Archaeological Prospection
Archaeol. Prospect. **14**, 1–23 (2007)
Published online 11 July 2006 in Wiley InterScience
(www.interscience.wiley.com). DOI: 10.1002/arp.280

Geological and Geophysical Investigations in the Roman Cemetery at Kenchreai (Korinthia), Greece

A. SARRIS,[1]* R. K. DUNN,[2] J. L. RIFE,[3] N. PAPADOPOULOS,[1] E. KOKKINOU[1] AND C. MUNDIGLER[4]

[1] *Laboratory of Geophysical–Satellite Remote Sensing and Archaeo-Environment, Institute for Mediterranean Studies, Foundation for Research and Technology of Hellas (FORTH), Melissinou and Nikiforou Foka 130, PO Box 119, Rethymno 74100, Crete, Greece*
[2] *Department of Geology, Norwich University, Northfield, VT, 05663, USA*
[3] *Classics Department, Macalester College, 1600 Grand Avenue, Saint Paul, MN, 55105-1899, USA*
[4] *InCA Research Services, PO Box 932, CSC, Victoria, British Columbia, V8W 2R9, Canada*

ABSTRACT The Kenchreai Cemetery Project (KCP) comprises an interdisciplinary archaeological research team that is exploring a major cemetery of Roman date in southern Greece. The cemetery is located on the Koutsongila Ridge just north of the ancient harbour of Kenchreai, the prosperous eastern port of Corinth. Surface remains that have been visible for centuries or exposed by looting include chamber tombs, cist graves and architecture. In 2004 KCP conducted geological and geophysical investigations to reconstruct the natural and settled landscape where ancient residents buried their dead. Geological study of the ridge and its vicinity has determined that the tombs are situated within a geologic unit particularly well suited for rock-cut construction, and that tombs were intentionally cut into the bedrock so that the vaulted roofs corresponded with a particularly resistant calcareous horizon (caliche), which provided a stable ceiling for the subterranean chambers. Moreover, several metres of coastline have eroded into the Saronic Gulf since antiquity. A systematic geophysical survey using electromagnetic, magnetic, ground-penetrating radar and gravity techniques was also carried out to map uncovered remains and to correlate visible with subsurface features. Several anomalies were identified that might represent previously unknown large structures and burial sites in the central and southern areas of the ridge. In addition, experimental tests using GPR and micro-gravitometry demonstrated the efficacy of these methods for surveying rock-cut tombs. The combined results of geological and geophysical investigation provide valuable information concerning local resource exploitation, structural distribution, and environmental change. These investigations model an innovative approach to the study of mortuary landscapes. Copyright © 2006 John Wiley & Sons, Ltd.

Key words: Kenchreai; cemetery; electromagnetics; magnetics; ground-penetrating radar; gravity

The Kenchreai Cemetery Project

The Kenchreai Cemetery Project (KCP) began in 2002 with the aim of exploring, through interdisciplinary collaboration, a major cemetery primarily of Early–Middle Roman date (middle

* Correspondence to: A. Sarris, Laboratory of Geophysical–Satellite Remote Sensing and Archaeo-Environment, Institute for Mediterranean Studies, Foundation for Research and Technology of Hellas (FORTH), Melissinou and Nikiforou Foka 130, PO Box 119, Rethymno 74100, Crete, Greece.
E-mail: asaris@ret.forthnet.gr

Received 28 September 2005
Accepted 26 March 2006

first to middle third centuries AD) in southern Greece. The cemetery is located at Kenchreai, which throughout antiquity served as the eastern port of Corinth on the Saronic Gulf of the Aegean Sea (Figure 1). KCP aims to document the physical remains of burial space and funerary ritual in order to understand the social structure of the local community. The site preserves a wealth of archaeological information concerning the residents' identities and relationships. The archaeological investigation of burial at Kenchreai can elucidate the social, cultural and religious complexity of Mediterranean port towns during the Roman Empire.

The historical significance of Kenchreai is attested in the literary and archaeological records. References to the port in Greek geographical, periegetic and rhetorical writings, Roman fiction and Early Christian scripture reveal that it was a populous and prosperous centre. Although the excellent natural harbour has been used continuously since early times, and the modern village at the site (*Kechrees*) preserves the ancient toponym (*Kenchreai*), scientific exploration in the area began only in the twentieth century. Sporadic survey and excavation by Greek research teams in 1904–1906, 1956, 1976 and 1988–1990 traced the broad extent of settlement and uncovered several peripheral burial grounds. Excavations on the harbour front by an American team in 1963–1968 revealed the cultural diversity and commercial vitality of the community. These explorations have shown that Kenchreai was a bustling port, probably one of the busiest in southern Greece during the Empire, a place where people of different backgrounds interacted and flourished (Georgiades, 1907, plate 2; Lampakis, 1907; Pallas, 1959, pp. 213–214, figure 29, 1975, pp. 7–9, figures 10–13; Cummer, 1971; Kristalli-Votsi, 1976 [1984]; Scranton *et al*., 1978; Wiseman, 1978, p. 52; Rife, 1999, pp. 207–209, 553).

Building upon the findings of these previous campaigns, KCP has pursued a multidimensional programme of field research for four seasons (2002–2005) under the auspices of the

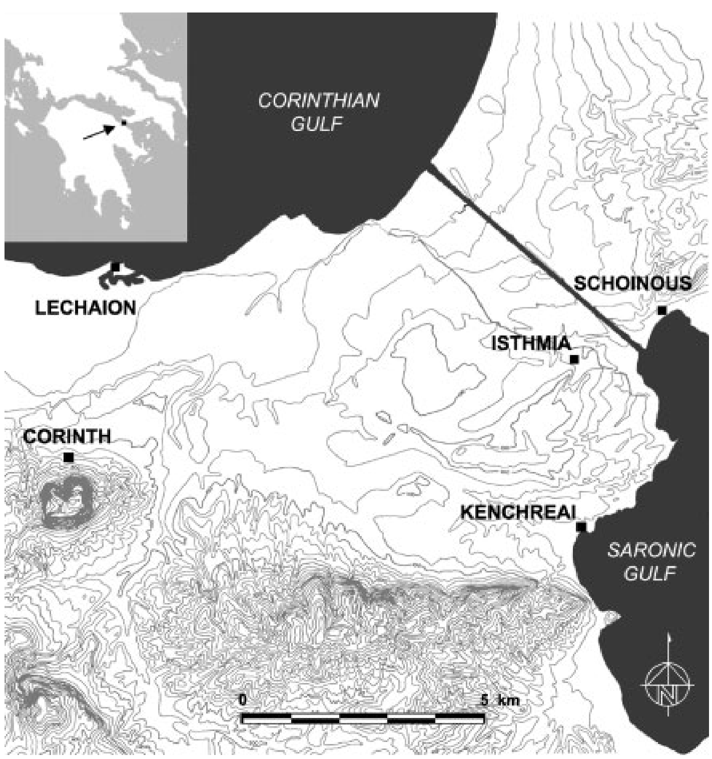

Figure 1. Location of Kenchreai and other ancient sites on the Isthmus of Corinth, Greece. Contour interval = 20 m. (Map by J.L. Rife.)

DOI: 10.1002/arp

American School of Classical Studies, with the sponsorship of Macalester College and the permission of the Greek Ministry of Culture (Rife, 2003, 2004, 2005; Rife and Pitman, 2005). Although previous campaigns have found at least three major burial zones of different periods ringing the harbour, KCP has concentrated on the Roman cemetery on the Koutsongila Ridge immediately north of the harbour (Figure 2). This large cemetery has not been systematically studied before, but it has been widely disturbed by illicit excavation in recent years, and this is still going on today. Nonetheless, looting activities have left much archaeological evidence *in situ*, so that this complex site furnishes important information on life and death at Roman Kenchreai. An international team directed by J.L. Rife has undertaken several activities on and around Koutsongila in order to accomplish the main objective of understanding local social structure as represented in the material components of ritual behaviour and mortuary space. These activities have included topographic, architectural, geological and geophysical survey; the

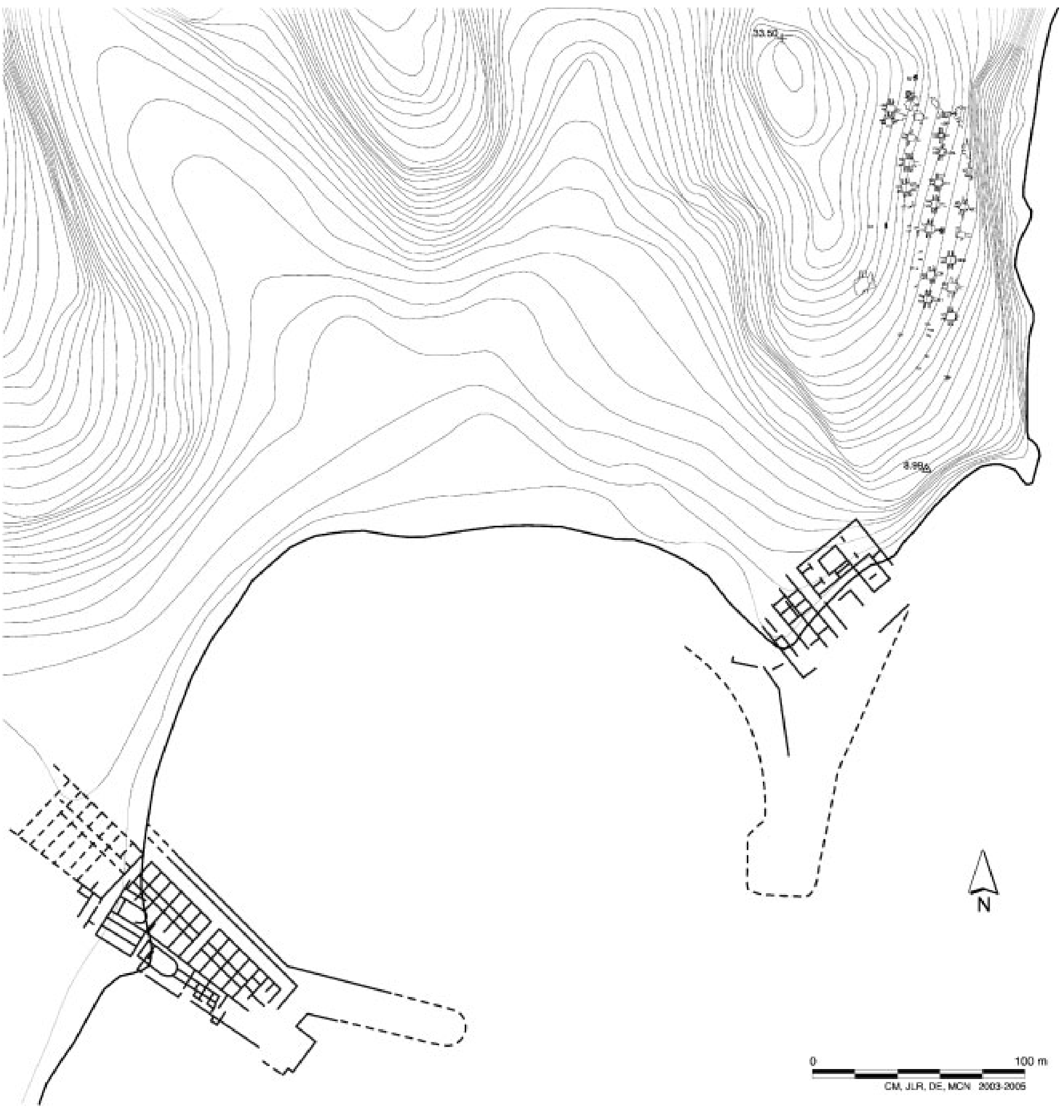

Figure 2. Kenchreai: The ancient harbor and the Roman cemetery on the Koutsongila Ridge. Contour interval = 1 m. (Plan by C. Mundigler, J.L. Rife, D. Edwards, and M.C. Nelson.)

