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AL-YAMĀMA: GEOMAGNETIC MAPPING

Bruno Gavazzi, Rozan Alkhatib-Alkontar, Marc Munschy

To cite this version:

Bruno Gavazzi, Rozan Alkhatib-Alkontar, Marc Munschy. AL-YAMĀMA: GEOMAGNETIC MAPPING. Jeremie Schiettecatte, Abdulaziz Alghazzi. Al-KHARJ I REPORT ON TWO EXCAVATION SEASONS IN THE OASIS OF AL-KHARJ • 2011-2012 SAUDI ARABIA, 40, 2016, Archaeological Refereed studies, 978-603-8136-34-8. hal-01625146

HAL Id: hal-01625146

https://hal.science/hal-01625146v1

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الهيئة العامة للسياحة والتراث الوطني
Saudi Commission for Tourism & National Heritage
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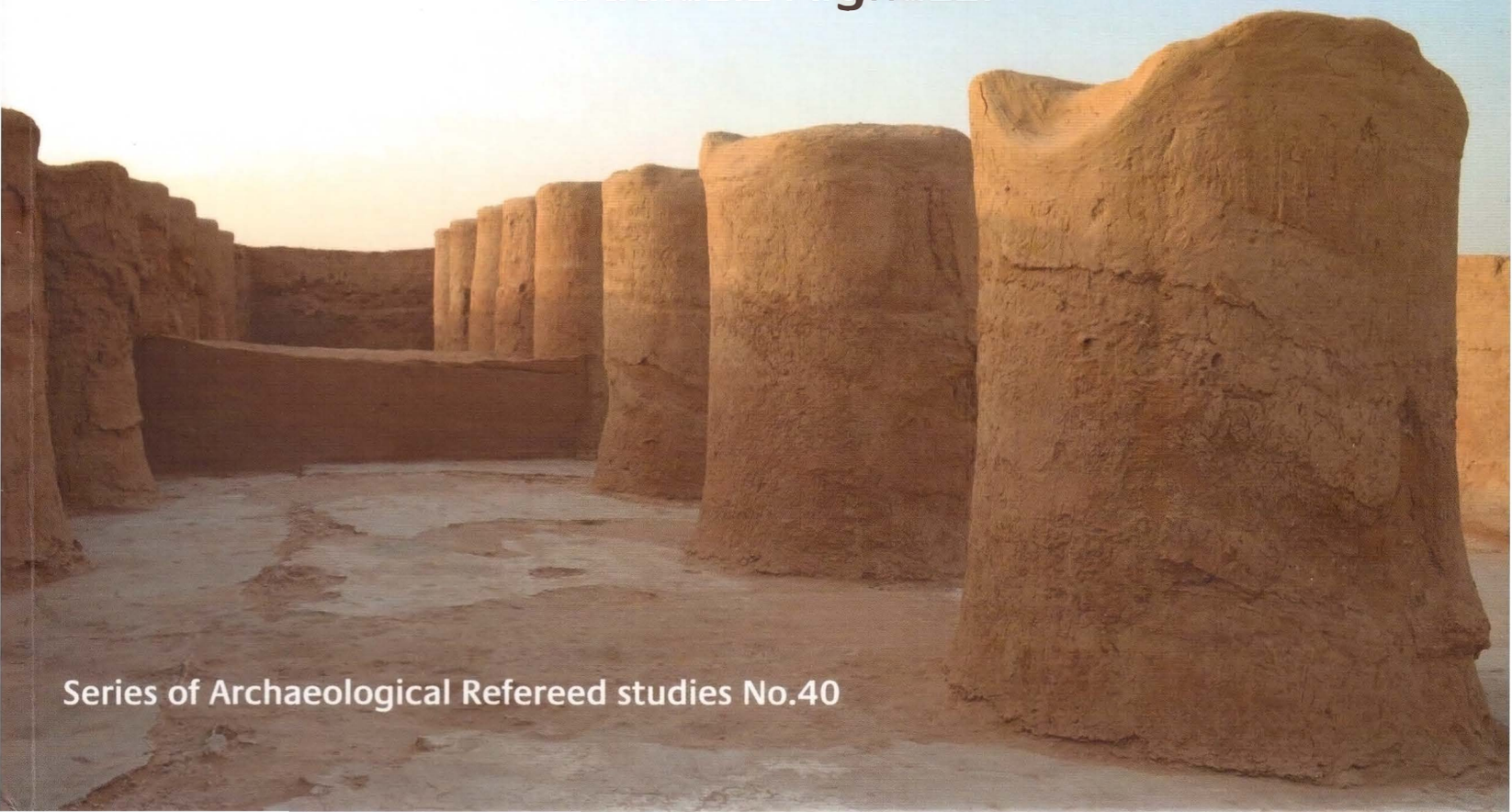
AL-KHARJ I

REPORT ON TWO EXCAVATION SEASONS IN THE OASIS OF AL-KHARJ • 2011–2012 SAUDI ARABIA

Jérémie Schiettecatte

Abdulaziz Alghazzi



Series of Archaeological Refereed studies No.40

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Riyadh
1437 - 2016

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King Fahd National Library Cataloging-In-Publication Data

