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GPR and ERT surveys in the "Giardino dell'Annunziata" in Cammarata (Sicily)

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***Abstract* – A recovery project has recently involved a garden sited in Cammarata (Southern Sicily), known as "Giardino dell'Annunziata" adjacent to the church of the same name (Chiesa dell'Annunziata). In this area, according to the scarce historical sources, there was a Benedictine convent, probably demolished in the eighteenth century. As a diagnostical support some geophysical surveys were carried out in the garden. A 3D geoelectric survey and 36 Ground Penetrating Radar (GPR) profiles were carried out which made it possible to reconstruct the corresponding 3D models of the subsoil. A large resistive anomaly has been detected, which has no match in the 3D GPR model showing only minor surface anomalies. The anomalous area can be due to an original flow route of the river, but it cannot be excluded that it is caused by an artificial channel or even underground environments, subsequently filled with landfill material. Archaeological excavations are planned to better clarify the nature of the anomaly.**

I. INTRODUCTION

Cammarata, in Southern Sicily, is a town of medieval origin and its history is linked to the vicissitudes that have marked Sicily since the Arabs. The area under investigation is a garden known to the local community as the "Giardino dell'Annunziata" (Figure 1) as it is adjacent to the church of the same name (Chiesa dell'Annunziata), and historical sources tell of the existence, between 1500 and 1700, of a Benedictine convent abandoned due to an unclear breakdown. It has been recently managed by the School Institute "Giovanni XXIII", which has launched a project aimed at recovering from degradation and making it public use. In this context, integrated geophysical investigations were carried out aimed at identifying the main anomalous structures of the subsoil and consequently clarifying the nature of the event which led to the destruction of the Benedictine convent and its abandonment in 1700.

II. HISTORICAL FRAMEWORK

The town of Cammarata (Sicily) is located at 689 m above sea level on the slopes of Mount Cammarata (1578 m) and is a town of medieval origins, although archaeological remains have been found in the Cammarata area which testify that the area was also inhabited in Roman times.
The conquer of Cammarata by the Normans should have taken place in 1077 even if the first official document relating to Cammarata is the Norman Diploma of 1141 which shows that the town already existed and was constituted as a feud [1]. We could postpone the existence of the inhabited center of Cammarata by at least three centuries, in the light of the chronicle of the Arab conquest of the territory around 840 [2].
The Annunziata female Benedictine Monastery where the Garden was situated, was located in the lower area of the town, which has always been considered the oldest.
Monasteries were usually built near a stream and the entire monastic complex was oriented so that the water could be channeled towards the fountains and kitchen.
The monastery of the Annunziata probably stood along the transhumance route periodically crossed by the flocks of Cammarata in the warm months, following the course of the Turibolo stream, a tributary of the Platani river, which still flows past the Garden today, but which is invisible because fifty years ago it was encased in reinforced concrete.
The foundation of the monastery probably dates to the 15th century [3, 1]. The Turibolo stream is mentioned numerous times in the accounts of the pastoral visits to the monastery that took place from 1540 to 1732. One of them also mentions the existence of a well and a garden adjacent to the convent [1]. The monastery building was abandoned in 1792, due to its poor static conditions.
Of the Monastery of the Annunziata today the Church and the Garden object of this study survive; at today there is no physical trace of the monastery building and we do not even know exactly what area it occupied.
From the first available aerial photo, from 1957, we can

deduce that it extended to the north-east area where a small building is located today, that a small part fell within the area of the current garden, and that perhaps it also extended to downstream of the current driveway that connects the garden downstream, since the continuity of a wall seems to be interrupted by this road. The east wall also continued to extend northward (Figure 1).

Fig. 1. Aerial view of the "Giardino dell'Annunziata, in Cammarata. The black points indicate the ERT electrode positions. The red lines indicate the GPR profiles.

A recent instrumental survey has allowed us to know more in detail the layout of the garden walls, which have a symmetrical configuration. We can see an apse located to the southwest of the perimeter, two wings similarly inclined on both sides with respect to the apse, and also two almost parallel wall fronts. This configuration is not typical in the gardens of Benedictine monasteries and could be of Arab origin. From aerial photos it is possible to identify the well, which was probably referred to in medieval reports.
Another area of research to be explored concerns the memory of Cammarata as an important Jewish center, before the expulsion of the Jews in 1492, probably corresponding to the foundation of the Monastery.

