ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15 – 18 February 2015 Perth, Western Australia

Seismic volumetric interpretation of a disseminated copper system in Kevitsa, northern Finland

Muhammad Shahadat Hossain
PhD Student
Dept. of Exploration Geophysics
Curtin University, Perth, WA
&
Deep Exploration Technologies CRC
PO Box 66, Export Park, Adelaide Airport
South Australia 5950, Australia
Muhammad.Hossain@student.curtin.edu.au

Milovan Urosevic
Associate Professor
Dept. of Exploration Geophysics
Curtin University, Perth, WA
&
Deep Exploration Technologies CRC
PO Box 66, Export Park, Adelaide Airport
South Australia 5950, Australia
Milovan.Urosevic@curtin.edu.au

Chris Wijns
Group Geophysicist
First Quantum Minerals Ltd.
1/24 Outram St, West Perth WA 6005
Australia
Chris.Wijns@fqml.com

SUMMARY

Improved mining technology and scarcity of near-surface deposits is forcing the mining industry to explore deeper in the search for economic mineralisation. Reflection seismic is one of the few geophysical methods that have sufficient resolution at depth to constrain geological information of an ore deposit at the drilling scale. Reflection seismic methods can be used to reduce drilling costs by focusing the drilling in strategically important areas. Recently introduced seismic volumetric interpretation techniques have advantages over conventional interpretation techniques where the interpretation is done by slicing the volume in 2D planes. Volumetric interpretation is performed in 3D, in real time, by applying various opacity and transparency filters to the seismic volume from different angles, which enables in–depth understanding of the volume. This initial stage of volumetric interpretation is followed by mapping the interfaces and associated structures of exploration interest.

A 3D high–resolution seismic dataset was collected to investigate steeply dipping to sub–vertical structures in Kevitsa, northern Finland. Automatic fault extraction using a modified ant–tracking workflow was done on the seismic volume.

Key words: Reflection seismic, seismic volumetric interpretation, disseminated copper system, Kevitsa.

INTRODUCTION

Reflection seismic provides high–resolution images of subsurface geological structures and petrophysical properties of the rocks e.g. density and seismic velocity (Malehmir *et al.*, 2014). Improved mining technology and scarcity of large, near–surface deposits has led the mining industry to explore deeper for economic minerals in order to meet future needs (Malehmir *et al.*, 2012b). Gravity and magnetic methods cannot resolve targets beyond 500 metres in depth, however, the seismic reflection method can delineate structures up to 1 km deep (Salisbury and Snyder, 2007, Malehmir *et al.*, 2012b). In some special cases seismic reflection can target structures up to 3 km deep (Salisbury and Snyder, 2007, Malehmir *et al.*, 2012a). Reed (1993) published a comprehensive review of mineral exploration employing the seismic reflection method.

During the last few decades, the reflection seismic method has been used for mine development and planning in South Africa, Australia, Canada, Sweden, and Finland (Malehmir *et al.*, 2007, 2011, 2012a, Urosevic *et al.*, 2007, 2008) . In some cases, seismic reflection has been able to directly target the ore-body (Milkereit *et al.*, 1996, Salisbury *et al.*, 2003, Malehmir and Bellefleur, 2009).

Kevitsa is a disseminated Ni-Cu-PGE deposit hosted by a mafic-ultramafic intrusion in northern Finland (Koivisto *et al.*, 2012; Figure 1). The Kevitsa intrusion is emplaced within layered sedimentary and volcanic rocks of the central Lapland Greenstone belt and is about 2.06 Ga old (Mutanen and Huhma, 2001).

The deposit was discovered by the Geological Survey of Finland in 1987 and open–pit mining by Kevitsa Mining Oy/First Quantum Minerals Ltd. was commenced in June 2012 (Malehmir *et al.*, 2014). In December 2007, a 2D reflection seismic survey was conducted as part of the HIRE project and the initial positive results led to a 3D survey for mine planning and deep exploration (Koivisto *et al.*, 2012). The main goal of the 3D survey was to delineate major faults and fracture zones, whereas the 2D survey was planned to provide a regional view of the Kevitsa intrusive complex (Koivisto *et al.*, 2012).

