Volumetric interpretation of 3D hard rock seismic data

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SUMMARY

Seismic reflection method has been successfully used in the petroleum industry for the last few decades. Until recently, the mining industry has been reluctant to use seismic methods for mineral exploration because of its high cost, uncertain performance, and potentially ambiguous interpretation results. However, shallow mineral reserves are depleted and exploration is moving towards deeper targets in order to extend existing and to find new mineral reserves. In that space it is perceptible that seismic method will become an important if not primary exploration tool to delineate subsurface structures hosting ore bodies. One of the outstanding issues along the application of seismic methods for mineral exploration is our ability to grasp and then interpret excessively complex seismic images.

Volumetric interpretation is performed in 3D, in real–time by applying opacity and transparency filters to grasp the global structures and by rotating and viewing the seismic volume from different angles which allows in–depth understanding of the volume analysed. This, initial stage of volumetric interpretation is followed by more specific tasks aimed towards mapping the interfaces and associated structures of exploration interest. The ore shoots or occurrences are predicted by numerical modelling based on the priori knowledge. The targeting strategy is constructed according to the numerical response and map of the main interfaces and structures. This, for hard rock, novel interpretation methodology is aimed towards direct targeting and estimates of the ore reserves. The implementation is demonstrated on the field data from Kambalda, WA.

Key words: Volumetric Interpretation, Hard Rock, 3D Seismic Reflection.

INTRODUCTION

The mining industry has traditionally been using geological field mapping, gravity and magnetic methods, and drilling to explore new mineral deposits, but with new discoveries of large, near–surface deposits becoming increasingly rare and the known reserves of most economic minerals in decline, it is clear that new deep exploration techniques are obligatory to meet the future needs (Figure 1, Salisbury and Snyder, 2007). With gravity and magnetic methods unable to resolve targets beyond 500 m, high resolution seismic method can directly target structures at depth of 3 km, the current maximum depth of mining (Salisbury and Snyder, 2007, Malehmir *et al.*, 2012). The primary objective of this study is to improve targeting of deep, small sized ore–bodies using high resolution 3D seismic data combined with volumetric seismic interpretation in the Kambalda region.

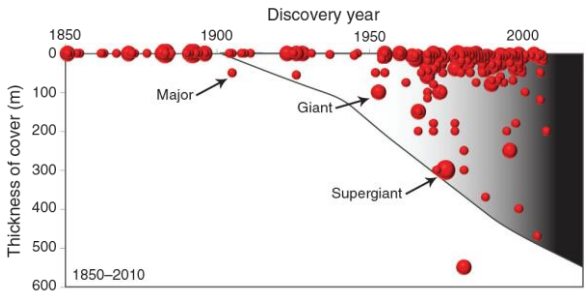

Figure 1. Depth of major mineral discoveries (bulk minerals such as coal, bauxite, and iron ore are excluded) in Australia during 1850–2010 shows a trend toward depth (Schodde, 2011).

Greenhalgh *et al.* (2000) conducted a research using cross–hole and vertical seismic profile to delineate mineralization and rock structure at the Kambalda nickel mines. Urosevic *et al.* (2005, 2007) initiated an experimental program in 2004 to perform high–resolution seismic reflection surveys in six mine sites hosting gold deposits. Earlier, in 2002, a few low and high–resolution seismic lines were reprocessed and reanalysed from the Kambalda area which allowed high quality seismic images of subsurface structures hosting gold mineralization (Urosevic *et al.*, 2007) which eventually led to the acquisition of ~150 km of new high–resolution seismic data in 2004. Preliminary results of this study were included in Urosevic *et al.* (2005). A considerable number of 3D seismic surveys have been conducted in the Kambalda region for Consolidated Minerals, Independent Group, Mincor, BHPB Nickel West, and a wider area i.e., Weebo Well (Poseidon Nickel), Spotted Qual (Newexco), Geraldton area, Golden Grove, Oxiana 3D (MMG), Pilbara region (Rio Tinto), and Ranger (ERA) (Malehmir *et al.*, 2012). Several 3D surveys were conducted for nickel exploration in the Kambalda region with great success (Urosevic *et al.*, 2008, Urosevic *et al.*, 2012)

METHODS AND RESULTS

In 3D volume visualization method of seismic interpretation the interpreter directly evaluates the seismic reflectivity of the subsurface media in three–dimensional space by applying various levels of transparency to the data (Kidd, 1999). This variation in transparency of the data is also referred to as variation of opacity. Opacity functions relate the visibility of particular voxels to their seismic attribute value (De Pledge, 2000). This enables a range of predominant attribute values to be subdued or entirely switched off, giving the viewer the ability to see through an entire volume (De Pledge, 2000).

In general, conventional interpretation methods produce maps while volume visualization methods produce 3D perspectives (Figure 2, Kidd, 1999). The basic principles of 2–D seismic data processing still apply to 3D processing. In 2–D seismic data processing, traces are collected into common–midpoint (CMP) gathers to create a CMP stack. In 3–D data processing, traces are collected into common–cell gathers (bin) to create common–cell stacks (Yilmaz, 1987).

