

## Seismic Imaging of the Massive Cu-Co-Zn Sulphide Deposit in Outokumpu, Finland

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### Summary

The study area, Outokumpu, is a hard rock area and it is well known for its unconventional Precambrian massive Cu-Co-Zn sulphide deposits (~1.97 Ga) which were discovered in 1910. This abstract presents the study of the seismic reflection characteristic in hard rock environment in Outokumpu, Finland. Research techniques used in this area consist of two 2D surface seismic lines and a vertical seismic profiling data. To preserve the high-frequency information and achieve a high resolution imaging in hard rock area, special attention was paid for data processing include definition of geometries, noise suppression and deconvolution. After processing, high resolution seismic results are obtained. And the final results show strong and distinct reflectors around 500 ms which are associated with Outokumpu-type massive sulphide deposits, and they agree well with the synthetic result. Moreover, there is a remarkable consistency between seismic surface results and the VSP result.

### Introduction

Outokumpu is located in southeast Finland (Figure 1). And it is the site of a historic base metal mine. Many studies have been carried out in this area, which involves geologic, geochemical, and geophysical methods. The general geology (Figure 2) was revealed by the study on a 2.5 km deep research hole which was drilled in 2004-2005 (I. T. Kukkonen et al., 2007). In the borehole, 90% of the drilled section is formed by mica schist and pegmatitic granite, and 10% of the rock types, which lie from 1314 m to 1515m, consist of serpentinite, diopside skarn, quartzite and black schist. These latter rocks have a high potential to host mineral deposits and they are called the Outokumpu-rock type assemblage. From logging information on Figure 2, the density remains nearly constant throughout the well except for the Outokumpu assemblage section. Large Vp velocity variations can be observed in this section. According to the laboratory

measurements (T. Elbra et al., 2011), the density from 1314 m to 1515 m varies from  $2514 \text{ kg m}^{-3}$  to  $3158 \text{ kg m}^{-3}$  with an average  $5622 \text{ m s}^{-1}$  for  $V_p$ .

In order to obtain high resolution imaging through this area and to determine detailed structure of the bedrock nearby the deep drill hole, in May 2006, University of Alberta, GTK (Geological Survey of Finland) and Institute of Seismology of University of Helsinki did a seismic VSP- (Vertical Seismic Profile) and two crooked 2D seismic lines near the Outokumpu deep drill hole (Figure 1). These two seismic lines are almost perpendicular to each other, but unfortunately no crossing point among the lines and the deep drilled hole.

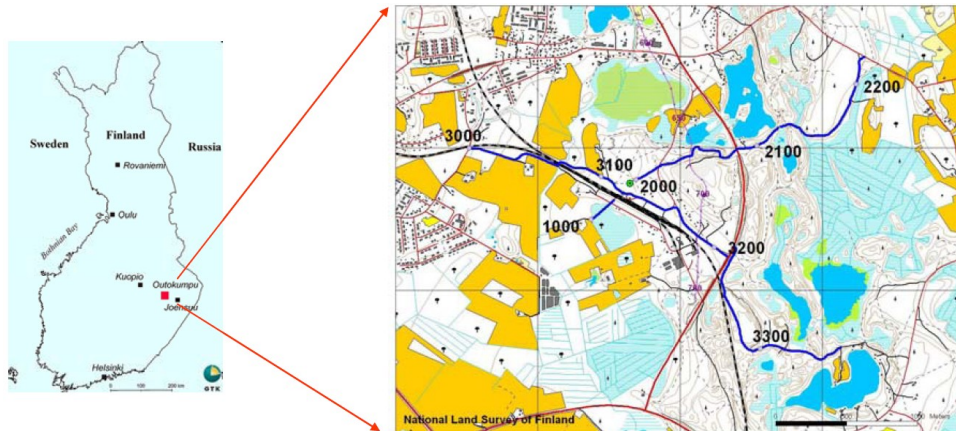


Figure 1 Geographic location of Outokumpu and seismic surveys in 2006. Green circle is the location of the 2.5 km deep research hole where VSP data was recorded. Blue lines are two crooked 2D seismic surface surveys, line2000 and line3000.

