

# **Imaging the Tell es-Safi/Gath Siege Trench with Ground Penetrating Radar: a Case Study in Archaeogeophysics**

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Ground Penetrating Radar (GPR) is a remote-sensing technique where electromagnetic waves are sent into the ground from an antenna and the reflected waves are received at the surface to show sub-surface features. This remote-sensing technique has been used in Archaeology for over 30 years in different applications and with varying results. The integration of geophysical methods and archaeology can be a daunting encounter if proper collaboration is not made between the two professional groups. A brief introduction to the technology and its applications is presented here with guidelines to completing a competent archaeogeophysical field survey where the results are useful for the end-user Chief Archaeologist. A case-study based on the archaeogeophysical surveys of the Tell es-Safi/Gath siege trench is discussed here as a final result of the presented guidelines.

## **Introduction**

Ground Penetrating Radar (GPR) is a remote-sensing technique that functions by transmitting radar (electromagnetic energy) waves into the ground from an antenna on the surface level. A portion of these waves are reflected back to the surface when the wave “bounces off” an interface between two different materials or sub-surface features. These reflected waves are then detected on the ground surface by a receiving antenna [4]. Interfaces are detected in the sub-surface by the electrical property changes of the sediment or soil, changes in water content of the material, changes in the bulk density of the geological or archaeological stratigraphy, or even void spaces present due to burials, tunnels, or caches of artifacts [4].

As the radar waves are propagated into the sub-surface at a particular frequency, the elapsed time from the initial transmission to the final receipt of the wave at the surface is recorded. The reflected waves return at a different velocity based on the electrical properties of the materials through which they were just traveling. The time it takes for the reflections to go from the transmitting antenna to the layer in the sub-surface and then be received by the antenna at the surface gives us the total travel time for each reflected wave. The combination of this two-way travel time and the velocity of the reflected wave is used to compute the depth at which the different reflected interfaces and any objects present in the ground, are located [4].

Depending on the types of targets and soil conditions of the survey, different frequency antennas are used. Low-frequency antennas (10-250 MHz) are low-resolution, and can find large objects such as walls and structure foundations. Their depth penetration can be up to 50 m/150 ft. These antennas tend to also be physically large. High-frequency antennas (e.g. 300-1500 MHz) are high-resolution and in some cases can find an object only centimeters or inches in size (thus very useful in Archaeology). Depth penetration is shallow and can be 1-5 m/3-15 ft. These antennas are smaller in size.

## **How Ground Penetrating Radar has been used**

GPR has been used in the field of archaeology since the mid-1970's to search for buried barn walls, stone walls, or underground storage cellars from historical sites [4]. The early promising results encouraged archaeologists to use the technology in further applications. Today GPR has been used to image and locate such archaeological features as buried house platforms, graves, caches of artifacts, postholes, and shallow caves [3, 4, 8]. Another major advantage to the use of GPR in archaeology is that proper surveying of a large area pre-excavation can result in knowing the best places to excavate in a time and cost-effective manner [4, 8].

### **Applications of the Ground Penetrating Radar Method**

As with any technology, proper use and method is essential to yield meaningful results. In the author's experience, a close relationship between the Project Director and the Geophysical Team is the most essential. The more both groups know and understand the other's goals, the better the two can strategically think about the site. Knowledge of the geology, archaeology, building methods (both past and present) at the site, and hypotheses of the Project Director are data that lead to the best success of the GPR survey at the site.

Completing a competent Archaeogeophysical field survey where the results are useful for the end-user Project Director include the following main steps:

1. decide on the area in which to survey, understanding what is the focus of the survey and what you expect/hope to see in the subsurface;
2. clear the area of rocks, brambles, etc, to create a smooth surface on which to pull the antennas;
3. mark out the grid, taking careful notes and pictures of the area as to what objects (e.g. vehicles, trees, or boulders) are unable to be removed from the surveyed area;
4. complete depth-analysis and distance calibration tests at the site in order to maintain a consistency of horizontal and vertical distance in the GPR data;
5. carefully survey the marked area with GPR;
6. transfer the data from the field to the lab for critical post-processing and computer-imaging – useful maps and figures are created at this time;
7. a report is created summarizing the actions taken, explanations of the results, attending to questions, and including recommendations for future actions that are useful to the Project Director of the site.

