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Seismic Reflection Surveys in Search for Iron Oxide Copper-Gold (IOCG) Deposits

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Abstract: *Seismic reflection method can delineate very complex geological structures hence it might be very effective for detecting the presence of Iron Oxide Copper-Gold (IOCG) deposits. Despite this superior attributes, there exist a real problem for exploration beyond the immediate vicinity of a known deposit. All previous studies have focused upon high resolution detection of mineralization and the hosting structures at mine scale. No argument for "regional" exploration have been proposed probably because a cost benefit analysis has never be conducted at such scale to proceed with such exploration venture. In this study, we analyze the feasibility of such regional exploration by modelling a Vulcan IOCGU deposit scenario were a 2D seismic survey with relatively sparse source-receiver geometry was used to detect the presence of a possible intrusive package within 2km depth range. The modelling results demonstrates that seismic reflection method using 10m geophones and 20m shot spacing can be used to image deposit within the depth of 2km. The presence of reflections was visibly observed especially at the edges of intrusive packages hence it is suggested that application of seismic reflection methods perhaps will remains the best alternative and most viable method for exploring deep seated IOCG*
Keywords: *IOCG, Regional, Search, Seismic Reflection*

I. Introduction

The Gawler Craton, South Australia, host numerous Mesoarchean to earliest Paleoproterozoic basement that is overlain by a series of Paleoproterozoic basins. These deposits are typically found in complex geological structures associated with crustal scale shear zones. Though they generally occurs in acoustically transparent, low impedance setting, the deposits themselves are well defined and dominated by hematite and magnetite which also have high impedance contrast thus making both deposits types to be detectable by seismic method. Successful exploration for deeper Iron Oxide Copper-Gold (IOCG) deposits below the regolith cover depends on the understanding of the location and geometry of the controlling structures of the deposits. In the past, traditional methods were routinely used to remotely sense these deposits. These methods though apparently effective, lack the lateral and depth resolution needed to image deeper mineral deposits for targeted mining, currently put at 2.9km, [2].

In Australia, [9, 12] carried out research on in-mine seismic delineation of mineralization and rock structure at the Kambalda nickel mines. High resolution surveys was also carried out in Western Australia to address the lack of complex structural and shallow imaging missing from the original 2D regional surveys[23,24]. Results from three-dimensional (3-D) seismic surveys over goldfields in South Africa [19] showed that under favourable circumstances, where there are large seismic impedance contrasts and flat, sub-horizontal rock units of a great extent, seismic methods can be effectively used to directly image deep mineral-bearing structures. High resolution data was also used to map three dimensional geological structures and assess the size, geometry and distribution of mineable blocks in Bushveld complex area of South Africa [7]. From the Canadian shield region, [20],[16,17] documented the potential of seismic methods for hard rock mineral exploration to a depth range of about 2500m the limit at which modern mining methods are capable of economically extracting ore. [4, 5, 14, 15] summarizes the results of 2D and 3D seismic profiles acquired by Noranda Inc. near the Brunswick No. 6 mine in a highly folded and deformed area characterized by steeply dipping stratigraphy. Two-dimensional surveys, reported by [8] and [26] were able to delineate the various volcanic/sedimentary facies, offsetting and, in some cases, the underlying feeder vents.

Though significant successes in the applications of seismic reflection technology have been recorded in the years, there exist some difficulties for exploration beyond the immediate vicinity of a known deposit. All previous studies have focused on high resolution detection of mineralisation and the hosting structures at local scales (less than 800m depth) without recourse to "deep seated exploration" where known deposits maybe within 2km or more depth range. This paper therefore is looking at the possibility of using seismic method for such exploration. As Iron Oxide Copper Gold deposits in the Gawler Craton has very large footprint due to its association with intrusion and large fault zones, We hypothize that by simply looking for the seismic signatures around the edges of intrusions along prospective structures, IOCG can be detected. Using 2D survey geometry with sparse acquisition parameters 10-30m geophones and 20-60m shot spacing, we might be able to pin down the areas venturing towards minimisation or in worst case detect the structures and lithological contacts.

1.1 The Gawler Craton

The Gawler Craton can be defined as the part of South Australia that has not been substantially metamorphosed, deformed or remobilized, excerpt by minor epeirogenic movements prior to deposition of Pandurra Formation sediments after 1424 Ma. The region is dominated by Neoarchean to Mesoproterozoic magmatic and mineralising events, and includes the formation of the giant Olympic Dam Cu-Au-U deposit. Nearly all of the presently discovered iron oxide copper gold (IOCG) deposits are within the basement rocks. The basement occurs within two belts located in the north-central and southern portions of the craton, which contain similar lithologies of similar ages and which are inferred to represent a formerly contiguous rock system now disrupted by Paleo- to Mesoproterozoic tectonism [6, 18, 25]. Sedimentation in these basins was terminated by the craton-wide c.1730–1690 Ma Kimban Orogeny, which was largely partitioned into regional-scale transgressional belts [27].

