2022 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
University of Calabria, Italy, October 19-21, 2022

Integrated Geophysical survey to evaluate the conservation state of a tomb in a Porta Nocera Necropolis

Malfitana[2] D., Mazzaglia[1] A., De Giorgi[1] L., Longhitano[2] L., Torre[2] C., Leucci[1*] G.

[1]*Institute of Heritage Sciences, National Research Council, 73100 Lecce*
[2]*University of Catania, 95124 Catania*
[*] *corresponding author, giovanni.leucci@cnr.it*

***Abstract* – The use of geophysical methods, have produced high-definition 3D models of one funerary monument in order to help the restoration work. Physical parameters such as seismic wave velocity propagation and electrical resistivity were optimal tools to store and manage scientific information about the degree of conservation of the studied monument. Conserve and preserve, also through the study and application of avant-garde technologies and methods in the field of restoration, means working not only for present generations, but also, and primarily, for future generations. New technologies and a multidisciplinary approach constitute a capital in which to invest in order to create a more responsible and aware society, capable of understanding how much of its future comes from growing up with respect for one's historical roots and own distinctive past.**

I. INTRODUCTION

The via nucerina necropolis constitute one of the six cemetery areas uncovered during excavations at Pompeii and which almost completely surrounded the ancient city. The sector of via Nucerina are situated to the south-east of the ancient city. The Via Nucerina necropolis, excavated by Antonio D'Ambrosio and Stefano De Caro in 1983, is slightly isolated to the east of the Porta Nocera and lies within an excavation area in the southern part of a greenspace outside the city walls (Fig. 1). The most common ritual practiced within the necropolis was cremation, and the urns containing the remains were buried in pits dug into the ground bordered by the numerous funerary enclosures present in the area. The individual burials were marked by "columelles", anthropomorphic steles, which often bore personal details of the deceased, as well as elements indicating the gender of the deceased. Geologically, the ancient city of Pompeii was located between the foothills of the south-western slope of the Somma–Vesuvius volcanic complex and the coastal-alluvial plain of the Sarno River. It stands on a hill with a maximum height of 54 m a.s.l., due to the relict structure of an ancient volcano [1], partially buried by alluvial and volcaniclastic deposits supplied from the southern slopes of the Somma–Vesuvius edifice. It is a semicircular morpho-structure mainly set in massive and scoriaceous lava flows by Strombolian activity. Its physical continuity near the archaeological area of Pompeii is interrupted by the Versilian palaeocliff along the Vesuvian coast (Cinque and Russo 1986). The activity of the Somma–Vesuvius complex in the last 17,000 years has been divided into eruptive cycles starting with the major explosive Plinian eruptions that have repeatedly shaped and changed the morphology of the volcanic edifice and ended with a minor intense, often effusive, eruption. Tephra levels covered large areas of the Campanian Plain and surrounding mountains, with a thickness of several meters. The 79 AD eruption, as described by Pliny the Younger, is one of the most important of Vesuvius, having buried the Roman cities of Herculaneum, Pompeii, Oplontis, and Stabiae, causing great destruction and casualties. Shallow instabilities that affect the site and produce monumental collapse are strongly related to the hill slope hydrological processes. Other factors are the geomorphological and stratigraphical conditions, together the climatic events. The kinematics of the shallow landslides are also related to hydro-mechanical properties and hydrological conditions. Particularly at the site, rainfall events related to surficial or sub-surficial flows strongly affect hydrological processes and subsidence events. In fact, during a rainfall event, the water reaches the ground surface causing an infiltration process within the soil that occurs at the ground surface along the slope. If the infiltration rate is greater than its infiltration capacity, the exceeded water will pond on the ground surface leading to the initiation of the runoff. The infiltration capacity of soil/rock derives from its hydraulic properties and represents the maximum amount of water that can infiltrate in a unit of time.

