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Voids Investigation at Gabbari Tombs, Alexandria, Egypt Using Ground Penetrating Radar Technique

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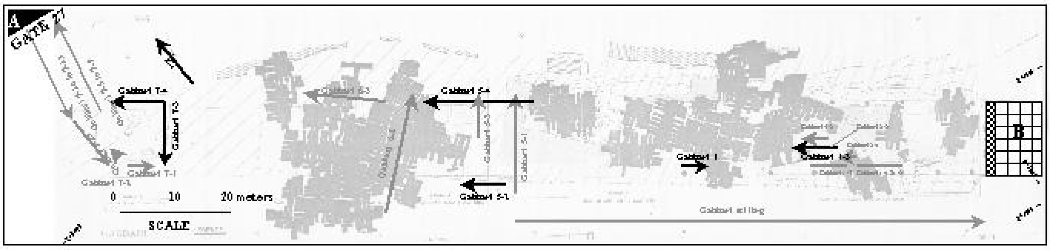
Abstract: In this study the ground penetrating radar (GPR) is used to investigate and differentiate between the Ptolomean graves and random voids due to common karsting at calcareous sandstone that belong to Alexandria Formation at Gabbari area, Alexandria, Egypt, during July 1998. The site is located in an old neighborhood at the southern main entry of Alexandria port. The discovery of the multi-level ancient Ptolomean Mecropolis in the Gabbari area, lead to the pending of the high way construction that built to serve the main gate traffic of Alexandria port. Lithologic units have been defined and the primary depositional structures have been identified. Water table is delinated in the area. Subsurface features considered mostly massive cross bedded calcareous sandstone underlined by lose calcareous sandstone. GPR profiles were acquired across various locations, some of which had been previously excavated and backfilled by archeologists. The main objectives of this study were to determine the utility of the GPR technique in a near shore marine environment with respect to locating subsurface features of archeological interest, and to determine the optimum field parameters for voids detection in the area.

Key Words: Ground penetrating Radar, GPR , site investigation, archeology, Gabbari, Alexandria, Ptolomean Mecropolis, karsting,Graves.

Introduction:

The necropolis is described as a site "of the utmost importance for the preservation of the cultural heritage" of Alexandria. The necropolis was discovered by chance, in June 1997, during road work in the western part of Alexandria district of Gabbari. Two days later excavations began. Archeologists have so far found funerary dining rooms only 20 inches beneath the soil's surface, and 33 feet deeper a huge, seven-level tomb was discovered.



Legend:

(A) Gate 27 of Alexandria Port

(B) The last part of the high way project built at July, 1998 (part of the ring road around the Mediterranean port city)

GPR reflection profiles discussed in this paper

GPR reflection profiles measures in the study area

Escavated Ptolomean Necropolis

Figure 1: Location map for the measured GPR reflection profiles and the excavated Ptolomean Necropolis at at Western Alexandria District of Gabbari July, 1998.

The site of the investigated area is located at the old neighborhood of Gabbari Alexandria, at the exit of gate 27 of Alexandria port. That control almost the majority of the total export and import activities in Egypt. Due to uniqueness of the ancient Ptolomean Necropolis architecture in the Gabbari area and archeological value that will add to the Ptomean history, a national project has been paused for many years to fined possible solution to satisfy all parties to save both the economic value of the high way and the cultural importance of the Ptolomean archeological site.

Egypt has agreed to a compromise to save the world's largest necropolis, with tombs dating back to the third century B.C., from the bulldozers. The proposed bridge was suppose to run 8 feet above the ancient cemetery. The high way project will be part of a ring road around the Mediterranean port city and supersedes an earlier plan that would have burried portions of the site beneath a layer of concerete.

Geology

The exposed rock units belong to Alexandria Formation (Pleistocene and Younger Quaternary). This term was first introduced by Said 1971. Lithologically it is composed of oolitic detrital limestone building a number of elongated bar to the coast, laggonal marl and gypsum in depression and separating the calcarenitic bars. The carbonate granules are formed under water and transported in and by the retreat of sea and by section of wind. They represent fossil off-shore bars.

The Gabbari tombs are carved in the calcareous sandstone. It is yellowish white massive fine to medium grained cross bedded sandstone cemented with calcareous cement. Intersected conjugated joints filled with very fine friable sand saturated with water in the lower parts. This unit is under lined by loose calcareous sandstone. It is brownish medium to fine grained calcareous limestone over saturated with groundwater. It overlies unconformably the El Hagif Formation (Pliocene) or the older Miocene. Surfacial Quaternary deposits obscure actual contact.

