

# Resource definition through geophysics:

## Case studies from a nickel laterite mine

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*ASEGWA, 24 November 2021*



# Acknowledgements

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**Lucy Soares (Curtin MSc – Andrew Pethick)**



**Tom Dronfield, (Matt Owers)**



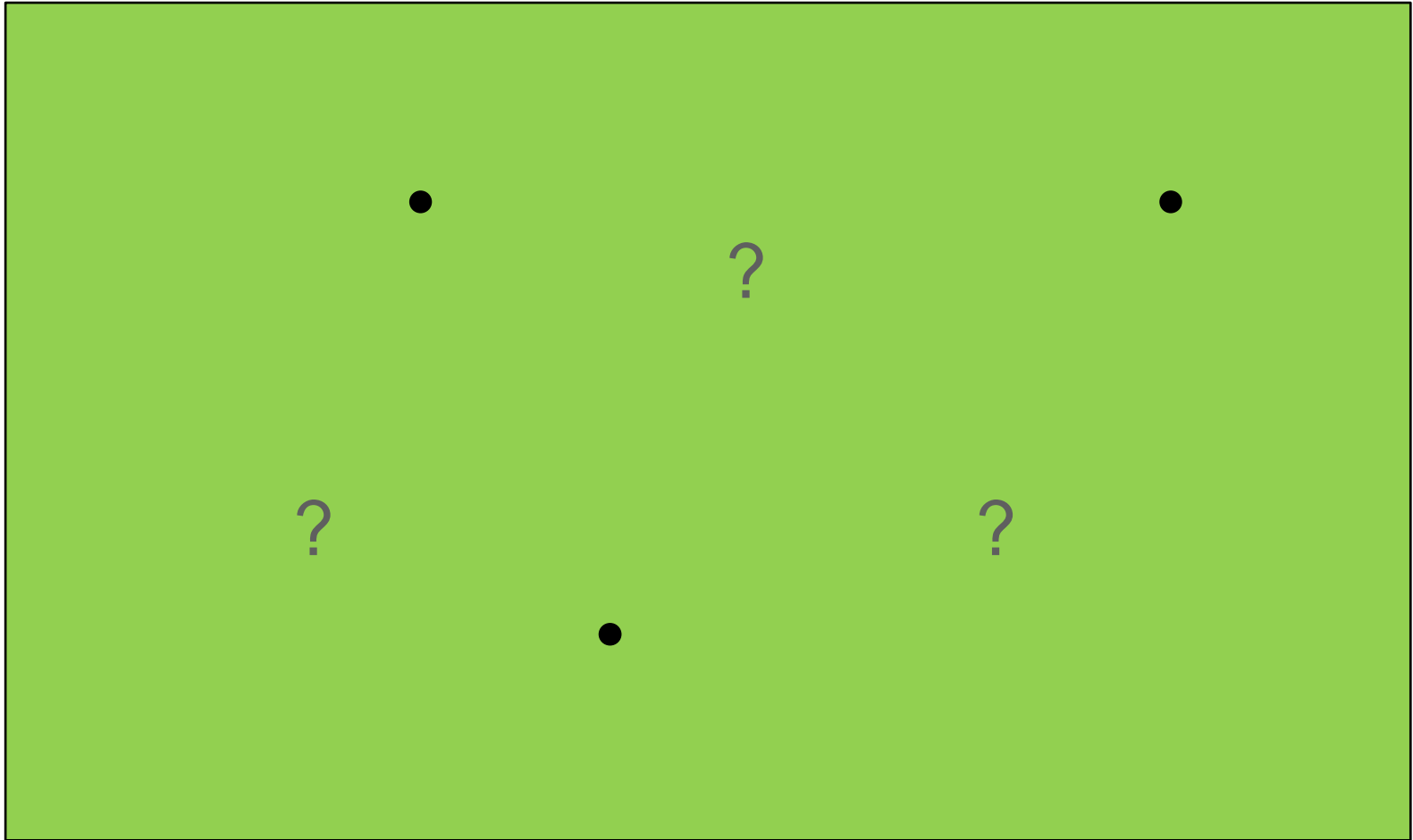
**Jan Francke**



**Andrew Duncan, Greg Street**

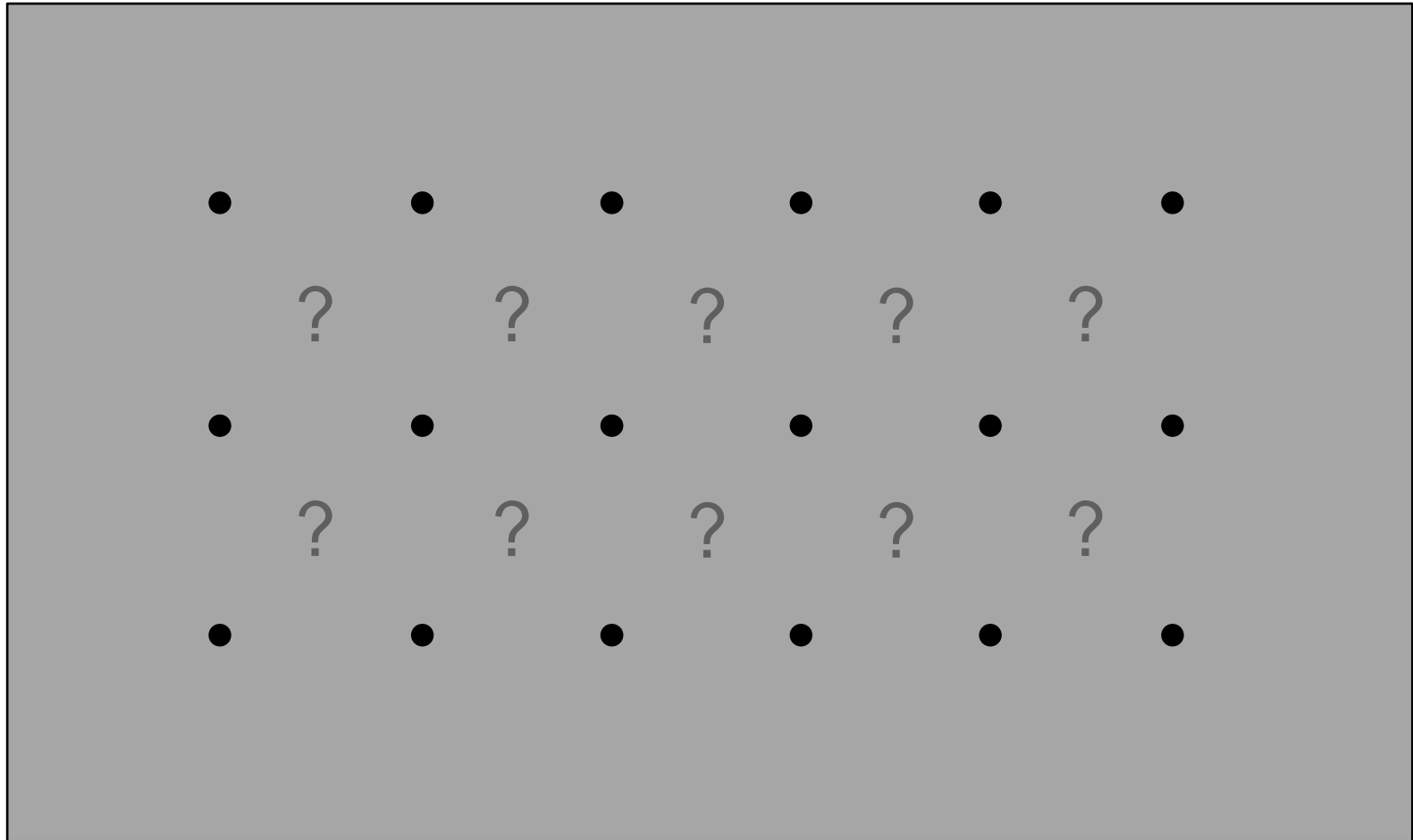
# Geophysics - the space filler

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# Geophysics vs drillhole information

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- RC hole diameter = 14 cm (5.5 in)
- Grade control with 10 m hole spacing
  - one hole per mining block
- Volume of drill hole per mining block = **0.015%**
- DDH (HQ) at 50 x 50 m → **0.000127 % = 1.27 ppm**  
→ **999,999 ppm unsampled!**

