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A Case for Large Scale Mineral Exploration in Hard Rock Environments using Seismic Reflection Method

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Abstract: *The seismic reflection method provides the possibility for delineation of very complex geological and this method might be good for detecting the presence of Iron Oxide Copper-Gold (IOCG) deposits. Despite many technically superior attributes, no arguments for regional seismic exploration have been proposed; probably because a cost-benefit analysis has never been conducted at such a scale. In this study we analyze such a case by modelling a Hillside IOCG deposit scenario where 2D seismic with relatively sparse source-receiver geometry is used to detect the presence of a possible intrusive package near a deep fault. The modelling results show that seismic reflection using 40m geophones and 80m shot spacing as an exploration tool is feasible, and that with the spacing halved we can definitely recover reasonable images of the upper parts of the mineralization. The presences of such intrusive are clearly detectable and with the seismic method are detectable from 100m to 1000m deep. Thus, we propose that using 2D seismic is viable for IOCG exploration as it can detect mineralised intrusive structures along known favorable corridors or structures*
Keywords: *Exploration, IOCG, Regional, Seismic Reflection*

I. Introduction

Since the discovery of the world class Olympic Dam IOCG deposit in 1975, the Gawler Craton in South Australia has been subjected to scrutiny by various explorers using a multi-disciplinary exploration approach (geology, geophysics and tectonic analysis) in search of similar deposits. Potential field geophysical methods are traditionally used for IOCG exploration. These methods though apparently effective lack the lateral and depth resolution needed to image deeper mineral deposits for targeted mining, currently limited at about 3.9km, [2]. Also, we don't know what deposits have been missed by the absence of detectable magnetic and gravity responses, despite their well-known limitations with depth of investigation.

Early applications of seismic profiling for mineral exploration were had difficulties and results were not often encouraging because data acquisition and processing were done without the required modification to the procedures typically used previously in hydrocarbon exploration. However, recent application of seismic reflection techniques provides much greater promise in the delineation of ore-bodies and for mine planning in complex hard rock environments as documented by [11,18,12,14,19,20,10,3,16,17,22,4,6,7,21,5,8].

Despite the relative successes of the above-mentioned applications of seismic reflection a real problem exists for exploration beyond the immediate vicinity of a known deposit. All previous studies have focussed upon high resolution detection of mineralisation and the hosting structures. For "greenfield" exploration, where known deposits are many km's away we look at whether the seismic method is viable for such exploration. To reduce costs we anticipate a 2D survey geometry and geophone and source spacing more akin to regional studies, such as 20m geophones and 40m shot spacing. Also, we look at Iron Oxide Copper Gold deposits in the Gawler Craton as an example, as these are often associated with large intrusive complexes. The study will focus on the Hillside deposit since we have a significant petrophysical data and experience from performing a 3D survey over the mineralisation. We test the idea that IOCG deposits can be found by looking for the seismic signatures of intrusions along prospective structures.

II. Geology of Study Area

The Hillside IOCG deposit Figure (1) can be classified as a recent discovery hidden by sequences of sediments approximately 10-30m thick comprising unconsolidated sand spreads and inland dunes, silty sandstone, siltstone, and limestone of the Rogue Formation and calcareous siltstone, calcarenite, sandstone of the Muloowurtie Formation [15,13]. It is bounded to the west by the Pine Point Fault with unmineraliszed sediments and volcanic units occurring in the hanging wall and to the east (footwall) by a large granitic intrusion. [1]. Host rocks include: Paleoproterozoic skarns and metasediments, which have been intruded by Granite and Gabbro equivalents. The mineralisatoccurs in Proterozoic age rocks including metasediment, granite, gabbro and skarn and is spatially associated with the regional Pine Point Fault Zone and locally identified with Songvaar, Zanoni, Dart and Parsee Fault zones. Primary copper - gold mineralization occurs in vertical to sub - vertical magnetite and hematite Rich lenses within the skarn/metasedimentary package while secondary copper – gold Mineralization occurs within a shallow sequence of weathered basement rocks.