DOI: 10.1002/arp

exploration of surface remains and subsurface depositional contexts; and the study and conservation of artefacts, building materials, wall-painting, and human and animal bones.

Among the activities of KCP, prospection and mapping have proven especially informative. All behaviours surrounding death and the disposal of the body in human cultures are meaningfully situated within a particular spatial context defined both by natural and artificial features. Moreover, any burial space bears a significant relationship with the natural and settled environments (Parker Pearson, 1999, pp. 124–141). Therefore, a detailed reconstruction of the topography of Koutsongila and its vicinity is crucial to the basic mission of KCP. Survey in the Roman cemetery can also address several specific questions. What geological resources existed on the ridge, and how did local residents use them? What was the shape of the ridge and coastline, and how has it evolved over time? What was the relative distribution of the urban settlement and its cemetery? Apart from the cemetery, what architectural features existed on the ridge? How was the ridge occupied after its use for burial?

Members of KCP conducted geological and geophysical surveys in 2004 to explore these dimensions of the natural and settled environments. These integrated studies have shed light on the exploitation of the natural topography and bedrock of the ridge for the placement and construction of tombs; on long-term morphological and habitational changes on the ridge and along the adjacent coast; and on the relationship between the spaces of the living and the dead during the efflorescence of the urban community. This application of geological and geophysical techniques for reconstructing the mortuary landscape is an innovative approach to understanding Roman cemeteries in Mediterranean archaeology, particularly in the ancient Greek world.

The cemetery on the Koutsongila Ridge

Before turning to the methods and results of the geological and geophysical investigations, it will be worth summarizing the nature of the terrain and archaeological remains of the cemetery on the Koutsongila Ridge. Surface and topographical surveys by Rife in 2002–2005, assisted by C. Mundigler in 2004 and 2005, have located numerous burial sites and structures that have either remained exposed since ancient and medieval times or have been uncovered by looting. Koutsongila is a low coastal ridge flanking the north side of the natural inlet that was used as the ancient harbour. The ridge drops off in a steep cliff over the seashore to the east (Figure 2). The area, which is owned by the Government, is an open meadow interrupted by small copses of coniferous trees and low stands of xerophytic vegetation. Archaeological remains have been exposed across the ridge by decades of clandestine excavation, which has left the surface riddled with over 250 trenches and holes cut by looters (Figure 3). Despite this rampant disturbance of the site by clandestine activity, extensive deposits, structures and artefacts survive in an intact or only slightly altered state. The archaeological record on Koutsongila includes subterranean chamber tombs, individual graves and architecture. Although the vast Roman cemetery extends northeast of the ridge ca. 500 m, the KCP is focusing on the portion closest to the harbourside, which was the city's commercial, industrial and residential core.

Looting on the ridge has uncovered 52 burial sites of two distinct classes: 25 were cist graves and 27 were chamber tombs. Most graves are located around the western periphery of the chamber tombs, back a considerable distance from the coast and invisible from afar. They are narrow cuttings (on average 1.98 m long × 0.66 m wide × 0.93 m deep) through the shallow soil into the uppermost horizon of bedrock. The graves take the form of either rectangular pits or oblique shafts covered by roughly cut limestone slabs or terracotta tiles (Figure 4). The tombs differ from the graves in placement and design. Almost all known tombs are evenly situated in three to four north–south rows along the slope facing eastward to the sea. Although very little remains of these buildings, the extant foundations are massive, indicating monumental façades with substantial doors (Figure 5). The interiors of the tombs display a canonical plan with few

DOI: 10.1002/arp

Figure 3. East slope of the Koutsongila Ridge, view from north-northwest. Note the looting pits in the right foreground and middle background. (Photograph by A.J. Suehle.)

Figure 4. Grave 2, view from east. (Photograph by E. Rackow.)

variations (Figures 6 and 7). A stairway descends into a roughly square, vaulted chamber cut deep into the bedrock (on average 3.73 m long $\times$ 3.27 m wide $\times$ 2.53 m high). In the walls are compartments to receive inhumed corpses (*loculi*) and urns for cremated bones (niches). The tombs were finished with plain white or painted plaster, furnished with benches or altars, and supplied with numerous funerary objects.

The chronology of the burials and the identity of the individuals who used the cemetery can be ascertained from both the sepulchral typology and the funerary assemblage. The graves date from the middle–late first century AD to the late sixth to seventh centuries. The few individuals interred in the known graves were residents of relatively low socioeconomic status without a clearly demarcated familial identity. The tombs were constructed and first occupied during roughly the middle first to middle third centuries AD, but residents during Late Antique and Byzantine times used them for continued burial or temporary occupation. An estimated total of at least 500 individuals representing several generations of single-descent groups used the separate tombs in their main phase. The location, scale and decoration of the tombs reflect the power and prestige of the owners and occupants. Moreover, the organized

DOI: 10.1002/arp

Figure 5. Monumental structure above Tomb 6, view from east. (Photograph by J.L. Rife.)

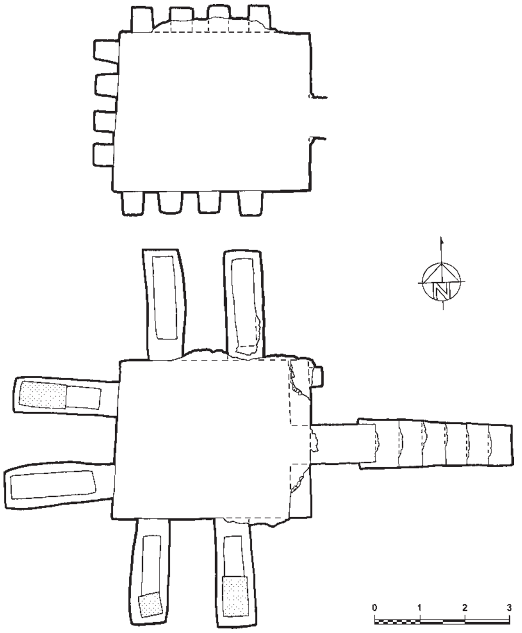

Figure 6. Plan of Tomb 4 at the level of the *loculi* (below) and niches (above). (Plan by J.L. Rife and M. C. Nelson.)

arrangement and standard form of the tombs points to a concerted strategy of burial by an elite group of families in the larger community during the first centuries of the Empire.

Apart from the graves and tombs, KCP has found various structural remains without a mortuary character on the surface of the ridge, especially near its south end. Among over 70 discrete recorded features are several enormous ashlar blocks belonging to monumental architecture of Archaic, Classical or Hellenistic date (ca. sixth to first centuries BC); fragments of brick masonry, mosaic pavement and marble revetment of Early–Middle Roman date (ca. first to third centuries AD); and one apsidal building and one square building, both in rubble and mortar masonry, probably of Late Roman or Byzantine date (ca. fifth to fifteenth centuries). The ashlar masonry must belong to a massive early structure, such as a fortification wall or a temple, which might still have been standing when the cemetery was in use. The brick structures with sumptuous decor are probably a northward extension of the elaborate buildings, possibly a

DOI: 10.1002/arp

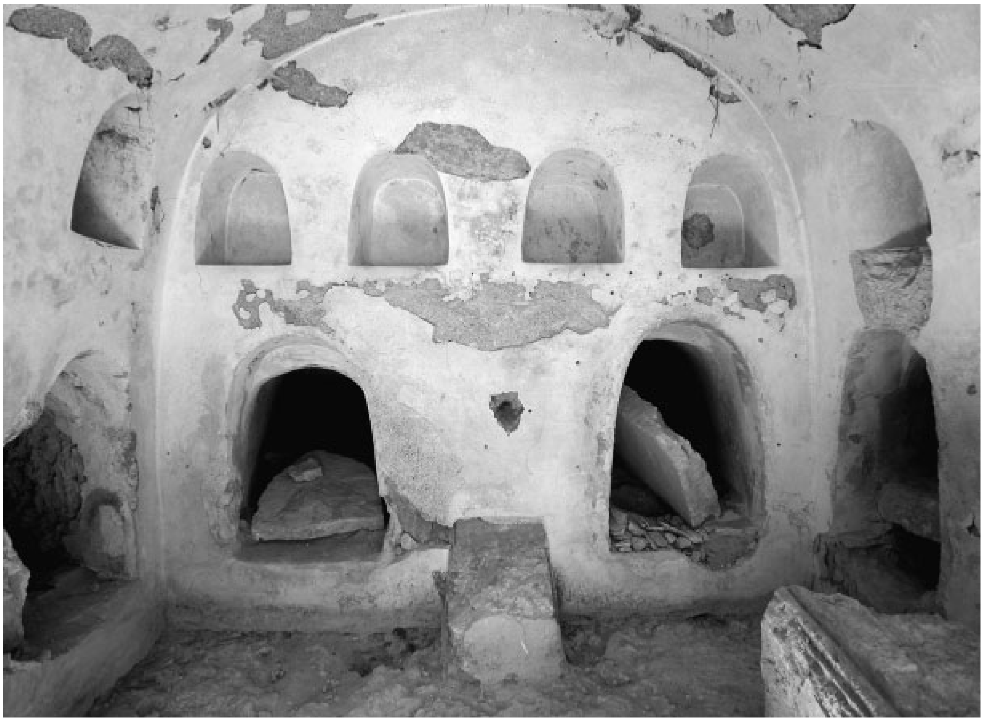

Figure 7. Back (west) wall of chamber of Tomb 13. (Photograph by J.L. Rife.)

seaside residence, that were excavated on the harbour's north mole in the 1960s (Scranton *et al.*, 1978, pp. 79–90; Rothaus, 2000, pp. 66–69; Figure 2). These structures were contemporary with the primary phase of the cemetery. Finally, the rubble and mortar structures might represent an Early Christian church and a Byzantine agricultural building or house succeeding the use of the cemetery. Although all these structural remains are located outside the area of dense burial on the ridge, they are situated less than ca. 15 m south and southwest of the southernmost known burial sites in the cemetery. In sum, it seems that civic space and mortuary space at Kenchreai during the Roman Empire were situated in close proximity. Moreover, the Koutsongila Ridge, especially the area closest to the harbour, appears to have been occupied long before and after the Roman era.

