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Nifty Cu Deposit Metals X Derisking Report

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Executive Summary

This report describes the phase 1 results of the seismic de-risking process at Nifty Copper Mine. The aim of the de-risking process is to increase confidence that the seismic reflection method can achieve desired exploration objectives prior to expenditure associated with field surveys. The work involved seismic characterisation of the geology and ore zones via rock property testing on core samples coupled with synthetic modelling of the local geological environment. A total of 561 measurements of sonic velocity (V_p) and density (SG) were undertaken on eleven boreholes representative of the Nifty deposit geology.

Key Findings of Rock Properties

1. There are strong AI contrasts across both lithological and stratigraphic units indicating good seismic reflectivity. We therefore anticipate that the fold geometry will be mapped by seismic.
2. Faults are likely to occur as breaks in the lithological/stratigraphic reflectors and as reflectors themselves when suitably oriented relative to the survey geometry.
3. Carbonate (including dolomite and siderite) and silica altered sediments show higher AI than unaltered rocks. We expect alteration to manifest as changes in reflectivity.
4. Based on the measurements high grade mineralisation shows variable contrast to host rock, dependent on AI of the host and whether the mineralisation has higher or lower AI. (Note that the densities of the high grade samples measured seemed anomalously low for the % of chalcopyrite – further investigation of the Nifty density database is recommended to ensure that our measurements are representative).

Theoretical Modelling Results

1. With the properties used in the model the mineralisation appears as a reflector but is not easily distinguishable from other reflectors.
2. Faults are well imaged both as reflectors and as “breaks” in reflectors.
3. The high contrast between the upper units such as the HWS and the ISHU or ISHL creates a reflector that overprints other thin layers
4. Dolerite acts as a strong reflector.

Based on the favourable results we recommend proceeding with the next stage of de-risking involving 2D and borehole seismic surveys. The 2D surveys will further establish the reflectivity of the Nifty environment and provide information on the overall geometry of the deposit and surrounding geology and insights into the geological architecture. The borehole surveys will provide in-situ measurements of the seismic properties and allow the seismic data to be directly correlated with geology.

We recommend parallel 2D seismic survey lines at least 6 km long across the deposit and at least 2 boreholes be surveyed. The lines should be perpendicular to strike or as close to it as possible and pass close to other ground-truth information (eg drillholes or mining) to assist with evaluation of the results. We recommend at least one longer line (approximately 10 km or greater) to assist with an understanding of the geological architecture of the deposit region. This understanding should assist in optimising the location of any subsequent 3D seismic survey.



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1 Background

Metals X engaged Hiseis Ltd. to evaluate whether the Nifty Copper Deposit would be amenable to seismic. Hiseis typically works in a phased approach to determine this:

- Phase 1: Analysis of seismic rock properties and computer simulation.
- Phase 2: 2D/Downhole seismic surveys and interpretation.
- Phase 3: 3D seismic surveys and interpretation.

Seismic reflectivity is controlled by contrasts in acoustic impedance (AI) which is equal to the product of Vp and SG. The Phase 1 de-risking process involves characterising the rock properties and predicting seismic reflectivity based on of sonic velocity (Vp) and density (SG) measurements on core samples.

Vp and SG measurements were taken for 11 holes from in and around the Nifty Mine (see Figures 1 and 2). The holes were chosen by HiSeis personnel in consultation with staff at Nifty and intersect significant mineralisation, geology and structures. The measured Vp and SG values were used together with schematic geological cross-section to produce a numerical simulation of a 2D seismic survey of the Nifty geology.

This report summarises the results of the Phase 1 rock property measurements and theoretical seismic modelling.

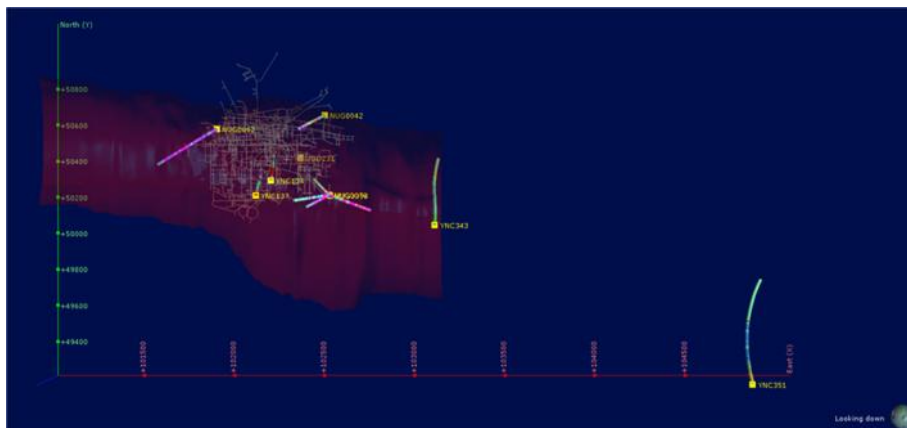


Figure 1. Location of chosen boreholes with underground workings and syncline wireframe in plan view.

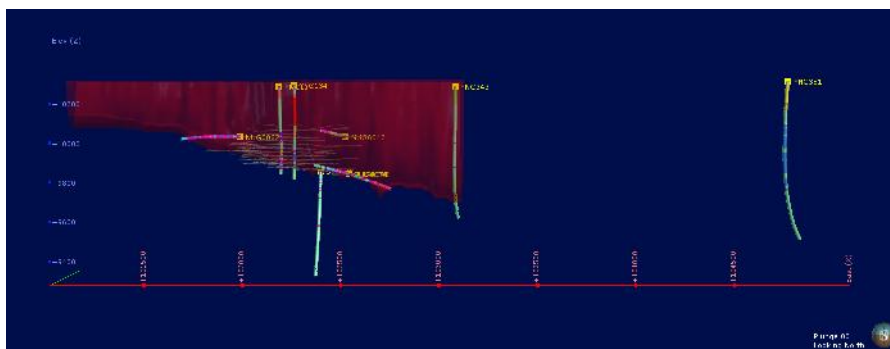


Figure 2. Location of holes in long section with syncline wireframe and underground workings.

