GPR AND MAGNETIC SURVEY AT THE KAMARINA ARCHAEOLOGICAL SITE (SICILY, ITALY) SUPPORTED BY AERIAL PHOTOGRAPHIC AND THERMOGRAPHIC DATA

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Archaeological information. Kamarina was a Greek city founded by the Siracusans at the beginning of the 6th century BC. (598-597 BC) on a plateau (ca. 50 m a.s.l.) delimited by the Ippari and Oanis rivers, located along the southern coast of Sicily (Italy). During the 5th century BC, Kamarina acquired floridity and prestige and at the end of the 4th century B.C. it reached its maximum urban expansion. As early as the 3rd century BC, conquered by the Romans (258 BC), the city started to decay until it declined in the imperial age.

Kamarina was definitively destroyed in 827 during the Arab conquest of Sicily.

The present remains are of great archaeological interest, and consists of archaic tombs (VII century BC) and the acropolis with ruins of a temple dedicated to Athena, successively 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.

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 from 1896 to 1911 and Pelagatti (1985). The Agora is located on the south-western end of the hill, between the temple of Athena and the harbour. Its excavations have not been fully completed.

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 (Chianese et al., 2004; Rizzo et al., 2005; Ranieri et al., 2016), 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. Terrestrial geophysical surveys involved an area of approximately 2500 m², overlapping the same zones in order to constrain the interpretation. Aerial surveys were instead performed over about the whole archeological site.

Aerial survey. 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) Unmanned Aerial Vehicle (UAV) equipped with an on-board digital camera, GPS and autopilot system. We used a quadricopter Phantom 3 Dji, well suited photogrammetry
and mapping. Moreover the UAV was also equipped with a thermal imaging camera Optris PI 640, with an optical resolution of 640x480 pixels, the PI 640 with 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 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 (Agisoft LLC, 2015). The DEM generated has a ground resolution up to 4.0 cm. 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 DSMs with standard cameras (Fonstad et al., 2013; Micheletti et al., 2015).

**Terrestrial 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 m². 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. 1a). 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.

![Magnetometry](image1.png)
![GPR depth-slice](image2.png)

Fig. 1 - a) Magnetometric map. b) GPR depth-slice ranging from 0.5 m to 1 m depth.
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.

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. 1b) 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.

Discussion and conclusions. A comparison between 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. Moreover, an arcuate geophysical anomaly, visible in the south-eastern portion of the investigated area, could be consistent with a large scale architectural element. The integration between the georadar depth-slices and the magnetometric and gradiometric maps shows a good correlation between electromagnetic reflectivity and magnetic field anomalies. This suggests the hypothesis that the reflective bodies highlighted by the GPR survey are generally also the sources of the magnetic anomalies of main archaeological interest.

References
Micheletti, N., Chandler, J.H., Lane, S. N., [2015] Structure from Motion (SfM) Photogrammetry, Geomorphological Techniques, Chap. 2, Sec. 2.2.