SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

Koivisto[1], E.A.L., Brodic[1,5], B., Kovacs[2], A., Kristekova[3], M., Kristek[3], J., Haefner[4], R., Joswig[4], M., Walter[4], M., Gaya-Pique[1], L., Rowlands[1], A. and Labak[1], P.

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INTRODUCTION AND MAIN RESULTS

In 2022 and 2023, the PTS **conducted 2 field tests for the development of seismic and non-seismic geophysical techniques for deep on-site inspection (OSI) applications**. The 2022 Field Test took place in the Austrian Alps over a karst cave system at depths of 40-350 m. The 2023 Field Test was conducted in the UK above the Channel Tunnel consisting of two rail tunnels excavated in chalk marl at 90 m depth. **We present results of resonance seismometry (RES) and active seismic surveys (ACT) conducted during the field tests. The ACT and RES results show unique seismic signals from the targets, including direct detection of the Channel Tunnel in the 2023 data.**

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Background

- **Field tests are a key element of on-site inspection (OSI) techniques development process.**
- During a field test, new hardware, software, procedures and/or workflows may be tested for OSI techniques application.
- Based on the results, new approaches may then be adapted for OSI use, leading to development of OSI documentation and training, and ultimately to comprehensive demonstration of the acquired capabilities in the OSI Exercises.

- **In 2022 and 2023, the PTS conducted two field tests for the development of the following seismic and non-seismic geophysical techniques for deep OSI applications:**

- Resonance seismometry (RES)
- Active seismic surveys (ACT)
- Gravitational field mapping (GRV)
- Electrical conductivity measurements (ECM)
  - Electrical resistivity tomography (ERT)
  - Frequency-domain electromagnetics (FDEM)

- These techniques are mandated by paragraphs 69(f) and 69(g) of Part II of the Protocol to the Comprehensive Nuclear-Test-Ban Treaty (CTBT), and can be applied from the start of a continuation period of an OSI.

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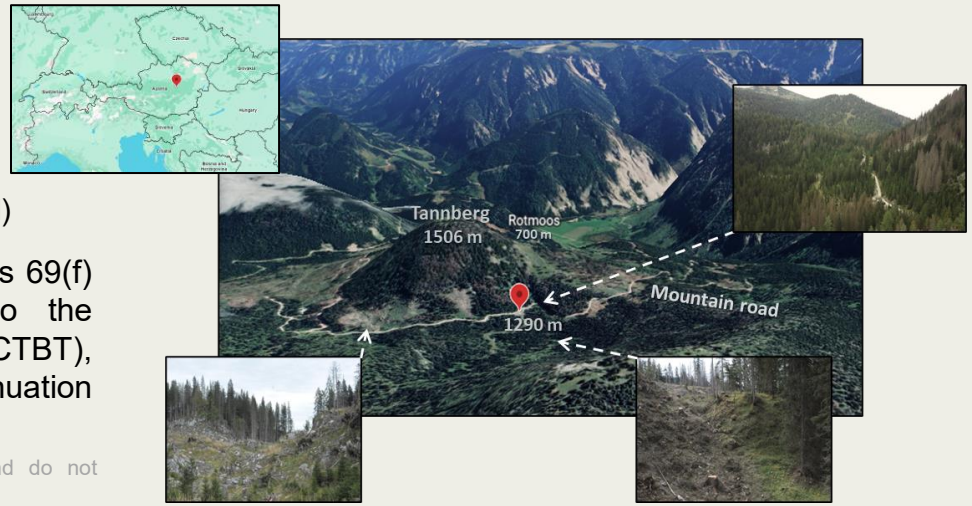
2022 OSI Field Test in Austria

- A Field Test of OSI Geophysical Techniques for Deep Applications in a Mountainous Environment was conducted September 5-16, 2022, in Styria, Austria over a cave system embedded in limestone with karst voids at depths of 40-350 m.
- The scope of the 2022 OSI Field Test was to assess the OSI geophysical imaging capabilities for deep applications in an integrated manner at a mountainous site with deep geophysical observables of OSI interest.
- This was the first time that an OSI field test was conducted in a mountainous environment. Consequently, a variety of operational, logistical, and technical challenges had to be addressed prior and during the conduct of the event.