Geological investigation

Geological investigation has significantly augmented this basic knowledge of the archaeological remains on the Koutsongila Ridge. The characterization of site geology, geomorphological evolution and resource exploitation associated with inland and coastal settlement is an established component of archaeological research in the Korinthia, as elsewhere (e.g. Mourtzas and Marinos, 1994; Higgins and Higgins, 1996, pp. 40–45; Hayward, 2003; Crouch, 2004, pp. 129–151). R. K. Dunn conducted a study of the surficial geology and stratigraphy in vertical exposures and subterranean contexts during June 2004 on Koutsongila, in the surrounding area, and along the adjacent Saronic coast (Dunn, 2004). The purpose of this study was to characterize local geology, to trace how it has changed over time, and to explore its relationship with settlement and site-use. Other major studies of rock-cut tombs and hillside cemeteries of Roman date in Greece, Asia Minor and Egypt have largely focused on architectural form and artefactual contents (e.g. Shear, 1931; Alföldi-Rosenbaum, 1971; Roos, 1985; Venit, 2002). Geological study, however, is essential for understanding the natural context of mortuary behaviours and the long-term history of

DOI: 10.1002/arp

burial sites. Moreover, when coordinated with geophysical prospection, it can elucidate the nature of subsurface features. It will be seen (below) that Dunn's characterization of the stratigraphy of the ridge and the geological setting of the tombs was instrumental in interpreting anomalies detected by geophysical techniques.

The area of Kenchreai consists of fluvio-terrestrial deposits and outcrops of marl and marine/nearshore sediments. Seven geological units have been identified in and around Koutsongila, including deposits of lacustrine or marine origin, fluvio-deltaic to nearshore marine origin, terrestrial valley fill origin, and colluvium (Figure 8). These units range in age from Pliocene–Pleistocene to recent. A relatively thick caliche horizon occurs at the surface, regardless of the underlying geologic unit. In general, units dip to the southeast, or seaward, the exception

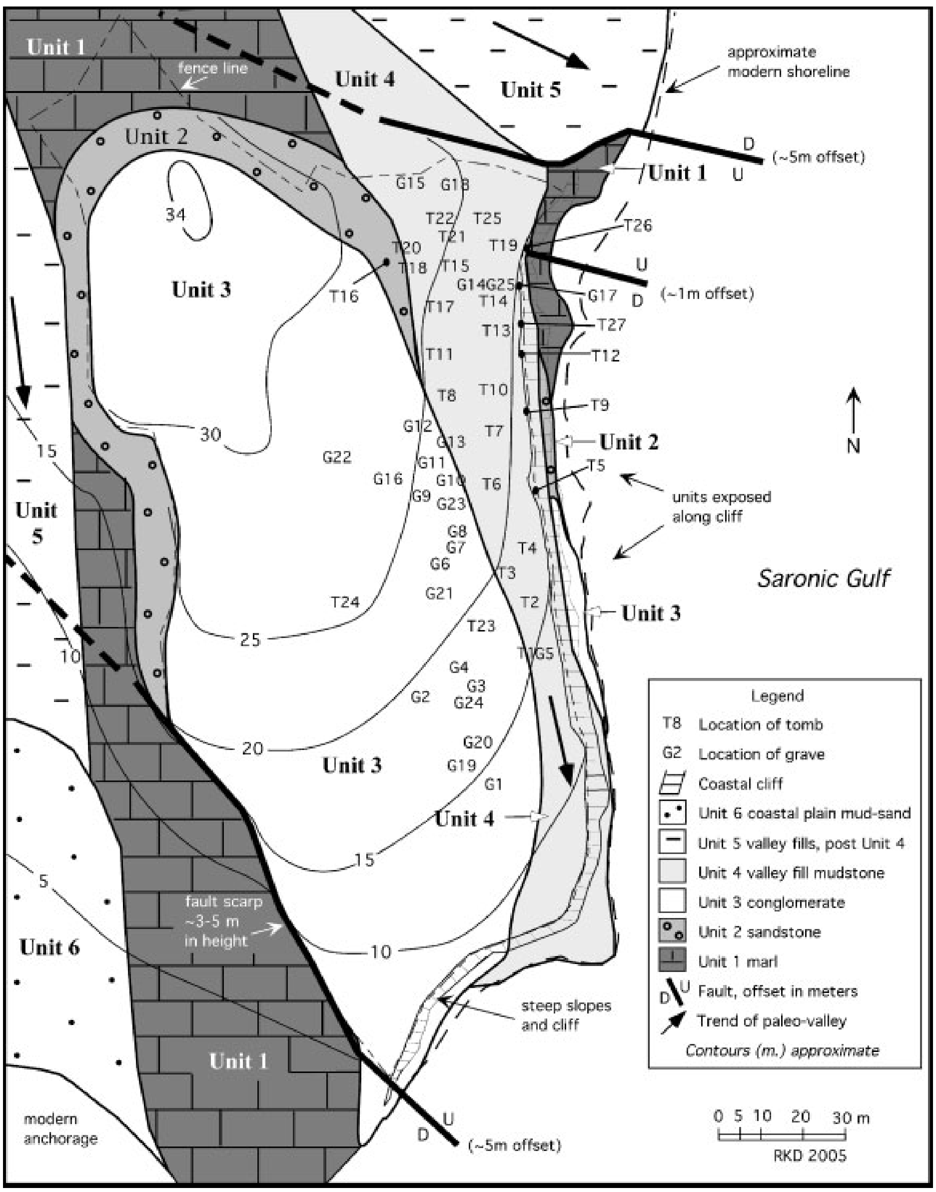

Figure 8. Bedrock geology at the surface of the Koutsongila Ridge. (Plan by R.K. Dunn.)

DOI: 10.1002/arp

being valley-fill deposits, which have various trends.

All but the youngest units are offset by normal faults (Figure 9) within the hanging wall of the 'Korinth fault' system (Noller, 1998; Goldsworthy and Jackson, 2001). On Koutsongila, two faults have downward displacement on the southwest side, and a third has opposite motion (Figure 8). The net effect of faulting has been the production of a small horst structure comprising the ridge. All the faults mapped have probably been inactive since the Roman era. Destruction of the harbour facilities by co-seismic subsidence has been dated to ca. AD 400 and attributed to motion on the large Korinth fault to the south (Noller *et al*., 1997). This implies that both the bay at Kenchreai and Koutsongila subsided. Although Noller *et al*. (1997) believe the Korinth fault was active as recently as 1928, when a major earthquake occurred (Ambraseys and Jackson, 1990, pp. 685–688, figures A19–20), no evidence for recent motion on the local faults was observed.

Most of the surface of Koutsongila consists of a pebble–cobble–boulder conglomerate 4–5 m thick (Unit 3, Figure 8). Ancient residents intending to construct chamber tombs usually avoided the surface layer of coarse-grained conglomerate that dominates the ridge, probably because of its resistance to excavation. Instead, most tombs were dug into a generally gravel-poor mudstone that could sustain smooth, stable walls (Unit 4, Figure 8). Moreover, the tombs were cut so that the level of the vault approximately followed the lower limit of the caliche horizon. This furnished a hard, durable roof for the chamber. The different subsurface depths of the chambers were thus determined by the differential thickness of the caliche across the ridge. Minor variations in the overall homogeneous design of the tombs, such as the placement of the niches relative to the springing

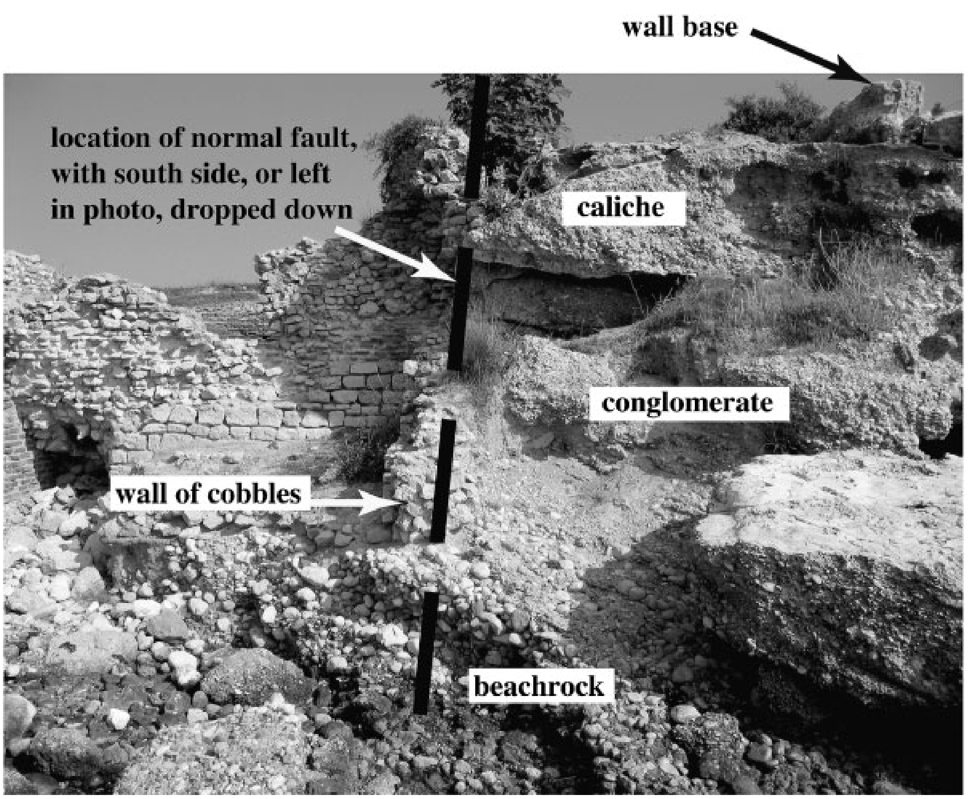

Figure 9. Fault at southern edge of the Koutsongila Ridge, view from southeast. Note the remains of Roman masonry (left) abutting the conglomerate exposed along the fault. (Photograph by R.K. Dunn.)

DOI: 10.1002/arp

of the vault, correspond with local variations in the thickness of the caliche. This suggests that the construction of the tombs was dictated at least in part by the material qualities of the local rock.

