A high-resolution seismic survey across the Balmuccia Peridotite, Ivrea Zone, Italy - Project DIVE phase two, site investigation

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Content:

- The Ivrea Zone.
- The *DIVE* project.
- Seismic acquisition.
- Data processing.
- Future steps and challenges.
- References.

The Ivrea Verbano Zone

- The Ivrea Verbano Zone is located in northwest Italy, delimited on its northwestern side by the Insubric Line.

- It is considered an exhumed continental crust-mantle transition, that exposes a relatively intact section of deep crust (Quick et al., 1995).

- Several studies have been conducted in the area, concluding that beneath the IVZ there is a structure characterized by high seismic P-wave velocity and a pronounced positive gravity high (e.g., Scarponi et al., 2020, Diehl et al., 2009), that suggests that the crust-mantle transition zone is located at shallow depths (ca. 3km depth). This anomaly is known as the Ivrea Body, commonly addressed in literature as the "*bird's head*" (*Berckhemer, 1968).*

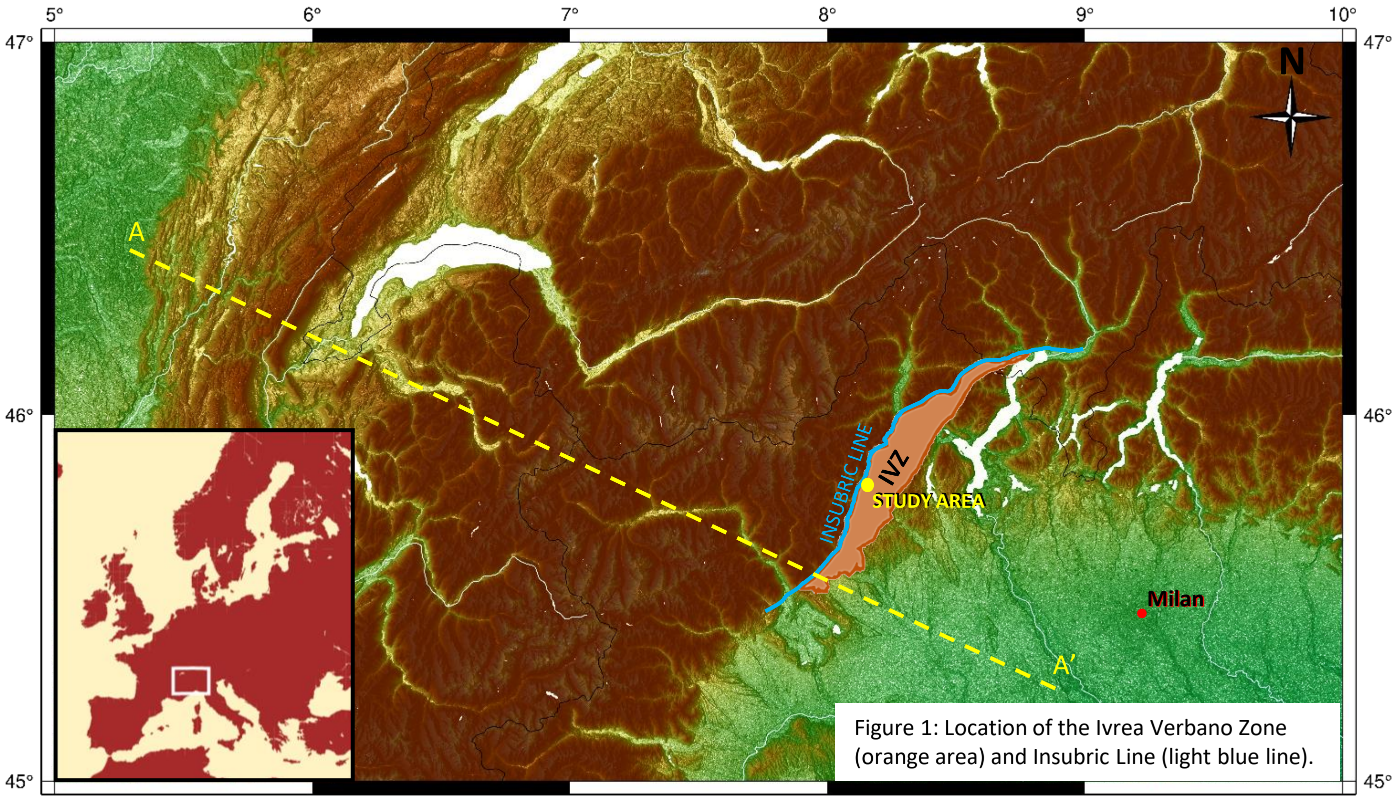

Figure 1: Location of the Ivrea Verbano Zone (orange area) and Insubric Line (light blue line).

