Ore-body delineation using borehole seismic techniques for hard rock exploration

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SUMMARY

Over recent years, seismic methods have emerged as a potential imaging technique for delineation of ore-bodies and for mine planning. The application of surface seismic methods in hard rock environments is however challenging due to various effects such as energy attenuation and scattering. Borehole seismic methods can be used to reduce these effects. The methods offer higher resolution at target depths, thus allowing better delineation and understanding of reflections from ore deposits.

We present a synthetic study to understand the ability of the cross-hole seismic method to delineate ore bodies. Three variations of a simple scenario typical of nickel deposits found in the Yilgarn Craton were considered. Of the three models, two consist of volcanics overlying a granite body and a thin sulphide mineralized zone along the contact but at different locations relative to the source and receiver boreholes. The third consists of only the rock units with no sulphide mineralized zone along the contact. Synthetic shot records were produced and wavefield separated. Up-going wavefields were then used to create depth migrated images. The resulting images correlate well with the volcanic-granite contact and massive sulphide lens, showing the potential of using the cross-hole seismic method to delineate ore bodies.

Key words: Cross-hole seismic imaging, hard rock, ore-body delineation.

INTRODUCTION

Ore bodies of economic importance are often only a few metres thick and the top and bottom are not resolvable by conventional geophysical techniques such as resistivity, gravity and magnetic. In contrast, seismic methods are considered a high resolution exploration tool. Seismic resolution is dependent on seismic wavelength which in turn depends on the acoustic velocity of the rock (deposit) and frequency of the seismic source (Salisbury et al., 1996; Salisbury and Snyder, 2007). The resolution of seismic images is generally a few meters, making it ideal for ore bodies' delineation. However, thick highly heterogeneous cover, altered and highly fractured-zones cause significant scattering of seismic energy which, in turn, produces complex seismic responses and highly variable reflection patterns, making its application challenging especially with surface seismic. In addition, steeply dipping structures are difficult to image with surface seismic methods as reflections are often not reflected towards the surface (Greenwood et al., 2009).

Cross-hole geometries represent an alternative approach that can potentially provide higher resolution seismic responses. This is deemed so, because the source and receivers are placed below the near-surface overburden which distorts and attenuates seismic wavefields (Hardage, 1983; Hinds et al., 1996). In this case, the resolution is dependent on borehole separation not depth.

In this paper, we explore the potential of the cross-hole seismic method to resolve ore-body's thickness and extent, using synthetic models.

METHOD

To test the viability of cross-hole reflection seismology in a hard rock geological setting, we considered three variations of a scenario typical of nickel deposits found in the Yilgarn Craton (Urosevic et al., 2007). Simple models consisting of volcanics overlying a granite body with a thin, 9 to 18 m, sulphide mineralized zone having a length of about 215 m, present or absent along the contact. In the first model, the ore body is placed such that the receiver borehole is cutting through the ore body, the second model places the mineralized zone entirely between the boreholes and in the third model, the ore body is absent. The model depicting scenario one is shown in Figure 1.

Two angled boreholes, S and R, approximately 260 m apart were used as source- and receiver-boreholes respectively. Both the source and receiver boreholes were populated with source's and receiver's stations at 10 m. Seismic velocities assigned to the various layers (model) were chosen from pre-set VSP and FWS studies in the north of Kambalda region of the Yilgarn (Greenwood et al., 2012).

Acoustic full-waveform modelling was performed using a Ricker wavelet with 80 Hz dominant frequency, a sampling rate of 0.5ms, and the total record length was limited to 500 ms. Synthetic seismograms and wave propagation time snaps were generated. Time snaps were used to understand P-wave energy propagation in the model. The wavefield propagation and synthetic seismogram for shot point 34 are shown in Figure 2. The figure identifies the different up- and down-going wavefields generated.

