A 3D spatial approach to post-excavation study, as exemplified at the Agia Triada Cave, Karystos

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Abstract

Η εργασία συνοψίζει τα αποτελέσματα της προσπάθειας αναβάθμισης ενός συμβατικού ανασκαφικού αρχείου με τη χρήση τεχνολογιών Γεωγραφικών Συστημάτων Πληροφοριών (ΓΣΠ), με στόχο τη διαχείριση των δεδομένων, την υποστήριξη της στρωματογραφικής ανάλυσης και την οπτική διερεύνηση της χωρικής κατανομής των ευρημάτων στις τρεις διαστάσεις (3Δ). Το ανασκαφικό πρόγραμμα στο σπήλαιο της Αγίας Τριάδας, στη Νότια Εύβοια, λειτούργησε ως περίπτωση εφαρμογής όπου επιχειρήθηκε η ενσωμάτωση διαφόρων τύπων ανασκαφικών δεδομένων (καταχωρίσεις ανασκαφικού ημερολογίου, σχέδια, κατάλογοι ευρημάτων, φωτογραφίες) σε ένα συνεκτικό σύνολο δεδομένων για 3Δ ΓΣΠ. Ο συνδυασμός όλων των τεκμηρίων σε ένα ενιαίο ψηφιακό αρχείο συντέλεσε στην αρτιότερη διαχείριση, την πρόσβαση και την αντιπαραβολή των πληροφοριών. Η χωρική αναπαράσταση στις τρεις διαστάσεις και η οπτική διερεύνηση των δεδομένων συνέβαλε στη συγκρότηση ενός χρήσιμου αναλυτικού μέσου για την τρέχουσα μετα-ανασκαφική μελέτη που επέτρεψε την καλύτερη κατανόηση των πολύπλοκων στρωματογραφικών και ταφονομικών συνθηκών εντός του σπηλαίου. Σε αυτό το πλαίσιο, η χρήση της ψηφιακής τεχνολογίας για την αναδιάρθρωση παλαιότερων ή συμβατικών συλλογών δεδομένων σε νέα συγκρίσιμα ψηφιακά αρχεία μπορεί να συμβάλλει σημαντικά τόσο στην ενδο-ανασκαφική όσο και στην περιφερειακή αρχαιολογική έρευνα.

Introduction[1]

In recent years, advances in spatial technologies have led to the development of applications that provide new impetus for intra-site documentation. Major problems of the past such as data capture and three-dimensional (3D) spatial representation have undergone noticeable developments, allowing for the broader application of spatial technologies in excavation fieldwork.[2] Following earlier efforts in integrating Geographic Information Systems (GIS) with excavation fieldwork practices, we focused on

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2. McCoy and Ladefoged 2009.

expanding these methodologies to include the digitization of conventional excavation archives.[3] GIS are tools that combine database management and spatial representation, emphasizing visual examination and quantitative analytic techniques. In this respect, they can be used in the identification and exploration of complex spatial patterns to reveal associations that may otherwise remain undetectable.[4]

The Agia Triada Cave excavation project in southern Euboea (Fig. 1) provided an interesting opportunity to assay these methodologies in the context of cave archaeological research. Caves are bounded spaces with particular conditions which differentiate them from other archaeological sites. In relation to our project, the most significant of these conditions were: the topography of the cave and its constraints for the human use of space in the past, the confines of the excavation layout, the taphonomic conditions with respect to the frequently waterlogged environmental settings and, last but not least, the attested complexities in the stratigraphic sequence within a cave.[5]

The research project attempted to integrate several categories of data (journal entries, plans and sections, finds and samples, etc.) from the excavation of the Agia Triada Cave in Karystos into a cohesive system that would support data management, stratigraphic analysis and the visual exploration of artefact spatial patterning in 3D. This process targeted the augmentation of an essentially partly paper, partly digital, excavation archive, and its correlation with specialist data, using GIS to produce new information and aid ongoing post-excavation study. 3D data representation was emphasized, as it can provide a better understanding of the stratigraphic sequence and the spatial relationships between structures and artefact categories.

