M035

High Resolution 3D Tunnel Seismic Reflection at Olkiluoto, Finland

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SUMMARY

ONKALO is the underground rock characterisation built for the final disposal of spent nuclear fuel at Olkiluoto, Finland. Geology, geophysics, hydro-geology, geochemistry and rock mechanics contribute to bedrock studies conducted during repository construction to ensure the suitability of the bedrock for the final disposal. A high-resolution reflection seismic imaging pilot test was conducted in 2007, followed by a more ample survey in 2009. Lines 100m and 240m long were measured, with source stations spaced at 1m and receivers at 1m and 3m, respectively. Measurements in 2007 were conducted with a hand-held electro-mechanical source held against the tunnel wall. In 2009 a more energetic hydraulic source and was used on the tunnel wall and floor. Fractures were imaged several tens, respectively hundreds of meters from the tunnel. In 2007, the one-dimensional tunnel layout left a certain ambiguity regarding azimuth relative to the tunnel. The location of the target features was improved in 2009, by using 3-component receivers, two parallel source lines and 3D vector migration schemes. IP (Image Point) migration was found particularly useful for imaging narrow and roughly planar features of diverse orientations.

Introduction

POSIVA Oy conducts bedrock investigations at the spent nuclear fuel final disposal site at Olkiluoto, in eastern Finland. The purpose of these efforts, which include a significant R&D component, is to ensure compliance with the requirements set forth for the long-term safety of final disposal. The excavation of the access tunnel to the repository hosts the ONKALO underground rock characterization facility. The investigations carried out at ONKALO focus on the bedrock and groundwater conditions prevailing on the final disposal site and how construction work affects them.

The main objective of the seismic investigations presented here have been to demonstrate the possibility to detect, locate and image cost effectively steeply and gently dipping fractures, at the side and/or below the tunnel and to characterize the volume of rock surrounding a 250m long segment of the ONKALO tunnel.

Reflection and refraction seismic surveys along the ONKALO tunnel wall

Seismic Reflection Imaging of rock structures ahead and aside the tunnel was firstly tried in a 2007 pilot test using a 100 2-components receivers, spaced at 1m intervals along the tunnel wall at a depth of ~170m (*Figure 1*). Seismic signals were produced at 120 1m-spaced source locations. Refraction imaging was also done from two groups of 10 shots, recorded, at each side of the 100m long receiver array. A larger survey was conducted at a depth of ~350m in 2009, over a 240m long line of 3-components receivers, spaced at 3m intervals. Seismic signals were produced at 1m intervals along two lines on the tunnel wall and floor, 290 and 240 m long, respectively.

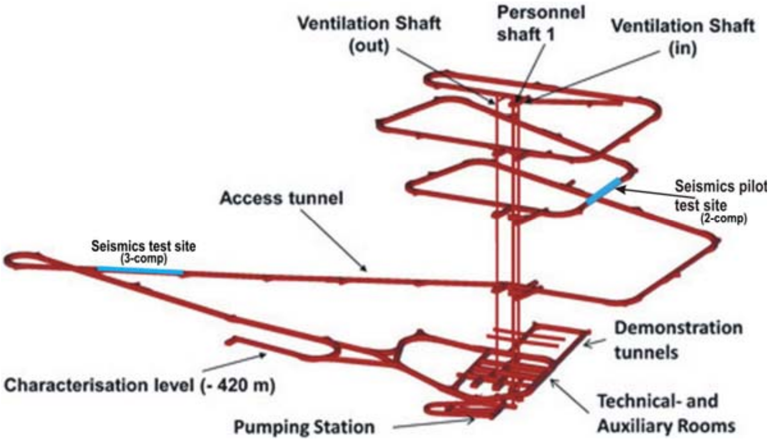


***Figure 1**. Location of the 2007 and 2009 seismic surveys (marked with blue lines) along the ONKALO tunnel at tunnel length (chainage) 1720 - 1820 m (vertical depth 170 – 180 m) and 3350 – 3600 m (vertical depth 330 – 360 m.*

A time-distributed swept-impact Vibsist-20 electromechanical source [Cosma, 2001] was used for the 2007 pilot test and a larger Vibsist-250 hydraulic source was used in 2009 (*Figure 2*). Impact sweeps of 15s were recorded on a Summit II seismograph and subsequently decoded to produce ¼ s seismic traces. With the pilot test, signals were also recorded from the percussion drill rig used for drilling the blasting holes for the tunnel excavation. Seismic signals generated by the drill rig were as good as those produced by the main seismic source (*Figure 3*). It was thence proven that blast-hole drilling can be used to produce seismic signals with penetration of more than 100m for measurements ahead of the excavation works. Greater signal energy and a penetration of ~300m was achieved during the 2009 survey, while the frequency content of the signals recorded remained comparable with the less energetic sources used previously (*Figure 3*).

