Passive seismic Horizontal-to-Vertical Spectral Ratio (HVSR) surveying for groundwater exploration at the Chilalo Graphite Project, Tanzania

by

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Perth, Western Australia

Presentation Outline

- Chilalo Project Location
- Chilalo Project Background and Geology
- Chilalo Project Hydrogeological Study
- Passive Seismic HVSR Method
- Passive Seismic HVSR Surveys and Exploratory Water Bore Results
- Conclusion

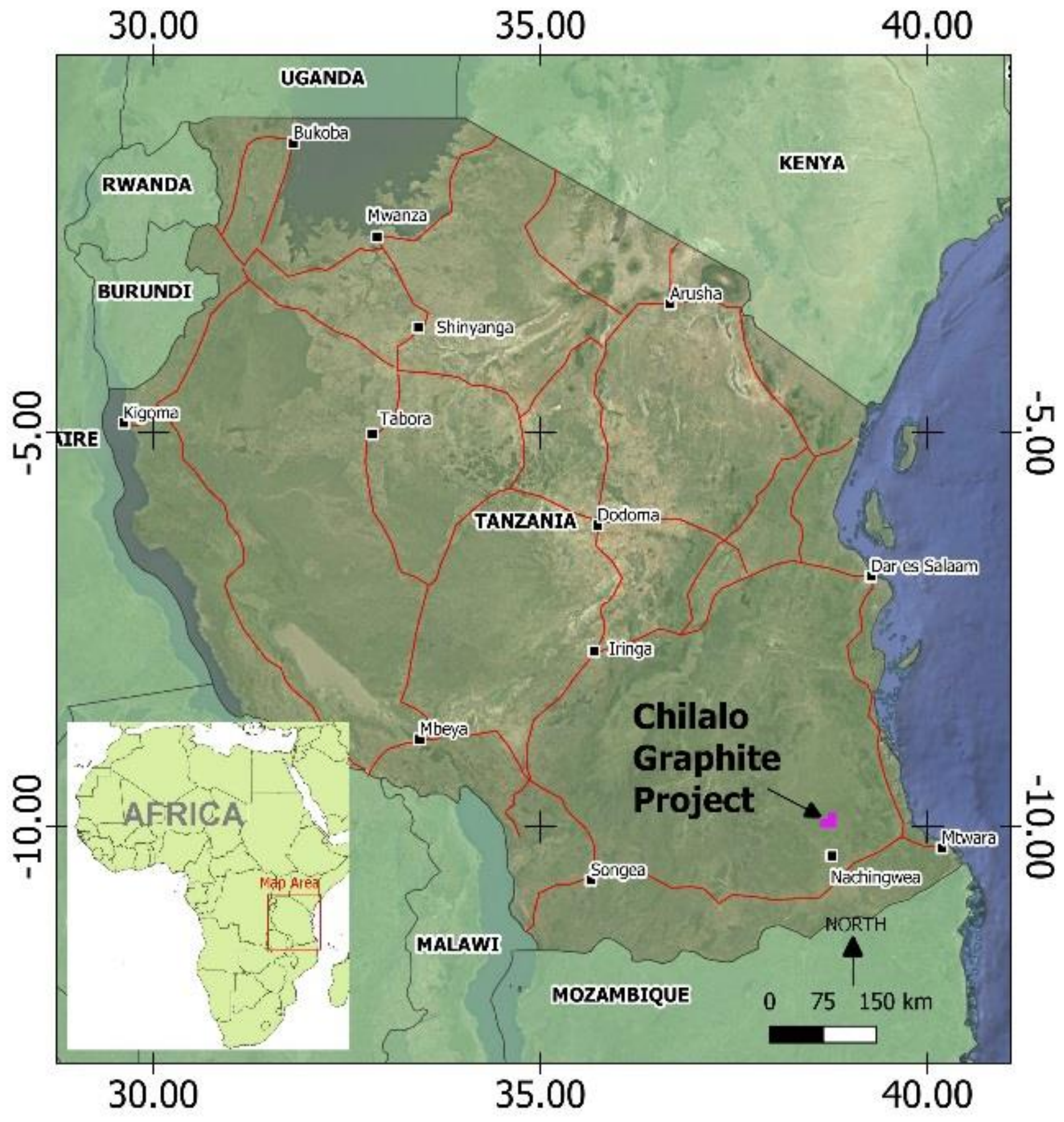
Chilalo Graphite Project - Location

- SE Tanzania, 50km north of Nachingwea, 150km north of the national boarder with Mozambique, and 250km by road to the port at Mtwara.

- Project previously operated by IMX Resources (Indiana Resources) within their Nachingwea Project, which was primarily focused on base metals and gold.

- Graphite assets sold to Graphex Mining Ltd (ASX:GPX) in 2014.

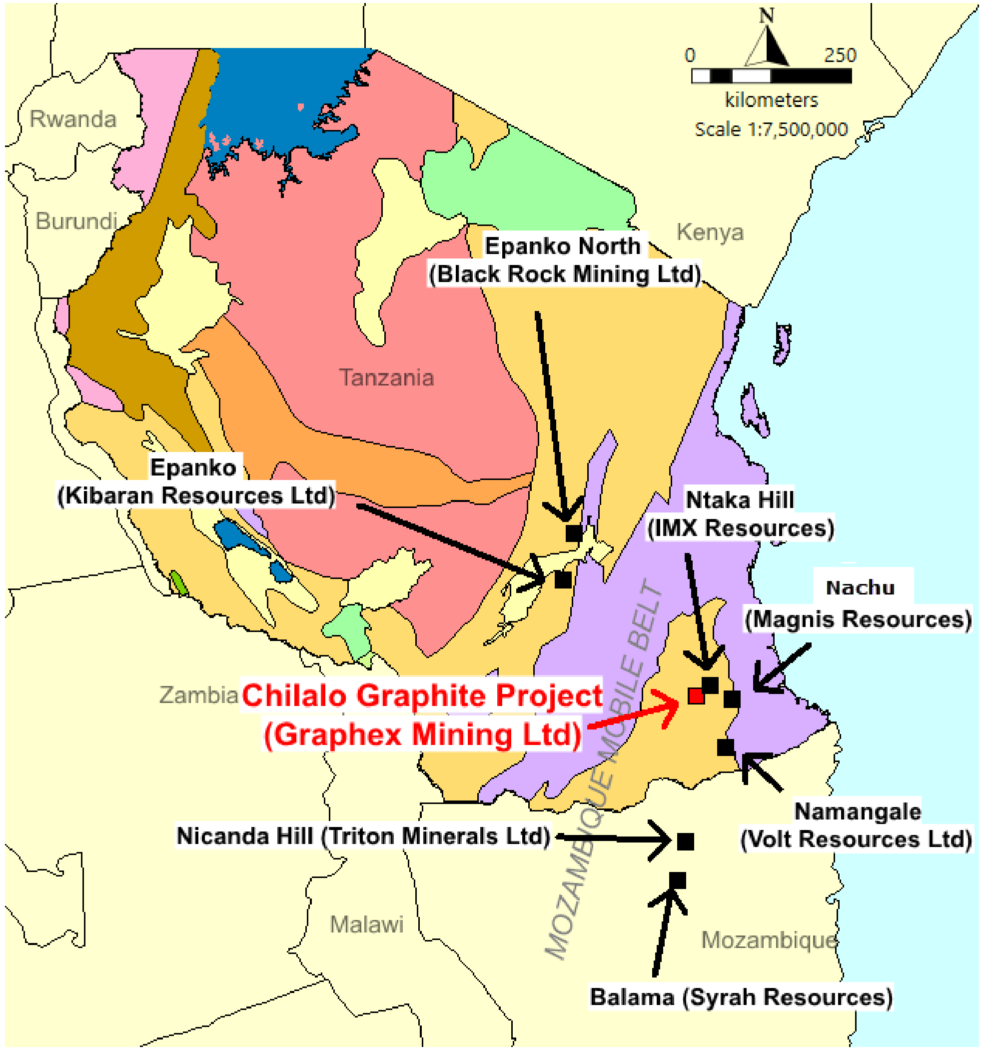
- Project consists of exploration licenses and a graphite mining lease was approved in early 2017.



Chilalo Graphite Project - Geology

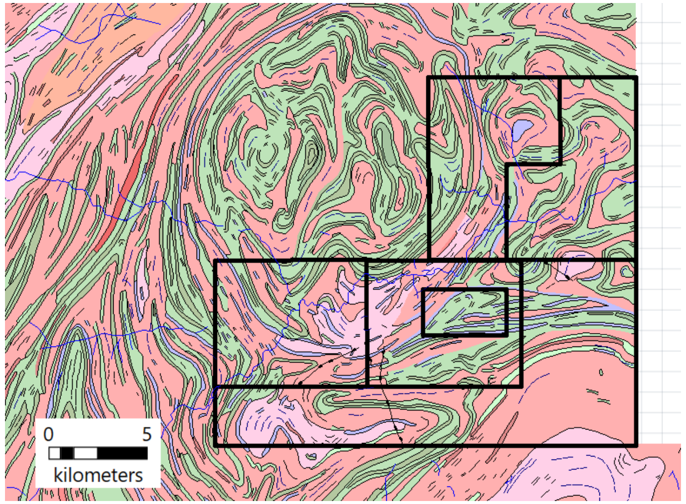
Resource Potentials

- Proterozoic Mozambique Mobile Belt – sedimentary and mafic to felsic gneisses.
- Belts hosts world-class, high-grade, large flake graphite deposits.
- Numerous granitic intrusions deforming regional geology and may have provided heat and pressure sources for increased local metamorphism within the belt required to convert organic carbon into graphite.
- Host geology is intermediate to high-grade metamorphosed sediments.

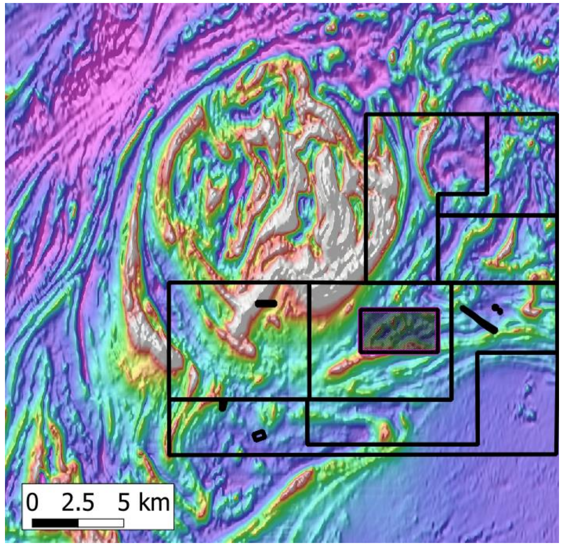


Regional geology of Tanzania, with major graphite projects.

Geological Interpretation



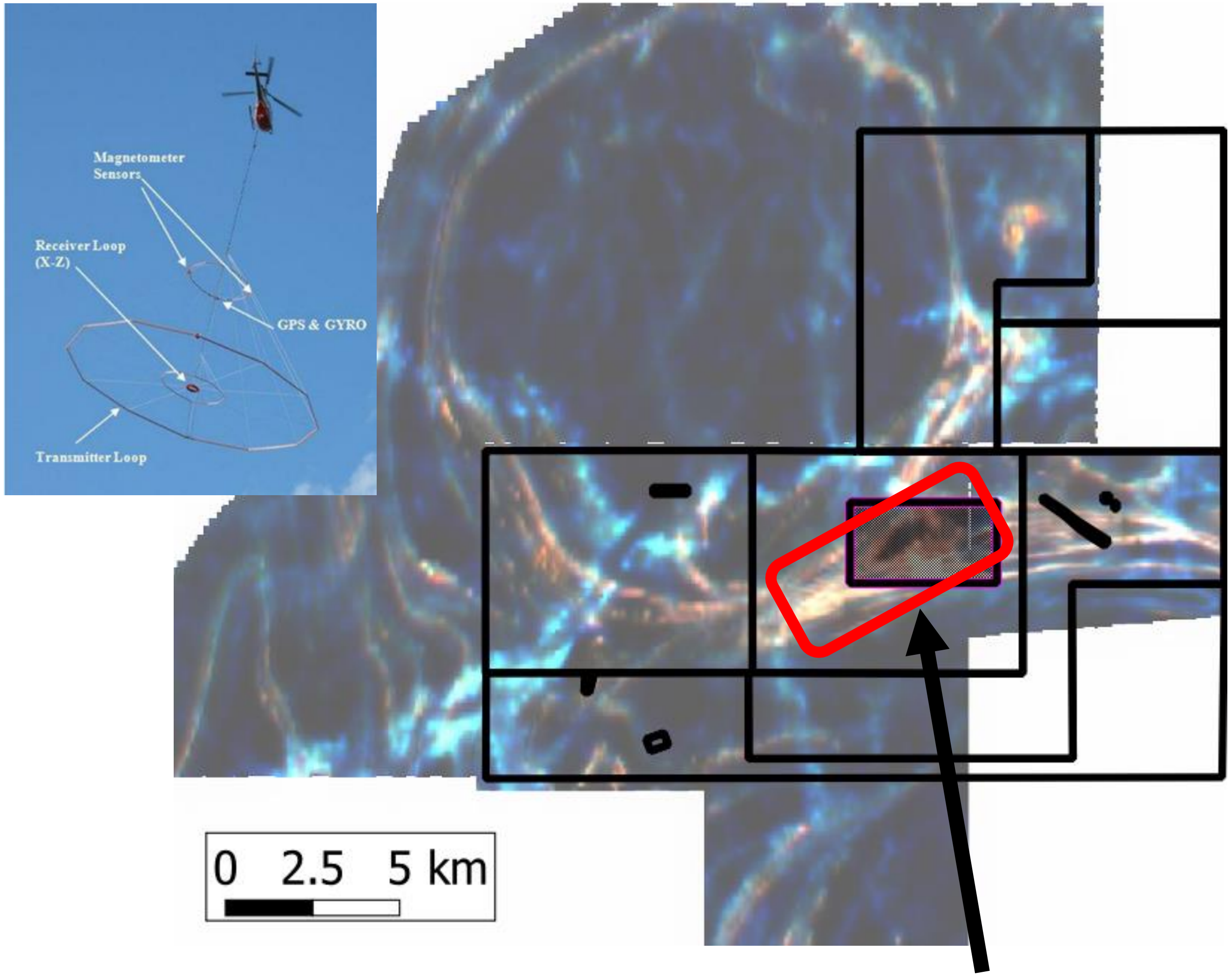
Magnetics TMI-RTP



Chilalo Graphite Project - Background

- Discovered in 2014 following up conductive trends in airborne EM (VTEM™).
- Multiple highly folded and highly conductive, strike extensive EM anomaly trends identified.
- Rock chips along strike demonstrated high graphitic C assays (20-30%).
- RC drilling confirmed high-grade, large flake graphite deposit zone.
- Multiple FLEM and DHEM surveys completed in order to define high grade and large flake graphite mineralisation, and to assist with resource definition and site sterilisation.