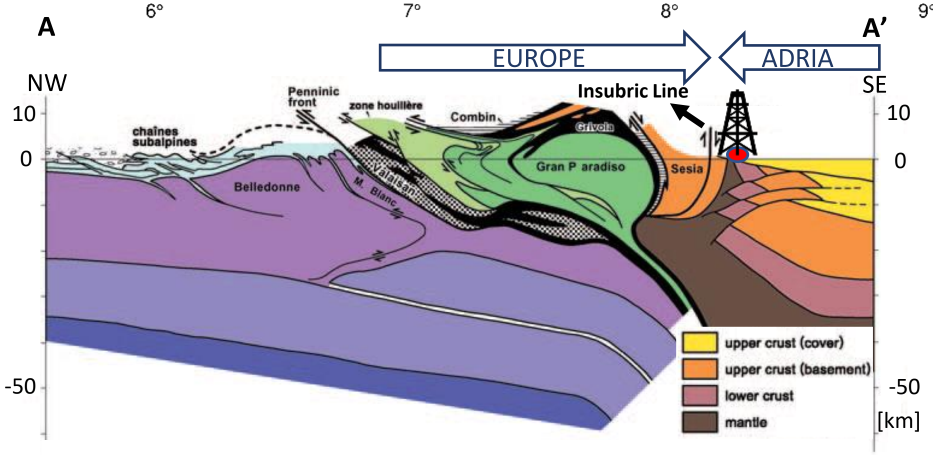

Figure 2: Schematic transect through the Alps modified from *Schmid et al., 2004.*

The DIVE project

Some objectives of DIVE:

- Identify the major characteristics of the **deep structure and composition of the crust-mantle transition zone** (shear zones, faults, rock properties, mineral and bulk composition).

- **Characterization of physical properties** of the drilled sections to improve the knowledge and identification of seismic reflectors (key study to generate a **correlation between geophysical studies**).

DIVE phase I:

- **Megolo:** Drilling into the pre-Permian continental lower crust.

- **Ornavasso:** Drilling into the pre-Permian heterogeneity of the intermediate to lower crust.

DIVE phase II:

- **Balmuccia:** Deep drilling into the roots of a large-scale Permian magmatic system. The objective is to approach the crust-mantle transition zone.

In each area, seismic site characterization will be made in order to define with precision the correct positioning and orientation of the boreholes, to assess potential drilling hazards and to allow for the spatial extrapolation of the borehole logs.

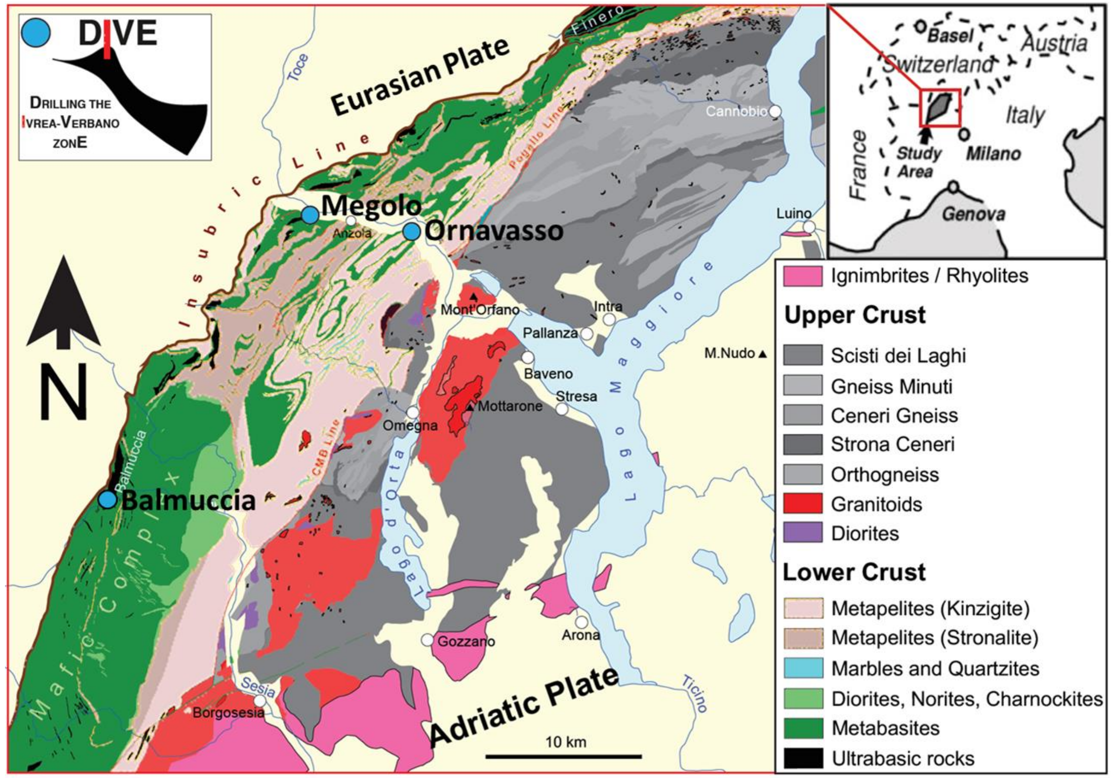

Figure 3: Overview of the geology of the IVZ and adjacent units, with the proposed drilling sites for the DIVE project as blue dots. Modified from Pistone et al., 2017.

DIVE phase II – Seismic survey October 2020:

- **SEIZE** (Seismic Imaging of the Ivrea Zone):Deep seismic survey by GFZ Potsdam. **Objective**: resolve the deeper structure of the IVZ.

- **HiSEIZE** (High-resolution Seismic Imaging of the Ivrea Zone). **Objective**: obtain high-resolution images of the drill site and to understand the structural features and boundaries of the Balmuccia Peridotite.

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The Balmuccia Peridotite

- The Balmuccia Peridotite is one of the mantle peridotite bodies occurring in the Southern domain of the Western Italian Alps, hosted by the Ivrea Verbano Zone. It consists of a ~ 4.5km long and ~ 0.5 km wide lens just east of the Insubric line.

