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PRELIMINARY REPORT ON THE GEOPHYSICAL SURVEY OF CENTRAL WAD BEN NAGA

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ABSTRACT: Within the framework of the Archaeological Expedition to Wad Ben Naga, a non-invasive, geophysical survey was conducted at the archaeological site of Wad Ben Naga, Sudan, in the course of the mission's fifteenth season. The objective of the survey was to explore selected parts of Central Wad Ben Naga, to map surface and subsurface structures. Almost 500 distinct anomalies were detected using a ten-sensor gradiometer array LEA MAX and interpreted in the context of the site's development.

KEY WORDS: Nubia – Meroe – Wad Ben Naga – Meroitic settlements – geophysical survey

Introduction

At the end of the year 2017, the Eastern Atlas Company conducted a geophysical survey at the archaeological site of Wad Ben Naga, the River Nile state, Republic of Sudan. The objective of the geophysical survey was to explore selected parts of Central Wad Ben Naga, to map surface and subsurface structures in between the above-ground ruins of the Meroitic buildings and temples still visible in the present-day landscape. A total area of almost 9 ha was investigated during the four-day prospection using a LEA MAX magnetometer survey system. With a spherical resolution of 0.25 metres, the magnetometer data were projected onto the local coordinate system set up by the Archaeological Expedition to Wad Ben Naga and presented in two different greyscale

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dynamics of +/– 5 nT and +/– 20 nT. These correspond to the vertical gradient measured for the magnetic field. The interpretation of the magnetometer survey data distinguishes between anomalies related to archaeological structures, anomalies of recent and natural origin, and unspecified anomalies. The anomalies of archaeological relevance are mainly assigned to fired brick walls, mudbrick walls, pits, and fillings. Almost 500 distinct anomalies are highlighted on the interpretative map.

Geology and landscape

The archaeological site of Wad Ben Naga is located on the right bank of the River Nile, circa 130 km northeast of Khartoum in the so-called Shendi Reach. The local landscape is characterized by a relatively flat surface covered with typical desert pavement, namely gravel residues of alluvial deposits transported to the area through various *wadis*, *khors* and tributaries. The topography of the archaeological site slopes slightly down towards the River Nile in the west, and the southwest. The central part of the archaeological site is delimited by two branches of smaller *khors* that seasonally transport water from the nearby hills to the east towards the Nile (Vacek *et al.* 2013: 30; Onderka 2014: 83; Onderka 2016: 12). In the western part of the site – as well as in the Nile Valley – thicker alluvial deposits can be found. These mainly consist of medium- to fine-grained sand, here locally with a higher quantity of quartz pebbles than in the Nile Valley (Vacek *et al.* 2013: 30). Two geological outcrops were previously identified in the study area: 1) a unit of Precambrian (Neoproterozoic) granitic intrusions and dykes, which form the basement complex; and, 2) a unit of overlying, horizontally bedded basalt conglomerates belonging to the Omdurman Formation (Vacek *et al.* 2013: 29–31), which measures several hundred metres and consists of sequences composed mainly of fluvial clastic sediment. Most of the conglomerates are massive and contain well-rounded quartz pebbles measuring a few centimetres in diameter, while lithic material occurs much less frequently. A feature of both geological units, the low content of coarse elements means that local material would have been unsuitable for fine masonry work. This deduction is supported by the limited evidence of local stone in building elements other than the foundations (Vacek *et al.* 2013: 29, 32).

Archaeological Background and Research History

Although sporadic discoveries and literary mentions of the site date back nearly two centuries, the first systematic archaeological research of the settlement site only started nearly sixty years ago. Between 1958 and 1960 the Sudanese Antiquity Service carried out prospection and excavations (Vercoutter 1962). Since 2009 the site has become the focus of archaeological research by the National Museum of the Czech Republic in Prague, which concentrates also on conservation and preservation work at the site (Onderka 2014: 83–84; and, Onderka 2016: 9, 18).

The present-day archaeological site of Wad Ben Naga covers about 4 sqkm and can be divided into three different sectors as follows (cf. Onderka 2016: 10, 12):

1) Central Wad Ben Naga comprises the ruins of the ancient Meroitic royal city. The aboveground urban layout of this sector stems mainly from the Classical Meroitic to Post-Meroitic periods.

2) The Northern Cemeteries are located directly north of Central Wad Ben Naga and gradually disappear under the expanding modern settlement and its train station and railway tracks.
3) The Southern Cemeteries sector stretches for several kilometres towards the south-western part of the site. This sector includes clusters of tumuli that are evenly distributed within the area; sometimes in clusters. The superstructures of these tumuli extensively employ local stone and material gained from collapsed buildings for their superstructure. The circular mounds appear to not exceed one to two metres in height, but their diameter can vary between three to twenty metres (Onderka 2016: 41–49).

Several above-ground structures have been previously discovered. Of these, five have been identified as temples belonging to the first four phases defined at Central Wad Ben Naga (cf. Onderka 2016). The five include the Typhonium (WBN 200), the so-called Isis Temple (WBN 300), the Small Temple (WBN 400), the Eastern Temple (WBN 500), and the so-called Circular Building (WBN 50), all dating between the Classical Meroitic to Late Meroitic periods. In addition, the present urban centre is dominated by the Palace of Queen Amanishakheto (WBN 100), which was constructed around the turn of the Common Era (Onderka 2016: 24, 28). Two non-monumental buildings supplementary to the Circular Building (WBN 600) were also previously excavated, as well as remains of monumental buildings to the west of the Typhonium (WBN 700, 800). Covering ancient ruins, various *koms* formed already in the antiquity from the construction debris. In the periods following the collapse of the Meroitic Kingdom these structures became coveted as burial grounds (Onderka 2016: 28).

