# High Resolution Geophysical and Topographical Surveys for the Characterisation of Fumane Cave Prehistoric Site, Italy

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# High Resolution Geophysical and Topographical Surveys for the Characterisation of Fumane Cave Prehistoric Site, Italy

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## SUMMARY

Small scale prehistoric archaeological sites, such as the Fumane cave, located north of Verona city in north Italy, poses a lot of challenges both to archaeologists and geophysicists. The cave is considered as one of the most important Middle and upper Prehistoric sites of Europe, discovered in 1884. It contains a well-preserved and impressive stratigraphic sequence of more than 12m thick where human activity remains are accumulated. In this work, we applied high resolution geoelectrical resistivity tomography and seismic passive geophysical methods to investigate, on one hand, the electrical properties of the shallowest part of the deposit, where, a number of medium to low resistivity anomalies were localised. On the other, a test using microtremors provide evidences on the probable maximum thickness of the deposit (4-5 m). In addition a high resolution and georeferenced laser scanner survey was carried out so as to have an high resolution topographic model that shall be used as a container to allocate in 3D the position of the already achieved findings as well as the geophysical results. This shall constitute the first step for the planning of a smart protocol for results conservation and dissemination both for cultural and scientific interests.

## Introduction

Ground surface geophysical prospection methods have been used extensively in archaeology for non-invasive exploration of shallow-depth targets by measuring the spatial variation of one or more physical property of the subsurface materials, hence indirectly localise buried structures in alternatively quasi homogenous medium (Piro *et al*. 2000; Reynolds, 2011). The improvement in data acquisition techniques and processing methods, during the last 20 years, have made the integrated geophysical surveys more frequent due to their capability to better define position, extension and physical characteristics of any anomalous bodies present in the subsurface in a completely indirect and non-invasive way. This study presents an integrated methodology based on the use of three distinct, although related fields of investigation, in order to better understand an already known archaeological site so as to spatially localise already known features as well as hidden ones to be investigated yet. Moreover, the paper tries to address the problem of simplifying already achieved findings and to organise future archaeological campaigns in a smart way. As an example we present the preliminary results of the integrated geophysical and topographical survey carried out inside the Fumane Cave (Grotto di Fumane “in Italian”), situated on the southern rim of the Venetian Pre-Alps, north of Verona city (Fig. 1). This cave is considered as one of the most important Middle and upper Prehistoric sites of Europe, discovered in 1884, but first excavations started in 1964, however, since 1988 regular field studies continue to be carried out annually. It makes part of a fossil karst system composed of several cavities formed during the Neogene in the Ooliti di San Vigilio carbonaceous sandstone. The cave (approximately up to 11m wide and 22m long) contains a well-preserved and impressive stratigraphic sequence of more than 12m thick that is partially exposed (Fig. 1). This deposit is composed of a succession of sands, dusts, small and sharp rock pieces as well as large blocks detached from cave ceiling and walls. The deposit sequence covers the temporal period Marine Isotope Stage (MIS) from 5 to 2 (Bartolomei *et al*., 1992; Broglio *et al*., 2006; Peresani *et al*. 2008; Peresani, 2012). Archaeological studies have identified three principle living-floors connected to Mousterian, Uluzzian and Aurignacian human occupation periods, based on the analysis of distinct levels composed of fine-grained materials.

## Materials and Methods

The geophysical survey was conducted by means of two techniques: Electrical Resistivity Tomography (ERT) and Horizontal-to-vertical Spectral Ration of noise mictrotremors (NHVSR widely-known as “Nakamura”, Nakamura, 1989). The decision to use two different techniques was justified by the possibility to cross-check and validate the data, therefore producing more reliable results. The ERT has the power to reconstruct the vertical and horizontal electrical stratigraphy (i,e, resistivity), while the H/V spectral ratio helps in inferring eventual presence of lithological discontinuities characterised by different seismic velocities. Such layers result in H/V peaks as a function of frequency which can be used to infer the discontinuity depth knowing the average shear wave velocity in the medium. The method is simple and quick. This method is widely known and applicable in microzonation studies. Data can be collected by compact and friendly equipment composed of a compact seismograph connected to a short-period three-component seismometer or accelerometer). The use of the H/V method aimed to infer the depth to the hard bedrock hence extending f the investigation depth of the ERT survey, confined to the shallowest 3-4 m of the deposit The proposed integrated methodology is intended to achieve the following objectives in the long-term period:

1) Execution of an high resolution geoelectrical resistivity survey to investigate the shallowest part of the deposit and to through more insight on its probable thickness,
2) To localise zones of greatest archaeological interest and to identify possible presence of voids and channels,
3) Use of passive seismic method to collect micrtotremors to infer probable discontinuity contrasts present within and/or at the base of the deposit,
4) Generation of high resolution and georeferenced three-dimensional model of the cave by means of 3D laser scanner and photogrammetry, which can be easily updated, integrated

with geophysical results, shared and presented to a wider professional and non-professional public with great visual impact,

The realisation of the above reported points require the availability of a detailed three-dimensional model of the entire cave area. Typically, models of this type may be achieved through a topographic survey. To do this, two different approaches were employed: a laser scanner (model Leica Scan station C10, Switzerland) relief and a photogrammetric surveys. The former survey aimed at getting a very high-resolution cloud of points of the entire cave area, while the latter one serve as a focus only on the areas of greatest interest, in order to obtain better chromatic details and more accurate geometry.