**Geophysics is the only option for filling in the space between drillholes with measured data**



# Trial methods

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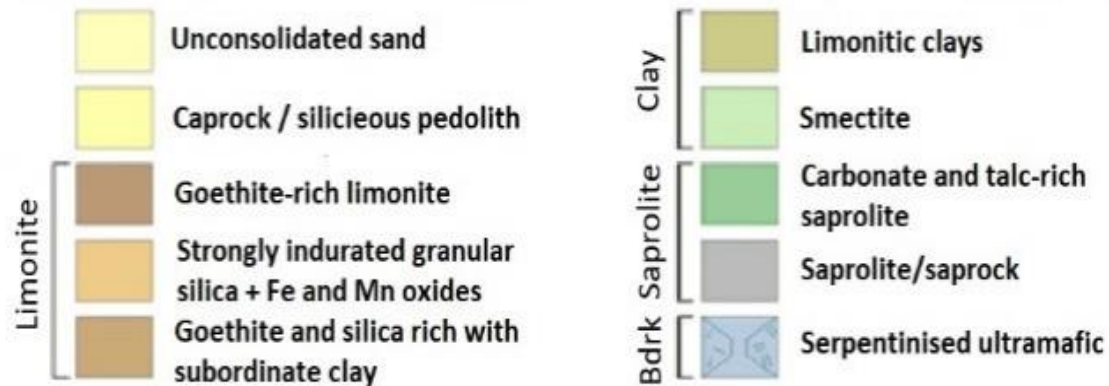
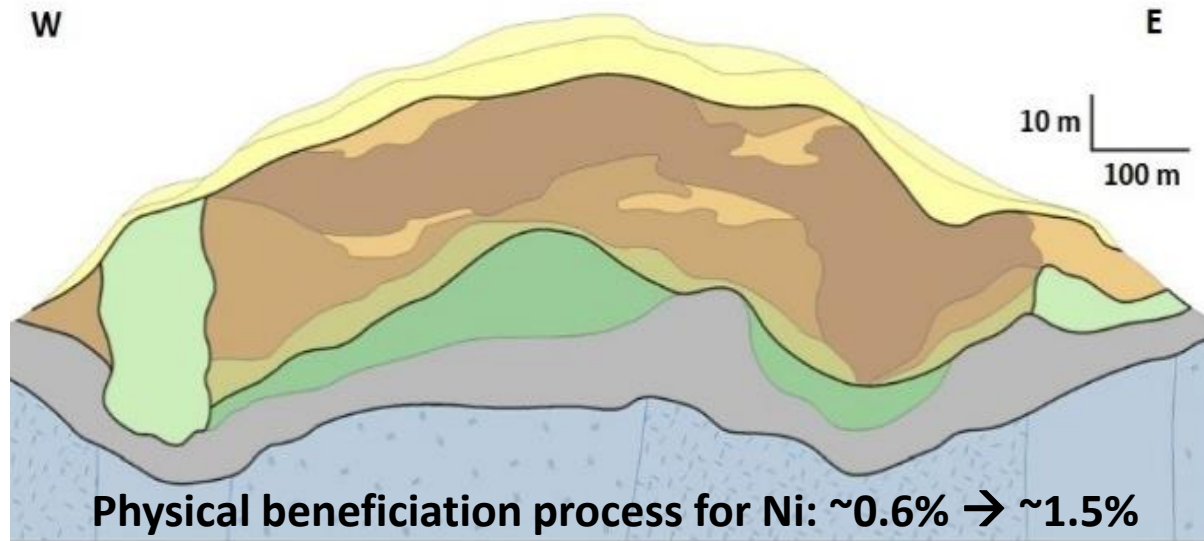
- **UAV magnetics:** structural and lithological mapping
  - **Passive seismic:** single station HVSR
  - **GPR:** Amira P1187 project → magnetic dipole Rx/Tx
  - **TEM:** Loupe backpack system
  - **Petrophysical logging:** material properties
    - Density, natural gamma, conductivity, magnetic susceptibility
  - **Ground gravity:** resource density modelling
- successful method: rapid, high spatial resolution, accurate depth



# Ravensthorpe location



# Ravensthorpe schematic geology



# Ravensthorpe: model this ...

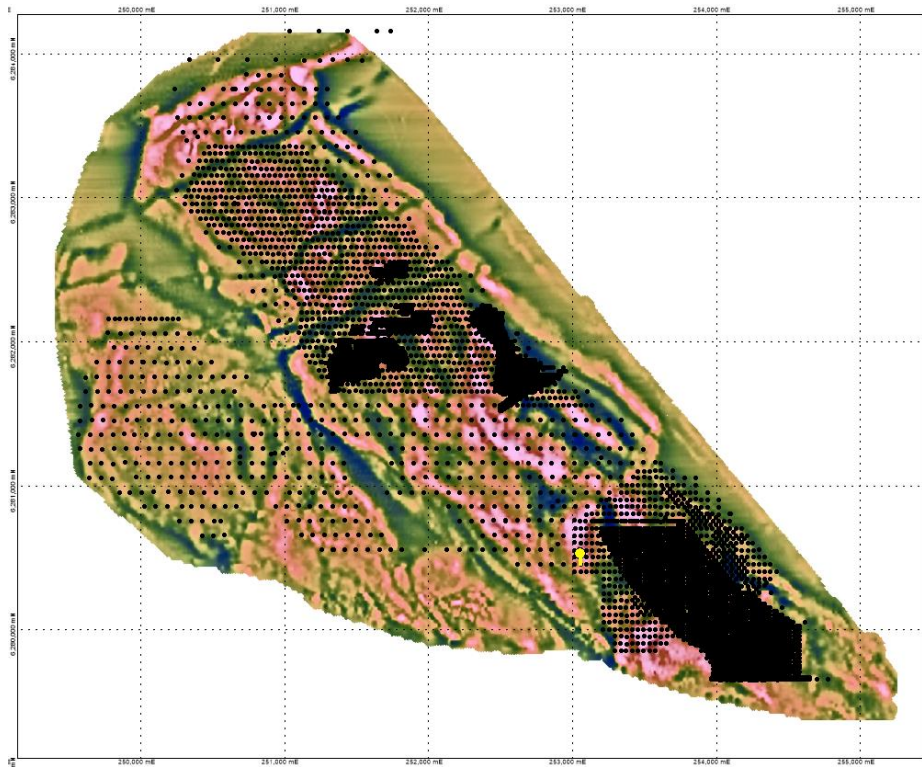
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- Grade control 10 x 12.5 m or 20 x 25 m
- Remember the 0.015% sampling ...



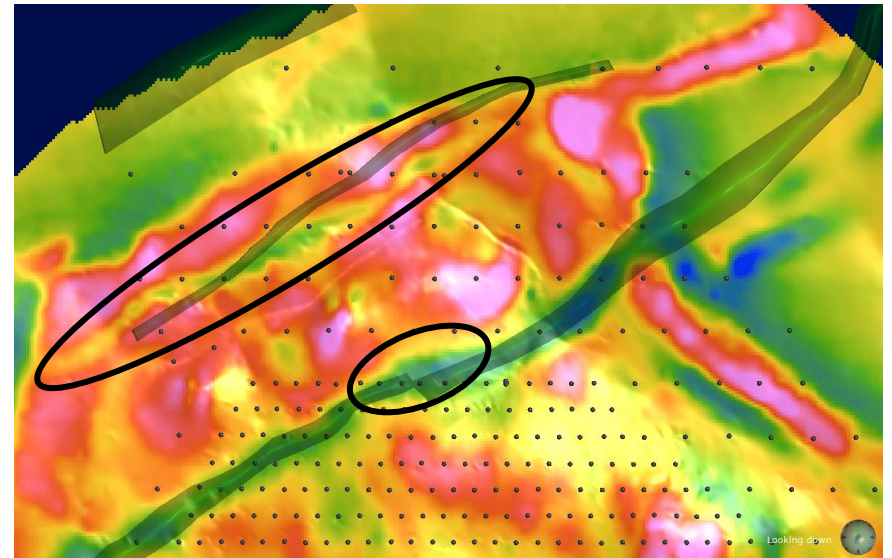
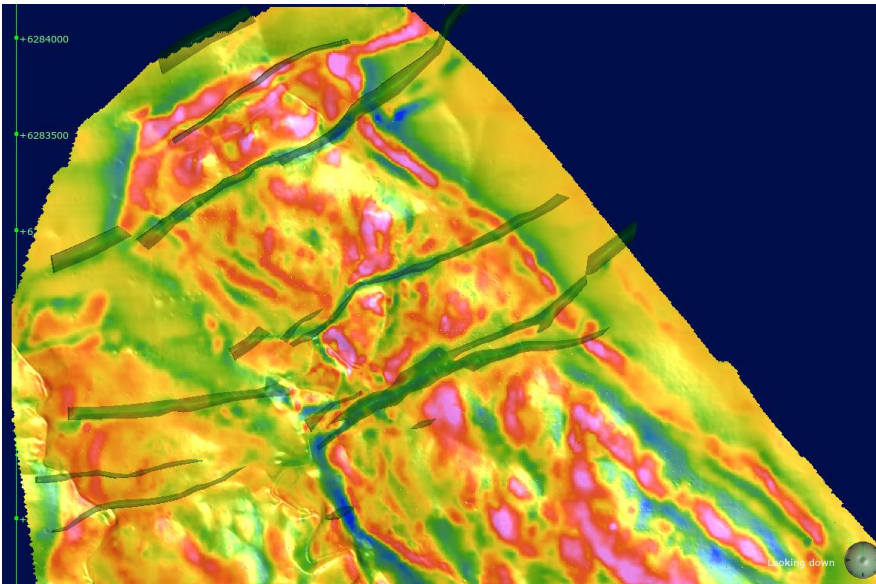
# UAV magnetics

- Define underlying ultramafic extents
- Map later mafic dikes that dilute grade
- Map structure that controls weathering depth



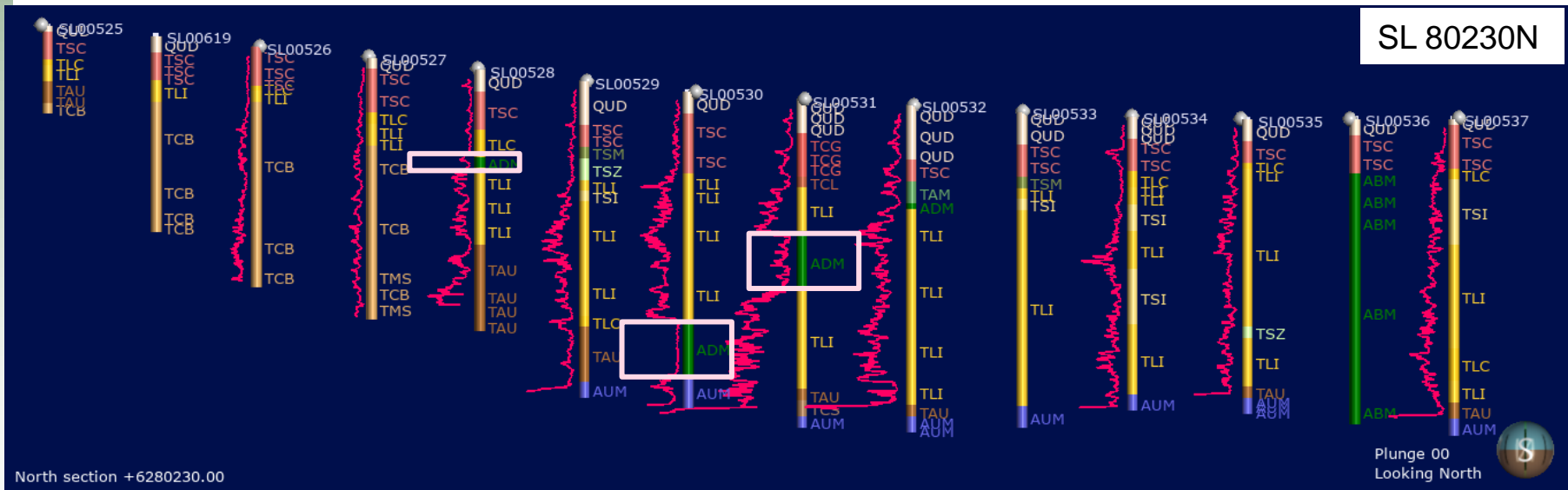
# UAV mag to guide mafic dike interp

- Missed dikes and structural offsets, refine geometry in sparse drilling areas



# Magnetic susceptibility vs lithology

- Younger mafic dikes are uniformly non-magnetic, dikes appear as magnetic lows in ground/UAV data



