Science 4 Technology – Poster Exhibition 2024

Department Applied Geosciences and Geophysics

Chair of Applied Geophysics

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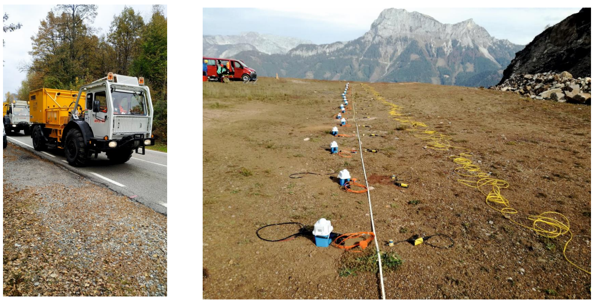
Controlled Source Seismology

Imaging of the Earth subsurface

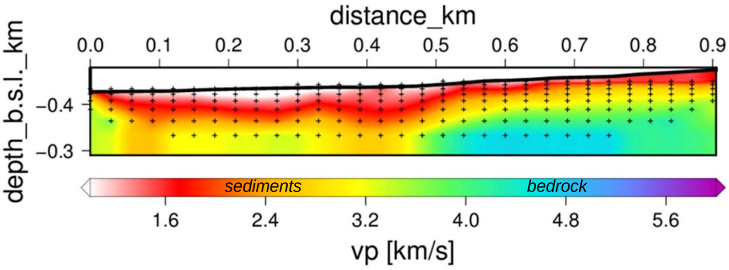
Controlled source seismology, using the reflection and refraction techniques, provides information on the stratigraphy and physical properties of the Earth's subsurface. Reflection seismology involves the generation and measurement of seismic waves that are reflected to the surface from geological interfaces, enabling the reconstruction of the subsurface structure. In contrast, refraction seismology focuses on measuring the seismic waves that are refracted to the surface providing information about the intrinsic physical properties of the lithologies at depth. Here we present two applied studies where the techniques were used to investigate the subsurface in different geological settings.



A typical seismic source (left), known as Vibroseis, generates seismic waves that are then recorded by an array geophones deployed in the field (right).

Sedimentary basin investigations

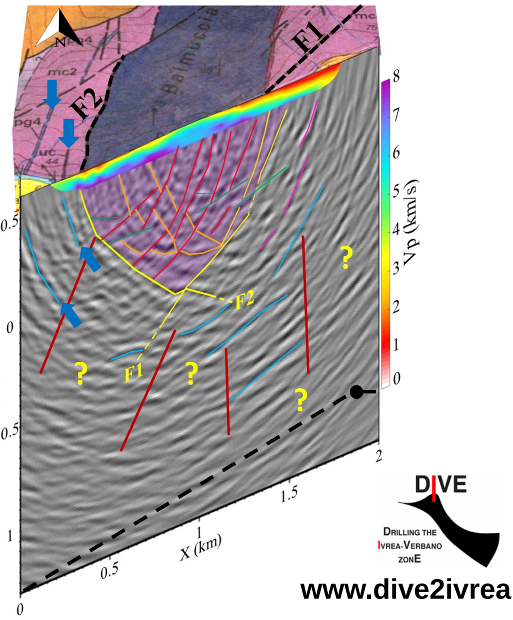
We are investigating the Cheb Basin located in north-west Czechia, within the Bohemian Massif. This area is of interest due to its seismic activity, with earthquakes and earthquake swarms occurring at shallow depths. To better understand the local geology, we acquired and processed 2D active seismic data to obtain a subsurface velocity model. This model was created by applying the traveltime tomography technique, which uses refracted seismic waves. The results illustrate the contrast in velocities between the sediments and the bedrock, which allows to interpret the geological structure of the subsurface.



Tomographic velocity model that allows the identification of lithologies in the subsurface. The color scale represents the velocity of the rock mass. For the bedrock the velocity is higher than for the sediments.