The aim was to investigate the degree of conservation state of the tombs by using geophysical methods. The tomb D (Fig. 2) was choose as an example of application of the geophysical methods.

Fig. 1. The location of geophysical surveys at necropolis of via Nucerina

Fig. 2. Tomb D

II. GEOPHYSICAL SURVEY AT TOMB B

Tomb D is located in the via Nucerina and shows many signs of deterioration [2] (Fig. 2). NDT measurements were undertaken to understand the causes of this deterioration. The ERT and seismic-ultrasonic geophysical methods were used.

Resistivity imaging surveys have not only been carried out in space, but also in time because changes in the subsurface resistivity with time have important applications. Such studies include the flow of water through the vadose (unsaturated) zone and changes in the water table due to water extraction flow. A simple, but very interesting, experiment to map the flow of water from the ground surface downwards through the unsaturated zone was performed. This experiment was carried out in the area near the studied tomb (Fig. 3) where some liters of water were poured on the ground surface over a period of three hours.

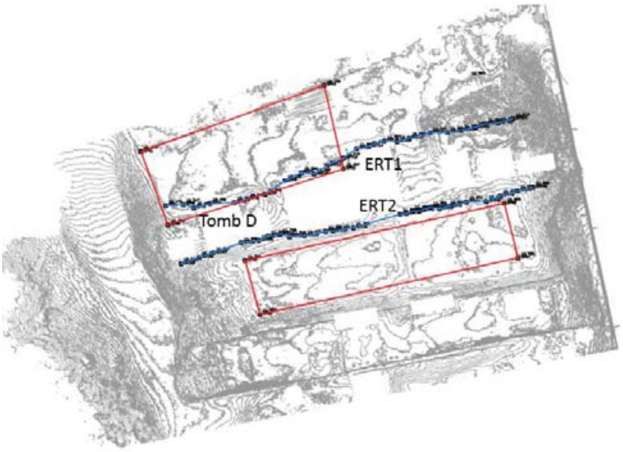

Fig. 3. The locations of ERT profiles

The 2D resistivity model, obtained after five iterations with a final RMS error below 4.6%, is shown in Fig. 4. The resistivity model shows the existence of an almost horizontal stratification with the follow resistivity values ranging between 80 ohm m and 2000 ohm m.

Considering the obtained resistivity values, the first layer with low resistivity values (100–200 ohm m) could be interpreted as the agricultural soil, the layer with higher resistivity values (500–1,500 ohm m) could be interpreted as more compact volcanic material, which could be related to the foundation line. It is visible at about 2 m in depth.

Figure 5 shows the results of a survey carried out at the beginning of the experiment, before the irrigation started.

