



THE “GROTTA DELLA POESIA” (LECCE, ITALY): STUDY THE CONSERVATION DEGREE USING GEOPHYSICAL METHODS

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2D seismic tomography and 2D electrical resistivity tomography (ERT) were combined to the instability of the hypogean archaeological site named “Grotta della Poesia”. The interpretation of integrated geophysical data resulted in evaluating some rock mass parameters, such as rock quality designation, linear fracture density, and fracture density.

A study on the instability assessment of the archaeological site “Grotta della Poesia”, located 20 kilometres east of Lecce near the Melendugno village (Lecce province, southern Italy), was performed by combining geological and geophysical methods. Two large dolinas (named respectively Large Poesia and Small Poesia) are the main surface landforms of a hypogean karst system developed inside a tabular coastal plain which is presently a few meters elevated above sea level. The system is furtherly made of intervening galleries, a large dome cave, some minor cavities and a gallery which connects the Small Poesia to the sea cliff (Fig. 1). In detail, is the Small Poesia which has a special importance by virtue of an impressive number of signs, symbols and inscriptions datable between the Second Millennium before Christ and the Republican Roman Age. The name derives from the Greek term “poesia”, which points out the rising of

sweet water and, in fact, in the small cave a spring flowed until few years ago [1].

Archaeological and geological studies have shown that the Small Poesia has suffered some morphological changes, evolving from an underground cave to a large dolina through a series of collapses of the ceiling, caused by a composite karstic and sea erosion phenomena probably triggered by artificial mediaeval excavation [2]. The zone of “Roca” is carved in soft calcarenites referable to the Upper Pliocene and it is elevated about 10 m above mean sea level.

This bedrock is covered by recent and present beach and dune sands. Landward, the landscape grades down to a number of depression, placed at about 1 - 2 m a.s.l., and filled by sandy-clayey deposits. In the northern part of the area, thick layers of calcarenites and calcirudites with abundant macrofossils crop out; they have been referred to the “Calcareniti del Salento” Pleistocene unit by [3].

Numerous karstic caves occur in the area, some of them recorded in the regional inventory of the “Federazione Speleologica Pugliese” [4] (such as “Grotta dello Spezzale”, “Grotta della Poesia Grande” and “Grotta della Poesia Piccola”).

The calcarenitic and calcilitic layers are affected by four systems of fractures, clustering around the directions N-S and E-W [2]. These fractures, to a large extent sealed by carbonatic concretions, show varying spacing from some decimeters to some meters. Fractures constitutes the preferential surface of detachment of numerous rockfalls occurring along the coastline. Some karstic caves develop at the base of the cliff along the fractures. The analysis of the spatial distribution of the density of fracture point out a substantial uniformity of the degree of the fracture. In some small tracts of the coastline, the density of fractures increases to about 0.65 m/m² [5]. Fractures are generally sealed by calcitic concretions; however, some fractures are widened by karstic dissolution. Fractures of this last type show at present openings of the order of some millimeter to some meters in the case of complete development of galleries. Some fractures are partially or totally filled by colluvial deposits.

Material and methods

Two geophysical methods, electrical resistivity tomography (ERT) and seismic travelttime tomography were used. In the ERT method the distribution of the electrical resistivity of the subsoil is obtained by injecting electrical current (by the current electrodes) into the ground and measuring the potential difference (potential electrodes) at two determined points of the surface. The method is based on the application of Ohm’s law

$$\rho = k (\Delta V/I)$$

where ρ is the apparent resistivity, k is a geometric factor that depends only on the reciprocal positions of the

current and potential electrodes; ΔV is the measured potential difference, and I is the intensity of the injected current. The apparent resistivity values depend on the true resistivity distribution. The true resistivity distribution in the investigated medium can be estimated by an inversion procedure based on the minimization of a suitable function [6,7].

For the ERT survey a 48-channel Syscal-R1 Resistivitymeter (manufactured by the Iris Instruments), in multielectrode configuration was used. Resistivity field data were collected using 48 electrodes with 0.5m spacing. The selection for electrode arrays was dipole-dipole. The dipole-dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity. This means that it is good in mapping vertical structures, such as voids, but relatively poor in mapping horizontal structures [6].