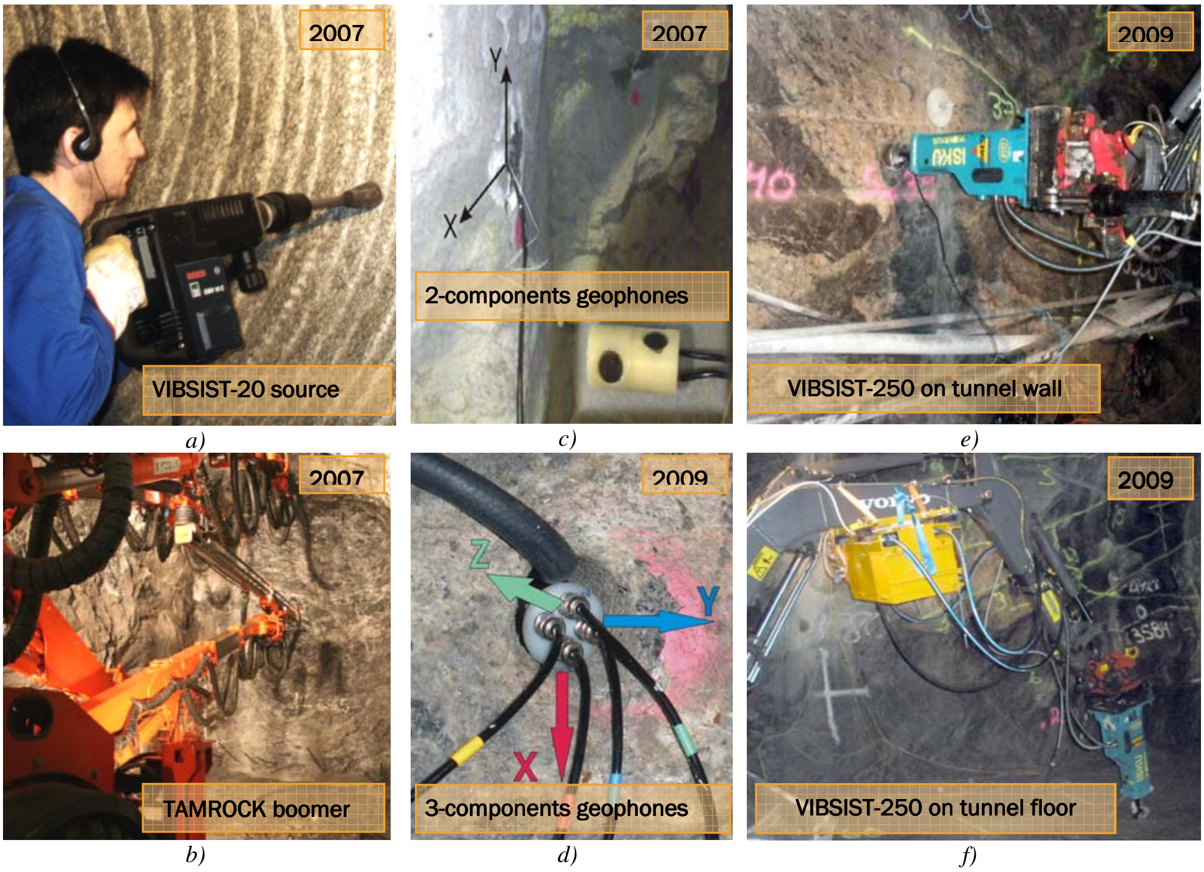


***Figure 2**. **(a)** The Vibsist-20 seismic source in the Onkalo tunnel, **(b)** a Tamrock boomer used as seismic source, **(c)** 2-components receivers installed in the wall for the 2007 pilot test, **(d)** 3-components receivers installed in the wall for the 2009 survey, **(e)** the Vibsist-250 seismic source on the tunnel wall* and ***(f)** on the tunnel floor.*

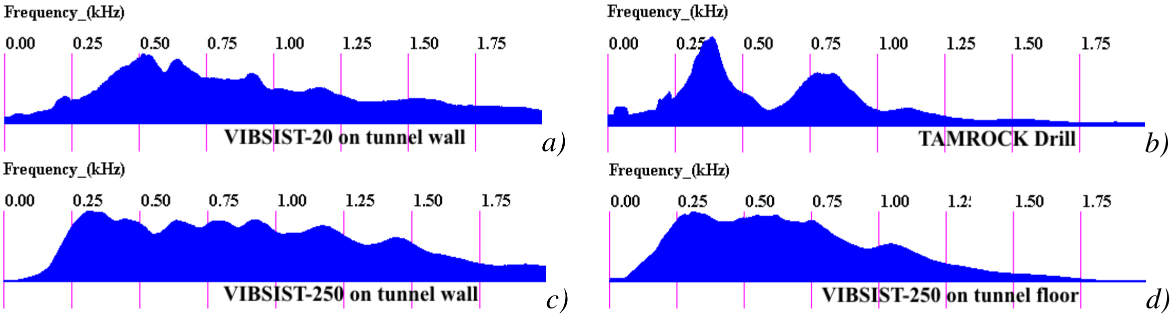


***Figure 3**. Average frequency spectra of data recorded with the Vibsist-20 **(a)** and the Tamrock boomer **(b)** in 2007 and with the Vibsist-250 on the tunnel wall **(c)** and tunnel floor **(d)** in 2009.*

