Passive seismic HVSR surveying for groundwater exploration in the West Musgraves, Western Australia

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Resource Potentials

Special thanks to Ciara Doherty and Erin Western

BHP

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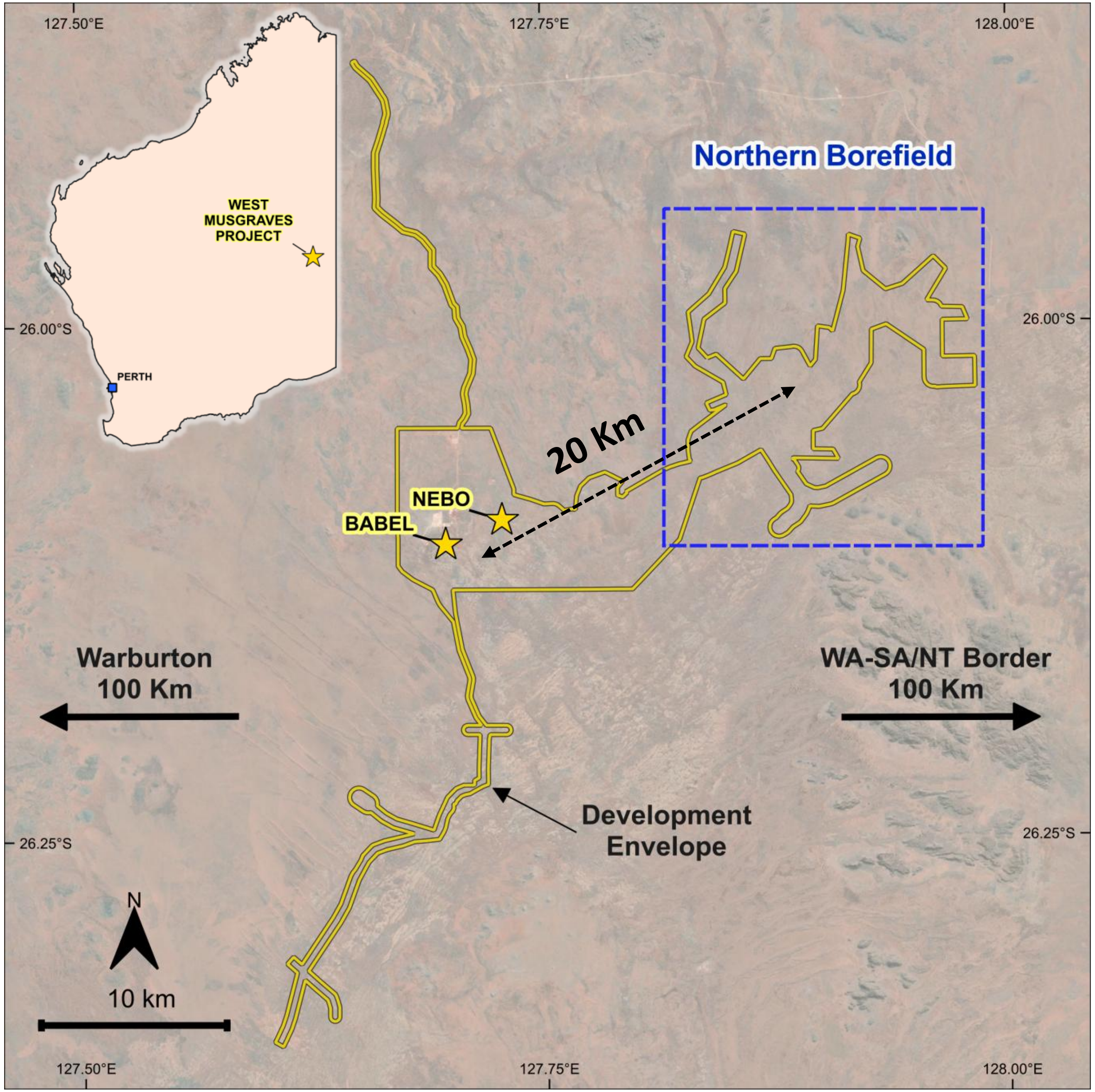
Introduction

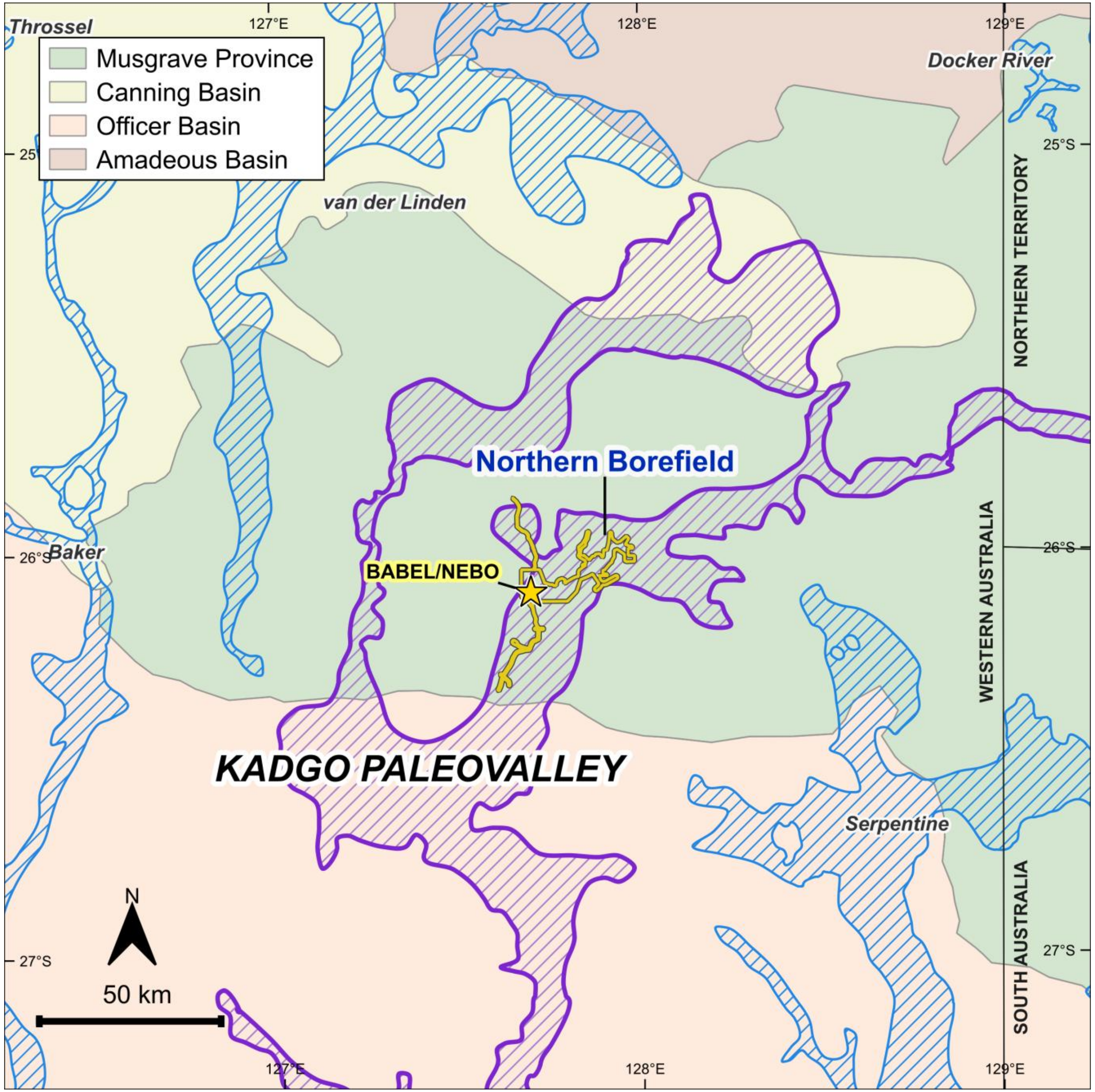
- West Musgrave Project hosts the Babel and Nebo Ni-Cu-PGE deposits, located approximately 1300 km NE of Perth.
- Discovered by WMC in 2000, hosted in Proterozoic Giles Complex intrusions.
- Currently owned and operated by BHP after acquiring Oz Minerals in May 2023.
- Mineral resource estimate of 390 Mt @ 0.3% Ni and 0.33% Cu (as of September 2022).
- Expected mine life of 26 years @ 10-12 Mtpa.
- Total water requirement of 7.5 GL/a to be sourced from local aquifers.
- Detailed hydrogeological studies required to develop a process/potable groundwater supply borefield.
- This study focuses on the Northern Borefield, located 20 km to the NE of the Babel and Nebo deposits.

Note that the West Musgrave project has been under temporary suspension since October 2024 due to oversupply in the global nickel market.



Geological Setting

- Situated within the Mesoproterozoic Musgrave Province in WA.
- Paleochannels incised into Mesoproterozoic bedrock following the Alice Springs Orogeny, erosion started at around 300 Ma (Permian) where subsequent glacial valleys and glacial outwash eroded into the Proterozoic bedrock.
- Paleovalleys are now mostly filled with Cainozoic alluvial sands, silts and clays, and more recently aeolian dune sand and alluvial fan cover deposits. May also contain Permian gravels and till at the base.
- Paleovalley geometry has been affected by continental-scale uplift, tilting and localised neotectonic faulting during the Cainozoic.
- Northern Borefield located within the upper part of the Kadgo Paleovalley, which drains into the Officer Basin to the south.
- Therefore, the main large-scale groundwater targets are sand and gravel aquifer layers located at the bottom of large paleochannel systems linked to large catchment areas.



Paleovalley outline sourced from the WASANT Palaeovalley Map by Bell et al. (2012)