Ternary VTEM Z dB/dt image, where red=Ch15, green=Ch7 and blue=Ch1



Strike extensive graphite beds

Chilalo Graphite Project - Background

- ASX announcement 28 August 2019:
  - **Mineral Reserves of 10.3Mt at 10.5% total graphic carbon (TGC) for 1.1Mt of contained graphite**
  - Indicated Mineral Resource of 10.3Mt grading at 10.5% TGC for 1.1Mt contained graphite
  - Inferred Mineral Resource of 9.8Mt grading 9.3% TGC for 0.9Mt of contained graphite (GPX Annual Report – 30 June 2018).
- 57% of product in the large, jumbo and super jumbo flake categories.
- Pre-feasibility study completed in 2016, and updated feasibility study completed in 2018, water requirements determined.
- Currently definitive feasibility study ongoing, results expected before EOY.
- **Ongoing hydrogeological studies to find required water supply sources for mine site and graphite ore processing.**

Chilalo Project Mineral Resource Estimate (re-produced from GPX ASX Announcement 28th August 2019)

Domain	Classification	Zone	Million Tonnes (Mt)	TGC (%)	Contained Graphite (Kt)
High Grade	Indicated	Main	9.2	10.6	982
		North East	1.0	9.5	100
		All	**10.3**	**10.5**	**1,082**
	Inferred	Main	7.4	9.5	704
		North East	2.3	8.8	205
		All	**9.8**	**9.3**	**908**
	Indicated + Inferred	**All**	**20.1**	**9.9**	**1,991**
Low Grade	Inferred	Main	37.8	3.4	1,282
		North East	9.5	4.1	394
		All	**47.3**	**3.5**	**1,677**
High Grade + Low Grade	**Indicated + Inferred**	**All**	**67.3**	**5.4**	**3,667**

1. The Mineral Resource was estimated within constraining wireframe solids using a core high-grade domain defined above a nominal 5% TGC cut-off within a surrounding low-grade zone defined above a nominal 2% TGC cut-off. The resource is quoted from all classified blocks above a lower cut-off of 2% TGC within these wireframe solids. Differences may occur due to rounding.

Hydrogeological Study Summary

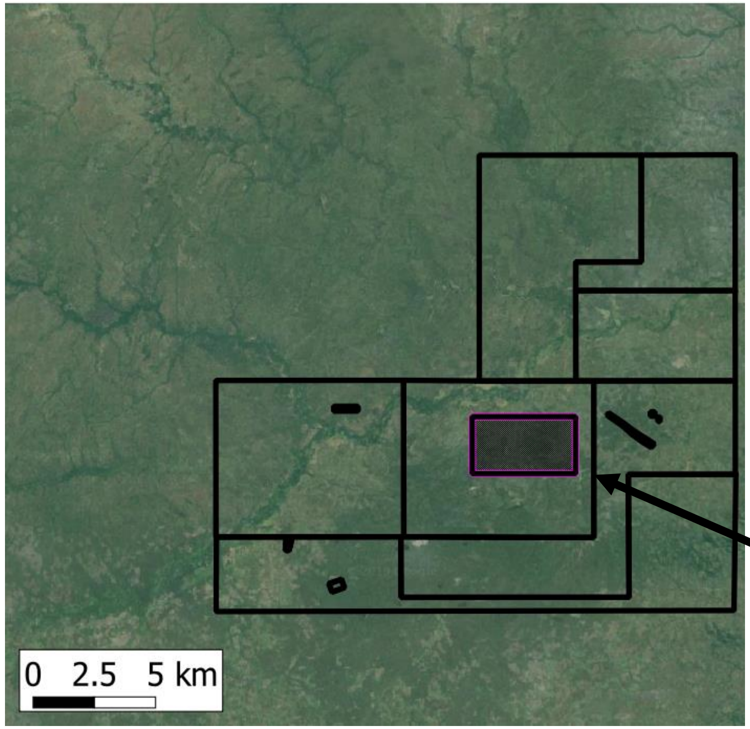
- Recent hydrogeological study suggests processing requirement of up to 500,000tpa for first 4yrs, then ramping up to 1,000,000tpa, plus camp, dust suppression, etc., therefore the project will eventually require a water supply of up to 41L/s.

- Therefore, requirement for a sizeable and sustainable groundwater reserve close to the mine site.

- Two potential viable groundwater target styles identified:

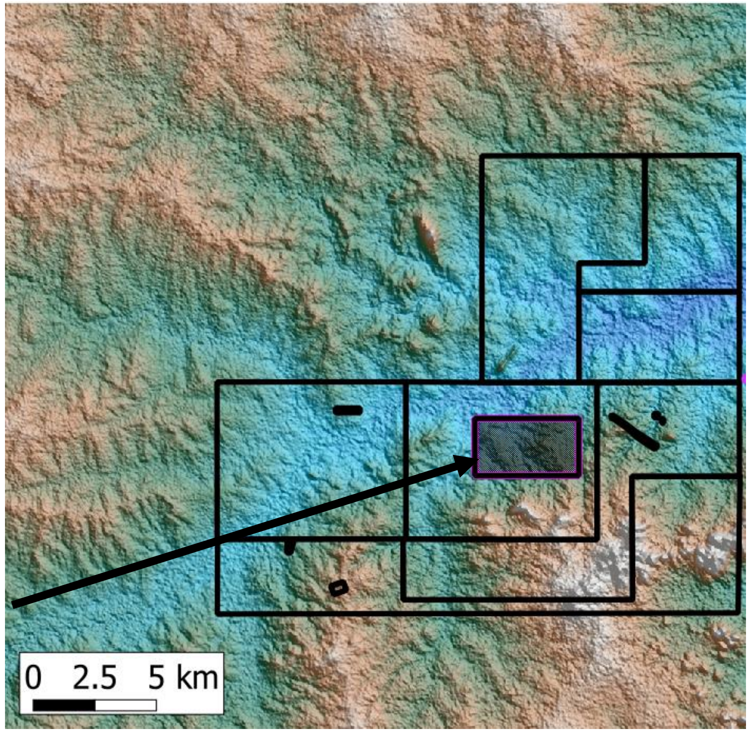
1) fluvial river deposits over and surrounding the Mbewmburu River system, located 1km to the north of the ML, and
2) fractured gneissic bedrock below and immediately surrounding the ML; dewatering required, but not likely sufficient to supply mine requirements.

Google Earth satellite



Mining Lease

SRTM image



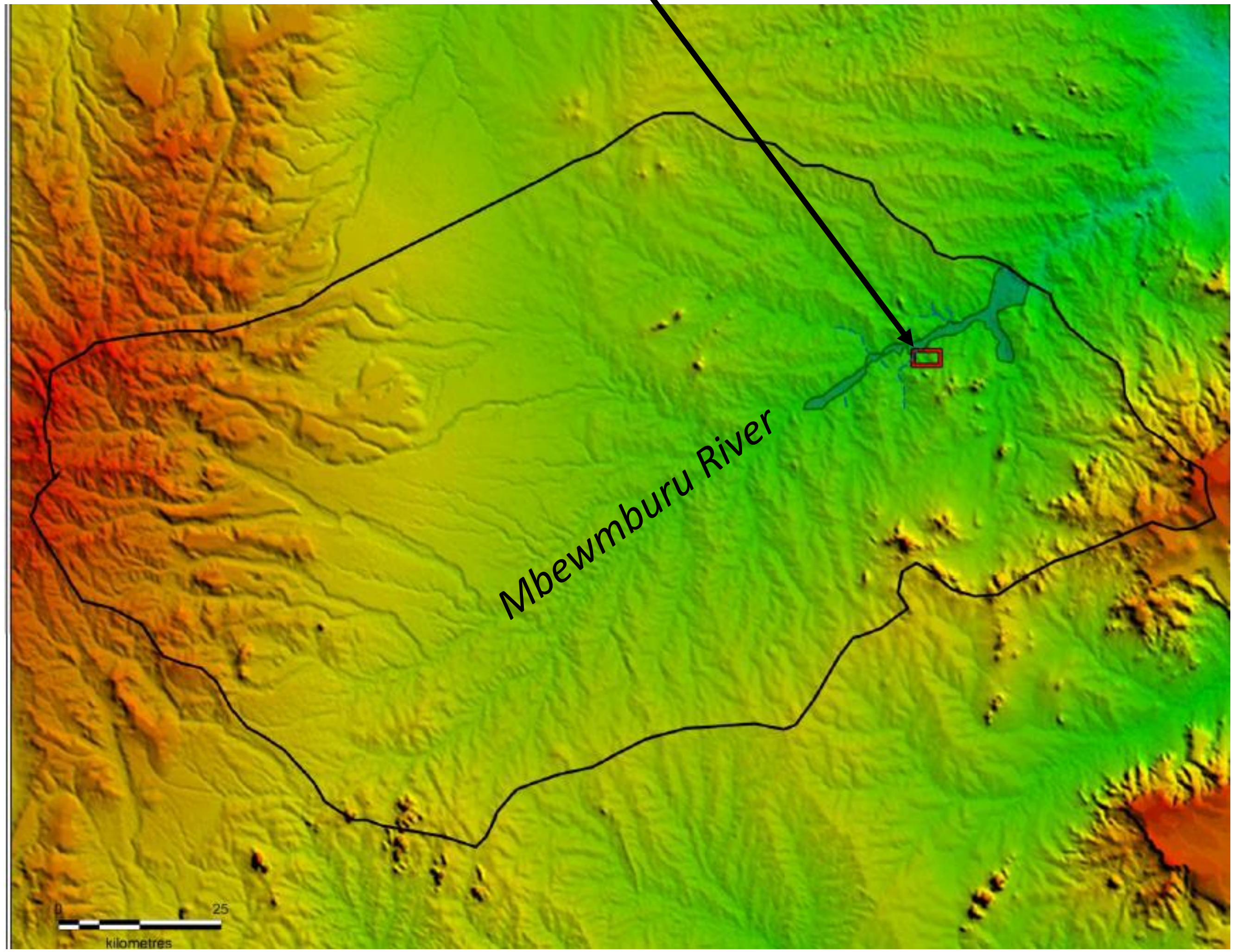
Hydrogeological Study – Fluvial Groundwater Target

- Favorable groundwater target due to:
  - large catchment area surrounding the Mbewmburu River,
  - numerous creeks and rivers feeding into it,
  - average yearly rainfall ~ 1,000mm/a,

- Typical hydrogeological parameters expected for the fluvial deposit materials were assumed:
  - effective porosity
  - hydrogeological connectivity
  - volume of groundwater reserve
  - Coarse sediment thickness forming a replenished aquifer

PASSIVE SEISMIC!

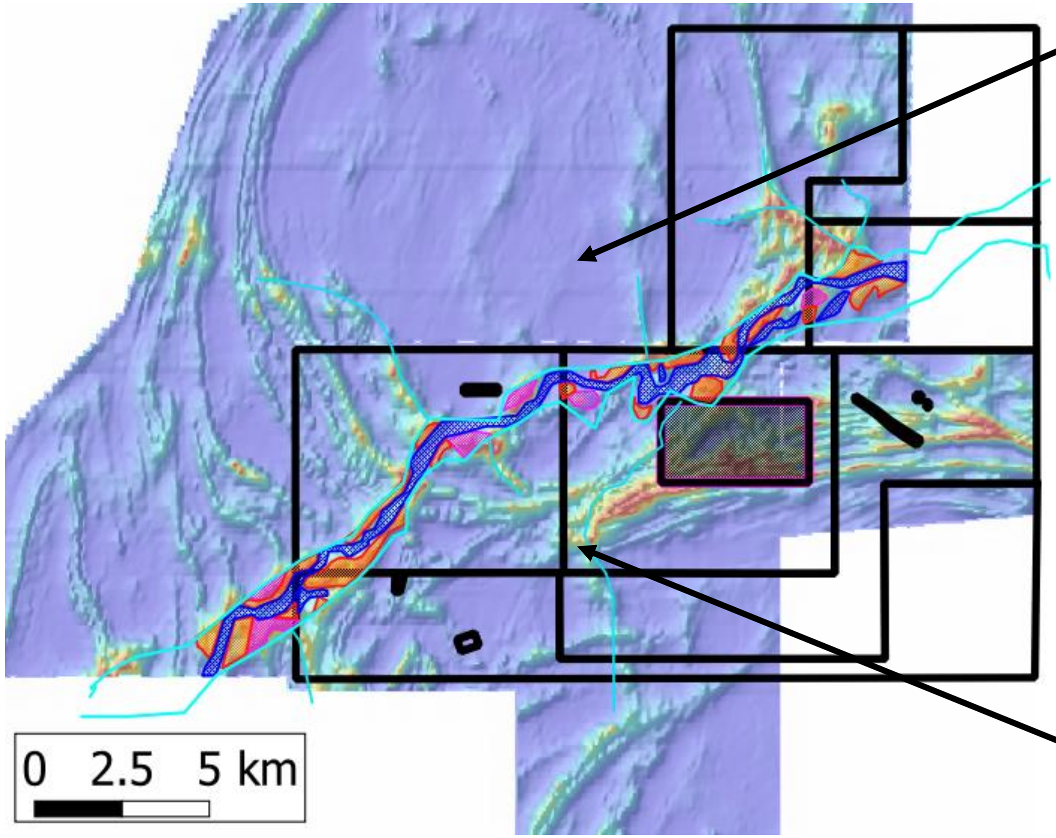
Digital elevation with mining lease, catchment area and river valley proximal to mining lease



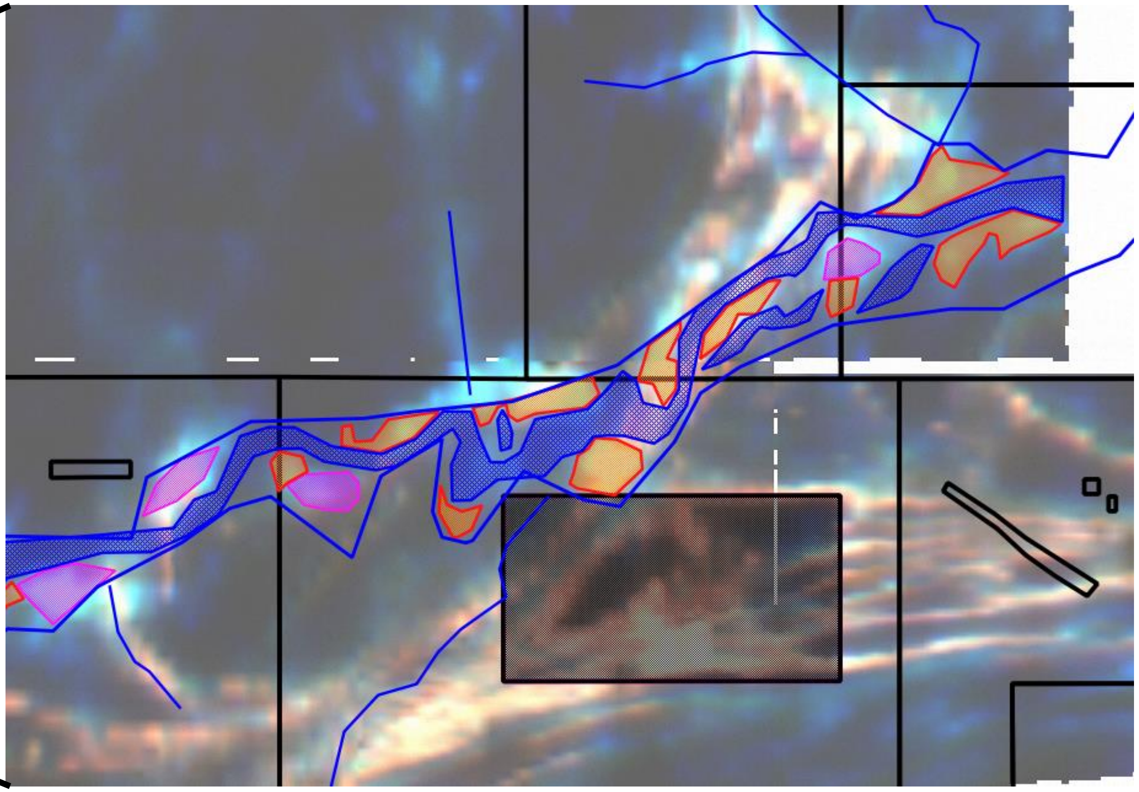
Fluvial Target - First Pass Assessment 2017

Resource Potentials

- AEM survey results over and surrounding the Mbewmburu River were reviewed.
- Multiple discrete conductive anomalies were identified – levee clay deposits within and on sides of river valley.
- Electrically resistive zone within river valley roughly correlating to current drainage system – likely fresh water saturated sand deposits.
- But where is the best place to drill to find thick accumulations of coarse clastic sediments?