Geological exploration has also determined that coastal morphology has changed significantly since the cemetery was in use. The coastline associated with the northern portion of the ridge consists of sandstone at the base overlain by conglomerate and valley-fill deposits (Figure 10), whereas the coastline associated with the southern portion consists mostly of conglomerate and a coastal promontory of valley-fill mudstone. Large mass-failure blocks found offshore show that strata exposed at the shore were gradually undercut by water action and collapsed over time. The distribution of fallen rock, the location of submerged beachrock and probable wave-cut notches, and the partial dimensions of the three easternmost chamber tombs (12, 26, 27) that have partially collapsed with the erosion of the seaward cliff together indicate that coastal retreat has been within ca. 10–30 m. The topography of the coast during the Roman period would have been similar to its present configuration, that is, a high, steep cliff to the north and a low cliff or gradual incline to the south. This reconstruction shows that the cemetery extended almost to the ancient shoreline.

Geophysical prospection

Geophysical prospection on the Koutsongila Ridge has revealed numerous subsurface anomalies that shed light on site-use over time. A. Sarris, assisted by N. Papadopoulos and E. Kokkinou, conducted intensive geophysical survey during June 2004 in the southern area of the ridge (Sarris, 2005; Figure 11). The techniques applied were electromagnetics (EM), magnetics, ground-penetrating radar (GPR) and microgravitometry. The purpose of this investigation was to locate graves or tombs that have not been opened by illicit excavation; to discover unknown architectural features and to correlate them with features already known; and to explore the transition between civic and burial space at the southern end of the cemetery. Experimental surveys were also conducted in order to compare the registered signals from known tombs to the actual measurements of the chambers. As will be seen, Dunn's (2004) simultaneous investigation of the ridge's geo-

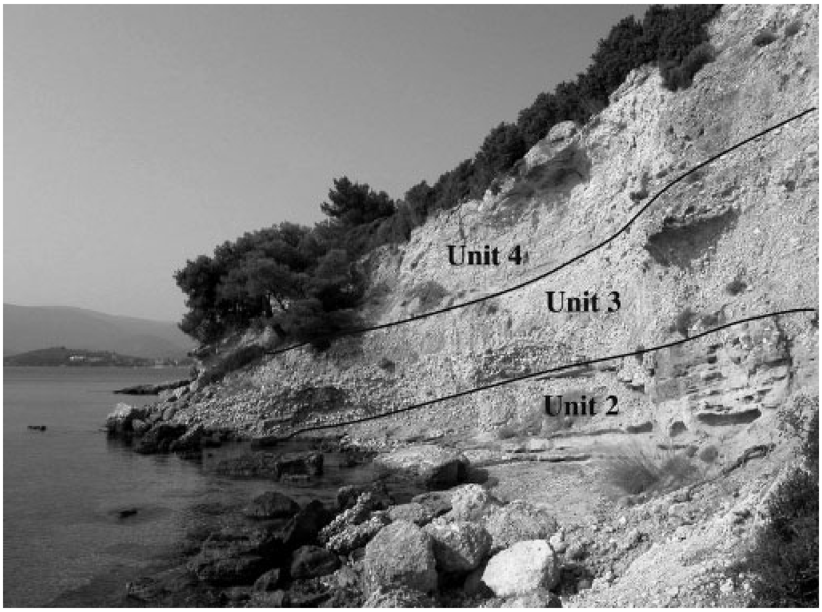

Figure 10. Coastline along eastern edge of the Koutsongila Ridge, view from north-northwest. Note the stratigraphy and collapsed rock. (Photograph by J.L. Rife.)

DOI: 10.1002/arp

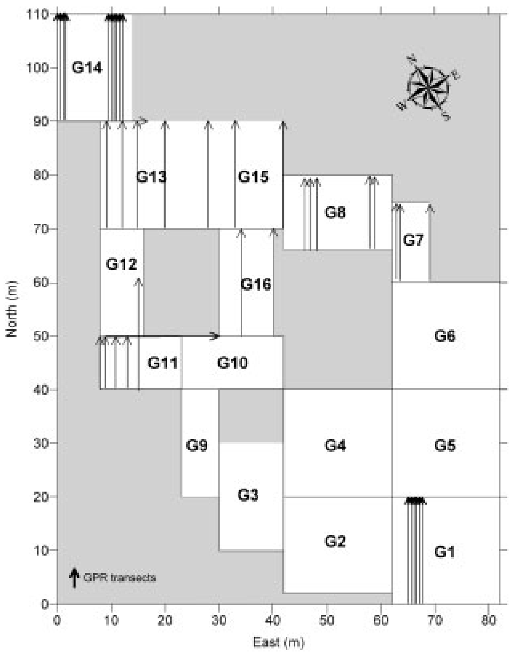

Figure 11. Layout of the geophysical grids and GPR transects. (Plan by A. Sarris.)

logical structure (see above) significantly aided the interpretation of geophysical data.

In the past, several techniques have been used in the detection of rock-cut tombs with variable degrees of success (Sarris and Jones, 2000). These include GPR in the southeast necropolis at Palmyra, Syria (Higuchi and Izumi, 1994, pp. 2–5, 7–8, figures 4–6), magnetometry in the Valley of the Kings near Thebes, Egypt (Weeks, 1998, pp. 84–86), gravity techniques in the Great Pyramid of Cheops at Giza, Egypt (Kerisel, 1988), seismic and resistivity techniques at Sabine, Italy (Bernabini *et al.*, 1989) and electrical resistivity tomography at the test site of ITABC-CNR in Rome (Piro *et al.*, 2001). The diverse results of more conventional techniques, such as magnetics, resistivity, and GPR, have been reported elsewhere in Greece and Cyprus (Tsokas *et al.*, 1994; Sarris, 1998; Sarris *et al.*, 2001). Since the geophysical surveys at Kenchreai applied common techniques to new material with unusual preservation, sometimes in an experimental capacity, they have a special significance from a methodological point of view. Moreover, the combination of geological and geophysical study at Kenchreai has contributed to a fuller, more accurate understanding of subsurface anomalies.

Survey techniques

A total area of 4385 m^2 was surveyed using electromagnetic techniques (Geonics EM31), and a subarea of 2360 m^2 (grids G1, G2, G4–G6, G14) was surveyed using magnetic techniques (Geoscan Research FM36; Figure 11). These applications aimed to generate a map of soil conductivity and magnetic susceptibility (through the simultaneous measurements of the quadrature and in-phase components of EM31), and vertical magnetic gradient anomalies within a shallow (<1 m for magnetics) to medium (<4–5 m for EM31) depth below the modern surface. Chamber tombs were expected to show low electrical conductivity anomalies, and substantial structures were expected to create magnetic signals. Both techniques were conducted with a 1 m sampling interval, because thick vegetation and uneven terrain prohibited high-resolution examination. In addition, 44 transects of different lengths were surveyed using a Sensors and Software EKKO 1000 GPR with antennae of 225 and 450 MHz (Figure 11). Finally, two transects were surveyed using a Lacoste and Romberg Model D land microgravitometer. This experimental application tested the registration of the gravity signal from well defined, previously known chamber tombs (4, 8).

Magnetic and electromagnetic data were processed following a standard procedure. The data were characterized by a constant shift in the average value within each surveyed grid due to differences in balancing the instrument and the shifting of the base/reference stations. For this reason, pre-processing of the data was necessary to create a common base level (zero-mean base line) for all grids. Statistical analysis of both the common rows and the average level of adjacent grids was carried out in order to provide a correction factor for each grid. Both the change of coordinates and the correction factors were used to create the mosaic of grids. In this way, the processing of adjacent grids was conducted simultaneously. Afterwards, a specific map coordinate system was chosen for each

DOI: 10.1002/arp

geophysical mosaic of grids that was registered to the Greek Geodetic Reference System of 1987 (GGRS '87) used for the EDM mapping of the ridge.

Kriging interpolation was used for gridding the data. In some cases, selective despiking techniques were used to isolate the extreme values that masked the anomalies of interest. Selective compression of the dynamic range of values was also used in order to isolate anomalies close to the background level. A mask file was created to isolate the areas that were not surveyed due to the existence of thick vegetation, fences, modern structures and other surface features.

The above procedures, with the exception of masking, were accomplished with the GPP package. The GPP package was developed on a LINUX platform using a GCC compiler and then ported using a Borland C compiler for execution in a command (GCC) window in the Windows NT environment (Kalokerinos *et al.*, 2004). The Golden Software Surfer package has been applied to produce the maps, the EKKO software suite has been employed to process the radar transects, and GM-SYS has been used to generate the gravity models.

Electromagnetic and magnetic surveys

Electromagnetics were used throughout the survey area in the central and southern parts of the ridge. Although some original data for electrical conductivity and magnetic susceptibility were affected by a gradual drift within individual grids, data processing has created a homogeneous mosaic (Figure 12). Light and dark colours indicate, respectively, high and low values of soil conductivity and magnetic susceptibility. Certain isolated features indicated by EM correlate well with known graves and pits cut by looters (Figure 13). Elongated anomalies stretching across the southern, southeastern and eastern areas of the ridge (grids G1–G8) probably represent areas of shallow bedrock. These anomalies were also present in the original data, and they do not seem to correlate with any specific topographic trends in the terrain. Linear anomalies in the central and southern areas point to massive architecture. One rectangular anomaly measuring ca. 17 m × 25–30 m and oriented southwest–northeast is located in grids G2–G4; the southwest side of the feature reaches the steep edge of the ridge. Another large rectangular structure with different wall orientations (separate construction phases?) is indicated by electrical conductivity and magnetic susceptibility in grids G10–G13, G15 and G16. The area between these grids, presumably representing the interior of the building, could not be surveyed due to dense vegetation coverage. This anomaly is not as well defined as the one in grids G2–G4, probably due to the presence of thicker colluvial deposits here than further south on the ridge. This trend is also evident from the general distribution of the anomalies across the survey area. Another smaller rectangular structure (ca. 8 m × 7 m) is faintly indicated on the magnetic susceptibility map in the northern part of grids G13 and G15. The size and location of this anomaly raise the possibility that it is a funerary monument over an unopened tomb, west of Tombs 23 and 3 (Figure 13).

Only part of the area was surveyed by magnetic techniques. This area was determined by the results of EM survey and the presence of terrain offering easy accessibility for the magnetometer. Areas near the chainlink fence enclosing Koutsongila and areas with dense vegetation or uneven ground were excluded. The original magnetic data included a few extreme values arising from the proximity of the geophysical grids to the southwest fence and the presence of metal fragments. The removal of these extreme values smoothed out the magnetic measurements and reduced the dynamic range of the data to $\pm 17\,\mathrm{nT\,m^{-1}}$ (Figure 14). Further processing of the magnetic data, such as the application of directional derivatives, emphasized several linear features aligned in a direction perpendicular to one of the corresponding filters.

