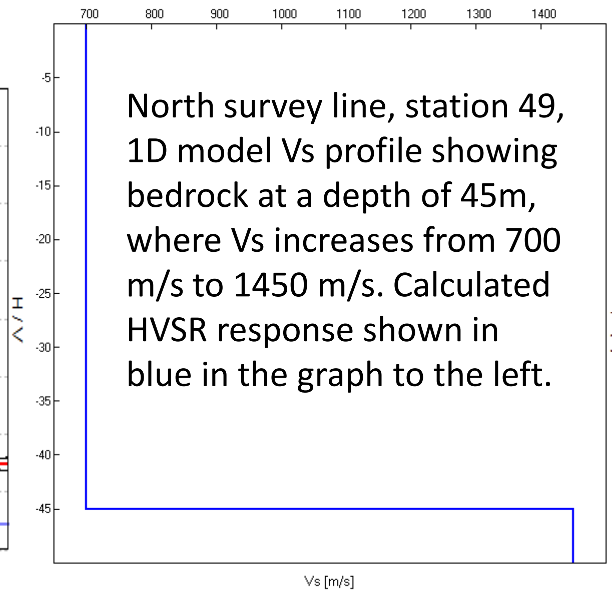
Velocity Analysis: 1D Forward Modelling

Resource Potentials

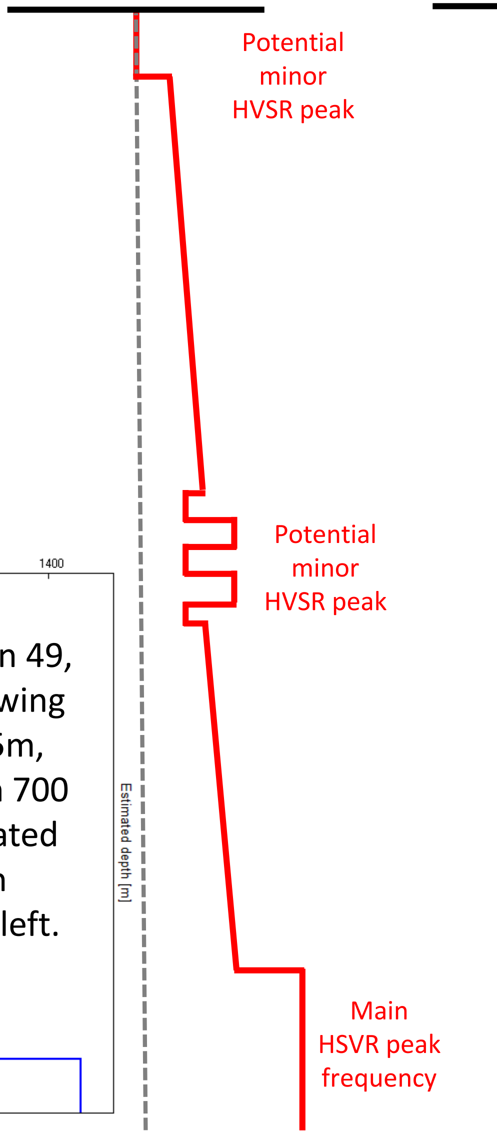
- An average Vs for the Wilga Basin was estimated from 1D forward modelling and by using Equation 1 for a passive seismic station located close to the drillhole with known fresh bedrock depth (h).
- A hypothetical simplified Vs profile for the basin is shown on the right, where the coal seams and the granite bedrock produce the largest impedance contrasts. A single intersection of granitic bedrock at 45m in drillhole WW122 located on the NE edge of the basin was used for estimation of Vs. The results of 1D modelling are shown below, where the modelled peak frequency response (blue line) has been adjusted to fit the observed peak frequency response at 3.44 Hz, resulting in an average Vs of **700 m/s** for this study, but this could be improved by taking additional readings next to deeper drillholes intersecting the granite-gneiss basement.