Economic copper-gold mineralization is thought to be a later feature in the regional development of these deposits [3, 25]. IOCG deposits within the craton are characterized by extensive hematite-magnetite (iron) alteration and brecciation, and typically comprise disseminated to massive chalcopyrite, chalcocite and bornite copper mineralisation with associated gold. The deposits often include uranium and rare earth elements. They are typically covered by a thick 10-1000m younger sedimentary sequences and volcanic rocks; thus, making the region extremely difficult and costly to explore. Fig.1 shows the prospective basement within the Gawler Craton.

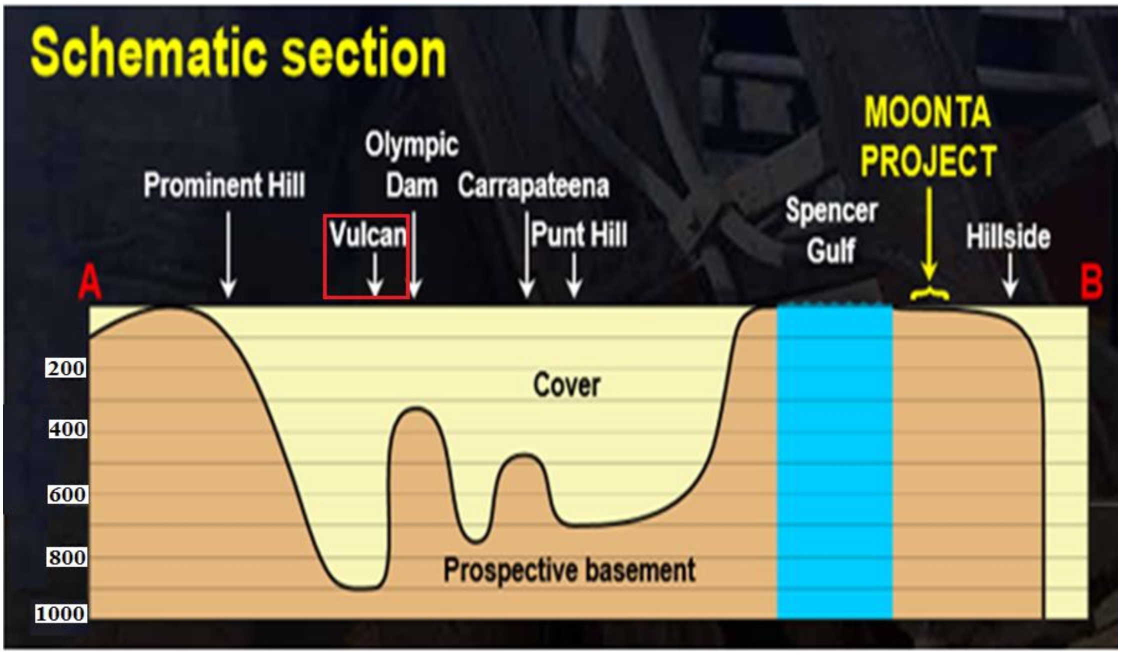

Figure 1: prospective basement within the Gawler Craton showing the location of Vulcan and other deposits (red rectangle). The arrows pointing dawn indicates the depths to prospective basement of each deposit. (Adelaide Resources, 2013)

1.2 The Vulcan IOCGU

The Vulcan iron oxide copper gold uranium (IOCGU) deposit is located within the eastern Gawler craton, South Australia (Fig.2). The first drill hole in the area was drilled in 1981 by WMC Resources, but was drilled off Tasman's current Vulcan target, and no mineralization was intersected Tasman [21]. The prospect is entirely subsurface and defined by a geophysical anomaly intersected by diamond drilling. Initial drilling was based on interpretation from untested gravity anomalies which indicated the deposit to be on the far North-Western margin. Subsequent interpretation based on geophysical data from Geoscience Australia (GA) indicated that the deposit is actually located in the North-Western corner of a potentially large system [21]. Mineralization at Vulcan is dominated by large hematite system (~12km^2) 30km north of Olympic Dam with very thick and strong alteration including 100's meters of hematite bressicas, low grade IOCGU mineralization (Cu, U,Au, Ag, Mo and REE).