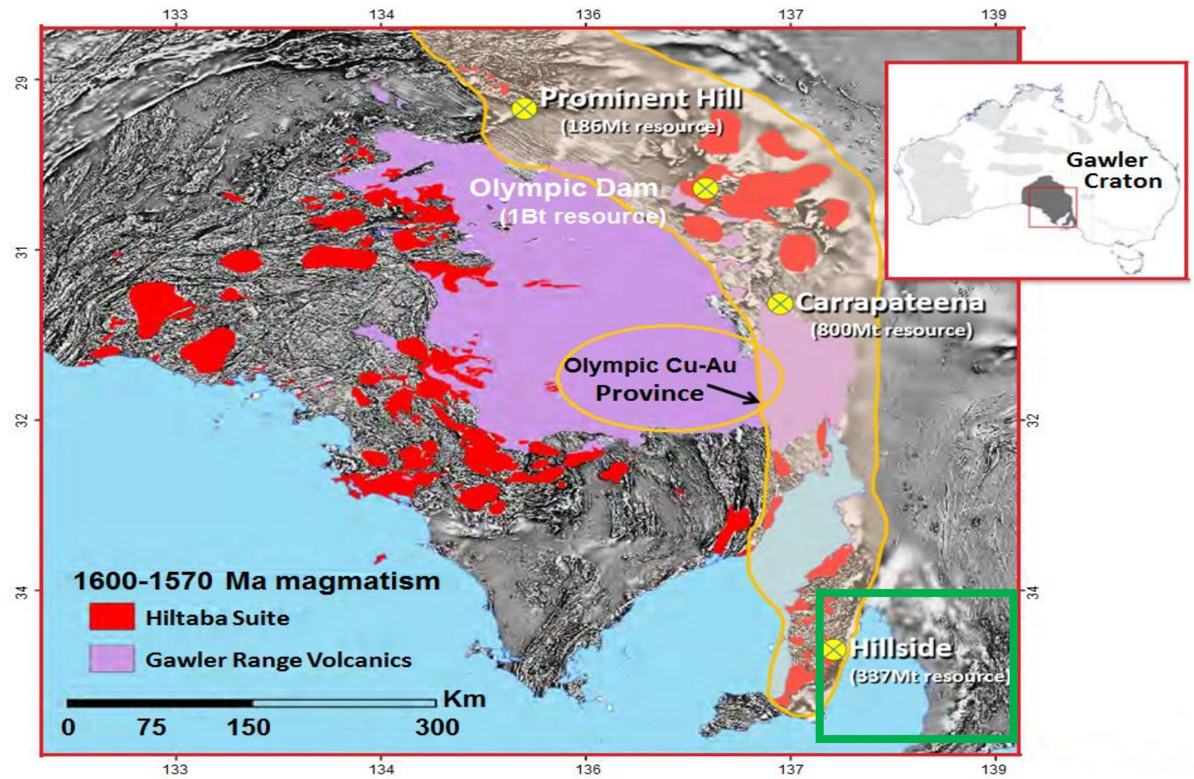


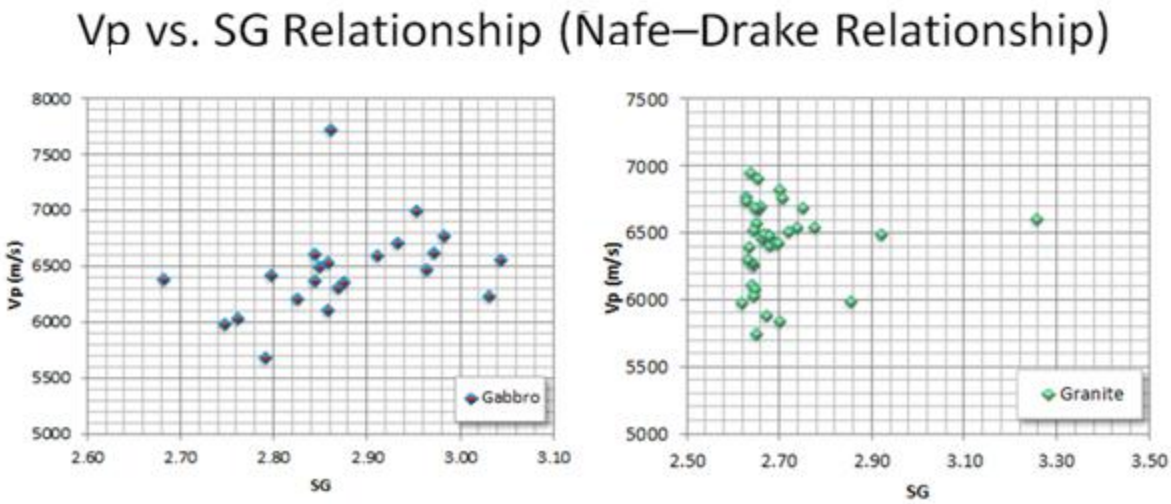
Fig. 1: Geology map of the Gawler Craton showing the location of Hillside Cu-Au deposits (green triangle)

