Article

https://doi.org/10.1007/s12303-023-0015-8
pISSN 1226-4806 eISSN 1598-7477

Geosciences Journal GJ

Archaeogeophysical investigation using magnetic and GPR surveys at Tal-Baltus, Menofia Governorate, Egypt

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ABSTRACT: An integrated geophysical survey using land magnetic and ground penetrating radar (GPR) methods was conducted to investigate the archaeological findings and ancient cultural relics at an undiscovered 100 m × 60 m in Tal-Baltus in El-Sadat city, Menofia Governorate, Egypt. The study area at Tal-Baltus was chosen among several archaeological hills in the Menofia governorate due to its archaeological significance in the Greco-Roman history of Egypt. The total area was first surveyed using the magnetic method, and then two small promising sites within this area were selected for the GPR survey. The obtained magnetic results showed the presence of remarkably high anomalies with different shapes of irregular geometry. Therefore, they are interpreted as ruins of old storage rooms related to an ancient harbor-shaped structure. Besides, numerous scattered pillars and column heads were also delineated and matched with remains of granite blocks in abundance in the study area, taking the same trend as the delineated magnetic anomalies. In addition, the GPR results highlighted several hyperbolas with variable amplitudes and sizes, which have been interpreted as the shallow foundation of a potential ancient harbor made of limestone. The comprehensive interpretation of the integrated magnetic and GPR surveys strongly suggests that the study area may be a part of an ancient harbor in addition to some other ancillary room-shaped structures used for cargo storage purposes and scattered portions of walls and pillars dating back to the Greco-Roman era.

Key words: magnetic gradiometry, GPR, the Greco-Roman, Tal-Baltus, Menofia

Manuscript received October 25, 2022; Manuscript accepted May 1, 2023

1. INTRODUCTION

Menofia Governorate is located in the Nile Delta, the northern part of Egypt, between the branches of the Nile Rashid and Damietta (Fig. 1). Although the governorate contains some archaeological places, it is less famous than other historical sites in Egypt. Menofia was named after the city of Menouf, an ancient Pharaonic city called "Bir Nob," which means the gold land, as it contained several gold mines in the past. In the Coptic time, its name became "Banoufis," and after the Islamic conquest of Egypt, the "Baa" letter changed to "Meem" in the Arabic language, becoming "Manoufis."

El-Sadat city is located west of Menofia Governorate, on the northeastern margin of the Western Desert. It is considered the largest city in Menofia Governorate, occupying around 55% of its total area. There are different archaeological sites in El-Sadat city, the most important of which is Kom El-Tarana, where the current village of El-Tarana is located to the north of the city of Menouf, about 70km north of Cairo on the west bank of the Rashid branch (Fig. 1). Tal-Baltus is a virgin area that has yet to be explored, located at about 2km from another archaeological site called Kom Abou Bilou, and at about 30km from the city of El-Sadat.

Regardless of the known global record of geophysical application in archaeological exploration, it is increasing on a large scale in Egypt, the land of ancient civilization and precious history. The application of geophysical methods in exploring virgin areas in Egypt has become very necessary, especially after

Editorial responsibility: Tae-Seob Kang

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the remarkable urban expansion and the urgent human need for housing to sustain life and work. Many different geophysical tools can be utilized together or independently to determine the layout of archaeological structures (David et al., 1995). Geophysical processes not only shape the archaeological features, but they can also reflect alteration caused by humans (Cammarano et al., 1997). Archaeological geophysics involves methods to collect data that support the field archaeologist to adequately image and map underlying archaeological features, which are otherwise impossible to be detected by the traditional field methods. Magnetic and GPR methods are considered the most applied ones in archaeological investigations in Egypt.

Published literature (e.g., Clark, 1990; Scollar et al., 1990) indicate that the application of the magnetic method in archaeoprospection was pioneered globally by British scientists in 1958. However, the use of the magnetic method in an archaeological investigation in Egypt was first initiated by Ralph (1973) in Malkata, Hussain (1983) in Fayoum, and Abdallatif (1998) in Giza, Fayoum, Sohag, and Sharqyia, and followed later by several international publications presented by Egyptian scientists (e.g., Atya, 1998; Abdallatif et al., 2003, 2005, 2019; El-Qady et al., 2019; Ahmed et al., 2020; Mohamed et al., 2020; El-Emam et al., 2021; Ebraheem and Ibrahim, 2022; Saleh et al., 2022) and non-Egyptians (Schmidt et al., 2015; Fassbinder, 2017; Gavazzi et al., 2017; Herbich, 2021).

A typical application of the magnetic method in different countries is to explore the buried archaeological remains of the earth's subsurface. It aims to measure the magnetic field of buried bodies composed of minerals with high magnetic susceptibilities. It is a relatively uncomplicated and inexpensive tool to apply to various subsurface exploration problems involving variations in the magnetic properties of rocks and minerals from near the base of the earth's crust to within the top meters of soil. These variations can highlight the dominant magnetic anomalies in the existing soil (Hinze et al., 2013). Measurements of the vertical magnetic gradient for archaeological prospection have been extensively used in Egypt (e.g., Kamei et al., 2002; Abdallatif et al., 2003; Ghazala et al., 2003; Herbich, 2003; Abbas et al., 2005; Abdallatif, 2005; Odah et al., 2005; El-Emam, 2006; Wilson, 2006; Gavazzi et al., 2017). In addition, the vertical magnetic gradient filters out the impact of the regional magnetic field, which is slightly affected by magnetic time variations, and can better define shallow magnetic anomalies (Bossuet et al., 2001).

The ground-penetrating radar (GPR) has high capabilities of detecting, imaging and mapping the subsurface conditions of soils and rock materials. The GPR method utilizes antennas that emit ultra-wideband frequencies (typically in the 10 to 2000 MHz), so higher frequencies within this range provide better subsurface resolution at a depth of penetration, while lower frequencies in this range allow for greater penetration depths but do not achieve good subsurface target resolution (Morey, 1974). The return time of GPR reflections from discontinuities of soil provides information about the depth of a buried feature, whereas the magnitude and phase of the reflected signal yield information on the nature of this feature. In addition to its civil and military applications, GPR is an essential tool in various investigations, including environmental, archaeological, and engineering, where the target depths are relatively shallow. Many archaeological, geological, and hydrological applications of the GPR have been described by Davis and Annan (1989), Annan (2009), Böniger and Tronicke (2010), Goodman and Piro (2013), Conyers (2015, 2016), Sarris et al. (2015), etc.

