Distributed Acoustic Sensing walkaway Vertical Seismic Profiling in Koillismaa deep drillhole

Introduction

Distributed acoustic sensing (DAS) is a relatively new tool in several geophysical applications (see recent overview by Li et al. 2022 and Willis, 2022). It allows recording of seismic signals along tens of kilometers along the fiber optic cables based on the principle of light backscattering (**Figure 1**). Most of the DAS applications so far focused on downhole measurements, especially vertical seismic profiles (VSP). DAS VSP measurements were already performed in hardrock / mining environment including fiber optic cables freely hanging in a water-filled drillhole (Riedel at al. 2018) or cemented in the boreholes (Bellefleur et al. 2020), indicating feasibility of DAS acquisition in such conditions. Here we report some initial results of the pilot multi-offset (walkaway) DAS VSP measurements carried out at the Koillismaa deep drillhole.

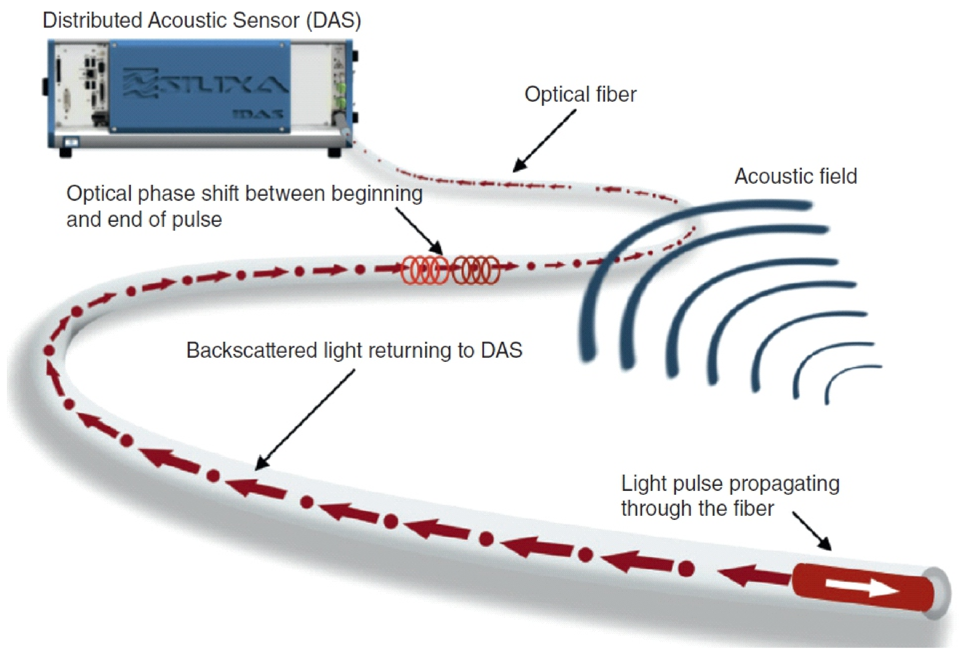

Figure 1. Schematic of the DAS measurement (after Silixa Ltd.).

DAS data and results of zero-offset VSP processing

Figure 4 compares zero-offset VSP records from a Vibroseis (single sweep) and a dynamite source. The data in the display were converted from strain rate to velocity by integration along the channels and scaled. Frequency spectra indicate a very broadband response for the dynamite shot, while the Vibroseis record is limited to the selected sweep bandwidth but shows higher amplitudes signal then dynamite. We can follow the downgoing P-wave energy down to maximum cable depth (1142 m), however the pulse gets strongly attenuated beyond ca. 800 m depth. We observe also the downgoing S-wave energy, as well as the tube waves inside the cased part of the borehole. Deeper parts are also masked by optical noise of the DAS system. The upgoing part of the wavefield (obtained by median filtering), contains some distinct reflected arrivals along the cable length.

