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Archaeology and Geophysics in Tandem on Crete

Jan Driessen [a] and Apostolos Sarris [b]

[a]Université Catholique de Louvain, Louvain-la-Neuve, Belgium; [b]University of Cyprus, Nicosia, Cyprus

ABSTRACT
Remote sensing techniques, both on the ground (geophysical prospection) and remote (aerial and satellite imagery), have repeatedly shown their usefulness in the detection and mapping of unknown archaeological features and sites, but their results remain relatively sterile and not fully unwrapped if no archaeological verification is implemented to evaluate the reliability of the signals encountered. Employing a more coupled approach of geophysical and archaeological investigations at the Bronze Age site of Sissi on Crete, we illustrate how optimal use can be made of the results, allowing the implementation of a proper research strategy and the concentration of costly archaeological resources in the most profitable and productive ways.

KEYWORDS
Geophysical survey; GPR; magnetics; soil resistance; remote sensing; Minoan Bronze Age; Sissi

Introduction

Remote sensing techniques, both on the ground (geophysical prospection) and remote (aerial and satellite imagery), have shown their usefulness in the detection and mapping of unknown archaeological features at resolutions that are higher than ever before. A complete Roman city (Verdonck et al. 2020), a huge Mayan temple complex (Inomata et al. 2020), a Viking drakar burial (NIKU – Norwegian Institute for Cultural Heritage n.d.), or hidden prehistoric landscapes (Ludwig Boltzmann Institute n.d) are just a few of the recent examples of the application of the techniques that have attracted the attention of public media. To a great extent, it is this kind of discovery that maintains increased interest in archaeology, connecting the romantic idea of undiscovered sites with notions of modern technologies. The success story of geophysical techniques is even further augmented by their ability to cover large-scale landscapes, on the one hand, and their contrast to the irreversible destructive footprint left by the excavation process, on the other hand. Geophysical results can map different occupation layers, provide evidence of the built and non-built space, and offer indirect evidence of the usage of structures, their degree of preservation, and even their chronology (Müller-Scheeßel et al. 2020).

The impact of such results is better manifested when geophysical campaigns work in tandem with long-term archaeological programs (both excavation and conventional surveys), working together to address the archaeological questions at stake. While further progress in the development and variety of geophysical techniques is to be expected, archaeological control remains necessary to evaluate the reliability of the signals encountered. Assessing the diachronicity of the remains based on geophysical stratigraphical data will never obtain the same resolution as actual control excavations that enable a proper distinction between chronological layers in long-lived settlements.

Moreover, geophysical exploration is not always possible, since environmental and contextual factors—geomorphology, soil noise, external or natural sources of noise, later surface occupation, and anthropogenic interventions (Schmidt, Dabas, and Sarris 2020)—play a major role in the success of the application of the methods. One can also occasionally notice a reticence on the part of the archaeological community against the use of geophysical methods because it judges from earlier experiences made at times when techniques were less developed or when preconceptions existed that the geomorphological conditions of sites were not appropriate for the employment of geophysical prospection methods. One of the chrono-typological cultures suffering from such a reticence vis-à-vis geophysical techniques because of unsuccessful application in the past is the island of Crete, home of a remarkable Bronze Age civilization, that of the Minoans, which flourished between 3000 and 1200 B.C. But a similar reticence was also typical until the end of the 1990s throughout Greece, as there were no large-scale and systematic geophysical survey programs being carried out. In Crete specifically, such geophysical campaigns raised many concerns and inspired a heavy dose of skepticism, as the geomorphological setting of the island is such that it was judged geophysical techniques would not be successful. The scope of the present paper is therefore not to prove how geophysical methods have changed our understanding of Bronze Age Crete but rather to show that this reticence is not only unfounded but also that an integrated combination of geophysical techniques and archaeological control excavation can be successfully employed even in ecologically difficult environments. It draws from our experiences at the coastal site of Sissi on the northern coast of the island.

Previous Geophysical Investigations in Crete

Before our work at Sissi, geophysical investigations had taken place on Crete at quite a number of archaeological sites dating to the Bronze Age (Figure 1), including Malia (Rudant and Thalmann 1976; Guest-Papamanoli and Hobbs 1980), Palaikastro (Boyd, Whitbread, and MacGillivray 2006), Zominthos (Siart, Eitel, and Panagiotopoulos 2008; Siart, Ghilardi, and Holzhauer 2009; Sarris 2016), Priniatikos Pyrgos (Kalpaxis et al. 2006; Sarris, Papadopoulos, and Soupios

CONTACT Jan Driessen jan.driessen@uclouvain.be Aegean Interdisciplinary Studies (Aegis), Université Catholique de Louvain (UCLouvain), Place B. Pascal 1, L30003, 1348-Louvain-la-Neuve, Belgium

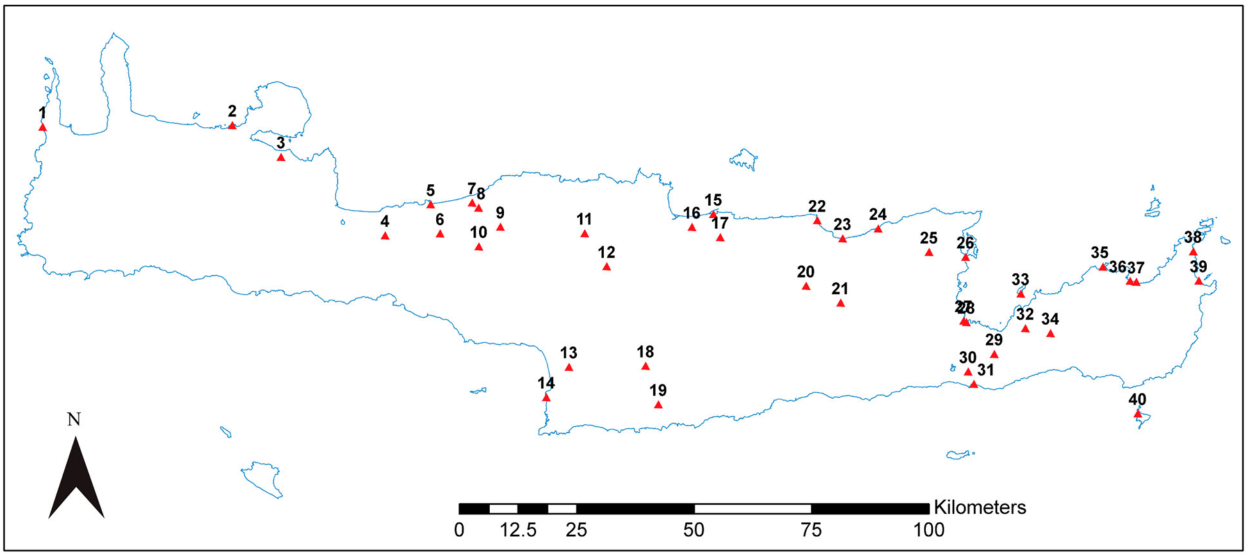

Figure 1. Map of archaeological sites on Crete that have been investigated through different geophysical prospection techniques (by A. Sarris). 1) Phalassarna; 2) Chania; 3) Aptera; 4) Agios Konstantinos; 5) Rethymno; 6) Onithe (Gouledianа); 7) Arsani; 8) Chamalevri; 9) Eleftherna; 10) Veni; 11) Axos; 12) Zominthos; 13) Phaistos; 14) Matala; 15) Heraklion; 16) Agioi Theodoroi; 17) Knossos; 18) Gortyna; 19) Koumassa; 20) Lyttos; 21) Plati; 22) Chersonisos; 23) Malia; 24) Sissi; 25) Driros; 26) Elounta; 27) Karavostasi; 28) Priniatikos Pyrgos; 29) Chalasmenos; 30) Rousses; 31) Ierapetra; 32) Azoria; 33) Mochlos; 34) Vronda; 35) Papadiokampos; 36) Siteia; 37) Trypitos; 38) Itanos; 39) Palaikastro; 40) Koufonisi. A number of these sites may include more than one locus of investigation. For example, in Rethymno, geophysical surveys have been carried out in the Venetian port, in the area of the Fortezza, and at the yard of the old Turkish School (Mikrasiaton square). The same holds for sites in the areas of Heraklion, Chania, and Ierapetra.

