Looking for Graves: Geophysical Prospection of Cemeteries

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Abstract: Geophysical prospection of cemeteries has been always challenging in terms of locating and recognizing untouched graves and tombs. Every cemetery has its own specific characteristics, with different types of graves of diverse conservation status. Various geophysical methods have been applied in the past for locating tombs and graves and delimitating the boundaries of the burial grounds and the mortuary landscapes. For the case of built tombs, results could be more straightforward than other cases where disturbed, isolated, prehistoric tombs are targeted.

A range of case studies consisting of various environmental settings and diverse types of tombs and graves are presented together with the specific geophysical approaches involving the application of Ground Penetrating Radar (GPR), magnetics, Electromagnetic (EM), soil resistance techniques and other. Examples are drawn from Eastern Mediterranean (Greece, Cyprus, Egypt) and they demonstrate the degree of efficiency of these methods to detect untouched graves and tombs. The above will signify the importance of geophysical prospection in mapping the mortuary landscape and provide guidance for future excavation.

Keywords: Geophysical prospection, cemetery, grave, tomb, mortuary space, archaeological survey.

Introduction: Searching for Tombs. Hunting the Dead!

Graves and tombs comprise the most common subterranean man-made cavities. The small size of the buried features in combination to slight physical contrast between the grave’s filling material and the surrounding soil renders the location of such structures a real challenge to archaeological geophysics. One of the first systematic works on the applicability of geophysical methods in outlining marked and unmarked graves was presented by Bevan in 1991. The specific work described mainly GPR and electrical conductivity results from nine different sites in the USA with graves dated later than the 17th century, with variable success in each different site. Since then, the non-invasive nature of the geophysical methods made them appropriate for the mapping of graves, burial sites and historic cemeteries through the employment of diverse techniques like ground penetrating radar, electrical resistance, electromagnetic and magnetic methods (e.g. NOBES, 1999; LINFORD, 2004; KISA and SUSZTA, 2006; JONES, 2008; DOOLITTLE and BELLANTONI, 2010).

In addition, more sophisticated methods like two-dimensional (2-D) and three-dimensional (3-D) resistivity imaging techniques have been employed in the detection of graves buried at small depths, in relation to their dimensions mainly in areas of relatively gentle topographic slopes (CANDANSAYAR and BASOKUR, 2001; NYARI and KANLI, 2007). Lately, the use of the geophysical methods has been initiated with satisfactory
results in the detection of buried human remains in forensic investigations (e.g. POWEI, 2004; SCHULTZ, et al., 2006; PRINGLE, et al., 2008).

The detection of tombs or burials inside tumuli like structures (artificially erected small hills) is an especially challenging geophysical problem pushing the applicability of the geophysical methods to their limits. Various approaches based on seismic refraction (TSOKAS et al. 1995) and seismic tomography (POLYMENAKOS, et al., 2004; FORTE and PIPAN, 2008) methods have been used successfully in the past for the investigation of these structures and the location of monumental tombs in inside tumuli. Ground-penetrating radar and electromagnetic methods have also been employed in the location of tombs buried inside tumuli (PIPAN, et al., 2001; PERSSON and OLOFSSON, 2004). Integrated approaches based on the application of magnetic gradiometry and electrical resistance mapping methods provided very good results mainly in tumuli with relatively low levels of topographical variation (Sarris, et al., 2000; Barton and Fenwick, 2005). The electrical resistivity method through the application of multiple vertical electrical sounding (VES) measurements has also been applied to define the structural stratification of a tumulus (PINAR and AKCIKG, 1997). 2-D and 3-D electrical resistivity tomography provided a powerful tool in reconstructing the complex geophysical properties of tumuli subsurface areas and the location of tombs (ASTIN, et al., 2007; PAPADOPOULOS et al., 2010).

