10 : REMOTE SENSING
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INTRODUCTION

When William Flinders Petrie briefly examined the Temple of Queen Tausret in 1896, he observed the existence of tombs of a later date immediately west of the complex.¹ As Petrie focused on the Tausret components of the site, no complete investigation of these tombs was made at that time. Furthering Petrie’s observations, the excavations at the western edge of Tausret’s temple by the University of Arizona Egyptian Expedition (UAEE) revealed archaeological evidence of several (possibly three or more) Late Period tombs.² As the evidence for these features was discovered late in the UAEE’s 2009-2010 field seasons the Expedition was only able to partially reveal the entrance of one of the features, whetting the appetite for later examination.

Therefore, a remote sensing (ground penetrating radar) project was implemented to map this western area of interest (Figure 1) in order to define the size and extent of any archaeological features in the section. Ultimately, the goal of this non-invasive survey was to determine whether additional excavation outside the temple proper is warranted, and if so, how to plan going forward. The survey was conducted with the approval of the Supreme Council of Antiquities, between August 10th – 24th, 2011.³

EVIDENCE AND DISCUSSION

The UAEE excavations at the northwest corner of Tausret’s temple, near the base of the modern road embankment, revealed a mud brick wall extending away from the temple which appears to represent the entrance area of a tomb (see Chapter 8).⁴ This is the area in which Petrie’s incomplete investigation indicated tombs might be found.⁵ The UAEE also uncovered indirect evidence of three or more tombs at the western edge of Tausret’s temple complex. Large, similarly sized mounds of rock chips above the strata of the
Figure 1. Aerial photo (Google Earth) of the study area with an overlay of the temple plan. The approximate location of the road embankment survey area is indicated.

temple are interpreted as the primary temple, whereas multiple factors seem to indicate a tomb at the northernmost corner, including: the large volume of the rock chip mound and its location; a mud brick wall with bricks that differ in size from those used in Tausret’s temple; location and direction of the mud brick wall construction (outside of and away from the temple); and Late Period date of various items of material culture scattered around the area in which the mud brick wall is located. Here, the scattered remains of at least ten individuals (see Chapter 9), coffin fragments, and other objects from one or more burial assemblage/s provide further evidence of a possible tomb, its likely date, and of looting in antiquity. Yet, the area around the two southern rock chip mounds yielded no indication of post-burial disturbance. For example, the 2008 season had found, in a stratigraphic layer above the remains of the temple, flakes from the nearby stone outcropping; when the edge of the first tomb came to light (see Chapter 8), these flakes were realized to be the byproduct of tomb construction. If the southern chip mounds indeed indicate nearby tombs, there is a possibility that they remain intact. Future
excavation in these areas could prove extremely informative.

In order to establish the identity of these anthropogenic features, their purpose, and their condition, a non-invasive remote-sensing survey was undertaken using ground-penetrating radar (GPR). The topography of the site presents a physical challenge to the use of GPR due to the modern road embankment, which impedes upon the area of interest (Figure 2). This necessitated positioning the GPR grid and maneuvering the equipment along a very steep slope, which rises 5 meters above the excavation level and in some locations exceeds 30 degrees. While the authors have previously undertaken GPR surveys on steep slopes in Egypt, each site presents unique challenges that must be addressed and resolved individually.\(^8\)

The road is constructed above a base material of rock and sand that forms a slope of critically stable material (i.e., the fill holds its general shape, despite the acute angle of the embankment) extending down to the current excavation

![Figure 2. A view of the road embankment looking south. The author is holding the radar antennas in place during data acquisition on the slope. The steel fence and buried utilities are potential sources of interference.](image)
limits. Presumably, this embankment covers the entrances to a number of tombs cut into the original sedimentary formations seen below and around the temple compound. Concern for the safety of the excavators and the fact that further disturbance of the embankment could endanger road stability contributed greatly to the decision to undertake a non-invasive GPR survey rather than excavation in this area.

METHODS

GPR uses echolocation to investigate the subsurface: features with contrasting electromagnetic properties backscatter transmitted radar waves back to a recording receiver. With knowledge of the subsurface velocity and the total travel time to and from the contrasting target, the depth and geometry of subsurface features can be imaged in three dimensions. Strong variations in topography within the GPR survey area, as is the case with this location, necessitate the use of topographic migration to correctly image the subsurface. Such advanced mathematics and methods are more commonly employed for seismic analysis, which can be adapted to an archaeological setting. In brief, the methodology utilizes a topographic model of the area to calculate a migration template for each GPR data point to put subsurface features back to their correct location for image construction. These images allow us to interpret the geometry of anthropogenic features within an area such as the road embankment and to identify areas of potential interest for further excavation.

The GPR data were collected with a Pulse Ekko 100 system using 200 MHz antennas. Common mid-point gathers were used to estimate the velocity at 0.13 m/ns. The three-dimensional GPR survey was collected with a constant antenna offset of 0.5 m. The GPR data was acquired at discrete sampling points with a spacing of 0.4 m in the inline (uphill) direction, and a 0.5 m spacing between lines. The spatial sampling is a compromise between minimizing aliasing and the limited time available for this survey. The antennas were positioned with a polarization in the inline direction. This polarization was chosen to minimize the potential interference from a steel wire fence at the top of the slope and buried utilities running perpendicular to the line direction (Figure 2).