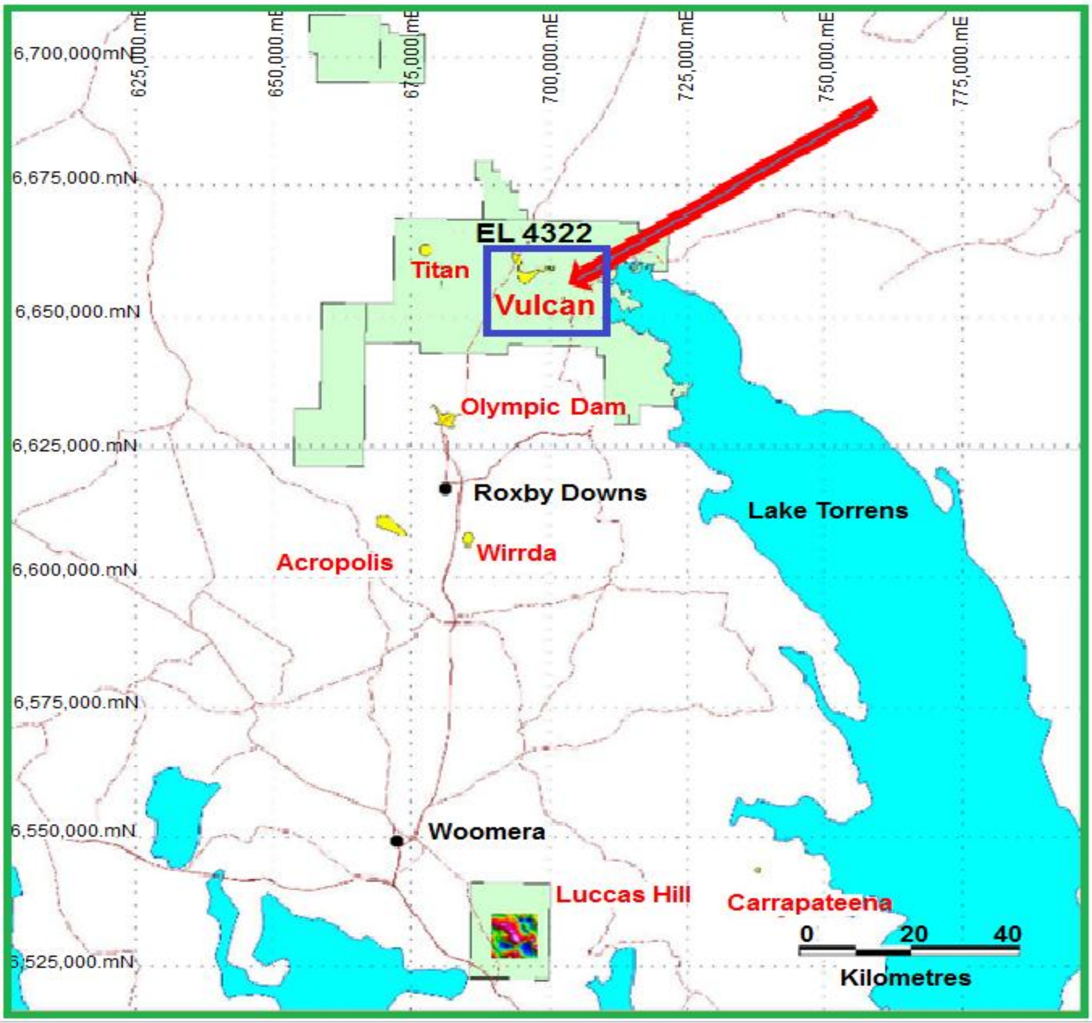

Figure 2: location of Vulcan IOCGU deposit within the Lake Torrens Area (Tasman 2009)

II. Materials and Method

Petrophysical measurements

Prior to building the geological models, an investigation was carried out to ascertain the viability of the geological model achieving its geophysical objective. This entails measuring velocity and density information on some selected drill holes. The information obtained did not only help to interpret potential sources of reflections in the study areas but also provides realistic goals for achieving the seismic survey [13]. Accordingly, a total of 550 samples from 20 drill holes were measured and analysed. Fig.3 shows the petrophysical properties measured from the core samples while Table 1 shows the reflection coefficient used for the geological model.

