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Multidisciplinary investigations at the Kamarina archaeological site (southern Sicily, Italy)

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***Abstract* – Multidisciplinary geophysical investigations have been carried out in a small area of the Greek archaeological site of Kamarina, in southern Sicily, in order to support some hypotheses, derived from historical and archaeological bases. After an aerial photographic and thermographic survey, a small area near to the Agora has been considered for magnetometric and GPR investigations. Obtained results show a good correlation and allow to highlight some structures oriented in agreement with the uncovered remains. The use of integrated geophysical techniques allowed a more robust interpretation of the detected anomalies in order to better address the choices for new excavations.**

I. ARCHAEOLOGICAL INFORMATION

Kamarina was a Greek city founded by the Syracusans at the beginning of the 6th century BC. (598-597 BC) on a plateau (ca. 50m a.s.l.) delimited by the Ippari and Oanis rivers, located along the southern coast of Sicily (Italy) facing the Sicily Channel. During the 5th century BC., Kamarina acquired floridity and prestige and lived another moment of prosperity at the end of the 4th century B.C. reaching its maximum urban expansion. As early as the 3rd century BC, conquered by the Mamertines at first (275 BC) and then by the Romans (258 BC), the city started to decay: greatly reduced in size, it survived in the Augustan age until it declined in the imperial age. Only its acropolis has been not abandoned.

The port-channel, made in the Greek age with adaptation of the mouth of the Ipari river, lasted for a long time being the hub of important commercial traffic up to the Roman age.

Kamarina was definitively destroyed in 827 by the army led by Asad ibn al-Furat during the Arab conquest of Sicily.

The present remains are of great archaeological interest, and they testify the vastness of the ancient site. There are archaic tombs (VII century BC) and ruins of a temple dedicated to Athena. The acropolis shows continuity of use: the ruins of the temple of Athena are embedded in the construction of the church of Our Lady of Cammarana. The building was destroyed by a fire in 1873; its remains were used for the construction of the farmhouse that hosts the local museum today.

Along the Ippari river the route of the ancient canal harbor is recognized. The city is still detectable in its original area by the remains of houses and pavements. The excavations carried out at Kamarina by Paolo Orsi from 1896 to 1911 provided copious archaeological material at the Museum of Syracuse.

At present, remains of civil and public buildings have been uncovered in the small portions of the whole archaeological site that have been investigated. At the top of the hill, there are visible the ruins of the Temple of Athena, explored by Orsi and [1]. New investigations were carried out in 1980 and 1987. The Agora is located on the south-western end of the hill, between the temple of Athena and the harbor. Its excavations have not been fully completed. The remains of the "House of the Altar" date back to the republican age, so called for the sacred structure placed in the center of the courtyard. The southern section of the fortification walls of the city, below the hill of Heracles is the best preserved part.

Since the importance of the site in the Greek period, archeologists supposed the possible presence of notable structure (i.e. a theatre), but any observable morphological evidence did not support such a hypothesis.

Preliminary multidisciplinary geophysical investigations involving Ground Penetrating Radar (GPR) and magnetic survey [2, 3, 4, 5], supported by 3D photogrammetry and UAV thermography were performed in a sector adjacent to the Agora aimed to find any clues that could address the future archaeological excavations (fig. 1). Terrestrial geophysical surveys involved an area of approximately 2500 m^2, overlapping the same zones in order to constrain the interpretation. Aerial surveys were instead performed over about the whole archeological site.

Fig. 1. Orthophoto of a sector of the Kamarina archaeological site. The magnetometric and GPR survey area is indicated by the red square.