2014; Shahrukh et al. 2012), Koumasa (A. Sarris, personal communication 2020), Papadiokampos (Stamos, Sofianou, and Brogan 2015), and Mochlos (Stamos 2006, 66–83), while a few projects concentrated on later periods, as at Archaic Azoria (Stamos 2006, 30–38), Hellenistic Itanos (Vafidis et al. 2005), Mochlos (Stamos 2006, 66–83), and Phalasarna (Papamarinopoulos and Stamou 1988), Roman Lyttos (Vafidis and Economou 2007), and Byzantine Gortyn (Sarris et al. 2016). Recently, work is also being done at the Minoan site of Plati in Lasithi (Papadea, Tsokas, and Stampolidis 2019), at the multi-period site of Knossos, where the Roman occupation is privileged (Bennet 2016, 31–33), and in the Mesara plain below Phaistos (Ghilardi et al. 2019). The results of the above studies have been highly variable, as geophysical methods were aiming at different types of targets in divergent contexts. For example, the small-sized (ca. 0.5 m in diameter) Minoan tombs at Chalasmenos (eastern Crete) were hardly detectable through 1000 MHz GPR antennas compared to the large size (ca. 2 m in diameter) of the Roman chamber tombs at Ellinospita Mouri (Axos, Rethymno), which produced clear reflection signals with 225 MHz antennas (Sarris and Papadopoulos 2012a). Similar was the case of the exploration of the Late Minoan settlement of Vronda, where electrical resistivity mapping and soundings took place. The detection of tombs here failed, owing in large part to the very high soil resistance background, originating from the calcitic bedrock, which would have drowned out any anomaly arising from existing tombs (Papamarinopoulos and Tsokas 1988). Such high resistance background values due to shallow bedrock were also encountered in the soil resistance survey of Priniatikos Pyrgos, which failed to identify wall foundations later seen to be badly preserved. In contrast, magnetic survey at Priniatikos Pyrgos was much more successful, due to the high magnetic susceptibility signature of the ceramic and metallurgical workshop architecture (Sarris, Papadopoulos, and Soupios 2014). In other cases, where measurements were conducted within the urban fabric, such as the mapping of the subsurface architecture in the vicinity of the Palaeochristian church of Saint Peter's Basilica in Heraklion and the Venetian basilica of Saint Frangiskos opposite the old Turkish School of Rethymnon, the methods produced a relatively clear image of the subsurface architecture, even if considerably polluted by high levels of noise (Sarris and Papadopoulos 2012b). Incidentally, paleoenvironmental geophysical surveys have produced interesting results in the context of Bronze Age settlements. Ghilardi and colleagues (2019), for example, identified a marsh or lake at the foot of the Phaistos hills. In most cases, however, it is evident that the quality of the results varies significantly according to geomorphological conditions, which severely influence the quality of the measurements. This was especially the case at Minoan Palaikastro, where geophysical explorations in 2001 had hinted at the potential existence of a large monumental complex, not confirmed by excavation in 2013 (Boyd, Whitbread, and MacGillivray 2006). C. Knappett, in his preliminary online report, remarks that "the geophysical results proved to be misleading, and the areas of most promise revealed little but deep, gradual accumulations of colluvium" (Knappett 2013).

To a large extent, therefore, the successful application of geophysical methods is closely connected to the presence or lack of sufficient soil depositions, the frequent outcrops of fragmented bedrock upon which most of the archaeological sites are located, and the state of preservation of subsurface architectural remains. With most sites being characterized by marls, bedrock degradation has resulted in a soil that comprises much disintegrated marl that was also used as building material, making the distinction between natural and man-made features particularly blurry and picking up contrasts very difficult. This situation is further aggravated when prospection relies only on a single method, without prior experimenting as to which technique may produce the best results in a particular environmental context. The answer is therefore to apply a research strategy that integrates different techniques in close collaboration with archaeologists and with a proper knowledge of environmental conditions (Sarris 2013).

The Research Setting and Past Geophysical Investigations at Sissi

This paper describes the application of geophysical techniques at the archaeological site of Sissi, on the northern coast of Crete, where, after initial negative results, very good signals were acquired, despite adverse environmental conditions. The core message that we want to convey is to advocate the combination of geophysical surveys with control excavation by teams that allow not only confirmation of the results but also allow temporality and diachronicity aspects to be added. The geophysics team should have considerable prior knowledge of environmental conditions so that the instruments can be calibrated accordingly. The synergistic interaction between the archaeological and geophysical teams can act as a catalyst to integrate the results from both approaches and drive towards a much better interpretation of the results of the geophysical surveys.

The *Kephali tou Agiou Antoniou*, locally known as *Bouffos*, is a 3 ha Cretaceous–middle upper Eocene limestone bluff with an elevation of ca. 20 masl (Driessen 2018) (Figures 2–12). The hill is located on the northern coast of Crete (Figure 2) within a 2 km wide plain consisting of Pliocene marls and marly limestones about 40 km east of Heraklion, the modern capital of the island and the main Bronze Age center of Knossos. With a beach on both sides and located at the mouth of the Selinari River that forms a natural route through the homonymous gorge to eastern Crete, the hill has some obvious strategic advantages, controlling circulation of movement. Following limited tests in the 1960s and expropriation of the hill in the 1990s by the local archaeological service, systematic excavations by the Belgian School at Athens started in 2007. These were preceded by a geophysical survey of the northern top of the hill, as well as the middle terrace, areas that continued to be excavated in later years (see Driessen 2009 for a general introduction to the site). This survey was implemented by C. Hübner of the GGH firm (Solutions in Geosciences), who, during earlier work around Troy (Hübner and Giese 2006; Bindow, Hübner, and Jansen 2014) and elsewhere in Anatolia, and later at Gobekli Tepe (Dietrich et al. 2016), had obtained robust results. Details of this georadar survey at Sissi were, however, because of the paucity of results, not published in detail, but only briefly referred to in the first preliminary report (Driessen 2009, 25–26). The work covered an area of 5.560 m², especially on the top and lower terraces to the north of the hill (Figure 3). The instrument used was a georadar GSSI SIR with a 200 MHz antenna. While some anomalies were recorded, consistent signals of regular structures could not be identified. Subsequent excavation in these surveyed areas did, however, reveal well-preserved, regular architectural features immediately below the topsoil, but these had not been picked up by the instrument. We assume that this was partly a result of the presence of tumble and fallen architectural remains within the rooms and partly because of the near proximity of the bedrock, on which the walls had been constructed, which may have disturbed the signal and did not allow any clear distinction of the architectural remains. This may have been further attenuated by the wide profile spacing (50 cm) and the rough terrain. In contrast, the Trojan setting (Kraft, Kayan, and Erol 1982), an alluvial plain with fields and very few stones, appears to have provided an environment that was much more adapted to geophysical survey, as has also been demonstrated by a number of large-scale prospection projects in various other ecological niches, be they central European (Chapman et al. 2014; Sarris et al. 2015a; Filzwieser et al. 2017; Musteaţă, Popa, and Voß 2017; Trinks et al. 2018; Wallner 2020) or central Greek, as in Thessaly (Sarris et al. 2015b; Kalayci and Sarris 2016; Kalayci, Simon, and Sarris 2017). This experience, together with the scarcity of Minoan sites where geophysical surveys had been conducted successfully, created a skepticism, shared by teams working on the island, towards the implementation of geophysical investigations. For the time being, we were therefore somewhat reluctant to invest more financial means into a further geophysical exploration of the hill settlement. The next excavation seasons concentrated on the excavation of the Early and Middle Bronze Age cemetery in the eastern part of the lowest seaside terrace of the hill, on some domestic buildings dating to the early Late Bronze Age (16th century B.C.) on the middle terrace, and on a very large residential complex dating to the advanced Late Bronze (14–13th century B.C.) on top of the hill, visible in Figure 3.