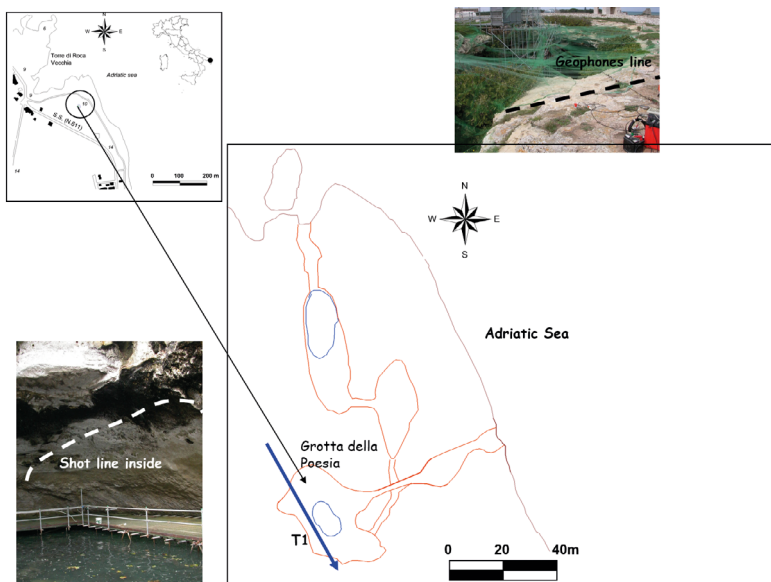
In the seismic refraction method, the seismic waves, created by artificial sources such as a hammer, propagate through the medium and are refracted at interfaces, where the seismic velocity or density changes. Geophones laid on a single line record the waves returning to the surface after travelling different distances through the ground. By measuring the travel time between the break and the recording of a seismic signal, the seismic velocity in the subsurface and the depth of the interfaces may be inferred. Conventional analysis of seismic refraction data sets makes simplified assumptions about the velocity structure that conflict with observed heterogeneity, lateral discontinuities, and gradients [7]. Refraction tomography is designed to resolve velocity gradients and lateral velocity changes, enabling it to be applied in settings where traditional techniques fail. The method used in this paper utilizes non-linear travel time tomography consisting of ray tracing for forward modeling and simultaneous iterative reconstruction technique (SIRT) for inversion.

In this method the velocity model is represented by quadrangle cells. The width of each cell is chosen as the receiver interval. First-arrival travel times and ray paths are calculated by the ray tracing method based on Huygen’s principle [7]. A ray is expressed as a line connecting the nodes arranged on the cell and the travel time between a source and a receiver is defined as the fastest travel time of all ray paths. A model is updated by the SIRT (for more information see [7]).

The seismic tomography was performed along one line (Figure 1) by distributing 48 geophones and 29 source locations (Figure 2a). 48 vertical geophones (14 Hz) with 1 m spacing and 29 shot points were located along two parallel lines. The geode instrument was used. The elastic signal was generated by striking a rod with a hammer. The 48 receivers were placed at the measurement surface ($z = 0$) every 1 m, and 29 shot were placed inside the cave every 1 m. The geode instrument were used.

The source-receivers geometry is show in Figure 2a.

▼ FIG. 1 : The “Grotta della Poesia” with the location of seismic and electrical profile.



Rock quality parameter

The degree of fracturing can be estimated by evaluating the ratio between the seismic velocity in the fractured rock and the not-fractured one. The number of fractures per unit length defines the linear fracture density (Γ). Its value is obtained by counting the number of fractures intersecting a unit length of the scanline. The fracture density parameter C is defined as [5]:

$$C = \frac{\Gamma}{\langle \cos\theta_i \rangle \cdot (1 - \ln r_{\min})}$$

where θ_i is the orientation of the i^{th} set of fractures ($\theta_i = 0^\circ$ for vertical fractures assuming vertical flow), $\langle \cdot \rangle$ denotes average, Γ is the linear fracture density and r_{\min} is the smallest fracture length.

