Hard rock seismic exploration of ore deposits in Australia

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Summary

We present an overview of the developments and achievements, over the past four years in the application of seismic reflection methods for mineral exploration in Australia. We show that seismic methods can be successfully used to delineate exceptionally complex hard rock environment in Australia providing that the acquisition parameters and data processing strategy are adequate for the task. Moreover methodologies for the direct targeting of specific ore reserves as well as rock identification from seismic data are discussed.

Introduction

The greenstone belts of the Yilgarn craton, Western Australia, host numerous Archaean gold and base metal deposits. These deposits are typically found in complex geological structures associated with crustal scale shear zones. The prospective geology is commonly hidden by a deep, heterogeneous regolith cover consisting of weathered Archaean rocks as well as transported colluvial and alluvial deposits. Mineral exploration in Western Australia is in a mature phase and future discoveries of large deposits will depend on focused exploration programs where there is little or no exposure of Achaean geology. Successful exploration for gold and base mineral deposits at greater depths and below areas of thick regolith cover is critically dependent upon an understanding of the location and geometry of the controlling structures at the scale of the deposits. The seismic reflection technique does not fundamentally lose resolution with depth; unlike magnetic, gravity, and electrical methods traditionally used for mining exploration. Consequently, seismic reflection surveys have the potential to provide images of underground structures at all depth levels. However seismic reflection methods have not been used in the hard-rock environment in Australia for direct exploration purposes until recently.

Previous work comprised of regional seismic lines recorded in 1999 in Western Australia across the Yilgarn craton has shown that deep reflection profiling can produce seismic reflections at depths greater than 2 km. CLear images of deep structures were obtained but the seismic data failed to provide structural information at the mine scale. Thus, while the data was good for developing conceptual targeting models in its delivered form it was of little use for exploration. In 2003 we have revisited these early works, analysed the pit faults and set for a comprehensive feasibility study. In several years, the application of seismic methods advanced from virtually non-existent to one of the principal methodologies for mineral exploration in Australia. Hard rock seismic research program has now diversified in the types of mineral deposits to be targeted (Gold, Nickel, Diamonds, Uranium, and Iron Ore). In this paper we show and discuss the results of our broad research efforts through several case histories.

Hard rock seismic data analysis

Hard rock (HR) seismic data are often recorded either through the existing mine workings, or near it. The excessive levels of ambient noise, deep and heterogeneous regolith zone and highly complex geology are typical for Australian conditions. In most cases, 2D seismic reflection data acquisition is restricted to existing roads and bush tracks, while 3D seismic tends to have a “patchy” coverage due to environmental and heritage restrictions. All of those obstacles have a systematic solution that can be summarised as follows:

-Careful selection of acquisition parameters
-Precise computation of refraction statics, stacking velocities and residual reflection statics
-Use of geological information early in the processing (geological maps, potential field data, borehole logs, core sample measurements, etc)
-Calibration of seismic images with borehole seismic data
-Revisiting processing decision points, re-processing and towards final stages of interpretation

In our experience, HR seismic data processing is inseparable from interpretation. Excessive image complexity and the wealth of events in HR seismic images often present processing geophysicist with a multiple choice, particularly when opting for a plausible velocity model. One of the key steps in computation of constant velocity stacks (CVS), either for 2D or 3D data sets, and their careful analysis. At this stage one in fact opt for the most likely structural model which in fact amounts for the first phase of the HR interpretation process (Figure 1). The next phase involves similar analysis except it is performed this time on dip move-out corrected CVS panels. Final refinement of the static and dynamic corrections is a lengthy process. Similarly, pre-stack imaging is also demanding and interpretation-driven process.

This paper was invited by the workshop organizer and was not reviewed by the Technical Program Committee.