3D Kirchhoff vector migration and 3D Image Point migration [Cosma, 2010] algorithms were used to create migrated sections where several reflectors could be identified and interpreted. The defining property of the Image Point (IP) migration method is its ability to accumulate reflection events in time distance and/or 2D/3D migrated data sets into points in the IP domain (*Figure 4*). This opens the way to a wide variety of filters, which increase significantly the resolution and the interpretability of the migrated images. Due to this defining property, coherency enhancement in the IP space is reduced to a scheme of point cluster building. Therefore, reflections from segments of planes with transverse dimensions larger than a few wavelengths are enhanced while incoherent noise, migration artefacts and coherent patterns due to other wave types and multiples are suppressed.

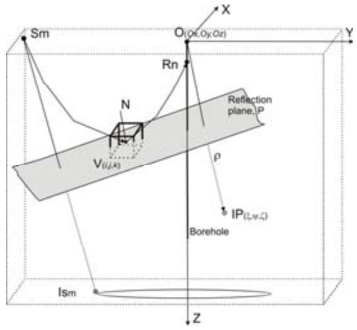


***Figure 4**. Principle of the 3D IP migration [Cosma, 2010]. The wave front produced at the Source S_m is reflected at point V before reaching the receiver R_n. The orientation of the reflector P at point V is uniquely determined by the source - receiver geometry and the velocity field. The planar reflector P is in turn uniquely associated with the point IP, defined as the reflected image of the origin O on the plane P.*

Results

For the pilot test data P- and S-wave first were picked and used to reconstruct refraction the P and S wave velocity tomograms [Cosma, 2009]. Tomograms of Young's modulus and Shear Modulus were also computed, using a local density model derived from the available geological data [Cosma, 2009]. The values obtained for the dynamic parameters are well within the typical range known for the Olkiluoto bedrock. Lower velocity is observed near the tunnel wall, but resolution from tomogram alone is not adequate for further interpretation. Also, some variations of velocity can be observed within the rock mass, ~10m away from the tunnel wall. The seismic profiles were processed by the IP migration technique to produce horizontal (P-) and vertical (S-) reflection profiles. The near-field (~100m depth) images are shown in *Figure 5*.

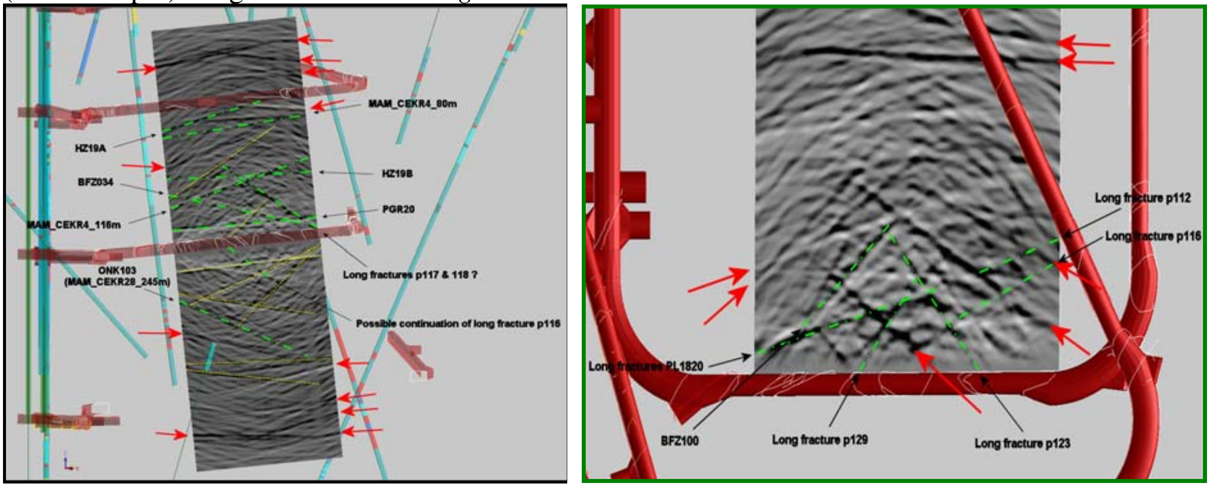


***Figure 5**. Synopsis of interpretations of the tunnel seismic images. **a)** The seismic reflection image above or below the tunnel and all geological, geophysical or hydrological features detected in the data (green = explained reflector, yellow = reflector explained on the other side of the tunnel and red arrow = unknown reflector). View to the NE. **b)** The seismic reflection image to the NE of the tunnel and all geological, geophysical or hydrological features detected in the data. View from above.*

Figure 6 shows a horizontal and a vertical-down IP migrated panel. Weak smiling artefacts are visible due to the wide aperture (-90/+90). Most features are roughly linear and continuous rock structures.

