New constraints on an existing mineral resource through 3D seismic

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SUMMARY

The Kevitsa nickel-copper deposit in northern Finland is a large, low-grade, mafic-hosted accumulation of disseminated sulphides with rare, spatially restricted occurrences of net-textured to semi-massive sulphides. The mineable limits of the resource grow or shrink with commodity prices, but it has also been recognised that subtle mafic layering in the intrusion controls sub-horizontal layering of sulphides. The net-textured and semi-massive mineralisation styles occur near the base of the intrusion. Data from a 3D seismic survey demonstrate the unpredicted ability to image the sub-horizontal mafic layering, as well as the expected reflections at the base of the intrusion in contact with interlayered volcanic and sedimentary country rocks. The ability to trace the lateral extents of the mafic layering, backed up by analysis of borehole sonic and density logging, offers the possibility to predict the ultimate envelope of the resource. The interpretation of the base of the intrusion provides a horizon along which to target the net-textured to semi-massive contact mineralisation.

Key words: 3D seismic, resource definition, nickel, copper, Kevitsa.

INTRODUCTION

Seismic surveys represent a growing option in the mineral exploration and mining industry for accurate information at depths beyond the reach and resolution of more traditional surface geophysical techniques. The Kevitsa nickel-copper deposit in northern Finland (Figure 1), hosted in a mafic intrusive, has a planned ultimate pit depth of 550 m. In order to obtain high-resolution structural information to help plan the pit design, regarding rock stability in consideration of fault zones, a 3D surface seismic survey, complemented by a single-hole VSP and sonic logging of 12 deep holes, was undertaken in early 2010 ahead of any mine development work. The data are also being used for resource definition and expansion. In this low-grade (0.3% Ni, 0.41% Cu), disseminated deposit, the remaining exploration mandate is to find pockets of higher-grade mineralisation within the resource area. These occurrences are so far classified as "contact mineralisation" occurring at or near the base of the Kevitsa intrusion.

The understanding of the geological controls on mineralisation was propelled forward in 2009 with the recognition of subtle mafic stratigraphy within what had previously been logged as a uniform, altered metaperidotite. Higher sulphide content, and grade, follows the bases of these mafic layers, which mostly alternate between olivine pyroxenite, websterite, and plagioclase-rich websterite. With this recognition, resource drilling expanded laterally rather than vertically, and the Kevitsa resource (including inferred) was quickly doubled from 141 Mt in 2008 to 275 Mt in 2010. While the 3D seismic data have been interpreted for fault architecture, they also image the mafic layering, providing a tool for predicting lateral continuity of mineralisation, and, ultimately, the extent of mineralisation equalling the extent of the mafic layering. Furthermore, high impedance contrasts, and stratigraphic discordance between the Kevitsa intrusion and surrounding country rock, lend themselves to an interpretation of the base of the intrusion that can guide the search for higher-grade contact mineralisation.