All very low values in regolith, average  $5.4 \times 10^{-3}$  SI

# Passive seismic: HVSR sounding

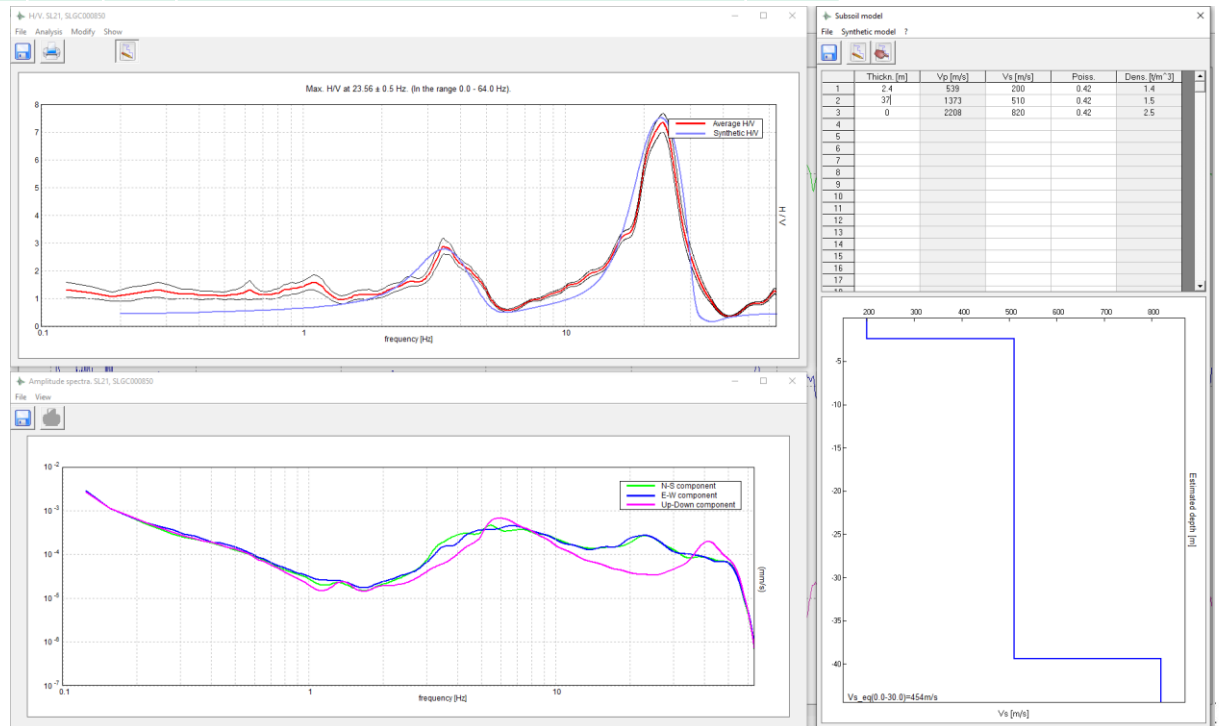
## Geology

HoleID	From	To	Lith	Description	Colour
SLGC000850	0	6	TSH	Caprock - leached; cellular / honeycomb textured silica	YLBR
SLGC000850	6	17	TSC	Caprock - Siliceous duricrust & leached silica & kaolin clay	NGY
SLGC000850	17	22	TLI	Limonite - Goethite - silica rich; w-m indurated laterite	BR
SLGC000850	22	24	TSI	Limonite - Silica dominated; goethitic; s.indurated laterite	DKBR
SLGC000850	24	39	TAU	Saprolite - Clay (major) +- Fe +- Si altered	BR
SLGC000850	39	46	AUM	Ultramafic -Undifferentiated Ultramafic	NGY

## Model

First interface – 2.4m  
– sand (unconsol) to caprock

Second interface – 39m  
– saprolite to saprock

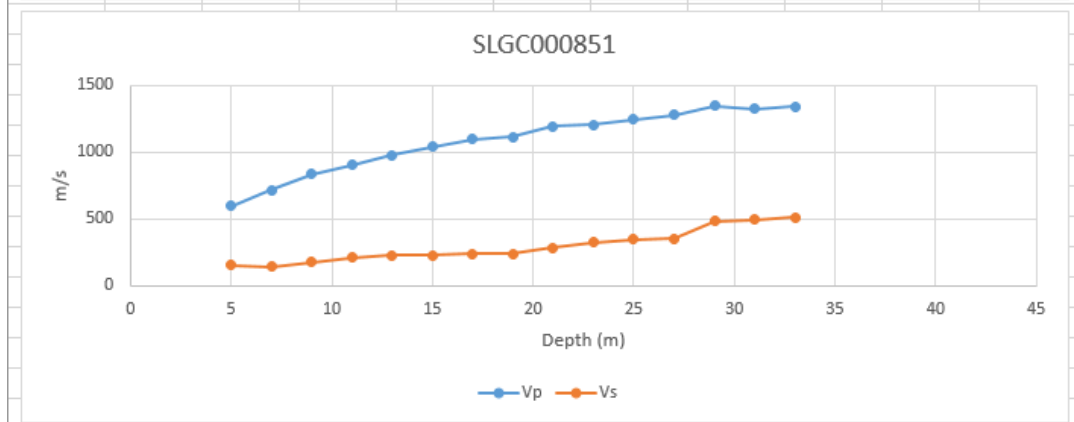
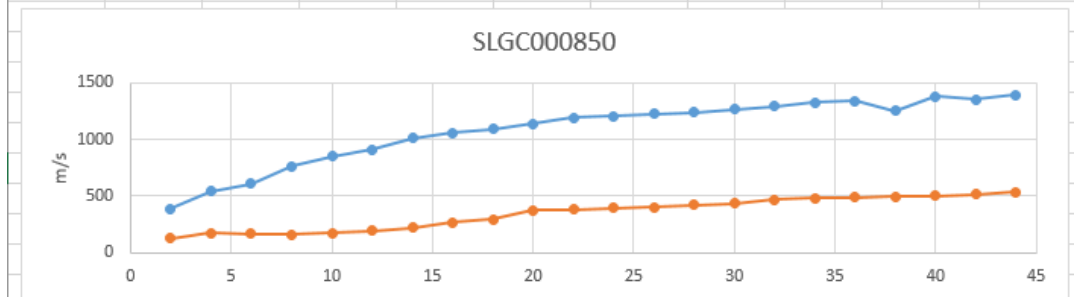
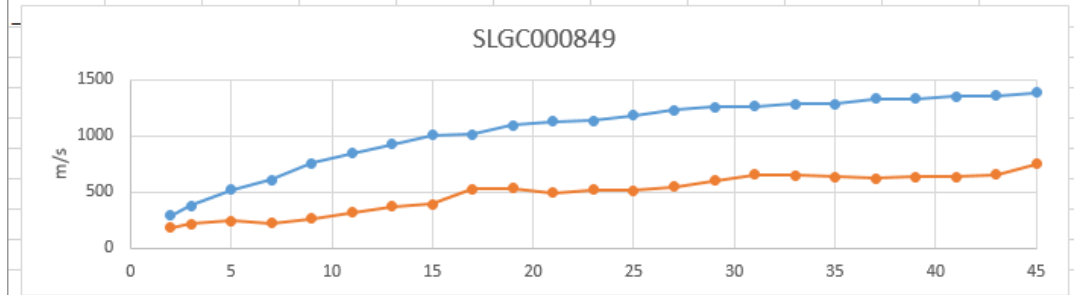


