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Optimizing search strategies in mass grave location through the combination of digital technologies

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ABSTRACT

Efforts to locate missing persons resulting from conflict often centre of excavation. Although this approach is the only way to definitively confirm the presence of human remains, it can be costly and labour-intensive, particularly when large areas need to be searched. This paper discusses a wide range of emerging non-invasive digital methods implemented with a view to locating burials and mass graves and increase the excavation recovery rate of the Committee on Missing Persons in Cyprus (CMP). Aerial and terrestrial survey and subsequent 3D modelling were combined with geophysical survey in order to record sites, two of which were excavated to ground-truth the findings. The results demonstrated the effectiveness of these techniques in defining the search parameters of potential burial sites and prioritizing features for investigation. The nature of the collaboration between archaeologists, digital technologists, and forensic experts allowed mutual trust to be built between all parties, whilst also testing the effectiveness of the methods employed.

1. Introduction

Since forensic archaeology became a recognized discipline in the mid-1990s, there have been considerable advances in the search for, and recovery of, human remains and other trace evidence. An increased appreciation of the role of archaeologists means that, in some countries, they are regularly engaged in forensic cases involving missing persons in the course of legal proceedings. Moreover, in many countries throughout the world, there have been pledges made to locate deceased and missing people for humanitarian purposes, with the main aim to ensure that they receive the basic dignity of a formal burial and to provide answers for their families.

Such a commitment has been made by the Committee on Missing Persons in Cyprus (CMP), a bi-communal body which was established in 1981 by the leaders of the Greek-Cypriot and Turkish-Cypriot communities, under the auspices of the United Nations. The objective of CMP is to determine the fate of 2002 missing persons who disappeared since the beginning of inter-communal fighting in Cyprus in 1963-64 and the events of 1974. So far, the remains of 1197 individuals have been exhumed; 930 of these have been identified. Searches for the burials of the remainder are ongoing [1].

In 2017, in the framework of the Digital Forensic Archaeology Project (funded through a Marie Sklodowska-Curie Individual Fellowship), a research project[1] was launched between archaeologists, forensic experts and digital technologists from the Centre of Archaeology of Staffordshire University, the CMP and the Cyprus Institute, in order to explore how tools from a range of disciplines could be utilized to detect and record unidentified individual and mass burials from the aforementioned periods of conflict. Using the example of the research undertaken in Cyprus, the objective of this paper is to demonstrate the application of innovative digital technologies in a forensic archaeological environment and to highlight the pros and cons of interdisciplinary approaches in the optimization of the research and time efforts. Specifically, the paper will

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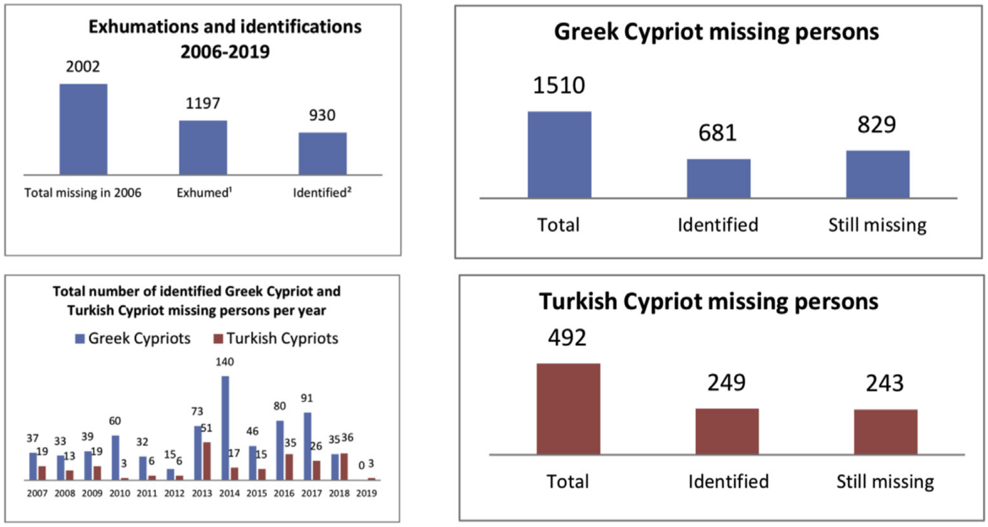

Fig. 1. Exhumation and identification statistic 2006–2019 (courtesy of CMP).

reflect on the potential of these methods to (i) to improve search efficiency and accuracy, (ii) to ease access to various environments, (iii) to characterize and create a more accurate record of elements recovered during subsequent excavations. The combination of traditional investigation and excavation methodologies with digital sciences has enabled the project team to reflect upon the specific forensic needs of CMP's future strategical planning program and to highlight how such approaches may be applied at other unmarked clandestine burials around the world.

2. Historical background

In 1960, Cyprus became an independent state [2]. Following this turning-point, thousands of individuals disappeared during inter-communal fighting on the island in the sixties and the seventies. Between 1975 and 1978, the UN General Assembly (GA) adopted three different resolutions on the missing persons in Cyprus, calling for the establishment of an investigatory body to tackle this humanitarian problem.[2] From 1977 to 1981, negotiations took place in Nicosia, Geneva and New York, leading to the establishment of a Committee on Missing Persons in Cyprus (CMP).

CMP's mandate has since been to “establish the fate of missing persons” who disappeared during the inter-communal fighting of 1963–1964 and the events of 1974, and to return to their remains to their families [3]. The CMP is a tripartite bi-communal committee, comprised of a representative of the Greek Cypriot community, a representative of the Turkish Cypriot community and a Third Member nominated by the International Committee of the Red Cross (ICRC) and appointed by the UN Secretary-General [4].

In this bi-communal effort, teams of Greek Cypriot and Turkish Cypriot scientists are involved in every stage of the search, recovery and identification process with regards the remains of missing persons. The total number of missing persons resulting from the two periods of fighting is thought to be 2002, comprising of 1510 Greek Cypriots and 492 Turkish Cypriots. Since 2005, the remains of at least 1197[3] individuals have been exhumed. Among the latter 930 individuals have been identified (Fig. 1) [4].

In July 2007, CMP began returning remains of Greek Cypriot and Turkish Cypriot missing individuals to their families. Most Cypriot families have been directly or indirectly affected by the tragic events of 1963-64 and 1974; it was hoped that the location and identification of the missing would help the overall process of reconciliation.

3. Current approaches and challenges

Since the establishment of CMP, the teams of forensic archaeologists have processed a wide variety of sites (e.g. wells, open-field, cemeteries), following archaeological processes to the highest possible standards [5,6]. Initially, as much contextual information as possible regarding a site is collected [7], and organized into what Haglund and Sorg [8] refer to as a biogeographic context. The team then performs a systematic site survey, selecting the appropriate methodology according to the terrain and any other environmental conditions [9,10]. The site's archaeological landscape is analysed and the taphonomy, which might have influenced the selection of a burial location, is considered [11].

After the completion of the survey, the team will begin investigating the area via controlled mechanical-aided excavation [9,12]. If human remains are encountered, the team will proceed to excavate the grave by hand, using standard archaeological techniques. Preserving the integrity of the stratigraphy and environmental context of the burial during the excavation are key elements in the entire process [13]. To that end, the excavation is conducted in layers, using the grid-system method whenever possible [9]. The documentation of finds and other trace evidence within the grave is extremely important, as various geotaphonomic factors need to be taken into consideration during the anthropological investigation of the retrieved remains [13].