- The origin of this peridotite body is not clear, having different hypothesis such as from Shervais (1979), that it is an uplifted and tilted mantle diapir that intruded the continental crust, or Quick (1995), stating that the body is actually an inclusion within the mafic complex of the IVZ.

- The data obtained through SEIZE and HiSEIZE will help in answering the uncertainties about the origin and the relationship of the peridotite body with the mantle.

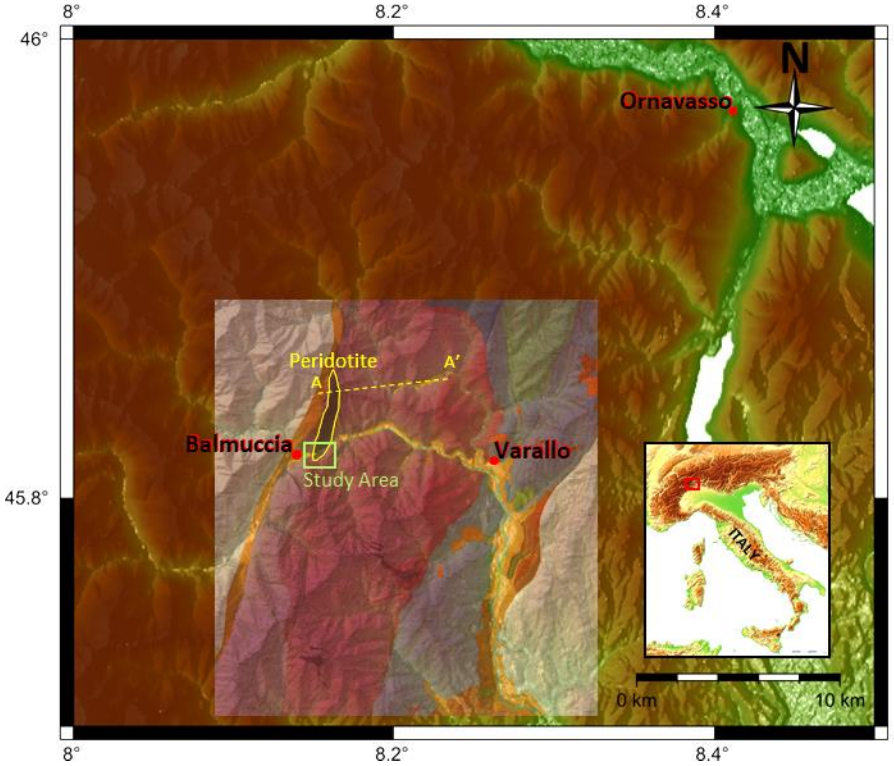


Figure 4: Location of the Balmuccia Peridotite within the Ivrea Verbano Zone. Overlaid geological features after *Quick et al., 2003.*

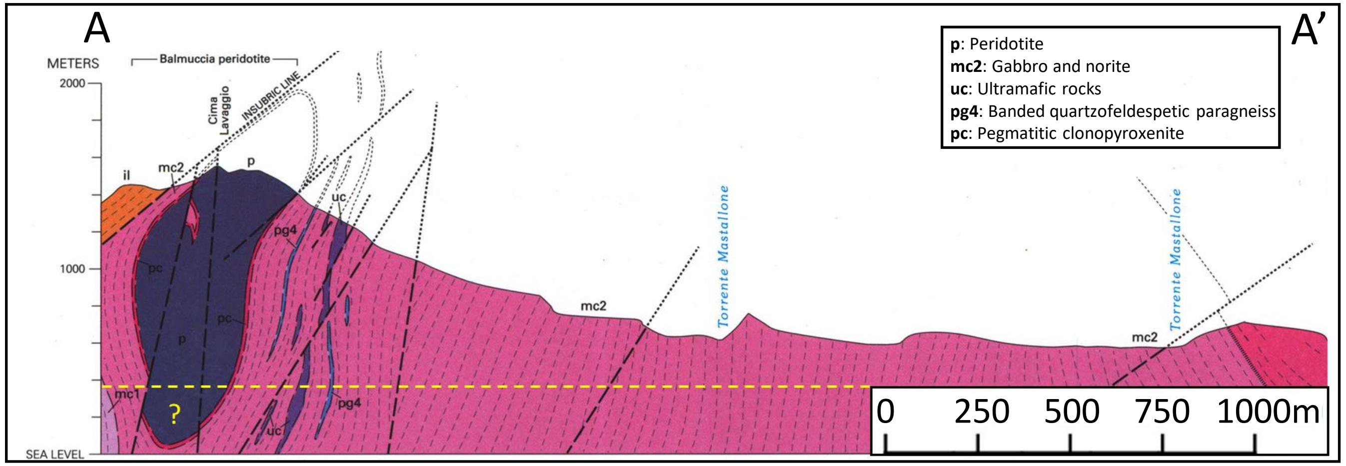


Figure 5: Geologic interpretation of the structure of the Balmuccia Peridotite. Modified from *Quick et al., 2003.*

Survey geometry

- Line 1: Geophones and accelerometers deployed alternately every 11m, forming a line of ca. 1800m length with 160 3C-sensors.
- Lines 2, 3a, 3b and 3c: 200 vertical geophones deployed every 10m to form two lines of ca. 1km length, spaced 50-80m apart.
- Source points following line 1, with 2.4km length and 22m spaced stations. In each source point, four shots were done in order to stack the data and enhance signal-to-noise ratio.