The Hillside deposit lies along the edge of the Pine-point fault, which has a history of deposits occurring near the fault. So Hillside will be used as a template for finding intrusive complexes near a deep fault, as such complexes are more likely to be mineralised

III. Materials and Method

3.1 Petrophysical Measurement

The best way to ascertain the viability of the geological model achieving its geophysical objective is by measuring velocity and density information on drill holes. The information obtained helps to interpret potential sources of reflections in the study area and set the realistic goals for the seismic survey, [9]. A total of 491 samples from 13 drill holes were measured and analysed. Figure (2) shows the petrophysical properties measured from the core samples from Well HDD-064 and the scattered distributions of the specific gravity vs P-wave velocity.



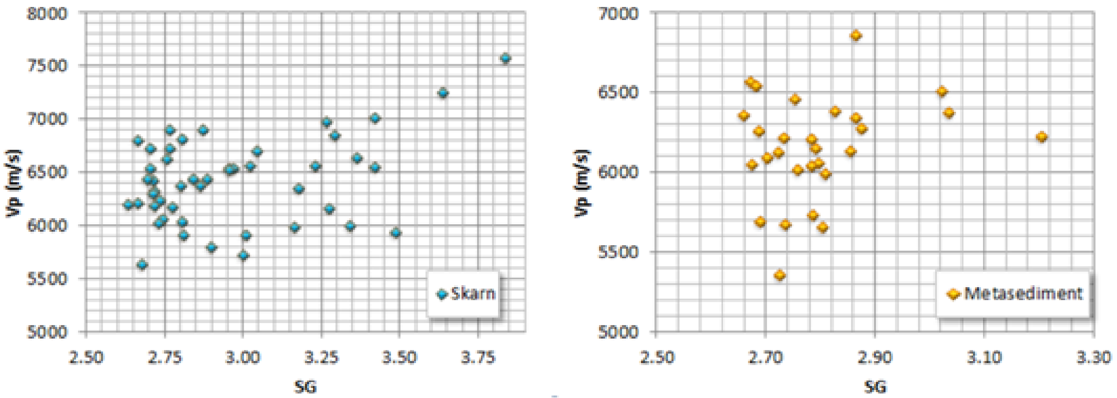
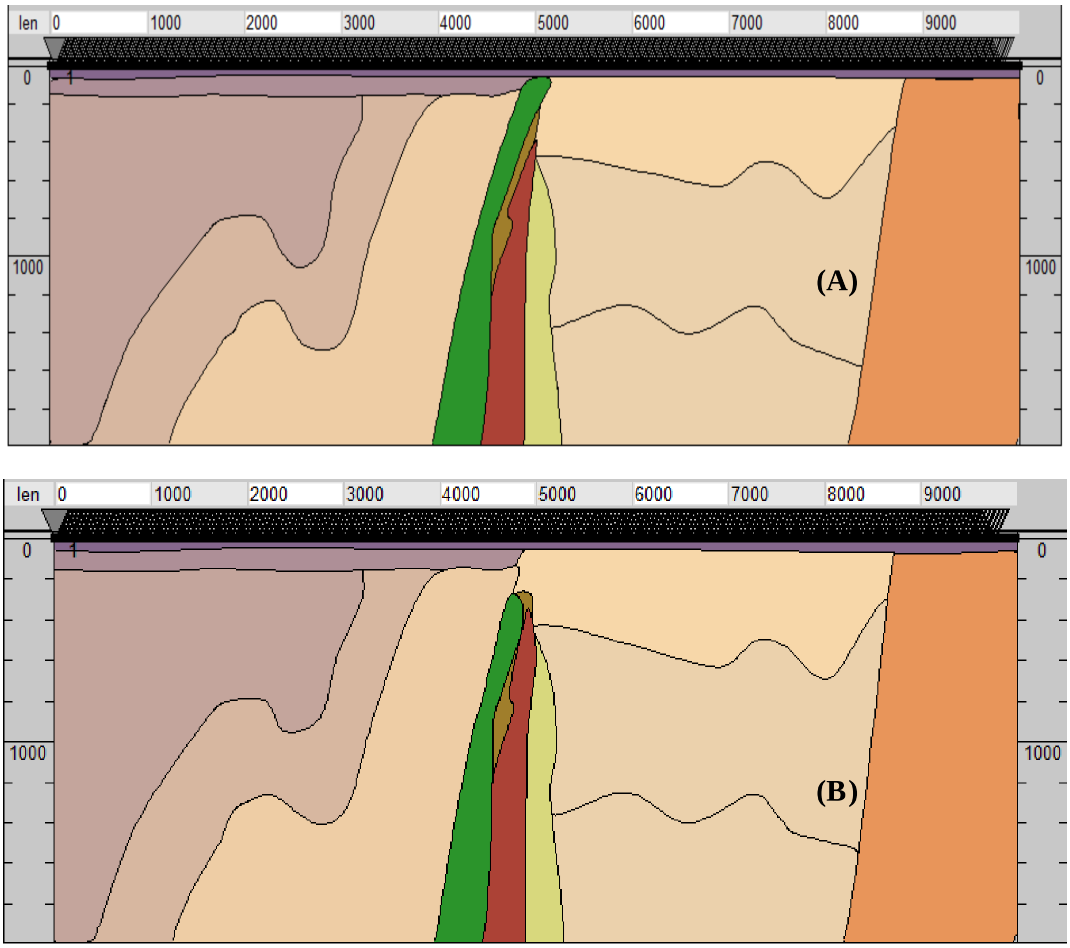