Most features indicated by magnetic survey appear as isolated anomalies of small dimensions (<ca. 1–2 m × 1–2 m). These can be correlated with known graves or looting pits, although a few, especially in grid G8, might represent unopened cists. A long linear anomaly aligned southwest–northeast is evident at the centre of the southern part of the area (grids G2 and G4). This coincides with the location of the eastern side of the monumental structure revealed by EM

DOI: 10.1002/arp

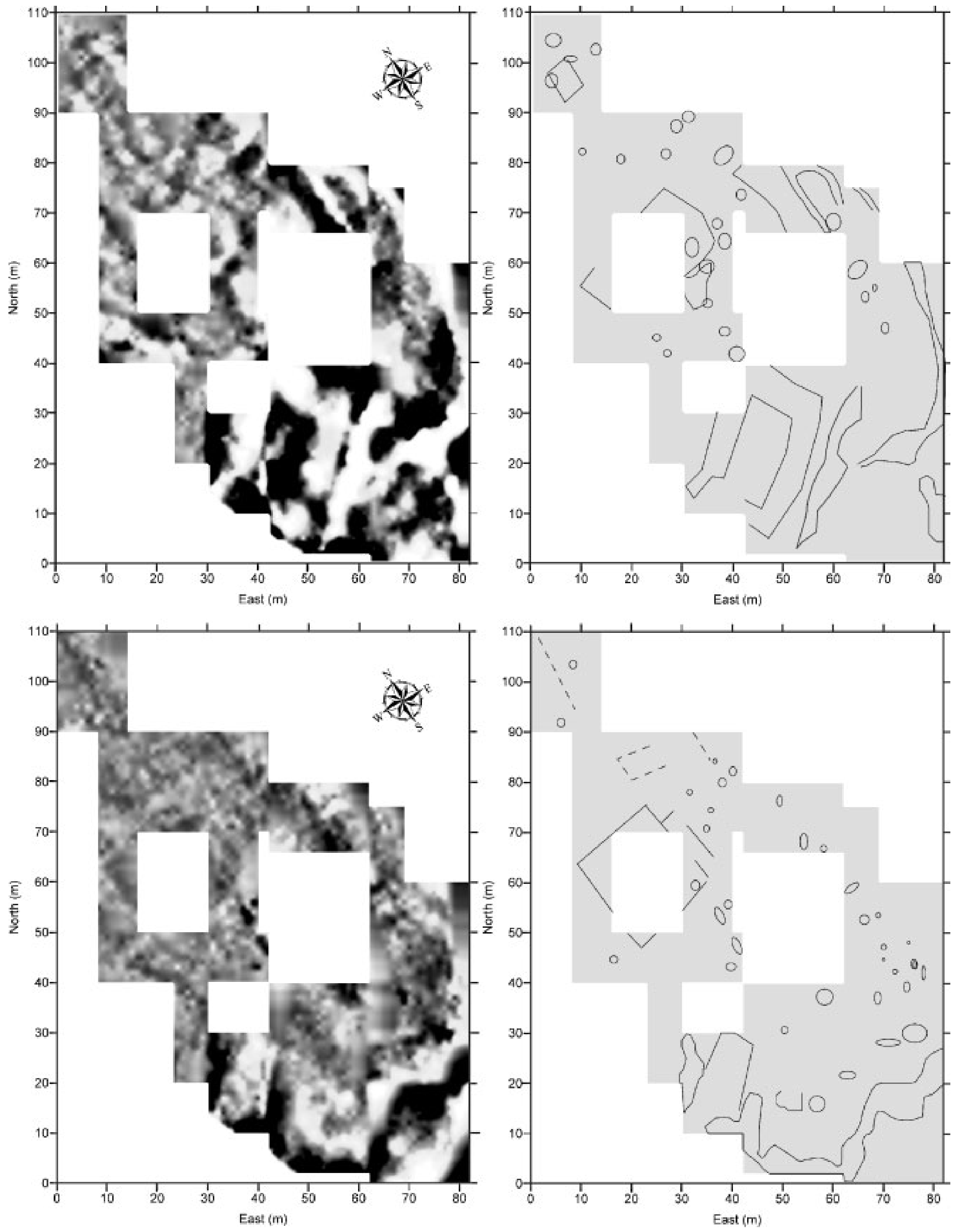

Figure 12. Results of the EM survey after despiking, grid and line equalization. Both electrical conductivity (above) and magnetic susceptibility maps (below) indicate a number of anomalies that can be correlated with visible features. Two rectangular structures are shown in the central and southern areas. (Plans by A. Sarris.)

DOI: 10.1002/arp

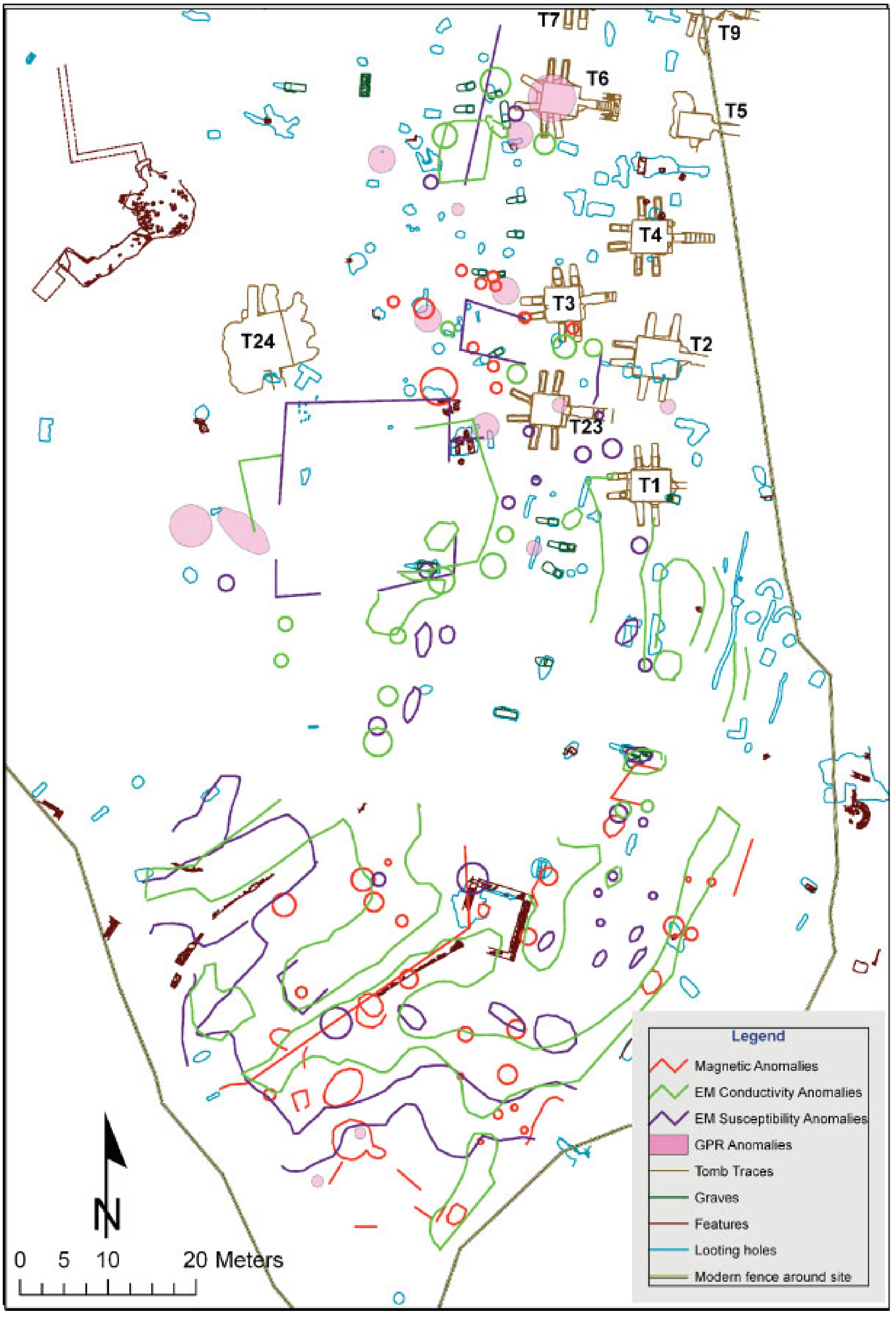

Figure 13. Composite plan of visible features, graves, looting disturbances, tombs, and anomalies identified by geophysical prospection in the central and southern areas of the Koutsongila Ridge. (Plan by A. Sarris.)

DOI: 10.1002/arp

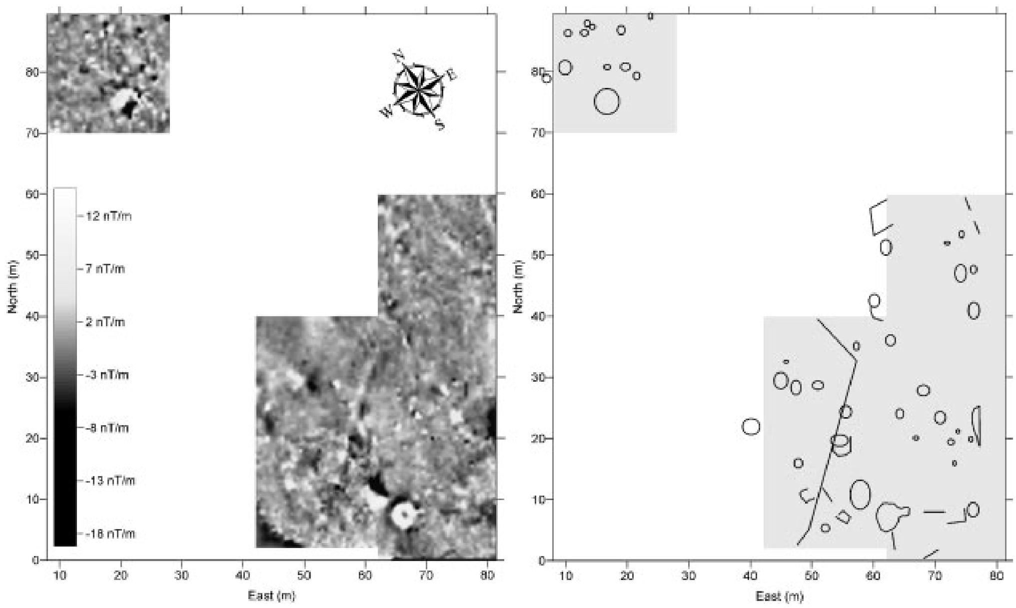

Figure 14. Vertical magnetic gradient readings smoothed away geological trends in the area and emphasized shallow-depth anomalies. Some anomalies indicated in the processed data agree with the corresponding results of the EM survey. A distinct circular anomaly is located at the southern end of the ridge. (Plans by A. Sarris.)

survey. A notable circular anomaly (ca. 4–5 m diameter) with a small southeastern extension is evident near the southern extremity of the ridge (grid G1). The shape and size of this feature demonstrate that this might be a chamber tomb, a large pit, or a lime kiln.