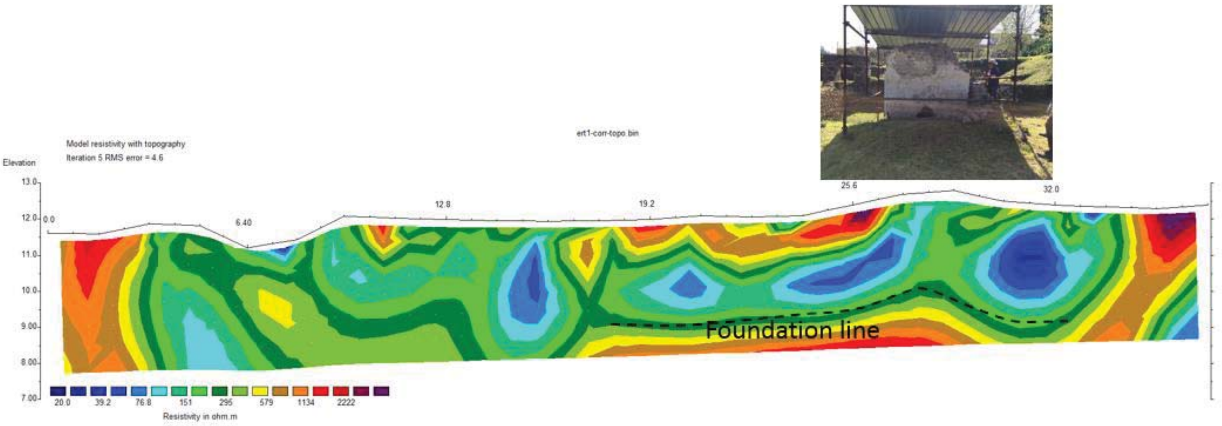

Fig. 4. 2D resistivity distribution related to ERT1 profile

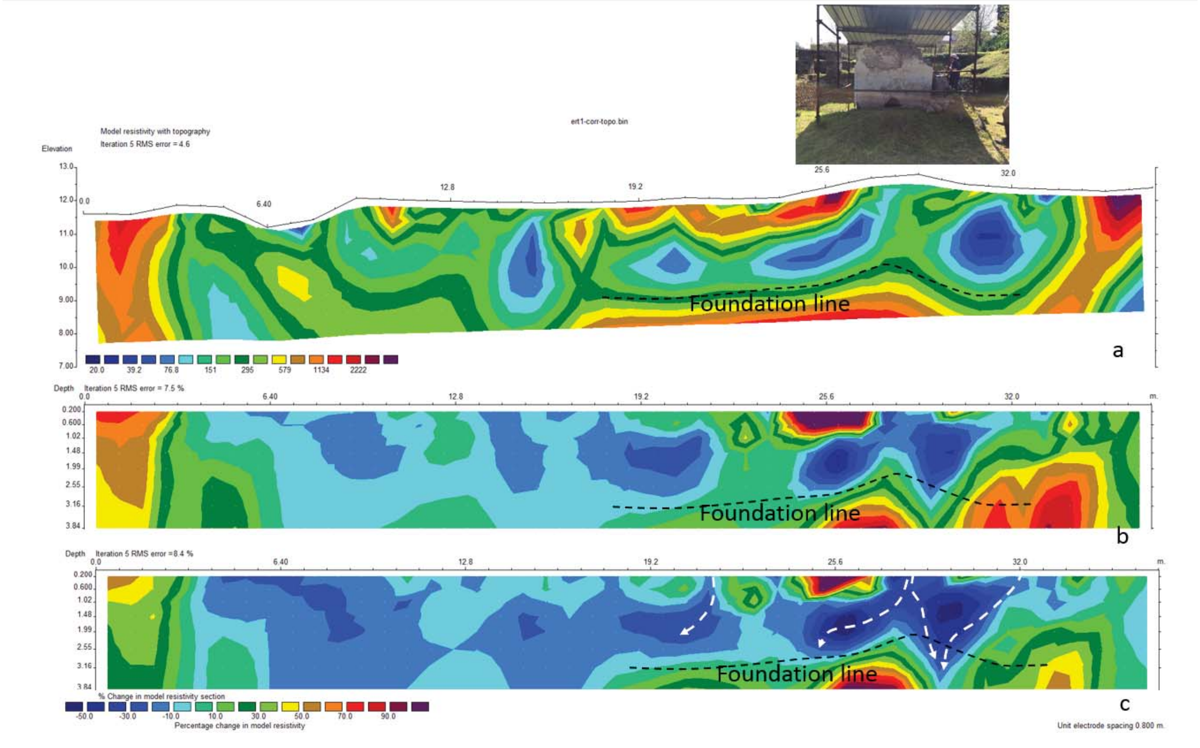

Fig. 5. Water infiltration mapping: (a) inversion model sections from the survey conducted at the beginning of the infiltration study. This shows the results from the initial data set that forms the base model in the joint inversion with the later data sets. As a comparison, the resistivity percentage change obtained from the inversion of the data set collected after two hours of irrigation (b) and after three hours of irrigation (c)