Figure 2: Scatter plot of specific gravity vs. P-wave velocity data measured from the core samples from Hillside Cu-Au Mining project

3.2 Geological Models and Synthetic Survey Design

The geological model and synthetic survey design 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 similar to what might be used in practice; a series of 2D lines crossing the main fault. This involved a 10km length by 2km depth geological model Figure (3), of which the primary zones of interest (the Hillside copper deposit mineralization) were situated within the central 1km. To ensure the reliability of the geological model, a magnetic response was simulated with results showing a good correlation between calculated and observed responses. Parameters for the survey design include 250 shot points at 80m interval and 500 receivers at 40m spread across the model with a 35-55 Hz Ricker wavelet which serves as the dominant frequency. The pattern of source positioning replicated a rolling split spread acquisition design such that the entire 500 active receivers were split in the centre by the source at all points.



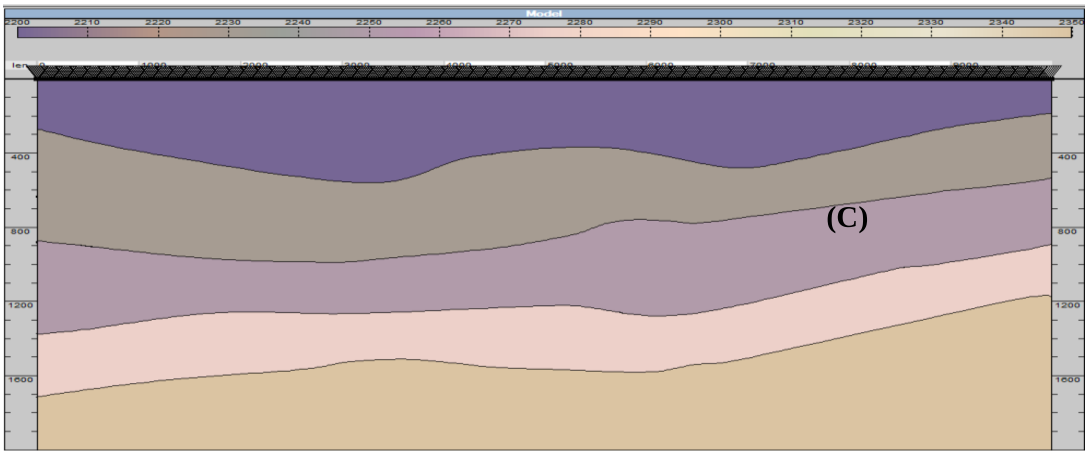


Fig. 3: A) Hillside Intrusive model 70m cover – intrusive near fault, possible mineralisation, B) Intrusive model 250m cover – intrusive near fault, possible mineralisation, C) Model with no fault boundary and no intrusive, just metasediments (non prospective)

3.3 Processing of Synthetic Data

All shot data was simulated using Tesseral-2D full elastic modelling software. This created shot records and SEG-Y data files for each forward model to be processed more thoroughly using RadexPro. Once SEG-Y data files were imported to RadexPro software, geometry was assigned to the data sets after which it was sorted by CDP for the purpose of binning and analysis of the wave field. Full processing was performed using a relatively standard data processing flow. However, to enhance the chances of imaging the complex structure hosting the deposit, considerable effort was applied to velocity analyses (Hammer et al (2004). The processing steps included quality control (trace editing and muting), and firstbreak picking. Prestack processing included band-pass filtering (35-55 Hz), spherical divergence, NMO and predictive deconvolution. Poststack processing included ensemble stack and finite-difference depth migration.