The excavation

The cave of Agia Triada is located in the vicinity of Karystos, southern Euboea (Fig. 2). The excavation has been conducted by the Ephorate of Palaeoanthropology-Speleology with the co-operation of the Southern Euboea Exploration Project, operating under the aegis of the Canadian Institute in Greece. The cave is shaped by several hundred metres of passages and chambers and contains water, mainly in the deepest parts. The site has provided the earliest thus-far-attested traces of human presence in the wider area of southern Euboea.[6] Unlike at other cave sites of the same period, only limited occupation evidence has been identified near the entrance. The main passage, a narrow, dark, steep corridor, branches after about 30 m, and two small chambers open up to the south and east. The eastern chamber, which is reachable through a second 20-m long passage, where an area of c.5 m^2 was excavated down to a depth of 2.5 m, became the focus of research between 2008 and 2010.[7]

Archaeological material dates to three main chronological periods: Late Neolithic I (LN I), Late Neolithic II (LN II)/Final Neolithic (FN), and Early Bronze Age II (EBA II).[8] As far as the latter phase is concerned, in the preliminary reports, public presentations, as well as more detailed studies organized by phase,[9] it was indicated that, within the uppermost layers and below a thin layer of stalagmitic crust (Layer 3), skeletal remains mixed with animal bones were encountered (Layer 4).[10] Within the

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3. Katsianis et al. 2008; Tsipidis et al. 2012.
4. Nigro et al. (2003) in one of the first working examples of intra-site GIS in a cave context demonstrated their efficiency in the representation and analysis of fossil, artefact and geological data.
5. See, for example, Bailey and Galanidou 2009; Karkanas 2013.
6. Mavridis, this volume; Mavridis and Tankosić 2009.
7. Mavridis and Tankosić 2009; 2012.
8. The material together with the stratigraphic sequence is under study for final publication. All results are therefore preliminary.
9. Mavridis 2014; Mavridis and Tankosić 2009; 2012; 2016a; 2016b; Mavridis et al. 2010.
10. Mavridis and Tankosić 2009; 2012; 2016a.

same layer, but just below the human and animal remains, were exceptionally large quantities of EB II pottery together with other finds. This deposit was followed by a layer rich in carbonized organic material (Layer 5b). This layer was mainly detected around the centre part of the chamber area and was circumscribed in most directions by a layer with similar composition but less evidence of burning (Layer 5a). Despite the strong indications of activities related to inhumation and mortuary rituals, further clarifications were necessary in order to establish a rigorous sequence of the events that resulted in the attested stratigraphic record.[11] The examination of potential spatial data patterning may offer a better understanding of the observed situation and enrich suggested interpretations.

Methodology

A necessary first step in every digital modelling project is the study of all available documentation, in order to identify the particularities of the excavation methodology and the recording procedure. In the case of Agia Triada's East Chamber, the excavation was undertaken in several small trenches of c.1 x 1 m, owing to the confined layout of the chamber. Control baulks were removed during the last season to reveal extended profiles of the excavation area and retrieve the remaining artefacts located within the balks.

Excavation proceeded by following and demarcating distinct cultural layers. A journal was kept with observations about each excavation context. X and Y measurements were taken manually from the sides of each trench, and a theodolite provided depth readings. Record drawings were prepared at regular intervals on graph paper by hand. These included a set of depth measurements for each surface drawn, and the location and depth of corresponding findspots were also noted. A digital camera was used to document the excavation process, whereas most finds were individually photographed *in situ*. Flotation, dating and micro-morphological samples were systematically collected to be used in the study of formation processes. All journal information was entered into a word processor and all coordinates were transcribed to a spreadsheet every evening. A digital catalogue was also employed for photos and drawings. At the end of each season, stratigraphic section drawings were sketched on graph paper using manual measurements.

The data modelling procedure and the ensuing analysis were performed on ArcGIS by ESRI, as it combines a robust database structure (Geodatabase), advanced geoprocessing tools and a working visualization environment (ArcScene) supporting spatial data investigation in 3D. During the modelling process, different programmes were also employed for editing the geometry of complex features, such as SketchUp.

Initially, it was necessary to transcribe original documentation into appropriate data structures. All information contained on paper (journal information, finds catalogues and photo lists) was digitized and stored in tables within a database, so this information could be linked to each spatial entity. Individual tables were created with information about the excavation and the section layers (Munsell colour values, texture, notes, etc.), finds (type, material, notes, etc.) and samples (contents, type). Separate tables were created for the drawings and the photographs of layers and finds that contain information about the date of creation, the subject, etc. All images were imported in a Binary Large Object Field (BLOB) within each table and can be used to display the image of each entry within the system.

