Archaeological Prospection
Archaeol. Prospect. **12**, 61–68 (2005)
Published online 31 January 2005 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/arp.245

Gradiometer Survey to Locate the Ancient Remains Distributed to the Northeast of the Zoser Pyramid, Saqqara, Giza, Egypt

H. ODAH,* T. F. ABDALLATIF, I. A. EL-HEMALY AND E. ABD EL-ALL

National Research Institute of Astronomy and Geophysics, 11722 Helwan, Cairo, Egypt

ABSTRACT The whole area to the northeast of Zoser pyramid, Saqqara, Giza, Egypt, is characterized by the distribution of a variety of tomb structures of the 1st and 2nd Dynasties. The main objective of undertaking a gradiometer survey is to detect the ancient remains as well as other archeological features hidden in this important area. A gradiometer survey with a raster of 0.5 m × 0.5 m has been carried out over a surface area of 100 m × 100 m to achieve the purpose and the magnetic data were processed using Geoplot software in order to obtain high quality images of the hidden structures. The results obtained show the presence of interconnected large tomb structures composed of mud-bricks; some other ancient rooms and walls are also present. The historical background of the study area confirms the existence of such tomb structures. Copyright © 2005 John Wiley & Sons, Ltd.

Key words: magnetic; gradiometer; ancient remains; Zoser pyramid; Saqqara; Giza

Introduction

Saqqara is characterized by an ancient and interesting history. In particular it was the main place of burials of different dynasties, and also has more than ten pyramids including the most famous one (Zoser). The upstanding remains make Saqqara a great attraction for visitors and also a significant role for the studies of researchers and archaeologists. However, the wide area located northeast of the Zoser pyramid (Figure 1) contains no known remains and therefore is an interesting place for investigating this site using geophysical surveys and techniques.

From the archaeological point of view, Egyptian and foreign archaeologists have studied many sites in the whole area of Saqqara. From the geophysical point of view, however, fewer studies have been done to investigate this important area. This encourages us to carry out a detailed magnetic survey in order to assess the buried archaeological features, which are expected to be found at shallow depths, with less effort, time and money.

The magnetic method is the most widely used method in prospecting for archaeology all over the world (Aitken, 1974; Clark, 1990; Scollar *et al*., 1990). It has been used extensively at many sites in Egypt (Abdallatif, 1998; Odah *et al*., 1998; Kamei *et al*., 2002; Ghazala *et al*., 2003; Herbich, 2003), including Saqqara (Elbassiony, 2001; Khozym, 2003), and has produced impressive results for buried mud-brick structures and features (rich with magnetic minerals), which show a reasonably high magnetic gradient.

A gradiometer survey has been applied in the present study in order to detect the archaeological features made of mud bricks or fire bricks. The application of the magnetic method will evaluate and help in the conservation of the

* Correspondence to: H. Odah, Geomagnetism Laboratory, Liverpool University, Oxford Street, Liverpool L69 7ZE, UK. E-mail: hatemodah@yahoo.com