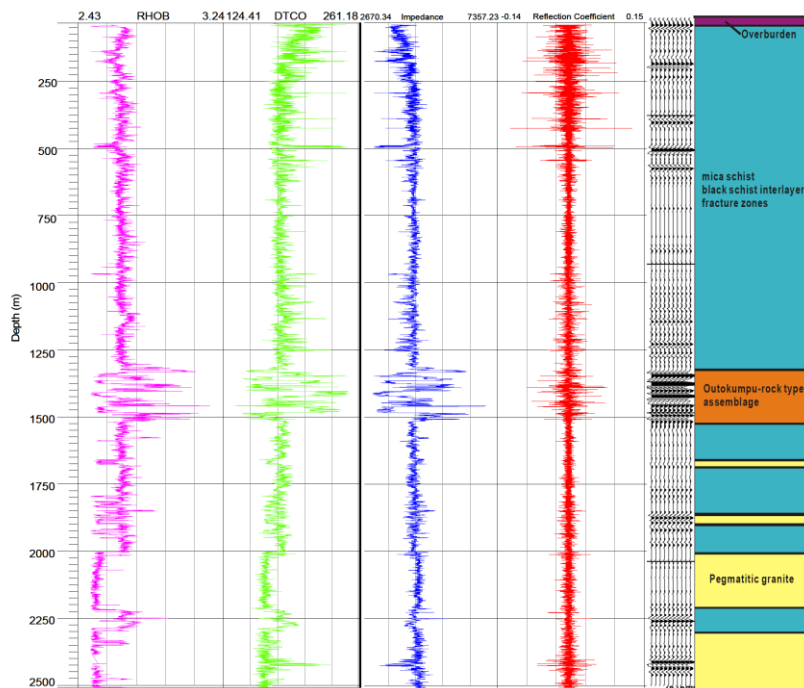


Figure 2 Geology and logging information from Outokumpu deep drill hole, calculated acoustic impedance, reflection coefficient and a synthetic seismogram. From left to right, they are the density log, the acoustic log, the acoustic impedance, the reflection coefficient, synthetic seismogram and geology information.

## Data Acquisition and Processing

Due to the complex physical properties in hard rock area, the signal to noise ratios is always low. And it is also difficult to find prominent and stable horizontal layers to track in hardrock environment. Usually high-resolution seismic survey techniques are applied to detect ores. Thus, special attention should be paid for data processing in order to preserve high frequency information and improve the resolution.

Two crooked seismic lines were recorded by using a semi-distributed system (Geode™, Geometrics, California). A high-frequency vertical seismic vibrator (IVI Minivib™, Industrial Vehicles International, Oklahoma) source employed an 8 s linear taper sweep with frequencies 15–250 Hz with a nominal force of 25 kN (~5500 lbs). The nominal source gap was 20 m and receiver gap was 4 m. The total recording length is 5 second with a 1 ms sampling period on 216 channels. And the zero-offset VSP was acquired every two meters, starting at 2500 m and ending at 50 m (bottom of casing) with the vibrator stationed 33.5 m away from the borehole. And the recording length is 5 second with 1 ms sampling rate.

The determination of whole processing sequence was based on the geometry and quality of seismic data. And the processing was performed by using VISTA 2D/3D™ Seismic Data Processing software and Matlab™. For the 2D seismic lines, processing sequence mainly includes defining geometry, amplitude compensation, noise attenuation, deconvolution, velocity analysis, CMP stacking and migration. Since these two seismic lines are particularly crooked and both have a very strong noise background, special considerations are given to the definition of geometry, noise attenuation and deconvolution. For the zero-offset VSP data, data processing mainly consists of defining geometry, calculating interval velocity, noise attenuation, wavefield separation, deconvolution and corridor stack. Special effort was made for the attenuation of tube waves and the wavefield separation by reason of weak upgoing energy.

## Results and Interpretations

The final results are shown on Figure 3 and Figure 4. Both seismic results and VSP result exhibit very strong reflectors around 500 ms which were recognized as Outokumpu-type massive sulphide deposits. Reflectors on line2000 are more continuous than those on line3000. And line2000 has a higher resolution than line3000 even though it crooked more seriously than the other. The reason that line3000 has a relatively low resolution is considered as the fact that line3000 has lower fold coverage because it was not fully covered by receivers and sources. The closest point between line3000 and VSP is CMP 386. From the correlation figures, the seismic result of line3000 is consistent with the VSP result around the target zone. However there is no comparison between line2000 and VSP because there are no reflectors around the closest point, CMP 1, on the seismic profile.

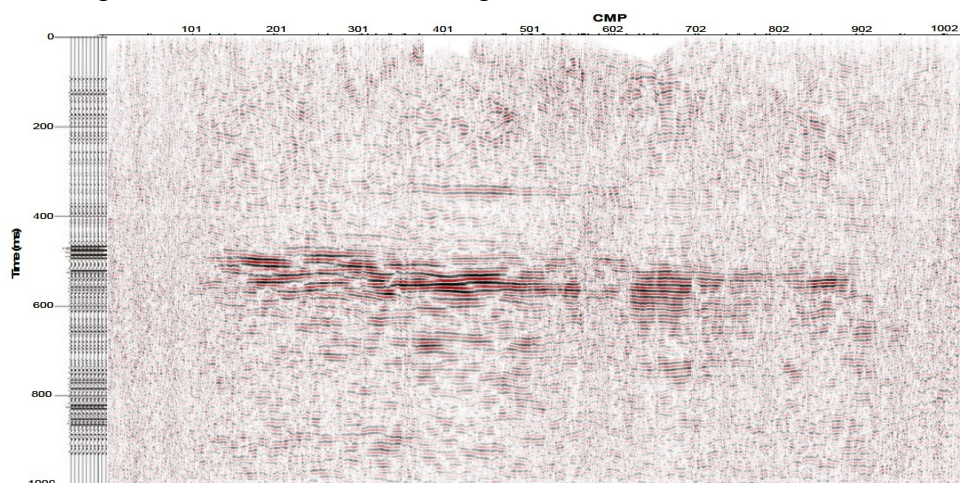


Figure 3 Correlation between the stack result of line2000 and VSP result.