The spatial data modelling procedure was initiated through the reconstruction of the chamber floor elevation prior to investigation, using data from the post-excavation topographic survey, in order

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11. See Mavridis and Tankosić 2016a.

that the context for situating the base point (datum) and the outlines of the excavation trenches could be generated (Fig. 3). Recent advances in 3D imaging technology, such as laser scanning or computer vision techniques, can be used in such situations for accurate 3D reconstructions of the chamber's internal terrain, including the ceiling relief.[12]

Next, each plan drawing was scanned, scaled and correctly positioned according to the local grid established within the cave. Depth measurements included on the drawings and in the excavation diary were used to generate Digital Terrain Models (DTMs) representing the terrain relief for each drawing. Each drawing can be draped over its corresponding DTM and visualized in 3D. Likewise, for each section drawing a Triangulated Irregular Network (TIN) structure was calculated which reproduced the vertical extent of each excavation section. Through this process, original documentation media were combined and used on a scale of 1:1 to represent the topography of a trench during the successive excavation stages and the recorded vertical stratigraphy. In both cases, plan and section drawings can be used as a background to digitize excavation material (e.g. slabs or pottery as 3D lines and stratigraphic deposits as 3D polygons) and link the material to database records.

Portable finds and samples were visualized as 3D point data on the basis of their recorded XYZ coordinates. Each point corresponded to an artefact record in the database with descriptive information (e.g. artefact type) and linked to its corresponding photos. Proportionately, point representation of flotation samples indicates the centre of the soil collection.

Using the coordinates measured at the corners and at the centre of each context, all excavation layers were modelled in 3D as multipatch objects.[13] These were also linked to records in the database containing descriptive information extracted from the journals. Despite their schematic appearance, these objects can be used effectively to depict variability summarized on layer level (e.g. soil texture values).

Consequently, the entire digitization procedure resulted in a rich spatial dataset that allows for the interactive investigation of the archaeological record within a digital surrogate of the physical excavation settings (Fig. 4).

Procedure results and data visualization

Data integration within a single cartographic background facilitates the simultaneous or selective visualization of all excavation features within their original spatial contexts, thus permitting a more interactive post-excavation investigation of the recorded evidence.

For example, the combined 3D display of drawings recording the same layer interface in separate trenches and different excavation seasons allows for their unification. 3D navigation, change of viewing angle and adjustment of focus can further support their inspection in relation to the stratigraphic sections. The ability to collate the extent of each layer with the section and plan drawings provides a direct way of assessing the success of locating and documenting the interface between different layers and allows for the timely detection of documentation inconsistencies, which in turn allows for potential bias to be taken into consideration.

The addition of further excavation data, such as the small finds recorded, facilitates their examination in their proper spatial setting and encourages the immediate visual assessment of their spatial relationships. Using definition queries, different themes can further be limited on demand to those instances that meet specific spatial, temporal and thematic constraints: e.g. display the finds of all

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12. See, for example, Puchol et al. 2013.
13. See ESRI 2008, 1: 'Multipatch: a 3D geometry used to represent the outer surface, or shell, of features that occupy a discrete area or volume in three-dimensional space'.

trenches that belong to Layer 4. The spatial variation of different attributes, such as soil Munsell colour for excavation layers and material type for finds, can subsequently be explored through typical data classification methods (Fig. 5).

On-screen selection and object identification provide direct access to descriptive information and related documentation material, such as detailed drawings or pictures (Fig. 6a). In addition, queries can be performed that select all features corresponding to certain criteria: e.g. retrieve all samples from layers with sandy soil texture. Finally, basic 3D spatial operations can be executed to calculate distance or locate intersections between entities: e.g. select all artefacts within a distance of 0.20 m from a metal object or those that intersect with Layer 3 (Fig. 6b).

All these facilities support an essential stage of visual data investigation for potential patterning that can be assessed with formal confirmatory spatial statistics. Excavation data can be approached in an inductive manner, and enhanced displays can be used to inform specialized material studies.

Post-excavation analysis

The Agia Triada 3D GIS dataset has been used to validate the preliminary interpretation of the EBA phase of the site and locate data patterns as well as topics for further investigation. An important aspect of every attempt to interpret an excavation context as an occupation or activity surface is to assess post-depositional disturbance and sediment accumulation processes. To this end, the study of the spatial characteristics of the excavated assemblage can provide important taphonomic evidence of active post-depositional processes. The definition of an occupation surface should be based on the restricted vertical concentration of artefacts, the abundance of refits, the absence of mixing or intrusions and the presence of non-random artefact distributions.[14] With regard to the EBA deposits, the interpretation of a relatively ephemeral episode of burial practices involving specific actions that left their traces in the cave, as proposed in the preliminary report,[15] seems to be substantiated by the spatial investigation of the excavation data.

