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Deep Ore Exploration of Sulfides with Seismic Reflection Profiling in Outokumpu, Finland

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SUMMARY

A network of high resolution seismic reflection profiles was acquired in Outokumpu, Finland. Outokumpu is one of the most important mining regions in Finland where active sulphide exploration is ongoing. Over 5 km long spread with 402 active channels and nominal vibroseismic source point interval of 25 m guarantee high fold and good signal-to-noise ratio of the seismic data. These high quality data have been commercially processed by Vniigeofizika, Moscow with standard hardrock seismic processing flow including careful static corrections. Seismic sections were migrated and depth converted with constant velocity (5400 m/s) that corresponds approximately to the seismic P-wave velocity in the main lithology of the area, mica schist. Additionally to seismic velocities, also densities of the main lithologies have been measured from the 2.5 km long drill hole. This enables estimation of the main sources of reflectivity in the Outokumpu area. Encouragingly, typical ore hosting lithological assemblage was found to be brightly reflective both externally and internally due to interlayers of high acoustic impedance skarns and low acoustic impedance serpentinites. All together nine interconnected seismic profiles combined with the drill hole logging data and other geophysical data, including ZTEM survey, enable the 3D-modeling of the Outokumpu subsurface structures.

Introduction

The Raahe-Ladoga belt in central Finland is a major NW-SE striking structure separating Archean rocks to the north and younger Paleoproterozoic island arc complexes to the south. This belt hosts numerous massive sulfide deposits and prospects. Several mines are and have been in operation in the Raahe-Ladoga belt, and one of the most sulfide rich areas is historical Outokumpu region in eastern Finland (Figure 1a). High ore potential of the area has motivated acquisition of high resolution seismic reflection profiles, drill hole logging data and ZTEM (Z-Axis Tipper electromagnetic) survey (Aatos et al., 2013). These high quality data sets enable 3D-modeling of the subsurface geology of Outokumpu area down to depths of 2-5 km.

Study area and data

Typical geology of the Outokumpu area consists deformed and metamorphosed Paleoproterozoic deep-water sediments and ophiolitic slices of upper mantle rocks from oceanic lithosphere (Figure 1a). Outokumpu type mineralization are often spatially associated with mantle derived serpentinite. Mechanical remobilization and fluid-rock interaction during Svecofennian orogeny (1.9-1.8 Ga) are the main causes of high grade ores of Outokumpu (Peltonen et al., 2008).

