

## *Ground Penetrating Radar and Ground-Truth Results at Khirbet er-Rasm*

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During the summer of 2003 Ground Penetrating Radar (GPR) data was acquired at Khirbet er-Rasm. The expedition first enlisted the support of Mnemotrix Systems, Inc. in 2003 for GPR (Ground Penetrating Radar) studies to be done to augment the existing archaeological record, and to assist in decision-making for the coming season. Surveys and excavations have been continuing at the site since 1997. In this paper we will focus on the GPR results and those of the ground-truth excavation that occurred soon after.

### **How GPR Works**

Ground Penetrating Radar is a geophysical technique that is used to "see" into the sub-surface. It has been used successfully for archaeogeophysical purposes throughout the world and is a technique that has been used to improve efficiency at archaeological sites for many years (Gaffney and Gater 2003).

This geophysical technique functions by transmitting radar (electromagnetic energy) waves into the ground from an antenna at the surface level. A portion of these waves are reflected back to the surface when the wave rebounds from an interface between two different materials or sub-surface features. These reflected waves are then detected on the ground surface by a receiving antenna (Gaffney and Gater 2003: 47). 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 (Conyers and Goodman 1997). When the radar wave

passes through a material that is significantly different from the previous material (an interface), it creates what is called a “reflection.” The greater the difference between materials the higher the amplitude of the reflection, which in turn is evaluated in post-processing as an anomaly of significance.

As the radar waves are propagated into the sub-surface at a particular frequency, the elapsed time from the initial transmission to the 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 radiowave reflections from the transmitting antenna to rebound off of the layer in the sub-surface and to 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 (TWT) 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. In so doing, a map of sub-surface features within the gridded area can be created. (Conyers and Goodman 1997: 23-28; Gaffney and Gater 2003; Reynolds 1997)

### **GPR Results**

Work focused in three main areas of the site, of which the results have been fully discussed in the original 2003 report, which can be seen on the Mnemotrix website at this address: <http://www.mnemotrix.com/geo/shepela.doc>. For the purposes of this paper we will address briefly the results of the area that was fully ground-truthed through excavation. Figure 1 shows the location of each original grid on the excavation map used in 2003.

GPR Study Area 1 was a long section near the modern entryway to the site from the road. The exact location can be found in Figure 1 below. Some walls had been located nearby, so it was thought that the area would show where a continuation of these walls might be. Therefore a 22 x 2.5 meter grid was marked out, in which



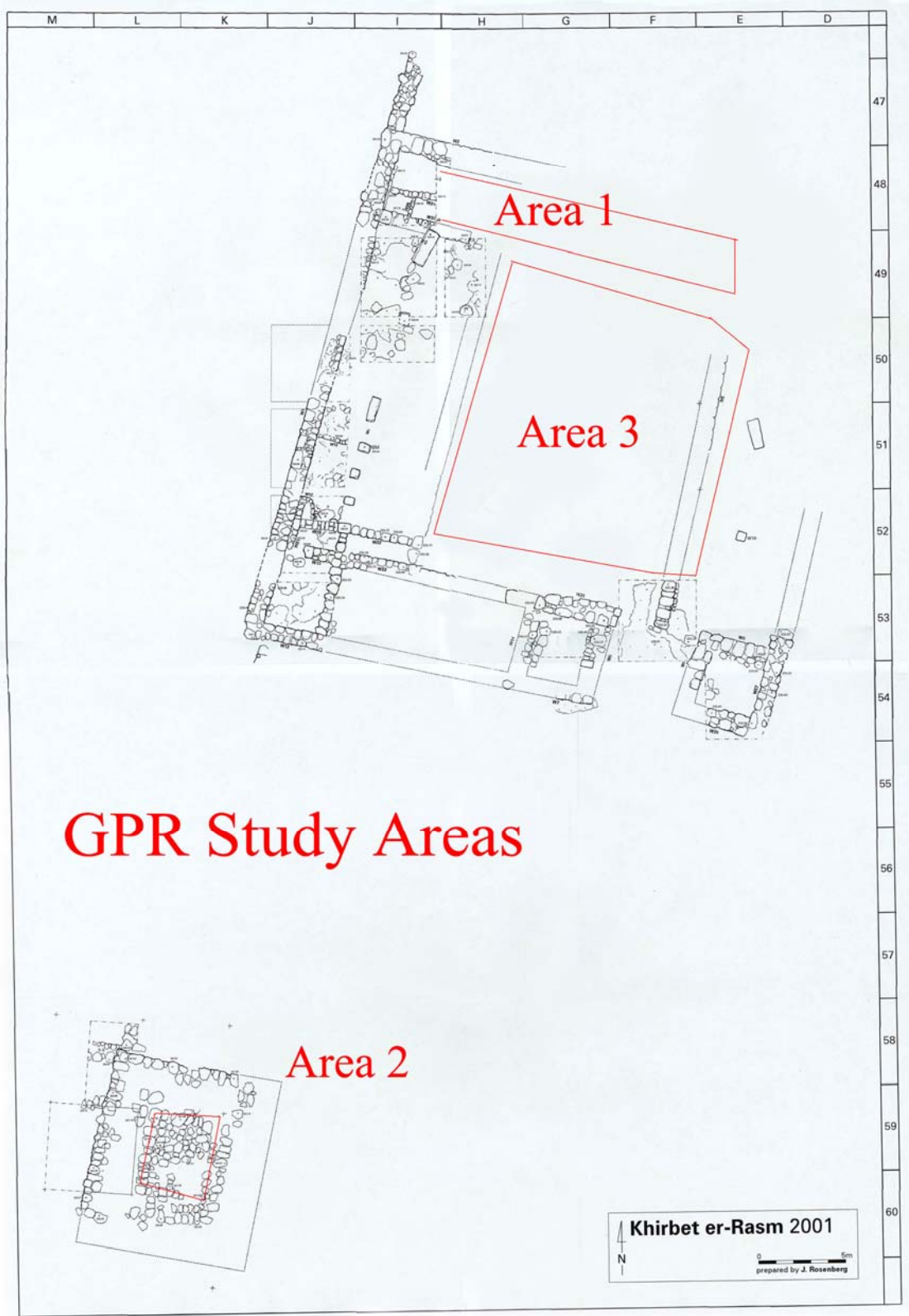
**Figure 2: Picture of GPR Survey Study Area 1 taken in 2003 before excavation.**

