DETECTING KARST CAVITIES AND FRACTURES BY GEOPHYSICAL METHODS

R. QUARTO, D. SCHIAVONE

Dipartimento di Geologia e Geofisica, Università di Bari, Bari, Italy

1. Introduction

Natural and artificial cavities are widespread in southern Italy due to regional geolithological and structural features. The investigation of their presence, sometimes unknown, and the definition of their characteristics, play an important role in many fields: archaeology, speleology, geological hazard connected to their occurrence in urban areas. In all of these fields, the geophysical techniques have gained increasing importance due to their non-invasive nature as well as to the possibility of executing extended surveys at reduced costs as compared to direct methods.

In this paper, the results of different geophysical surveys carried out on a karst prehistoric cave, are presented. The site studied is located in a southern Italian area characterized by a complex hydrographic system composed of different channels, all flowing into the S. Croce valley (Fig. 1). Many natural caves are present in the area and the S. Croce one is the largest and most important both for archaeological and speleological interest. Moreover, the presence of a system of caves found in the area has urged the municipality to test, by means of non-invasive methods, the possible presence of undiscovered caves which could be of speleological interest, starting with the yet un-studied S. Croce one.

The studied cave extends for about 100 m in the North-South direction. On the cave walls, there are calcite concretions and small stalactites. Furthermore, both on the wall and on the ceiling, karstic holes and fractures, either empty or filled by residual products of karstification, mainly clayey red deposits (“terra rossa”), can be observed. Some holes and fractures seem to continue toward the ground surface. In one case this is verified where a chimney-like fracture reaches the surface. At the time of survey, the cave ended against a natural filling composed of “terra rossa”. These deposits blocked the cave, making any assumption on its continuation impossible.

4. Searching for the cave extensions

The goal of the geophysical study in the area above the cave was the determination of its possible extension. The search for cavities is always a difficult geophysical task, made more difficult in the present case by the...
following two factors:
- The large depth-to-diameter ratio estimated from the existing cave.
- The lithological variability connected with the karst geology.
These two characteristics of the study area rendered the use of surface resistivity methods inapplicable (Militzer et al., 1979), even though arrays, such as the two or the three-electrodes ones, with the greatest depth of detection both of resistive and conductive targets (Apparao et al., 1992), were used. Thus, the best strategy to adopt in this case is the use of different methodologies justified by the target characteristics. In particular, the self potential (SP), the mise-à-la-masse (MALM) and the GPR surveys were applied supported by a ground resistivity survey for defining the shallow resistivity distribution. All the electrical measurements were obtained by using the same 5 m x 5 m square grid (Fig. 2).
4.1. Resistivity survey

The resistivity survey was performed by adopting a Wenner profiling technique with a 5 m electrode spacing. (Fig. 3) shows the contour map of the calculated apparent resistivity values. The map shows large resistivity variability ranging from 100 ohm-m to 1000 ohm-m. The resistivity values decrease from north to south with high gradients at about N 70. A localized resistive anomaly is present around the cave at N80, indicating a shallow, heterogeneous overburden. The most resistive zone can be correlated with a compact limestone outcrop, whereas the least resistive one with more fractured and karstified limestones, covered by a thin conductive weathering. A sharp contact between the two zones, directed E-W, could be assumed.

![Figure 3. The Wenner apparent resistivity map.](image)

4.2. Self potential survey

The self-potential method was proposed by Quarto and Schiavone (1996) for the first time as a preliminary investigation in cavity detection problems. The survey was carried out along E-W directed profiles. We used a fixed base technique. To obtain reliable data, measurements were taken going forth and back and calculating the mean value at each station. Due to possible seasonal change of the SP intensity values (Quarto and Schiavone, 1996), measurements were repeated in different seasons. Two of the three measurements are shown in the maps of figure 4. Considering the anomalies present in both the measurements, the largest ones are located on the central part of the cave where its axis changes direction, at N70 and N100. A further, large anomaly is found on the SW corner without any apparent connection with the cave. Electrokinetic phenomena acting downward in a more fractured and karstified rock mass, with underground voids, may explain this anomaly. Finally, no persistent anomaly occurs along the possible continuation of the cave.