The Recent Archaeological and Geophysical Campaign at Sissi

In 2011, we finished our first 5 year program and interrupted fieldwork for study and publication. During the final days of the 2011 campaign, however, some remarkable architectural features were revealed in the southeastern part of the hill plateau. These included part of a rectangular building with a fine western façade made of large limestone slabs, constructed in the early Late Bronze Age, but largely reused in the advanced Late Bronze Age, and a single east-west wall that was perpendicularly placed to the northwest of this limestone facade. A short stretch of wall made of sandstone ashlar blocks had also been found about 9.50 m to the west, parallel to the western limestone façade of the rectangular building. Close to all these walls were remains of a fine, plastered surface, suggesting the presence of a court. This archaeological evidence made us suggest that a potential central court existed between the two parallel walls, forming the core of a complex that had a clear north-northeast orientation of about 16.5° off north. Bronze Age complexes organized around central courts similar to this are traditionally labelled "palaces" on Crete (Palyvou 2002; Driessen 2003). They remain relatively rare on the island and are almost exclusively located in fertile regions that must have served as their economic, political, and ritual catchment areas. The three major "palaces" excavated thus far are at Knossos (from A.D. 1900 onwards) in the fertile Kairatos basin near Heraklion, at Phaistos (from A.D. 1900 onwards) in the Mesara valley, and at Malia (from A.D. 1915 onwards) in the homonymous plain. Rather than using the term "palace," which comes with an intellectual baggage that is too often taken for granted, we prefer the term "court-centered building," since the court seems clearly the essential feature of these complexes, while their function as a royal abode remains disputed (Driessen 2002, 2003). A score of smaller court-centered buildings are also known, such as those at

Figure 2. The Bouffos hill at Sissi, seen from the north (Cretan Sea). Drone image (2018) by N. Kress (©EBSA).

Gournia, excavated from 1905 onwards, Zakros (from 1962 onwards), Galatas, and Petras (both from 1992 onwards) (various contributions in Driessen, Schoep, and Laffineur 2002). On the basis of architectural remains, or because of other parameters, other court-centered buildings no doubt remain to be (fully) excavated at Palaikastro, Chania, Protoria, Archanes, Monastiraki, and elsewhere. In each case, the court-centered building site dominates, if not topographically, then economically, a fertile hinterland. As mentioned, the site of Sissi possesses such a fertile catchment area, watered by the Selinari River, but it is only 3 km east of the large court-centered building at Malia, too close in traditional thinking to assume the presence of yet another central building. The distance between Malia and Sissi is, however, about the same as that between the major centers of Phaistos and Agia Triada in the Mesara plain, and this last site also possesses notable palatial architecture. Still, the potential presence of a court-centered building at Sissi was also unexpected, because none of the finds made during the excavations between 2007 and 2011 suggested anything more than an unpretentious settlement of relatively small size (3 ha) that only outclassed Malia in the advanced Late Bronze Age, or 13th century B.C. To support our claim for the existence of yet another palatial building organized around a central court, we initiated a collaboration with the Institute of Mediterranean Studies at Rethymnon (Crete) when our second 5 year program started in 2015 in order to retry a geophysical exploration of the site through an integrated approach of three different methods (magnetic, soil resistance, and ground penetrating radar [GPR]) (Figures 4, 10–12).

As mentioned, the 2015 geophysical survey did not start from scratch, as parts of the complex suspected to be a court-centered building had already been uncovered. After surface cleaning, a number of experiments were carried out in the vicinity of the structure in order to test the signals created by the different methods. In light of achieving a good comparison dataset among the different methods, it was decided to scan this particular section of the site with all three methods. A Bartington G601 fluxgate gradiometer with a sampling of 0.5 × 0.125 m was employed for the magnetic scanning, while electrical resistivity measurements were carried out with a Geoscan RM85 electrical resistance meter with a Twin probe configuration and a sampling of 1 × 1 m. Finally, the Sensors&Software Noggin Plus GPR unit with 250 and 500 MHz antennae was employed with a sampling of 0.5 × 0.025 m covering the site in both x- and y- directions. The total area covered (labelled Zone C) was 615 m^2 (Figure 5). Different types of processing techniques were applied to all datasets to remove the noise levels and enhance the registered signals. Despiking, line equalization, and high pass filters were applied to both magnetic and soil resistance data. Processing of the GPR signals included trace reposition and time zero correction, together with the application of Dewow, SEG, background noise subtraction, and high pass and band pass filtering. Due to the high-resolution sampling and the low depth extent of the underlying architecture, the GPR managed to provide the most detailed image of the subsurface structures. Even though the soil resistance measurements were compatible with the GPR results, they did not manage to provide comparable detail. Similarly, the magnetic methods managed to locate only areas that were correlated with residues of burning. The most surprising signal apparent in the diagrams is a large, more or less rectangular, area devoid of structures, contrasting with the area to the west, where plenty of signals suggest the presence of architectural features. The size of this "empty" trapezoid is ca. 31 × 8–14 m (see Figure 5). The location and orientation of the void, however, did not correspond with that expected on the basis of known architectural comparative evidence. Moreover, a small rectangular structure with a clear east-west orientation (and hence different from the void) was identified to the southwest, while a regular wall pattern can be distinguished in the more

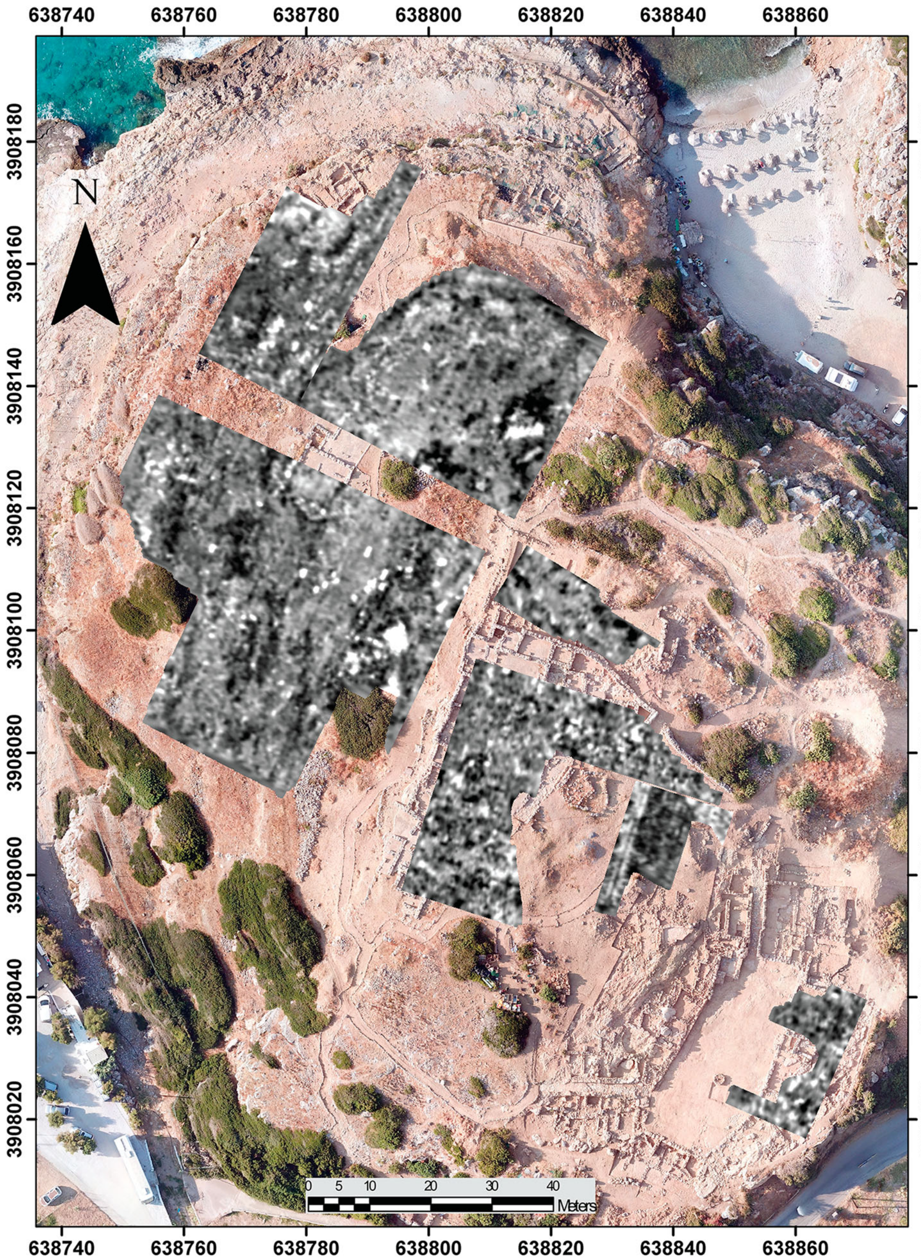

Figure 3. Sissi archaeological site: mosaic of the GPR depth slices for a depth of 50 cm (results of C. Hübner's 2007 survey) superimposed on the 2019 aerial (by N. Kress and C. Hübner).

northwestern parts. Our subsequent excavation strategy was therefore altered and adapted to this new knowledge, and the following excavation campaigns confirmed both the position and orientation of the void formed by the central court, the presence of a rectangular building to the southwest, now known as the Basin Building, and the existence of internal spaces within the western and northwestern wings of the complex. The geophysical survey therefore provided us with a good idea of what to expect during the following five excavation campaigns, when the entire complex was painstakingly explored, and our excavation strategy took into account the geophysical data concerning the general outline of the work, the orientation of the walls, and the location of the trenches. Excavation was evidently necessary to give flesh to this bony structure; it was discovered that, because of the outward collapse of the facades surrounding the court, the GPR had in fact picked up the tumble aligning the facades rather than the facades themselves, and the court was actually even larger than expected (9–15 × 33 m). Moreover, complex stratigraphy, with an occupation going back to the Early Bronze Age and multiple modifications of the early Late Bronze Age architecture, was documented during excavation, as well as aspects related to room function, abandonment processes, and many other details that remain invisible to geophysical recognition (Driessen 2017; Sarris et al. 2017). Interesting, too, is that the geophysical survey suggests that the central court does not seem to have earlier architectural remains.