Ground-penetrating radar

In order to examine further a few candidate anomalies revealed by EM and magnetic survey, 44 transects were scanned with GPR. Due to topographic irregularity, most GPR transects were laid out along the iso-elevation lines of the terrain on a southwest–northeast orientation. In all, GPR measured more than 600 m along these transects and registered 13 anomalies (Figure 13).

The GPR sections were treated in a systematic way (Annan, 1993). The first peak for each different line was determined from the intensity percentage of the first reflected wave. An attempt was made to bring the first reflections of each line into a common starting time according to the line equalization based on the first peak. The application of AGC, Dewow and DC shift filters enhanced the reflected signal, and a trace-to-trace averaging filter was applied to remove the background noise and smooth out the data. Finally, vertical cross-sections and horizontal time and depth slices were created (Goodman *et al*., 1995).

Controlled experiments were conducted above two known tombs to study the signals registered from the corresponding targets (Table 1). Transects 10 m long were laid out over the chambers of Tombs 4 and 8 in the central area of the ridge. As the surface geology at Tombs 4 and 8 consists of valley-fill mudstone (Figure 8), the velocity of propagation of the GPR electromagnetic pulses was set to 0.060 m/ns on the basis of comparable published studies. Tomb 4 was scanned with antennae of 225 MHz and 450 MHz. The signals produced multiple reflections above the target and a clear anomaly (Figure 15). The reflections were registered from 0.81 m to more than 1.90 m deep, a pattern that was especially evident in data collected with the 225 MHz antenna. The width of the target was estimated at ca. 4 m along the transect, which is comparable to the actual north–south width measured inside the tomb chamber (3.55 m). Tomb 4 has an interior height

DOI: 10.1002/arp

Table 1. Dimensions of T4 and T8, actual versus estimated by GPR and gravity methods

Tomb	Description	Actual measurements (m)	Estimated by GPR (m)	Estimated by gravity (m)
4	Depth from ground level to ceiling of chamber	~1.10	0.81	—
	Width (N–S)	3.55	~4	4.5–5
	Depth from ground level to the centre of the anomaly	~2.35	>1.76	~1.43
	Interior height	2.41–2.57	>1.10	—
8	Depth from ground level to ceiling of chamber	~0.55	0.40	—
	Width (N–S)	3.55	~3	4.5–5
	Depth from ground level to the centre of the anomaly	~1.45	>1.35	~ 1.30
	Interior height	1.80	>1.50	—

of 2.41–2.57 m, and the depth from ground level to the centre of the chamber ceiling is ca. 1.10 m. These actual dimensions correspond closely with the estimated dimensions derived from the GPR data.

Similar results were obtained from surveying Tomb 8, where reflections were registered from 0.40 m to 2.30 m deep. The estimated width of Tomb 8 was 3 m along the transect, as compared with the actual north–south width of 3.60 m. Tomb 8 has an interior height of ca. 1.80 m, and the depth from ground level to the centre of the chamber ceiling is ca. 0.55 m. These actual measurements also correspond closely with the estimated measurements derived from the GPR data.

Elsewhere in the survey area, GPR transects reveal a distinct geological trend related to the contact between the conglomerate and the valley-fill deposits (Figure 8). According to these data, the local stratigraphy consists of conglomerate layers rising toward the north-northwest where the ridge's eastern cliff drops away abruptly to the coast. The GPR measurements also indicated deep stratigraphy that had been disturbed in places by pits and trenches cut by looters.

In the southern extremity of the ridge in the western part of grid G1, six parallel transects were laid out near the circular anomaly indicated by magnetic survey. The processed radargrams were georeferenced to produce ten slices representing the average signal amplitudes at different depths below the surface up to 90 ns signal reflection time (Goodman *et al*., 1995), corresponding to ca. 3 m below the surface. Two anomalies register well in the radar slices, one at ca. 2 m and the other at ca. 7.5–8 m along the transects, both in the upper layers of the subsurface (starting from 9 to 18 ns and 18 to 27 ns, respectively). The first anomaly extends deep, which suggests that it is related to bedrock variability. The second anomaly extends to a depth of ca. 1.5 m, and its location is in good agreement with the circular feature indicated by the magnetic data.

In the central southern area of the ridge at the interface of grids G11 and G12, the radargram cross-section of the transect registered reflections at 6–10 m along the transect and within 0.50–1.20 m deep. These reflections correspond with the linear anomalies identified by electromagnetic survey, which seem to represent a large rectangular structure in grids G10–G13, G15 and G16.

In the central area of the ridge in the southwestern and northeastern parts of grid G14, ten parallel transects were laid out, each 20 m long and separated by 0.5 m. The first four transects registered reflections in the southwest corner of the grid, at 0–3 m along the transects from 0.67 m to more than 2.00 m deep. These seem to comprise a concave shape similar to the signals generated in the experimental surveys over Tombs 4 and 8. If so, this anomaly might represent another unopened chamber tomb, west of Tombs 3 and 6 (Figure 13). This cannot, however, be ascertained, because the anomaly extends to the southwest and outside the zone of the GPR survey. The next six transects registered three strong reflections in the southwestern and northeastern parts of grid G14. The first anomaly, in the southwestern corner, corresponds with a circular looting pit (L35). The second anomaly, located to the northeast, corresponds with a deep looting pit (L20) containing an exposed limestone slab (F46). The third anomaly, located in the northeastern corner, has a distinct concave shape that originates from the vaulted ceiling of a

DOI: 10.1002/arp

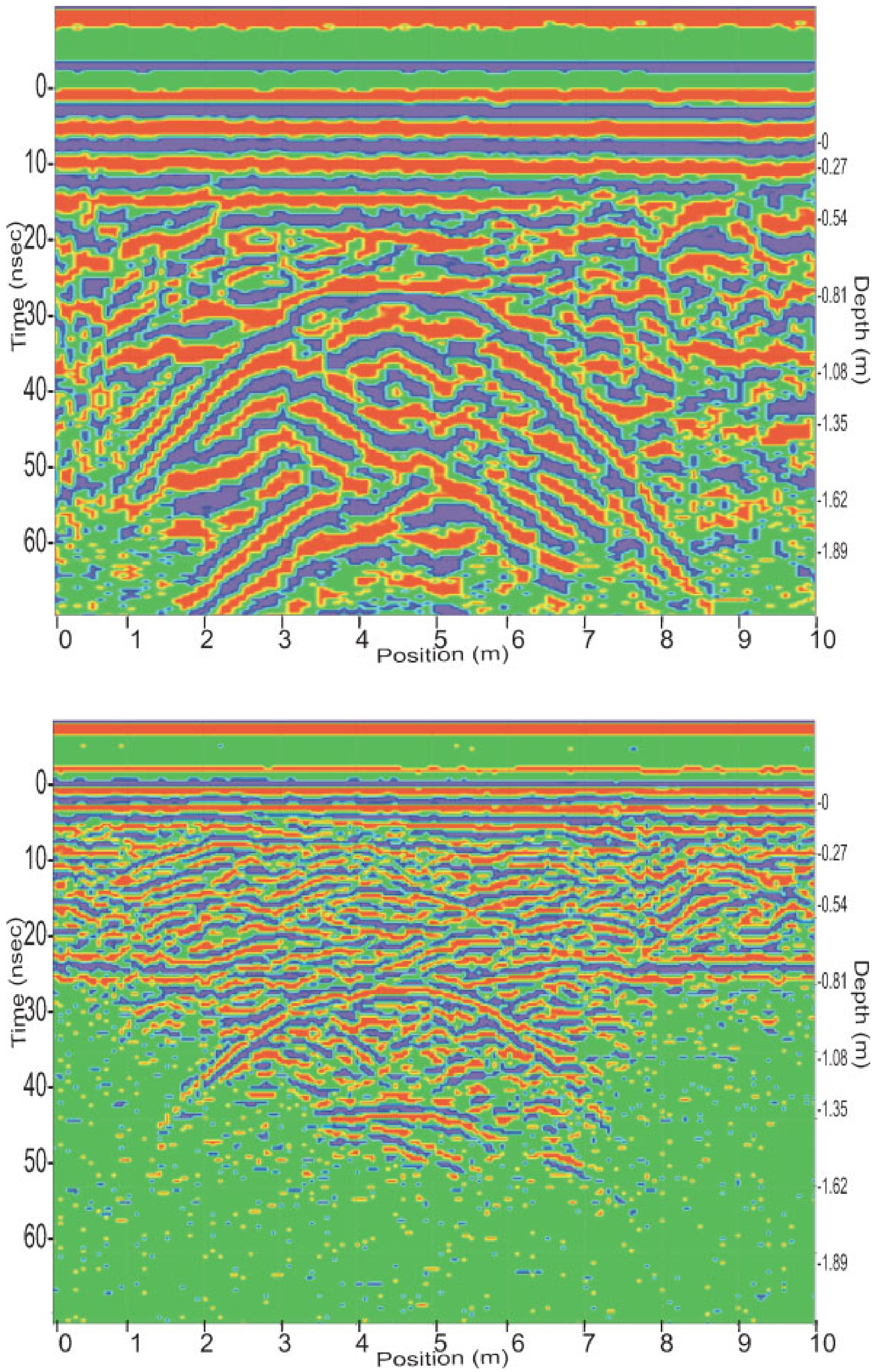

Figure 15. Controlled experiments above Tomb T4, using EKKO 1000 ground-penetrating radar with antennae of 225 MHz (above) and 450 MHz (below). The horizontal axis represents the spatial variation of the measurements, and the vertical axes indicate reflection time in nanoseconds (left) and estimated depth in metres from ground level (right). (Images by A. Sarris.)

DOI: 10.1002/arp

known tomb (6). A three-dimensional model of these three anomalies was constructed out of radargrams decomposed into horizontal slices by averaging the amplitude of the reflection signals (Figure 16).

