Integration geoConvention 2013 geoscience engineering partnership

Investigation of Seismic Imaging Capabilities for Small, Shallow Carbonate-Hosted Massive Sulphide Deposits

Laura Quigley*
Department of Earth Science, University of Toronto, ON, Canada
quigley@es.utoronto.ca
Bernd Milkereit
University of Toronto, ON, Canada

Summary

In this study synthetic seismic data was generated in an effort to better understand the behavior of the seismic wave field for a shallow carbonate-hosted Pb-Zn massive sulphide orebody. Shallow (<400m) seismic imaging of orebodies presents many processing and detectability challenges; most of the reflected/scattered energy sits too close to surface and p-waves to be easily discerned and secondly their finite size and heterogeneity of the geology often present effects how strong the seismic response is. Despite these challenges, the high density contrast of the orebody with the surrounding carbonate rocks make it a viable target for reflection seismic imaging. In order to study the full wave field response associated with this geologic setting it is necessary to have modeling capabilities that can simulate the elastic wave field for heterogeneous media. In this research we present a forward modeling study that utilizes a 2D finite difference elastic wave code (Bohlen 2002) to generate realistic synthetic high resolution seismic data for a carbonate-hosted shallow massive sulphide lens. In addition to impedance contrast and depth of a target, the size of the deposit and seismic source frequency play an important role in the scattering response and detectability. For orebodies with dimensions similar to the incident seismic wavelength, as is the one modeled here, the response is characterized by scattering of the seismic energy as oppose to specular reflections (Wu, 1999). Using a seismic source frequency centered at 75Hz and a shallow (175m) Pb-Zn orebody lens with a lateral dimension of 100m and maximum thickness of 20m, synthetic seismic data addresses concerns in acquisition and processing procedures for imaging such a deposit.

Introduction

It is important to study new exploration methods for carbonate-hosted massive sulphides for numerous reasons. For orebody targets at depths greater than 100m, traditional exploration methods such as EM, CSEM and DC/IP become less effective due to their signal penetrating capabilities. At depths greater than 100m seismic methods may prove effective for mineral exploration due to their sensitivity to impedance differences, relatively high resolution at depth and ease of interpretation (Salisbury et al., 2003). An important source of lead and zinc for North America and Europe are stratabound carbonate-hosted Pb-Zn deposits, such as the Pine Point deposit in the North West Territories, Canada that is hosted in barrier carbonate facies (Pirajno 1992). As a rule of thumb a minimum reflection coefficient of 0.06, for two adjacent rock types, is needed to generate a detectable reflection on a seismic record (Salisbury et al., 1996). The reflection coefficients for all lithologies in our model, derived from borehole data, are greater 0.06, thus we expect reflections from all lithologies. The 2D geological model consists of a shallow Pb-Zn orebody lens, hosted in a carbonate layer within a background limestone rock where the orebody lens has a lateral dimension five times its thickness (Figure 1(a)). When we assume a third dimension of 100m, we calculated the tonnage for Pb-Zn deposit of varying thicknesses (Figure 1(b) and (c)). This illustrates that a smaller sized deposits (> 0.2 Mt) may not be of economical interest and this is considered when evaluating the seismic imaging capabilities for mineral exploration. By utilizing an accurate petrophysical database and elastic wave field modeling, realistic synthetic seismic data was generated. A major challenge present in the seismic data is that much of the scattered energy is in close proximity to the source generated noise (Figure 2). Careful processing was able to attenuate most of the source generated noise, while retaining reflections from the orebody. Additionally, reflections from the orebody at large offsets are significant in this data. Processing sequences are tailored so stretch mutes applied after NMO corrections do not remove the far offset signal.

Methods

Synthetic seismic data was generated using a 2D finite difference elastic wave field code (Bohlen 2002). The 2D geological model was constructed in Matlab and the resulting matrix was populated with p- and s- wave velocities and densities for the various lithologies. The massive sulphide orebody is a lens with a semi major axis of 100m (length, a) and semi minor axis (thickness, h) of 20m that is centered at a depth of 175m Nineteen shot points were positioned on the surface and spaced 100m apart. A total of 450 receivers lined the surface spaced 4m apart. This source/receiver geometry resulted in a maximum fold of 19.The source used is a Ricker wavelet with a central frequency of 75 Hz.