These searches often involve the excavation of vast areas of land due to the need to eliminate or confirm locations as burial sites in their entirety. Over the last decade, CMP has faced a steady decline in the excavation recovery rate, mainly due to the amount of time that has passed since the events (Fig. 2).

The main reasons for this are:

- *Non-specific or absent testimonies relating to specific missing persons and/or events.* In the Cypriot context, it should be noted that there has not been a conscious effort to locate and interview everyone who witnessed deaths and/or burials. Rather,

[2] http://www.cmp-cyprus.org/content/origins.

[3] The numbers refer to the progress of analyses at the time of writing this article. Please refer to the official website for the latest progress, at www.cmp-cyprus.org.

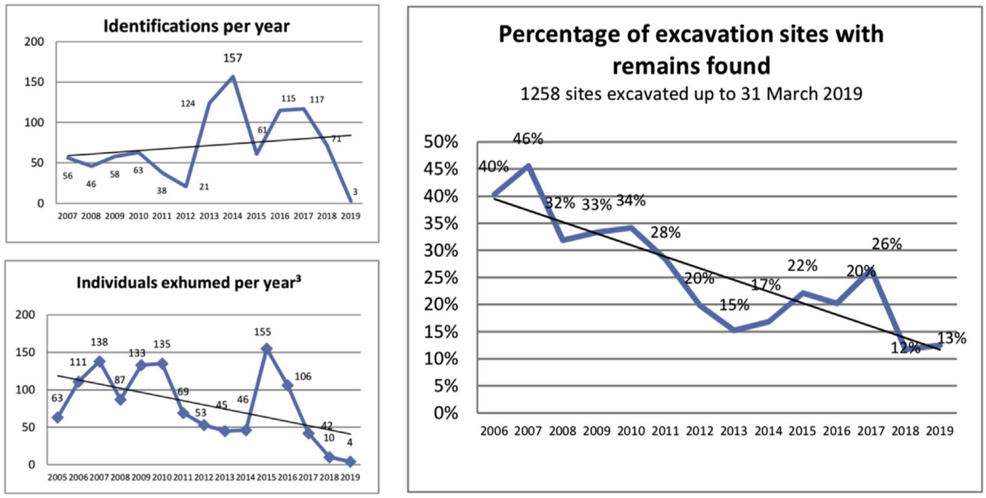

Fig. 2. Identification and exhumation rate per year (courtesy of CMP).

testimonies have been provided spontaneously and CMP have responded by investigating this information. As many witnesses are gradually passing away, interviewing/reinterviewing in order to collect more specific details that may aid in future searches is becoming increasingly difficult.

- *Environmental and topographic changes in the landscape during the 50-plus years since the events.* These are sometimes natural, sometimes man-made. Such changes may limit the opportunities to find markers indicated by witnesses, identify taphonomic indicators such as vegetation change, depressions etc which may indicate a burial and/or access sites, for example.
- *In some cases, remains were moved to secondary locations as a result of man-made or natural interventions.*

Hence, 805 missing persons are yet to be located [14].

The CMP's vision for 2017–2020 is to achieve the highest possible number of exhumations and identifications through a combination of strategies aimed at finding new information. These strategies effectively include: (i) thorough research in the archives of all security forces and international organizations present in Cyprus during 1963-64 and 1974, and more effective use of existing information more effectively through digitization of combined records; and (ii) the use of a wide range of new technologies, such as remote sensing techniques, aerial and terrestrial 3D modelling, and geophysics amongst others [14]. To this end, CMP entered into a collaboration with the Digital Forensic Archaeology project, led by the Staffordshire University and in collaboration with the Cyprus Institute. This project aims to identify and apply a wide range of appropriate emerging technologies and scientific applications which could be implemented in forensic scenarios now and in the future. In light of the issues faced by CMP with their recovery rates, the Digital Forensic Archaeology team felt that they would benefit from the use of digital technologies which would be specifically selected for the Cypriot context (see Section 4 below for specific methodological details).

4. The emergence of digital archaeology

As mentioned above, forensic archaeology has developed since the mid-1990s into a recognized discipline [15]. It has been variably adopted around the world with regards to search and recovery exercises involving missing persons and other buried evidence in both legal and humanitarian contexts [16]. For the most part, methodologies continue to centre on an excavation-based approach, usually preceded by a foot search [17]. Some forensic archaeologists have embraced advances in geosciences and digital techniques from a range of disciplines. New techniques have been developed and methodologies offer the possibility to move from the macro scale to a micro scale through the use of a range of remote sensing technologies and terrestrial survey techniques [15,18,19]. Because each of these techniques detects different properties in the material being examined, the use of multiple, complementary methods is usually necessary [19,20].

Satellite imagery has been extensively tested and applied to archaeological detection problems and nowadays represents one of the most effective ways to pinpoint large multiple locations or targets across a wide area [21]. This technology is mainly based on the interaction between the light and the material. When incident radiation from the sun interacts with materials on the surface of the Earth, based on the wavelength, light is transmitted, reflected or absorbed. The recording and analysis of this interaction through multispectral sensors (UV, NIR, IR, Thermal) can provide useful hints for the identification of ground anomalies in the two dimensions [22]. Likewise, Brilis et al. [23,24] presented the applications of a range of remote sensing in environmental forensic contexts and highlighted benefits of these methods, which included aerial photography, topographic mapping, satellite imagery and Global Positioning System (GPS). The use of historical images in forensic investigation has been described by Ruffell and McKinley [25]. The authors compared recent aerial imagery and historical ones to determine the potential location of burials, a method which is now commonly used by forensic archaeologists in both domestic and international cases.

In the 3D domain, image-based and range-based techniques, such as aerial photogrammetry and LiDAR, are becoming an essential asset for forensic investigation, mainly thanks to the latest developments in sensor size, speed of data collection, accuracy and reliability of the data, and stability of the platforms (UAVs) [26,27]. The outputs of these techniques are mainly represented by (i) high-resolution Digital Surface Models (DSMs); (ii) high-resolution Digital Elevation Models (DEMs); (iii) orthophotos which can allow identifying geometrical ground anomalies and target more in-depth analysis on the ground by other means. The main benefit of these techniques is represented by the ability to delimit large areas, giving an approximate knowledge of the location of any anomalies on the ground since all maps are georeferenced to a known coordinate system. In Urbanová et al. [28], the authors explore how low-end drone technology can operate as professional crime scene equipment, and they test aerial 3D modelling techniques in the forensic context. Murray et al. [29] present a study focusing on the detection and documentation of terrestrial clandestine graves and surface remains, including of humans remains using UAVs, sensors, and automatic processing algorithms. Preliminary experiments were performed at the Forensic Anthropological Research Facility (Texas State University) using UAVs, hyperspectral imaging, thermal imaging, and Structure from Motion (SfM).

Once anomalies and features have been identified and pinpointed through desk-based assessment of remote sensing data, geophysical survey methods can be utilized to further narrow down a search area. As proven in the literature [20,30–37], geophysical methods are not capable of providing clear images of graves or identifying a body per se. Instead, these methods function by detecting differences between two or more materials, including different soil strata, other natural deposits and man-made interventions. The detection of ‘anomalies’ within the data e.g. features that are not consistent with the natural, undisturbed strata, may provide the opportunity to identify disturbances which may be *consistent with* burials (and other man-made features) based on a comparison of the size, depth and overall form of these features when compared to other information e.g. witness testimony, aerial imagery, previous investigations etc. Most practitioners agree, however, that these methods – although not as conclusive as excavation – can assist in narrowing down search areas; they can provide important details about buried features prior to excavation and, in cases where excavation is not permitted for ethical or religious reasons, they can provide a means to examine sites that would otherwise go unrecorded [19]. A wide range of geophysical methods exist and have been tested in a forensic context. Notable works include those by Watters and Hunter [38] and Schulz [33]. However, despite these developments, non-invasive approaches are still commonly absent from forensic searches involving buried remains in favour of approaches which proceed straight to excavation.