Already in advance of conducting the survey in December 2017, there were high expectations of determining subsurface archaeological features in the magnetic data of the prospection of Central Wad Ben Naga. In addition, the types and dimensions of these anticipated features and buildings were expected to vary from smaller profane structures to larger monumental architecture appropriate to a settlement of royal stature. The latter is already evident in the present-day landscape of Central Wad Ben Naga, which is dominated by the vestiges of the Palace of Queen Amanishakheto located in the western part of the survey area. The main construction was completed with mudbricks; however, fired bricks were used for the outer casing and bearing walls, after which the walls were finished with lime plaster. Sandstone was used for special architectural features: columns, thresholds, door frames, etc. (Onderka 2016: 37, 51–52).

The eastern one of the two main axes of the royal city extended from the Palace of Queen Amanishakheto with the main temples and royal buildings constructed along these axes. Several of these structures are still visible above-ground. Although the dimensions of these buildings all differ from the Palace of Queen Amanishakheto, to some extent the construction materials are all similar, i.e. mudbricks and/or fired bricks and lime plaster (Onderka 2014: 84; Onderka 2016: 26, 57–58, 60, 62–67). However, only the structures on the northern side of the westernmost axis have been preserved. Those on the southern side have likely been eroded by seasonal waters flowing through the adjacent *khor* (Onderka 2014: 84; Onderka 2016: 26). Besides mudbrick and fired brick walls and foundations, additional fortifications were expected to occur as several structures with suggested defensive function had already been noted (Vercoutter 1962: 271, fig. 2; Hinkel – Sievertsen 2002: IX.72, nos. 55, 56; Onderka 2016: 25, 39–40). Multiple walls were made of local coarse-grained granite and of bricks and brick

fragments in the western part of the survey area. A possible gate was even identified in the vicinity of the Circular Building (Onderka – Vrtal 2016: 113).

Other major archaeological elements that are visible above the surface of Central Wad Ben Naga are the various *koms* or mounds. These are scattered throughout an area that not only involves Meroitic buildings but also contains various burial structures. Most of these funerary monuments are tumuli dating from the Late- or Post-Meroitic periods (Onderka 2016: 12). Prior to the December 2017 survey, four different cemeteries had been distinguished at Central Wad Ben Naga (WBN C100–C400). Each contained multiple tumuli built from a range of materials from fired bricks to local stone and reused sandstone (Onderka 2016: 25, 45–47). In addition to this, numerous spoil heaps from 1844, 1958–1960, as well as recent excavations are located in the vicinity of excavated structures. The most prominent spoil heaps are located to the north, south and east of the Palace of Queen Amanishakheto and to the south of the Eastern Temple.

Table 1 General information about the survey conditions at the site of Central Wad Ben Naga.

Site	Central Wad Ben Naga
Archaeological Context	Ruins of buildings, the scattered building material of both mudbricks and fired bricks used as casing/covering and burial structures.
Terrain	Flat terrain with several *koms*/mounds covering ruins and spoil heaps.
Geology	One unit of granitic intrusions and dykes; second unit of overlying horizontally bedded basalt conglomerates comprising sequences of sediment.
Soil	Desert pavement, i.e., gravel residue of alluvial deposits.
Surface	Partly flat, with exception of the spoil heaps and *koms* covering ruins.
Vegetation	Occasional bushes or small (mostly acacia) trees.
Land Use	Uncultivated.
Disturbances	Historical ruins, *koms*, trees, bushes, and (historical) construction debris.

Methodology, Measuring Parameters, and Data Processing

Magnetic Anomalies of Archaeological Origin

The objective of the magnetometer survey is the identification and description of spatial changes (anomalies) in the magnetic field. At archaeological sites, anomalies occur as a consequence of a contrast between the magnetic properties of archaeological features and those of the surroundings. Both are mainly composed of natural materials such as rock or soil. The anomalies in the magnetic field are caused by two different kinds of magnetization: induced and remanent. Induced magnetization refers to the material properties of an external magnetic field, while remanent magnetization is mainly assigned to the thermal history of a cultural feature, and rock and soil particles.

Another important magnetic phenomenon is diamagnetism. Structures that are primarily composed of diamagnetic materials, including quartz and calcite, may cause

noticeable negative local anomalies. Diamagnetic materials literally repel the external magnetic field and thereby form a magnetic field in the opposite direction. This results in an anomaly field with negative amplitudes. Due to this effect, buried limestone and quartzite constructions, as well as infill composed of sand and calcareous sediments can be identified in the magnetic data as negative anomalies.

Magnetic Prospection with the LEA System

The convertible LEA system [Pl. 1] designed by Eastern Atlas was used for the magnetic prospection at the archaeological site of Wad Ben Naga. The system was equipped with ten Foerster fluxgate gradiometer probes mounted on a light and foldable cart, the data recording device LEA D2, and two independently working positioning systems, a GNSS and an odometer. The Foerster FEREX CON650 fluxgate gradiometer probes register the vertical gradient of the z-component of the magnetic field with an accuracy of 0.2 nT (nanotesla). The gradient is measured as the difference between two vertically arranged fluxgate sensors (distance 650 mm) in the gradiometer probes. This measured value is insensitive to the various time changes of the external magnetic field, which occur as daily, diurnal, or short-term variations. For this reason with gradiometer surveys, a base station is not required to record the external effects for making further corrections to the reference measurements.