II. AERIAL PHOTOGRAPHIC AND THERMOGRAPHIC SURVEY

Recent developments in the use of Unmanned Aerial Vehicles (UAVs), also known as Unmanned Aircraft Systems (UAS), for remote sensing applications provide new opportunities for ultra-high resolution environmental mapping and monitoring. An aerial photographic and thermographic survey was performed in order to produce a high resolution digital surface model (DSM) and a thermal map of the archaeological site, contributing to a reconstructive history of architectural structures. The system consists a lightweight (1.1 kg) UAV equipped with an on-board digital camera, GPS and autopilot system. We used a quadricopter Phantom 3 Dji, well suited photogrammetry and mapping (Lens FOV 94° - 20 mm, Sony Sensor EXMOR 1/2.3”, effective pixel resolution of 12.4 M). Moreover the UAV was also equipped with a thermal imaging camera Optris PI 640, with an optical resolution of 640x480 pixels, the PI 640 delivers pin-sharp radiometric pictures and videos in real time with Frame rate of 32 Hz. Spectral range 7.5 - 13 µm, temperature ranges from –20 °C to 1500 °C and accuracy: ±2 °C. Data acquisition from the entire survey was accomplished by a combination of two missions in a uniform crossed grid pattern. The coverage of the entire area has been achieved by acquisition of 5400 frames for the visible spectrum and 120 for thermal. The locations of the selected geo-points were determined using a GPS NAVCOM SF-3040 with angular accuracy of 1 cm. The survey has been performed at an altitude of 30 m and a speed of 3 m/s. Photo overlap is user-set in the 75-85% range, allowing for high-quality photogrammetric image matching. A set of ground control points have been used for geo-referencing the Digital Model. The aerial photographs were processed into georeferenced orthoimages, a high-resolution digital surface model (DSM) and Digital Elevation Model (DEM), using the photogrammetric 3D reconstruction technology software by AgiSoft PhotoScan [6]. The digital elevation model generated has a ground resolution up to 4.0 cm (Fig. 2). Advances in computer vision and image analysis are, however, generating innovative developments in photogrammetry through the technique of Structure-from-Motion (SfM), which offers an automated method for the production of high-resolution digital surface models (DSMs) with standard cameras [7, 8, 9].

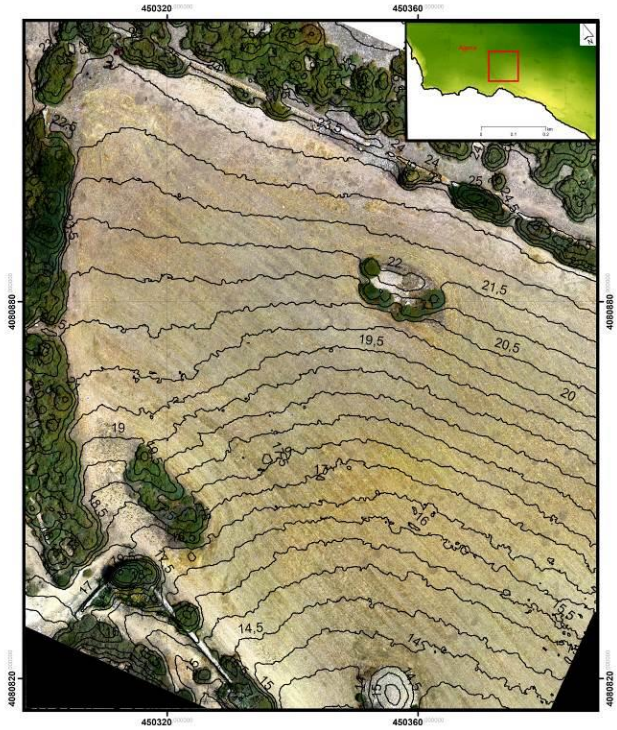

Fig. 2. Contour lines of elevation over the aerial photographic map.

Archaeologists have long used thermal infrared images to locate buried architecture and other cultural landscape elements. The thermal infrared radiation associated with such archaeological features depends on several variables, including the soil texture, its moisture content and vegetation cover.

The coupling of the thermal camera and the drone is still new. The aerial thermography makes it possible to gather field survey data across a much larger area in much less time. This combination allows the use of thermal prospection for archaeological detection at low altitude with high-resolution information, from a microregional scale to the site scale. The high potential is regarding the detection of archaeological structures whose presence is manifested on the surface by different temperature from that of the atmosphere and the surface of the soil. The first results are shown in figure 3.