The rock quality designation (RQD) parameter, based on number and spacing between fractures, is simply defined as the sum of lengths of rock pieces (intact lengths) or fracture spacings greater than 10 cm expressed as a percentage of the total length of the scanline. Table 1 shows the rock quality classification based on RQD parameter.

Once the thickness of the rock that forms the roof of the cave had been estimated, a seismic travelttime tomography survey was undertaken.

| RQD % | ROCK QUALITY |
|--------|--------------|
| 0-25 | Very low |
| 25-50 | Low |
| 50-75 | Discrete |
| 75-90 | Good |
| 90-100 | Very good |

◀ **TABLE 1:**
Rock quality classification based on RQD parameter

Geophysical results

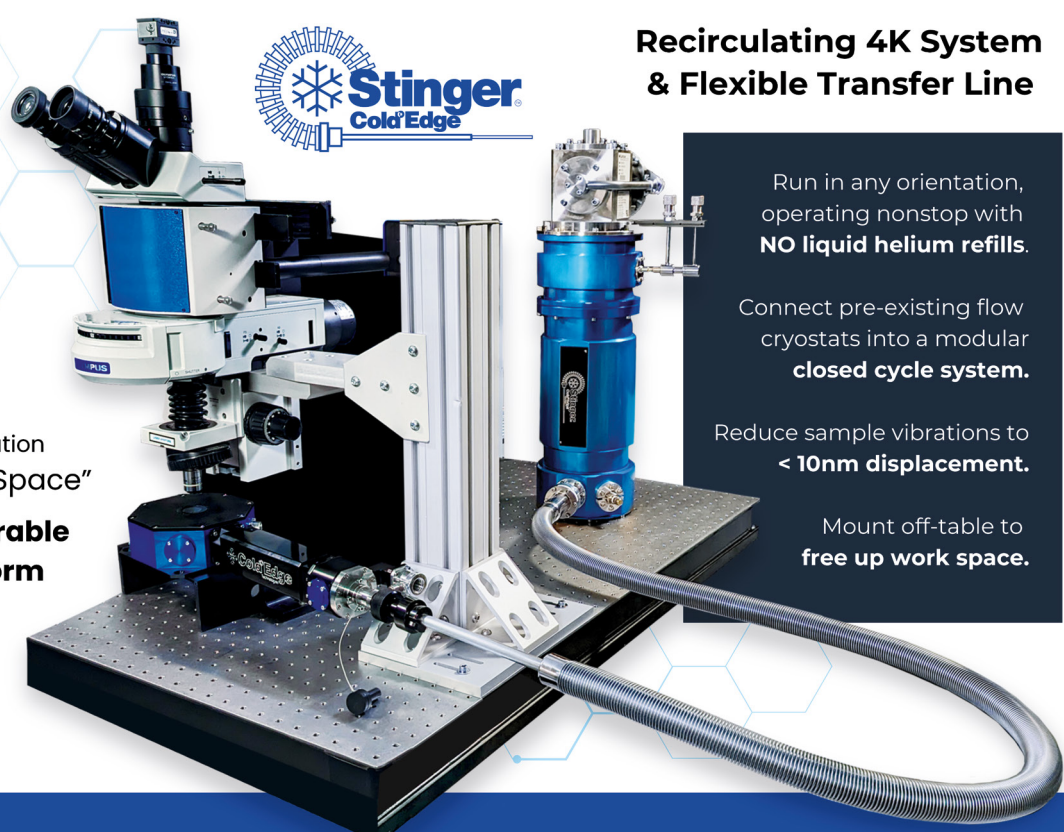
Seismic refraction tomography allows to obtain information about the seismic waves velocity in the roof of the cave. Figure 2b illustrates the seismic wave velocity variation model. A low seismic velocity area is noted, labelled L ($300 < V_p < 600$ m/s).

Using the relationship 1 is possible to obtain the parameter density of fracture C (Figure 2c).

Figure 2c show an higher density of fractures (H) in correspondence with the low (L) seismic velocity.

