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Application of Seismic Reflection Surveys to Detect Massive Sulphide Deposits in Sediments-Hosted Environment

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Abstract: *Seismic reflection techniques, the most widely used geophysical method for hydrocarbon exploration has the capability to delineate and provide better images of regional structure for exploration of mineral deposits in any geological settings. Previous tests on detection and imaging of massive sulphide ores using seismic reflection techniques have been done mostly in crystalline environments. Application of seismic reflection techniques for imaging sedimentary hosted massive sulphide is relatively new and the few experiments carried out are at local scale (<500m). In this study, we analyze the feasibility of such regional exploration by modelling three massive sulphide ore and norite lenses scenario using 2D seismic survey with relatively sparse source-receiver geometry to image these deposits within 1.5km depth range. Results from the modelling experiment demonstrate that 2-Dimensional seismic reflections survey can be used to detect massive sulphides at any scale. The test further indicates that geologic setting and acquisition parameters are very important for the detection of these ore bodies. Overall, the outcomes of the results support our started objective which is to demonstrate that seismic reflection surveys can be used to detect the presence of sediment hosted massive sulphides at regional scale.*

Keywords: *Deposit, Massive Sulphide, Regional, Seismic Reflection, Sediment-hosted*

I. Introduction

Massive sulphide ores are generally characterized by high acoustic impedance (Z), which is the product of compressional wave velocity (Vp) and density (P) [8, 7, 6, 2, 4]. Study into their physical rock property indicates that massive sulphide bodies will make strong seismic reflectors in many geological environments. As interesting as this revelation seems, most studies involving the application of seismic reflection techniques to detect and delineate massive sulphide ores have only be restricted to crystalline environments. Application of seismic reflection techniques for imaging sedimentary hosted massive sulphide is relatively new and the few experiment carried out have are at local scale [3]

In this report, we extend the work of [3] by applying seismic reflection surveys for detecting massive sulphide deposits in sediment hosted environment at larger scale were the deposit may be located within 5km or more. The overall objective is to demonstrate that these massive sulphide ores can be detected at any scale using seismic reflection method which maintains resolution even at depth. Three sulphide deposits and a norite lens were the reflective targets in the model. The acoustic impedance differences between all the lithologies are greater than 2.5 x 105 g/cm2s, a minimum value for strong reflections [8]. This study is particularly unique in that it is the first time such regional scale experiment is applied to target sediment-hosted massive sulphide deposits.

II. Materials and Method

2.1Survey Design

The geological model and synthetic survey design was intended to represent suitable field techniques that are applicable to real-life seismic acquisition. For these reasons synthetic data was modelled with survey parameters similar to what would have been used in real life situation. This involved a 5 km by 1.5km geological model (Fig. 1), of which the primary zones of interest the (three sulphide deposit and norite lenses) were situated within the centre 500 m. Two different survey parameters were used to collect the data; in the first case, data was collected over 240 source shots, modelled at 20 metre intervals across the entire model, with a 35 Hz Ricker wavelet input as the dominant source frequency. Source positioning replicated rolling split-spread acquisition, such that 1000 active receivers were split in the centre by the source at all shot points. Receivers were spaced at 10 metre intervals, which provided 2400 metres of offset, each side of the source, at each shot point.

In the second survey parameter, data was collected over 120 source shots, modelled at 40 across the entire model maintaining same source positioning (rolling split-spread) and dominant source frequency (35 Hz) Ricker wavelet. Receivers were spaced at 20. These sparse survey parameters were carefully adopted as we anticipate that due to high acoustic impedance contrast; seismic reflection survey will be able to pin down the likely structures. The petrophysical data used for this model is shown in table 1.