Schiettecatte, Jeremie

Report on two Excavation Seasons in the Oasis of Al-Kharj 20112012- Saudi Arabia. / Jeremie Schiettecatte; Abdulaziz Al-Ghazzi.- Riyadh, 2016

388 p; 29.7x21 cm - (Series of Archaeological Refereed studies No 40)

ISBN: 978 - 603 -8136 - 34 - 8

1- Oasis- Saudi Arabia I- Abdulaziz Al-Ghazzi (co. author) II- Title

333.73609531 dc 1438 / 221

L.D. no. 1438 / 221

ISBN: 978 - 603 - 8136 - 34 - 8

Foreword

Antiquity is the most distinctive component of a country's national and cultural heritage, as well as a scientific and cultural treasure, an economic source and a cornerstone of the tourism sector.

SCTH, represented by the Antiquity and Museums Sector, offers an opportunity to scholars and experts to publish their research work, academic dissertations and studies with the goal of protecting, raising awareness and promoting Saudi Arabian antiquities through all available means, including publication and authorship.

This book is the end product of implementing the policy of the Antiquity and Museum Sector, in promotion of the objectives of the custodian of the two holy mosques program for the kingdom's cultural care, By making available scientific publications that highlight and boost the public interest and awareness about the Saudi Arabian culture, the cradle of Islam, we are able to bridge the cultural links and communication across the continents that have existed since ancient time.

SCTH president
Sultan Bin Salman Bin Abdulaziz

Glimpse

As part of the action plan for the Antiquities and Museums Sector of the Saudi Commission for Tourism and National Heritage (SCTH) has given special attention to scientific research and developed different publication venues in which results of ongoing discoveries, researches and archaeological investigations are presented so as to promote and raise public awareness and knowledge on all archaeological sites and research activities in the Kingdom, to enrich libraries with specialized publications and to provide students and researchers with valuable resources on Saudi cultural heritage.

In this regard, Antiquities and Museums Sector has released a series of publications - archaeological studies and introductory books to raise awareness among the general audience about the importance of archaeology and their role in preserving them. Further, several academic dissertations, periodicals and scientific magazines have been published.

Furthermore, SCTH is keen to provide various gateways for publications to make them accessible to the public such as CDs, electronic media and the website.

Vice-President General Supervisor on the custodian of the two holy mosques program for the kingdom›s cultural care
Prof. Ali bin Ibrahim Al Ghabban

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CHAPTER 6
AL-YAMĀMA: GEOMAGNETIC MAPPING

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Introduction

Archaeologists often deal with buried objects and structures over large surfaces. Most of the time, extensive excavations of a whole site cannot be conducted as they are highly time and labour consuming. Thus, only carefully selected parts of a site are actually excavated.

An elegant solution to localize and investigate a site at a greater scale is to use sub-surface geophysics. This discipline consists in the study of the ground from a few centimetres to hundreds of metres below the surface using non-invasive techniques. Six different methods are available. They are separated into two groups: active and passive. Seismic, electric, electro-magnetic and geo-radar methods are active, i.e. they are defined as the study of the reaction of the media to stimuli (respectively acoustic waves, DC current, low frequency AC current and high frequency AC current). Gravimetry and geomagnetism are passive. They deal with the study of disturbances in earth fields (respectively gravity and magnetic fields), i.e. inherent capacities of the medium, hence no stimuli are required for the measurements.

According to Linford (Linford 2006: 2205–2257), geomagnetism is probably the most widely used geophysical technique for archaeological purposes for two main reasons:

- the rapidity of measurement allows extensive surfaces to be covered with a high density of data within a relatively short time;
- as most of the man-made traces show a contrast of magnetization with their surrounding media, even subtle archaeological features might be identified.

At al-Yamāma, geomagnetic mapping was chosen for the same reasons. The aim was to investigate the whole site to determine the different areas of possible remains. Moreover, we used an original device based on fluxgate vectorial magnetometers, which are usually used in space and airborne studies (Primdahl 1979: 241–253; Nabighian *et al.* 2005: 33–61), in order to improve on the rapidity and density of data acquisition normally obtained with the commercial gradiometers developed for archaeology.[30]

30 Comparison of the commercial gradiometers for archaeology: Bartington & Chapman 2004: 19–34.

Method

Principle and devices

The earth's magnetic field is vectorial, i.e. it is defined for every point in space by both a direction and an intensity measured in Tesla (T). Almost 99% of the field is relatively stable and comes from deep internal sources: core, mantle, crust (Campbell 2003; Roy 2010). Around 1% comes from external sources, mainly from the interaction between the earth and the sun, and is highly time-dependant (Courtillot & Le Mouel 1988: 389–476; Thébault *et al.* 2010: 95–127). Nevertheless, local features of natural or man-made origin might generate subtle disturbances in the earth's magnetic field: the magnetic anomalies. The principle of the method is to measure and map these anomalies and to identify the ones created by humans.