Hardrock seismic imaging

In the Ivrea Verbano Zone (western Italian Alps) geophysical studies have shown that the Earth’s Mantle is at very shallow depths (1-3 km), forming what is known as the Ivrea Geophysical Body (IGB). Project DIVE (Drilling the Ivrea Verbano zonE) aims to drill a 4 km borehole in the area to reach the Earth’s Mantle for the first time in history. To aid in the drilling plan, we performed a seismic survey at the proposed drill site to generate a seismic image and gain insight into the subsurface. The site coincides with the location of the Balmuccia Peridotite, a body with an unknown geological structure. The image obtained helped to define the shape of the peridotite body and its internal structure.



www.dive2ivrea.org

Seismic section showing the interpreted geological structure. The seismic image allows us to follow the faults F1 and F2 mapped at the surface, defining the shape of the peridotite body as a lens.

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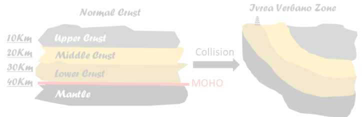
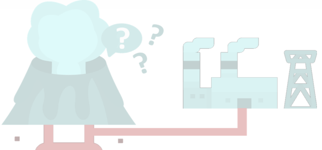


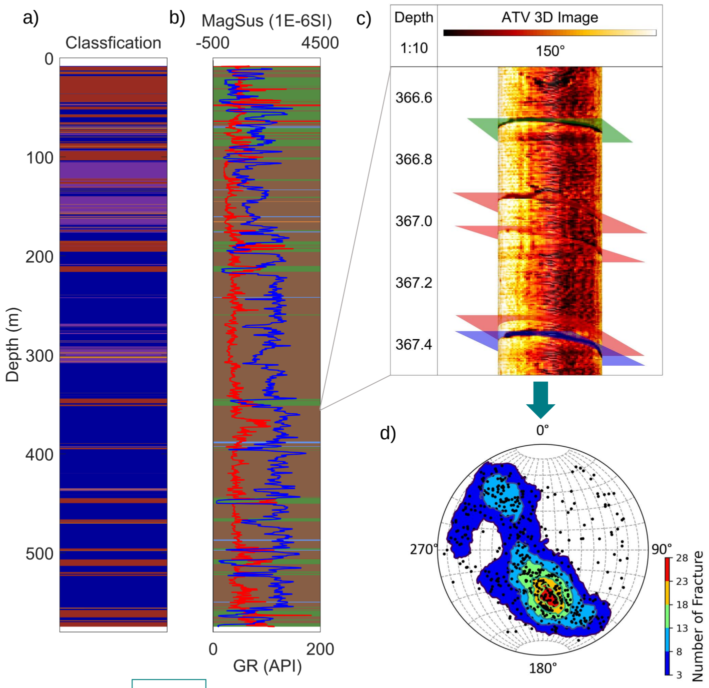
BOREHOLE GEOPHYSICS

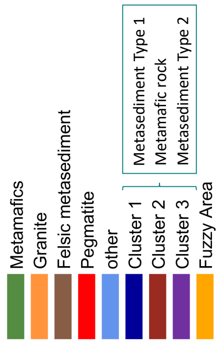


Machine learning in research and geoenergy applications

Drilling is the only way to directly access subsurface rocks at depth in order to investigate fundamental geological processes and the rock's potential as an energy resource. In borehole logging a sonde is raised or lowered in the borehole, while measuring the subsurface properties. The recorded high-resolution profiles of key physical and structural parameters under in-situ conditions form the basis for characterizing subsurface rock masses. A powerful approach to characterization problems are machine learning algorithms.

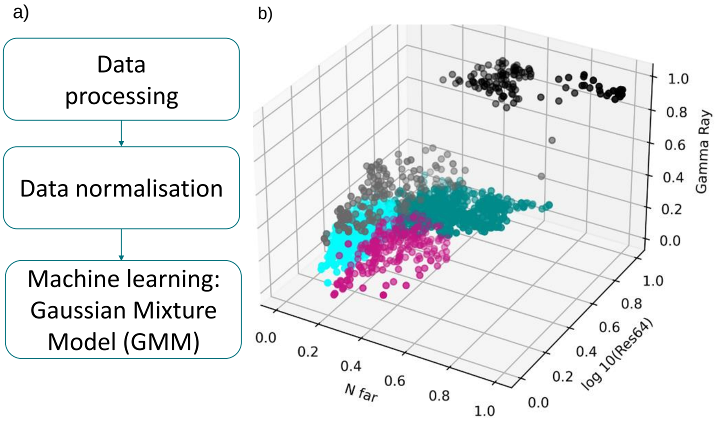
Drilling the **I**vrea-**V**erbano zon**E** (**DIVE**) project aims at drilling through the lower continental crust–mantle transition for the fist time in history. To achieve this three boreholes are planned. In this study, we utilize geophysical logging and classification techniques to characterize the lithological and structural properties of lower continental crustal rocks encountered in the first drilled borehole.