During measurements, the magnetic data of each sensor in the array are registered along straight profiles of any length, defined by the starting and stopping positions. The point distance in the profile direction depends on the sample rate set for the registration unit and the speed at which the system is moved. At the end of each profile, the raw data are decoded and normalized. The GNSS positions and/or the wheel markers are used for decoding the registered time-series data into geo-referenced data. The standard decoding process uses a polynomial fit (second order) to calculate the long-term sensor variations. The residual data show local variations (anomalies) while sensor drift and regional field effects are suppressed.

The data positioning for the magnetic survey was realized by means of a differential GPS using two GNSS ReAct (Førsberg) receivers in Real-Time Kinematic (RTK) mode to achieve a relative accuracy of ±2 cm. The coordinate system used during the magnetic measurements was the WGS84 UTM Zone 36N (EPSG: 32636). Subsequently, the magnetic data were projected onto the local reference system by means of several fixed points available at the site.

Results of the Geophysical Survey and Archaeological Interpretation

The magnetometer surveys at Central Wad Ben Naga cover an approximated area of 9 ha stretching over 600 m by 190 m. Additionally, two separate small areas were surveyed: one area, approximately 40 m by 25 m, located west of the railroad; and, another area, approximately 1,000 sqm, located to the north, which was surveyed to gain magnetometer data at the visible tumuli in the surroundings of Central Wad Ben Naga. The geophysical survey data were re-projected onto the local coordinate system. The following specifications of directions relate to this local system, which is rotated (counter-clockwise) to geographic north. Compass directions mentioned below are meant for this local projection.

The results of the magnetometer survey in Central Wad Ben Naga are presented on three maps at a scale of 1:2,000. On Map 1749-1 [Pl. 4], the magnetometer data are displayed using a grayscale dynamic of ±5 nT; and, on Map 1749-2 [Pl. 5], a grayscale dynamic of ±20 nT is used. The preliminary interpretation of the magnetic data can be found on Map 1749-3 [Pl. 6]. The geophysical data shown on the maps are not only strongly shaped by the geological basis of the area, but also by the presence of modern reconstructions of the ancient buildings and the especially high quantity of ancient construction debris, i.e. fired bricks that are scattered over the surface, as well as concentrated together in spoil heaps dating back to the modern excavations. In the magnetic data, the high values of the measured magnetic field, especially in the vicinity of the spoil heaps, complicate the identification of anomalies related to potential archaeological structures in the ground. In addition, some parts of the survey areas could not be covered by the magnetic measurements due to the spoil heaps and presence of above-ground historical ruins, trees, bushes, fences, and other constraints.

Table 2 Technical parameters of the magnetic prospection.

Method	**Magnetic Prospection**
System	LEA MAX (Eastern Atlas)
Sensors	10 Foerster Fluxgate Gradiometer FEREX CON650
Data Logger	LEA D2 with 10 channels (Eastern Atlas)
Measurement Category	Vertical gradient in nT
Configuration	10 sensors, mounted on a cart; Vertical sensor separation: 0.65 m
Resolution	Profile distance: 0.5 m; Point distance: 0.1 m (max.)
Topographic Measurement	2 x single-frequency NovAtel SMART GNSS receivers
Data Positioning	Relative accuracy: 0.02 m
Processing and Filters	Decoding program, including offset and drift corrections
Data Format	ASCII, GeoTiff
Image Resolution	0.25 m x 0.25 m

Interpretation Approach

After data processing, the magnetic data images were thoroughly examined to detect any anomalies related to archaeological features. The depicted and described interpretation is the outcome of a subjective approach that takes both the general archaeological context and environmental conditions into consideration and by no means claims exhaustiveness. It is rather intended as a cautious proposition that might serve as a basis for further archaeological research.

The general approach to classifying the magnetic anomalies is to distinguish them by means of their amplitudes, character, extension, and shape. First of all, anomalies of recent origin were separated and marked in blue. Secondly, anomalies that were assumed to have a geological or geo-morphological background were sorted out in a separate class and marked in green. The specific characteristics of the anomalies, the related archaeological structures, and the colour scheme used in the interpretation maps are set out in Table 3.

Table 3 Scheme of magnetic data interpretation.

Class	Color	Anomaly Type	Related Structures
Anomalies Related to Archaeological Structures			
1		Distinct circular and oval positive anomalies	Fillings of pits and post holes; fillings possibly containing pottery fragments, metal objects, and burnt material
2		Linear and irregularly shaped zones of positive anomalies	Organically enriched fillings of ditches and fillings of construction debris
3		Linear anomalies with low to medium amplitudes	Mud-brick walls and foundations
5		Linear anomalies with medium to high amplitudes and dipole character	Burnt brick walls and foundations
6		Single anomaly with very high amplitudes	Accumulated burnt material, furnaces, kilns, fire-places, remains from metal workshops
7		Linear anomaly with moderate amplitudes	Roads, paths, streets
9		Areas of scattered dipole anomalies with mainly high amplitudes	Brick rubble, disseminated debris, layers of destroyed material often related to mounds
Unspecified Anomalies			
8		Weak dipole patterns; positive and negative anomalies	Anomalies of uncertain origin, possibly archaeologically relevant; superimposed anomalies of varying character and origin
Anomalies of Recent Origin			
		Single and aligned dipole anomalies; extensive areas with significant varying character	Iron poles, scrap metal, floodgates from the water supply, fences, pipes, and other recent objects above and below the surface; areas with irrigation systems, topsoil accumulations, and spoil heaps
Anomalies of Natural Origin			
		Linear and curved dipole anomalies with varying amplitudes	Granite dykes and outcrops, and basalt conglomerates relating to the geological units

Discussion

At first glance two main types of magnetic anomalies are recognizable. These are large scale, mainly straight linear anomalies with a uniform dipole character and areas with scattered dipole anomalies of high amplitudes. The first corresponds to the natural geological formation in the subsurface while the latter is related to the buried architectural remains of the archaeological site.