To understand past societies and prepare well for professional geophysical surveys, it is crucial to analyze how people lived and interacted and the layout of the archaeological sites, which provides the essential keys to the correct choice of geophysical methodology and interpretation techniques. The ancient Egyptians lived in different archaeological constructions and buildings of various materials (e.g., stone, mud, mortar, wood, alabaster, granite, sandstone, etc.). However, limestone and mud bricks are basic materials in most of these constructions. Abdallatif et al. (2005) mentioned that the Egyptian mud bricks consisted mainly of Nile mud and were widely used by Egyptian builders to build several structures such as tombs, pyramid casing, storage rooms, etc. Mud bricks were used to some extent in pre-Roman Egypt, and their use was amplified at the time of Roman influence (Bard, 1999). Buried archaeological features with magnetic contrast will produce small anomalies in the measurements on the surface, and detailed interpretation of the recorded data can often lead to meaningful archaeological explanations. The techniques are generally not used to "treasure-hunt" but rather for features delineation like foundations, ditches, pits, or kilns (Sutherland and Schmid, 2003).

In the present study, the magnetic and GPR methods were applied to delineate the archaeological features that may be buried at a shallow depth beneath the soil. Both approaches have successful records and applications in archaeological setting assessment all over the world. For this reason, we used them in an integrated manner to assess the archaeological potentiality of the study area and to map all possible subsurface findings.

2. HISTORICAL AND ARCHAEOLOGICAL BACKGROUND

Menofia Governorate is a forgotten center for the most important Islamic, Coptic, Roman, and Pharaonic antiquities. Most of its villages officially belong to the Authority of Egyptian Antiquities, and excavation activities are only allowed with permission from the competent authorities. In Quesna city, three thousand Pharaonic, Ptolemaic, and Roman relics were discovered in 1990 at one cemetery on o ne acre out of 365 acres. Archaeological expeditions have identified this cemetery as a certified archaeological area in Quesna. The Archeology department of Menofia University has carried out some excavations at this cemetery, located in the southern part of the site, and concluded that it dates back to the late period and the Ptolemaic and Roman eras.

The study area of Tal-Baltus belongs to the village of Tarana, northwest of the city of Menouf, and it is currently affiliated with El-Sadat city. It was given an ancient Egyptian name called "Screwdrivers," It was found by the archaeologist Edgar as a script written on a plate of Ramses II, which means the headquarter of Hath or the Lady of Screwdrivers. It was known in Greek texts as "Thermothes", a name changed in Arabic to "Tarana". The first roots of the region go back to the Pharaonic era, especially to the 26th family. It was known from the list of the Assyrians of the seventh century BC that it had a great location on the western bank of the Nile (McCleary, 1987).

The closest archaeological site to Tal-Baltus is Kom Abou Bilou, considered one of the most important archaeological sites in the village of Tarana, located about 2 km from the western side of Tal-Baltus. The whole region flourished in the 3rd century BC because it was located at the crossroads of the trade caravan routes that were used as a hub for transporting goods from the Mediterranean ports to the west of the delta, especially the trade of salt that was imported from Wadi El-Natron. As a result, many tombs of Egyptians and Greeks were found in this region, in addition to several small antiquities and amulets.

The archaeological site of Kom Abou Bilou is about 200 acres on the cadastral maps, and this vast areal extension provides much archaeological evidence, represented by broken pottery, blocks of limestone and granite, blocks of marble, and perhaps parts of columns and walls in Greco-Roman temples (Abdelgafar, 2007). The Khabiyeh site for stone tools north of Al-Tarana Bridge, known as Mfkat, continued inhabited until the late Pharaonic Era-1. It consists of bricks, probably because it was used in the Roman baths in the western part of the hill. It has some remains of huge walls, thick walls, and early tombs from the Late Period-2.

The vast cemetery of Kom Abou Bilou contains tombs arranged from the Sixth Dynasty (2420–2280 BC) to the fourth century AD. Thus, the site where this cemetery is located contains archaeological features belonging to four levels of historical times, the first from the Pharaonic era, the second from the Ptolemaic era, the third from the Roman era, and the fourth from the Byzantine era. The cemetery of Kom Abou Bilou slopes slightly from south to east because the study area is fully covered with several meters of dense sand deposits.

Based on an archaeological survey and initial excavation in 1935 by a mission of Michigan University, the results indicate some areas having several archaeological evidence with various sizes and shapes of tomb structures. Around forty tombs and 5,000 artifacts representing the customs of the ancient people were discovered at a depth of about 5 m from the ground surface.

3. FIELD SURVEY AND DATA ACQUISITION

An area of 100 m × 60 m (Figs. 1 and 2) was selected for the geophysical survey using magnetic gradiometry and GPR methods. The top surface of the study area is relatively flat and densely covered with grass and passion red pottery. At the same time, a limestone tomb is observed in the middle and surrounded by reclaimed farmland in the west, north, and south parts. However, the existing grass and red pottery did not affect the survey and methodology.

3.1. Magnetic Data Acquisition

The vertical magnetic gradient measurements were carried out over 100 m × 60 m near recent cemeteries using the Fluxgate gradiometer (FM256) of Geoscan Research (2006). Before the measurements, the study area was cleared of any apparent superficial iron materials, and its corners were marked with wooden sticks. After that, it was divided into 15 grids; each grid is 20 m × 20 m, subdivided into several parallel traverses with 1 m spacing. As a result, the Fluxgate gradiometer (FM256) with 0.5 m sensor spacing could acquire the magnetic data correctly and efficiently with the existing rough and irregular topography.

The readings are displayed on an alphanumeric liquid crystal display in either digital or analog form, the latter being very useful for scanning. The acquired data have been stored in the instrument memory and then transferred to the computer through Geoplot software (Geoscan Research, 2005). The raw data were then presented in grayscale color, as shown in Figure 2. The dark areas in the grayscale magnetic image indicate anomalies of higher magnetic signatures. In comparison, the lighter areas indicate anomalies of lower magnetic signatures.