2023 OSI Field Test in the UK

- A Field Test of OSI Active Seismic Surveys and Selected Geophysical Techniques was conducted May 8-19, 2023, at a farm in Folkestone, Kent, UK, above the Channel Tunnel, consisting of two rail tunnels excavated in chalk marl at 90 m depth.
- The scope of the 2023 OSI Field Test was to complement and expand on the outcomes of the 2022 Field Test in Austria.
- Due to the complementary nature, the objectives of the Field Test varied depending on the specific status and needs of the different geophysical techniques.

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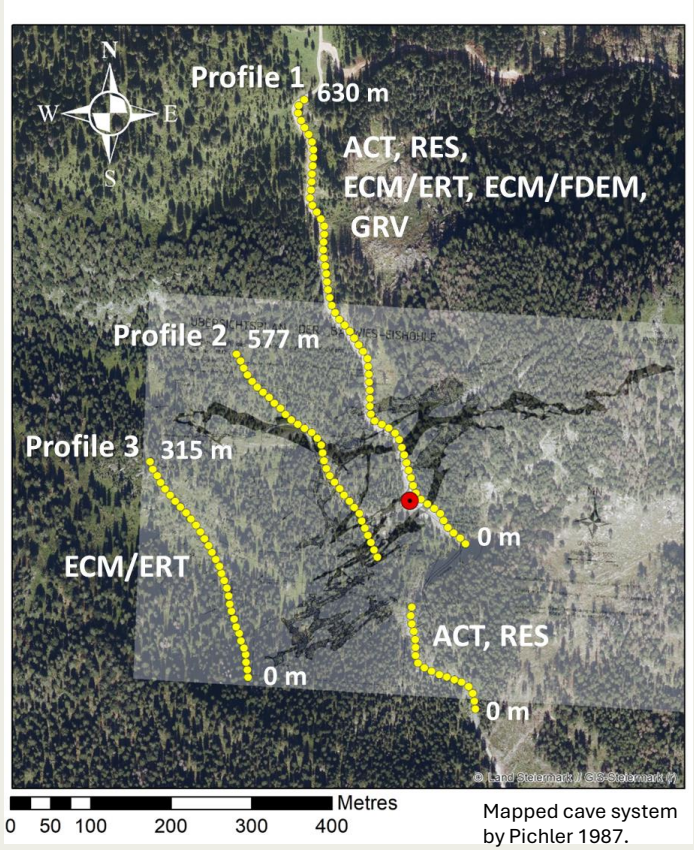
Survey Layout of the 2022 Field Test



Mapped cave system by Pichler 1987.

3 survey profiles over a cave system embedded in limestone with karst voids 5-15 m in diameter at depths of 40-350 m mimicking tunnels and underground cavities associated with a UNE. Depending on the technique, the lengths of the profiles varied.

Survey Parameters of the 2022 OSI Field Test

RES	Profile 1	Profile 2
Data recording system	Reftek RT130 data recorders with Lennartz 3C LE-3Dlite seismometers/ACT nodes	Reftek RT130 data recorders with Lennartz 3C LE-3Dlite seismometers
Profile length	1010 m/325 m	777 m
Coverage along the profile	-300 m-710 m, one full mini-array at 710 m/0-325 m	-200 m-577 m
Number of stations along the profile	21/12	19
Station spacing	25 m to 100 m/25 to 50 m	25 m to 100 m
Sampling frequency	500 Hz/500 Hz	500 Hz
Gain setup	High gain (x32)/NA	High gain (x32)
Recording time	3-7 days/3 days	5-7 days
Recording format	RefTek 130 data format	RefTek 130 data format

ACT	Profile 1	Profile 2
Data recording system	Geospace GSB-3 data recorders with single 3C GS-ONE LF 5 Hz geophones	Geospace GSB-3 data recorders with single 3C GS-ONE LF 5 Hz geophones
Profile length	600 m	575 m
Coverage along the profile	0-600 m	0-575 m
Spread type	Fixed spread with 241 channels	Fixed spread with 207 channels
Receiver spacing	2.5 m	2.5 m; break in receivers at 177.5-240 m
Source type	Accelerated Weight Drop (AWD)	AWD and sledgehammer
AWD nitrogen pressure	1500 psi	1500 psi
Source spacing	5 m densified to 2.5 m over the cave targets	2.5 or 5 m (mostly 2.5 m); break in sources 177.5-240 m
Total number of source points	172	186
Number of hits at each source point	7 to 8	7 to 8
Sample rate	1 ms	1 ms
Record length	2 s	2 s
Recording format	SEG-Y	SEG-Y

