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Seismic Exploration of Mineral Resources - An Australian Perspective

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SUMMARY

The only geophysical method that can image deep structures with the precision required for targeting and discovering new resources is reflection seismic. However, mineral prospecting with seismic methods is not straightforward. Lack of understanding of the seismic response, necessity to adapt the method to the specifics of each target and underestimating the complexity of mineral environments introduced complexities that have resulted in its sporadic rather than systematic application. Here we present and briefly discuss the results and the lessons learnt after more than a decade of dedicated investigations in different mineralised environments. We expect that seismic will become a standard geophysical method for exploration of most brown and then green fields.

Introduction

The need to explore deeper and under cover is of crucial importance for the future of mineral exploration in Australia, and the greater world, where a constant decline of new discoveries has been recorded over the last decade. The only geophysical method that can "see" deep and at the same time resolve fine geological features is seismic. However, mineral prospecting with seismic methods is not straightforward and hence it has not been established yet as a primary exploration method. One of the main issues is the lack of understanding of the seismic response and its variability over an often complex hard rock environment. In some cases we have observed excellent seismic results, while in others not so useful. To understand this better one needs to be investigate each site or mining camp in a systematic way. A so-called de-risking strategy is necessary for generating successful seismic projects. Here we discuss the results and the lessons learnt after more than a decade of dedication to the seismic exploration of mineral deposits. To be able to come to that point, many field trials, laboratory tests, core measurements, borehole measurements and experimental surveys have been conducted, and specific processing and interpretation strategies have been developed to combat typically highly complex and discontinuous seismic responses in these environments.
Various case histories over diverse types of mineral deposits are therefore discussed as well as the lessons learnt. From this background, a view on the future application of seismic methods for mineral exploration is presented.

A brief history on the application of seismic for mineral exploration

One of the earliest high-resolution seismic surveys in a hard rock environment was carried out in the early 1950's in Russia (formerly the USSR) (Berson, 1957). In the 1970's and 80's, many tests of high-resolution seismic imaging methods for mineral exploration had been conducted in western countries. One of the early exploration works included the seismic imaging of shallow sedimentary hosted mineral deposits (Wright, 1981). High seismic activity for mineral exploration was recorded in the 80's in South Africa (Pretorius et al., 1989). Since that time the application of seismic for mineral exploration has had its highs and lows and is still to be accepted as a standard geophysical method in the mineral industry.

Mineral exploration utilising seismic in Australia and the World

The application of seismic for mineral exploration in Australia over the last two decades has recorded both successful and not so successful case histories. There are many reasons and some are listed below:

- Inconsistent application of the method; methodology transferred from oil sector without adaptation to the specifics of the mineral targets.
- Inappropriate survey designs with respect to the line length, receiver-shot spacing, 3D data density, etc.
- Inappropriate processing strategies.
- Inappropriate interpretation strategies.
- Survey cost too high, output left to the client for "the best use".

For these reasons the Department of Exploration Geophysics (DEG) conducted a significant number of experimental surveys (Figure 1) in the period 2004-2009. The lessons learnt were subsequently transferred to HiSeis P/L, a largely Government owned specialist seismic company, HiSeis Pty Ltd formed as a dedicated hard rock seismic exploration entity. Since its formation in 2010, the company has acquired 19-2D surveys, 9-VSPs and 12-3D surveys for mineral exploration objectives (Figure 1 and Table 1). The results from these seismic projects have in general always been positive however the image quality in terms of continuity and amplitude brightness has varied as a function of geological setting and rock types. The very high and largely successful seismic activity for minerals in Australia was transferred to Europe. First to Finland, where a 3D survey was carried out in

Kevitsa, and subsequently over the next two years HiSeis acquired the world's largest high-resolution 3D seismic survey in Portugal for the characterization and also direct targeting of VMS deposits. This was followed by 3D surveys in Ireland as well as the USA. In 2016, HiSeis P/L appears to have come full circle as it enters the African continent, essentially to the place where the application of the seismic method for mineral exploration largely originated.