Discussing the use of Ground Penetrating Radar (GPR) technique in voids determination:

There are a number of geophysical techniques that can be used to detect the presence of caves and other voids below the surface. Micrografix is popular and effective since there is clearly a large difference in density between the surrounding substrate and the void (Butler, 1984; Smith & smith, 1987; Linford, 1998). However, gravity methods have the limitation that they do not detect the actual shape of the void but rather require the surveyor to postulate a possible shape, run a simulation, and see whether the simulated outcome matches the observed data. With a prior knowledge of likely shape (when verifying documentary evidence of a mine or tunnel, for example) this can be very effective, but when prospecting for an unknown cavern it is a major disadvantage. Resistivity tomography can also be used since the resistance of the void will be higher that the surrounding substrate (Noel & Xu, 1992; Manzanilla el al., 1994). Unfortunately, the calcareous sandstone it-self has a very high resistance which means that this technique is less likely to be successful. A third technique is geophysical diffraction tomography using low-frequency sound waves, an approach which has been used with some success (Levy et al., 1996). The main disadvantage with this technique is that the placing of the geo- and hydrophones required can be difficult and time consuming which makes it less appropriate for prospecting. The ground penetrating radar (GPR) is an effective means of detecting small (i.e. less than 10 m diameter) voids and fissures in karstic terrain (Collins et al., 1994; Benito et al., 1995; Harris et al., 1995).

GPR systems detect reflections from short bursts of electromagnetic radiation emitted by a portable radar transmitter (Millsom, 1996; Convers & Goodman, 1997). The principles of the method are similar to those of seismic sounding: in the case of GPR the reflections come from objects and layers within the ground which alter the speed of transmission of the radar signal. Thus air-filled voids and layers of water-saturated sediment are strong radar reflectors. The depth of penetration of GPR depends on the frequency of radar signal as well as the electrical properties of the substrate. The power of the radar transmitter, the sensitivity of the receiver and numerical signal processing of the acquired data are also important considerations.

Previously published archaeological applications of GPR have tended to use antenna centre frequencies of 300 Mhz or greater (Goodman et al., 1994; Beck & Weinstein-Evron, 1997; Conyers & Cameron, 1998; Toghe et al., 1998; Dobbs et al., 1999). These radar frequencies provide excellent resolution, but they limit the subsurface depth penetration of the GPR to less than 5 m. On open archaeological sites this depth of penetration is often sufficient to reach the base of any archaeological deposits, and Beck & Weinstein-Evron (1997) have used a 500 MHz GPR inside a cave to detect interfaces between unconsolidated sediments and limestone bedrock at a depth of 2 to 3 m below the surface of the sediment. However, when working at Gabbari site from the surface of the calcareous sandstone outcrop lower radar frequencies are often necessary because archaeological and palaeontological voids may be several tens of meters below the ground surface. The selection of an appropriate antenna frequency is probably the most important choice when undertaking a GPR survey, since lower frequency antennas allow much greater depth penetration, but they will fail to detect small diameter anomalies (Jol, 1995). Lower frequencies also require the use of much larger antennae, which can be unwieldy especially on uneven and densely vegetated terrain.

Post-acquisition processing of the radar data is another area for consideration when using GPR. A digital recording system is required because the GPR system records a continuous datastream, consisting of several thousand datapoints, at each survey station. The data are generally recorded directly onto a laptop computer in raw form, and digital signal processing techniques are used to extract the features of interest. Data from a single transect can be presented as a vertical section showing the depth and location of anomalies along the line of the transect. Data from a grid can be processed to produce three-dimensional models or depth slices both of which are powerful visualisation tools. One of the major difficulties is that the radar beam is not collimated and reflections are obtained from a broad cone below each recording station. There are a number of mathematical techniques, such as synthetic aperture time-domain focussing (Johansson & Mast, 1994) that attempt to compensate for the problem, but they are often only successful where the substrate is largely homogeneous and when the signal transport properties are well characterised (Nelson, 1994).

Data Acquisition

Up to 18 GPR reflection profiles were shot at 50 Mhz frequencies using the PulseEKKO100 ground penetrating radar system, manufactured by Sensors and Software Inc. All of the data were acquired using the common-offset reflection profiling method. The transmitter-receiver separation for the 50 MHz data is 2 m. Station spacing along each line is 0.3 m. The GPR reflection profiles lengths ranging from 4 meters to 86 meters respectively, which comes to a combined length of 285 meters. The location of surveys are shown in Figure 1.

