3D reflection seismic investigation for mine planning and exploration in the Kevitsa Ni-Cu-PGE deposit, Northern Finland

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Summary

A 3D reflection seismic survey was conducted over an area of about 9 km^2 at the Kevitsa Ni-Cu-PGE (platinum group elements) deposit, northern Finland. The principal objective of the survey was to image major fault and fracture zones at depth. Understanding the geometry of these zones is important for designing a steep open-pit for mining. Initial processing results suggest that the 3D seismic survey has been successful in imaging both gently dipping and steeply dipping reflections as shallow as 50 ms (or about 150 m), many of which correlate with fault systems and lithological contacts observed at the surface. Several new target areas can be identified in the seismic data that require further investigations for their mineralization potential.

Introduction

Although it is generally believed that future mining is underground mining, there are probably many open-pittable deposits buried under shallow cover of 20-300 m. This thickness can still render the deposit blind to conventional geochemical and geophysical measurements at surface. To be successful in exploration, extensive geological and geophysical studies are required to thoroughly model geological structures hosting the ore at depth and in three-dimension. Although a wealth of drill holes is eventually required, by filling the gap, reflection seismic methods can be used to partly reduce the drilling cost by optimally drilling only in key or strategically important areas. There are not many published accounts of the use of 3D reflection seismic methods in mine planning in the crystalline environment, especially in Europe. 3D reflection seismic methods have been used in South Africa with encouraging results, allowing imaging of fault systems that in turn control the geometry of the ore horizon (Stevenson et al., 2003). Nevertheless, 3D reflection seismic surveys have been used for the exploration of deep-seated deposits with several examples from Canada and Australia (e.g., Milkereit et al., 2000; Adam et al., 2003; Malehmir and Bellefleur, 2009; Harrison and Urosevic, 2009).

In this study, we present preliminary results from a 3D reflection seismic survey conducted over the Ni-Cu-PGE Kevitsa deposit, northern Finland (Figure 1). Kevitsa is a large deposit with measured and indicated resources of 165 million tones grading 0.30% nickel, and 0.42% copper. Mining is planned to start with an open pit. The stripping ratio is expected to be in the order of 4:1. The main objectives of this study are (i) to evaluate the capability of the 3D reflection seismic methods to image fracture and fault systems at and near the Kevitsa deposit, which is important for designing the final geometry of the open pit, and (ii) to identify new target areas for deep (< 1.5 km) exploration of both Ni-PGE and base-metal mineralization.

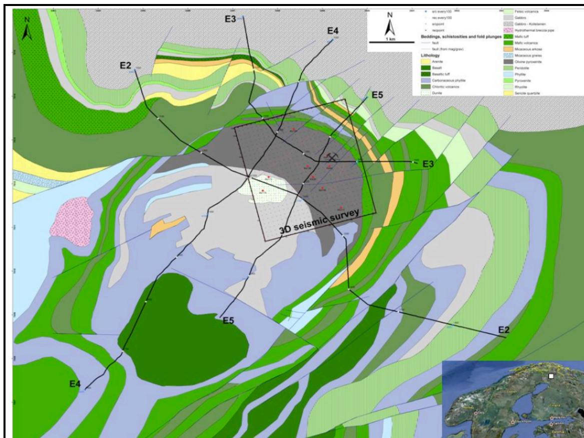

Figure 1: Geological map (modified from GTK) of the Kevitsa Ni-Cu-PGE deposit, showing locations of the previous 2D seismic profiles (E2-E5) and the 3D survey area (boxed area).

Kevitsa deposit and general geology

The Kevitsa deposit is located in northern Finland in the central Lappland, comprised of Paleoproterozoic basement gneisses, greenstone belts and major igneous intrusions. At about 2.05 Ga, igneous activity generated a series of layered intrusions, one of which, the Kevitsa intrusion, hosts the Kevitsa deposit (pers., comm., Tapani Mutanen, 1997). The Kevitsa intrusion is an oval shape intrusion oriented NE-SW with long axis of 7 km (Figure 1). The bedrock geology comprises mafic to ultramafic rocks, including olivine pyroxenite, peridotite, gabbro and granophyre. The intrusion is characterized by internal layering defined by changes in composition resulting from successive pulses of magma and not simple differentiation of a single pulse.