North survey line, station 49

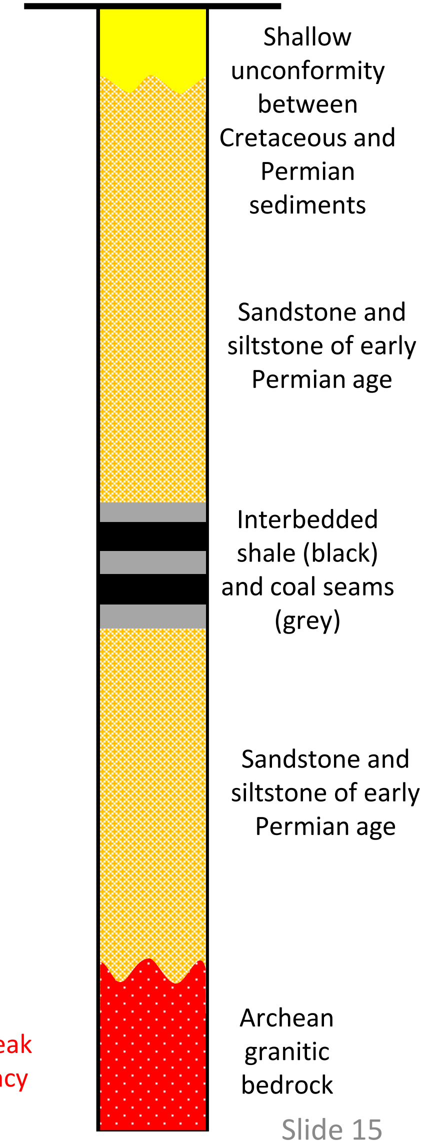




Simplified Vs Profile

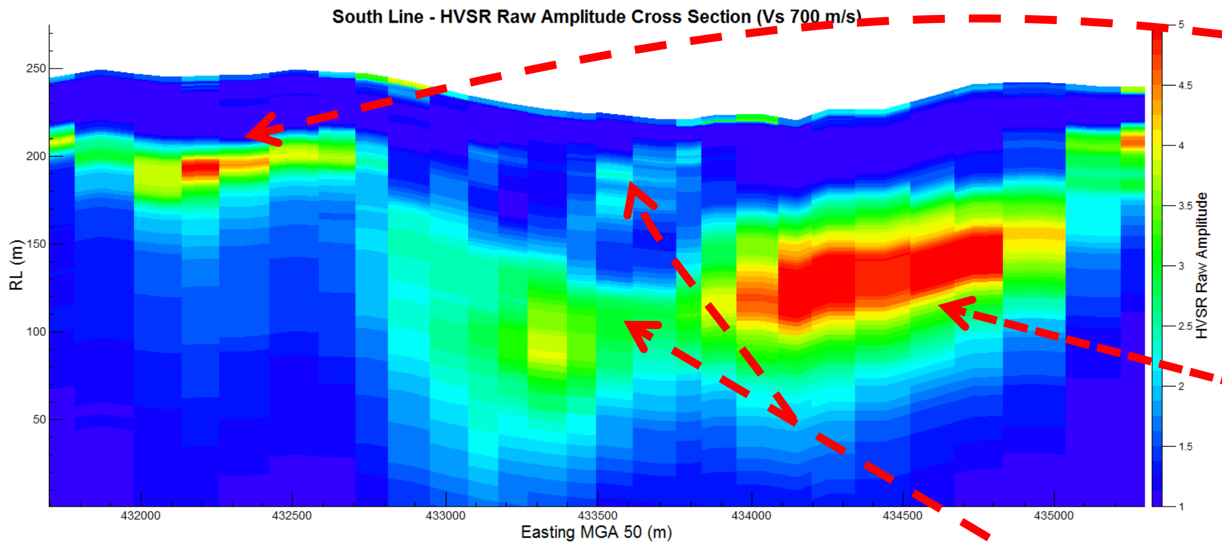


Simplified Geology of the Wilga Basin

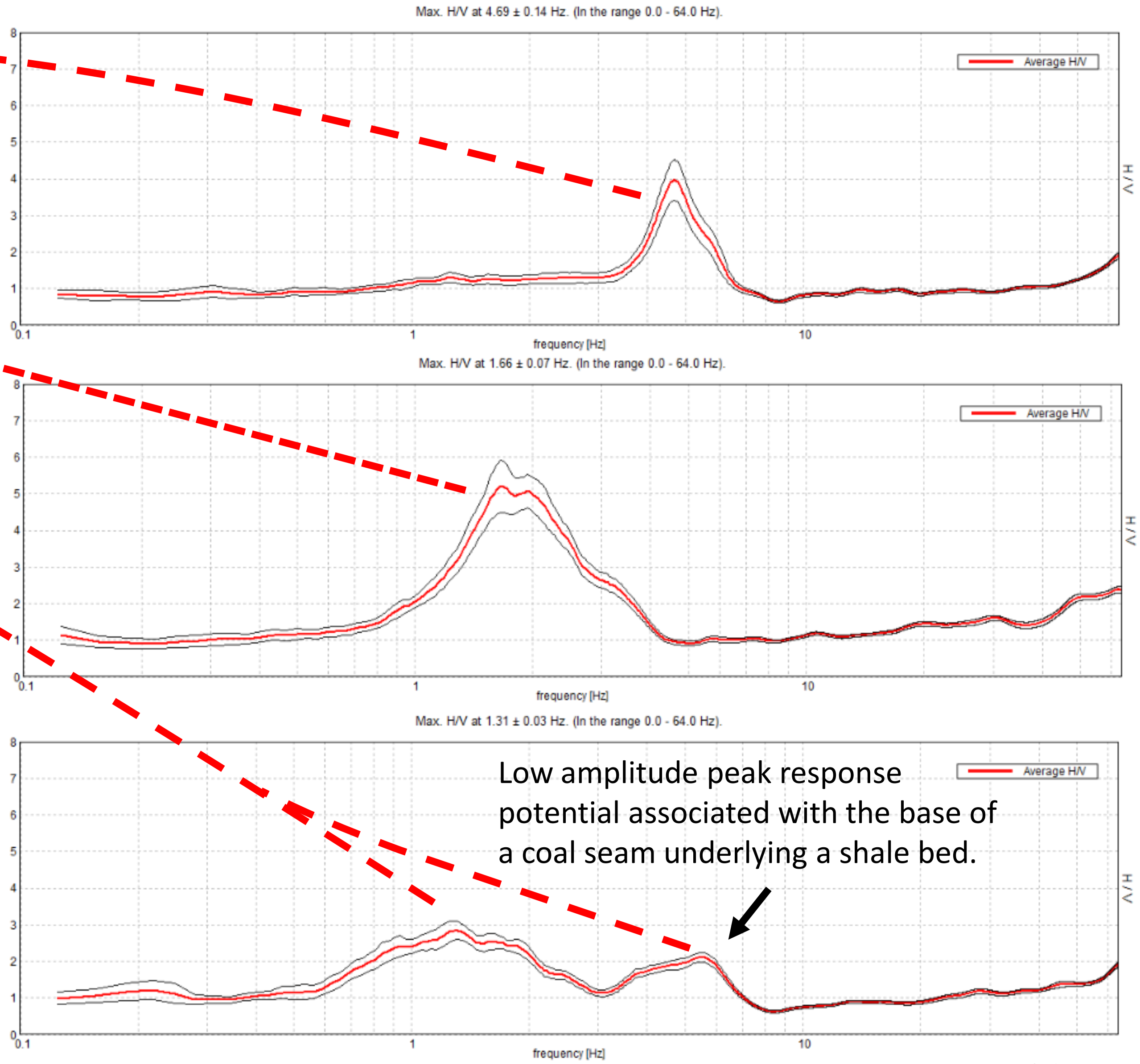


Data Observations – South Line (Raw Amplitude)

