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Multidisciplinary Research at the Castle of Santapau (Licodia Eubea, Italy): New Data for the Research, Protection and Enhancement of the Site

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Abstract. Since 2019, a multidisciplinary research project is in progress at the Castle of Santapau (Licodia Eubea, Italy). Different non-invasive investigation techniques, such as proximity remote sensing (UAV) and geophysical prospecting (GPR, electromagnetic, geoelectric and seismic surveys), were integrated in order to enrich the knowledge of the site. The results will be the starting point to plan and develop restoration projects for the protection and enhancement of the castle.

Keywords: Castle of Santapau · Archaeological survey · Proximity remote sensing · GPR · Electromagnetic · geoelectric and seismic surveys

As part of the research on the archaeological landscapes of the Hyblaean Plateau, on the edges of Ragusa and Catania districts (Sicily, Italy) (Fig. 1a), a multidisciplinary project aimed at the reconstruction of the ancient topography of the Castle of Santapau (Licodia Eubea, Catania) has been launched in 2019 (Figs. 1b and 2). The castle stands on a hill (Colle Castello, 582 m asl) in a perched position in the hinterland of south-eastern Sicily. For centuries, the site was one of the most important fortresses of the Sicilian feudal system in the western sector of the Hyblaean region. Positioned along the road that led towards the Etna area, from its top the view ranges from the Dirillo valley to the Gela Plain and even sees the African Sea.

The fortress appears in the official documents of the Angevin Statute of the Sicilian castles of 1274. However, there are numerous hypotheses in the literature relating to its relevance to an older castrum, from the Middle Ages [1]. A possible occupation of the Byzantine era, suggested by the numerous testimonies that emerged during the research conducted in the urban area and in particular along the slopes of the hill [2–4], was probably obliterated in the years of the Islamic conquest (late 9th century) [5]. However, from the sources, the military vocation of the hill emerges only starting from the

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aforementioned documents of the 13th century, when Licodia was an important military post of the Angevin kingdom. Indeed, at the time of Charles I of Anjou, the place assumed the name of *Castrum Licodiæ*, closely connected to the network of fortification works, which militarized the landscape of the island's hinterland, aimed in particular for the control of the major routes communication. From the complex history of the castle, it is possible to reconstruct the pertinence to the fiefdoms of great noble families: from the Santapau family, Spaniards who gave the castle its name, the property passed to the Ruffos of Calabria, related to the first, who maintained control of the monument until 1812. The castle had actually been reduced to a state of ruins by the disastrous earthquake of 1693. Structures that survived until the beginning of the 20th century were demolished during the Fascist period due to the danger of collapse [6].

Thanks to the project launched, a new interpretation of the ruins visible today has been possible. The data on the elevations has been integrated with what is known of the underground structures of the hill of which the most interesting element is certainly constituted from the axis of an ancient aqueduct, to be traced back to the inhabited area of the Greek age [7], partly adapted in the Roman age and in the following phases [8]. The Angevin castle is characterized by an irregular plan, similar to a pentagon on whose southern side a rectangular body is flanked.

As already tested by the excavations and prospecting [4], the site presents an interesting multi-stratification largely still not adequately investigated. Covered by the ruins of the castle, the top of the hill was identified with the acropolis of the Hellenized Sicilian settlement largely known from funerary contexts [4–9]. However, on the western side of the hill investigations identified the traces of the aforementioned underground aqueduct, pertinent to this phase, but also numerous elements relating to the history of the settlement in Roman and early medieval times late antique burial grounds and Byzantine underground buildings near the church mother, in the northern slopes [4]. The project at the base of the Spanish castle exploits the peculiar geomorphology of the hill, taking advantage of its natural defendability and rocky overhangs, occupying the entire top: the walls insist on the rock and its general layout is still legible. It consists of mighty rectilinear walls and circular towers (originally, a total of six); almost the entire wall circuit remains visible even if for a modest elevation. The most consistent part is found in the portion of the walls, which includes the two twin towers placed at the southern corner. The construction technique is of the sack type with external masonry in stone ashlars; in the surviving towers, there are string courses and a summit cordon. Inside the area, there are legible traces of environments whose destination is unknown: most of the structures are, however, covered by thick layers of debris accumulated due to the collapses and filled up intentionally to consolidate the structures, as well as confirmed by recently conducted investigations.

This paper presents the first results of the surveys carried out on the hill of Licodia Eubea. The research was conducted through the integrated application of different non-invasive investigation methodologies, i.e. remote and proximity remote sensing (UAV) and geophysical prospecting (GPR, electromagnetic, geoelectric, seismic refraction induction). The study aims to support the enhancement of the monument and the engagement of the local community.