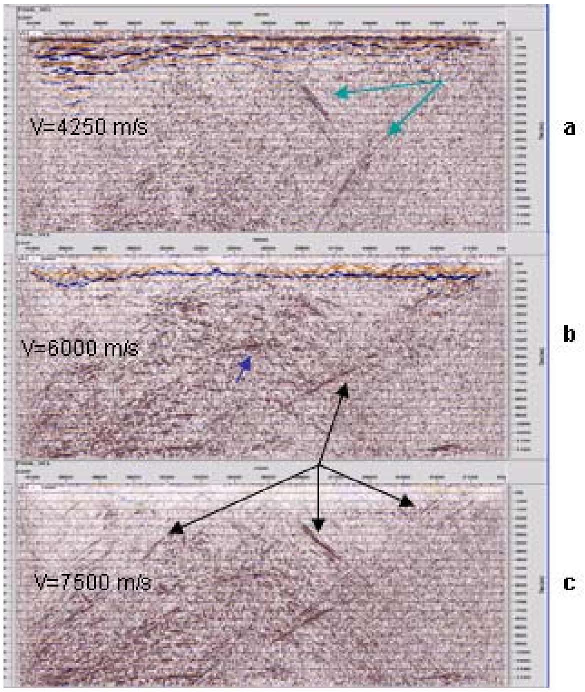

Figure 1: Figure 1. CVS panels: a) V=4250 m/s, b) V=6000 m/s and c) V=7500 m/s. Out off-the-plane events are denoted with green arrows, blue arrow indicate sub-horizontal events appearing at expected velocities and black arrows mark steeply dipping events also appearing with expected velocities (scaled by the dip).

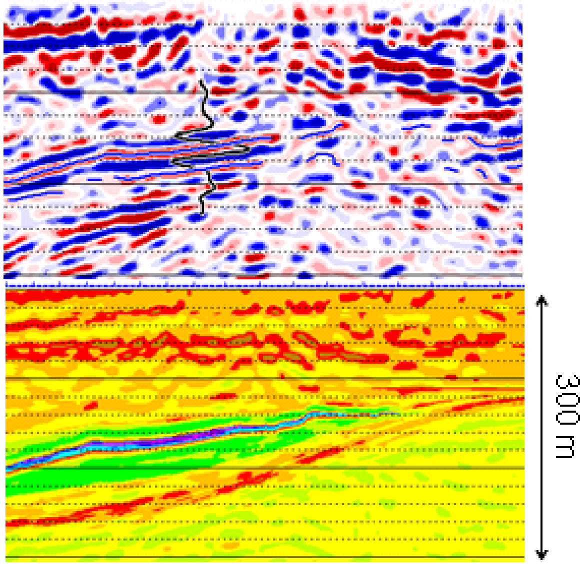

Figure 2: Model-based impedance inversion used for targeting gold bearing dolerites.

If logs and VSP were available we could say that the final processing is finalised if a good quality well-tie is achieved.

Our primary objective is to identify structural elements that could be mineral bearing. This could be a structure that could have provided a path for hydrothermal solutions and hence precipitation of minerals. Our ultimate goal would be a direct identification of rock units from seismic data through, perhaps seismic inversion (Figure 2). Full Waveform Sonic logging can be used to build a statistically significant relationship between seismic attributes, such as acoustic impedance, for rock units which are of interest to mineral exploration. This is particularly important for gold exploration where a direct geophysical signature is absent.

Conclusion

Our understanding of the seismic signature of hard rocks has greatly improved over the last few years. As the data from 2D surveys are less than perfect necessity has provided the impetus to create various means to extract more information out of these surveys. Several advances have been made in data processing flows and imaging techniques. In addition, the role of interpretation in guiding the processing and imaging of HR seismic data is becoming more science and less art. The first seismic inversion attempts appear promising and open new avenues in interpreting seismic data in hard rock environments. However, there is lot to be learnt and accomplished in an often overwhelmingly complex geological setting. Wider use of 3D seismic methods in the last two years is highly encouraging. Better use of boreholes data and calibration of surface seismic images is crucial for further advances in seismic exploration for mineral deposits.

References

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