tight, overlapping survey lines in perpendicular directions could be acquired.

A 400 MHz antenna (with a 100 nanosecond pulse range) was chosen for this task, which can be seen with the survey wheel in Figure 2. This setup was chosen in order to have very high resolution at a relatively shallow depth of 1-3 meters below the surface. The Study Area was chosen for its ease of accessibility in addition to the understanding that known walls ran perpendicular to the area in a north to south direction. Thus a survey that would transect these features in a west to east direction was believed to be most beneficial in determining their continuation in the sub-surface.

Within the grid, which was marked out in the dimensions of 22 meters (East-West) by 2.5 meters (North-South), GPR signal data was acquired in a tight set of 12 overlapping parallel lines taken first East to West, and then transected by 36 lines in a perpendicular direction North to South. These sets of data were put together into a 3D cube for follow-up study in a post-processing environment.

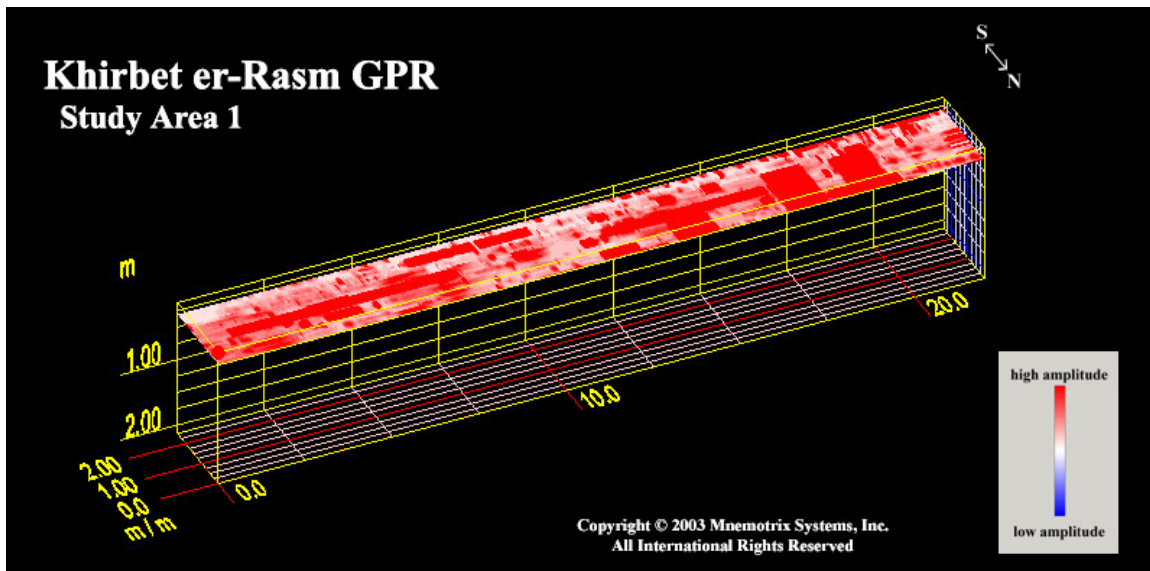
During post-processing, the GPR signal data collected for Area 1 was analyzed