Wavefield separation to remove the direct and surface reflected down- going waves was performed using *f-k* filters and muting. This left only reflected up-going waves and their multiples. VSP Kirchhoff migration (Dillon, 1985) was then performed on the wavefield separated seismograms to generate depth seismic profiles. The Migration used a velocity of 5200 m/s representative of the basalt country rock. The lateral migration aperture was constrained between 300 m to 650 m and the depth imaged down to is 1000 m. Only the sources and receivers above the target zone were used in the migration. Figure 3 shows the pre-stack depth migrated images for the three different scenarios. For comparison, all the images are presented with the same visualization gain.

RESULTS

In migration Case 1; the ore body is very well defined, it has contoured the contact and shows thinning and thickening. In Case 2; the main reflection is strong but it is generally featureless, and in Case 3 the reflection from the contact is weaker and also featureless. The migrated image for Case 1 (ore zone intersected by the receiver borehole) has been overlaid on the geologic section and is shown in Figure 4.
In all, the migrated sections, the depth to the reflector and its dip have been accurately represented and correlate well with the geologic section.

CONCLUSIONS

Models representative of thin nickel sulphide deposits in the Yilgarn Craton have been generated and the cross-hole seismic reflection method has been tested to resolve ore-body's thickness and extent. Synthetic seismograms were generated and processed to recover only the reflected wavefields and then pre-stack depth Migrated. The resulting images mapped precisely the volcanic-granite contact and massive sulphide lens. This synthetic study shows that, using a down-hole energy source that can provide the appropriate frequency, cross-hole seismology in angled boreholes will serve as ore-body detecting and imaging tool in hard rock environment.