On the other hand, the prospects of the survey of smaller isolated graves remain weak. Historical burials, usually associated with a presence of coffins, have been identified successfully through the use of magnetic, soil conductivity and GPR techniques (ELLWOOD 1990, JONES 2008). Recently, Schultz and Martin (2012) proved the ability of the GPR to locate pig carcass under controlled experiments they made. Similar conclusions have been drawn by Powel (2004) for the employment of electrical resistance techniques under controlled investigations of shallow buried kangaroos, pigs and human cadavers. Juerges et al. (2010) went even further, as their controlled experiments indicated that the exposed pig cadavers accelerates decay and thus produces higher levels of electrical conductivity compared to the more resistive signal produced by wrapped cadavers, stimulating secondary burials. Following a diverse approach, Dalan et al. (2010) suggested the use of down-hole magnetic susceptibility measurements to document the magnetic signals of grave shafts (relating the low magnetic susceptibility with the variations of soil compaction in the area of the grave shafts). Still, the above conclusions cannot be easily projected to older graves where only the skeleton remains are left.

Soil Resistance Prospection of Cemeteries

Various electrode configurations have been used in the soil resistivity prospection of cemeteries. These followed the accomplishment achieved in the early experiments that were conducted within a tank to model the response to the tombs. The experimental results lead to the prospection of actual tombs in Tarquinia, Cerveteri (Italy) employing the Dipole- Dipole array with 1, 2 and 3m electrode separation (a) (LERICI 1961; CARABELLI 1967). Years later, the Wenner array (a=2 and 3m), together with seismic techniques, were employed in the cemetery of Sabine in Rome for the detection of tombs and cavities (BERNABINI et al. 1986; CRUCIANI et al. 1991). In general, the application of soil resistance techniques has been successful in surveying large monumental tombs, as it was the case of the tumuli at Kasanlak in the valley of the Thracian
Kings in Bulgaria, where Schlumberger array of various electrode spacing among a radial-circular grid was used to provide a plan of the tumulus interior which proved to be in a good agreement with the subsequent excavation results (TONKOV 1996). On the other hand, as we move to smaller sized tombs, the prospection becomes more problematic – see for example the application of Twin probe mapping at the Roman cemetery of Limori at Epanomi, Greece (TSOKAS et al. 1996) and the Minoan cemetery at Vronda, E. Crete (PAPAMARINOPoulos and TSOKAS 1988). In the latter case, the high resistivity background was mainly responsible for the disappointing results of the resistivity survey.

But what happens when we are dealing with an extensive area and large depths of investigation? This was the case of the investigations that were conducted at the old Jewish cemetery of Alexandria in Egypt looking for voids and monumental structures that could be related to the tomb of Alexander the Great (Fig. 1). In antiquity, the area in which the Old Jewish Cemetery of Mazarita is placed, belonged to the Royal Quarter. Strabo (793-4 s 8) describes the region as the “Palaces” (τα Βασίλεια), which formed a third or a quarter of the city. With a need to prospect the whole cemetery (~25,000 square meters) at a depth of about 10m below the surface and avoiding the noise produced by the historical tombs, soil resistivity methods were engaged making use of electrical profiling and mapping (~10m below the surface), electrical soundings and electrical tomography/imaging. Resistivity mapping was carried out by taking measurements with sampling interval of 2m along 17 profiles extending in the South to North direction. The distance among the profiles varied substantially (less than 10m in most cases), due to the problems encountered in spreading the transects through the corridors and among the tombs. A Wenner array with a=10m spacing interval among the electrodes was employed to map the subsurface layers of the site within a depth of less than 10m below the current soil surface. Electrical soundings were applied along 4 profiles at the west, east, south and central sections of the cemetery. Finally, resistivity imaging/tomography Dipole-Dipole array techniques were applied along 5 profiles. The measurements in the cemetery showed an abnormal level of ambient noise, which affected the quality of the images. This type of noise is related to the highly heterogeneous subsoil layer that is disturbed by the shallow buried tombs in the cemetery. In the central region of the cemetery, a characteristic inverted W anomaly (reaching the value of 160 Ohm-m) was observed along a number of transects. This was confirmed by the tomographic profiles to be located within a depth of about 3-10m below the current surface. The dimensions of the anomaly are estimated to be about 20m (in the E-W direction) by 50m (in the S-N direction) and it constitutes a prominent target for future investigation (SARRIS, et. al. 2001) (Fig. 1).
Graves in an Urban Context

