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Special Section

Seismic methods in mineral exploration and mine planning — Introduction

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Across the globe, the mineral industry is seeking technology to improve exploration efficiency at depth and to help design safer and more productive mines. Seismic methods are increasingly used by this industry for a wide range of commodities including base metals, uranium, diamonds, and precious metals. Seismic methods provide high-resolution images of geologic structures hosting mineral deposits and, in a few cases, can be used for direct targeting of mineral deposits. Applications are not limited to only surface seismic surveys, but also include borehole seismic methods such as VSP and crosshole imaging. To date, tens of 2D and 3D surface seismic surveys have been acquired in Canada, Europe, Australia, and South Africa (see Malehmir et al., 2012) to help in targeting mineral deposits at depth or for designing deep mines. The steadily increasing usage of reflection seismic methods demonstrates that they are finally becoming recognized and established within the mining sector. This brings new opportunities for geophysicists, but also new challenges. Some of these challenges and opportunities are presented and discussed in the special section.

This special issue contains a wide range of topics, from petrophysical studies to data acquisition, processing and imaging, as well as 2D and 3D seismic modeling of mineral deposits and their host-rock structures. Papers from both industry and academia are presented, which illustrate the importance of seismic methods not only in the hydrocarbon industry, but also in the mineral industry.

Malehmir et al. review important contributions that have been made in developing seismic techniques for the mining industry with focus on four main regions: Australia, Europe, Canada, and South Africa. A wide range of case studies are covered including some that are published in the special section accompanying this article, from surface to borehole seismic methods as well as petrophysical data and seismic modeling of mineral deposits.

Duff et al. summarize the seismic properties of the host rocks and massive sulfides of the world-class Voisey's Bay Ni-Cu-Co deposit and describe physical properties and how they guide the choice of appropriate seismic methods to solve a particular imaging problem. The data presented demonstrates that physical properties variations, even within a single mineralized system, may dictate different choices of seismic methods.

Bellefleur et al. show elastic finite-difference modeling over a geologically realistic 2D representation of the Halfmile Lake volcanic-hosted massive sulfide deposit, New Brunswick, Canada, and predicts P-P, P-S, S-P, and S-S waves generally having strongest amplitudes in the stratigraphy down-dip direction. The finite-difference simulations successfully reproduce many events observed on VSP data, in particular P-S and S-S events on the radial component and P-P and S-P events on the vertical component, indicating that all wave modes potentially comprise useful signals that could help the targeting of deep sulfide mineralization.

Dehghannejad et al. present results from 3D swath imaging, prestack migration and finite-difference modeling of 2D crooked-line seismic data to provide further insights about the nature of observed reflections in the Kristineberg mining area, northern Sweden. Synthetic data suggest processing artifacts manifested themselves in the final 2D images as steeply dipping events that could be confused with reflections; fewer artifacts are observed when the data are processed using prestack time migration.

Malinowski et al. show how seismic forward modeling using the phase-screen method could address imaging and interpretation issues related to a 3D seismic survey acquired in a mining camp (Flin Flon mining camp, Canada). The authors demonstrate that the ability to detect a clear signature of the massive sulfide ore deposits is dependent on the mineralization type (pyrite versus pyrrhotite-rich ore), especially when ore-host rock interaction is considered.

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Harrison and Urosevic present results of seismic processing, inversion, and amplitude versus offset analysis for characterization of gold-bearing rocks in the Kambalda region of Western Australia. The relationship among acoustic impedance, elastic impedance, and the known gold content is analyzed and discussed.

Heinonen et al. use drillhole logging data from the Pyhäsalmi massive sulfide mine in Finland to calculate average acoustic impedances of typical rock types, and this information is used to constrain interpretation of seismic reflection profiles. The ore hosting contact zone between mafic and felsic volcanic rocks is detected by using crossing seismic profiles, and a high-amplitude reflection arising from this contact zone is attributed to a mineralization.

Koivisto et al. present a 2D reflection seismic study from the Kevitsa Ni-Cu-PGE deposit, northern Finland, and discuss the implications of the 2D seismic data for the structural context of the Kevitsa intrusive complex and for mineral exploration in the area.

Kukkonen et al. present seismic reflection data to study Paleoproterozoic ophiolite-derived host-rock formations of Cu-Co-Zn massive sulfide deposits in the Outokumpu mining and exploration area, eastern Finland. The host-rock assemblages (comprising different varieties of altered ultramafic rocks) generate strong laminated packages of reflections, which provide direct clues of potentially interesting exploration environments.

White and Malinowski present 3D migration of 2D seismic profiles to directly correlate reflections with out-of-plane geology. This provides a useful interpretation tool when other supporting 3D constraints are available.

White and Kjarsgaard present a network of 2D high-resolution profiles to delineate a diamondiferous kimberlite complex. Kimberlite architecture is imaged, including faults and volcanic feeder vents.

Cheraghi et al. present application of 3D seismic survey methods in a crystalline rock environment from the Bathurst Mining Camp, Canada. The authors present the effect of proper geometry on imaging subsurface geologic structures and strategies for their optimum imaging.

Juhojuntti et al. use 3D seismic data to assist mine planning at the Millennium uranium deposit in Canada. The seismic interpretation shows the depth to the crystalline basement and several faults close to the orebody, and there is also a seismic response from the alteration zone surrounding the orebody.

Malehmir et al. present results from high-resolution surface 3D reflection seismic data acquired over a major Ni-Cu-PGE deposit in northern Finland. Seismic data in combination with VSP data image reflections from magmatic layering and faults zones, which are crucial for mine planning, and identify seismic targets for future deep exploration.

Manzi et al. use 3D seismics to image the gold bearing reefs from some of the deepest gold mines in the world and identify geologic structures that have direct impact on ore resource evaluation.

Manzi et al. show that 3D seismics can now be used to mitigate the risks to mine workers posed by water inrushes and the ignition of flammable gases in deep underground gold mines of Witwatersrand Basin, South Africa. Potential conduits that may transport water and methane to underground workings are successfully mapped using edge detection attributes, some of which show as little as 10 m displacement.

Urosevic et al. use advanced volumetric interpretation supported by seismic forward modeling to discover new zones of massive nickel sulfide orebodies.

White et al. present imaging of an ore-bearing mine horizon in the Flin Flon mining camp using 3D seismic data. Seismic images are compared directly with drillhole-constrained ore zones.

Greenwood et al. present results from a borehole hydrophone array that was used to produce seismic images in a hard-rock mineral exploration borehole. The hydrophone VSP results correlate well with the geology and exhibit analogous wavefields to that of traditional clamped geophone data collected within the same borehole.

Mueller et al. investigate the performance of lowfold scalar migration in their case study of downhole seismic imaging for massive sulfide ore deposits at Norman West, Sudbury, Canada. Low-shot fold VSP data will create ambiguous images around the borehole if 3C geophone information is not available and can be partly overcome by using diffraction coherency migration as the imaging approach.

Wood et al. present 3D surface and multiple borehole seismic surveys as part of the prefeasibility study for mine development at the Millennium uranium mine, located within the Athabasca Basin, Saskatchewan, Canada. The program successfully imaged the location and character of the unconformity, the post-Athabasca structural setting at both camp and deposit scales, adding significant insight into numerous geotechnical issues that will have to be addressed during mine planning and development.

REFERENCES

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