3.2. GPR Data Acquisition

The GPR survey was conducted using a GSSI Subsurface Interface Radar (SIR) System-4000. The GSSI with a 200 MHz antenna and a high vertical resolution was calibrated and used for data acquisition to detect all abnormal features that might be found in the study area (Fig. 3). Effective data acquisition depends on a well-designed survey and effective implementation. Therefore, two sites were selected for the GPR survey based on

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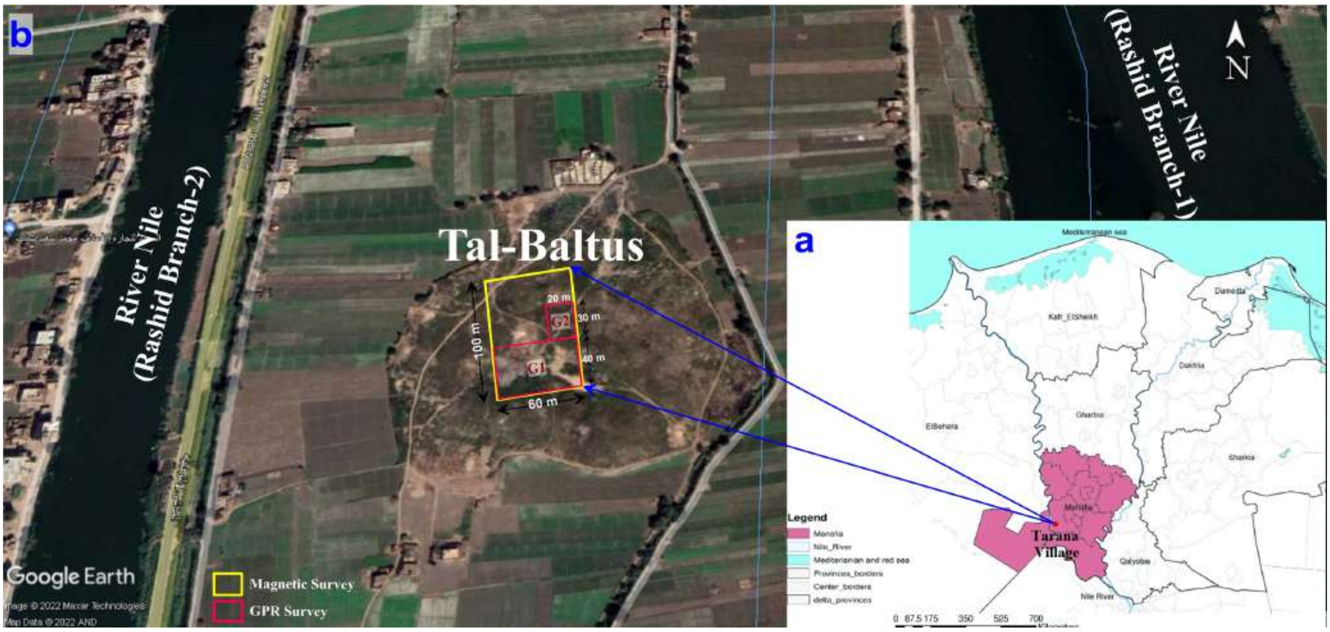

Fig. 1. (a) Map of Nile Delta showing the location of Tarana village at E-Sadat City. (b) Base map of the magnetic gradiometry and GPR surveys at the study area.

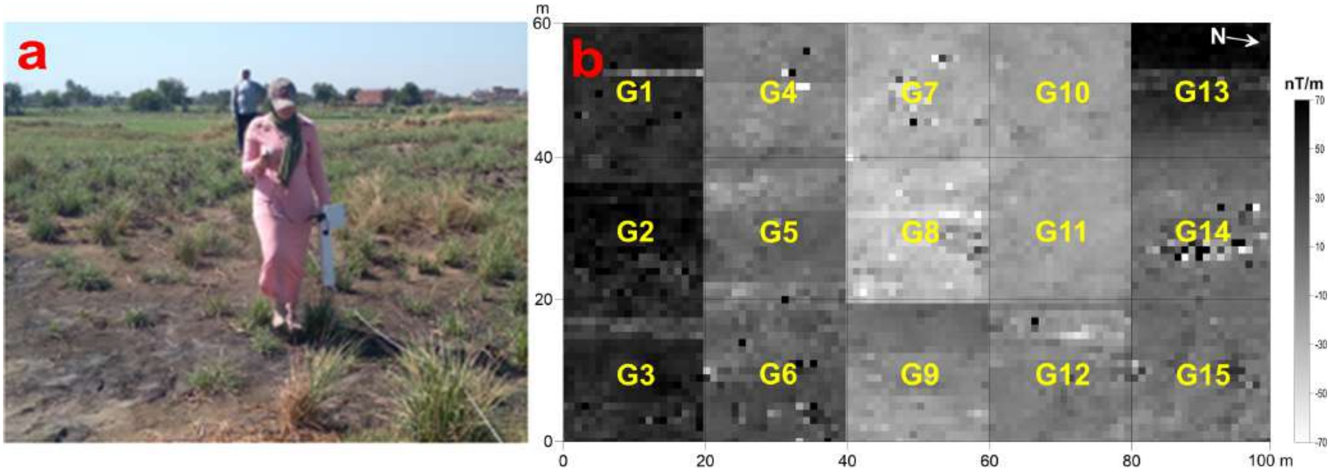

Fig. 2. (a) Data acquisition of the vertical magnetic gradient at the study area of Tal-Baltus using the FM256. (b) Raw magnetic gradiometry data.

the magnetic survey results. The first one (G1) is 40 m × 60 m consisting of 41 profiles, while the second one (G2) is 20 m × 30 m consisting of 31 profiles (Fig. 3). Each site was surveyed with a set of 1 m-spacing zigzag lines. The GPR equipment was set up to acquire 20 scans/m at a sampling rate of 512/trace over an absolute scope of 150 ns. A survey wheel, attached to the GPR equipment, was used to control the surveyed distance and trigger the electromagnetic wave during the data acquisition (Fig. 3).

4. DATA PROCESSING

4.1. Magnetic Data Processing

The main objective of magnetic data processing is to remove any potential noises and enhance data for further clear presentation and interpretation to upgrade and highlight all possible archaeological features in the study area. The acquired data of the vertical magnetic gradient were analyzed and processed using Geoplot software (Geoscan Research, 2005) before being extracted and prepared for high-resolution display using some other software. The raw magnetic data of the investigated area displayed magnetic impacts from numerous sources, a part of these sources indicate the presence of some noises that might affect the visibility of the main archaeological features.