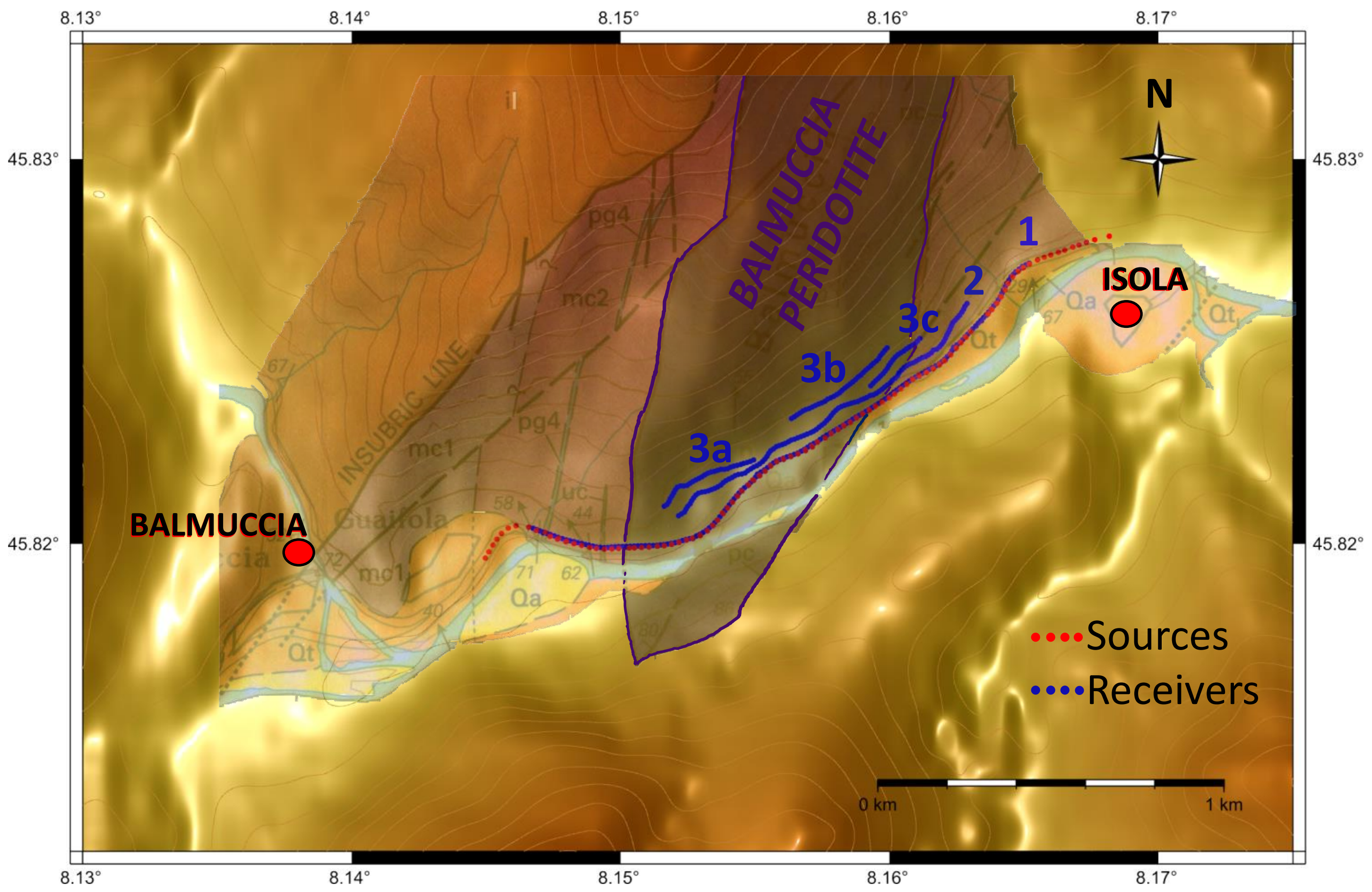


Figure 6: Digital Elevation Model of the Study area depicted in *figure 4*, with seismic lines, source line and overlaid geological features (modified from *Quick et al.,2003*) .

HiSEIZE

LINE	RECEIVER	ACQUISITION SYSTEM	SOURCE
1	80 3C-Accelerometers, linear response up to 800Hz 	SERCEL UNITES 	Prakkla-Seismos vibrator (GEOTEC S.P.A.)
1	80 3C-Geophones, 4,5-150Hz 	CUBE3 (GFZ Potsdam) 	Sweep 12-140Hz linear, 10-second sweep and 3-second listening time 
2, 3a, 3b, 3c	200 10Hz-Vertical-component geophones 	SUMMIT X ONE 	

