Ground-penetrating Radar Tests in Hippos

Introduction

A number of ground-penetrating radar (GPR) tests were performed in Hippos during March 2005 in order to determine the efficacy of the method in different environments, and also to test its ability to produce images of a number of archaeological features. I will detail below the acquisition parameters for each test, what was known about the subsurface, show some of the results of the data, and give my analysis of the results.

GPR: Use and Background

Ground-penetrating radar data are acquired by transmitting pulses of radar energy into the ground from a surface antenna, reflecting the energy off buried objects, features, or bedding contacts and then detecting the reflected waves back at the ground surface with a receiving antenna. When collecting radar reflection data, surface radar antennas are moved along the ground in transects within a surveyed grid and a large number of subsurface reflections are collected along each line. As radar energy moves through various materials, the velocity of the waves will change depending on the physical and chemical properties of the material through which they are traveling (Conyers 2004). The greater the contrast in electrical (and to some extent magnetic) properties between two materials at an interface, the stronger the reflected signal, and therefore the greater the amplitude of reflected waves. When travel times of energy pulses are measured, and their velocity through the ground is known, distance (or depth in the ground) can be accurately measured (Conyers and Lucius 1996). Each time a radar pulse traverses a material with a different composition or water saturation, the velocity will change and a portion of the radar energy will reflect back to the surface and be recorded. The remaining energy will continue to pass into the ground to be further reflected, until it finally dissipates with depth.

The success of GPR surveys in archaeology and historic preservation is largely dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial and surface topography and vegetation. Electrically conductive or highly magnetic materials will quickly attenuate radar energy and prevent its transmission to depth. The best conditions for energy propagation are therefore dry sediments and soil, especially those without an abundance of clay. Soil and sediment types confronted in Israel ranged from wet conductive clay to dry sand, which is about the whole spectrum of conditions usually seen in GPR studies. The presence of mineralogic clays or salts in soil can also attenuate radar energy very quickly, which affects how deep the energy can potentially resolve features of interest. It is not known if these affected the results seen, as no chemical tests have been made. The marginal or poor results in the one failure discussed below appears to be the result of wet clayey soils.

The depths to which radar energy can penetrate, and the amount of resolution that can be expected in the subsurface, are partially controlled by the frequency (and therefore the wavelength) of the radar energy transmitted (Conyers 2004). Standard GPR antennas propagate radar energy that varies in frequency from about 10 megahertz (MHz) to 1000 MHz. Low frequency antennas (10-120 MHz) generate long wavelength radar energy that can penetrate up to 50 m in certain conditions, but are capable of resolving only very large buried features. In contrast, the maximum depth of penetration of a 900 MHz antenna is about one meter or less in typical materials, but its generated reflections can resolve features with a maximum dimension of a few centimeters. A trade off therefore exists between depth of penetration and subsurface resolution. In these surveys the 400 MHz antenna was used, which produced data of good resolution at depths up to about 3 meters. The GPR system used for the project was a Geophysical Survey Systems Inc. (GSSI) Subsurface Interface Radar (SIR) 2000 model. The GPR antennas used produces a radar pulse of about 30 cm in wavelength, which is capable of delineating features down to a minimum dimension of about 20 cm.

The "time window" within which data were gathered varied from 30-50 nanoseconds. This is the time during which the system is "listening" for returning reflections from within the ground. The greater the time window, the deeper the system can potentially record reflections. In most ground conditions a 30 nanosecond window translates to about 2 meters in real depth.

To convert time in nanoseconds to depth, it is necessary to do a velocity test. For this project, this was done using the program Field View, in which hyperbolas found on reflection profiles are measured to yield a relative dielectric permittivity (RDP), which is a way to calculate velocity (Conyers and Lucius 1996). The shape of hyperbolas generated in programs is a function the speed at which energy moves in the ground, and can therefore be used to calculate velocity (Conyers 2004). This was done for all grids where good hyperbolas were generated. All profiles and processed maps can then be converted from time in nanoseconds (ns) to depth in meters using this average velocity.