The raw data were first presented in shade plots to find out the main field error and noise. Then, a group of processing functions was applied to eliminate noisy data, strengthen the delineated archaeological response, and improve the representation

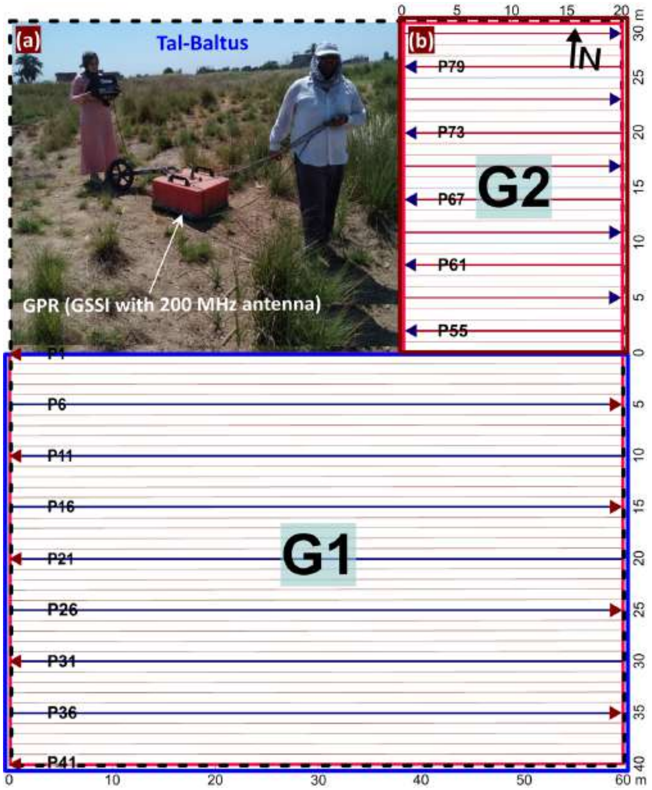

Fig. 3. (a) Layout map of the detailed GPR profiles. (b) Data acquisition at the selected sites using the GPR survey.

of the resultant images. For example, the difference in the mean gradient values between grids was corrected using a zero-mean grid function. In contrast, the effect of traverse stripping was corrected using a zero-mean traverse function, the effect of near-surface iron materials distributed randomly at the study area was reduced using the despike function, and remarkable small shifting of lines and archaeological features were treated using the destagger function with a traverse shift value of −1 m at some grids, e.g., G2, G3, G6, G8, G14, G15, etc. Moreover, a Gaussian low-pass filter was applied to suppress higher frequency features, smooth the data, and enhance the anomalies of interest. Finally, the acquired data was clipped to reduce and eliminate some common errors that may occur during the field survey. Figure 4 shows the processed gradiometer data.

The processed magnetic image reveals several buried remains of positive and dipolar anomalies, which can be considered the main features delineated in the study area (Fig. 4). They can be thus interpreted and correlated with the GPR results to correctly infer the nature of dominant findings and the archaeological setting of Tal-Baltus area.

4.2. GPR Data Processing

GPR data processing aims to produce an image that can be deciphered to distinguish buried features, highlight targets of interest, and prepare results for further interpretation and correlation with the magnetic gradiometry data. The GPR data processing was conducted using the ReflexW software package (Sandmeier, 2016). The program displayed the acquired raw data as a line scan of gray color to depict amplitude. Several gain functions can be applied depending on the data quality and the profile elements that require emphasizing, e.g., automatic gain control, spherical and exponential compensation gain, and user-defined gain function. Following the best practices in GPR data processing for archaeological investigation (Manataki et al., 2015), the gathered data were handled in 1D and 2D time slicing. All through the 1D analysis, the data were exposed to noise

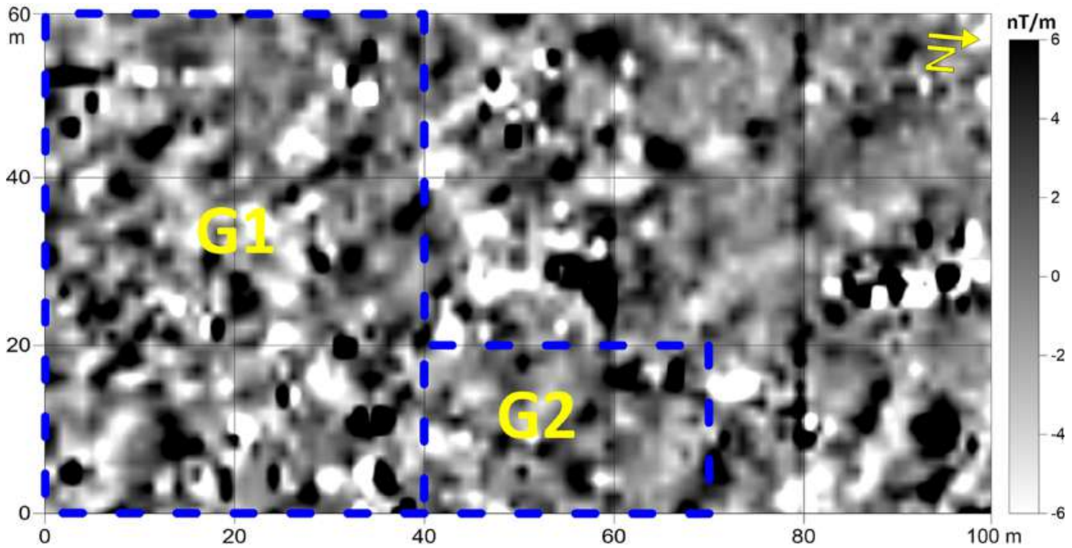

Fig. 4. Gradiometer data after applying all the applicable processing functions. G1 and G2 represent two promising sites selected for the GPR survey.