Results of the 2022 OSI Field Test

- Testing of a new concept of operations for **RES**, including two passive approaches:
  1. Finite-Interval Spectral Power, i.e., the FISP method utilizing 3C seismic ambient noise data to search for increases in amplitude of spectral power at selected frequency intervals (See also **O3.3-604)**.
  2. Onset Delay Method, i.e., the ODM utilizing regional and teleseismic earthquake and man-made seismic event data to search for increases in amplitude of spectral power at selected frequency intervals as well as wave propagation changes in time and amplitude (See also **P3.3-817**).
- First testing of newly procured GSB-3 nodal data acquisition system and field workflows for **ACT**.
- **Position finding** workflows for the techniques.
- Development of **GIMO** for the techniques.
- Operational, logistical and technical challenges of a **mountainous environment** addressed.

See poster **P3.3-528** on the non-seismic geophysical techniques

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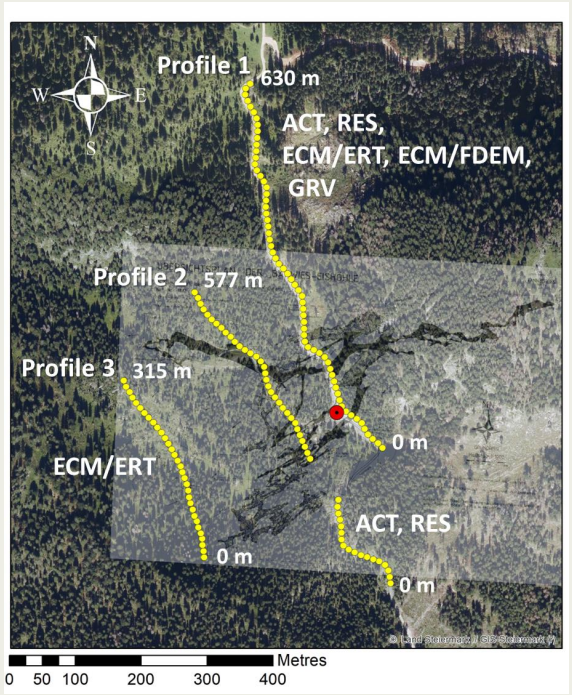
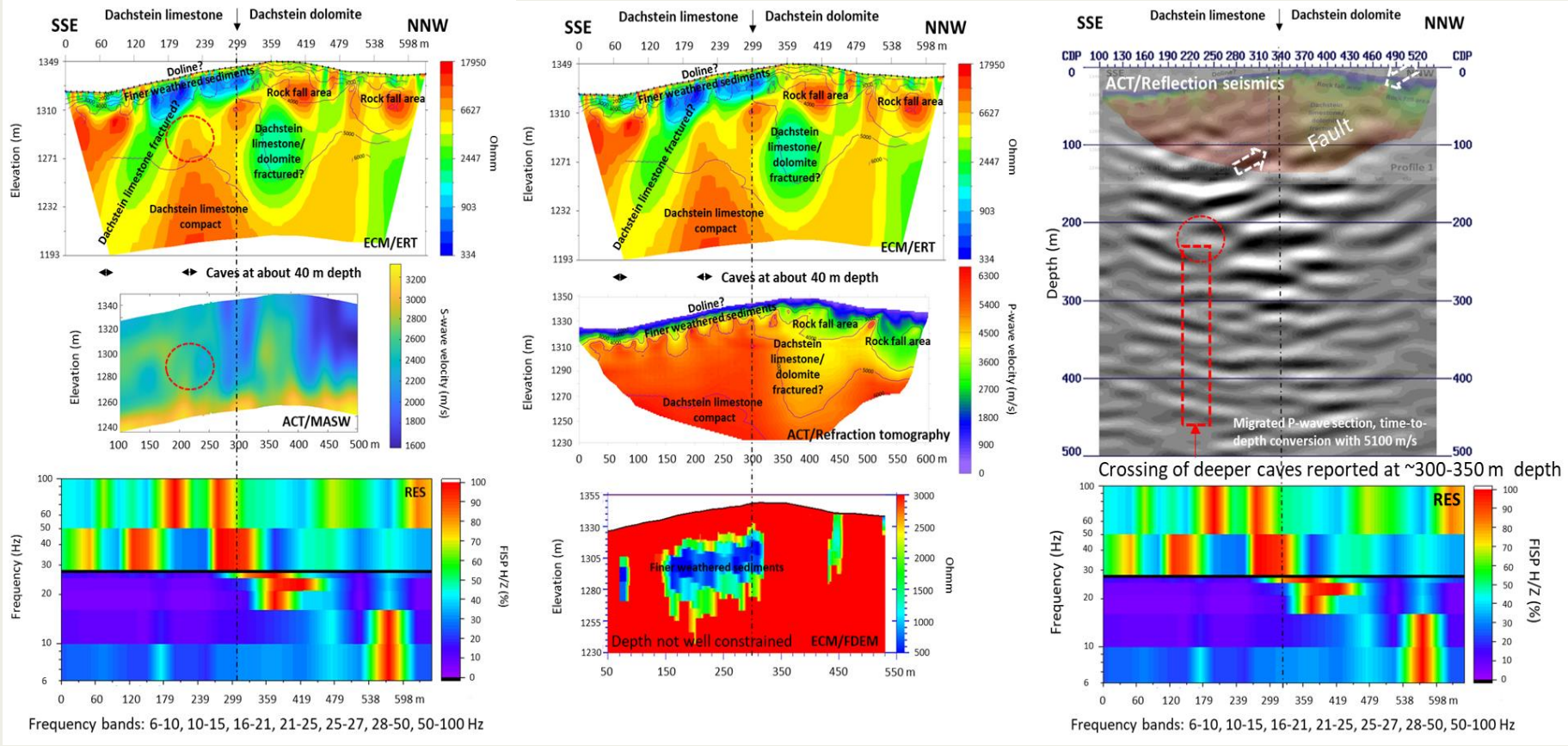