Micro-gravity measurements

Micro-gravity survey aims to determine the subsoil's lateral density by measuring variability in the gravity field of the Earth's surface. Micro-gravity measurements were collected above Tombs 4 and 8 along the same transects used for GPR. This was another experiment to test the signals generated by known targets. Readings were taken every 1 m along the transects, and a datum point within the site was used for monitoring the time interval between readings. Latitude, free air, Bouguer and topographic corrections were applied to the data to produce

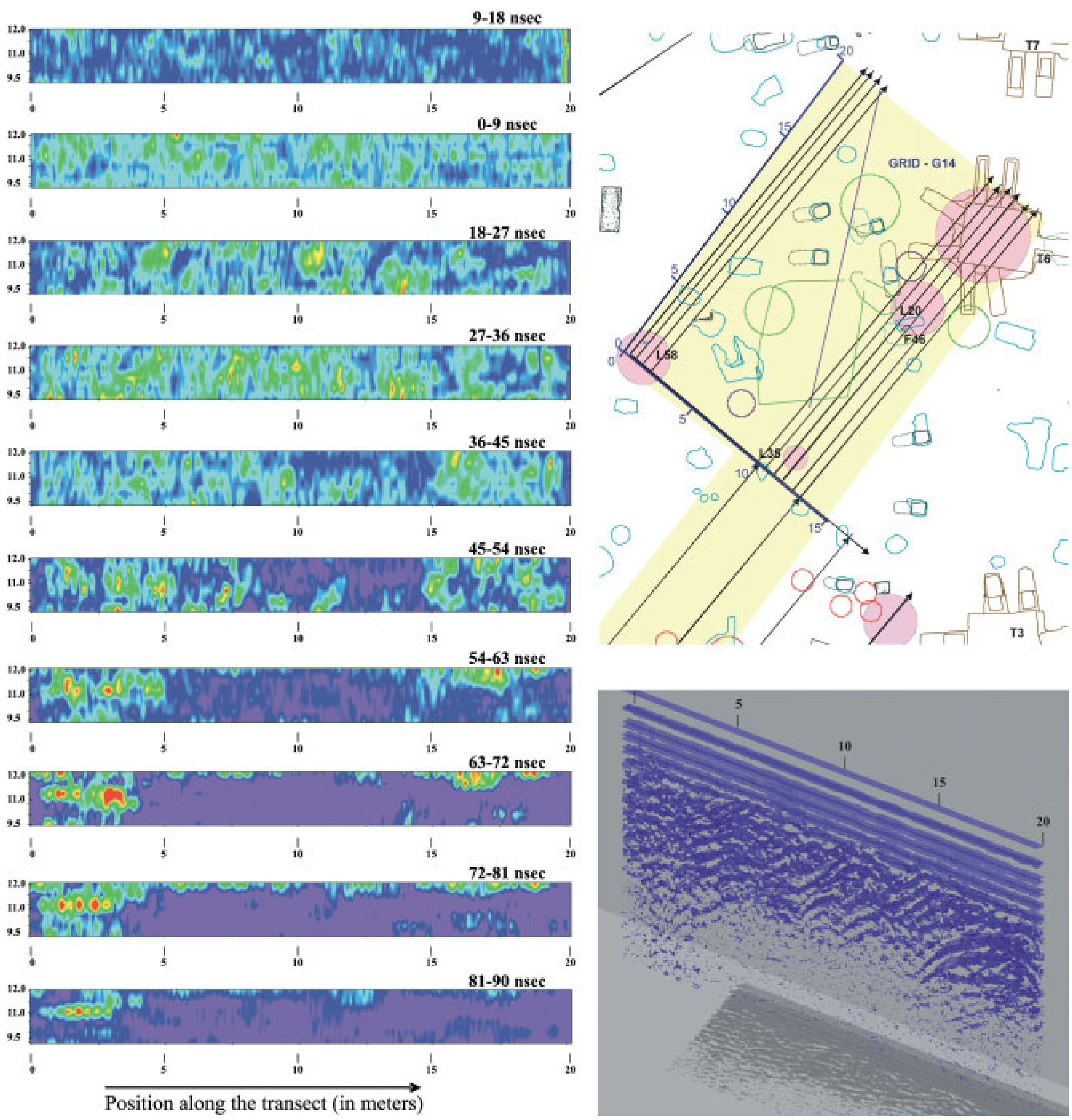

Figure 16. Plan of transects in grid G14, horizontal slices and 3D model of the subsurface layers constructed from GPR measurements using an EKKO 1000 with a 225 MHz antenna. The GPR signals correlate well with a circular looting pit in the southwestern part, a deep looting pit to the northeast, and the chamber of Tomb 6 in the northeastern corner. (Plans and images by A. Sarris.)

DOI: 10.1002/arp

Bouguer curves. Residual curves were also calculated by removing the regional gravity field (Figure 17). In order to estimate the dimensions of the targets from the gravity measurements, it was assumed that the tomb chambers were spherical in shape. The depth from ground level to the centre of the targets was determined by the rule of thumb equation $\mathrm{H} = 0.65 \times w_{1/2}$, where $w_{1/2}$ is the full width of the half maximum amplitude of the gravity signal.

The gravity measurements over Tombs 4 and 8 indicated that both tombs have a north–south width of ca. 4.5–5 m. The depth from ground level to the centre of the anomaly was calculated at ca. 1.43 m for Tomb 4 and ca. 1.30 m for Tomb 8. These estimated measurements for the tombs correlate approximately with the actual measurements (Table 1). The gravity signature of Tomb 4 is better resolved than that of Tomb 8, probably because Tomb 4 is situated within the relatively homogeneous geological unit of valley-fill deposits, whereas Tomb 8 is situated at the interface between the valley-fill deposits and the conglomerate that extends across the central area of the ridge (Figure 8). Furthermore, a tall pine tree is rooted near Tomb 8, which has probably influenced the target's gravitational signature. Nonetheless, both tombs produced a well-

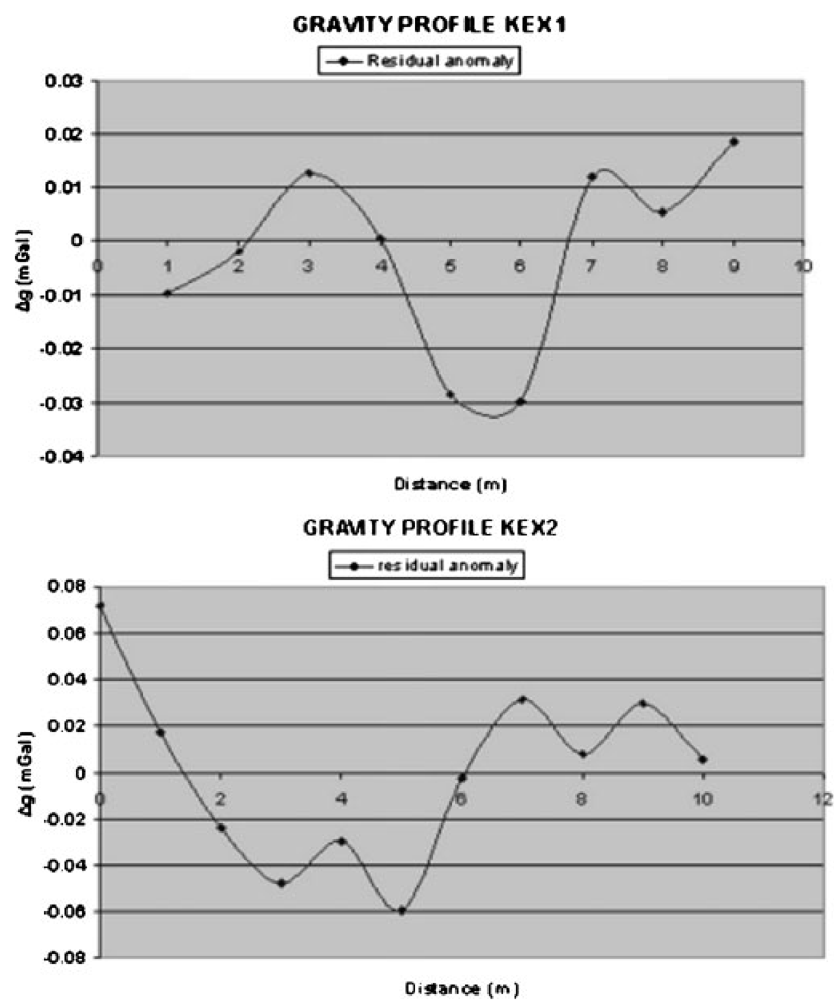

Figure 17. Gravity residual anomalies recorded at Tombs 4 (above) and 8 (below). The centres of the tomb chambers are located approximately at the middle of the transect. (Graphs by A. Sarris.)

DOI: 10.1002/arp

defined gravity anomaly with at least 0.04–0.08 mGal maximum variation relative to the average background.

Discussion

Geological and geophysical investigatons conducted by KCP on the Koutsongila Ridge in 2004 have significantly improved the understanding of mortuary behaviours, social identity and site-use over time that was already derived from standing archaeological remains.

The stratigraphy of the ridge consists of marl, sandstone, conglomerate and valley-fill deposits capped with caliche (Figure 8). Although the area of Kenchreai exhibits multiple faults and has undergone co-seismic subsidence, this does not seem to have fundamentally altered the landscape of the ridge since the time when the cemetery was in use. Shallow bedrock in the central and southern areas of the ridge was indicated by EM and GPR survey, and the contact between the conglomerate and valley-fill deposits is particularly evident. In antiquity, the surface probably had a thicker soil layer. This has shifted to the lower (eastern) area of the ridge due to erosion, creating locales of shallow and exposed bedrock. The conglomerate over much of the ridge provided a solid footing for ancient and medieval walls, such as the substantial walls in the southern and central areas registered as linear anomalies by EM, magnetic and GPR techniques.

Residents during the Roman Empire also responded to geological variability when constructing chamber tombs. Most were cut into the mudstone unit, which afforded greater structural integrity than the conglomerate, and the springing of the vaults was aligned with the lower level of the caliche horizon. Builders were aware of local geological properties, they exploited them to improve the design of the chambers, and they responded creatively to natural variability. Perhaps they also worked in the thriving local stone industry, which is attested by large, long-lived quarries of oolitic limestone ca. 750 m northeast of Koutsongila (Hayward, 2003, pp. 28–29, figure 2.9). The employment of professional assistance would have marked the affluence of the owners of monumental tombs. The elevated visibility and accessibility of the tombs on the coastal ridge also fit the elite status of the owners, who were concerned to display their prestige and wealth through mortuary splendor. According to the reconstruction of ancient coastal morphology, the tombs, particularly the monumental buildings at the surface, would have been highly conspicuous to seaborne traffic entering and exiting the harbour.

Geophysical prospection revealed numerous anomalies that probably represent structures or burial sites (Figure 13). The most distinct, largest anomaly is a linear feature running roughly northwest–southeast through grids G2 and G4 in both the EM and magnetic datasets and an adjacent rectangular feature, apparently a massive building measuring ca. 17 m × 25–30 m, located in grids G2–G4 in the EM dataset. The architectural complex is situated at the southwestern edge of the ridge, roughly between the residential structures on the north mole and the known southern extent of the cemetery. Although there are no consistent traces at the surface, several enormous ashlars in the vicinity, including one monolithic foundation block over 8 m long (Figure 18), can be correlated with the feature. This seems to have been an impressive building, perhaps displaying a rectangular *peribolos*, or precinct, as would a sanctuary or a large courtyard. Another possibility is that these structures belonged to a fortification with a massive wall. The presence of ashlar masonry here and elsewhere on the ridge points to major building on Koutsongila before the Roman Empire, although it is quite possible that monumentral structures of Archaic, Classical or Hellenistic date still stood when the dense cemetery developed nearby in the first century AD. If the large rectangular building was a temple contemporary with the burials, then religious and mortuary space would have been closely arranged. If the ashlar masonry instead represents a fortification wall or a civic circuit, then the graves and tombs would have occupied the extramural periphery of the harbour settlement.