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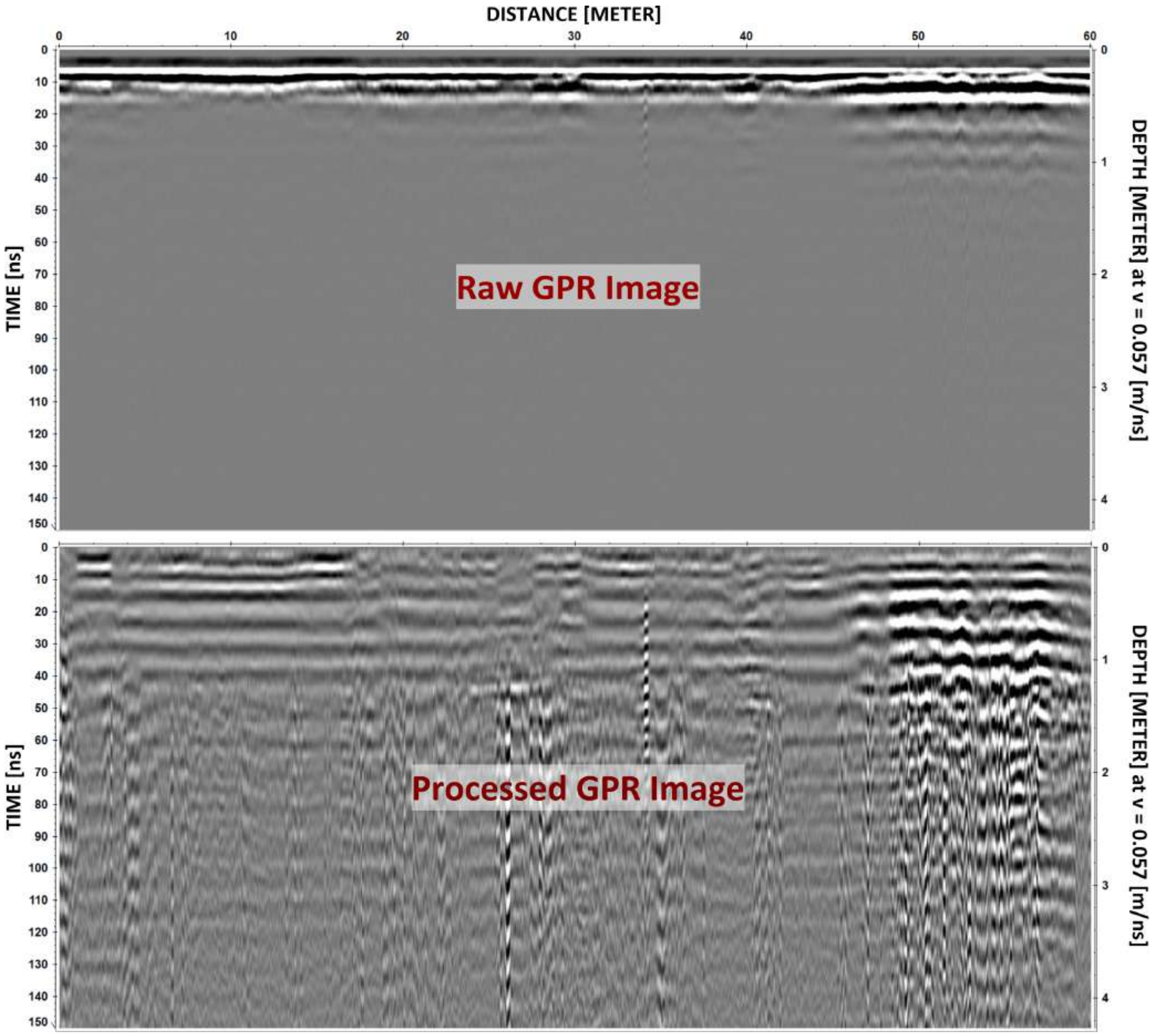

Fig. 5. The unprocessed (upper) and processed (lower) GPR data of profile P38.

removal and signal upgrade preparation. Four preparing steps were applied: a) Zero-time adjustment for the static shift was applied to connect zero time with zero depth. Thus, any time offset because of instrument recording was eliminated before interpretation. b) X flip profile was applied to flip the profiles in the x-direction to obtain reverse profiles. c) Background removal filters worked on the picked number of traces to remove the predictable clamor from the entire profile transiently and, consequently, perhaps make the signals visible. It additionally smothers horizontal coherent energy. Its impact is added to highlight signals which differ laterally, for example, diffractions. d) Butterworth band-pass filter of 300–800 MHz was applied to remove unwanted high- and low-frequency signals. Filtering the data typically removes the unwanted background noise resulting from the electronic ringing of the antenna during the data acquisition. Figure 5 shows the raw and processed GPR data.

5. DATA INTERPRETATION

5.1. Magnetic Data Interpretation

The processed gradiometer data (Fig. 6) indicate a clear magnetic contrast between the hosting soil and sources of interest, emphasizing the existence of several apparent anomalies in different parts of the study area. Light-colored areas in the grayscale magnetic image indicate negative anomalies, while dark-colored ones indicate positive anomalies. The processed data reflects the main findings in the study area, which is located

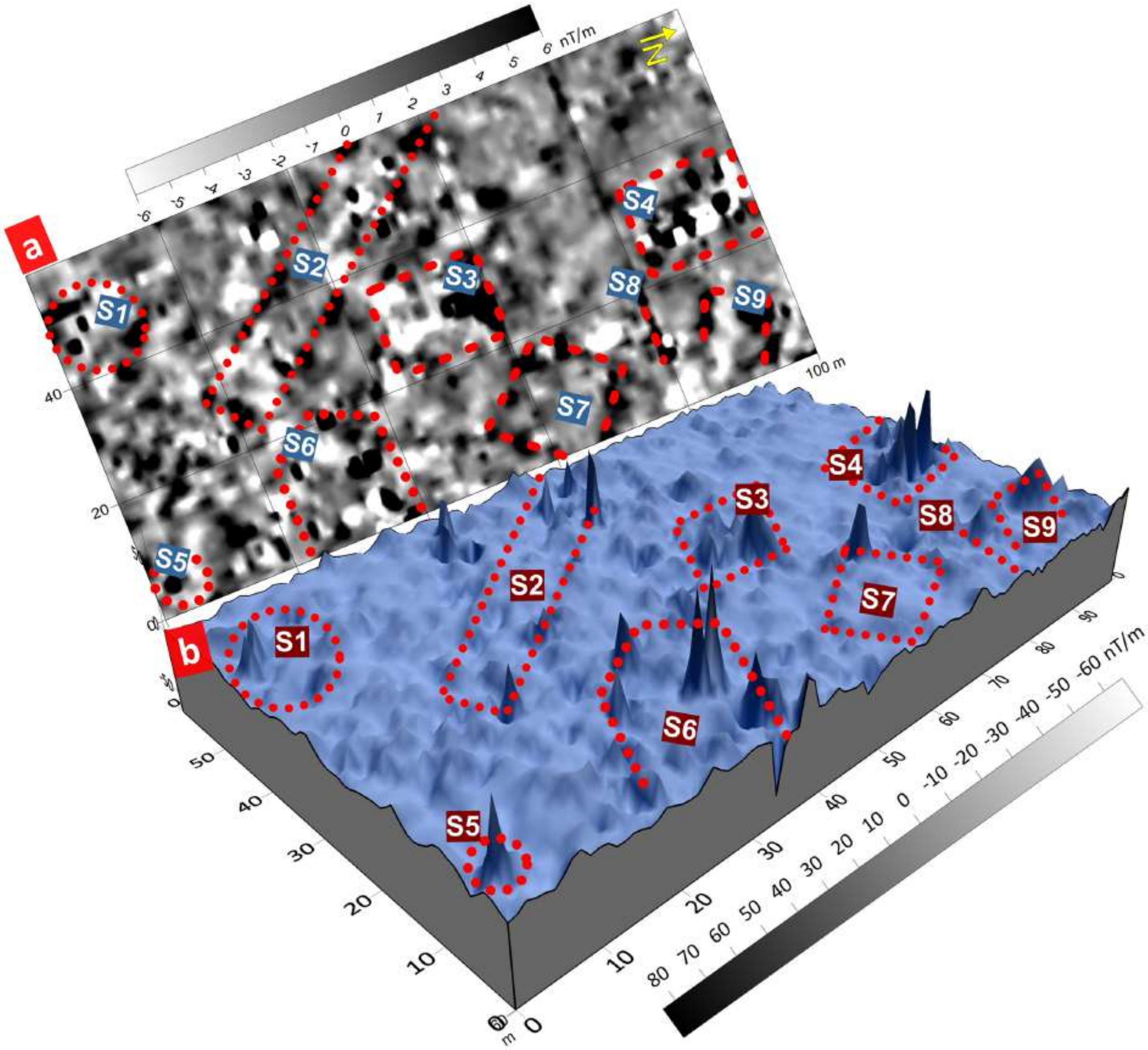

Fig. 6. Processed gradiometer data shows the magnetic anomalies in the gray shade image, indicating the main delineated findings in this study.

near recent existing cemeteries.