As can be seen from the image (see Figure 5), the shape of the central court, as suggested by the geophysics and confirmed by the excavations of 2015–2019, is neither rectangular (nor uniformly) oriented, nor of regular proportions. While we expected the final plan of the complex to conform to the concepts of rectangularity, orientation, and proportions well-known from the major court-centered buildings at Knossos, Phaistos, and Malia (Palyvou 2002; Shaw 2010, 305), this is obviously not the case. In retrospect, we assume that the incorporation of Early Bronze Age

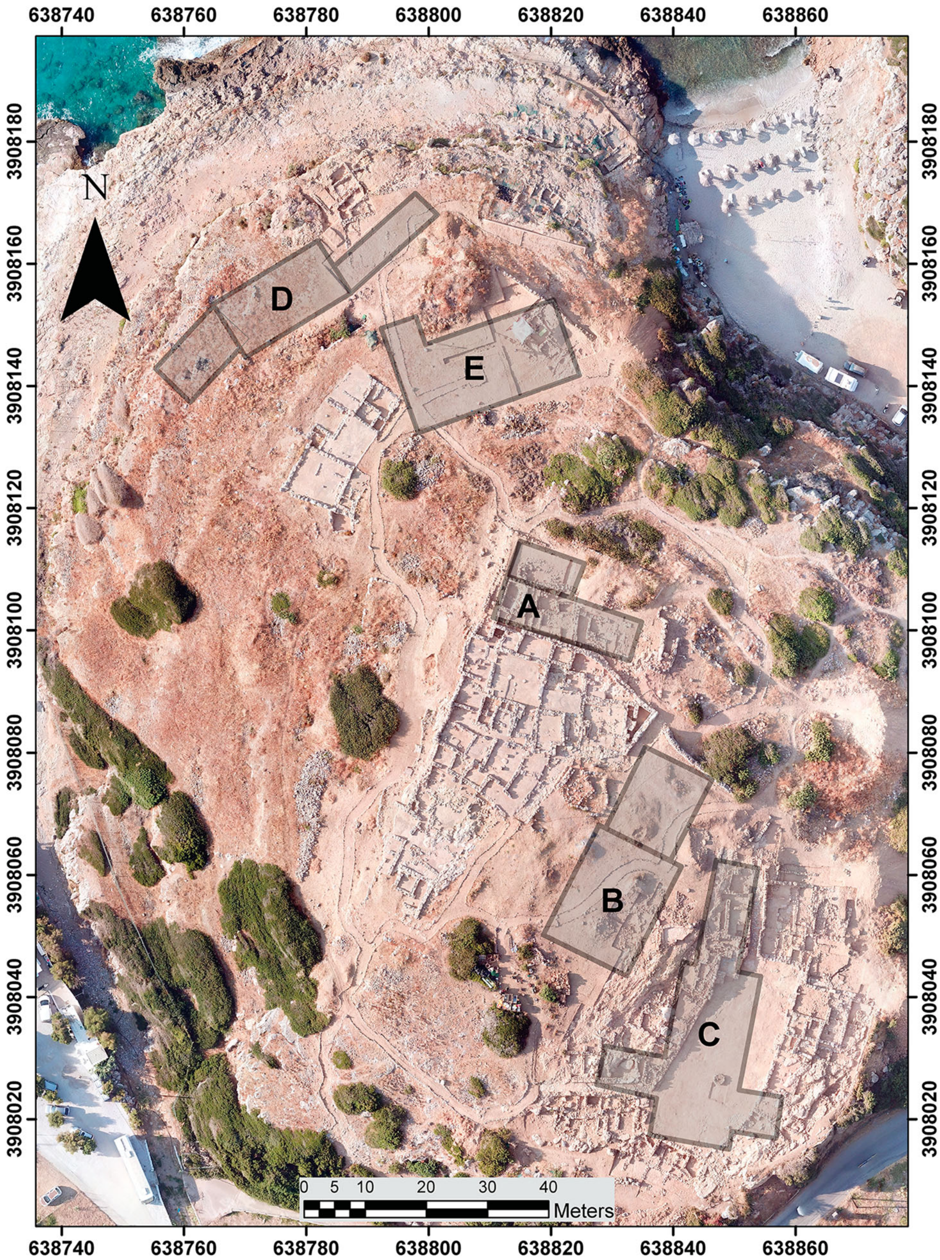

Figure 4. Sissi archaeological site with areas investigated with geophysical survey during 2015–2017 (by N. Kress and A. Sarris).

remains, the terrain and protruding bedrock of the building site, the prior existence of a street system, and the progressive enlargement of the complex are responsible for these anomalies. Other reasons may be an intention to adapt to specific astronomical observations and the wish to keep an open view to the mountains forming a natural backdrop to the south of the site.

In 2016, two further areas of the Sissi site were explored (see Figures 4, 10–12). Zone A, located immediately north of a large complex (Building CD) of the advanced Late Bronze Age that had been the core of the 2007–2011 excavation campaigns, and Zone B, the upper terrace located west of the Court-Centered Building. Based on the results of the 2015 geophysical survey, it was decided to abandon magnetic survey and focus on GPR and resistivity surveys only. The instruments were the same as in 2015, but this time it was decided to proceed with a denser sampling strategy, namely 0.25 × 0.025 m and 0.5 × 0.5 m for the GPR and soil resistance survey, respectively. An area of 228 m^2 in Zone A was covered by both GPR and soil resistance techniques, and an area of 482 m^2 in Zone B was covered only by GPR. The GPR measurements were acquired along both x- and y- directions, and their processing was carried out independently for each direction and in combination of both. Unfortunately, the dry conditions of the soil and the relatively shallow bedrock were responsible for the poor results of the soil resistance survey.

Zone A, the area to the north of the advanced Late Bronze Age complex, is formed by a large area consisting of two flat, stepwise-organized terraces (see Figure 4). A small test excavation was made in the higher terrace in 2009, immediately outside the northern façade of the advanced Late Bronze Age complex (Gomré 2011, 139–140). This had shown the presence of near-surface architectural features and deposits dating to the Middle Bronze Age, and it was hoped that the geophysical exploration of this area would propose a schematic outline plan that could be used to decide on a proper excavation strategy. The GPR results (Figures 6, 10–12) were indeed quite promising, as they provided a plan with, on the higher terrace, a series of rooms that