The digitization of excavation features and bulk inclusions (such as slabs, layered concentrations of pottery or bones) from the plan drawings has facilitated the improved visual inspection of all excavated material. All deposits that belong to this phase are concentrated within a restricted vertical area stretching between 10 and 20 cm in the entire space. As seen in the profiles, these deposits exhibit a gentle slope from the north-west corner towards the south and the centre of the chamber. In the whole area of Layers 3 and 4, human bones are generally located higher than the pottery material, whereas organic material samples are found below the pottery (Layer 5b) and in accordance with the proposed stratification (Fig. 7). Post-depositional activity or later disturbance seems to be relatively low, as there are no posterior artefacts found in contexts that are earlier than Layer 3 and no anterior artefacts in contexts later than Layer 6.

Unlike other data types, human and animal bone material exhibits a significant degree of disarticulation and seems to be concentrated in distinct clusters found at the edges of the chamber or in between schist slabs. In this respect, horizontal or vertical movement seems relatively small and should be related to low-energy taphonomic conditions present in the cave, mainly soil settling and water-solution accumulation, which do not seem to have affected data distribution considerably.[16] Data examination indicates that although pottery underneath the slabs is attested, skeletal remains are gen-

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14. Dibble et al. 1997.
15. Mavridis and Tankosić 2009; 2012; 2016a.
16. Mavridis and Tankosić 2016a.

erally lacking. Accordingly, the orientation and linear placement of these slabs may indicate that these rocks were placed intentionally to divide the burial area into distinct zones (Fig. 8). Taking into account the fact that the upper part of the slabs and many of the bones were embedded in the stalagmitic crust, it seems that the human remains were left exposed on the surface. That being the case, the large slab located immediately in front of the chamber entrance[17] may have been placed there deliberately as an obstruction to deter interference from scavengers.[18] In any case, the completion of the skeletal assessment will provide evidence for possible refits between different areas, allowing us to establish a firmer relation between the slabs and the skeletal remains.

The best candidate for study through point-based distributions is the lithic material, which comprises chiefly obsidian blades and flakes. In total, 72 artefacts were recovered in the EBA deposits. The bulk of the material comes from Layer 4 (47 objects). As shown in Fig. 9, most material is located within a very tight vertical boundary (c.4 cm) following the pottery distribution. The largest cluster is located on the NW outskirts of the excavated area at the interface between L5a and L5b, where the presence of pottery and bones is rather low. The cluster contains artefacts belonging to both Layer 4 and Layer 5b, although this may be the result of soil settling. Smaller clusters can be discerned mostly on the outskirts of the excavation area and not in direct relation with the spatial arrangement of the skeletal material. This situation may be indicative of actions related to the deliberate spreading of the material before the inhumations.

As more information from specialized studies is integrated into the system (e.g. ceramic, palaeobotanical and skeletal analyses), a formal spatial analysis that will assess the scale of clustering intensity and second-order interactions with other material[19] may aid our understanding of the activities that took place within the cave.

Conclusion

To sum up, the integration of non-digital data in GIS can greatly enhance post-excavation study and direct the investigation of specific research questions. As can be seen from the case of Agia Triada, moving from a conventional archive to a 3D digital environment can be a complex, but also rewarding, process. 3D representation facilitates better comprehension of excavation space and artefact spatial relations. The unification of data that were recorded and stored separately allows for their better management and comparison. During this process, a series of data-recording shortcomings can also be detected and corrected, which allows for the avoidance of unnecessary bias. A series of visualization techniques involving classification, identification and querying in 3D can lead almost intuitively to different and more informed interpretations of a given dataset, which can be verified by formal spatial statistics.

It should be noted of course that GIS cannot change the way a site is excavated. They can, however, maximize the potential of the collected data for answering questions concerning human socio-spatial behaviour. In this regard, spatial technologies can provide a key mechanism in non-digital data reuse and reinvestigation, as well as data comparison between excavations distant in space or time, thus giving new impetus to intra-site and regional research.

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17. See above, Fig. 4.
18. See, for example, Dowd et al. 2006, 17.
19. See Bevan et al. 2013.