Plots of the full set of measurements have been provided in the Appendix.

2 Results of Rock Property Measurements

A total of 561 Vp and SG samples were made on core samples from 11 holes as summarized in Table 1. All measurements were made at the Nifty core farm.



Table 1. Summary of holes, lengths and number of samples.

Hole	Samples	Depth
NUG0042	37	162
NUG0062	76	367
NUG0074	33	123
NUG0077	32	140
NUG0079	24	195
NUG0093	63	246
UGD231	77	560
YNC134	29	453
YNC137	28	430
YNC343	78	792
YNC351	84	996
Total	561	4464

Strip logs were generated in WellCad showing:

- P-wave velocity,
- Density,
- Acoustic Impedance,
- Lithology,
- Stratigraphy,
- Assays (or chalcopyrite estimates for newly drilled holes),
- Alteration and
- Synthetic Seismograms (f=50Hz)

The lithology legend used in the strip logs is shown below in Figure 3. The stratigraphy legend is shown in Figure 4.

Lithology

	Silty Shale
	Carbonaceous Shale
	Breccia
	Siliceous/Dolomitic Sediments
	Dolomitic Shale
	Vein
	Fault Zone
	Carbonaceous shale/Silty Shale
	Siltstone
	Shale
	Silified Shale
	Quartz
	Mafic Dyke
	Carbonate Rocks

Figure 3. The lithology legend used for the rocks at Nifty Mine

Stratigraphy

	Lower Carb Member
	Middle Carb Member
	Footwall Shale
	Lower Interbedded Shale
	Shale
	Barren algal carbonate
	Nifty Carbonate Member
	Hanging Wall Shales
	Pyritic Marker Bed

Figure 4. The stratigraphy legend used for the rocks at Nifty Mine.

While data is acquired, the Vp and SG are plotted by lithology in order to define any initial

relationships in the data. Typically altered rock versus unaltered rock can be differentiated in the plots and initial observations can be made about a particular lithology's properties. However, in our experience it is important to note spatial variations in AI since temporally these units are unique within a sequence. Additionally, the variation of seismic velocity can be complex in highly mineralised environments as the velocity is also influenced by ore and alteration as well as structure. Geological logging of core was completed while taking measurements to help capture variations that may be affecting AI. The crossplots in Figure 5 and Figure 6 are representative of the measurements taken at Nifty Mine for the NUG series holes and categorized by lithology and stratigraphy respectively.

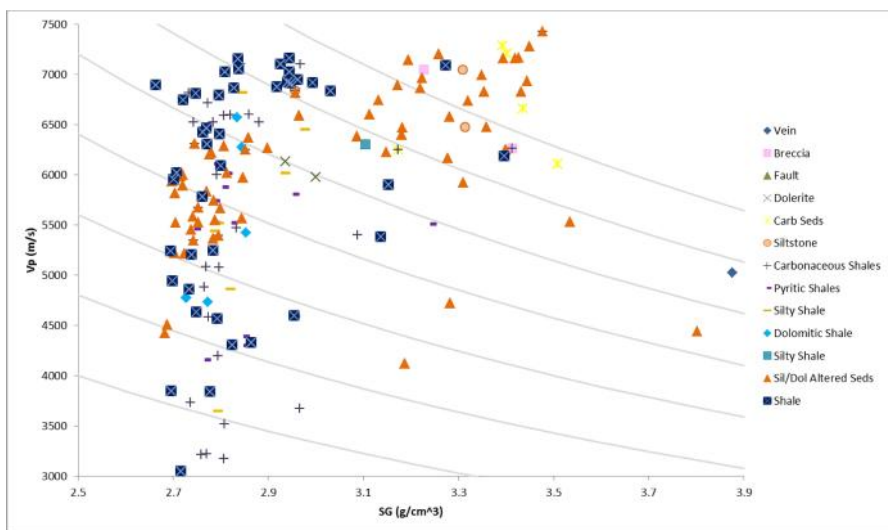


Figure 5. The crossplot representing the rocks at this deposit, where SG is plotted on the x-axis and Vp is plotted on the y-axis. Lines of constant AI are represented as light grey curved lines on the plot. Separations between these are sufficient for a reflection coefficient of ~6% (typically considered sufficient to generate a mappable reflection). Note the strong vertical trend seen representing shales strongly cleaved along bedding (low Vp and SG) and those without (higher Vp). The strongly cleaved shales may have higher in-situ Vps due to closing of microfractures.

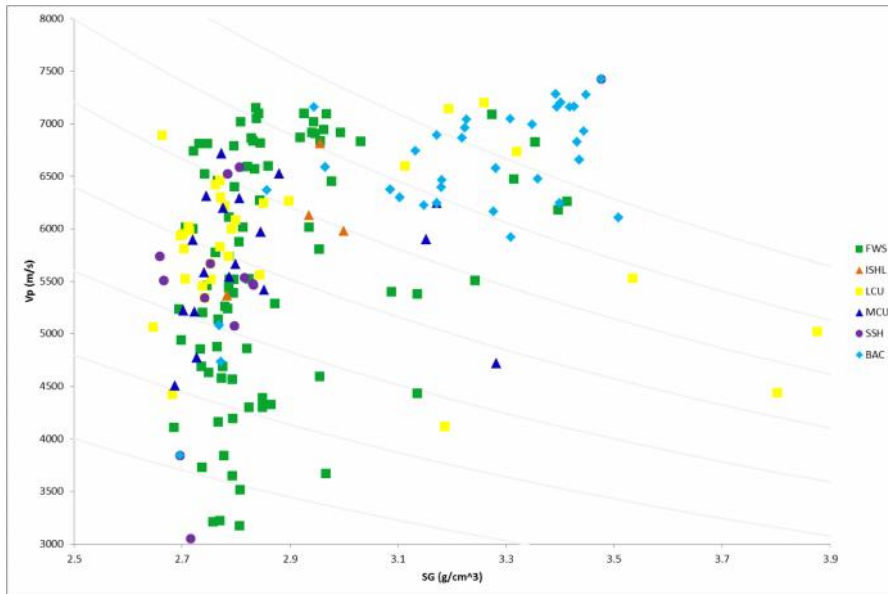


Figure 6. The crossplot representing the rocks categorized by stratigraphy at Nifty, where SG is plotted on the x-axis and Vp is plotted on the y-axis. Lines of constant AI are represented as light grey curved lines on the plot.