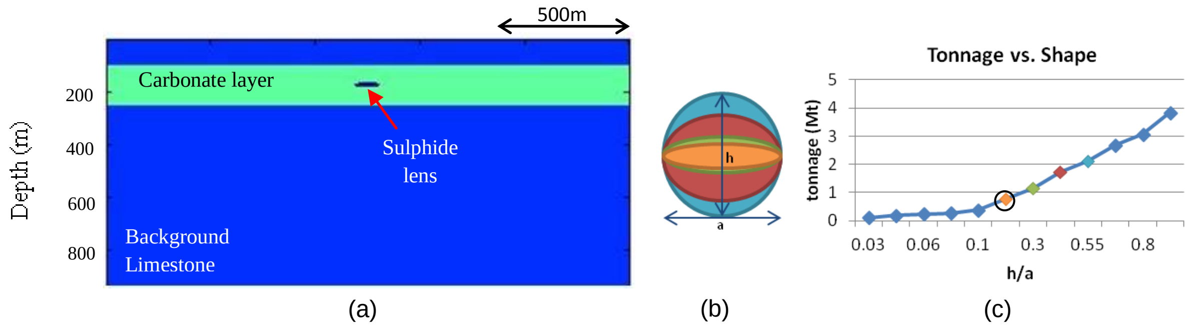

Figure 1: (a) Our 2D geological model of a shallow carbonate hosted massive sulphide deposit. (b) Lenses, (h/a <1), and a sphere (h/a=1) showing the end member sizes for an orebody of lateral dimensions 100x100m differing in thickness, h, from 3-100m. (c) Tonnage, calculated using a density of 3840 kg/m^3, versus shape. The one lens modeled here is represented by the orange lens where h/a= 0.2.

Synthetic seismic data were processed using Vista processing software. The processing sequence (listed below) was tailored to remove the source generated noise while maintaining the orebody reflections. F-k filtering with a pie shaped filter was used to attenuate the surface wave. First breaks were picked and used to apply a time shift to the data which flattened the direct wave. Then, transforming the data to the f-k domain allowed us to mute the direct wave energy that was now focused around the k=0 axis. Figure 2 shows the shot record before and after f-k filtering to attenuate the surface and direct waves. In conventional processing after applying an NMO correction large offsets are generally muted. We see in figure 3, a stretch mute of 50% or less would result in significant data loss. Here we use a stretch mute of 90% when processing the data.

The following processing sequence was applied for the synthetic data:

1. Assign geometry (CMP binning)
2. First break picking
3. F-k pie filter to attenuate surface wave energy
4. Apply a static shift using first break picks
5. F-k filter to remove direct wave

6. Reverse static shift
7. Apply NMO correction to CMP gathers (constant velocity of 5000m/s and a stretch mute of 90%).
8. Common Midpoint Stack
9. Apply gain for amplitude scaling
10. Finite difference migration using 90% stacking velocity

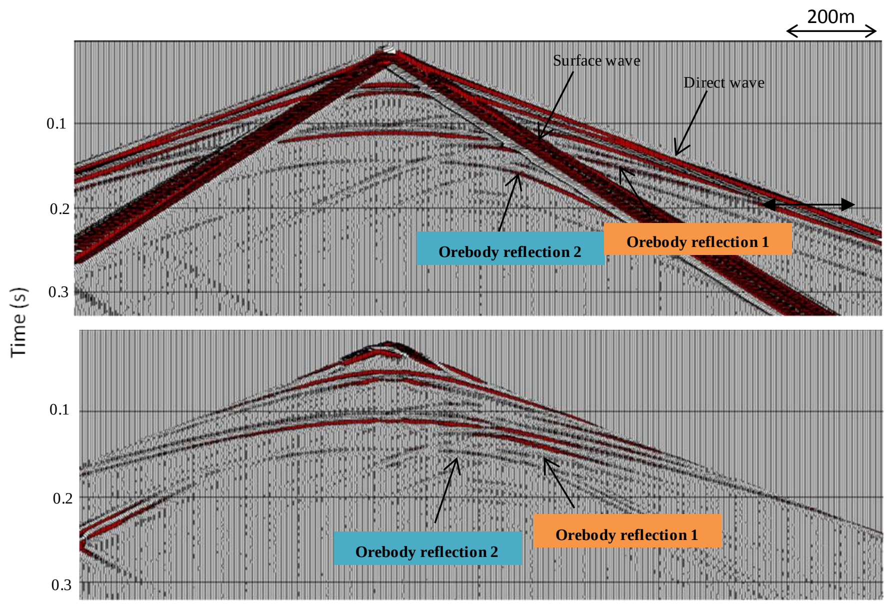

Figure 2: (Top) A synthetic seismogram (shot position at x=800m) highlighting the close proximity of the orebody reflections and the source generated noise (Bottom) the same shot record as in (a) with f-k filter applied to surface and direct waves. Some of the orebody reflections are labeled