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Figures

Figure 1.
Cave location in relation to wider Karystos region. Map composition based on satellite imagery DZB1206-500031L005001 distributed by LP DAAC, USGS/EROS Center.
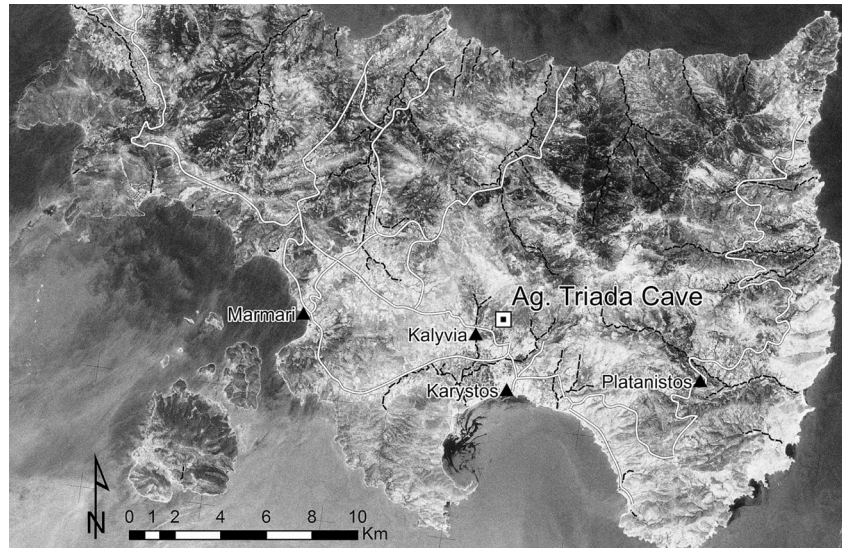

Figure 2.
The entrance, the east corridor and the east chamber of the cave.
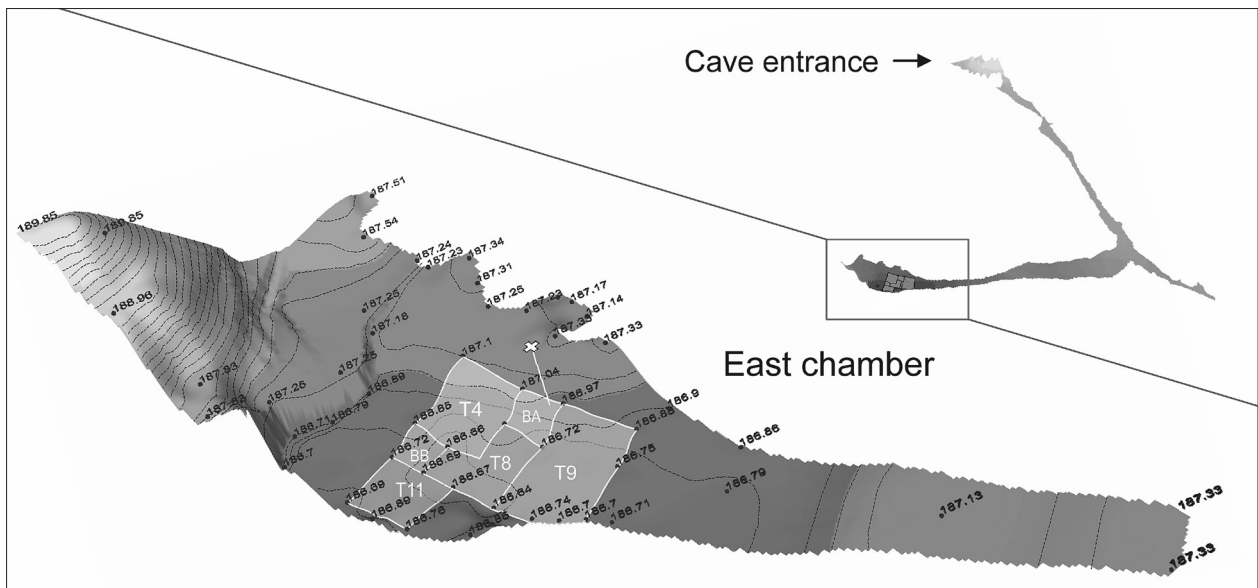

