DC resistivity surveys compared to direct 3D surveys methods to characterize underground cavities in eastern Sicily (Italy)

Gabriele Morreale[1*], Sabrina Grassi[1], Danilo Messina[2,3], Pietro Monforte[4], Gaetano Giudice[2], Gabriele Quattrocchi[1], Sebastiano Imposa[1]

[1]Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Catania, Italy.
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania – OE, Catania, Italy.
[3]Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Palermo, Italy.
[4]Dipartimento di Ingegneria Civile e Architettura, Università degli Studi di Catania, Catania, Italy.

1. INTRODUCTION

The exploration of caves is a complex challenge because accessible subsurface spaces can be characterised using direct geological and geodetic techniques, while caves and cavities that have not been discovered yet and are inaccessible require an indirect approach to study. Geophysical surveys are an optimal tool for reconstructing and identifying underground cavities.

The main goal of this study was to test the effectiveness of the DC resistivity method for mapping and reconstruction of underground voids.

Two underground caves marked by different geological contexts and located in the eastern part of Sicily (Italy) (Fig. 1a) were investigated: "Micio Conti Lava tube", a lava tube located in the area of San Gregorio di Catania and the "Chiusazza cave"(Fig. 1b), a complex karstic cave located near the municipality of Syracuse (Fig. 1c).

To obtain highly accurate 3D digital models of the two cavities through the application of Unmanned Aerial Vehicle (UAV) aerophotogrammetric surveys and Terrestrial Laser Scanner (TLS) surveys. These direct models were compared with 3D resistivity models obtained from DC Resistivity surveys performed in both areas.

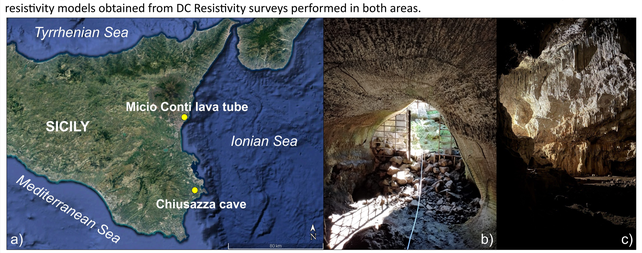

Fig. 1 - a) Location of the investigated sites; **b)** internal view of "Micio Conti lava tube" and **c)** photo of "Chiusazza cave".

2. METHODS

3D SURVEY METHODS

To generate digital models of the hypogean and epigean environments, 3D surveying methods were applied. The epigean space was investigated by performing an aerophotogrammetric survey using an unmanned aerial vehicle (UAV) while the internal reconstruction of the two caves was performed using a terrestrial laser scanner (TLS). To reconstruct all the accessible areas of the "Micio Conti lava tube", 18 TLS stations were placed inside the cave, while 23 TLS stations were placed inside the "Chiusazza cave". The point clouds obtained were aligned and georeferenced using targets distributed in the epigean environments of the investigated areas.

DC RESISTIVITY SURVEYS

DC resistivity surveys allow to map the distribution of resistivity in the subsoil; the choice of this method is related to the strong influence that the presence of voids/cavities has on resistivity values (Keller and Rapolla, 1974; Loke, 2004). Data were collected using a dipole-dipole (DD) quadripolar configuration that offers high-resolution data and is very sensitive to lateral variations in resistivity (Barker, 1989).

In the area of the "Micio Conti lava tube", 11 ERT profiles were carried out, each consisting of 24 electrodes spaced 3 m apart, with a total length of each array of 69 m (Fig. 2a). The spacing between the profiles is approximately 5 m. 11 ERT profiles were also carried out in the "Chiusazza Cave" area (Fig. 2b). N° 9 profiles were performed using 32 electrodes spaced 3 m apart, with a total length of 93 m for each array. Due to the logistical conditions at the site, it was not possible to run equidistant profiles. For this reason, 2 profiles were performed, intersecting in the central area, in the WNW-ESE and NNW-SSE directions, each consisting of 40 electrodes with a total length of 117 m.

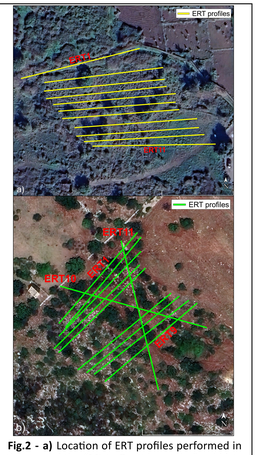

Fig.2 - a) Location of ERT profiles performed in the area of the "Micio Conti lava tube"and **b)** in the area of the "Chiusazza cave".