5. Materials and methods: developing digital methodologies in Cyprus

In light of recent developments in the application of non-invasive technologies - and in pursuance of CMP's goals and new strategic plan - the Digital Forensic Archaeology team developed and applied a pyramidal approach which exploited different devices mounted onto aerial and terrestrial platforms for use in Cyprus. As discussed above, in ideal scenarios, initial search methods tend to be those which can narrow down a larger search area into smaller defined units. These smaller units can be examined more closely, usually using different set of techniques.

Hence, the survey was planned based on the following steps:

- Review of the case information;
- Source background analysis (reports, geology and soil maps, map regression);
- Site reconnaissance;
- Survey planning;
- Field Survey;
- Final Report.

During 2017, a pilot research project was established which involved a series of non-invasive and non-destructive surveys in Cyprus using this methodology, with the main aim of optimizing the search strategies and time efforts involved in the locating possible graves of some of the individuals who went missing during the intercommunal fighting between Greek-Cypriots and Turkish-Cypriots in 1963 and 1974.

After an initial review and assessment of intelligence data and site reconnaissance visits, four sites were identified which were deemed suitable for aerial and geophysical survey.[4] Two sites were selected in the Greek-Cypriot sector and two in the Turkish Cypriot sector (described in Section 6). This decision was taken to serve both communities, consistent with the goals of CMP. This approach also aimed to strike a balanced relationship in the framework of the ongoing political process, which intends to lead to the reunification of the country after almost 45 years of internal division.

With regards the in-field methodology, a number of non-invasive techniques were selected. Aerial photography continues to serve as an invaluable tool in archaeology. Nowadays, close-range photogrammetry and, more recently, Structure from Motion, have also revolutionized the acquisition and 3D modelling of objects and scenes due to lightweight aerial platforms, such as Un-Manned Aerial Vehicles (UAVs), and the ability to reconstruct complex areas. UAVs currently represent a low-cost alternative to the traditional, manned aerial photogrammetry. Thanks to advances in the image-based 3D modelling domain, the accuracy and reliability of digital outputs have improved considerably.

Within the field survey stage, UAVs were first employed, coupled with image-based modelling techniques, to create Digital Elevation Models (DEM), Digital Surface Models (DSM) and high-resolution ortho-photos. Other maps and historical aerial photographs were georeferenced to this data in a Geographic Information System (GIS) within the Cypriot coordinate system. This approach provided a first assessment of surviving anomalies, both in terms of surface geometry and vegetation growth that may indicate the presence of burials.

The UAV used for the survey in Cyprus was a Spreading Wings S1000 + manufactured by DJI. It was equipped with a 3 Degree of Freedom (DoF) stabilizer gimbal and a DSLR Camera Canon Eos 5D Mark IV equipped with a 24 mm prime lens. For each of the sites examined, a flight plan was *a priori* created with the main aim to acquire digital aerial imagery and produce high-resolution DSMs and orthophotos with a Ground Sample Distance (GSD) of sub-centimetric resolution (~8 mm). A traversal and forward image overlap of 80% was chosen to achieve a correct photogrammetric reconstruction. Ground Control Points (GCPs) were placed on the ground and surveyed with a Leica RTK GPS system. The flights were split into two sessions, and lasted 30 minutes each. Images were collected in RAW file format for further optimization. An initial preprocessing was necessary to equalize the radiometric values of the data and improve the 3D image-based reconstruction.

The photogrammetric reconstruction and DEM creation were realized in Agisoft PhotoScan Software. A standard photogrammetric pipeline was used consisting of (i) image pre-processing; (ii) 2D correspondence detection; (iii) bundle adjustment; (iv) dense image matching [39].

This was followed by geophysical surveys (using Ground Penetrating Radar) of selected areas to accurately scan the subsoil, and identify and characterize potential underground targets (including potential burial sites). A GSSI SIR-3000 GPR with a 400MhZ antenna was used to analyze the case study sites. GPR can assist with the characterization of buried remains by recording reflections or attenuations of electromagnetic (radar) signals that are continuously emitted from a roving antenna [40]. These reflections or attenuations are affected by the physical properties of the subsurface and any buried features within it. These reflections are then recorded

[4] Four sites were surveyed during 2017 by Digital Forensic Archaeology team. In 2018, the three CMP members granted permission to survey three additional sites.

and visualized in two- and three-dimensional data plots that can be analysed in order to determine the presence, size and nature of buried remains. An advantage of GPR is that the signal emitted can propagate through most materials and, therefore, this method can be used over concrete and in rural areas, providing the vegetation is not too high, and there are not too many obstructions. A 400MhZ antenna offers the opportunity to record subsurface remains to a depth of between 4 and 5 m depending on the soil conditions and this was necessary given that the graves being sought likely exist at some depth below the current ground surface. The position of survey grids and other features of interest within these areas were recorded using a Leica RTK GPS.

Following the survey, the GPR data was processed using RADAN software. Various processing steps were undertaken in order to remove background noise and the air gap between the GPR and the ground surface. Data interpretation was then undertaken using the individual section profiles (generated from each individual line of data collected) and time-slices (generated when all of the individual lines of data were joined together in a 3D grid file). The fusion and visualization of the remote sensing and GPR data were then undertaken alongside more traditional means of witness interviews and excavation. Although there is no *off-of-the-shelf* digital device which allows for the identification of graves, a holistic approach which includes a wide range of methods offers the highest chance of success. These methods ensured that whole (often very large) search areas could be examined as efficiently as possible, whilst the identification of anomalies on the ground allowed the Digital Forensic Archaeology team to indicate specific areas that CMP should target during their excavations.

In this study, due to the sensitive nature of the sites and privacy issues, no information about the case study locations will be disclosed. The surveyed areas will be named (i) Site 1, (ii) Site 2, (iii) Site 3 and (iv) Site 4. Following the non-invasive approach, CMP proceeded to excavate two of the sites (1 & 2) using the methodology outlined in Section 4. In order to evaluate the successes and challenges of the non-invasive techniques, this paper will focus solely on these two sites.