In order to apply the technique, two devices were used on the site: the 'backpack' and the 'sledge'. Both work on the same principle. The difference lies in the speed and precision of the measurements.

The Backpack (**fig. 90**) is composed of the following parts:

- Four magnetometers (Bartington MG-03MC70) are fixed on an aluminium stick 50 cm apart from each other. The structure is attached to a backpack in such a fashion that the sensors lie horizontally in front of the operator, one meter above the ground.
- A GPS antenna (Trimble 5800) is fixed to the top of the backpack.
- An electronic digitizer is attached to the backpack. It acquires the magnetic and GPS data (respectively at 30 and 1 measurements per second) and stores them on a SD card. It also has a remote control to start and stop the measurements as well as to record points of interest. The digitizer is linked to a mini-PC, itself linked to a head mounted display (HMD) on which magnetic and positioning data are shown in real-time. The remote control allows the operator to interact directly with the computer without removing the backpack.

With such a configuration almost continuous and geo-referenced magnetic profiles (30 samples per second) are recorded every 50 cm, one meter above the ground.

The Sledge (**fig. 91**) uses most of the Backpack components with the following differences:

- The magnetometers are fixed at the front part of a sledge, 10 cm apart from each other and a few centimetres above the ground.
- The GPS is attached at the back, 90 cm away from the captors.
- The digitizer is fixed in the middle of the sledge.
- The mini-PC and HMD are not used.

With this configuration the magnetic profiles are acquired every 10 cm, at 10 cm above the ground.

In both cases the device is powered by a 12 V, 7 Ah lead sealed battery placed within or on top of the digitizer.

Fashion of measurement and data processing

The sessions of measurements always follow the same routine with both devices. The difference is the number of operators required for the data acquisition: a single person with the Backpack, two with the Sledge.

- *Calibration*

Fluxgate magnetometers are not absolute but relative devices. Each sensor shows its own errors in offset, sensitivity and angle. In order to get the same signal from each of the four

captors they must be calibrated at the beginning and end of each session of measurements: the device is rotated in all directions above a fixed point where it is assumed that the magnetic field is constant and therefore that the measured disturbances are only due to the device itself. Corrections can then be calculated by different mathematical methods. The approach for the calibration of the magnetometers of the Ørsted satellite (Olsen *et al.* 2003: 11–18) was selected because of its proven efficiency in the detection of unexploded ordnance (UXO) with the same device (Munschy *et al.* 2007: 168–183).

- *Static measurements*

On the site the effects of the change of temperature on the sensors and the diurnal variations of the magnetic field due to external sources are both sources of time-dependant variations. At the scale of a session of measurement (60 to 90 minutes) both are assumed to create a linear drift, which can be easily corrected by measuring the differences over a same point (the static point) at the beginning and end of each mapping session.

- *Mapping*

The device is carried along pre-set routes (every 2 m for the Backpack, every 50 cm for the Sledge) in a back and forth fashion. The beginning and end of each route is recorded using the remote. Thus magnetic profiles are acquired every 50 or 10 cm over the whole area of investigation.

- *Data processing*

Once the data are calibrated and the time-dependant variations corrected, the magnetic anomalies are calculated along each profile by subtraction between the measured total field and a modelled regional field. By interpolation between each profile a grid of the magnetic anomalies of the area is generated and displayed for interpretation.

Results

During the two field campaigns, around 180 km of profiles were measured with the Backpack. This corresponds to an area of approximately 30 hectares divided into four different zones (**fig. 92**):

- 1/ Three quarters of the site within the fences;
- 2/ A test in the cemetery outside the western wall;
- 3/ A test in the south-west, close to a camel enclosure, where some fossilized agricultural structures are still visible on the surface.
- 4/ A fourth zone of 1,875 m² was covered with the Sledge.

The Backpack

- *Zone 1*

In the first zone numerous elements can be observed (**fig. 93**). The anomalies on the edges are most likely due to the structures closing the area: a wall on the west and a metallic fence elsewhere. These differences of sources explain the differences of the shapes of the anomalies. In addition, the massive anomalies in the north are most likely due to the buildings across the access road.

Apart from these, two other main types of anomalies can be identified: bodies of very low frequency which are probably linked to the underlying geology, and higher frequency anomalies forming lines. Some of the latter are due to remains of walls still visible on the

surface. Because of the similarities of the signal it may be assumed that the other lines correspond to similar structures which have been completely buried. In this way the magnetic map can be used as a tool to fill the gaps between different surface elements as well as finding new ones.

Figure 94 displays both the walls visible on the surface and the magnetic lines. The latter are less precise than the former but allow the completion of some walls, especially in the northern part. In the south and the west, the anomalies reveal unexpected structures. However, the eastern part seems to be empty of any remains, apart from one long east–west structure. Only a few more structures are present in the central-western part. Thus it seems that the area is composed of two main zones with a high density of remains: one in the north and one in the south. Nevertheless the south-western quarter still needs to be investigated to understand the full extent of the south area.