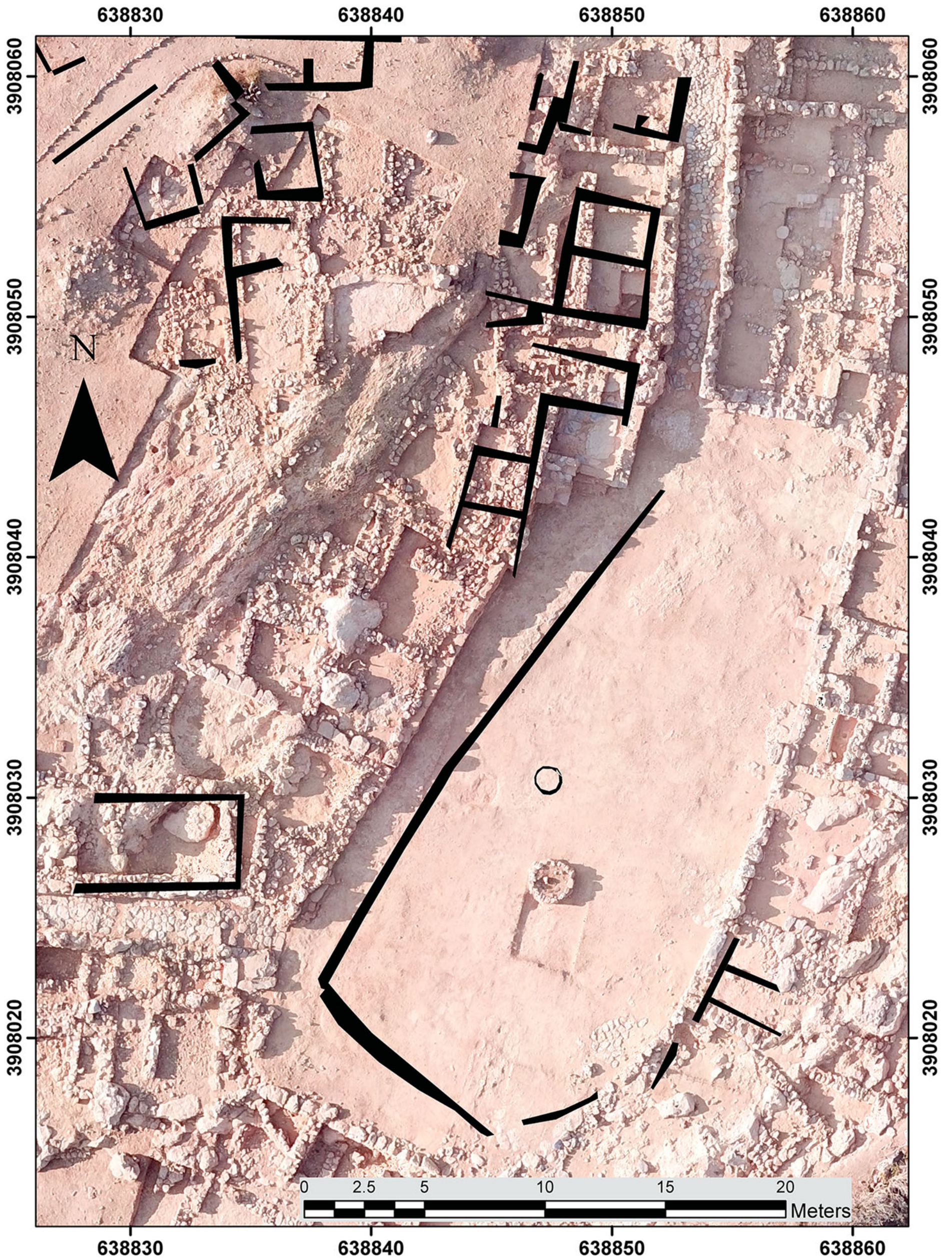

Figure 5. Sissi archaeological site: Zone C, the Court-Centered Building, with signals picked up by GPR survey superimposed on the 2019 aerial (by N. Kress and A. Sarris).

formed a coherent plan of units organized along a corridor, separated from a much larger room located on the lower terrace by a diagonally-running east-west wall. Because of its regularity, we judged the plan to reflect a single architectural phase, and, since the earlier test had suggested a Middle Bronze Age date for the architectural remains, we assumed this to be the date of the entire complex, which was compared to similar multi-roomed architectural complexes, such as that of Quartier Mu at nearby Malia, or in other Middle Bronze Age sites, such as Monastiraki and Apodulu, both in the Amari valley. Moreover, since this Middle Bronze Age phase remained thus far little known at Sissi, while it was the period during which nearby Malia knew its largest expansion, with many public and semi-public buildings, the existence of such a multi-roomed complex at Sissi had an obvious historical importance in that it would show how a primary and a secondary center within the palatial state of Malia could have related and functioned. Subsequent excavation from 2016 onwards (Claeys in press) confirmed the general outline of the architectural features suggested by the geophysical survey but forced us to reconsider our initial hypothesis. It could be shown that the specific walls, which we had assumed to form a coherent plan, in fact belonged to different periods within a long and complex diachronic occupation that spanned the entire period between the beginning of the Middle Bronze Age to the mature Late Bronze Age, ca. 1900–1350 B.C., before being overbuilt by the advanced Late Bronze Age complex of the 14th–13th century B.C. And, while during this long period, some wall lines were reused, many were in fact no longer in use during the final phase of occupation. Moreover, rather than a single complex, it is now clear that at least three individual buildings were successively constructed, with each phase inaugurating a new area on the terrace in a horizontal displacement. Here, excavation has therefore considerably corrected our mistaken interpretation of geophysical results.

Geophysical research in Zone B (see Figure 4) was preceded by considerable surface cleaning, since the area

Figure 6. Sissi archaeological site: Zone A, the north part of the plateau, with signals picked up by GPR survey superimposed on the 2019 aerial (by N. Kress and A. Sarris).

comprised several large heaps of stone resulting from earlier agricultural field clearings and, because of bedrock outcrops, had been chosen as appropriate for our excavation dump. Their presence, however, cautioned us against being over-enthusiastic. As was expected, the signals received were quite fuzzy and difficult to interpret. Still, it was possible to recognize a number of wall structures (see Figures 7, 10–12), some oriented north-south and others east-west, extending up to a depth of ca. 1 m. Most of the spaces had dimensions of ca. 2–2.5 × 2.5 m. Those to the southeast of the surveyed area were adjacent to each other and suggested the presence of perhaps three building complexes. A few more linear reflectors suggested more wall structures, mainly confined in the southwestern section of Zone B. GPR signals became weaker towards the northern section, most probably due to recent interventions. The contrast between the almost random organization of the potential wall alignments and their contrasting orientations in this area as seen against the regularity of the signals acquired in Zones A and C made the archaeological interpretation of Zone B difficult. Since the Kephali hill had been used by Italian occupation forces during World War II as a guard and observation post, and, during excavation, military equipment had been collected (Driessen 2011, 24–25), we initially assumed that the signals in Zone B belonged to a recent period, potentially indicating the presence of Italian barracks. Excavations of this area in 2018–2019, however, brought to light well-preserved Early Bronze Age (ca. 2500 B.C.) domestic structures of a date, type, plan, and orientation not attested on the site before but with clear parallels with other contemporary sites (Hagia Triada and Chalepa). Their proximity to the surface makes their conservation even more surprising, since no later intrusions were noted. We uncovered the remains of at least two individual dwellings that diverge in orientation, consist of relatively small rooms, and together must have formed part of a very early hamlet located on top of the hill (Letesson in press). In retrospect, then, the GPR showed almost exactly the outline of these buildings. Moreover, the

Figure 7. Sissi archaeological site: Zone B, the top of the hill, with signals picked up by GPR survey superimposed on the 2019 aerial (by N. Kress and A. Sarris).

other signals retrieved to the west could then also indicate further structures and the continuation of the Early Bronze Age hamlet. Interestingly too, the change in orientation of the walls, first shown by geophysics and later confirmed by excavation, can be used as a chronological indicator, suggesting an earlier date for alignments that differ from the main north-northeast orientations of the Late Bronze Age buildings.

In 2017, a final GPR survey took place on the lowest and middle terraces of the hill, Zones D (400 m^2) and E (slightly more than 400 m^2) (see Figure 4). The same instrument and sampling procedures as in 2016 were applied for the acquisition of the measurements: sampling took place at 2.5 cm along parallel GPR transects separated 25 cm apart, and scanning took place in both x- and y- directions (Sarris, Manataki, and Déderix 2018). Zone D (see Figure 3) comprises the then-unexcavated western part of the Early and Middle Bronze Age cemetery that has been under investigation since 2007 on the seaside terraces of the hill. More to the east, excavation had already uncovered several burial structures, some consisting of simple stone compartments built closely against each other, with others taking the form of substantial, independent structures that are known as House Tombs in Minoan archaeology, corresponding to a type well-known from other coastal sites of eastern Crete (e.g. Gournia, Mochlos, Petras, and Palaikastro) (Legarra Herrero 2014). These structures essentially served primary, articulated inhumations, even if many signs of manipulation and secondary depositions were also encountered. Yet another type of funerary structure has a box-like appearance and served to contain secondary bone deposits, probably the result of cleaning operations of the first two types. The proximity of these three types and their continuous use, with plenty of architectural modifications, in the period between 2400 and 1750 B.C., resulted in a complex, agglutinative plan in the eastern part of the cemetery, while in the western part, a large, seemingly independent burial structure was unearthed (Schmitt and Sperandio 2018). West of this last burial structure, excavation had come upon an open area that seems to have served the deposition of the remains of

Figure 8. Sissi archaeological site: Zone D, the western part of the cemetery, with signals picked up by GPR survey superimposed on the 2019 aerial (by N. Kress and A. Sarris).

funerary feasts (Schmitt and Sperandio 2018, 65). These took the form of thick deposits of broken pottery, usually of drinking vessels, occasionally associated with other types of pottery and organic remains. We were therefore curious to find out the extent of this funerary feasting area and if burial structures existed elsewhere on the same terrace and in the unexplored area more to the west.