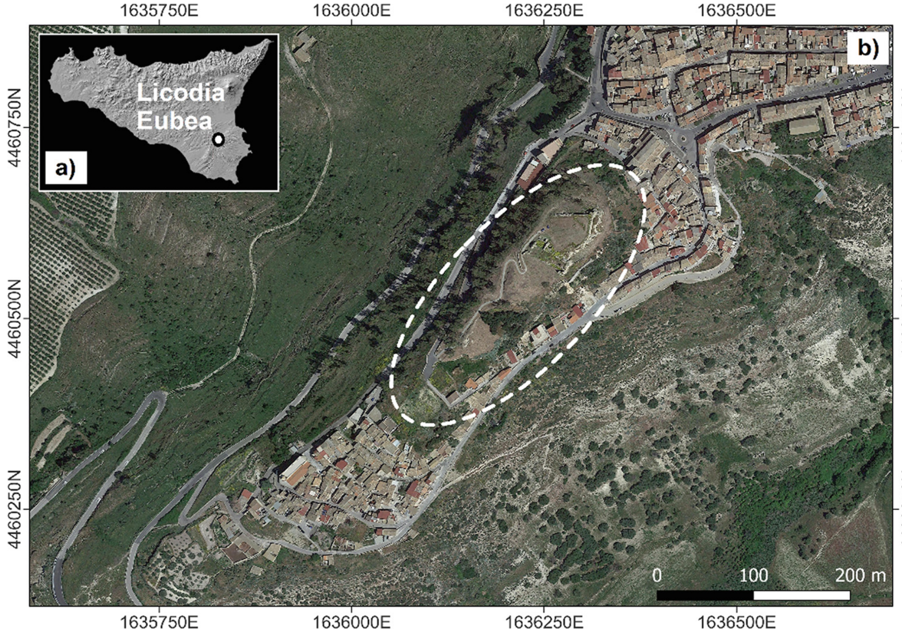

Fig. 1. Location of Licodia Eubea on a Google Earth™ satellite image of Sicily (a) and a detail of the Castle of Santapau (b).

Fig. 2. Colle Castello (Licodia Eubea), view of the southern structures of the Santapau Castle.

1 Methodology

The survey project of the historic hill of Licodia Eubea and of the structures was carried out through the integrated application of different non-invasive investigation methodologies. In recent years, scientific disciplines as geophysics and geomatics are widely applied in archaeological surveys for representing all that is visible with what is hidden into the surfaces. Geophysics, in particular, plays today an important role in site evaluation, mapping of soil and fill layers, foundation design, detection of cavities and underground structures. Methods such as seismic prospections [10, 11], induced electromagnetic method (EMI) [12, 13], electrical resistivity tomography (ERT) [14, 15], GPR surveys [16, 16] and magnetometry [17, 18] are very efficient for these purposes. On the other hand, geomatics allows the acquisition of highly accurate point clouds that represent the reference basis for all the information acquired in the evaluation process of a site. In the last decade, the use of close-range aerial photography using platforms operating at low altitude have grown impressively in terms of instrumentation, information handling, representation strategies, as well as processing and combined systems. A comprehensive overview has been published by Vernoeven [19], while in Campana [20] a summary of the available platforms, along with their main merits and disadvantages, is proposed. However, masts, poles, booms, towers, kites, balloons and blimps seem to have less intense use in recent years due to the development of UAVs. The latter applications has shown considerable progress in the field of aerial photography for documenting archaeological excavations [21–23], three-dimensional survey of monuments and historic buildings [24–27], the survey of archaeological sites and landscapes [28, 29]. In a recent comprehensive literature review [30] the technological developments in UAVs and in lightweight sensors operating with visible (VIS), near-infrared (NIR), thermal-infrared (TIR), multi-spectral (MS) and hyperspectral (HS) cameras, laser and radar sensors are analyzed. RGB cameras are often used in combination with other sensors and, in general, studies report the implementation of multiple devices [31–34].

In this work, an integration of geophysical and geomatic methods is applied for the study of the hill of Licodia Eubea. The drafting of the archaeological, digital and multiscalar documentation of the site was conducted through the integration of traditional survey techniques and remote/ proximal sensing for aerial and terrestrial photogrammetry, exploiting the potential of each method in order to maximize the final result [20]. Two UAVs (DJI av6v S900 hexacopter and the DJI Mavic Due Pro quadcopter) equipped with RGB and thermal sensors have been used for a large-scale sensing of the area of research. The first step was the planning of several aerial photogrammetric surveys to understand the extent of the site and to analyze the relationships between the different sectors of the complex. The UAV-Based High Resolution Thermal Imaging for the archeo-architectural anomalies detecting in vegetation was performed through the use of a FLIR Vue Pro R 640 camera.

