A geophysical survey at Zahrat adh-Dhra‘ 2 and its implications for Pre-Pottery Neolithic A architectural traditions in the southern Levant

Phillip C. Edwards[1], Armin Schmidt[2]

Abstract

A geophysical survey of subsurface architectural remains at the Pre-Pottery Neolithic A (PPNA) site of Zahrat adh-Dhra‘ 2 (ZAD 2), located south-east of the Dead Sea in Jordan, has provided new perspectives on building practices and settlement layout at the site. ZAD 2 was conducive to geophysical prospecting because it is a short-lived, relatively shallow occupation consisting of one major constructional episode; additionally, the site is unencumbered by later cultural remains at the surface and is grounded on deep natural sediments. Prior measured differences in magnetic susceptibility between the imported limestone used for construction and the natural calcarenitic sands incorporated as fill in the site provided the impetus to conduct the survey. A magnetometer survey was carried out using a Geoscan Research FM256 fluxgate gradiometer, and a handheld ZH (SM-30) magnetic susceptibility meter was used to record additional measurements in the field. The recording traverses were spaced 0.5 meters apart within a set-out grid measuring 40 meters by 40 meters. The results indicate that ZAD 2 is larger and architecturally more elaborate than had been envisaged and bring the site closer in scale and complexity to other regional PPNA sites, such as Dhra‘ and Wadi Faynan 16.

Keywords: Geophysical prospection, magnetometer survey, Pre-Pottery Neolithic A period, Jordan, Dead Sea, architectural practices, settlement layout.

1.0. Introduction

In this article we discuss the results and significance of a geophysical (magnetometer) survey of sub-surface architectural remains conducted at the Pre-Pottery Neolithic A (PPNA) site of Zahrat adh-Dhra‘ 2 (ZAD 2), Jordan, in December 2019 (**Figure 1**). The impetus for the project lay in encouraging conditions for geophysical investigations: ZAD 2 is a single-period site, with one phase of buildings and a limited number of superimposed occupational phases. The constructions are accessible at the surface, unencumbered by the remains of later

[1] Corresponding author: email, P.Edwards@latrobe.edu.au, (Phillip C. Edwards). Orcid number: https://orcid.org/0000-0003-4960-721X, Department of Archaeology & History, La Trobe University, Australia.

[2] Second Author: email, A.Schmidt@geodatawiz.com, (Armin Schmidt). Orcid number: https://orcid.org/0000-0002-4241-5381, GeodataWIZ, Germany.

* Received on 30/12/2020 and accepted for publication on 13/2/2021.

periods, and grounded on a large body of natural sediment without any underlying archaeological presence. Limestone was used to build the houses of the settlement, a material which is extrinsic to the immediate locale of the site and significantly different from the sandy sediments that infilled the architecture. Consequently, it was considered that systematic magnetic differences between the building materials and fill deposits might lead to detection of sub-surface architecture by geophysical survey. Geophysical prospection was initiated in Jordan on prehistoric sites some twenty years ago, from northern Jordan (Kafafi and Vieweger 2000) to regions further south, including at Pre-Pottery Neolithic sites in Wadi Fidan (Witten et al. 2000), and at the Dhra‘ PPNA site (Finlayson et al. 2003), which lies less than two kilometers distant from ZAD 2. At ZAD 2, the method promised additional information about settlement layout without recourse to destructive excavation.

1.1 Site summary and significance

Zahrat adh-Dhra‘ 2 is a low occupation mound up to five meters thick and initially estimated as 2,000 square meters in area (Edwards et al. 2001), located on a high ridge on the Dhra‘ plain, overlooking Wadi adh-Dhra‘, east of Mazra‘a village (**Figure 1**), at longitude 31°17’ N. and latitude 35°35’ E. (grid reference 460 203, Natural Resources Directory ‘Ar Rabba’ Geological Map, 3152 IV). The plain ranges in elevation from -80m to -210m, sloping down at 4.5 degrees to the west and the site lies at an altitude of between 135 and 140 meters below mean sea level. The surface of the site is littered with flint tools and groundstone plant-processing tools such as pestles, querns and cup-hole mortars. The settlement consists of one major constructional phase of curvilinear stone huts (**Figure 2**), four of which have been excavated (Structures 1, 2, 3 and 4). Within individual structures there are multiple floor phases, and a series of fixtures such as stone-paved hearths and cup-hole mortars (Edwards et al. 2004; Edwards and House 2007). The site has yielded characteristic PPNA lithic categories such as small, single-platform bladelet-cores and bladelets, retouched tools such as borers, Beit Ta‘amir sickles, Hagdud truncations, picks, tranchet axes, and edge-ground axes, and groundstone querns, pestles, vessels and cup-hole mortars (Sayej 2004). Other artefact categories include limestone plaques, an incised pebble, a fragmentary ceramic figurine, and large bone tools and smaller bone points. Structure 2 yielded three incised plaques and pebbles, decorated with very similar geometric motifs, together with two limestone blanks intended for the production of more incised pieces (Edwards 2007). The contexts of these finds, limited to only one of the four excavated dwellings, may indicate that the decorated stones functioned as symbols denoting aspects of identity.

The settlement was connected to the external world by the exchange of exotic materials such as marine Scaphopod shells, a handful of flaked obsidian artefacts from Turkey, and lozenges and small beads of green copper ore, which were probably procured from Wadi Faynan in southern Jordan. An adult human burial was found in the fill of the uppermost floor between Structures 1 and 2. Deep below Structure 1 and its underlying series of midden deposits, a child’s skull was placed

in a small pit dug into natural sediments and capped with a small dome of mud mortar.

The site has furnished support for the existence of 'pre-domestication agriculture' with evidence for the cultivation of wild barley, and possibly legumes, together with the collection of wild figs and pistachios from the highlands to the east (Meadows 2004). The most common prey animal was the ibex (*Capra* sp.), with the occasional presence of aurochs (*Bos primigenius*) and hare (*Lepus* sp.). Other fragmentary bones attest to the presence of birds and small rodents.

Zahrat adh-Dhra' 2 is a short-lived, single-period settlement, which is unusual for the PPNA period. It is dated consistently by radiocarbon samples to the late phase of the PPNA (9,600 – 9,300 BP/ 9,250 - 8,330 cal BC); a rare benefit, since most PPNA sites are, by contrast, long-lived and have ambiguously-dated, complex depositional histories. Due to these qualities, Zahrat adh-Dhra' 2 has served as a key benchmark in a chronological revision of the final stages of the PPNA and the beginnings of the Pre-Pottery Neolithic B (PPNB) period in the southern Levant (Edwards 2016; Edwards and Sayej 2007).

2.0 Geological background and geomorphological context of Zahrat adh-Dhra' 2

The following discussion focuses on three aspects of the geological context of ZAD 2: to outline the landforms at Zahrat adh-Dhra' that are germane to understanding the conformation of the site and its state of preservation, to describe the natural sediments that underlie the site, and which principally form its fill deposits, and to track the sources of limestone used to construct the settlement's architectural units.

ZAD 2 is located within a roughly triangular region of the Dhra' Plain, bordered by the Dhra' Monocline to the east, Wadi adh-Dhra' to the south and Wadi Kerak to the north. The area is known as *Zahrat adh-Dhra'* (the hinterland of Dhra') by local people, and so this term was adopted by the project. Zahrat adh-Dhra' is characterized by badlands topography, with steep-sided, flat-topped ridges bordered by deeply incised wadis (**Figure 3**). The site is truncated to the west and the south by a deep, un-named wadi channel. Its activity has evidently destroyed a significant portion of the site. The nearby channel of Wadi adh-Dhra' to the south of the site forms the northern border of an alluvial outwash fan, composed of clayey sediments and cobble to large boulders of limestone, emanating from the Jordan Valley margin of the Dead Sea Basin. On both sides of this feature are perched remnants of the large Middle Bronze Age II settlement, Zahrat adh-Dhra 1 (Falconer et al. 2001; Berelov 2006). Groundwater carried by pipeline from the 'Ain Waida' spring (Kuijt et al. 2015) at the head of Wadi adh-Dhra' is now used to irrigate the plain for agriculture. Formerly, this water fed Wadi adh-Dhra' and the outwash fan.

The flat-topped ridge underlying and surrounding ZAD 2 is composed of marine sediments of the Dana Formation, with its distinctive reddish hue. The Dana Formation, which dominates the Dhra' Plain, is composed of tilted blocks of red and

white calcarenites, interbedded with massive alluvial chert veins (Powell 1988: 93; Khalil 1992: 40-41). Basaltic dykes also intrude the Dana Formation. The deposits constitute the remnants of a Miocene sea, with the cherts representing alluvial deposition by wadis near the seashore. Near the edge of the Jordan Valley, fault blocks of Dana Formation sediments are exposed in the channel of Wadi adh-Dhra‘ as tilted blocks of red, white and black banded sediments. West of the main fault, the Dana blocks are backtilted at steep angles, and further into the plain the Dana blocks begin to level out at shallow angles of dip. Zahrat adh-Dhra‘ 2 lies near the boundary of the Dana Formation with the Lisan Formation, which occurs just to the west of the site.

The Lisan Marl Formation is a sediment body deposited by Lake Lisan, the Pleistocene precursor of the Dead Sea, between 70,000 and 11,000 years BP (Kaufman et al. 1992; Yechieli et al. 1993). Lisan sediments attain up to 60 meters in thickness on the Lisan Peninsula, bordering the Dead Sea. The lacustrine deposits consist of finely laminated marls comprised of fine alternating layers of white aragonite, deposited over summer, and dark calcite with clay detritus, laid down during winter months (Begin et al. 1974; Powell 1988; Khalil 1992).

Limestone rock does not occur in the immediate vicinity of the site but is a major constituent of the Dead Sea Basin margin, located two kilometers to the east of the site. Here the Dhra‘ Monocline is formed by steeply dipping outcrops of several limestone formations, including the Umm Rijam Chert-Limestone Formation, the Muwaqqar Chalk-Marl Formation, and the Amman Silicified Limestone. The eastern cliff margins are principally composed of the Amman Silicified Limestone. The formation is steeply tilted by tectonic activity and has shed rock to form spectacular ‘flatiron’ structures. Enormous amounts of limestone blocks and rubble litter the cliff base. So, limestone was ultimately derived from the plentiful supplies littering eastern margin of the Dhra‘ plain. However, the material did not have to be transported that far to the site, since limestone blocks have washed far out onto the Dhra‘ alluvial fan, only a few hundred meters to the south of ZAD 2.

While the main basaltic area in Jordan is the plateau of flood basalt in the north, bordering Syria (Jreisat and Yazjeen 2013), there are localized flows and plugs that also extrude in other parts of the country. Previous geological fieldwork has identified several areas that could have provided source material for basaltic artefacts found in archaeological excavations throughout Jordan (Webb in Edwards et al. 2018). Some of these basaltic provinces, centered on old shield volcanoes and their lava flows, were found within approximately 50 kilometers from ZAD 2. More pertinently, basaltic dykes intrude the local Dana Formation, and it is likely that this type of material was used for manufacturing basaltic artefacts found in the site.

3.0 Review of excavated ZAD 2 architectural remains

In order to provide some context for the description of sub-surface remains detected in the geophysical survey, it is instructive to review the range of buildings, architectural features and fittings excavated at ZAD 2 (Edwards et al. 2002; Edwards et al. 2004). An inspection of the site that was conducted before

excavations commenced revealed seventeen curvilinear wall-stubs breaking topsoil. Twelve pits resulting from clandestine excavations were also encountered, with some large groundstone artefacts, exhumed from the structures below, found in the sediment piles thrown up next to the pits (Edwards et al. 2001). These items included five cup-hole mortars made from large slabs of basalt, limestone, and sandstone. Large, dense pieces of basalt stone might produce identifiable magnetic anomalies in a geophysical survey. Judging by the frequency and distribution of these groundstone items, perhaps many of them were installed in individual housing units. This was certainly the case for Structure 2 (below). Four houses were excavated (Structures 1, 2, 3 and 4). Within individual structures there are multiple floor phases, up to four in Structures 2 and 3.