### **Implementation of guidelines – what has been done thus far at Tell es-Safi/Gath**

During the summer of 2004 Mnemotrix Systems, Inc. continued its 2003 GPR work at the Tell es-Safi/Gath Archaeological project to further explore and locate remains of an ancient siege trench that may have led to the ultimate destruction of that phase of civilization during the mid-8<sup>th</sup> century BCE (Iron IIB). Excavations have continued at the site since 1996 unearthing an important chapter in Philistine archaeology [1, 2, 6]. The trench is over 2 km long, and surrounds the site on the eastern, southern, and western sides [1, 6]. An area of about 75 square meters was surveyed using GPR in 11



**Figure 1: Aerial view of excavated siege trench at Tell es-Safi looking S-SW. Photo provided courtesy of Tell es-Safi/Gath Archaeological Project.**

contiguous separately acquired grids of parallel GPR transects in addition to a 12<sup>th</sup> Control Study grid close to the already excavated trench in Area C6. These grids were put together into a Super-3D grid which covers the side of the hill sloping down towards the current cultivated fields to the north. The area that we chose to work in, following the guidance of Project Director, Dr. Aren Maeir, forms an upward gradual slope as we head south but

is rather steep close to Area C, as seen in Figure 1.

As mentioned above, when acquiring GPR data, the ground-surface must be as flat and smooth as possible. All areas were cleared of thorny brush and stones before acquiring GPR data for that grid. Elevation data must also be accounted for in the GPR data and thus should be recorded in the field.

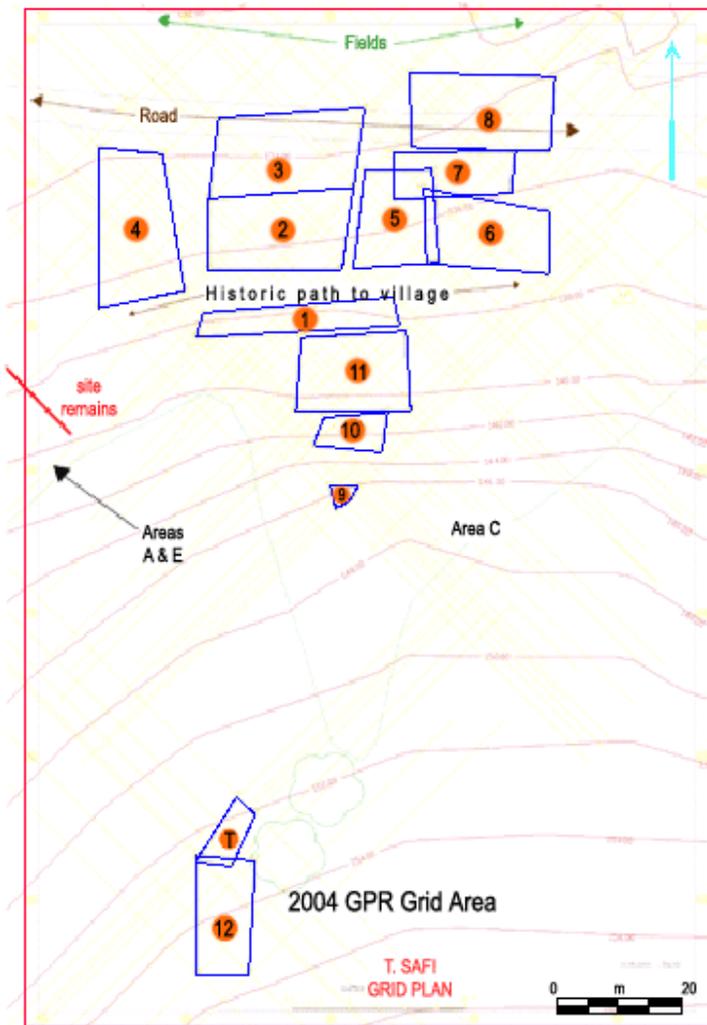
In beginning the 2004 GPR survey of Tell es-Safi, a broad area was marked in which it was believed that the continuation of the siege trench may be, based on the landscape and archaeological information available. Figure 2 is a map of the 2004 GPR Area that shows the placement of our GPR grid using a GPS device to record our corner points. Figure 3 is a schematic map of the GPR grids as we placed them on the ground on the tell.

Geophysical Survey Systems, Inc. (GSSI) equipment was used to acquire all data this summer. We used a 200 MHz antenna to “see” three to five meters below the surface along with a calibrated survey wheel to mark horizontal distance within each grid of acquired GPR transects. Standard field methods were used including a guideline cord placed at equal distances along the edge boundaries of each grid to help the GPR surveyor pulling the antenna maintain the correct distance within the grid itself. GPR profile lines were acquired in north-south and east-west directions 1.0 to 1.5 meters apart depending on the chosen density for each of the twelve grids. In addition, a velocity analysis test was performed in the field to correct for depth in the GPR data once the surveying was complete for use in post-processing.