Another type of anomaly can also be noted: small dipolar anomalies (**figs. 97–98**). They could be linked to metallic waste (barrels, car pieces, etc.) as well as ancient kilns for ceramics or smith work. Further investigation is required before drawing any conclusions.

- *Zone 2*

On the second zone (**fig. 95**) low frequency anomalies can be observed. They are most likely due to underlying geological features except for the square anomaly in the south (within the black circle). Such shapes are often related to human activities. Further analyses (excavation or other geophysical investigations) would be required to confirm or invalidate a human origin. The same reflection can be applied to the line pointed out by the arrows. Given these facts it seems that the area is worth further investigations.

- *Zone 3*

On the third zone (**fig. 96**) the only noticeable element is an east–west alignment showing an anomaly of more than 1,000 nT. This could easily be caused by the metal water-pipe whose opening is visible a few hundred metres to the east. From an archaeological point of view, the lack of other structures would indicate that further measurements do not seem relevant.

The Sledge

The measurements with the Sledge (**fig. 97**) were carried out above a zone where a concentration of misfired and wasted pottery sherds (usually found close to kilns) is visible on the surface (zone 4 on **fig. 92**; area L7 and L8 on **figs. 85–86**). There, the magnetic map obtained with the Backpack (**fig. 98**) shows a strong anomaly which could be interpreted as the trace of the burning place of a kiln.

Despite a problem of calibration on the south-western part of zone 4 (**fig. 97**), different structures can be seen with a greater precision than with the Backpack (**fig. 98**). The alignments are most likely due to walls (arrows). Parts of them are visible on the surface (**fig. 98**) and the anomalies reveal their continuation underground. The centre of the strong anomaly in the south-west could be the location of a ceramic kiln (marked by a circle on **fig. 97**).

Conclusion

The magnetic cartography conducted on the site of al-Yamāma proved the efficiency of the use of vectorial magnetometers for archaeological purposes. The method also showed an important complementarity with the surface surveys which gave precise information for

the interpretation of the sources of the signal. In fact, the results obtained with the Backpack revealed the presence of two main areas with a high density of buildings partly or totally covered by sand: to the south-east and in the centre-west of the site. Moreover, the technique allowed the surrounding areas to be investigated to detect zones of potential interest.

However, comparison with the surface structures showed that only the main elements could be mapped in such fashion. A solution to this lack of precision was found by using the Sledge on a targeted zone. The map obtained this way revealed much subtle details at the cost of speed of measurements.

Thus, the combination of the two devices proved to be a powerful tool to investigate the sub-surface of al-Yamāma. In order to complete the study, the south-western quarter as well as targeted areas will be mapped using the Backpack and the Sledge in the next field season.

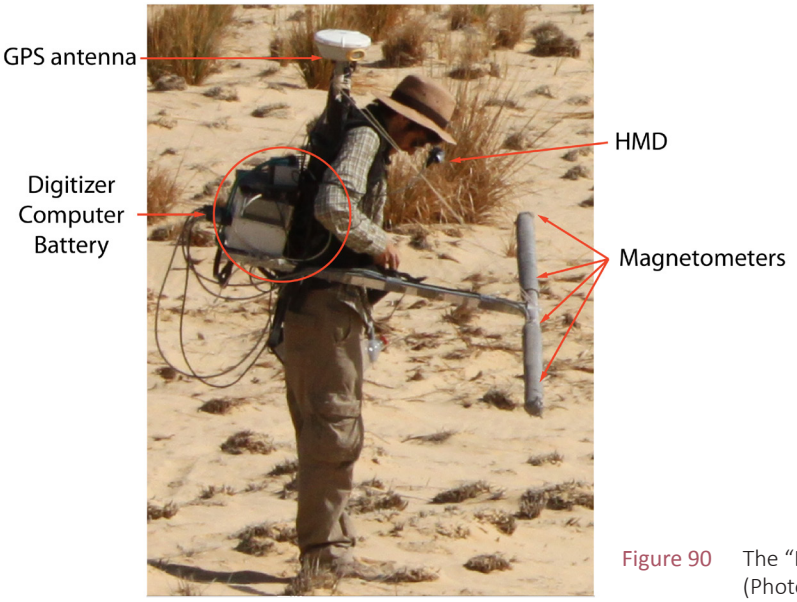


Figure 90 The “Backpack” device (Photograph: F. Colin)

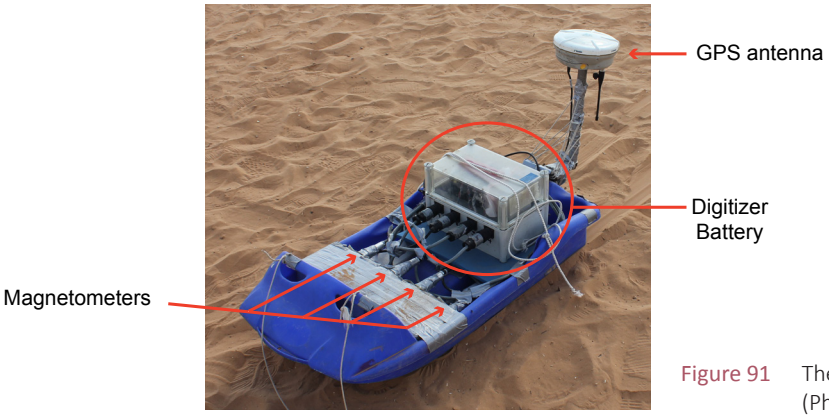


Figure 91 The “Sledge” device (Photograph: B. Gavazzi)