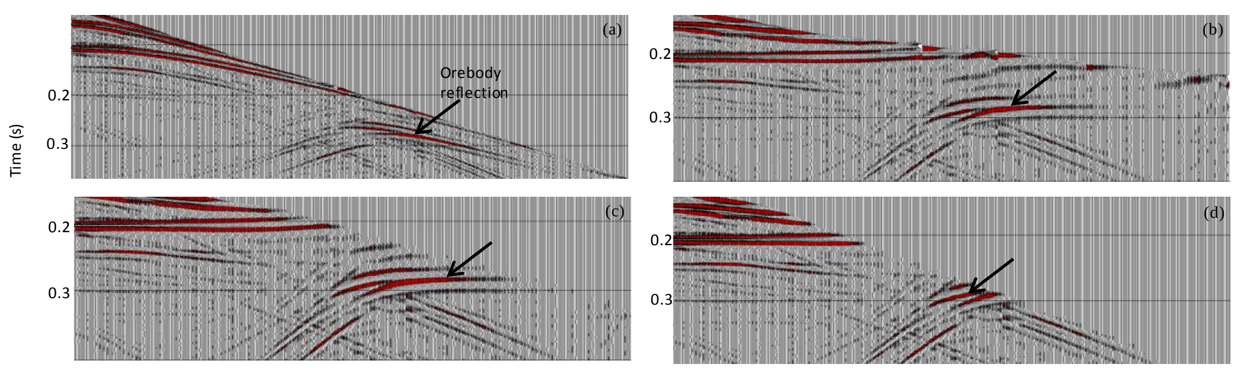

Figure 3: Arrows indicate the positions of orebody reflections for a shot record at x=100m with direct and surface wave energy removed using an f-k filter. (a) without NMO applied, and with NMO correction using a constant velocity of 5000 m/s for (b) no stretch mute, (c) a stretch mute of 90% and (d) a stretch mute of 50% .

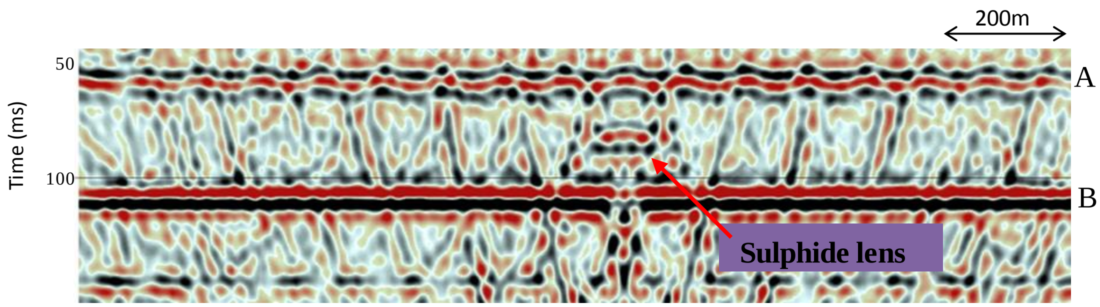

Figure 4: The Final migrated section for the 2D sulphide model in Figure 1. Reflector A and B are the top and bottom of the carbonate layer respectively.

Results

The challenge in imaging such small, shallow targets lies in the ability to remove the surface and direct waves. The scattered orebody energy has relatively low amplitudes compared to the amplitudes of the source generated noise and thus is hard to discern unless the noise is successfully attenuated. For low fold data, that is characteristic of shallow targets, this proves challenging when strong p- and surface waves are present. The reflection coefficient for the carbonate layer and the limestone in this model is more than twice the reflection coefficient for the orebody and the limestone; however, due to the small size of the massive sulphide, it appears as a weaker reflector in the migrated section (Figure 4). We see from the synthetic data that the reflected energy from the orebody can be in close proximity to the source generated noise making it challenging to preserve. In this model, significant reflections are at large offsets and needed careful attention when applying a stretch mute. In addition small trace spacing (4-5m) is needed so that spatial aliasing of shear and surface waves is avoided. With a seismic source frequency centered at 75Hz and we were able to image the orebody in this study as a weak reflection on the final migrated section. If we consider larger (thicker) lenses they should appear as brighter reflectors on a migrated seismic section making them viable targets for high resolution seismic imaging.

Acknowledgements

This project was supported by NSERC and a research grant from Teck Resources Ltd.

References

Bohlen, T. (2002). “Parallel 3-D viscoelastic finite difference seismic modelling”, Computers and Geosciences 28, pp.887-899.

Piranjo. F. (1992). “Hydrothermal Mineral Deposits:Principles and Fundemental Concepts for an Exploration Geologist.” Germany: Springer-Verlag Berlin Heidelberg.

Salisbury, M.H., Milkereit, B., Bleeker, W. (1996).”Seismic Imaging of Massive Sulphide Deposits: Part I. Rock Properties”, Economic Geology 91 (5), pp.821-828.

Salisbury, M.H., Harvey, C.W., Matthews, L. (2003), “ The Acoustic properties of Ores and Host Rocks in Hardrock Terranes” in W. Eaton, B. Milkereit, and M. H. Salisbury, eds., Hardrock seismic exploration: SEG, pp.9-19.

Wu, R.S. [1999] “Seismic Wave Scattering” In: D.E James (Eds.) *The Encyclopedia of Solid Earth Geophysics*, Van Nostrand Reinhold, New York, 1166-1186.