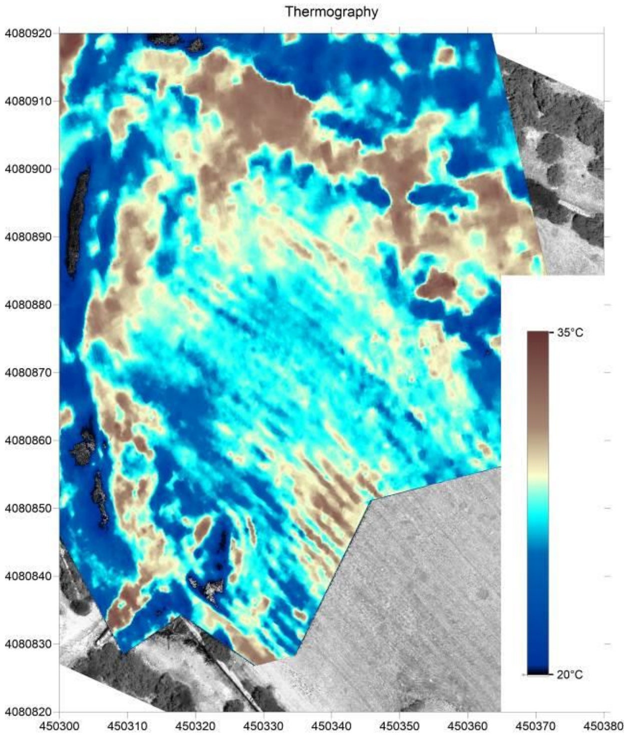

Fig. 3. Thermal infrared map

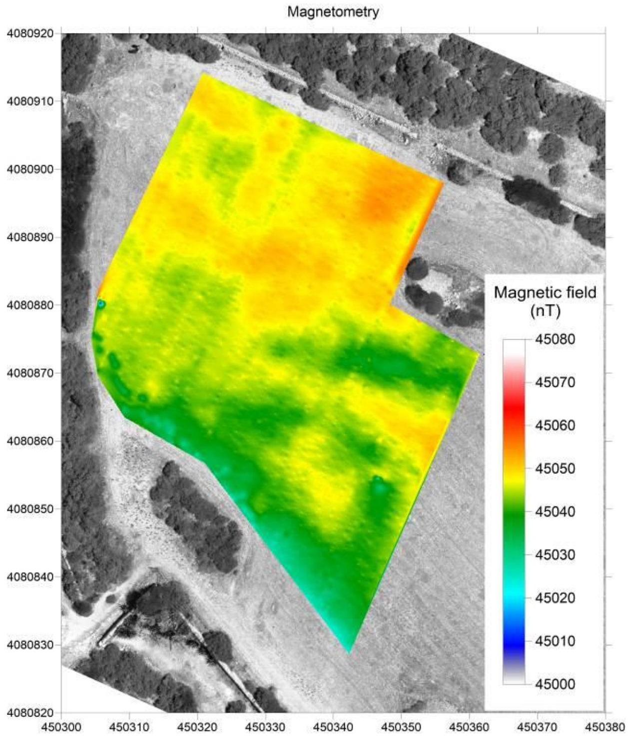

Fig. 4. Magnetometric map.

III. MAGNETOMETRIC SURVEY

The magnetic survey was carried out by means of the Overhauser magnetometer-gradiometer GEM-19 from GEM Systems which has an accuracy of 0.2 nT. The device was set as gradiometer with two parallel sensors spaced by 56 cm and carried by the operator on a specific backpack. Measurements were performed walking along parallel lines spaced by 0.5 m and materialized on the field with measuring tapes; the survey area extends for about 2500 m^2. The magnetometer is equipped with a GPS providing the position and the time for each magnetic measures (5 Hz sampling frequency), for more than 37,600 readings.