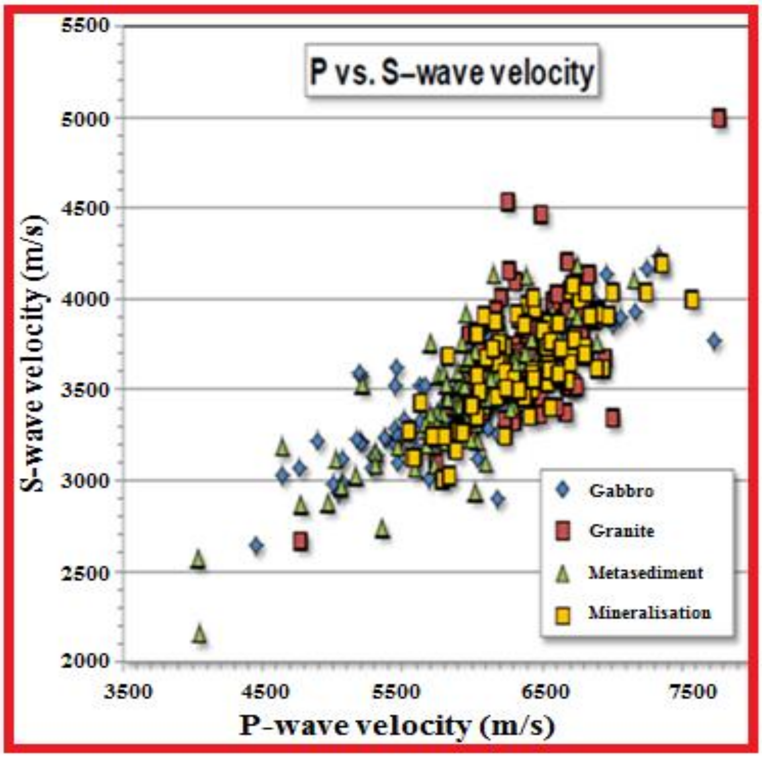

Figure 3: Types of Petrophysical properties (P &S- wave velocity,) measured from selected drilled cores.

Rocks Types	Vp (m/s)	Density (g/cc)
Shale	2240	1.85
Sandstone	3510	2.02
Siltstone	4925	2.63
Metasediment	4140	2.46
Granite	4552	2.58
Volcanics	6317	3.75
Mineralization	6525	4.29

Table 1: Summary of petrophysical data used for the geological model

2.1 Survey design

Due to the small size of most deposits, low signal to noise ratio as well structural complexity associated with hard rock environment, carefully designed survey parameters is needed. The geological models and synthetic survey used here was intended to represent suitable field parameters that are applicable to cost-effective 2D seismic acquisition. For these reasons, the synthetic data was modelled with survey parameters akin to what might be used in real practice; a series of 2D lines crossing the main intrusive package. This involved a 5km length by 2km depth geological model Figure 4 of which the primary zones of interest were situated within the central 1km. Parameters used for the survey includes 240 shot points at 20m intervals and 500 receivers at 10m spread across the model with a normal polarity Ricker wavelets of 35Hz as the central frequency. The pattern of source positioning replicates a rolling split spread acquisition design such that all active receivers were split in the centre by the source at all points.