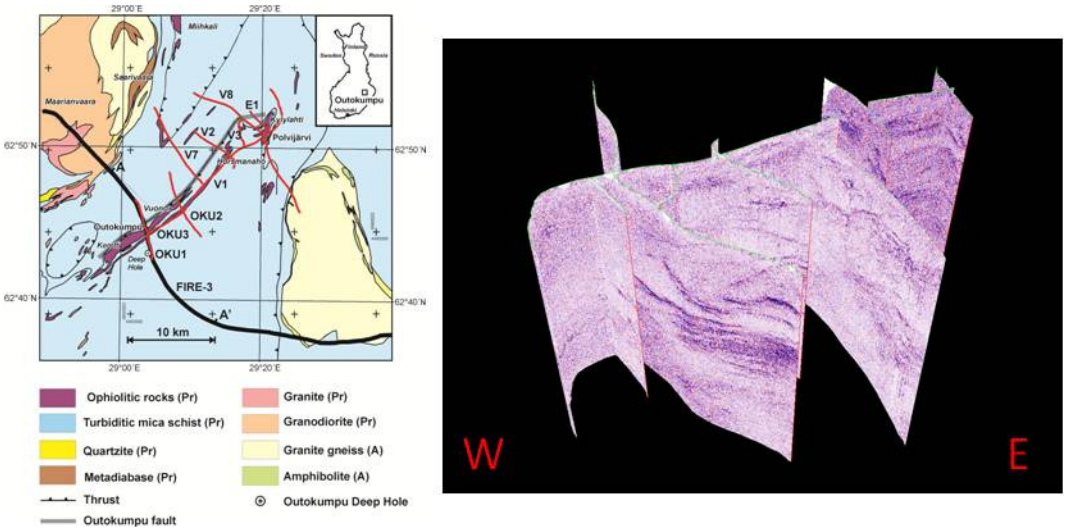

Figure 1 *Reflection seismic profiles of the Outokumpu area presented on top of geological map (Figure adapted from Kukkonen et al., 2012) and 3D-visualization of the seismic reflection profiles viewed from North-East.*

A network of seismic reflection profiles (Figure 1) was acquired in Outokumpu sulfide mining camp within the HIRE-project (HIgh REsolution reflection seismic for ore exploration, 2007-2010) led by the Geological Survey of Finland. Seismic surveys in Outokumpu employed both Vibroseis sources (sweep frequencies 30-165 Hz) and explosives with a nominal source spacing of 25 m and receiver spacing of 12.5 m. The spread length was 5025 m with 402 active channels. The seismic data were commercially processed by Vniigeofizika, Moscow. Quite standard processing flow with static corrections, amplitude enhancement and deconvolution was used and after stacking data were migrated with Stolt algorithm. Main lithology of the study area is mica schist and final seismic images were depth converted accordingly with constant velocity (5400 m/s). Acquired seismic sections show excellent data quality and image subsurface structures well beyond 5 km.

In 2006, a 2.5 km deep hole was drilled in the study site. This enables the correlation of high resolution reflection seismic profiles with continuous geophysical and geological drill hole logging results. Sonic and density logging provided information about average densities and seismic velocities of typical lithologies in the Outokumpu area (Heinonen et al., 2010). Logging results show that

typical host rocks of Outokumpu type ore are reflective when in contact with the main lithologies of the area. Moreover, massive sulphides often have high acoustic impedances and they are expected to be bright reflectors (diffractors) if geometrical constraints are met. Thus variation of physical rock properties form as good basis for seismic ore exploration in the region. Accordingly, the ore hosting rock assemblage observed in the deep drill hole can be followed as a series of reflectors in adjacent seismic profiles over a wide subsurface volume.

In 2013, GTK acquired a helicopter-borne Z-Axis Tipper electromagnetic (ZTEM) survey over the Outokumpu area from Geotech Ltd. The ZTEM system measures naturally occurring magnetic fields in the earth in a fashion similar to the magnetotelluric (MT) technique, and the depth-penetration (skin-depth) is expected to be 0.5 - 2 km. Compared to the seismic sections, preliminary ZTEM models are not very detailed. High resolution reflection seismic profiles will be used to define the source of ZTEM anomalies more precisely and on the other hand conductivity information provided by ZTEM data is expected to provide additional information about geological source of observed reflectivity. Petrophysical data forms basis for the lithological interpretation and we expect that future modelling work will result in detailed information about subsurface conductivities and reflectivity that can be utilized in the exploration of deep sulphide deposits.

Conclusions

Results of the HIRE seismic soundings in the Outokumpu district encourage the use of seismic reflection profiling for deep ore exploration. Analysis of the geophysical logging data measured in the Outokumpu deep drill hole show that the typical ore hosting rock units have distinct acoustic impedances from other typical rocks in the area. Network of seismic reflection profiles creates the framework on which geological 3D-models of reflective subsurface structures can be build on. Future modelling work includes combining the results of reflection seismic data with the conductivity information provided by ZTEM data. Combining different geophysical and geological data sets restricts the number of possible interpretations and helps to identify relevant and irrelevant reflectors from the exploration point of view. Final aim of the work is a common earth model (CEM) that is a geological 3D-solution of the subsurface structures that not only explains the results of geophysical and seismic data but also is geologically compatible with field observations and presumed tectonic evolution of the area.

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