The photographic datasets were obtained by flying over the area at low altitude (about 30 m above ground level) while maintaining a high frontal and lateral overlap between shots ($\geq 80\%$) and making use of Ground Control Points (hereafter GCP) on the ground, surveyed using a GNSS antenna in RTK (Real Time Kinematic) mode. The survey of GCPs was performed with Topcon Hyper V Differential GPS. Data processing of images was performed with Agisoft Metashape software (LLC. St. Petersburg, Russia) using the Structure from Motion (SfM) technique (Fig. 3) [35].

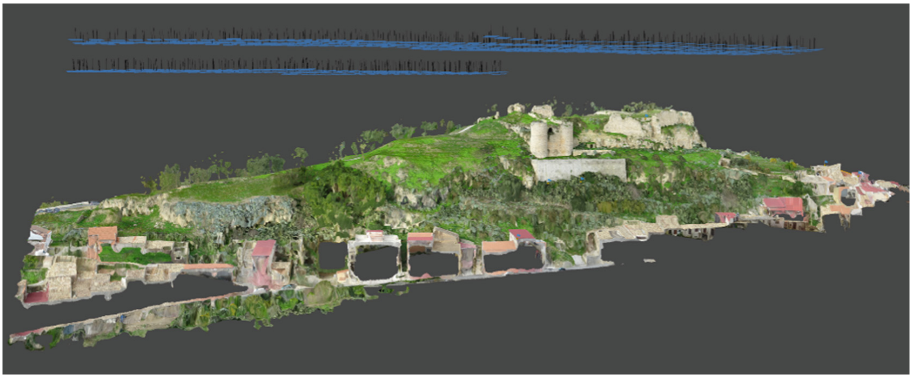

Fig. 3. 3D model of the hill and camera positions at frame capture.

As regards geophysical prospections, considering the typology of searched targets (archaeological remains, geological layers, cavities), their supposed depth (from centimeters to 5 m), their constitutive material (stones, landfills), their physical properties (density, conductivity, susceptibility) and their geometry (punctual targets, stretched objects, layers) the proper method that is suitable for solving the goal of the research has been chosen. Thus, seismic refraction tomography (SRT), EMI, ERT and GPR prospections were preferred over other methods.

Seismic Refraction Tomography had as its purpose the measurement of the difference in density of the different lithological and sedimentary layers that overlap below the surface, and therefore the measurement of the average thickness of the upper sediment layer in the various unexcavated segments. During the research, in collaboration with the Geophysical Institute of Israel, five refraction prospections were conducted using the Geometrics, Geode seismic recorder (Fig. 4, Area A, green lines). Each spread consisted of 34–45 geophones and source points every second geophone (2 m). The location of the lines was chosen by the department of archaeology and were surveyed using an RTK GPS for each line edge. Data was recorded and saved in the industry standard for refraction surveys – SEG-2. In each shot point, a sledgehammer hitting a metal plate was used. The data recorded was analyzed using the Geometrics - SeisImager program. Each shot was examined, and some basic processing procedures were applied when needed such as AGC/Gain, Filter etc. (refraction surveys usually do not need processing due to its short offsets and good signal to noise ratio). The QC procedure also included geometry check to ensure shots were located correctly along the spread. After the QC procedure, the first arrival time for each shot was picked and saved for interpretation. The interpretation process utilized the Intercept Time method to create an initial model (velocity and depth). After the initial model is created, a travel time tomography procedure is initiated [36]. This process attempts to minimize the difference between the observed (picked arrival times) and the calculated (model calculated arrival times). Each spread had appx 100 iterations done to achieve relative low error values. Error here refers to the difference between the observed travel time to the calculated.

Fig. 4. RGB image obtained thought aerial photogrammetric survey with indication of the geophysical survey.

ERT was carried out using a multi-electrode resistivity meter, the A3000E (M.A.E. s.r.l., Frosolone, Italy). For ERT, three profiles with a length of 32 m were measured. The electrode spacing was in any case set to 1 m (Fig. 4, Area A, light blue lines). Regarding archaeological prospections, the selected electrode spacing has been considered proper to reach supposed large deep walls. A dipole-dipole (DD) configuration was used. The measured apparent resistivity datasets were processed in order to remove dragging effects that are typical of DD array and model the survey targets converting the values in real electrical resistivity values displayed as a function of depth below surface. To this end, data-adaptive probability-based ERT inversion (PERTI) method [37] has been applied for imaging the sources of anomalies into the analyzed grounds.