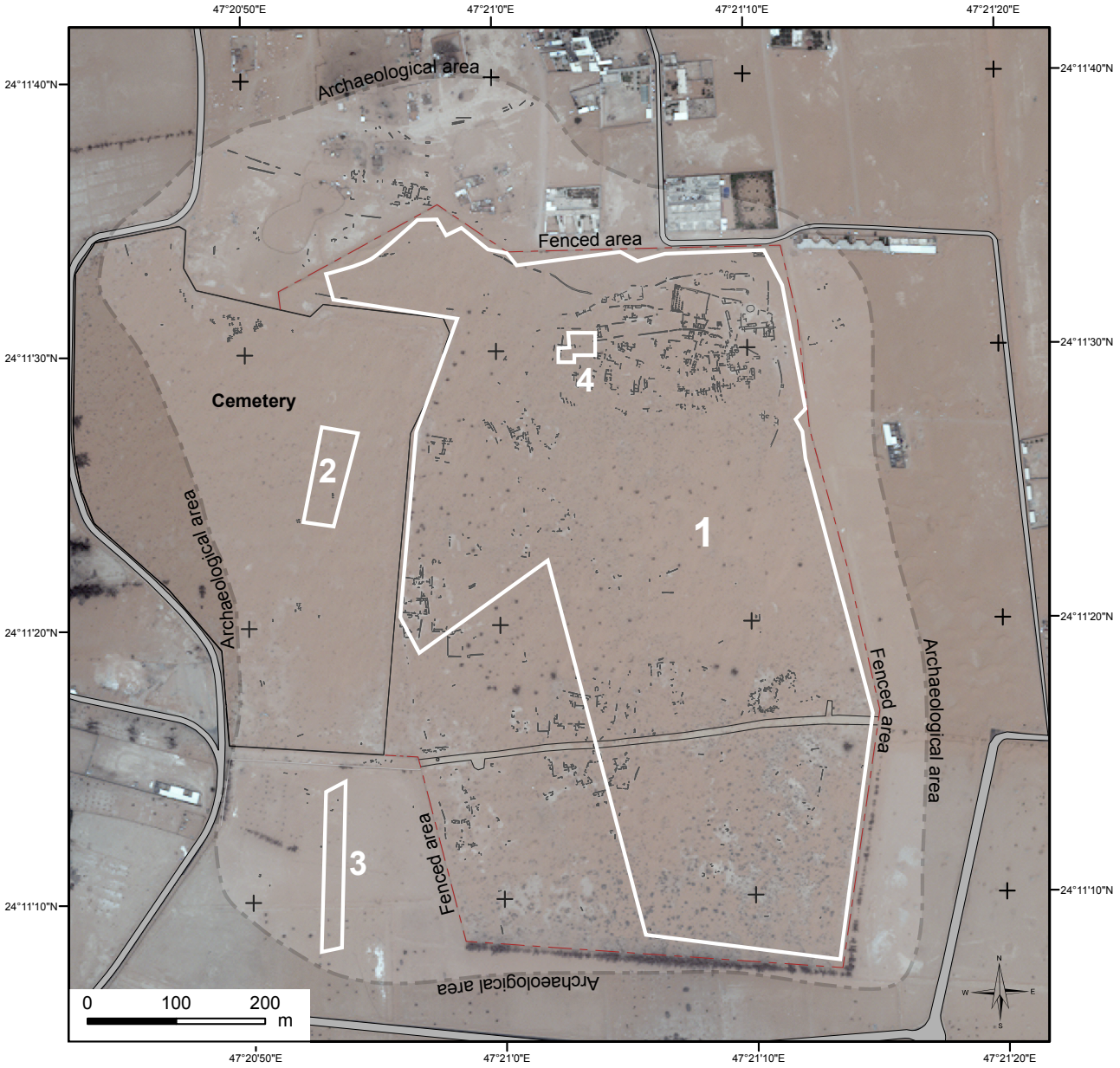


Figure 92 Al-Yamāma: map of the different zones of geomagnetic survey. Zones 1, 2 and 3 were investigated with the Backpack, Zone 4 with the Sledge (B. Gavazzi, J. Schiettecatte – French-Saudi Archaeological Mission in al-Kharj/Includes World-View-2 Products © DigitalGlobeTM, distributed by e-GEOS)