Data Processing

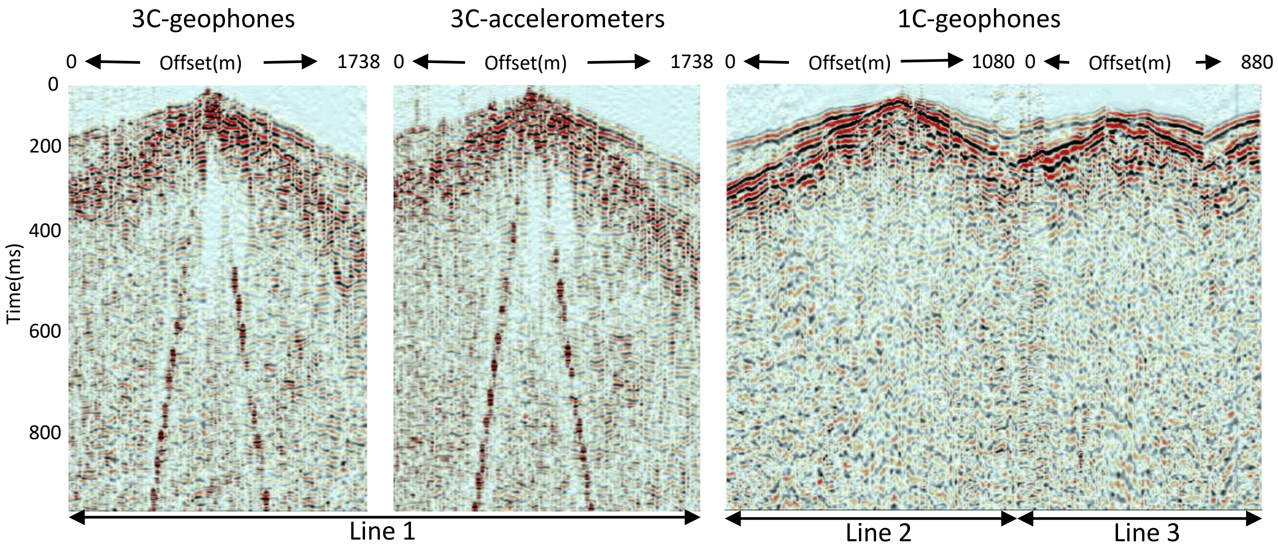


Figure 7: Example of raw shot records (AGC applied for better visualization) of vertical components in line 1 and 1C-geophones in lines 2 and 3.

Line 1: Pre-stack processing

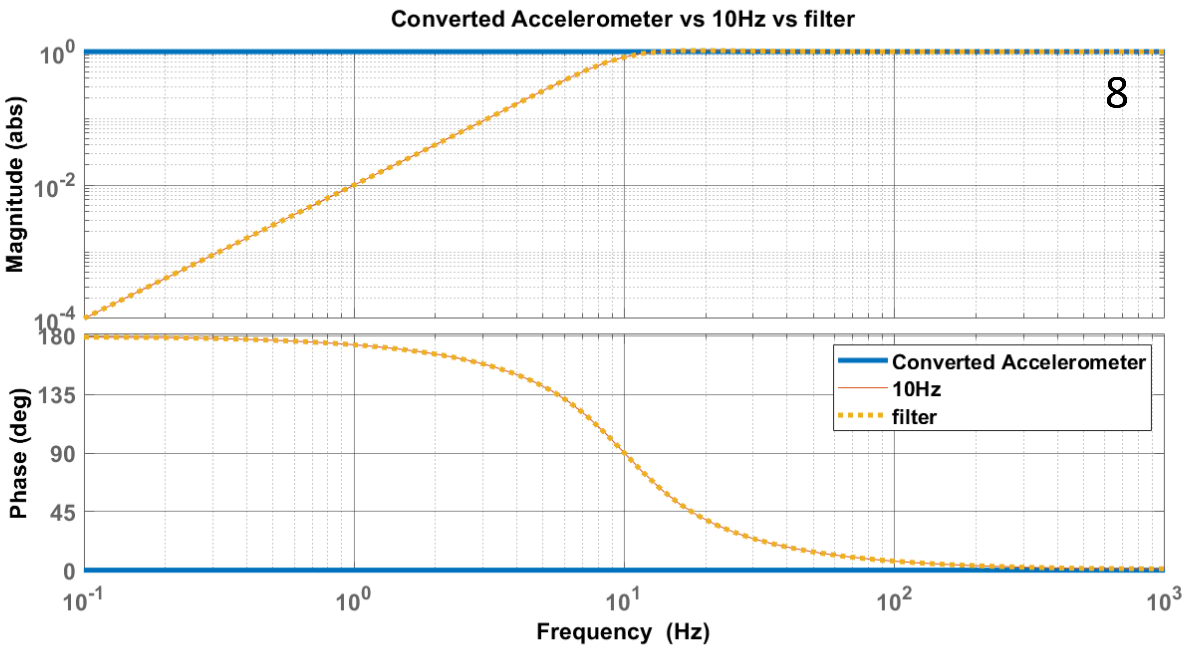
1. Separation of 3-component data in vertical and horizontal components. Further processing only applied to vertical component.
2. Diversity stacking (stack of 4 shots per source point).
3. Accelerometer to geophone conversion (integration).
4. Instrument simulation:
   - The amplitude and phase response of the sensors are different. A conversion must be made in order to combine the data.
   - Data converted to the response of a 10Hz geophone, matching the sensor deployed in lines 2 and 3.