2.1 Rock Property Measurements

This section summarises the observed rock property variations associated with:

1. Lithology/Stratigraphy
2. Alteration
3. Mineralisation and
4. Faulting

1. Lithology/Stratigraphy

The lithologies at Nifty consist mainly of shales, altered shales and altered fine grained sediments. Strong variations in AI occur within these lithologies indicating that other physical properties such as rock quality (faulting, fracturing and weathering etc.) and/or alteration also influence the Vp and SG.

The crossplots in Figure 5 and Figure 6 show vertical trends (ie. consistent density but highly variable velocity) for the shale and altered sediment units. We infer the vertical trend for the shales is due to the strong bedding cleavage. When the overburden pressure is removed this cleavage weakens the rock and produces voids, which may not be visibly apparent, and therefore reduces the measured velocity. The lower velocities measured for the shales may not be representative of the in-situ velocities for this reason. Table 2 indicates that siltstone (or slightly coarser sediments than mud)



will have higher AI than shales. Additionally, it appears that mainly carbonate or silica altered rocks have higher AI. Alteration is a very important control on seismic rock properties in the Nifty deposit and is covered in more detail in the following section. In Table 3 unmineralised rocks of the barren algal carbonate (BAC) exhibit high Vp and high SGs. It has been suggested from previous studies that this may be caused by siderite.

Overall, it is expected that a seismic survey will produce rich seismic images as a result of the large variations in acoustic impedance (e.g. Figure 7 and Figure 8).

Table 2. Lithology ranked from high AI to low AI.

Lith	Vp	SG	AI
Carbonate Rocks	6695	3.40	22.7
Siltstone	6722	3.08	20.7
Breccia	6037	3.25	19.6
Silicified Shale	6300	3.10	19.6
Vein	5023	3.88	19.5
Mafic Dolerite	6307	2.96	18.7
Silica/Dol Altered Seds	6022	2.97	18.0
Shale	6039	2.85	17.3
Silty Shale	5819	2.83	16.5
Dolomitic Shale	5726	2.77	15.9
Carbonaceous Shale	5521	2.84	15.7
Pyritic Shale	5082	2.85	14.5
Carbonaceous Silty Shale	5093	2.79	14.2
Quartz Vein	5063	2.65	13.4

Table 3. Average Vp, SG and AI ranked by AI and categorized by strat type.

Strat	Vp	SG	AI
BAC	6426	3.20	20.7
LCU	5876	2.89	17.0
FWS	5675	2.88	16.4
MCU	5746	2.83	16.3
ISHL	5665	2.80	16.0
SSH	5496	2.78	15.4

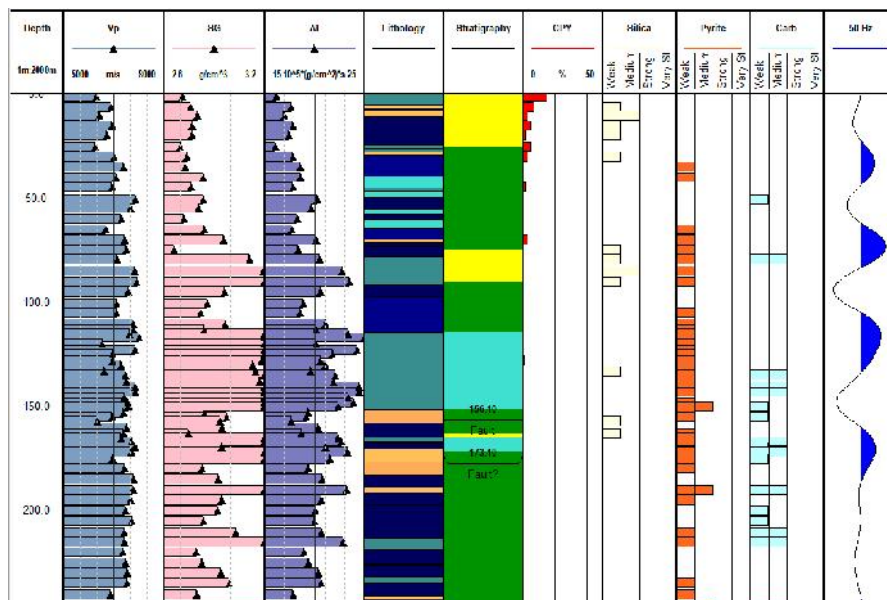


Figure 7. NUG0093 plot profile showing highly variable AI of the sedimentary beds. Note the higher impedance of the siliceous/dolomitic lithology units

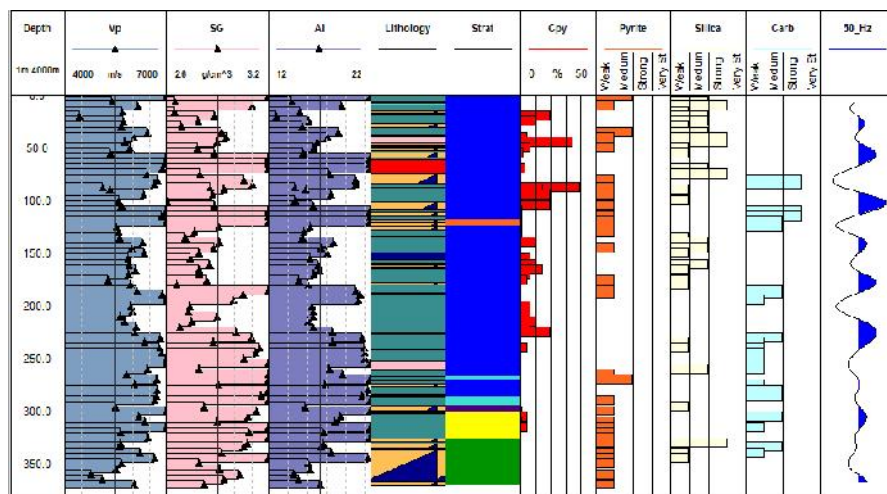


Figure 8. Plot profile of NUG0062 showing a number of thin, highly reflective beds.