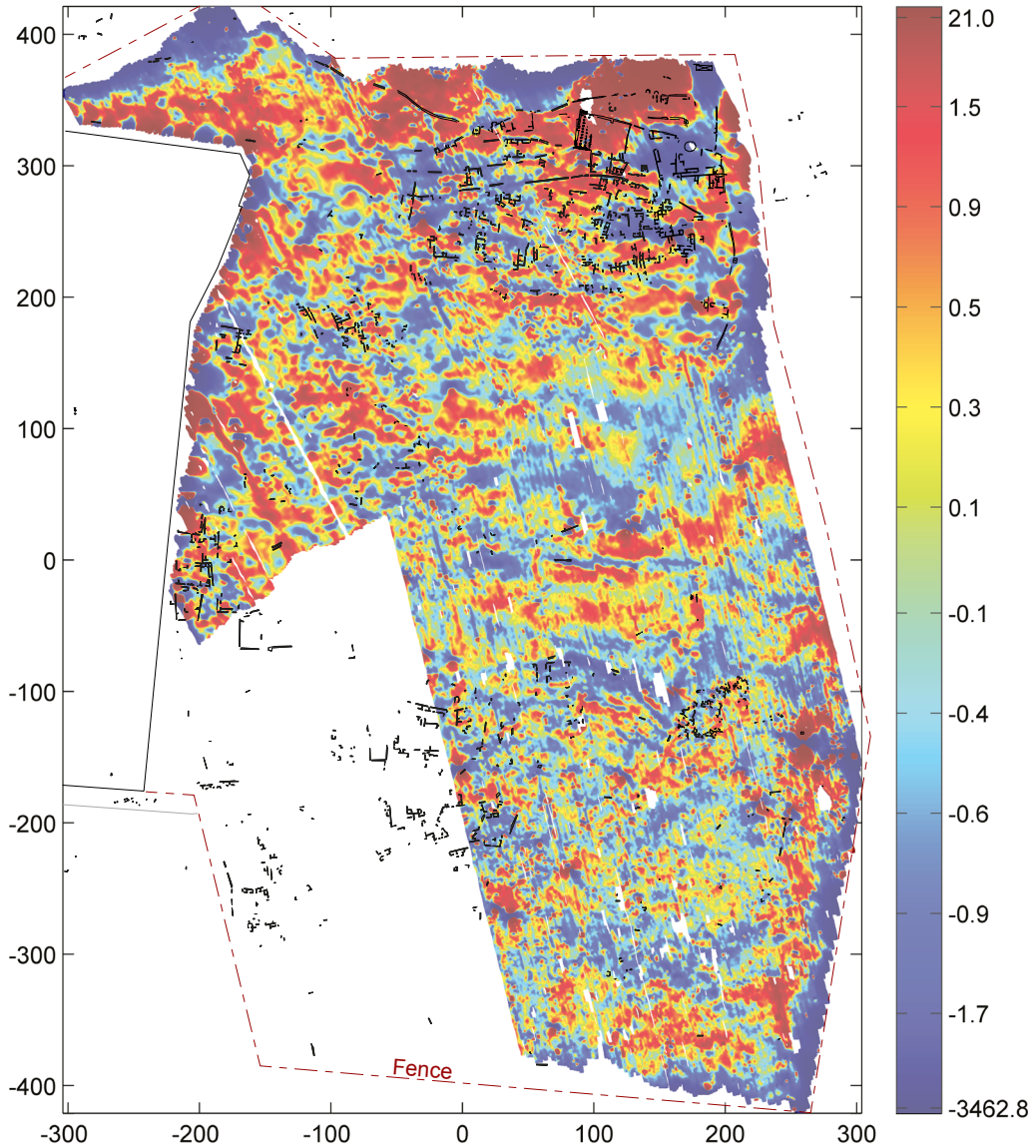
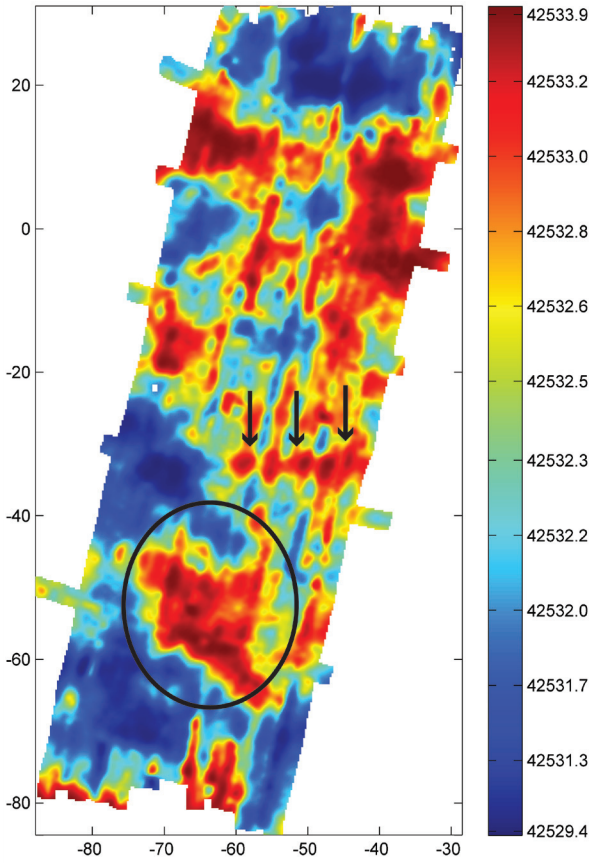