Received 1 September 2003
Accepted 7 December 2004

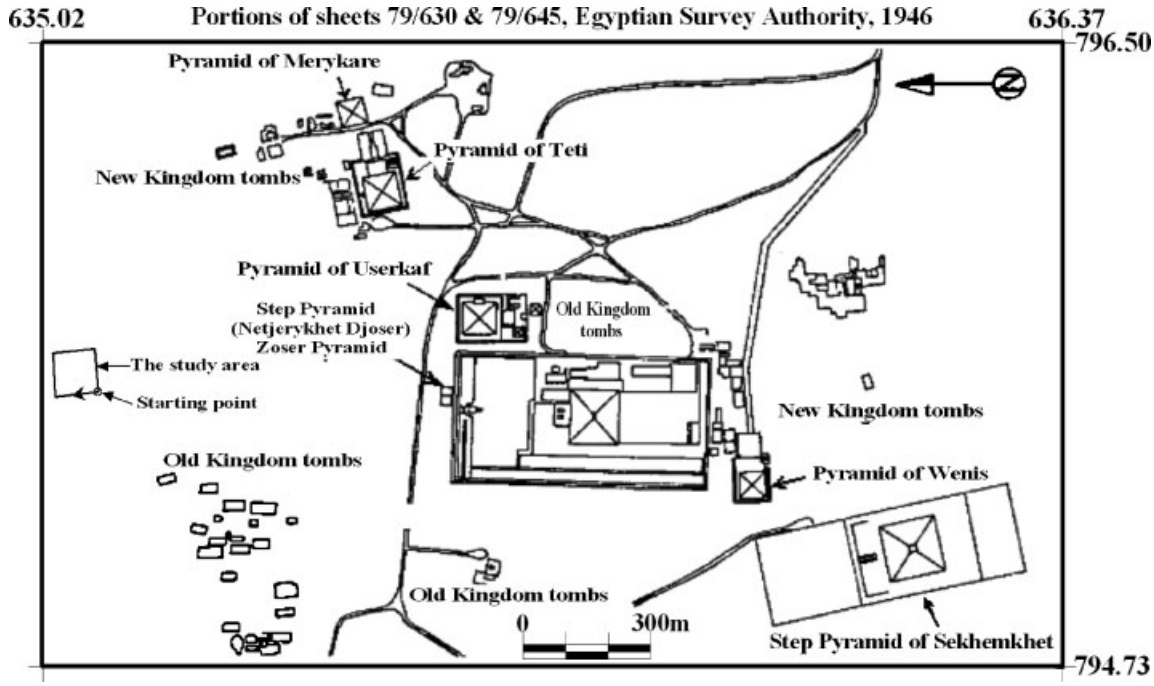

Figure 1. Location map of the Saqqara archaeological site, including the study area.

hidden monuments at Saqqara by focusing on the areas of interest.

Archaeological background

Saqqara (3000 BC), south of Cairo, covers an area of 6 km from north to south and 1.5 km from east to west. It is one of the largest and most important areas of archaeology in Egypt (Figure 2). Fifteen royal pyramids have been discovered in Saqqara. The most conspicuous landmark of Saqqara is the step pyramid, the tomb of the 3rd Dynasty ruler Zoser, which is probably the earliest major stone structure erected in Egypt (Baedeker, 1978).

Ancient Egyptians believed that deceased rulers, their families and their courtiers would live as they had on Earth if necessities were provided for their comfort and existence (Rogers, 1992). So tombs were built and furnished with comforts of the home: food, wine, pottery, furniture, games, weapons, small clay servants to perform necessary work, chests of garments and jewelry. In the afterlife, the Weighing of the Heart in the Hall of Judgment measured the heart of the deceased against Truth, symbolized by a feather of the goddess Maat. Travel to the afterlife took place on a solar or funerary boat through the sky (Rogers, 1992). The history of Saqqara can be divided into the following main stages:

Before pyramid construction (Dynasties 1 and 2)

The earliest royal name, which the archaeologists have so far found at Saqqara, is that of Na'rmer, whom some Egyptologists equate with Menes, the legendary founder of Memphis. It is engraved on a porphyry bowl which, together with thousands of other complete and fragmentary vessels of magnificent craftsmanship, was discovered in one tomb of a later date, dating to the reign of King 'Aha (Menes according to another school of thought, probably Na'rmer's successor).

Mastaba tombs of the 1st Dynasty lie in an almost continuous line along the eastern side of the large plateau north of the step pyramid of Zoser, above the modern village of Abusir. The generally smaller private Mastaba of the large tombs of the 2nd Dynasty continued to be built in

Figure 2. The Zoser pyramid.

an apparently haphazard way in the area west of the large tombs of the 1st Dynasty.

The pyramid builders (Dynasties 3 to 13)

Saqqara contains many interesting monuments, which have been recorded by many authors (Seton-Williams and Stocks, 1993). Nowadays, Saqqara has ten recorded royal pyramids, named Unas, Horus Sekhemket, Zoser, Userkaf, Teti, Pepi I, Merenre, Djedkare Isesi, Pepi II and Userkare Khendjer. The most splendid of these is the step pyramid of Zoser (mainly stone), which is considered as unique in the Egyptian architecture. It was built by Imhotep, the chief of works of Zoser and second king of the 3rd Dynasty (Seton-Williams and Stocks, 1993).

