C034

Recent Experience with Use of High Definition Seismic Reflection for Nickel Sulphide Exploration in Western Australia

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SUMMARY

Nickel Sulphide ore systems in Western Australia are generally small, but very high value. They are typically found in complex geological settings at depth that is beyond the reach of potential geophysical methods. Only seismic methods can be expected to help prospecting such systems. Indeed petrophysical properties of the nickel ore environment in Kambalda region indicated that the ore is likely to cause detectable events. Consequently several experimental 2D and 3D surveys were undertaken by Centre for High Definition Geophysics. In all cases, especially exploring in the volume of rock below about 500m depth high quality seismic images were produced. 2D seismic was mainly used to test seismic response over complex deposits of Yilgarn Craton but also helped refine existing geological models. Subsequent experimental 3D seismic surveys produced high quality images of potential massive sulphide (MS) deposits. In the last two years several of these targets were verified in the Kambalda region. We show several case histories documenting successful application of seismic methods over MS deposits. Despite the success, the high cost of seismic surveys is still an issue for mineral exploration companies.

Introduction

Nickel Sulphide Ore systems in Western Australia are generally small, but very high value. The Geology and Geochemistry of such systems has been studied exhaustively for the last 40 years. Whereas they have utility in providing vectors to the ore environment, they often fail to be able to provide high definition vectors to ore within the mineralised environment. As importantly they fail to provide insights into the geometrical integrity of the ore bodies. Only more recently has a systematic investigation begun on the petrophysical properties of such ore systems. Western Mining Company (WMC, now BHPBilliton) launched such a program of systematically measuring and reconciling such measurements against primary lithology, alteration and nickel ore types in all of its nickel mines (Trench and Williams, 1994; Williams and Mutton, 1994; Emerson et al., 1998). In 1992 a major research programme was initiated at Kambalda to develop high resolution seismic and radar imaging techniques to aid mining of and exploration for nickel sulphide ore bodies (Williams, 1996; Greenhalgh and Mason, 2007). The focus of these studies was on in-hole and cross-hole seismic techniques.
In continuation of these efforts the Centre for High-Definition Geophysics (CHDG) was established in 2006 with West Australian State funding m and followed the completion of a successful project using seismic methods for gold exploration in the goldfields of Kambalda. The CHDG was supported by major mining companies. The CHDG completed a number of 2D and 3D seismic surveys and studies, most noticeably over the Kambalda nickel and gold fields. The CHDG was able to complete many aspects of seismic survey deployment, which has greatly enabled seismic to be become more attractive to mineral companies (Urosevic et al., 2007).

WA nickel deposits

Nickel sulphides of Yilgarn craton occur in komattiitic (extrusive) or mafic/utramafic intrusive host rocks. The combination of acoustic velocity and density contrasts between the ore and the host rock, and the host rock and the country rock, mean that in certain structural and geometrical environments, the ore and to a lesser degree the basal contact (footwall) or contact of the intrusive is able to be imaged by seismic methods. The best results have been recorded in geological terrains of relatively flat dip, like that seen in the southern portions of the Beta Hunt Mine (Kambalda), Prospero (Leonora), McLeay (Kambalda) and South Windara Prospect, all located in the eastern part of Yilgarn craton. The Kambalda dome is characterised by high degree of structural complexity; its exploration for massive sulphides present challenge for seismic methods and is far beyond the reach of potential field methods. Several case studies are discussed here including wider Kambalda area (Figure 1).

Petrophysics of Kambalda Ni-fields

The basic petro-physical properties of direct interest to the application of seismic methods for Ni exploration are shown in Figure 2 and table 1. The values shown are typical for Kambalda region. Clearly when massive ore is in contact with mafic or ultramafic rock there is a sufficient reflectivity to grant seismic prospecting. This is less so for the case of dissiminate ore considering high structural complexity associated with these deposits and characteristically excessive ambient noise in brown fields of Kambalda. Rock alterations and unfavourable geometries of MS deposits (size comparable to Fresnel zone radius) present further challenges for seismic exploration. Despite all these difficulties the recent application of seismic methods in this area proved very promising for mineral exploration.