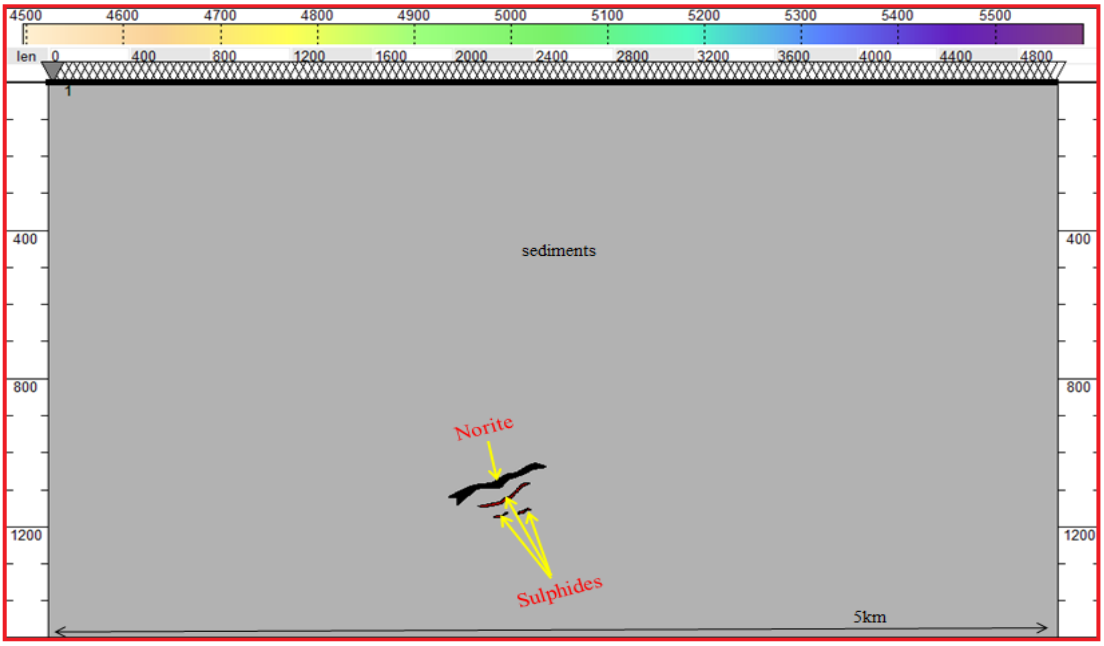

Figure 1: Synthetic 2D geology model showing the location of sulphides, norite and a sediment host rock.

Lithology	Average Vp(m/s)	Average Vs(m/s)	Vp/Vs Ratio	Density (kg/m^3)
metasediment	4235	2137	1.98	2.69
Sulphides	5612	3430	1.64	3.81
Barite	4602	2715	1.69	3.92

Table 1: Petrophysical data used as input for the 2D synthetic geology model

2.2 Modelling and Processing of Synthetic Data

All Synthetic seismograms were computed using stress-velocity formulation [9, 1] implemented in Tesseral-2D full Elastic modelling software The created shot records in SEG-Y format were processed more thoroughly using RadexPro package with basic processing steps shown in (Fig. 2). Once SEG-Y data files were imported to RadexPro software, geometry was assigned to the data sets after which it was sorted into Common Depth Point (CDP) bins, which had been defined in the geometry process. The CDP bins were defined at 10 m intervals based on the source-receiver midpoint locations. All traces from any shots which had source-receiver midpoints that fell within the predefined CDP location bins were gathered into the same CDP bin along the already defined geometry. We then applied first amplitude correction to the data in order to account for the spherical divergence of the seismic energy as it propagated from the source and band pass filter to remove noise outside the seismic sweep signal frequency band.

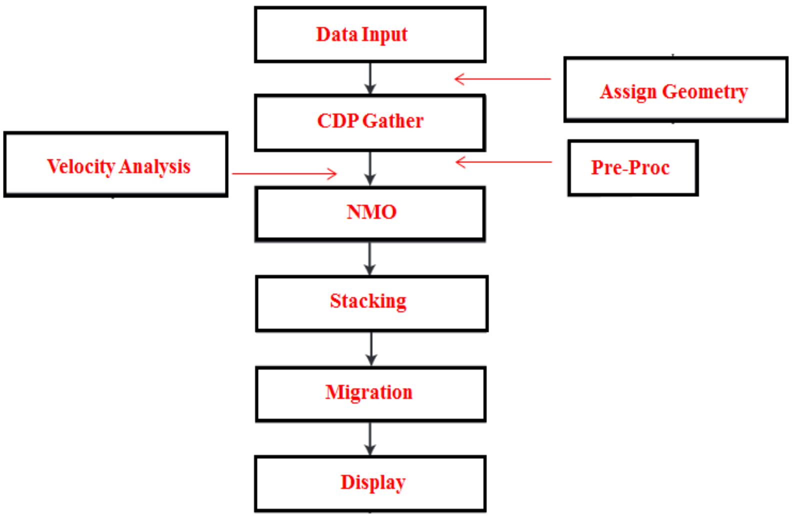

Figure 2. Basic processing flow used in this experiment

Stacking velocity analysis was carried on the synthetic data using velocity estimation and plotting module that applied a series of normal move-out corrections to designated CDP gathers according to user specified velocity functions. Velocity picks for reflections were made on the basis of maxima in coherency, flattening across the CDP gather and the quality of narrow stack panels. Several passes were made, including initial estimates of velocity.