Processing Procedures

The initial data processing step involved in all grids was the generation of reflection profiles. In this way a two-dimensional vertical slice through the ground can be visualized for each profile in each grid. Using this method, vertical axes are converted from time to depth, and actual depth along the ground in each transect is displayed. Reflection data are commonly processed to remove background noise and filter out frequencies of disruptive electromagnetic noise. It became very clear early on in this project that Israel in general is an extremely "noisy" area, with respect to the amount of radio, cell phone, pager, television and military transmissions. In some cases these transmissions almost completely overwhelmed the energy coming from the ground, making the survey less than optimal. I have found over the years, however, that this usually only occurs when the reflections from within the ground are so weak as to be almost undetectable anyway, due to energy attenuation in electrically conductive ground.

After analysis of the profiles in each grid, reflection profiles were processed to create amplitude slice-maps (Conyers 2004). Amplitude slice-maps are a two-dimensional tool for viewing differences in reflected amplitudes across given surfaces at various depths in the ground. Reflected radar amplitudes are of interest because they reflect the degree of physical and chemical differences in the buried materials. Strong, or high amplitude reflections often indicate dense buried materials, such as solid rock foundations or other archaeological features of interest. They can also be generated at contacts between naturally occurring stratigraphic horizons, and at contacts with bedrock or other layers in the ground. Amplitude slice-maps are generated through comparison and averaging of all reflected amplitudes within all profiles in a grid, at all depths that are of interest. This allows for spatial mapping and three-dimensional interpretation of radar data over a wide area.

In this method, amplitude variations recorded as digital values are analyzed at each location in a grid where there is a reflection recorded. The amplitudes of all traces are then compared to the amplitudes of all nearby traces along that profile. A series of maps is then produced that shows amplitudes in map view, but also with depth in the ground. The database can then be "sliced" horizontally and displayed to show the variation in reflection amplitudes at a sequence of depths in the ground. Often when this is done changes in the soil related to disturbances such as the presence of walls, floors, and even the digging of trenches and other disturbances can become visible, making many visible to the human eye. Using the computer program Surfer 8, grid files were created and the data interpolated using a cubic Inverse Distance Weighting. When there were rocks present in the ground, which appeared to be randomly distributed, a large search radius was utilized in order to remove the clutter created by them and distinguish more substantial reflection anomalies from this "clutter." Using this method removes small rocks from the dataset because the computer program is only searching for features that extend beyond a single reflection transect.

Slicing of the data generally begins with the reversal of even numbered profiles, to compensate for the data collection technique, which is usually to move the antenna both up and back along transects. Since every other line is collected in the opposite direction, reversal is necessary prior to mapping the data. Following profile reversal, the typical processing protocol requires the creation of .xyz files. This step creates a Cartesian coordinate grid into which the amplitude data are eventually incorporated. The final step is the actual generating of amplitude slice-maps. From profiles produced first, features visible in the amplitude maps are then compared and contrasted as a check to the origin of mapped anomalies.

Hippos-Sussita

A number of profiles and test grids were collected at this site. They are broken down into the grids shown below:

Grid 3_13_05: These two profiles were collected just north of a Hellenistic wall north of the Byzantine Church. The two transects were placed about 1 meter apart along the tracks of a truck path along the north side of the excavation. The purpose of these profiles was to determine depth of energy penetration and the ability to resolve features known to project into the area from the excavation trenches.

In general the energy penetration at Hippos was excellent, with good resolution to about 2 meters depth, or greater. One of the test profiles, shown in Figure 1 below, shows the projection of a wall that is quite thick. This wall can be seen in the excavation trench just to the north of the road along which the data were collected. To the east a second thinner wall, whose top is very close to the ground surface, can also be seen, adjoined by a very nice floor just to the east.