Nine fundamental anomalies have been distinguished as S1 through S9 (Fig. 6). These anomalies can be interpreted as linear features excavated in silt containing a high ferromagnetic mineral content. Most of these features, i.e., S2, S3, S4, S6, S7, and S9, primarily represent the room's shape structure with different sizes and geometries. However, the delineated features, such as S1 and S5, do not show a clear geometrical shape that can be interpreted as a room structure but rather appear to be scattered parts of walls or pillar heads. Also, the S8 feature looks like a separate wall as it does not have full connectivity to other features. Considering the previous history of the study area and the surroundings, we believe these features express the ruins of walls and pillars of an ancient harbor structure found at a very shallow depth of less than 5 m. According to the positive signs of the detected magnetic anomalies and the surface archaeological record of the site, we expect that significant parts of these ruins are made of granite. Other previous discoveries of some granitic structures at Tal-Kom Abou Bilou, very close to the study area, support this expectation. Figure 6 also shows some other scattered anomalies that are very likely to be remains of walls and pillar heads.

5.2. GPR Data Interpretation

Several reflected events are visible in the processed GPR data of sites G1 and G2 (Figs. 7–10). Continuous and slightly undulating reflected events indicated with rectangular red lines are visible on each GPR profile. The GPR data generally indicate different unearthed archaeological features at a shallow depth ranging

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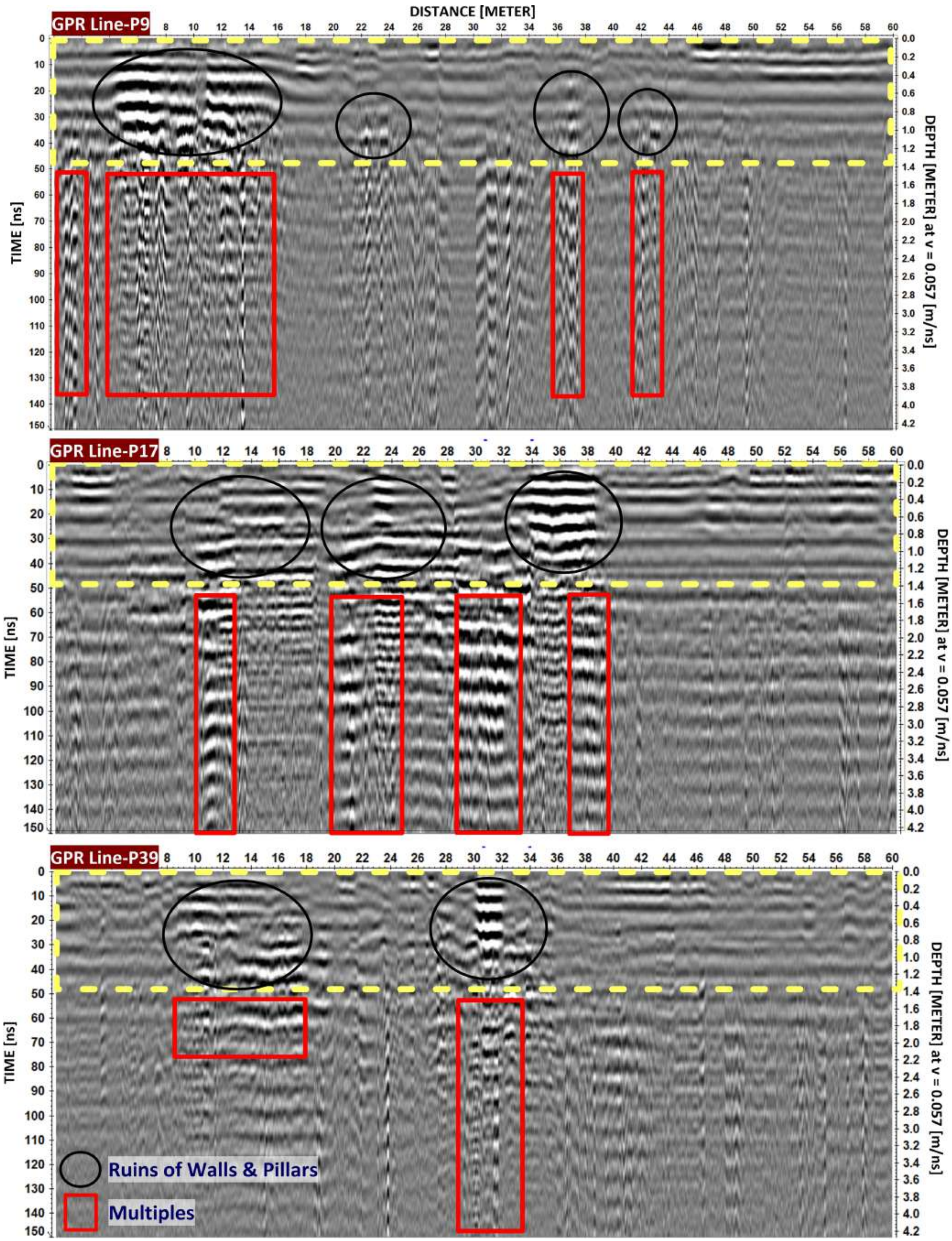

Fig. 7. Two-dimensional processed GPR profiles P9, P17, and P39, indicating ruins of shallow foundations consisting of walls and pillars.

from about 0.5 to 1.4 m. They were buried in the soil and covered with clay and sandy clay formed during the depositional periods of Nile flood cycles before the construction of Aswan High Dam. They probably represent the ruins of the wall foundation and vary in their width when going deeper under the study area (Figs. 7–10).

To correctly highlight subsurface features, the GPR data of the scanned sites G1 (60 m × 40 m) and G2 (30 m × 20 m) were represented in 3D plots (Figs. 8 and 10) with 1 m line spacing. The GPR data showed a relatively large, curved structure encountered at 1 m depth and having a handgrip shape indicated with a red polygon line. It probably refers to the ruins of the shallow foundation of a potential ancient harbor composed of massive rock boulders (Figs. 8 and 10).