METHODOLOGY

Improved computer technology e.g. increased processing power, faster data transfer rates, improved 3D graphics rendering engines with volume visualisation techniques have empowered the interpreter to directly evaluate the seismic reflectivity in real–time applying various opacity/transparency filters (Roberts, 1998, Kidd, 1999). This enables a range of predominant attribute values to be restrained or entirely switched off, giving the viewer the ability to see through an entire volume (De Pledge, 2000). In general, 2D interpretation generates cross–sections/maps, whereas a volumetric interpretation method produces a 3D perspective of the target volume (Kidd, 1999).

The ant–tracking method is a coherent signal tracker based on “swarm intelligence” to find optimal connectivity for fault features within an edge-detected seismic volume (Schlumberger, 2013). A modified ant–tracking workflow to extract faults from the Kevitsa seismic cube is shown in figure 2. The edge-detected volume is prepared by conditioning the amplitude volume by applying a number of filtering attributes e.g., bandpass filter, median filter, structural smoothing. The ant-tracking process emulates ant colony behaviour in nature and how these insects use pheromones to mark their paths in order to optimize the search for food. Using the same approach, "artificial ants" work as seeds on a seismic volume to look for fault zones (Schlumberger, 2013). The output is an attribute volume with very sharp and detailed fault zones.

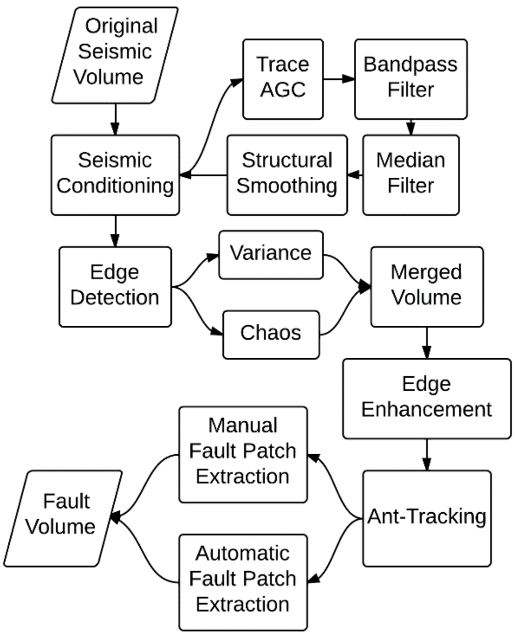

Figure 2: Modified ant–tracking workflow to extract fault patches from the Kevitsa seismic volume.

SEISMIC INTERPRETATION

Seismic attributes are the information attained from seismic data by direct measurements or by logical reasoning (Taner, 2001). Koivisto *et al.* (2012) took an approach to interpret 2D seismic lines E2, E3, E4, and E5 on the basis of density–velocity relationships of different lithological units measured in 12 drill holes in the area. Their study unveils that the complex internal reflectivity structure within the intrusion stems from multiple magmatic layers. They also interpret a deeper continuation of the intrusion than previously thought. Surface seismic reflection has generally failed to directly image steeply dipping to sub–vertical structures, but Malehmir *et al.* (2012b) correlated 3D seismic data with the VSP data and suggested that steep reflections observed in the VSP data match steep or near–vertical faults displacing gently–to–moderately dipping reflectors (Figure 3).

Automatic fault extraction was done directly in 3D using Schlumberger Petrel’s ant–tracking algorithm. The basic workflow has been modified as needed during the process. The final result is an ant–tracked volume which is then used for manual and automatic fault patch extraction (Figure 4).

