Ground Penetrating Radar Survey Report:

Tel Hazor, Israel

Data Acquired June 23, 2003
Report compiled September 22, 2003

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Introduction:

On June 23, 2003, a Ground Penetrating Radar (GPR) survey was executed on a portion of the upper city area of Tel Hazor, the largest biblical-era site in Israel. The entirety of this site is some 200 acres. According to the information given on the official Hazor Excavation website, the city of Hazor was "approximately 10 times the size of Jerusalem in the days of David and Solomon."

Hazor has been excavated on and off since 1928. Large-scale excavations in the 50's, again in the 60's, and resumed in the 90's have been conducted and have revealed information of much historic relevance, such as "21 superimposed cities containing a wealth of relics from biblical Hazor, including temples, fortifications and a huge water system."

Under the direction of Dr. Amnon Ben-Tor of the Institute of Archaeology of Hebrew University, a small test portion of the excavation site was chosen for this 2003 GPR study. Given some earlier experience with a Ground Penetrating Radar study in 1997 which was less than successful in pinpointing the location of archaeological features, it was hoped that a test survey in an area closest to the known locations of

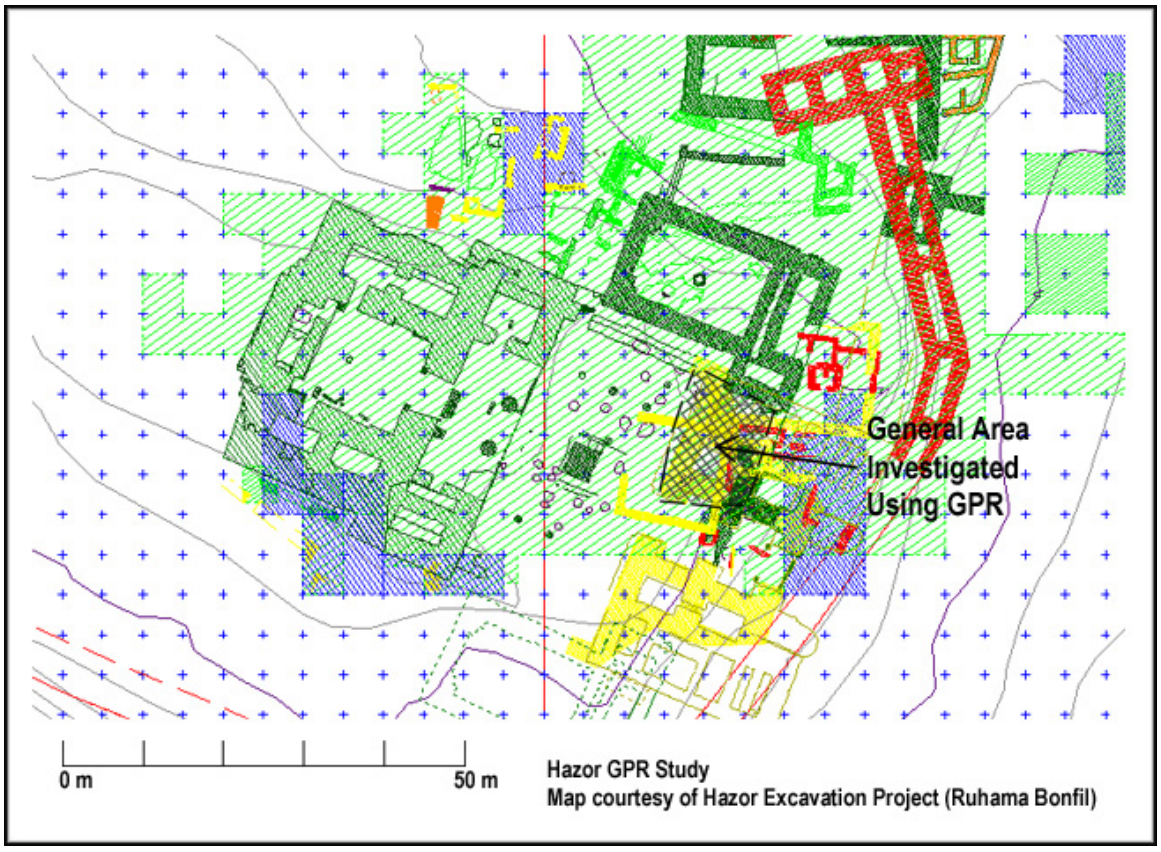
excavated walls might shed some light on the GPR process in this locale, and the nature of its functionality and its efficacy for archaeological site support here at Tel Hazor. Thus, in collaboration with Dr. Ben-Tor and his assistant Doron Ben-Ami, this area near the site of the Palace complex was chosen as a starting point.