2. Alteration

Alteration is of particular importance for the categorizing the rocks at Nifty. The rock properties show that rocks with high percentages of carbonate and silica alteration generally have the highest densities and velocities (refer to Table 2 and Figures 9 and 10). The carbonates include dolomite and siderite that may occur within the algal sediment units.

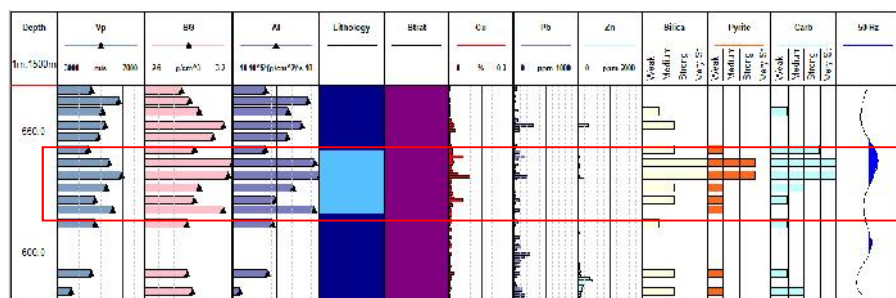


Figure 9. YNC343 plot profile showing the alteration logged within the silicified shales is higher than surrounding units.

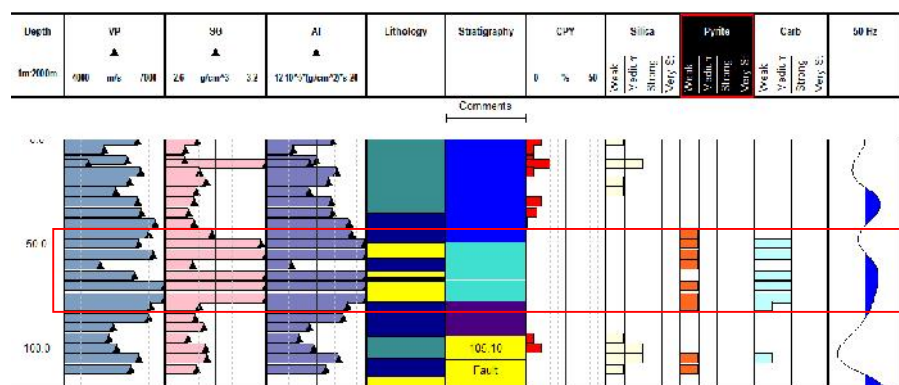


Figure 10. Plot Profile of NUG0079, BAC strat unit appears to overall have the highest AI. Presence of siderite may be enough to create such large increases in density.

3. Mineralised Zone

Based on the measurements, high grade mineralisation shows variable contrast to host rock and this contrast is dependent on the AI of the host whether the mineralisation has higher or lower AI. (Note that the densities of the high grade samples measured seemed anomalously low for the % of chalcopyrite – further investigation of the Nifty density database is recommended to check that our measurements are representative)

Chalcopyrite, which is the main ore forming mineral of the Nifty Carbonate Member, has an average

velocity and density of approximately 5400 m/s and 4.1 g/cm³ respectively. Therefore, the expected AI of massive chalcopyrite ore is higher than the vast majority of sediments at Nifty and therefore should be a high amplitude reflector (except against high AI sediments such as the BAC). This relationship is seen in YNC137 and YNC134, however the effects of exposure to the elements after removal from the drillhole may have lowered density values. The plots show that, as measured, in shales the ore is higher AI and when in the silty sediments it is lower than the surrounding rock. Both would create a reflection except the polarity of the reflection would be different.

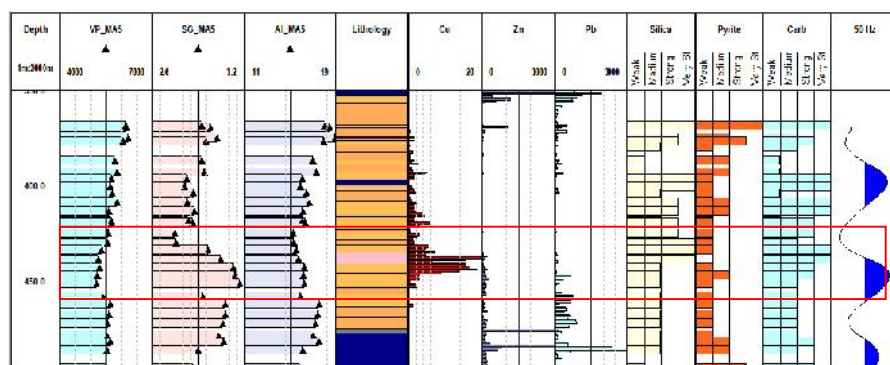


Figure 11. Plot profile showing mineralisation with lower AI than the surrounding silty sediments.

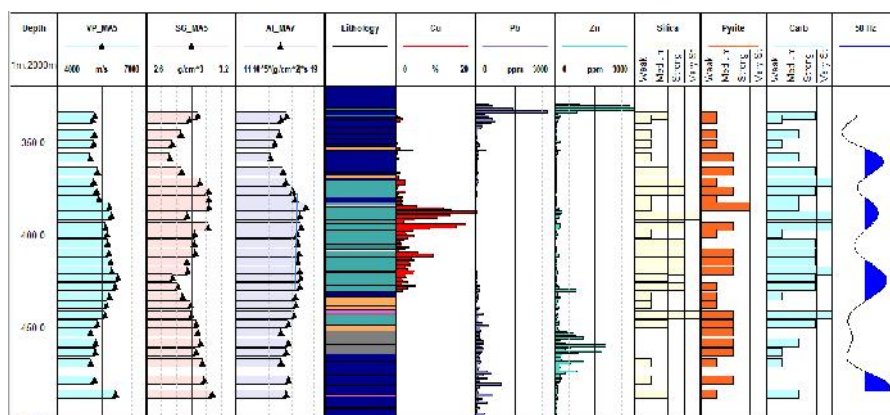


Figure 12. Plot profile of YNC134 showing the mineralisation having high AI compared to host carbonaceous shale.