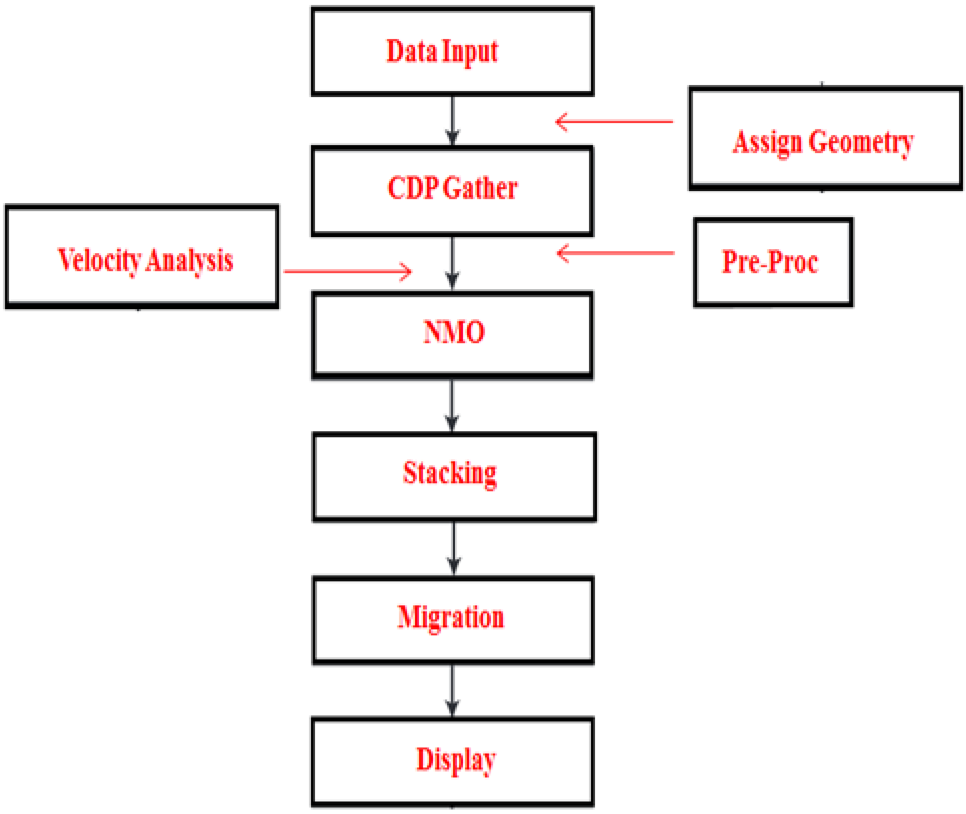


Figure 4. Basic processing flow used in this experiment

IV. 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. Full processing was then performed using a relatively standard data processing flow. Figure (5) displays the migrated sections for the three cases considered.