Data Processing

The GPR lines for the study were saved on a PC in the field. Field data is processes to a quality suitable for interpretation. To improve image quality, a majority of the processing was done using GRADIX software from Interpex limited. The first step in processing was to input geometry information and edit headers. Next, a short (3-sample) temporal median trim filter was applied to each trace to attenuate noise spikes that contaminated some of the data. A background dc level was present in all of the data sets. The dc level was removed by calculating the average amplitude before the first breaks and removing this value from each sample of each trace. A residual median filter was then applied to attenuate the wow. Test show that this filter successfully attenuates both the low and high-frequency components of wow, without adding precursors or other artifacts to the wavelets. (Gerlitz et al., 1993). Time zero determination and l datuming was also performed.

The next step in the processing sequence was amplitude compensation. For each line, we determined the rectified-amplitude versus time fall-off of the data. The inverse of this curve was scaled by a multiplier (0.3) to form the gain function. The multiplier is used to reduce the gain function somewhat so that anomalously high amplitude values are not clipped after amplitude compensation. The direct air and ground waves were attenuated by subtracting the average trace for each line from each trace. The net effect is that the air wave is almost completely removed.

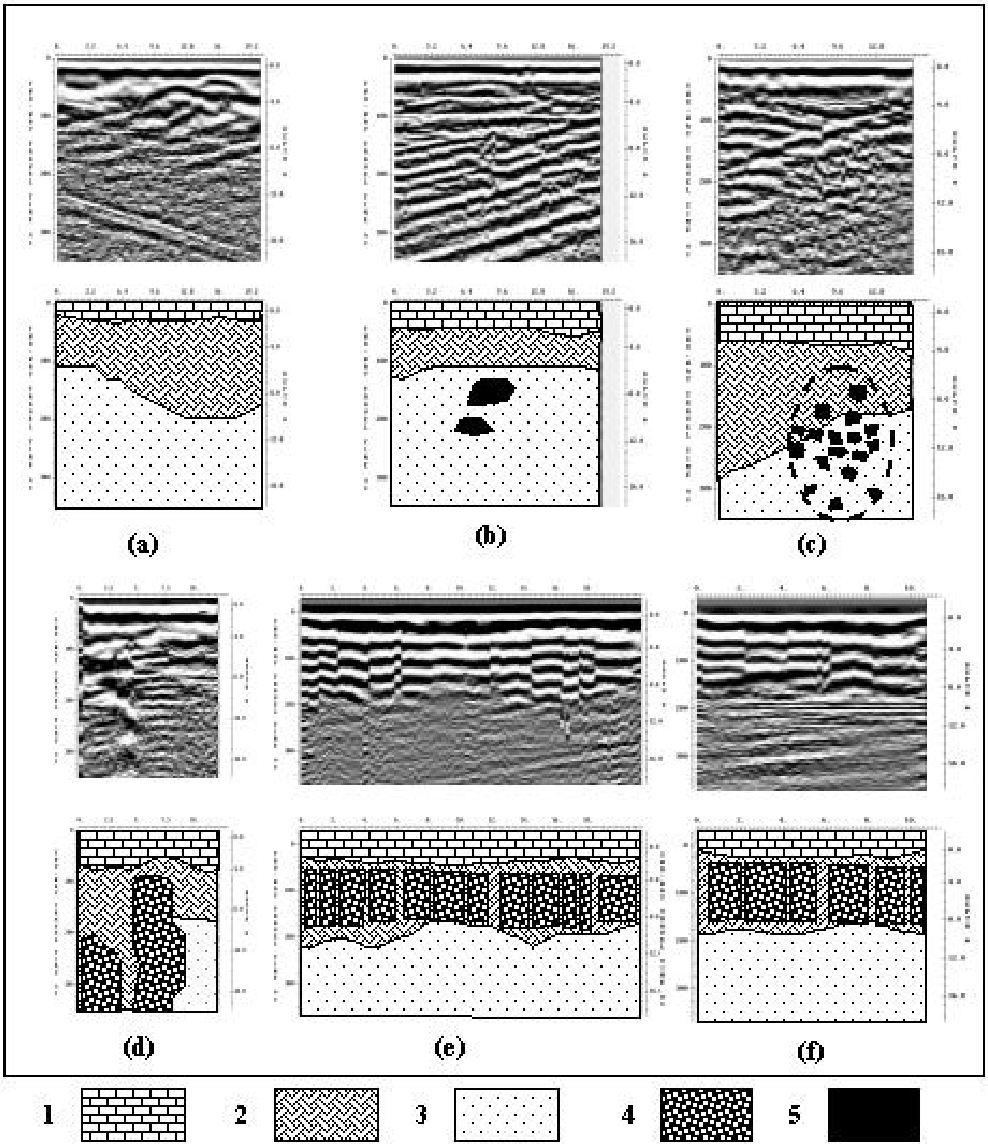


Figure 2. Six GPR reflection profiles with data collected using 50 MHz antennas showing the main different voids patterns variation in Gabbari area, Alexandria, Egypt. (a) shows primary sedimentary structures in the massive calcareous sandstone measured along GPR reflection profiles Gabbari 1-3 (Fig.1). (b) Shows isolated voids measured along GPR reflection profile Gabbari 7-4 (Fig.1). (c) shows group of voids arranged in circular pattern measured along GPR reflection profile Gabbari 7-3 (Fig.1). (d) shows two archeological levels the first at five meters depth and the second at 9 meters depth (e) and (f) show two examples of shallow one level of chambers carved in the massive calcareous sandstone measured along GPR reflection profiles Gabbari 5-4 and Gabbari 5-2 respectively (Fig. 1).

Discussion

Most of the ancient Ptolomean graves in the study area (fig. 1) are carved in Alexandria Formation (Pleistocene and Younger Quaternary). These graves are mostly constructed in the calcareous sandstone from two levels up to 16 meters depth (Fig. 2d) and showing rhythmic geometric patterns. These patterns facilitate the differentiation among the random natural voids in the northwestern part of the area. The survey is designed to have a horizontal resolution of 30 cm and to reach the depth of 18 meters. These Ptolomean graves are carved inside the massive calcareous sandstone without using or adding any onsite or foreign building or binding materials. That makes them difficult to differentiate between natural voids due to karsting in calcareous sandstone. Ptolomean graves design of the already discovered ones help us to recognize the various geometric patterns to be used in this study.