Case studies

Deep and tiny MS bodies situated in complex structures of Yilgarn and added high ambient noise require application of high resolution seismic surveys. Careful design of field acquisition parameters, source/receiver geometry, choice of seismic sources and recording parameters are crucial for seismic prospecting of MS deposits. Such surveys have typically very high spatial data density to properly sample complex structures and high fold to combat intrinsically low signal to noise ratio. Consequently the cost of such survey designs is high and mining companies are often reluctant to utilise the full power of seismic reflection method for prospecting of Ni deposits. It is therefore important to evaluate the real value of seismic methods for mineral prospecting through case histories

which should also help with devising alternative ways for acquiring seismic data in cost effective way.
I) The Prospero deposit is positioned approximately 500 metres below surface on the Cosmos ultramafic sequence, in the Leonora district of Western Australia, with mineralisation extending over a defined strike length of 450 metres, dip extent of 400 metres and ranges in thickness from 1 to 30 metres. It is comprised of remobilised high tenor massive, massive-breccia and massive-stringer nickel sulphides hosted by felsic volcanic rocks internal to the ultramafic rock sequence. Ni grade averages around 4%. The Tapinos Deposit is located 3.5 kilometres south of the Cosmos Mine and lies on the same contact position that hosts Cosmos, Prospero and Alec Mairs. The Tapinos deposit is positioned some 300 metres below surface and approximately 200 metres up-dip of the Prospero deposit. Nickel grade averages around 7.15%.
An experimental seismic line was recorded in 2006 using 24-bit distributed telemetric system and a high resolution mini-vibrator. Most of the seismic line sits on a thick and highly heterogeneous transported regolith. The line was processed as a crooked. Despite relatively weak source and high ambient noise (large passing vehicles and underground development activities) a good quality depth image was produced in agreement with geology inferred from drilling (Figure 3).
II) The Windara greenstone belt is host to the Windara nickel sulphide occurrences, which have been previously mined by WMC and presently held by Poseidon Nickel. Mineralisation occurs within the basal ultramafic unit, in channel positions. The predicted flat dip/plunge of the greenstone, and the existence and juxtaposition of BIF again ultramafic and granite, as well ultramafic against basalt made seismic attractive as an exploration surveying tool. Poseidon postulated from a re-examination of the drill core and geological logs that the nickel sulphide mineralisation could have a plunge significantly different to that previously interpreted. Consequently 2D high definition seismic surveying was undertaken to test this hypothesis. This time we used a concrete breaker (free fall weight drop, mass of 750 Kg). This has made the survey significantly less expensive in comparison to vibrator source. The results of the seismic survey supported the proposed geological model and more so defined a new target, permissively down plunge (Figure 4).
III) The Kambalda Dome is one of the largest commercially mineralised high grade nickel sulphide camps in the world. The nickel mineralisation occurs within channels in the basal Komatiite as elongate depressions in the footwall contact. After successful 2D test line a small experimental 3D seismic survey was acquired over the southern portion of the Kambalda Dome for Consolidated Minerals. The survey employed irregular 3D survey geometry due to numerous obstacles, with nominal geophone separation of 10 meters, and shot spacing of 20 meters. Small explosive charges of 150 g, at 1.5 m depth were used over most of the survey area. For some 300 shots a free fall weight drop was utilised. Very high quality, high resolution data were recorded (Figure 5). The final depth images after validation against borehole demonstrated capability of detecting very small fault blocks and thin bodies (Urosevic et al., 2008). Since then several new targets were identified and drilled.
IV) The Long Victor mineralised complex is located approximately five kilometres from the town of Kambalda. After several test lines and experimental 3D seismic survey was undertaken over the southern mine leases held by Independent Group, encompassing the historically mined Victor deposit and the current actively mined McLeay deposit. The geological setting is similar to that of Beta Hunt. The survey utilised a combination of small explosive charges over the salt lake area and the free fall weight drop on the solid ground. Again high density, high fold data were acquire to combat ambient noise (active mine) and complex geology. Main objectives of the surveys were to investigate if seismic can image major shears and map interface between Basalts and Kambalda Komatiite (Ultramafics). It was also of interest to check if intrusive rocks (porphyries, felsics and intermediates) into Ultramafics produce a measurable seismic signature (Urosevic et al., 2008). Several zero-offset and offset VSP surveys were also undertaken to help depth conversion and to produce high resolution images around boreholes (Figure 6).