# VSP velocities

Modelling  
 $150 \text{ m/s} < V_s < 800 \text{ m/s}$

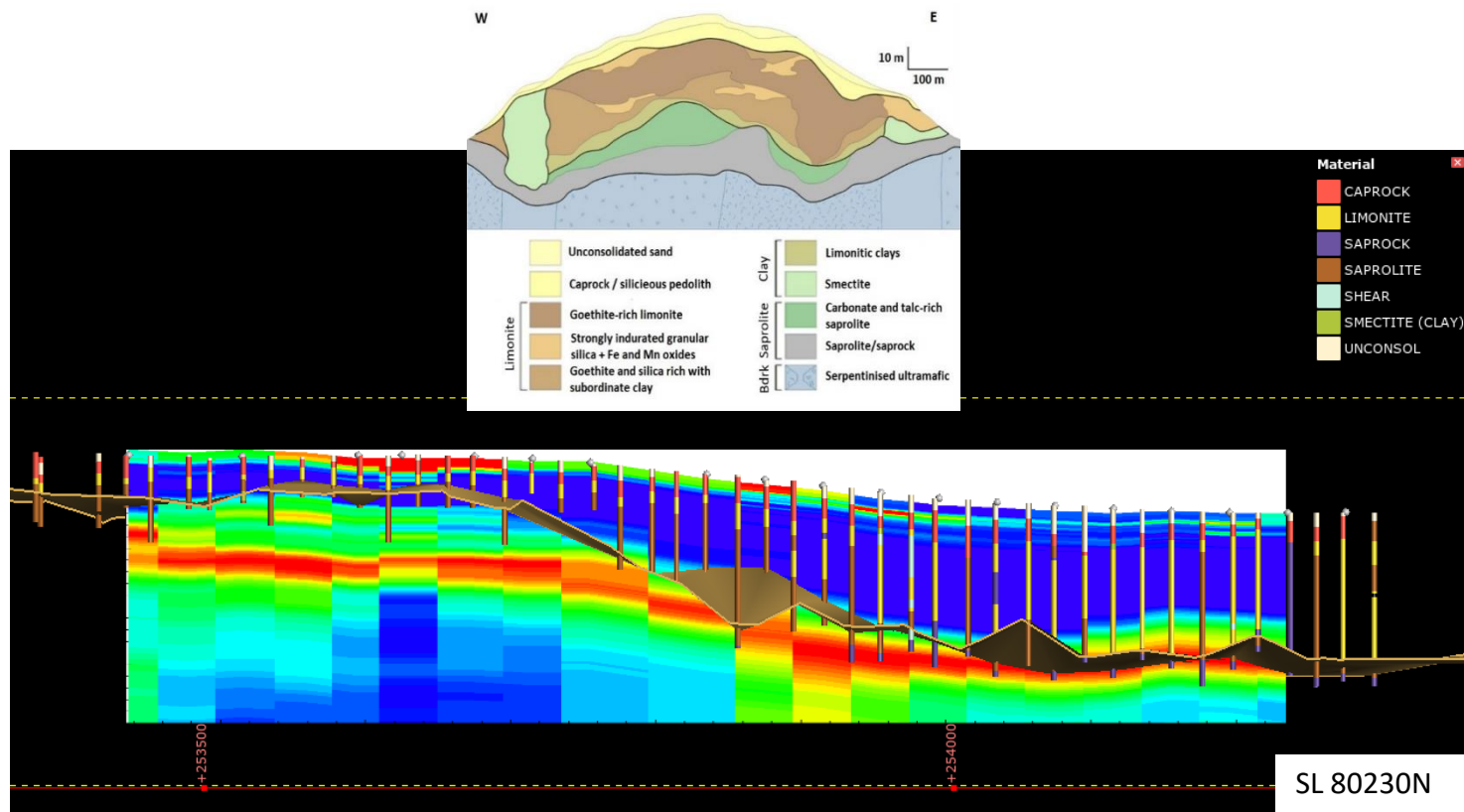
Subsoil model					
File Synthetic model ?					
	Thickn. (m)	Vp [m/s]	Vs [m/s]	Poiss.	Dens. (t/m <sup>3</sup> )
1	2.4	539	200	0.42	1.4
2	37	1373	510	0.42	1.5
3	0	2208	820	0.42	2.5
4					
5					
6					
7					

VSP Data depth-averaged velocities



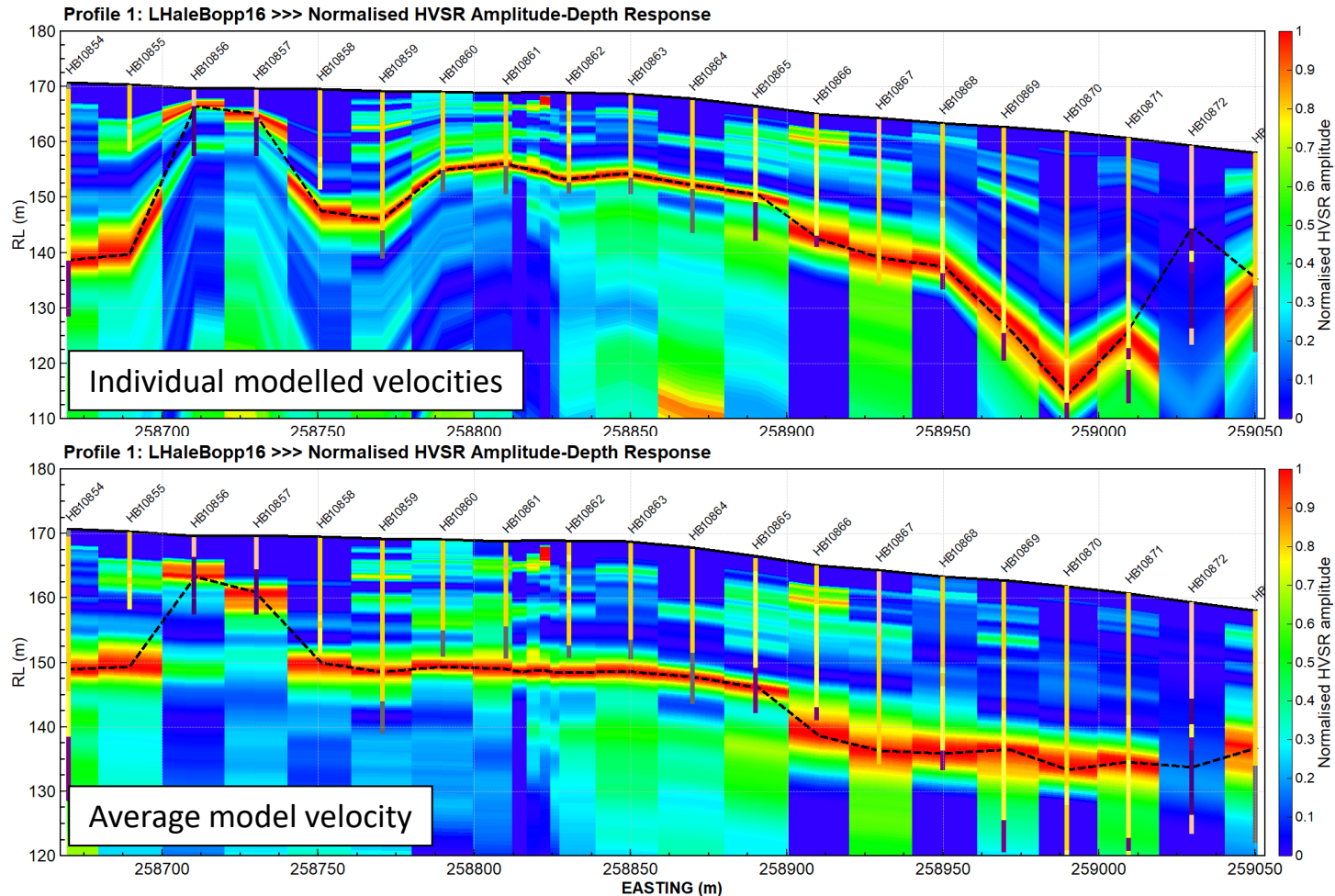
# Passive seismic (HVSR)

- Picking top of saprock/fresh rock, Vs contrast where weathering drops off



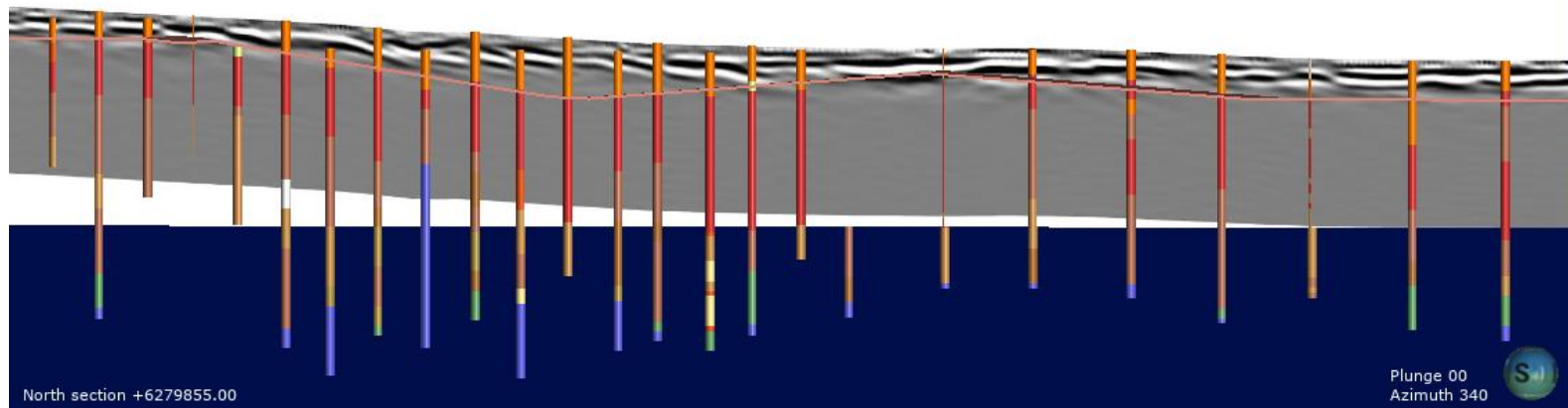
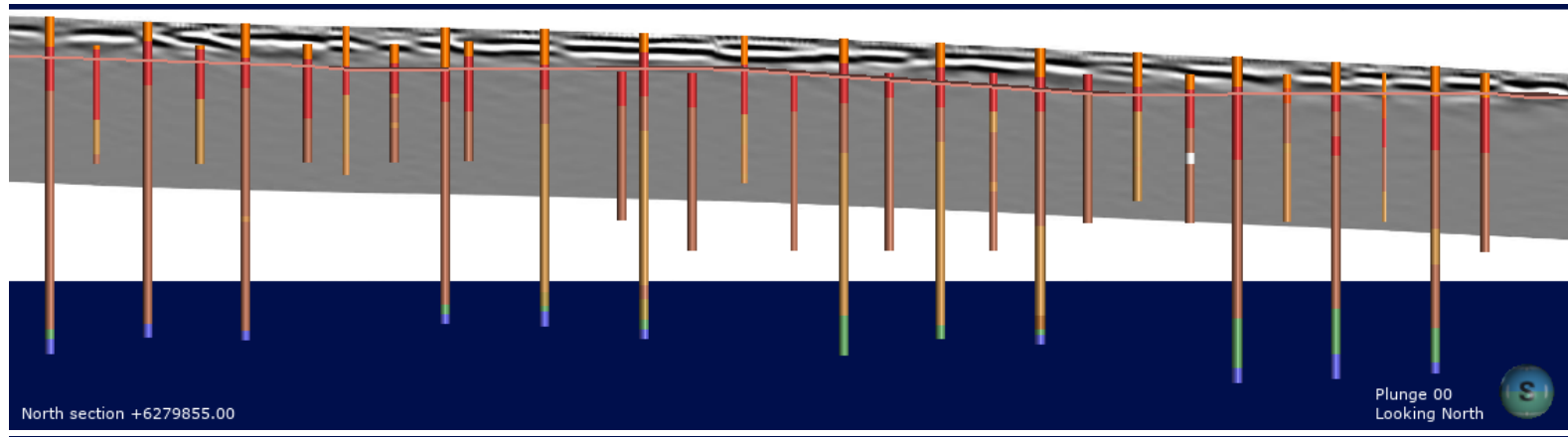
# Passive seismic (HVSr)