6. Grave location through the combination of digital technologies: two case studies

At both sites 1 and 2, the surveys were undertaken at the request

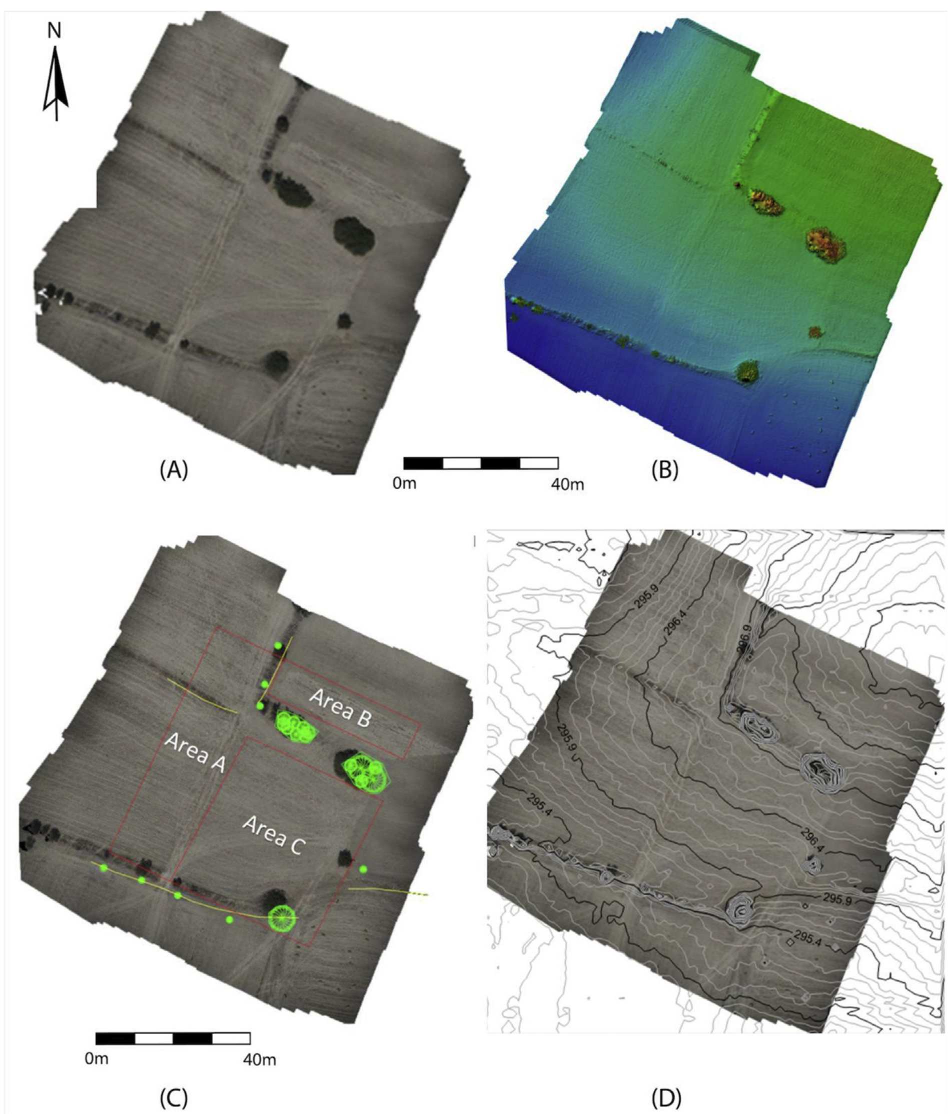

Fig. 3. Site 1, High-Resolution Orthophoto (A); Digital Surface Model (B); GPR Grids Outlines (C), Contour lines map (D) (courtesy of the Centre of Archaeology, Staffordshire University and the Cyprus Institute).

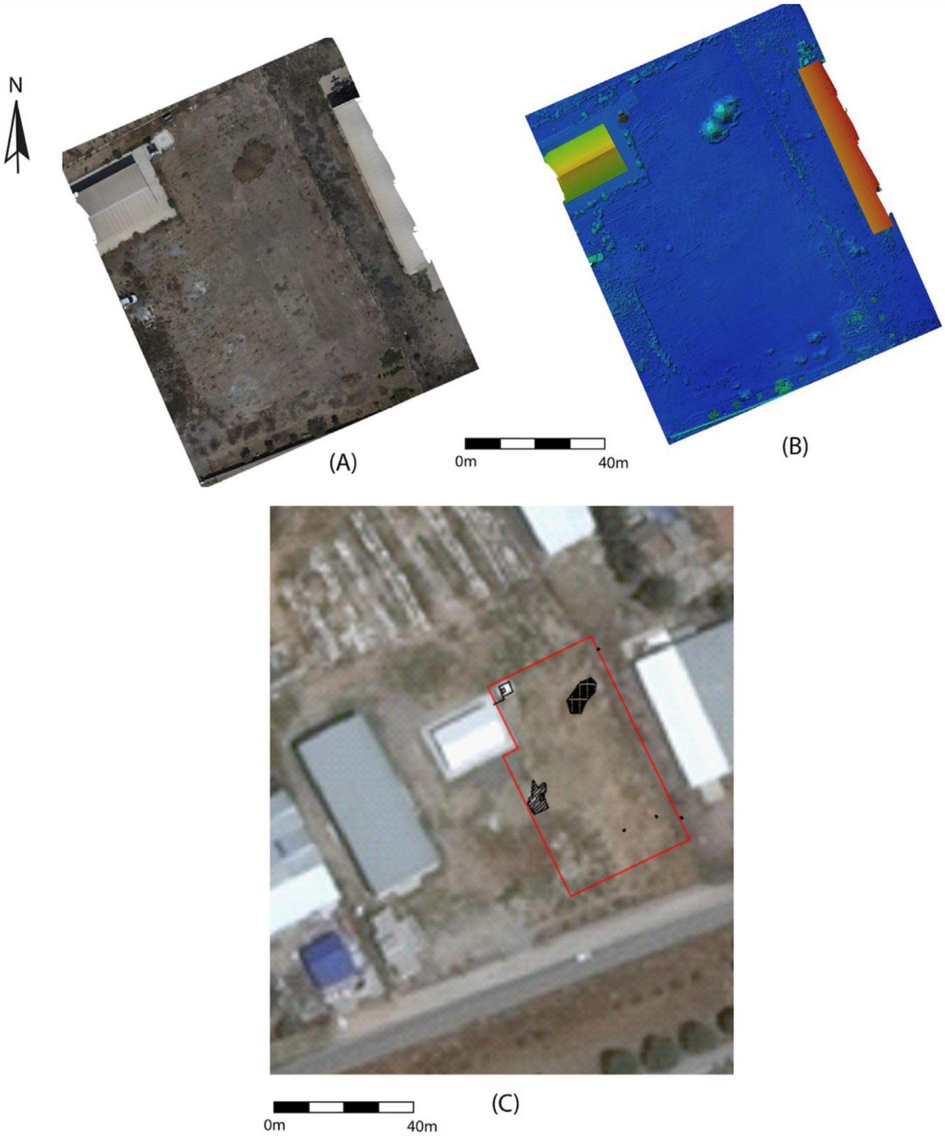

Fig. 4. Site 2, high-resolution orthophoto (A); digital surface model (B); GPR grid outline (C) (courtesy of the centre of archaeology, staffordshire university and the Cyprus institute and Google maps.).

of CMP who supervised the work. The results of the UAV surveys are shown in Fig. 3 and Fig. 4A and B. Plans displaying the locations of the GPR survey grids at Sites 1 and 2 are shown in Figs. 3C and 4C respectively. The areas that could be examined at each case study site was influenced by environmental conditions (e.g. physical obstacles, vegetation etc.). The GPR survey grids were therefore positioned to: (1) include as much of the area of interest as possible; (2) account for obstacles within the survey area, such as vegetation, structures and other obstacles. The data collection was carried out in a systematic grid formation to ensure total and accurate coverage of the area. A selection of the data plots pertinent to the discussion of the results are shown in Figs. 5–8.

During the post-processing of the GPR data, a number of surface and subsurface features were observed, and some of them are described below along with other important considerations that were highlighted to CMP team when planning their excavations of the sites.

6.1. Site 1

The intelligence information concerning the alleged deposition suggested that a group of individuals were killed before being transported to a field for burial. This field (Site 1), used today and at the time of the purported burials for cultivation activities, has a geological composition of gravels, sands and silts. The site is morphologically flat and is located in a rural area. A walkover survey of the field did not identify any human remains on the surface.

