02 | GEOPHYSICAL PROSPECTING

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Recovering the Urban Network of Ancient Sikyon Through Multi-component Geophysical Approaches

Abstract: A suite of different geophysical techniques was applied in the course of multidisciplinary research conducted within the framework of the Sikyon survey project, whose goal is the study of the landscape and human activity on the plateau of ancient Sikyon (NE Peloponnese). During the first 3 years of the geophysical campaign, more than 60,000 m^2 of the city centre were covered using magnetic measurements, electrical resistivity mapping and tomography techniques, and ground penetrating radar. Controlled experiments covering large sections of the site using different methods and instrumentation allowed the evaluation of these methods' effectiveness in detecting and mapping the subsurface targets and improved representation of the lateral and stratigraphic extent of the architectural remnants. Already a number of architectural features and even whole structures have been identified and mapped, starting to reveal the urban network of the ancient city and its diachronic phases.

Sikyon: Archaeological and Geomorphologic Background

In 2004, a consortium consisting of the University of Thessaly, the Institute for Mediterranean Studies (FORTH) and the 37th Eforeia of Prehistoric and Classical Antiquities of Corinth initiated a multidisciplinary archaeological campaign dedicated to the study of the diachronic human presence on the plateau of ancient Sikyon which rises about 3.5 km SW of the Corinthian gulf, and covers some 250 ha. The plateau, which is accessible from the coastal plain to the east, is naturally divided into an upper (altitude 180–260 m) and a lower section (altitude 100–180 m).

During Ancient and Classical times, the settlement of Sikyon was located on the coastal plain, between the Helisson and Asopos rivers. This would explain Homer's referring to Sikyon as "eurychoros", meaning "spacious". In the early Hellenistic period (at the end of the 4th century), the city was destroyed by Demetrios Poliorketes and refounded on the site of its former acropolis — a natural stronghold that secured the interests of the Macedonian ruler. The city prospered throughout the Hellenistic period, but in the Roman period it was overshadowed by the neighbouring city of Corinth. Evidence of settlement is also extant for the Frankish, Ottoman and Venetian periods. Today, the small village of Vasiliko occupies the southern corner of the lower plateau of the site.

Previous investigations of the site include large scale excavations by the American School of Classical Studies and the Archaeological Society, which brought to light sections of or entire monumental buildings, including the theatre, palaistra complex, bouleuterion, a long stoa, and a Roman bath complex. An extensive surface survey of the area was also carried out by Lolos (LOLOS 2008; forthcoming), who was able to identify the remains of the fortification, the gates, construction walls, ancient streets and other features that provided evidence for the great extent of the site. Based on this information, the current approach is aimed at a more