The New Kingdom

Private tombs representing only the important burials of the period immediately preceding the rise of the 18th Dynasty have so far been found at Saqqara. New Kingdom tombs, as known at present, are concentrated in two areas of Saqqara: (i) in the vicinity of the pyramid complex of Teti; (ii) in the area south of the causeway of Wenis, defined by the ruins of the Coptic monastery of Apa Jeremias to the east and the pyramid enclosure of Sekhemkhet to the west.

The Late and Greco-Roman Periods

During the 26th Dynasty the designers of Egyptian tombs apparently achieved what they had attempted in vain for the previous two millennia: they designed an almost completely secure tomb. The majority of the tombs of the Late and Greco-Roman Periods are near the step pyramid enclosure. However, the area of Saqqara also contains different kinds of Mastaba. In the northwest of the area, Serapeum, the burial place of the Apis bull, can be seen; also called the House of Osarapis by the Ancient Egyptians (Seton-Williams and Stocks, 1993).

Previous geophysical work

The whole site of Saqqara is an attractive place for scientists and archaeologists, and studies at this interesting area are continuous. Geophysical investigations involving the application of geophysical tools in detecting and evaluating the

archaeological setting of the Saqqara archaeological site have been undertaken regularly.

In 1995, magnetic prospecting for archaeology in Saqqara was applied by Myslivwiec and Herbich (the Polish Archaeological Center in Egypt) using a proton magnetometer, and producted very distinct results, especially for mud-brick burials included in sandy desert.

North of the Polish team area, exactly at the western side of Zoser pyramid, a gradiometer survey has been carried using a fluxgate gradiometer over an area of 46 500 m^2 (Abdallatif, 1998). The results obtained showed the presence of tombs, kilns, ring gullies, ritual sites and remains of ancient walls.

At the end of 1999, a geophysical survey including the magnetic method was carried out at the northeastern side of the Zoser pyramid using a fluxgate gradiometer, over an area of 10 000 m^2 (Elbassiony, 2001). The results pointed to the existence of three NW–SE orientated tomb structures made of mud bricks.

During of 2001, another geophysical study including use of the magnetic method took place at the northeastern side of the Zoser pyramid, about 120 m from the previous work of Elbassiony along the same direction. A fluxgate gradiometer was used in the magnetic survey over an area of 12 000 m^2 (Khozym, 2003). The results revealed the existence of similar NW–SE orientated tomb structures made of mud bricks, with some wells and dissected walls.

It has been shown that the previous geophysical work in Saqqara was dependent mainly on the magnetic results and confirmed the possibility of obtaining high quality results using magnetism only. In the present work, therefore, the magnetic method was applied in order to locate the ancient remains distributed at the northeastern part of the Zoser pyramid.

Magnetic data acquisition

The acquisition of magnetic data has been done using fluxgate gradiometer FM36 (Geoscan Research, 1987) to cover a surface area of 100×100 m (10 000 m^2). The study area was divided into 50 grids to facilitate the survey process. The dimension of each grid was set to 20×10 m. The field accessories such as measuring tapes, wedges, etc., were made of non-magnetic materials. The tapes were marked at 0.5 m intervals for accurate and fast survey. Routinely in gradiometer surveys, the instrument is balanced and zeroed at a selected zero reference point, normally situated in a stable magnetic field. The fluxgate gradiometer (FM36) was set to a sensitivity of 0.1 nT. Its height above the ground surface was about 0.15 m. The measurements started from the top left-hand corner of the study area at 0.5 m intervals with a zig-zag traverse pattern. The readings obtained were then downloaded to a microcomputer three times owing to the small memory of the instrument with respect to the surface area of the surveyed site. The total number of readings of the study area is 40 000.

The preliminary results obtained are represented in a grey colour scale using Geoplot software to show the acquired gradiometer raw data (Figure 3). The gradient of the vertical component of the geomagnetic field ranges from −14.0 to +14.0 nT (The actual range after clipping the obtained data). The resultant magnetic image looks unclear and disturbed with noise that makes it difficult to interpret. However, it shows some features requiring some processing steps to be more enhanced and smoothed for interpretation.

Magnetic data processing

The gradiometer survey is normally accompanied by some field errors and noise owing to the relatively high sensitivity of the instrument, weather conditions at the time of the survey, and also the experience of the operator. Removal of these errors and noise is significant in our present study in order to enhance the presentation of the data obtained and also to facilitate the interpretation process.