The geological model established by means of a 2-D resistivity imaging profile (Figure 3), allows for two different zones to be detected. The first zone (upper 1–2 m):

- the high resistivity zone (about 400 ohm m), labelled H in Figure 5, clearly indicates a zone of poor quality rock. The resistivity values indicate that the zone consists of fractured carbonate rock;



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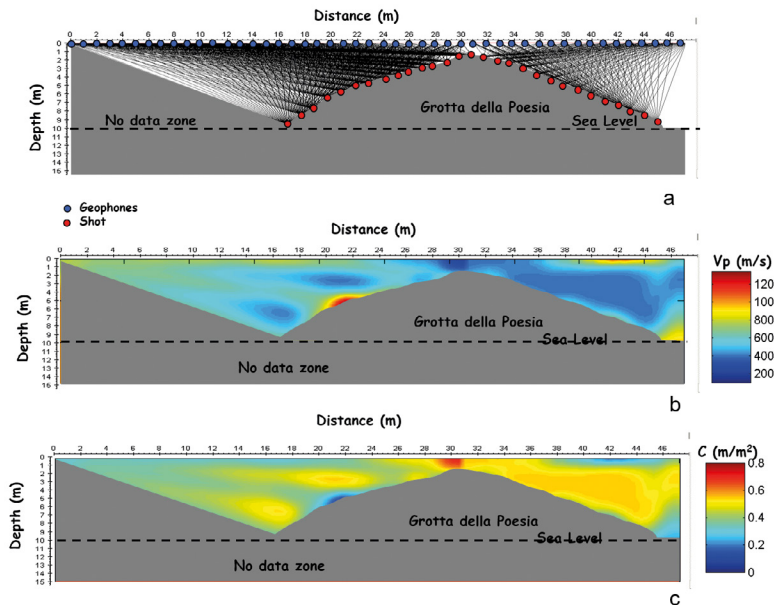
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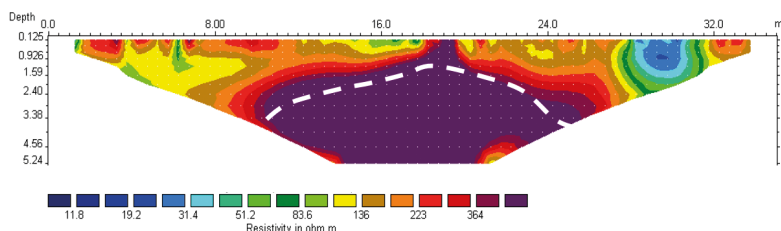
▲ FIG. 2: a) The traveltime tomography acquisition geometry; b) Seismic velocity V_p distribution; c) The density of fracture C distribution.

the low resistivity zone (about 30 to 40 ohm m), labelled (L) in Figure 5, corresponds to the fractured carbonate rock, although the resistivity values are low enough to indicate that the carbonate rock is fractured and the fractures could be filled with clay or “terra rossa”.

Conclusions

Geophysical methods are crucial for assessing and maintaining rock stability because they provide non-invasive ways to investigate subsurface conditions, identify potential hazards, and monitor the behavior of rock masses. These methods help characterize the physical properties of rocks, locate fracture zones, and assess the impact of factors like water content and weathering on stability. In this research it was used an integrated interpretation of the results obtained from ERT and seismic tomography data sets to identify fractures in a calcarenite and therefore to assess its quality in order to perform a preliminary evaluation of the stability of the roof of the Grotta della Poesia. The ERT method provided estimates of the resistivity distribution in the shallow subsoil. By combining resistivity and P-wave velocity distributions in the subsoil ambiguities in the interpretation were minimised. The integration of the two geophysical methods is a useful tool in carrying out geognostic investigations at restricted sites, where invasive techniques such as drillings cannot be performed. The integrated geophysical analyses outlined, in the studied area, a highly unstable region in the zones labelled L in the seismic results that indicates very intense anomalies, most likely referable to open fractures.

▼ FIG. 3: 2D distribution of the resistivity.



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