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A new multiscale and multisensor strategy for the characterization of groundwater discharge in coastal areas.

First results of the SUBGEO project in Pianosa island

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The **SUBGEO** project aims to develop an investigation strategy based on the integrated use of geophysical methodologies for the multi-scale and multi-resolution characterization of coastal areas, aimed at sustainable and optimal management of water resources and the areas themselves. Among the various geophysical techniques currently available, SUBGEO focuses on the integration and methodological advancement of electrical and electromagnetic survey methodologies, characterized by almost negligible environmental impact, the ability to investigate extensive areas in relatively short times, and, above all, high sensitivity to the presence of fluids in the medium under investigation and their characteristics. The plan is to test the same strategy in three different areas.

Fig. 1: The island of Pianosa and its position in the Tuscan Archipelago. (Google Earth, 2024). Red lines are the ERT surveys acquired in 2023 (NS oriented) and in 2024. The point shows the location of the borehole ERT.

The first test area

The island of Pianosa has been selected as a test site because of the availability of prior geological/hydrogeological information, the availability of previous geophysical investigations, the relevance of the geographical context, and the presence of favorable logistical conditions (potential use of facilities on the island owned by CNR). The experimental phase begun in October 2024. The first measurements, acquired according to the defined geophysical investigation strategy, were carried out on Pianosa Island. Here a total of more than 3.5 km of geoelectric data were acquired testing both well-surface acquisitions, pseudo 3D acquisitions and land-marine acquisition. In addition to this data, following the data integration criterium, in the same area where geoelectrical data were collected, georadar and electromagnetometer surveys were conducted.

Geological framework

The island of Pianosa is in the northern Thyrrenian sea, southwest to Elba island, in the Tuscan Archipelago. It is notably flat, and unlike the other islands in the archipelago, it is the only one entirely made up of sedimentary rocks, whose formation ranges from the Neogene to the Holocene. Two Miocene formations, namely the Marina del Marchese formation (Burdigalian) and the Golfo della Botte Formation (Late Tortonian–Messinian), are found along the cliffs in the northwest (Golfo della Botte area) and at Cala della Ruta on the southern coast of the island. These formations consist of marls and silty marls with intercalations of calcarenites and conglomerates, and silty clays with intercalations of sandstones and conglomerates (Foresi et al., 2007): a succession of permeable and impermeable layers.

The Pianosa Formation (yellow in Fig. 2), dating from the Upper Pliocene to the Lower Pleistocene, outcrops extensively across the entire island. It is composed of highly fossiliferous calcarenites and calciruditesi, which are very permeable due to primary porosity and are locally affected by systems of jointing that intersect the stratification (Raggi, 1983; Graciotti et al., 2003).

Finally, there are limited outcrops of Late Pleistocene coastal units along the eastern coast (coral pink in Fig. 2). The different types of sediments described indicate the variability of the depositional environment related to the Quaternary tectonic phenomena of uplift and subsidence in the area. The Miocene units have a southwest-dipping monocline structure, while the Pianosa formation has a sub-horizontal structure. The Quaternary tectonic movements in this area of the Tyrrhenian Sea caused the Miocene units to rise above sea level in the northwest, while they remain submerged in the east, where the Pianosa formation is also partially below the coastline.

The characteristics of these rocks account for the lack of surface hydrology and the flatness of the island. Meteoric waters permeate the calcarenites, which form a complete aquifer, and feed the shallow groundwater, which is limited at the bottom by the impermeable Miocene units. However, the shallow groundwater meets the conglomeratic and calcarenitic levels of the Marina del Marchese and Golfo della Botte formations. These communication channels would have fed a deep aquifer structured in multiple levels (Raggi, 1983). This is confirmed by the numerous wells scattered across the island (Fig. 3). Wells drilled to 100 meters in the 1970s show this link. Those no deeper than 30 meters only intercept the shallow groundwater, widely used for the water supply of the prison structures while they were in operation. The chemistry of the well waters indicates the saline water intrusion , which becomes more pronounced the more the shallow aquifer is depleted, reducing the hydraulic pressure of the fresh water.

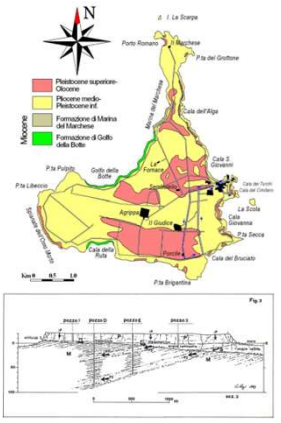

Fig. 2: Schematic geological map of Pianosa island. In yellow the Plio-Pleistocene units and in coral pink the Pianosa Formation (Foresi et al., 2007). Below, the WE-oriented hydrogeological cross section (Raggi, 1983).