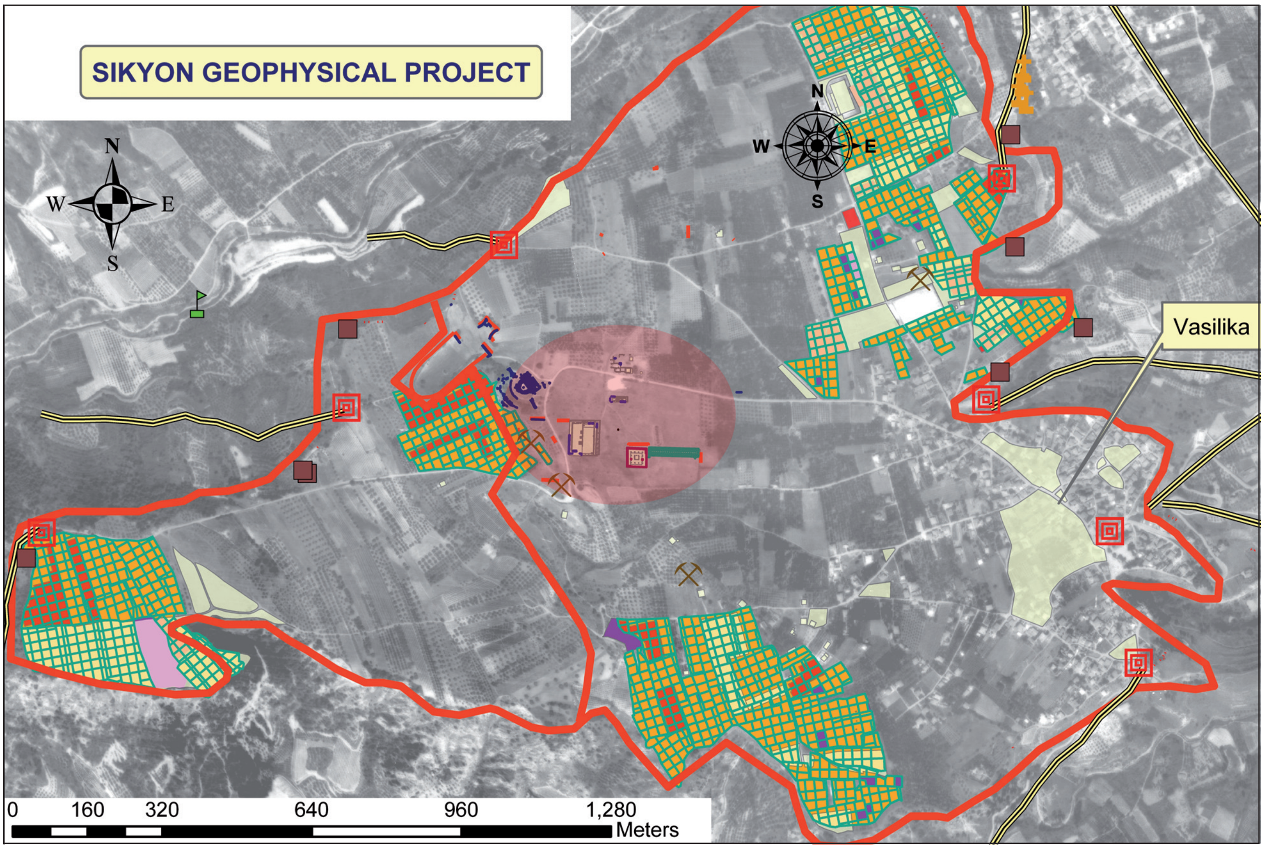

Fig. 1. An aerial photo mosaic of the site of Sikyon indicating the extent of the site, surface features and areas that have already been surveyed with intensive surface survey techniques. The focus of geophysical investigations discussed in this paper is shown at the centre of the site (ellipse), where most of the monumental structures have been identified by past excavations.

systematic and integrated capture of the archaeological evidence of the site, through a surface survey and geophysical prospection (The Sikyon Survey Project 2007) *(Fig. 1)*.

The Geophysical Approach – Methodology and Techniques

Geophysical investigations of the site were initiated at the very beginning of the campaign, in order to cover large sections within and around the ancient Agora *(Fig. 2)*. Two fluxgate gradiometers, a Geoscan Research FM256 and a Bardington GRAD 601, were employed in the high resolution (0.5 m sampling) magnetic scanning of the site. A Geoscan Research resistivity meter RM15 with a multiplexer MPX15 and a Twin probe electrode configuration with 0.5 m and 1 m electrode separation covered large sections of the region for comparison with the magnetic methods.

Three-dimensional volumetric data of the subsurface was obtained through electrical resistivity tomography (ERT) and ground penetrating radar (GPR) techniques. Three-dimensional ERT data was collected in two different ways. The first took measurements of the apparent resistivity along parallel transects using a Syscal Pro ERT unit with a 10-channel multiplexer module (Switch Pro) and a dipole-dipole electrode configuration. The second method incorporated two directional (along x- and y-axis) resistivity measurements using the Geoscan Research RM15/MPX15/PA5 system with a pole-pole array and a modified field procedure which gathers dense parallel tomographies as has been described by Papadopoulos (Papadopoulos / Tsourlos / Tsokas 2006). Penetration depth reached a maximum of 3 m below the surface.