The inversion model (Fig. 5a) shows that the subsurface is highly inhomogeneous. The water distribution is determined by plotting the percentage change in the subsurface resistivity of the inversion models for the data sets taken at different times (Fig. 5.19b and c), when compared with the initial data set model. The inversion of the data sets was carried out using a joint inversion technique where the model obtained from the initial data set was used to constrain the inversion of the later data sets. The data set collected two hours after the water infiltration began shows a reduction in the resistivity (of up to more than 20%) near the ground surface in the vicinity of the 2-m in depth. The near-surface low-resistivity zone reaches its maximum amplitude after about three hours. Here, the low resistivity plume has spread downwards and slightly outwards due to infiltration of the water through the unsaturated zone. There is a decrease in the maximum percentage reduction in the resistivity values near the surface due to migration of the water from the near-surface zone. The model of the percentage variations of the resistivity (Fig. 5c) shows, particularly, the presence of zones (see the with arrow lines) in which the resistivity values decrease to about 30%. Such reduction is clearly due to an increase of the volumetric water content. These zones are therefore the preferential zones of outflow of the water.

After three hours water flow reaches the foundation line at about 2m in depth. In this way, it is possible to estimate a hydraulic conductivity of about 1.85 x 10-4 m/s. Using a noninvasive micro-resistivity instrument (Fig. 6), a resistivity survey was performed on the north wall of the studied tomb. It enabled acquiring of a map of resistivity values that, using an empirical relationship, enable creation of a volumetric water-content map of the same wall. Results are shown in Fig. 7.

Fig. 6. Micro-resistivity data acquisition

Results reveal an inhomogeneous distribution of resistivity values ranging from 40 to 500 ohm-m, an interesting distribution that shows increasing resistivities from the bottom to the top of the wall.

The same thing is possible to say of the distribution of the volumetric water content and from the bottom upwards that varies from 35% to 10% from the bottom to the top of the wall. It seems that dampness is rising from the ground. Seismic tomography used in the evaluation of the wall consisted of 2D reconstruction based on the travel-refracted wave amplitude. Images were obtained exclusively from the first arrival of the waves, which allows the best resolution possible, because those first arrivals are always clearly detected. A piezoelectric pulse of 55 KHz was used as the seismic source. Data were acquired with a high- frequency sensitivity accelerometer (55 KHz).

In order to cover the whole space, the medium was divided into cells or elements, and the results were obtained as the sum of the values in each of the cells. In the case of non-homogeneous media, the seismic wave was refracted, because of changes in the wave velocity associated with adjacent cells, and the tomography equations were solved in an iterative computational process until convergence on the solution. The computational process, the simultaneous interactive reconstruction technique (SIRT), contemplated ray curvature as a consequence of internal refractions. The characteristics of each cell were defined in the case that at least one ray path crosses the cell. The reflex software was used to invert the seismic tomography data.

Seismic tomography seems to confirm the existence of a discontinuity (Fig. 8). Several zones presenting lower velocities (1,200–1,500 m/s) can be associated with cracks or more damaged parts of the wall. Irregular and small changes on the velocity are most likely caused by the irregular arrangement of materials inside the structure. However, it is noticeable that the wall exhibits high nonhomogeneity. At the top of the wall the P, wave velocity seem to be higher (about 2,000–2,500 m/s). This indicates the probable presence of more compact material. Irregular and small changes on the velocity are most likely caused by the irregular arrangement of materials inside the structure. However, it is noticeable that the wall exhibits high nonhomogeneity. Furthermore, using the P-wave velocity distribution, it is possible to estimate the compressive strength by using the relationship implemented in [3, 4, 5, 6, 7].

The distribution of compressive strength, shown in Fig. 8c, seems to vary in the interval, ranging from 40 to 74 Kg/cm^2. This results confirm the existence of an high degree of deterioration of the wall confirmed by the low physical-mechanical characteristics of the same wall.