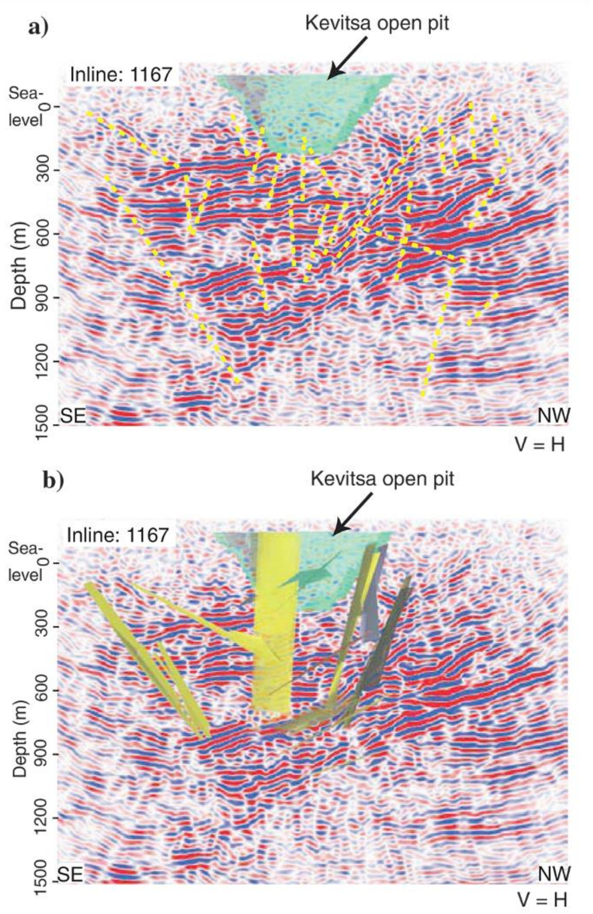

Figure 3: (a) Interpreted seismic sections along inline 1167, (b) visualised with the surfaces obtained from the VSP data provide evidence for the presence of steeply–dipping faults as manifested by time-shifts across some of the reflections (Malehmir *et al.*, 2012b).

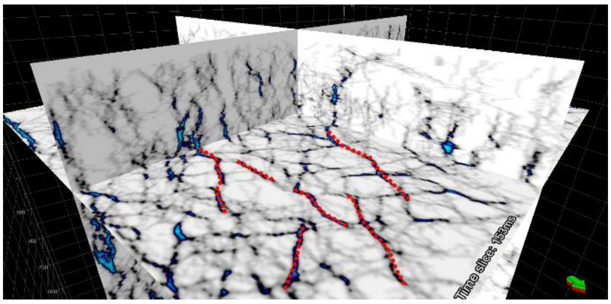

Figure 4: Faults extracted using Schlumberger Petrel’s ant–tracking attribute on a seismic volume collected from Kevitsa.

CONCLUSIONS

3D seismic exploration methods have the capability to map complex geological structures, and to help rock characterisation and targeting of mineral resources. Previous successes in South Africa, Canada, and Australia advocate that seismic methods could become an important exploration tool to image subsurface structures hosting ore bodies. This is probably the only way to efficiently explore for deep mineral resources. The introduction of seismic volumetric interpretation should enable targeting with improved understanding of the seismic volume. It is currently the best way to approach a seismic volume to target deep, small–sized features.

ACKNOWLEDGMENTS

This work has been supported by the Deep Exploration Technologies Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Programme. This is DET CRC Document 2014/552. We would also like to thank First Quantum Minerals Ltd. for the use of their data.

REFERENCES

De Pledge, J.E., 2000, Derivation of a 3-D Seismic Volume Interpretation Workflow for Fast Track Evaluation of a Large 3-D Seismic Data Volume: Gph1/00. Curtin University of Technology.

Kidd, G.D., 1999, Fundamentals of 3d Seismic Volume Visualization. 1999 Offshore Technology Conference, Houston, Texas.

Koivisto, E., Malehmir, A., Heikkinen, P., Heinonen, S., and Kukkonen, I., 2012, 2d Reflection Seismic Investigations at the Kevitsa Ni-Cu-Pge Deposit, Northern Finland: GEOPHYSICS, 77, WC149-WC62.