VTEM channel 8 image



VTEM ternary image, RGB = Ch 15-7-1

Chilalo Graphite Project – Passive Seismic

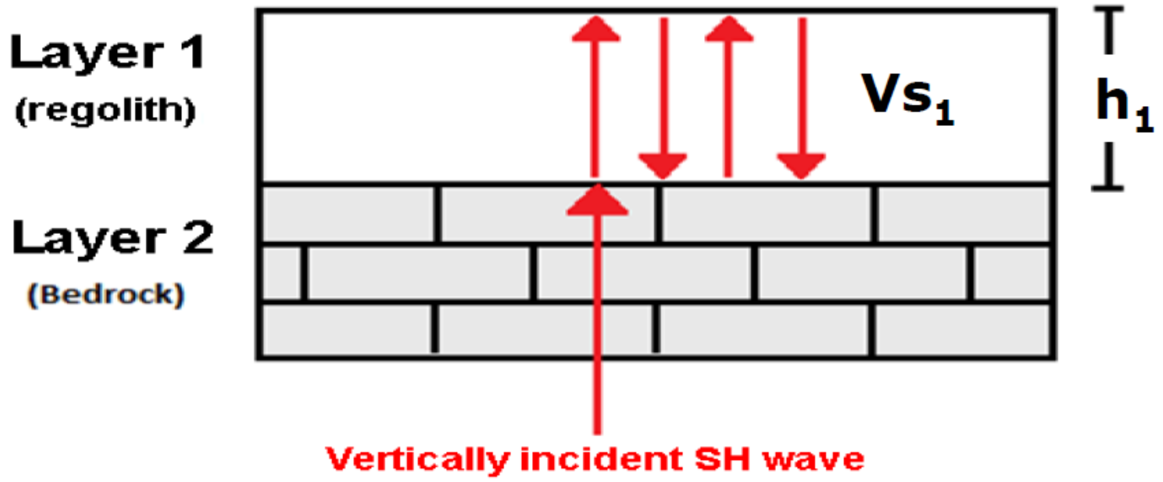
- Passive seismic HVSR surveying proposed to assist with:
  - Detecting depth to bedrock in river valley,
  - identify paleochannel targets for direct drill targeting,
  - assist with groundwater volume estimation,
  - identify possible aquiclude clay layers, which could effect hydraulic connectivity and recharge of groundwater.

- Two passive seismic survey phases completed, 1) wide spaced trial survey lines on south side of the river valley, and 2) once proven to work, then detailed surveying across the entire river valley during the dry season. Exploratory water bore drilling and pump testing carried out after each survey phase.

Tromino seismometer

Passive Seismic HVSR Method

- Based on theory by Nakamura (1989 and 2000).
- Ambient seismic signal (primarily surface Rayleigh and Love waves) generated from natural sources (ongoing crustal microtremors, distant ocean waves, wind etc.) become trapped in soft and slow velocity regolith cover sediments and weathered bedrock overlying harder and higher velocity bedrock.
- Background seismic energy acts as a permanent excitation source of the Earth excites the local resonances of the geological layers.
- The resonance frequency (f_0) is a function of thickness (H) and shear-wave velocity (Vs) of the low velocity sub-surface layers, forming a strong acoustic impedance (AI) contrast with the underlying hard bedrock layer.
- Depth to the fresh bedrock interface can be estimated from f_0 and Vs, which is assumed, modelled or calculated using a calibration reading at a drillhole into fresh bedrock



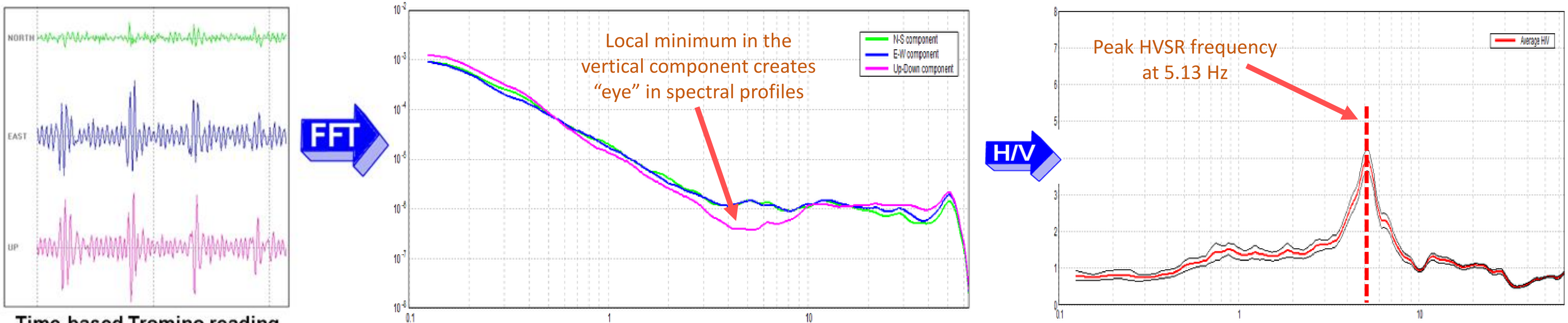
AI = ρ (density) x Vs

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

Passive Seismic HVSR Method cont.

Resource Potentials

- Sensitive seismometer (Tromino®) units that employ three velocimeters to record horizontal (relative X and Y) and vertical (Z) vibration components of natural ground motion over a broad range of frequencies (0-128 Hz generally), and over a time period of 10-30 minutes; 20 minutes used for this study.
- It has been established that at the resonant frequency of a geological layer the vertical component of the Rayleigh waves shows a minimum.
- thereby creating an ‘eyelet’ shaped separation between the horizontal and vertical components.
- Calculating the averaged X and Y horizontal (H) to vertical (V) spectral ratio (HVSR) will produce a peak at the resonant frequency of the low velocity layer.
- No active source is required, and the Tromino units are small and self contained, and therefore no track clearing is required.



Time-based Tromino reading

Frequency power spectrum

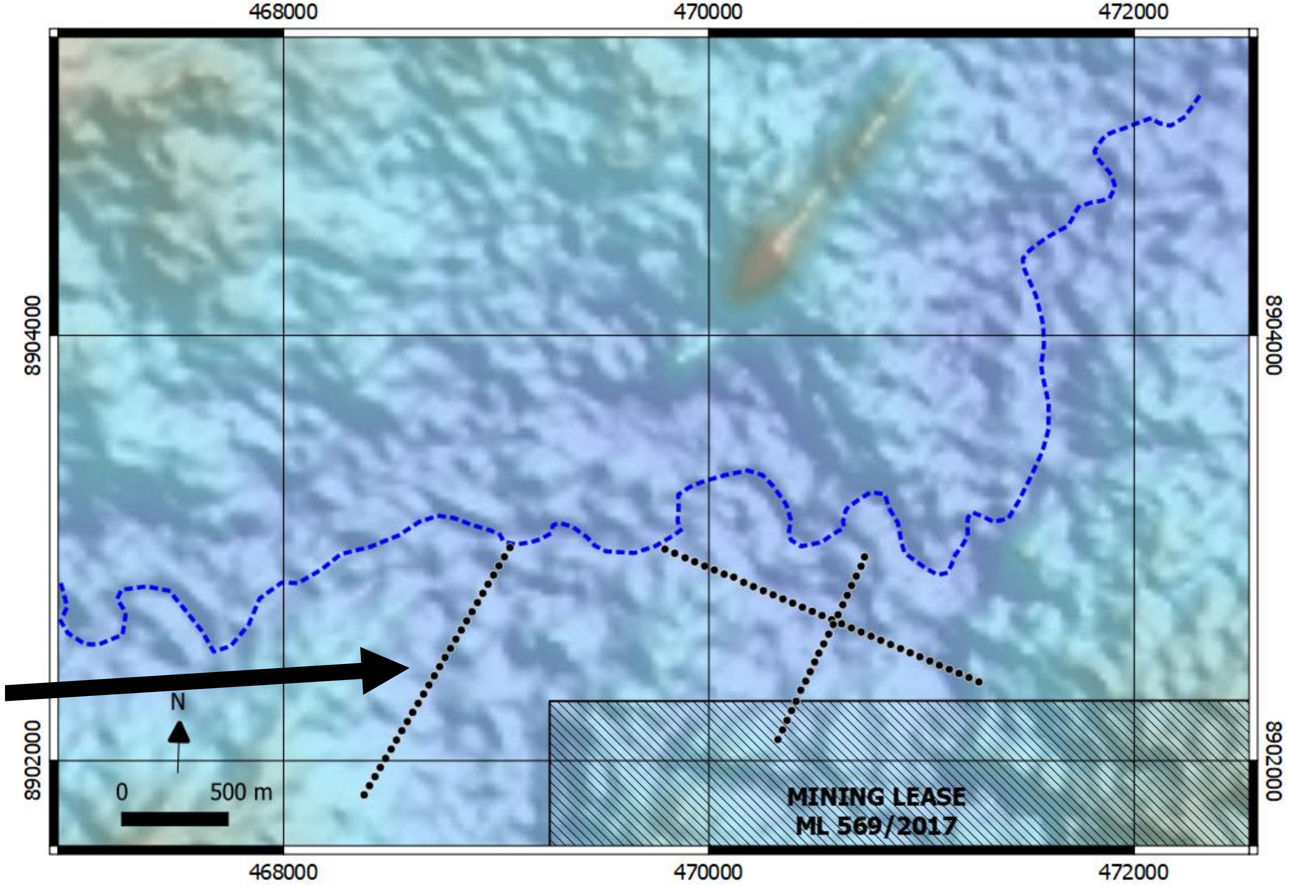
HVSR profile

Chilalo Trial Passive Seismic HVSR Survey 2017

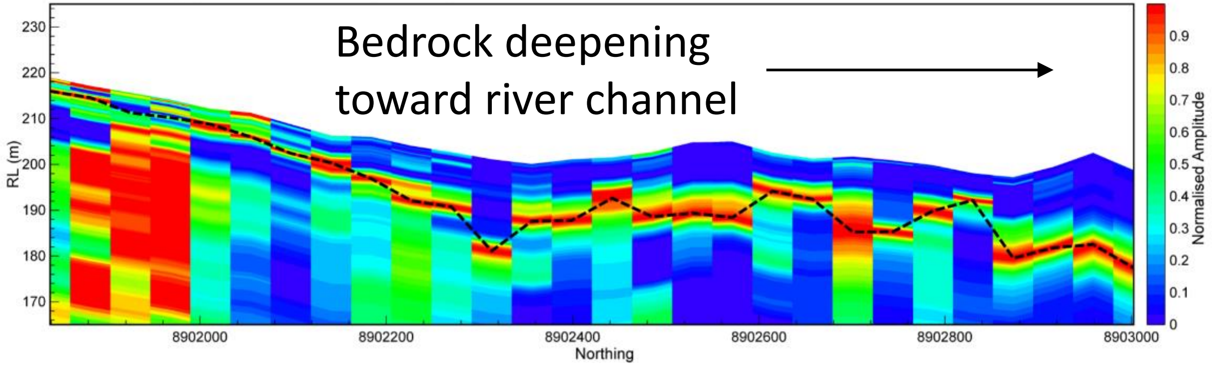
Trial survey specifications:

- 3 survey lines orientated NE-SW and NW-SE on south side of river channel
- Station spacing 50m
- Acquisition time: 20 minutes
- Sampling frequency: 128Hz (standard)
- Acquired during start of wet season by local Graphex staff members and villagers
- Assumed Vs of **400m/s** used to convert recorded HVSR frequencies to depth, until bedrock depth drill data become available
- On UTM with SRTM elevation

SRTM elevation image, with current river axis (blue dashed) and passive seismic stations (black dots)