Lithological classification results (a) using fuzzy c-means clustering applied to magnetic susceptibility and gamma ray logs (b) compared to core lithologies described on the drill site shown as background in (b). Structural characterization from acoustic televiewer (ATV) data: (c) 3D ATV amplitude image of the borehole wall and interpretated fractures color-coded by their thickness, (d) orientation and inclination of fracture planes encountered in the borehole plotted as poles to the plane (black dots).

Borehole IDDP-1 of 2.1 km length was drilled to explore the potential of supercritical geothermal resources in the Krafla geothermal filed in Iceland. The drilling encountered unexpected challenges, such as hitting magma, highlighting the complexities of drilling in volcanic environments. This study explores machine learning algorithms applied to geophysical logging to characterize the rock mass in IDDP-1 to develop tools for better decision making and safer geothermal drilling.

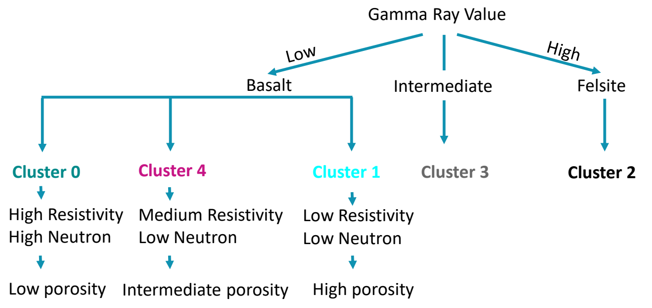


Data processing

Data normalisation

Machine learning: Gaussian Mixture Model (GMM)

(a) Workflow of cluster analysis (b) 3D visualization of the data distribution and clustering results obtained by applying GMM to three well logs: Gamma ray, neutron, and resistivity.



Gamma Ray Value

Low

Intermediate

High

Basalt

Felsite

Cluster 0

High Resistivity
High Neutron

Low porosity

Cluster 4

Medium Resistivity
Low Neutron

Intermediate porosity

Cluster 1

Low Resistivity
Low Neutron

High porosity

Cluster 3

Cluster 2

Flowchart detailing the characteristics of the identified clusters. The data is grouped into 5 distinct clusters characterized by composition and texture differentiating between felsic, intermediate, low porosity basalts, medium porosity basalts, and high porosity basalts.

DIVE
DRILLING THE IVREA-VERBANO ZONE

FWF Austrian Science Fund

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NEAR SURFACE GEOPHYSICS

Archaeological prospection and landfill monitoring

Human activity continually changes our environment and landscape. Understanding the impact we have on our environment, be it through historical times or recent industrial activities, helps us to safeguard our future. To locate and monitor activity without the need to excavate, near surface geophysical techniques such as ground penetrating radar (GPR) and electrical resistivity imaging (ERI) can be employed. These techniques detect contrasts in electro-magnetic properties within the subsurface. Imaging and inversion techniques are applied to the data to highlight and map these contrasts.

GPR archaeologic investigations

In November 2022 Master students in Applied Geophysics carried out GPR measurements next to the Necropolis at the Linea Cadorna, Ornavasso, Italy. GPR is ideally suited to archaeologic investigations as it is: high-resolution; non-destructive; and can examine large areas in a short time at low cost.

Above left: PulseEkko geo-radar unit mounted on a non-ferrous cart with 500 MHz antennae and integrated Trimble RTK-GPS receiver. Right: Location map of three GPR survey areas conducted with the 500 MHz antennae near the Necropolis (red outlined area) at the Linea Cadorna, Ornavasso, Italy.

Using signal processing and display techniques, to enhance the GPR response, different features in the near surface can be illuminated.