- Challenging environment with severe access limitations
- Overall, consistent results for all techniques
- Some indications of a deeper cave in the reflection seismic data
- Possible Multichannel Analysis of Surface Waves (MASW) S-wave signature of shallow caves
- ERT signatures of shallow caves

Integrated Results for the 2022 Field Test – Profile 1



See also
P3.3-817 Advancing the Onset-Delay-Method for Resonance Seismometry
O3.3-604 Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Contact us if you are interested in working on the data!

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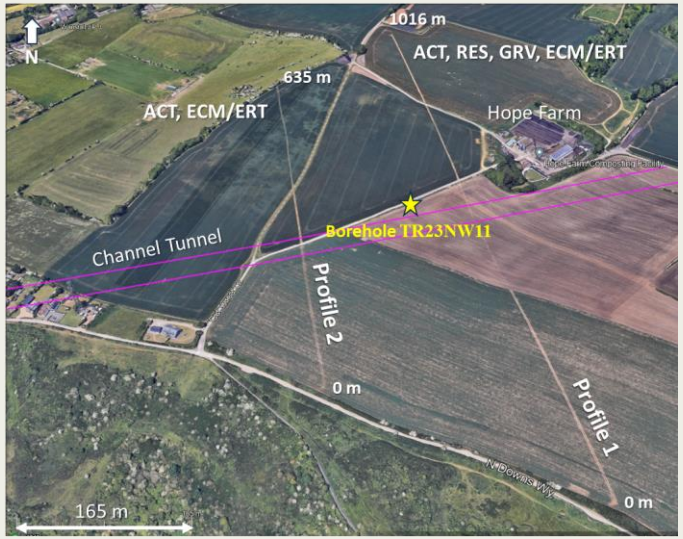
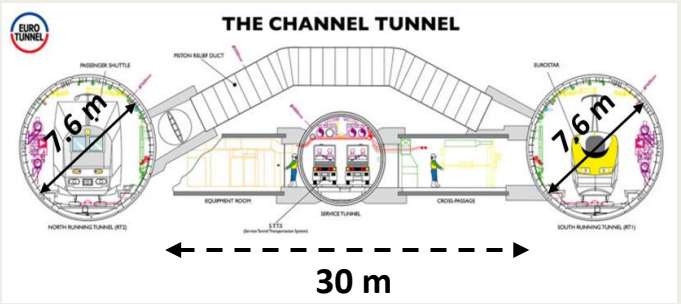
Survey Layout of the 2023 Field Test





2 survey profiles across the Channel Tunnel, consisting of two rail tunnels 7.6 m in diameter and 30 m apart, excavated in chalk marl at 90 m depth. Depending on the technique, the lengths of the profiles varied.