Magnetics

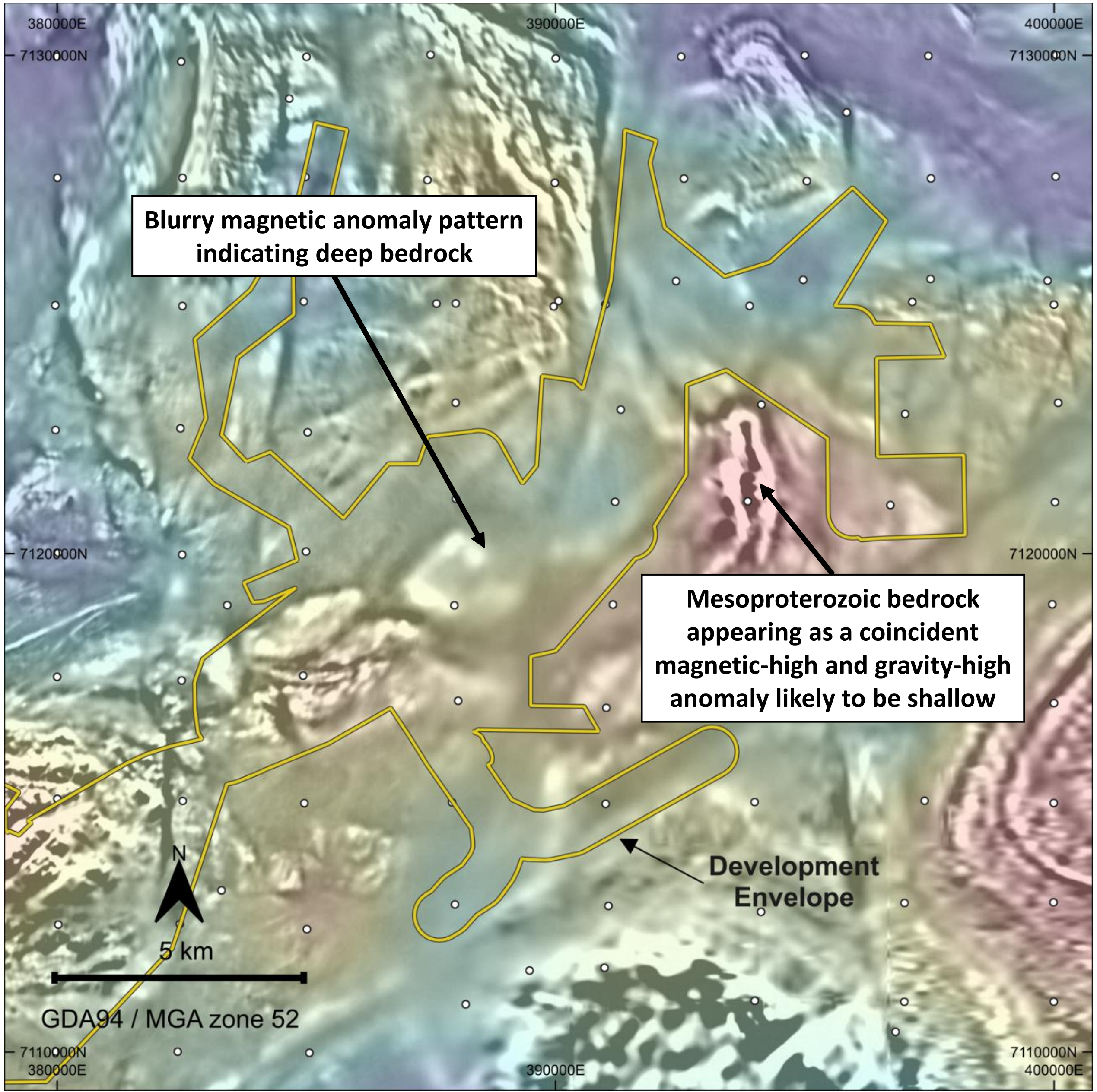
- Northern Borefield predominantly covered by 100 m to 200 m line-spaced airborne magnetic and radiometric survey datasets.
- Magnetic data show long wavelength anomaly patterns associated with magnetic crystalline bedrock buried under non-magnetic sedimentary cover, causing a “blurry” magnetic anomaly pattern.

Gravity

- Statewide gravity dataset consists of regional 2.5 km x 2.5 km ground gravity survey stations (white dots).
- Broad-spaced gravity data show coincident and broad-scale low-density zones related to thick accumulations of low-density sedimentary deposits.

Both potential field survey methods are qualitatively used to estimate the approximate location and geometry of buried paleochannels, but this interpretation is ambiguous for defining detailed bedrock geometry and depth required for planning groundwater exploration drillholes.

Filtered gravity (pseudocolour) over filtered magnetics (greyscale)



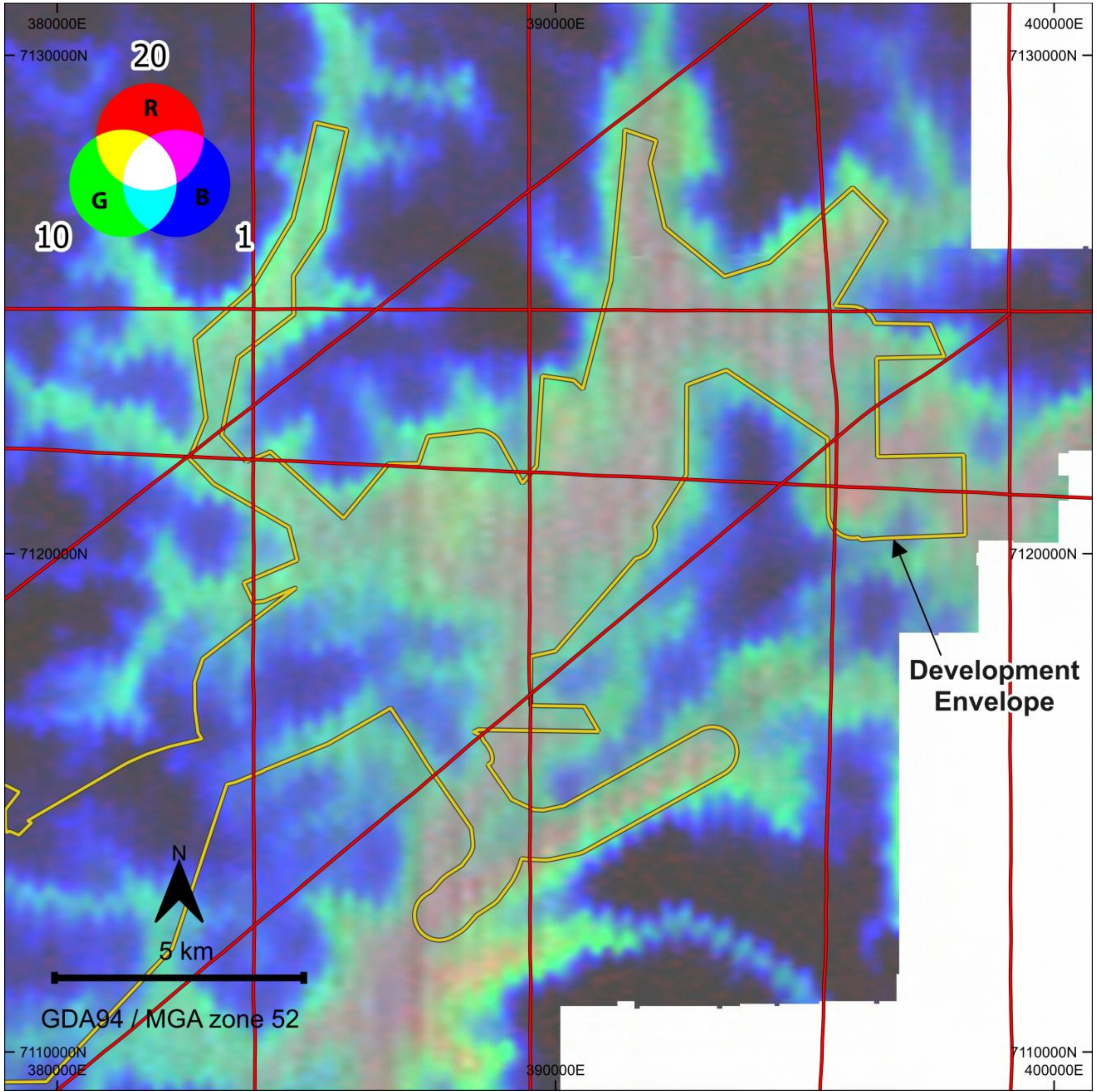
Existing Open-File Geophysical Survey Datasets

Resource Potentials

Airborne Electromagnetics (AEM)

- Northern Borefield covered by N-S orientated and 200 m line-spaced AEM flown using the GEOTEM system in 2002.
- AusAEM surveyed wide-spaced 5 km AEM survey lines N-S and E-W (red lines on map) in 2022 using the TEMPEST system.
- Ternary image of Z-component GEOTEM data shows paleovalley geometry represented by the transition from weaker and shallower EM conductors in blue-green, to deeper and stronger EM conductors in red, such as clay-rich sediments and saline groundwater at depth.
- Paleochannel geometry appears dendritic in early-time EM decay channels, but EM anomalies become more linear in late-time EM decay channels because erosion and incision followed soft bedrock units, faults, mafic dykes, etc.
- AEM detects and maps out the paleochannel system at a broad to detailed scale, but inversion of AEM data can underestimate the true sedimentary cover thickness and bedrock geometry due to the wide footprint of AEM systems and uncertainty with inversion modelling algorithms.

GEOTEM ternary Z dB/dt time-decay EM channel image with AusAEM flight lines



Why do Passive Seismic HVSR Surveying if you have AEM?

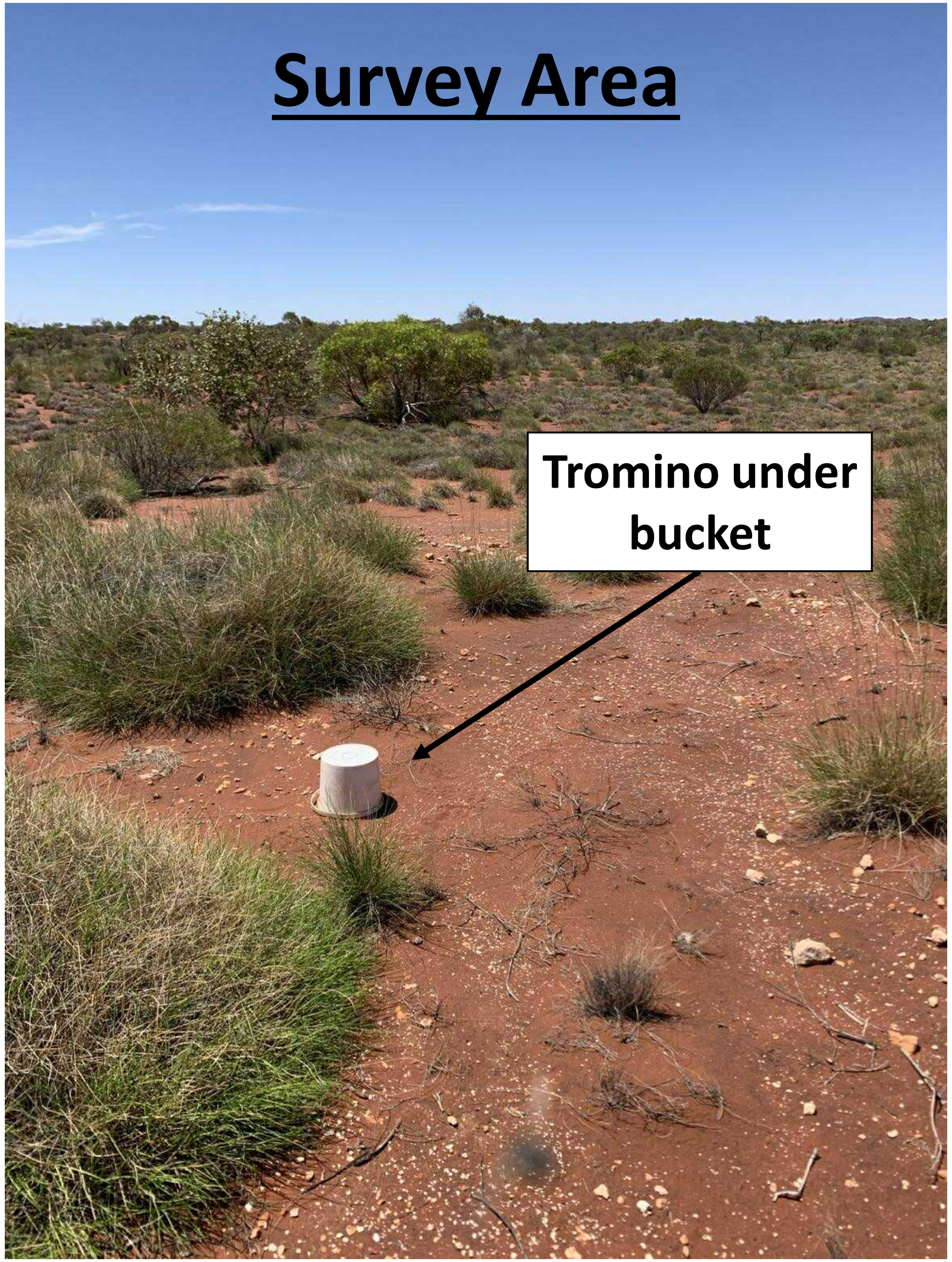
Resource Potentials

- Main aquifers are associated with Cainozoic sediments filling paleochannels incised into Proterozoic bedrock - **need accurate bedrock topography for targeting thalweg zones and other coarse clastic target zones, such as the base of fault scarps, potentially hosting large groundwater supplies.**

Main advantages:

1. Simple and rapid, no-impact survey method for detecting the strong impedance contrast produced at the regolith to fresh bedrock interface.
2. Fresh bedrock depth calculated from peak resonance frequency produces clear images of bedrock topography along survey lines, especially deep thalweg zones.
3. Reliable seismic method for detecting steep-sided acoustic bedrock using tight station spacings, such as fault scarps, erosional scarps and U-shaped valleys.
4. Cheap to acquire, simple data processing and provides instant results within 24 hours.
5. Can also detect shallow layering within the regolith cover.