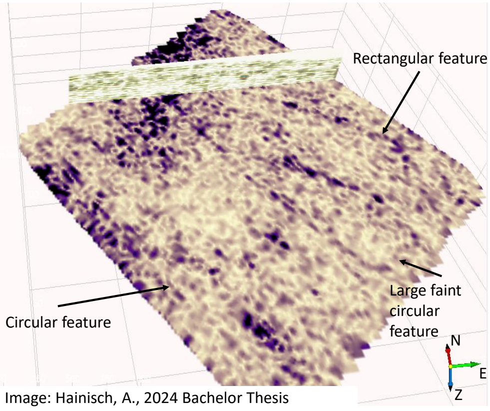
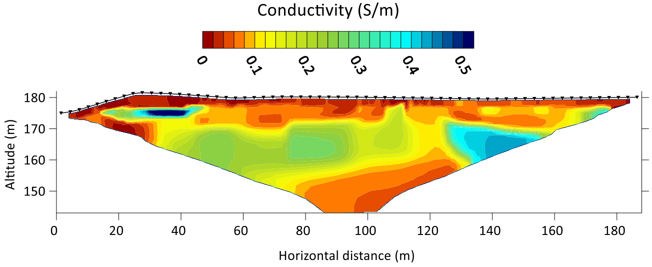


Image: Hainisch, A., 2024 Bachelor Thesis

Left: Orthographic view of Area 3 GPR results after attribute analysis. The main plane is a depth slice at c.a. 1.7 m. Potential (Roman) anthropogenic structures are identified by their rectangular and circular shapes which are rarely produced in nature.

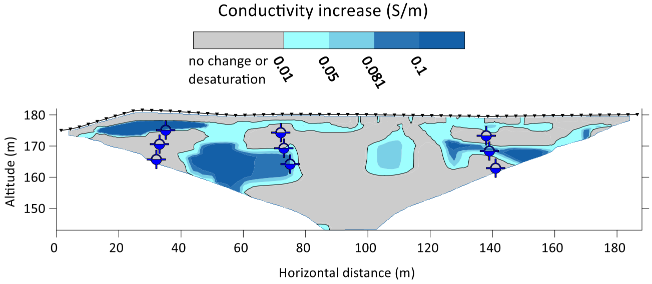
Geoelectric monitoring

Electrical Resistivity Tomography (ERT) monitoring was carried out in a landfill to investigate spatial and temporal changes of the water saturation of domestic waste-volumes during controlled irrigation to stimulate biogas production. The landfill leachate was used for irrigation, and it was introduced via irrigation lances and gas wells.



Above: Conductivity variation in a profile before irrigations (zero-measurements). The gradual decrease of conductivity at the bottom indicates the lower boundary of the domestic waste.

Electrical resistivity tomography can be used to determine leachate flow paths if the difference in conductivity between the substrate and the fluid is large enough. The best geometry of irrigation lances can then be determined to enhance microbial activity and bio-gas production.



Above: Conductivity increase after irrigations (1500 m^3 leachate with 0.57 S/m). Slag and ash-concrete retaining walls and other barriers limited the spread of water. Positions of the irrigation lances are marked in the plot.

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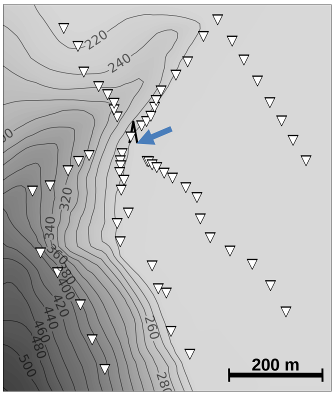
Passive Exploration Seismology

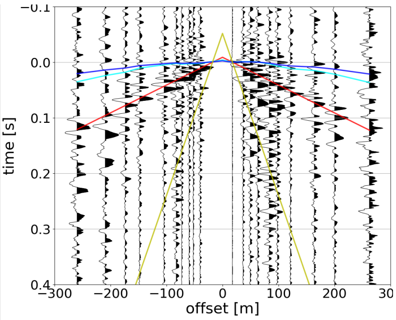
Signals from the Subsurface

Controlled seismic sources are expensive, potentially harmful to infrastructure, and cannot always be deployed for logistical reasons. Passive exploration seismology attempts to constrain subsurface properties and processes from natural, or man-made, noise sources. It benefits from technical advances and an ongoing price drop of seismic sensors for continuous monitoring. Passive seismic data can be used to locate noise sources, or to use the noise for seismic structural imaging and velocity modelling.