The field errors and noise in the present study are mainly summarized as tilting of the FM36, discontinuities at grid edges, striping of traverses and displacement of the obtained features. However, enhancement of the data obtained has also been extended to removing the effects of scattered iron objects and hidden high-frequency objects.

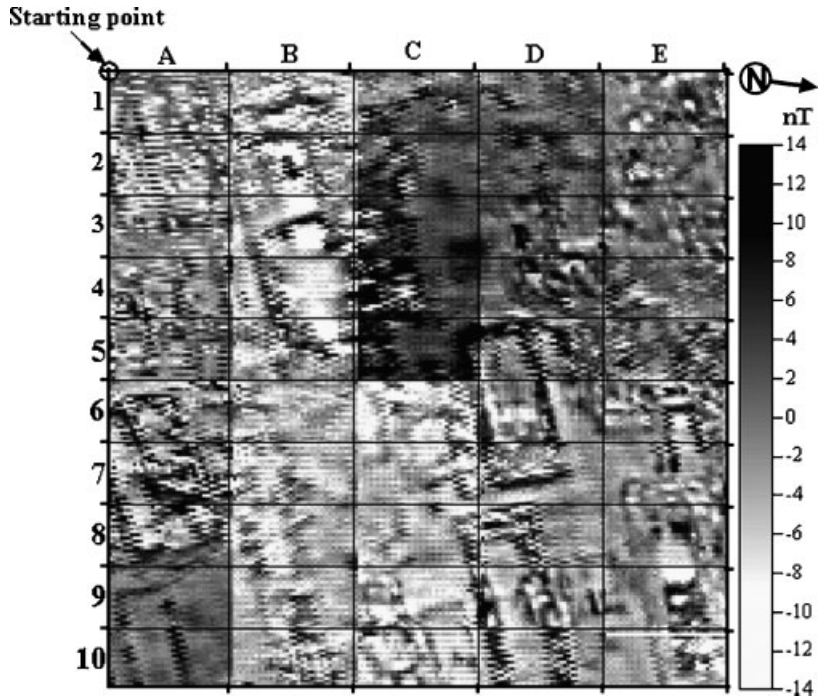

Figure 3. Magnetic image showing the raw data of the study area at Saqqara.

Geoplot software (Geoscan Research, 1994) has been used to process the acquired gradiometer data. Geoplot has many functions for this purpose, such as zero mean grid, zero mean traverse, despiking, destaggering, low-pass filter and clipping.

The grid edge discontinuities have been treated by the application of zero mean grid (ZMG) with a threshold value = 2.5 standard deviation, and the stripes between traverses have been removed by the application of zero mean traverse (ZMT) with least mean square fit.

The study area was cleaned of any obvious iron materials before starting the corrections. The data were clipped initially (−14/14 nT) to remove the high frequencies resulting from any expected surface iron spikes. Also, the despike function (K) was applied for more enhancement and good presentation.

Stagger defects arising due to a simple mispositioning of the instrument along the zig-zag traverse have been corrected using the destagger function, which displaces the even numbered traverse of the specified grid in the X direction by an integer amount (positive or negative). Figure 3 shows obvious displacements for the resultant archaeological features in several grids. These displacements have been corrected by separately dealing with each grid. An even traverse shift of +1 m has been applied to correct the displacements at grids A3, A4, A5, B2, C2 and E10, and a traverse shift of −1.5 has been applied to correct grid D10. Also, a traverse shift of 1.5 has been applied for grids A8, A10, B9 and B10, and a traverse shift of 2 has been applied for grids A9, B8, E4, E5 and E6.

To smooth the magnetic data of Figure 3, a Gaussian low-pass filter has been applied to remove the high frequencies as well as to enhance the weak anomalies of deep archaeological features. The low-pass filter parameters were set to X and Y radii = 2. The resultant processed magnetic image is presented in Figure 4. It is considered the best magnetic image following the application of all the processing functions.