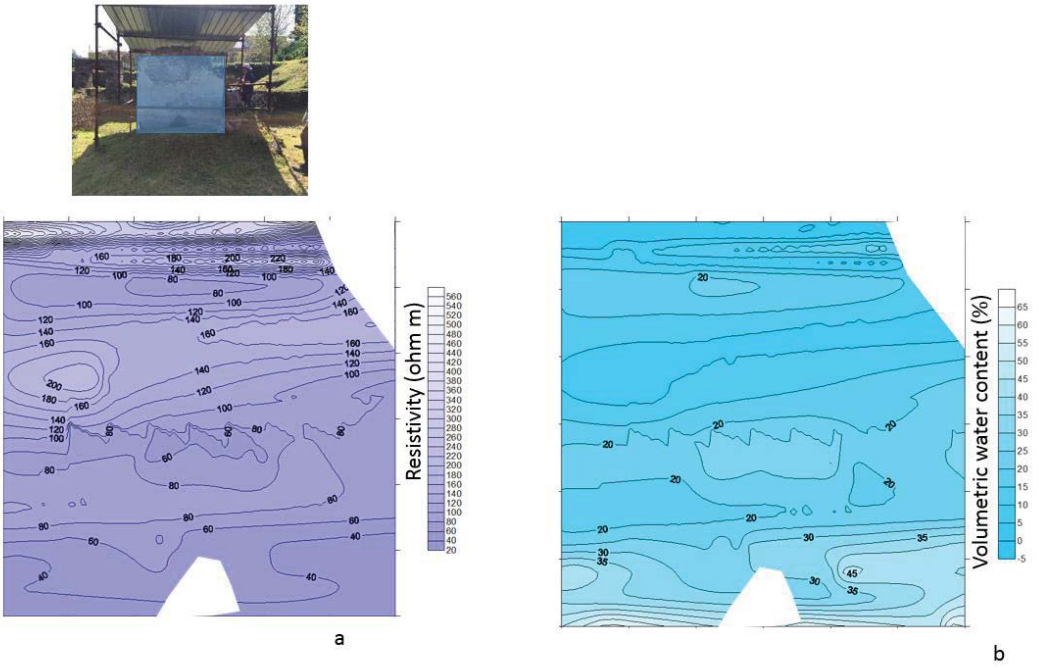

Fig. 7. 2D models: (a) electrical resistivity; (b) volumetric water content

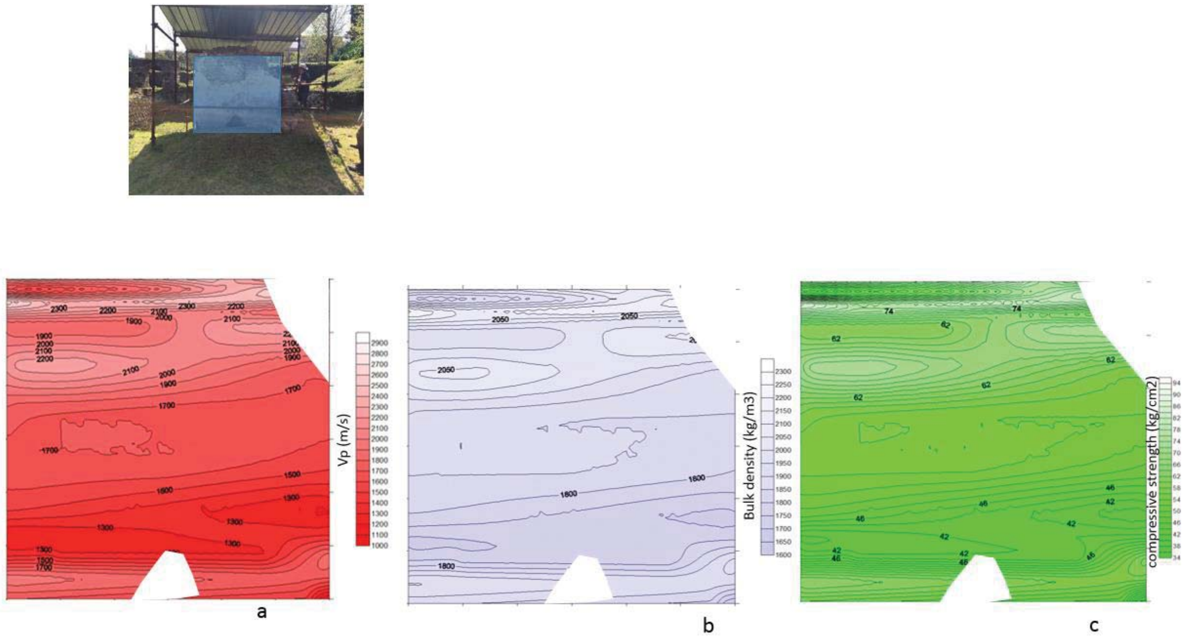

Fig. 8. The tomb's wall: (a) seismic-wave velocity (Vp); (b) bulk density; (c) compressive-strength distribution.

III. CONCLUSIONS

An experimental comparison between ERT and seismic ultrasonic measurements to determine the conservation degree of a sample tomb in the via Nucerina was proposed.

The ERT measurements on the case study tomb D allowed to evidence a water rising from the subsoil to the tomb. On the wall of the tomb is clearly evident a distribution of the resistivity that increase bottom up.

The ultrasonic wave velocity distribution evidence several zones presenting lower velocities (1,200–1,500 m/s) that can be associated with cracks or more damaged parts of the wall.

The research carried out in the area of the Necropolis of via Nucerina at Pompeii has led to the creation of an innovative system for the documentation, representation, and preservation of archaeological contexts.

.

REFERENCES

[1] Cinque A, Irollo G. Il "vulcano di Pompeii": nuovi dati geomorfologici e stratigrafici. Il Quaternario, 17, 101–116. (2004)