Resource Potentials

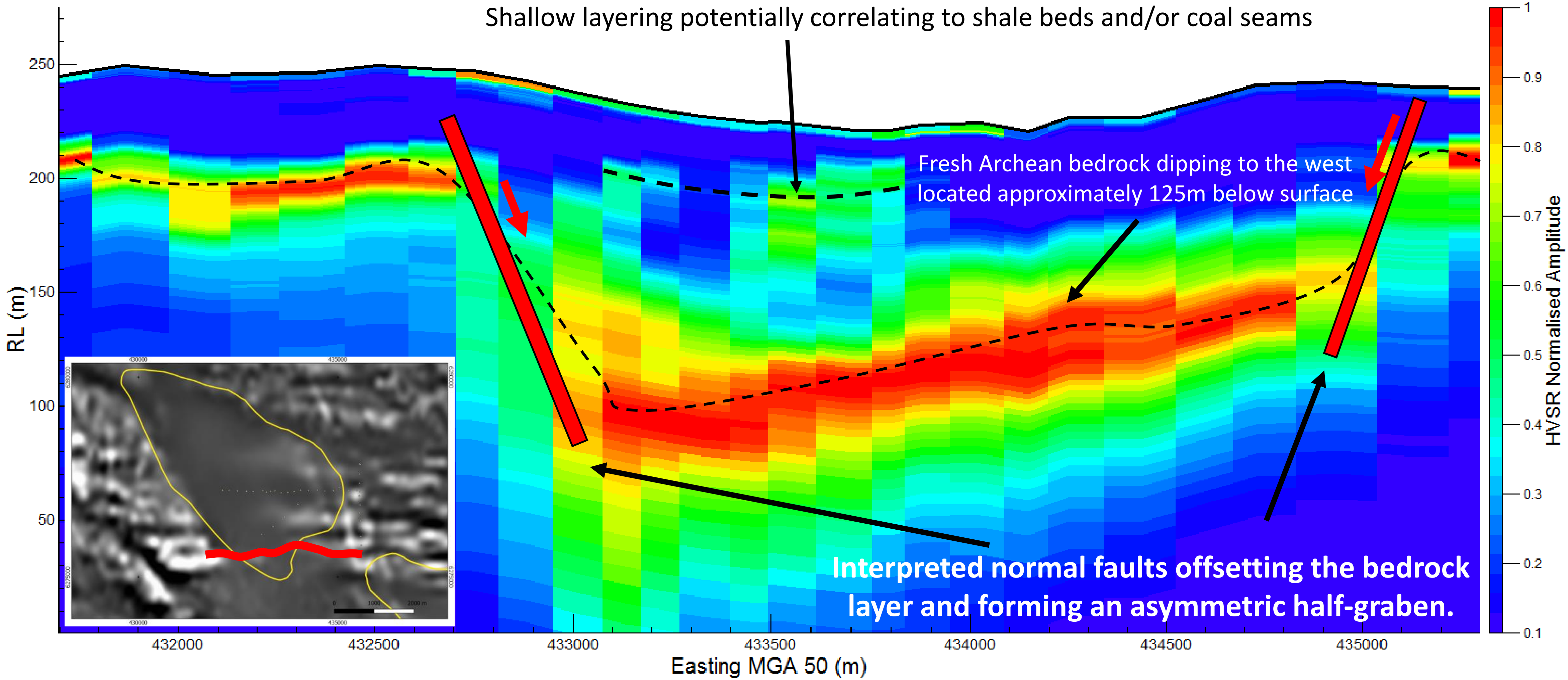


- The HVSR profiles on the right illustrate that a higher frequency peak response is associated with a shallower acoustic impedance contrast layer.
- The high amplitude peak frequency response shown in the center corresponds to a large acoustic impedance contrast shown by warmer colours along the bedrock interface.
- The HVSR profile on the bottom right shows 2 main HVSR peaks.



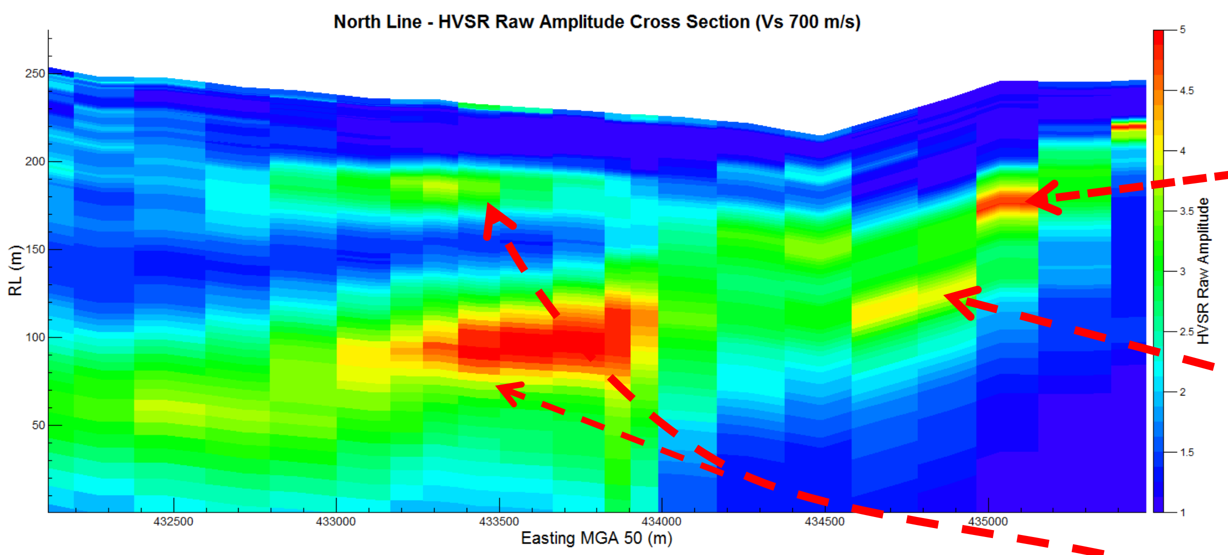
Data Observations - South Line (Normalised Amplitude)

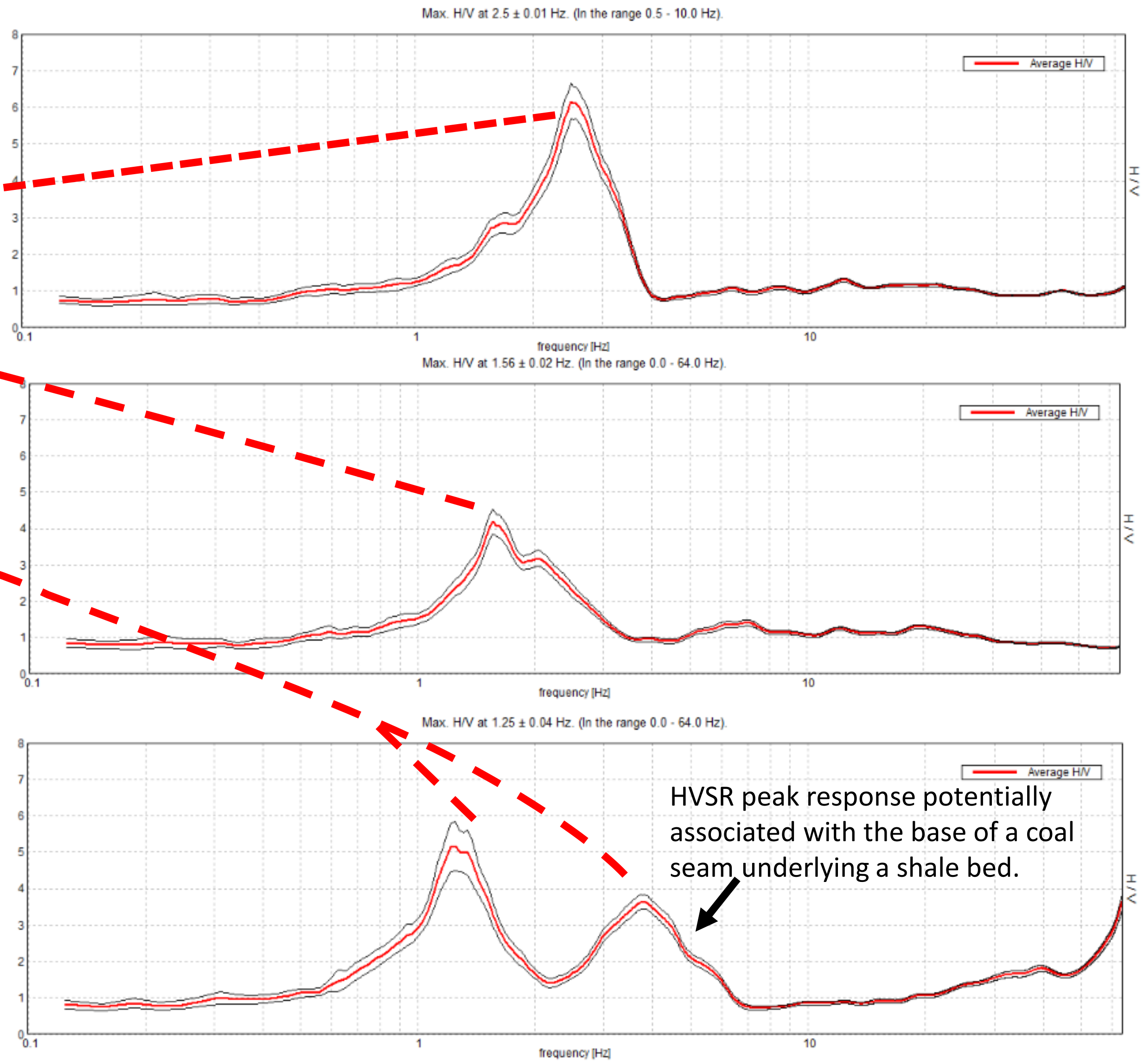
Resource Potentials



Data Observations – North Line (Raw Amplitude)