Conclusions

Recent experiences with the application of 2D and 3D experimental seismic surveys conducted in Yilgarn craton of Western Australia show clearly that reflection seismic is by far the most powerful prospecting tool for MS deposits. In all cases high quality seismic images were produced. 2D seismic helped refine existing geological models, while 3D seismic surveys produced many new targets. In the last two years several of these targets were verified in the Kambalda region. Despite this success and the fact that 2D and 3D seismic is now applied to nickel sulphide exploration far more commonly than previously, the high cost of seismic surveys is often prohibitive for mineral companies. Introduction of inexpensive and easy to deploy seismic sources such as concrete breaker made these surveys much more attractive to the mining community. However this source performs the best on hard ground, hence the search for other alternative and inexpensive seismic sources continues. Alternative 3D acquisition geometries, rapid processing and interpretation of hard rock seismic data need further developments if seismic is to become conventional exploration method in mineral exploration and hence be used over both brown and green fields in future.

Acknowledgement
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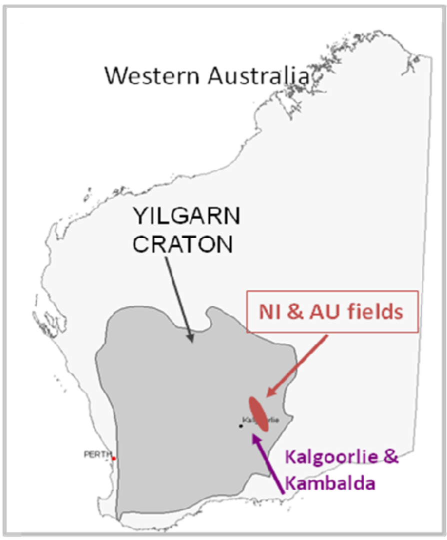

Rocks in contact	Refl. Coeff. %
Ultramafic/Mafic	5
Mafic/Massive Ore	8
Ultramafic/Massive Ore	15
Mafic/Matrix Ore	1
Ultramafic/Matrix Ore	8
Mafic/Disseminated Ore	3
Ultramafic/Disseminated Ore	3

***Table 1** Nickel and gold fields of Kambalda region, Yilgarn craton, Western Australia.*

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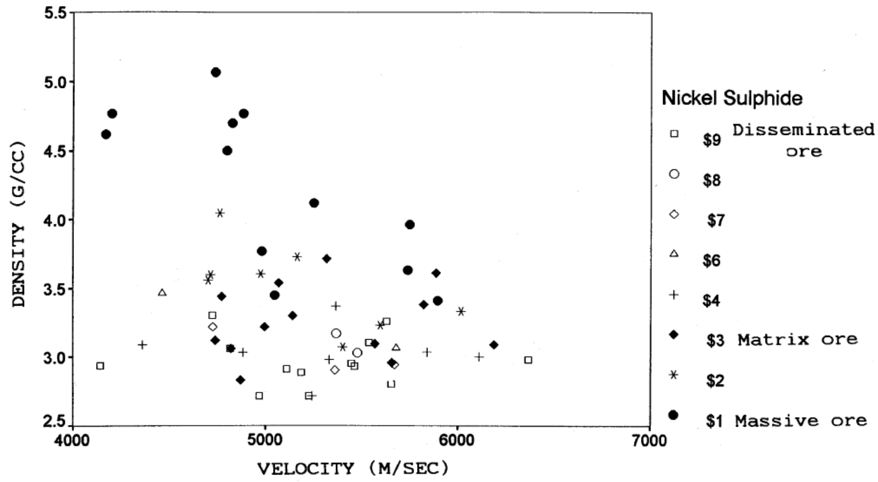

Figure 2 *Plot of the variation of velocity and density for different nickel ore types (Greenhalgh and Mason, 2007).*