The survey of graves within an urbanized context is of similar interest. Having to deal with a number of modern facilities and networks, the only alternative left is to apply either the GPR (still dealing with side reflections on the structures' walls) or the electrical resistivity tomography (ERT). Hašek and Unger (2010) have recently reported a number of examples and approaches of prospecting religious architecture in the Czech Republic in search of crypts (e.g. through the use of a micro camera for the search of the royal crypt of the Cathedral of St. Vitus in Prague Castle), masonry foundations, tombs and graves (e.g. using mainly GPR techniques in the Chapel of Assumption of the Virgin near Veveří Castle, the Church of St. George and
2-D Dipole-Dipole and 3-D gradient electrode arrays employed during a micro-resistivity survey inside Varzea Church in Portugal, identified successfully a 2.7x0.8x1.7m tomb probably associated with the 16th century Portuguese humanist Damião de Goes (MATIAS et. al. 2006). Similar approaches have been used prior to the renovation works of the new quarters of the Institute for Mediterranean Studies (IMS) in the center of the old town of Rethymno. Two elongated tholos rooms in the basement of this new building have been used as a church in the past. Since during the Venetian period it was a custom for priests to be buried after their death in the church, it was found necessary to carry out a geophysical survey prior to the test excavations in the foundations of the building. The rooms were investigated through the 3-D ERT method using 2-D parallel sections with 0.5m spacing of electrodes employing a Dipole-Dipole array. Having a penetration depth of 1.25m below the surface, the ERT results identified relics of the cooking area belonging to a house of historical times and a few more linear anomalies probably associated to the priests' graves (Fig. 2).

**Moving to a More Integrated Approach:**

**Electromagnetic, Magnetic Techniques and GPR Survey of Tombs**

Electromagnetic, magnetic and GPR techniques have been used in the past for investigating the mortuary landscape in various contexts: graves within an indigenous burial site (NOBES 1999, ANON 2003), prehistoric cemeteries (McKINNON 2009, BIGMAN 2012), historic graveyards (BUCK 2003, JONES 2008, CONYERS 2006) and forensic archaeology (NOBES 2000, DAVENPORT 2001). In many cases, geophysical approaches utilize more than one method for the prospection of cemeteries and tombs (see for example the prospection of graves and grave markers in a North Queensland cemetery, Australia, employing GPR, magnetometry and soil resistance techniques (STANGER and ROE 2007)). In the above studies, the
difficulties of the detection of graves due to the increased levels of noise by the surrounding environmental conditions (e.g. existence of roots in a forested landscape, the absence of a good signal due to the small dimensions of the graves, variations of the signal intensity due to climatic conditions, etc.) has been pinpointed.

Geonics EM-38 conductivity meter has been used in 1990s in the survey of the boat grave burials in Vendel, Upland, Sweden (PERSSON & OLOFSSON 1995). Being able to adjust the frequency of the EM survey to 12150Hz through the employment of a multifrequency conductivity meter (GSSI, Inc. GEM-300 with coil spacing of 1.67m), Bigman (2012) successfully identified over 60 potential Native American burials around the funeral mount at Ocmulgee National Monument in the USA. This kind of frequency adjustment may be critical in the investigations of graves, as other examples have shown that the detection of tombs via conventional EM techniques may not always guarantee a successful result. This was the case of the experiments conducted with a Geonics EM-31 at a section of the Bronze Age and Iron Age cemetery of Dhenia in Cyprus, consisting of a dense distribution of large rock cut chamber tombs. It seems that the empty volume of the chamber tombs did not create sufficient contrast with the calcareous bedrock to identify positively the tombs, but at least the EM signals were registered better than the magnetic signals with the location of the chambers (SARRIS, 2002) (Fig. 3).