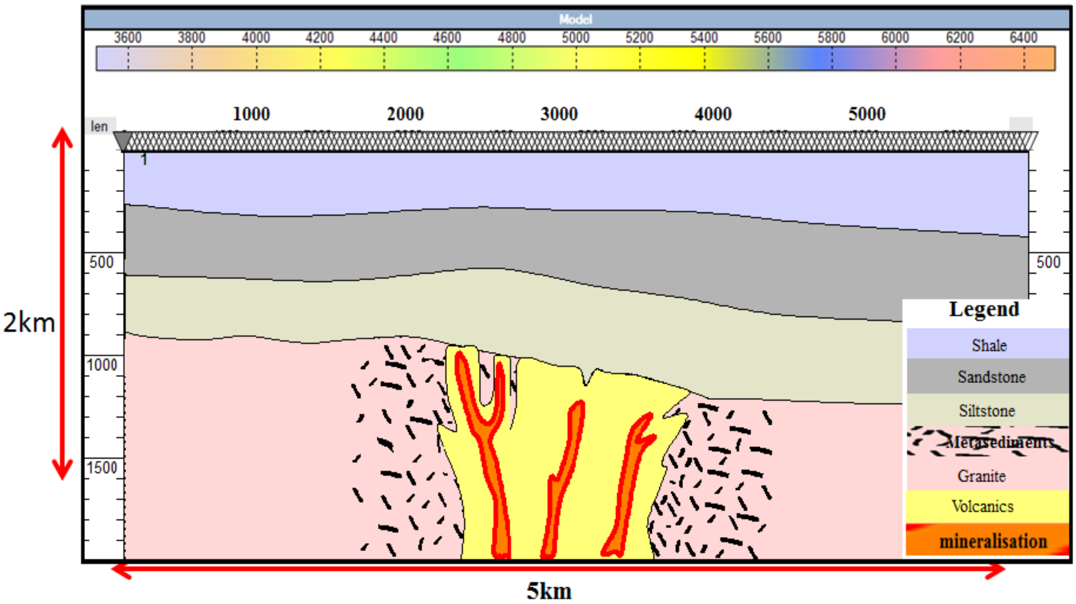

Figure 4: 5 by 2 km Geological Model of Vulcan Deposit used for forward modelling

2.2 Modelling and Processing of Synthetic Data

Forward modelling was carried out using a 2D acoustic modelling package in order to generate synthetic seismic reflection gathers. Data was modelled with 240 shots separated at 20 metre intervals spread across the 10km length model with a 35 Hz Ricker wavelet input as the central frequency. This input parameters created shot records and SEG-Y data files for the forward model to be processed more thoroughly using RadexPro. Immediately SEG-Y data files were imported to RadexPro software, geometry was assigned to the data sets followed by CDP sorting. Further processing was performed using a relatively standard data processing flow Fig.5. To enhance the chances of imaging the complex structure hosting the deposit, emphasis was placed on velocity analyses [10, 11].

Parameters	Synthetic Survey	Real Seismic survey
Length of model	5x2 km	2x2km
Number of shots	240	100
Number of receivers	500	250
Source spacing	20	20
Receivers spacing	40	40
Wavelet	Ricker	Ricker
Central frequency	35Hz	50Hz

Table 2: Parameter for synthetic and real surveys; the slight difference in the number of shot and receivers is due to the size of the survey under investigation. The synthetic model is 5 by 2km while the real survey is 1 by 1.2km. The processing for both the synthetic and real data follows the same routine except for static correction and geometry assignment.

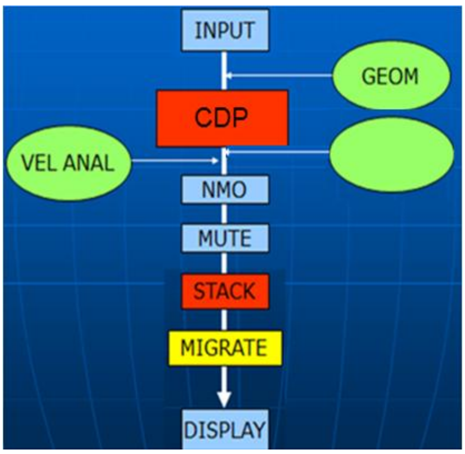

Figure 5: Processing flow used

III. Results and Discussion

All shot data was simulated using 2D full elastic modelling package which enabled the data in SEG-Y to be exported into processing software. For comparing purpose, some Gaussian noise was added to synthetic data to produce another synthetic section. Fig. 6 shows the synthetic shot records from the forward model.

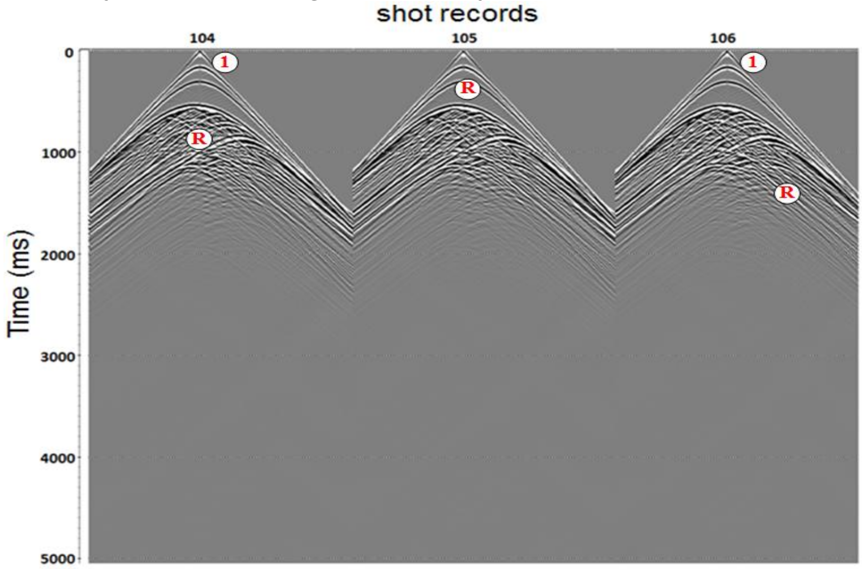

Figure 6: An example of noise free synthetic shot records for source number 104-106 from Vulcan complex model. (1) is the direct signals and (R) is the reflected signals or waves. Records are displaced from 0-5000 ms while actual reflectivity events are visible up to 2000ms. The shots are displayed using true relative amplitude without correction for spherical divergence. Shot depth for all gathers is 0m. Gathers are generated using Ricker wavelet source cantered at 35Hz.