Actions Taken:

About 12 hours between 5:00 am and 7:00 pm on June 23, 2003 was devoted to the GPR survey at Hazor. The excavation area near the palace is quite rocky and filled with obstacles, so flat survey access was an issue throughout the day. Because of this, small grids of perpendicular survey lines were measured out and taken in pieces around the stone blocks and excavated areas.

Five different overlapping areas were measured out and intensively surveyed using a 400 MHz antenna. Some subsets of this area were also tested with a 200 MHz antenna. The total area of investigation was approximately 8 by 11 meters. This can be seen in the map in Figure 1 below.

Figure 1: ***Site map of the palace in Area A as provided by Ruhama Bonfil, from the Hazor Excavation Project. General area of our GPR study is shown below in black.***



Near the northern boundary of our main study area was a small cave which was of interest to the chief excavators. A small 2x3 meter grid in this vicinity was also surveyed using GPR with both the 400 MHz and 200 MHz antennas, but is not shown as we were unsure of its exact location on the site map.

Note: The exact locations would have to be confirmed and verified with the site excavators, as we have incomplete information regarding the key used on this map, and have had no opportunity as of yet to confirm these details since the survey was done in June.

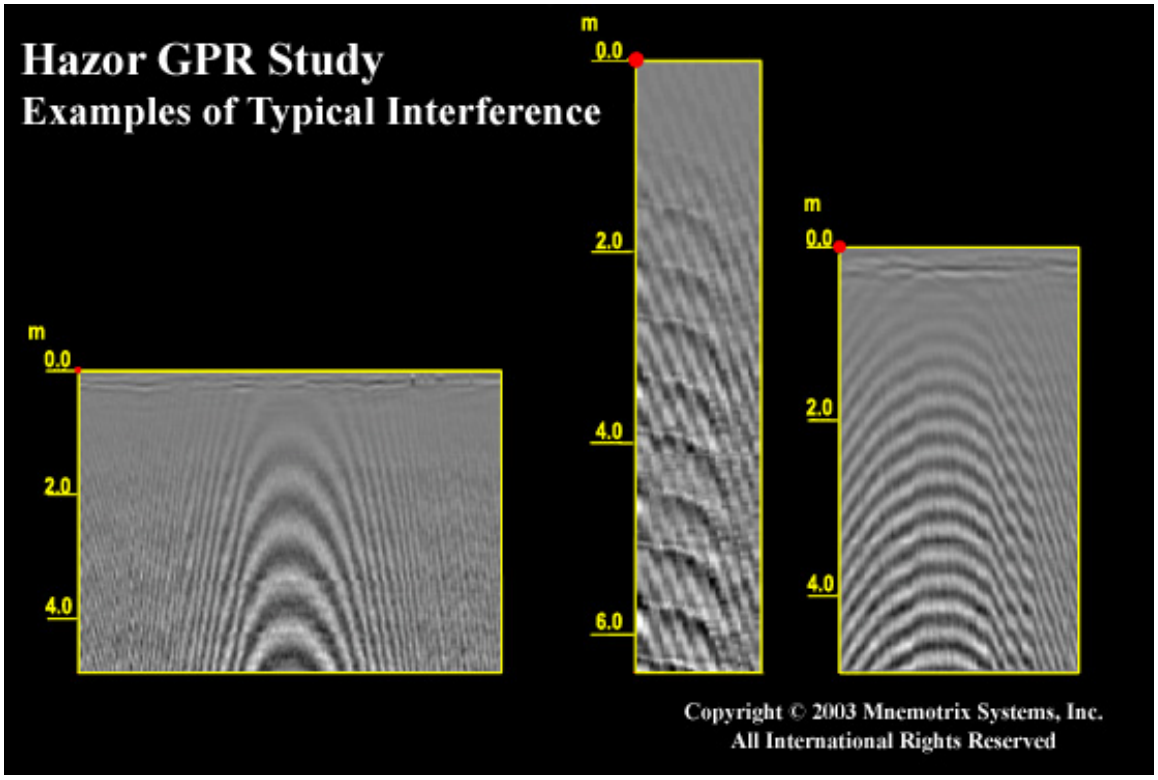
Signal Interference Issues:

The survey team was aware that another earlier attempt at GPR had been made at the Hazor site in 1997. From the Site Excavation Reports, it can be seen that in 1998 a ground truth excavation was undertaken to locate the walls north of the palace which the 1997 survey indicated should be present. In the 1998 report it was noted that "the G.P.R. tests [i.e., those executed and reported on in the 1997 Excavation Report], at least in this area, were a total failure: there was no resemblance between the walls indicated by the G.P.R. tests and the walls actually found during excavations." We were all aware that these results were less than satisfactory; however, there was insufficient information to discover exactly what had happened, and no written GPR report was available for study.

During our June GPR acquisition, it appeared in the field that we were finding features of some magnitude which could possibly be the continuation of the walls which were elsewhere visible from past excavation. However, upon post-processing of all the survey results in the lab, we discovered that our preliminary conclusions were incorrect.

Upon closer inspection, we became aware that a significant amount of consistent interference in the GPR radar signal was present throughout all areas of the GPR studies done. It was not until we were able to examine this in detail in the lab that we were able to see the consistency of this interference, and to separate the "good" from the "bad", or signal interference, data. In fact we realized that to an inexperienced eye it might appear that large features were being seen in the sub-surface where in fact this has turned out to be a consistent repeating pattern of diagonal banding which is electronic interference. This electronic interference was so prevalent and consistent in the survey that we have included an example of this in Figure 2 below.

Figure 2: ***Samples of the electronic interference found at Hazor, and manifesting consistently throughout all surveyed areas.***



Upon further consultation with technicians at Geological Survey Systems, Inc. (GSSI), the makers of our hardware, we discovered that there can be a phenomenon encountered where this type of diagonal banding is present that seems to mimic an actual feature. We believe this is what we are seeing above. Given that this electronic interference is so consistently prevalent, it might also have been present in the same way in the 1997 GPR study.

In addition to this external above ground signal interference, we also encountered another type of interference in the sub-surface itself which was unexpected. It should be known that highly conductive materials such as those with a high clay content, soluble salts, or caliche soils (found in desert environments) affect the radar transmission and

inhibit the depth penetration of the signal as it is literally absorbed and cannot extend to greater depths. According to the Geological Survey of Israel, as can be seen on their published map, Hazor itself is largely composed of limestone formations that extend east from the west (Barkokhba Fm., Timrat Fm., Meroz and Yisre'el Fms., Bina Fm., etc.). Thus because limestone is generally an excellent environment for GPR, we were optimistic before attempting the survey.

However, upon more detailed study of the map, it can be seen that the case is more complicated, in that Tel Hazor seems to be a small peninsula of limestone surrounded by alluvium consisting of gravel, sand, and clay. In addition, the area is exposed to a strong wind which seems to scatter this alluvium throughout the palace complex, if not also throughout the rest of the tel. As this seems to be the case, the soil present at the site itself then contributes much attenuation and affects depth penetration of the GPR signal due to its soil content.