Figure 3. Cave layout and chamber floor relief showing the location of excavation trenches. Survey points by T. Chadzitheo-dorou (Ministry of Culture and Sports). The excavation base point (datum) marked in Fig. 2 is indicated with a white cross.
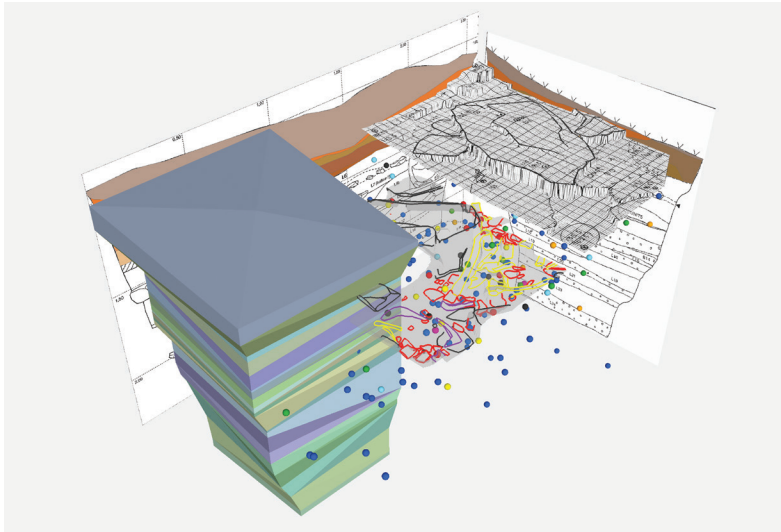
Figure 4.
Sample of digitized features in the excavated area. Excavation units are displayed as multipatch objects, finds as 3D points, stratigraphic sections and plan drawings as scaled surfaces. Individual section layers are depicted as 3D polygons. Excavation features and bulk material are depicted as 3D lines draped on top of plan surfaces.
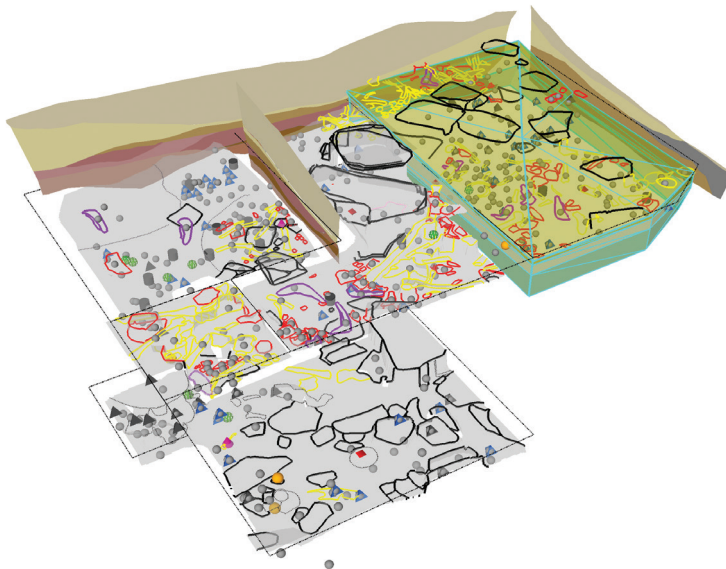

Figure 5.
Combined display of excavation data: Geometry of layers 3-5 from Trench 9 shown as transparency, Layers 1-5 as derived from the section drawings, finds from Layer 4 classified by artefact type and excavation features digitized from separate plan drawings and classified by type.
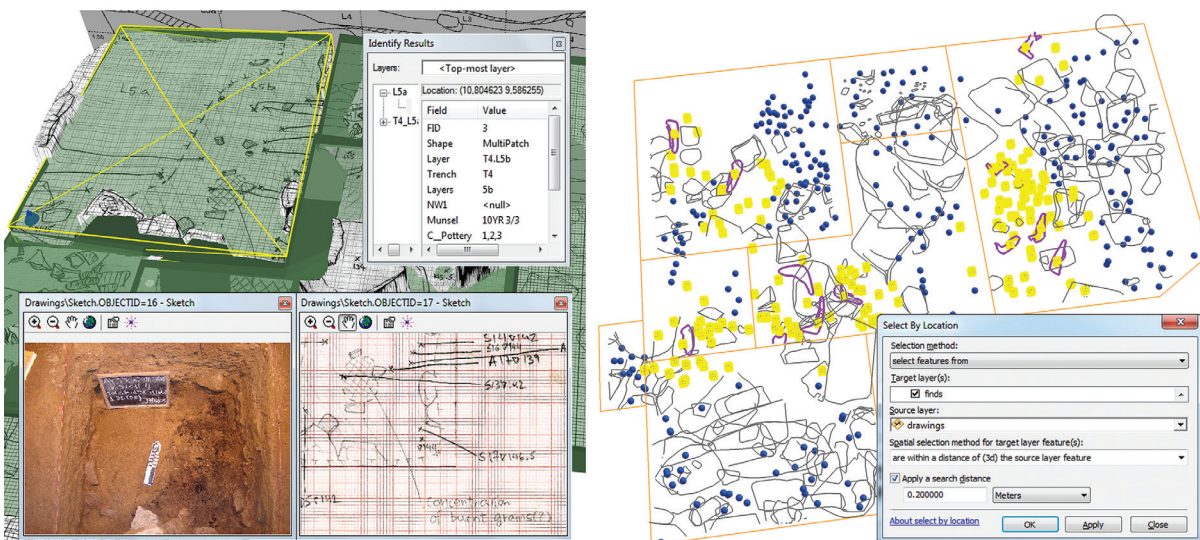