Migrated synthetic sections in depth are shown in Fig. 7. The layers within the sediment cover have weak reflections due to the low impedance contrast (low velocity-density values assigned). Strong reflection as expected was noticeable between the granitic basement rock and sediment cover contact in all the parameters tested and this might be due to high impedance contrast. Anomalous reflectivity within the IOCGU complex area (indicated with yellow) was also visible and this could be a possible target for drilling.

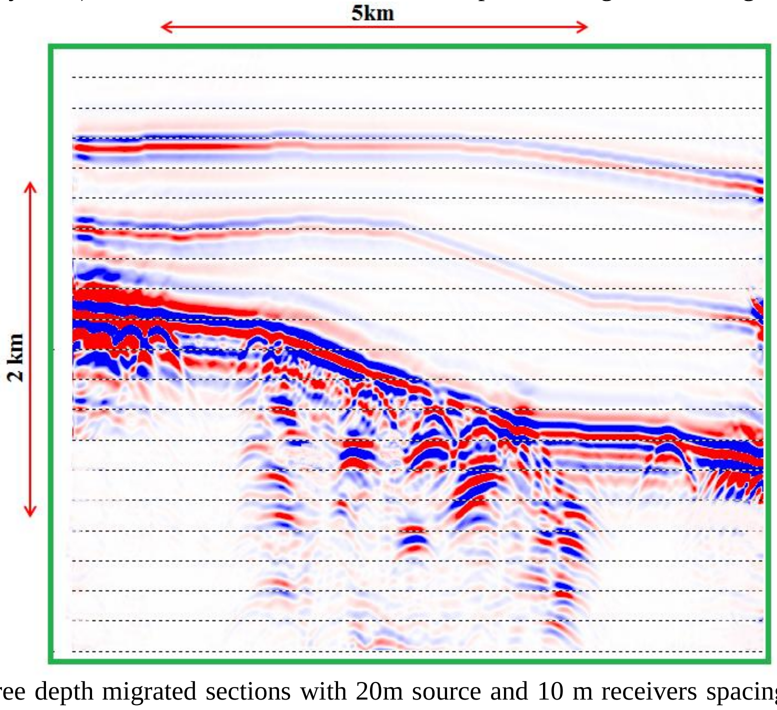

Figure 7: Noise free depth migrated sections with 20m source and 10 m receivers spacing. The layers within the sediments as well as the intrusive structure within the basement rocks are fully recovered. A strong reflection was also observed between the basement rock and the sediment layers due to high impedance contrast between the two layers.

The results from Gawler craton seismic survey are shown in Fig. 8A for Vulcan IOCGU while results from our modelling experiments using the geological model in Fig. 4 is shown in Fig. 8B. We also observe a loose similarity between the noise-free numerical data and very sparse deep crustal data. A subtle change in the reflection character in field data is visible around the granitic basement and may indicate mineralised zone with very high potential if drilled. The real data has higher resolution when compared with the synthetic data and this might be due to differences in the dominant frequency as well as the acquisition parameter used. The layers within the sediment also have weak reflection due to the low impedance contrast (low velocity-density values assigned). Strong reflection as expected was noticeable between the basement rock and sediment cover contact.