**Figure 1: Map of the GPR Study Areas from the 2003 GPR data acquisition. Ground-truth analysis during 2005 focused on Area 1 results.**

closely as to depth (vertical axis) and movement along the horizontal axis in a 3D cube. A velocity analysis showed that the estimated signal depth of useful data was approximately 2.25 meters, traveling through ground made up primarily of limestone. An overview of the area and the features/anomalies within can be seen in a 3D cube in Figure 3.

An in-depth animated visualization of the anomalies of Area 1 is available at: [http://www.mnemotrix.com/geo/sh\\_a1.gif](http://www.mnemotrix.com/geo/sh_a1.gif). In this animation it is possible to see that as the vertical depth slices proceed from the surface down to a depth of approximately 2.25 meters, the presence of long rectangular anomalies can be traced. These could be interpreted as walls, or features of similar physicality. An intentionally shallow profile



**Figure 3: Overview of the features seen in the GPR data from Study Area 1.**

was used for the collection of the data in Study Area 1 since the major focus of interest, walls, were known to exist only a few meters down.

As is the case with much GPR, in order to be sure of the true identity and location of the features seen in the sub-surface results, ground-truth excavation is the key. GPR

does not create an exact picture of features in the sub-surface with exact dimensions. Very often are GPR features found in reality located at a shallower or deeper depth, or thicker or thinner depending on the situation. The scans show areas of significant change and there are most certainly "grey zones" in the dimensions. What it is particularly efficient in is demarcating the general location of objects that are worth excavating in the sub-surface separate from a larger area of lesser or no archaeological interest. If the exact placement is slightly "off", it is expected and not a surprise.

It is important to recognize that many times archaeogeophysical results are not able to be directly ground-truthed through excavation. Therefore, documentation of the exact offset of features within the sub-surface is hard to find in the literature concerning archaeogeophysics. Thus we paid close attention to the archaeological results of the site in this area and took careful in-the-field measurements. We now turn our attention to the excavation results that occurred soon after our initial survey.

### **Archaeological Results**

Several rooms were discovered through excavation by the presence of walls (see Figure 5). We studied the area where the actual GPR survey had been taken. This can be seen in Figures 4 and 5.

In the excavated section there is a well-formed wall that runs from the east to the west. This wall was measured to be about 1.0 meter wide (see Figure 5). In addition, there are several smaller walls that run in a north-south direction from the east to the west. These were measured in the field to be about a half-meter wide. The walls were made of large chunks of limestone, about 5 or 6 courses in height, with smaller stones

placed at the bottom of each course to fill in gaps (see Figure 8). During excavation we were told that the now-empty spaces between each section had been filled with stone and soil fill mixed together. Discrepancies became apparent when we found that the excavated walls are located about 2 meters south of their location in the GPR scans.



**Figure 5: Close-up view of eastern section of Area 1 seen in Figure 4. This was taken after excavation, looking West.**



**Figure 4: View of excavated survey area looking West. Pictures taken after completed excavations.**

### **Discrepancies Between the Archaeogeophysical and Excavated Data**

Archaeological ground-truthing of the GPR data has shown that the east-west running wall is located about 1.5 to 2.0 meters south of its location in the GPR data, outside of the GPR surveyed area. North-south walls were visible at different depths in the GPR data. Their placement in the excavations seems to be in the generally correct