- Great follow-up tool to AEM interpretations of paleochannel targets for groundwater, with drilling planned along HVSR survey transects to reduce risk.

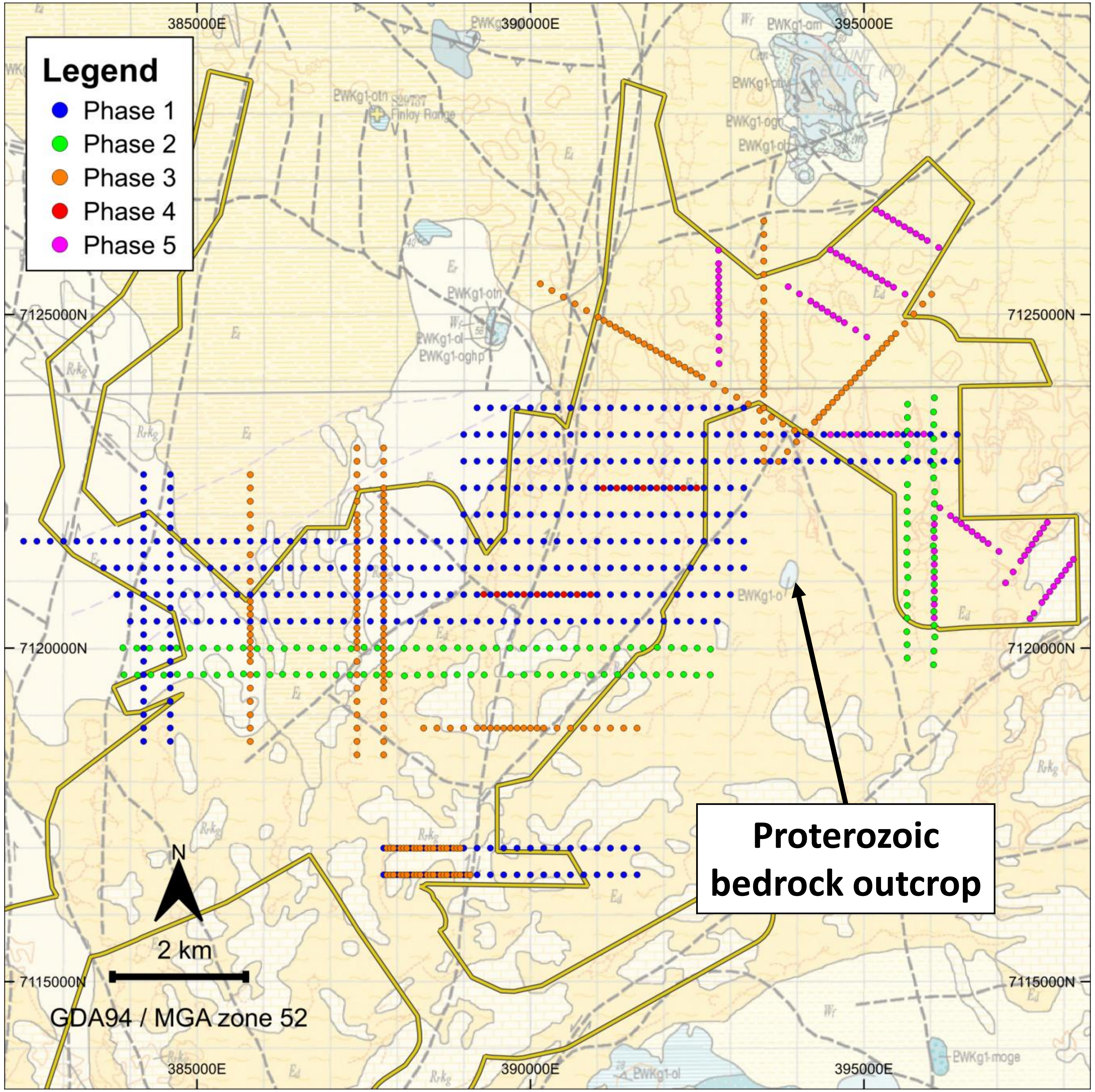


HVSR Survey Specifications

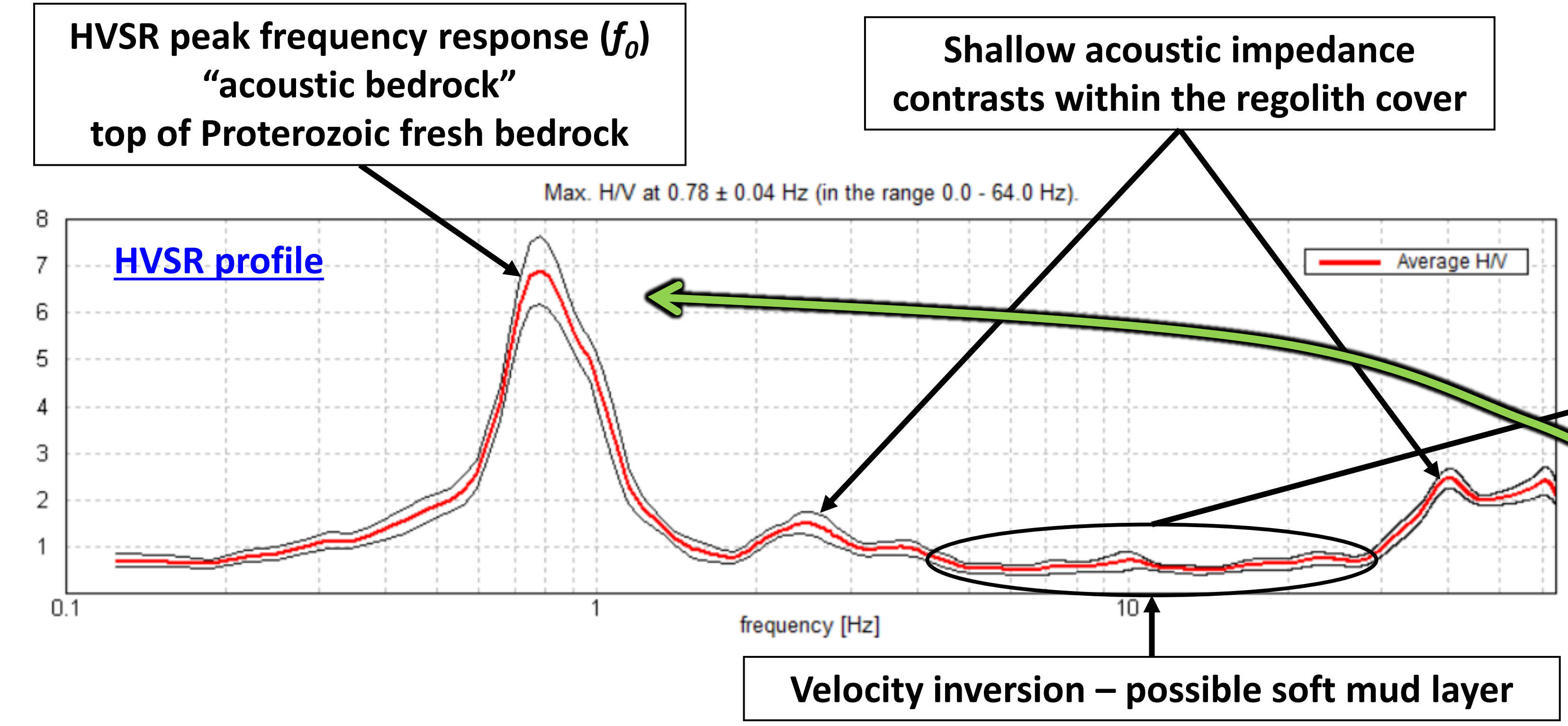
- 5 HVSR survey phases between 2018 to 2023 for initial reconnaissance and then infilling wide-spaced transects and improve the subsurface mapping of the Kadgo Paleovalley.
- A total of 880 stations acquired using 50 m to 200 m station spacing, data coverage allowed for gridding of bedrock topography.
- A total of 31 survey lines totalling 143.4 survey line-kms.
- Acquired with Tromino TEB and TE3 seismometers.
- 20-minute recording time.
- 128 Hz sample rate.
- Trominos covered by sturdy plastic buckets during acquisition to reduce wind noise.

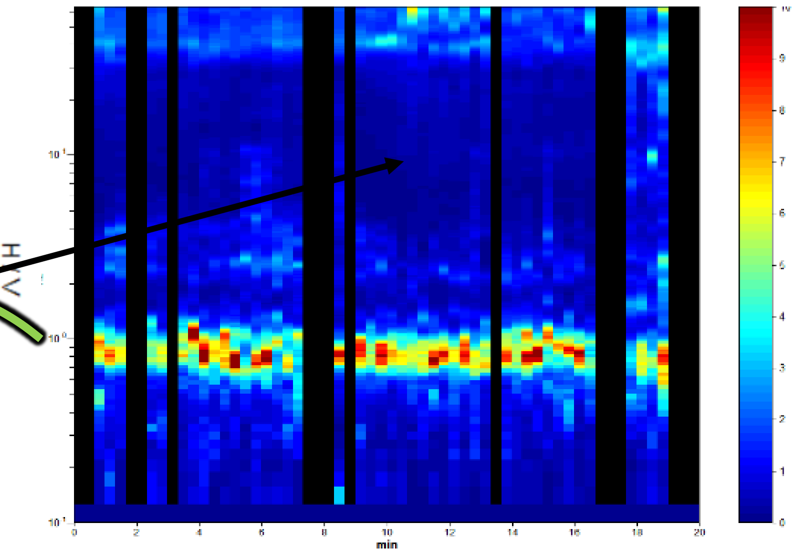
Based on the theory by Nakamura (1989 and 2000).