Additionally, significant dipole anomalies with very high amplitudes originating from recent objects are notable in both the ±5 nT and ±20 nT presentations. Subsurface features originating from human activity and natural processes producing anomalies with low amplitudes become clearer in the presentation with the lower dynamic of ±5 nT. The detection of the subsurface building remains becomes clearer in the magnetic data when single building phases are to be expected and no (or less) debris hampers the interpretation of the magnetometer data. In case of superimposed magnetic anomalies from *in situ* structures and coverage of debris and remains, the interpretation can become difficult.

In detail, the following non-archaeological anomalies marked on Map 1749-3 [Pl. 6] are notable. A linear east-west oriented anomaly stretching over 300 m is marked as a natural rock formation in the western area of Central Wad Ben Naga. The anomaly consists of several parts and is not always visible as in the case of coverage with debris at the mound of the so-called Isis Temple and the interruption north of the Circular Building. At its most eastern edge, the anomaly from the geological formation is probably superimposed by anomalies from recent structures. South of the main anomaly, parallel lines of anomalies from additional magnetic rock formations are visible and marked in green. A possible anthropogenic origin of the southernmost line of rock concentrations was previously suggested based on a trial trench transecting it (Onderka – Vrtal 2014: 78–79). This suggestion remains to be validated. Another dipole anomaly of similar character and shape is highlighted in the eastern part of the survey area. This is visible over almost the entire 150 m width of the survey area as a north-south running dipole anomaly. These anomalies are very likely produced by a rock formation related to the granite basement.

The marked features of archaeological relevance contain more than 400 single anomalies attributed to Classes 1 to 7 [Table 3]. Furthermore, there are seven areas attributed to Class 9 that mark the outline of distributed debris and subsurface building remains. The main highlighted archaeological features derived from the magnetometer data are discussed below, starting from the local northeast and going towards the local southwest.

In the north-eastern part of Central Wad Ben Naga, a zone around the Eastern Temple is marked as an area with anomalies that are interpreted as building remains. This area stretches across an approximated 1 ha and is characterized by scattered dipole anomalies. Several floor plans from subsurface buildings can be derived from the magnetic data. The structures mainly show a clear orientation to the Eastern Temple. The most remarkable remains are the three sides of a square building complex measuring 6 m by 6 m, detected about 30 m northeast from the Eastern Temple, and labelled WBN 550/560 in the archaeological data (Onderka *et al.* 2016: 110). The dipole character of these anomalies points to walls of fired bricks. What is notable about the linear anomaly mentioned above is that it originates from a rock formation running through the area along the south-western front of the Eastern Temple.

The area further southwest contains almost no archaeologically relevant anomalies in an expanse with a width of more than 100 m. Several north-south running tracks are marked, some as recent and some as ancient. Parallel to the tracks, there is a row of significant single dipole anomalies with very high amplitudes caused by poles and marked as recent on the interpretation map. Iron bars representing GIS trig points and set out in a 50 m grid produce additional dipole anomalies of recent origin with very high amplitudes. Furthermore, dipole anomalies grouped as rectangular floor plans are interpreted as of recent origin. Among them, the nearly square remains of a recent building measuring 4 m by 5 m – and a smaller structure further north with a similar type of anomaly with respect to its orientation and character – are marked as recent anomalies (excavation house of Sudanese Antiquities Service expedition; cf. Hinkel – Sievertsen 2002: IX.72; Onderka 2016: 93, nos. 161, 162).

East and northeast of the Palace of Queen Amanishakheto, magnetic anomalies with very different characters are interpreted as of archaeological relevance. They are grouped around the excavated Small Temple. An area of about 3,000 sqm is marked as debris. The presence of economic activity extending from the palace towards this area was attested also during most recent excavations by numerous pottery finds and deliberate surface levelling (Onderka – Vrtal 2018: 143). Around the Small Temple lines of dipole, anomalies are marked as fired brick walls which are partly known from excavations. Further north, scattered anomalies probably point to hidden remains of a larger building ensemble. Several floor plans of remains from fired brick walls can be derived from the magnetic data. It is likely that the building(s) is/are slightly rotated in orientation to the known Palace of Queen Amanishakheto and the Small Temple nearby. Extended north-south oriented anomalies are notable and are interpreted as filling and mudbrick walls. At the eastern edge of the Palace of Queen Amanishakheto, two anomalies – marked as fired brick walls and measuring 15 m in length, at a distance of 4 m from each other, and originating from the ramp of the Palace (WBN 162; cf. Hinkel – Sievertsen 2002: Pl. IX.75) – are visible in the data.

Very different anomalies of varying origin are visible in the magnetic data for the area around the Circular Building. The most striking magnetic anomaly is a linear one about 4 m to 5 m wide running from the edge of the Circular Building towards the north. This anomaly can be redrawn along a 28 m feature or line running towards a spoil heap. A continuation of the anomaly is visible in the data a few metres on the other side of the heap. It is thus very likely that the entire length of the anomaly is an approximated total of 58 m. The detected northern edge of this anomaly is located close to the south-western corner of the Palace of Queen Amanishakheto. This anomaly probably originates from a ditch structure or pavement. One hypothesis to explain the positive magnetization is a channel filled with organic material. Besides this remarkable anomaly, additional subsurface features such as mudbrick and fired brick walls, pits, fillings, and rock formations can be expected from the magnetic data around the Circular Building.