Resource Potentials

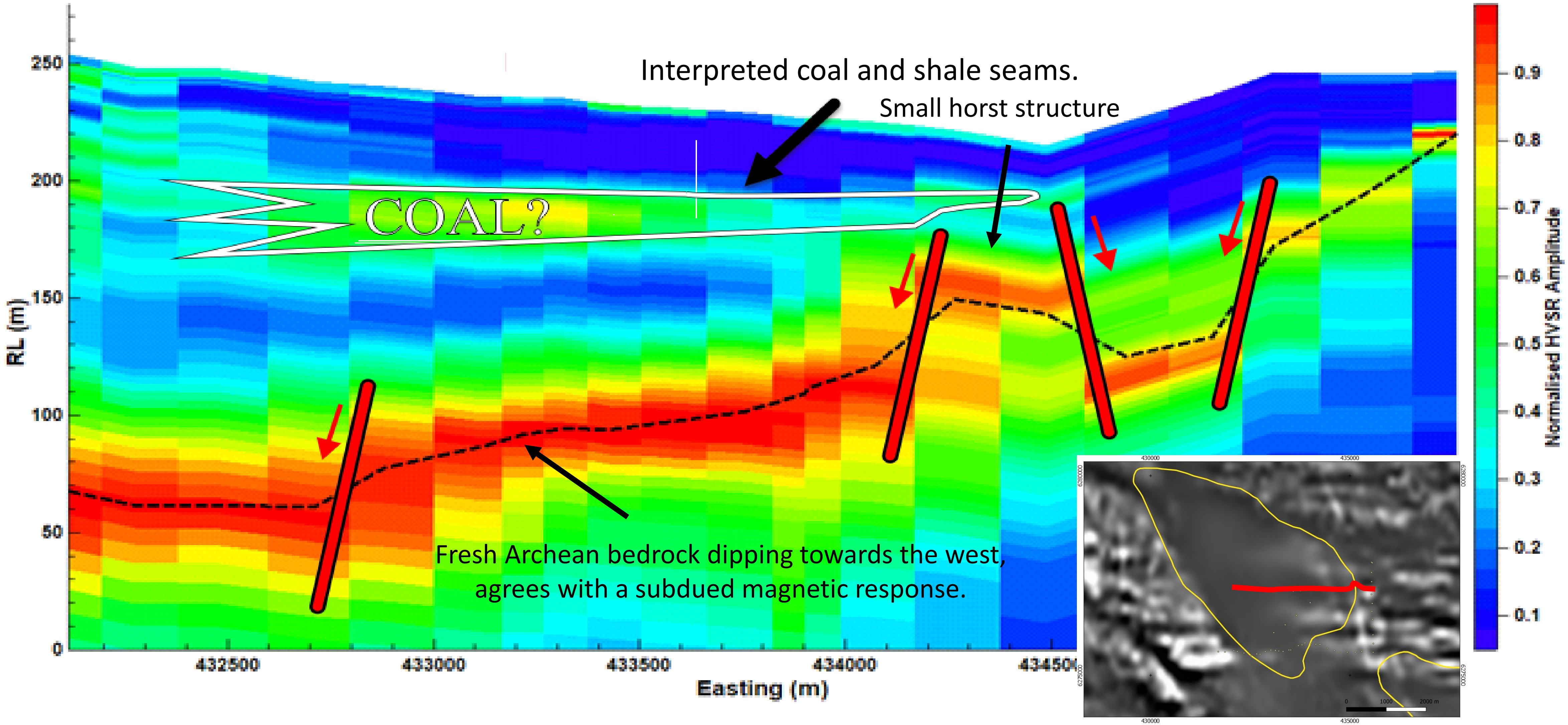




- The HVSR profile on the bottom right shows 2 main HVSR peaks which are shown on the cross section above. The higher frequency HVSR peak response is interpreted to potentially correlate to the base of a relatively thick coal seam overlying shale beds.

Data Observations - North Line (Normalised Amplitude)