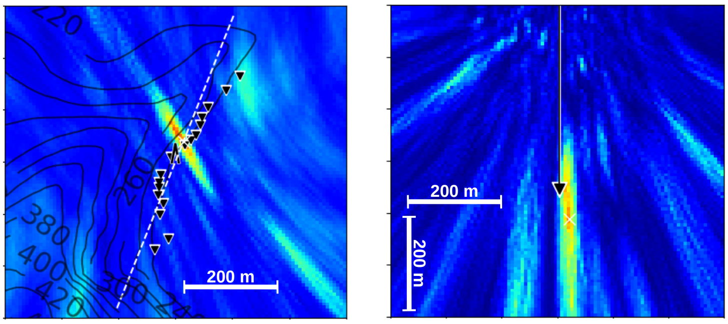
In an FWF-funded project we work towards using the very weak vibrations of a diamond drill bit that we recorded with a surface array of 64 sensors during a scientific drilling project in the Western Alps for seismic imaging. In a first step we employ the method of *Matched Field Processing* to locate the noise source. This procedure serves to verify the usability of the noise signal.



Seismic sensor array in Val d'Ossola, Italy. Arrow indicates the drill rig whose vibrations are a strong surface noise source

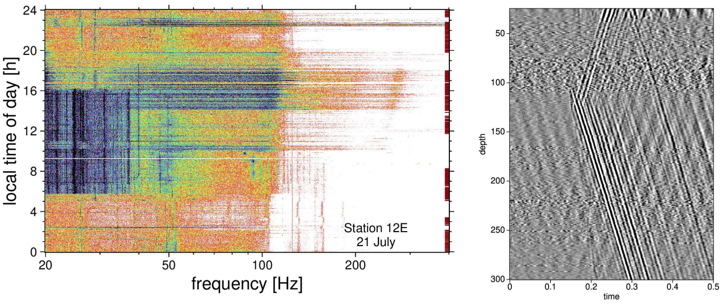


Virtual shot gather obtained from cross-correlation with a sensor near the rig and hypothetical travel-times of surface waves from the rig (red) and P- (blue) and S-waves (cyan) from the drill bit.

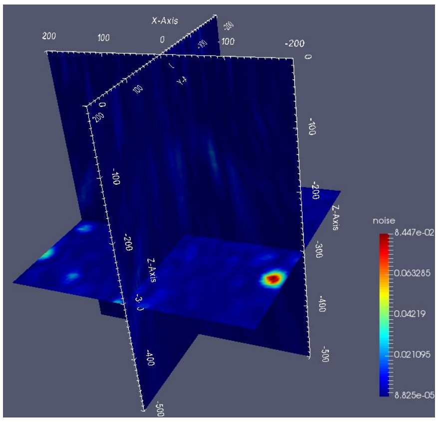


Depth slice (left) through a 3D image of the subsurface noise distribution. Dashed white line marks the position of the vertical profile (right). Black triangle is true position of drill bit. Blue colors indicate quiescence, red colors indicate strong noise.

In cooperation with OMV we work towards adapting the passive seismic technology to find elevated concentrations of natural hydrogen (H_2). H_2 is produced in lower crustal rocks from where it migrates to the surface. We want to detect elevated concentrations of H_2 from the weak signals it might produce when it overcomes natural seals in the subsurface. In this experiment, we aim at calibrating our imaging algorithms. To that end we deployed a controlled source in an inactive borehole in the Vienna Basin that mimics natural sources of variable strength.



Left: One day spectrogram of one of 24 seismic sensors. Source activity is not visible but strong anthropogenic noise during working (6 - 16) hours. Right: Stacked receiver gather from a magnitude -1 source over a depth range of 300 m. Most coherent signals are tube waves propagating up and down in the borehole.



Slices through a 3D image of the subsurface noise distribution obtained from one hour of recordings during which the source was located at 300 m depth. The borehole is in the origin (0,0) and the high amplitudes at (-190,80) indicate an erroneous location due to insufficient calibration.

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