Can we use sparse 3D seismics in mineral exploration? Takeaways from COGITO-MIN project

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3D seismic surveys were first used in mineral exploration two decades ago, and many successful case studies have followed since then. Still, low signal-to-noise ratio, scattering of seismic waves, near-surface heterogeneities, rough terrain conditions are among the key challenges faced in this context. The COGITO-MIN project aimed at developing cost-effective geophysical imaging methods for mineral exploration. The study area was the Kylylahti polymetallic mine located in the Outokumpu mining district in eastern Finland. At Kylylahti, semi-massive to massive sulfide mineralizations are hosted in the multiply-deformed Outokumpu ophiolitic sequence. The complex geometry associated with the Kylylahti formation, with near-vertical contacts, constitutes a difficult target for surface seismic methods.

The original COGITO-MIN survey comprised two active 2D seismic lines and a dedicated 3D receiver grid for continuous passive recording. As a measure of cost-effectiveness, we used the same 3D receiver grid and the 2D sources with additional dynamite and Vibroseis shots to complement our active 3D survey. A total of 738 shots (mix of dynamite and Vibroseis) recorded by 994 receivers with 50 m receiver interval and 200 m line spacing resulted in a 3D seismic dataset with sparse and irregular source pattern over an area of 10.5 km^2. We investigated three different approaches to produce final stacks in the time domain: NMO stack, DMO stack followed by a constant-velocity post-stack migration and pre-stack time migration. All approaches resulted in unsatisfactory results down to the target depth of ~1500 m. The reflectivity is sparse and incoherent, however there is a general increase of reflections in the Kylylahti formation.

Subsequently, we tried various approaches for pre-stack depth migration (PreSDM). The velocity model for imaging was built by first-arrival traveltime tomography using two different approaches. In the first approach we performed tomography with the original first-arrival picks, and in the second case we corrected the picks by the same refraction statics as applied during data processing in order to account for the near-surface weathering layer. As expected, we obtained a smoother velocity model with better spatial ray coverage and a deeper depth extension with the second approach. Firstly, we run standard Kirchhoff pre-stack depth migration (KPreSDM), which produced a good image of the base of the mineralization-hosting Kylylahti formation, but the image was very noisy in other parts especially in the shallower section. As the condition of sufficient interference is never fulfilled in case of sparse acquisition, we employed a specialized KPreSDM approach (i.e. coherency-based Fresnel volume migration, CBFVM) which resulted in a much cleaner image of the shallow steeply dipping reflectors as well as some additional deeper reflectors.

In conclusion, depth-domain imaging of the sparse and irregular 3D seismic data acquired over a complex target performed much better in comparison to time-domain imaging. In particular, CBFVM was found superior, as an accurate emergence angle can be determined to back-propagate the wavefield and to restrict the migration operator to physically relevant parts (Fresnel volumes) around the specular reflection points. This procedure results in a focused image with less migration noise and artefacts due to the low coverage or limited aperture such as in our case.