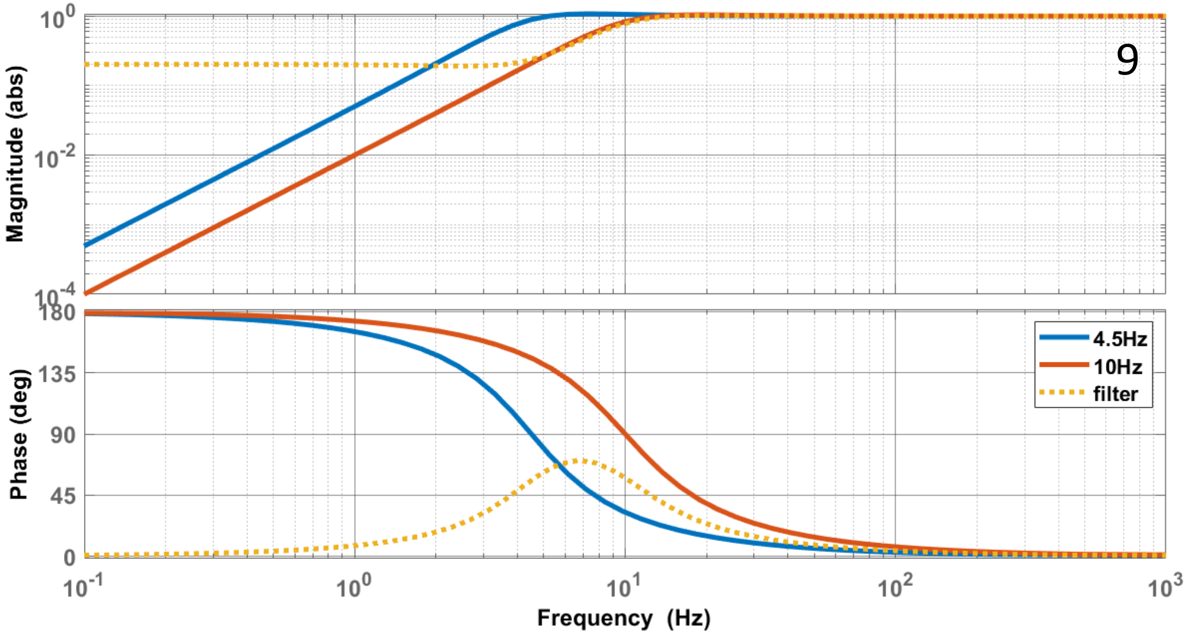
- The instrument simulation is performed through convolution of the data with the impulse response of a filter.
- The filter is built as:

$$FT^{-1}(S_a/S_b)$$

Where FT^{-1} is the Inverse Fourier Transform. S_a/S_b is the ratio of the transfer functions of the instrument to mimic, with eigenfrequency *a* (S_a), and the instrument deployed on the field, with eigenfrequency *b* (S_b).

Data Processing





- The comparison of amplitude and phase for the 4.5Hz geophone and converted accelerometer data against the 10Hz geophone to be simulated, shows differences between the instruments that must be considered to homogenize the complete dataset.

- To obtain S_0 and S_1, one must consider the complex-valued frequency response function of the sensor:

$$\frac{Z}{U}(\omega) = \frac{\omega^2}{\omega_0^2 - \omega^2 + i2D\omega\omega_0} = S(\omega) = S_{\omega_0}$$

Where Z is the measured and U the true ground motions, ω_0 is the eigenfrequency of the sensor and D is the damping coefficient.

Figures 8 and 9: Comparison between amplitude and frequency response of the instrument to be simulated (blue), the current instrument (orange) and the filter to be applied (yellow).

Data Processing

- In figure 11, it is clearly visible that the alternating geophone and accelerometer traces do not match and there is no continuity of the first breaks or S-wave arrivals.
- Figure 12 shows the results after the conversion from accelerometer to geophone, and the application of the instrument simulation technique. As can be seen, the first breaks and S-wave arrivals are aligned.

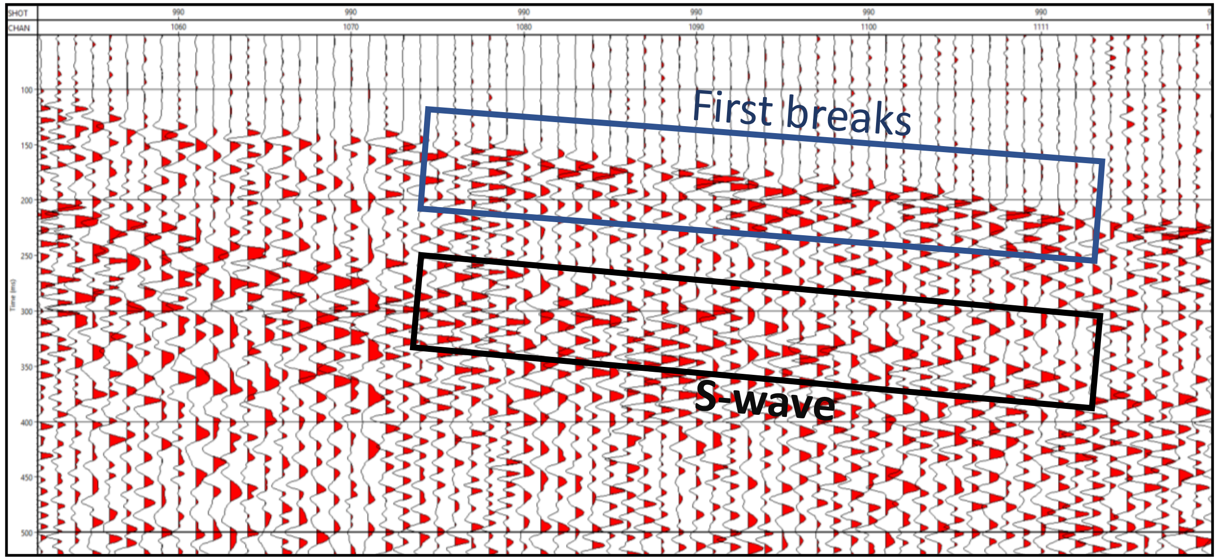


Figure 10: Raw data with **before** accelerometer to geophone conversion and instrument simulation .