The GPR survey was conducted over three areas measuring 70×20 m (Area A), 40×11 m (Area B) and 46×40 m (Area C) respectively. The results first provided useful information about the stratigraphy of the site. Across the three surveys grids, a layer of ploughed soil existed, followed by subsoil and, at a depth of approximately 1.4 m, an undisturbed layer, which was most likely natural bedrock. After the post-processing and analysis of the time slices and maps, a number of features were identified.

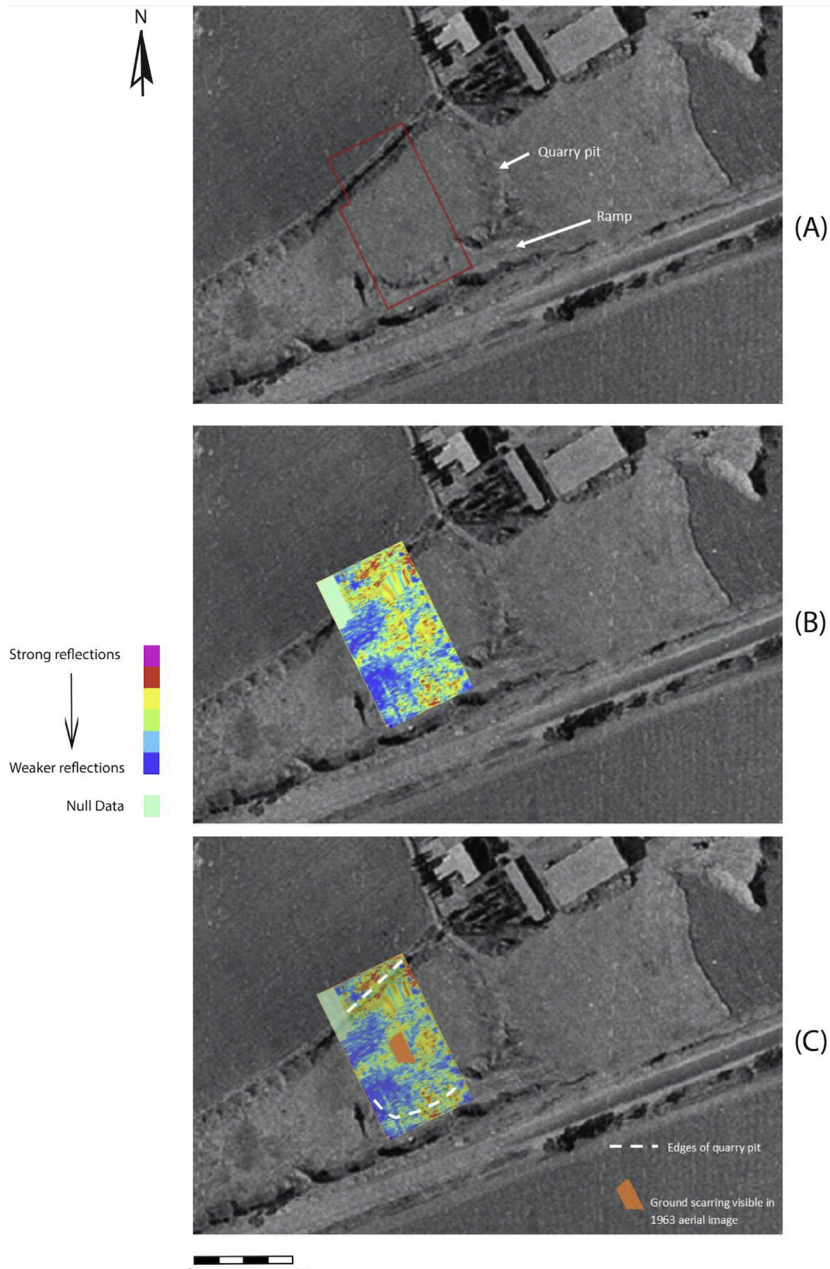

Fig. 5. Site 2, Location of the GPR grid overlaid onto a 1963 aerial photograph (A), the GPR results overlaid in the same location (B), and (1963 aerial images (C) (courtesy of the Centre of Archaeology, Staffordshire University and CMP).

In the northern part of area A, a linear feature was observed. When the GPR data was compared to the GPS data, drone data and modern satellite imagery, it became apparent that the feature likely represented an old field boundary or hedgerow. A rectilinear feature was then observed on a NNE-SSW alignment in Area C. This anomaly measured approximately 9.7 m long, 4.5 m wide and 0.65 m deep. As shown in Fig. 6, when a comparison was made with the 1963 aerial photograph of the area, it became apparent that a tree/bush (now removed) previously existed in this location.

At a depth of 0.6 m, it appeared that this feature extended in length. Thus, even though this likely represented the trace left by the removal of the bush/tree that previously existed here, excavation was still recommended in order to rule out the presence of an adjacent burial. In conclusion for Site 1, the GPR survey identified a small number of features within the survey areas. Most of the site consisted of ploughed subsoil and seemingly undisturbed bedrock. Based on the GPR results, these areas were deemed unlikely to contain human remains buried in an in situ mass grave.

6.2. Site 2

Site 2, originally a quarry, was reportedly a body deposition site of six individuals according to witnesses. In the years since the reported burials, the former quarry pit was used as a dump area for industrial and other types of waste. At this site, it was not possible to establish a useful geological pattern prior to the survey, since the undisturbed level of the cavity lay at a depth of more than 10 m. Due to limited resources and the possibility of disturbing human

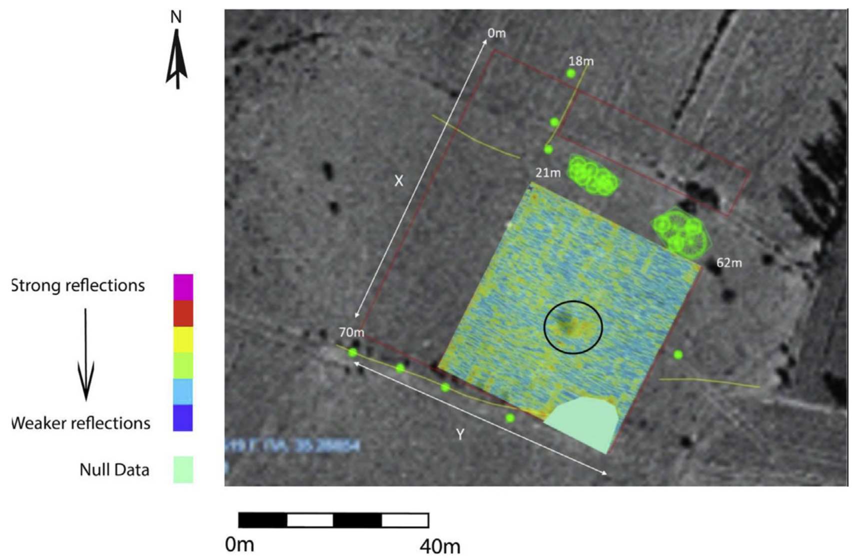

Fig. 6. Site 1, GPR data from Areas C overlaid onto a 1963 aerial image of the site highlighting the removed bush, (1963 aerial image courtesy of CMP, GPR data courtesy of the Centre of Archaeology, Staffordshire University).

remains, no coring was possible.

Walkover survey revealed that most of the area originally used as a quarry pit was covered with loose gravel with some patches of concrete or asphalt in poor condition. Uniform patches of this material visible on the surface were recorded using the RTK GPS system. Knowing the locations of above-ground features such as trees/stumps, spoil, concrete, gravel, metal etc., assisted greatly in the interpretation of the GPR data (Fig. 7).