Bedrock deepening toward river channel

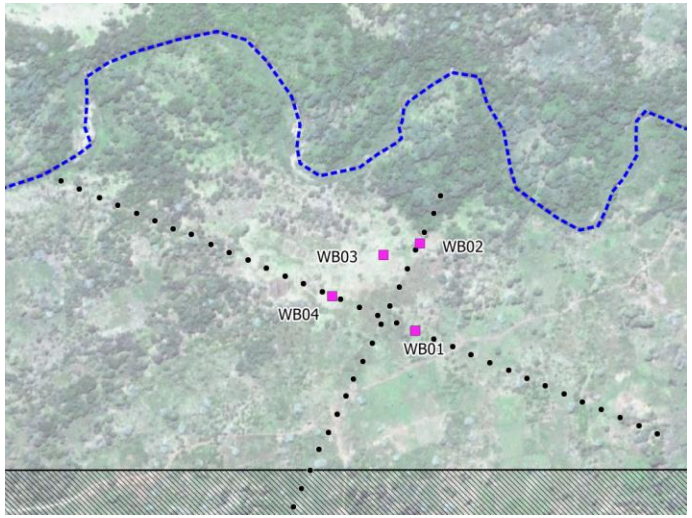


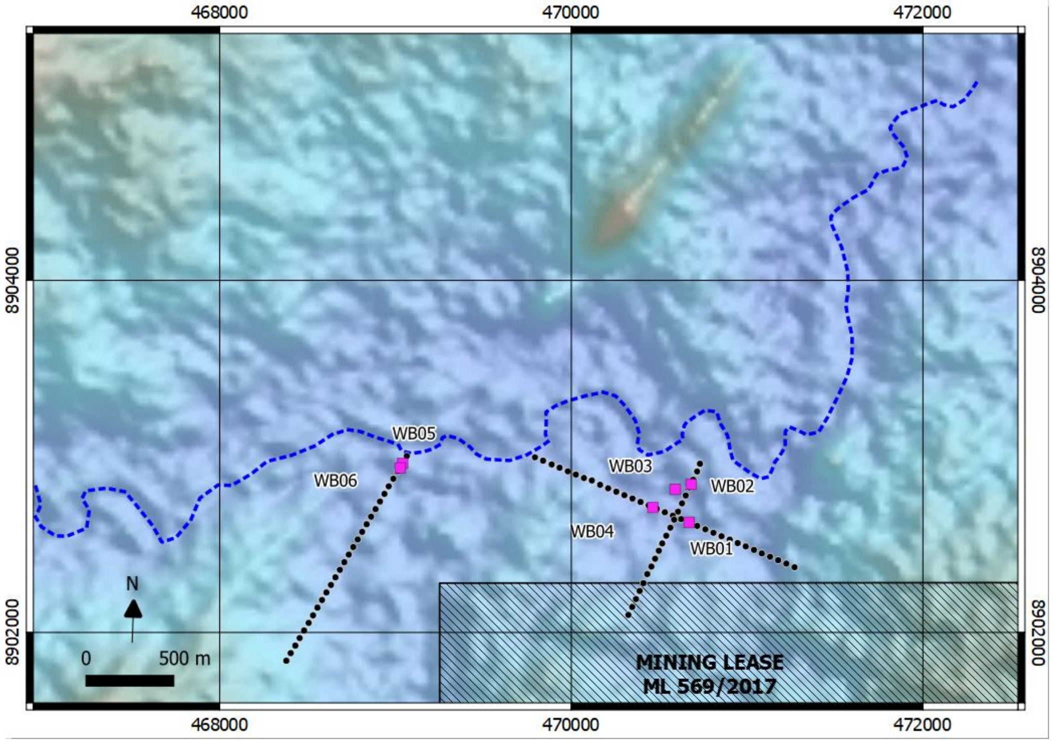
Encouraging results identified sub-horizontal acoustic impedance contrast (gneiss bedrock – fluvial deposit interface) on all survey lines, water bore drilling commenced at deepest bedrock on survey lines.

Chilalo Trial Passive Seismic HVSR Survey – Water Bore

Resource Potentials

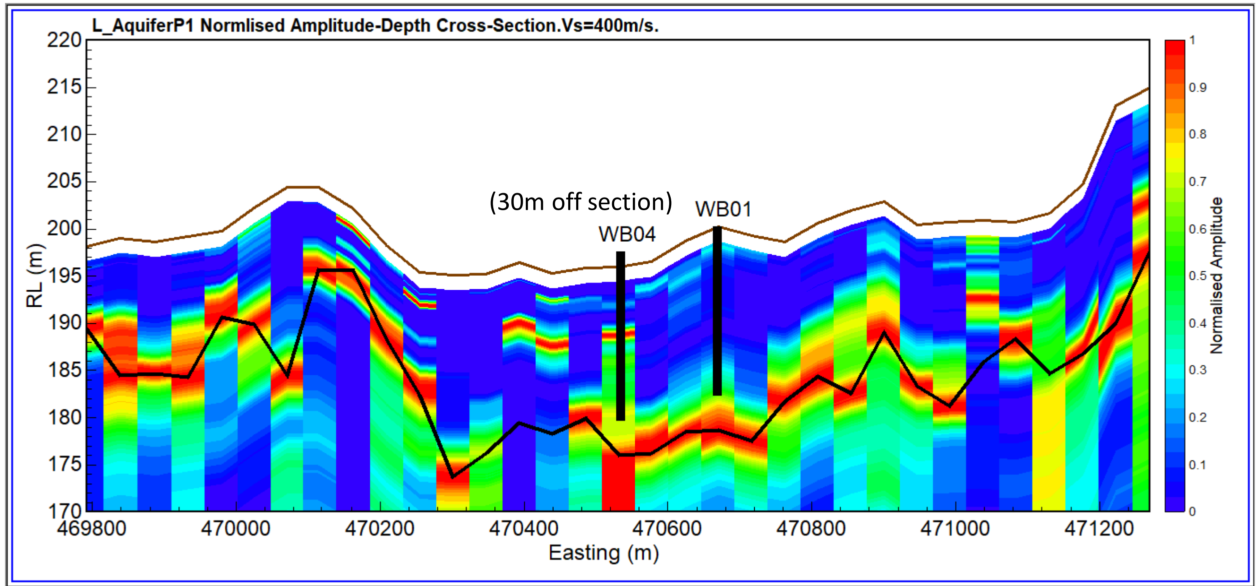
- Exploratory water bores planned to target thick alluvial deposits identified by passive seismic results.
- Program completed during wet season – only 6 water bores completed (flooding issues).
- Only an RC drill rig designed for mineral exploration was available.
- Preliminary pumping tests were not considered reliable, but results indicated water bores with thickest fluvial deposits recorded higher yields.
- Bedrock intercepted close to predicted depth using assumed Vs, and then drilling data used to refine average Vs.

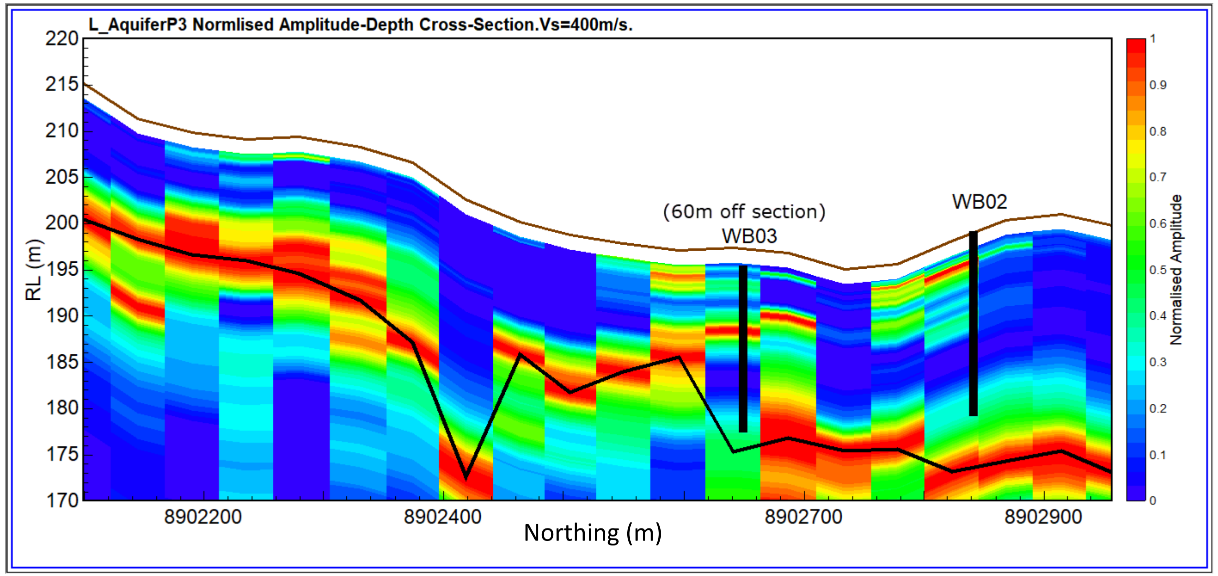


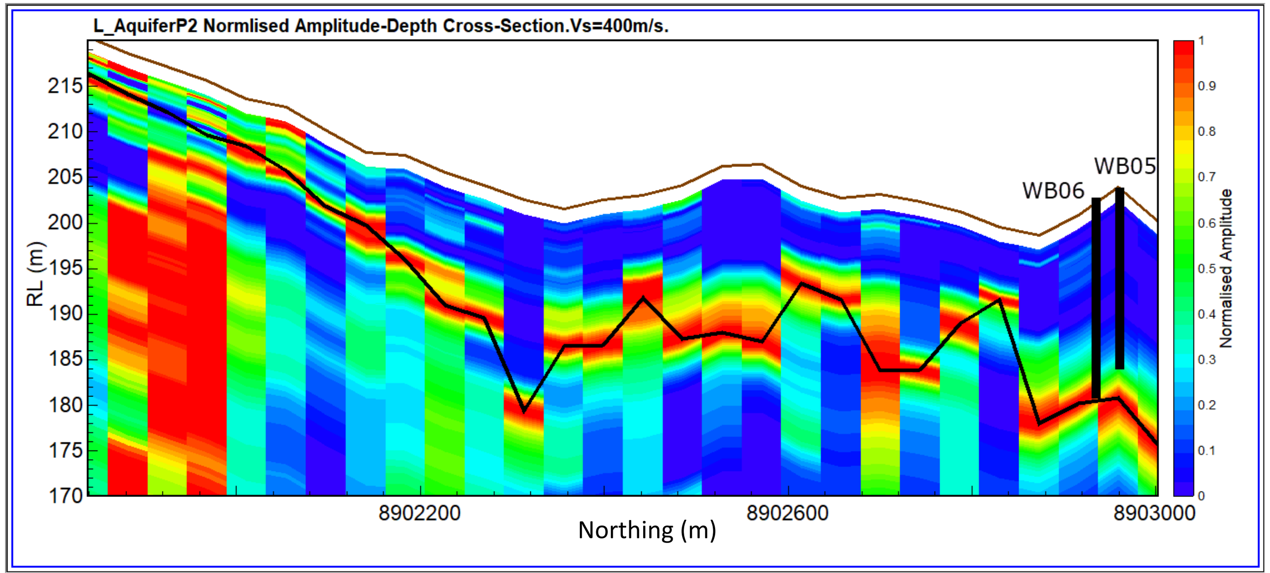


Chilalo Trial Passive Seismic HVSR Survey – Water Bore

- Normalised amplitude-depth cross-section of three trial survey lines.
- Black profile represents main acoustic impedance contrast (estimated bedrock).
- Brown profile is SRTM surface, data start at 1.5m.
- All boreholes intersected fluvial material and ended in gneissic bedrock.
- **It works, MORE PASSIVE SEISMIC REQUIRED.**





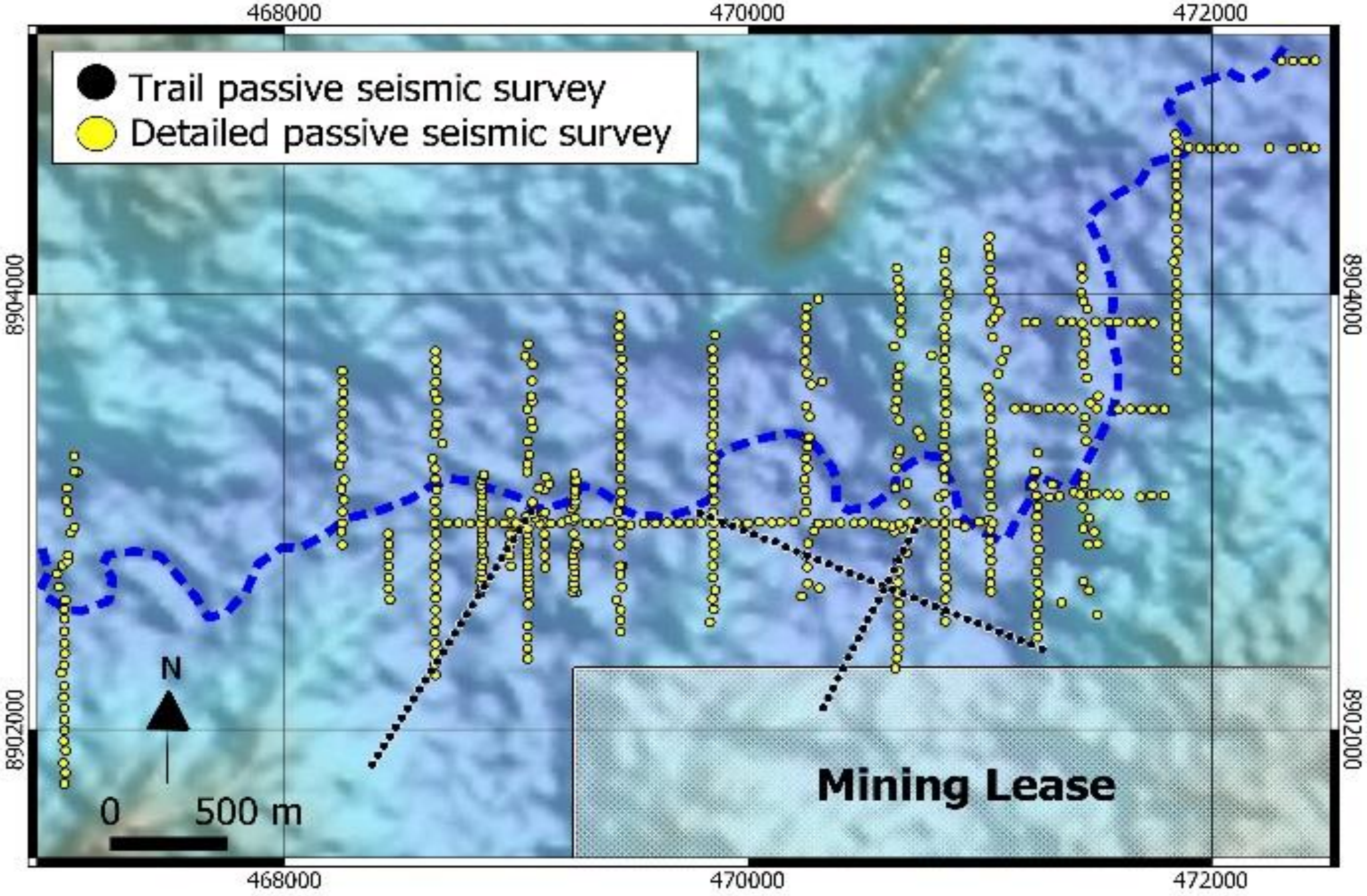


Chilalo Detailed Passive Seismic HVSR Survey 2018-2019

Resource Potentials

Survey specifications:

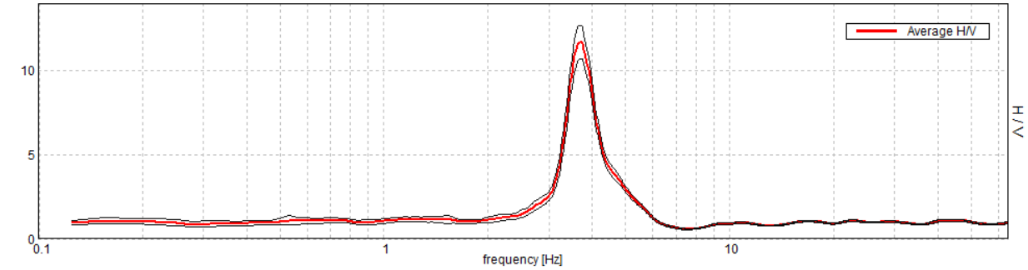
- 33 survey lines orientated N-S and E-W
- Station spacing 50m
- Acquisition time: 20 minutes
- Total of 620 stations, NE lines unable to be surveyed due to start of wet season
- Sampling frequency: 128Hz (standard)
- Acquired during dry season and start of wet season
- Total of 1 month surveying period using local labourers

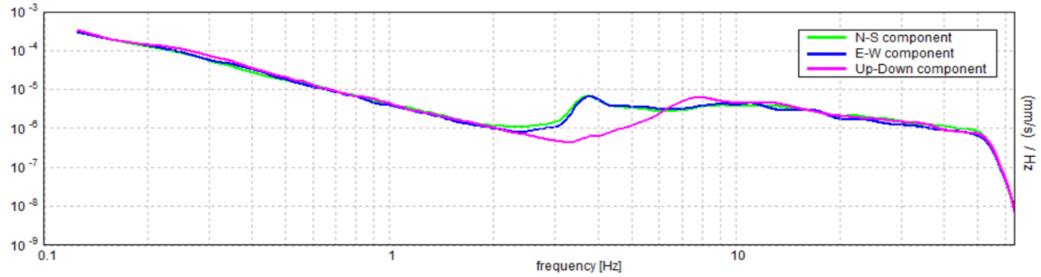


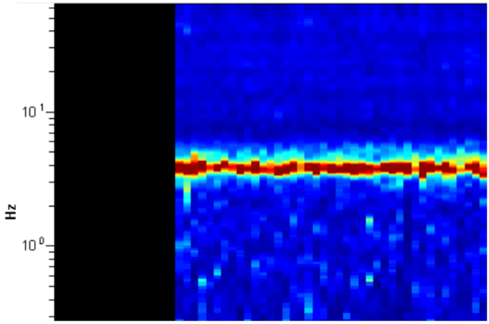
Passive seismic stations (black = trial survey lines, yellow dots = detailed survey lines) overlain on SRTM image

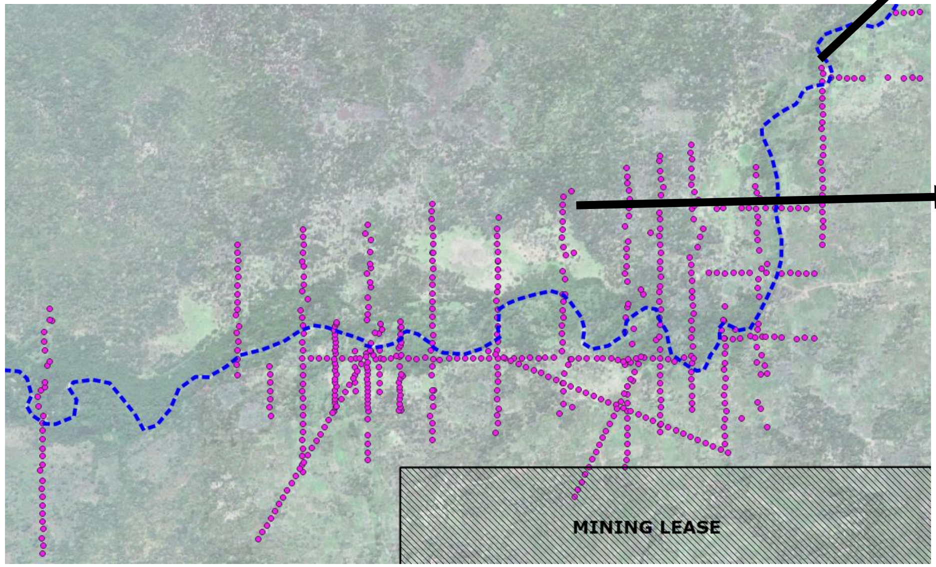
Chilalo Detailed Passive Seismic HVSR Survey - Data

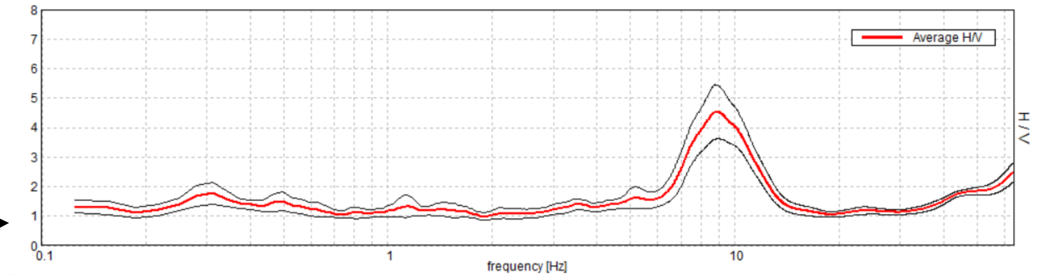
- Overall, the data were of good quality, and only required minor editing.
- Consistent high amplitude HVSR resonant frequency in the range of 3Hz – 12Hz.
- Window normalisation of HVSR resonant peak frequencies was completed on each individual passive seismic station recording to enhance layer continuity.

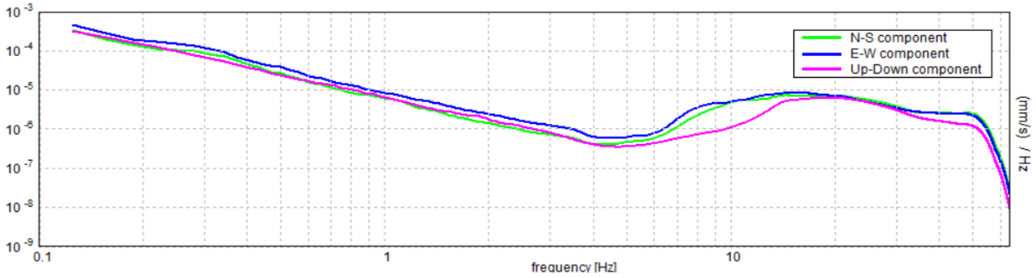


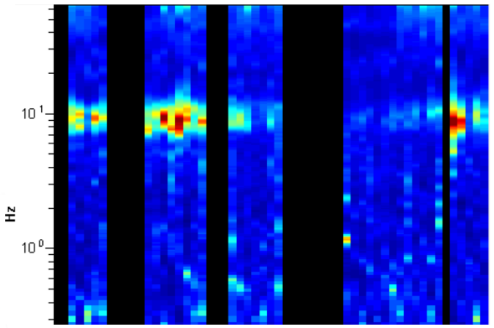












Chilalo Detailed Passive Seismic HVSR Survey - Velocity Analysis

- Multiple methods available to convert the recorded HVSR frequencies to accurate depths - requires calibration of shear wave velocity (Vs), which can be achieved by:
  - 1D forward modelling,
  - empirically using equation 1 and calibration reading at drillholes into fresh bedrock,
  - computing a trendline based on an empirical correlation between f0 and logged bedrock depths for a series of readings taken at drillholes with different fresh bedrock depths,
  - using other *a priori* information (MASW or downhole Vs measurements).

Logged depth of bedrock from water bores, and resonant frequency from the closest passive seismic recording station.

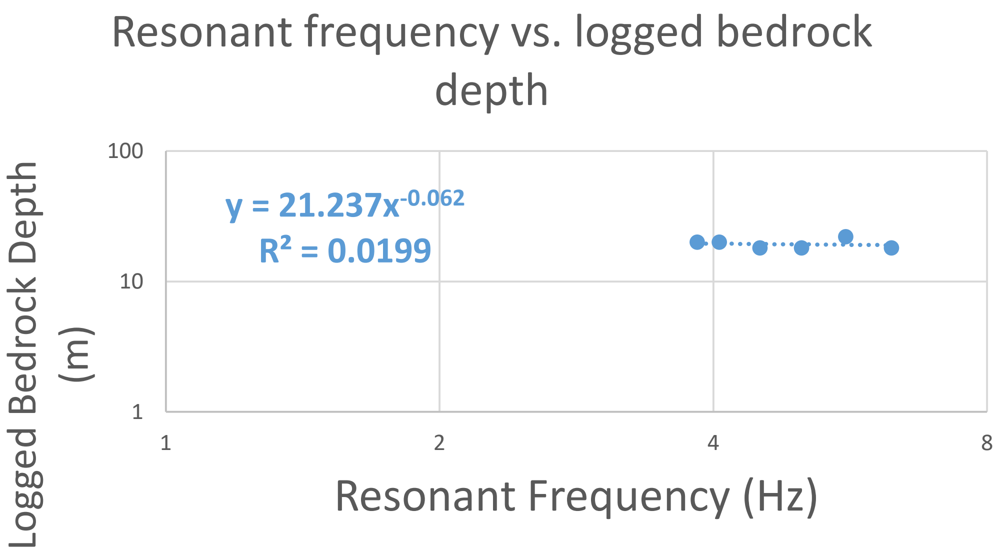
Borehole	Bedrock depth (m)	Resonant Frequency (Hz)
WB01	18	4.5
WB02	20	3.84
WB03	18	6.28
WB04	18	5
WB05	20	4.06
WB06	22	5.59

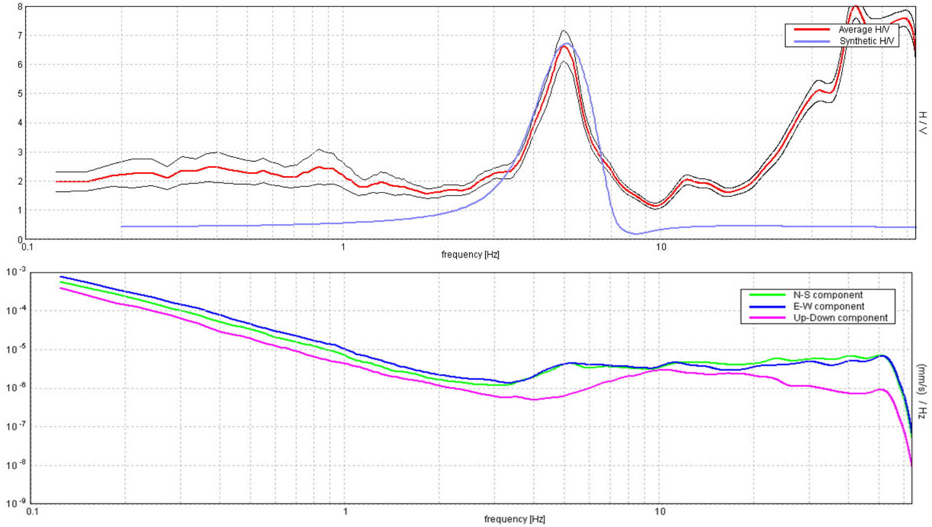
Chilalo Detailed Passive Seismic HVSR Survey - Velocity Analysis

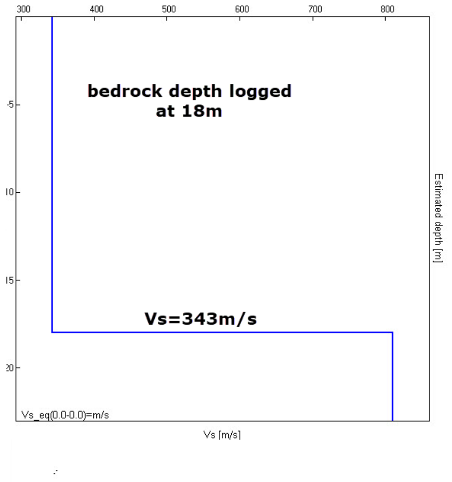
- 6 exploratory water bores logged gneissic bedrock at similar depths (18m-22m), therefore correlation coefficient is poor (less than 0.02).
- Using Equation 1 and 1D forward modelling, an average Vs of **370m/s** was obtained, and then all recorded HVSR frequencies were converted to depth using this average Vs.
- From the initial estimated Vs of 400m/s, the new drilling constrained average Vs of 370m/s has made the estimated depth 7.5% shallower.

Borehole	Bedrock depth (m)	Resonant Frequency (Hz)	Equation 1 Vs (m/s)	Forward modelled Vs (m/s)
WB01	18	4.5	324	324
WB02	20	3.84	307.2	290
WB03	18	6.28	452.16	444
WB04	18	5	360	343
WB05	20	4.06	324.8	310
WB06	22	5.59	491.92	484
		AVERAGE	376.68	365.8333

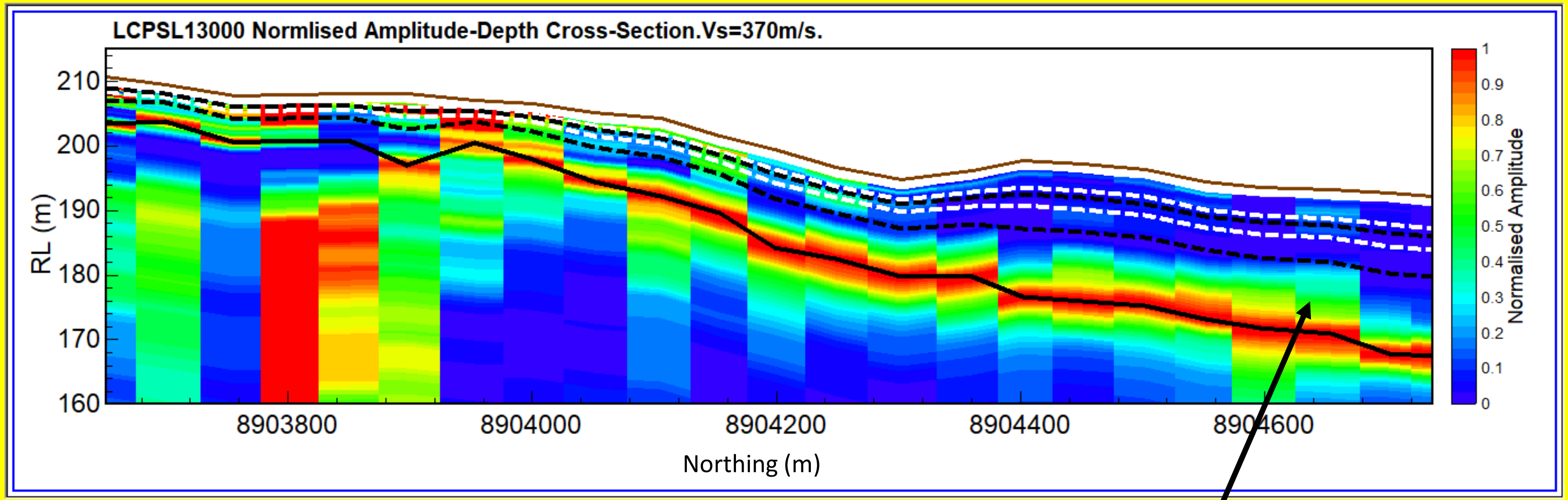
$$f_0 = \frac{V_s}{4h} \quad \text{(Equation 1)}$$