Malehmir, A. and Bellefleur, G., 2009, 3d Seismic Reflection Imaging of Vhms Deposits, Insights from Re-Processing of the Halfmile Lake Data, New Brunswick, Canada: Geophysics, 74, 209-19. doi:10.1190/1.3230495.

Malehmir, A., Durrheim, R., Bellefleur, G., Urosevic, M., Juhlin, C., White, D.J., Milkereit, B., and Campbell, G., 2012a, Seismic Methods in Mineral Exploration and Mine Planning: A General Overview of Past and Present Case Histories and a Look into the Future: Geophysics, 77, WC173–WC90.

Malehmir, A., Juhlin, C., Wijns, C., Urosevic, M., Valasti, P., and Koivisto, E., 2012b, 3d Reflection Seismic Imaging for Open-Pit Mine Planning and Deep Exploration in the Kevitsa Ni-Cu-Pge Deposit, Northern Finland: Geophysics, 77, WC95-WC108.

Malehmir, A., Juhlin, C., Wijns, C., Urosevic, M., Valasti, P., Koivisto, E., Kukkonen, I., Heikkinen, P., and Paananen, M., 2011, 3d Reflection Seismic Investigation for Mine Planning and Exploration in the Kevitsa Ni-Cu-Pge Deposit, Northern Finland.

Malehmir, A., Koivisto, E., Manzi, M., Cheraghi, S., Durrheim, R.J., Bellefleur, G., Wijns, C., Hein, K.A.A., and King, N., 2014, A Review of Reflection Seismic Investigations in Three Major Metallogenic Regions: The Kevitsa Ni-Cu-Pge District (Finland), Witwatersrand Goldfields (South Africa), and the Bathurst Mining Camp (Canada): Ore Geology Reviews, 56, 423.

Malehmir, A., Tryggvason, A., Juhlin, C., Rodriguez-Tablante, J., and Weihed, P., 2006, Seismic Imaging and Potential Field Modeling to Delineate Structures Hosting Vhms Deposits in the Skellefte Ore District, Northern Sweden: Tectonophysics, 426, 319–34.

Malehmir, A., Tryggvason, A., Lickorish, H., and Weihed, P., 2007, Regional Structural Profiles in the Western Part of the Palaeoproterozoic Skellefte Ore District, Northern Sweden: Precambrian Research, 159, 1-18.

Milkereit, B., Eaton, D.W., Wu, J., Perron, G., Salisbury, M.H., Berrer, E., and Morrison, G., 1996, Seismic Imaging of Massive Sulphide Deposits: Part Ii. Reflection Seismic Profiling: Economic geology, 91, 829−34.

Mutanen, T. and Huhma, H., 2001, U-Pb Geochronology of the Koitelainen, Akanvaara and Keivitsa Layered Intrusions and Related Rocks: Special Paper - Geological Survey of Finland, 33, 229-46.

Reed, K., 1993, Seismic Reflection Surveying for Mining Exploration Applications, a Review of Practice Past and Current with an Outlook for the Future. Unpublished report, Mineral Industry Technology Council of Canada, 219.

Roberts, D.M., 1998, Voxel Technology. Offshore Technology Conference, Houston, 167-68.

Salisbury, M., Harvey, C.W., and Matthews, L., 2003, The Acoustic Properties of Ores and Host Rocks in Hardrock Terranes. Tulsa, Okla. (8801 South Yale St., Tulsa OK 74137-3175) : Society of Exploration Geophysicists.

Salisbury, M. and Snyder, D., 2007, Application of Seismic Methods to Mineral Exploration. in W.D. Goodfellow (ed.) Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods, Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, 971-82.

Schlumberger, 2013, Schlumberger Petrel 2013 User Manual. Copyright © 2013 Schlumberger. All rights reserved.

Taner, M.T., 2001, Seismic Attributes: CSEG Recorder, 26, 48-56.

Urosevic, M., Kepic, A., Juhlin, C., and Stolz, E., 2008, Hard Rock Seismic Exploration of Ore Deposits in Australia: Post-Convention Workshop on High-Resolution Seismic Methods. 77th Annual International Meeting, SEG, Expanded Abstracts, 3613–14.