Comparison with the Wenner resistivity map shows no correlation between self potential anomalies and shallow resistivity features. This discrepancy suggests that the SP negative anomalies are caused by electrokinetic phenomena and, accordingly, by underground fractures and voids which drain the waters downward.

4.3. "Mise à la masse" survey

The presence of high conductivity deposits filling fractures and cavities suggested the use of a focusing electrical technique, such as the mise-à-la-masse (MALM) to delineate the boundaries of these deposits. The MALM technique was used to estimate boundaries of old flooded mine workings (Rodriguez and Rodriguez, 2000) and to map fracture zones (Jaemtlid et al., 1984; Beasley and Ward, 1986), besides the more frequent application to mineral exploration.

The survey was carried out using the pole-pole array configuration, with a current electrode placed at the end of the cavity inside the conductive deposit, while the other one was placed on the surface, at a distance of 500 meters from the former. The fixed potential electrode was placed at the same distance, but in the opposite direction. The mobile potential electrode occupied the same points used for SP and Wenner surveys. Figures 5a and 5b show the measured normalized potential and the calculated apparent resistivity maps, respectively. The two maps show anomalies located differently with respect to the cavity. In particular, a
positive potential anomaly is centered at about N 60, while the resistivity map presents a negative anomaly where the earthing electrode is located.

The potential distribution indicates the presence of filled fractures or cavities rising toward north with respect to the earthing position, while the apparent resistivity anomaly delineates a large, confined, filled cavity in the south-east continuation of the known cave.

Figure 4. Self potential map for winter (a) and summer (b) surveys.

Figure 5. MALM potential (a) and apparent resistivity (b) maps. The black dot indicates the surface projection of the current earthing.
4.4. GPR survey

This methodology is frequently used with success in the search for cavities (Daniels, 1988; Mellet, 1995). However, the targets generally considered are cavities lying within few meters from the surface. Eight profiles were surveyed in the area above the cavity (Fig. 2). Due to the great depth of the Santa Croce cave, a low frequency system (pulSekko IV, Sensor & Software Inc.), with 100 and 50 MHz antennae, was adopted. Figure 6 shows the results for profile 5. In general, the radar sections show a very good penetration and a large number of anomalies, either as hyperbolas or discontinuous signals, more evident in the upper five meters. At greater times, only few anomalies appear, mainly in hyperbolic form, with strong reverberations, strictly under the apices. We believe that the hyperbolic anomalies are generated by reflection signals from fractures and cavities located in the limestones. For the purpose of the present study, we have neglected the shallow anomalies, focusing our attention on the deeper ones.

4.5. Joint analysis of the geophysical results

The results of all geophysical surveys are synthesized in the composite map of figure 7. The elements considered to prepare the map were:

- The location of the largest radar anomalies.
- The trends of the high gradients in the MALM resistivity map evidenced by the 600, 800 and 1000 ohm-m isolines.
- The positive MALM potential anomaly.
- The roundish, conductive MALM anomaly.
- The largest, time independent, negative SP anomalies.

The main evidences in this map can be summarized as follows:

- Correspondence of SP and GPR anomalies around the cavity at about N90.
- Correspondence of SP, MALM and GPR anomalies around the cavity at about N60.
- A south trend of radar anomalies starting from the previous zone.
- A limited, large MALM conductive anomaly located at the end of the cavity.
- Large SP and radar anomalies present in the south-western corner of the area.

Following the geophysical survey, an excavation program in the cavity was performed. First, the red clayey deposit filling the end of the cave was removed. After this removal, an about 400 m$^3$ closed chamber was brought to light. Another excavation was carried out, just under the main anomalous zone detected, near the cavity floor, where a small hole was found. Behind and under this hole, a filling of clayey red deposit was also found and partially removed. A very interesting karstic tunnel that seems to enlarge at depth was, thus, discovered. The plan of these two excavations is drawn in Fig. 18 as a thick continuous line.
Figure 7. Composite map of the results of all geophysical surveys. a) Wenner apparent iso-resistivity lines; b) MLEM apparent iso-resistivity lines; c) Plan view of the cavity at the time of survey; d) New cavities discovered; e) Self potential main negative anomalies; f) MLEM high potential anomaly; g) MLEM low apparent resistivity anomaly; h) Position of the most important radar anomalies.

References