GPR data was taken to the lab for post-processing and appended together to create the cross-grid 200 MHz datasets. In order to correct time to depth in the GPR data, a traditional bar-test was completed in the field by pounding a metal bar into the side of an excavation at a known depth and dragging the antenna across this location to note its depth in nanoseconds [4]. From this we were able to make approximate velocity conversions commonly used for mineral/sandy soils and limestone [5, 7]. Each dataset/grid was analyzed and key sub-surface features were noted for each surveyed area. Maps and orientation figures were created, a few

of which are available in this case-study. Full results can be found at: <http://www.mnemotrix.com/geo/essafi/trench/safi04.pdf>.

Grid 12 was done as a control study at the end of the GPR Study. We had been surveying an approximately 75 square meter area down the hillside trying to plot the course of the trench. Grid 12 was an area at the top of the hill where the trench had been fully excavated in previous seasons. While the geology was somewhat different at the top of the hill, and while the excavation itself would alter the GPR results, we still believed a sub-surface signature of the trench in an area where we knew it was located could be acquired. In post-processing, we found this signature to reappear in the areas where the trench seemed to be located. As we analyzed the rest of the grids we looked for this type of signature to locate remains of the ancient siege trench downslope from Area C.



2004 Map of Tell es-Safi/Gath Archaeological Project Provided Courtesy of Surveyor Yehuda Shapiro. GPR diagram and labels provided by Mnemotrix Systems, Inc.

**Figure 2: Bird's eye view of 2004 GPR Area. A full-size version is available at: <http://www.mnemotrix.com/geo/essafi/trench/zsite5.html>.**

A fairly consistent anomaly could be seen and traced throughout the area, starting with the Grid 12 Control Study and working its way downslope north towards the fields. We studied the individual grids (which allows for higher 3D resolution) to locate what seemed to be a similar anomaly, or GPR "signature" denoting where the trench might be. We then plotted their location on the Super-3D GPR grid (Figure 4) using black dots.

The distance between the cluster of dots to the west and to the east is about 23 meters towards the middle of our survey area at a lower elevation, so it seems unlikely this distance could represent two sides of a siege trench. The berm area can be seen visually where noted to the east as a raised area, as that area has been left relatively undisturbed, while the area coming closer to the road and beyond it has been cleared, cultivated, and planted.

The area at the top of the hill (Grid 9) is located just beneath and north of the excavated trench area, and is

between two boulder areas. According to Dr. Maier, looking at the ancient and modern landscape, this section should be directly in the trench, with berm remnants to the east.

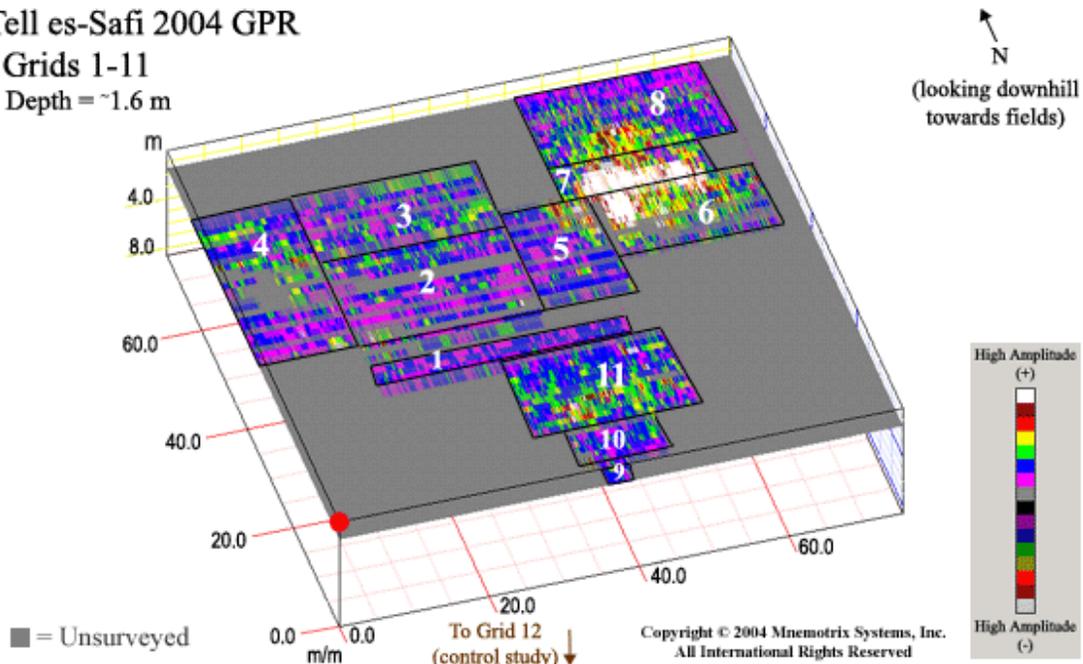
Thus it seemed logical to connect the dots coming down the hill and veering to the east as shown. This can be seen in Figure 4 where black lines mark “probable course of the trench and berm”.