EMI prospections were conducted utilizing the GSSI Profiler EMP-400 [38]. Measurements were collected in continuous mode using frequencies in the range 5–16 kHz with vertically oriented dipoles. The investigation area was covered by profiles spaced 0.5 m inserted in a regular grid (Fig. 4, Area A and B, red dotted polygons). During data elaboration the measured values of conductivity were transformed in values of resistivity and visualized in 2D maps through a contouring software.

GPR was implemented through an IDS Georadar (IDS GeoRadar s.r.l., Pisa, Italy), equipped with a multi-frequency TRMF antenna (200–600 MHz). All radar reflections were recorded digitally in the field as 16-bit data, 512 samples per radar scan at 25 scan s^{-1} (1 scan approximately corresponds to 0.025 m). Half meter equally spaced GPR profiles were acquired in grids adapted to the available areas (Fig. 4, Area A and B, black dotted polygon). As the interpretation of each section can lead to underestimation or overestimation of the reflected signals and makes it not easy to identify the effect of lateral bodies present in the subsoil, all sections were processed together using standard methodological approaches in order to obtain 2D horizontal maps at a different range of depth (GPR-SLICE 7.0 software) [39]. Data were converted by subtracting out the dc-drift (wobble) in the data, and at the same time adding a gain with time of 20. A time-zero correction was determined to designate the starting point of the wave and the center frequency of the antenna was matched. Then the bandpass filter and the background removal were respectively applied to reduce noise from oscillating components that had a regular frequency cycle in the frequency domain and to remove striation noises that occurred at the same time. Processed radargrams were subsequently corrected with an automatic gain function applied to each trace based on the difference between the mean amplitude of the signal in the time window and the maximum amplitude of the trace. Thus, horizontal sections (time slices) were processed considering the whole dataset. Data were gridded using the inverse distance algorithm, which includes a search of all data within a fixed radius of 0.75 m of the desired point to be interpolated on the grid and a smoothing factor of two. Grid cell size was set to 0.01 m to produce high resolution images.

The management of the data collected during the activities took place through a GIS platform: all the topographic and archaeological data, in fact, were georeferenced (photographs, photoplans, lines and polygons of the anomalies) and managed through a geodatase created to integrate the new data to the mass of legacy data surveyed and specially digitized. The digital management of the research project data is the premise to allow real accessibility for the purposes of research, protection and enhancement of the Mediterranean archaeological heritage, whose documentation is traditionally heterogeneous, because created with different and often obsolete documentation technologies.

2 Results and Discussion

As is known, in the context of archaeological research, proximal remote sensing allows the contextual reading of non-adjacent architectural elements, making clear the possible topographical relationships that exist between elements visible on the surface of the recognized areas (areas of fragments, outcropping structures, etc.). In Fig. 4 a detailed orthophoto of the castle is shown, while in Fig. 5 the thermal image is displayed which