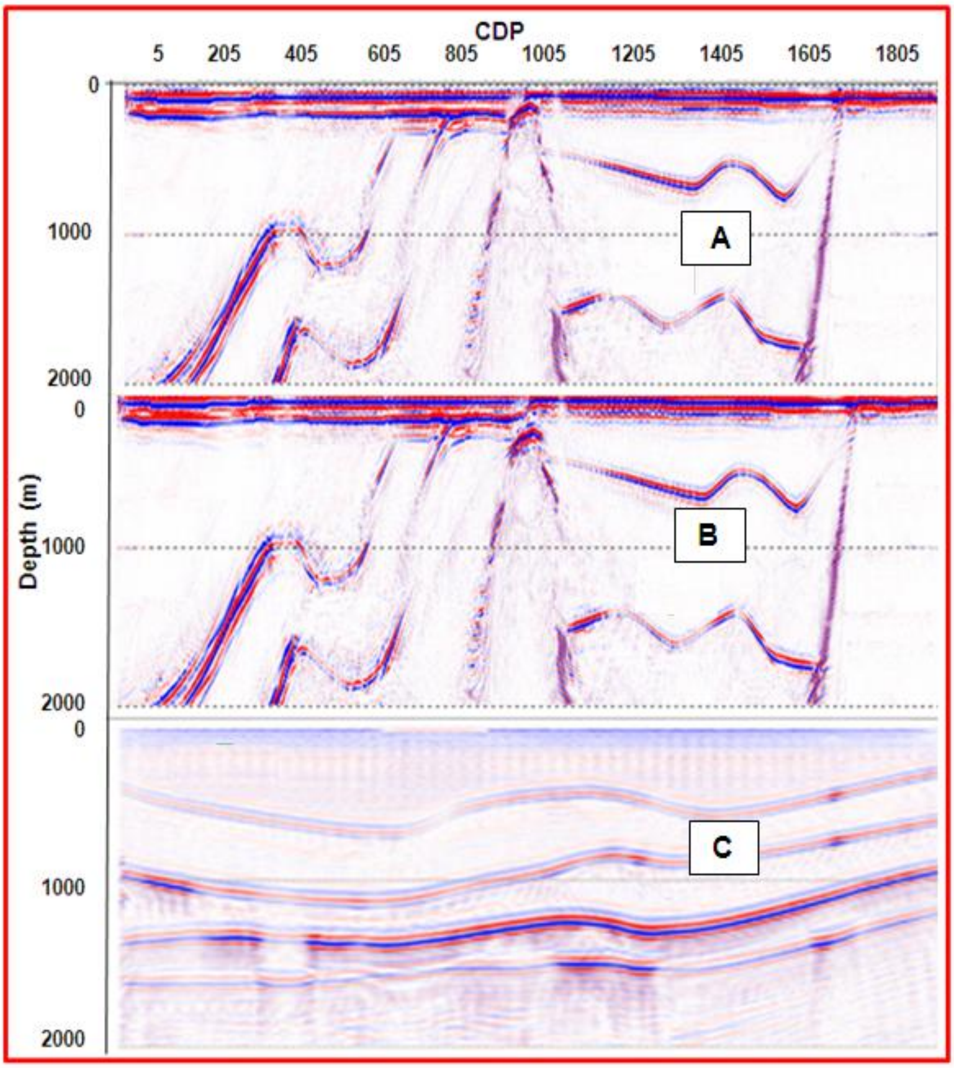


Figure 5: Migrated section: Panels (a), and (b) show the effect of different survey paarmeters in imaging the intrusive near the fault boundary (tight vs sparse). Panels (c) is the migrated section of non intrusive structure (only metasediments). In panels (a) and (b), the top of the intrusive can be detected near the fault.

The migrated images were able to resolves the various layers as well as the complex structure of the sub-vertical intrusion. Reflections from the edges of the intrusions as well as the various lithological contacts are well defined and more visible compared with the geological model. We equally observed a similar relationship of the image with the geological model, and this was also the case with our real 3D seismic survey over the actual mineralization; however, the intrusive complex itself is composed of many separate blocks and scattering faults within it (pers comm with Rex geologists and M. Hossain). The modelled data obviously looks better than available"real" data due to the lack of "noise" in modelled data plus the relatively simple interfaces and an absence of scatterers, which are dominant in a "hard rock" terrain. Also, the layers within the meta-sediments are of low contrast, but the lack of other interfaces and noise makes the internal structures within extend to stand out. However, it is hard to not observe the presence of an intrusive complex or fault in the simulated data

V. Conclusion

Results from this modelling experiments has further revealed the applicability of seismic reflection techniques as a veritable tool for regional exploration of IOCG deposits, even when hosted in complex geological terrains. Despite the subtle nature of seismic response in the study area (highly deformed metasediment intruded by vertical intrusions) which have the potential of generating a complex reflected wave-field that could conceal the reflections from the target, it was relatively feasible to image the various layers and see where the intrusives overprint the reflections from the basement geological structures and the cover sediments. Thus in the case of investigating the intrusive structures or deep fault hosting ore-deposits using say 10 km lines with a 80-40m (source-receiver) geometry, we might be able to cover an area of 15km of strike length with a series of 5 km long lines thereby making it cost effective.

Acknowledgments

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