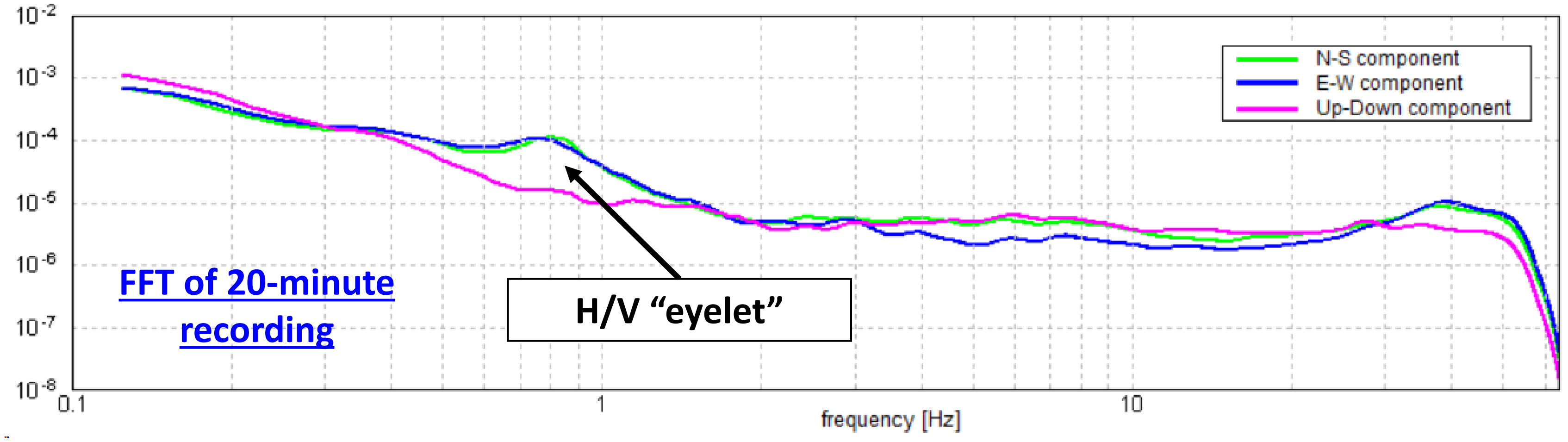
Tromino TEB seismometer

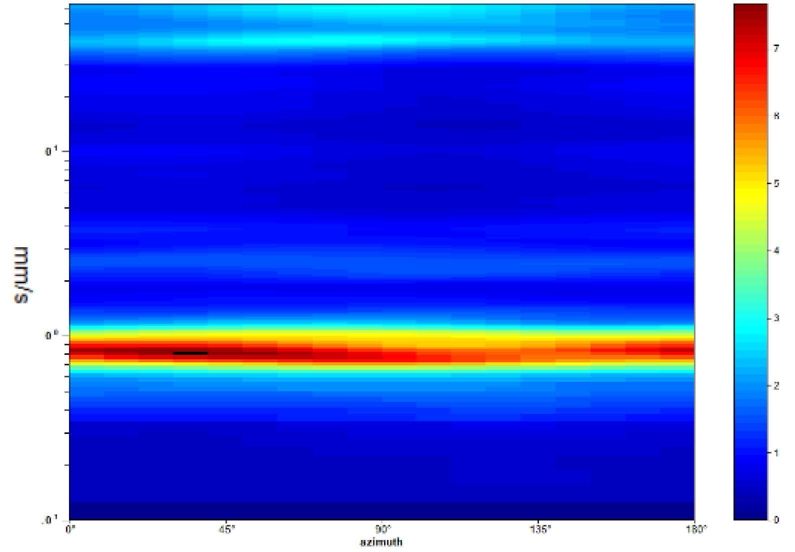


Example HVSR Profile from a Single Station Recording

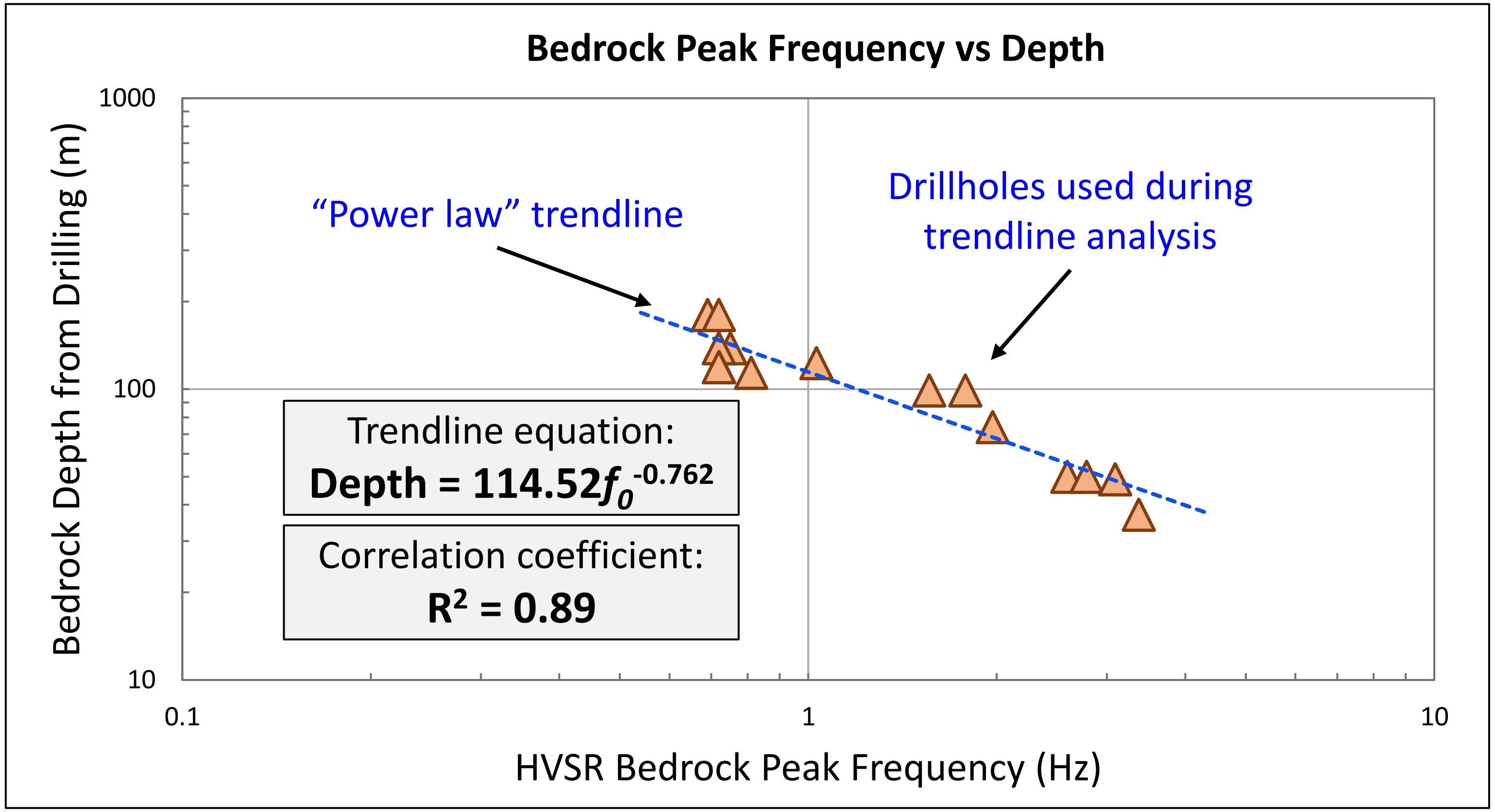




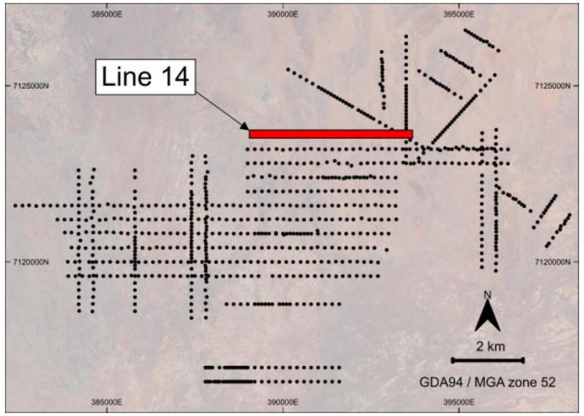


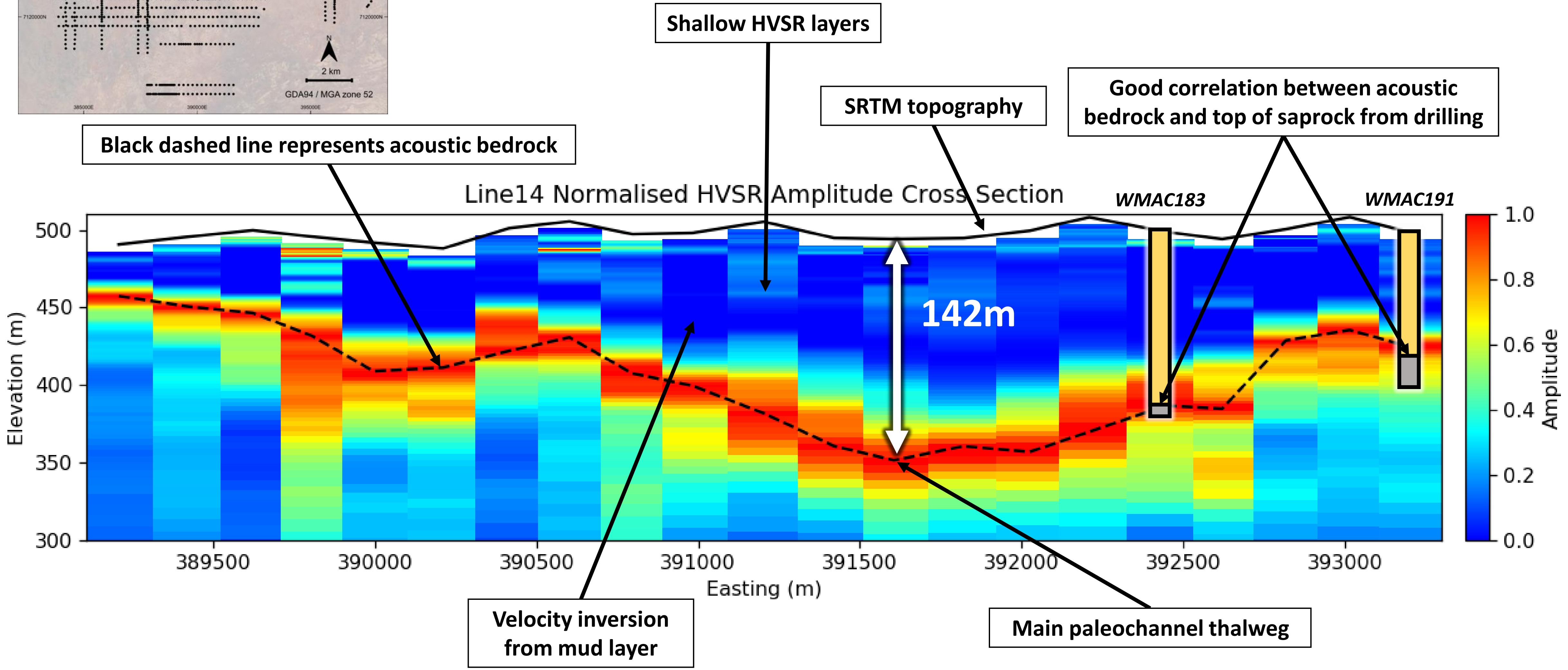


- HVSR bedrock peak frequency (***f_0***) data were compared to logged depths of hard bedrock and saprock at drillholes near HVSR recording stations.
- Cross-plotting of these datasets form a trendline with the equation: ***Depth = 114.52 $f_0^{-0.762}$*** *(correlation coefficient 0.9)*
- All HVSR data were converted to depth using this equation.
- Acoustic bedrock depth ranges between 21 m and 170 m across the survey area.

