3D Seismic Surveying in Kevitsa Open Pit Mine

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SUMMARY

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. About 1000 active receivers and 3000 shots in nine overlapping swaths were used to acquire the data. 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. Geological structures are complex and a varying thickness of overburden combined with various weather conditions during the data acquisition pose the data processing very challenging. However, a careful processing design combined with our experience on this type of data helped to produce interesting results. Processing results suggest that the 3D seismic survey has been successful in imaging both gently dipping and steeply dipping reflections as shallow as about 150 m, many of which correlate with fault systems and lithological contacts observed at the surface. Several new target areas, bright spots, are identified in the seismic data that require further investigations for their mineralization potential.

Key words: 3D reflection seismic survey, open pit mine, Kevitsa

INTRODUCTION

During the winter 2010, a 3D reflection seismic survey was carried out in an area that is about to become Kevitsa open pit mine for nickel, copper and PGE metals to be opened during 2012 in Northern Finland (see Figure 1). The aim of the survey was partly to determine geological structures such as faults, shear and fracture zones which have to be taken into account while planning excavation and partly to assist in drilling targeting. The final result is presented as a seismic volume, which can be sliced in any given direction to correlate data with geology.

Three kinds of sources were utilized in the field; smaller and heavier hammers (VIBSIST) and conventional explosives. Winter 2010 had quite varying conditions from freezing to slush and this posed problems especially for the smaller VIBSIST source to obtain a proper coupling with ground. While heavier VIBSIST source did result better coupling by far best results were given by dynamite that was used in swamp areas.

Reflection survey tends to give information of horizontal or gently dipping structures. Steep structures are not likely to produce reflections strong enough to be captured and that is why also a Vertical Seismic Profiling (VSP) was carried out in one of the deep drill holes inside the survey area (Cosm *et al.*, 2010). Sonic logs were obtained for several drill holes to give in situ velocity information to be utilized in time to depth conversion.

After exhaustive processing first by field operator following by the work of Uppsala University, finally a 3D seismic cube was produced a year after starting the project. A viewing session with 3D projector was arranged and cube was correlated against several geological and geophysical datasets. Several structures were recognized and new drilling targets to be tested while writing this article were obtained. And this is only beginning of the story as the cube will be tested again and again against new information as it is gathered when excavation proceeds and new drill holes are drilled.

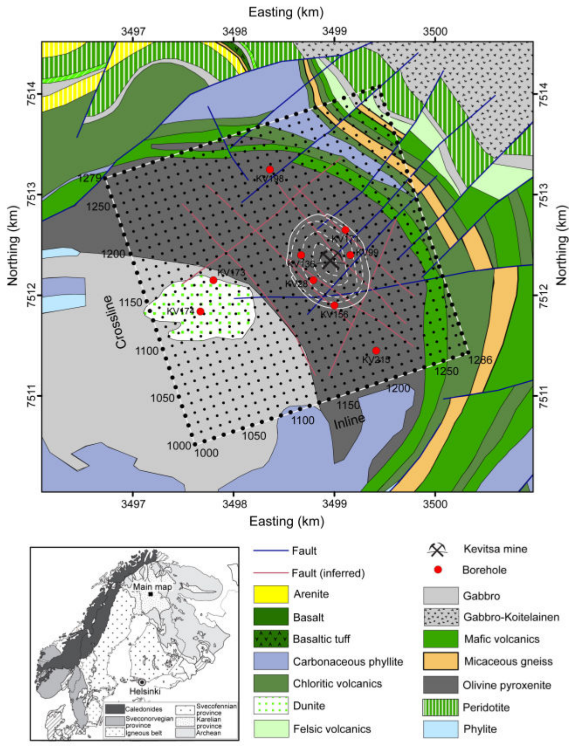

Figure 1. 3D survey area and geological map of the Kevitsa open pit mine in the municipality of Sodankylä, Northern Finland (about 160 km from Polar Circle to the North. Figure from Malehmir et al., (2011).