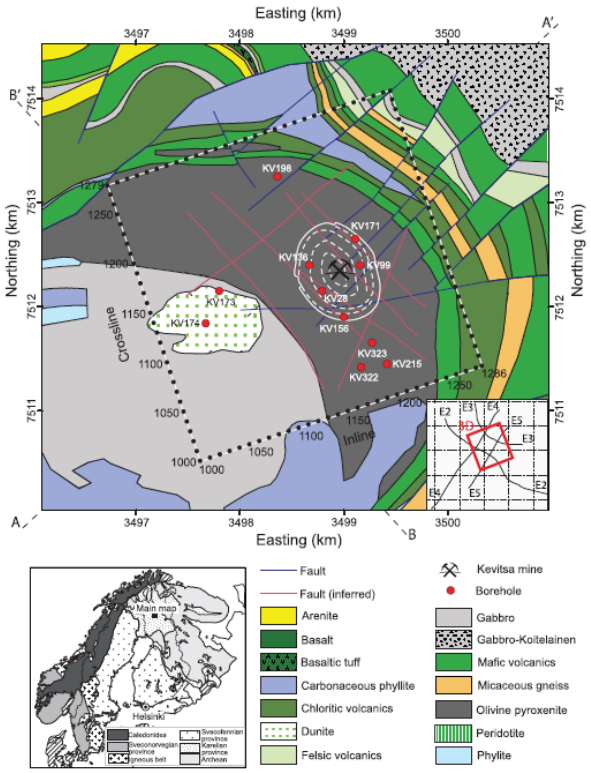

Figure 1. Area of 3D seismic survey over geology, with ultimate pit outline and sonic logging holes. Inset shows 2D seismic lines and bottom map shows location in northern Finland. Figure from Malehmir et al. (2012).

The seismic interpretation has benefitted from extensive petrophysical logging, including the 12 sonic holes, high-resolution surface magnetic and gravity surveys, seven MT lines, airborne EM, and nearly 1000 diamond core holes.

METHOD AND RESULTS

The 3D reflection seismic survey, carried out in the Finnish winter of 2010, was designed to provide imaging capabilities to about 2 km, and to elucidate the fault architecture over the resource area, particularly with respect to the ultimate pit design. Malehmir et al. (2012) provide the full details of the acquisition and processing parameters. Source lines were spaced at 80 m and perpendicular receiver lines at 70 m. Source stations every 45 m and geophone groups every 15 m resulted in a fold of 60-75 over all but the margins of the survey area. The survey was extended considerably further west of the planned pit in order to capture what was at the time interpreted as a preponderance of west-dipping faults (Figure 1). The source was mostly a hydraulic hammer (Vibsist-3000, Cosma and Enescu, 2001) supplemented by explosives in swampy areas inaccessible to the tractor-mounted hammer (even in winter, due to incomplete freezing).

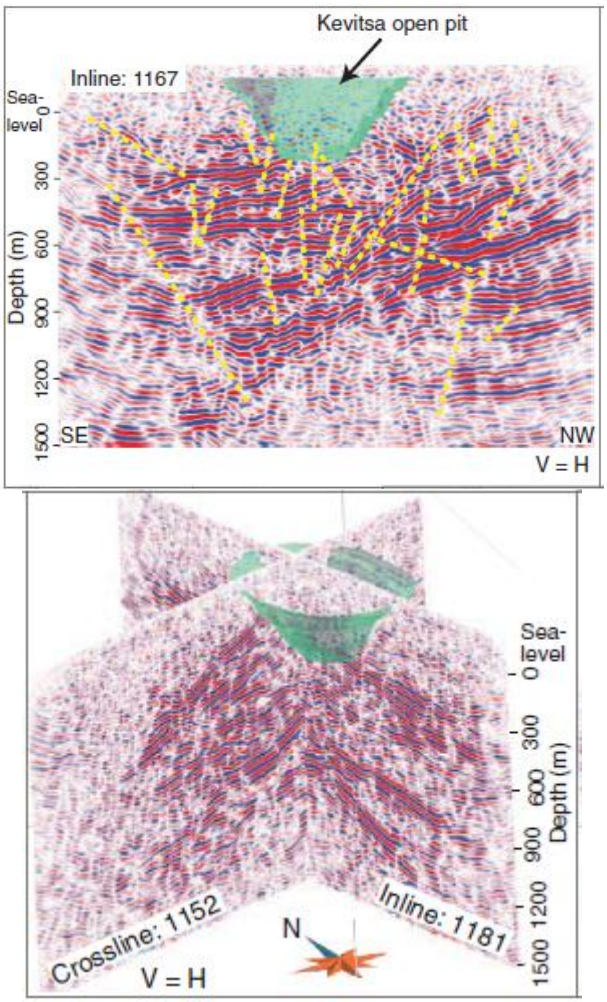

Figure 2. (top) Cross section of seismic amplitude with yellow dashed lines showing the positions of VSP reflectors. The strong correlation of VSP reflectors with terminations and phase shifts in the 3D cube reinforces the interpretation of faults via these features. (bottom) 3D view illustrating the reflectors internal to the intrusion and their lateral extents, which may provide the ultimate boundaries to the mineral resource. Figure from Malehmir et al. (2012).

