Subsoil investigation through geophysical surveys on the shores of the "Bagno dell'Acqua" lake in Pantelleria, Italy

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Summary

This work presents preliminary results from geophysical studies within the "Conservation of the biodiversity of Lake Bagno dell'Acqua (Island of Pantelleria, Italy)" project aimed to reconstruct the lake's geological structures. Electrical Resistivity Tomography (ERT), Seismic Refraction Tomography (SRT), Multichannel Analysis of Surface Waves (MASW), and Horizontal to Vertical Spectral Ratio (HVSR) surveys were carried out along the lake's shores to delineate shallow subsurface stratifications. Sesismic and electrical profiling were positioned coincidentally along the southwestern shores, aiming to facilitated joint interpretation. The integrated interpretation, constrained by MASW results and compared to HVSR results, provided a subsurface reconstruction of the lake's shores. These preliminary results will be interpreted more effectively when compared with the results of coring conducted on the lake bed and with sub-bottom profiles obtained within the lake.

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Introduction

A set of geophysical studies were conducted within the scope of the "Conservation of the biodiversity of Lake Bagno dell'Acqua (Island of Pantelleria)" project. The geophysical surveys were aimed at detailed mapping of geomorphological structures, with particular attention to structures associated with fluid emissions.

The island of Pantelleria, located in the Sicily Channel (Fig. 1a), is a volcanic island that represent the emerged part of a more huge submerged volcanic structure. The island is indeed composed by volcanic products of both effusive and explosive activity like basalts, trachytes and rhyolites. In the north-eastern part the morphology of the island is characterised by the presence of the calderic depression of Caldera Cinque Denti that was formed by a collapse linked to the Green Tuff Plinian eruption dated at about 50,000 years BP (Civetta et al. 1984). The caldera hosts the Bagno dell'Acqua lake (Fig. 1b), also known as Specchio di Venere lake that is characterized by a sub–circular shape 450 x 350 m wide and a maximum depth of 13 m. The calderic debris and the Green Tuff deposits compose the geological substratum of this endorheic body of water; its composition is a mixing of both meteoric, hydrothermal and sea water (Aiuppa et al. 2007). Moreover, several hydrothermal springs are present within the lake close to the shoreline (Rotolo et al. 2017).

This work presents preliminary results from Electrical Resistivity Tomography (ERT). Seismic Refraction Tomography (SRT), Multichannel Analysis of the Surface Waves (MASW) and Horizontal to Vertical Spectral Ratio (HVSR) microtremor surveys conducted along the shores of the lake, aiming to achieve a detailed reconstruction of the shallow subsurface stratifications. The goal is to correlate the geophysical models obtained with those acquired offshore from sub-bottom profiles and core drillings. Figure 1 displays the locations of the geophysical surveys. The seismic and electrical profiling were positioned coincidentally along the southern shores of the lake, to facilitate a joint and mutually constrained interpretation of the inverse models (Cafiso et al., 2023).