METHOD AND RESULTS

The survey are was acquired between February and April 2010, in challenging and changing weather conditions with temperatures ranging from -40 degrees centigrade (freezing) to +8 degrees centigrade (melting). The survey was completed in about two months, which included 9 standby days, due to extreme weather conditions such as very low temperature (below –30), excessive wind or snow, or combination of the these elements. The 3D survey contains 3,057 shot points. The survey employed a shot point spacing of 45 m, a shot line spacing of 80 m, geophone spacing of 15 m and geophone line spacing of 70 m. Survey design served the aim to maximize fold in open pit area. Table 1 summarises survey details (Williams *et al.*, 2010).

Full fold area (higher than 30):	4.0 km^2
Acquisition Area:	8.4 km^2
Max. N – S Extent:	11.900 km
Max. W – E Extent	6.950 km
No of Rec. Lines:	33
Total Receivers:	6336
Total Rec. Lines Length:	93.6 km
Live Channels:	1056
Live Receivers Lines:	11
Live Channels per Rec. Line:	96
Receiver Interval:	15 m
Rec. Line Interval:	70 m
Nominal Rec. Density:	377.0 / km^2
Total (Fired) SPs:	2989
Total Source Lines Length:	80.0 km
Nominal SP Density:	377.0 km^2
No of Source Lines:	30
Total Number of Sources:	2989
Source Interval:	45 m
Source Line Interval:	70 m
Bin Size:	10 m x 10 m
Nominal Fold:	60
Record Length:	3 sec.
Sample Rate:	1 msec.
Seismic Source: explosive	VIBSIST or

Table 1. Survey design details. Source: Williams *et al.*, 2010

Two acquisition systems, Seistronix, operated by field operator and Sercel 408 operated by personnel from Uppsala University (Sweden), were simultaneously used to record seismic data.

After assigning the 3D cube geometry and editing bad traces, picking of the first arrivals took place. Nearly 2,500,000 first arrivals were picked using first an automatically designed algorithm and then later manually inspection and correction where needed. Refraction static corrections were calculated using two approaches. First, a one-layer model with varying velocity (between 1000-3000 m/s) and depth was used, and then later a one-layer model with a fixed velocity (1800 m/s). The resultant statics were not significantly different, however, in a few places (mainly at the lower inlines) improvements were observed using a fixed velocity model. After the calculation of the refraction static corrections, the following main processing steps were applied on the shot gathers:

- Application of refraction static corrections,
- Elevation static corrections using a floating datum of 290 m and a replacement velocity of 5500 m/s,
- Band-pass filtering (20-35-150-170 Hz),
- Spectral balancing (20-30-140-150 Hz),
- Surface-consistent deconvolution (10 ms gap),
- Band-pass filtering (20-35-150-170 Hz),
- Residual static corrections (two pass).

Refraction static and surface consistent residual static corrections helped markedly to improve the quality of the shot record. Frequency and surface-consistent deconvolution filters were designed to preserve the highest frequency content with useful signal. Although optimistic, frequencies as high as 150 Hz were kept in the data. VSP data suggests that the frequency band to be between 20-135 Hz (Malehmir, 2011). Spectral balancing followed by surface-consistent deconvolution in both source and receiver domains helped to attenuate source-generated high-amplitude noise and to compensate for the effects of variable coupling conditions caused by the sources and receivers being placed on exposed bedrock, or overburden, or on compacted snow. No strong shear-wave and ground roll is observed on the data after the implementation of the band-pass filtering and surface-consistent deconvolution. The remaining source-generated noises (and in parts VIBSIST ghosts) appeared to stack destructively during the stacking procedure, thus, no further treatment were carried out.

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 7300 m/s. 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 (Malehmir, *et al*., 2011).