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This poster presents the models resulting from the inversion of the tomography data acquired during the 2024 survey. A first NS-oriented electrical tomography was acquired in 2023 as part of HYDRO-ISLAND project, in figure 3, intersected with the most recent ERT. The EW tomography, at the bottom, reaching a depth of about 40 meters below sea level, clearly shows a nearly continuous conductive body identified as the clay layers on which lies the shallow aquifer of the island. The joint analysis of the tomographies and the borehole stratigraphy will explain the presence of zones with higher resistivity values, visible in the image below. Figure 5 instead shows a cross-section of the 3D model resulting from the inversion of the data of three electrical resistivity tomographies centered on the borehole named PN_S (Fig. 4), which reveals the presence of the aquifer at 15 meters below the ground level. This data is confirmed by the measurements acquired on the same days by the hydrogeologists.

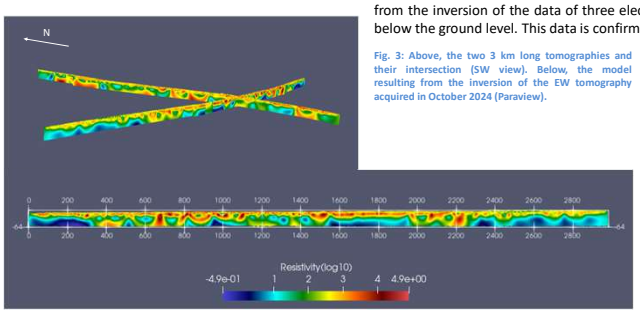

Fig. 3: Above, the two 3 km long tomographies and their intersection (SW view). Below, the model resulting from the inversion of the EW tomography acquired in October 2024 (Paraview).

Fig. 4: Location of the three electrical resistivity tomographies centered on the borehole PN_S.

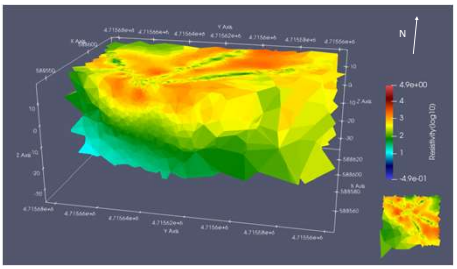

Fig. 5: Cross section of the 3D model resulting from the inversion of the three electrical resistivity tomographies on the borehole (RESIPY on PARAVIEW).

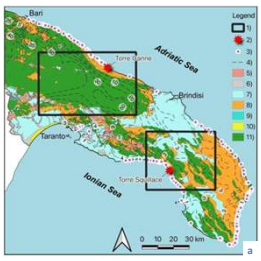

Fig. 6: a) Schematic hydrogeological map of preliminary study area and test site areas. 1) Torre Canne study area and Torre Squillace study area, 2) study area main location, 3) coastal spring, 4) piezometric contour line (m asl), 5) clayey deposits, 6) pelitic deposits, 7) silty-sandy and/or arenitic deposits, 8) arenitic deposits, 9) ruditic deposits, 10) sandy-gravelly deposits, and 11) limestone or dolostone. b) Torre Canne site and (c) Torre Sant'Isidoro site with the yellow lines representing the planned ERT.

Other test areas

Two sites in the Pugliese territory were designed as the most optimal for planned experiments: the first is between Murgia and Salento, on the Adriatic coast at Torre Canne (municipality of Fasano, Brindisi), while the second is Sant'Isidoro, located on the Ionian coast in the municipality of Nardò, near the border with the municipality and marine protected area of Porto Cesareo. The selection is based on knowledge of spring presence, surveyed on land and/or through aerial infrared thermal remote sensing, as well as the site's geological and geomorphological conditions, also considering the technical feasibility of conducting the planned geophysical surveys.

Both sites show the presence of drinking well used by the public water service due to the high groundwater quality and monitored by the regional monitoring network . The areas suffer of the decrease of the aquifer recharge for the combined effects of increasing temperatures and decreasing rainfall. Sinkholes and doline dominate widespread the areas of limestone and dolostone outcropping, characterising the carbonate aquifer as karstic coastal aquifer while coastal caves are frequent (S. Isidoro).

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