**Data acquisition**

The survey included 11 ERT profiles in total placed on every meter and covering the main excavation area following the orientation NE-SW (ERT1-6) and SE-NW (ERT 7-11). The inner-electrode spacing was set to 0.5m. All the data were collected using the ABEM SAS 4000 Multichannel georesistivity meter (Sweden). The longest profile is 12m long, while the shortest is 6.5m long (Fig.1). Having in mind the goals of the survey, resistance measurements were collected using both the Wenner-Schlumberger and Pole-Pole electrode arrays, so as to achieve greater depth of investigation offered by the latter with the greater resolving power of the former. The passive seismic data were collected using a three component 2 Hz electromagnetic seismometer connected to a 24 bit three channels seismograph model Vibralog (M.A.E.Italy) which is particularly indicated for recording seismic noise. The equipment was positioned at three strategic points (yellow crosses in Fig. 1a) with the seismometer northwards horizontal component oriented towards the geographic north (i.e. parallel to cave walls). Noise data were recorded continuously for one hour at 250 Hz sampling rate.
Considering the complexity of the site and the presence of numerous obstacles that hindered the complete visibility of the entire cave, so it was necessary to perform multiple scans whose relative positions tied to a common reference point was necessary to be performed. A total of 11 scans were performed, then merged into a single three-dimensional unique model perfectly georeferenced to fixed benchmarks that were newly established. The obtained model (Fig. 1c) is believed to represent the first accurate 3D representation of the cave morphology to be created for this important archaeological site. The digital model shall serve as a basis both for archiving salient outcomes obtained from previous excavation campaigns archaeological and for future investigations yet to be conducted. Moreover, this model shall provide a smart support for the exact positioning of future photogrammetric surveys (Fig.2). Photogrammetry, in particular the so-called "close range photogrammetry", has become in recent years a powerful tool especially where details are needed to outline important features. To this end, more than 500 images were acquired using a CANON EOS 7D camera. These were processed with a modern "structure from motion" software, PhotoScan (Agisoft LLC, Russia). An example is shown in Figure (1c) where surface morphology resolution is enhanced by high quality chromatic details.

**Data processing**

Apparent resistivity data must by processed numerically “inversion” in order to get the best estimate of the subsurface model parameters (i.e. resistivity) distribution. To this end, the Res2dinv/Res3dinv inversion codes (Geotomosoft, 2013) were employed. The algorithm implements Occam’s inversion style that adopts an efficient regularization approach to deal with the nonlinearity of apparent resistivity data inversion. Gauss-Newton optimization method is used to minimize or maximise some penalty on the model parameters, whilst demanding that the model fits the observed data to within some reasonable error between experimental and theoretically calculated apparent resistivity data based on the real distribution of resistivity model parameters. Both codes can handle rough topography and allow for the addition of boundary conditions. In our case these are represented by the free surface contacts of two walls of the deposit. Data inversion has been applied firstly along each 2D profile then all data have been processed in 3D.

Concerning the passive seismic data collected at the three sites (HV, Fig. 1a) we applied the Horizontal to vertical Spectral analysis method implemented in the Geopsy code for their processing (Di Gulio *et al.* 2006).

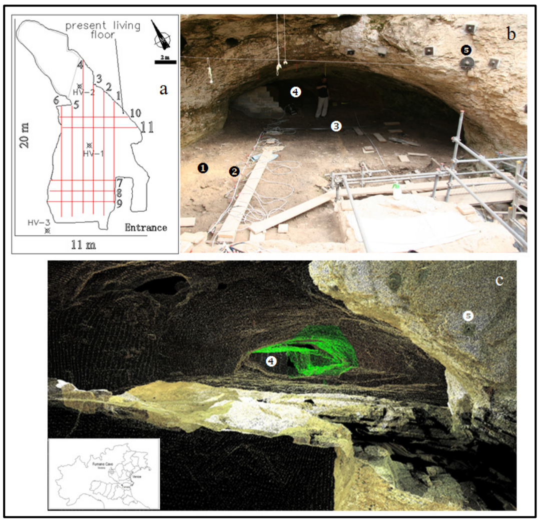


***Figure 1*** *a) Simplified map showing the location of the ERT profiles as continuous red lines b) NE view of the cave showing the present living floor. Numbers from 1 to 5 indicate, respectively, the archaeological deposit, ERT-5, ERT-10, yellow cross: NHVSR sites. b) view of the main gallery. c) point cloud of the cave obtained by multiple scans. The green points represent the far end of the cave. They are coloured in green (arbitrary colour) because there's no light to estimate colour intensity.*