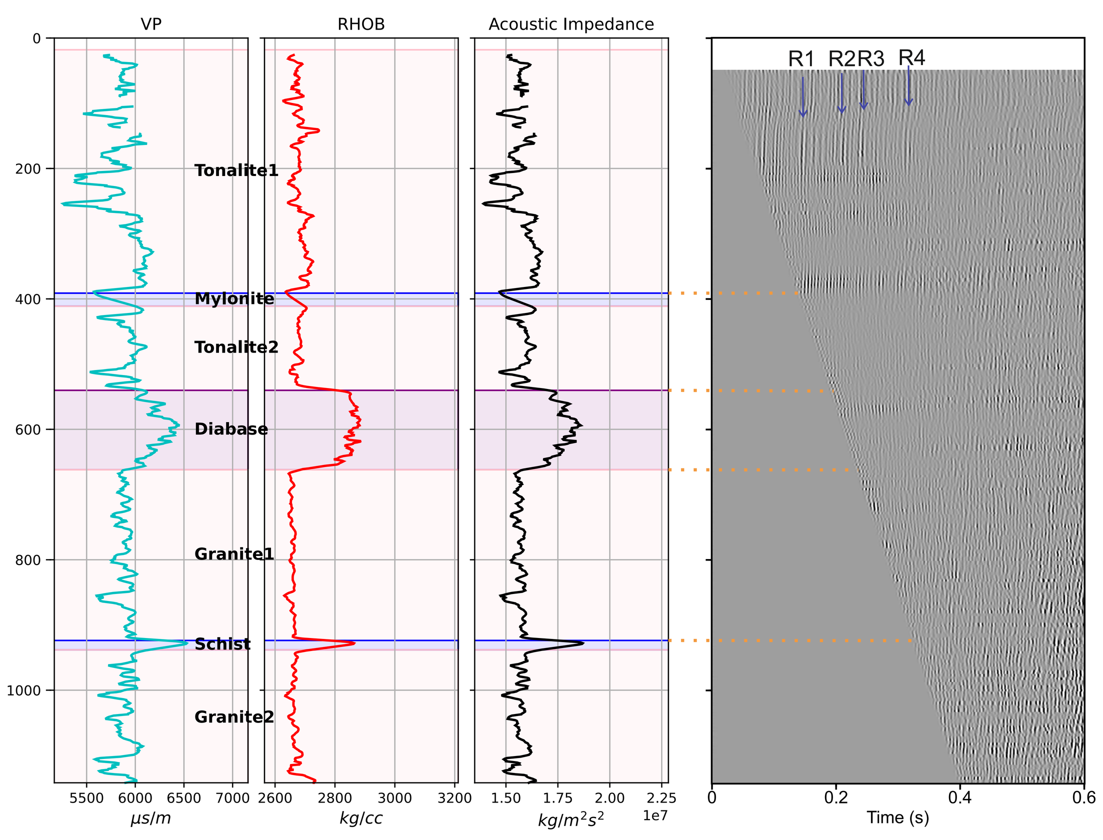

Figure 5. P-wave velocities and densities from the laboratory measurements on the core samples (Heinonen et al. 2022) and processed zero-offset VSP section from a dynamite shotpoint (shifted to a two-way time).