The GPR signals produced in Zone D indicated a dense, but still diffuse, pattern of reflectors that were related to structural remains generally following the same orientations (Figures 8, 10–12). In the very western part of Zone D, the linear reflectors matched the surface alignments of a series of building blocks, suggesting the existence of a structure oriented northeast-southwest. The interpretation of the GPR measurements suggested a structure of dimensions ca. 7 × 11 m, consisting of internal divisions and extending to the limits of the terrace to the north-northwest. Similar evidence was produced from the more central section of Zone D, where architectural remains appeared in shallow strata (ca. 40 cm below the surface). In general, the structure follows the orientation of the convex shape of the terrace wall, deviating from the orientation of the architectural remains to the south or northeast. Two small tests in this area (Déderix in press) came upon architectural remains close to the surface. No human bone was observed, and the objects encountered were similar to those found in early Late Bronze Age domestic structures. Hence, the structure is probably also a residential building, similar to that found to the south, on a higher terrace. It suggests that habitation continued in this area of the hill, and the ceramics collected suggest an early Late Bronze Age date (16th century B.C.), the main period of expansion of the Sissi settlement. Towards the northeastern part of Zone D, the thinner soil produced a number of weaker linear reflectors that indicated the presence of wall structures appearing at a depth of ca. 40–50 cm below the surface. The particular features show a slightly shifting orientation that runs vertical to the terrace wall. Taking into consideration the excavated burial structures

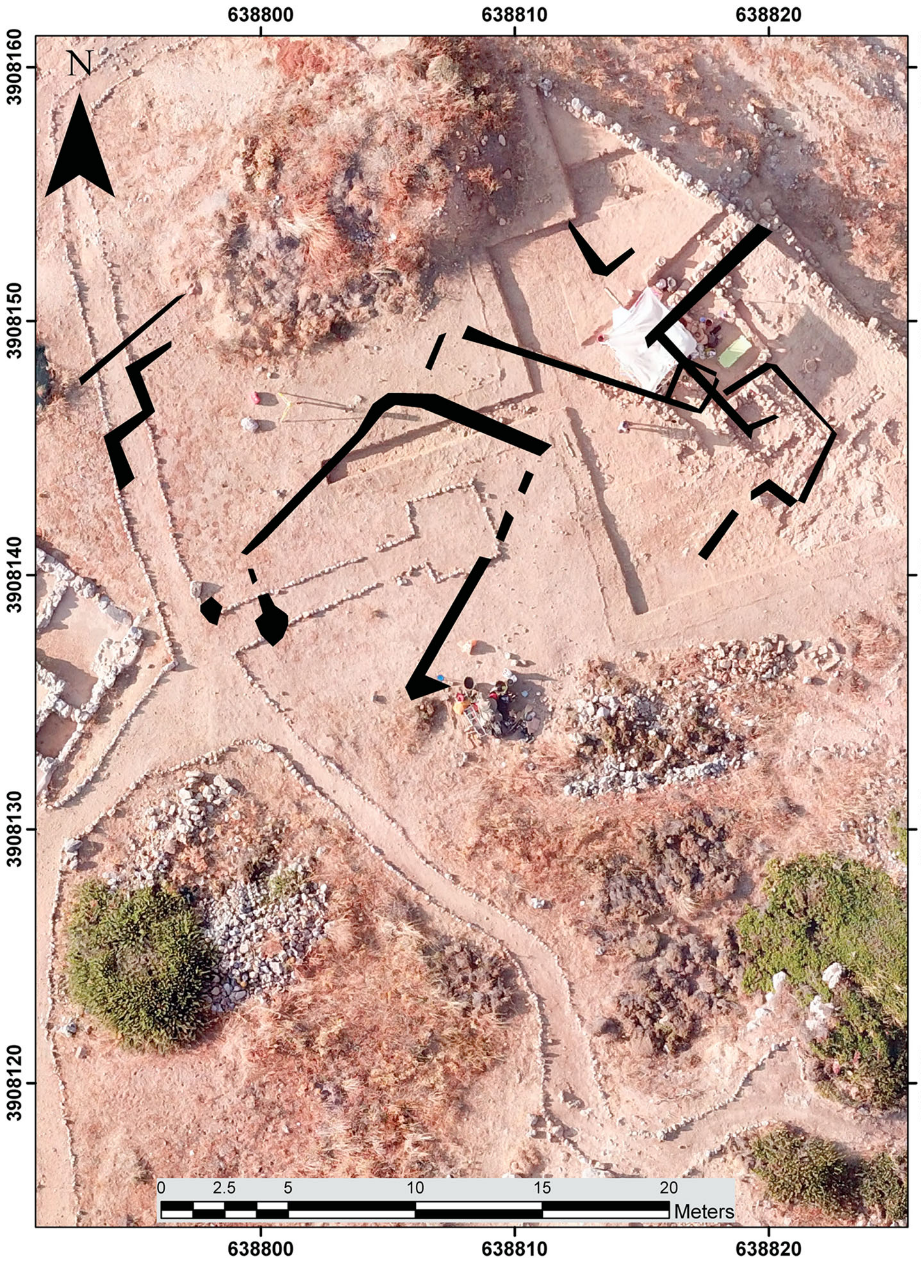

Figure 9. Sissi archaeological site: Zone E, the middle terrace, with signals picked up by GPR survey superimposed on the 2019 aerial (by N. Kress and A. Sarris).

to the south and to the east of Zone D, it may be suggested that the cemetery continued towards this particular area. More to the northeast, however, no signals were acquired, which suggests that the funerary feasting zone continued for at least 5 m to the southwest, originally forming an area of more than 25 m².

Finally, Zone E was laid out on the middle terrace that is located immediately above that of the cemetery just described (see Figure 4). It covered the main area that had been surveyed during the initial 2007 geophysical investigation, when it did not yield any features that invited exploration. In the meantime, however, substantial architectural remains of the early Late Bronze Age had been explored in the western part of this middle terrace that had a clear domestic and residential function. While several areas were indeed devoid of signals, confirming the 2007 investigation, substantial signals were recovered from almost all sections of Zone E (Figures 9–12). A prominent structure with dimensions 7.50 × 24 m and a northeast-southwest orientation was clearly outlined in the western part of the sector. The building does not have any internal divisions, but its orientation is similar to that of the excavated remains to the southwest of Zone E, suggesting a similar chronological phase. A long test trench across these areas succeeded in identifying the northeastern and northwestern walls but did not come across any internal partitions. Perhaps the area formed an enclosed yard or garden. Three meters to the northeast of the northeastern wall of this structure, a parallel linear reflector extends for ca. 9.8 m, which runs east up to a square-like building located in the most eastern part. This may suggest a potential track (3 m wide) that separated the two structures. The eastern building, however, has a slightly different orientation and follows the edges of the terrace to the east, after which the hill drops considerably. Due to their differing alignments, it was suggested that the two clusters, east and west, belonged to different occupation phases or usages of space. The presence of these remains, as well as the existence of internal partitions, made us expect the existence of another early Late Bronze Age domestic structure in the eastern part of the terrace. It was also noticed that different parts