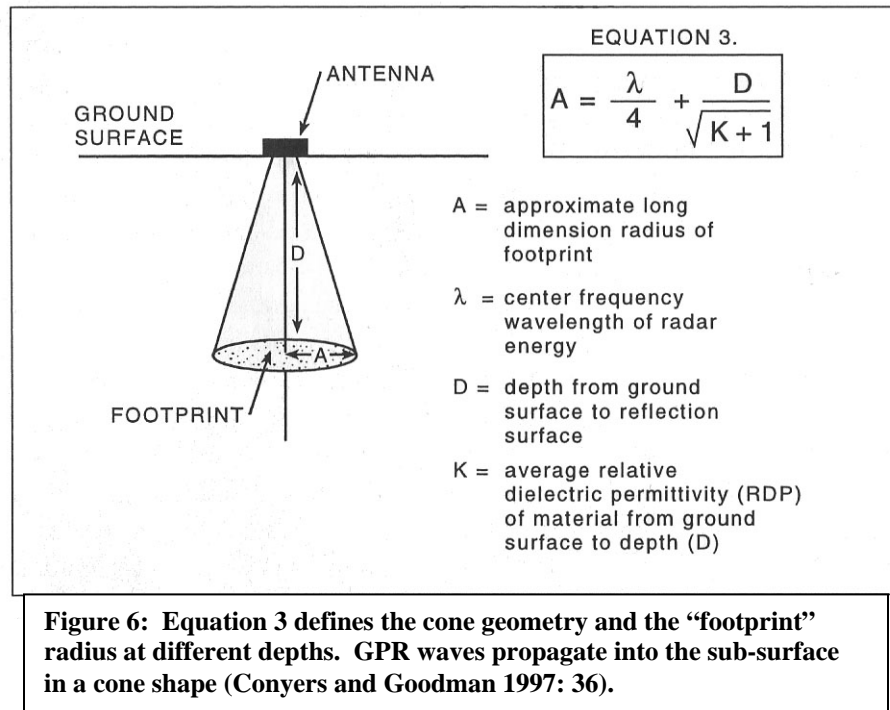
position (according to the GPR data), within a half-meter buffer zone. All things considered, these are very good results.

### Explanation of the Discrepancies

As with all types of radar data, various degrees of scatter and attenuation of the signal are present in all scans. Depending on the actual physicality of the sub-surface features of the area, the degree to which this scatter affects the survey results varies.

As radar energy is propagated into the sub-surface it spreads in the shape of a cone. It is most narrow when it just exits from the antenna and spreads out wider with depth. Based on the wavelength of the antenna frequency and the sediment type of the sub-surface, the width of this cone varies. This is based on an equation that is explained in Figure 6.

This creates what is called a "footprint" of horizontal space that the antenna is able to image at different depths. This



means that as the antenna is being dragged on the surface, it is seeing past the boundaries of what is directly below it. It is seeing to the sides, the front, and back. Further, this