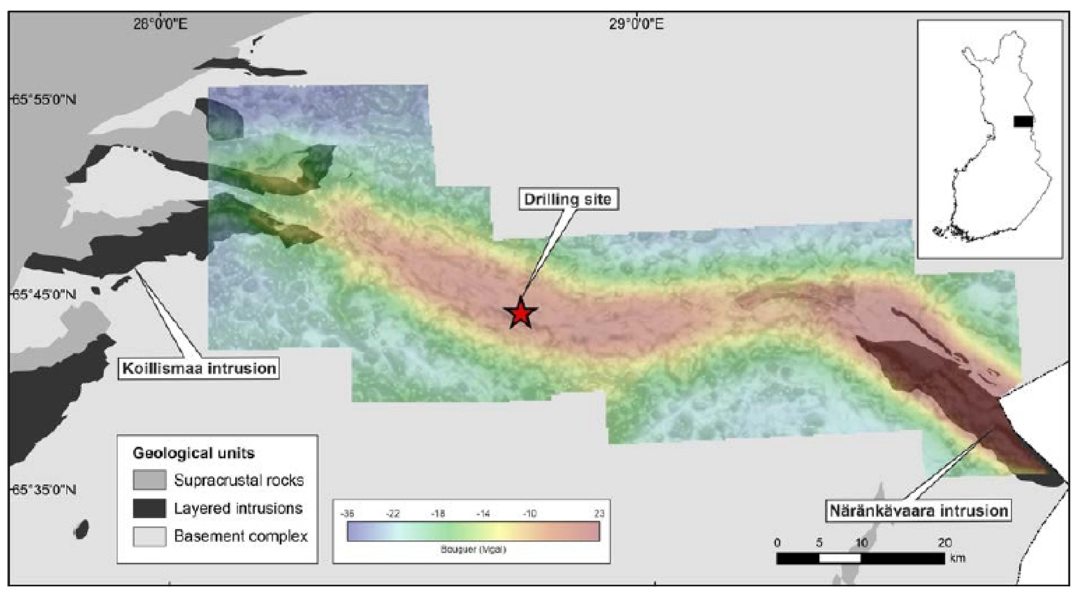

Figure 2. Location of the Koillismaa deep drillhole at the background of a simplified geological map and Bouguer gravity anomaly map (from T. Karinen).

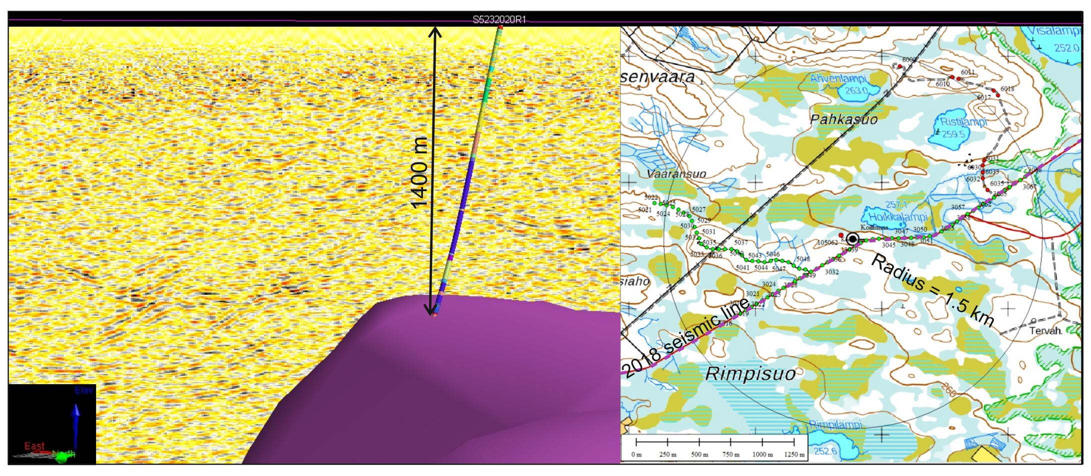

Figure 3. View at the seismic section acquired prior to drilling together with the Koillismaa borehole trajectory and lithology. Koillismaa intrusion is reached at ca. 1400 m depth. Map shows the location of the Vibroseis (green dots) and explosive sources (red dots) that were recorded by the fibre-optic cable.

Data acquisition

Koillismaa deep borehole was drilled in Kuusamo area (**Figure 2**) as a part of the Geological Survey of Finland project devoted to studying the Koillismaa Layered Intrusion Complex (Karinen, 2010). The borehole reached maximum depth of 1700 m, but due to numerous fracture zones was open for wireline logging down to ca. 1045 m depth. The 76-mm diameter borehole is deviated, with a mean inclination of 15 degrees, cased to ca. 240 m depth and water filled.