3.1 Structure 1

Structure 1 (**Figure 2**) comprises a curvilinear wall enclosing a small, semi-circular dwelling. The wall was composed of angular and oval stone fragments, set into a mud mortar. To the west of the perimeter wall, an interior floor was stepped down about 30 centimeters. Outside, to the east, a cold-puddled plaster floor formed the occupation surface at a higher level.

3.2 Structure 2

The largest house, Structure 2, is a teardrop-shaped structure opening to the east, with major axes measuring some 7 meters in length. Interior fixtures include fireplaces, a stone hearth and a single, large cup-hole mortar, the latter set into a framework of cobblestones **(Figure 4**). Excavations revealed a six-coursed, double-rowed, well-mortared limestone wall standing to a height of 0.8 meters. No foundation trench was discovered at its base, although hard mortar and numerous stones associated with the base of the wall functioned to stabilize it. Four successive floors were laid in Structure 2. For the most part, they were simple earthen surfaces, but towards the western part of the house where substantial domestic features were provided, floors were laid with cold-puddled lime plaster. In Phase 2, the boundary between the plastered and earthen surfaces was marked by a low, single-coursed partition wall of stones set into mortar - and some use of mudbrick, which is rare for the site.

An oval cuphole mortar was inset into the uppermost Phase 1 floor and framed by a surround of cobbles and pebbles. Close by at arm's length, to the north, was an oval hearth constructed of stones set in plaster. Although a standalone architectural unit, Structure 2 was evidently connected to adjacent buildings. To the south-west, a second wall abuts its perimeter wall (in Square J 22) and curves away in the opposite direction. To the north-east, Structure 2 is linked to Structure 3 through an extension of its long perimeter wall. This follows a sinuous path, returning to the south-east as Structure 3.

3.3 Structure 3

The Structure 3 walls did not cut the surface, on initial inspection of the site, but underlay a floor level lying close to it (**Figure 4**). The floor capped Structure 3's curvilinear perimeter, wall stepped down to the north, and curving east to west from Square V 22 to U 22, with the interior floored surface some 25 centimeters below the exterior one. The Structure 3 wall was dismantled in Square V 22 during excavation, showing that the stones were set into cold-puddled mortar deposits.

3.4 Structure 4

Whereas Structure 3 appears to be small, like Structure 1, Structure 4 is large, like Structure 2. Located near the northern margin of ZAD 2 where cultural sediments thin out, the perimeter wall of Structure 4 is not preserved to the same height as the other structures (**Figure 5**). However, the wall as well as the architectural space it encloses was just as substantial as the more southerly examples, judging by their large dimensions. Excavation in thirteen squares tracked a large curvilinear wall running from northwest to southeast. In Squares P 10-11 and Q 10, the wall is only one course thick with a maximum height of 0.25 meters, and a width ranging from 0.55 – 0.68 meters. The wall was associated with a cobblestone floor composed of pebbles and small stones set into a coarse plaster. Three oblong circular stone installations were positioned in Squares L/M 8 (Fs 2-4). The middle feature (F.2) consisted of limestone cobbles and fragments fixed with mortar, forming an enclosed ovoid area. Evidently, due to its low height, this wall has shed much of its masonry. The loss is also evident not only from many stones missing from the wall in Squares O 11 and O 12, but from the large quantity of tumble scattered on its southern, exterior side.

3.5 Summary of ZAD 2 architecture

In summary, the following generalisations exemplify the settlement layout and architectural character of ZAD 2:

- Architecture extends all over the preserved site area.
- The sizes of architectural units range from large to small.
- Buildings are curvilinear and include asymmetric architectural units.
- Curvilinear to linear partition walls occur within buildings, including interior walls that are tangential to perimeter walls.
- Inbuilt site furniture and facilities occur, often sub-rectangular to oblong in plan.
- Items of large groundstone equipment are fixed into floors, including basalt objects with different magnetic properties, compared to the limestone used for building.

4.0 Sediment types of Zahrat adh-Dhra‘ 2

A micromorphological analysis of the ZAD 2 sediments by Emily House (Edwards and House 2007) clarified the nature of the deposits infilling the site.

House determined that the majority of infilled sediments were grey-brown to dark orange-brown micrites (52-65%) and broken and intact foraminifera (18-35%). Micrites consist of very small calcareous particles (up to 4 micrometers) that make up lime muds or carbonates. The material was derived from the marls of the underlying Dana Formation, and possibly also from the Lisan Formation, nearby to the west. It was concluded that the majority of sediments (apart from unfired lime floors and the detritus of daily life such as charcoal, chert, animal bone and plant fragments) derived from the gradual build-up of local sediments, mainly from the Dana Formation. In terms of architecture, a key finding of the study was that there are no small limestone fragments (less than 2 centimeters) in the ZAD 2 sediments, confirming that limestone is not a constituent of the local geology at the site, and that limestone blocks were not dressed or shaped at the site.

4.1 Initial investigation of magnetic susceptibility of ZAD 2 sediments

Eight samples from the site were investigated in the laboratory for magnetic susceptibility prior to the 2019 magnetometer survey. Although all samples showed fairly low magnetic susceptibility (**Table 1**), it was established that the building material of the structural remains (for example limestone sample #23, with a volume specific magnetic susceptibility $\kappa < 0.001 \times 10^{-3}$) has a negative magnetic contrast to the in-filled sediments ($\kappa = 0.26 \times 10^{-3}$). It was anticipated that this level of contrast could produce negative magnetic anomalies of approximately -4 nano-Tesla (nT) in a magnetometer survey.

5.0 Methods of geophysical survey

The geophysical investigations were undertaken between 15 and 18 December 2019 (**Table 2**).

To complement the initial magnetic susceptibility investigations, a handheld magnetic susceptibility meter from ZH Instruments (SM-30) was used to collect data from selected stones and sediments in the field. For these measurements, the instrument was held against the stone or the local sediment and a measurement was recorded. This instrument is an active electromagnetic device that is calibrated to measure the volume specific magnetic susceptibility within a volume underneath the sensing coil of 0.05 m diameter. The depth of sensitivity is about 0.02 m and the units of measurement are 10^{-3} (SI). The results represent the magnetic susceptibility of the individual samples (or of topsoil when placed on the ground) and provide information on potential induced magnetisation that would be measured with a magnetometer. Such information can be related to human habitation of a site or to the magnetic properties of individual building materials (Clark 1990: 99-117; Aspinall et al. 2008: 27). The description of the measured samples is based on visual inspections in the field (**Table 3**).

A site grid had previously been established in a 5 meter raster and had been used for surface mapping and referencing of the excavation trenches (which were fitted into this raster) between 1999 and 2002. The corners of this site grid had been

marked with iron stakes (sharpened iron re-bars of approximately 0.4 m length) buried below ground level. Most of these markers were still in place prior to the start of the magnetometer survey; some of them were severely corroded. During the excavations of the site, strings had been stretched across the excavation trenches for the drawing of plans and sections and had been fixed to the ground with iron nails (ca. 8 cm long). Many of these nails were left in the ground after the end of the excavations and some of them were also severely corroded.

For the current geophysical survey, data grids were laid out with a size of 10 meters × 10 meters, aligned with the existing site grid and covering an overall block of 40 meters × 40 meters. The data grids were given Cartesian labels (e.g., ‘B2’) which are shown in **Figure 6**. It was found that the ‘north’ direction of this site grid lay approximately 9° west of magnetic north at the time of the geophysical survey. For the magnetometer surveys, the initial iron grid markers (re-bars) were removed as far as possible (see below) and after the end of the surveys four of them were re-inserted in their original places, forming a 20 meters × 20 meters square, so as to allow usage of the initial site grid again, should this become necessary in the future. The topographic plan of the site, incorporating all excavation outlines and surface finds, was converted to a GIS data set and used as a base map onto which the geophysical data were superimposed.

A fluxgate gradiometer survey was carried out over these data grids (**Figure 7**) since the prior magnetic susceptibility measurements of samples had suggested that a magnetometer survey might detect anomalies created by the stone structures forming the site’s habitation area (see above). Due to the difficult access to the site, lightweight equipment was required and the Geoscan Research FM256 was selected. The data were recorded walking with a single instrument along transect lines 0.5 m apart and using automatic sample triggering to record data every 0.125 m along these transects. The traverses were walked in alternative directions (i.e., bi-directional). The electronic and mechanical setup of the instrument was adjusted approximately every 3 hours.

The ferrous remains from previous field seasons (grid markers and nails) strongly impacted the data of the magnetometer measurements. Three separate magnetometer surveys were therefore necessary on the site to mitigate this problem. The first survey (V1) covered data grid C5 and showed that the anomalies produced by the iron stakes at the original 5 m grid corners and the nails around the excavation trenches were very strong, masking the sought-after anomalies from the stone structures. By using the fluxgate gradiometer in continuous mode as an ‘iron detector’, a number of these ferrous objects were located and removed with a trowel. A second survey was then undertaken (V2) covering nine of the data grids (B5 to D3). After analysing these data many very strong ferrous anomalies were still apparent. These were marked on a site map and the fluxgate gradiometer was again used to find the exact location of these anomalies so that they could be removed. Some of the iron stakes had corroded so severely that even after their removal a considerable amount of decomposed metal flakes remained in the ground, giving rise to magnetic anomalies. Some stakes could simply not be found and their measured anomaly seemed to have originated entirely

from corrosion flakes. Nevertheless, nearly all of the 5 m markers were removed. It was more difficult to remove the many nails that were left during the excavations, especially those that were inserted into the vertical sections of the trenches. In many instances they could not be found by shallow digging with a trowel (to a maximum depth of 0.3 m). The final data, collected after this clearance (V3), still show strong anomalies around the excavation trenches caused by these nails. **Figure 8** displays the numerical difference between data from surveys V2 and V3, highlighting the anomalies that were removed during this clearing operation.

5.2 Processing

Data were downloaded and processed using *Geoplot V4*, initially levelling the transects with Zero Median Traverse. Due to the uneven terrain and the large number of stones on the surface, the recording speed was not always constant, resulting in small staggering/shearing in the data caused by slight shifts in the forward and reverse direction. This effect was found to be more pronounced in the data grids that were the most difficult to walk. To remove these effects, 'destaggering' processing was applied to several data grids individually (see **Table 4**). All the processed data grids were then assembled into an overall 'composite' (Schmidt et al. 2015). Finally, to produce a smoother data plot, data were interpolated between traverses resulting in a 0.125 m × 0.25 m data raster. Interpolation consists of estimating values between readings and inserting these new data into the data set. The resulting data look less 'pixelated' and more aesthetically pleasing. Since the process can produce 'halos' around singular readings it was used sparingly and was limited to improving the inter-line resolution from 0.5 m to 0.25 m. For this task the Geoplot interpolation function sinc(x)=sin(x)/x (Scollar et al. 1990) was used. **Table 4** lists all the processing steps used, indicating also the number of the respective data grids as shown in **Figure 6**.

5.3 Methods of data presentation

The geophysics data were converted to greyscale images, clipping the overall data range between the 5 and 95 percentiles, and presenting low as white and high as black. All data and georeferenced images were integrated in *QGIS*, which is a GIS package available as an Open-Source download. It allows the integration of raster and vector data and produces high quality maps. GIS was also used to incorporate the site plan, which was georeferenced to the local coordinates.

6.0 Results

This results section commences with a discussion of handheld magnetic susceptibility surface investigations of the site constituents.