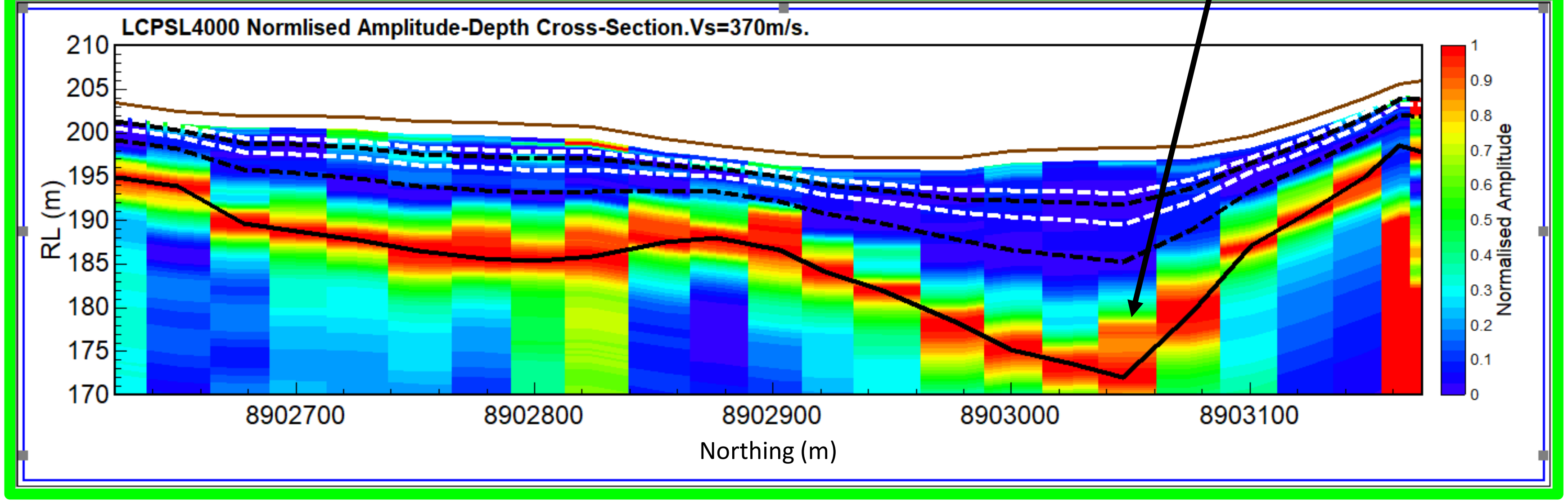


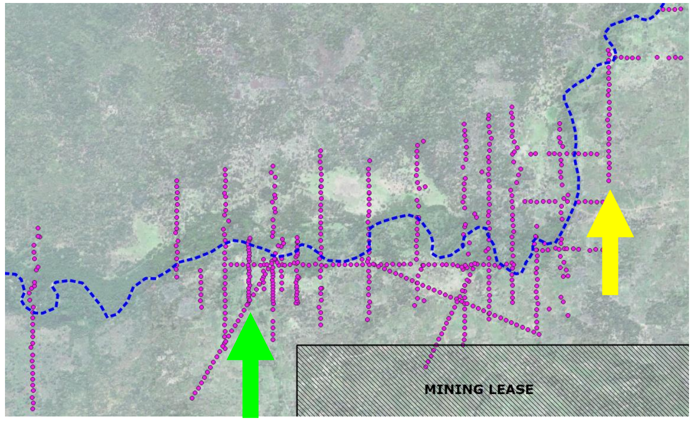
Chilalo Detailed Passive Seismic HVSR Survey - Results



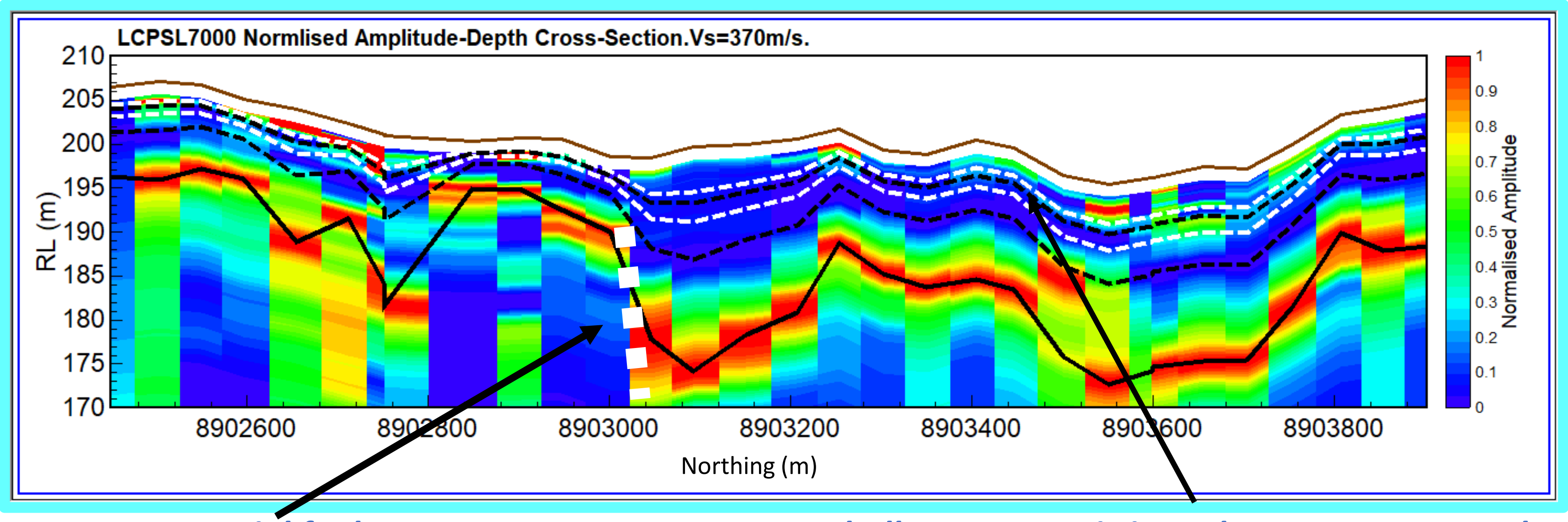
- Main fresh bedrock acoustic impedance contrast (solid black profile).
- Modals or 'multiples' of the main bedrock layer shown as black dashed profiles (even modes) and white dashed profiles (odd modes).

Paleochannel and thicker alluvial deposits



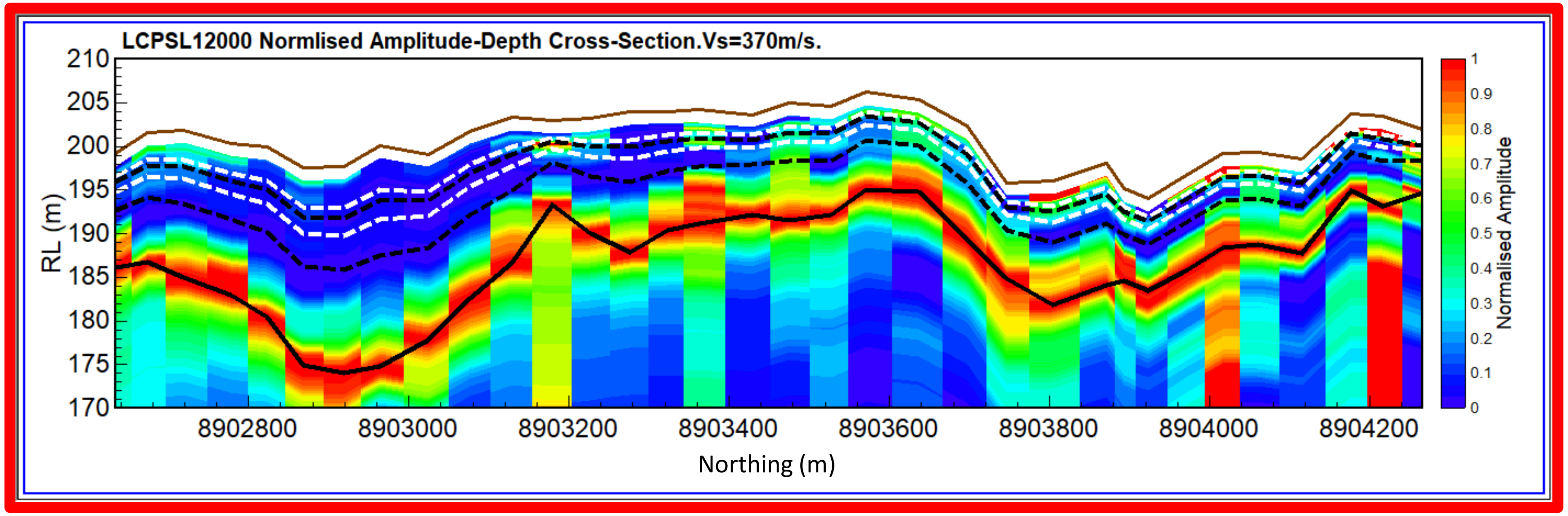


Chilalo Detailed Passive Seismic HVSR Survey - Results

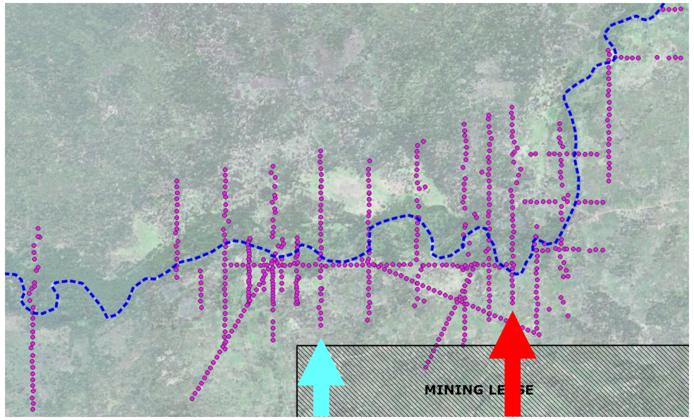


Potential fault
Observed on multiple lines

Shallower acoustic impedance responses – clay deposits?



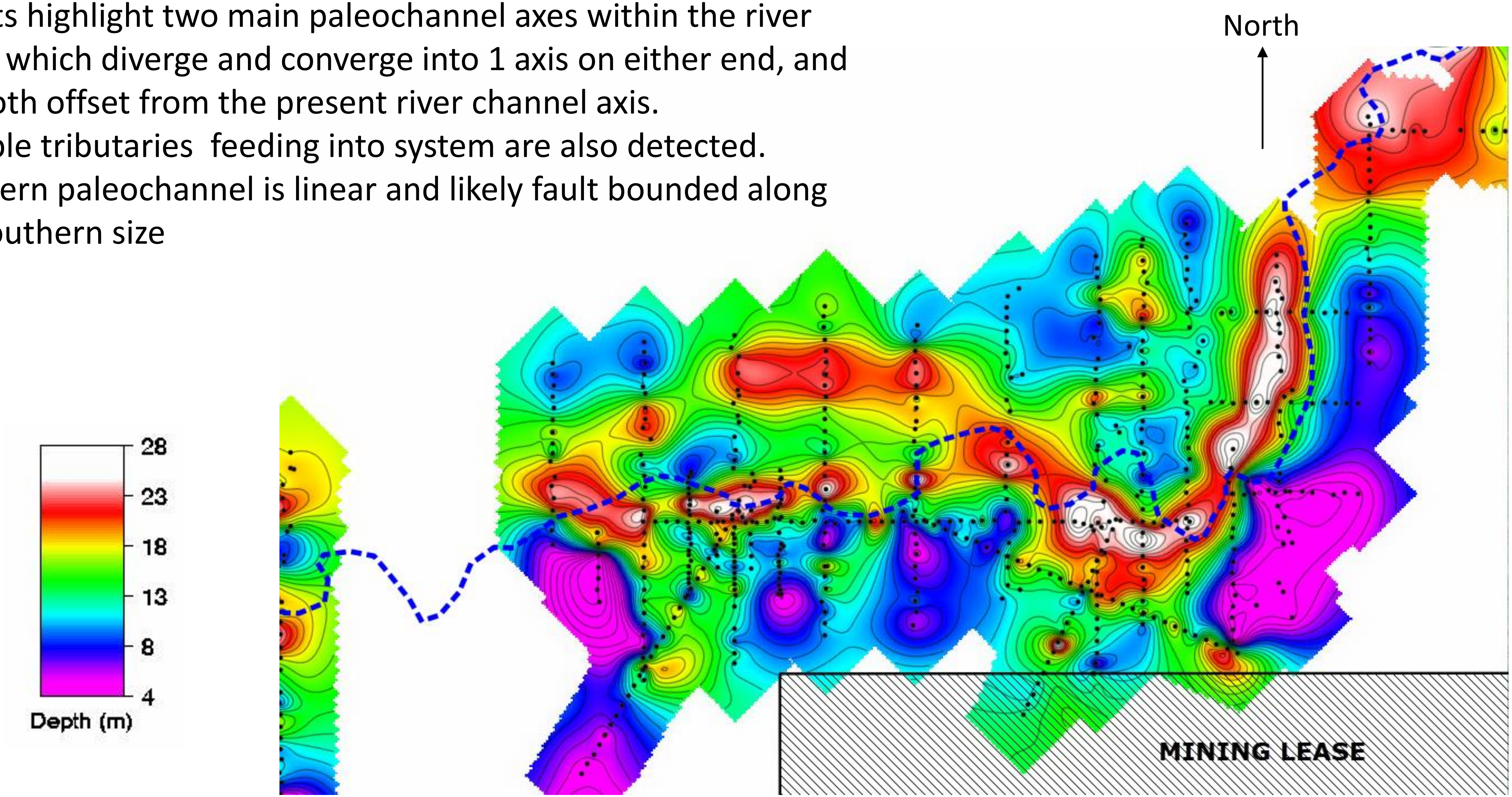
- Results highlight subtle, shallower acoustic impedance contrast over northern channel that are not coincident with modals, and are likely real clay, calcrete and/or silcrete layers.
- Clay deposits will impact the hydrogeological model, and could act as aquicludes to affect hydrological connectivity.