VSP measurements were performed in the beginning of September 2022. We used fiber optic cable manufactured by Solifos (BRUsens DTS) armoured with stainless steel loose tube. The cable hosts 2 multi-mode and 2 single-mode optical fibers. The cable was deployed using a dummy and reached maximum depth of ca. 1140 m. After some testing, it was concluded that a cable under tension is providing a better signal-to-noise ratio. For the actual DAS measurements, we used an ASN OptoDAS interrogator provided by NORSAR. During the acquisition we tested different gauge lengths (GL) (5, 10, 15 m) with different energy sources (Vibroseis and dynamite) and finally used 10 m GL for the dynamite shots and 15 m GL for Vibroseis. DAS channel spacing was set to 1 m. For dynamite shot points a small charge (240 g) at 2 m depth was used. Vibroseis acquisition was made with Failling Y-2400 Vibrator mounted on Mark IV buggy (provided by Geopartner Geofizyka). We used 20-s long sweeps from 20 to 160 Hz (+1dB per octave), repeated 6 times at given shotpoint. The shotpoints were distributed along available forest paths (with 50 m spacing) providing surface offsets up to 2.5 km from the borehole. During the acquisition, we noted that the maximum distance at which we observe seismic signal was ca. 1.5 km. In the end, we recorded about 90 sources with clear seismic energy (**Figure 3**).