III. GEOLOGICAL FRAMEWORK

The Cammarata area falls on the slopes of the Monte Cammarata relief (1,578m asl), at the south-eastern end of the Sicani mountains. The soils present are attributable to the deformation of sediments of the paleogeographic domain called the "Sican basin" [4-5]. The outcropping successions are made up of Mesozoic-Cenozoic calcareous-marly terms, a formation of glauconite calcarenites deposited in the lower Miocene followed by the "Marl of S. Cipirrello" Formation (lower Miocene-lower Tortonian). On these, a groundwater complex was placed in place in the middle Miocene, represented by various formations of the Imerese basin (Montagnola Series, outcrops of Numidian Flysch emerging east of the Platani River) [4].
The area under investigation, sub-flat, falls at the base of the relief on which the historic center of Cammarata was built, whose morphology follows the structural arrangement of the glauconite calcarenites of the lower Miocene (Aquitanian-Burdigalian) that outcrop there with a dip to the SE and an inclination between 30° and 45°. The calcarenite complex, comprised between Oligo-Miocene marly clays and the subsequent Middle Miocene gray marls, is made up of sandstones with intercalations of marly-sandy levels [5]. The area directly affected by the investigations (average altitude 558m a.s.l.) should show the presence of calcarenites under the wall that separates it from the inhabited center to the NW, but the presence of the backfill makes it impossible to understand from the surface whether this lithotype is still present below the ground or if instead the following stratigraphic term is present, i.e. the Middle Miocene gray marls. In fact, these outcrop extensively on the hydrographic right of the Turibolo stream which was originally set on the sandstone-marl stratigraphic contact but today is closed inside a reinforced concrete underground channel.

IV. GEOPHYSICAL SURVEYS

In the last decades geophysical methods have proved to be an essential and valuable support to archaeology and Cultural Heritage [6], thanks to their non-invasive nature, rapidity of execution, and reasonable cost [7]. Furthermore, intrinsic limitation of each geophysical method can be overcome by combinations of two or more geophysical techniques [8-9].
The geophysical investigations here presented were conducted on 23 May 2023, in the Annunziata Garden, with the aim of clarifying the geological asset of the subsoil and identifying buried archaeological structures in the area. 3D Electrical Resistivity Tomography and Ground Penetrating Radar (GPR) measurements [10-11] were carried out on an area of approximately 500 m^2.

A. 3D Electrical Resistivity Tomography

240 electrodes were planted on the ground, with a minimum equidistance a = 1.5 m along the two perpendicular directions, forming a regular grid of 20 x 12 electrodes, with dimensions equal to 28.5 m x 16.5 m (Figure 1). The measurements were made by connecting four rows of 12 electrodes each time, using a dipole-dipole type electrode sequence with dipole lengths from a to 4a and dipole orders n from 1 to 10. In total, therefore, a total of 3500 measurements were performed (Figure 2, a). The data was preliminarily filtered, eliminating the outliers and all data showing a standard deviation greater than 20% with respect to the average value. The apparent resistivity measurements were inverted using the RES3DINV software, obtaining an inverse 3D model with Abs Error equal to 8.4%. The graphic volume rendering of the electrical resistivity model was created using the Voxler

software (figure 2, b). In it, the electrical resistivity assumes values between 2 Ωm and 200 Ωm, with average values of about 30-40 Ωm, but with well-defined areas in which they exceed 60 Ωm. These high-resistive zones have been highlighted in the volume rendering by means of an isosurface (figure 2, b).