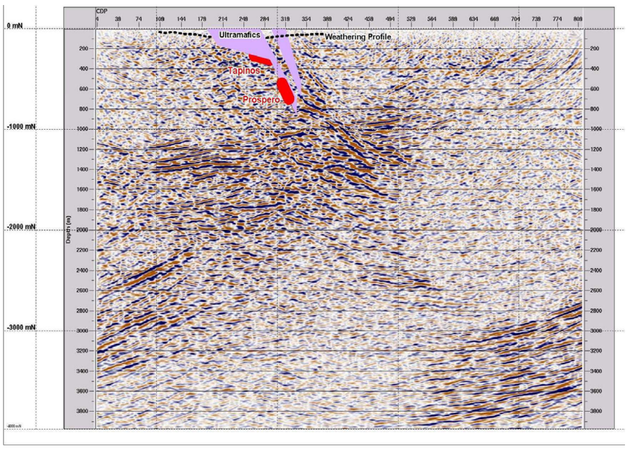

Figure 3 *High definition image from a 2D seismic survey over the Tapinos and Prospero deposits.*

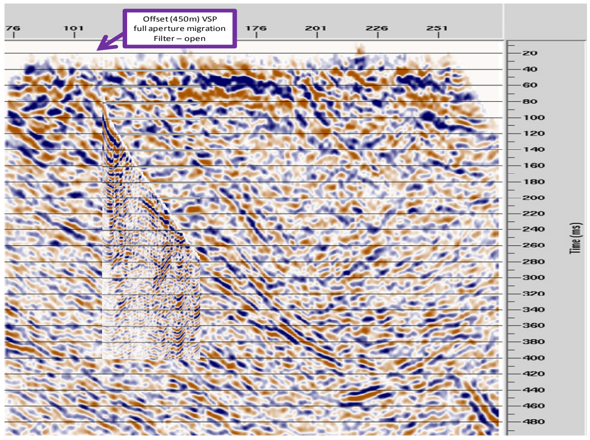

Figure 4 *In-line extracted from IGO 3D experimental survey. Offset VSP image inserted.*

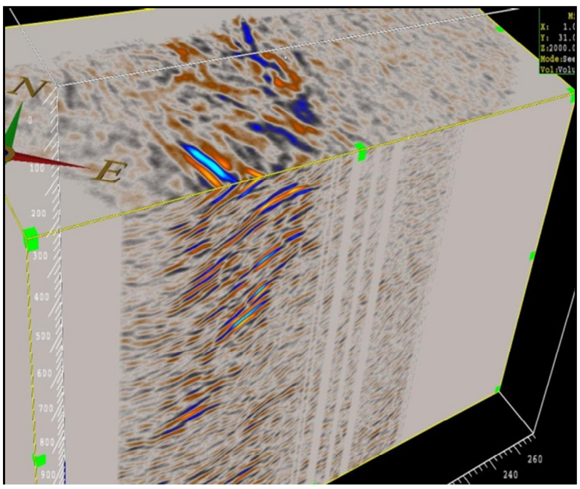

Figure 5 *High resolution Beta Hunt experimental 3D data. Ni targets are identified as spatially limited high amplitude events.*

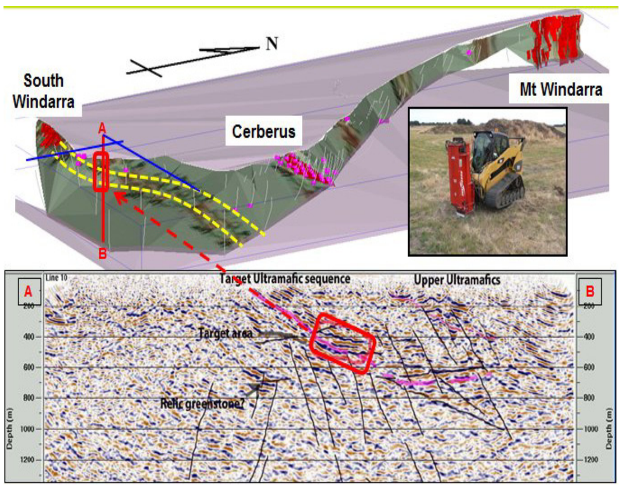

Figure 6 *Simplified geological interpretation. The purple line traces the interpreted footwall contact. The red box is the interpreted target area. Black lines are interpreted faults.*