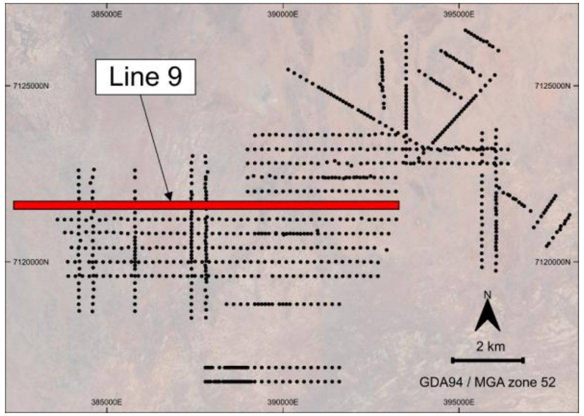


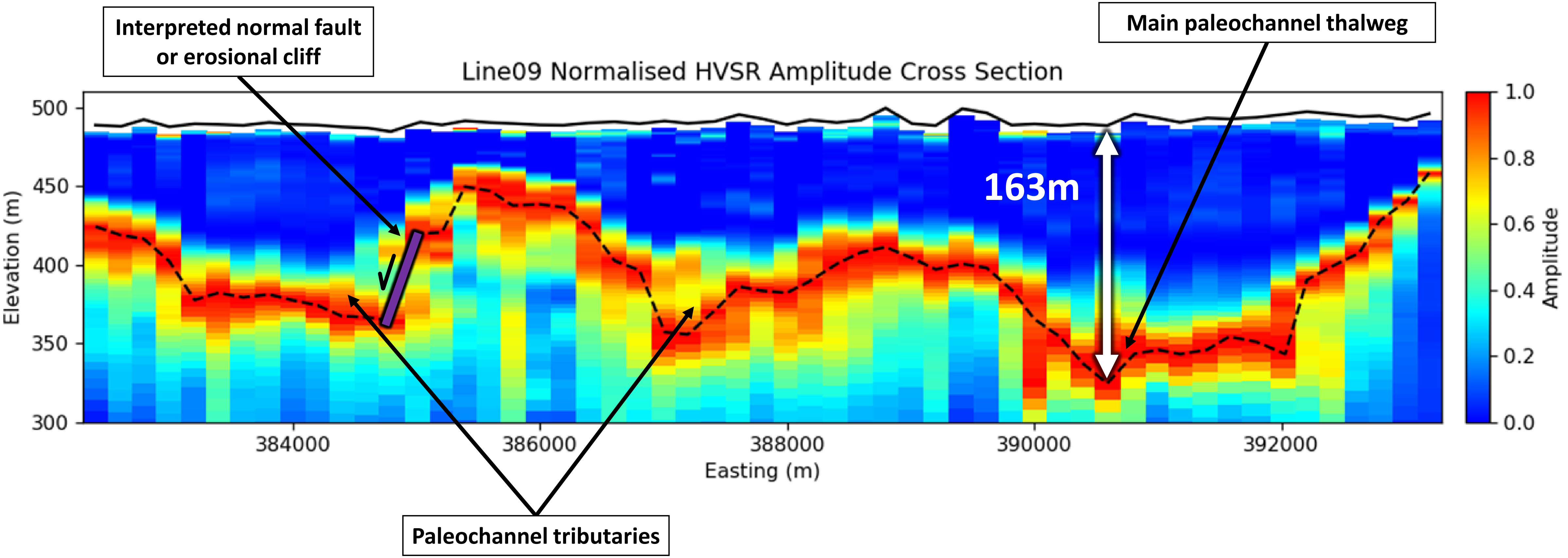
Example HVSR Cross Sections





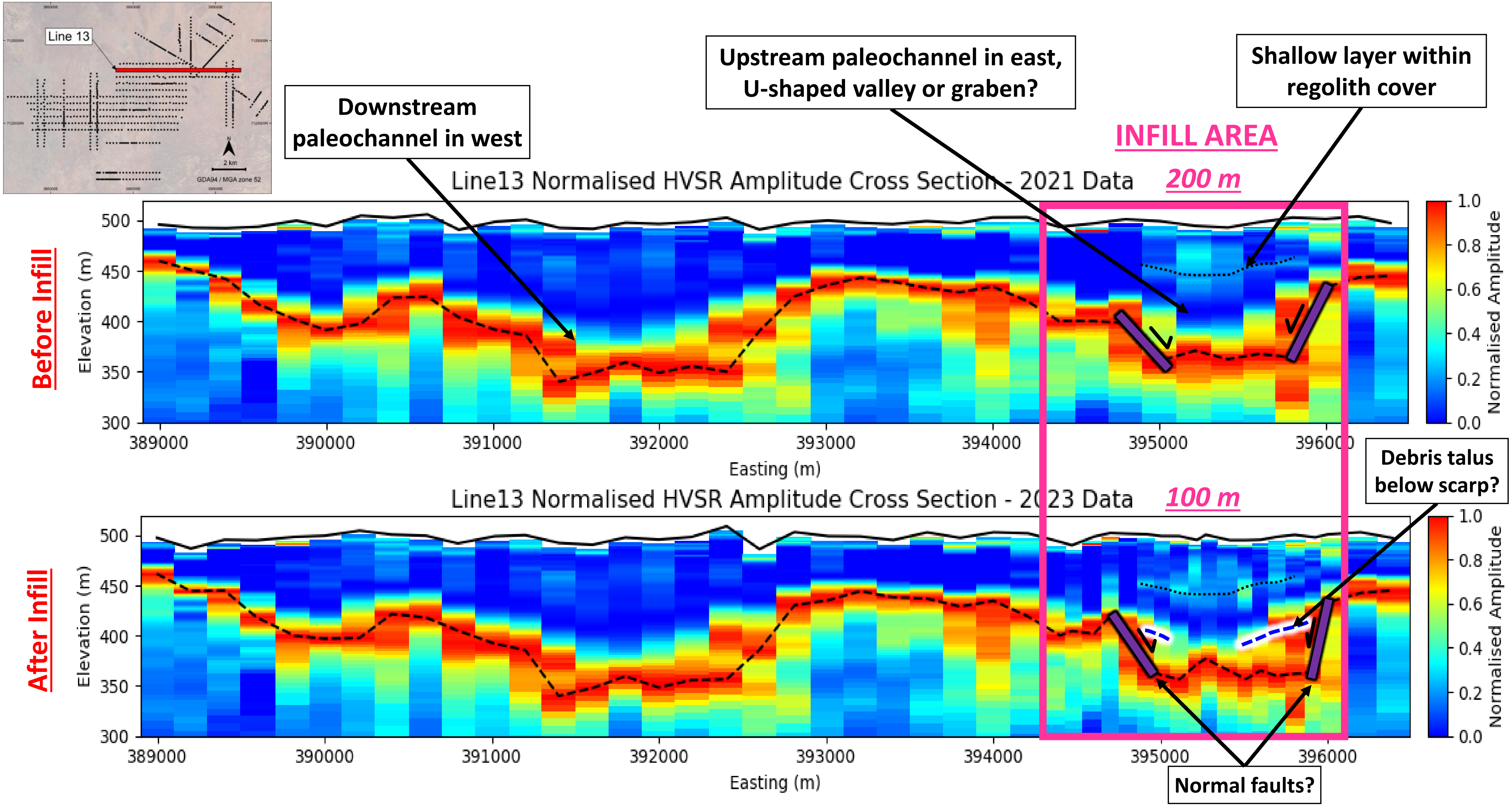
Example HVSR Cross Sections





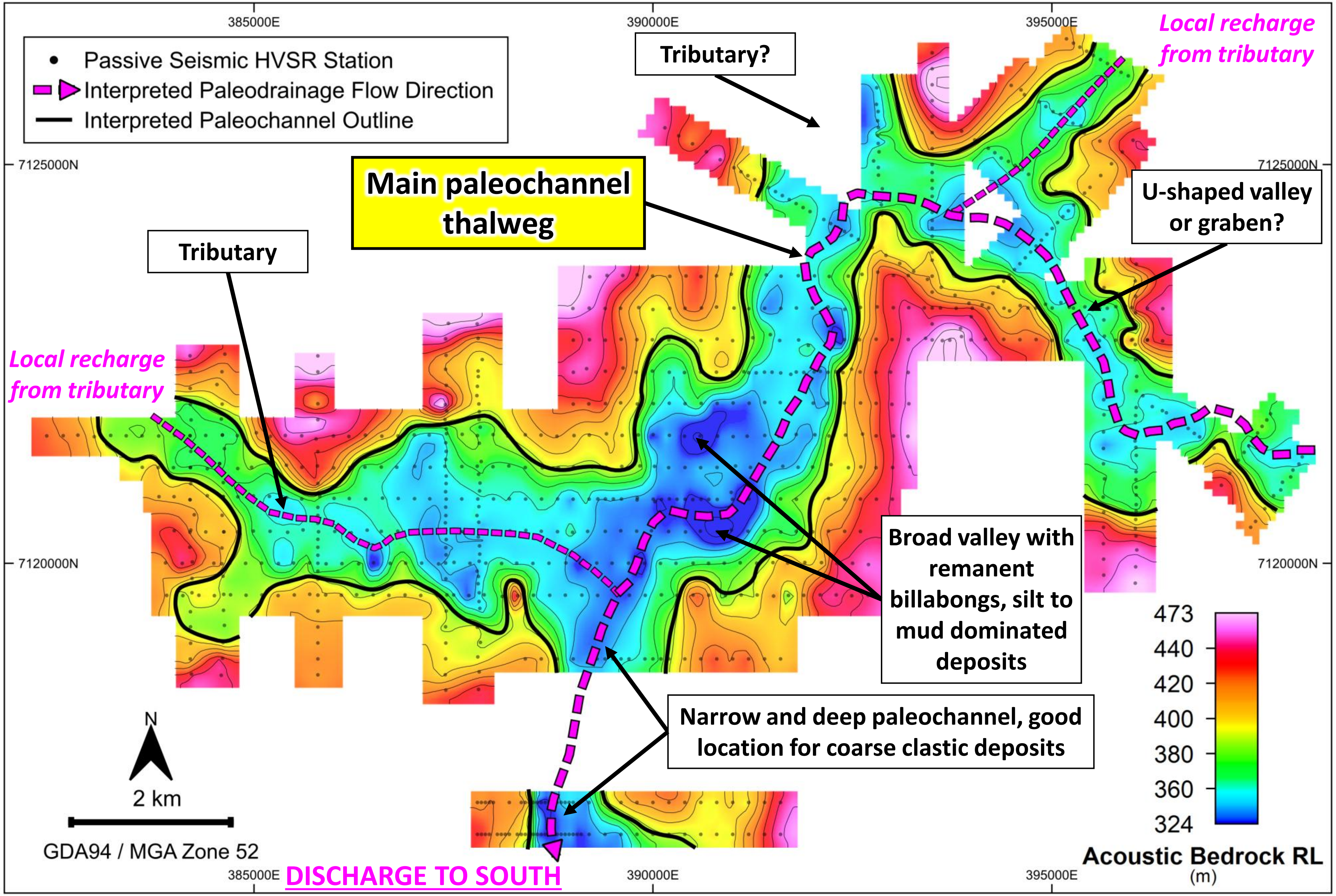
Example HVSR Cross Sections – Infill Survey Line for Improved Geometry