6.1 Magnetic susceptibility

The results from the handheld magnetic susceptibility surface investigations (**Table 3**) demonstrate that data fall into three distinct groups:

1. Basaltic materials with dark grey colour and slightly porous surface. Of particular interest is a large basaltic cuphole mortar. For this group of materials, κ lies between 4.4 and 24.5 × 10^{-3}.

2. Soils and fill of slightly higher magnetic susceptibility than those samples of site deposits already investigated prior to the survey (see above, **Table 1**), with κ lying between 0.24 and 0.38 × 10^{-3}.

3. Limestone fragments, similar to those used in the walls of the excavated buildings, with κ between -0.01 and +0.02 × 10^{-3}.

These measurements confirmed that building remains can exhibit a small negative magnetic contrast against the site's sediments, while basaltic stones may create a marked positive contrast.

6.2 Fluxgate gradiometer survey

Measurements made with a FM256 fluxgate gradiometer represent buried features that exhibit a magnetic susceptibility contrast or a contrast in remanent magnetisation. The instrument contains two fluxgate sensors positioned vertically, one above the other. In first approximation, the upper sensor mainly detects variations in the earth's magnetic field due to geological structures and diurnal variations, while the lower sensor *in addition* detects variations due to features buried at shallow depth. The instrument records the difference between these upper and lower measurements, which becomes the gradiometer readout, expressed in nano-Tesla (nT). As the two sensors are 0.5 meters apart and the buried features are at a similar depth this gradiometer measurement is not an approximation for the magnetic field's gradient. For the sensors to work together correctly they must be aligned as carefully as possible. Otherwise, the instrument readings have a slight directional dependence, which can lead to errors on surveys walked bi-directionally. The instrument should therefore be adjusted regularly. For a more detailed discussion of the techniques, see Scollar and colleagues (1990: 422-516, 1990: 64-98) or Aspinall and colleagues (2008: 34-41). Fluxgate gradiometer surveys are most effective when searching for areas of high magnetic enhancement, such as burnt areas, cut features like ditches and pits that are filled with magnetic topsoil, stones embedded in a highly magnetic soil, or metallic objects. If the data quality is sufficient then weak magnetic anomalies can also be identified.

The results of the magnetometer survey are shown in **Figure 7,** and **Figure 9** shows the data overlaid with an interpretation diagram, highlighting positive (dark) and negative (light) anomalies. **Figure 10** and **Figure 11** show the magnetometer interpretations together with the prior recording of excavation results and surface finds. On **Figure 11** the shadings represent the different strengths of anomalies. For the interpretation, the magnetometer anomalies are categorized in analogy with the magnetic susceptibility results (see above): weak negative anomalies and pronounced positive anomalies. The very strong bipolar magnetic anomalies seen in the data (positive directly next to negative, **Figure 7**) are caused by ferrous debris (nails and corrosion flakes from the grid stakes; see above). As this is not relevant

for the interpretation of the archaeological features from this site it was considered to be 'noise' and therefore excluded from the interpretation (Schmidt et al. 2020).

While the positive anomalies could easily be delineated with polygonal outlines for the interpretation diagram, this was considerably more difficult for the weak negative anomalies. As their magnetic contrast was very low and their width fairly narrow (only ca. 0.2-0.3 m) joining separate small data areas into individual anomalies required informed judgement. To document this subjective stage of data interpretation (Schmidt 2019) the authors' level of confidence in the interpretation of each magnetic anomaly is shown in **Figure 12** (low, medium, high). This is useful for the subsequent archaeological analysis of magnetic anomalies.

The negative anomalies have strengths of -1 to -2 nanotesla (nT) and are probably caused by limestone building blocks in the soil. Based on the magnetic susceptibility measurements and the size of the excavated building foundations a burial depth of approximately 0.2 meters can be inferred, which is compatible with the excavation results. Variations in the strength of these anomalies (**Figure 11**) can occur for different reasons. Weaker values may be caused by deeper features, but this is difficult to ascertain from the data alone, due to the limited definition of the anomalies. Assuming that the magnetic susceptibility of the sediments and deposits is fairly uniform across the site, weaker anomalies may also be the result of thinner wall structures that incorporate less building material. The positive anomalies have strengths of +1 to +4 nT compatible with large basaltic stones, lying at a burial depth of 0.2 to 0.4 m. The variation of anomaly strength (**Figure 11**) may again reflect burial depth, or it may be a result of variations in the magnetic susceptibility, as determined by the handheld magnetic susceptibility measurements (**Table 3**). On balance, the spatial size of the positive anomalies is probably a fair reflection of the size of the buried stones.

When combining negative magnetic anomalies with results from the excavations and the mapping of surface structures (**Figure 10**) some overlaps as well as some alignments and connections become apparent. The strong positive magnetic anomalies (**Figure 10**), attributed to basaltic stones, do not show any obvious clustering. However, they are mostly associated with the building structures, but not with the actual foundations of their walls (the weakly negative anomalies). It is therefore likely that these stones were specifically brought to the site not for building purposes, but for other reasons, for example because they are considerably stronger than the locally available limestone. Querns and cuphole mortars, for instance, would require such harder material.

7.0 Conclusions

The geophysical survey reported on here has augmented our knowledge of architectural practices and settlement layout at Zahrat adh-Dhra' 2 and it has also drawn the site closer in scale and organisation to some of its regional counterparts such as Dhra', situated a short distance away, and Wadi Faynan 16, further to the south.

- Buildings were encountered in all excavated areas, suggesting that architecture is more or less ubiquitous across the site. The geophysical survey has corroborated this finding, demonstrating that the site area is composed of a consistently populous series of curvilinear structures.
- It appears that buildings are often asymmetrically curvilinear, or composed of a series of long, arcing walls that interleave to a certain extent, rather than forming simple, closed circles or ovals.
- The small oblong areas of high magnetic anomalies dotted throughout the site may be understood as the provision of residential structures with a large cup-hole mortar or groundstone item, of the type found in Structure 2, made of slabs of basaltic stone.
- Cultural sediment feathers out towards the well-preserved northern and eastern margins of the site, but the magnetometer survey shows that wall stubs continue to the limit of the settlement in these areas. On the other hand, architecture is more densely agglomerated towards the southern margin of the site where sediments are thickest. The truncation of Structure 1 by the westerly cliff-line indicated that the site has been diminished by erosion (**Figure 13**) and depth of sediment increases from 0.25 meters at Structure 4 in the northern sector to 0.97 meters at Structure 2 to its south, and up to 1.55 meters at Structure 1, lying to the south-west of Structure 2. The thickening of the sediments in the south and the denser architectural traces there indicate that a significant area of the site has been washed away. A previous estimate for the areal extent of Zahrat adh-Dhra‘ 2 was around 2000 square meters; that being simply an estimate of the preserved portion of the site. The recent survey indicates that the settlement was originally at least twice as big as that and that it attained a size approaching half a hectare.
- A larger size estimation for Zahrat adh-Dhra‘ 2 indicates that the site was more substantial than previously estimated, and so brings it further into line with the establishments at Dhra‘ and Wadi Faynan 16.
- At the north-eastern margin of the site, the magnetometer evidence indicates the presence of a large complex structure with curvilinear and straight wall segments. To understand these shapes better it is useful to show them in juxtaposition to excavation results from Wadi Faynan 16 (**Figure 14**). This finding indicates that Zahrat adh-Dhra‘ 2 also features a series of small (e.g., Structure 1) and large buildings; that the large buildings are as large as those of other key sites in the region, and that some of the Zahrat adh-Dhra‘ 2 buildings may have been of the same order of complexity as found elsewhere.
- Some buildings seem to include straight partition walls, emphasizing the limited evidence for this practice known from the excavation of Structure 2. Their inclusion facilitated the development of buildings with more complex internal arrangements; such as occur in the local regions either as rectilinear partitions or divisions as at Wadi Faynan 16 (Mithen et al. 2011; Mithen et al. 2018), or rectilinear arrangements of support features designed to support beams, as at Dhra‘ (Kuijt and Finlayson 2009). Further afield, Jerf al-Ahmar in north Syria gives the

clearest evidence that the addition of straight internal walls to round buildings furthered the transition from curvilinear to rectilinear architecture (Stordeur 2015). Notably, ZAD 2 is a late PPNA site, corresponding to the periods in the north called PPNA-PPNB transition, or into the Early PPNB (Stordeur and Abbes 2002).

- The magnetometer survey undertaken at Zahrat adh-Dhra‘ 2 has modified our understanding of the site. And last, but certainly not least, the survey has pointed directly to the places needing to be excavated in the future to reveal more of the settlement's complexity.

Acknowledgments:

Thanks are due to the White Levy Fund for supporting this project, to the Department of Antiquities of Jordan for permitting the work, to our team members Muhammad al-Tarawneh and Rifat Rahmi for their assistance, and to Bill Finlayson and colleagues for permission to present the plan of Wadi Faynan 16 shown in Figure 14.

Tables

Table 1: Overview of magnetic susceptibility measurements

Sample	*Description*	*Magnetic Volume Susceptibility [10^{-3}]*
1	Deposit from Structure 1	0.260
2	Deposit from Structure 2	0.167
3	Deposit from Structure 3	0.075
4	Deposit from Structure 3	0.071
5	Deposit from Structure 3	0.028
21	Red calcarenite, natural sediment on which the site is located	0.015
22	White calcarenite, natural sediment on which the site is located	0.009
23	Limestone sample used in buildings	0.000

Table 2: Magnetometer survey at ZAD 2.

Survey technique	**Magnetometer**
Instrumentation	FM256 fluxgate gradiometer, from Gesocan Research
Reasons for choice of survey technique	Magnetic susceptibility contrast had been established
Date	15-18 Dec 2019
Area surveyed	0.13 ha (13 data grids)
Method of coverage	gridded data
Traverse separation	0.5 m
Reading interval	0.125 m
Effective spatial resolution	0.33 m
Sampling position	Centre of grid cells
Data grid size	10 m× 10 m@0.125 m×0.50 m
Survey direction of first traverse	E
Line sequence	Bi-directional (i.e. zigzag)
Magnetic north	Y East of North: -9 degrees
Instrument drift	not recorded

Table 3: Magnetic susceptibility of sediments and stones. Three distinct groups of anomaly strengths are highlighted.

Item ID	Description	Magnetic Volume Susceptibility [10^{-3}]
3	Dark brown rock fragment	24.500
2	Dark brown rock fragment	14.400
5	Basaltic grey rock fragment	8.580
6	Large basaltic cuphole mortar	6.530
4	Brown-grey rock fragment, basaltic on broken face	4.390
13	Red stone	2.190
1	Soil	0.378
18	Soil	0.243
7	Reddish brown fragment	0.102
9	Grey? basaltic rock	0.064
19	Light terracotta stone	0.050
17	?	0.033
12	Reddish/grey stone	0.020
14	Light grey stone	0.019
16	Brown stone	0.004
20	Light stone	0.003
15	Limestone piece	0.002
10	Limestone piece	-0.003
8	Red mudstone	-0.009
11	Limestone piece	-0.011

Table 4: Data processing steps.