The most striking area with scattered dipole anomalies of high amplitudes corresponds to the mound of the so-called Isis Temple complex. An outline of 80 m by 60 m is marked as a debris area. The extension clearly corresponds to the area marked in the present maps [Pl. 3] for Central Wad Ben Naga. A spoil heap from former excavation work located in the northern and eastern part of this area probably covers parts of the building remains inside the mound; therefore no anomalies related to the archaeological material can be detected here.

The square building remains of the so-called Isis Temple complex and a row of later tumuli (WBN C300) further south are already known as archaeological objects. The small-scale mounds of the tumuli are recognizable from surface data [Pl. 3, left]. The overlay of magnetic data and marked tumuli [Pl. 3, right] mainly show dipole anomalies with high amplitudes, with the exception of the northernmost and southernmost mounds of the line. The magnetic anomalies are mainly a topographic effect of the elevated burials. Therefore, they are not interpreted as southwest-northeast oriented structures, as suggested by the data. Rather, the known burials have been marked as anomalies of infill. Although building structures related to the so-called Isis Temple complex can be expected below the tumuli, the overlay of building remains and later burials hampers clear interpretation of the expected structures. For this reason, the ensemble of anomalies related to mudbrick and fired brick wall remains in the central part of the mound of the Isis Temple complex show no clear orientation.

At the southern, eastern, and northern edges of the mound, elongated anomalies of subsurface constructions are marked on the interpretation map. In the southern part a complex mudbrick building can be expected (possibly a palace; for the relationship between palace and temple in Nubia cf. Kendall 1999 and O'Connor 1989), while in the eastern and northern parts fired brick walls seem to be aligned respectively to a building complex and parts of a courtyard or enclosure. The orientation of these structures is similar to that of the main known structures of the Palace of Queen Amanishakheto and particularly the Typhonium. However, mudbrick walls with a different orientation are also interpreted at the north-western corner of the mound of the so-called Isis Temple complex, which may point to several building phases.

The magnetic data from the large open area between the Palace of Queen Amanishakheto in the eastern part, the Typhonium complex in the western part, and the mound of the so-called Isis Temple complex in the southern part show a large open courtyard in the western part and buildings annexed to the Palace of Queen Amanishakheto in the eastern part. Walls and scattered dipole anomalies from brick rubble indicate the building remains annexed to the Palace of Queen Amanishakheto. Most of these anomalies likely represent destruction debris from the Palace itself, similarly to the situation in trench T55 (Onderka – Vrtal 2018: 141–143). Structural remains are further interpreted within the area between the two known walls running from the corners of the Palace towards the west and the linear anomaly with the north-south orientation. Presence of buildings of non-monumental character (WBN 900) in the area was ascertained during the excavation of a trial pit in the spring of 1959 (Vercoutter 1962: 275, fig. 2, no. 1; Onderka 2016: 38; Vrtal 2017: 69). A north-south running wall is interpreted at a distance between 36 m and 39 m from the western front of the Palace. This wall, marked over an entire length of 90 m, forms the eastern edge of the courtyard measuring an approximate 43 m by 68 m and continues further south to the complex of the so-called Isis Temple. The walls of the interpreted courtyard are open towards the west and show the orientation of the Typhonium to be slightly rotated in relation to the Palace of Queen Amanishakheto.

Around the mound of the Typhonium complex, an area of building debris is marked on the interpretation map. Several building structures positioned at the same orientation as the so-called Isis Temple complex are to be expected. Nevertheless, the interpretation is difficult because of the thick layers of burnt material, resulting in extended anomalies with very high amplitudes. The spoil heaps from the excavations of the Typhonium

complex might further complicate the interpretation. Three rectangular building remains with the same orientation as the Typhonium complex were interpreted further south. One of these buildings most likely corresponds to tumulus WBN C204 (cf. Onderka *et al.* 2017: 99; Onderka *et al.* 2018: 103–104).

The magnetic data from the westernmost surveyed area at an elevated mound northwest of the railway mainly shows archaeological relevant anomalies with medium amplitudes, which were very likely produced by fired bricks and mudbricks. Fired brick walls are concentrated in the southern part of the mound. The orientation of the interpreted wall remains corresponds to that of the Typhonium complex. The suggestion was validated by parallel rescue excavations (Onderka *et al.* 2018a: 95–108). The very high amplitudes at the edges of the surveyed area originate from modern construction (archaeological site border stones).

In the northern part of Central Wad Ben Naga, a single area approximately 1,100 sqm was surveyed. Here a small elevation indicates a burial mound. No structures were visible at the surface. The magnetometer data clearly show alignments of dipole anomalies that are likely produced by wall remains. Interestingly, two different orientations can be derived from the linear magnetic anomalies, which are probably related to different phases of the subsurface remains.

Conclusion

The magnetometer survey at Central Wad Ben Naga reveals the following results: A large continuous area and two small separated areas (in total, approximately 9 ha) were covered using a ten-sensor gradiometer array LEA MAX. The geo-referenced magnetic data are presented in dynamic ranges of ±5 nT and ±20 nT for the vertical gradient of the z-component of the magnetic field. An interpretation scheme is introduced in which magnetic anomalies have been classified into the following three categories: archaeological relevance, natural origin, and recent effects. In total, almost 500 distinct anomalies are depicted. Most of the archaeological relevant anomalies are assigned to fired brick walls and mudbrick walls. The interpretation of magnetic data enables the redrawing of subsurface architectural remains as rectangular ground plans reflecting the fired brick walls and foundations. This interpretation results mainly in cases where there was no or only limited coverage with building debris. The interpretation of the data revealed at the elevated mounds (*koms*) is rather complicated, due to the superposition of anomalies originating from the remains of multiple building phases and scattered building debris.

Altogether, the results of this geophysical survey encourage further non-invasive investigation in order to gather data about the subsurface structures in the surroundings of Central Wad Ben Naga related to the civil township and cemeteries.

