Refraction tomography at the Nova Ni-Cu mine

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SUMMARY
The mining industry is increasingly using 3D seismic reflection datasets, from project genesis through to mature mine sites. During processing of the reflection data, the refracted arrival is digitised and used to correct for near-surface velocity variations. By performing a 3D inversion of these first arrivals, a high-resolution, tomographic velocity model can be obtained that provides additional information in the top portion of the seismic volume.

The Nova Operation, owned by IGO, is located in the Fraser Range of Western Australia. The Nova-Bollinger ore bodies are magmatic Ni-Cu deposits being mined from within an eye-like structure visible on magnetic datasets. In 2018, a 60 sqkm seismic reflection survey was acquired over the Nova mining lease to assist in exploration. The velocity model derived from the refraction tomography provided useful information in the near-surface, including insights into hydrogeology and the base of cover interface. When compared to current models created from drilling and AEM, additional detail can be observed, including additional palaeochannels in the southeast.

Key words: seismic refraction, mining

INTRODUCTION
The Nova project is located in the Fraser Range of Western Australia, approximately 160 km east-northeast of Norseman. It was discovered in 2012 by drilling geochemical and electromagnetic anomalies located within an eye-like structure. This feature, the Nova Eye, is an elongated doubly plunging syncline forming a bowl shape. The Nova Eye is visible in the magnetics data as shown in Figure 1.

![Nova Eye](image)

Figure 1. Magnetics data over the Nova project area highlighting the Nova Eye.

The Nova-Bollinger magmatic Ni-Cu deposits are hosted within the lower granulite facies mafic rocks of the Fraser Zone of the Albany-Fraser Orogen. The geology of the project can be characterised by two domains separated by the Nova fault trending northeast.

In early 2018, during the first full year of production on the minesite, a 60 sqkm 3D hardrock seismic reflection survey was acquired over the Nova mining lease. This survey was conducted using both a cabled system, and a higher density central section using nodal seismic receivers. Multiple vibroseis sweeps were recorded at each shot location using INOVA AHV-IV, 60,000 lb vibrators as an energy source sweeping from 8 - 120 Hz.

As part of the seismic reflection processing, refraction statics corrections are applied to account for the near-surface variations in refractor velocity and depth. This was performed using several methodologies, from layer-based and delay-time algorithms through to tomographic ray tracing. The 3D tomography produced a velocity model for the top 300 m, thereby extending the interpretable seismic data to surface.

Previous studies (Malehmir et al., 2016) have had success in correlating the results from the tomography to RQD. Here the velocity model correlated well with the base of cover interface derived from drilling and AEM. The additional detail provided by refraction tomography indicated a number of unidentified palaeochannels.

METHOD AND RESULTS
The seismic refraction method measures the travel time of seismic energy that have been critically refracted at horizons of interest. This acoustic return is called the first break, and the angle of refraction depends on the ratio of velocities in the two materials (Snell’s Law). The first arrival times for the wavefront to reach each geophone are picked from the seismograph records. From those travel times, seismic velocities in each layer and depths to each layer can be calculated. This recorded travel time information is used to generate a velocity model of the subsurface. Due to the surface topography and possible complexity of the bedrock interface, a tomographic approach was also employed to achieve better results (Ha, Pyun, & Shin, 2006; Zhu, 2002; He & Zhang, 2011).

First arrivals were picked, and an initial 3-layer model created. A total of 43,369 shots were picked, with over 45 million first break picks used in the inversion across 49,586 receivers. Figure 2 illustrates the first arrival data for all shots plotted as time (ms) against shot to receiver offset (m). The data are coloured by pick density, from blue (low) - pink (high). It can clearly be observed that there are 2 trends visible in the data, corresponding to the different geology in the northern and southern domains of the survey area.
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A non-linear, first-arrival tomographic traveltine inversion (Zhang & Toksoz, 1998) was run until convergence was achieved. This process ray traces synthetic traveltimes for each shot such that the difference between the input and synthetic first break picks are minimised. VSP data collected on site within 6 boreholes were used as a weak inversion control, with some difference allowed between the borehole velocities and the refraction tomography.

Initial analysis of these models was conducted, analysing the model misfit on a shot by shot basis. Where a significant misfit was present, the first break picks were checked for consistency and repicked if required. Figure 3 shows a comparison of the picked (red) and modelled (blue) traveltimes for a portion of a representative shot showing the excellent level of misfit.

Results from the refraction tomography compare well to other geophysical datasets over the project area. Figure 4 depicts a depth slice from the refraction tomography at 2223 mRL (approximately 57 m below surface), displayed over a background of the magnetics. The Nova Eye is clearly visible, as are the two geological domains separated by the Nova fault. Additionally, previously unknown palaeo drainage is visible to the southeast.

The existing base of cover model being used at Nova was derived from AEM data tied to drilling. Figure 5 illustrates a comparison of this model (green contour) compared to a velocity contour created from the refraction tomography at 1950 m/s (orange). There is an excellent correlation between the two datasets, with the refraction based model providing a much higher resolution model. To the south of the Nova Eye, it is now visible that there are drainage system and palaeodrainage channels.

The refraction data provides additional detail in the shallow section in comparison to the reflection dataset. Figure 6 depicts a shallow depth slice from the seismic reflection data. This dataset has been padded before migration, adding additional information to the south and east of the survey footprint. Above this depth slice, the refraction data provides a higher-resolution product and assists in extending the seismic interpretation to the surface.
CONCLUSIONS

The refraction tomography dataset provides a high-resolution velocity model in the top 300 m of the seismic volume. This extends the interpretable seismic dataset to the ground surface and provides an updated and higher resolution base of cover model which highlighted additional palaeo drainage within the mining lease.

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REFERENCES