Similar stratigraphic data was collected in the same regions using an EKKO 1000 unit with 225 MHz and 450 MHz antennas. A Noggin Plus smart cart with a 250 MHz antenna was ultimately employed for the extensive mapping of areas with problematic survey conditions, such as asphalt roads, cement-covered parking lots and areas within the wider complex of monumental buildings. GPR measurements were obtained along parallel lines 0.5 m apart, with a 0.05 m and 0.1 m sampling interval for

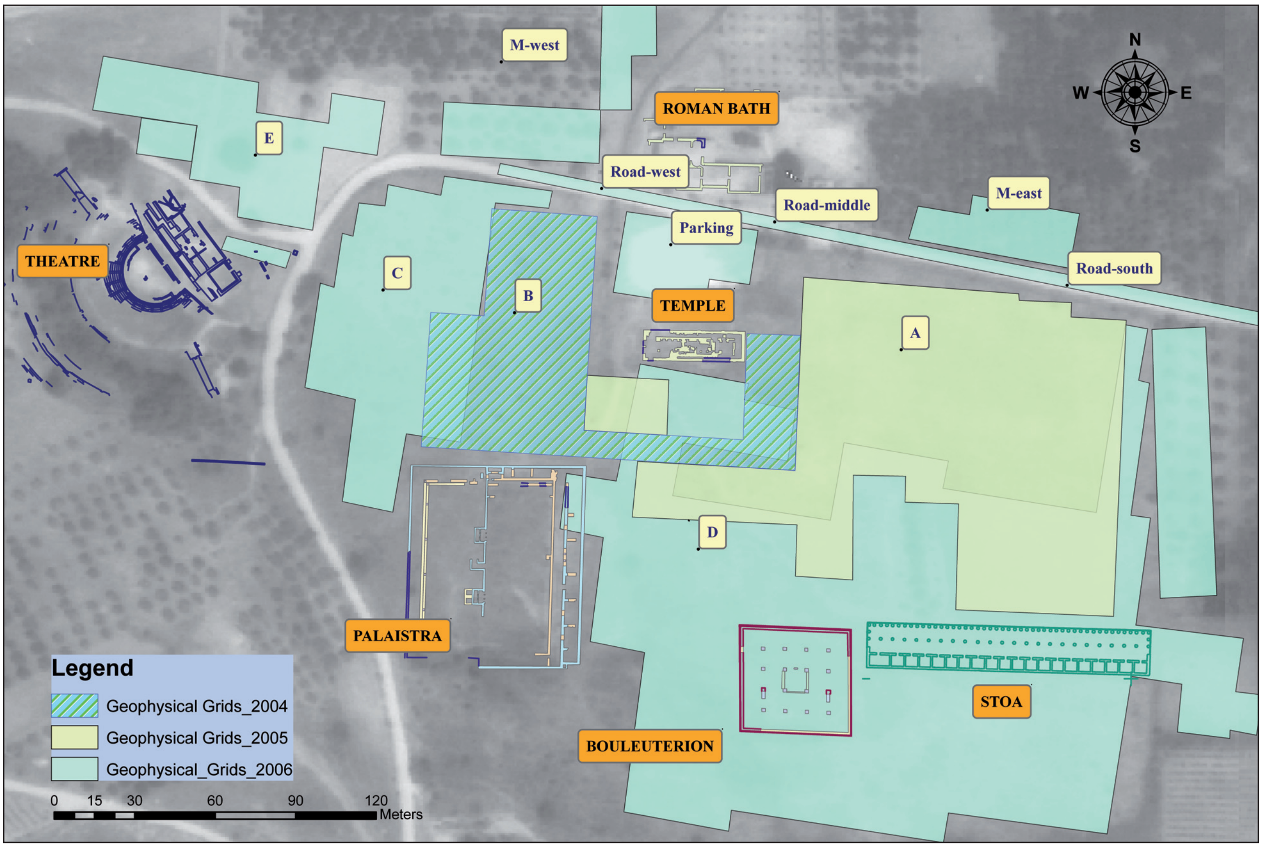

Fig. 2. The focus of geophysical investigations was the area of the Agora and the fields surrounding it. In three survey seasons more than 60,000 m² have been covered using complementary geophysical methods.

the Noggin Plus and EKKO 1000 units, respectively. A 3 m penetration depth was achieved through the GPR techniques.

Finally, a Leica GS 20 GPS unit and a Leica TC307 total station were systematically used to accurately map the geophysical grids and the surface remains of the ancient structures. Their contribution was vital in the final steps of processing, where synthesis of all datasets was required through georeferencing of the individual maps.

