

# Mt Woods 2D Seismic Reflection Survey, Gawler Craton, South Australia: An Integrated Minerals Exploration Case Study.

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## SUMMARY

Five seismic reflection profiles for *ca* 130 line km were acquired over the southern Mt Woods Inlier, near the Prominent Hill IOCG deposit in South Australia. The aim was to provide high resolution images of the under-cover region in the shallow to mid crust, to augment existing potential field and drilling data and, through a combined interpretation, to optimise exploration targeting. The application of seismic reflection using vibroseis sources in hard rock terranes presented significant challenges to processing and interpretation. Notwithstanding this, the resulting 2D images clarified a number of important fault and fold patterns that were also apparent in, but poorly constrained by, the potential field data. The major faults include: the Southern Overthrust imaged as a major north dipping feature that truncates a series of gently dipping reflectors within the Palaeoproterozoic and Archaean basement, and the Bulgunnia Fault as a complex set of steeply dipping divergent faults. The major folds are large amplitude refolded features that include the Kennedys Dam antiform and Larissa synform. The White Hills mafic complex, which has an impressive positive gravity and magnetic response, occupies a broadly synformal position. The Gawler Range Volcanics and their contact with Palaeoproterozoic metasediments is well imaged using the seismic method. A thrust duplex structural setting has been inferred around the Prominent Hill deposit.

**Key words:** Seismic Reflection, IOCG, Exploration, Mt Woods Inlier, Gawler Craton

## INTRODUCTION

Exploration for IOCG deposits in the Gawler Craton, South Australia, is constrained by the under-cover environment that exists over much of the region. Traditionally, potential field and electrical geophysics have been the main techniques used to generate and evaluate targets for drilling. The application of seismic methods in this terrain has been piecemeal, in part limited by cost and in part by the limitations of seismic methods in hard rock terranes. Yet, the results of seismic reflection surveys in this region (Gawler Craton) and similar environments (Tasmanides, Yilgarn, Mt Isa Inlier) have always provided insights to the mineral systems under investigation (e.g. Goleby *et al.* 2004). In an attempt to resolve key aspects of the geological architecture, a high

resolution 2D seismic reflection survey across the southern margins of the Mt Woods Inlier (MWI) was acquired by OZ Minerals during March and April 2012. Terrex Seismic were contracted to collect the 129.9 line km of seismic reflection data on 5 profiles. Wide-angle seismic refraction and gravity data was also collected on these profiles and 54.63 line km of magneto telluric (MT) data was acquired along two of the profiles. These datasets facilitate a combined interpretation approach using all available geophysical and geological datasets. This contribution summarises the acquisition, processing, results and current interpretations of these data.

The objective of the high resolution seismic survey was to image major lithological domains, intrusive bodies and major fault and fold structures in the upper 10km of the crust. The data was used to inform the geological model of the inlier that hosts the Prominent Hill iron oxide copper gold (IOCG) deposit (Carter *et al.* 2003) and numerous regional Cu-Au prospects (e.g. Manxman, Joes Dam, Neptune-Triton) and to prioritise targets for IOCG mineralisation (Funk, this publication in press). While direct detection of IOCG mineralisation was not the primary aim of the survey, the OZ12-04 profile was collected 250m east of the Prominent Hill mine to determine if the deposit has a seismic signature.

The geology and mineralisation of the MWI has been described by Betts *et al.* (2003) and by Freeman and Tomkinson (2011). The MWI is a multiply deformed Palaeo- to Mesoproterozoic mobile belt located along the eastern margin of the Gawler Craton, South Australia (Flint, 1993). These prospective basement rocks are predominately overlain by flat lying Phanerozoic cover sequences that vary from 100 to 400m in thickness (Freeman & Tomkinson, 2011). The application of the seismic method in such hard rock terranes poses significant problems as reported by Jones *et al.* (2005). The 2003 Gawler Craton (Lyons & Goleby, 2005) and 2010 GOMA (Korsch & Kositsin, 2010) seismic reflection surveys, collected by Geoscience Australia (GA) and the Department of Minerals, Industry, Trade, Resources and Energy (DMITRE), are similar surveys albeit at regional scales with a greater emphasis on deeper crustal architecture.