Figure 93 Al-Yamāma: superimposition of archaeological remains visible on the surface over the map of the magnetic anomalies of the zone 1. Scale in m, colour-bar in nT, mudbrick walls in black (B. Gavazzi, R. al-Khatib, M. Munschy; design: B. Gavazzi, M. Niveleau, J. Schiettecatte)

Figure 94 Al-Yamāma: map of the archaeological structures visible on the ground and reconstitution of the layout of underground structures according to magnetic data (B. Gavazzi, M. Niveleau, J. Schiettecatte – French-Saudi Archaeological Mission in al-Kharj)



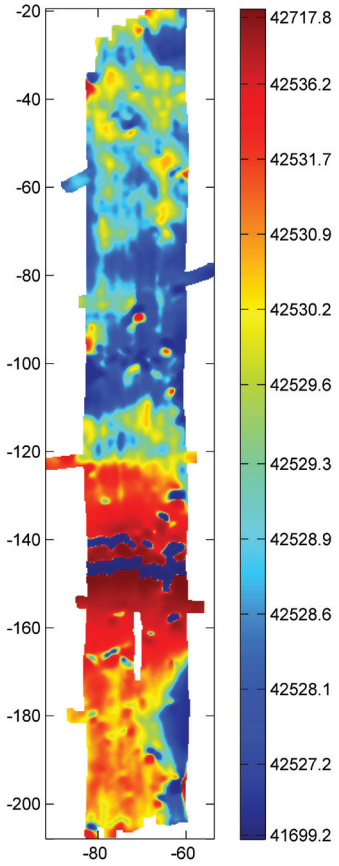


Figure 95 (left) Al-Yamāma – zone 2 of the geomagnetic survey: map of the magnetic anomalies. Scale in metres, colour-bar in nT (B. Gavazzi)

Figure 96 (right) Al-Yamāma – zone 3 of the geomagnetic survey: map of the magnetic anomalies. Scale in metres, colour-bar in nT (B. Gavazzi)

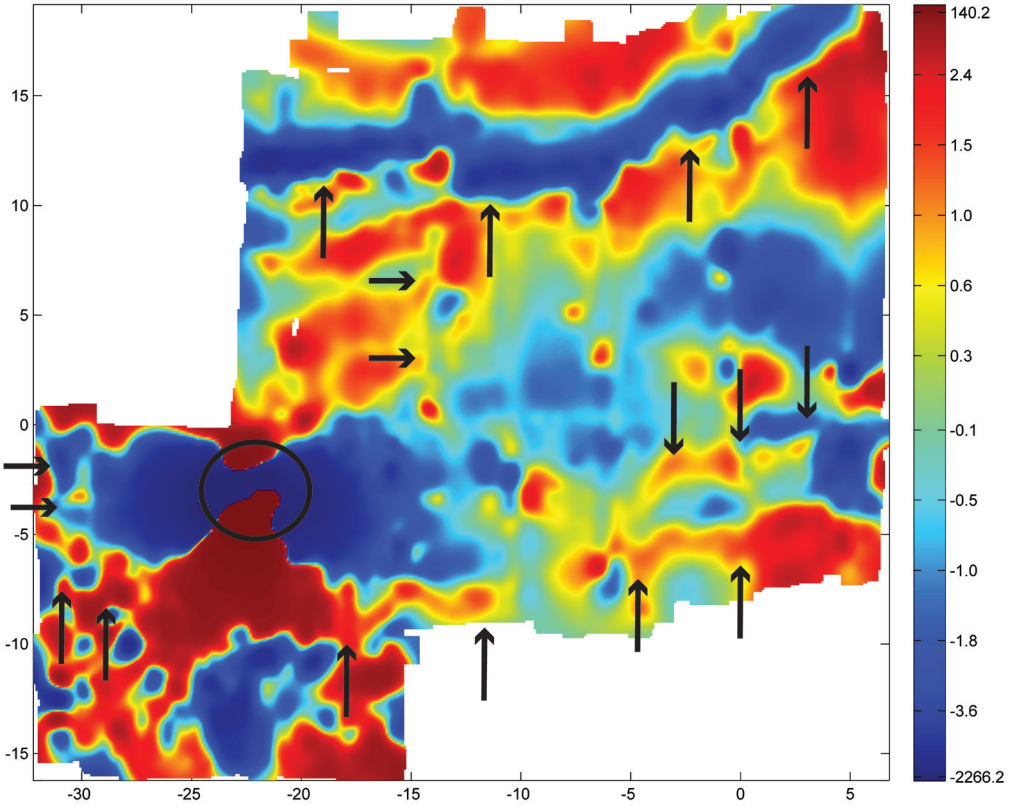


Figure 97 Al-Yamāma – zone 4 of the geomagnetic survey: map of the magnetic anomalies. Scale in metres, colour-bar in nT (B. Gavazzi)