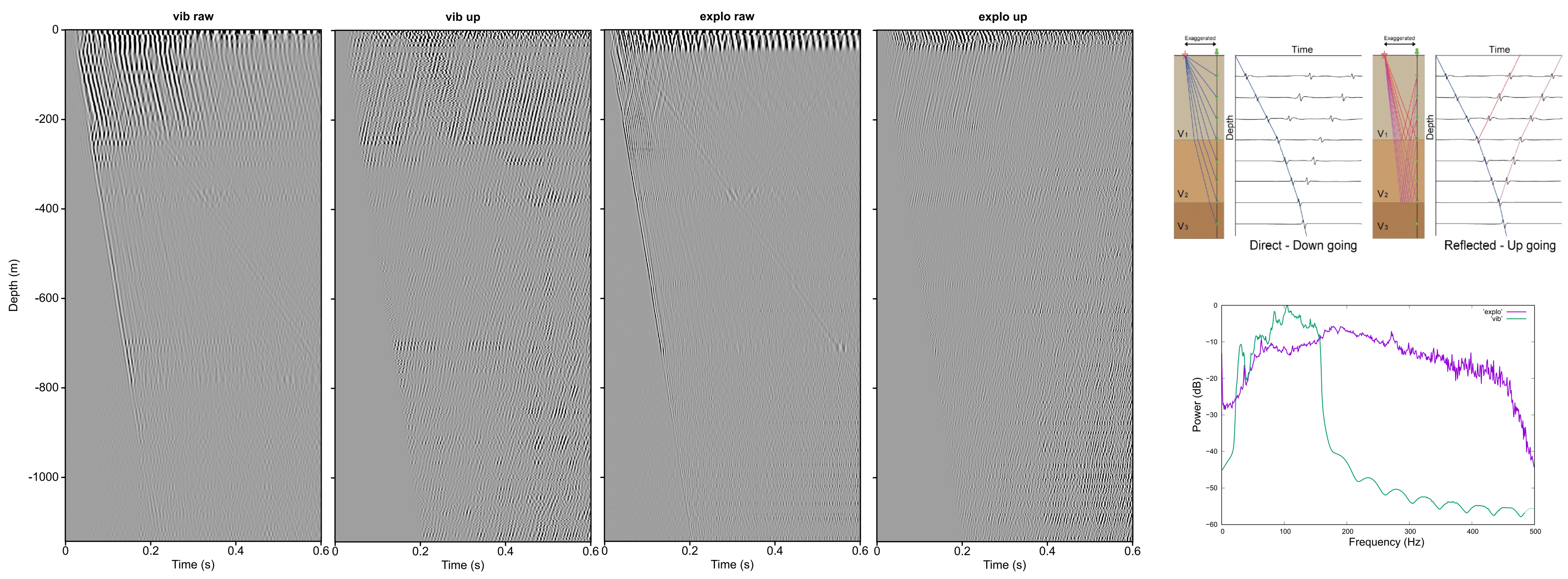

Figure 4. Raw and processed DAS shot gathers recorded in the Koillismaa borehole from zero-offset Vibroseis and dynamite sources. Upgoing wavefield ('up' - see cartoon) was separated by median filtering, followed by bandpass filtering of 82-86-200-250 Hz. Right panel: amplitude power spectra of the zero-offset Vibroseis ('vib') and dynamite records ('explo').

Figure 5 shows a comparison of logging based acoustic impedance plot with the two-way-time shifted upgoing wavefield from the same dynamite shot as in Figure 1. We can note the correlation of the reflections marked R1-R4 with the distinct lithology and rock property change: R1 at a major fault/fracture zone at 400 m (mylonite), R2 and R3 at the top and bottom of a diabase dyke (550-650 m), R4 at schist (altered diabase) at ca. 900 m. Deeper reflectors, beyond the extend of the cable (especially from the mafic intrusion, i.e. beyond 1400 m) are harder to be identified. However, some offset shot points contain deeper reflectors (see example in **Figure 6**).

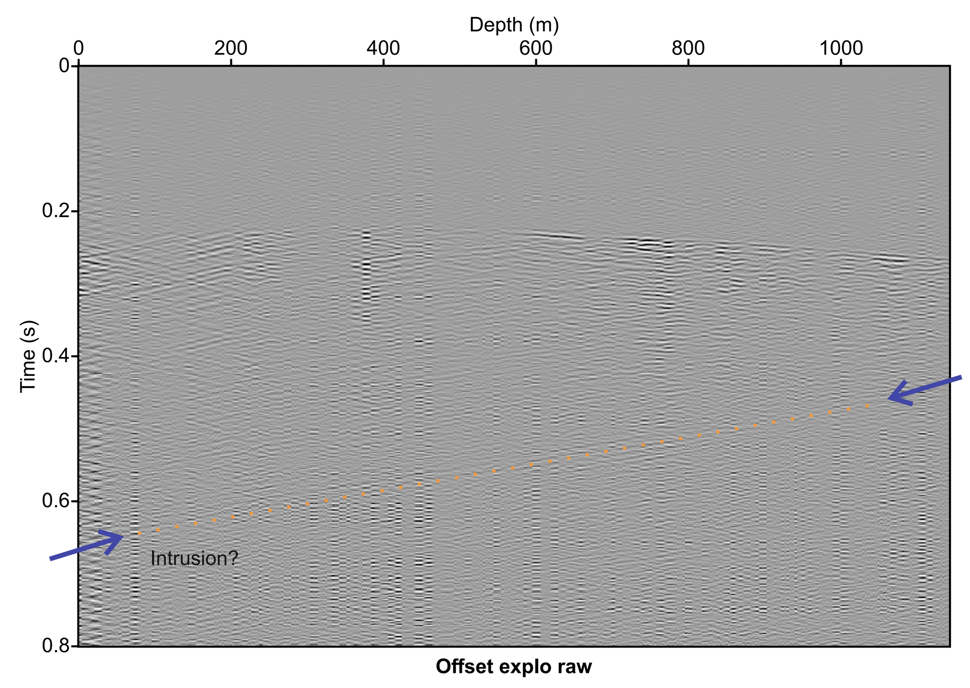

Figure 6. Raw VSP record from an offset (1.2 km distance from the collar) dynamite shotpoint. There is a clear deeper reflector (projected depth is ca. 1600 m, which corresponds to a granodiorite – peridotite contact).

Acknowledgements

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