A five point (25m) averaging or smoothing has been applied to the Vp and SG in Figure 11 and Figure 12. This is a way of estimating how the seismic signal sees the variations as the seismic signal mostly responds to the cumulative changes over approximately this interval (approximately ¼ of the seismic signal wavelength).

4. Faults



Few faults were encountered in the measurements made in this study. Faulting encountered in other environments is marked by broken ground, fault gouge, slickensides and alteration. Measurements cannot always be taken on faults as the ground is not competent unless it has experienced rehealing/recementation. Faults are typically represented in the seismic in two ways:

1. Faults often have very low AI and therefore provide an AI contrast to surrounding rock and appear as a reflector when suitably oriented relative to the survey geometry.
2. Faults often occur as 'breaks' or offsets in the texture of the seismic.

In Figure 7 at approximately 156 m depth a fault was noted while measurements were being taken. In the plot profile a number of low AI measurements exist around where the fault is logged.

2.2 Summary of Rock Property Measurements

The main findings of the rock property measurements are:

1. Strong AI contrast across both lithological and stratigraphic units which is conducive to high reflectivity.
2. Carbonate and silica altered sediments show higher AI than unaltered rocks.
3. High grade mineralisation shows variable contrast to host rock, dependent on AI for the host whether the mineralisation has higher or lower AI.
4. Faults are likely to occur as breaks in the lithological/stratigraphic reflectors and as reflectors themselves when suitably oriented relative to the survey geometry.

3 Synthetic Model

Theoretical modelling studies assist with understanding the resolution of seismic reflection and how the geometry of interfaces affects the seismic response. They are also helpful in optimising survey design to meet the desired survey objectives. The modelling does not capture the variations within units and these variations can very helpful in generating a seismic texture which helps to differentiate different rock units. The velocity distribution is typically complex in highly mineralised environments as the velocity is influenced by ore and alteration as well as structure. Our sampling has only covered part of the deposit area and therefore using "averaged" values as seen in Table 4 is our current best estimate of the rock properties in these complex environments.

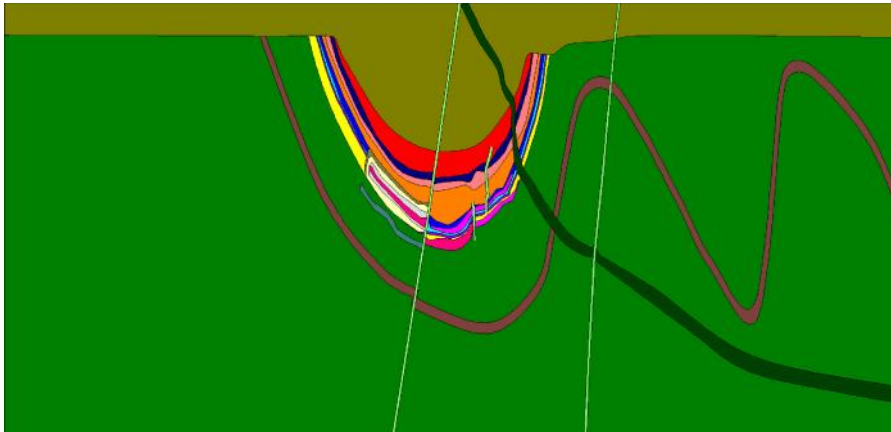
It is necessary to condense the data to a small number of distinct units for the modelling. This is a process we apply based on our experience of calibrating RPM with 2D/3D seismic data and observations made during measurement. However it has an element of subjectivity given the internal variability and relatively small sample of the rock volume involved.

Table 4. Summary of rock property measurements used in the modelling.

STRAT	VP	SG	AI
BAC	6425	3.2	20.6
DOLERITE	6300	2.96	18.6
CPYL	5500	3.30	18.2
LCU	5880	2.90	17.1
CPYU	5600	3.00	16.8
SS	6000	2.75	16.5
FWS	5675	2.88	16.3
MCU	5750	2.83	16.3
ISHL	5670	2.80	15.9
SSH	5500	2.78	15.3
ISHU	5250	2.82	14.8
PMB	5000	2.79	14.0
FAULT	5000	2.70	13.5
HWS	4500	3.00	12.8
Regolith	4000	2.65	10.6

The model was created using a 10 m receiver and 20 m shot spacing, 1ms sampling rate and a centre frequency of 100 Hz. Processing consisted of pre-stack depth migration to “migrate” reflectors back to their correct spatial positions.





3.1 Test Area

A region on the south western limb of the syncline was created with Vp and SG values for massive ore and those expected for associated alteration which is circled green in Figure 13. This was done to illustrate how alteration around the mineralisation might manifest in the seismic data. A small high AI, highly silicified shale unit within the footwall shale was also created to match an altered unit observed in our measurements. The circled area in Figure 13 is denoted as the “test area” for this paper. The contrast between the host rock, alteration and mineralisation are demonstrated as bright, interfering reflectors as exemplified in Figure 14 and Figure 15. This relationship is shown in more detailed images in Figure 16 and Figure 17.