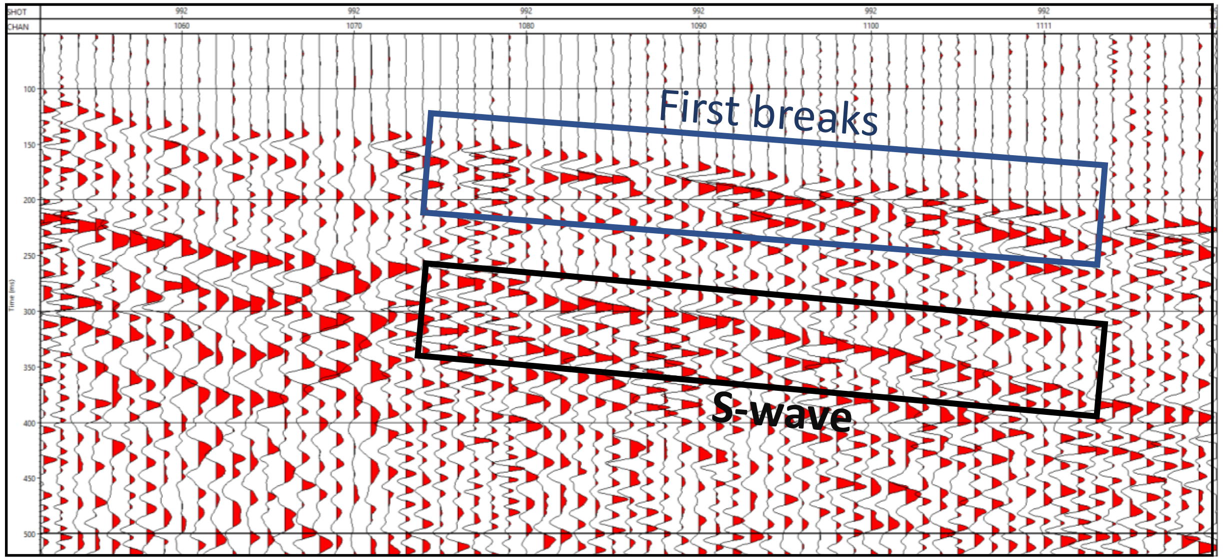


Figure 11: Raw data with **after** accelerometer to geophone conversion and instrument simulation .

Data Processing

Line 1: Pre-stack processing (continuation)

4. Merging of data after simulation.
5. Geometry.
6. Trace editing.
7. Elevation Statics.
8. First break picking.

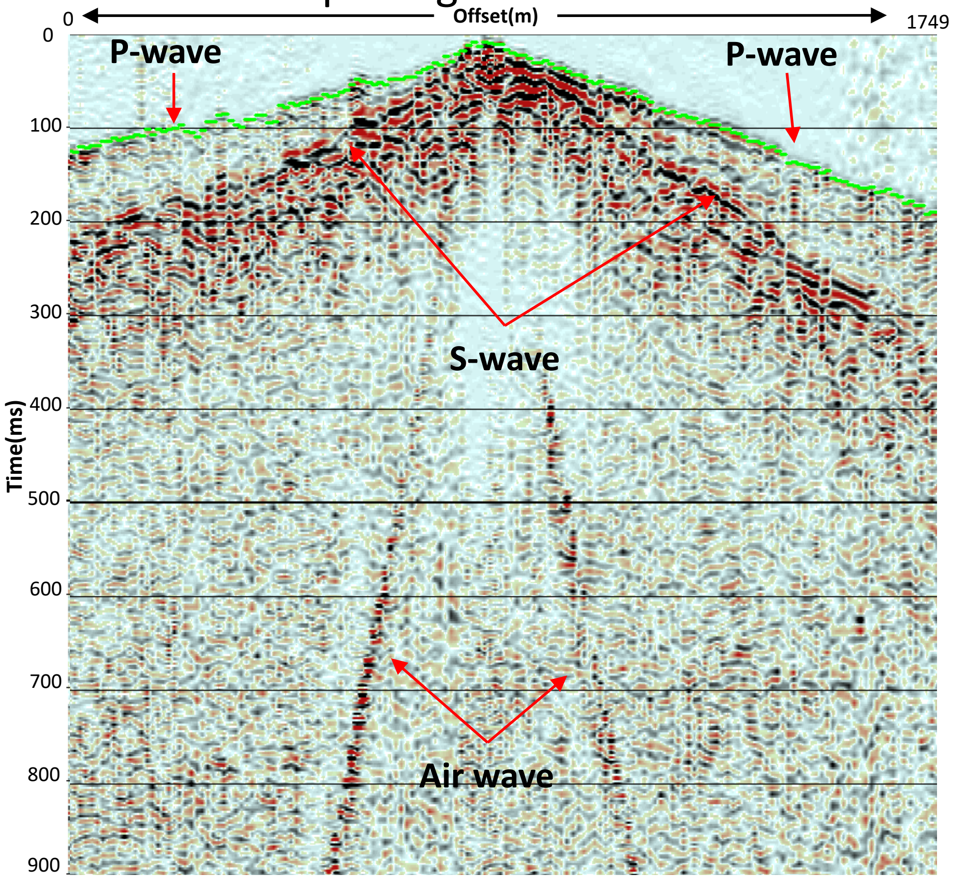


Figure 12: Example of shot record for line 1 after instrument simulation and data merge, with first breaks (green line) and elevation statics applied(AGC applied for better visualization).