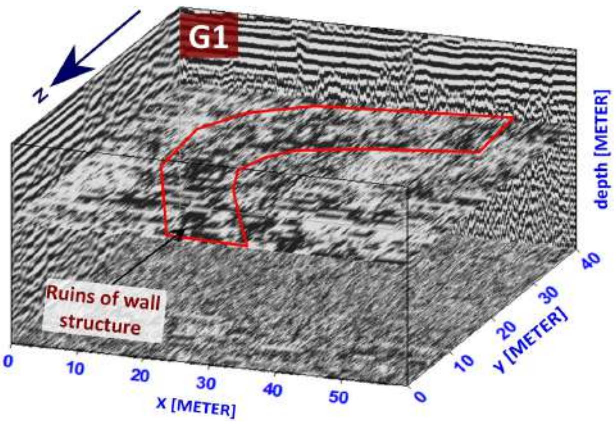

Fig. 8. Three-dimensional GPR elucidation of the G1 site (60 m × 40 m) showing extensive ruins of wall foundations consisting of rock boulders.

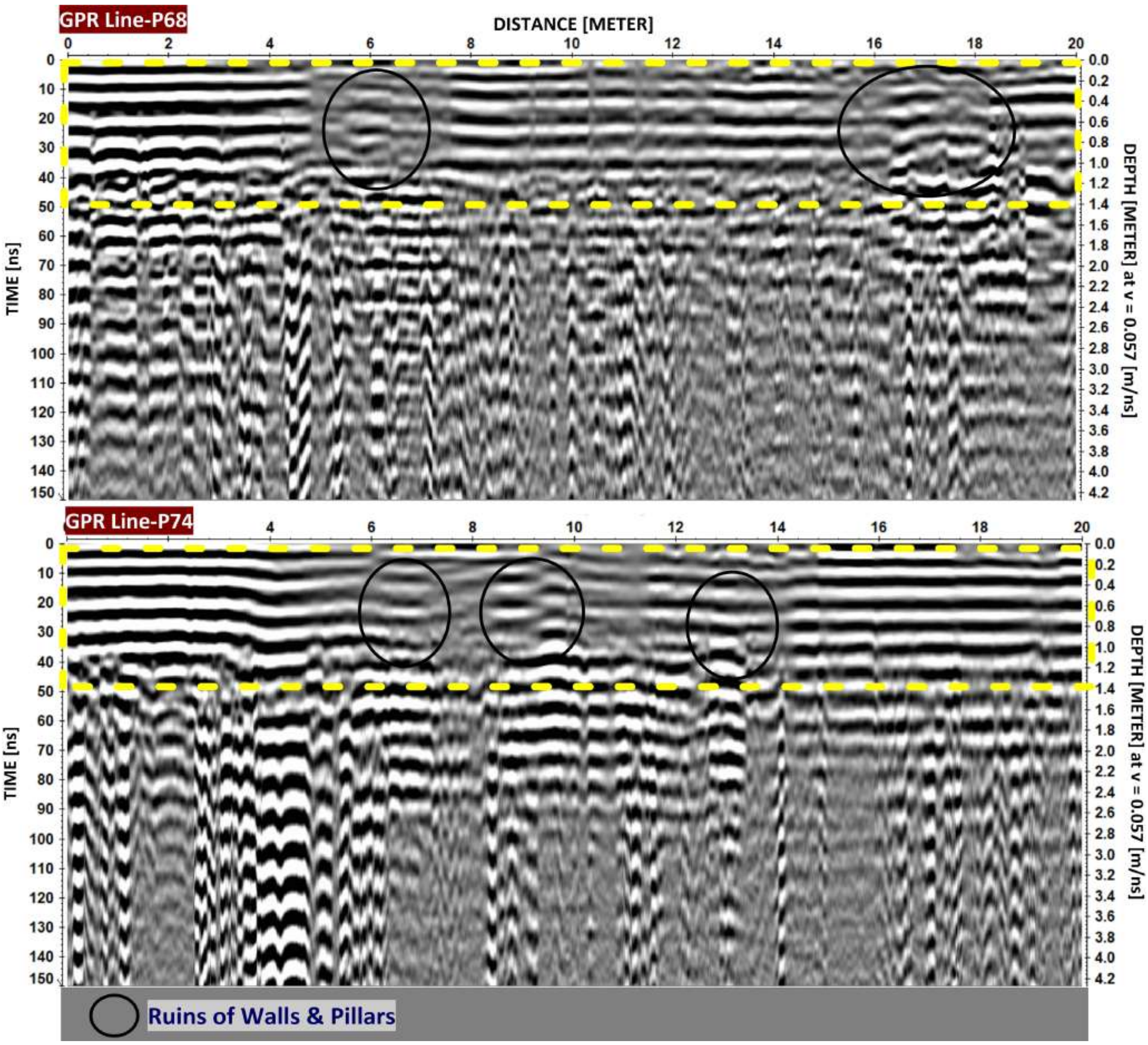

Fig. 9. Two-dimensional processed GPR profiles P68 and P74, indicating potential shallow foundations ruins consisting of walls and pillars.

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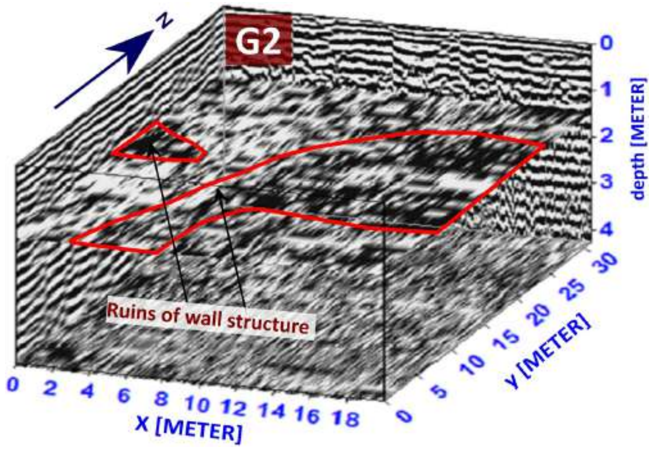

Fig. 10. Three-dimensional GPR elucidation of the G2 site (30 m × 20 m) showing extensive ruins of wall foundations consisting of rock boulders.

Figure 11 shows how far the delineated archaeological findings are from the present course of the branches of the River Nile. They are located about 330 m to the west and about 430 m to the east. These findings might indicate ruins of an ancient harbor dating back to the Greco-Roman era.