Mineralization in the Kevitsa deposit occurs within an olivine-pyroxenite zone of the Kevitsa intrusion, which contains up to 5% sulfide, the majority of which is found as granular masses interstitial to the silicate mineral crystals. The silicate mineralogy is predominantly composed of olivine and orthopyroxene with finely disseminated sulfides. The sulfides comprise pyrrhotite (manily), pentlandite, chalcopyrite, troilite and pyrite. Other copper and nickel sulfides include cubanite, millerite and heazlewoodite, with minor associated gold, cobalt and PGE concentrations (pers. comm., KMOY geologists).

Data acquisition and processing

Prior to the 3D data acquisition, the Geological Survey of Finland through a nation-wide seismic program, the HIRE project, acquired four short (each about 4-6 km long) high-resolution seismic profiles (Figure 1). The 2D seismic profiles successfully allowed imaging general structures of the Kevitsa deposits. In order to image the very shallow structures (< 1 km) of the deposit for mine planning and potentially to find new targets for detailed exploration and increasing the mine-life, a 3D seismic survey was conducted over an area of about 9 km^2 in winter 2010. Using two recording systems (a Seistronix, operated by HiSeis and a Sercel 408, operated by Uppsala University) with a joint capability of recording of up to 1000 channels, nearly 3000 shot points were fired using an hydraulic hammer.

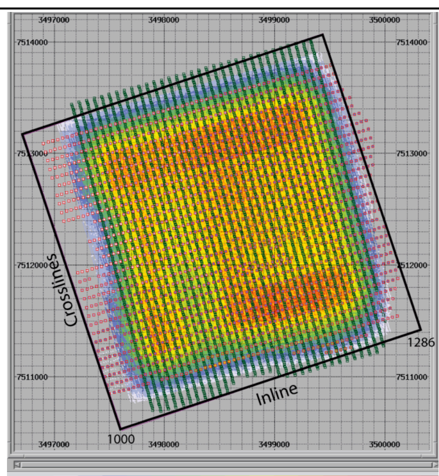

Figure 2: CDP fold coverage, shots and receiver locations of the Kevitsa 3D survey.

Each shot point consisted of three sweeps which were decoded and stacked together during the data processing to increase the S/N (Park et al., 1996). In areas with no source accessibility, an explosive source was used to increase the fold. The 3D survey area was divided into 9 swaths. The swaths were advanced in the following way: when moving north the receiver lines were overlapped by 50% while when moving east shot lines were overlapped 50%. In that way a uniform and smooth coverage was achieved. Receiver and source spacing were 15 m and 45 m, respectively. In total 35 receiver lines each 70 m apart and 34 source lines each 80 m apart were used to allow a nominal receiver and source density of about 800 and 400 per square kilometer to be achieved, respectively (Figure 2).

Significant effort was made into the decoding of the seismic sweeps. Noisy and low-quality sweeps were rejected during the decoding. The seismic data are generally good to excellent with strong reflections occasionally observed in a few raw shot gathers. Prior to the main processing work, a series of tests was conducted to obtain an optimum CDP bin size. First, seismic data were binned using a 15 by 15 m bin size to quickly evaluate the data quality in the resulting seismic cube. Later, in order to increase the seismic resolution, the bin size was reduced to 10 by 10 m, leading to an average fold coverage of about 60 in most part of the seismic cube, except at its margins (Figure 2). The main contactor performed the steps mentioned above.

Key processing steps

Several recent seismic data processing studies suggest that a prestack DMO and poststack migration algorithm can be useful in imaging complex structures of major mining areas and allow diffractions to be preserved that might originate from faults or smaller bodies like mineralization zones (e.g., Adam et al., 2003; Urosevic et al., 2005; Malehmir and Bellefleur, 2009). We used this strategy for the processing of the data. The key processing steps prior to stacking the data involved:

- Geometry check, trace editing and polarity reversal
- Ambient and coherent noise attenuation
- Refraction and residual static corrections
- Velocity analysis
- NMO and DMO corrections.