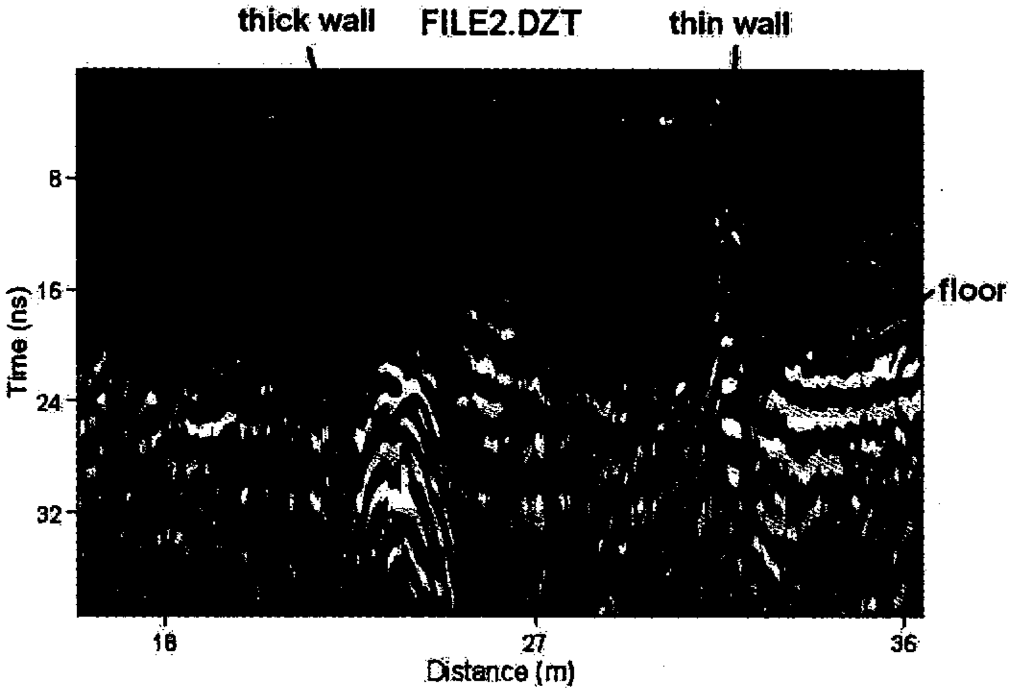

Figure 1: Reflection profile from Hippos showing walls and a floor

This profile shows the great resolution of standing architecture at the Hippos site. The data are quite clear, and depth penetration was excellent. During the following excavation season, July 2005, The Polish team, excavating the northern wing of the NWC, exposed segments of the thicker wall (W769, Fig. 15).

3_13_05.001. This grid of data was collected inside the Hellenistic Courtyard. The surface was cut stone blocks, and a number of column pieces and other blocks of stone were found on the surface (F423, Fig. 5). Data were quite good in this test, and energy penetrated the stone floor blocks quite readily. In many of the profiles the base of the stone floor is visible, but even more important, there appears to be an additional floor below that. It is truncated in places, and also shows evidence of foundation walls or perhaps column bases that project a few tens of centimeters above that surface (Fig. 2). Most of the material below the Hellenistic floor is stone rubble and other finer grained material used as fill.