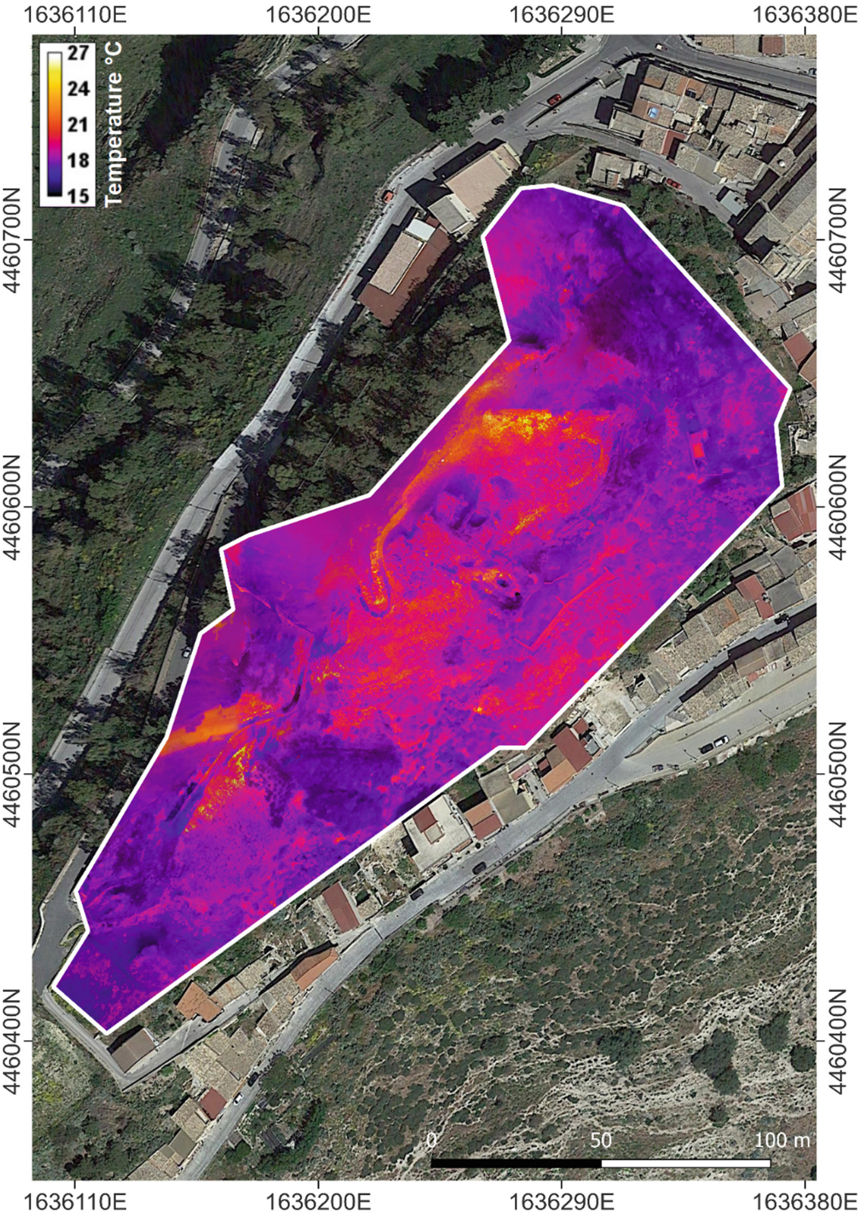

Fig. 5. Aerial thermal image.

highlights the ground cover, soil composition, or the depth and character of archaeological features. The Digital Elevation Model (DEM) obtained from the data processing highlights the current state of the structures of the Santapau Castle in three dimensions (Fig. 6).These images support the design of direct surveys to be programmed and the graphic rendering of the site plan of the Castle. Moreover, the oblique shots taken during the reconnaissance were of great use, not only because they allowed us to grasp some anomalies from above that are not visible from the ground but also because they allow us to ascertain the state of conservation of the castle structures.

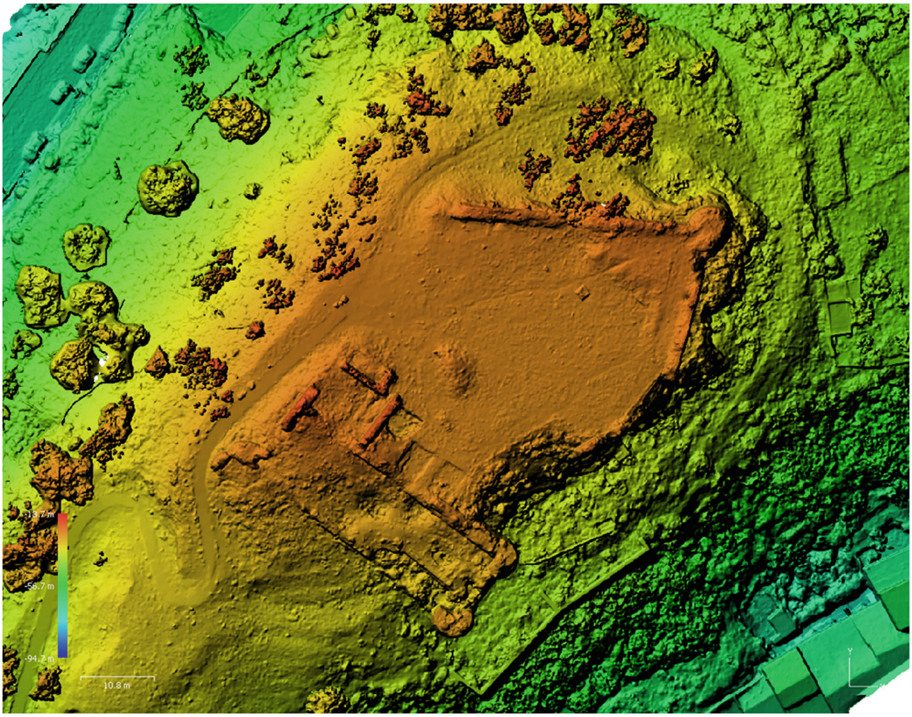

Fig. 6. Digital Elevation Model (DEM) of the Castle.

Thanks to the management of data in the GIS environment, it was therefore possible to contextually analyze the archaeographic data that emerged from archive research, such as the partly unpublished surveys [4] and the new topographical documentation produced (graphic survey; photogrammetry; geophysical survey).