- Accuracy insufficient to predict interfaces for mining



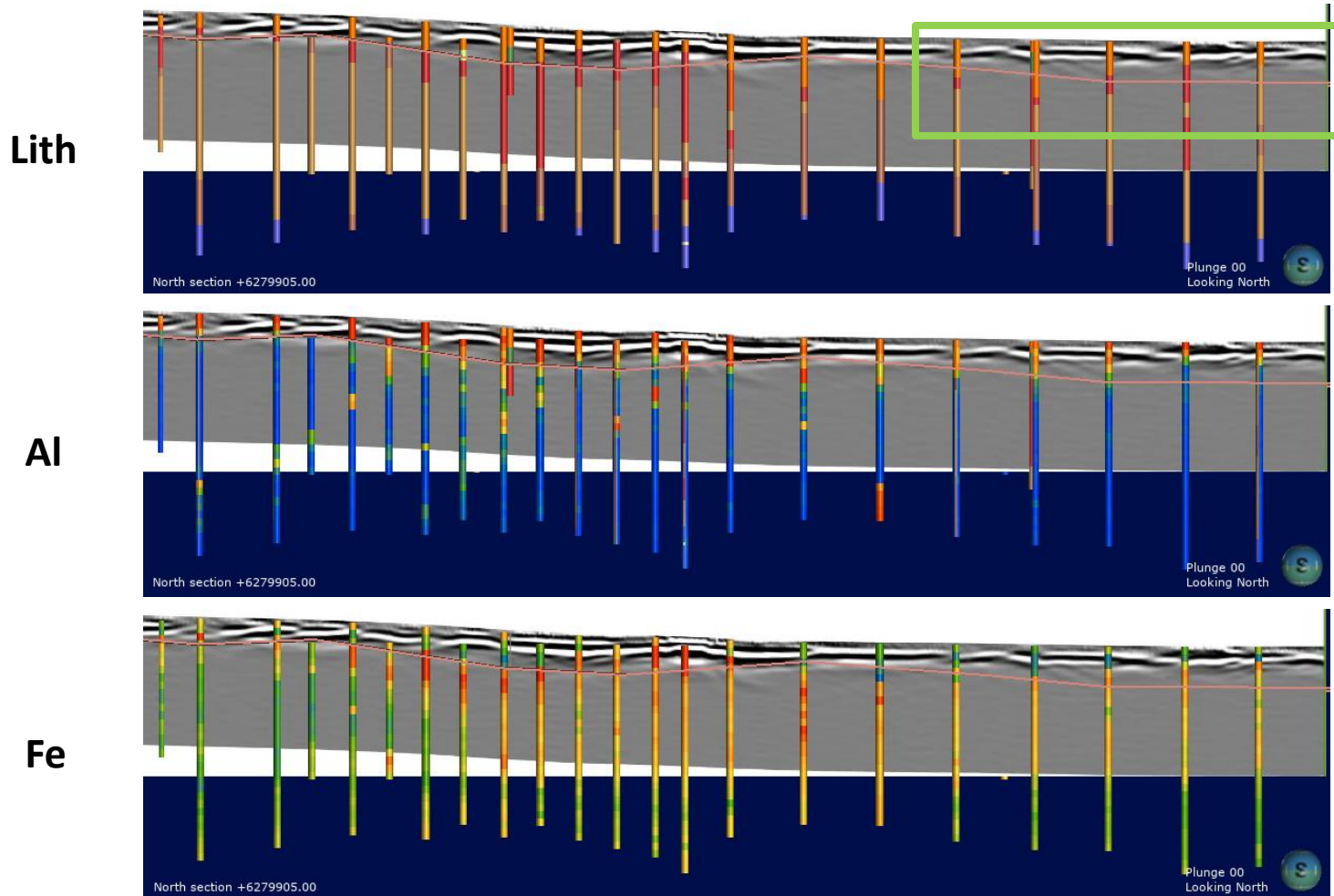
# Ground penetrating radar (18 MHz)

- GPR maps sand/caprock as zone of reflectivity
  - Absence of reflectivity below caprock = clay/moisture



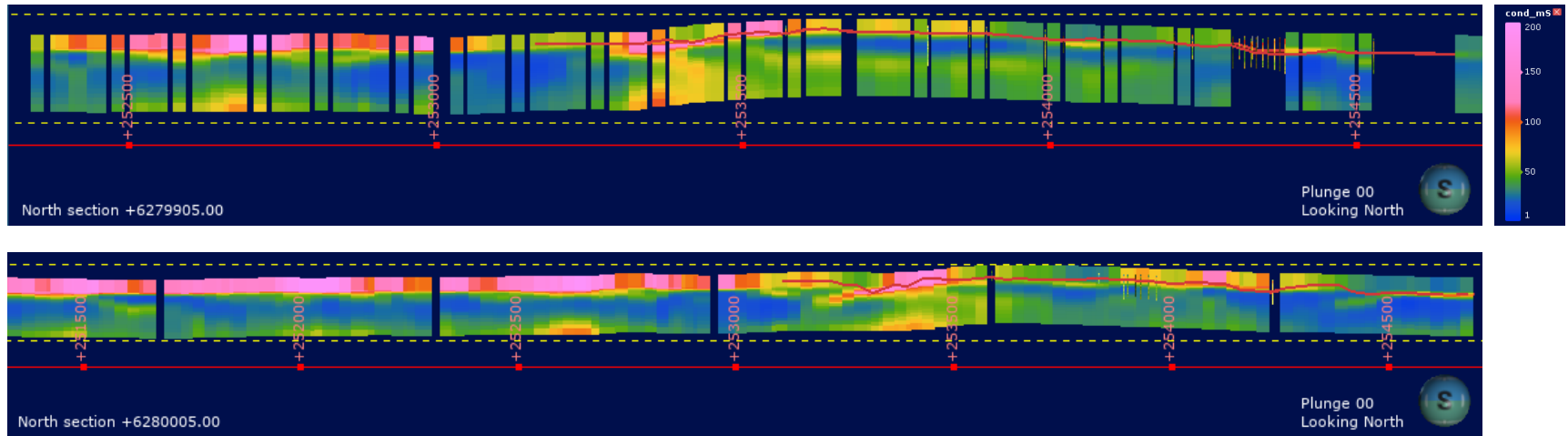
# Ground penetrating radar (18 MHz)

- GPR has the accuracy to map between drillholes

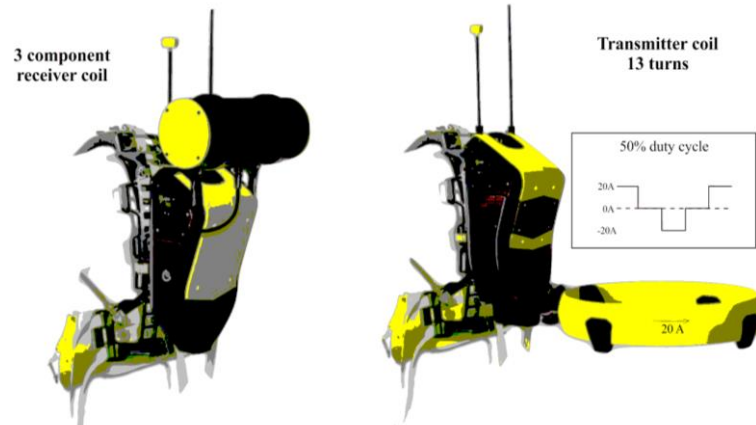


# Ground EM

- Motivation from AEM (low-moment SkyTEM)

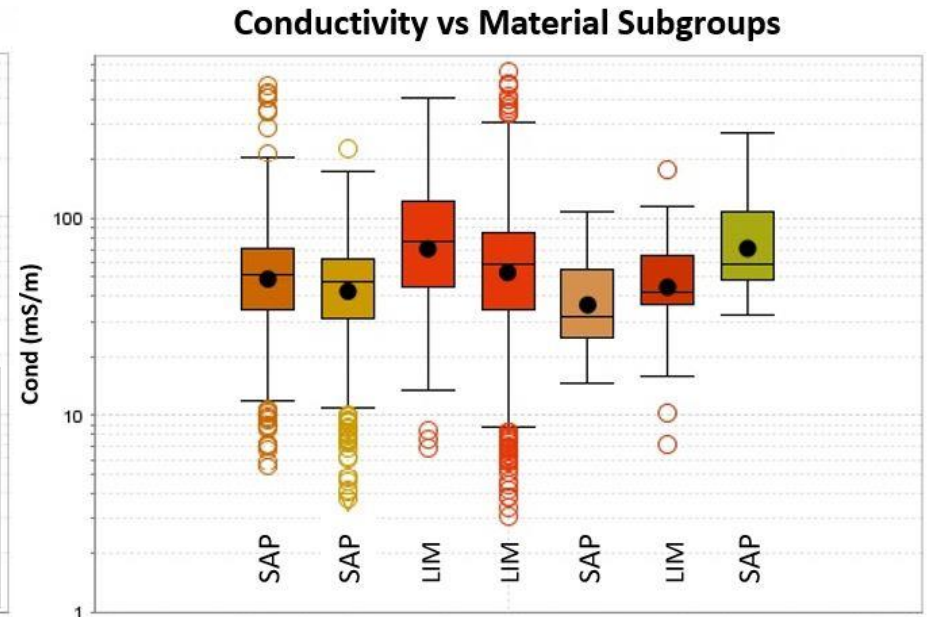
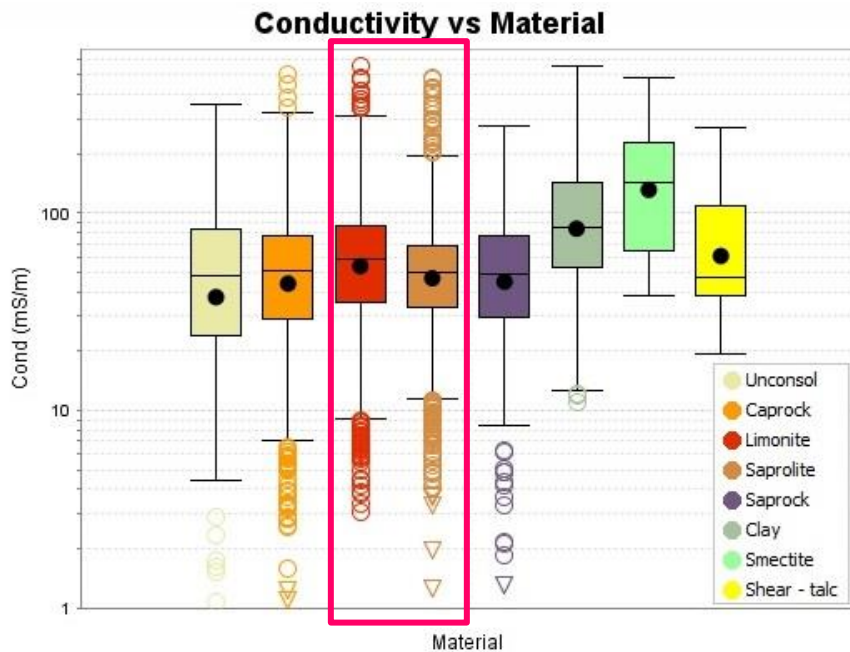