Results and discussions

The application of the magnetic method to mudbrick remains at Saqqara appears to have promising results, supported by some previous

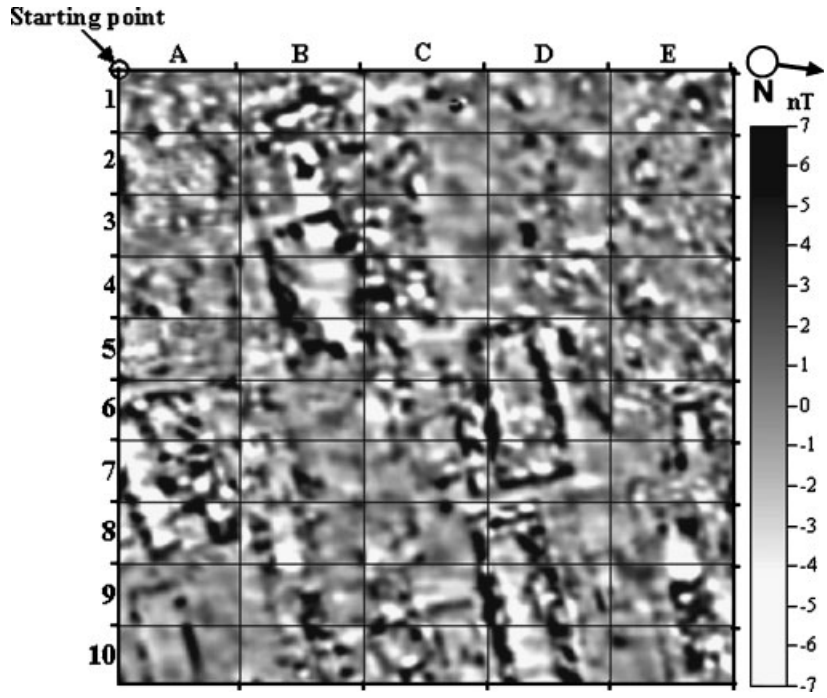

Figure 4. Magnetic image of the study area at Saqqara after application of the processing functions of the Geoplot program.

studies around the study area. In the present study the archaeological features obtained (Figure 5) show similar anomalies, trends, thickness, elongation and polarities. This suggests the continuation of the same regime ruler (1st and 2nd Dynasties) in this important area.

Moreover, the resultant magnetic image of the northeast area of the Zoser pyramid (Figure 5) has shown buried archaeological remains formed of mud bricks represented by near-surface features with enhanced magnetic susceptibilities. However, the study area in general shows no traces of any past industrial activity. The image shows the existence of linear features parallel to each other and on the same axis (NW–SE). The black features distributed throughout the study area are caused by high magnetic gradients resulting from mud-brick remains, which may refer to thick mud-brick walls surrounding tomb structures. The eight features of interest have been highlighted on Figure 5.

Feature A is represented by a positive high magnetic gradient anomaly with respect to the surrounding medium. It occupies grids C8, C9, D8, D9 and D10 and is produced by mud-brick features constructed in a rectangular form with dimension of about 30×12 m and average thickness of about 3 m. It is orientated NW–SE with no clear shaft or opening from the traced sides on the image. However, the breaks in the anomaly may indicate small openings. Moreover, the missing side at the southern border of the image may contain an opening or entrance gate. It is important to confirm that the walls of the surrounding excavation areas contain no openings for entrance, which may refer to defensive requirements.

Feature B is also represented by a positive high magnetic gradient anomaly. It occupies grids C5, C6, C7, D5, D6 and D7 and generally has nearly the same characters as feature A with smaller dimension of about 27×13 m and thickness of about 2 m. The construction of this feature is divided into two parts, the main part located at grids D5, D6 and D7, and another adjoining small part located at grids C6 and C7. The main part has an opening of about 2 m width located at its northwestern side and may lead to the internal burial room. The smaller part has an opening of about 1.5 m width located in its southeastern wall.