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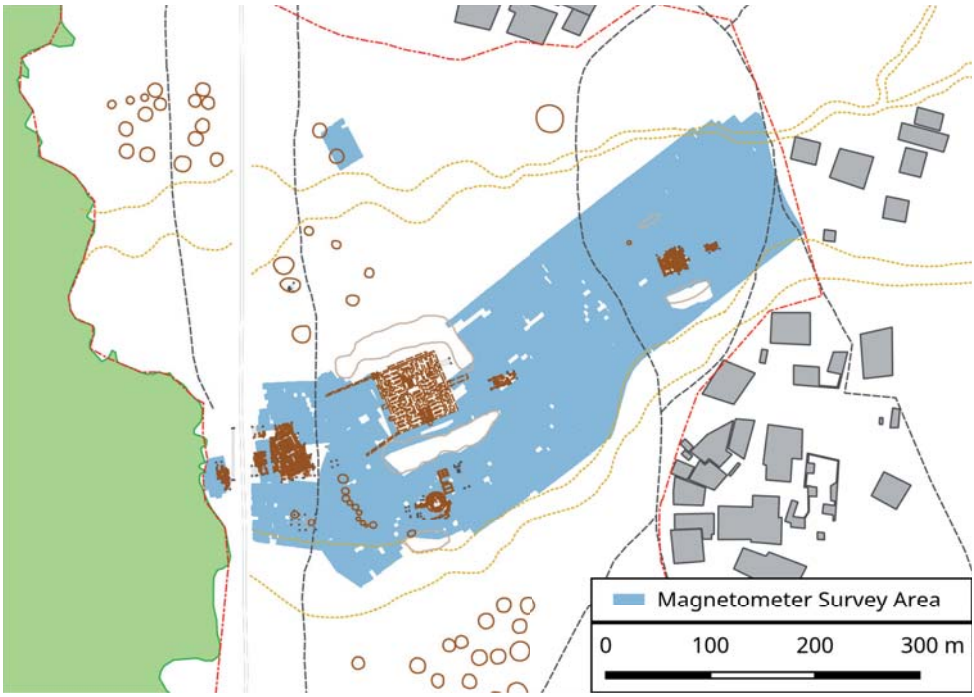
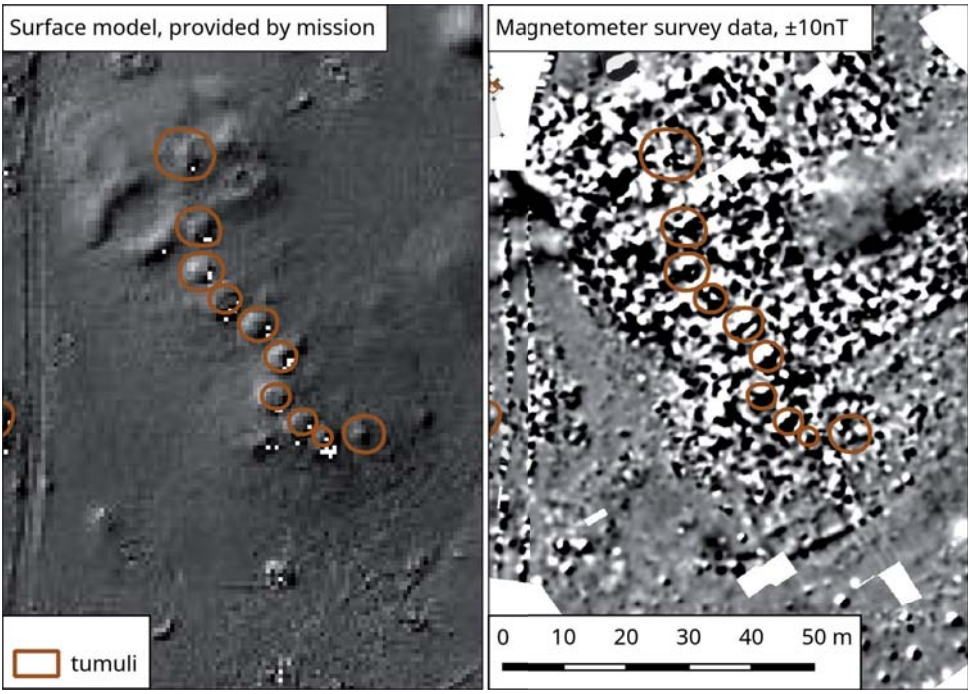
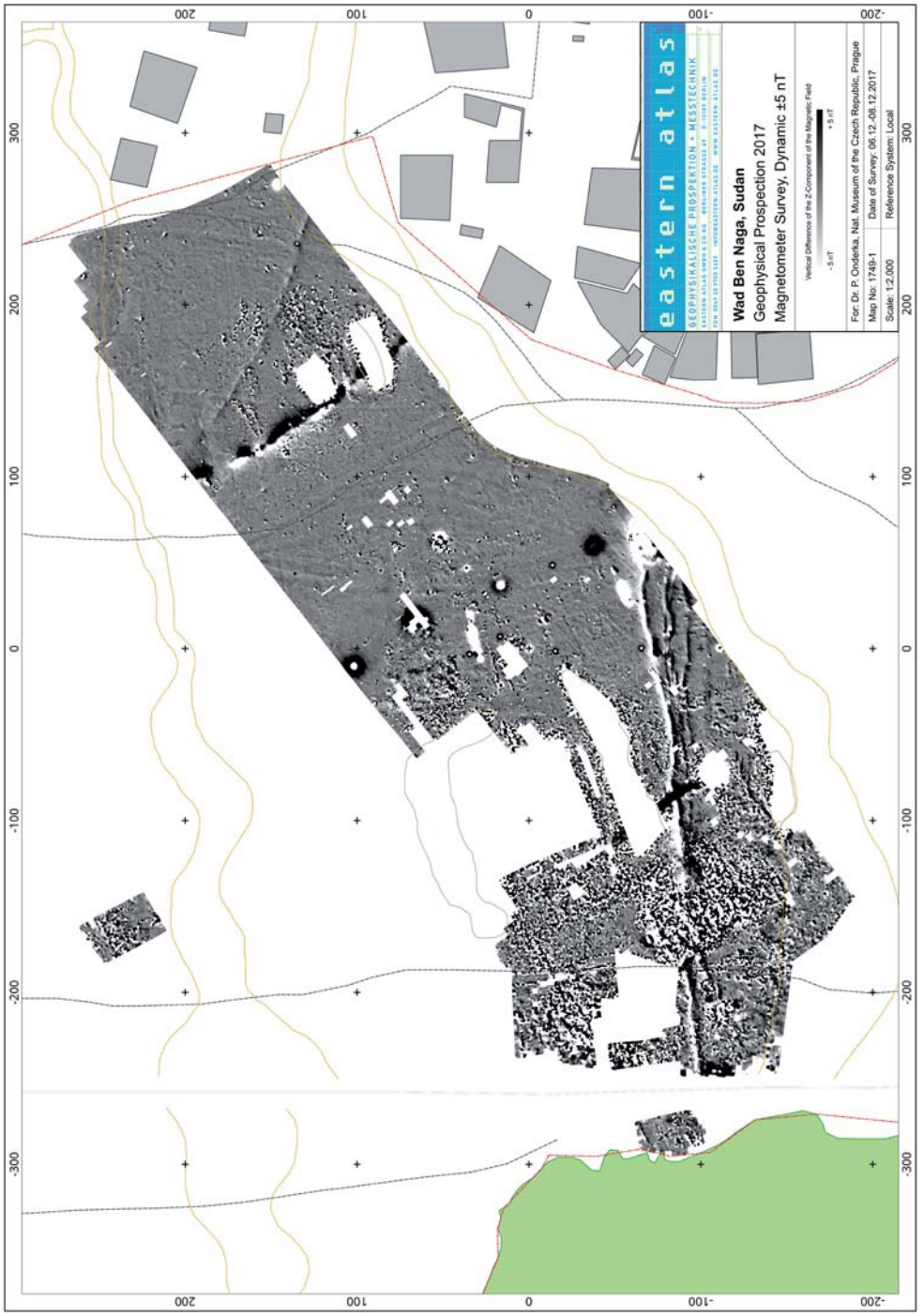
Pl. 1 Magnetometer survey with the LEA MAX system at the site of Wad Ben Naga (Photo: Pavel Onderka).