Resource Potentials



HVSR Bedrock Topography – Map View

Resource Potentials



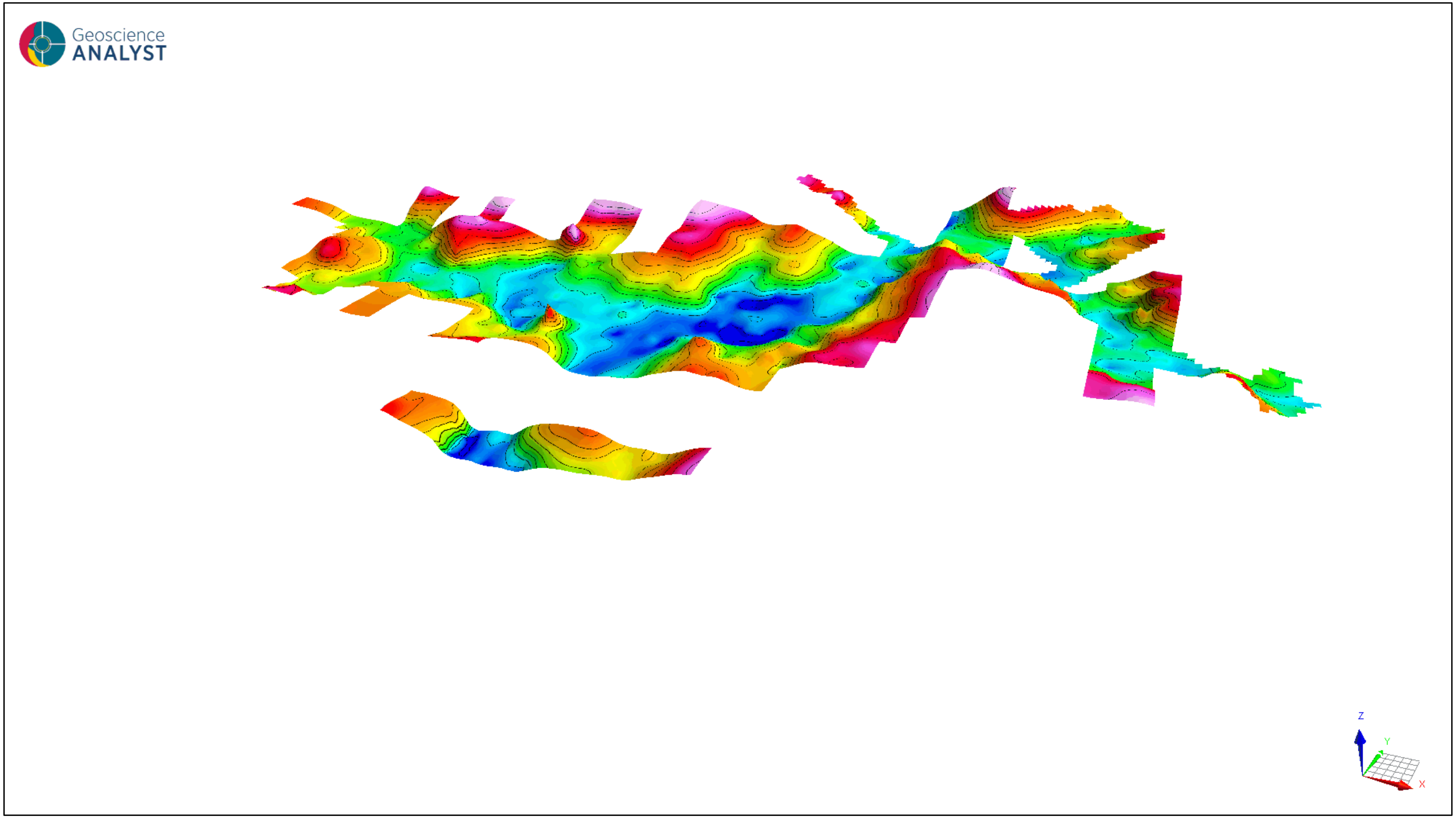
RECHARGE FROM EAST

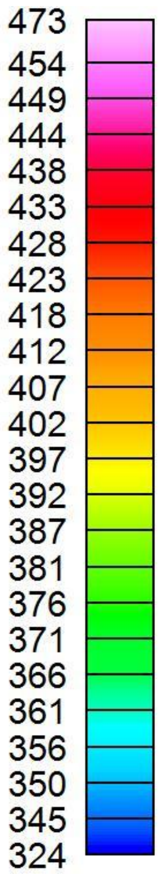
DISCHARGE TO SOUTH

HVSR Bedrock Topography – 3D View

Resource Potentials

Acoustic bedrock elevation surface



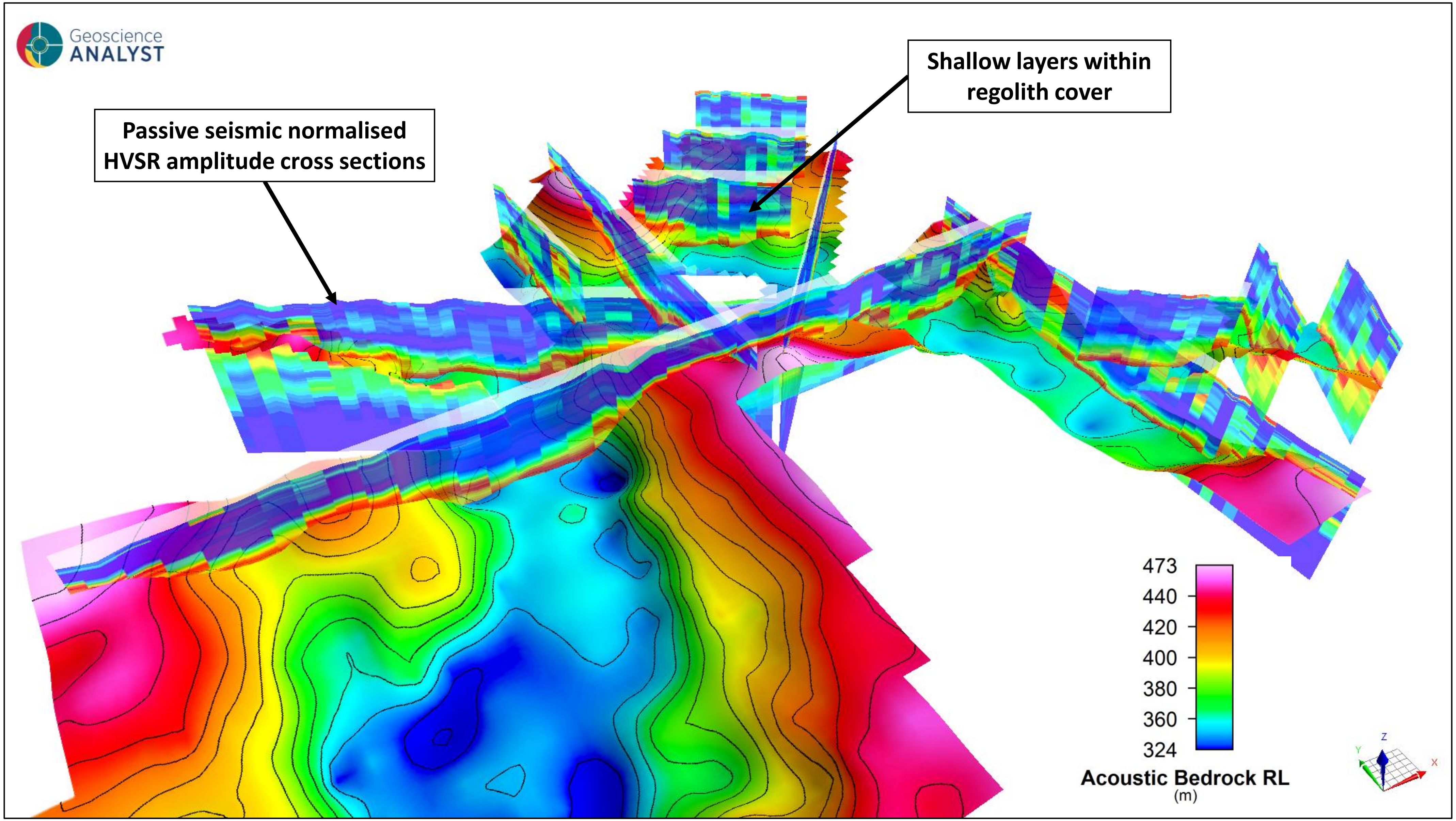


Acoustic Bedrock Elevation (m)