The Mt Woods 2D seismic reflection survey differs from these previous studies as the scale of the survey was optimised to image the near surface (0-1km) to mid-levels (1-10km) of the crust. The seismic data collected over Mt Woods has good reflectivity for the most part, except in the higher grade metamorphic domains. Despite this, there still remains a large amount of ambiguity with processing and interpretation of the data. Additional information that significantly contributed to the interpretation was derived from potential field modelling, multi-scale edge detection techniques and basement interface

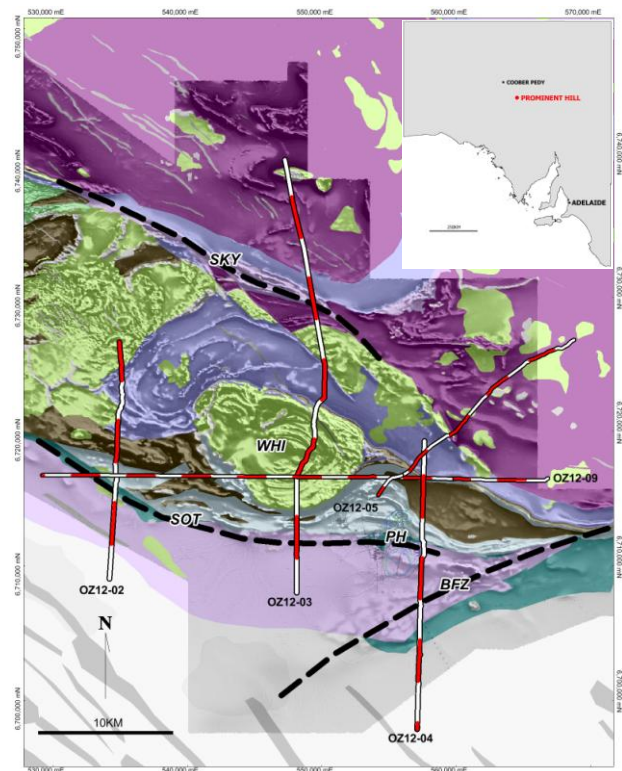
refraction velocities. The survey was successful in imaging the major fault and low angle fold structures and broad lithological domains. From this an updated geological model for the MWI has been derived and the distribution of key contacts and prospective regions has been inferred. A thrust duplex structural setting formed in a 'thin-skinned' tectonic environment is inferred around the Prominent Hill deposit.

## DATA ACQUISITION AND PROCESSING

Survey design was guided by an initial scoping study that involved petrophysical measurements on diamond drill core and forward modelling to investigate likely seismic responses. The results indicated significant acoustic impedance contrasts existed within the basement and determined minimum surveying parameters required to detect such contrasts. Line design was optimised to utilise existing pastoral tracks whilst avoiding cultural, topographical and geologically problematic areas. The final line locations consisted of three north-south (OZ12-02, OZ12-03, OZ12-04), one northwest-southeast (OZ12-05) and one east-west tie line (OZ12-09). Collectively these encompass a ~40x40km study area (Figure 1).

The survey was collected with a nominal fold of 225, using standard split-spread roll-along geometry and two to three Hemi-50 vibrator trucks (6-150Hz, 14sec, linear sweep) centred in 9km of active receiver spread. Data was recorded using a Sercel 428 24 bit system, 10 to 20m shot interval and a group interval of 10m (6 geophones inline) over 900 active channels. The large offsets and fold coverage were designed to maximise imaging of steeply dipping geology and achieve the highest possible resolution in both the near surface and mid-levels of the crust, respectively. Data quality was very good despite noise from wind, haul trucks and mining operations.