Survey has revealed the presence of other subsurface features. Another major building, also rectangular and perhaps exhibiting separate

DOI: 10.1002/arp

Figure 18. Massive ashlar blocks (F69) in segment of monumental wall in southern area of ridge. (Photograph by J.L. Rife.)

construction phases, is indicated by linear anomalies slightly to the north, in grids G10–G13, G15 and G16. A circular feature measuring ca. 4–5 m diameter was registered by magnetometry in shallow stratigraphy at the southern extremity of the site. This might well be a lime kiln, because its form and size resemble other known examples in the region (e.g. Gregory, 1993, pp. 37, 80, 102, figure 17, plates 21, 33). Such a feature could be associated with the scattered occupation of the ridge during Late Antique or Byzantine times, when residents were plundering earlier structures in the area for limestone, such as ashlar blocks. Finally, geophysical survey by all three methods registered anomalies that might represent previously unknown cist graves in the central area of the site and two chamber tombs, one west of Tombs 23 and 3 and another west of Tombs 3 and 6. If so, the cemetery on Koutsongila served as a more complex and prominent context for the funerary expression of social identity than is indicated by those burial sites uncovered by clandestine digging.

Geophysical prospection has thus revealed not only considerable structural and burial density in this transitional area on the periphery of the urban settlement, but also variation in the date and purpose of occupation on the ridge. Apart from providing evidence pertinent to questions of funerary ritual, social structure and settlement history, the clearer composite picture of surface and subsurface remains in their geological context also lays the groundwork for future exploration on Koutsongila. Finally, these integrated studies contribute more generally to the discipline of funerary archaeology through experimentation on the efficacy of survey methods and an innovative contextual approach to exploring the mortuary landscape.

Acknowledgements

This project was presented at the 6th International Conference on Archaeological Prospection in Rome (September 2005). Field research was authorized by the Greek Ministry of Culture, overseen by the ephor, Alexandros Mandis, and the staff of the 37th Ephoreia of Prehistoric and Classical Antiquities at Archaia Korinthos, and supported by the American School of Classical Studies at Athens and the Institute of Mediterranean Studies, FORTH, at Rethymno. Funding was provided to J.L. Rife through a Summer Stipend from the National Endowment of the Humanities (FT-52951-04) and a grant from the

DOI: 10.1002/arp

Office of the Provost of Macalester College, Dan Hornbach, and to R.K. Dunn through a Faculty-student Research Grant from Norwich University.

References

Alföldi-Rosenbaum E. 1971. *Anamur Nekropolü: The Necropolis at Anemurium*. Türk Tarih Kurumu Yayinlarindan seri VI:12. Türk Tarih Kurumu Bsaimevi: Ankara.

Ambraseys NN, Jackson A. 1990. Seismicity and associated strain of central Greece between 1890 and 1988. *Geophysical Journal International* **101**: 663–708.

Annan AP. 1993. Practical processing of GPR data. In *Advanced Ground Penetrating Radar: Technologies and Applications. Proceedings of the Second Government Workshop on GPR*. Ohio State University: Columbus.

Bernabini M, Brizzolari E, Orlando L, Piro S, Versino L. 1989. Searching for superficial cavities and buried man-made objects using indirect geophysical methods. In *Archaeometry: Proceedings of the 25th International Symposium*, Maniatis Y (ed.). Elsevier: Amsterdam and New York; 375–383.

Crouch DP. 2004. *Geology and Settlement: Greco-Roman Patterns*. Oxford University Press: New York.

Cummer WW. 1971. A Roman tomb at Corinthian Kenchreai. *Hesperia* **40**: 205–231.

Dunn RK. 2004. Report on the Geology and Geomorphology of the Koutsongila Ridge, Kenchreai, Corinthia, Greece, 2004. Unpublished technical report, Norwich University: Northfield, Vermont.

Georgiades AS. 1907. *Les Ports de la Grèce dans l'antiquité qui subsistent encore aujourd'hui (Exposition maritime internationale de Bourdeaux de 1907)*. Taroussopoulos: Athens.

Goldsworthy M, Jackson J. 2001. Migration of activity within normal fault systems: examples from the Quaternary of mainland Greece. *Journal of Structural Geology* **23**: 489–506.

Goodman D, Nishimura Y, Rogers JD. 1995. GPR time slices in archaeological prospection. *Archaeological Prospection* **2**: 85–89.

Gregory TE. 1993. *Isthmia V: The Hexamilion and the Fortress*. American School of Classical Studies: Princeton.

Hayward CL. 2003. Geology of Corinth: the study of a basic resource. In *Corinth XX: The Centenary, 1896–1996*, Williams CK, Bookidis N (eds). American School of Classical Studies: Princeton; 15–42.

Higgins MD, Higgins R. 1996. *A Geological Companion to Greece and the Aegean*. Cornell University Press: Ithaca.

Higuchi T, Izumi T. 1994. Outlines of excavations. In *Tombs A and C, Southeast Necropolis, Palmyra, Syria*, Higuchi T, Izumi T (eds). Research Center for Silk Roadology: Nara, Japan; 1–10.

Kalokerinos G, Kokkinou E, Sarris A, Vallianatos F. 2004. GPP: a program to automate the geophysical data processing. *First International Conference on Advances in Mineral Resources Management and Environmental Geotechnology (AMIREG 2004)*, Chania, Crete.

Kerisel J. 1988. Le Dossier scientifique sur la pyramide de Kheops. *Archeologia* **232**: 46–54.

Kristalli-Votsi K. 1976 [1984]. Eforeia Klassikon Archaioteton Nafpliou: Nomos Korinthias, Kenchrees. *Archaiologikon Deltion* **31**(B′1): 64–65.

Lampakis G. 1907. Christianikai Kenchreai: topografia ton Kenchreon. In *Miscellanea di archeologia, storia e filologia dedicata a Professore Antonio Salinas nel XL anniversario del suo insegnamento accademico*. Virzi: Palermo; 71–80.

Mourtzas ND, Marinos PG. 1994. Upper Holocene sea-level changes: paleogeographic evolution and its impact on coastal archaeological sites and monuments. *Environmental Geology* **23**: 1–13.

Noller JS. 1998. Geomorphological survey of eastern Korinthia (GeoSEK): report on activities for the 1998 permit year. Unpublished technical report, Institute for Geological and Mineral Exploration (IGME): Athens.

Noller JS, Wells L, Reinhardt E, Rothaus RM. 1997. Subsidence of the harbor at Kenchreai, Saronic Gulf, Greece, during the earthquakes of AD 400 and AD 1928. *Eos (Transactions of the American Geophysical Union)* **78**: F636.

Pallas DI. 1959. Scoperte archeologiche in Grecia negli anni 1956–1958. *Rivista di archeologia cristiana* **35**: 187–223.

Pallas DI. 1975. Investigations sur les monuments chrétiens de Grèce avant Constantin. *Cahiers archéologiques* **24**: 1–19.

Parker Pearson M. 1999. *The Archaeology of Death and Burial*. Texas A&M University Press: College Station, TX.

Piro S, Tsourlos PI, Tsokas GN. 2001. Cavity detection employing advanced geophysical techniques: a case history. *European Journal of Environmental and Engineering Geophysics* **6**: 3–31.

Rife JL. 1999. *Death, ritual and memory in Greek society during the Early and Middle Roman Empire*. PhD thesis, University of Michigan: Ann Arbor, MI.

Rife JL. 2003. Archaeology in Greece 2002–2003: Kenchreai, Koutsongilla. *Archaeological Reports* **49**: 17–18.

Rife JL. 2004. Archaeology in Greece 2003–2004: Kenchreai, Koutsongila. *Archaeological Reports* **50**: 16–17.

Rife JL. 2005. Archaeology in Greece 2004–2005: Kenchreai. *Archaeological Reports* **51**: 15–16.

Rife JL, Pitman T. 2005. *Kenchreai Cemetery Project*. Macalester College. http://www.macalester.edu/classics/kenchreai/ (accessed 20 August, 2005).

Roos P. 1985. *Survey of Rock-cut Tombs in Caria, Part 1: South-Eastern Caria and the Lyco-Carian Borderland*. Studies in Mediterranean Archaeology 72:1. P. Åströms Forlag: Göteborg.

Rothaus RM. 2000. *Corinth, First City of Greece: An Urban History of Late Antique Cult and Religion*. E.J. Brill: Leiden.

Sarris A. 1998. Geophysical issues in archaeological research: paradigms, uncertainties and inferences. *International Conference on Remote Sensing in Archaeology from Spacecraft, Aircraft, on Land, and in the Deep Sea*, Boston University, Boston.

Sarris A. 2005. Technical Report of the Geophysical Prospection Survey at the Kenchreai Cemetery, Rachi Koutsongilas, Kenchrees, Korinthia. Unpublished technical report, Laboratory of Geophysical- Satellite Remote Sensing and Archaeo-Environment, Institute for Mediterranean Studies, FORTH: Rethymno, Crete.

Sarris A, Jones R. 2000. Geophysical and related techniques applied to archaeological survey in the Mediterranean: a review. *Journal of Mediterranean Archaeology* **13**: 3–75.

Sarris A, Vargemezis G, Karimali E, Toumazou M. 2001. Geophysical approaches in the archaeological investigations of the area Athienou-*Malloura*, Cyprus. In *Archaeometric Studies for Greek Prehistory and Antiquity*, Bassiakos Y, Aloupi E, Fakorellis G (eds). Greek Archaeometric Society and Society for Messenian Archaeological Studies: Athens; 173–183.

Scranton RL, Shaw JW, Ibrahim L. 1978. *Kenchreai I: Topography and Architecture*. E.J. Brill: Leiden.

Shear TL. 1931. Excavation of Roman chamber tombs at Corinth in 1931. *American Journal of Archaeology* **35**: 424–441.

Tsokas GN, Giannopoulos A, Tsourlos P, Vargemezis G, Tealby JM, Sarris A, Papazachos CB, Savopoulou T. 1994. A large scale geophysical survey in the archaeological site of Europos (northern Greece). *Journal of Applied Geophysics* **32**: 85–98.

Venit MS. 2002. *Monumental Tombs of Ancient Alexandria: The Theater of the Dead*. Cambridge University Press: Cambridge.

Weeks KR. 1998. *The Lost Tomb*. William Morrow: New York.

Wiseman J. 1978. *The Land of the Ancient Corinthians*, Studies in Mediterranean Archaeology 50. P. Åströms Forlag: Göteborg.

DOI: 10.1002/arp