## Results

In Figure (2) we present a series of 2D ERT inversion models, Wenner-Schlumberger array, oriented in the NE-SW direction (Fig. 1a). The models show high spatial resistivity variations especially in the orthogonal direction. Main features of interest results to have resistivity values of less than 100 Ohm.m (ERT lines 1 to 4, Fig. 2), which extends to a depth of about 3 to 4 meters below the present living-floor. Such zones represent areas where future studies can be carried. In these zones high content of fine-grained materials is hypothesised to be present. On the contrary, ERT- lines Nos. 2 and 3 show the presence of very high homogenous resistivity volumes that can be associated to medium to large blocks detached from the ceiling. This means that such zones are of trivial interest from the archaeological point of view. The medium and high resistivity volumes predominates the subsurface of the southern part of the deposit (i.e. towards the entrance) where sediments are expected to be dry and contain medium to large blocks (i.e. frost-shattered stones of medium and big size rocks). A relatively shallow anomaly, around 40 cm deep, can be observed in profile No. 3 with regular geometry, which almost certainly can be attributed to the old test pit whose traces are still visible today in the northern part of the cave. The preliminary ERT results, however, did not give any indications neither about the maximum thickness of the deposit nor its basal morphology, for this reason we acquired the seismic noise at three sites (Fig. 1a). The spectral analysis of the microtremor data did not provide a unique result however a frequency peak at around 15 Hz was encountered by comparing the results of test Nos. 1 and 3 (not shown) where the latter was measured on an exposed rock site below the deposit. Assuming a shear velocity value of about 250/300 m/s we get an approximate depth of around 4-5 meters. Other high frequency peaks are visible however their transformation to depth requires the reconstruction of the shear wave velocity profile which shall be done in the near future. Finally, the passive seismic results did not provide evidences on the presence of voids or channels within or below the deposit at least beneath the two sites where microtremors data have been collected (HV-1 and 2, Fig. 1a).

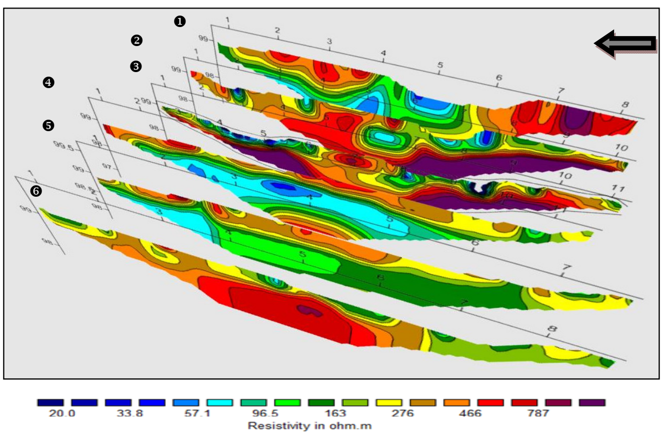


***Figure 2*** *Pseudo three dimensional representation of the 2D inversion ERT models of profiles Nos. 1-6, acquired using the Wenner-Schlumberger array. Orientation of the ERT profiles is NE-SW, large arrow: Cave entrance.*

## Conclusions

Prehistoric sites have been greatly ignored by the wider geophysical community due to the nature and fragility of archaeological material and the almost complete absence of permanent structures. Due to the presence of numerous occupation layers, packed very close together and numerous archaeological remains of small dimension, any kind of invasive testing (test pits, coring) and verification has been ruled out, making the results of integrated geophysical and topographical survey even more significant. Features present on the site such as simple hearts and areas associated with the exploitation of large mammals and stone flaking, implicate that the site was occupied only periodically by human groups which left traces that could be detected using very high resolution geophysical methods such as georadar coupled with high frequency antenna (> 900 MHZ) to be executed before each excavation campaign, thus effecting the objectives of the investigation. The results of geophysical survey proved to be successful in description of subsurface morphology and nature and thickness of sedimentary infill, delineating potential areas of archaeological interest in a completely non-invasive way. Also, this geophysical work lead to methodological insights and should improve both efficiency and effectiveness of future archaeological campaigns and better management of the available funds. Having in mind that archaeological excavations are by force destructive, it is extremely important to correctly document the data using all the valuable techniques in order to faithfully reconstruct them later after data treatment and interpretation. In this sense the application of terrestrial laser scanner and photogrammetric method not only provides the topographical correction for the geophysical lines and produces the high quality images for the data library, but also contributes greatly to the better interpretation of the geophysical results and the ground morphology of the karst. The final goal of the implementation of the different techniques however remains wider and implies only the creation of high definition three-dimensional models of the cave which can be easily updated with the new data, shared and presented to the wider professional and non-professional public with great visual impact, but also aims to raise awareness about the importance of prehistoric sites and their role in explaining the human history and evolution.

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