Geophysical Signal Processing

Due to the extensive coverage of the site and the variety of the methods employed in the geophysical surveying, specific protocols were applied in processing the geophysical data. Magnetic and soil resistance data related to mapping purposes underwent coordinate correction based on a local coordinate system of the survey unit. Pre-processing steps involved despiking of the raw data and grid equalization based on the statistical analysis of the data. Line equalization with respect to both axes (x- and y-axis equalization) was followed by the construction of grid mosaics. The individual mosaics were processed through the application of a number of convolution filters, such as high pass filtering or directional derivatives, in order to highlight linear or subtle anomalies. The final images were also processed through different compressions of the original dynamic range of data in order to further enhance them. Greyscale and colour maps were created and by comparing them with the original data, it was possible to construct diagrammatic interpretation maps which describe the candidate geophysical targets.

The GPR signals were processed with a suite of software packages provided by Sensors & Software. Variable thresholds (5–30%) were used to define the first peak arrivals and datum zero level of radargrams. Enhancement of signals was further carried out through the application of AGC, Dewow and DCshift filters. Ten horizontal slices with variable depth were made for each region of interest (up to a maximum depth of 3 m) by applying an average envelope amplitude and background noise removal filter. Signal migration was also taken into account with a velocity estimate of 0.1 m/nsec. Horizontal or vertical (time) filtering proved to be dissatisfactory in further improving the stratigraphic slices.

The inversion routine that was applied to the ERT datasets was based on a non-linear smoothness constrained algorithm (Sasaki 1992). The smoothness constrained inversion tries to find the simplest and smoothest resistivity model of the earth which could be a reasonable representation of the earth. The particular type of inversion guarantees the stability of the solution (Loke / Barker 1996; Tsourlos / Ogilvy 1999).

GPS and total station readings helped the final georeferencing of the maps and their correlation to the surface relics. ArcGIS 9.2 was employed for the particular purposes and finally a master project containing the geophysical images overlaid on aerial imagery and other data from the surface survey contributed to the creation of thematic maps.

Results of the Geophysical Survey Approach

Magnetic data covered most of the region of interest. The composite image of the magnetic data is shown in *Fig. 3*. Starting from the west section of the site, in area E, north of the theatre, a rectangular, 12 x 15 m peristyle was identified. The particular structure has an east-west alignment and follows the general orientation of the city's monuments. Its relationship to the theatre remains unknown, as the intervening space has not yet been covered with geophysical methods. In the same region, a linear strip of high magnetic values running in a NW-SE direction extends for more than 76 m leading to a possible entrance to the Agora. In area C, a much larger peristyle building, particularly evident in the soil resistance data, extends for about 62 m in a north-south direction, due north of the excavated palaistra complex. The north portico of this complex features a back wall with series of semi-circular and rectangular niches. At approximately the centre of this complex, we detected a small tripartite building, 10 x 6 m in size, resembling a temple with pronaos and opisthodomos. The whole complex could represent the sanctuary of Dionysos that Pausanias saw as he was approaching the Agora coming from the theatre. To the north and east of this complex, more building remains are suggested mainly from the soil resistance and GPR measurements, but their structural and temporal relation to the north portico of the complex remains obscure *(Fig. 4a)*. The temple-like structure inside the complex became one of the targets of the ERT survey using the Geoscan RM15 / MPX15 / PA5 system, and a pole-pole electrode configuration with inter-electrode and inter-line spacing of 0.5 m and maximum electrode separation of Nmax=4a (a=0.5 m). The independent tomographic data which were acquired along X, Y and XY were combined to three individual data sets corresponding to the 3D X, Y and XY survey and a non-linear 3D inversion algorithm was used to process them. The reconstructed 3D models for the X, Y and XY survey are of comparable accuracy *(Fig. 4b)*. The outline of the remnants of the building and its

Fig. 3. Composite image of the vertical magnetic gradient measurements. Light scales correspond to high magnetic readings, while darker scales represent low magnetic values.