Survey Parameters of the 2023 OSI Field Test

ACT	Profile 1	Profile 2
Data recording system	Geospace GSB-3 data recorders with single 3C GS-ONE LF 5 Hz geophones	Geospace GSB-3 data recorders with single 3C 5 Hz geophones
Profile length	412.5 m	412.5 m
Coverage along the profile	300-712.5 m	50-462.5 m
Spread type	Fixed spread with 276 channels	Fixed spread with 276 channels
Survey type	P- and S-wave survey	S-wave survey
Receiver spacing	1.5 m	1.5 m
Source type	Seismic Mechatronics Lightning eVibe	Seismic Mechatronics Lightning eVibe
Sweep frequencies	6-160 Hz	6-160 Hz
Sweep length	20 s	20 s
Contact force	1200N for the P-wave survey, 1700N for the S-wave survey	1700N
Source spacing	3 m	3 m
Total number of source points	139	138
Number of sweeps at each source point	3	3
Sample rate	0.5 ms	0.5 ms
Record length	0.5 s	0.5 s
Recording format	SEG-Y	SEG-Y

RES	Profile 1
Data recording system	49 Reftek RT130 data recorders with Lennartz 3C LE-3Dlite and Lennartz LE-1DV 1C seismometers + 4 Nanometrics Pegasus Rapid Deploy Kits with Trillium Compact 120s 3C seismometers + ACT nodes with 3C GS-ONE LF 5 Hzgeophones, 3C GS-1 1 Hz Seismonitor or 3C HS-1 2 Hz Seismonitor
Profile length	940 m
Coverage along the profile	30-970 m
Overall number of stations along the profile	53
Number of mini-array stations	17
Distance of the 1C satellite elements from the 3C central seismometer	30 m
Number of 3C stations	36
Station spacing	20 m, densified to 10 m in parts
Sampling frequency	500 Hz
Gain setup	High gain (x32)
Recording time	5-9 days
Recording format	RefTek 130 data format

Results of the 2023 OSI Field Test

- Development of **ACT workflows, documentation and training** for (See also **P3.3-527**):
  - Reflection seismic 2D surveys
  - Refraction seismic 2D surveys

  with up to 800 autonomous Geospace GSB-3 ACT nodes
- Initial testing of ACT workflows for (See **Brodic et al. 2024**):
  - Seismic forward modelling
  - Multichannel Analysis of Surface Waves (MASW)
- Further testing of RES approaches and new hardware options for RES (See also **O3.3-604**).
- To address the status of the techniques' development, Expert Meeting on OSI Seismic Techniques October 22-25, 2024, in Austria. As a follow-up:
  - Development of **new software for RES**
  - Testing of **new approaches for RES and ACT**

See poster **P3.3-528** on the non-seismic geophysical techniques

See also Brodic, B., Koivisto, E., Kovacs, A. and Labak, P., 2024. Detection of voids/tunnels relevant for CTBT's on-site inspections via P-and SH-wave active seismic survey and forward seismic modeling. AGU Fall Meeting2024 contribution NS43D-04: AGU 2024 - iPosterSessions - an aMuze! Interactive system