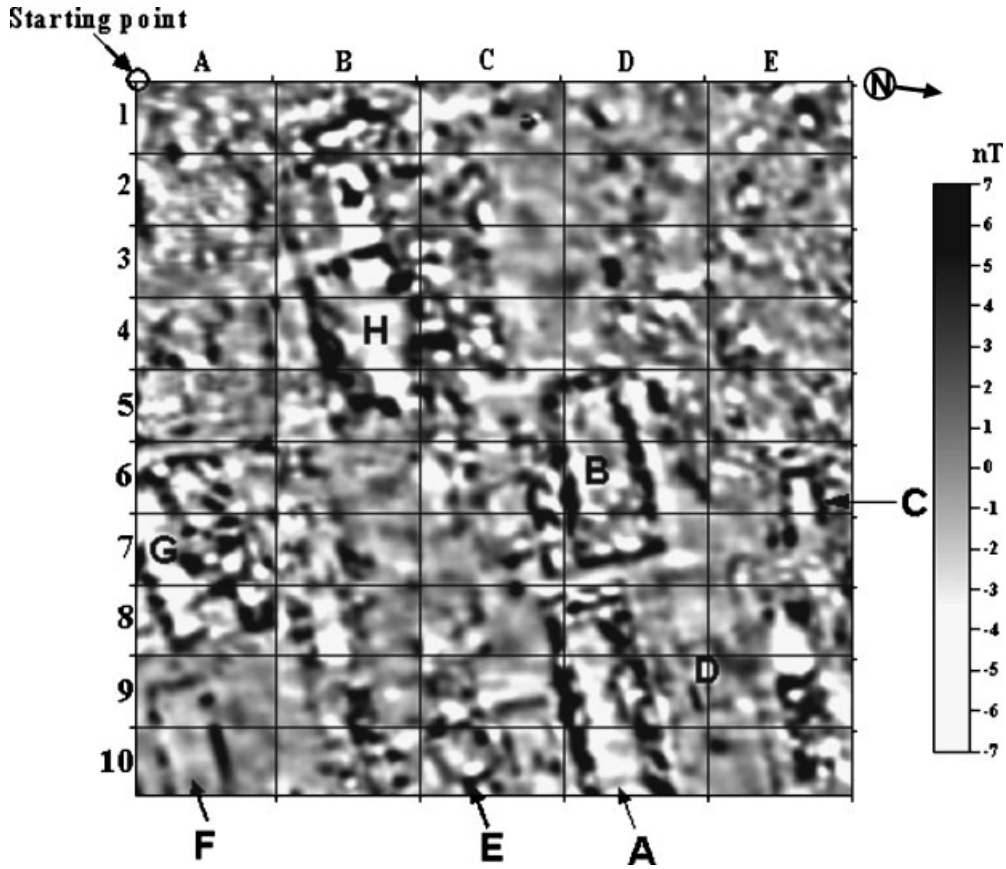

Figure 5. Magnetic image of the study area showing the mud-brick remains derived from the most expressive image of Figure 4.

Features C, D and E are represented by positive moderate to high magnetic gradient anomalies. They are generally characterized by their small size with respect to the other features; C is about 10.5×5.5 m, D is about 10×5 m, and E is about 10×8 m. Three openings have noticed in features (C) and (D): one in C and two in D. No openings are found in feature E.

Feature F is represented by a positive moderate magnetic gradient anomaly. It occupies grids A9 and A10 and its dimensions are about 17×9.5 m, with a thickness of about 1.5 m. Three openings can be noticed on its two longest sides and may lead to the internal burial room. However, it is difficult to decide which one of them is the main gate and which is just a destroyed part.

Feature G is represented by a positive high magnetic gradient anomaly. It is located in grids A6, A7 and A8 with dimensions of about 25×17 m and thickness of about 1.5 m. This feature is divided internally into different partitions, which are mostly destroyed. However, a clear entrance gate is noticed its northeastern side with a width of about 4 m. This entrance gate leads to another gate of the same width. It may be some kind of construction for camouflage.

Feature H is represented by a positive high magnetic gradient anomaly. It is located in grids B3, B4, B5, C4 and C5. Its dimensions are about 24×17 m, with an average thickness of about 2 m. It has a main gate at its northeastern side with an average width of about 2.5 m which may lead to the internal burial room.

In addition to the features discussed previously, some other features represented by positive magnetic anomalies (black spots) may be noted in grids B9, B10, C8, D3, D5, D6, E1, E8, E9 and E10. We tend to interpret them as separated parts of destroyed walls and not tombs. This is supported by the existence of similar surface wall features. However, some of them

may lead to interpretation as tombs particularly with regard to their size and form, which agree to a large extent with known tombs found at Saqqara and some other sites.