![Figure 3](image-url) -- Details of the EM survey at the Bronze Age and Iron Age cemetery of Dhenia in Cyprus. Correlation of the results of the EM survey with the surface indications, mainly originating from the marking of the dromoi (entrances) of the tombs.
A detailed experimental survey to test the strength of the signals in relation to the ability of the detection of small sized urn tombs has been carried out at Békés Koldus-Zug site, where scattered burned human bones and Bronze Age ceramics (with sporadic Árpád and Late Medieval ceramics) suggested the existence of a cremation urn cemetery, which may be dated in two different periods, Bronze Age and Árpád period. In Bronze Age Hungary, beginning around 4500 BC, both inhumation and cremation were common mortuary practices. Oakfield cores (by Dr. Rod Salisbury) indicated a grayish brown loam layer extending about 16-60cm below the plow zone (top 40-45cm). Taking into account this information, together with the suspected dimensions of the burials, the magnetic survey was materialized with a sampling of 25cm in both directions. In order to accomplish the correlation task among the geophysical anomalies and the actual buried targets, 27 small excavation trenches (most of them 1x1m in dimension) were dug, both during the course of the geophysical survey and immediately after the completion of it, upon targets that were pinpointed especially from the magnetometry signals (magnetic anomaly approach) or following a checkers planning. Furthermore, the correlation with the distribution of bones, lithics and ceramics was also taken into account. Even though most of the intensive magnetic anomalies that were dug were correlated with metal fragments and modern intrusions, 6 human burials were excavated (of which 5 were found in urns or with pottery grave goods) (Fig. 4). It was concluded that most of the magnetic anomalies that are related to archaeological features in the area of the cemetery were very weak and close to the noise level of the region (graves were indicated with anomalies within the range of +/-2.5nT/m, while pits were indicated within the range of +/-5 nT/m). Even the enhancement of the shallower depth anomalies (lying within a depth of about 45-65cm below the surface) via the application of FFT techniques and Euler deconvolution was not very effective in identifying archaeological targets (graves and pits) with a high degree of confidence.

The limited results regarding the application of magnetometry in the detection of tombs has been also demonstrated in the past. Even if the goal was often to have an indirect suggestion of the existence of the tombs, mainly originating by a relative high anomaly of the earth-filled dromoi or by a relative low signal of the void (due to missing soil) of the chambers, most of the examples of the magnetic survey of cemeteries resulted in relative poor results (see for example the magnetic survey of the rock-cut chamber tombs in the Etruscan necropolises at Tarquinia and Cerveteri, Italy (LERICI 1961), the magnetic surveys at Tell El Ful and Ben-Shemen, Israel (HESSE 1973; 1980) and at Mt. Bibele necropolis, Italy (BOZZO et al. 1990)).

In contrast, a relative positive association among rock-cut tombs and magnetic signals was demonstrated in the survey of the Hellenistic-Roman cemetery of Athienou Malloura (Cyprus), results that were verified by GPR on specific targets (SARRIS et al. 1996). Indeed, rock cut chamber tombs produce strong reflection signals and even smaller tombs and voids can be detected through the stratigraphy anomalies identified in the radargrams. GPR antennas of 225 and 450 MHz were capable of detecting small size (~0.5m diameter) Minoan tombs at Chalasmenos (E. Crete, Greece) (SARRIS 1998). At Ellinospita Mouri, close to the ancient city of Axos (Oaxos) in Rethymno, Crete, a number of terraces were surveyed, below which underground Roman tombs were excavated in the past. GPR transects expanded in other regions of the site and registered strong reflectors, similar to those produced by the corresponding experiments above the
controlled targets (excavated tombs) (Fig. 5), suggesting the presence of more underground rock cut tombs or voids (Sarris 2011:20).