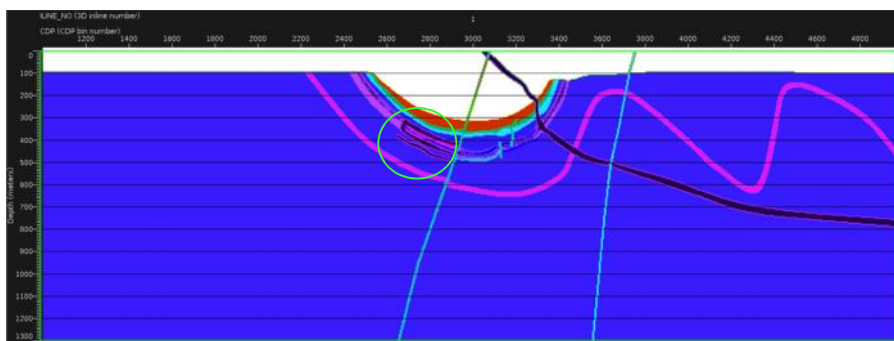


Figure 13. Schematic geology section of 6 km line length showing syncline at approximately 102450 E.

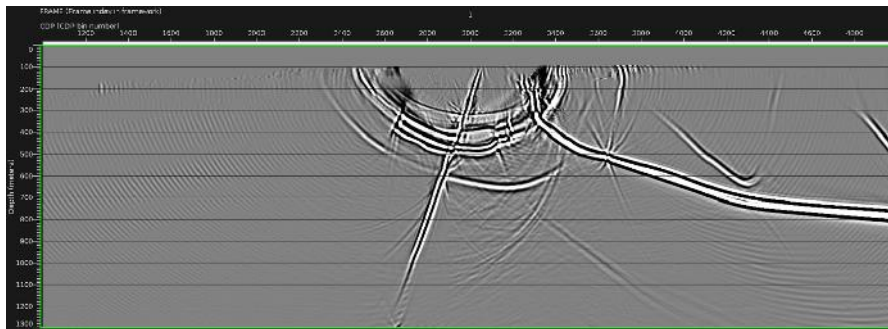


Figure 14. Results of the 6 km synthetic model using a 20 m shot spacing and 10 m receiver spacing. The data has undergone prestack depth migration.

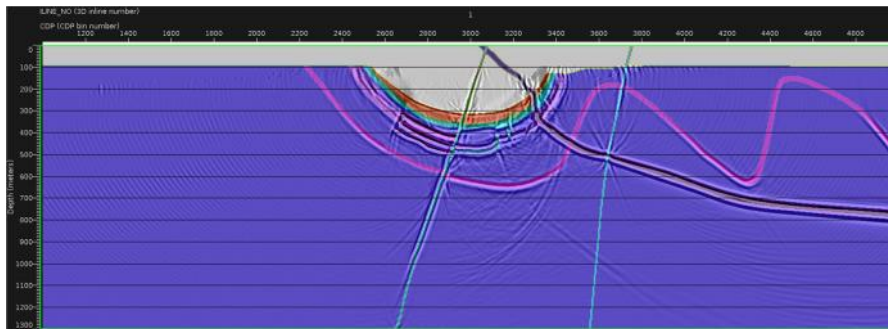


Figure 15. The 6 km synthetic seismic image with geology overlay.

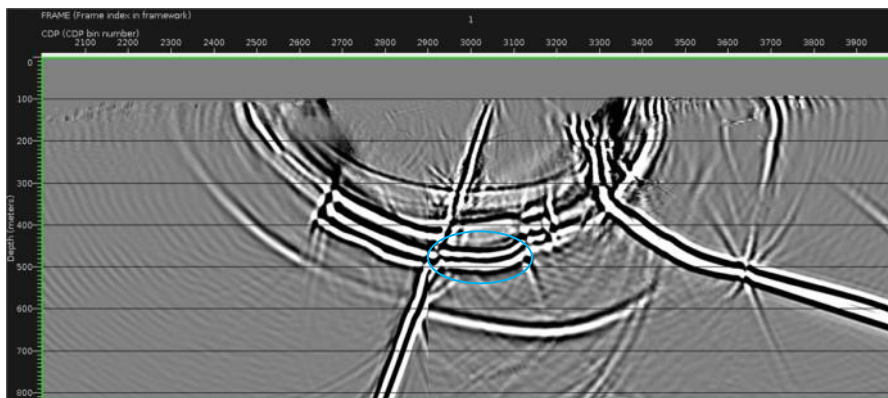


Figure 16. Magnified image of the syncline for the 6km line.

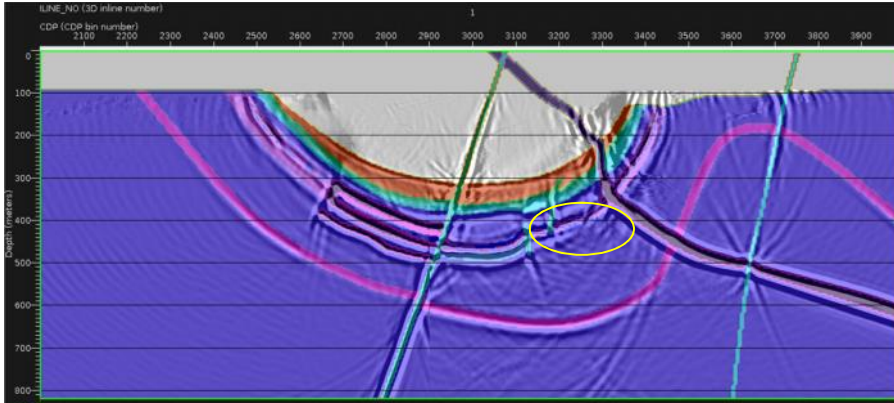


Figure 17. Magnified image of the syncline area with the velocity model overlain.

Outside of the “test area” discussed in the previous section, there appears to be a number of strong reflectors including the dolerite, faults and the massive ore. Massive and semi-massive units are included in the model with a higher density and lower velocity assigned to the massive ore (consistent with expectations for chalcopyrite ore. (circled blue in Figure 16) and the semi-massive ore has slightly higher V_p and lower density (circled yellow in Figure 17). Both act as reflectors. A sandstone unit seen below the syncline as a pink colour in Figure 15 and Figure 17 has been added to the cross-section to represent the change from the footwall shales to the Coolbro sandstone.

The examples shown in Figures 14 to 17 were obtained by simulating a 6km seismic line. Shorter line lengths will be limited in their ability to image steep structures particularly at depths beyond a few hundred metres.