Urosevic, M., Kepic, A., Stolz, E., and Juhlin, C., 2007. Seismic Exploration of Ore Deposits in Western

Australia. Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration. , 525-34.

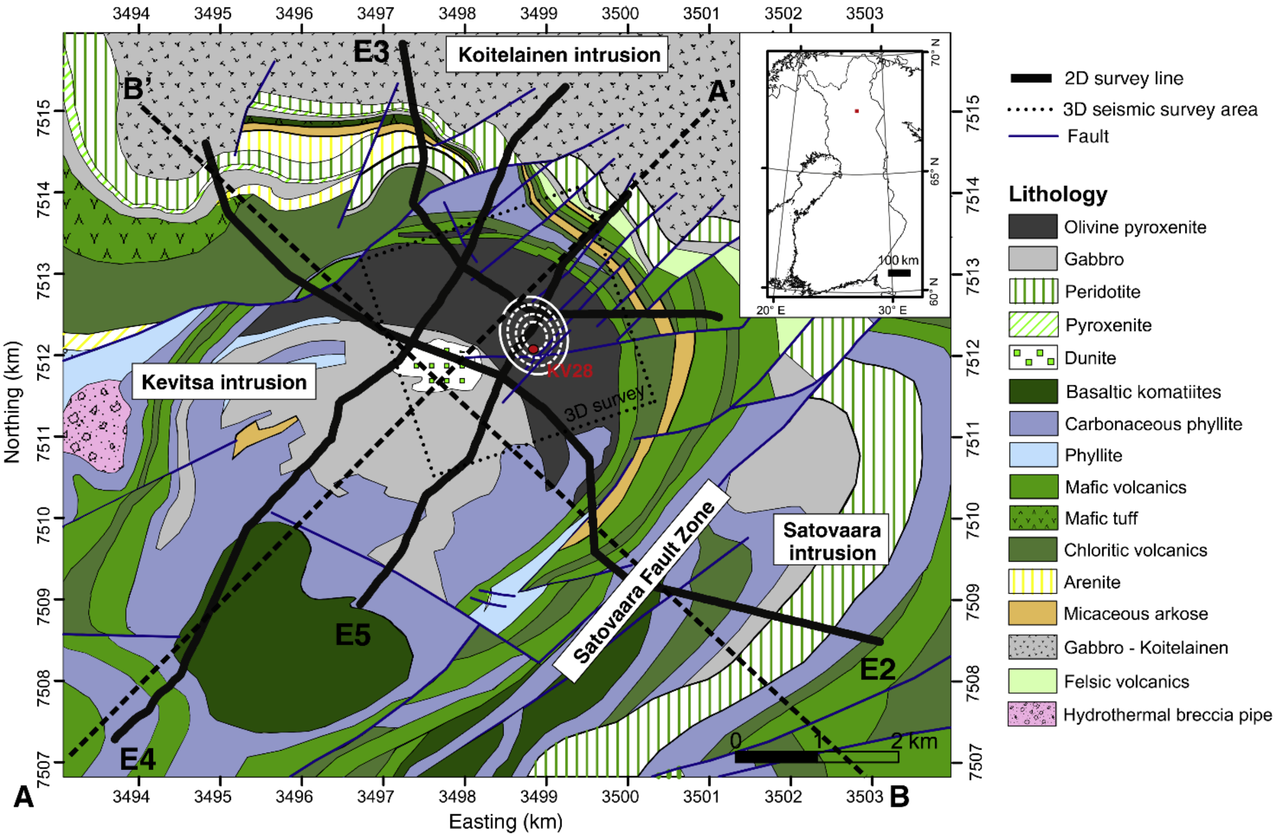

Figure 1: Geological map of the Kevitsa area, with 2D seismic survey lines E2, E3, E4 and E5 and the 3D seismic survey area. Geology was adapted from Kevitsa Mining Oy/First Quantum Minerals Ltd. (Malehmir *et al.*, 2014).