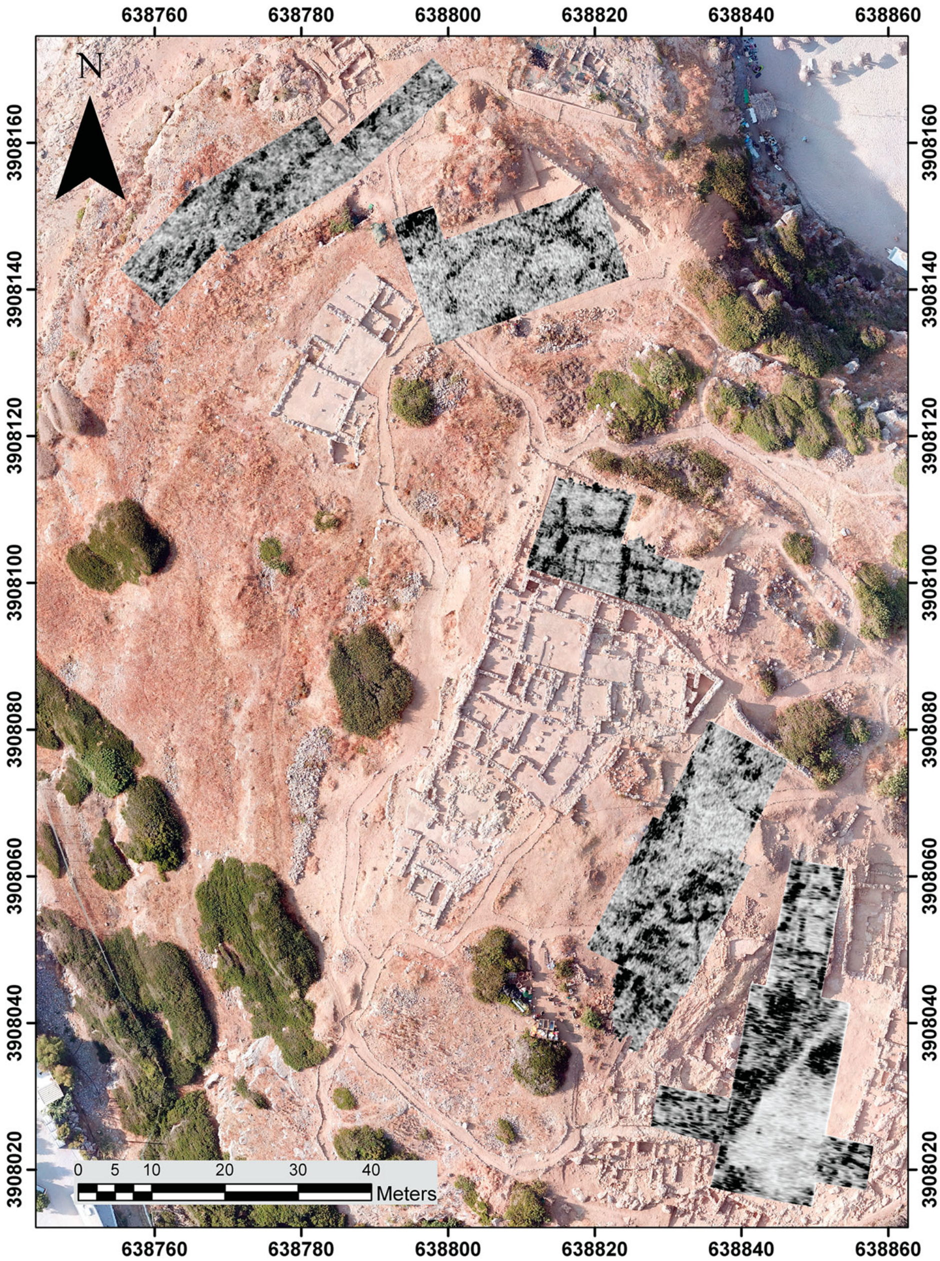

Figure 10. Sissi archaeological site: GPR rough data superimposed on 2019 aerial (by N. Kress and A. Sarris).

of Zone E (to the northwest and east) produced fuzzy signals, which could suggest that intrusions or damage had been done to the architecture. The subsequent excavation strategy of the area closely followed the calibrated signal outline suggested by the geophysical survey and soon managed to recover the outline of the rectangular structure in the eastern part of the terrace (Sager in press). We were also able to confirm the reason for the fuzziness of the signal, since several of the walls were either damaged or destroyed, and much tumble was found within the structure, covering well-preserved floor deposits. An earthquake may explain this taphonomy. Our greatest surprise, however, was the discovery of human bones in all of the spaces encountered, as well as small pottery deposits in the courtyards around. This suggests the building also had a funerary function, similar to the ones found on the lower terrace, and that the surrounding areas were probably also used for funerary feasts and depositions. The chronology, however, is different from that of the seaside burial structures, since thus far only early and mature Late Bronze Age ceramics were encountered from the funerary structure in Zone E (16th–14th century B.C.). The most surprising observation is that the area served as a burial ground during the period when contemporary domestic structures existed only 15 m west of it, a proximity that is quite unusual. Since burial structures of this phase are very rare on the island, the discovery has important implications, not the least in suggesting an overall continuity of practices, and perhaps even of population, on the hill between 2400 and 1400 B.C. Again, this shows, however, to what extent prior geophysical exploration helped us to avoid the excavation of empty grounds while strategically identifying areas that were potentially interesting. But it also shows the extent to which archaeological confirmation remains necessary to evaluate the nature, chronology, and historical relevance of signals.

Final Remarks

These various explorations at Sissi have clearly shown the validity and usefulness of geophysical exploration prior to

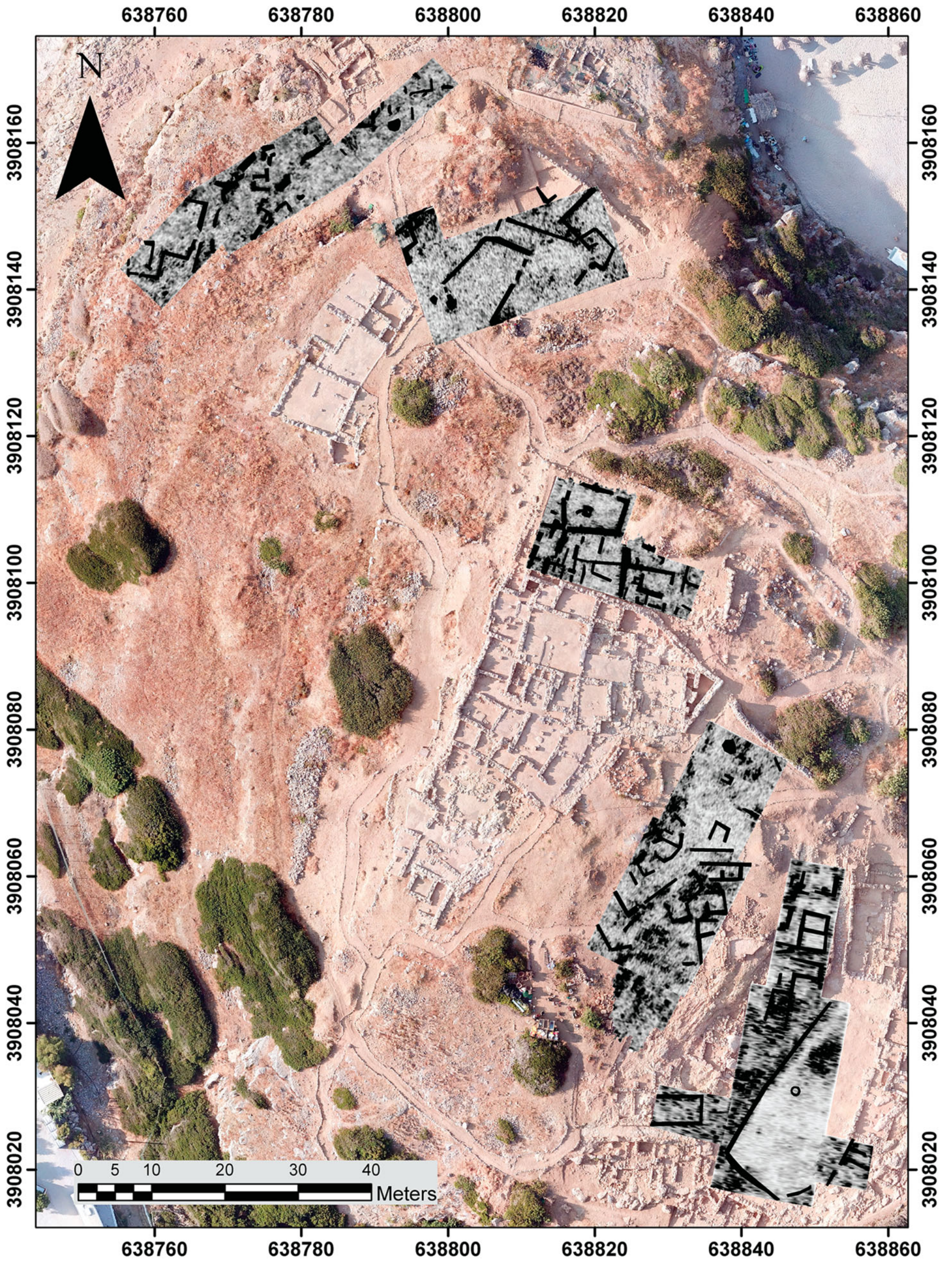

Figure 11. Sissi archaeological site: interpreted GPR and rough signals superimposed on 2019 aerial (by N. Kress and A. Sarris).

and in parallel with archaeological investigations. Moving away from any earlier skepticism towards geophysical prospection, the multi-year research design at Sissi successfully exploited the geophysical component, adopting it as an integral part of the archaeological exploration of the site. The interplay between the geophysical and archaeological teams, through the exchange of information related to archaeological residues found during the initial steps of the excavations and the geomorphological settings of the site, led to more productive decisions with respect to the appropriateness of the geophysical methods to be used and the strategy for the collection of measurements that were adapted to the archaeological research questions. Through this stage of experimentation and the careful design of fieldwork activities, a higher quality of measurements was achieved.