The processing stream was designed to enhance reflectors in the 0 to 4 sec region of the section and avoid processes that could potentially degrade the data. Numerous processing challenges were encountered and are largely attributed to the complex structure and velocity of the subsurface. These included treating the Phanerozoic cover in the refraction statics correction solution, irregular velocity model with spurious interval velocities, post-stack migration artefacts and difficulty time to depth converting the data. Substantial efforts were made to trial alternative processing methods to overcome these challenges and maximise the geological information within the recorded data. The most significant improvement in the interpretability of the data was achieved by applying linear post stack filters and whitening operators as opposed to a short window automatic gain control (AGC) filtering. This greatly improved retention of amplitude information and overall reflectivity character of the final sections. The processed data was received as stacked and migrated 6sec two way travel time (TWT) sections in SEG-Y format. The data shows good reflections down to ~4sec where the signal to noise ratio (S/N) becomes too low to permit confident interpretations (Figure 2). For this reason the sections were clipped to 4sec TWT. Assuming a constant velocity of ~5500m/s (consistent with petrophysical measurements) the bottom of these sections are equivalent to ~11km in depth. The most prominent non-geological artefacts in the data are interpreted to arise from out of plane seismic events and post stack migration effects.



**Figure 1. (Main) Mt Woods survey location map displaying seismic reflection line locations (red and white lines), major structures (black dashed lines) and Prominent Hill mine site layout overlying basement geology draped on 1VD aeromagnetic image. PH = Prominent Hill, WHI = White Hills mafic complex, SKY = Skylark Fault, SOT = Southern Overthrust, BFZ = Bulgunnia Fault. (Insert) South Australian location map.**

## INTERPRETATION AND IMPLICATIONS FOR EXPLORATION

Preliminary interpretations were made in the time domain on filtered stacked and migrated sections. The SEG-Y sections were imported into the GOCAD software package for digitizing the interpreted line work and evaluated with respect to additional datasets (drilling, gravity, aeromagnetic, MT and refraction statics). Due to the complex geology, the profiles often lacked significant reflector continuity in the basement. The interpretation relied on *a priori* geological information and the integration of other geophysical and drilling datasets for validation. While it is beyond the scope of this contribution to discuss the interpretation of each profile, some of the most important features with implications for exploration are outlined.

The most significant major fault interpreted from the seismic data is the Southern Overthrust (SOT) that bounds the southern margin of the inlier (Betts *et al.* 2003). This structure is imaged as a major crustal scale, north dipping feature that truncates a series of gently dipping reflectors within the Gawler Range Volcanics (GRV), Palaeoproterozoic metasediments and Archaean basement and extends at least into mid-crustal levels (>10km) (Figure 2A). The seismic data indicates that south dipping antithetic splay faults are associated with the main structure whose location when projected to surface is ~1 to 2km further south than previously interpreted from gravity data. The Bulgunnia Fault Zone

(BFZ), situated ~9km to the south of the Prominent Hill deposit, appears as a complex set of steeply dipping divergent faults that dip towards the north-east and south-west. This is in agreement with potential field data that suggests the gravity and aeromagnetic expressions dip in opposite directions. The basement contact is disrupted over the BFZ and is interpreted to indicate very late movement during the Phanerozoic. Large amplitude, continuous, gently inclined reflectors at the base of interpreted lithological domains are a feature in the region between the Skylark Fault (WNW-ESE trending structure in the centre of the inlier) and the SOT (Figure 2B). This layering is deformed with large amplitude open folds that affect the distribution of geological units. The major folds imaged by the seismic data are the Kennedy's Dam Antiform, Larissa Synform and White Hills Synform. The continuation of these fold patterns has been subsequently mapped using gravity and aeromagnetic data. These are interpreted to be late stage, Kararan deformation, post the intrusion of the Hiltaba Suite.