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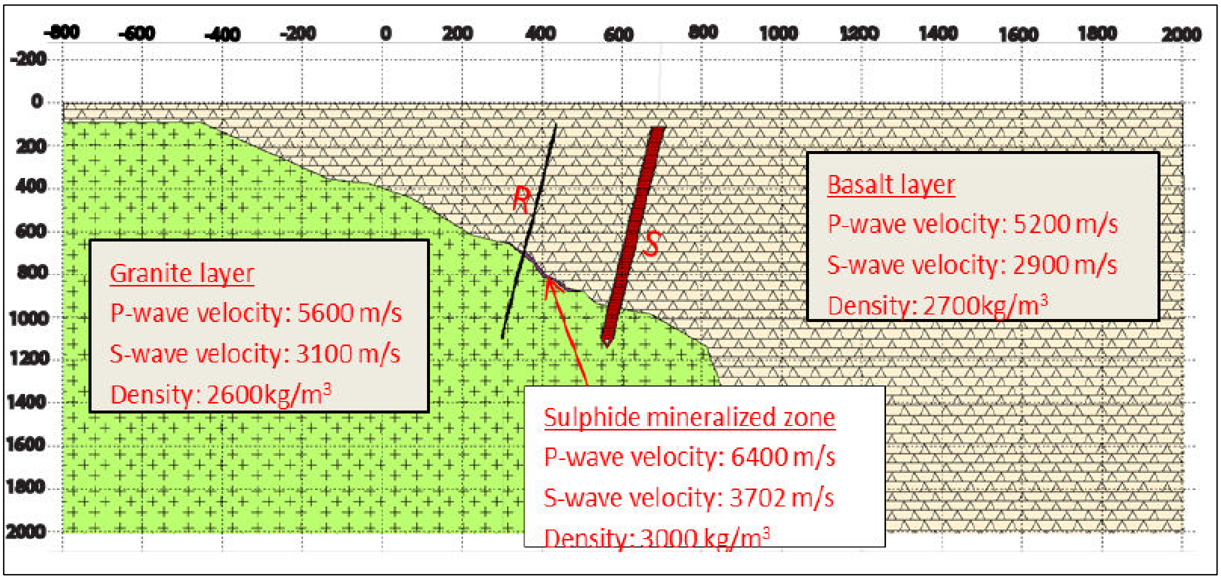
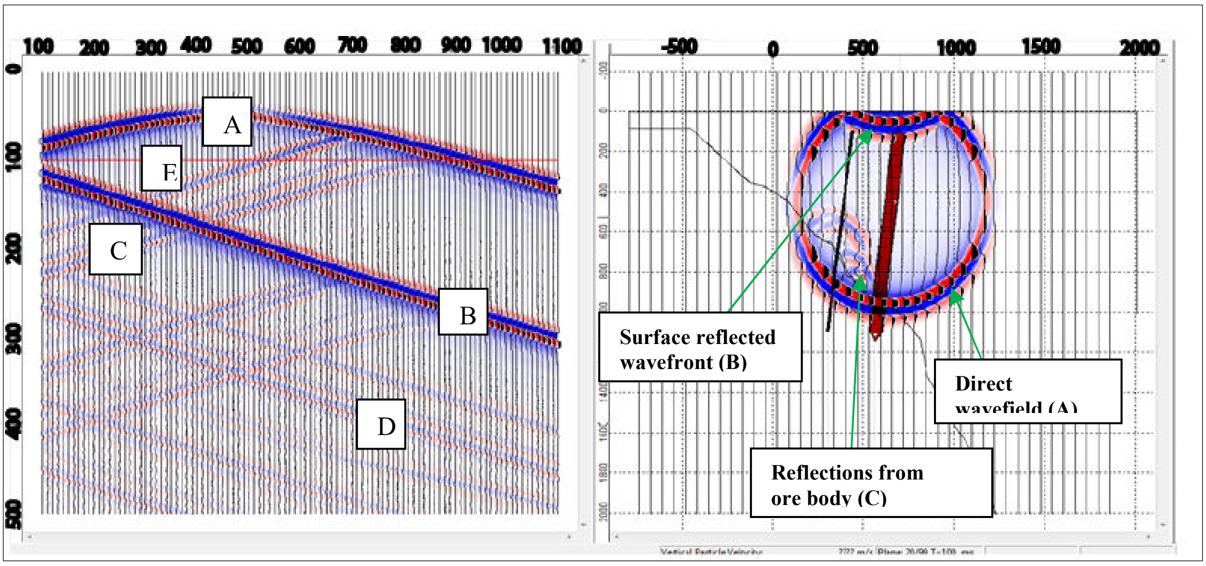
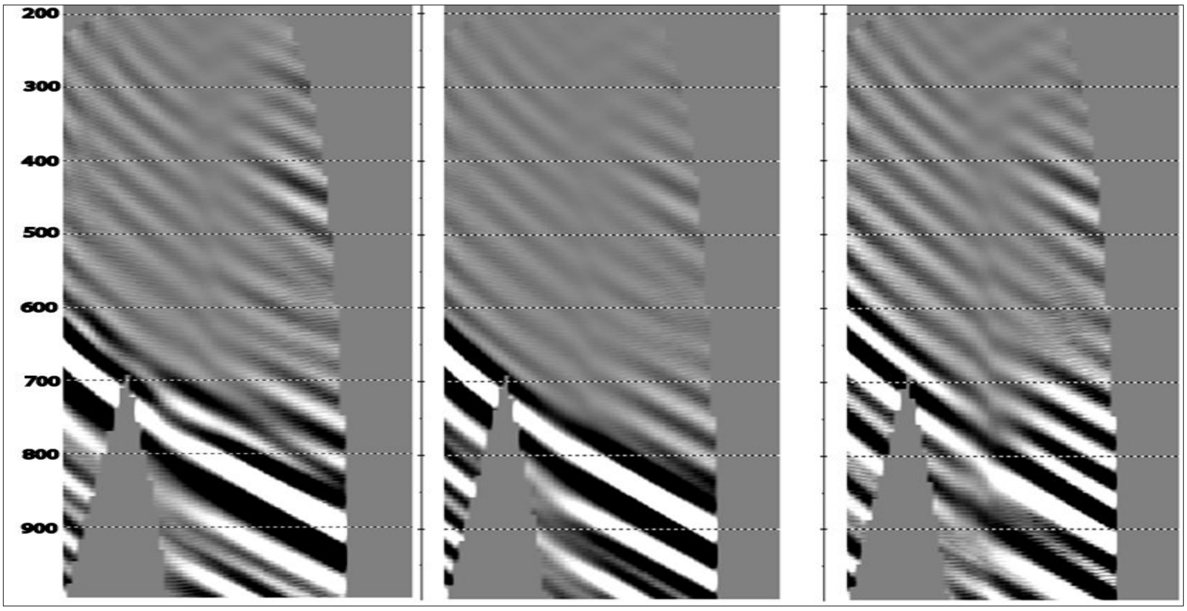