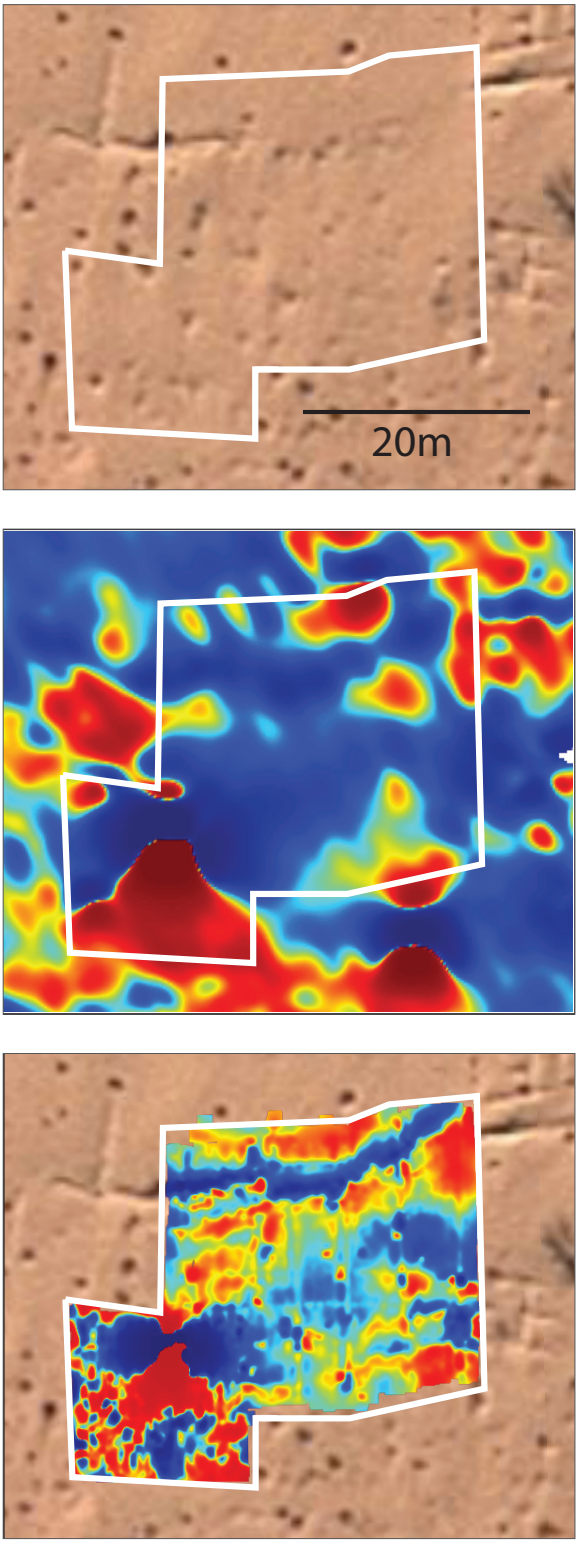


Figure 98 Al-Yamāma – zone 4 of the geomagnetic survey: comparison between satellite image (left), Backpack map (middle) and Sledge map (right) (B. Gavazzi)

APPENDIX 11

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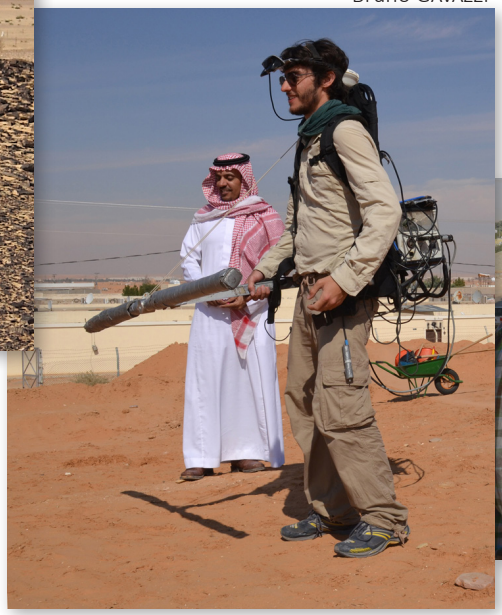

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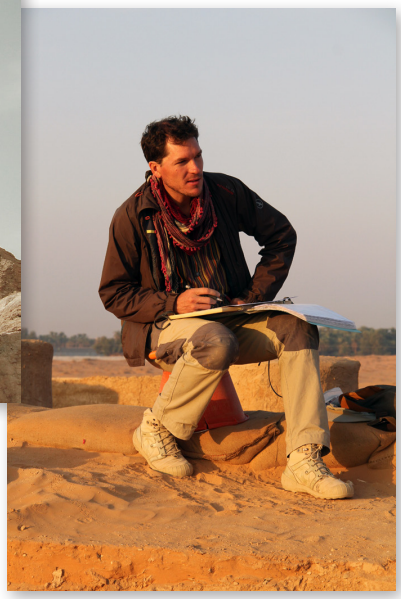

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