The cluster of "dots", or similar GPR signature to the west, could indicate something from the same time period, or at least something which would leave the same trace on the sub-surface as would the trench. A follow-up ground truth study on both areas will shed light on this subject, perhaps next season.

**Tell es-Safi 2004 GPR**

**Grids 1-11**

Depth = ~1.6 m

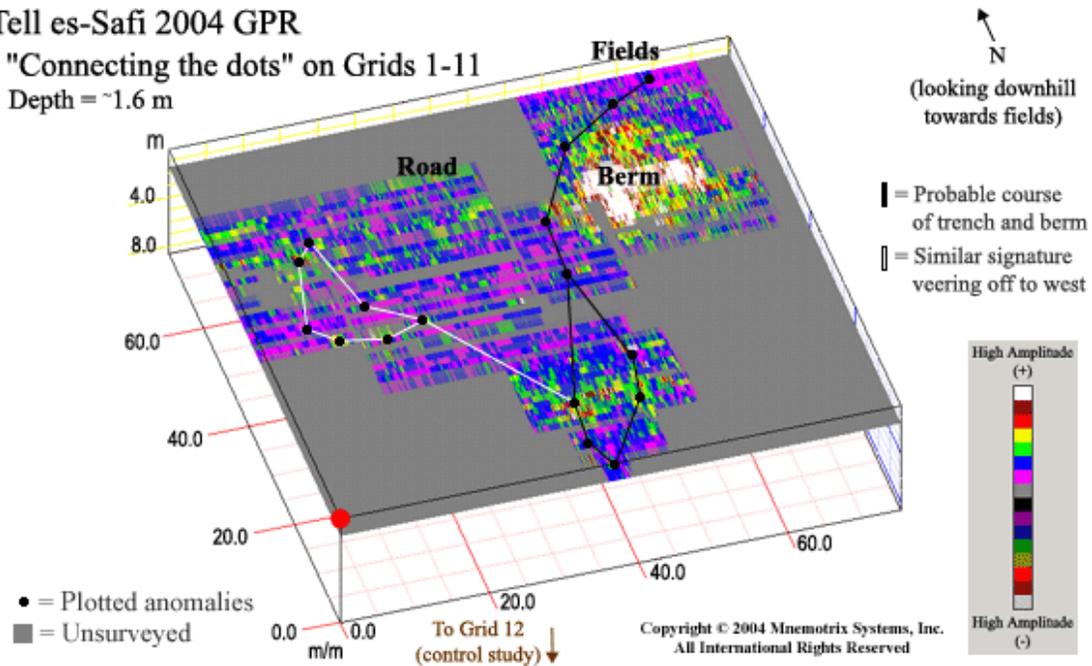


**Figure 3: Schematic map of 2004 GPR Grids 1-11.**

**Tell es-Safi 2004 GPR**

**"Connecting the dots" on Grids 1-11**

Depth = ~1.6 m



**Figure 4: After studying the individual grids, we were able to plot the signatures labeled in each to trace the probable course of the trench and berm. A similar signature seemed to veer off to the west in Grids 2, 3, and 4. Ground truth excavation will be the key to understanding the true nature of these GPR anomalies.**

In addition to the figures you see here, animations of the sub-surface were created as if stepping down through the sub-surface to aid the Project Director in analysis and strategic thinking. These can be seen in the full report at: <http://www.mnemotrix.com/geo/essafi/trench/safi04.pdf> .

## Conclusions

What has been provided here is the result of many years of fieldwork and experience in applying Ground Penetrating Radar at archaeological sites. The successful acquisition of geophysical data and the explanation to the archaeologist is a team effort. In order for a survey to end in useful results that allow the archaeological site to become more streamlined and strategic, a hands-on approach must be taken where information is exchanged between parties on a regular basis. The more information known, the more effective the geophysical data can be at a particular site.

In this paper certain steps have been elucidated to come to a good result and examples of post-processing imaging that can aid the archaeologist have been shown. A summer's fieldwork at Tell es-Safi resulted in roughly 75 sq. meters of previously unknown Tell es-Safi/Gath sub-surface becoming known. In addition, a plan has been proposed for further excavation in the coming season. Without GPR countless hours could have been wasted simply excavating in areas that probably would not yield considerable results. The final result is a map that the archaeologist can take into the field and use to guide his plans. This is one of the prime purposes of GPR in archaeology, and something that will only improve as more archaeologists take advantage of the technology at their respective sites. This case-study has provided a general background and specific steps to that ultimate goal.

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