A number of strong artefacts unrelated to geology can be seen in the numerical simulation plots. These artefacts are due to imperfections in the numerical modelling process and are highlighted in Figure 18.

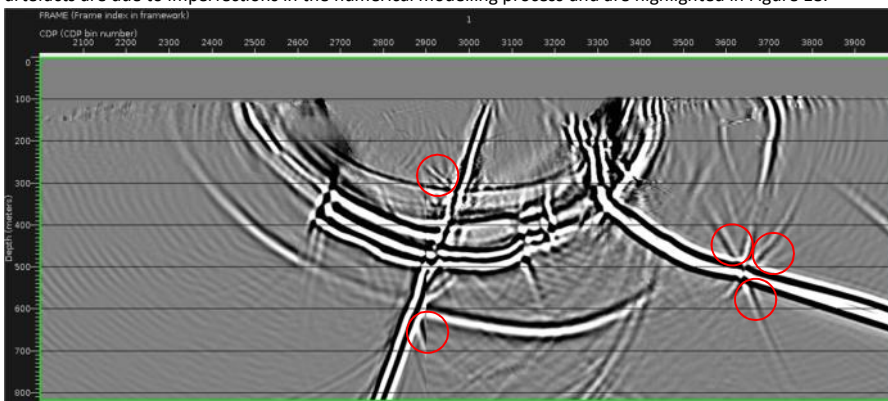


Figure 18. Seismic image with artefacts associated with the numerical modelling highlighted

The main findings from the synthetic modelling were:



1. With the properties used in the model the mineralisation appears as a reflector but is not easily distinguishable from other reflectors.
2. Faults are well imaged both as reflectors and as "breaks" in reflectors.
3. The high contrast between the upper units such as the HWS and the ISHU or ISHL creates a reflector that overprints other thin layers
4. Dolerite acts as a strong reflector.
5. A number of strong artefacts unrelated to geology can be seen in the numerical simulation plots. These artefacts are due to imperfections in the numerical modelling process.

4 Conclusions

Based on the favourable results we recommend proceeding with the next stage of de-risking involving 2D and borehole seismic surveys. Wireline velocity measurements known as full waveform sonic (FWS) will provide denser velocity measurements and measurements through broken ground. Vertical seismic profiling (VSP) surveys will assist with linking the seismic reflectors to geology observed in the drillhole. We recommend parallel lines at least 6 km long across the deposit. The lines should be perpendicular to strike or as close to it as possible and pass close to other ground-truth information (eg drillholes or mining) to assist with evaluation of the results. We recommend at least one longer line (approximately 10 km or greater) to assist with an understanding of the geological architecture of the deposit region. This understanding should assist in optimising the location of any subsequent 3D seismic survey.



5 References

Salisbury, M.H., Harvey, C.W. and Matthews, L. 2003. Chapter 1: The Acoustic Properties of Ores and Host Rocks in Hardrock Terranes. In: Hardrock Seismic Exploration, Ed. Eaton, D.W., Milkereit, B. and Salisbury, H. pp. 9-19. Tulsa, OK, USA: Society of Exploration Geophysicists.

Appendix A

Rock Property Measurements

Reflectivity and Acoustic Impedance

Seismic reflections occur at subsurface interfaces where there is a change in acoustic impedance. Acoustic impedance (AI) is the product of the density (ρ) and p-wave velocity (V_p) of each interface. It is often quoted that interfaces with a contrast of around 12% or $\sim 2 \times 10^5 \text{g/cm}^2$ (resulting in around 6% of seismic energy being reflected) are detectable by seismic. Whilst this is not a “hard and fast” figure it is a good guide.

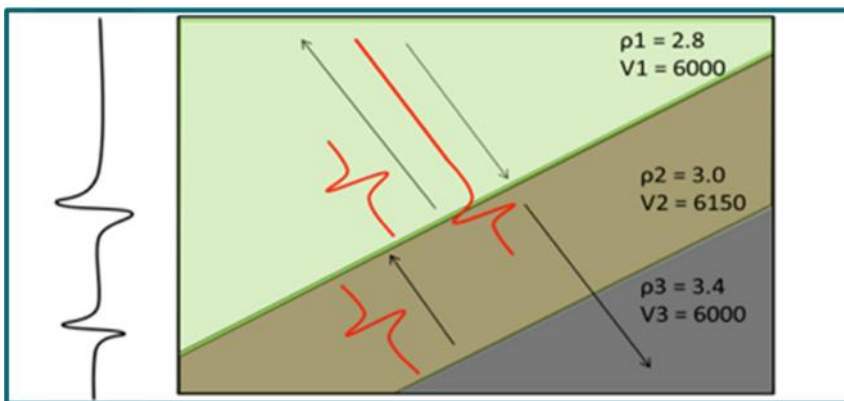


Figure 19. A diagram illustrating how a portion of seismic energy is reflected at each interface where there is a change in acoustic impedance which is the product of density (ρ) and p-wave velocity (V_p). The remainder of the energy is transmitted through the interface and portions of this energy are subsequently reflected from other interfaces beyond the first reflector.

Equipment

The V_p measurements were taken using the Surfer Ultrasonic Detector UK1401. Density measurements were taken using a calibrated scale. A half section of PVC pipe attached to the underside and suspended in water was used for wet core measurements.

Method

The sonic tool was applied to dry, consolidated core between 0.15 to 0.45m in length. Measurements were taken at 3 points on the core sample avoiding fractures where possible. Each measurement was recorded over a 15s interval. The tool was moved to different points on the core to record 3 separate measurements and then averaged.

- Representative samples were chosen avoiding lithological contacts or highly fractured and/or faulted core.
- Lithology, alteration and mineralogy were noted in order to aid understanding of variations



within a particular lithology.

Logs were created in WellCAD to allow a side by side analysis of all rock properties, including a synthetic seismogram. The synthetics are created by deriving reflection coefficients from the Vp and ρ values between interfaces, which is then convolved with a 50 Hz wavelet. Expected frequencies recorded during the seismic survey in this environment ranged between 50 and 100 Hz. It is important to note that this is variable and that reflectivity of seismic images may differ from the synthetics. Rocks that are measured *in situ* (wireline survey) often show less variation of Vp than those measured on the core at surface. These measurements are used as a guide for processors and interpreters to relate seismic with borehole geology and measurements.