The dominant frequency of the seismic data is about 60–80 Hz. The single VSP near the middle of the survey, down to 915 m below the surface, provides the 1D velocity model used so far for processing the 3D data. The average velocity is about 6500 m/s, so using the Rayleigh quarter-wavelength criterion of Widess (1973), the vertical resolution is about 20–30 m, implying that layers thinner than this will not be correctly resolved within this depth interval. However, thin layers of as few as 2–3 m and some lateral continuity should be detectable if signal-to-noise ratios and the impedance contrast are sufficiently high. Thus fault zones (2-3 m) should in theory be imaged to within 20-30 m of their correct position.

Prior to the survey, predictions for the intrusion were of a seismically featureless zone in contrast to the multiple reflections expected from the interlayered volcanics and metasedimentary host rocks. Figure 2a contains an inline cross section that illustrates the unpredicted imaging of sub-horizontal reflectors attributed to the mafic stratigraphy within the intrusion. Phase shifts and terminations along these laterally continuous reflectors form the basis for fault interpretations, rather than the rare case of reflections off faults themselves from long offset shots. The good correlation of sub-vertical VSP reflectors with such phase shifts and terminations lends strong support to this interpretation method. The clearly imaged lateral extents of the mafic layering, particularly to the west as shown in the 3D view of Figure 2b, are not due to a drop-off in fold. Furthermore, west of the resource area, drillholes intersect only homogeneous olivine pyroxenite, with none of the websterite and other layers encountered within the mineralisation. This reinforces the interpretation of the stratigraphic reflectors and the idea that their extents may mirror the extents of any ultimate resource area, thus providing bounds on near-mine exploration.

The reflective character of the internal stratigraphic interfaces need not have been a surprise, as the impedance contrasts from post-survey sonic logging analysis are great enough to cause reflections. Figure 3a shows the average P-wave velocity versus density for the various Kevitsa lithologies, compiled from the sonic logging. Lithological units sitting on different iso-impedance curves should be capable of causing reflections. The actual spread of data for each lithology is quite large (Figure 3b), and this arises from the variation across one mafic layer due to the grain size and sulphide content factors described above. At the boundary between two such layers, the grain size and mineralisation changes should actually be greatest, so the impedance contrasts will rise above the averages of Figure 3a.

Mapping the base of the intrusion against the country rock was an original goal of the 3D survey. Figure 3a illustrates the large impedance contrasts between the intrusion rocks and the metavolcanics, metasediments, and black schists of the country rocks. The country rock units all display very similar impedances, yet the reflectors outside the intrusion are many and strong. They are also discordant to the base of the intrusion, which fact was unknown before the 3D survey results were available. This facilitates the job of tracing the intrusion contact, whether as a reflector in its own right, or as a boundary between discordant reflector dips. Figure 4 shows the base of the intrusion interpreted from both the 3D cube and 2D lines, constrained by all drillholes crossing into country rock. This surface now provides a focus for

exploration for the higher-grade contact mineralisation, via the identification of both discrete, high-amplitude seismic reflectors, and conductive anomalies from the MT or shallower AEM data, in proximity to the basal surface.