Project & Location	High-resolution 3D Survey Size	Year Acquired	Primary Commodity	Deposit Type
Tropicana Gold Mine, Western Aus	12 km^2 + 12 km^2	2015 & 2014	Gold	*
Cracow Gold Mine, Queensland, Aus.	6 km^2	2014	Gold	Steeply dipping low sulphidation epithermal veins
Pajingo Gold Mine, Queensland, Australia	9 km^2	2014	Gold	Structurally controlled epithermal quartz veins
Eagle Mine, Michigan, USA	8 km^2	2014	Nickel & Copper	Ultramafic-intrusive-hosted
Plutonic Gold Mine, Western Australia	9 km^2	2014	Gold	Archaean mafic & ultramafic volcanics & sediments
Kilbricken Mine, Ireland	2.6 km^2	2012	Zinc-Lead-Silver	Volcanogenic massive sulphide
Neves Corvo Mine, Portugal	20 km^2 + 50 km^2	2011 & 2012	Copper-Zinc	Volcanogenic massive sulphide
O'Callaghan's Mine, Western Aus.	2.2 km^2	2011	Copper-Lead-Tungsten-Zinc	Polymetallic skarn deposit

Table 1 *Some of the 3D seismic projects worldwide conducted by HiSeis P/L. Deposit types are listed in the last column. Symbol (*) stands for an undisclosed type.*

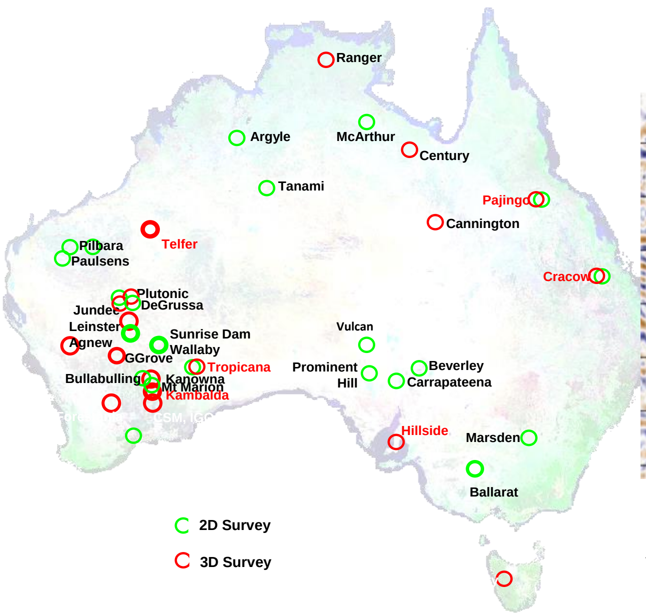

Figure 1 *Distribution of HiSeis surveys over the Australian continent.*

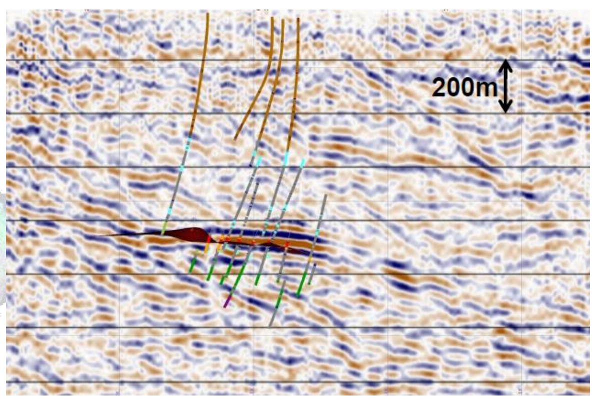

Figure 2 *Neves Corvo 3D, extract from the cube over the Semblana deposit.*

Massive ore deposits present one of the best and most obvious seismic mineral targets. Hence it is not too surprising that one of the largest 3D hard rock seismic surveys in the world has been conducted over the massive VMS deposits that exist in Neves Corvo, Portugal. These are characterised by a significant concentration of iron and ore minerals and as such often have higher impedance than the host rock. Consequently, mineralised bodies appear as bright amplitudes. The structures can be large, as is the case in Figure 2, where the seismic response over the Semblana ore body is shown. It is clear that such massive ore bodies present an excellent target for reflection seismic. Similar deposits in Australia are typically much more limited in size and of complex shape (Urosevic et al., 2012). In both cases, 3D seismic is the only appropriate method for characterising and targeting such deposits.

Despite gold having no direct geophysical signature, reflection seismic is particularly useful in recovering complex structures and alteration zones that host gold minerals. An example is shown in Figure 3 (see also Table 1). Characteristic reflectivity and relatively high continuity enabled the successful seismic characterisation of this gold deposit.