Zero M Trav., Grid=All LMS=On ZM=Median - Thresholds not applied
Destagger Grid C5, X dir, Shift= 5 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid D5, X dir, Shift= 2 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid D4, X dir, Shift= 8 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid C3, X dir, Shift= 1 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid D3, X dir, Shift= 6 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid B5, X dir, Shift= 4 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid B4, X dir, Shift= 3 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid B3, X dir, Shift= 2 - Line Pattern - 2 - 4 - 6 - 8
Destagger Grid B2, X dir, Shift= 1 - Line Pattern - 2 - 4 - 6 - 8
Interpolate Y, Expand - SinX/X, x2

Figures

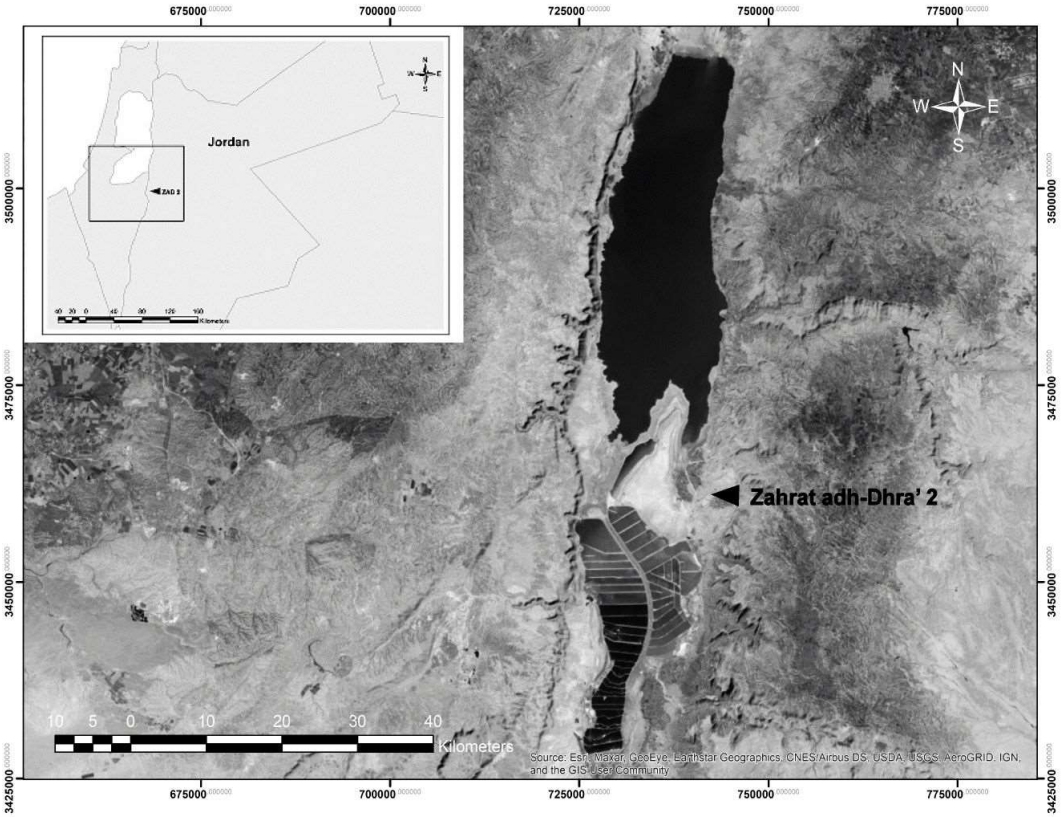

Figure 1. Location of ZAD 2, south-east of the Dead Sea in Jordan.

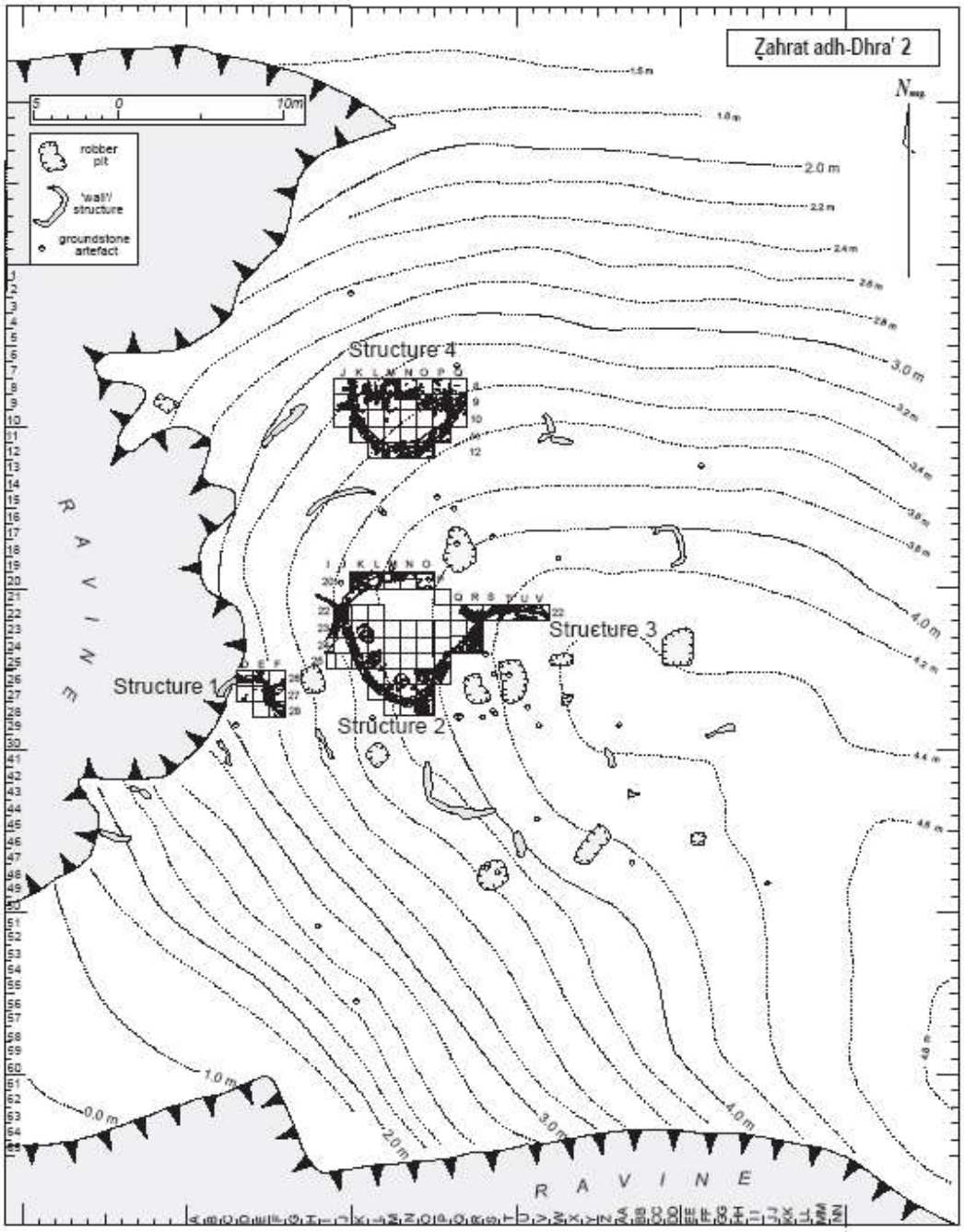

Figure 2. Plan of ZAD 2 after excavations, indicating exposed architectural remains of Structures 1, 2, 3 & 4.

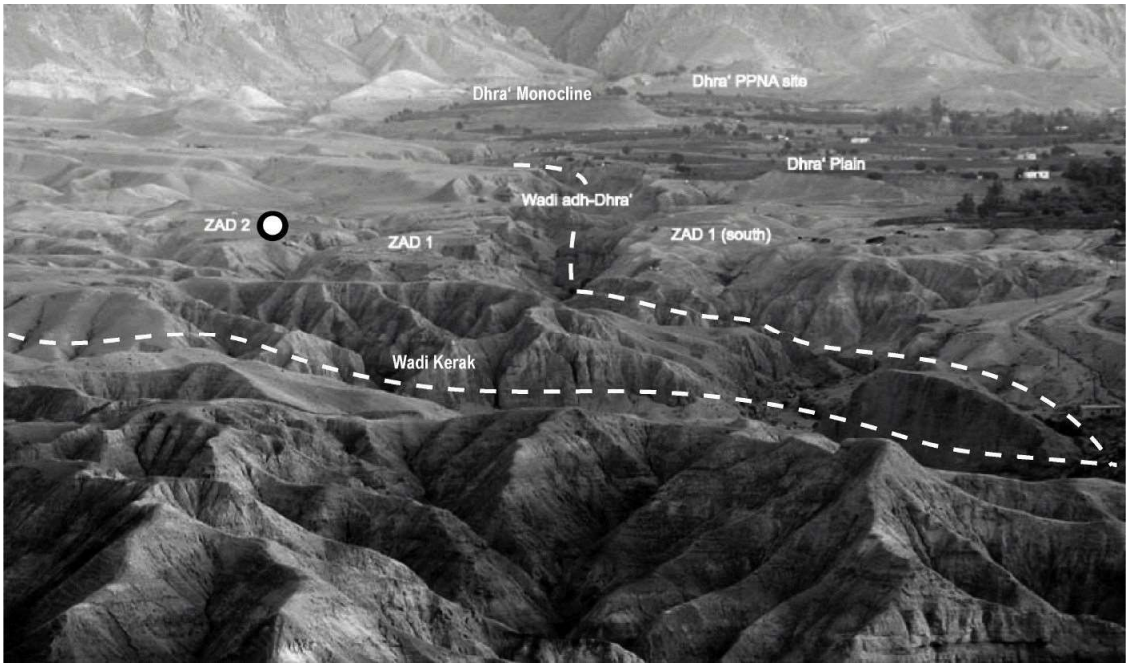

Figure 3. Position of ZAD 2 amidst the badlands terrain of Zahrat adh-Dhra‘.

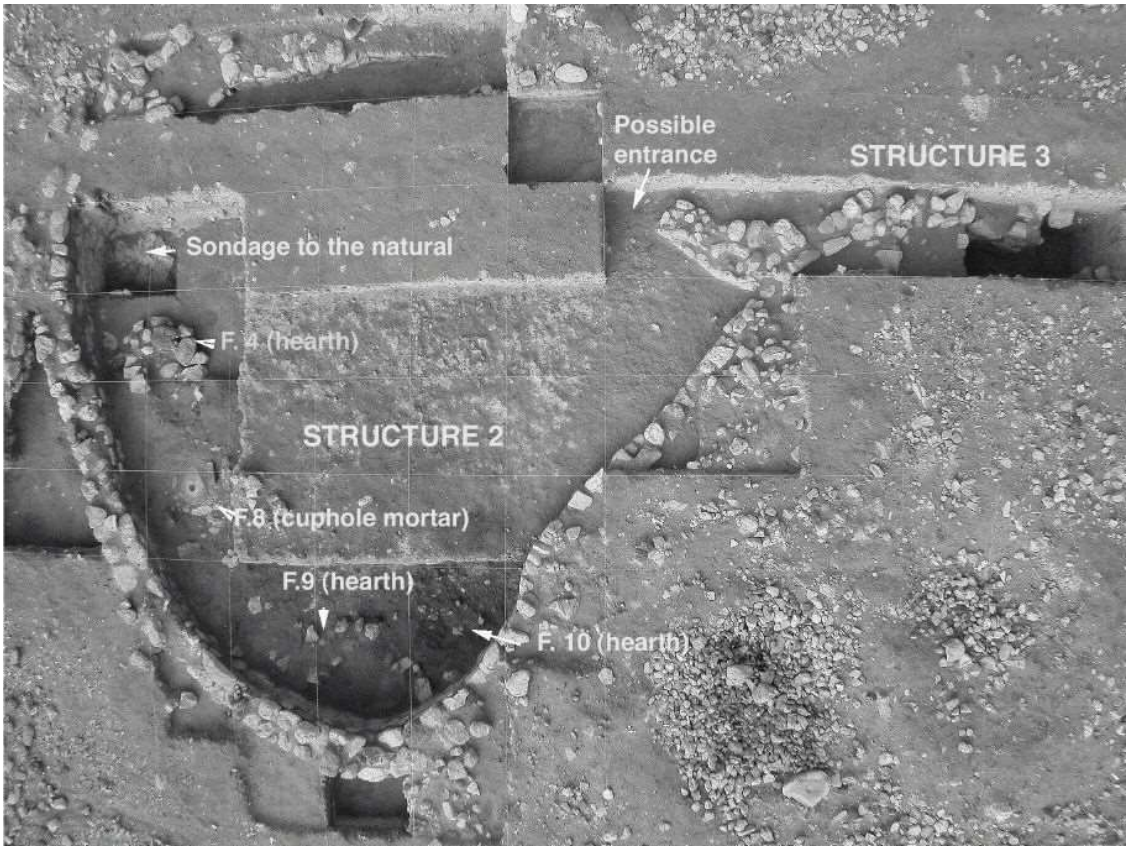

Figure 4. Aerial view of Structures 2 and 3.