Chilalo Passive Seismic HVSR Survey – Paleochannel Targets

Resource Potentials

- Gridded modelled depth to main acoustic impedance contrast
- Results highlight two main paleochannel axes within the river valley which diverge and converge into 1 axis on either end, and are both offset from the present river channel axis.
- Possible tributaries feeding into system are also detected.
- Southern paleochannel is linear and likely fault bounded along the southern size



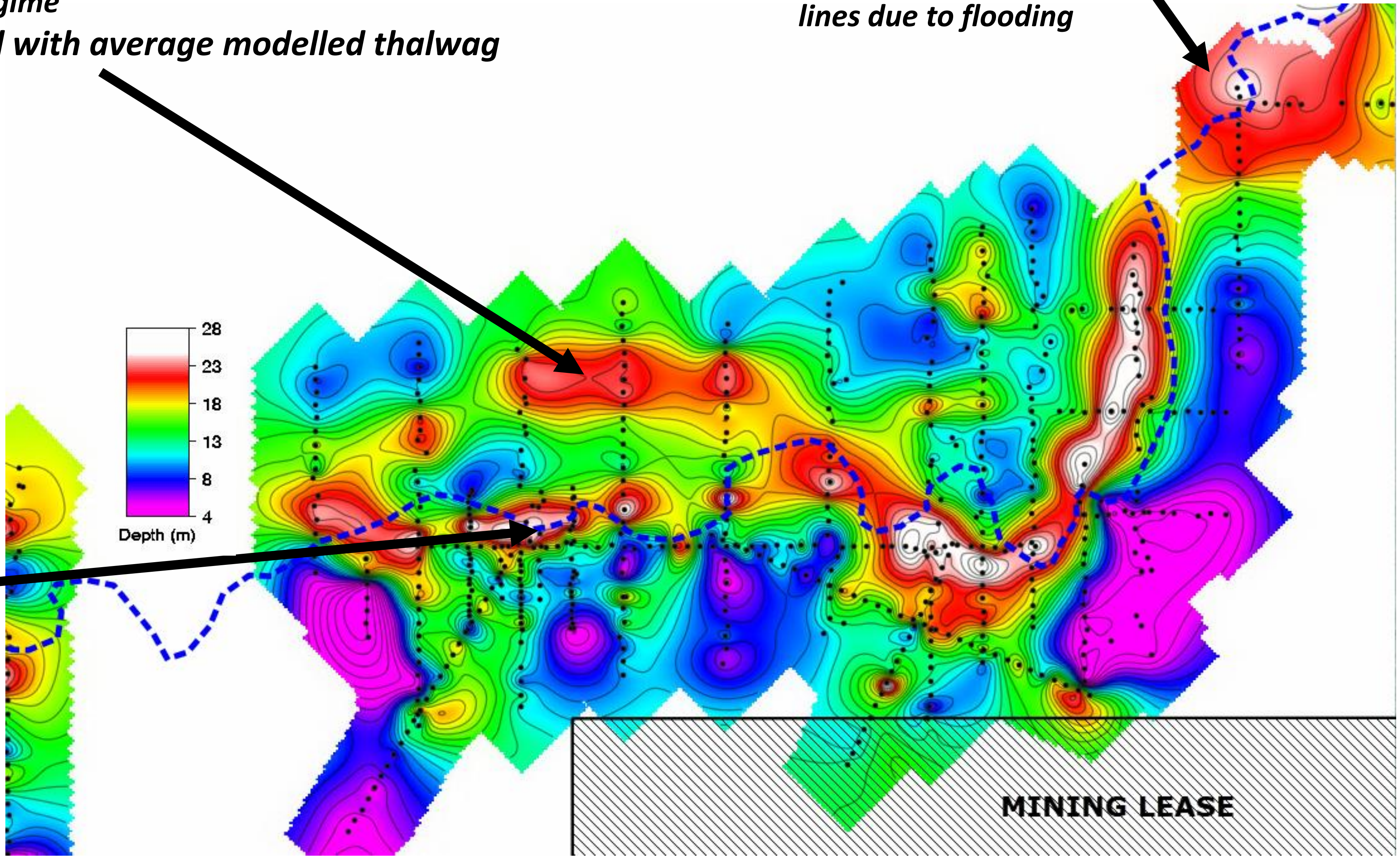
Chilalo Passive Seismic HVSR Survey – Paleochannel Targets

***Northern Paleochannel** – coincident with AEM conductor and shallow responses in passive seismic HVSR recordings – likely abundant clay layers deposited in a lower flow regime*

Meandering and wider channel with average modelled thalwag depth of 18m

Deepest modelled interface of +28m, and not closed off by survey lines due to flooding

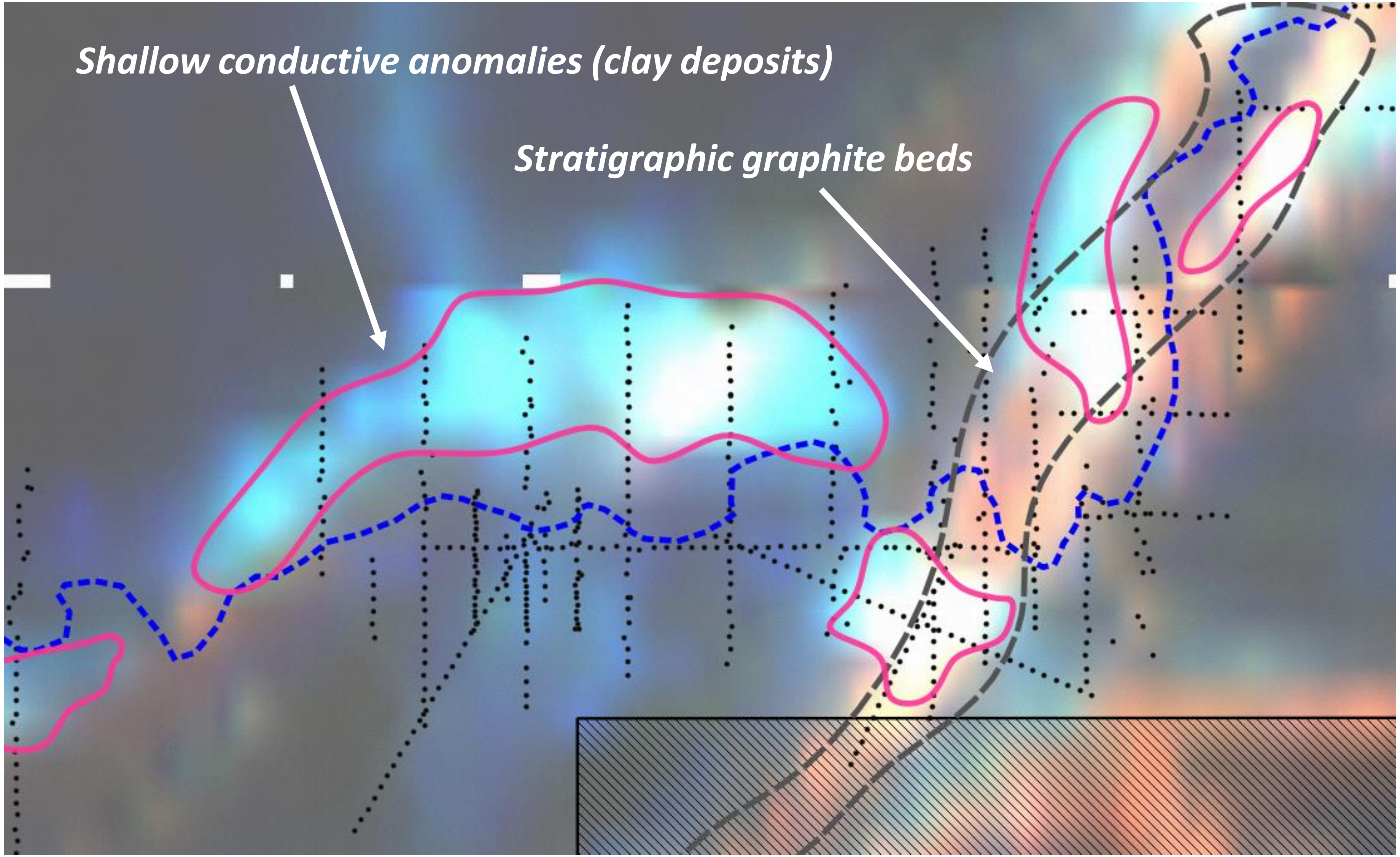
***Mainstream Paleochannel** – linear and narrow channel with average modelled thalwag depth of 25m. Very few shallower layer responses, and the fill deposits are likely coarse clastic sediments (sand and gravel)*



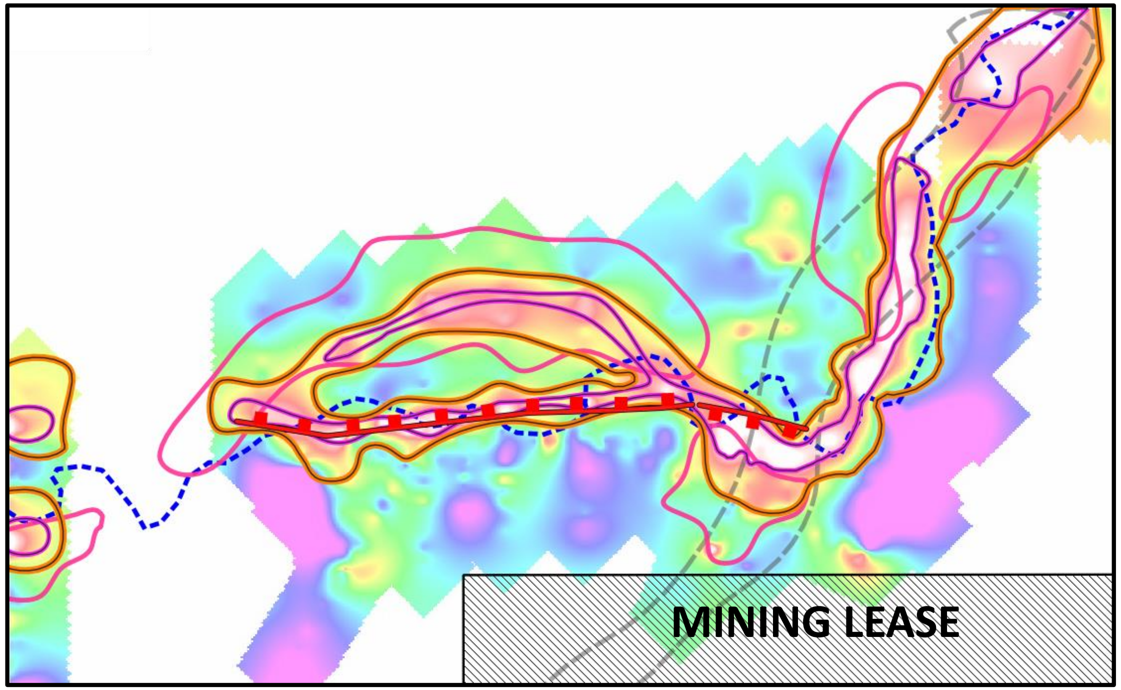
Chilalo Passive Seismic HVSR Survey – Airborne EM

- Blue colours represent shallow conductive anomalies coincident with shallow acoustic impedance contrast layering within the northern paleochannel based on passive seismic cross-sections.
- Red and white anomalies represent strong EM conductors – graphite units in bedrock (red), or a combination of graphite in bedrock and overlying weathered graphite and clay deposits (white).

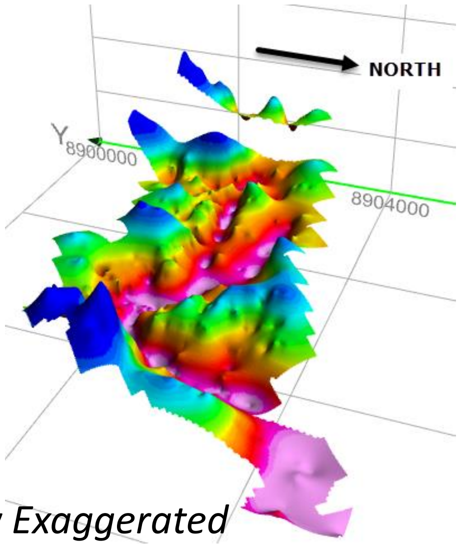
VTEM ternary RGB image where Red = ch15, Green = ch7, Blue = ch1



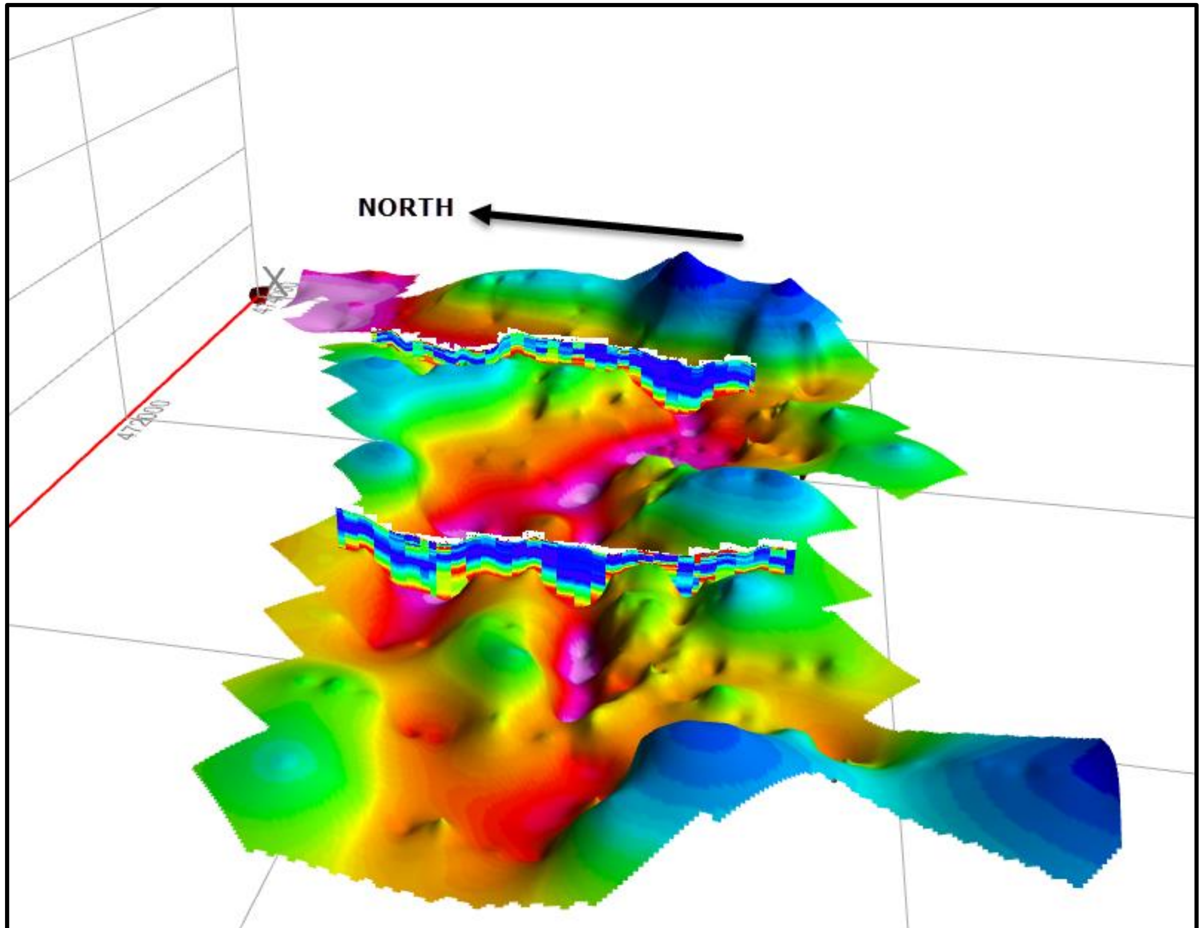
Chilalo Passive Seismic HVSR Survey Results – 3D View



This modelled bedrock depth surface can be used for aquifer volume estimation in the Mbewmburu River valley (hot colours are deep and cool colours are shallow).