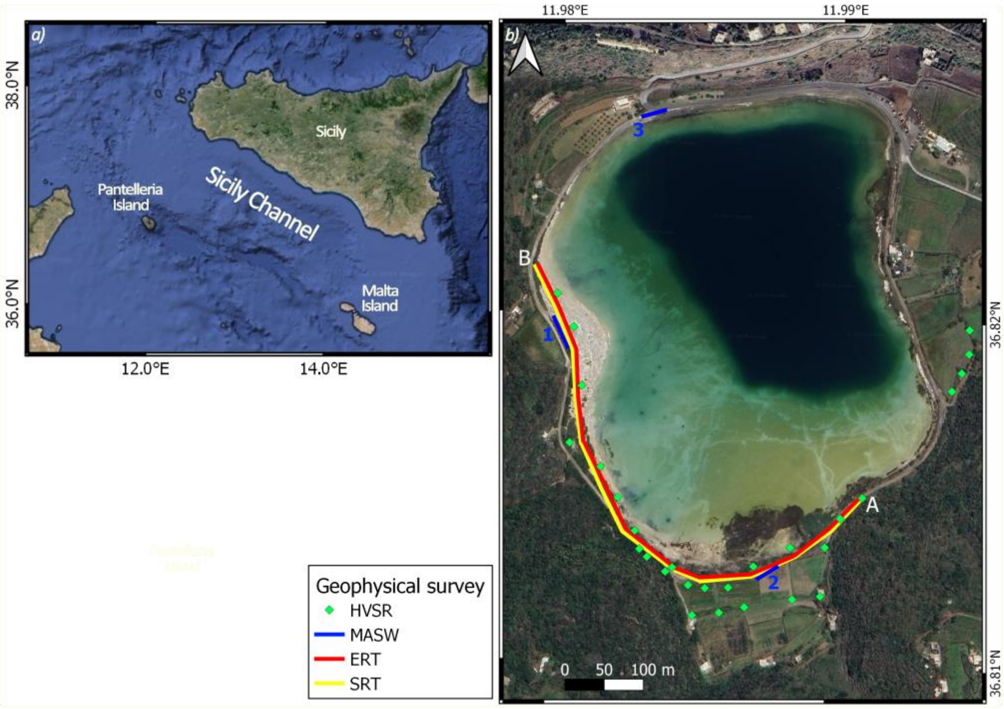

***Figure 1** a) Geographic location of Pantelleria Island in the Sicily Channel. b) Location of geophysical measurements along the shores of "Bagno dell'Acqua" Lake on Pantelleria Island, including electrical resistivity tomography (red line), seismic refraction tomography (yellow line), three MASW surveys (blue lines), and HVSR (Horizontal to Vertical Spectral Ratio) recordings (green diamonds).*

Method

The ERT survey is carried out by injecting electrical current into the ground through electrodes and measuring the resulting voltages, aiming at inferring the distribution of subsurface resistivity (Loke et al. 2013). The ERT survey was conducted along the southwestern shores of the lake (Fig. 1b) to identify variations in electrical resistivity of the shallow layers, providing indirect information about sediment porosity, water saturation percentage, and pore water salinity. The survey consisted of deploying 144 electrodes with an inter-electrode spacing of 5 meters, resulting in a total length of the spread of 715 meters. The survey utilized a mixed acquisition configuration that included both the dipole-dipole array and the Full Range Gradient array (Martorana et al., 2023). This choice was made to fully utilize the capabilities of the multichannel acquisition instrument used, the X612-EM+ multichannel resistivity meter from MAE s.r.l., capable of acquiring up to 96 simultaneous voltage measurements for each current dipole (Martorana et al., 2017). In total, 10,291 measurements were taken.
SRT is used to investigate the subsurface structure and properties of geological materials based on the travel times of seismic waves (White, 1989). These are generated by a seismic source (in our case a hammer hitting a metal plate), propagate through the subsurface and are detected by a linear array of geophones placed along the ground surface. The SRT survey was conducted to detect variations in the velocity of pressure waves in the subsurface, which are related to stratigraphic variations. The array used for the survey consisted of 144 geophones positioned coincidentally with the electrodes (fig. 1, b), with an inter-geophone spacing of 5 meters. A total of 25 shots were conducted, resulting in a total spread length of 725 meters. The multichannel digital seismograph X610-S from MAE s.r.l. was used. The length of the spread allowed to reach an investigation depth of 60 meters.
MASW method utilizes the dispersive nature of surface waves (Rayleigh waves) to determine the shear wave velocity profile of the subsurface (Park et al. 1999). This technique is particularly effective for assessing the mechanical properties of soils and rocks. Three MASW surveys were conducted (Fig. 1b) to obtain the variation of shear wave velocities with depth. This information was used to develop 1D models for a robust interpretation of the SRT and ERT results. Also in this case, the X610-S digital seismograph from M.A.E. was also used. Three MASW surveys were conducted with an inter-geophone spacing of 2 meters and an offset of 5 meters.
The Horizontal to Vertical Spectral Ratio (HVSR) method is a geophysical technique (Nakamura 1989) used to estimate the predominant frequency and amplification of seismic waves. It is particularly valuable for site characterization, seismic hazard assessment, and earthquake engineering studies. However, it has been successfully applied in several other contexts and different domains (e.g. Antunes et al., 2022; Galone at al. 2024; Iannnucci et al. 2020). The HVSR method involves the comparison of the amplitude of the horizontal and vertical components of ground motion across a range of frequencies, aimed at obtaining the spectral ratio of horizontal to vertical ground motion as a function of frequency. The key advantage of the HVSR method lies in its ability to identify resonance frequencies of the subsurface layers, which can amplify seismic waves and lead to increased ground shaking during earthquakes.
In this study, we acquired several single-station recordings of ambient seismic noise using the Micromed Tromino™ digital tromograph. A total of 29 measurements have been taken around the lake with the aim of identifying some potential geological features around the lake (fig. 1, b).