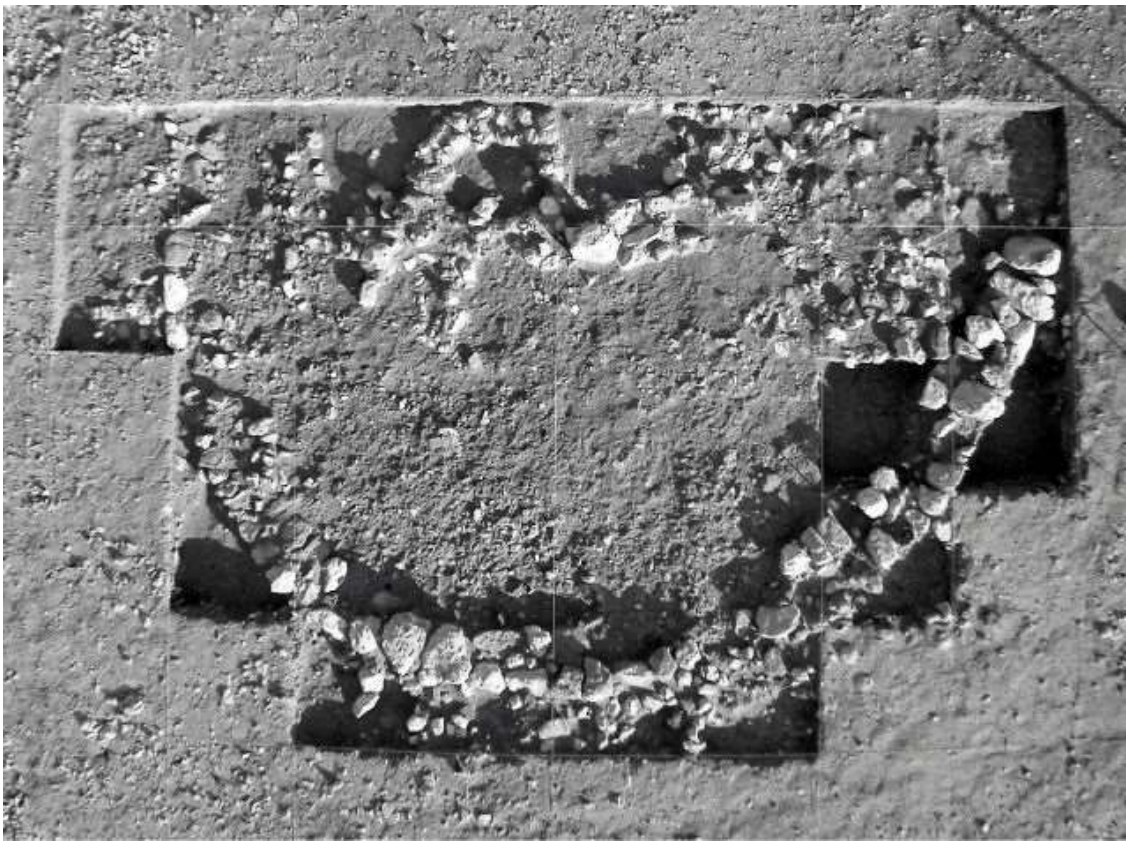

Figure 5. Aerial view of Structure 4.

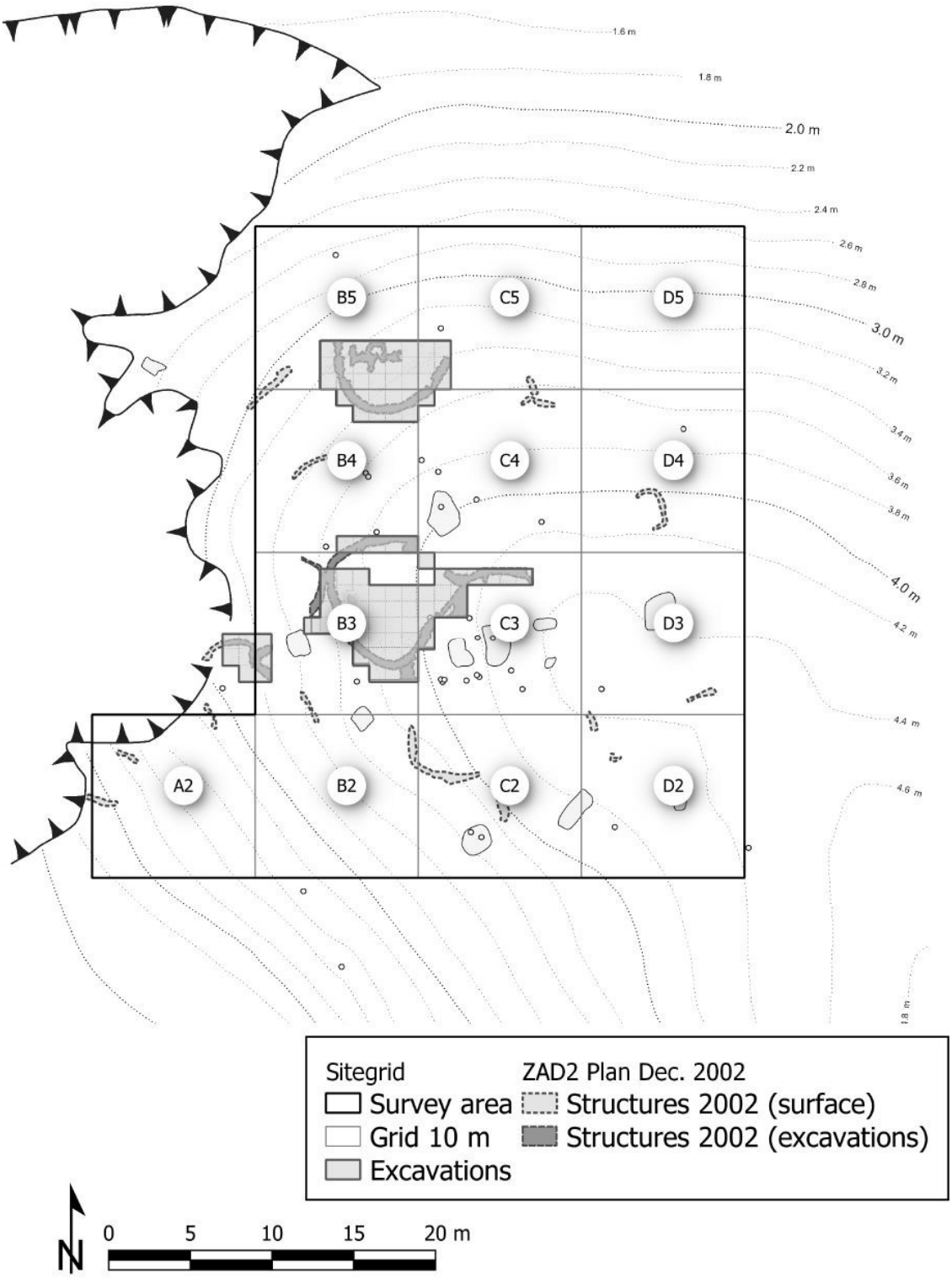

Figure 6. Magnetometer survey area and layout of data grids.

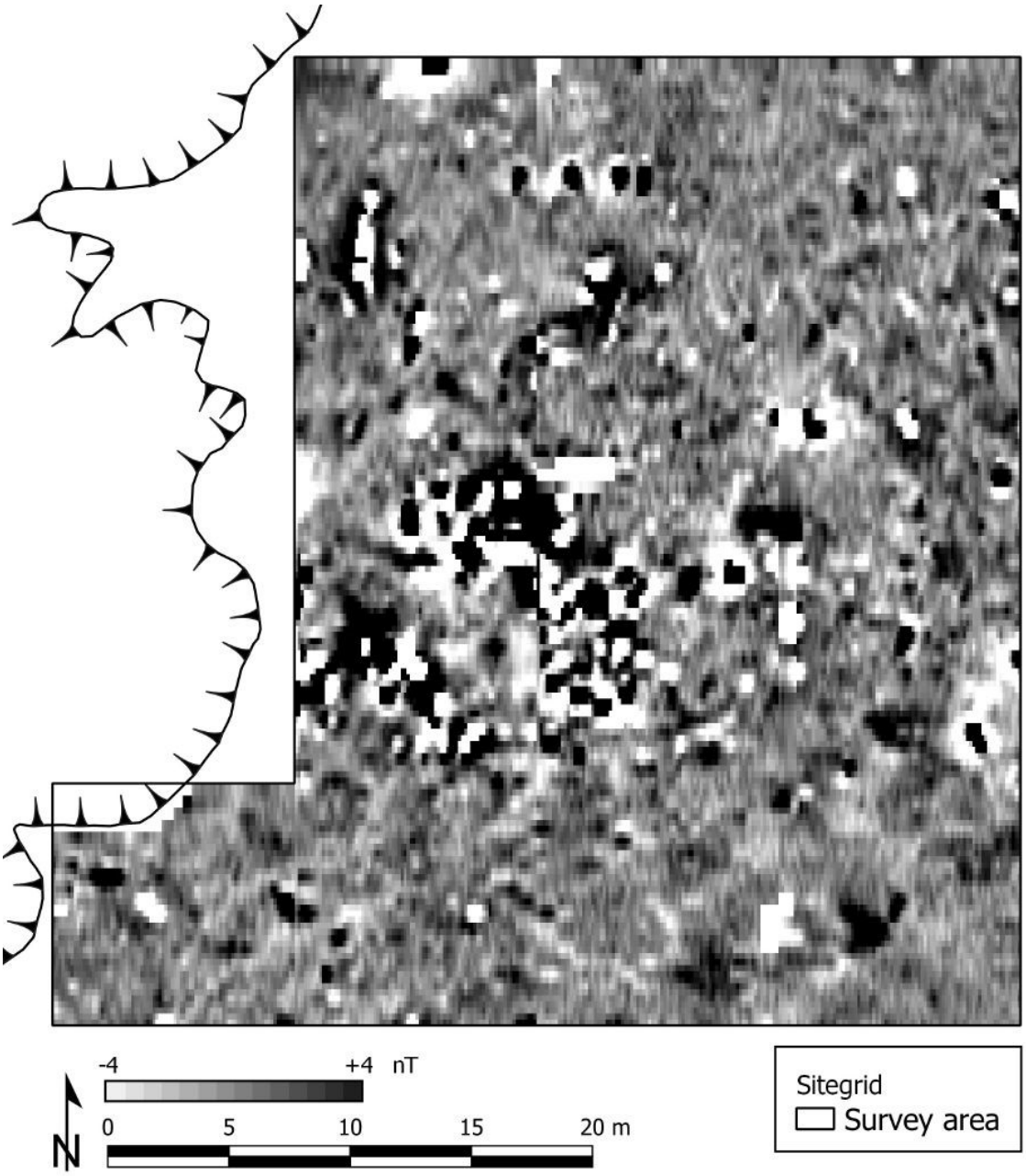

Figure 7. Results of the fluxgate gradiometer survey.