Finally, post stack depth migration was applied in order to move data to its correct spatial location. The depth migration methods were applied to the stacked data using a smoothed velocity model derived from the stacking velocities using Stolt F-K migration algorithm. This enables dipping reflections visible on the stack to move up dip and become steeper and shorter while diffractions visible on the stack collapse to a small region on the migration. Further improvement in the processing of the data was achieved by applying F-K filters. This greatly improved retention of amplitude information and overall reflectivity character of the final sections.

III. Results and Discussion

Results from this modelling experiment are presented below. Fig (3) is an example of synthetic shot records for source no 112. Records are displaced from 0-2000 ms while actual reflectivity events are visible up to 1500ms. The shots are displayed using true relative amplitude without correction for spherical divergence. Shot depth for all gathers is 0m. Gathers are generated using Ricker wavelet source cantered at 35Hz. The synthetic seismogram is composed of a large hyperbolic diffraction-like event (L).

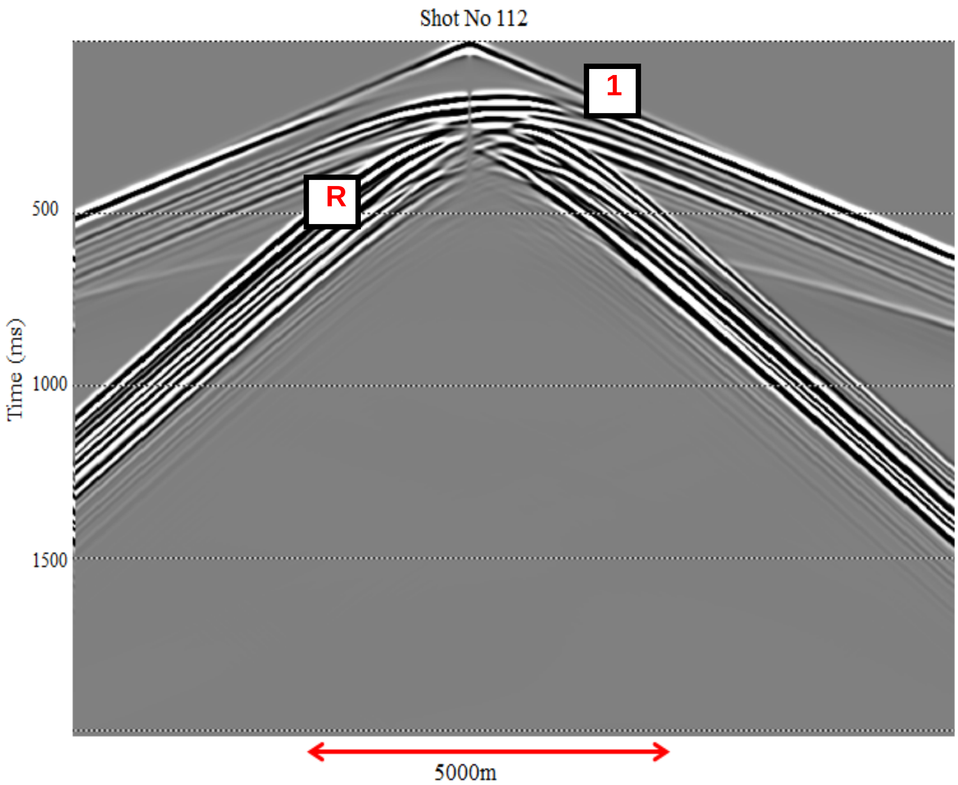

Figure 3: Synthetic shot records for source number 112 from the geological model (1) is the direct arrival signals, (R) is the reflections signals. The shot is displayed using true relative amplitude without correction for spherical divergence. Shot depth for all gathers is 0 m.

Fig (4a and 5a) are the depth migrated sections for both survey parameters (20 m source vs 10 receivers spacing and 40 m source vs 20 m receivers spacing respectively). Fig. 4b and 5b are the expanded sections of both tested parameters. Results in (Fig.4) has higher resolution when compared to results in (Fig.5) due to the densely acquisition parameters of 20 m source and 10 m receivers spacing used as opposed to the 40 m source and 20 receivers spacing used for result in Fig. 5.