Resource Potentials

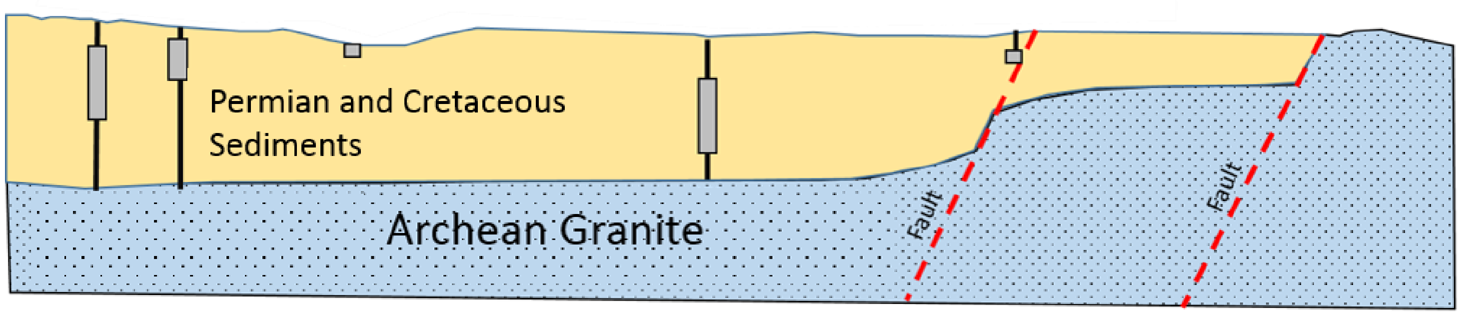


Comparison of HVSR Passive Seismic to Known Geology

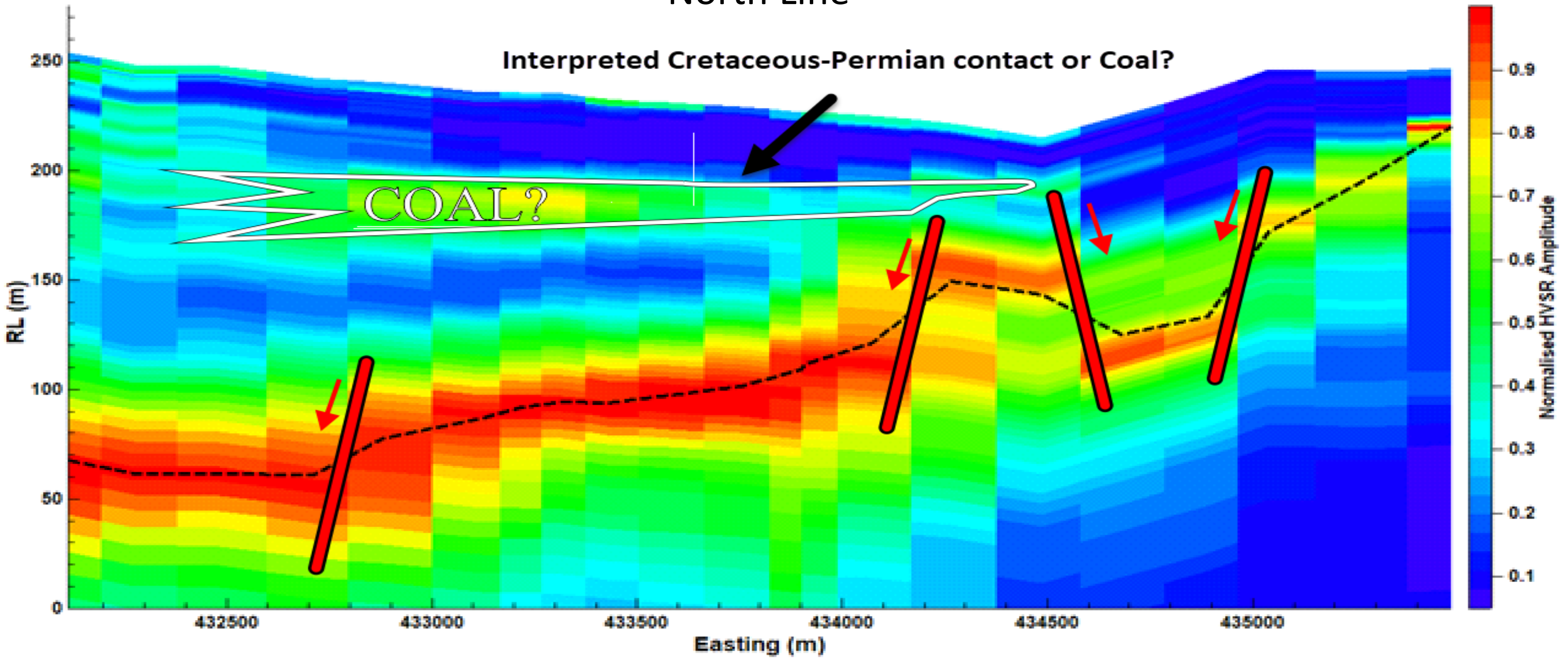
Resource Potentials

- A geological cross section from Wilson (1921), located in a similar location to the north line shows similarities, but the passive seismic cross section show greater detail of bedrock and fault locations due to direct detection.

Geological cross section of the northern Wilga Basin (image modified from Wilson, 1921).