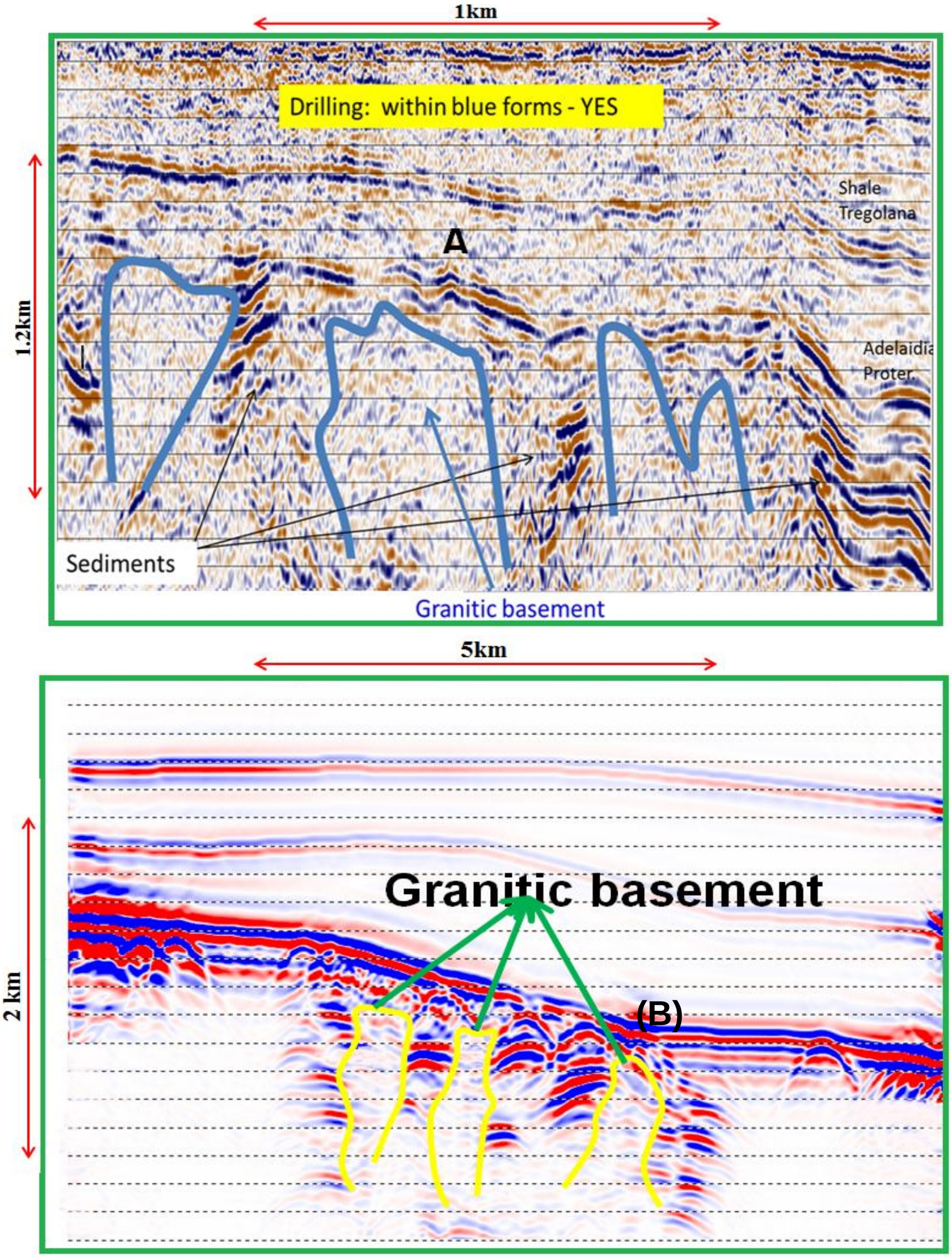

Figure 8: Real data vs Synthetic data, A) Expanded section directly below projection of Vulcan IOCGU, B) expanded section from the noise free synthetic model. The real data has higher resolution when compared with the synthetic data and this might be due to differences in the dominant frequency used. A loose similarity between the noise-free migrated data B) and the sparse deep crustal data A) is observed. A subtle change in the reflection character in field data is seen at the edge of mineralized complex**.**

Gaussian noise of 25% was added to the data before processing to establish the stability of the method in the presence of noise maintain same frequency range as the noise-free data. An example of the seismogram with the 25% Gaussian noise is shown in Fig. 9. There is a considerable difference when compared to the same seismogram from the same modelling shown in Fig. 6. Migrated image with 25% Gaussian noise is shown in Fig.10. The image from the noise free data in Fig. 7 looks better than the noisy image for obvious reasons. However, the contact between the eastern granite and that of the metasediment package as well as the instructive structure are largely recovered.