The management of data in the GIS environment has therefore allowed the production of updated and scalable cartography available to the Municipality and the Superintendency based on protection and enhancement needs. On the other hand, the data collected form the basis of the analysis geo-spatial analysis (vieshed analysis and least path coast analysis) also useful for archaeological research. In fact, the recomposition of the original volumes of the structures of the modern age, and the ratio of the current height of the top of the hill with respect to the original walking surface, which can be inferred from the surveys refraction geophysics, allow a new reading of the topography of the hill and its relationship with the territory. This is fundamental for understanding its diachronic function in the context of the fortified landscape already in ancient times, still perpetuated in the Middle Ages and modern times.

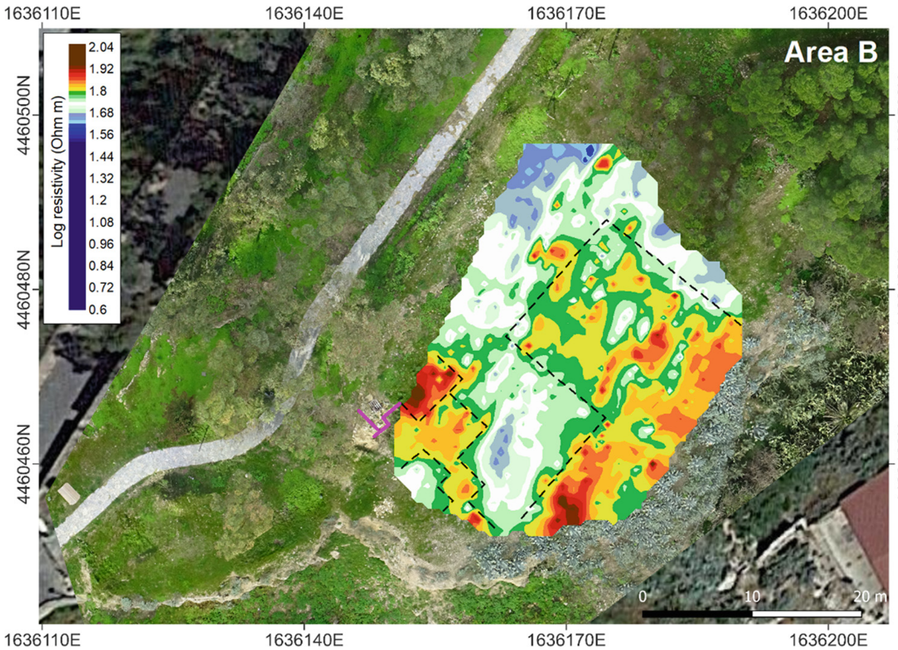

Fig. 7. Area B, horizontal section of electrical resistivity obtained through EMI prospecting at the frequency of 8 kHz.

Figure 7 shows the horizontal section of electrical resistivity obtained through EMI prospecting in the southern area (Area B) relative to the 8 kHz frequency. The results highlight two groups of resistive anomalies. In the eastern area, the anomalies clearly show the continuation of the section of the wall partially brought to light by the recent excavations underground and define a probable room of considerable size whose major septum has a NNO-SSE orientation. In the eastern area, the inhomogeneities with clear regular contours are distributed with a similar orientation to the southern circuit of the castle.

Inside the castle walls (Area A), the EMI surveys (Fig. 8) and GPR (Fig. 9) highlight, albeit with different resolutions, different areas with atypical values compared to the average values measured (nn. 1–4 in Figs. 8 and 9). In particular, around the recently discovered cistern, the anomalies define the probable size of the cavity, partially filled with backfill material, which appears to be approximately 7 m x 6 m in size (n.4 in Figs. 8 and 9). Elsewhere, while the EMI investigations broadly indicate areas of high resistivity, the GPR investigation returns a detailed image of probable buried environments, some of which are clearly connected to the partially excavated structures.