Figure 3 shows an example shot gather recorded into two receiver lines after various processing steps. Frequency and surface-consistent deconvolution filters were designed to obtain the highest frequency content with useful signal. Surface consistent spiking deconvolution using a 100 ms operator length helped to improve resolution and to compensate for the effects of variable coupling conditions due to source and receivers being placed on exposed bedrock or overburden.

Obtaining good refraction static corrections was demanding due to the high topographic relief combined with highly fractured and broken rocks near the surface. A careful inspection of a few shot gathers with clear refracted arrivals allowed us to identify two thick (about 80-120 m) low-velocity zones in the area. The identification of these refractors along with a series of geotechnical boreholes were helpful in examining and validating the estimated refraction static model. The 3D refraction static corrections were estimated using nearly 2,500,000 first arrivals automatically picked, but manually inspected. Resulting source and receiver static corrections including the effects of large topographic variations, varies from 0 up to 80 ms. Near-surface travel time distortions were largely removed after applying refraction static corrections and the coherency of reflections were markedly improved (Figure 3).

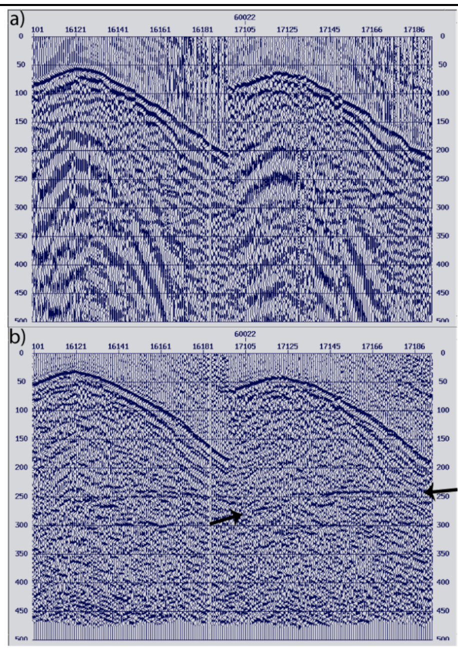

Figure 3: An example shot record (shown for two reciver lines) before (a) and after (b) various processing steps. Note the increase in the signal quality in (b) and specially the reflection marked by the arrows.

The stacked volume is highly sensitive to lateral and vertical velocity changes. An extensive wealth of borehole sonic seismic data in the study area already suggested a large velocity variation in the bedrock ranging from 5300 m/s to as high as 7400 m/s (Figure 4). To obtain an optimum velocity function, we ran a series of iterative velocity analyses, interactively controlled by inspecting stacked velocity panels. Before DMO corrections, surface-consistent residual statics were estimated using only NMO corrected gathers. DMO corrections were applied to obtain a dip-independent stacking velocity. This improved the continuity of dipping reflections and successfully allowed us to image a series of diffraction type signals by increasing the signal-to-noise ratio and simultaneously imaging crossing seismic events.

Preliminary results and interpretations

Figure 5 shows two time-slices through the unmigrated seismic cube at 150 and 200 ms, respectively. The time-slice at 150 ms clearly shows a series of parallel reflections that are crosscut by a set of reflections of a different orientation. A curved shape seismic signal in the middle of the time-slice seems to be a diffraction with a controlled scattering directivity towards the southwest. Similar to the time-slice at 150 ms, the time-slice at 200 ms also shows a series of parallel reflections in the northwestern part of the cube crosscut by a series of almost northwest-southeast striking reflections. A bright-spot seismic anomaly in the southeastern part of the seismic cube attracts immediate attention and might be a potential target for further investigations. Since the seismic data is not yet migrated, at this stage neither the relationship between these reflections nor their true geometry is clear.