Fig. 4 – (Upper Left) Details of the magnetic survey at Békés Koldus-Zug site. (Lower Left) Power spectrum of the magnetic data aiming towards the isolation of the shallower buried targets. (Right image moving from top to bottom - the red rectangles correspond to the outline of the excavation trenches): Cremation grave; Urn grave & pit; Iron tractor screw (93gr) and Bronze Age Round Pit; Iron wire (33 g, folded but over c. 30 cm long total) at 35cm; Iron wire (21 g, 25 cm long) at 15cm.

The importance of the complementary application of various methodologies in the investigation of cemeteries has been manifested in the exploration of the Roman cemetery at Kenchreai (Korinthia), consisting among others of subterranean chamber tombs (on average 3.73m long x 3.27m wide x 2.53m high), cist graves and related architecture (SARRIS et al. 2007). The first subsurface targets of the cemetery were suggested by the application of a detailed EM31 and magnetic survey. The GPR followed as a verification method covering only portions of the site, since the coverage of the terrain did not allow an extensive GPR survey. Again, the importance of the controlled experiments above known targets was of crucial importance. Both 225MHz and 450MHz antennas produced multiple reflection signals above the known chamber tombs providing a good estimate of the depth extent and the dimensions of the features. Based on the signals of the experimental
surveys it was possible to have a better interpretation of the concave shaped signals produced by the vaulted ceiling of other candidate unopened chamber tombs, graves and pits, existing in the deep sloping stratigraphy of the Koutsongila Ridge. Having an even larger margin for experimental work, the residual curves produced by microgravity measurements above the known tombs generated (after the application of the corresponding corrections) clearly estimates not only for the location of the tombs, but also their depth and dimensions in very good agreement to the GPR data.

Fig. 5 – Typical GPR reflection signals produced by underground rock cut or build tombs. The particular example is from the region of Axos, where a Roman cemetery has been identified through test excavations. The reflection signals (top image) were produced along a transect above the two tombs shown at the bottom image, using the Noggin Plus (Sensors&Software) GPR with 250 MHz antennas.

Mapping the Mortuary Space. Final Remarks
The investigation of cemeteries is always a difficult and challenging task in archaeological prospection. The identification of individual graves through geophysical techniques is relative problematic and thus in the prospection of cemeteries and graves there are no rules or specific guidelines. The success of such a survey depends on the conservation of the graves, the various artifacts that may accompany a burial, the depth and dimensions of the burial, the environmental noise, the geology, etc.
Keeping this in mind and having an understanding of the limitations imposed by both the conditions of the graves, their surrounding soil matrix and the confinement of the prospection methods, there is always a need for experimentation and neither a case of extreme expectations nor a complete rejection of the involved methods needs to exist. Rushing to extremities and drawing rush conclusions such as those mentioned by a recent U.S. Army's Memorandum for Record (MFR) based on the ambiguous and hazy results of a single test GPR survey at Arlington National Cemetery, is not convincing and does not lead us to a further progress and enhancement of the prospection techniques.

Whatever the case, the taphonomic processes and the general disturbances of the soil stratigraphy influence the identification of graves. The best approach is the combination of various techniques (namely the manifold approach - Sarris 2012) which still may produce limited results if the targets are of very small dimensions and soil strata are heavily disturbed.

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References
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1 Among others, the moratorium which was signed by the Executive Director of Arlington's National Cemeteries (ANC) on September 9, 2012, included the following: "Extensive pilot tests completed at Arlington National Cemetery in 2010 demonstrated that ground penetrating radar (GPR) and other technology currently being used to determine irregularities below the ground with regards to interred individuals, caskets and urns are statistically unreliable and subject to a wide range of interpretation. Subject matter experts have provided analysis stating that the results of GPR introduce more uncertainty than conclusive evidence for individual gravesite. ...

a. Based on the results described above from tests completed at Arlington National Cemetery, effectively immediately, GPR and other technology currently being used to determine irregularities below the ground will not be used for cemetery purposes on Army property until further notice.

b. The moratorium includes GPR and other technology currently being used to determine irregularities below the ground conducted at U.S. Government or private expense."