Moreover, our multi-annual integrated approach has also made it clear that, without archaeological investigation, the interpretation of geophysical results remains at the least haphazard, and potentially rife with error. This is a general conclusion that springs not only from the current investigations in the hilly, mountainous, and rocky environments of Crete and the Cyclades, but also from places (e.g. the alluvial plains of Thessaly or Thrace in Greece) that provide ideal conditions for geophysical prospection. Even in these exemplary conditions, geophysical results can provide a wealth of information related to the intra-site organization of the settlements, the distribution, density, size, and orientation of the dwellings, etc. fueling modeling and theories behind their organization, but still they fail to a certain degree in revealing the wealth and the details of the material culture that gives a meaning to the architecture. Considering the limited number of fully excavated Bronze Age sites in Crete, it becomes evident that the implementation of extensive geophysical surveys can provide a more holistic image of the plan of the unexcavated or partly excavated sites and lead to a reconsideration of the settlements' organization. Unquestionably, the resonance between excavations and geophysics can improve archaeological research and provide a brand-new protocol of how we need to approach archaeological sites in general.

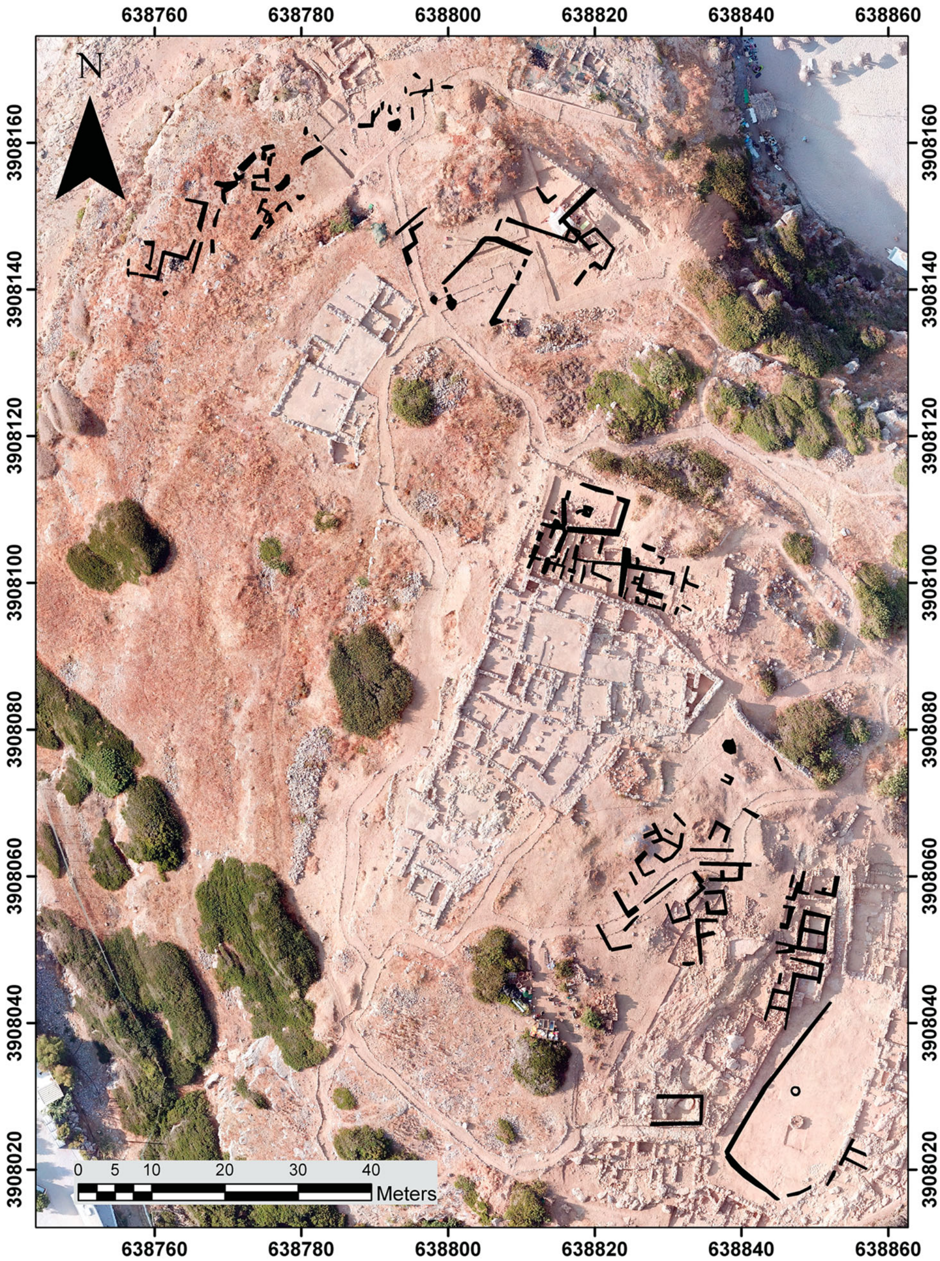

Figure 12. Sissi archaeological site: interpreted GPR data superimposed on 2019 aerial (by N. Kress and A. Sarris).

While a fair number of Bronze Age sites have thus far been investigated on Crete with geophysics (see Figure 1), the limited success cannot be blamed solely on adverse environmental conditions, since these are roughly similar to the local Sissi geomorphology. GPR and magnetic methods remain the most efficient in terms of mapping the architectural remains of settlements or cemeteries, with magnetic methods indicating the presence of kilns and thermal targets, and even delineate the outline of architectural remains. However, the application of high resolution GPR surveys, as at Sissi, was seen to provide optimal results in the mapping of architectural residues that allowed the implementation of a proper research strategy and the concentration of costly archaeological resources in the most profitable and productive ways.

At Sissi, the geophysical techniques, and especially the application of the GPR, provided information about the horizontal and vertical extent of the underlying architecture and considerably contributed to the planning of the following excavations. In each case, archaeological excavation confirmed the general outline and plan as proposed by geophysical survey but added considerably in terms of chronological and contextual understanding. This is most clear in the case of the Court-Centered Building, where the geophysics corroborated, at the same time as corrected, the original archaeological hypothesis of the presence of a central court, provided evidence of the shape of it, and confirmed the absence of any substantial structures within it. More buildings were identified around the court, adding to the picture of past excavations, and the presence of other structures and internal divisions was outlined in detail. Importantly, the different orientations of the structures registered by the GPR signals were seen to reflect diachronic changes in the layout of the buildings on the site between the Early, Middle, and Late Bronze Ages. Since the organization of the settlement (and that of the buildings within) at Sissi shows a number of similarities with other Bronze Age sites on Crete, the successful implementation of geophysics at the site should serve as an appeal to investigate, or re-investigate, through geophysics other sites in which court-centered buildings are expected or suspected prior to excavation. Moreover, testing the central courts of already excavated centers could easily provide information of the diachronic use of these spaces that are considered essential to Minoan society and clarify whether earlier subsurface architectural remains exist.

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Notes on Contributors

Jan Driessen (Ph.D. 1989, University of Leuven) is a professor of Mediterranean Archaeology at UCLouvain and Director of the Belgian School at Athens, Greece. His research interests include the social structure of Bronze Age Crete, the effects of the Santorini Eruption on Minoan society, and the archaeology of crisis in the eastern Mediterranean.

Apostolos Sarris (Ph.D. 1992, University of Nebraska-Lincoln), is a professor of Digital Humanities at the Archaeological Research Unit, University of Cyprus, and Director of Research at the Foundation for Research and Technology, Hellas (FORTH). His research interests include applied geophysics in archaeology, GIS spatial analysis and modelling, and satellite remote sensing.

ORCID

Jan Driessen http://orcid.org/0000-0001-6146-5010
Apostolos Sarris http://orcid.org/0000-0001-6071-4767

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