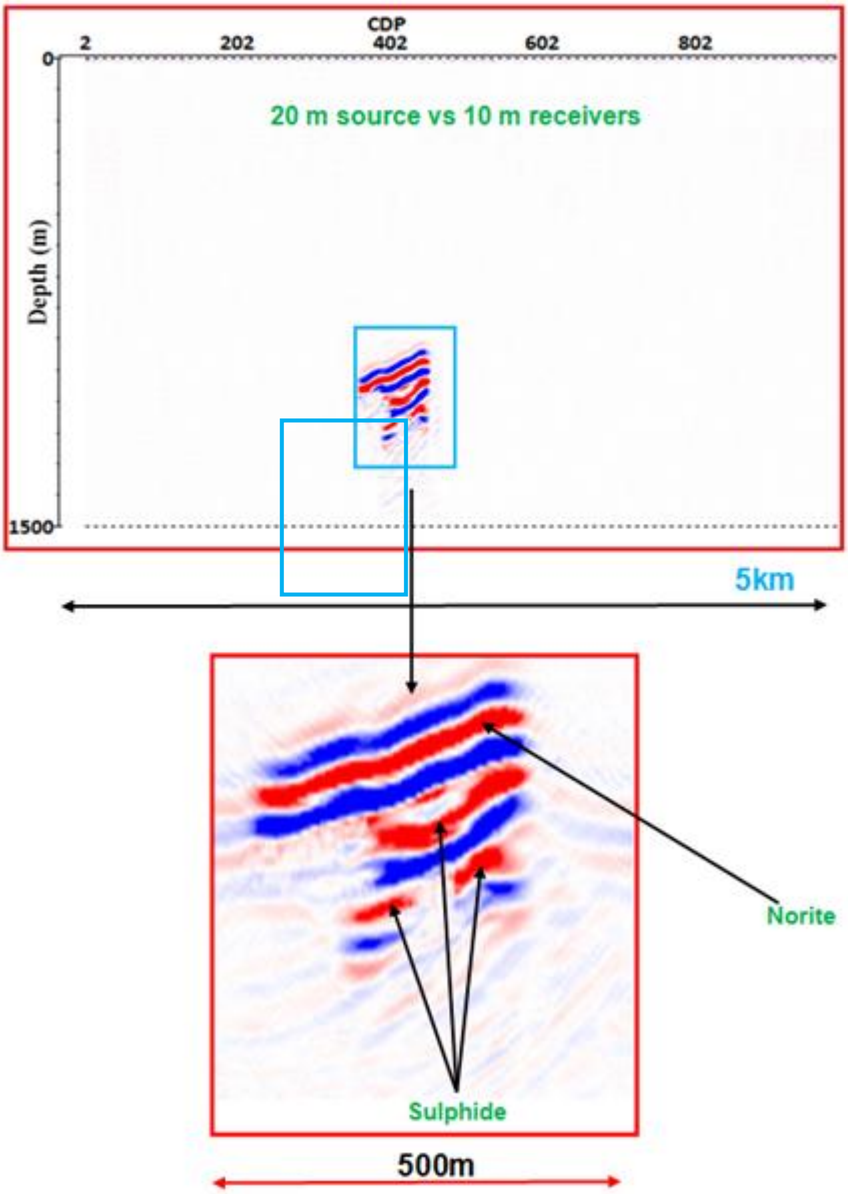

Figure 4a) Depth migrated sections with 20m source and 10 m receivers spacing 4b) Expanded section of the massive sulphide region in the model. Arrows in the expanded section indicate reflections from sulphides and norite.