## Conclusions



Hard rocks have more complex properties and structures than sedimentary rocks. The signal-noise ratio and continuity are usually very low, which makes the acquisition and processing challenging. Outokumpu-type assemblage has evident strong reflectors on synthetic result (Figure 2). And it can also be imaged by seismic exploration techniques. Consider the effects caused by crooked lines and data quality, seismic lines and VSP data were processed successfully. Strong reflectors can be observed from both seismic results and VSP result. And there is great consistency between seismic and VSP results. Our images provide a reasonable estimation for Outokumpu-type massive sulphide deposits.

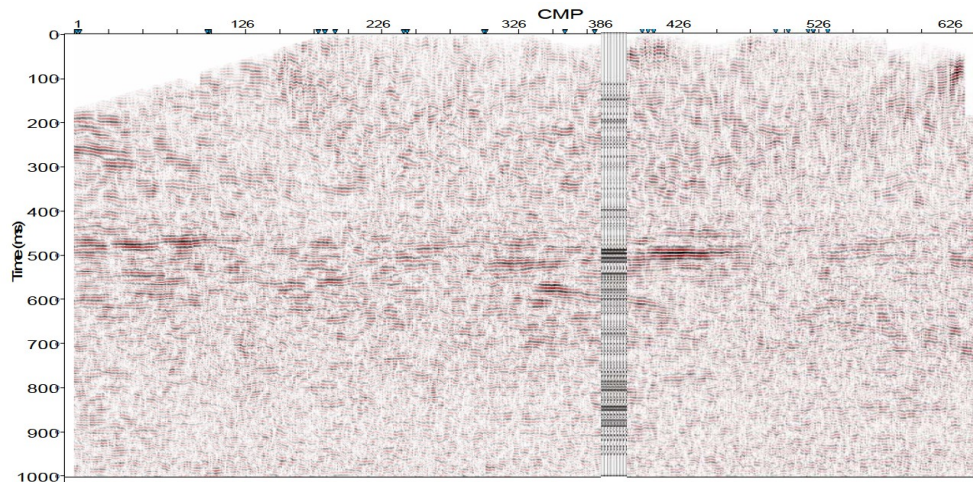


Figure 4 Correlation between the stack result of line3000 and VSP result.

## Acknowledgements

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## References

- Bellefleur, G., Müller, C., Snyder, D. and Matthews, L., 2004, Downhole seismic imaging of a massive sulfide orebody with mode-converted waves, Halfmile lake, New Brunswick, Canada: *Geophysics*, **69**, 318-329.
- Eaton, D. W., 1999, Weak elastic-wave scattering from massive sulfide orebodies: *Geophysics*, **64**, 289-299.
- Eaton, D., Guest, S., Milkereit, B., Bleeker, W., Crick, D., Schmitt, D. and Salisbury, M. H., 1996, Seismic imaging of massive sulfide deposits; Part III, Borehole seismic imaging of near-vertical structures: *Economic Geology*, **91**, 835-840.
- Elbra, T., Karlqvist, R., Lassila, I., Haggstrom, E. and Pesonen, L. J., 2011, Laboratory measurements of the seismic velocities and other petrophysical properties of the Outokumpu deep drill core samples, eastern Finland: *Geophysical Journal International*, **184**, 405-415.
- Kukkonen, I. T. and the Outokumpu Deep Drilling Working Group, 2007, Outokumpu deep drilling project-introduction to geology and geophysics of the deep hole and research within the project: Second International Workshop Espoo, Finland: Programme and Expanded Abstracts, 11-16.
- L'Heureux, E., Milkereit, B. and Adam, E., 2005, 3D Seismic Exploration for Mineral Deposits in Hardrock Environments: Focus article, CSEG recorder, 36-39.
- Milkereit, B., Eaton, D., Wu, J., Perron, G., Salisbury, M.H., Berrer, E. K. and Morrison, G., 1996, Seismic imaging of massive sulfide deposits; Part II, Reflection seismic profiling: *Economic Geology*, **91**, 829-834.
- Nedimovic, M. R. and West, G. F., 2003, Crooked-line 2D seismic reflection imaging in crystalline terrains: Part 1, data processing: *Geophysics*, **68**, 274-285.
- Park, A., 1988, Nature of the early proterozoic Outokumpu assemblage, Eastern Finland: *Precambrian Research*, **38**, 131-146.
- Salisbury, M. H., Milkereit, B., Ascough, G. L., Adair, R., Schmitt, D. and Matthews, L., 2000, Physical properties and seismic imaging of massive sulphides: *Geophysics*, **65**, 1882-1889.
- Wu, J., 1996, Potential pitfalls of crooked-line seismic reflection surveys: *Geophysics*, **61**, 277-281.
- Wu, J., Milkereit, B. and Boerner, D.E., 1995, Seismic imaging of the enigmatic Sudbury structure: *Journal of Geophysical Research*, **100**, 4117-4130.