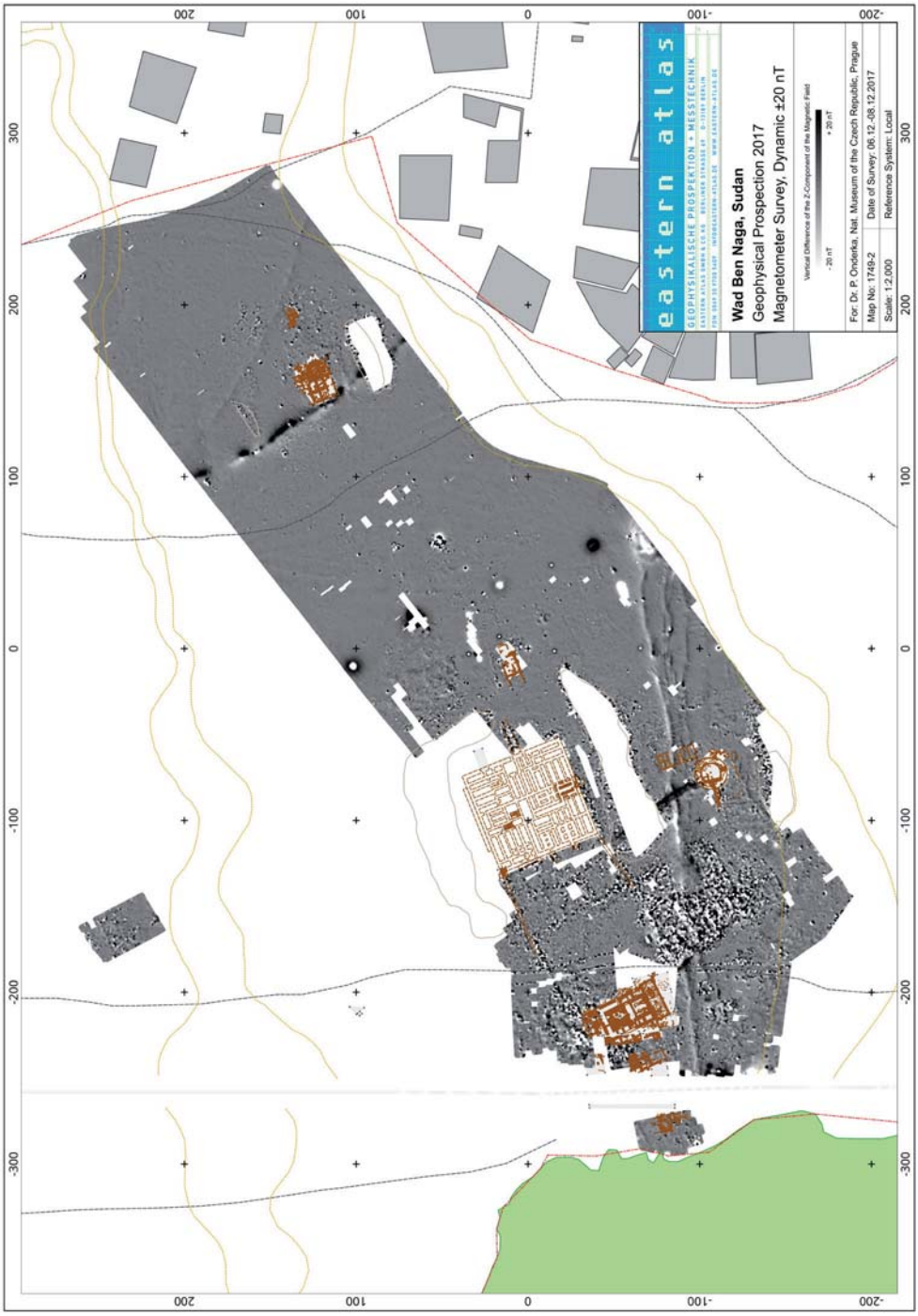
Pl. 2 Map of Central Wad Ben Naga with the surveyed area (blue) (Illustration: Eastern Atlas).