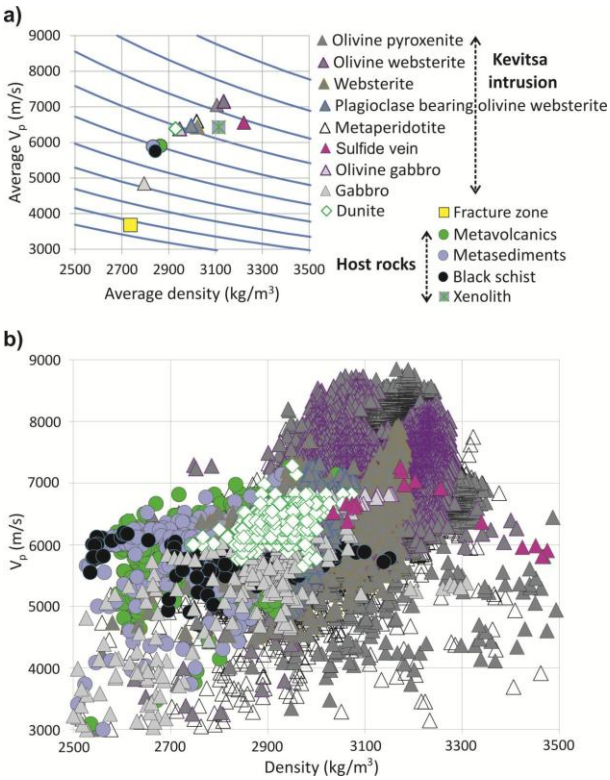

Figure 3. (a) Average P-wave velocity versus density for Kevitsa lithologies, measured in 12 drillholes in the study area. Blue lines represent lines of constant acoustic impedance. The difference between two sets of lines should be enough to cause a reflection at the contact between two lithologies. These data explain the reflections obtained internal to the intrusion, caused by mafic layering. (b) Full spread of velocity versus density. Figure from Koivisto et al. (2012a).

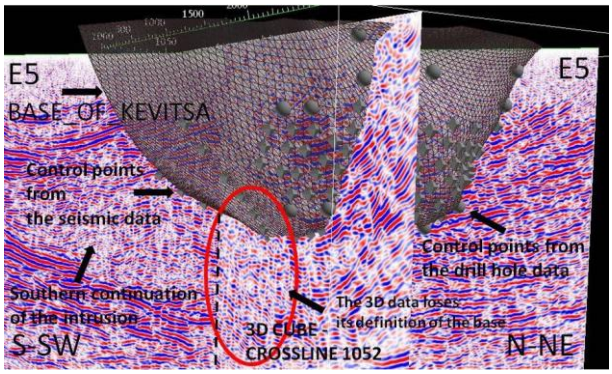

Figure 4. Interpreted base of the Kevitsa intrusion with 2D and 3D data. In the north-northeastern and eastern parts of the intrusion the base is mostly defined by disruption of the reflectors internal to the intrusion. Toward the south the 3D data loses its definition of the base. Grey balls represent drill control points. Figure from Koivisto (2012b).

CONCLUSIONS

Results of the Kevitsa 3D seismic survey have upheld the original intent of imaging the fault geometries, albeit more through interpretation of offsets and terminations to reflectors, rather than as reflectors themselves. This has been possible due largely to the imaging of sub-horizontal mafic layering within the intrusion, made possible by the combination of subtle lithological changes and variation of grain size and sulphide content. This mafic layering, recognised as a control on sulphide distribution, can be traced to its lateral boundaries and offers an estimate of the ultimate extent of the mineral resource. The interpreted faults provide hard boundaries for modelling mineral domains within the resource, where ambiguity exists between drillholes. Finally, the interpretation of the base of the Kevitsa intrusion, constrained by a small number of holes, yields a surface around which to focus the search for contact-style, higher-grade mineralisation.

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REFERENCES

Cosma, C., and Enescu, N., 2001, Characterization of fractured rock in the vicinity of tunnels by the swept impact seismic technique: International Journal of Rock Mechanics and Mining Sciences, 38, 815–821.

Koivisto, E., Malehmir, A., Heikkinen, P., Heinonen, S., and Kukkonen, I., 2012a, 2D reflection seismic investigations at the Kevitsa Ni-Cu-PGE deposit, northern Finland: Geophysics, 77, WC149–WC162.

Koivisto, E., 2012b, Kevitsa 3D lithological model from the 2D and 3D seismic data: Internal Report to First Quantum Minerals, Sept. 2012.

Malehmir, A., Juhlin, C., Wijns, C., Urosevic, M., Valasti, P., and Koivisto, E., 2012, 3D reflection seismic imaging for open-pit mine planning and deep exploration in the Kevitsa Ni-Cu-PGE deposit, northern Finland: Geophysics, 77, 1–14.

Widess, M. B., 1973, How thin is a thin bed?: Geophysics, 38, 1176–118.