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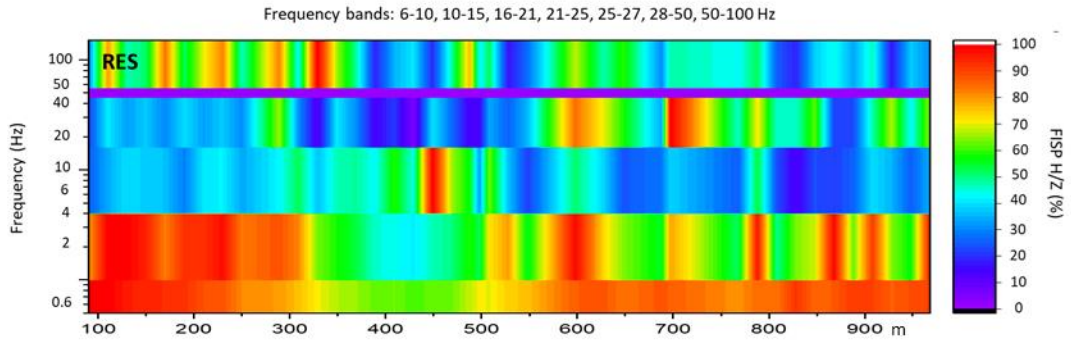
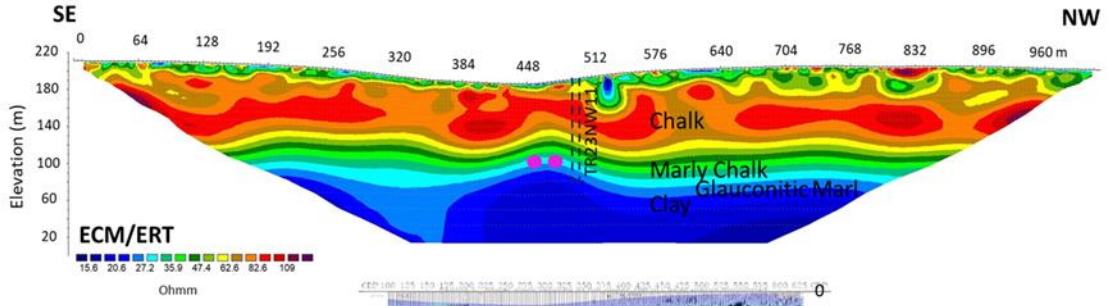
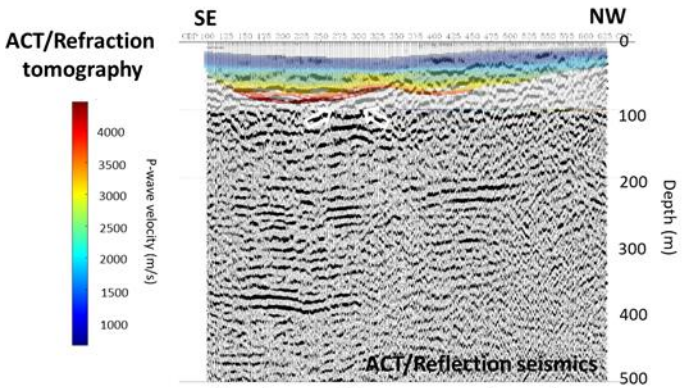
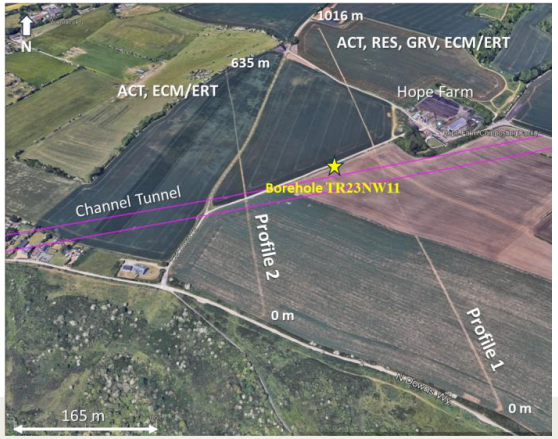
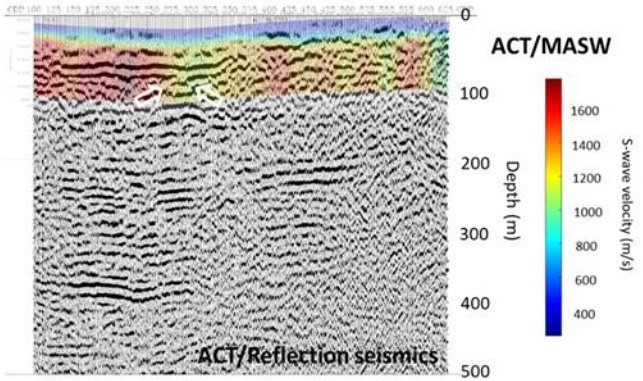






Unmigrated P-wave section, time-to-depth conversion with 2000 m/s





Unmigrated P-wave section, time-to-depth conversion with 2000 m/s

- Direct P- and S-wave diffraction signals from the tunnels
- Overall, consistent results for all techniques

See also **P3.3-527** Automated workflows for rapid understanding of ACT and RES imaging potential in an OSI context
O3.3-604 Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

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