Results and Discussion

From the results obtained by inverting the apparent resistivity measurements (Fig. 2, top), a highly conductive near-surface layer (with resistivities less than 1 Ωm) is observed with variable thicknesses ranging from a few meters up to 20 meters. This conductive layer is evident in the zone between $x = 0$ m and $x = 250$ m, as well as in the zone between $x = 630$ m and $x = 715$ m. A more resistive layer (resistivity between 5 and 20 Ωm), showing significant heterogeneity, is visible between approximately $x = 250$ m and $x = 600$ m, and extends to a maximum depth of about 30 m. However, this resistive layer is not present in the southwestern part of the profile ($x < 250$ m). Below 30 m depth, a heterogeneous layer is characterized by resistivity between 2 and 8 Ωm, and it extends throughout the entire section up to the maximum depth investigated.

The results of SRT (fig. 2, bottom) are strongly correlated with ERT. In fact, in correspondence with the very conductive superficial electrical layer, the SRT shows a seismic layer characterized by a relatively low seismic velocity, between 500 and 2000 m/s. The thickness trend of this layer is well correlated with that shown by the ERT, particularly with a thickening for 200 m < x <300 m and a thinning for x > 300 m. Between x = 300 m and x = 600 m there is a high seismic velocity layer underneath (v_p between 400 m/s and 5000 m/s) in good correspondence with the highly resistive layer shown by the ERT. The MASW surveys are characterized by shear wave velocities of about 200 m/s for the first 20 m (fig.3a). As an example, MASW2 inverse model (fig. 3b) shows a shallow layer with v_s = 230 m/s, followed by underlying layers with lower velocities (around 180 m/s) down to a depth of 18 m. Below that, v_s increases to nearly 600 m/s. These results align well with the seismic stratification shown by the SRT at x = 150 m, except for the velocity inversion which cannot be identified by the SRT.