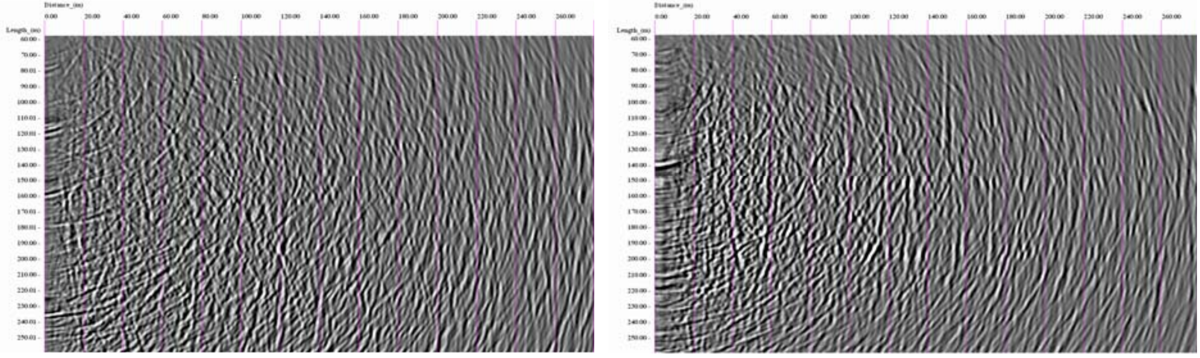
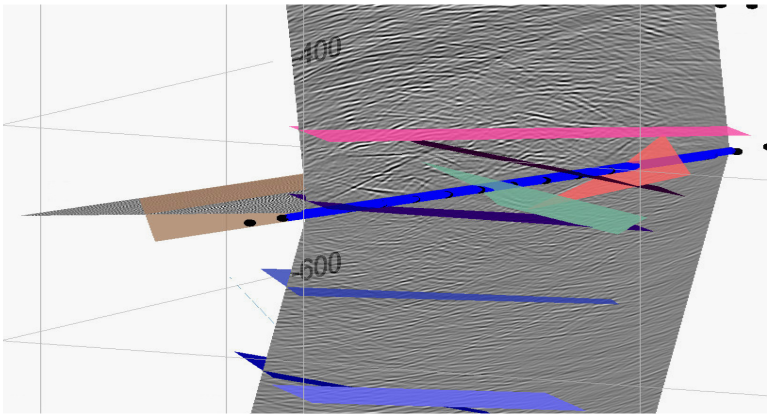


***Figure 6**. IP migrated sections obtained from the two lines measured in 2009, **(left)** horizontal plane, with source on the tunnel wall and **(right)** vertical plane, with source on the tunnel floor.*



Oriented migrated panels are also shown in perspective in *Figure 7*. The coloured rectangles mark intersections predicted by vintage VSP data.

Figure 7*. 3D IP migrated sections obtained from the line on the wall measured in 2009, at different orientations around the ONKALO tunnel.*

Conclusions

A general conclusion is that seismic surveys along the tunnel can be used, economically, for rock mass characterization. A percussion drill rig can be used efficiently as a seismic source, with no loss of resolution. High quality results can be obtained by operations in tunnel conditions, provided that due attention is given for the design of the work flow. One of the tasks of the seismic surveys carried out in the ONKALO access tunnel was to test the methods suitability for detecting and locating different kind of geological features. By comparing the processed seismic data with known geological, geophysical and hydrological features observed in the tunnel, it seems to be possible to locate by seismics many features from site-scale (e.g. brittle fractured zones) to tunnel-scale (e.g. single long fractures). It is also possible to locate hydraulically conductive zones. It is also obvious that electrical conductors can be seen as seismic reflectors. Thus, these two methods support each other and give good information for integrated modelling, especially when the electrical conductors are mostly also hydraulically conductive. Due to the one-dimensional survey geometry and the use of two-component geophones in 2007, it was not possible to detect fracture zones or single fractures of certain orientations, which could be detected by the two source-line geometry and, especially, by three-component geophones in 2009. For creating a good and detailed model (or prediction) of the geological and hydrological features of the repository area, integrated modelling should be carried out using all geological, hydrological and geophysical data at the same time. The examination of the seismic data shows that by combining the results from different methods it is possible to create a reasonable model.

Acknowledgements

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