Vertically exaggerated 5x

HVSR Bedrock Topography – 3D View of NE Corner

Acoustic bedrock topography with HVSR cross sections along survey lines

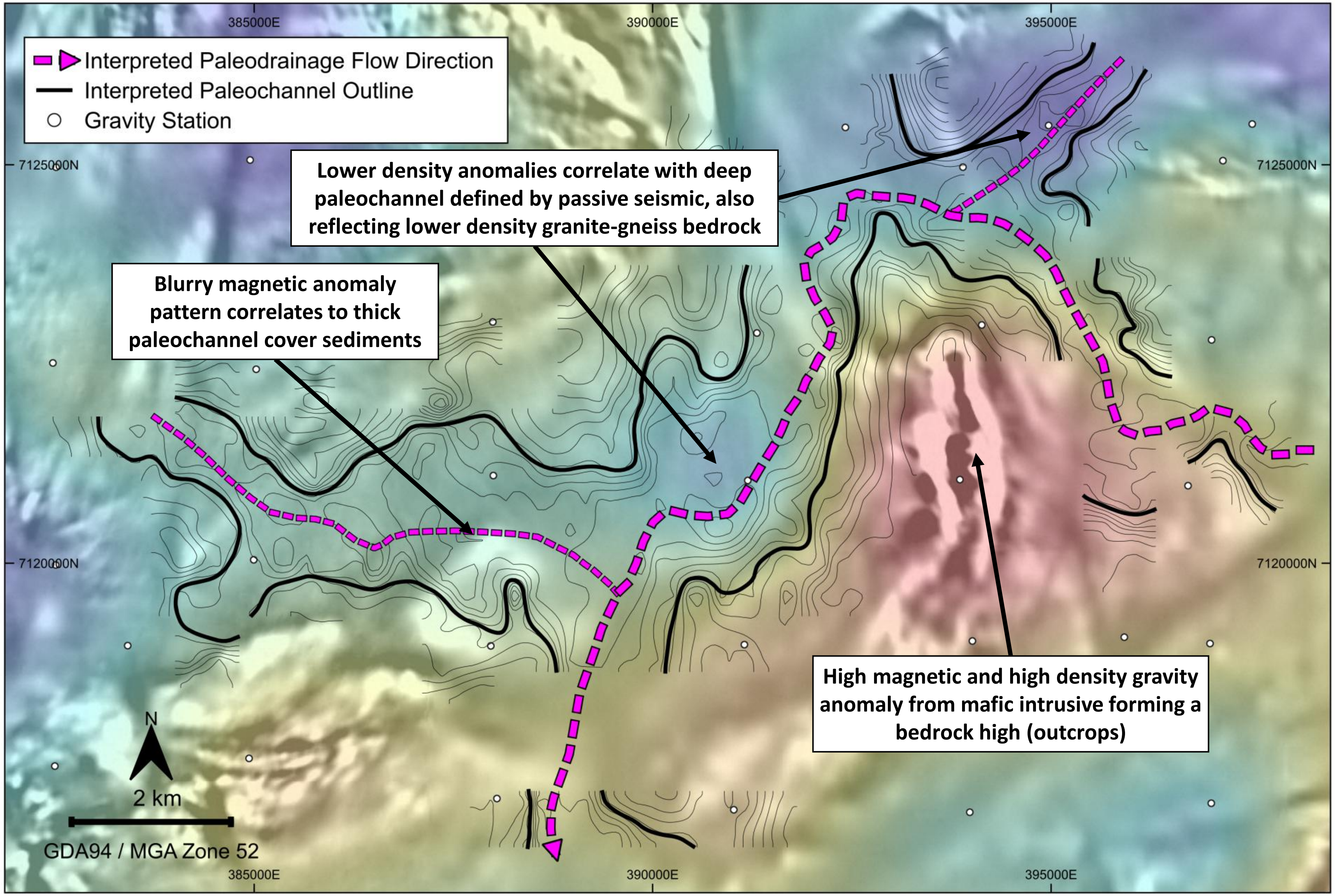


Vertically exaggerated 5x

HVSR Bedrock Contours Compared to Magnetics and Gravity

Resource Potentials

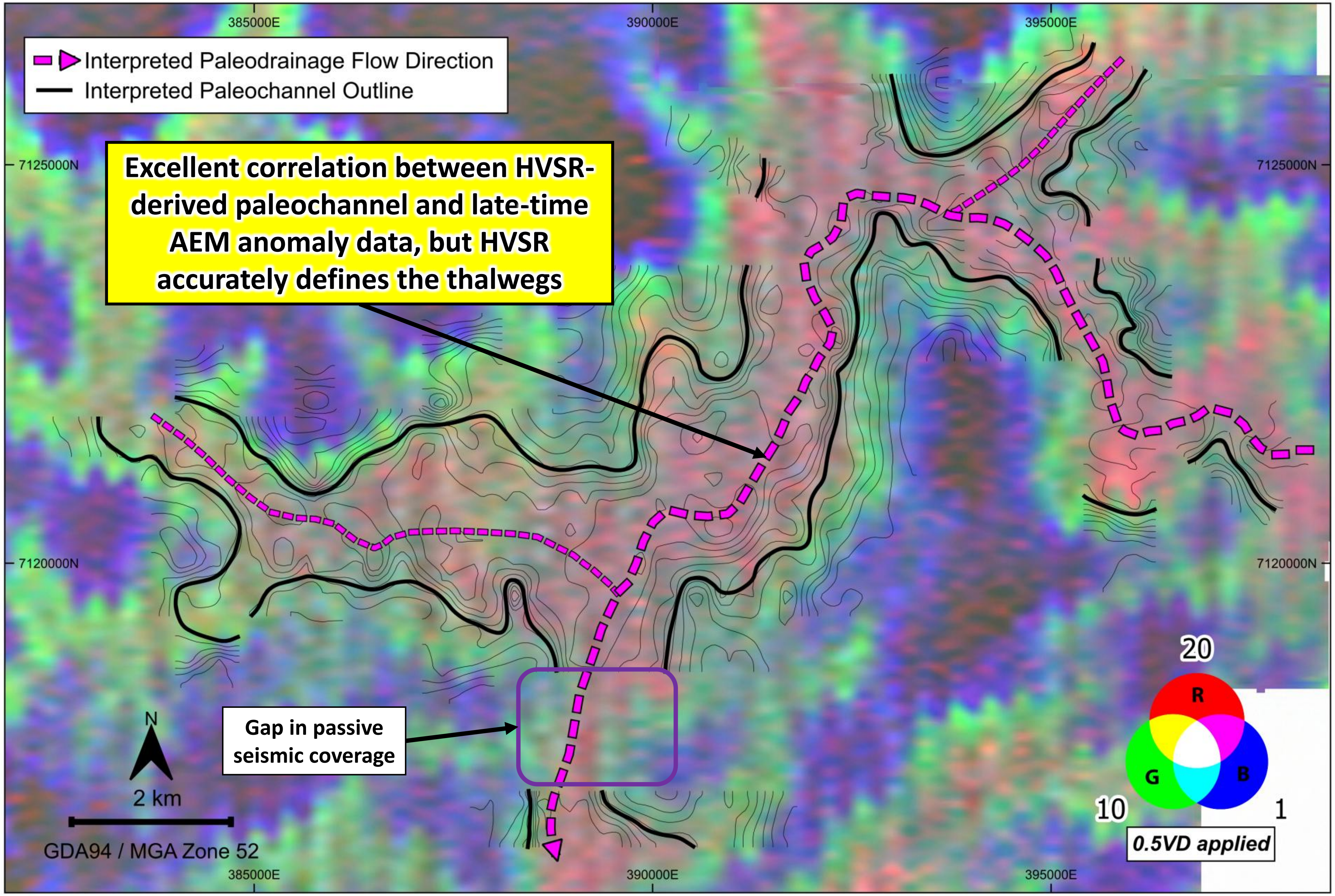
Acoustic bedrock elevation contours (10 m) over filtered gravity (pseudocolour) and filtered magnetics (greyscale)



HVSR Bedrock Contours Compared to AEM - GEOTEM

Resource Potentials

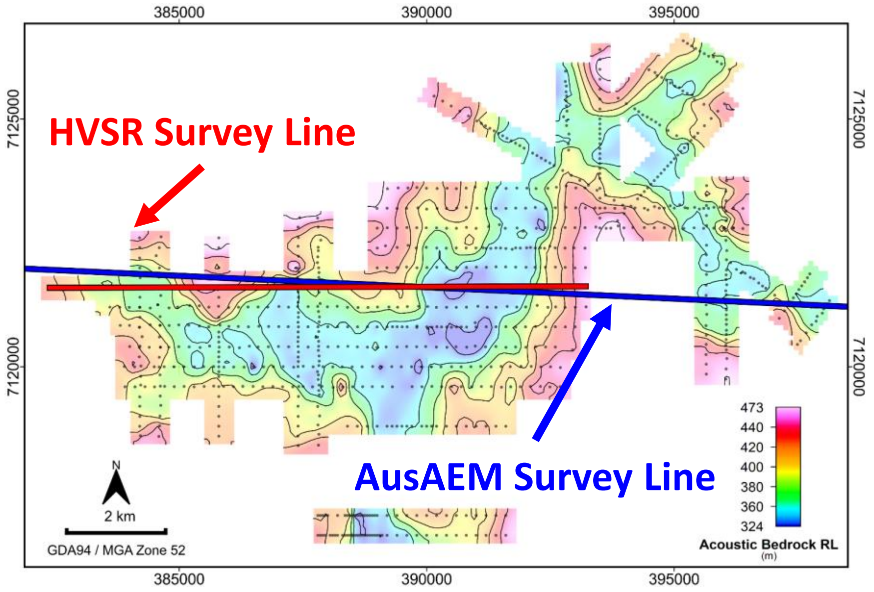
Acoustic bedrock elevation contours (10 m) over filtered GEOTEM ternary Z dB/dt time-decay EM image



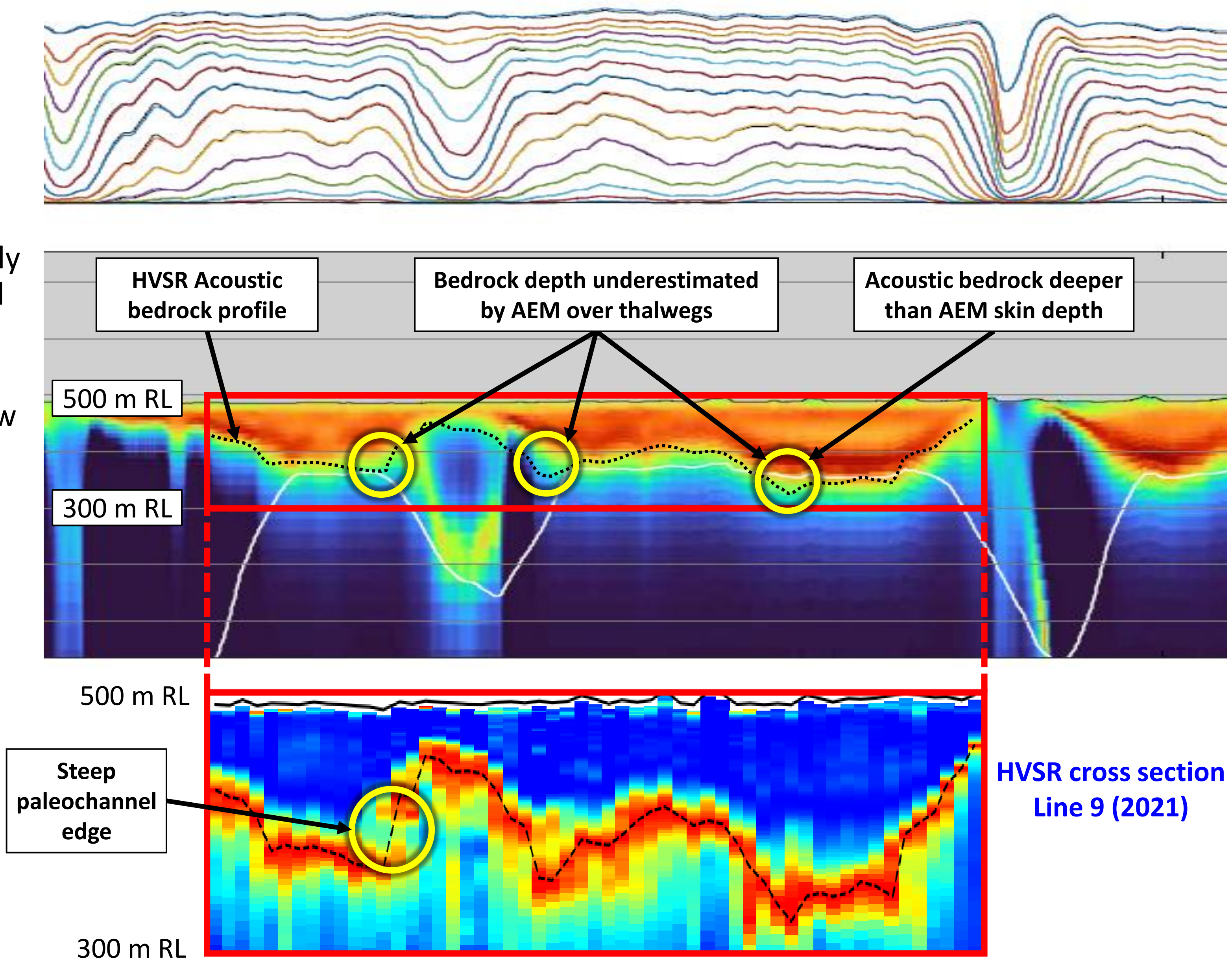
HVSR Results Compared to AEM - AusAEM

Resource Potentials

- Acoustic bedrock derived from HVSR data generally correlates with the base of the regolith conductor from 1D inversion of AusAEM TEMPEST data.
- The base of AEM regolith conductor is underestimated over deeper HVSR acoustic bedrock, and this underestimation is common in other similar paleochannel studies.
- HVSR surveying images bedrock depth below highly conductive paleochannels, where AEM surveys fail to penetrate.
- HVSR surveys detect steep-sided bedrock along paleochannel edges, whereas AEM inversions show a more gradual and smoothed paleochannel edge.

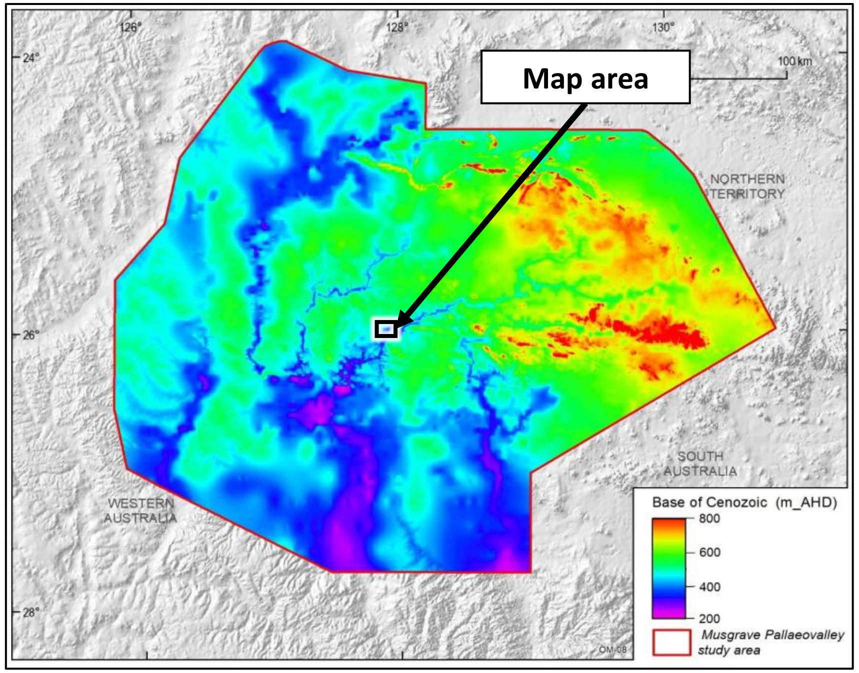


TEMPEST Z dB/dt EM time-decay channel profiles and 1D inversion cross section (2022)