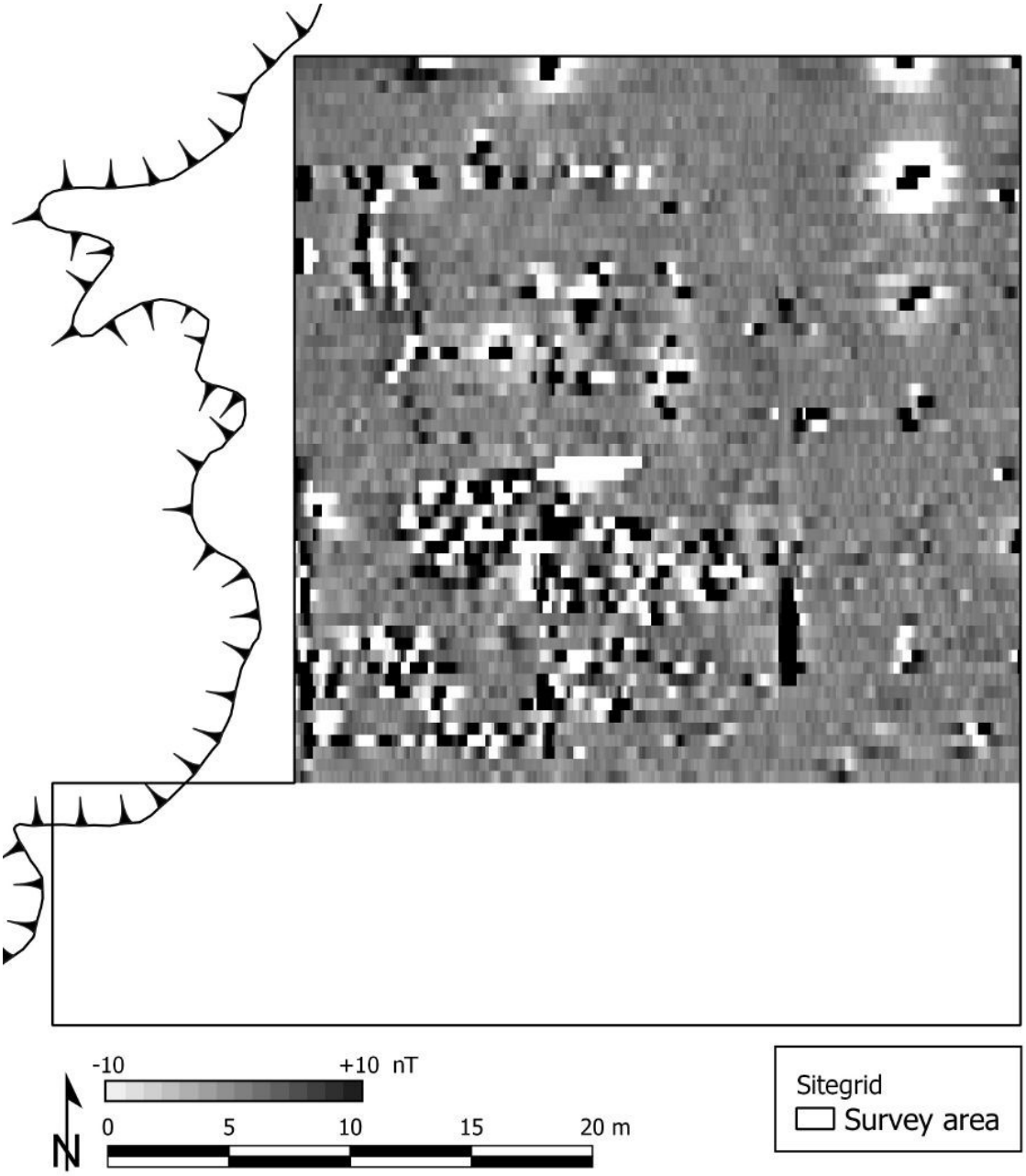

Figure 8. Difference between second and third survey indicating the ferrous debris that was removed.

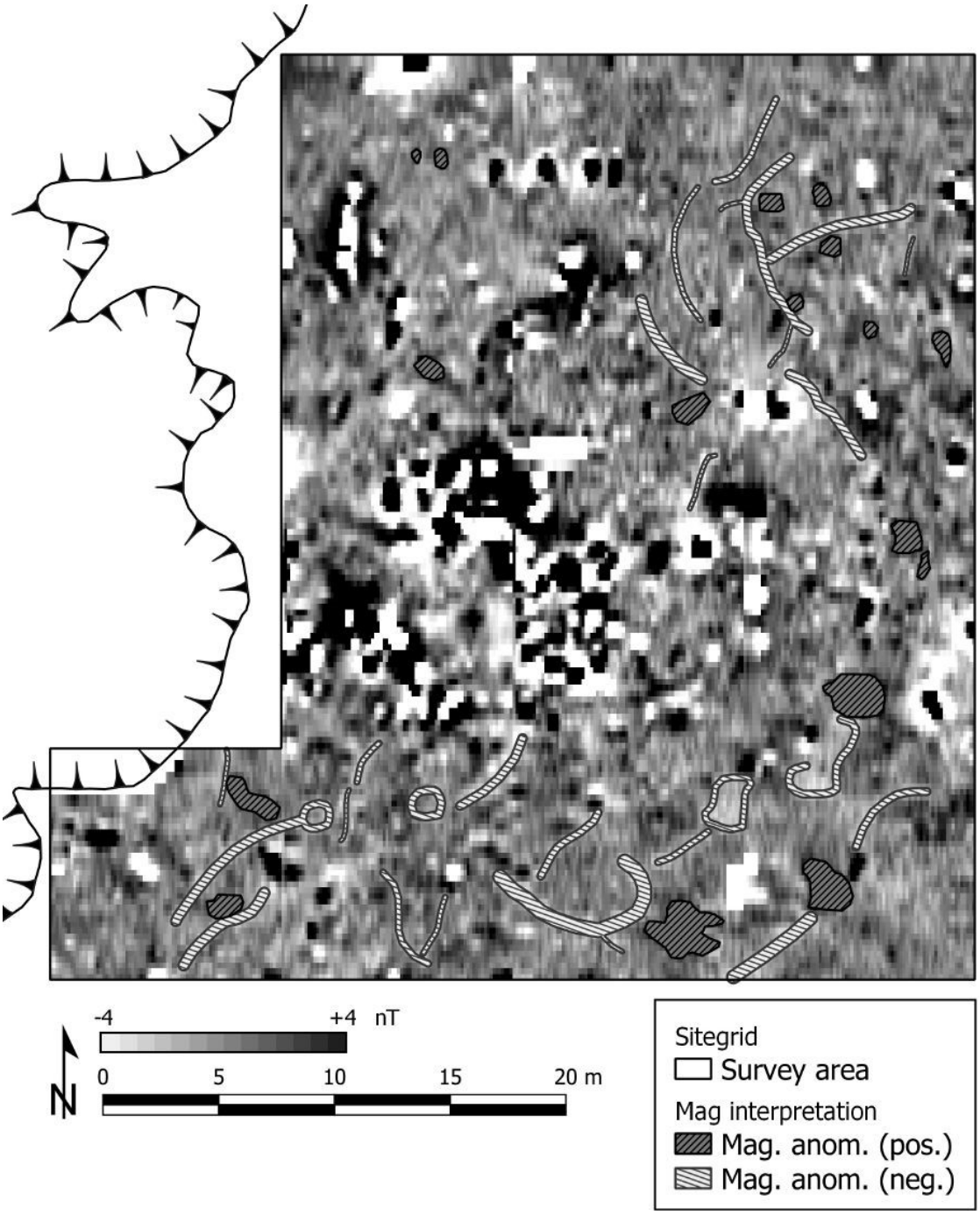

Figure 9. Magnetometer data with interpretation.

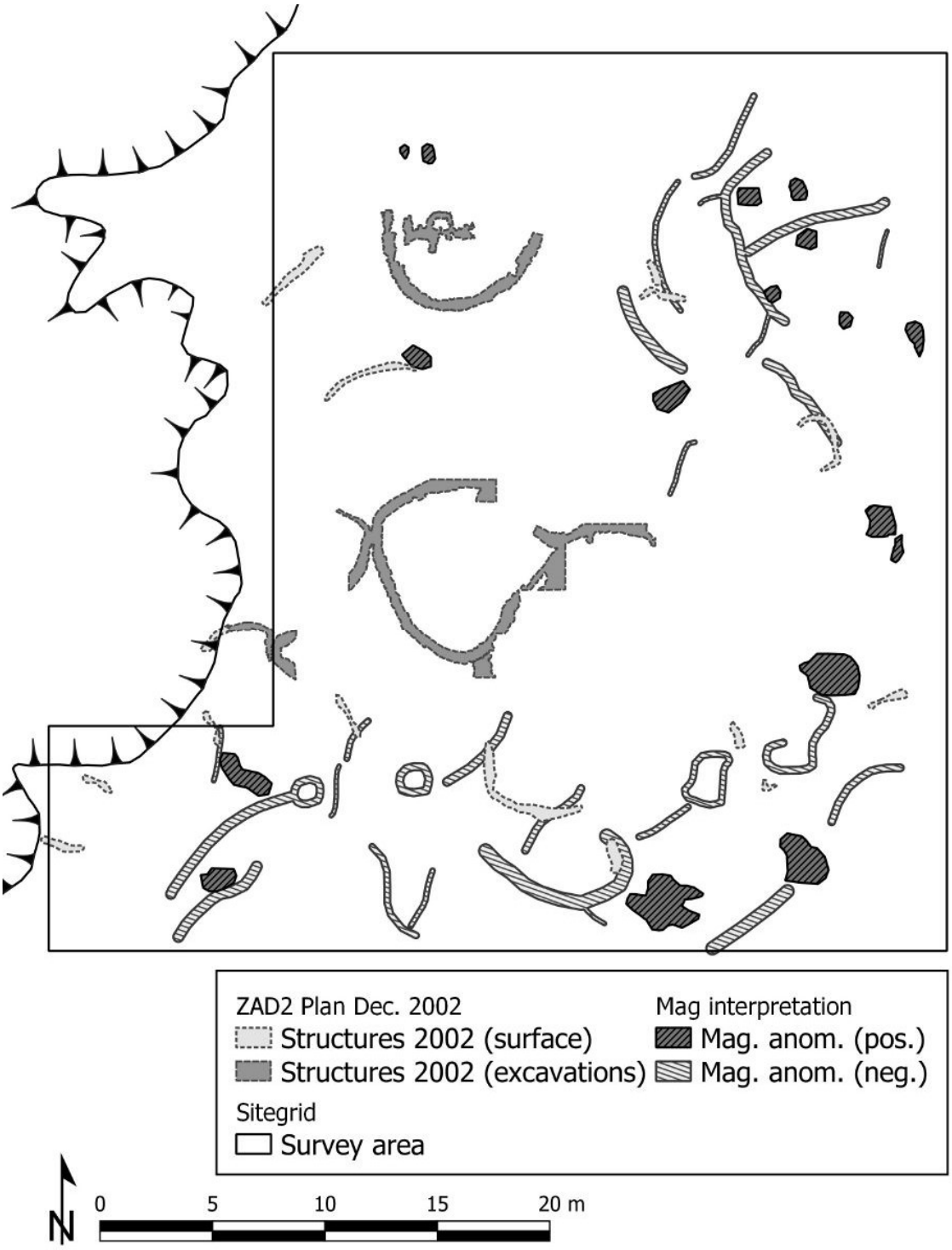

Figure 10. Data interpretation together with results from excavations and surface mapping.