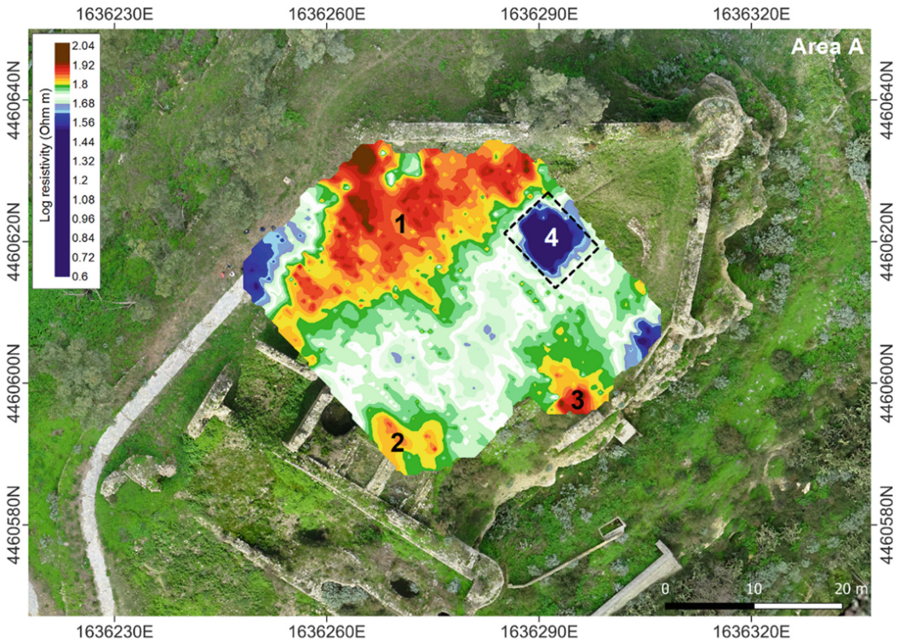

Fig. 8. Area A, horizontal section of electrical resistivity obtained through EMI prospecting at the frequency of 8 kHz.

The three tomographic sections confirm, in the anomalous points found with the EMI and GPR investigations, the presence of surface resistive anomalies (indicated with black arrows in Fig. 10, right) attributable to buried archaeological structures. Furthermore, ERT 2 defines the depth of the tank at approximately 3 m in the x-axis range between 14 m and 16 m.

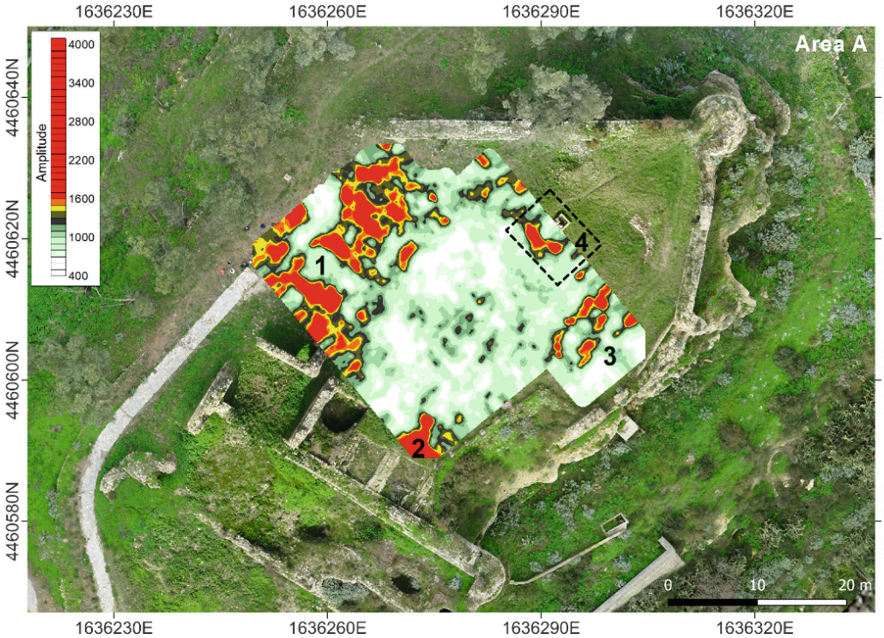

Fig. 9. Area A, GPR slice relative to 0.5 m in depth.

The seismic tomographies confirm, in the anomalous points found with the EMI and GPR investigations, the presence of surface resistive anomalies attributable to buried archaeological structures (Fig. 11). The results comprise of a 2D section of the spread, showing the velocity layers and their respective depth from the surface. Since the study area is relatively flat, no elevation information was gathered. Line L5 that does show minor elevation changes in its first few meters (appx. 1.5 m above the rest of the survey even surface). Each section shows a dotted line representing the limit for the interpretation. This is done since the short length and 1m spacing limits the penetration of seismic waves ray path (a ray path needs to travel from the source to the receiver).

The examination of the final velocity profiles indicates that a shallow layer with a velocity of ~ 200 m/sec exists in from the surface to 2–4 m. This layer could be attributed to the upper loose ground. The layer is sometimes very thin and perhaps not present (Line 4 around 25 m and line 3 around 30–35 m). There are two velocities interpreted beneath the first layer, one with a velocity of appx 600–800 m/sec and the second with appx 1000-1200 m/sec. It is hard to give a good interpretation of the material that is indicative of the velocities observed since no data exists to define the subsurface geology. In any case, these velocities are not indicative of a massive bed rock and are generally indicative of weathered rock or consolidated soil. The higher the velocity, the harder the soil/rock are. To give some interpretation to the results we can assume that two scenarios can be thought of. The first, is that higher velocities are indicative of a man-made structure. In that case, areas with higher velocities are structures or walls in the subsurface. The other assumption could be that the lower velocities are soil filled "chambers" and the surrounding are the natural undisturbed soil. In any case, these are assumptions that need to be examined both by the archaeologist findings, and by other investigation tools.