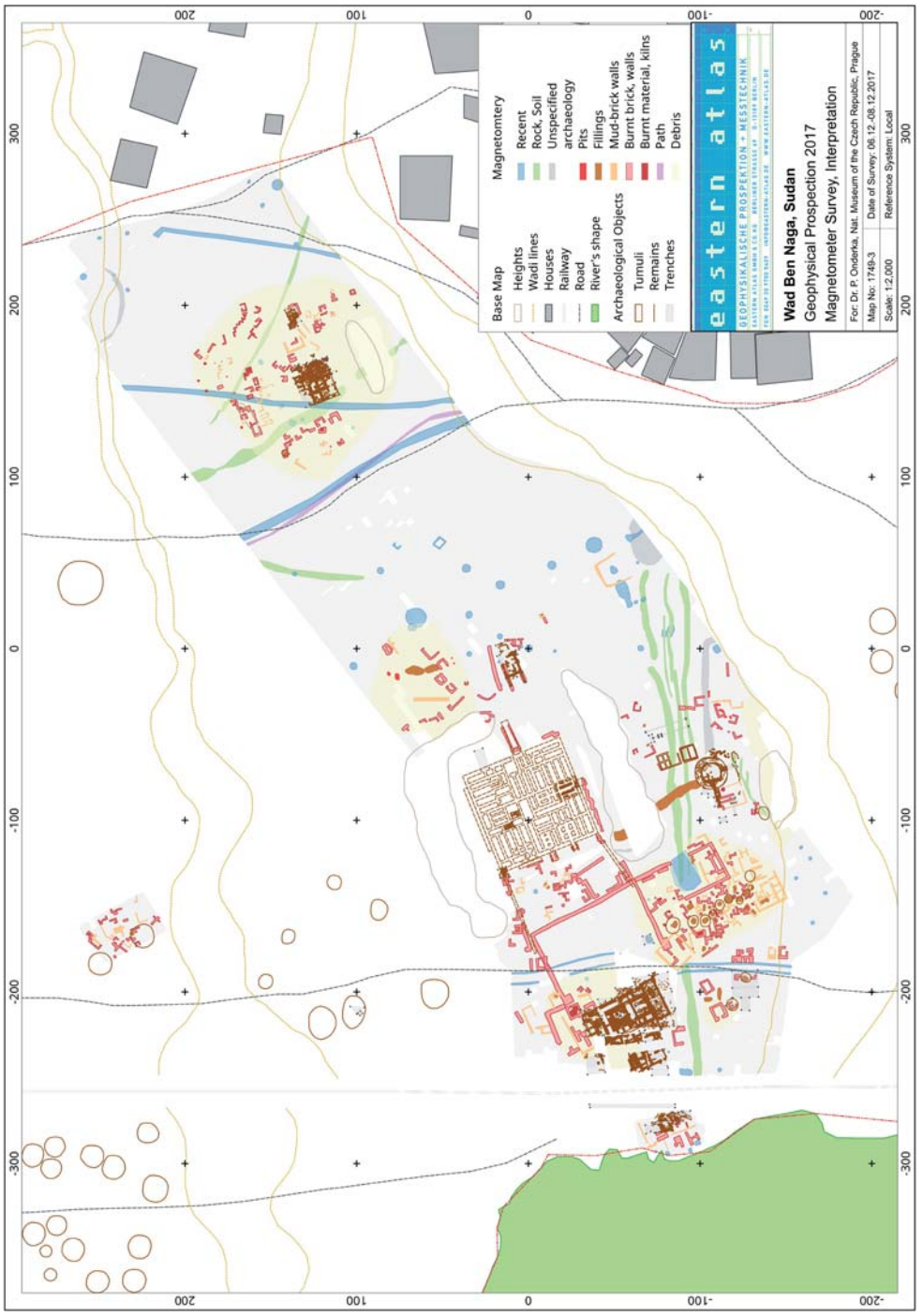
Pl. 3 Tumuli atop the kom covering the so-called Isis Temple complex (WBN 300) in the terrain data (left) and in the magnetic data (right) (Illustration: Eastern Atlas).



Pl. 4 Map 1749-1 showing the magnetometer data displayed using a grayscale dynamic of ±5 nT (Illustration: Eastern Atlas).



Pl. 5 Map 1749-2 showing the magnetometer data displayed using a grayscale dynamic of ±20 nT (Illustration: Eastern Atlas).



Pl. 6 Map 1749-3 showing the preliminary interpretation of the magnetic data (Illustration: Eastern Atlas).