The GPR survey – which covered an area of 65 × 38 m - revealed that buried metal was present across many parts of the survey area. However, given the shallow depths that these metal objects were observed, they likely related to more recent activity at the site. The presence of this material did result as 'noise' in the data which had the possibility to mask the presence of other features.

Most of the survey area appeared to be covered with approximately 10 cm of topsoil. In some locations, this sat underneath concrete or gravel which was visible on the surface. The subsoil layers varied within the in-depth within the pit, depending on the topography and the material used when it was infilled. Natural undisturbed soil was not recorded in the GPR results at their full extent of c. 4 m, suggesting that further man-made layers existed in the quarry pit beyond the depth of the survey.

The survey highlighted a number of additional features within the subterranean layers, some of which are described below. A linear feature was observed on a SSW-NNE alignment. This feature extended across the full width of the northern part of the survey area and likely continued in both directions beyond its parameters. When the location and orientation of this feature were compared to

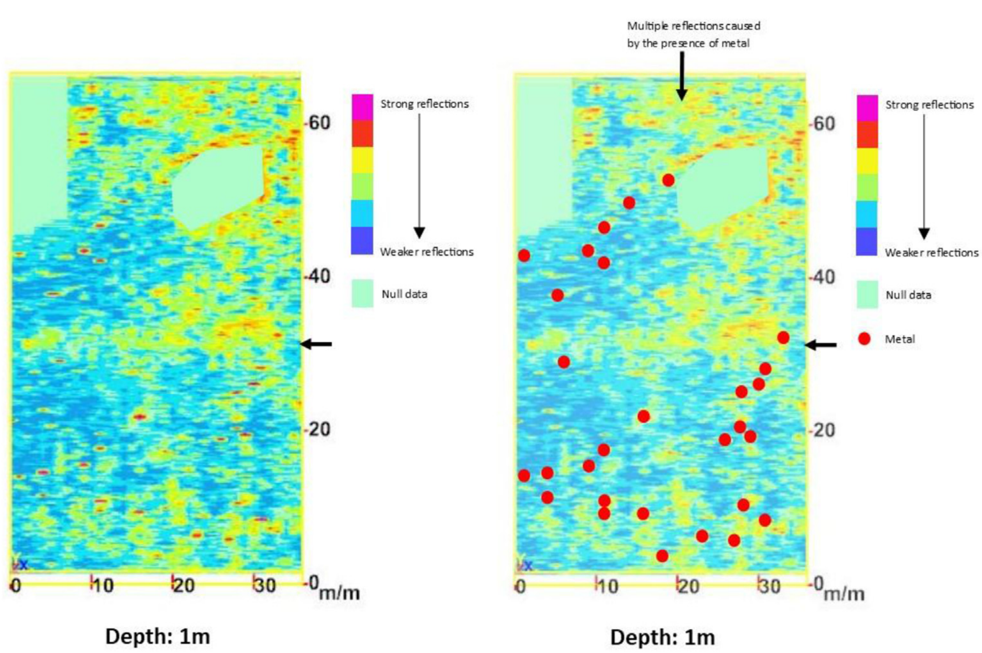

Fig. 7. Site 2, Timeslices at depth of 1 m showing some of the buried metal objects detected by the GPR (courtesy of the Centre of Archaeology, Staffordshire University).

a 1963 aerial image, it was apparent that this feature represented the northern boundary of the quarry pit within which the bodies of the victims were reportedly buried. This comparison was achieved via the georectification of the 1963 aerial image onto modern maps and UAV-generated DTMs, as well as via the georectification of the GPR results (using the GPS coordinates recorded in the field). This allowed the exact positions of features to be determined. This comparison also allowed the southern boundary of the quarry pit to be located (Fig. 5C). It also demonstrated that the east and west boundaries of the pit were situated outside the survey area. Access to them was obstructed by fences and other recent constructions, preventing further survey in these areas from taking place.

In the 1963 aerial image, an area of ground scarring was visible. When the GPR results were overlaid onto the image, it was possible to observe that this ground scarring corresponded to a feature visible through a section of the GPR profile. Here, the horizontal, compacted layer that existed across the rest of the site appeared to dip. It was deemed possible that there was something buried in this area that caused the ground to sink prior to the formation of the compacted surface above (Fig. 8A). Confirmation of the anomaly described above was also provided by the analysis of the DSM which showed a clear depression on the ground (Fig. 8B and C). Excavation of this feature was thus recommended in order to confirm its exact nature. A number of other discrete features were observed and measured within the GPR survey and these too were recommended for test-pitting by the CMP archaeologists during