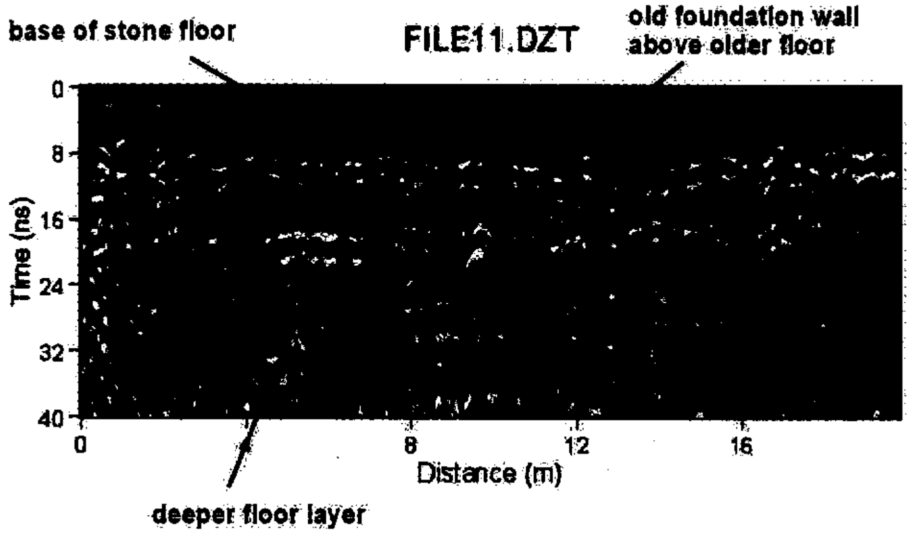

Figure 2: Reflection profile under the floor of the Hellenistic Courtyard at Hippos.

3_13_05.002 Winery

This grid of data was collected on the basalt stone floor of a grape processing facility just northeast of the Hellenistic Courtyard (F271, Fig. 5). There is a screw hole in the middle of the floor, leading to a pipe that appears to project to the southwest and come out in a wine vat just to the west. These data were collected to test the ability of radar energy to penetrate basalt stone, which has been assumed to be very poor for energy transmission. It became immediately apparent that there was good energy penetration within the basalt, and into the underlying material. The pipe, which allowed grape juice to flow into the vat, was also apparent in the profiles as a distinct reflection hyperbola (Figure 3).

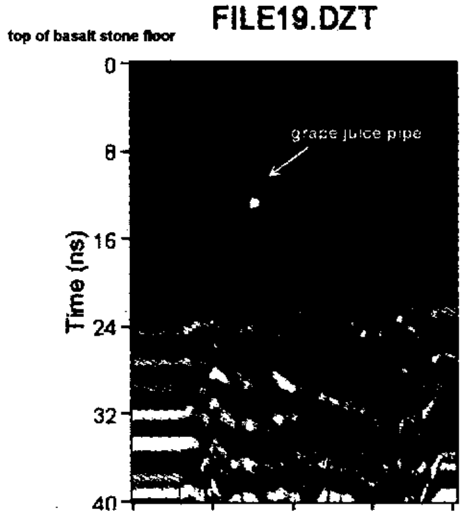

Figure 3: Small reflection hyperbola caused by a pipe for grape juice to flow into a vat.

Little else in this small grid was interesting. But I was happy to have dispelled the idea that radar energy will not penetrate basalt.

3_13_05.003 Public Roman Space: Tractor Path Grid

This grid of data was collected in a tractor path just east of the Byzantine Church. To the east of the grid was a large rubble pile of excavated building stone from previous excavations. For the most part the reflection data suggests that this area has seen a great deal of disturbance in the past. There was little in the way of coherent reflections. I a few places what appear to be floors and a few portions of walls remain. But most of the profiles showed a jumble of rocks and other building materials in random placements. One profile does show a wall and a floor (Figure 4).

The amplitude slice-maps of this site confirm that most of this grid consists of random reflections from jumbles materials in the ground (Figure 5). However there are two areas that show consistent linear features, one of which is a wall, and the other a possible room block, whose wall is seen in Figure 4. These intact features are located between 50 and 75 cm below the surface.