Data were interpolated on a regular grid to draw a map of the total magnetic field and a map of the magnetic gradient. The values of the total magnetic field range from about 45000 to 45080 nT (Fig. 4). There is evidence of magnetic features with magnitude in the order of ~5 - 20 nT. Such features are preferable ESE-WNW oriented (and, in a minor way, perpendicularly) and have dimension ranging for 2 to 6-8 m. For their characteristics they are ascribable to buried structures (e.g. roads or buildings). Differently, the anomalous low magnetic values in the southernmost part of the study area, are clearly influenced by the occurrence of a metal fencing that delimits the archaeological site. The gradient map does not show clues of relevant features, except for some very localized bipolar anomalies ascribable to metal objects buried in the shallow subsurface.

IV. GROUND PENETRATING RADAR

GPR survey was performed using a SIR-3000 system of GSSI, equipped with a 400 MHz antenna. Profiles were carried out along parallel traces 1 m spaced. The 2D profiles have been rearranged in time-slices to obtain a three-dimensional model of the electromagnetic reflectivity of the shallow sub-soil, until a depth of about 2 m. By analyzing the main reflection hyperbola, we considered an average velocity of 0.1 m/ns for the electromagnetic waves to convert the time-slices in depth-slices. The GPR depth-slice ranging from 0.5 to 1 m (fig. 5) shows linear anomalies ESE-WNW oriented that retraces the magnetic ones. In the south-western part of the map a clear curved anomaly 6-8 m wide is present. In correspondence, the magnetic map shows a low value anomaly with a similar shape.

V. DISCUSSION AND CONCLUSIONS

A comparison among thermal, GPR and magnetometric data, constrained by DSM, highlights numerous buried features coherently arranged respect to the ancient urban pattern, clearly visible in the western area, close to the Agora (fig. 1). Moreover, an arcuate geophysical anomaly, visible in the south-eastern portion of the investigated area, could be consistent with a large scale architectural element.

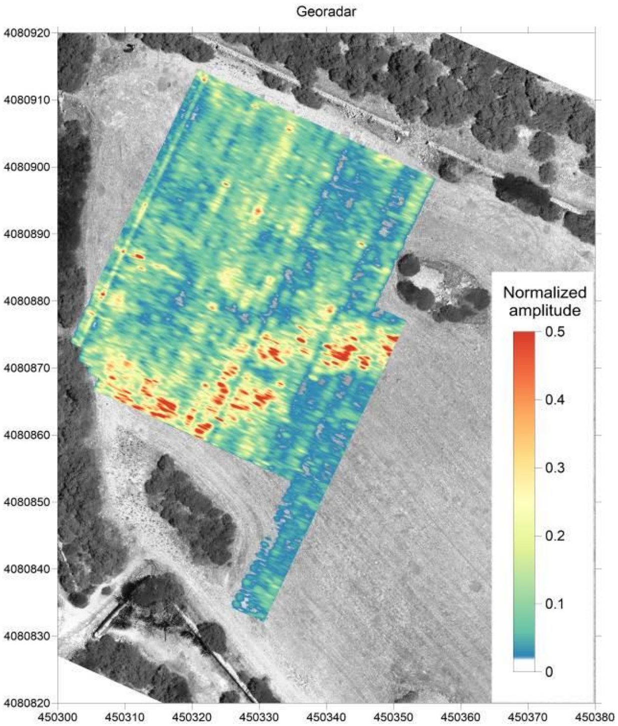

Fig.5. GPR depth-slice ranging from 0.5 m to 1 m depth.

The integration between the georadar depth-slices and the magnetometric maps shows a good correlation between electromagnetic reflectivity and magnetic field anomalies. Some of these anomalies are evident also in the thermal map, especially in the north-western corner of the investigated area. This suggests the hypothesis that the reflective bodies highlighted by the GPR survey are generally also the sources of the magnetic and thermic anomalies of archaeological interest.

It is evident that these detailed geophysical surveys for archeological purposes, can only be conducted in some spots that, after extensive general analysis, are considered of particular archaeological interest.

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