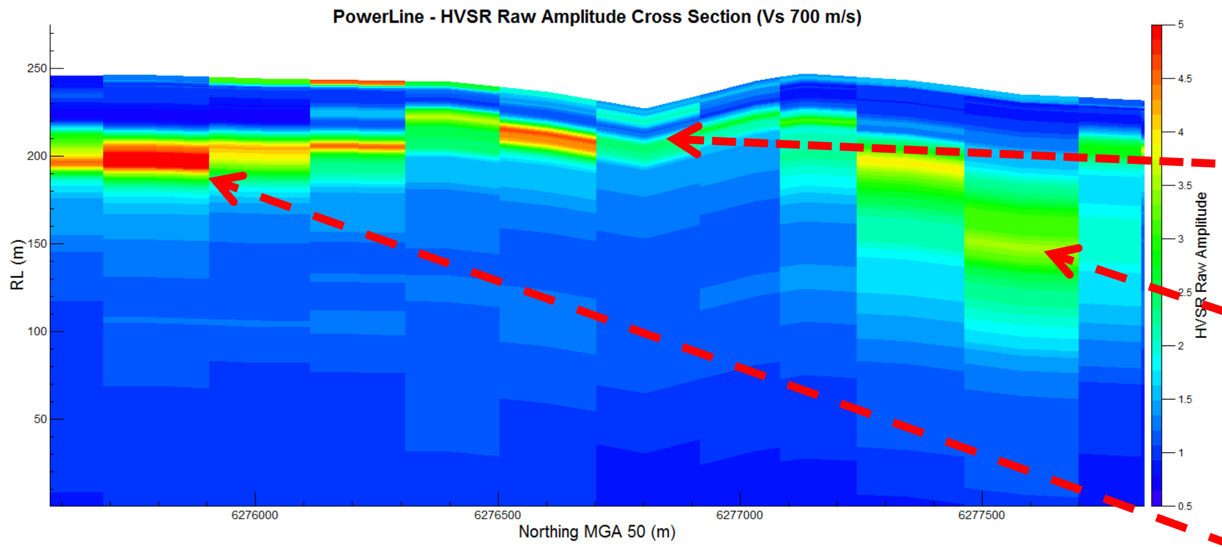


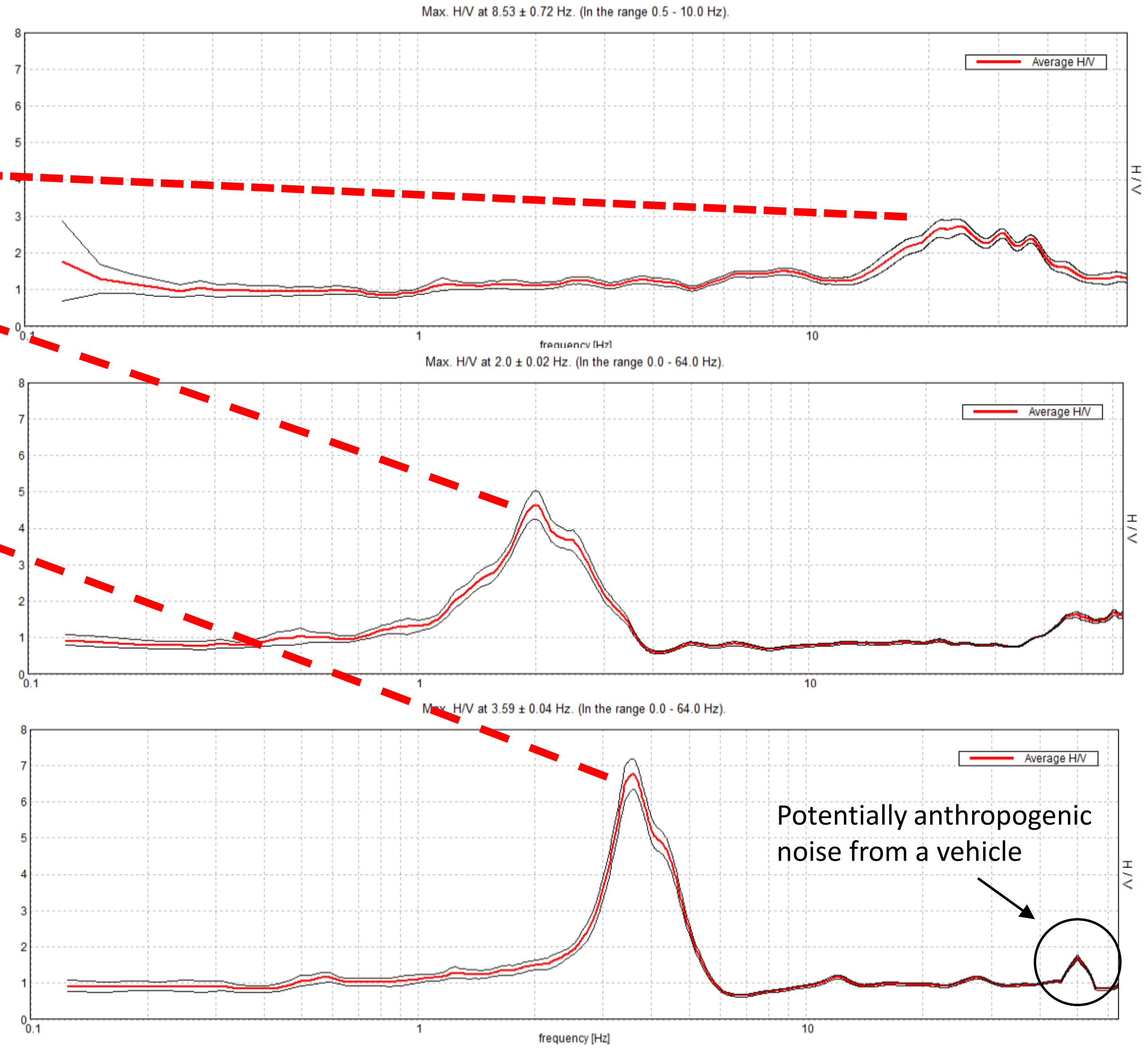
North Line



Data Observations – Powerline (Raw Amplitude)

Resource Potentials





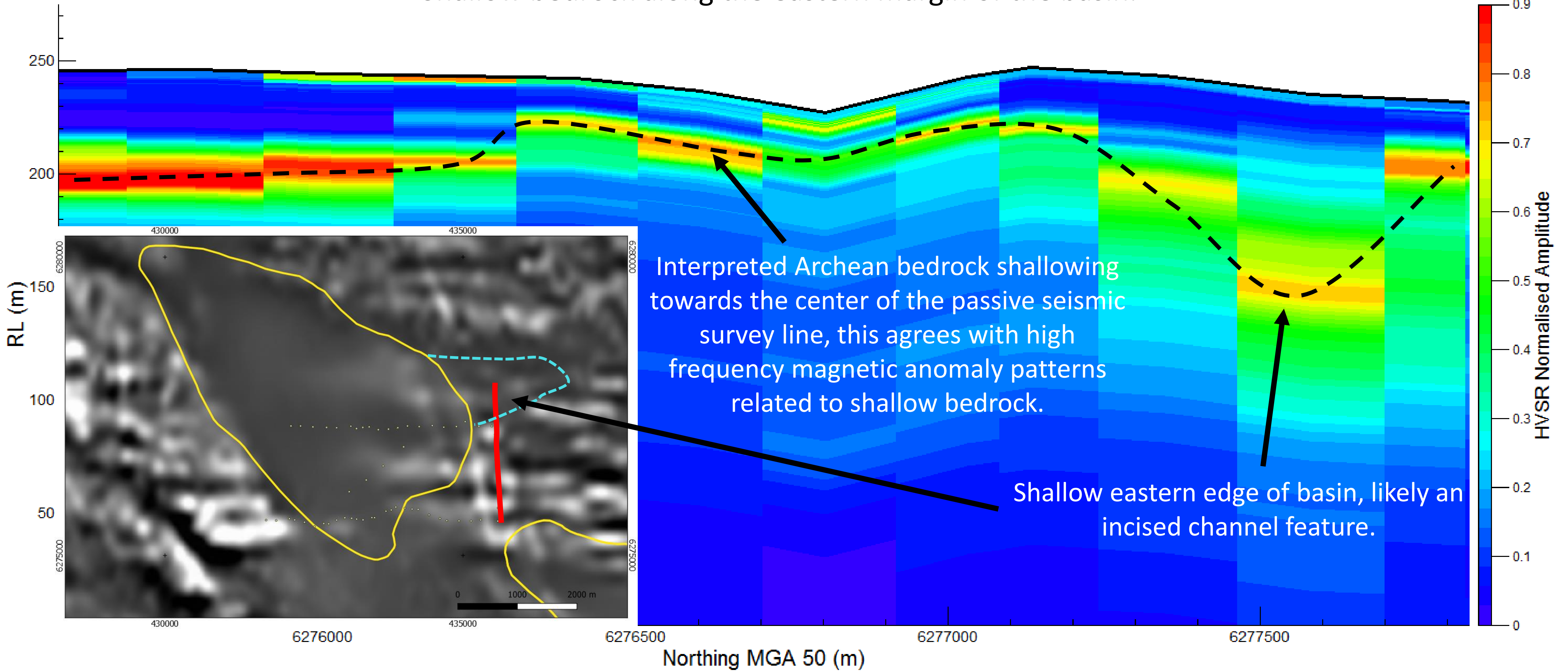
HVSR peaks in cross section view

- The change in amplitude of these HVSR peak frequency responses may be related to a different width of saprolite profiles over the fresh bedrock interface with a higher amplitude peak corresponding to a narrower saprolite weathered profile.

Data Observations – Powerline (Normalised Amplitude)