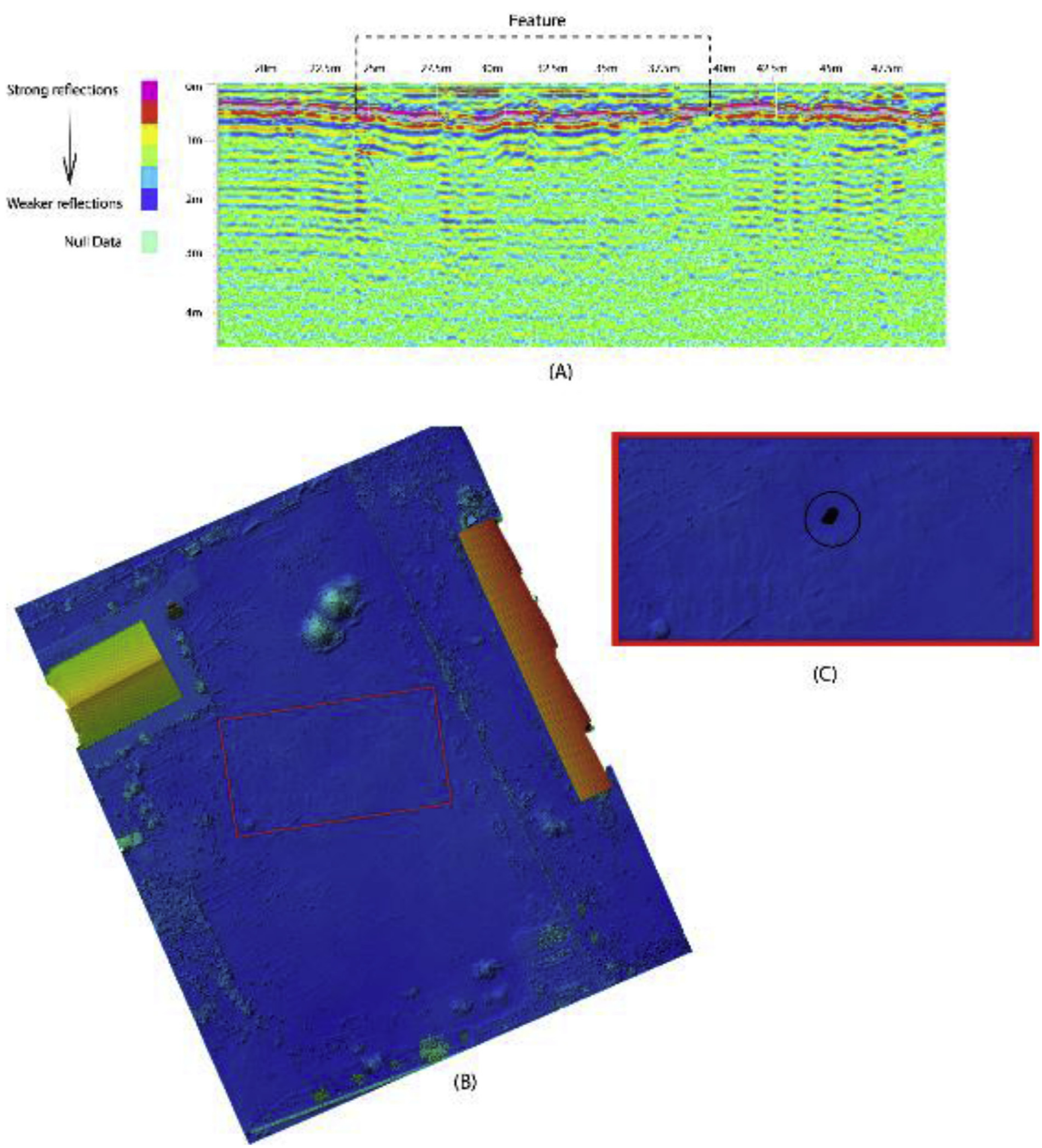

Fig. 8. Site 2, A 2D section profile of GPR data showing a feature of possible interest (A) and the corresponding anomaly within the DSM data (B and C) (courtesy of the Centre of Archaeology, Staffordshire University and the Cyprus Institute).

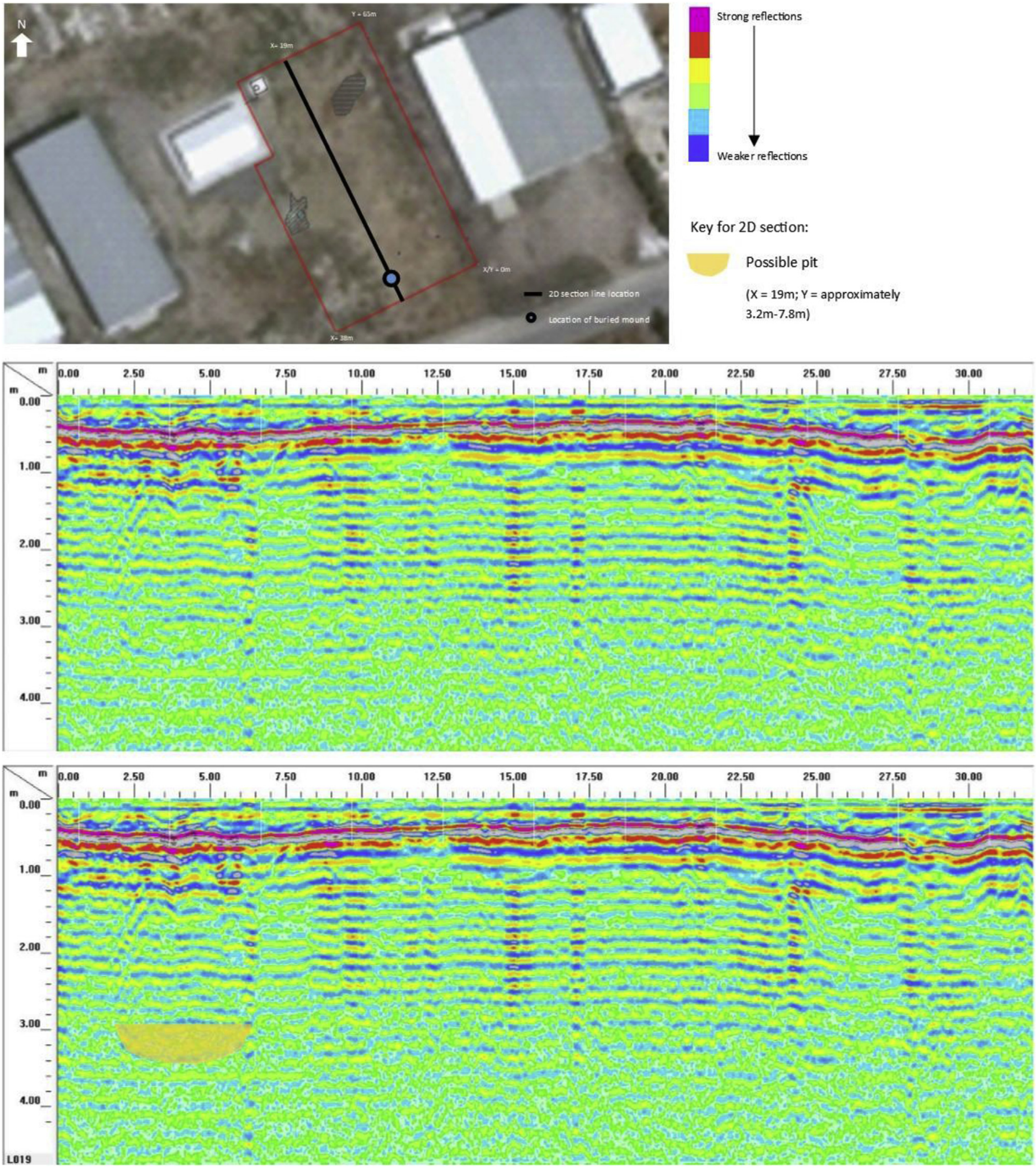

Fig. 9. Site 2, A 2D section profile of GPR data showing a feature of possible interest (marked orange in the bottom image) and its location within the survey area (top) (aerial image courtesy of Google, GPR data courtesy of the Centre of Archaeology, Staffordshire University). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the first phase of their planned excavations. These included a possible infilled pit at a depth of approximately 2.7 m on the south side and 3 m deep on the north side (Fig. 9). It measured approximately 4.6 m in length. Its width was difficult to estimate as it only appeared in one GPR survey line but, for this reason, it was likely less than 1 m wide. Features such as this needed to be further investigated by CMP as witness information suggested that the bodies were dumped into the quarry whilst it was still open, which suggests that they might be at a greater depth than some of the shallow features observed previously. A reference plot and co-ordinates were provided to CMP to aid them in locating this feature during the excavation phase.

In conclusion, the GPR and UAV survey allowed the locations of several man-made and natural landscape features to be determined. Although the survey team deemed that most of these anomalies were unlikely to be burials, several were prioritized for excavation to determine their exact nature (see section 6.3). The discovery of the exact boundaries of the former quarry pit, in which a grave was believed to have been dug, meant that phase 2 of the project (in which CMP planned to excavate the whole site) could be limited to within these boundaries. One challenge that did exist for the survey team was the lack of information concerning the depth of the burials. The range of the GPR antenna used was between 4 and 5 m, thus any burials that might have existed below this depth would not have been detected during this survey.

6.3. Excavation

After the completion of the survey and the delivery of final reports, Sites 1 and Site 2 were excavated by CMP archaeologists, initially targeting those features which were pinpointed as anomalous in the non-invasive datasets (Fig. 10 and Fig. 11). Each area was located through the use of a GPS device which used the same reference system used during the digital data collection.

At both sites, when excavated, the features identified in the GPR survey were shown to be represented by deposits and cavities filled by gravel, river pebbles and sand. Their size and composition were consistent with the ground anomalies shown on the DSM and GPR data. None of them contained any human remains or related items. Each time the excavation team encountered these ground anomalies the soil was thoroughly sieved.

When all the areas highlighted in the survey reports were fully examined, the remaining zones of both sites were excavated following the traditional CMP methodology described in Section 3. After the conclusion of the excavation, no graves were identified, ruling out the two areas as possible burial sites and confirming that the digital forensic investigation was accurate in its assessment of no anomalies beyond those identified.