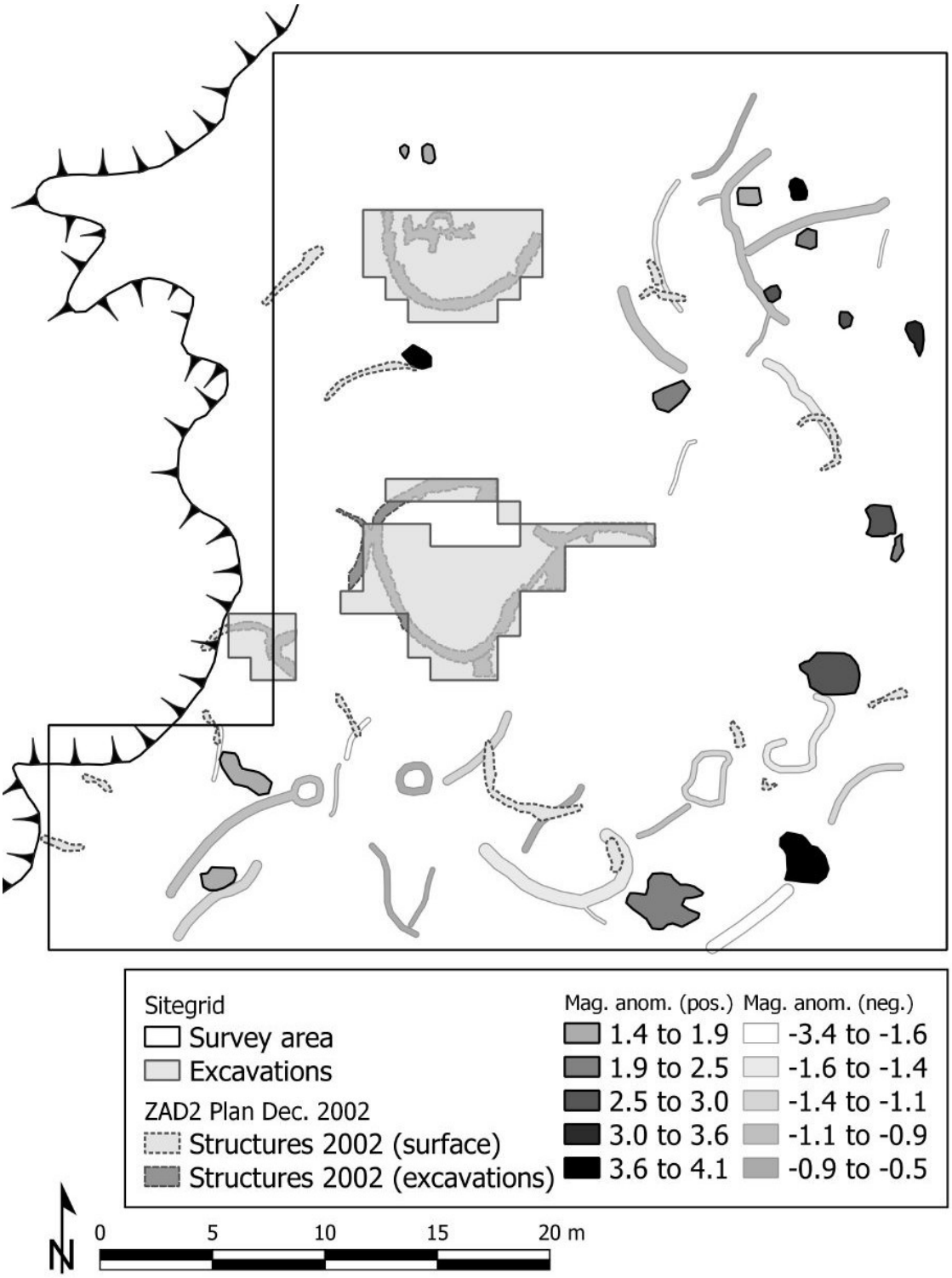

Figure 11. Data interpretation with grey-scale codes based on the *strength* of magnetic anomalies, shown together with results from excavations and surface mapping.

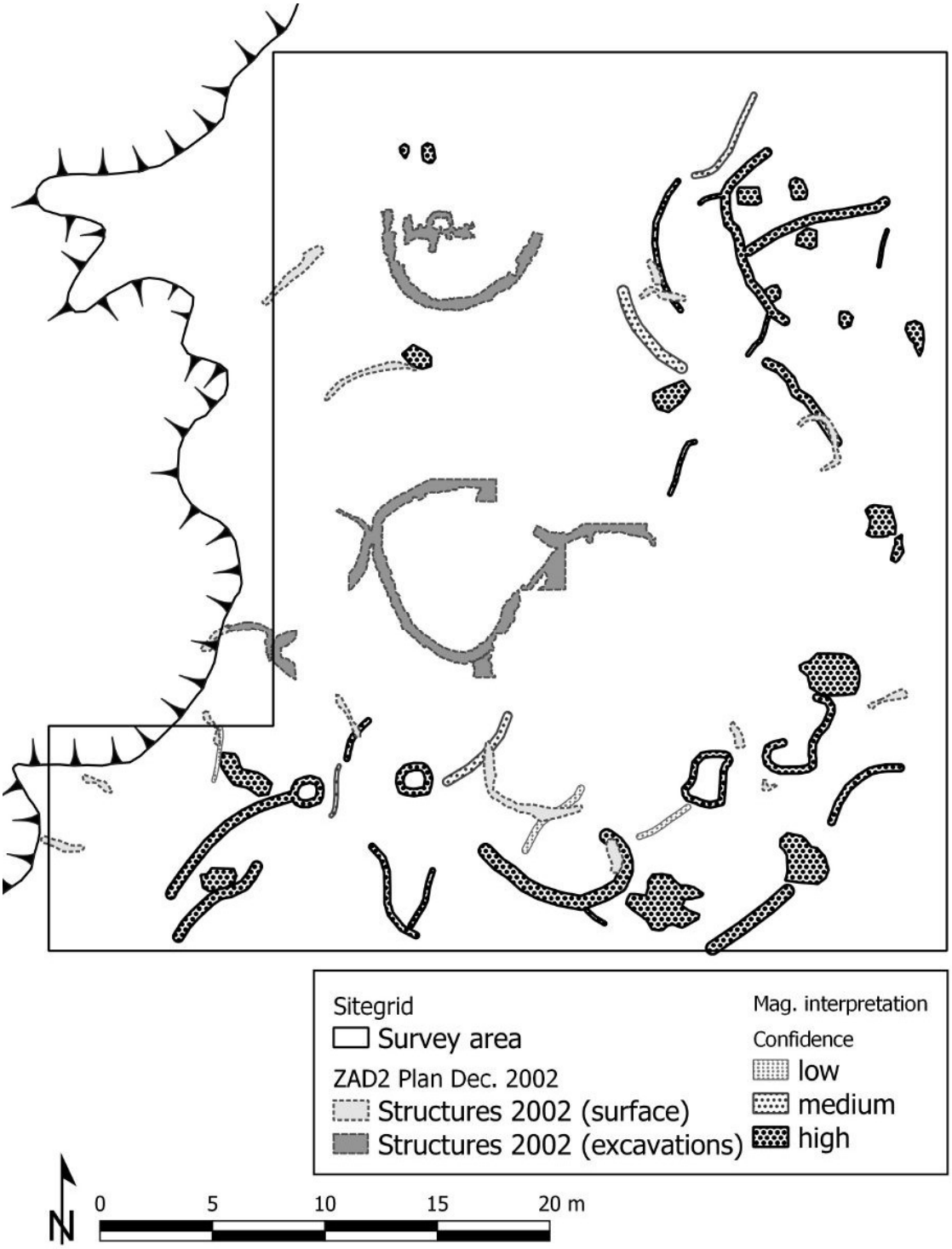

Figure 12. Confidence levels for the interpretations of magnetic anomalies.

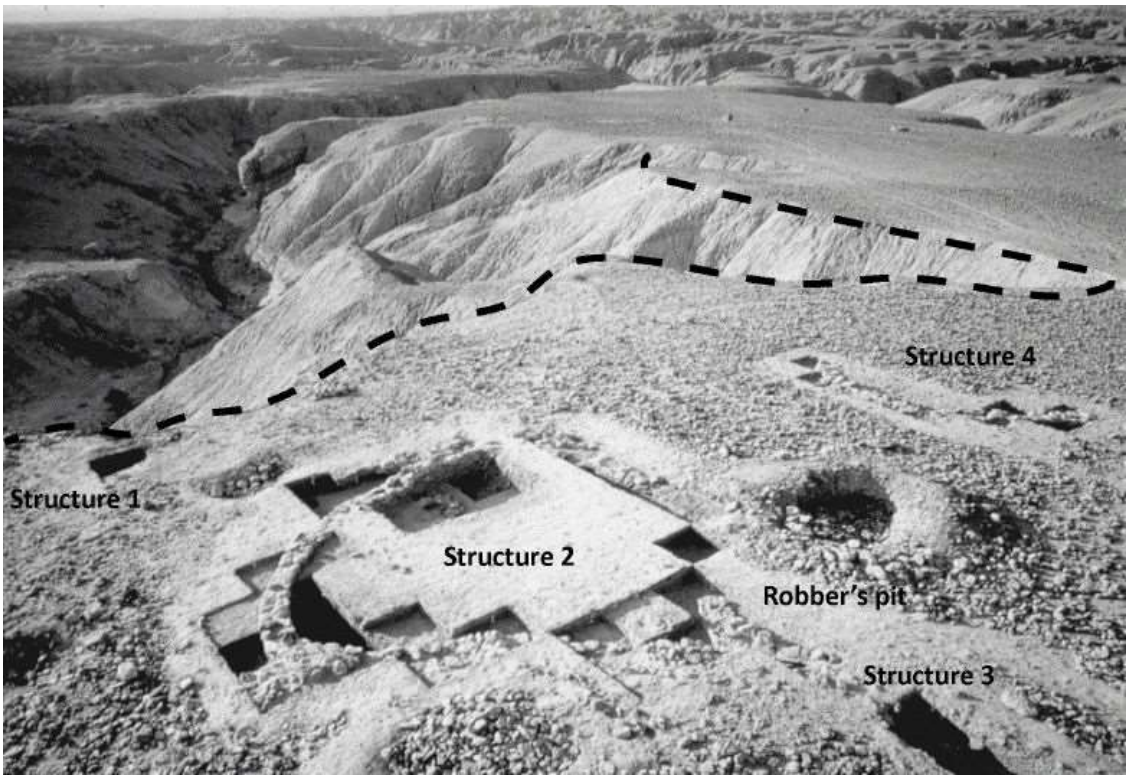

Figure 13. View over ZAD 2 during the excavations. The dashed line indicates the cliff line bordering the westerly margin of the site.