Vp and ρ Values

Typical ranges of Vp and ρ in igneous and metamorphic rocks are summarised in **Error! Reference source not found.** and **Error! Reference source not found.**. In general, mafic and ultramafic rocks have Vp values ranging from 6000-8000 m/s. Quartz rich metasediments typically have lower velocities (5000-6500 m/s). Rocks rich in pyrrhotite and pentlandite typically have low Vp in the range of 4500-5000 m/s. Weathered mafic and ultramafic rocks can display much lower values due to serpentinisation of olivine minerals. In highly tectonized rocks Vp can be faster parallel to fabric than it is normal to the fabric some times as much as 2000-3000 m/s difference between axes.

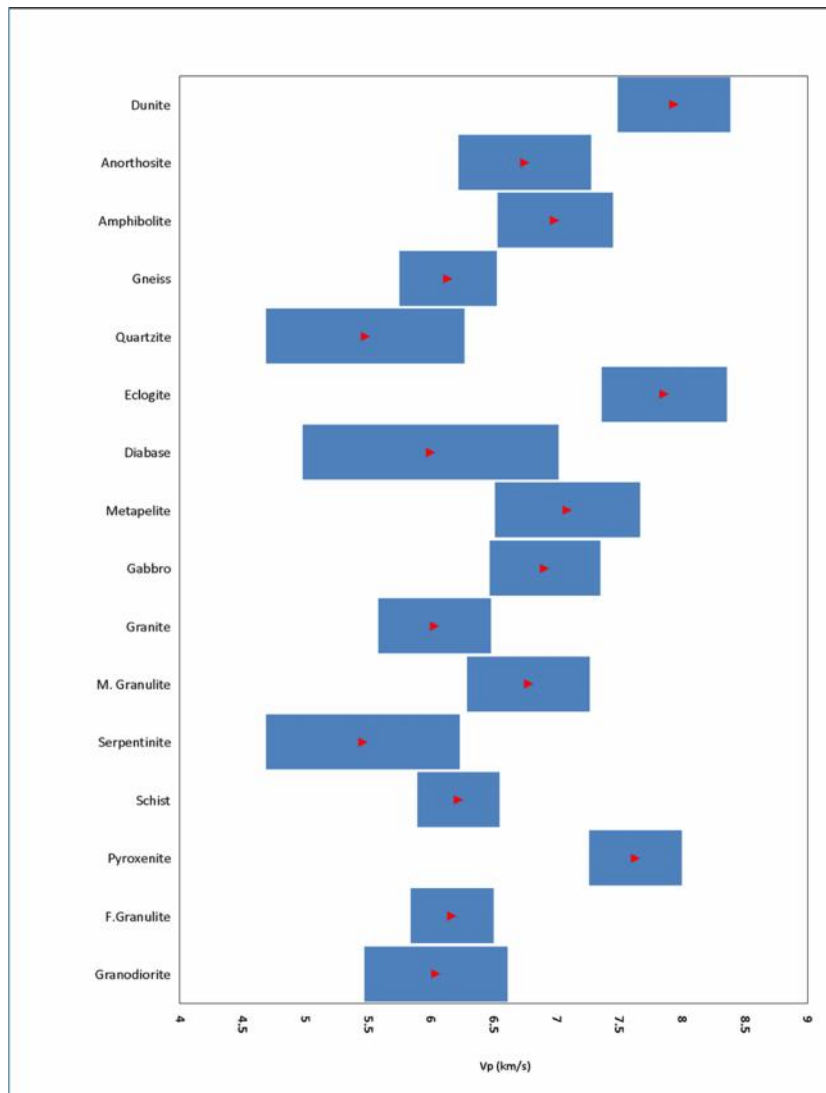


Figure 20. Typical Vp values for igneous and metamorphic rocks summarized from (Salisbury et al. 2003). Average Vp demarcated by the red triangle.

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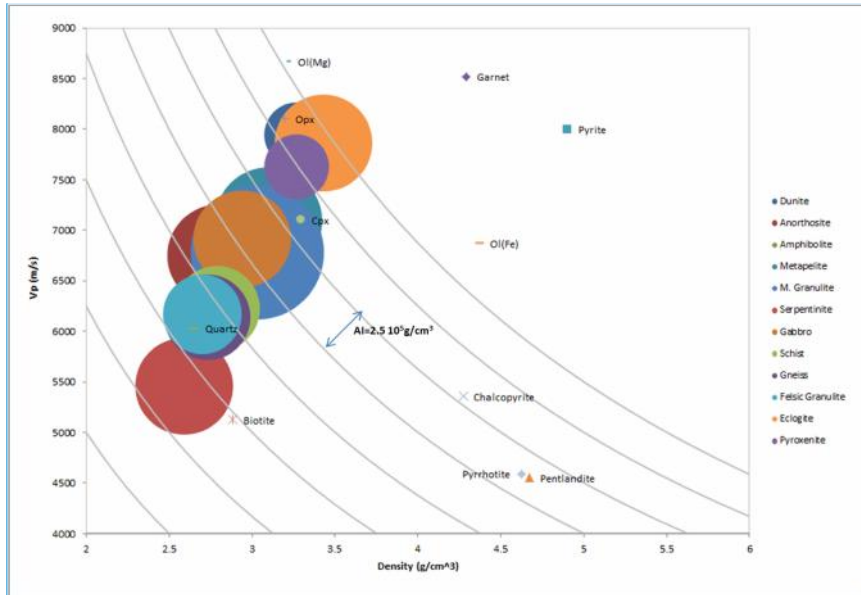


Figure 21. Vp vs. density for typical igneous and metamorphic rocks. Acoustic impedance (AI) lines are superimposed in gray with differences in $2.5 \times 10^5 \text{ g/cm}^3$. The values for various mineral constituents are overlain for reference

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