3. TLS - UAV RESULTS

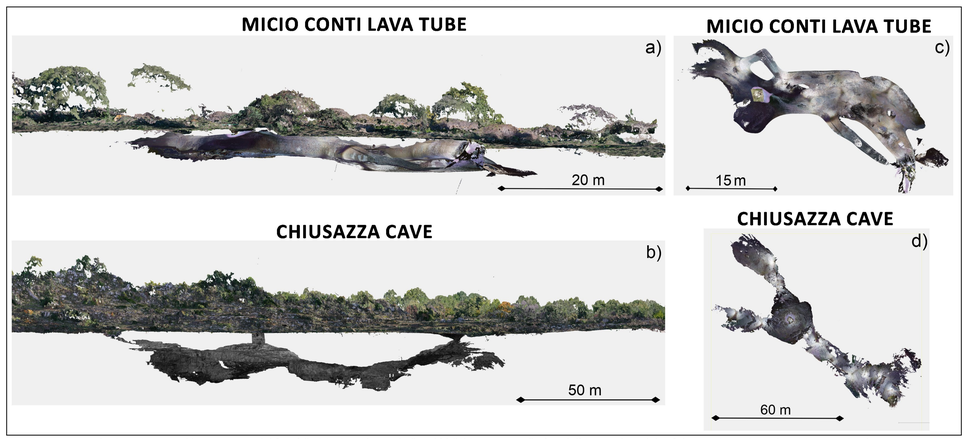

Fig. 3 - Epigean and hypogean model for **a)** "Micio Conti lava tube" and **b)** "Chiusazza cave"; **c)** and **d)** internal models of the two investigated cavities seen in plan.

4. DC RESISTIVITY RESULTS AND CLUSTER ANALYSIS

The DC resistivity data were processed using the software ERTLab 64 to obtain 3D resistivity models that provided a detailed mapping of resistivity variations in the subsoil. In both areas, the models show anomalies characterised by high resistivity values, which may be associated with air voids.

The 3D model of "**Micio Conti lava tube"** (Fig. 4a) shows resistivity values in the range of 10^3-10^4 Ωm, with the highest resistivity values located in the central portion of the model with an extension consistent with the size and position of the cave.

The 3D resistivity model of the "**Chiusazza Cave**" (Fig. 4a), shows resistivity values between 800 and 5000 Ω-m, lower by an order of magnitude than the previous ones. The areas with the highest resistivity are located in the north-west and south-east portions of the model, and also in this case their distribution is compatible with the location of the cave in the subsoil.

The **cluster analysis** performed on the resistivity values of the 3D models, using the K-means method (Rousseeuw, 1987), made it possible to identify two clusters (Fig. 4b). The model for the "Micio Conti" lava tube area shows a well-defined cluster located in the central areas of the model, and all the values surrounding it belong to a second cluster. Similarly, the model of the "Chiusazza cave" area shows a cluster of data located in the central portion of the model within a second cluster of data.

A joint plot was made between the clustered models and the resistivity models. This comparison revealed for each site investigated, a resistivity value delimiting the areas associated with the position and shape of the cavities studied (Fig. 4c). In the area of the Micio Conti lava tube, the cavity is characterised by resistivity values > 17000 Ωm, while in the area of the Chiusazza cave, the cavity is identified by resistivity values > 4000 Ωm.