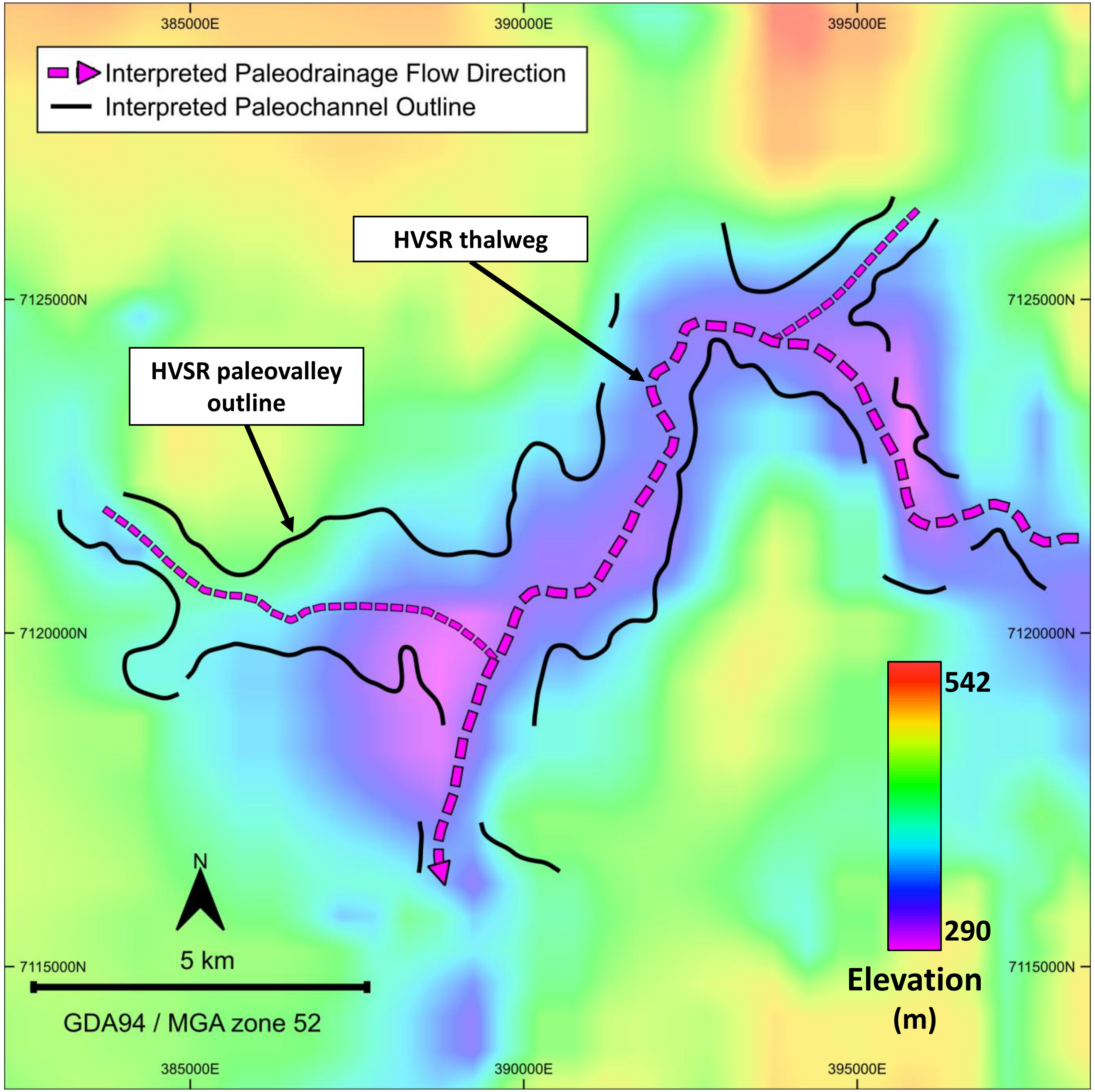


HVSR Results Compared to GA Paleovalley Model

- Geoscience Australia 3D model of West Musgrave paleovalleys (Record 2024/07).
- Model generated from AEM conductivity models, borehole data, surface elevation and geological maps, resulting grid cell size of 500 m.
- The Kadgo Paleovalley model generally agrees with HVSR results at a broad scale, but thalweg location offset and not detailed enough for reliable drillhole planning.

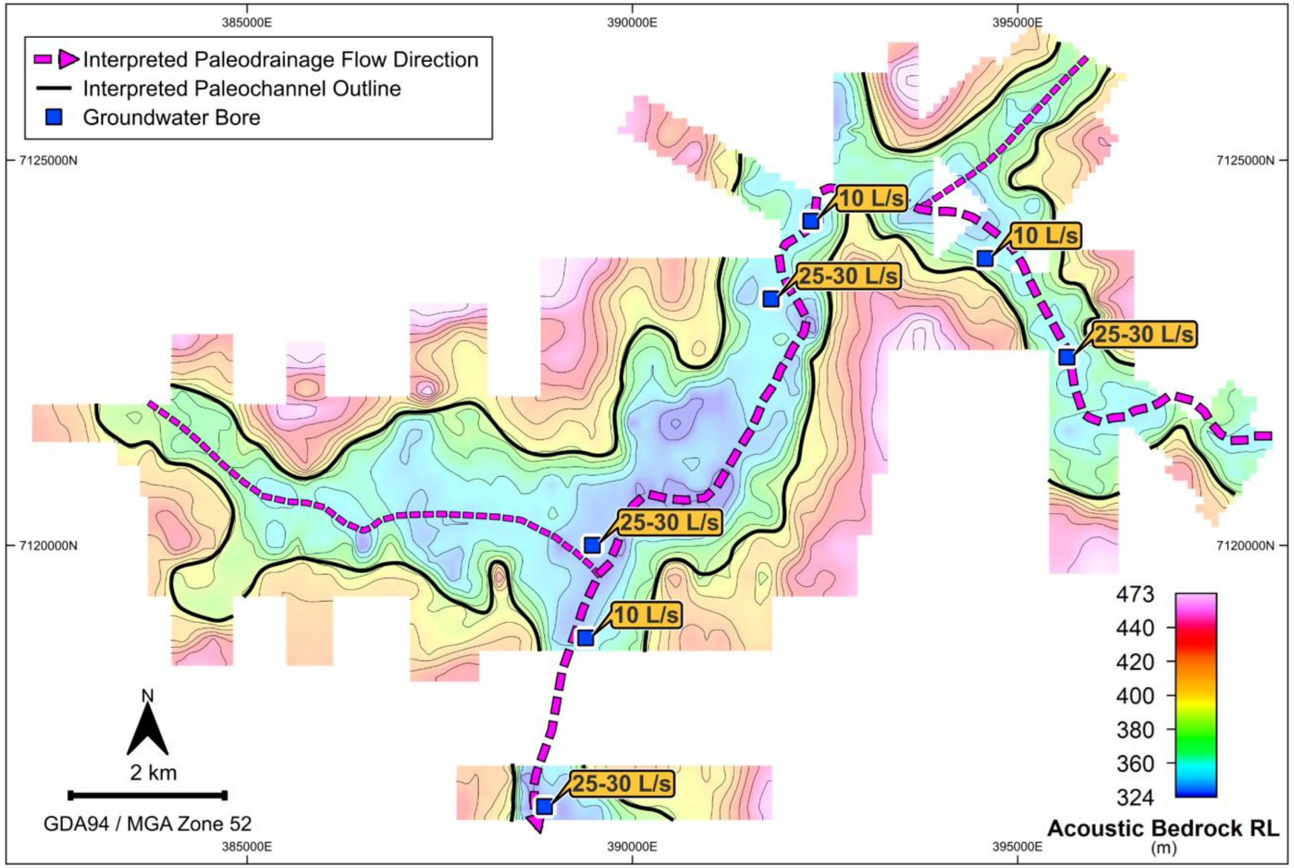


Reproduced from Symington et al. (2024)

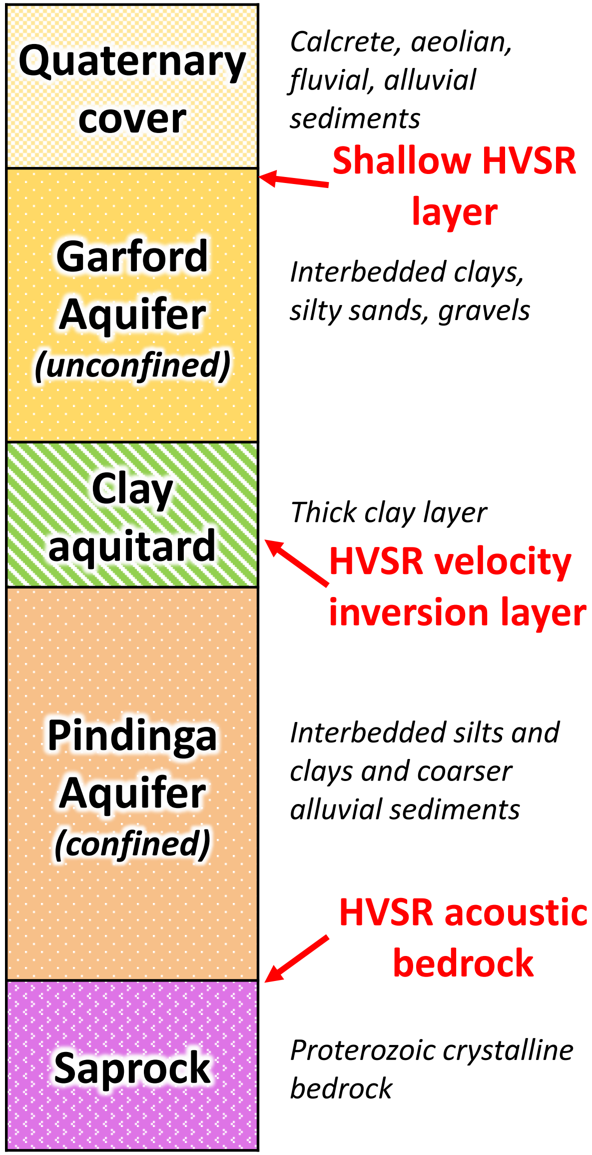


HVSR Planned Water Bore Results

- Groundwater test bores planned and carried out by AQ2 in 2021.
- Production bores screened in basal Pindinga Formation sediments within the paleovalley.
- EOH sediments generally finer in wide paleochannel zones (slower paleo-flow regime) and coarser sands occur in narrow choke points (faster paleo-flow regime).
- Very high groundwater flow rates of 25-30 L/s occur along the HVSR-defined main paleochannel thalweg.



Generalised hydrostratigraphy of the Kadgo Paleovalley



Conclusions

- Passive seismic HVSR surveying has successfully mapped the geometry of Permian to Cainozoic paleochannels incised into Mesoproterozoic crystalline bedrock near the Babel and Nebo Ni-Cu-PGE mine.

- Drilling of groundwater test bores on HVSR-defined paleochannel thalweg targets has proven to be very successful at discovering high water flow rates of 25-30 L/s from basal Pindinga Formation sediments.

- Integration of surface geology, AEM, magnetics, gravity, radiometrics and satellite DEM for interpretation of broad paleovalleys, then follow up with targeted passive seismic survey transects over key areas for reliable bedrock depth estimation and refined interpretation of paleochannel geometry and thalweg for direct drill testing.

- Passive seismic paleochannel mapping results generally agree with AEM paleochannel geometry, but provide more detail of bedrock topography and the main thalweg, reliable bedrock depth estimation, penetration to bedrock in very conductive areas where AEM does not penetrate to bedrock, and definition steep-sided paleochannels.

- Tight-spaced infill stations across steeply dipping bedrock, related to erosional cliffs and fault scarps, can be resolved in greater detail for targeting drilling into zones containing coarse clastic deposits and talus debris with high porosity for hosting groundwater.

Acknowledgements

- Ciara Doherty and Erin Western at BHP for allowing us to present these results.
- Michael Wood, Simon Rose and Zoran Seat for their assistance during passive seismic programs.
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