Prior to imaging, interfering signals, antenna ringing, and above-ground reflections were removed via filtering and muting. Antenna ringing was
confined to a damped sinusoidal signal of approximately 180 MHz and was removed with a digital notch filter. A low-pass filter centered at 200 MHz removed high-frequency noise. These filters had little effect on the quality of the data, as the recorded signals had a peak power at approximately 120 MHz and approached the noise floor at 180 MHz. Strong interference from the metal fence posts was deleted from the data when found, with the consequence of degrading the imaging resolution potential near the road. The data were corrected for geometric and material attenuation using a SEC gain.\textsuperscript{11}

The topography of the site was surveyed at a 2 m x 2 m sampling grid, using a stadia rod and survey level. These topographic data were then interpolated for each of the 3,438 transmitter and receiver locations (Figure 3). The topographic migration algorithm used this topographic model to calculate the migration template for each data point during imaging. The resulting image represents the geometry and relative electromagnetic contrasts of the embankment (Figure 4). Following imaging, instantaneous

![Figure 3. Topographic model used to calculate the migration template for subsurface imaging.](image)

![Figure 4. Three-dimensional perspective of the GPR image of the road embankment interior.](image)
amplitude attributes were extracted using a Morlet Wavelet and the discrete wavelet transform. In this particular case, this attribute was used to remove the oscillatory nature of the GPR wavelet from the data to simplify interpretation.

**INTERPRETATION**

The main features of the road embankment are, first, the high-amplitude and unevenly textured upper layer interpreted as recent debris associated with the road, and, second, the low-amplitude, finely structured lower layer interpreted as the consolidated sedimentary material seen in and around the temple site (Figure 5). In the lower portions of the slope near the present-day limits of the archaeological excavation, several ancient features can be seen (Figures 6-9). At 3.9 m below the reference elevation (1.5 m below current...
excavation levels), two strongly reflective rectangular features appear (Figure 6-A) with significant vertical extent (Figure 7-A). These rectangular features are likely associated with tombs; a surface expression of these features can be seen at the site (Figure 8). Both in cross section and in depth view, several other potentially anthropogenic structures can be seen close to the current extent of the archaeological excavation (Figures 9 and 10 B-F). The subsurface area near the road is devoid of any obviously anthropogenic features.

![Figure 7. A depth slice at -3.9 m, showing an instantaneous amplitude extraction. The rectangular features are seen in A. Other high amplitude features include E and F.](image)

**LIMITATIONS AND SUGGESTIONS FOR FUTURE INVESTIGATIONS**

The interpretation of the GPR data in this case is limited to resolving features of sufficient size and contrast so as to separate them from the background material. With decreasing size, features of less than the dominate wavelength of the signal (~1 m) become increasingly difficult to differentiate from the background. Additionally, differentiating structural features from modern or ancient debris (evident on the surface of the survey area) becomes difficult if the electromagnetic properties of the materials used in construction are similar to those of the background materials. This occurs, for example, if prior excavation, looting or construction activities have disturbed the structures in such a way that building material has become mixed with surrounding debris. Accumulation of small errors in data acquisition and image processing further complicates these limits. Features B though F (Figures 9-10) should be considered only potential targets for further examination. Other features lacking the size or contrast to be seen with the GPR may exist within the road embankment and could also be revealed by subsequent excavation.
Figure 8. A view of the road embankment looking north with the Ramesseum in the background. The excavated area in the foreground is the location of the rectangular pits seen in figures 6 and 7.

Figure 9. Profile view of the interior of the road embankment, 1 m from the baseline, looking toward the road from the temple. Antenna coupling dominates the image for the first meter below the surface. The rectangular components of a feature are seen in the box labeled A. Other potentially anthropogenic features are labeled B-F.
Figure 10. A depth slice at -3.5 m showing an instantaneous amplitude extraction. The rectangular features are seen in A. Other high-amplitude features include B through F. The white dashed line is the interpreted limit of temple-related features for this horizon.

NOTES

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5 Petrie, Six Temples, 18-19.


9 When significant undulations in surface topography exist, such as in the survey area, certain algorithms can be used in combination with basic surveying data collected on site to help provide cleaner and more accurate interpretations of the GPR data.


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THE TEMPLE OF TAUSRET:

The University of Arizona Egyptian Expedition Tausret Temple Project, 2004-2011

Edited by Richard H. Wilkinson

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Ceremonial Blue Ware vessel from the Temple of Tausret. Computer-assisted reconstruction by Lyla Finch-Brock.

The Temple of Tausret summarizes the University of Arizona Egyptian Expedition’s excavation of the monument built by one of the few women to rule ancient Egypt as pharaoh in all the thousands of years of Egyptian history. This project, conducted 2004-2011, demonstrated not only that the temple site was only partially excavated in 1896 by the great British archaeologist, Sir William Matthew Flinders Petrie, but also the belief that the temple was unfinished in ancient times is unfounded. The book looks at the often surprising evidence the Arizona excavations have recovered regarding both the temple and the reign of this female pharaoh.