As will be discussed, the issue of the soil content is not prohibitive of GPR as a methodology, but does require attention in the setup chosen for optimum results.

Lessons Learned and Strategies for Future Surveys:

As has been noted earlier in this report, the feature of most interest during our June GPR data acquisition was the continuation of the old walls of the palace complex. Because these walls were expected to exist only a few meters deep if they did extend into our surveyed area, a 400 MHz antenna was chosen as under normal conditions it should have revealed more than the necessary depth for the major survey target with maximum resolution.

In fact, and as has been noted earlier in this report, during the survey it appeared we were finding our target as the nature of the signal interference we were encountering seems to have mimicked the presence of a large feature or features below the surface. However, once we discovered that the apparent wall-like features were signal interference, we discovered that the 400 MHz data collections were largely too marred to show anything of interest in an archaeological sense.

Even so, in addition to the 400 MHz grids, we also did test acquisition lines using the 200 MHz antenna which sends the pulse deeper, though its resolution capability is for larger objects. Upon evaluation following the survey, we discovered that the 200 MHz antenna actually was obtaining the better signal. We believe that the stronger, deeper pulse is better able to extend through the types of interference present at the Hazor site; i.e., external electronic interference plus a high soil absorption level. In fact, since the features of interest being sought with GPR are mostly quite large (a few meters wide in the case of the walls), the 200 MHz antenna would be adequately suited for the task.

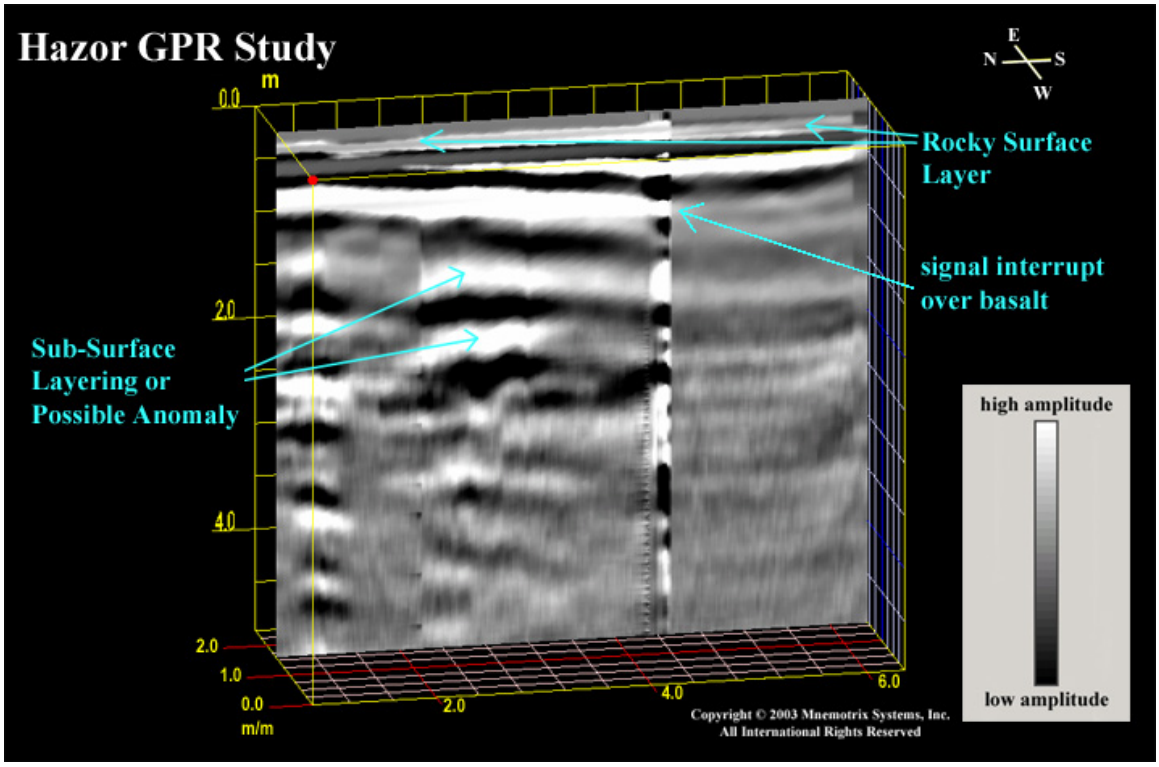
While a 200 MHz antenna was used to send a pulse which might have extended $10 – 15^{+}$ meters through the sub-surface, a useful signal depth was seen only down to about 6-8 meters in the area of the excavation which was surveyed. Again, this is not really a barrier as the major features of interest are likely to be located within this depth.