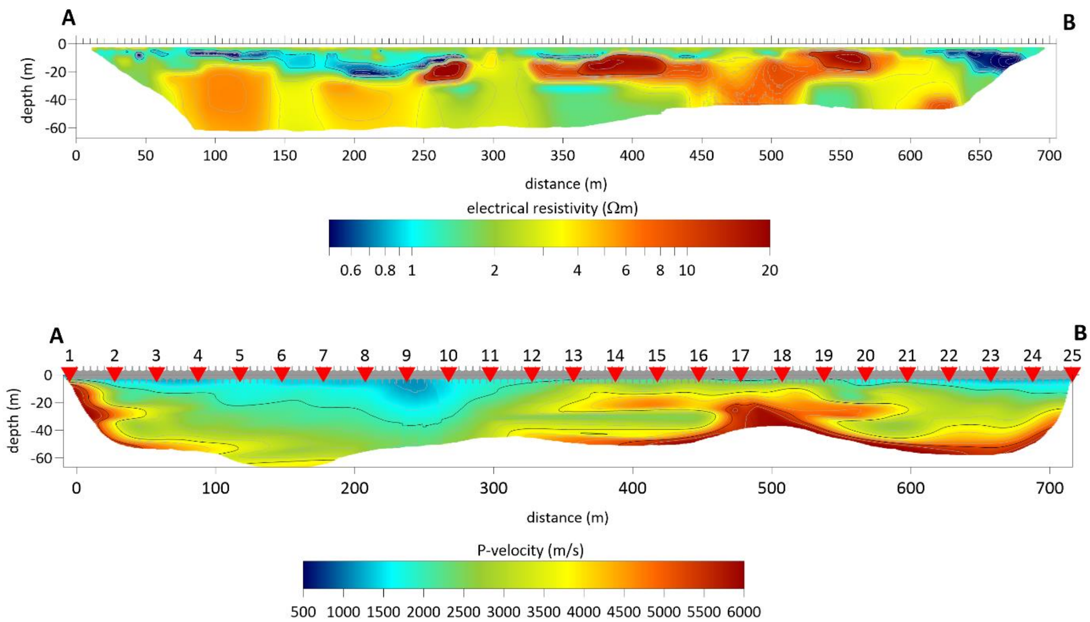

Figure 2 *Results of electrical resistivity tomography (top) and seismic refraction tomography (bottom) conducted along the southern shores of Bagno dell'Acqua Lake in Pantelleria Island.*

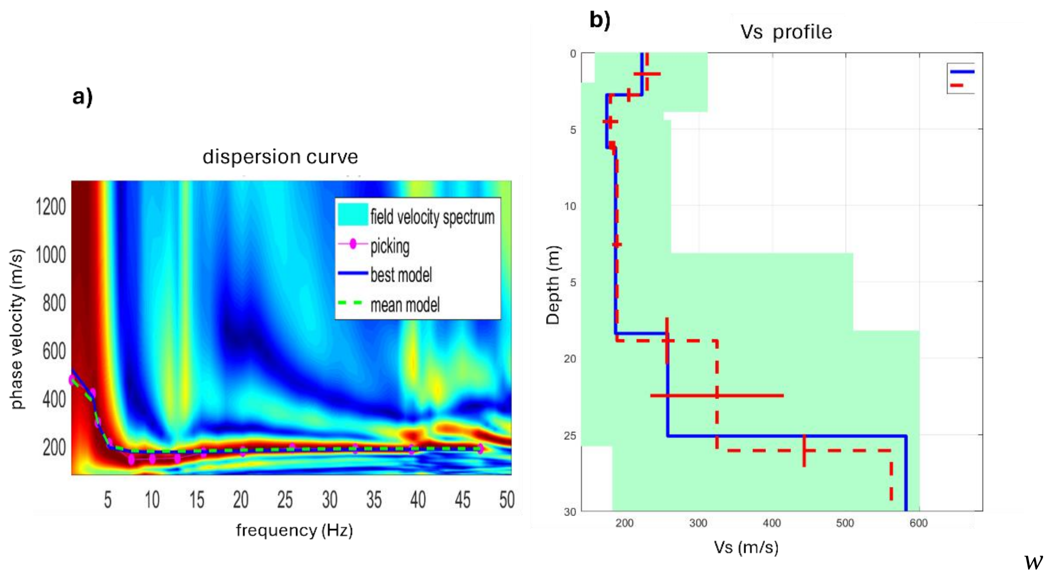

Figure 3 *Results of MASW 2 carried out in the southern shores of Bagno dell'Acqua Lake in Pantelleria Island. a) phase velocity spectrum with dispersion curve picking. b) model of Vs/depth by the dispersion curve inversion.*

In general, HVSR curves show a low-frequency peak (below 1 Hz) potentially attributed to deep interface and in several locations a deep below 1 in amplitude which can be related to potential velocity inversions in the stratigraphy. However, this needs to be better investigated and confirmed with more measurements and data from other techniques. In the eastern part of the lake stratigraphic peaks around 2 Hz were identified. In the southern part we identify potential features in the spectra which needs further investigation. These could be attribute to potential shallow velocity inversion zone or they could be related to the bantic formation present to the shores of the lake. In fact, moving inland, toward the cultivated areas and picks are at higher frequencies (more than 5 Hz) and they can be associated with the coverage of the agricultural soil. A similar trend is seen on the western side of the lake.

Conclusions

The results of the integrated geophysical surveys conducted on the shores of Lake Bagno dell'Acqua in Pantelleria, although in a preliminary phase of interpretation, have allowed for a geophysical reconstruction of the subsurface. This reconstruction can lead to a true stratigraphic interpretation when compared with the stratigraphic data obtained from the coring carried out on the lake bed and with the reflection seismic profiles conducted within the lake, which are still undergoing processing and interpretation. This integrated approach will provide valuable insights into the geological and hydrogeological characteristics of the lake, facilitating informed management and conservation strategies for the biodiversity of the lake.

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