7. Discussion

As early as 2004, Watters and Hunter [38] demonstrated the effectiveness of non-invasive methods for the detection of clandestine burials within both domestic contexts and mass grave scenarios. However, these techniques are still not deployed as standard practice. The main obstacle to the widespread use of remote sensing and geophysical techniques in forensic archaeological searches in particular does appear to be a reluctance by decision makers and even archaeologists to deviate from excavation-based approaches. As only excavation can provide 100% certainty regarding the presence or absence of buried remains [15], there is often a reluctance to commit to other techniques which often come with additional costs and which may just delay the inevitable e.g. the total excavation of a site. However, as will be discussed, these methods can offer complementary data that can help optimize search and recovery efforts, preserve the integrity of evidence (where it exists) and help generate comparative datasets which will aid future searches.

The case studies examined in Cyprus, which were subsequently excavated by CMP, provide valuable illustrations of the varied role of non-invasive technologies in searches for buried remains, whilst also offering the opportunity to reflect on challenges with their use. Because the technology-driven approach was then followed by the total excavation of the site by CMP according to their Standard Operating Procedures (SOPs), it is possible to comment on the effectiveness of both methodologies.

The main benefits of the GPR and DSM data in Cyprus was that they enabled the Digital Forensic Archaeology team to advise CMP about search parameters and they facilitated a phased approach to excavation. Firstly, when geographically-specific witness testimony existed about the reported location of burial – as in the case of Site 2 and the infilled quarry that existed there – the non-invasive

Fig. 10. Excavation area site 1 (courtesy of CMP).

Fig. 11. Excavation area site 2 (courtesy of CMP).

techniques offered the opportunity to locate this feature, and thus focus search and excavations within its boundaries. This limited the scale of the excavations required but it also illustrated that CMP needed to extend their search east and west into neighbouring properties in the future.

Next, the methods identified several targets within the search areas at both sites that were deemed worthy of priority-level investigation and more delicate excavation. In light of the usual machine-driven methodology followed by CMP, this offered the opportunity to ensure that features which could have plausibly been graves were approached with caution. Had human remains been present this would have undoubtedly helped to maintain the integrity of any buried remains and it would have equipped the forensic archaeologists carrying out the investigation with advance knowledge regarding, for example, the dimensions and orientation of the burial(s) [38]. By targeting these specific features first, had one of them contained the individuals being sought, CMP could have potentially saved considerable time and resources compared to a search strategy that involved excavating the entire site. Upon excavation, all anomalies were located at the same approximate observed depths and bore the same dimensions as indicated by the GPR. This confirmed that this device did not return false or unreliable readings, and provided ground-truthed data which can be referred to in future searches in Cyprus.

As already noted, after first examining the discrete features pinpointed by the non-invasive survey, CMP then proceeded to excavate the entire field at Site 1 and the quarry pit area at Site 2. The fact that this occurred also transpired to be an interesting and useful exercise as it revealed that the only disturbances existing at both sites were those defined by the GPR and DSMs and facilitated exploration beyond the depth achieved by the geophysical survey; thus, it both validated the results of the non-invasive surveys and eliminated the sites as burial locations.

In a broader sense, in the Cypriot scenario, where many hundreds of sites need to be searched, one of the main benefits represented by the holistic use of digital non-invasive technologies is the opportunity to investigate a higher number of sites. Non-invasive survey teams working ahead of the arrival of the excavation teams could implement a traffic light grading system [41], whereby individual sites and the anomalies within them are coded according to which sites should be excavated most urgently, e.g. either because they exhibit features which could be consistent with unmarked burials or because non-invasive methods could not be used effectively, thus excavation is the only option. Due to the high number of missing people spread all over the island, excavations could be planned in a more efficient manner, relying more consistently on non-invasive techniques. Likewise, the photogrammetry technologies employed as part of this study can also be redeployed during the excavation and recovery stages in order to document the site and any remains contained therein. The results presented in this paper are part of an on-going research project which will eventually include the survey and excavation of seven sites in total. To date, only two of them have been fully excavated. The remaining five reports are currently being compiled, and the site excavation by CMP is expected to happen in 2019. Hence, it is hoped that the outcomes of the archaeological process can be used to further evaluate the conclusions reached after the analysis of the non-invasive digital data.

It should be noted that digital technologies will not be effective at every site and, their use should be evaluated on a case-by-case basis. Understanding the limitations of these methods, is essential to ensure they are used most effectively. Research conducted by CMP regarding the positive identifications of graves that they have made over the fifteen years does reveal some important additional information of relevance when planning future searches in Cyprus. Of 935 bodies recovered, 822 were found in mass burials, whilst 113 were in single graves. Given their larger size, mass burials lend themselves more readily to detection from the air or using geophysical methods, and they are less likely to be entirely masked by the presence of "noise" or other anomalies present in the data than single burials. It should be noted that 76 out of 795 bodies found in open fields were present at a shallow depth ($<$ 0.3 m) due to the disturbance caused by ploughing. In such cases, and others where the ground surface has been disturbed, the use of both the UAV and geophysical surveys would be less effective in identifying body deposition locations. Hence, walkover survey coupled with the use of witness information and the analysis of aerial images remain vital steps in the search process. The described non-invasive techniques must be deployed with full consideration of case-specific circumstances and with adequate planning otherwise they might lead to unsuccessful results [42]. The success of the methods will also be influenced by factors such as the availability and precision of witness information, as well as how effectively this is communicated between the various members of the field team. Failure to select the most appropriate method(s) and to define search areas cannot only potentially create the risk of missing buried evidence, but it can also lead to a lack of trust between practitioners and a lack of confidence in new methodologies. These feelings may remain for many years and can be challenging to overcome.

Finally, traditionally archaeologists and geophysicists involved in searches for graves in a forensic setting have published results only when human remains were detected [15]. However, reflecting on searches in which no human remains were found – either because none were present or because non-invasive methods failed to detect them – is also necessary in order to evaluate the effectiveness of the methods being used. Likewise, as a few recent examples and this study in a Cypriot context have shown [16], discussions concerning what anomalies turn out to be (if not human remains) are equally useful in order to highlight, for example, common geophysical signatures or circumstances that may help or hinder investigations. The approach taken in Cyprus also involved clear discussions at each stage about the advantages and pitfalls of non-invasive techniques in order to manage CMP's expectations regarding the application of these methods. To build mutual trust between technologists, archaeologists and law enforcement, and to ensure non-invasive techniques are used appropriately, then such an approach should be integrated into methodologies as standard practice.

8. Conclusion

This paper presented a pilot research project during which non-invasive digital technologies provided support for the location of burials and mass graves in Cyprus, and for the optimization of the excavation efforts led by CMP. The contribution of the paper to address these needs is twofold. First, a holistic approach is described by coupling aerial and terrestrial methods combined with traditional forensic archaeological techniques. The proposed workflow highlighted the advantages of pinpointing specific ground features, focusing the excavation efforts to specific areas. This approach could be of benefit to numerous agencies worldwide during searches for buried human remains and other forensic evidence. Second, although the excavation did not recover any human remains, the outcome of the survey and the main benefits of the technology-driven approach allowed a mutual trust to be built between archaeologists, digital technologists, and forensic experts, whilst also testing the effectiveness of the methods employed. By developing strategies that responded to the specific needs, but also the concerns of CMP, regarding the application of technology, it is more likely that the methods used will be adopted in the long term. According to the latter, a future training programme for CMP forensic archaeologists has been suggested so that they can more fully understand the use and analysis of geophysical, aerial and terrestrial 3D modelling techniques and data, and how to deploy them during data collection at sites prior the excavation process.

Conflict of interest

Author declare no conflict of interest.

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