The best defined and only continuous reflector imaged by all survey lines is the contact between the Phanerozoic cover sequence and the basement. The cover sequence generally lacks reflectivity, varies in thickness and generally thickens towards the south from 70 to 300m. This contact is poorly defined over some regions and is interpreted to reflect facies variation in the Boorthana Diamictite as reported by Menpes *et al.* (2010). To the south of the BFZ a ~1km thick Neoproterozoic-Phanerozoic basin overlying the GRV and underlying the Boorthana Diamictite is interpreted from the seismic data. The White Hill mafic complex, which has a large gravity and aeromagnetic response, is defined as a region of low reflectivity contrasted against high amplitude, synformal, continuous reflectors that are internal to the intrusive body. This observation supports an interpretation of multiple intrusive phases. The strongest of these reflectors was initially interpreted to be the basal contact and implied a maximum thickness of ~2500m. The contacts are interpreted to be moderately inward dipping though poorly defined in the seismic data and have largely been inferred from potential field data. The lack of resolution could be due to contact metamorphism on the margins of the intrusive body which decrease the acoustic impedance contrast. The interpreted spatial extents are supported by a notable increase in the basement contact refraction statics and stacking velocities up to ~7000m/s. Forward modelling of the gravity data has provided further constraints on the geometry and suggests the complex is thicker and more laterally extensive to the south than interpreted from the seismic data. The basal GRV contact with the Palaeoproterozoic metasediments was imaged well by the seismic survey. The GRV displays very strong reflectivity signatures defined by high amplitude, continuous, gently dipping reflectors (Figure 2C). The survey was successful in differentiating the upper and lower GRV sequences that are separated by a disconformity with a combined maximum thickness of up to 4.5km. The contact between the Prominent Hill mine sequence (low grade greenschist facies metasediments) and the higher grade amphibolite to granulite facies Skylark and Mt Woods metamorphics to the north is less well defined by the seismic data. The northern parts of the seismic lines contain very little information in the high grade metamorphics. Archaean units are interpreted in the bottom part of the sections with a non-reflective domain distinguished above a more reflective lower domain. The contact with these domains is well defined beneath the GRV in the south, but less well defined beneath the metasediments

to the north. Nonetheless the survey was successful in defining the thickness of the Palaeoproterozoic units of the Mt Woods Inlier that increase to greater than 10km north of the Skylark Fault.

In the west the SOT extends into the Archaean basement whereas beneath Prominent Hill the geometry suggests a 'thin skinned' regime. A thrust duplex is interpreted which developed in response to kilometre scale sinistral shear on the adjacent BFZ (Figure 2D). In the immediate hanging wall of the SOT, there are a series of antithetic faults that may have acted as "short-cuts" for fluid flow related to the SOT.

## DISCUSSION

Confidence in these interpretations was greatly increased by the ability to image the majority of these features on the east-west tie line that facilitated 2.5D interpolation of features. A generalisation from the results of this survey is that the seismic method was most useful in imaging the geology in the south of the study area compared to the north where both alteration and metamorphism substantially increase. This assertion is in agreement with workers such as Chopping (2008) who concluded that these factors will predominately decrease acoustic impedance contrasts.

The combined interpretation methodology was critical in providing confidence in the seismic interpretations. However, it should be noted that the combined interpretation approach can be ambiguous as the scalability and geophysical responses of geological features is manifested differently for each geophysical technique. For example it is evident in this interpretation that the seismic reflection data was biased towards flat lying structures, whilst potential field datasets highlighted steeper structures. Furthermore the aeromagnetic data was greatly affected by short wavelength responses from alteration and metasomatism around structures and intrusives whilst the gravity data was most affected by longer wavelength responses of intrusive bodies such as the White Hills mafic complex. Similarly, whilst drilling provides the ultimate constraint, it was often difficult to incorporate in the interpretation. Drilling is only available at shallow depths and provides much higher frequency information when compared to the seismic reflection data. While not a focus of the survey design no response was detected from the iron oxide alteration at Prominent Hill.

## CONCLUSIONS

The results of the Mt Woods 2D seismic reflection survey generally display good reflectivity and allowed for interpretation of major structures and lithological domains. The survey was successful in its primary aim of testing the geological model of the MWI to assist in regional exploration targeting. A thrust duplex structural setting formed in a 'thin-skinned' tectonic environment has been inferred beneath the Prominent Hill IOCG deposit. Significant challenges and ambiguity were encountered during processing and interpretation of the combined dataset. Challenges increase with structural complexity, alteration and metamorphism of the geology as noted in other hard rock surveys. Nonetheless the findings of this survey indicate that tenement scale seismic reflection surveys can greatly assist mineral exploration programs through increasing the geological understanding of these terranes.