Conclusions

The aim of the present study was to detect the ancient remains located at the northeastern side of Zoser pyramid using a gradiometer survey. The archaeological site of Saqqara generally shows a variety of royal pyramids, tombs and mud-brick structures with different ages from the 1st Dynasty to the 26th Dynasty.

The study area in general contains complete and dissected mud-brick walls surrounding tomb structures and burial rooms. This is similar to some other sites beside the study area. The dissected mud-brick walls may point to random digging by non-specialists and/or robber actions.

The probability that these mud-brick remains are mainly tomb structures containing interconnected underground burial rooms is supported by earlier excavation work near the study area.

The presence or absence of openings in some remains is a mystery amongst a huge assembly of ancient Egyptian mysteries.

Thus, we conclude that the area located northeast of the Zoser pyramid contains mud-brick remains, which represent the normal continuation of the old kingdom tombs of the 1st and 2nd Dynasties. Moreover, the detection of these remains using gradiometer survey confirms the greater efficiency of magnetic methods than other geophysical tools in locating mud-brick features in sandy soil. Although this was the reason for using only the magnetic survey, we also recommend that other geophysical methods be applied for more detailed surveys, especially on such important archaeological sites.

Acknowledgements

The authors thank the Department of Geomagnetism and Geoelectricity, National Research Institute of Astronomy and Geophysics (NRIAG) for kind support with field instruments, cars and required facilities. Also, many thanks to the Authority of Egyptian Archaeology for their kind permissions and field inspectors.

References

Abdallatif TF. 1998. *Magnetic prospection for some archaeological sites in Egypt*. PhD thesis, Faculty of Science, Ain Shams University.

Aitken MJ. 1974. *Physics and Archaeology*, 2nd edn. Oxford University Press: Oxford.

Baedeker K. 1978. *Egypt from A to Z, Handbook for Travelers*. Jarrold and Sons: Norwich.

Clark JA. 1990. *Seeing Beneath the soil: Prospection Methods in Archaeology*. B.T. Batsford: London.

Elbassiony AAA. 2001. *Geophysical archaeoprospection in Saqqara and Qantir areas, Egypt*. Master thesis, Faculty of Science, Ain Shams University.

Geoscan Research. 1987. *Instruction Manual Version 1.0 (Fluxgate Gradiometer FM9, FM18, FM36)*. Geoscan Research: Bradford.

Geoscan Research. 1994. *Instruction Manual 1.01 (Geoplot 2.01)*. Geoscan Research: Bradford.

Ghazala H, El-Mahmoudi AS, Abdallatif TF. 2003. Archaeogeophysical study on the site of Tell Toukh El-Qaramous, Sharkia Governorate, East Nile Delta, Egypt. *Archaeological Prospection* **10**: 43–55.

Herbich T. 2003. Archaeological geophysics in Egypt: the Polish contribution. *Archaeologia Polona* **41**: 13–55.

Kamei H, Atya MA, Abdallatif TF, Mori M, Hemthavy P. 2002. Ground-penetrating radar and magnetic survey to the west of Al-Zayyan Temple, Kharga Oasis, Al-Wadi Al-Jadeed (New Valley), Egypt. *Archaeological Prospection* **9**: 93–104.

Khozym A. 2003. *Geophysical prospection of some archaeological sites in Saqqara area, Giza, Egypt*. Master thesis, Faculty of Science, Ain Shams University.

Odah H, Abdallatif TF, Hussain AG. 1998. Micromagnetic prospecting to delineate the buried solar boats in Abydos area, Sohag, Egypt. *Journal of Environmental Sciences*. (Mansoura University, Egypt) **16**: 121–133.

Rogers A. 1992. *New Complete Guide of Egypt*, La Fotometalgrafica Emiliana Spa: Bolonga; 146 pp.

Scollar I, Tabbagh A, Hesse A, Herzog I. 1990. *Archaeological Prospecting and Remote Sensing. Topics in Remote Sensing*. Cambridge University Press: Cambridge; 375–516.

Seton-Williams V, Stocks P. 1993. *Blue Guide—Egypt. Atlas, Street Atlas of Cairo, Maps, Plans and Illustrations*. A&C: London and W. W. Norton: New York.