Parameters	SkyTEM (low moment)	Loupe TEM
Current	39 A	20 A
Peak moment	12,246 Am <sup>2</sup>	90.76 Am <sup>2</sup>
Tx height	30 m	1 m
Duty cycle	50 %	50 %
Base frequency	222.22 Hz	75 Hz
Total listen time	1 ms	2.731 ms
Tx ramp off time	9.58 μs	8 μs



# Conductivity logging

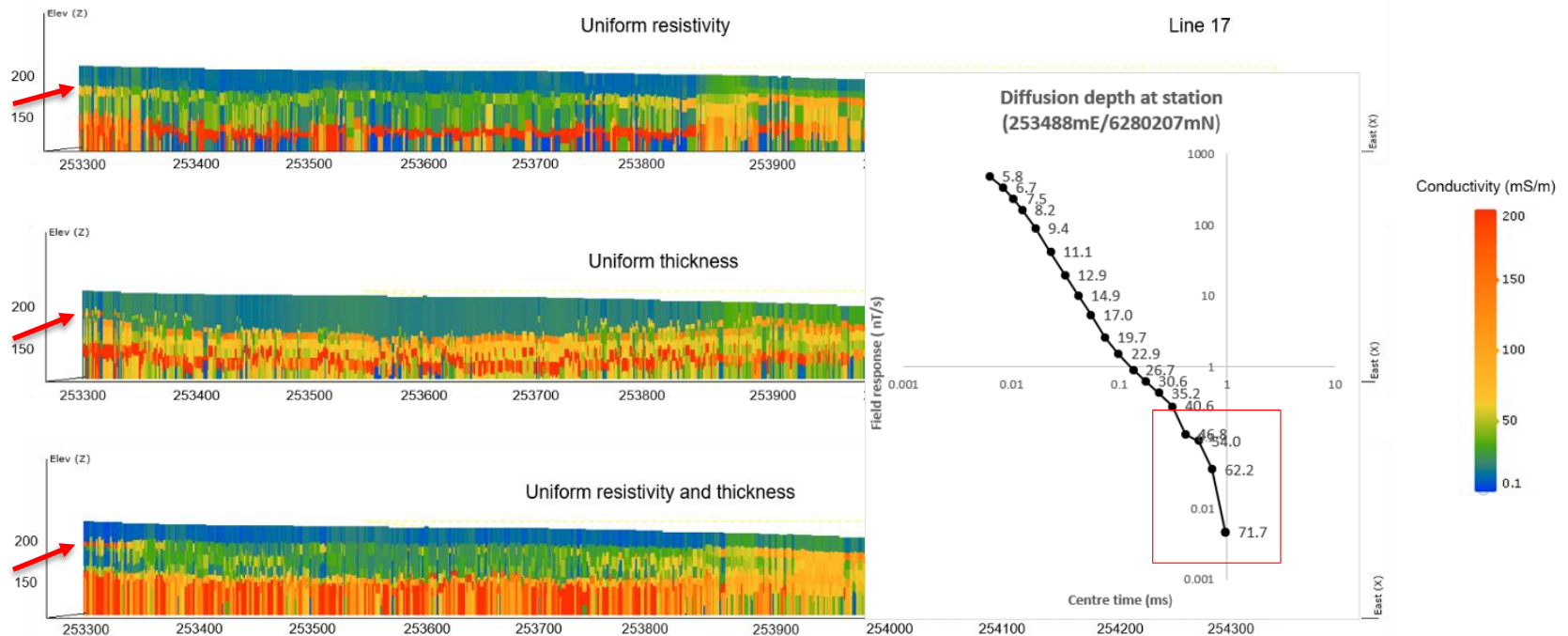
- Disappointment ...





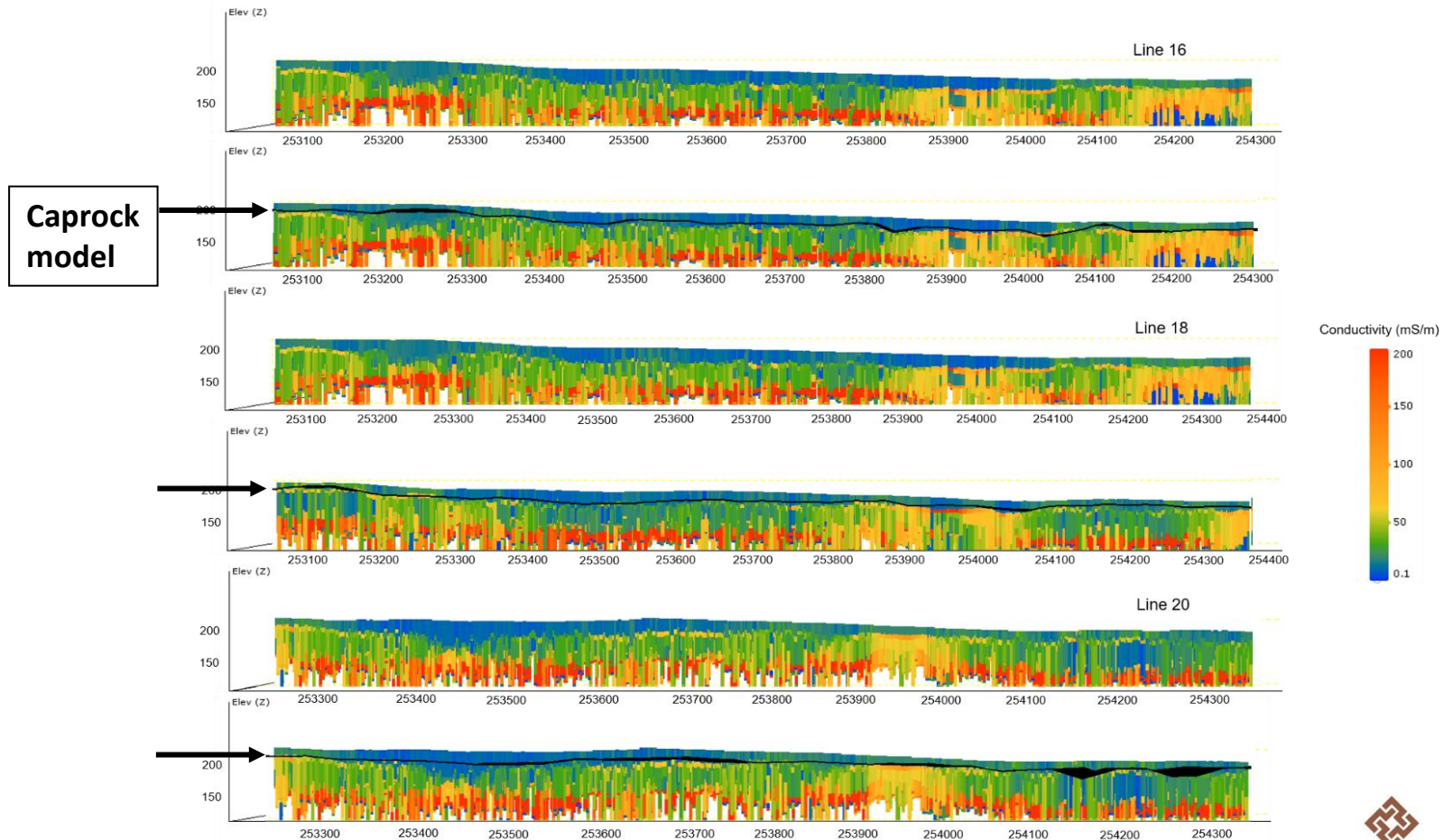
# Loupe TEM inversions

- Mapping caprock and thin conductive layer beneath caprock are both robust inversion results