Knowing the typical soil type, we would use the 200 MHz antenna, and have worked out the settings more appropriately to capture the available signal information. We would also seek to discover the source of the interference and find a time to accomplish the survey when such external interference was not in play.

Observations and Results:

It was hoped we could construct a 3D animation of the surveyed area and the features encountered. The amount of electronic interference encountered precluded our having sufficient grid data to do this, or to offer much advice on feature location. However, we were able, with the 200 MHz antenna, to establish a typical view of the sub-surface. An example of this is shown in the next figure:

Figure 3: ***Sample of sub-surface layering seen using the 200 MHz antenna in an area near the excavated walls of the palace complex.***



In a GPR study, high amplitude colors signify a strong reflection of the material, while low amplitude colors signify a weak reflection in the surrounding material or matrix. Therefore, when using the color table shown in Figure 3 above, where the

contrast is strongest, there exists a strong difference between layers of sub-surface materials, which can be viewed as an anomaly or natural layering depending on the particular context.

The above view offers a conjecture that what is seen could be an anomaly. Given that we had a larger grid area in which to demonstrate the norm of the site, anomalies would stand out more strongly. In the absence of a broader view of the “norm”, it is difficult to say if this is an anomaly or merely the usual view of the geologic layering existent here.

At the point of greatest contrast in the figure above, the width of the “anomaly” seems to be a meter or more (of adequate dimension to be considered for a wall or other large feature). The depth is estimated only and as can be seen the signal becomes fainter as it is absorbed into the soil.

At the end of our study, as mentioned earlier, we did a brief GPR grid of a 2x3 meter area near the mouth of a cave close to the palace area. It was hoped to determine whether a burial might exist beneath. At the time of the survey we thought we might be seeing a cavity in the center of this area, but upon closer investigation of our results we found the electronic interference signal cutting across our data, and so we cannot say anything for certain about this. We would hope to include this area in a follow-up study, and also to extend the survey a few meters further past the area which had been dug out in previous years.

Summary and Recommendations:

For reference, this report can also be seen on the Mnemotrix website at: http://www.mnemotrix.com/geo/hazor.doc.

Because of the intense study given to this general area, we were able to establish a consistency of issues which would have to be properly attended to in order to conduct a more complete and effective survey of this area.

We now know that Tel Hazor has two chief issues which must be dealt with in order to accomplish a useful GPR study:

1. The source of the above ground electronic interference must be better understood, and avoided if at all possible.

2. An antenna which looks “deeper” than one would think to find features of interest should be used.

We established that the 200 MHz antenna has the potential of finding what we are interested in, such as large features including walls, cavities, or remnants of a water system, and a better profile for its use.

In spite of the difficulties that have been seen in the application of GPR at this site, we do believe that GPR can be a very effective tool in locating the large sub-surface features that are suspected to be here, if the issues unique to this excavation site are taken into account. In light of the fact that the whole site is over 200 acres, a tool which can do reconnaissance on walls and cavities in a non-invasive manner can be very helpful to the archaeologists. Other remote sensing methods may also be of use.

We would look forward to the opportunity of applying what we have learned here to a new broader survey.