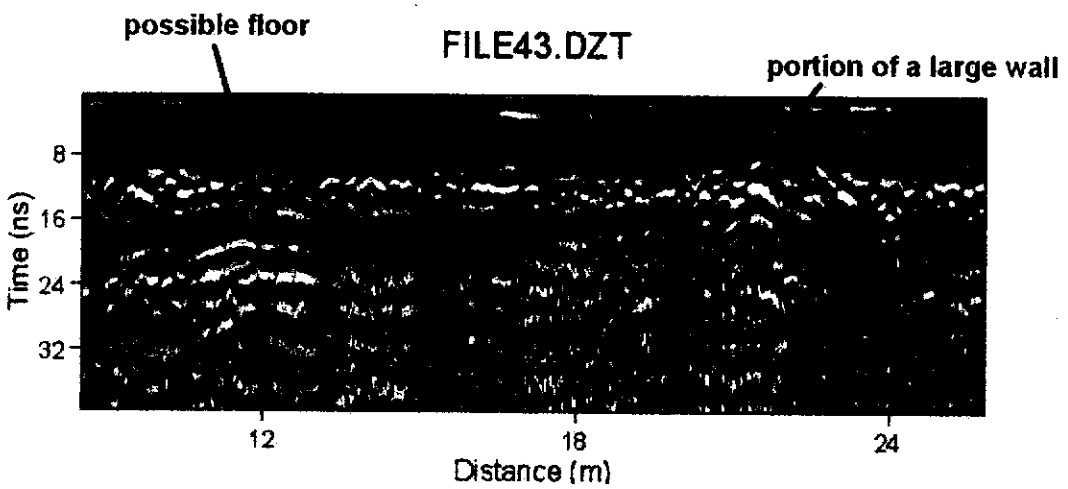

Figure 4: Reflection profile from Hippos showing a floor and wall, in what is otherwise a very disturbed area just east of the Byzantine Church.

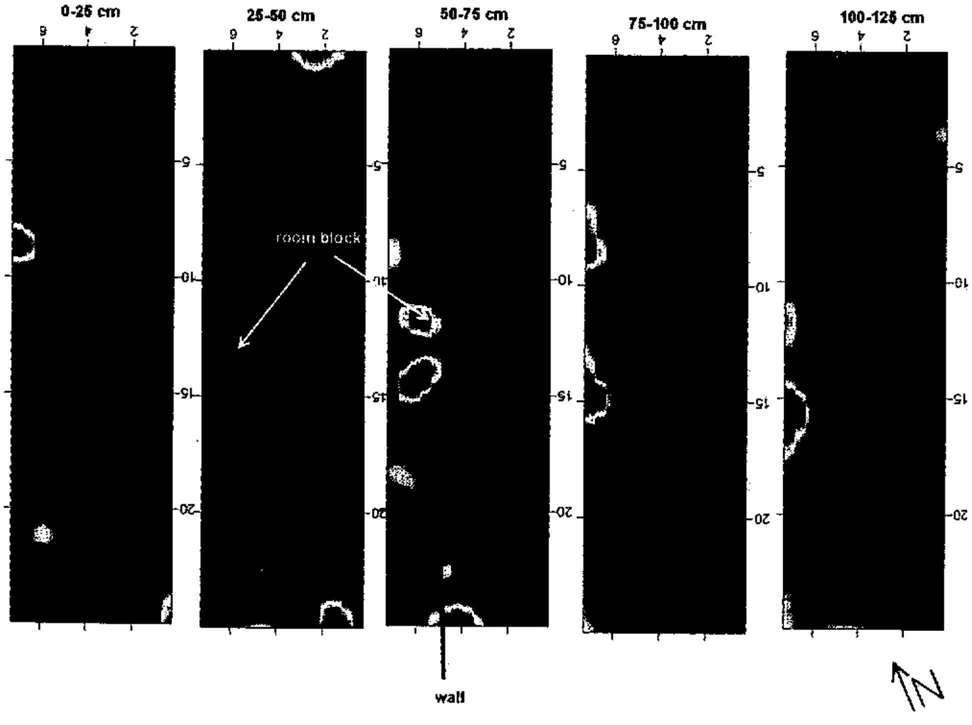

Figure 5: Reflection Amplitude maps from the tractor path grid, Hippos

I was very pleasantly surprised at how consistently good the reflection data were at the Hippos site. There was excellent continuity of many intact wall and other architectural features throughout all the grids. The only trouble with Hippos is that much of the area close to the site is either in un-excavated rubble from collapsed structures, is already partially excavated, contains debris removed from excavations, or has modern structures built on it. Although I did not explore all the site when there, as the grass was quite long in most places, there appears to be few places within which to collect large GPR grids for the placement of future excavations. This is something that perhaps Michael Eisenberg and I should consult on in the future.

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