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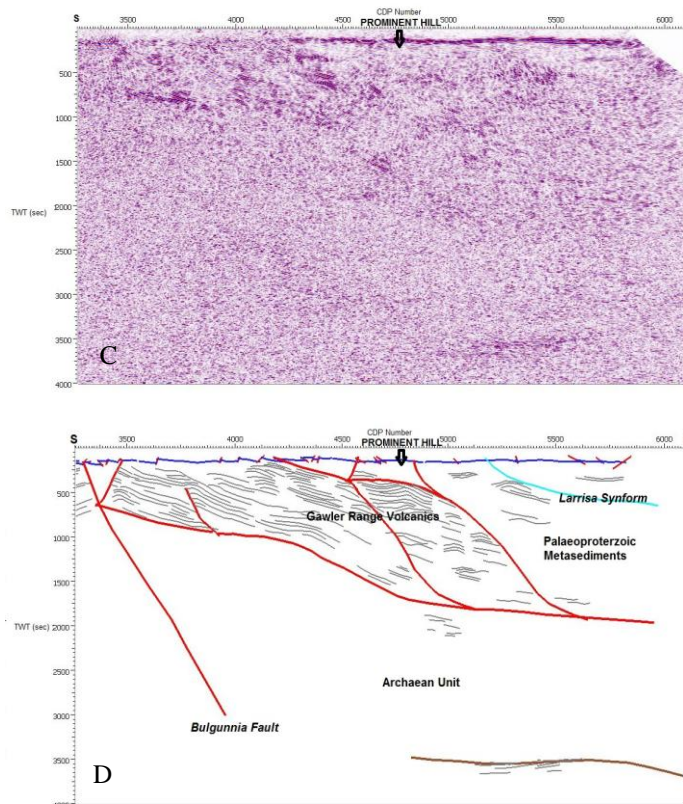
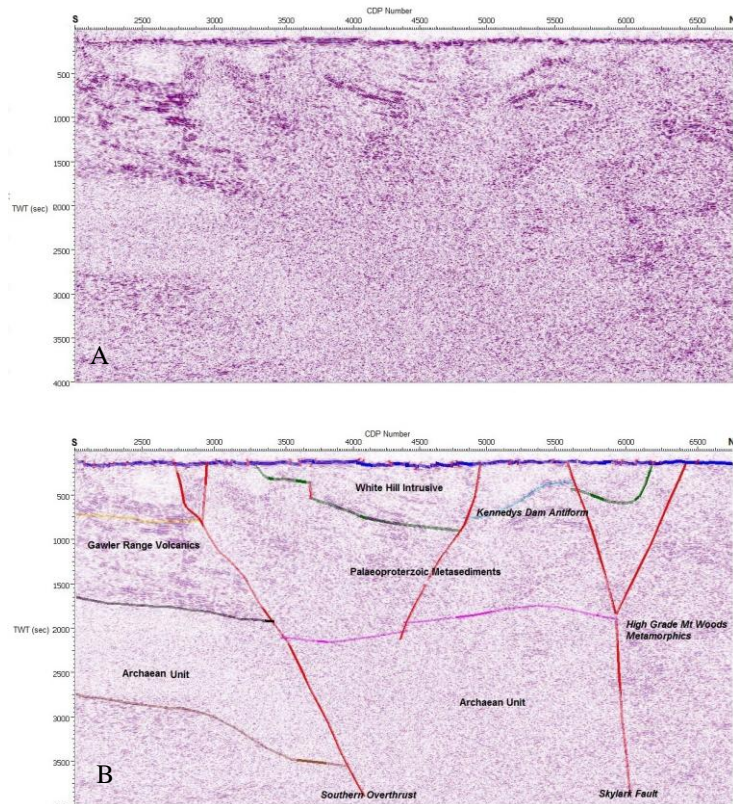
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**Figure 2.** Examples of migrated seismic data and interpretations from the Mt Woods 2D seismic reflection survey. (A) Southern part of OZ12-02 migrated seismic section (B) interpretation line work for OZ12-02 overlying southern part of migrated seismic section (C) Northern part of OZ12-04 migrated seismic section (D) Interpretation line work for OZ12-04.