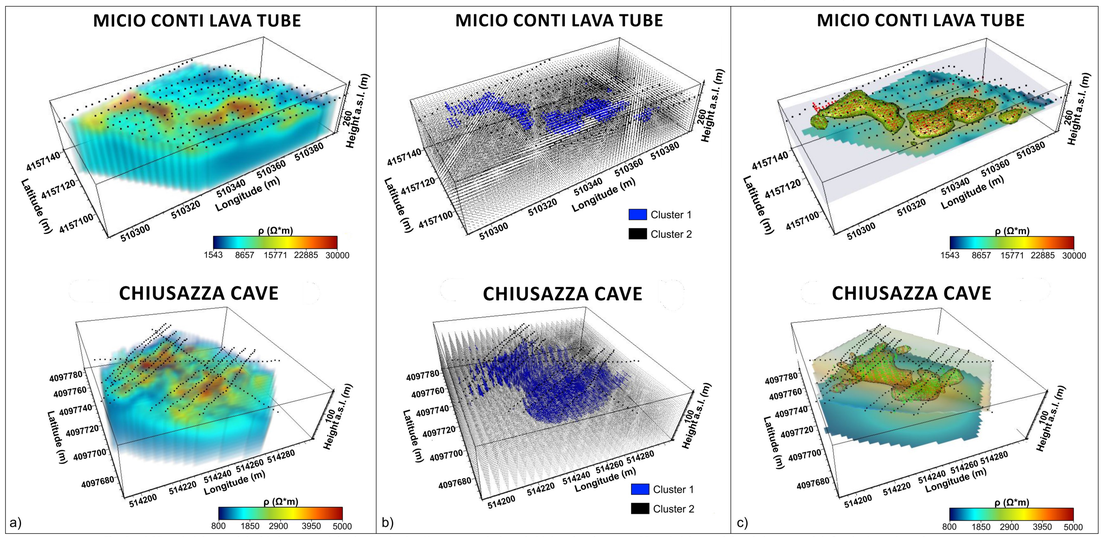

Fig. 4 - a) 3D resistivity models; **b)** cluster models obtained using K-means analysis and **c)** joint plots between 3D resistivity model and cluster models for the investigated caves.

5. RESULTS COMPARISON AND CONCLUSIONS

Comparing the results obtained with both methods, it could be observed that the 3D resistivity model aligned well with the TLS model with regard to the longitudinal shape, position and extension of the "Micio Conti" lava tube (Fig. 5a). Moreover, the model highlights further anomalies in the southeastern portion associable to the possible presence of other cavities without direct access. Figure 5b show the results of the model comparison for the "Chiusazza cave".The resistivity data seem to fit the model poorly, probably because the adjacent areas are affected by karst not directly connected with the cavity. Presumably, the resolution of the geoelectrical survey performed does not allow this separation to be visualised.

The integration of geophysical data and 3D surveys allowed the reconstruction of detailed models of both caves, increasing the ability to map and understand these geological structures.

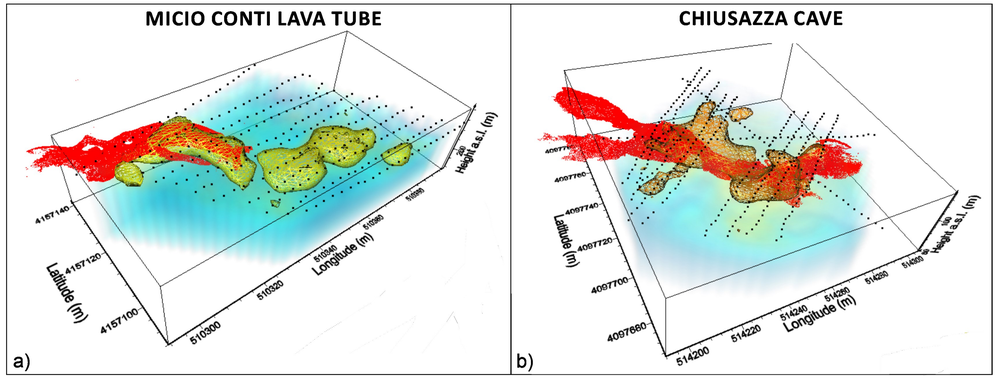

Fig. 5 - a) Comparison of "Micio Conti lava tube" 3D models obtained from TLS and ERT surveys (the TLS model is depicted with red dots) and **b)** comparison of "Chiusazza cave" 3D models (the TLS model is depicted with red dots).

6. REFERENCES

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics*, *20*, 53-65. https://doi.org/10.1016/0377-0427(87)90125-7

Keller, G. V., & Rapolla, A. (1974). Electrical prospecting methods in volcanic and geothermal environments. In Developments in Solid Earth Geophysics (Vol. 6, pp. 133-166). Elsevier. https://doi.org/10.1016/B978-0-444-41141-9.50012-7

Loke, M. H. (2004). Tutorial: 2-D and 3-D electrical imaging surveys.

Barker, R. D. (1979). Signal contribution sections and their use in resistivity studies. Geophysical Journal International, 59(1), 123-129.