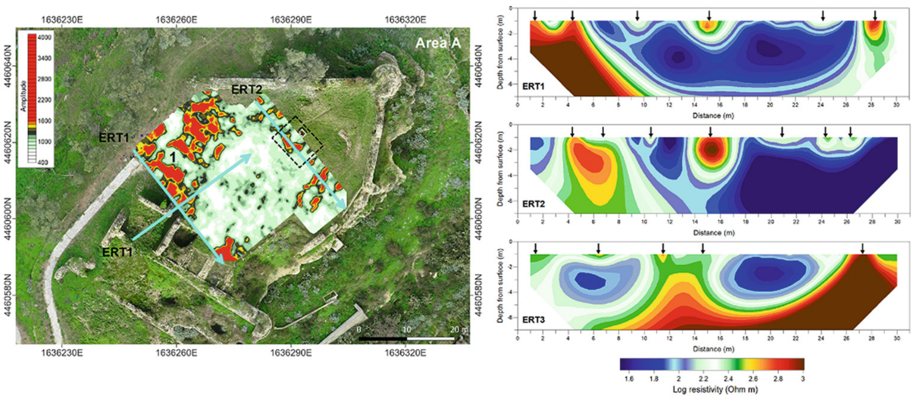

Fig. 10. Location of ERT surveys overlaid on the GPR slice (left) and ERT sections (right) with indication of shallow anomalies.

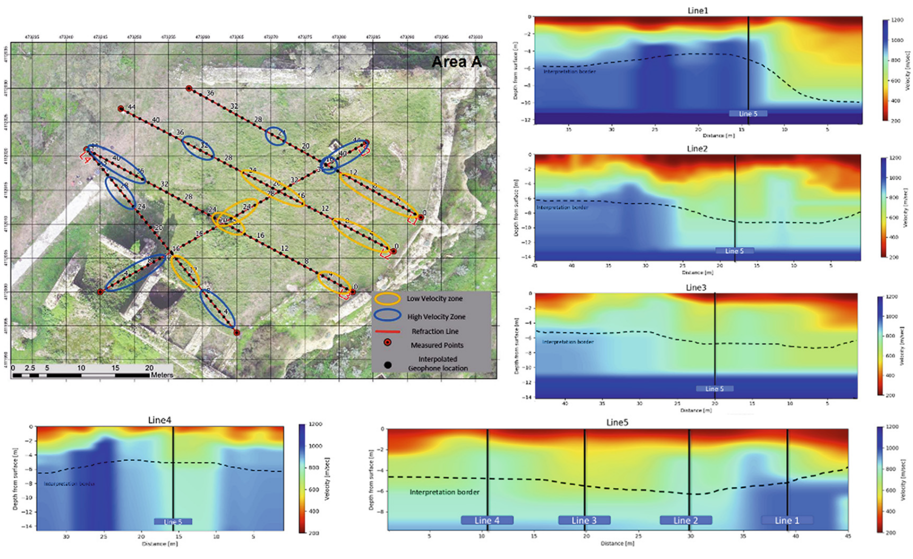

Fig. 11. Seismic refraction tomographies and location of low and high velocities zones on the map of the castle.

3 Conclusions

The preventive assessment of the archaeological interest through non-invasive geophysical diagnosis at the Castle of Licodia Eubea was carried out using different geomatic and geophysical methodologies. Beyond the differences in the operating principles, in the type of instrumentation involved in the measurements, in the type of response provided and in the fields of applicability of the various prospecting techniques used, the common objective was to provide as many elements as possible for a general evaluation of the sites being researched.

In some points the environmental conditions of the places to be investigated possessed logistic features, which allowed the application of a single method of investigation. Individually, the three methods have guaranteed satisfactory results and, in particular, it has been possible to reconstruct, in a rapid and totally non-invasive way, the distribution in three-dimensional space of the structures buried in archaeological environments known or vaguely suspected of containing objects of anthropic nature. The supports provided by the prospecting represented valid information for planning in advance systematic excavations or enhancement of the relevant elements. In the areas where it was possible, a multi-methodological approach was followed with the aim of obtaining high-quality information through a global assessment of the convergence of data subject to different physical factors. Thanks to the integration of several techniques, the same geophysical anomalies were found which, despite having been detected through various physical behaviours, identified the same buried object. However, direct verification with archaeological excavations is necessary for the complete study of the sites.

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