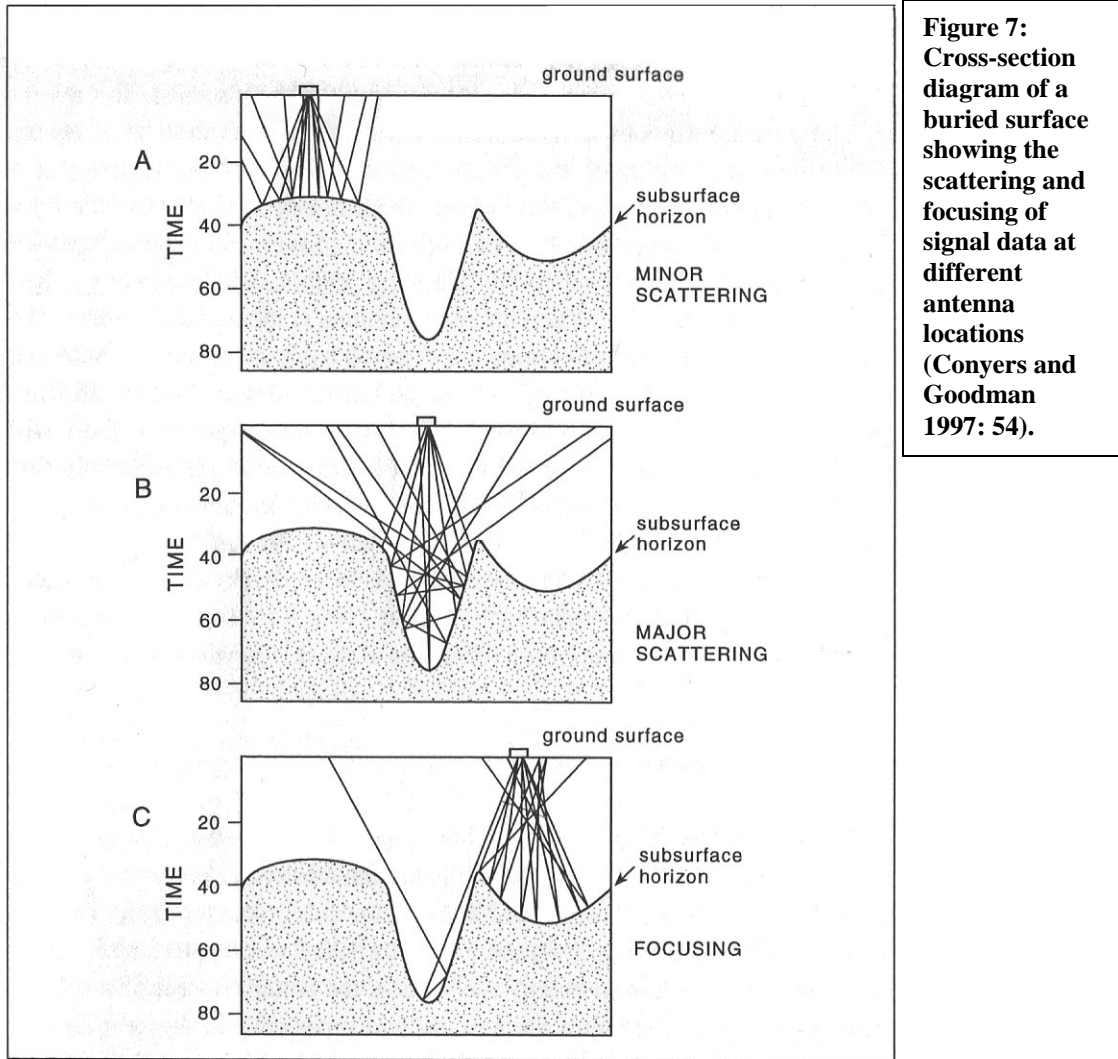


means that when the antenna is sitting on the edge of a grid, it is actually seeing past those boundaries and into the surrounding area. This is one reason why high-resolution GPR surveying creates a higher accuracy allowing us to lessen the chances for gaps in our data.

Calculations to find the range of the footprint present in this survey were completed. The approximate long dimension radius of the footprint (Figure 6: A x 2) was 0.60 - 2.16 meters long in the depth range of 0.25 – 2.0 meters. This is within the distance range of the discrepancies and thus is part of the explanation for the phenomenon in this survey.

Additionally speaking, all radar data is affected by focusing and scattering of the signal once it leaves the transmitting antenna. This has been studied and models have been created to understand the effects better. One such example is shown in Figure 7 with various convex and concave surfaces occurring in the sub-surface.

When the antenna is located above a gradual convex surface (A) little scattering of the signal occurs and there is a low amount of focus back to the receiving antenna. When the antenna is located above a strongly concave surface (B) (e.g. a moat or ditch), there is a high degree of scatter because the signal is reflected multiple times while in the ditch before it makes its way back to the surface. There is an even lower amount of focus as many reflections never make it back to the receiving antenna as they are sent in a completely different direction from where they started. Finally, when the antenna is located above a gradually concave surface (C) what happens is a high degree of focus back to the receiving antenna as they are sent out originally as a cone (discussed earlier). (Conyers and Goodman 1997: 54).



**Figure 7:** Cross-section diagram of a buried surface showing the scattering and focusing of signal data at different antenna locations (Conyers and Goodman 1997: 54).

When we look at the surface of these walls, seen in Figure 8, it can be argued that we are dealing with a concave surface. This is because the ridges on the sides due to the way the rocks were placed to make the wall create a small concave surface in the middle. In addition, the pockets between each top rock surface are arguably concave (with a high degree of focus), rather than convex (higher amount of signal scattering). These observations thus create the more focused effect that seems prevalent in the survey data.

After much study, it seems that it is the combination of these effects (i.e. the cone-shape footprint allowing us to see past the borders of the grid and the amount of focus

back to the  
antenna in a  
buried concave  
surface) that has  
caused these  
discrepancies in  
location of the  
sub-surface

**Figure 8: View of excavated east-west wall of Area 1. Notice the concave areas created by the ridges of the edge rocks forming the wall, in addition to pockets in between each individual rock on the edge surface. The overall effect is an increased amount of focus in the survey data.**



features at the site. There is an increased amount of focus back to the antenna because essentially we are dealing with gradually concave edges of the walls. Combined with the high-resolution GPR data acquisition at the site and the footprint that extends past the boundaries of the grid, we can explain why the walls are so distinct in the GPR data (the amount of clarity is rare), and the amount of focus that is present because the walls were indeed discovered at very shallow depths.

### **Final Comments**

Ground penetrating radar was used at this site in hopes of increasing efficiency at the location. What we were able to do was to survey three main areas at Khirbet er-Rasm and provide useful data to the archaeologists involved that told them what location would yield the best archaeological results. Because of the particular conditions at the site we were additionally able to document for ourselves the phenomenon that caused the discrepancies and study it in further detail. The more archaeologists are able to ground-truth their archaeogeophysical data, the more accurate archaeogeophysicists will be able

to pinpoint the locations of the sub-surface features found in the data. This site has been an important step towards the goal of increased efficiency and research of geophysical methods at archaeological sites.

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