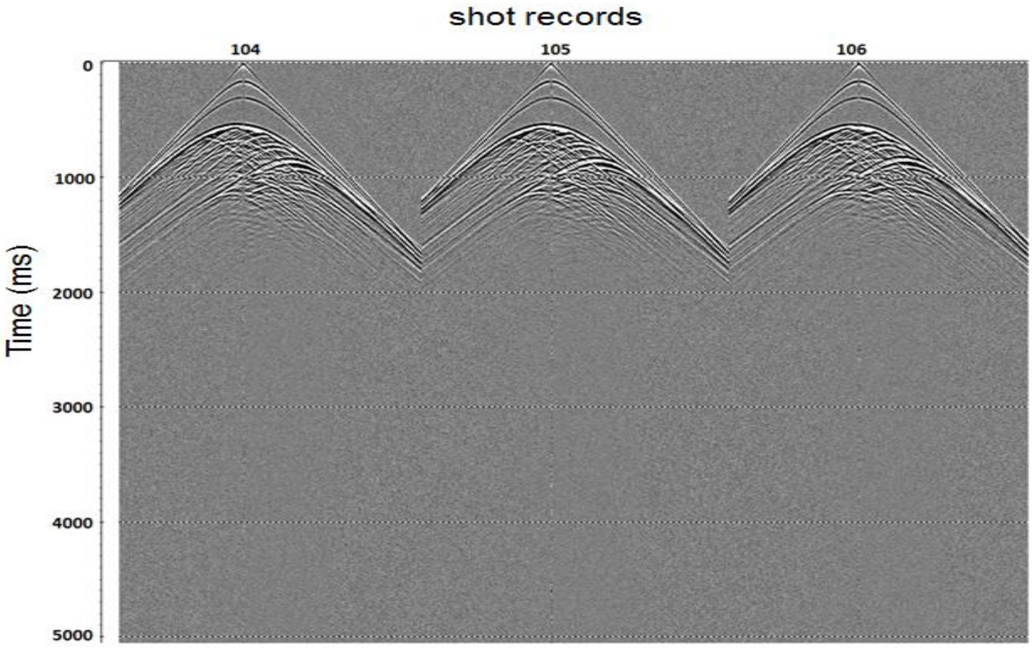

Figure 9: some synthetic shot records for source number 104-106 with 25% Gaussian noise. Record displaced from 0-5000 ms but reflectivity event are visible up to 2000 ms.

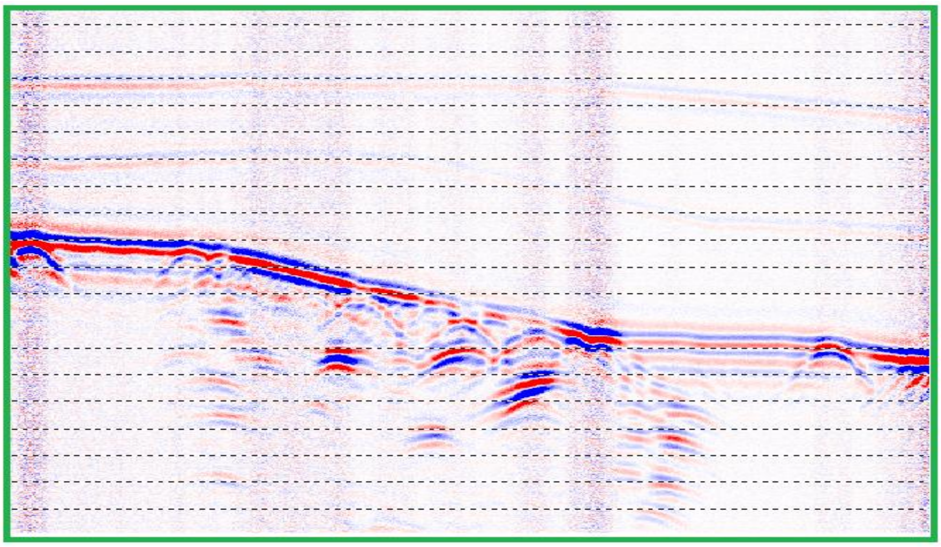

Figure 10: Top panel) 2x2 km interpreted seismic line over an expanded section of Vulcan, Middle panel) 5x 2 km noise free synthetic depth migrated section, Bottom panel) 10 x 2 km noisy synthetic depth migrated section.

IV. Conclusion

This modelling study has shown that seismic reflection techniques remains an important tool for exploration of deep seated IOCG deposits at any scale, even when hosted in complex structures as can be the case the case in the Gawler Craton. Using seismic reflection techniques to detect IOCG in the Gawler Craton is still very challenging and highly complicated because the structures hosting the deposits are generally steeply deeply and almost vertical which have the potential of generating a complex reflected wave-field that could conceal the reflections from the target. However, even with sparse acquisition parameters, it is feasible to image the various layers and see where the intrusive overprint the reflections from the basement geological structures and the cover sediments. Though not all intrusive - related packages can be image directly, however, we can see their presence, and the possibility of mineralization in a well-endowed province such as the Gawler craton is very promising.

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