5km

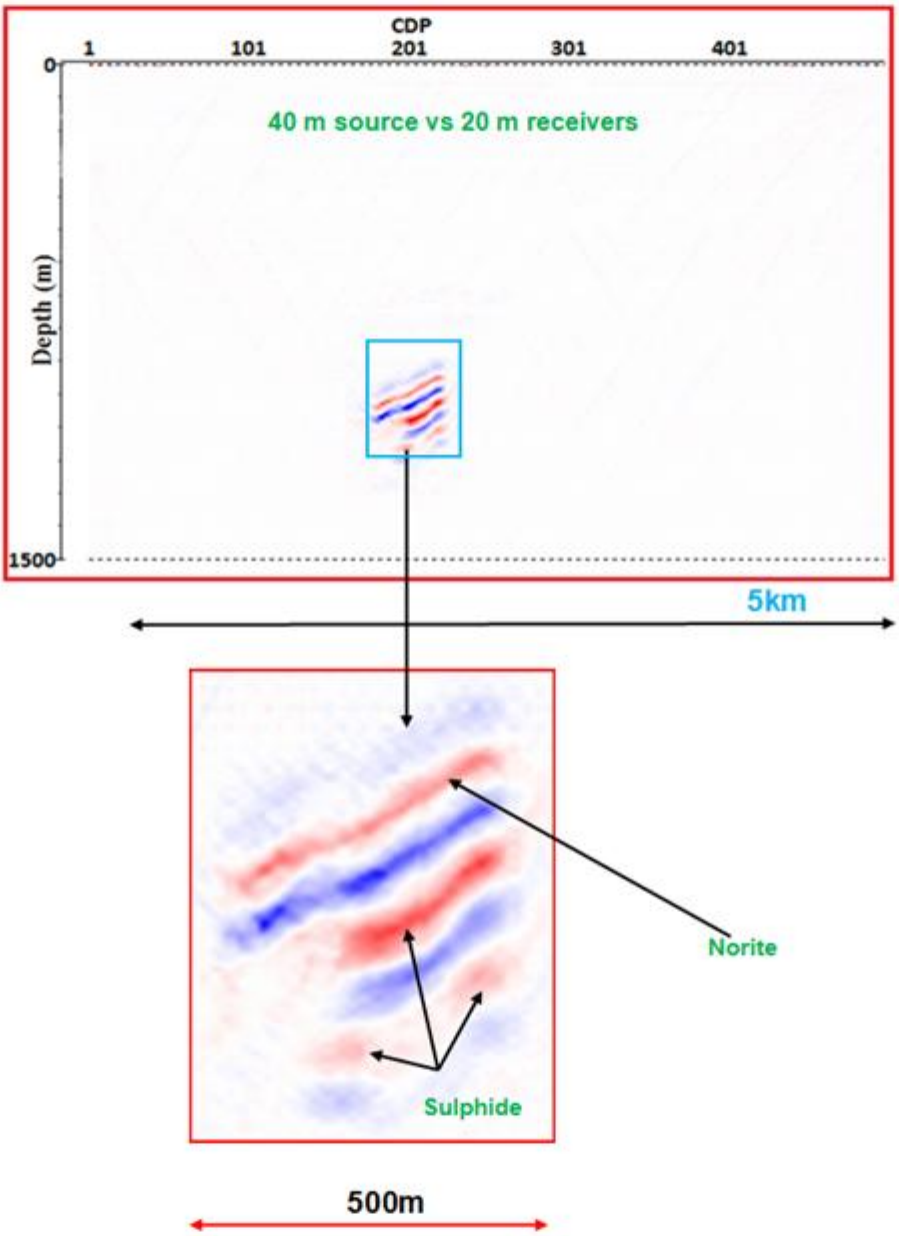

Figure 5a) Depth migrated sections with 40m source and 20 m receivers spacing 4b) Expanded section of the massive sulphide region in the model. Arrows in the expanded section indicate reflections from sulphides and norite.

The observed migrated sections for both cases are in good agreement with the synthetic geological model. The three sulphide deposits and the norite lenses generate very strong reflections amplitude as expected due to its high impedance contrast associated with them. The high impedance contrast between the steeply dipping norite and the sulphide ores will obviously cause the characteristics high amplitude of the reflection responses observed in the migrated images. This high amplitude reflection caused by the massive sulphides can be observed at a distance which is considerably larger than the actual size of the orebody.

IV. Conclusion

This modelling experiment has demonstrated that 2-Dimensional seismic reflections survey can be used to detect massive sulphides at 1000m or more depth. The results also indicate that geologic setting and acquisition parameters are very important for the detection of these ore bodies. The success of imaging the target structures depends on the effective removal of the strong surface waves and this was aptly demonstrated during processing as the presence of strong surface waves in sediments environments were removed via F-K filtering. However, to image the true shape and location of these sulphide orebodies, a three dimensional seismic survey design is required. With such 3D designs, optimum offset windows are used such that reflections from the target can be seen with minimal interference from the surface and direct waves. Overall, the outcomes of the results support our started objective which is to demonstrate that seismic reflection surveys can be used to detect the presence of sediment hosted massive sulphides at regional scale.

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