[2] Daniele Malfitana, Giuseppe Cacciaguerra, Giovanni Leucci, Antonino Mazzaglia, Giovanni Fragalà, Samuele Barone, Lara De Giorgi, Alessio Iabichella, Danilo Paolo Pavone, Salvatore Russo. Pompeii sustainable Preservation Project, In scavare documentare conservare viaggio nella ricerca Archeologica del CNR, ISBN 978 88 8080 195 5 2016;

[3] Leucci G., 2015, Geofisica Applicata all'Archeologia e ai Beni Monumentali. Dario Flaccovio Editore, Palermo, pp. 368. ISBN: 9788857905068

[4] Leucci G., 2019, Nondestructive Testing for Archaeology and Cultural Heritage: A practical guide and new perspective. Springer editore pp 217, ISBN 978-3-030-01898-6

[5] Leucci G., 2020, Advances in Geophysical Methods Applied to Forensic Investigations: New Developments in Acquisition and Data Analysis Methodologies. Springer editore, pp 200, ISBN 978-3-030-46241-3

[6] Malfitana D., Leucci G., Mazzaglia A., Cacciaguerra G., De Giorgi L., Barone S., Fragalà G., Pavone P. D., S. Russo. Archaeo‑Geophysics Surveys in Pompeii. Surveys in Geophysics vol. 39 n. 6, 1219-1238, 2018

[7] Emilia Vasanelli, Maria Sileo, Giovanni Leucci, Angela Calia, Maria Antonietta Aiello, Francesco Micelli, 2015. Mechanical characterization of building stones through DT and NDT tests: research of correlations for the in situ analysis of ancient masonry. Key Engineering Materials Vol. 628, pp 85-89 Online available since 2014/Aug/28 at www.scientific.net Trans Tech Publications, Switzerland doi:10.4028/www.scientific.net/KEM.628.85 2015