Based on indications provided by the existing sonic logs and VSP data, a 1D-velocity model was created which is 5800 m/s at 0 ms, 6400 m/s at 100 ms, 7200 m/s at 300 ms, and 7400 m/s at 1000 ms. This velocity model used for the migration. The migrated cube has obviously less reflections than if slower velocities were used as a majority of the reflections are steeply dipping and are located outside the edge of the cube (they migrate out), however, remaining reflections are stronger and cross each other less. At this stage, time-to-depth conversion was performed using a similar 1D-velcity as used for the migration. The shallowest reflection in the cube is found at about 210 m below the floating datum (290 m) in the north-eastern part of the cube. Assuming an average elevation of 230 m in the study area, this would place the first clear reflection at a depth of about 150 m (Figure 2).

While it is not possible to be specific here, we were able to correlate successfully many of the geological and geophysical datasets with the 3D seismic volume and new fault candidates and bright spots were recognized. The pit area is not as reflective as areas below and surround it and strongest reflections seem to originate from the bottom of the pit, at depth of about 450 m. The reason for this lack of reflectivity is not fully known. Is this mainly due to geology or survey setting, can be debated. Pre-stack time or depth migration might improve the near surface resolution and is under consideration.

processing of 3D

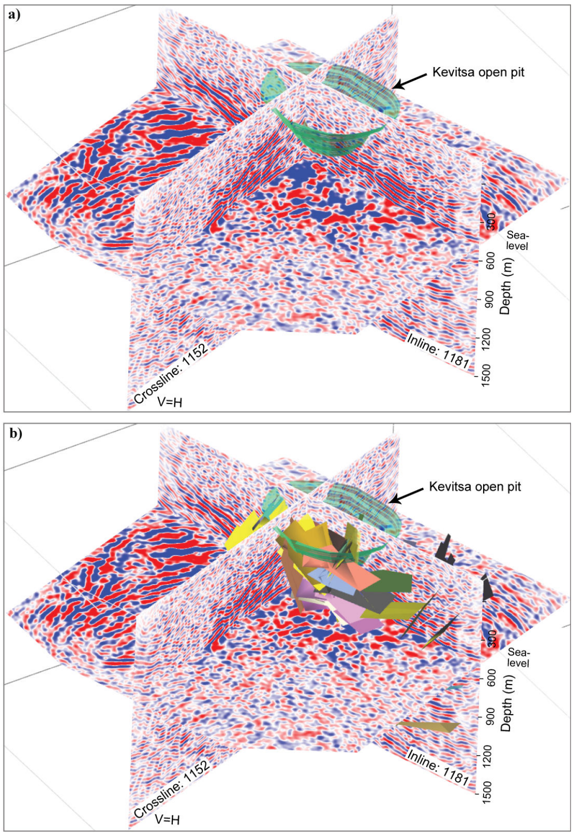

Figure 2. 3D views (a and b) from the migrated and time-to-depth converted 3D volume integrated with the surfaces obtained from VSP data. Pit is marked by green colour. Figure is from Malehmir et al. (2011).

It is worth mentioning that the process of utilizing the seismic data for open-pit mine planning has only begun. To our knowledge, the Kevitsa 3D surface seismic data is today the first as such and will motivate mining companies to implement this state-of-the-art technology, that has been used for the past three decades for hydrocarbon exploration and reservoir monitoring, in their prospects and mine development. As the Kevitsa mine starts operating and at some stage, we will "mine the reflections" and actually see (hopefully) the rocks causing the reflections and we will gain knowledge on continuous basis. In addition, the ongoing drilling conveys more information to be contrasted with the cube. New target areas, seismic bright spots, will be drilled and would allow to provide knowledge about the nature of reflections and a methodology for automatic identification of highest potential targets for mineralization at depth. New sonic and VSP measurements are under consideration to improve near surface velocity information.

CONCLUSIONS

3D reflection seismic survey was conducted in order to assist in mine excavation planning and create more understanding of pit geology. In case of Kevitsa, the process of utilizing the collected dataset although preliminary indicates that known geological and geophysical datasets correlate well with seismic data and new structures could be deciphered. Results are so far preliminary but promising and will be tested by both excavation and drilling during the coming years.

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