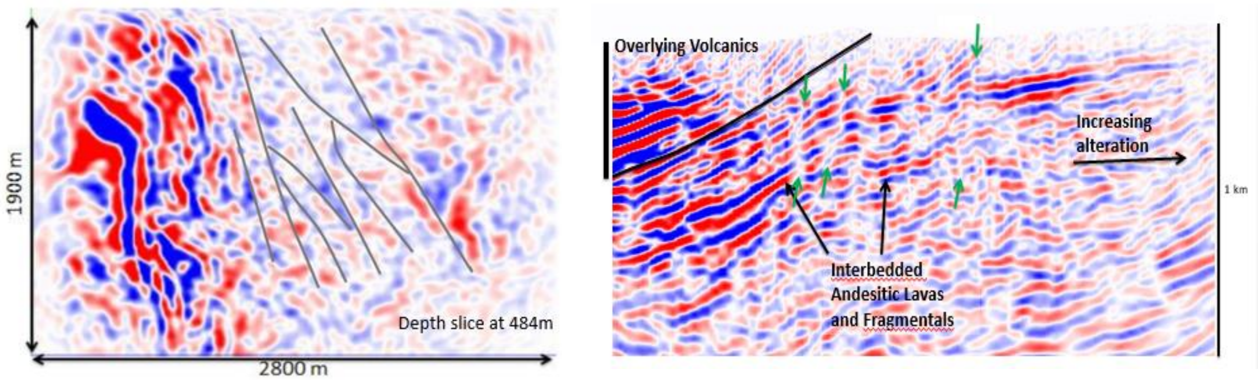

Figure 3 *Shown left is the depth slice (484 m) from the Cracow 3D survey. Grey lines represent faults, some of which correspond to the location of faults and epithermal veins. Right is the cross section from the 3D volume. Arrows indicate mineralised zones.*

A very significant "gold belt" in remote Western Australia has been well mapped and characterised by several consecutive 3D seismic surveys. This is illustrated in Figure 4. Seismic images from this

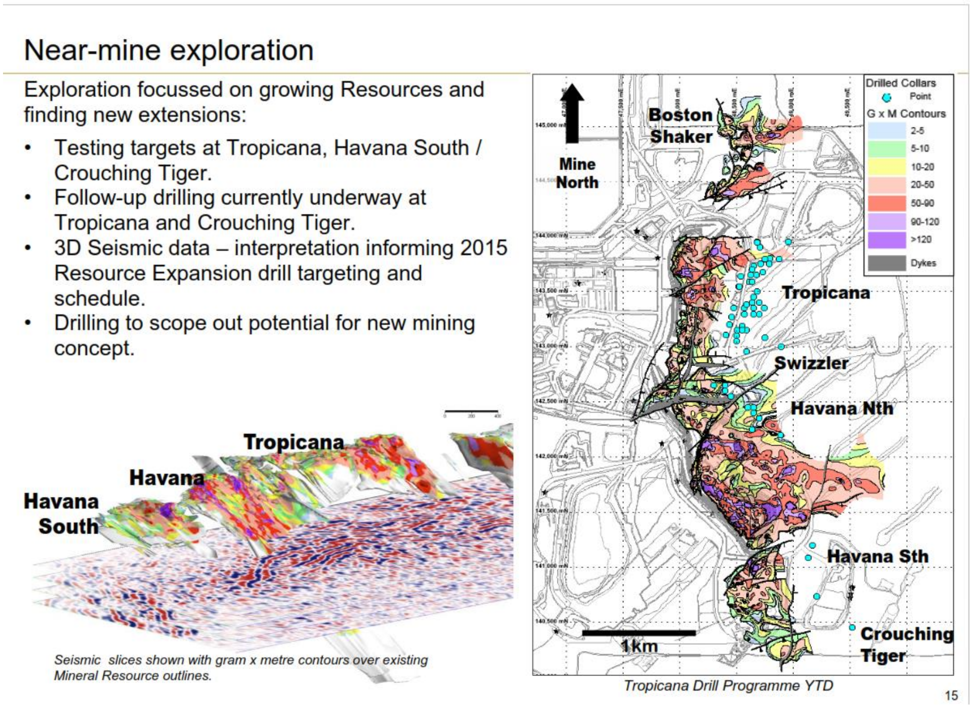

Figure 4 *Near mine exploration of the large gold bearing belt, remote WA (IGO, 2015).*

region are of exceptional quality. Such results enabled precise the characterisation and identification of gold bearing structures. Such so-called near mine seismic has become a valuable exploration tool in this gold bearing belt of Western Australia.