Figure 6. On-screen selection of excavation layer with attribute data and related documents (a). Selection of all finds within a 3D distance of 0.20 m from the locations of mandibles marked with thicker purple line. Slabs are indicated with a thin grey line (b).
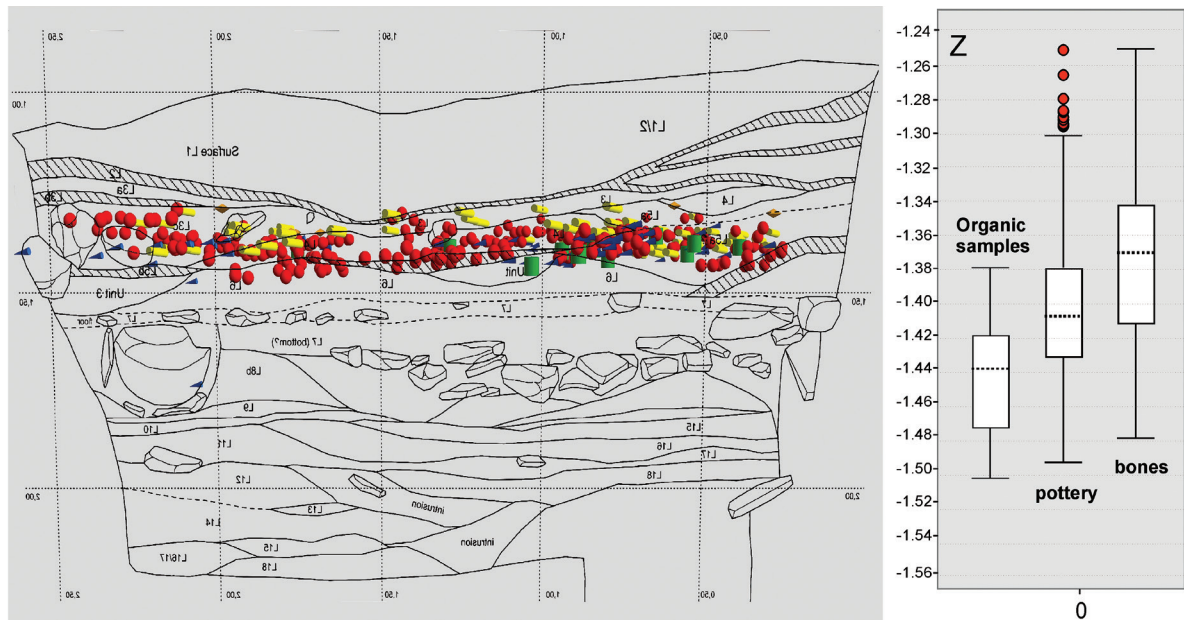
Figure 7. Vertical display of EBA material shown as points. Pottery (in red) is located largely below human skeletal material (in yellow), as is clear from the collation in the stratigraphic section (shown in transparency from N). Most samples of carbonized organic material (in green) are present at even lower levels. Boxplot to the right illustrates clustering along the Z-axis for each artefact class.
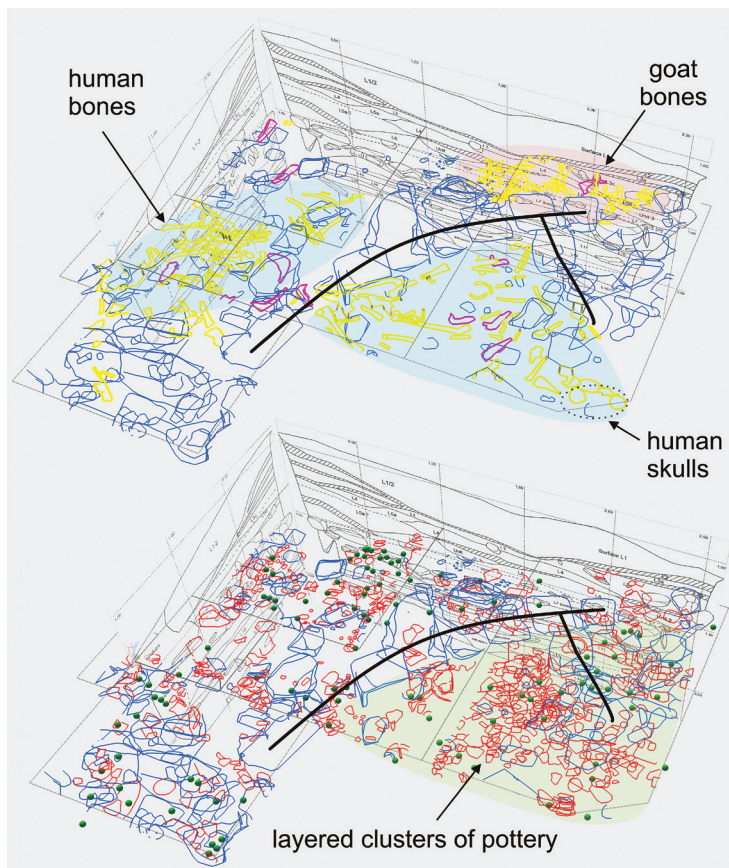