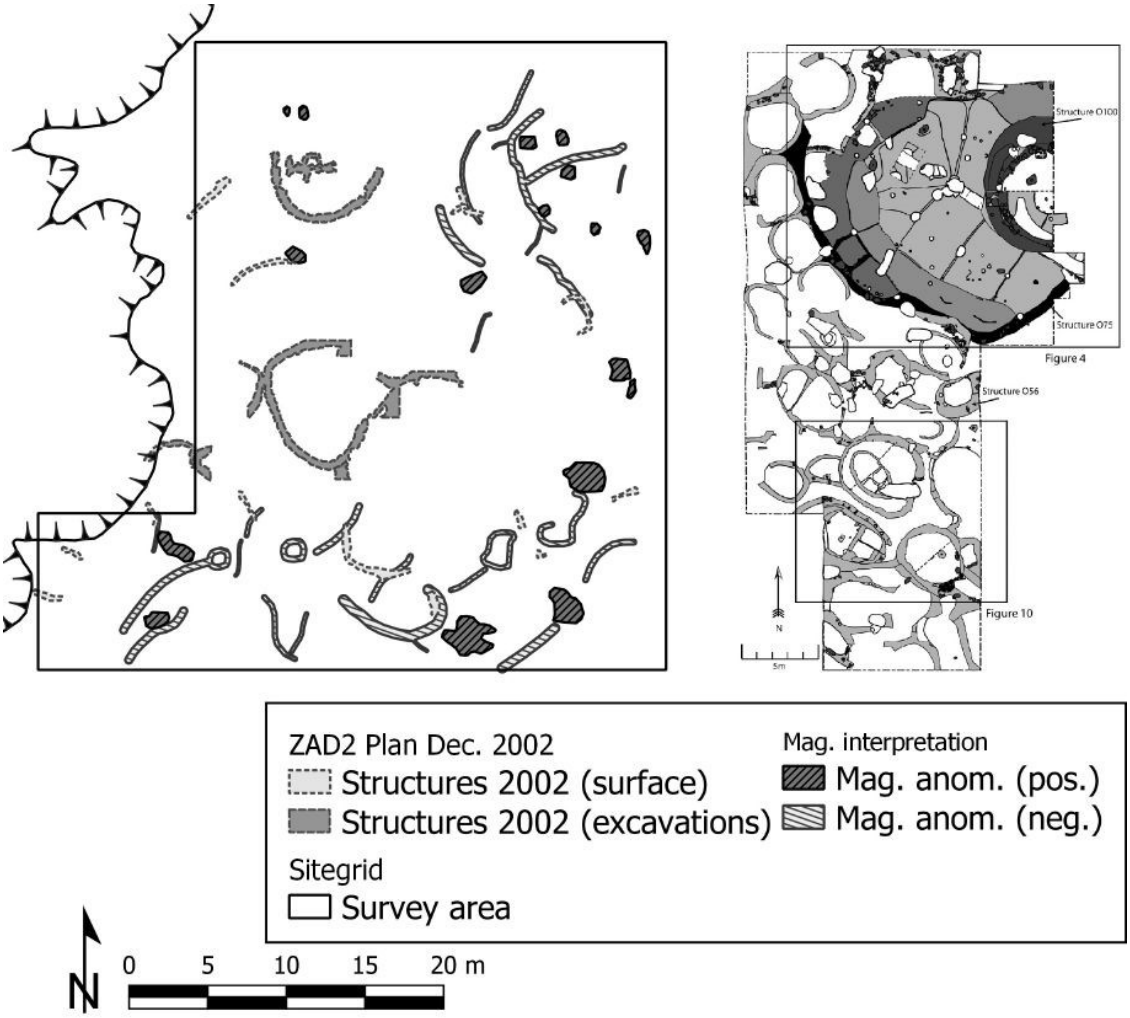

Figure 14. Interpretation of anomalies and excavation results from Wadi Faynan 16 (after Mithen et al. 2011, plotted at the same scale).

المسحُ الجيوفيزيائيّ في ظهرةِ الذراع 2 وآثارُهُ في التقاليد المعماريّة لفترة ما قبلَ الفخّار منَ العصر الحجريّ الحديث "أ" في جنوب بلاد الشام

فيليب ادواردز [1]، ارمين شمدت [2]

ملخص

قدّم المسحُ الجيوفيزيائيُّ للبقايا المعماريّة الجوفيّة في موقع ظهرةِ الذراع 2 الواقعة جنوب شرق البحر الميّت في الأردن، ويعود لفترة العصر الحجريّ الحديث ما قبل الفخّاريّ (أ) وُجهاتِ نَظَرٍ جديدةً حولَ ممارسات البناء وشكل الاستيطان في الموقع؛ إذ كان إجراء هذا النوع منَ المسوحات في الموقع يسيرًا؛ وذلك لِقِصَرِ الفترة الزمنيّة التي سُكن فيها ولاحتوائه على حلقة إنشائيّة رئيسة واحدة، إضافة إلى أنه غيرُ مثقل ببقايا ثقافيّة لاحقة على السطح ومرتكز على رواسبَ طبيعيةٍ عميقة. ولقد كانت الاختلافاتُ المقيسةُ مسبقًا لقابليّة الحجر الجيريّ المستورد المغناطيسيّة والمستخدم في البناء والرّمال الكلسيّة الطبيعيّة المستخدمة في الموقع الدافعَ لإجراء المسح؛ حيث أُجرِيَ مسحٌ للمغناطيسيّة باستخدام مقياس التدرّج (Geoscan Research FM256 fluxgate)، كما استُخدِمَ مقياسُ الحساسيّة المغناطيسيّة ZH (SM-30) المحمول لتسجيل قياسات إضافيّة في هذا المنطقة، كما جرى تباعدُ المسافات المسجّلة 0.5 متر داخلَ شبكة قياس 40 x 40 مترًا. ولقد أشارت نتائجُ الدراسة إلى أنّ موقع ظهرةِ الذراع 2 أكبرُ حجمًا وأكثرُ تفصيلاً منَ الناحية المعماريّة ممّا كان يُعتقد، وهذا يجعلُهُ أقربَ من حيثُ الحجمُ والتعقيدُ إلى مواقع العصر الحجريّ الحديث ما قبلَ الفخّاريّ (أ) الأُخرى في المنطقة المحيطة، مثل موقعي الظهرةِ و وادي فينان 16.

الكلمات الدالة: التنقيب الجيوفيزيائيّ، المسح المغناطيسيّ، العصر الحجريّ الحديث ما قبلَ الفخّاريّ (أ)، البحر الميّت، الممارسات المعماريّة، التخطيط المعماريّ.

1 قسم التاريخ و الاثار، جامعة لاتروب، استراليا؛ 2 المؤسسة الاستشارية للمعلومات الجيولوجية، المانيا. تاريخ استلام البحث 2020/12/30م، وتاريخ قبوله للنشر 2021/2/13م.

REFERENCES

Aspinall, A., Gaffney, C.F. and Schmidt, A. (2008), *Magnetometry for Archaeologists: Geophysical methods for archaeology.* Lanham: AltaMira.

Begin, Z.B. et al. (1974), Lake Lisan: The Pleistocene precursor of the Dead Sea. *Bulletin of the Geological Survey of Israel.* 63, Pp. 1-30.

Clark, A.J. (1990), *Seeing Beneath the Soil.* London: Batsford.

Edwards, P.C. (2016), The chronology and dispersal of the Pre-Pottery Neolithic B cultural complex in the Levant. *Paléorient* 42/2, Pp. 57-77.

Edwards, P.C. (2007), The context and production of incised Neolithic stones. *Levant* 39, Pp. 27-33.

Edwards, P.C. and House, E. (2007), The third season of investigations at the Pre-Pottery Neolithic A site of Zahrat adh-Dhra‘ 2 on the Dead Sea Plain, Jordan. *Bulletin of the American Schools of Oriental Research* 347, Pp. 1-19.

Edwards, P.C. and Sayej, G. (2007), Resolving contradictions: the PPNA - PPNB transition in the Southern Levant (L. Astruc, D. Binder and F. Briois, eds), *Systèmes techniques et communautés du Néolithique précéramique au Proche-Orient: / Technical Systems and Near Eastern PPN communities,* Pp. 117-125. Antibes: Editions APDCA.

Edwards, P.C. et al. (2018), La Trobe University’s 2015 geological survey and archaeological excavation season at the Natufian site of Wādī Ḥammeh 27. *Annual of the Department of Antiquities of Jordan* 59, Pp. 259-271.

Edwards, P.C. et al. (2004), From the PPNA to the PPNB: new views from the southern Levant after excavations at Zahrat adh-Dhra‘ 2 in Jordan, *Paléorient* 30/ 2, Pp. 21-60.

Edwards, P.C. et al. (2002), Zahrat adh-Dhra‘ 2: a new Pre-Pottery Neolithic A site on the Dead Sea Plain in Jordan. *Bulletin of the American Schools of Oriental Research* 327, Pp. 1-15.

Edwards, P.C. et al. (2001), Archaeology and Environment of the Dead Sea Plain: preliminary results of the first season of investigations by the joint La Trobe University/ Arizona State University Project. *Annual of the Department of Antiquities of Jordan* 45, Pp. 135-157.

Falconer et al. (2001) Archaeology in Jordan: Zahrát adh-Dhra'. *American Journal of Archaeology* 105, Pp. 441-443.

Finlayson, B. et al. (2003), Dhra‘, Excavation Project, 2002 Interim Report. *Levant* 35, Pp. 1-38.

Jreisat, K and Yazjeen, T (2013), A Seismic Junction. In Ababsa, M (ed.) *Atlas of Jordan: History, Territories and Society*. Beirut: Presses de l’Ifpo.

Kafafi, Z. and Vieweger, D. (2000), Geoelectric and Archaeological work at Sal, Jordan: a preliminary report about the 1999 season at the Chalcolithic and Early Bronze age site. *Annual of the Department of Antiquities of Jordan* 44, Pp. 173-191.

Kahlil, B. 1992. *The geology of the Ar Rabba Area, Bulletin 22*. Mapping Division, Geological Directory, Amman, Natural Resources Authority.

Kaufman, A., Yeichieli, Y. and Gardosh, M. (1992), Reevaluation of the lake sediment chronology in the Dead Sea basin, Israel, based on new ^{230}Th/^{234}U dates. *Quaternary Research*. 38, Pp. 292-304.

Kuijt, I. and Finlayson, B. (2009), Evidence for food storage and predomestication granaries 11,000 years ago in the Jordan Valley. *Proceedings of the National Academy of Sciences of the United States of America,* 106 / 27, Pp. 10966–10970.

Kuijt, I. et al. (2015), Pottery Neolithic landscape modification at Dhra'. *Antiquity* 81, Pp. 106-118.

Meadows, J. (2004), The earliest farmers? Archaeobotanical research at Pre-Pottery Neolithic A sites in Jordan. *Studies in the History and Archaeology of Jordan VIII*, Pp. 119-128.

Mithen, S. et al. (2018), WF16*: Excavations at an Early Neolithic Settlement in Wadi Faynan, Southern Jordan Stratigraphy, Chronology, Architecture and Burials*, Oxford: Council for British Research in the Levant.

Mithen, S. et al. (2011), An 11 600 year-old communal structure from the Neolithic of southern Jordan. *Antiquity* 85 / 328, Pp. 350-364.

Powell, J. 1988. *The geology of the Karak Area, Bulletin 8.* Mapping Division, Geological Directory, Amman, Natural Resources Authority.

Sayej, G. (2004), *The lithic industries of Zahrat adh-Dhra' 2 and the Pre-Pottery Neolithic period of the Southern Levant*, BAR International Series 1329, Oxford: Archaeopress.

Schmidt, A., Dabas, M. and Sarris, A. (2020), Dreaming of Perfect Data: Characterizing Noise in Archaeo-Geophysical Measurements. *Geosciences* 10 /10, P. 382.

Schmidt, A. (2019), Guidelines for the use of geophysics in archaeology: should they be prescriptive? In Meylemans, E and De Smedt, P (eds) *The use of geophysical prospection methods in archaeology*, Pp. 23-34. Brussels: agentschap Onroerend Erfgoed.

Schmidt, A., Linford, P., Linford, N., David, A., Gaffney, C., Sarris, A. and Fassbinder, J. (2015), *Guidelines for the use of Geophysics in Archaeology: Questions to Ask and Points to Consider*. Namur: Europae Archaeologia Consilium (EAC).

Scollar, I., et al. (1990), *Archaeological Prospecting and Remote Sensing. Topics in Remote Sensing Vol. 2.* Cambridge: Cambridge University Press.

Stordeur, D. (2015),. *Le village de Jerf el Ahmar (Syrie, 9500–8700 av. J.-C.). L'architecture, miroir d'une société néolithique complexe*. Paris: CNRS.

Stordeur D. and Abbès F. (2002), Du PPNA au PPNB: mise en lumière d'une phase de transi- tion à Jerf el Ahmar. *Bulletin de la Société Préhistorique Française* 99 /3, Pp. 563-595.

Witten, A. J., Levy, T.E. and Adams, R.B. (2000), Geophysical Surveys in the Jebel Hamrat Fidan, Jordan. *Geoarchaeology* 15/ 2, Pp. 135–150.

Yechieli, Y., et al. (1993), Late Quaternary geological history of the Dead Sea area, Israel. *Quaternary Research* 3, Pp. 59-67.