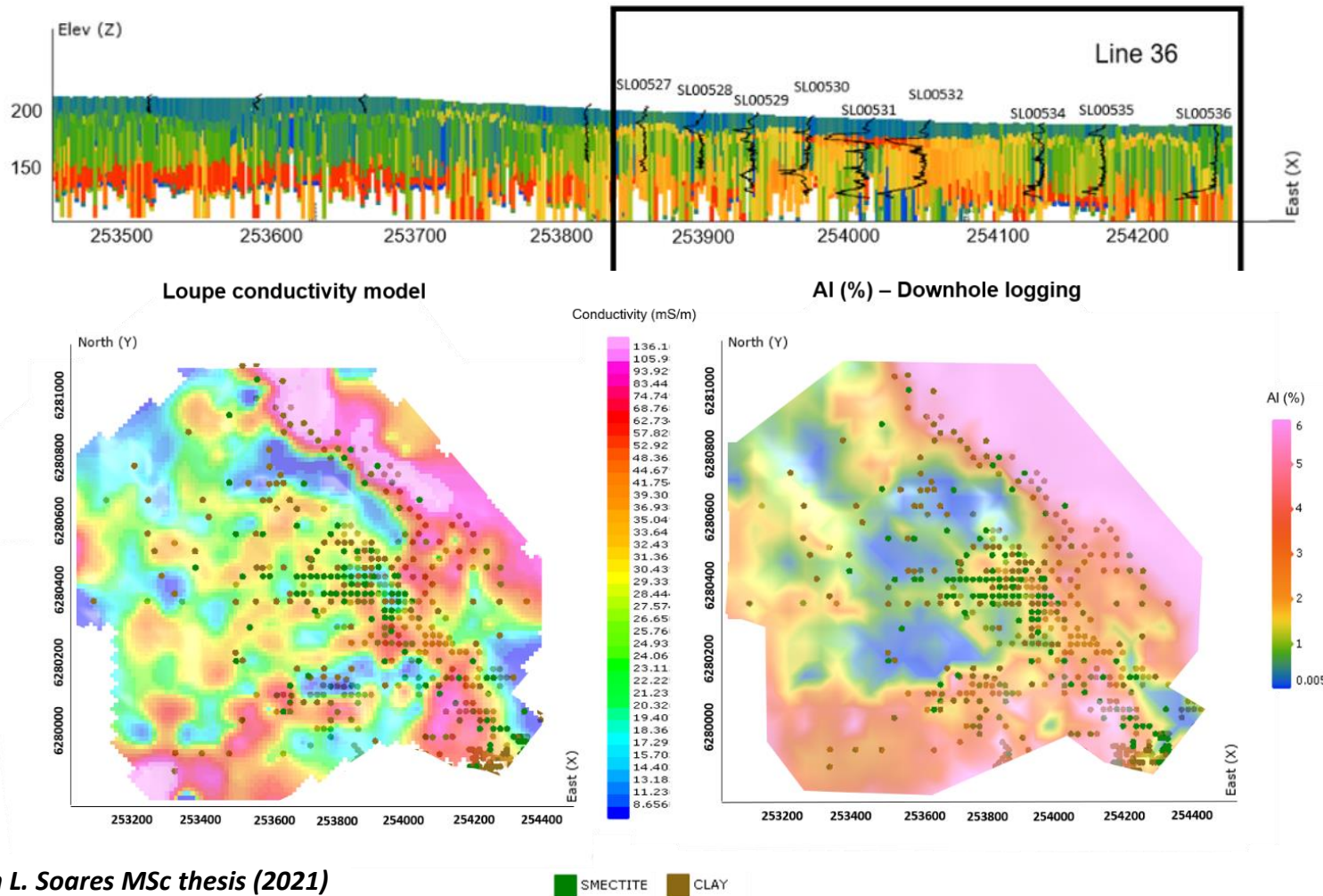
# Loupe TEM caprock mapping

- Caprock mapping consistent with prior modelled surface



# Loupe TEM thin layer mapping

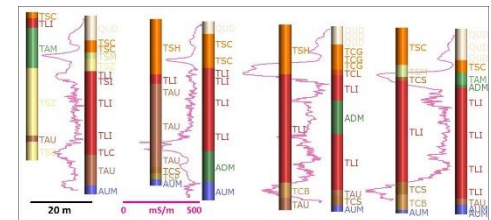
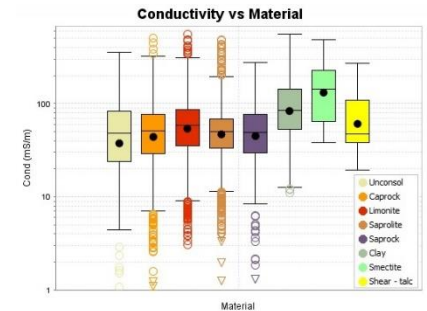
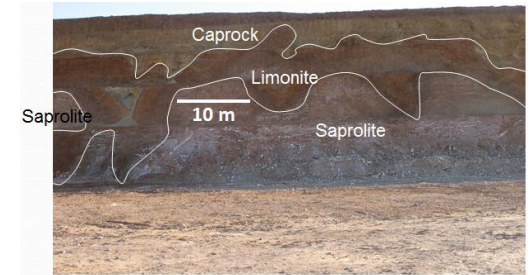
- Mapping variations in clay content beneath caprock?



from L. Soares MSc thesis (2021)

# Conclusions

- The Ravensthorpe nickel laterite deposits are geometrically complicated → can geophysics map between drillholes?
- Accuracy and rapid acquisition are the key criteria → 10x10x3 m ore blocks
  - c.f. HVSR, ERT, active seismic (streamer?)
- The limonite / saprolite boundary remains geophysically elusive
- There may be equally important material property variations that are mappable (petrophysics, TEM)
  - clay, silica, porosity, moisture, ...



# Extras

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# Gravity for resource density models

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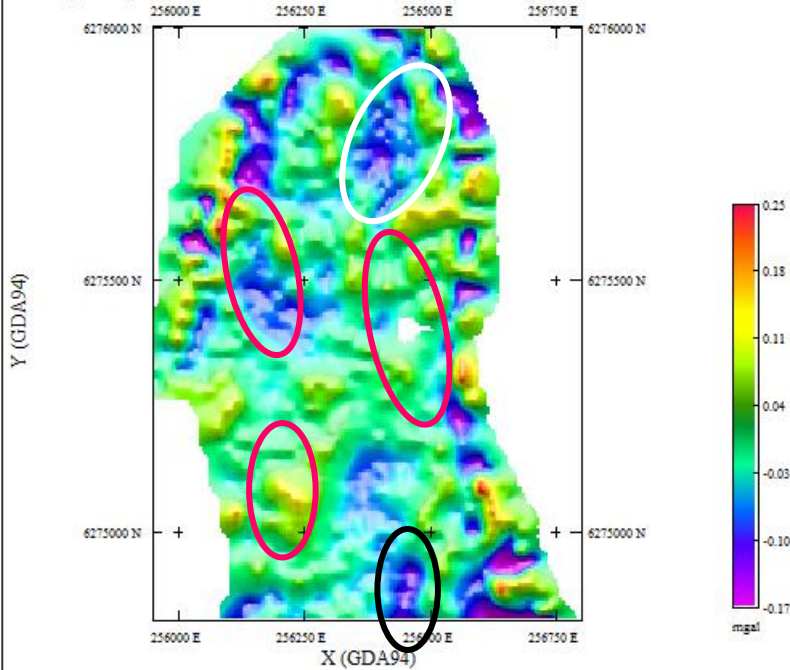
- Density is a fundamental physical property required in a mining operation → translates volume into tonnages
- Optimised pit shell is based on grade; density turns this into tonnes
  - Tonnes of waste to be moved / scheduled
  - Tonnes of ore → tonnes of metal
- Material interfaces well-defined by multi-element geochemistry → fixed on drill holes
  - Method: honour drillhole density and interpolate between holes using ground gravity



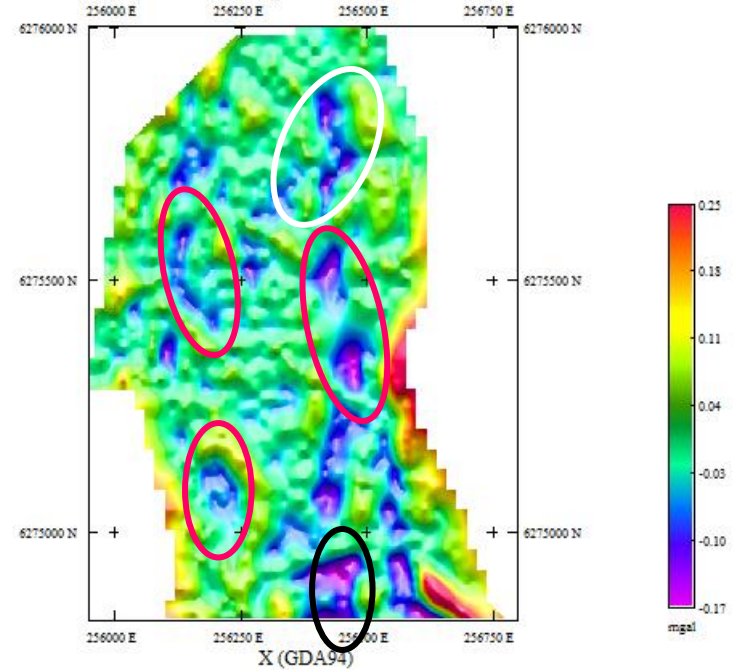
# Gravity for resource density models

- Initial resource density model (from downhole density) does not produce a gravity field that matches reality