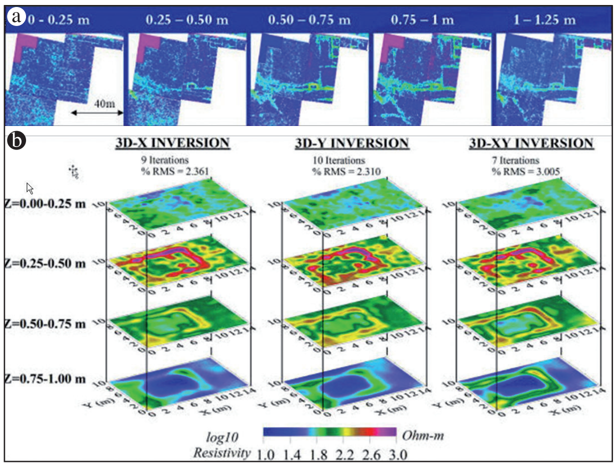

Fig. 4. a. Increasing depth slices from the area north of the Palaistra. Measurements were gathered with Noggin Plus Smart cart (250 MHz antenna) along transects 0.5 m apart and 0.05 m sampling interval along the transects. - b. Three dimensional models from the area of the small structure located within the large peristyle, in the form of horizontal slices, along X, Y and XY, which resulted from the 3D inversion of the parallel electrical tomographies. The logarithm of the apparent resistivity has been plotted.

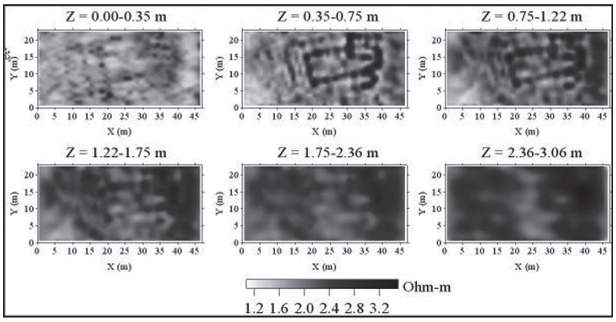

Fig. 5. Three dimensional resistivity model of the Agora basilica resulting from the 3D inversion of the dipole-dipole parallel tomographies carried out with Syscal Pro ERT unit. The %RMS error out of 9 iterations is 4.5%.

inner details (wall sections dividing it into two compartments) are depicted within the second depth slice (0.25 – 0.50 m). The traces of the structure fade away towards the larger depth slice (0.75 – 1.00 m).

In the centre of the Agora, architectural relics do not appear regularly and it is likely that many of them belong to statue bases, altars or other free-standing features that Pausanias describes inside the Agora, or to structures of later historical periods. An obvious example is suggested by the traces of a 30x18 m tripartite building, which was located to the south-east of the excavated temple. It is clearly a basilica with an inner and outer narthex, perhaps from the early Byzantine, and geophysical investigations indicated that it has at least two different construction phases that extend 1.5 m below the surface. More particular information was obtained by ERT (dipole-dipole configuration of electrodes) *(Fig. 5)* and GPR (EKKO 1000) measurements.

A linear magnetic anomaly, also verified by the soil resistance data, extends for more than 80m along the north part of the fenced area of the archaeological site, projecting towards the north side of the peristyle that was located in area C. GPR measurements along the asphalt road that runs around the archaeological site revealed a number of structures that extend to the north of that anomaly and are probably related to a stoa designating the northern limit of the Agora. Similar conclusions are drawn from the geophysical data from the carpark directly south of the Roman Baths where the local museum operates today.

Turning to the south section of the Agora, the Bouleuterion (40 x 45 m) and the long Stoa (105 x 16 m), both of which have been partially excavated, have been mapped in detail. The long Stoa consists of 22 columns and 20 compartments of similar size. Residential blocks of the city have started to appear further to the south.

Large building blocks and a network of orthogonal streets, together with a high density of surface ceramics suggest the expansion of the city in this direction. The roads that run in a north-south direction appear close to the west side of the Bouleuterion and to the east of the Stoa, while a third one can be made out almost midway between the two. Finally, an east-west road runs directly south of the Bouleuterion for 160 m, and probably extends further to the east. The variable width of the aforementioned streets indicates a hierarchy in the road network of the city, which is still under investigation.

Concluding Remarks

The integrated geophysical approach conducted thus far has enhanced our knowledge of the ancient city exposing details of the town plan that remained concealed until today. The employment of different geophysical techniques proved extremely valuable, since each one contributed in a different way to revealing the architecture and layout of the ancient city. Although GPR and ERT methods were not able to cover extensive areas of the site, which the magnetic and resistivity methods did achieve, their impact was of critical value in covering areas that were excluded by other methods or in providing 3D information regarding monumental structures.

In the coming years, geophysical prospection will cover more of the plateau, and hopefully reveal the majority of the structures of the ancient and historical city, thus exemplifying the importance of geophysical techniques in large scale surveying of archaeological sites.

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