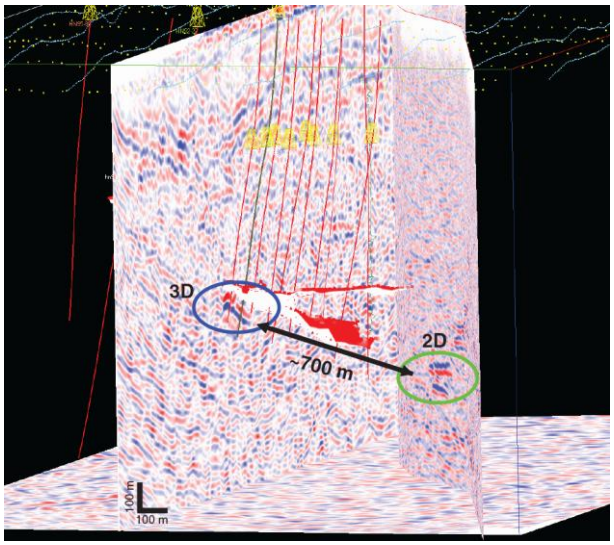

Figure 2. Comparison of a seismic anomaly observed in 2D data with its actual location in 3D data (Malehmir et al., 2012).

The interpretation based on 2D imaging is significantly different from interpretation based on 3D imaging. The traditional approach to looking inside a data volume is to slice the volume in the X–Z or Y–Z planes to create inline and cross–line sections (Yilmaz, 1987). Time slices are created by slicing the volume horizontally. The individual slices can be interpreted using 2–D techniques but clearly we lose valuable information when we do this since we cannot see data coherency along the axis normal to the slice plane (Wolfe and Liu, 1988).

Kambalda has always been exceptionally challenging ground for the application of geophysical methods for nickel and gold exploration. Urosevic *et al.* (2012) conducted a study in the Lake Lefroy area in Kambalda to assess the true potential of 3D seismic methods to delineate the Kambalda dome and its complex nickel–bearing structures. Subsurface main structures, mineralization zones, and seismic anomalies relevant to nickel sulphide deposits were delineated using advanced volumetric interpretation method. Nickel sulphide deposits in the Kambalda area are closely associated with Archean komatiite, an ultramafic rock (Lesher, 1989, Cowden and Roberts, 1990, Urosevic *et al.*, 2012). Most individual ore shoots in this region are located very close to the contact between Lunnon Basalt and the overlying ultramafic Kambalda komatite (Urosevic *et al.*, 2012). Urosevic *et al.* (2012) identified 78 potential nickel targets using average maximum amplitude over a 100 m window, 60 m above and 40 m below the Lunnon basalt and by limiting their size to 20–100 voxels (Figure 3). These targets were then ranked according to the level of confidence and the top three targets were drilled and massive nickel sulphide mineralization were intercepted in all of them. Figure 4 shows the RMS amplitude around the ultramafic–Lunnon basalt interface computed for a narrow window encompassing only 10 m above and 4 m below the Lunnon basalt, and limiting the spatial extent of the potential mineralization to 30×30 m.

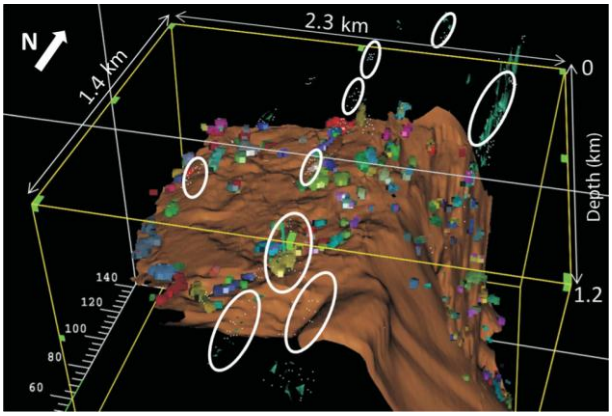

Figure 3. Potential "geobodies" or "geoanomalies" (bright colours) mapped in 3D volume (Urosevic *et al.*, 2012).

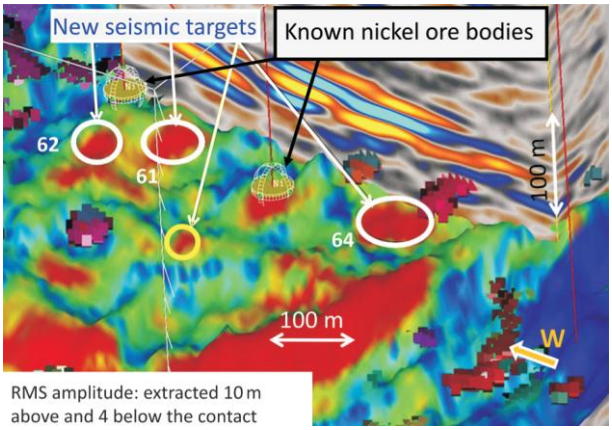

Figure 4. The RMS amplitude map. Proposed new targets are labelled by circles. White circles are seismic anomalies verified by underground drilling as mineralized bodies. Yellow circle has not been verified by drilling at present (Urosevic *et al.*, 2012).

CONCLUSIONS

3D seismic exploration method has the potential to improve seismic resolution, delineate complex geological structures and to help rock characterisation and targeting of mineral resources. Previous success in Kambalda region indicate that seismic method could and would become an important, if not primary exploration tool to delineate subsurface structures hosting ore bodies. This is probably the only way to efficiently explore deep mineral resources. Consequently the introduction of the volumetric seismic interpretation in mineral exploration should enable improved understanding, and hence, targeting of deep mineral resources. It is certainly the best way to approach seismic volume when it comes to targeting of deep, small sized, nickel–sulphide ore–bodies as found in the Kambalda region in Western Australia. Proposed methodology will be deployed to several seismic cubes recorded over Kambalda nickel–gold bearing zone.

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