In the southeastern and central parts of the study area most of the GPR reflection profiles demonstrate the arrangement of the tomb chambers and the primary structures related to the hosting sedimentary rock.

The reason of carving the tombs in the calcareous sandstone, because it is massive, not cracked or fractured, and it provide enough room for burial due to it depth that range from 9 and can reach up to 18 meters in some locations. The Ground penetrating radar techniques succeed to delineate the primary sedimentary structures in the massive calcareous sandstone (Fig. 2a and along GPR reflection profiles Gabbari 1-3). Figure 2d, shows two archeological levels the first at five meters depth and the second at 9 meters depth. Figures 2e and 2f show an example of shallow one level of chambers carved in the massive calcareous sandstone along GPR reflection profiles Gabbari 5-4 and Gabbari 5-2 respectively.

In the north western part of the study area near, the Gate 27 of Alexandria port, the calcareous sandstone became less massive and the dissolution commences along cracks and fissures as water percolates into the sandstone to reach the water table. Solution is most active in the zone around the top of the water table that is subject to seasonal variations in the height of the groundwater. Voids are primarily produced because of the fact that calcium carbonate cementing the sandstone is readily dissolved in carbonic acid. The reaction for this form of acid hydrolysis is

$$CaCO_{3(s)} + H_2CO_{3(aq)} <=> Ca^{2+}_{(aq)} + 2(HCO_3^-)_{(aq)}$$

The ionic Ca-CO_3 bond in the calcite crystal is severed and the released CO_3 anion attracts enough H^+ away from the H_2CO_3 to form the stable bicarbonate ion HCO_3^-. This reaction neutralises the acid contained in water. Note that carbonate minerals are nearly insoluble in pure water, and a source of CO_2 is required to produce carbonic acid. Representing organic matter by the generalized formula for carbohydrate, CH_2O, the reactions to produce carbonic acid are

$$CH_2O + O_2 => CO_2 + H_2O <=> H_2CO_3$$

Voids are enlarged to form isolated voids and group of voids. These isolated voids can be observed in figure (2b) and along GPR reflection profile Gabbari 7-4 and the group of voids are well defined in figure 2c and along GPR reflection profile Gabbari 7-3.

Conclusions

It has been proven with ground truth how effective the ground penetrating radar techniques in subsurface imaging for archeological site investigation and sedimentary structure identification. In this investigation the man made and natural voids pattern have been differentiated using the geometric pattern and the arrangements for the available types presented in figure2. This differentiation will help us discover all possibilities for archeological expectations in the current sites or in future similar sites. All outputs presented in this study have been confirmed by immediate on site excavation at Gabbari Ptolomean graves.

Newly discovered Ptolomean graves have been successfully delineated using GPR techniques like those along GPR reflection profiles Gabbari 5-4 and Gabbari 1, which can be observed at figure2d and 2e respectively.

Isolated and circular natural voids patterns can be observed in calcareous sandstone at the northwestern part of the study area. Carved Potolomian graves are absent in that part of the area.

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