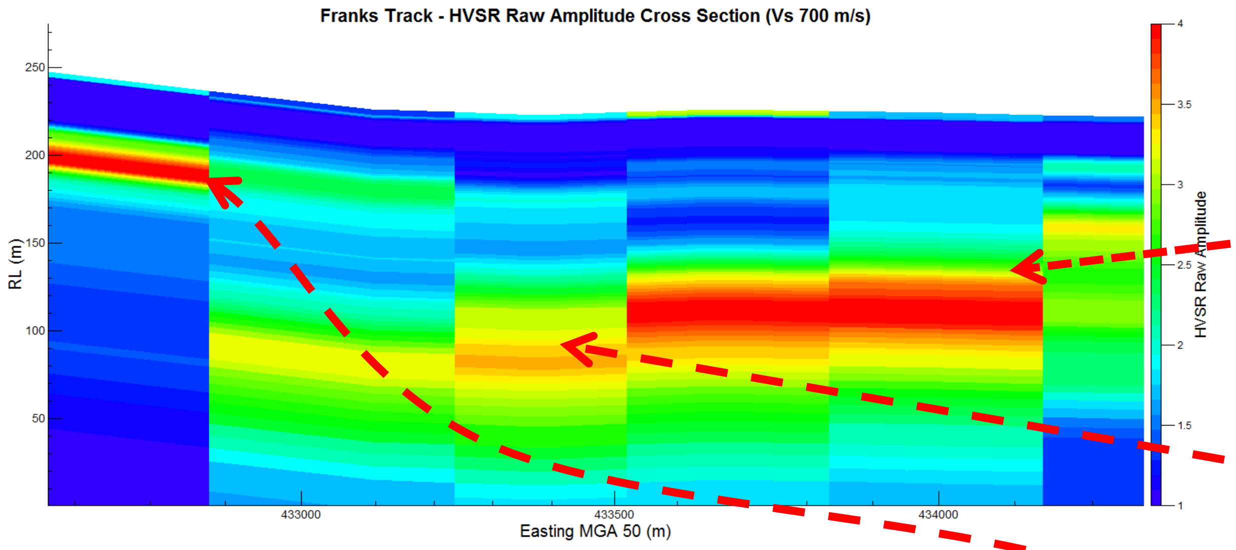
Resource Potentials

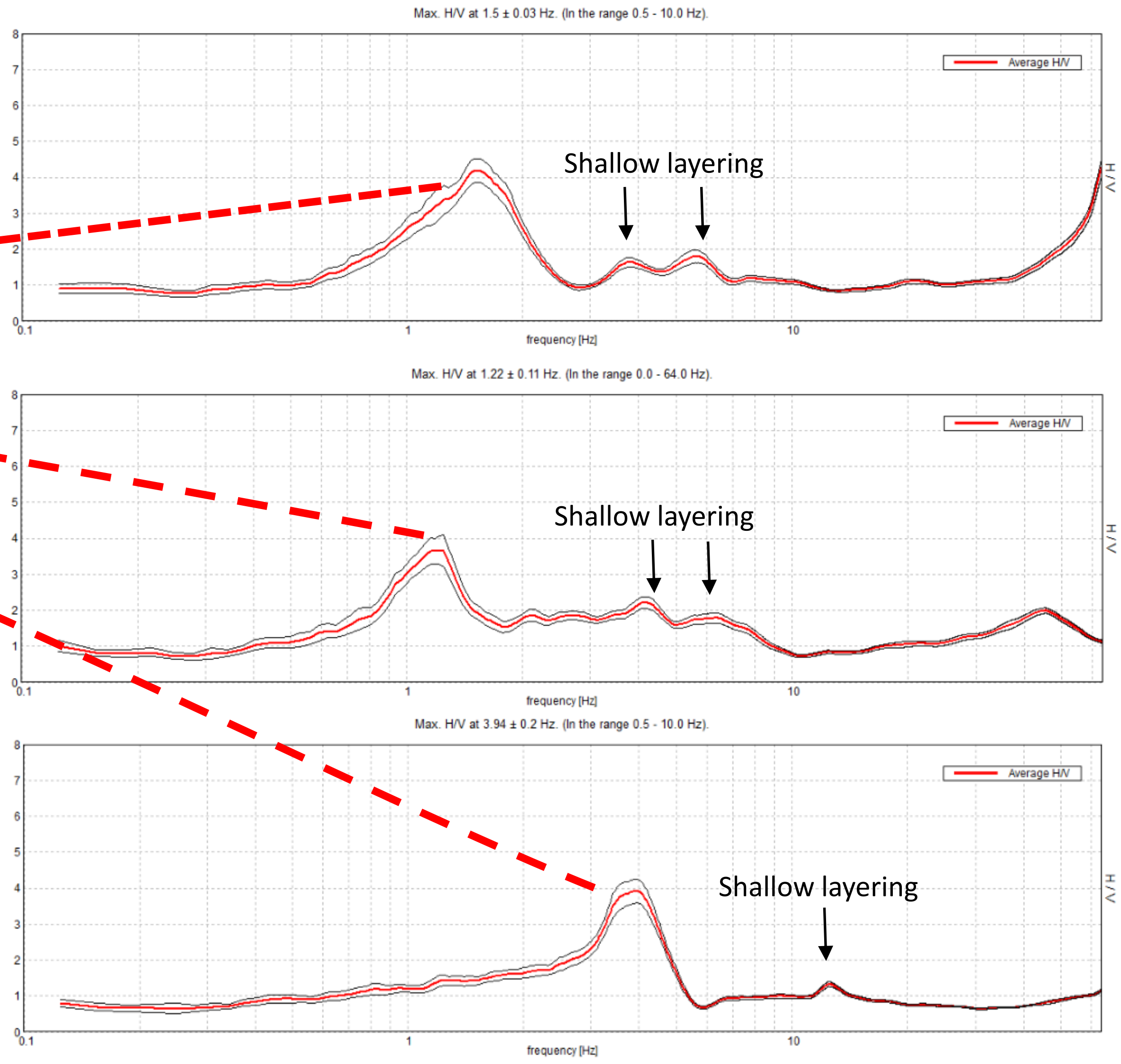
Shallow bedrock along the eastern margin of the basin.



Data Observations – Frank’s Track (Raw Amplitude)