6. DISCUSSION AND CONCLUSION

The enormous efforts of Egyptian and foreign archaeologists to investigate or search for discoveries are cumbersome, time-consuming, and require a huge budget which is very difficult nowadays. On the other hand, the endeavors and attempts of geophysicists are the best alternative solution to overcome the time-consuming and low budget allocated to such archaeological excavations. This preferable solution is due to the great advantage of geophysical methods in surveying large areas quickly and without dispersing soil materials and affecting existing cultural structures. We applied common geophysical techniques such as magnetic gradiometry and GPR to delineate the archaeological setting of Tal-Baltus in Tarana village, Menofia Governorate. Both methods have been successfully implemented and have provided fascinating results about the historical monuments of this area regardless of the rugged terrain and challenging site conditions. The integration and correlation between magnetic and GPR data provided a comprehensive site characterization of the subsurface archaeological findings in the study area, especially since the Tal-Baltus area has yet to be investigated or discovered.

The archaeological findings delineated from the magnetic gradiometry indicate the presence of several room-shaped structures in addition to some scattered portions of walls or pillars. They are likely composed of granite rocks due to their remarkable positive signature. The recorded discoveries of a few exposed similar granitic structures at the Tal-Kom Abou Bilou area also support this. Meanwhile, the findings identified from the GPR data refer to a shallow foundation made of limestone and some scattered parts of walls and pillar ruins. Several hyperbolas represent these findings with variable amplitudes and sizes.

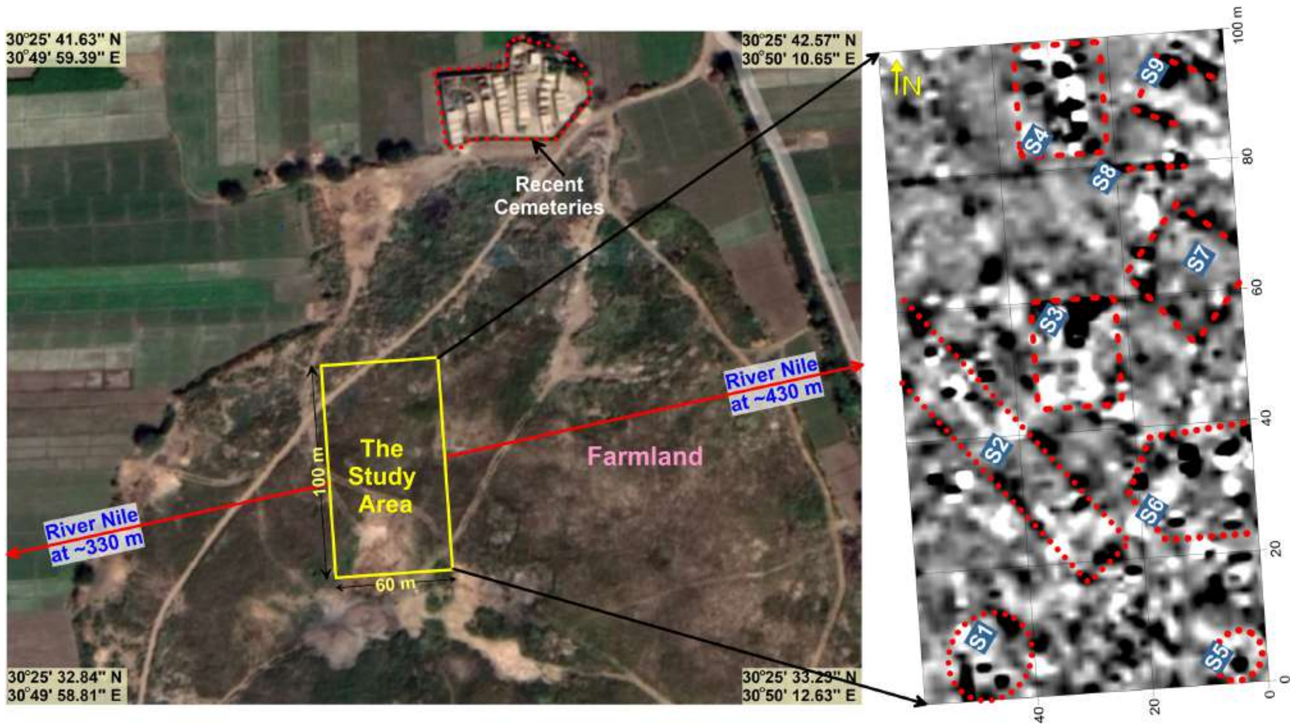

Fig. 11. The delineated findings are located at relatively short distances from the branches of the present course of the River Nile.

We tend to interpret the geophysical results as the remains of an ancient harbor rather than a temple after referring to the historical background of the entire region and considering the proximity of the study area to the current course of the River Nile. Historically, the whole region flourished in the 3rd century BC because it was located at the crossroads of the trade caravan routes that were used as a hub for transporting goods from the Mediterranean ports to the west of the delta, especially the trade of salt that was imported from Wadi El-Natron through the River Nile. In addition to this historical data, the current geographic reality also supports this hypothesis where the study area is very close to the current pathway of the River Nile; for example, it is located at about 330 m from the present course to the west and at about 430m to the east. This current course of the River Nile differs historically and topographically from that one in the ancient times of Egypt, which means that the study area was supposed to be closer to the old course of the River Nile than today's location, supporting the interpretation that the delineated structures much probably refer to ruins of an ancient harbor.

The comprehensive interpretation of the integrated magnetic and GPR surveys strongly suggests that the study area could be part of an ancient harbor. In addition, some other ancillary room-shaped structures used for cargo storage and scattered portions of walls and pillars dating back to the Greco-Roman era were also delineated. These findings are found at very shallow depths of less than 5 m. Indeed, excavation plans for this area will disclose the nature, shapes, and sizes of the interpreted geophysical data. Still, these plans require a considerable budget and time to implement.

Both geophysicists and archaeologists must implement more collaborative efforts to extend the investigation into all parts surrounding the study area to figure out a complete picture of the archaeological setting of the entire region. This could undoubtedly guide and support the archaeologist's plans when deciding to undertake further new excavations at Tal-Baltus.

ACKNOWLEDGMENTS

This work was funded by the National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt. The authors, therefore, acknowledge with thanks NRIAG technical and financial support. The authors also thank the Egyptian Supreme Council of Antiquities for the permits required to conduct the fieldwork in Menofia Governorate and the field inspectors who provided all the necessary archaeological information. We would like to commend the time and effort that the respected reviewers have devoted to improving the quality of the manuscript and appreciate the detailed and helpful comments we received from them.

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