Vertically Exaggerated

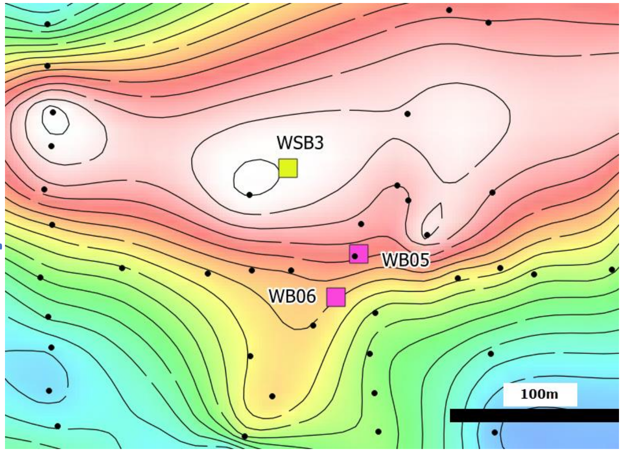


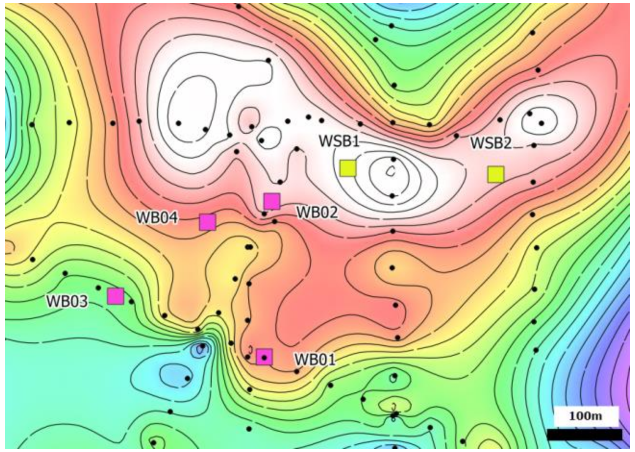
Vertically Exaggerated

Chilalo Passive Seismic HVSR Survey – Water Bore Phase 2

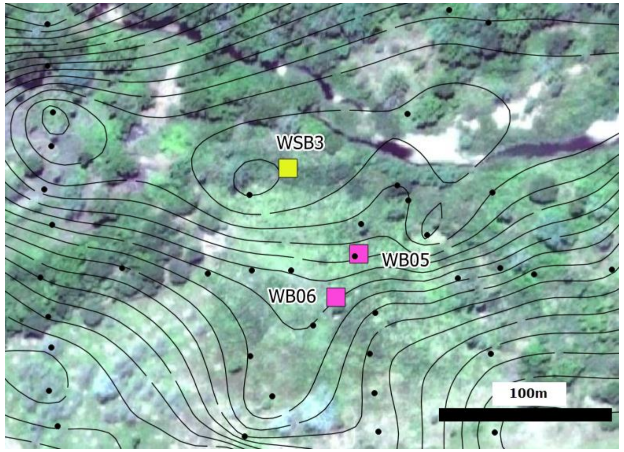
- Second phase of water bores completed during wet season 2019, so access was once again limited to south side of the river.
- Only 3 water bores completed, but this time we were targeting the deep parts of the paleochannel system.
- Coarse fluvial sands were intersected where expected, bedrock occurred at predicted depths, and flow rates were substantial and very encouraging.
- More drilling is required upstream and downstream to monitor pumping effects on the surrounding water table level.

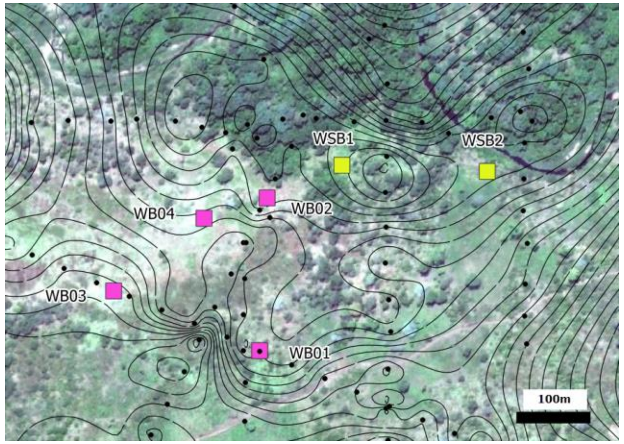
Modelled bedrock depth

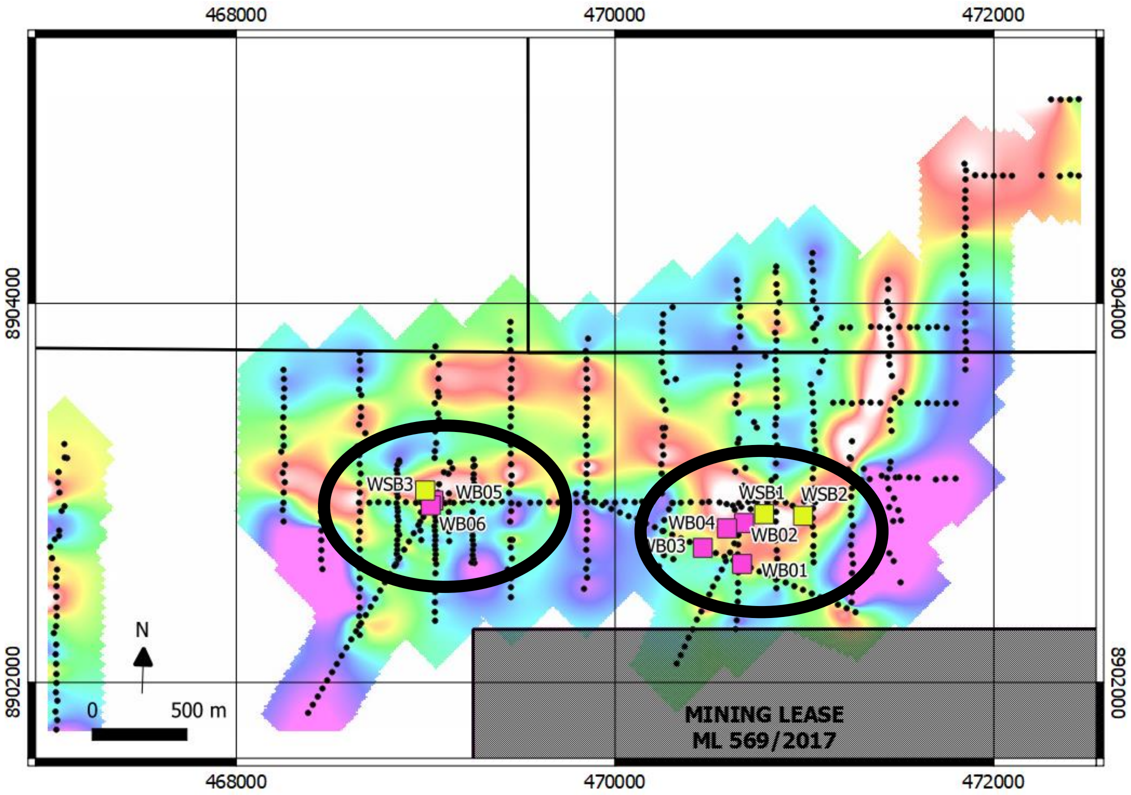




Google Earth with bedrock depth contours

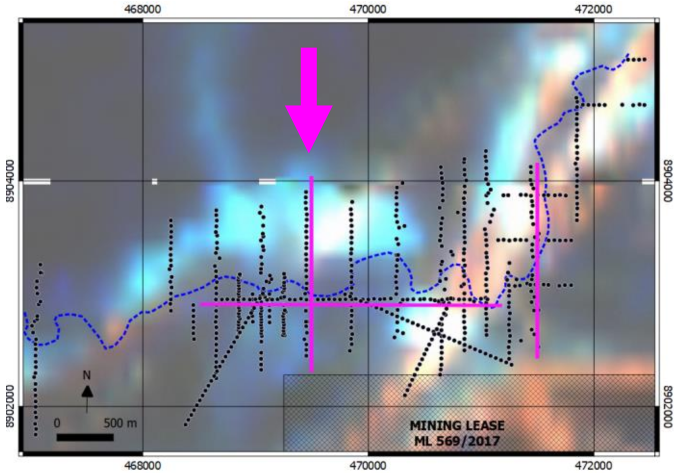






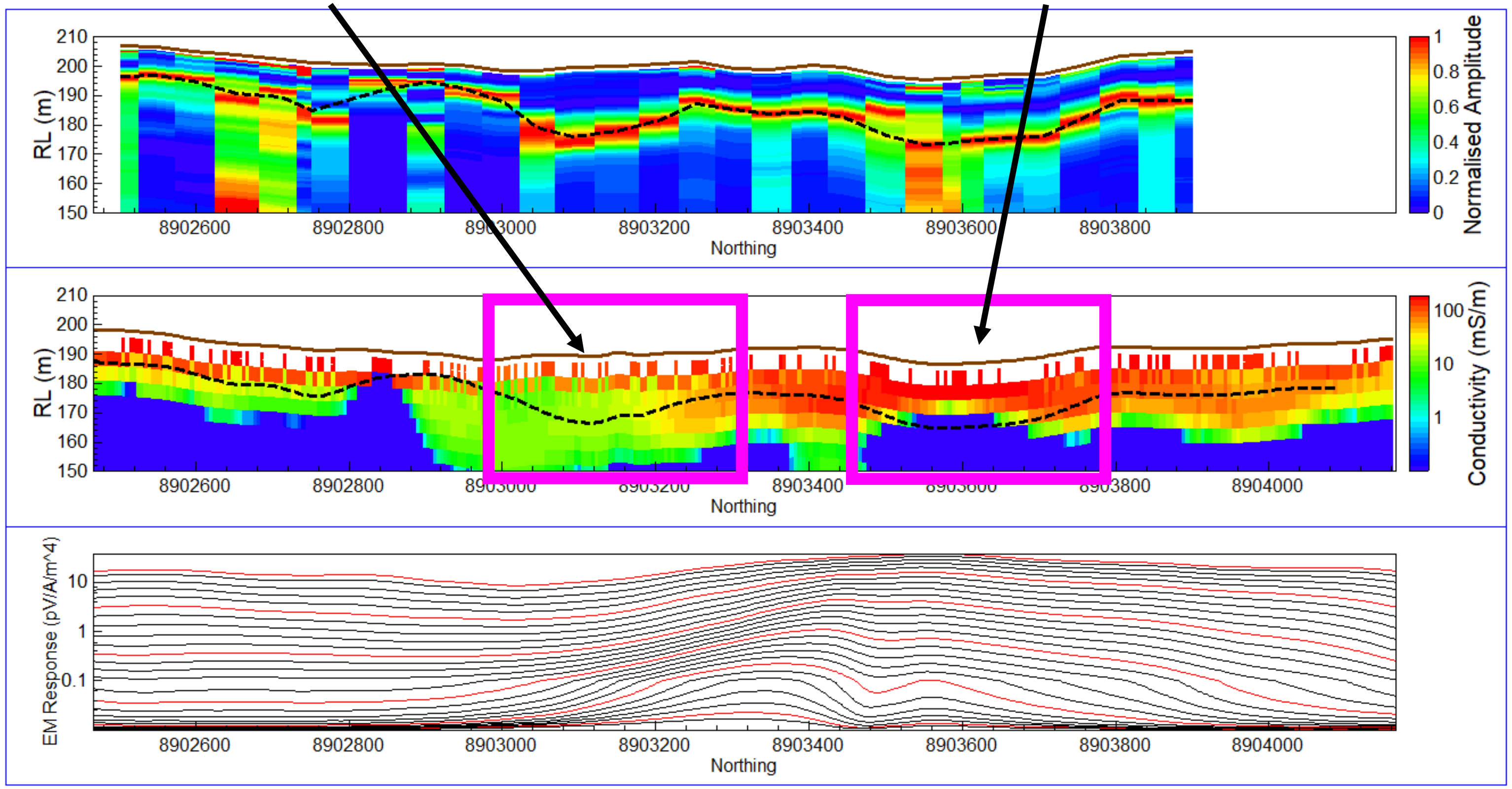
Passive Seismic – AEM comparison

- AEM and passive seismic results are highlighting two very different physical properties: Vs and conductivity.
- Although AEM is useful for hydrogeological study at broad scale, such as for identifying fluvial clay deposits, the passive seismic method was far superior for identifying fluvial deposit thickness and paleochannel geometry for direct drill targeting and volume estimation.



AEM over estimated

AEM under estimated



Passive seismic cross-section with main acoustic impedance contrast

Airborne EM conductivity-depth inversion results with main passive seismic fresh bedrock horizon / acoustic impedance contrast layer

VTEM Z dB/dt EM decay profiles

Conclusions

- Passive seismic successfully identified groundwater targets in the form of paleochannels and interpreted thick fluvial deposits (coarse vs clay deposit layers) that have potential to supply the required volume of groundwater for the mine site and graphite ore processing.

- Paleochannel axes detected from passive seismic surveying are offset from the present river channel, with modelled bedrock depth ranging from <4m to >28m.

- Northern paleochannel interpreted from passive seismic and VTEM data as a shallower and wider channel system with higher concentrations of clay likely deposited under a lower flow regime.

- Southern paleochannel currently represents the best target for significant groundwater reserves, due to thicker and coarser fluvial deposits, allowing for higher water content and hydraulic connectivity along the length of the river valley system, linking to a large catchment area with recharge potential.

- Preliminary pumping tests show that better yields are obtained from bores located close to thickest fluvial deposits determined from passive seismic surveying.

- Initial hydrogeological study results pending, likely more bore holes and test wells required, as well as extending the passive seismic surveying to the NE DURING THE DRY SEASON.

Acknowledgments

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