Resource Potentials



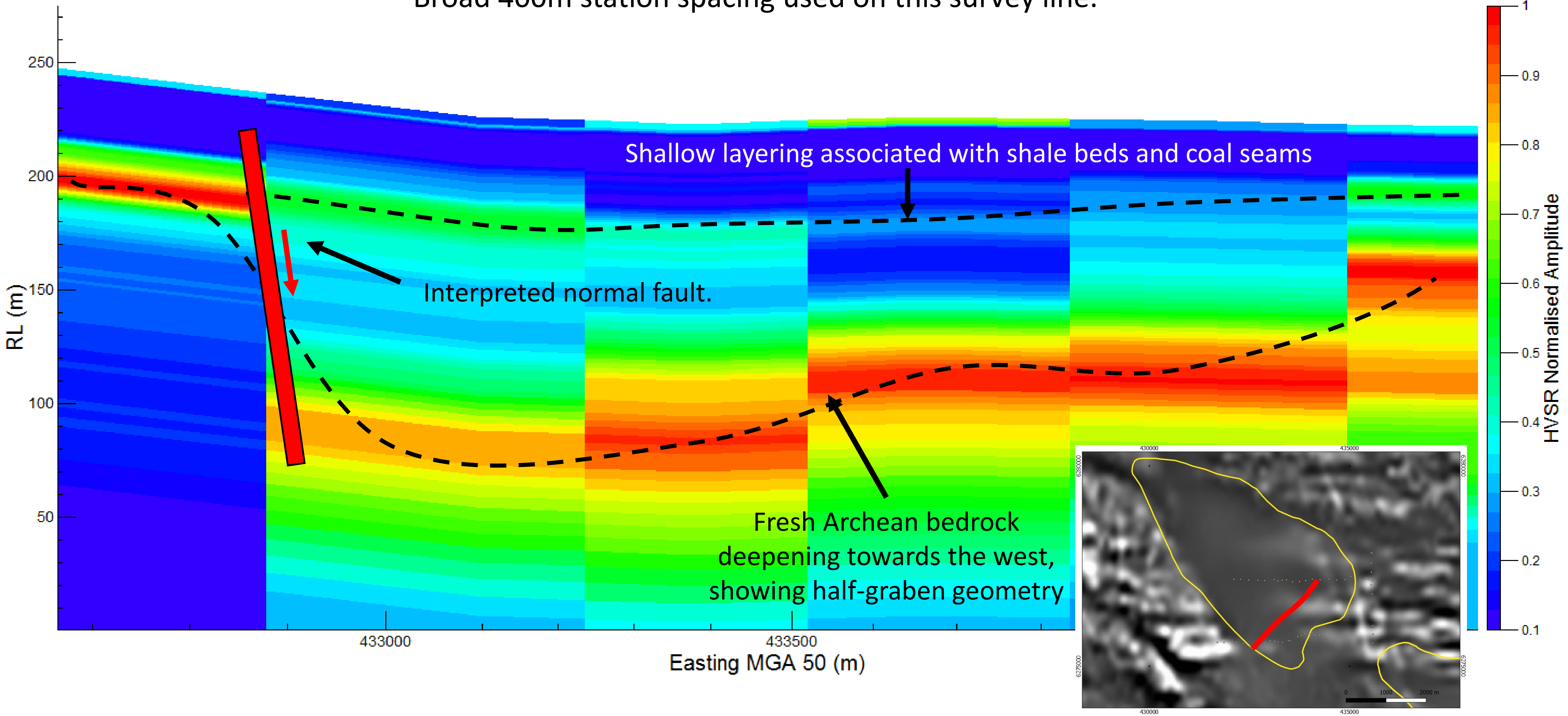


HVSR peaks in cross section view

- Several small HVSR peaks responses likely caused by shallow layers sitting above the main bedrock acoustic impedance

Data Observations – Frank's Track (Normalised Amplitude)

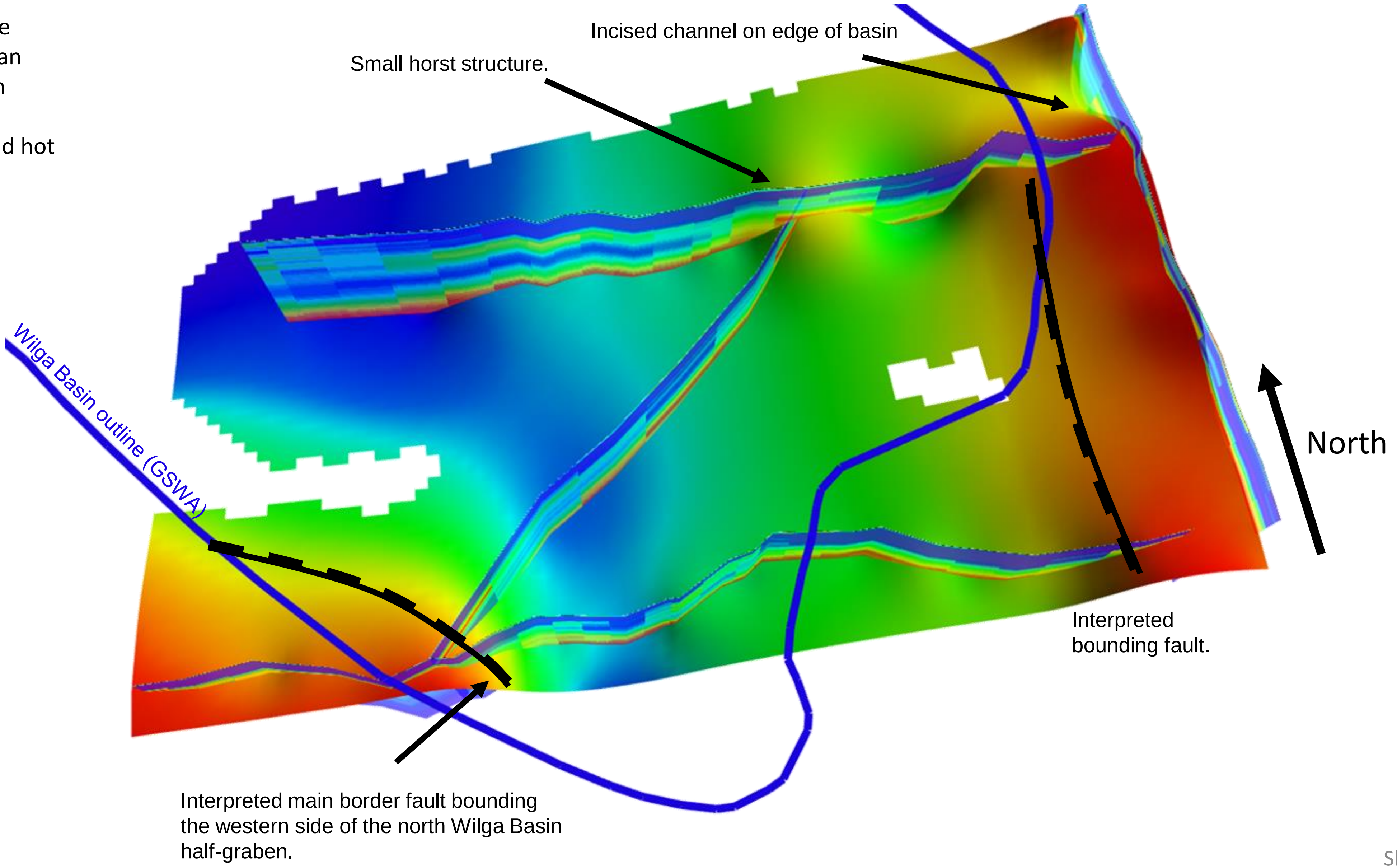
Broad 400m station spacing used on this survey line.



HVSR Passive Seismic Data Review

Resource Potentials

- 3D fence diagram of passive seismic cross sections and an interpolated bedrock depth surface, with cool colours indicating greater depth and hot colours indicating shallow bedrock.



Concluding Remarks

Resource Potentials

- The HVSR passive seismic survey method cannot detect layering below the first major acoustic impedance contrast from well lithified and thick rock units, in this case granite-gneiss bedrock as acoustic basement. Therefore, this method will not work in most coal basins where sedimentary layers sitting above the coal horizon are well lithified, and where the bedrock to the basin is greater than 1km.
- HVSR passive seismic data acquisition is a very easy, small and lightweight, non-invasive surveying technique that requires no active seismic source.
- HVSR passive seismic surveying is a rapid and cost effective method for initial studies of coal basin geometry and stratigraphy, and has further applications for delineating the location of non-magnetic intrusive bodies that cross-cut coal bearing horizons.
- The HVSR method has been shown to detect fresh bedrock to a depth of over 700m in this presentation, and greater depths have been achieved from other case studies which are confidential at present.
- Resource Potentials have carried out some trial HVSR surveys in other coal basins, where negative acoustic impedance contrast layers have been calibrated against drilling information and seismic reflection data to correlate to coal bearing horizons at depths of up to 400m, and more trial surveys are required to test the effectiveness of this technology, so please contact me to discuss carrying out trial surveys in your coal basin.