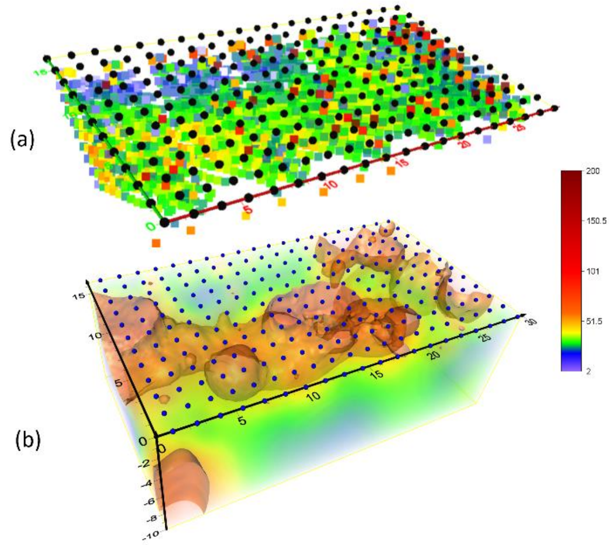

Fig. 2. Electrical Resistivity Tomography of the subsoil of the "Giardino Dell'Annunziata": (a) spatial pseudo-distribution of the apparent resistivity measures; (b) 3D inverse model of electrical resistivity. The orange isosurfaces comprise the volumes with resistivity greater than 60 Ωm.

B. Ground Penetrating Radar

The georadar surveys (GPR) were carried out using the georadar instrumentation of IDS – Ingegneria dei Sistemi S.p.a. – RIS MF HI-MOD model, with a double antenna at a frequency of 200 and 600 MHz, which made it possible to obtain a good surface resolution (600 MHz) and an adequate depth of investigation (200 MHz), compatible with the intended purposes from the studio.
In the investigation area, 36 profiles were acquired, with a regular grid and 1 meter spacing (Figure 1), in order to ensure the most appropriate coverage of the surface to be investigated and a significant interpolation of the data. For ground penetrating radar investigations, an acquisition range of 50 ns was used, for the 200 MHz antenna, and of 100 ns, for the 600 MHz antenna. The investigation depths were estimated considering a propagation speed of the electromagnetic waves average of 0.10 m/ns, for floor surveys. This mean value was obtained from the slopes of the branches of the reflection hyperbolas present in the data.
Each ground penetrating radar profile has been elaborated to eliminate coherent and incoherent noise present in the original data through a standard sequence (static correction, background removal, frequency filter...)
The 3D ground penetrating radar model (Figure 3) was elaborated through an interpolation algorithm implemented in Matlab, while the Voxler software (Golden Software LLC) was used for the 3D rendering.

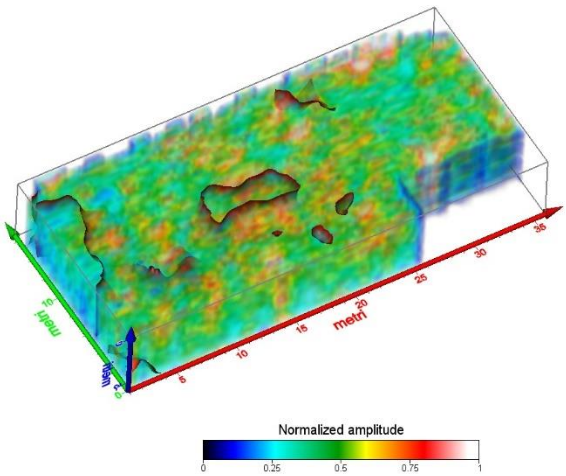

Fig. 3. Ground Penetrating Radar survey of the subsoil of the "Giardino Dell'Annunziata": 3D GPR model.

V. JOINT ANALYSIS AND INTERPRETATION

Observing the 3D ERT model (Figure 2, b) we note an elongated structure with a sub-parallel trend to the perimeter walls which deepens slightly as we proceed from the apse towards the north-west. This anomaly is characterized by resistivity values greater than 60 Ωm but in any case, not higher than 200 Ωm, therefore hardly compatible with voids, but rather with fillings of more porous and less cohesive material. At the center of the area there is also an approximately circular anomaly that descends from the surface into the depth, intersecting the previously described elongated structure. The latter anomaly could be justified by the presence of a well, which was subsequently filled.
Indeed, the GPR model (Figure 3) does not show an anomaly in the area of high electrical resistivity, but shows substantially homogeneous data throughout the area, apart from some alignment that can be seen in the upper part of the model. This would lead to the exclusion of the presence of still empty natural or anthropic cavities in correspondence with the main resistivity anomaly, but it cannot be ruled out a priori that any paleo-riverbeds, artificial canals or even underground environments were subsequently filled with material having the same dielectric properties as the enclosing lithologies, albeit slightly higher resistivities. Subsequent archaeological excavations, in planning, will be able to better clarify the nature of the anomalies.

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