Figure 8.
Artefact distribution patterns in the entire EBA phase. Red: pottery, yellow: bones, pink: mandibles, blue: stones. Green points mark locations of individual artefacts. Spatial arrangement of slabs indicated with a thick black line.
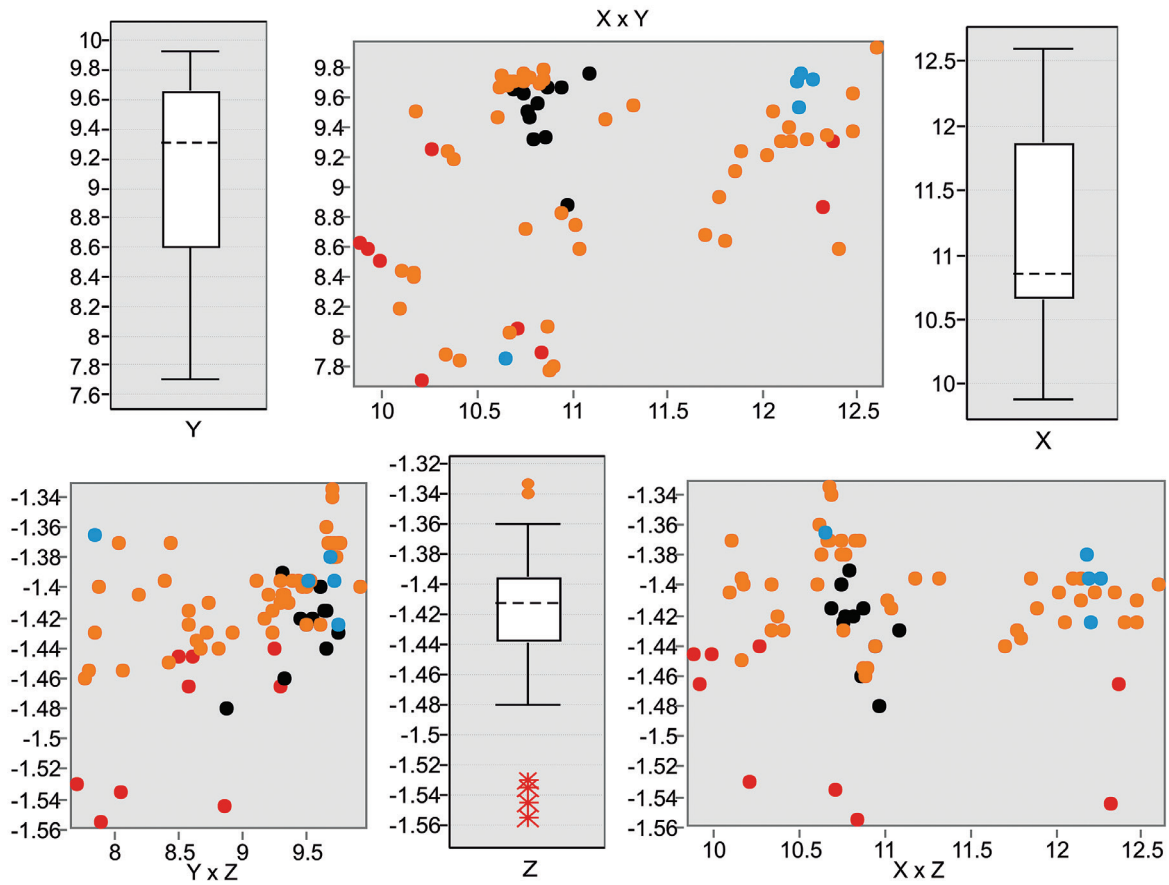
Figure 9. Cross-sections of the EBA phase along all axes (X, Y, Z) with the projection of all chipped stone and respective boxplots depicting concentrations in each axis. Artefacts are colour marked according to layer (blue: L3, orange: L4, red L5a, black L5b).