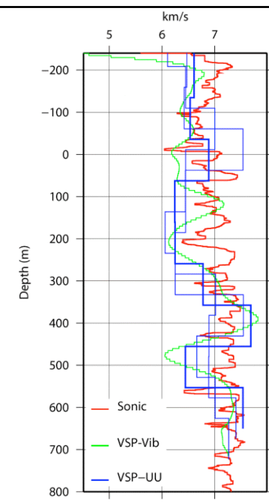

Figure 4: Sonic and VSP data indicate a large velocity variation within the bedrock in the Kevitsa area.

Figure 6 show two unmigrated crossline sections clearly indicating complex geological structures at this location with reflections with various dips and a strong diffraction at about 300 ms.

Conclusions

Reflection seismic results from the Kevitsa Ni-Cu-PGE demonstrate that the complex structures and fault systems of the study area can be successfully imaged at depths as shallow as 200-300 m. The seismic cube and images of the reflections and their correlation with borehole data will be useful for designing the Kevitsa open-pit. There are several high-amplitude anomalies observed at depths between 600-1000 m, which are recommended for further investigations for their mineralization potential. If further exploration is successful, these would place the Kevitsa seismic work at the forefront of using 3D seismic methods for advanced exploration of deep-seated mineral deposits in Europe.

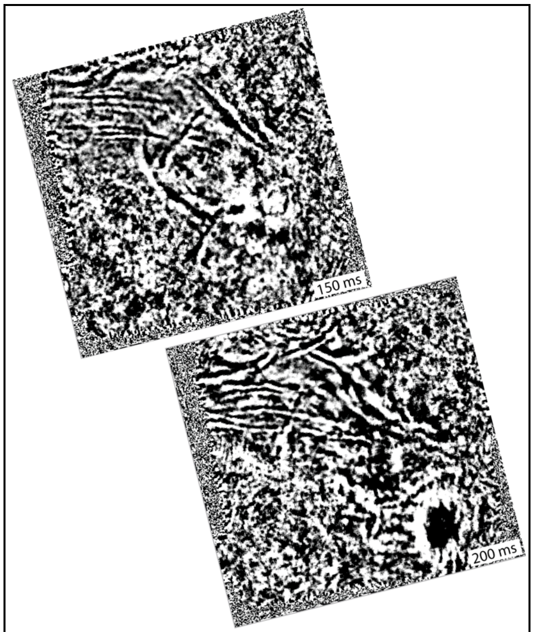

Figure 5: Unmigrated time-slices at 150 ms (a) and (b) 200 ms, showing cross-cuting reflections and a strong curved shape event in the southeastern part of the cube.

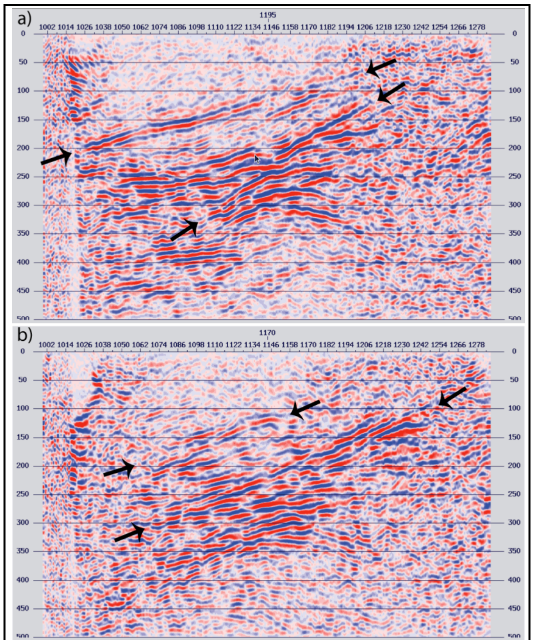

Figure 6: Unmigrated crosslines (a and b) in the eastern part of the seismic cube, clearly showing a series of gently and steeply dipping reflections and even diffractions.

Acknowledgments

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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