Gravity response of resource density model, 200 m residual

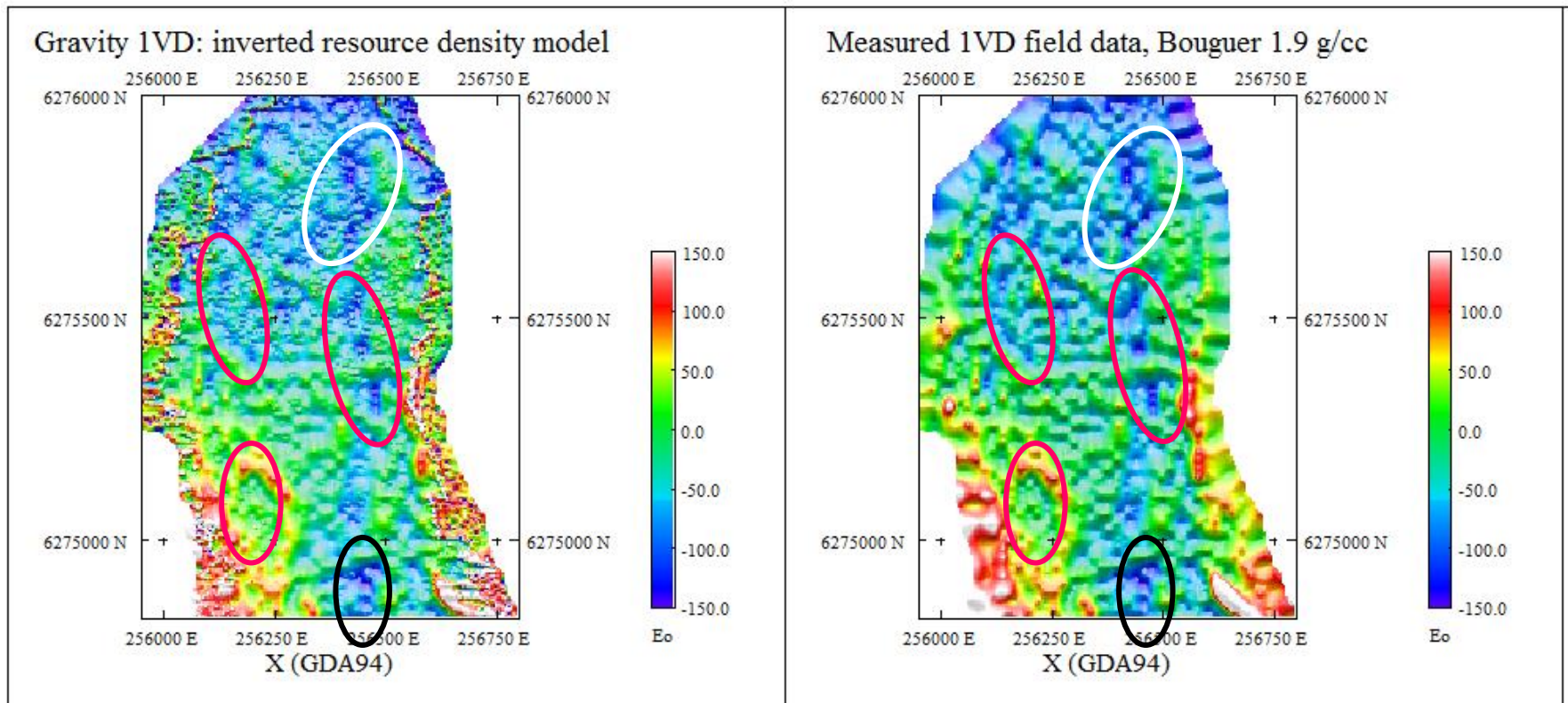


Measured field data, Bouguer 1.9 g/cc, 200m residual



# Gravity for resource density models

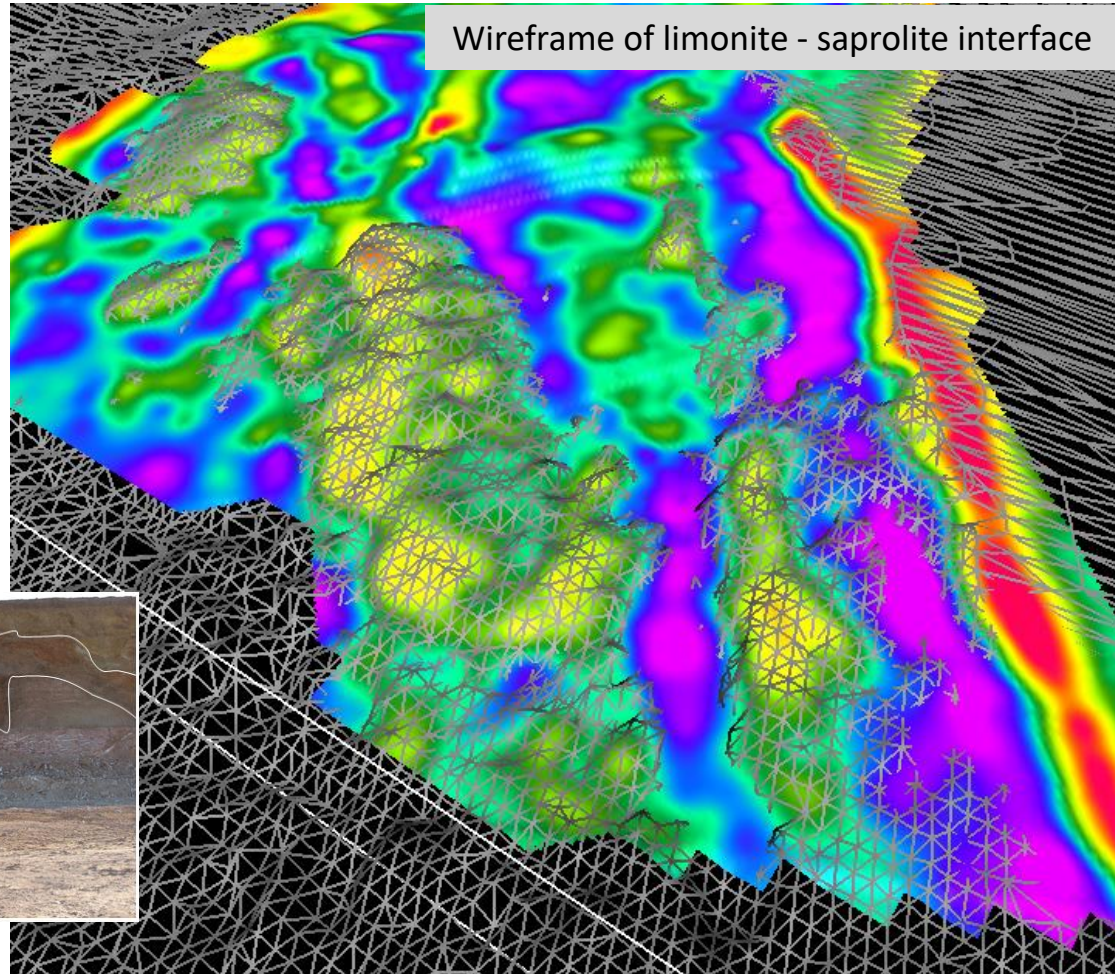
- Invert surface gravity constrained to honour resource density model on drillholes but free to vary off holes



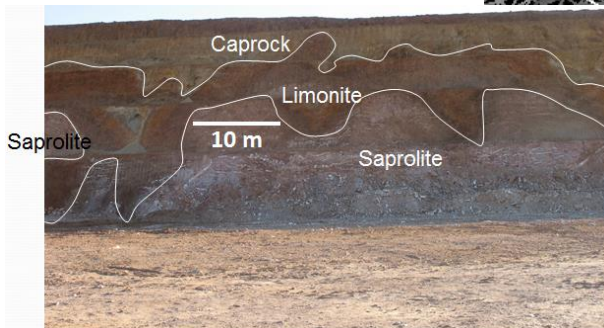
# Gravity: defining regolith types

- Gravity low = limonite trough, gravity high = sap high

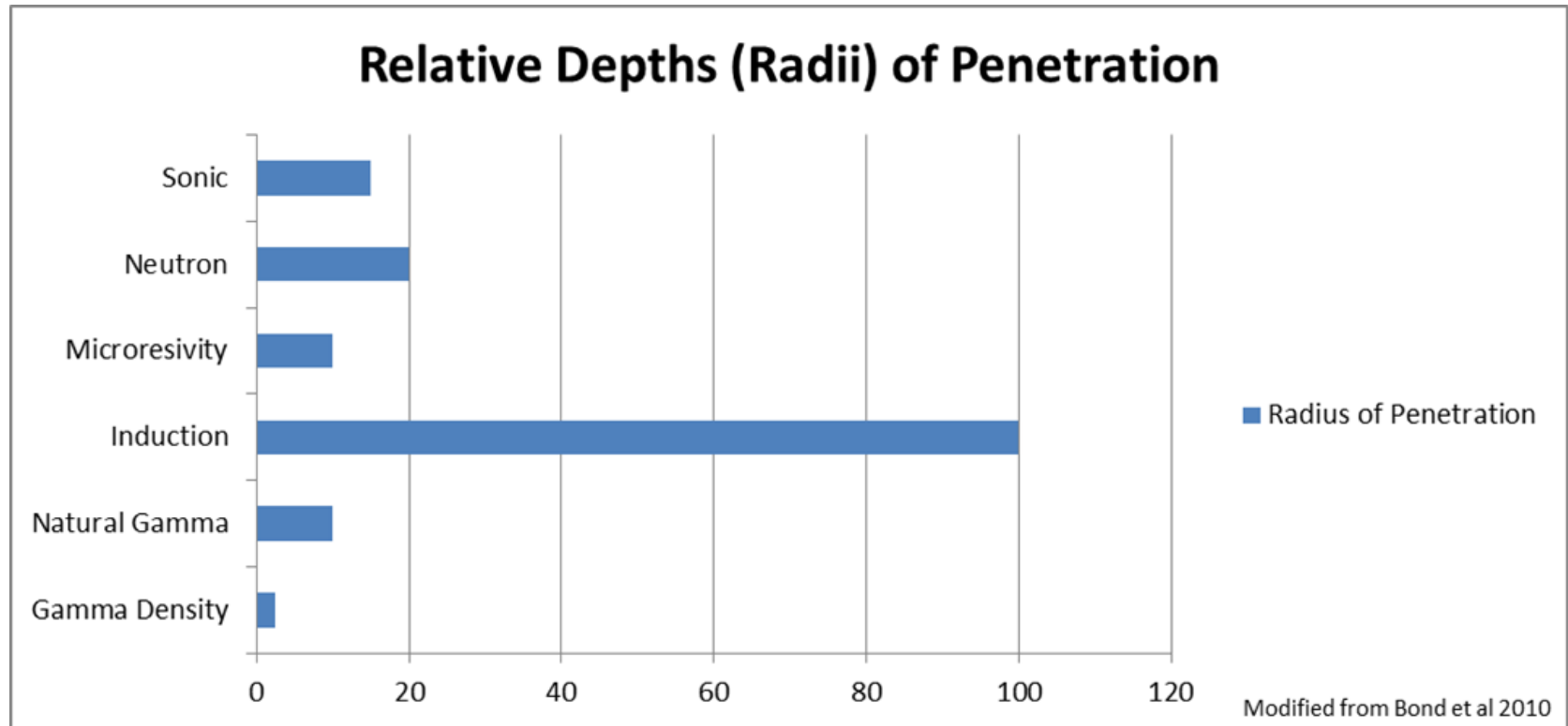
Wireframe of limonite - saprolite interface



$\rho_{\text{sap-lim}} \geq 0.2 \text{ g/cc}$



# Petrophysical logging representativeness



# Gamma vs lithology : 80180N