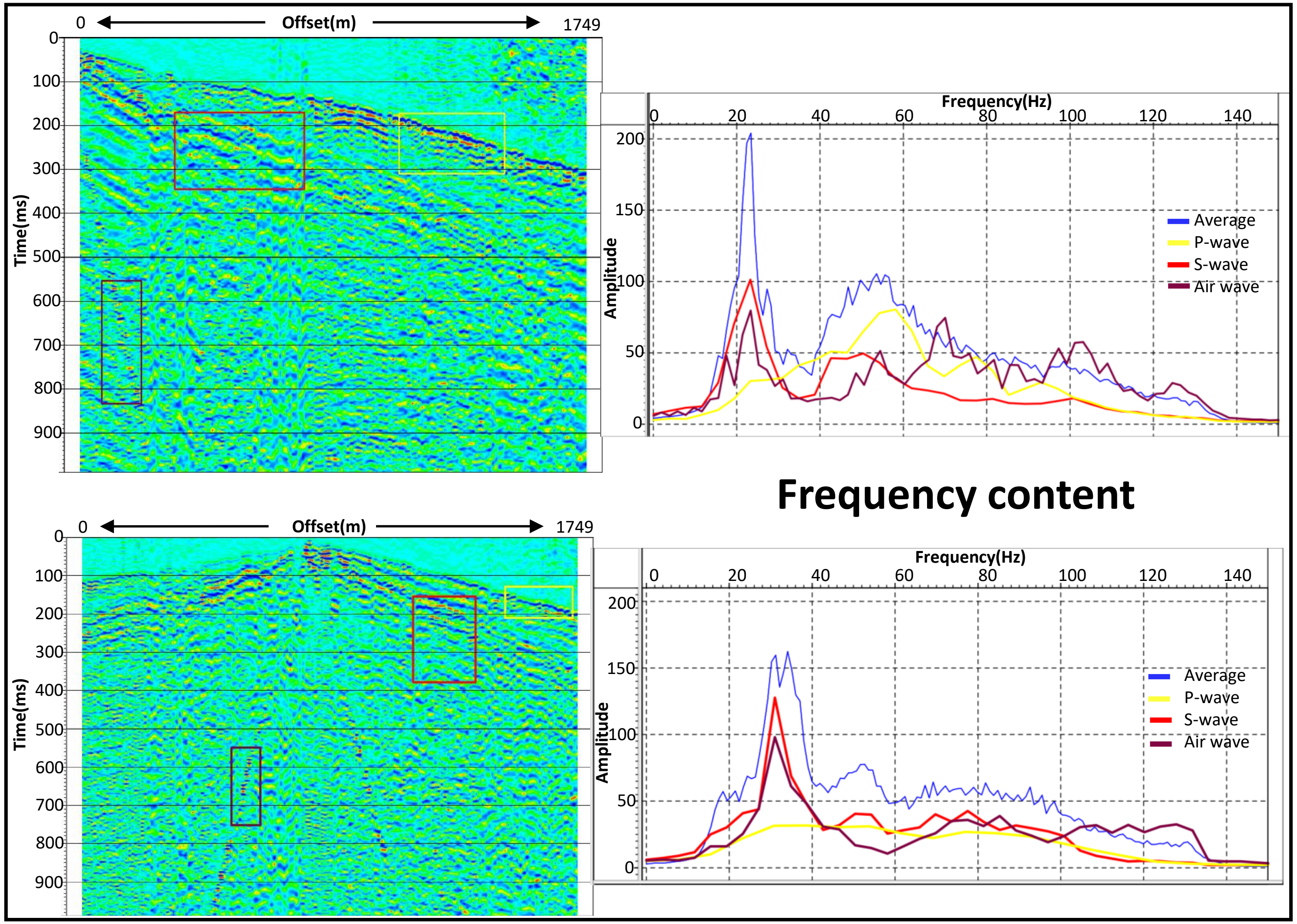


Figure 13: Frequency content of the data with an analysis of the frequency content of the P-wave, S-wave and air wave.

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Future steps and challenges

- Refraction tomography will be carried out to obtain a shallow velocity model and to perform refraction statics corrections.
- P-waves and S-waves will be separated.
- The absence of horizontal structure does not allow for the application of typical processing workflows for velocity analysis, such as semblance velocity analysis, thus, velocity modeling will be performed through other techniques, such as travel time tomography.
- After a successful processing workflow is generated for the vertical components in line 1, a similar processing workflow will be applied to lines 2 and 3.
- Data from lines 1,2 and 3 will be combined to derive a 3D model of the Balmuccia Peridotite.
- Data from the horizontal components of line 1 will be used to obtain and analyze Vp/Vs ratio and anisotropy in the area.
- The structural complexity of the area encourages the use of advance imaging techniques, such as S-wave imaging

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