Fig. 1: The geological model used to generate synthetic seismograms. In this particular case, receiver borehole, R, has intersected the ore body. Similar geological model has been used for all the cases except the position and/or placement of the sulphide mineralized zone.



(a) Cross-hole data animation pane for source 34 **(b) Wavefront animation pane for source 34**

Figure 2: The figure depicting the seismic section and wave propagation animation in the case when the ore body is placed along the contact zone such that the receiver hole cuts across it. A – Down-going (Direct) wavefield, B – Surface reflected down-going wavefield, C – reflected up-going wavefield, D – some multiple reflections, E – time step line.



(a) Case 1 **(b) Case 2** **(c) Case 3**

Figure 3. The migrated images of the various models. (a) depicts the case the ore body is placed such that it has been intersected by the receiver borehole; (b) when the model placed the ore body between the holes; and (c) no ore deposit ore in place.

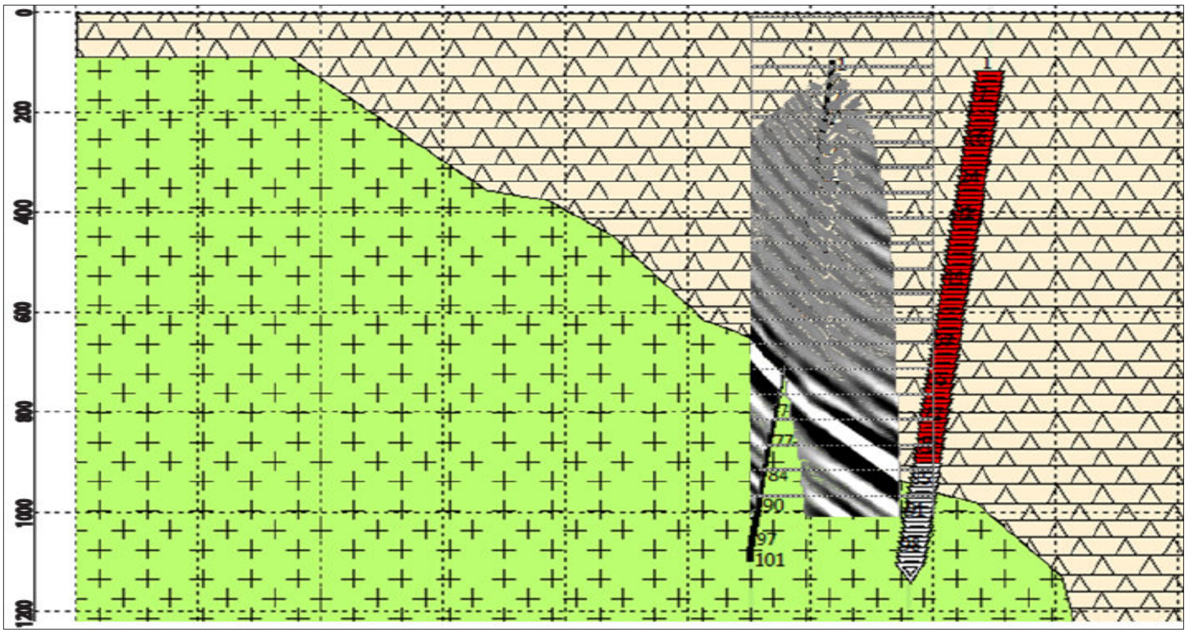


Figure 4. The geologic section (for the case where the receiver borehole cuts through the ore body) is overlaid by its corresponding migrated section.