Another interesting case that's been selected comes from 2D seismic recorded in the Yilgarn craton, remote Western Australia (Figure 5). In this case steeply dipping gold bearing structures were successfully imaged by 2D seismic. The resultant section also confirms the initial geological model as well as providing another level of structural complexity.

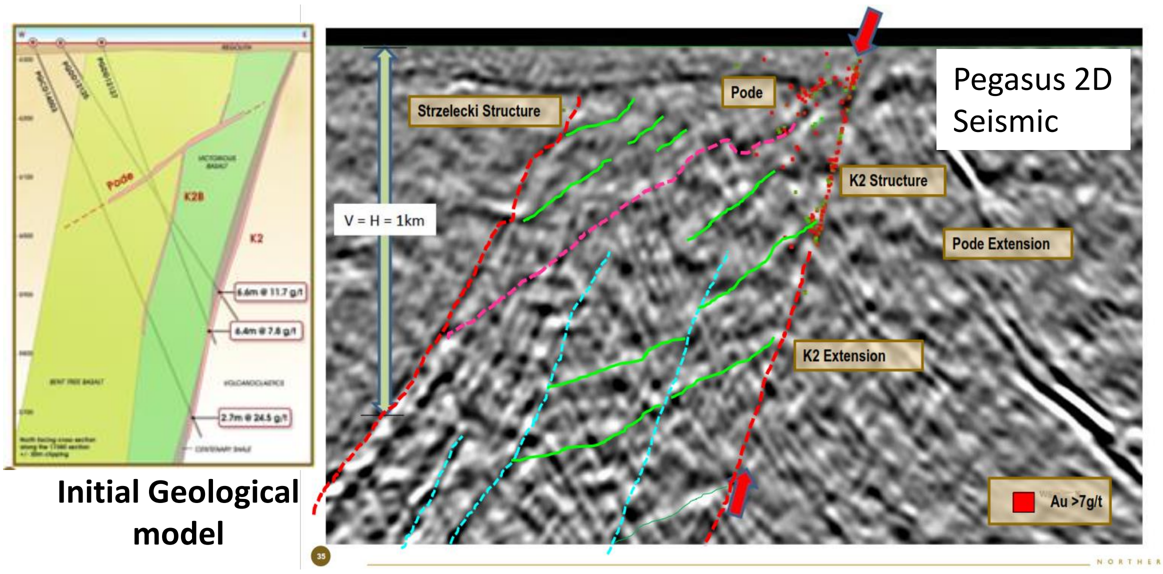

Figure 5 *Seismic of Pegasus gold deposits. Very steep structures (70-75^0) are clearly imaged.*

Conclusions and recommendations

Reflection seismic, particularly 3D, is capable of producing subsurface images of exceptional quality even in very complex geological situations. The main issues revolve around its proper utilisation and adaptation for each unique exploration environment. Each site requires proper de-risking in the form of background investigations prior to the first seismic line even being laid. As further changes in exploration practices take place due to the need to explore deeper and under cover the standardised application of the reflection seismic method for mineral exploration should become more and more accepted. It has been demonstrated that in the right environment, reflection seismic is unrivalled as a geophysical method in terms of maintaining resolution with depth and is therefore crucial for the future exploration of mineral targets around the world.

References

Berson, I.S. [1957] *High-frequency seismic*. Moscow, the USSR Academy of Science, 239. (in Russian).

Independence Group NL [2015] Investors presentation.

Pretorius, C.C., A.A. Jamison, and C. Irons [1989] Seismic exploration in the Witwatersrand Basin, Republic of South Africa. *Proceedings Exploration 87, Third Decennial International Conference on Geophysics and Geochemoical Exploration for Minerals and Groundwater: Special Publication, Ontario Geologic Survey*, **3**, 241-253.

Urosevic, M., B. Ganesh, and G. Marcos [2012] Targeting nickel sulphide deposits from 3D seismic reflection data at Kambalda, Australia. *Geophysics*, **77**, 123-132.