Introduction

On June 24 (2006) ground-penetrating radar (GPR) data were collected in order to map three areas of the Raqefet Cave. The primary goal of the survey was to prospect for certain bedrock features that were visible on the exposed portion near the entrance to the cave (Fig. 17). These appeared to be HBHs, and so it was assumed that such features inside the cave,

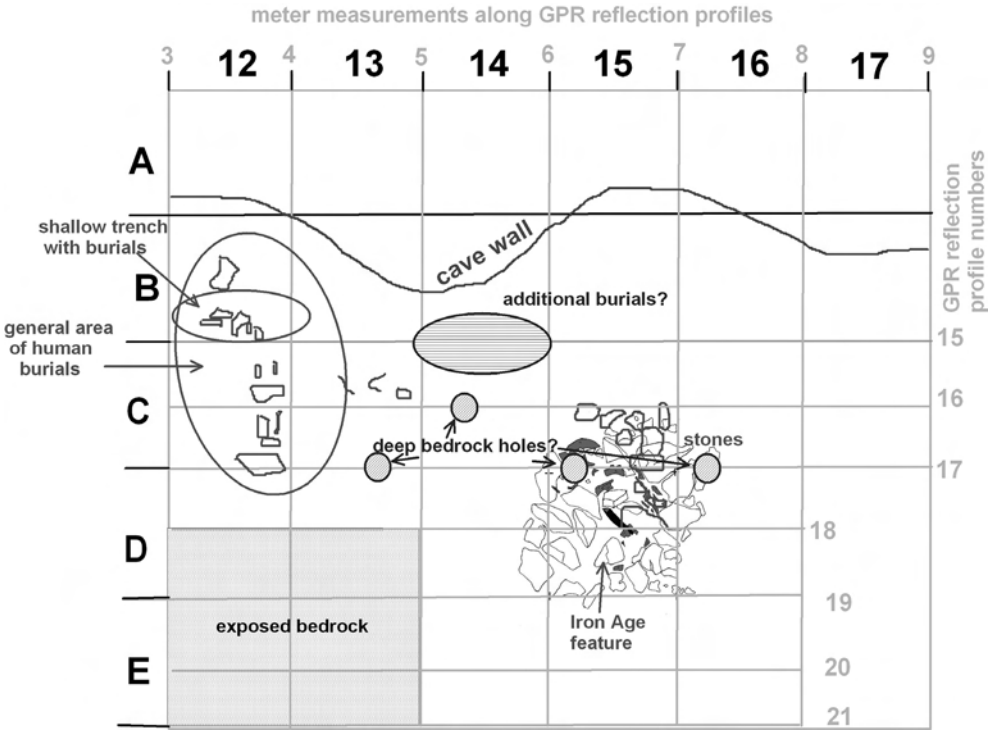

Figure 17. Base map of the GPR grid on the cave floor in chamber 1, with the excavation grid squares. Some of these features are within the sediment package, some on bedrock, and others very close to the surface.

covered by sediment would be the target of the GPR surveys. There was also a portion of a skeleton exposed along the north wall of chamber 1 (Locus 1), which was an additional target. Inside the cave two surveys were conducted, one in chamber 1 where sediment covered the bedrock (scheduled for excavation in the summer of 2006) and one in the far recess under the chimney where unknown sediment layers were preserved. Additionally it was decided to test the method in a narrow terrace along the exposed apron of the cave, well outside the drip line. In this area the goal was to look for possible walls or other Natufian features on or in the bedrock surface that might be buried by slope wash sediment.

The Geophysical Survey Systems Inc. SIR-2000 system was used with the 400 MHz antennas and a survey wheel for distance calibration. Reflection data were collected with a time window of 50 nanoseconds inside the cave and 40 nanoseconds on the terrace. Velocity analysis using hyperbola fitting (Conyers 2004:99) showed that each nanosecond of two-way travel time represents approximately 5 cm in the ground, making a depth of energy penetration of 50 nanoseconds about 2.5 meters.

Surveys were conducted with a 50 cm transect spacing and the survey wheel was calibrated to collect approximately 33 reflection traces each meter, producing a very dense reflection data set along lines. It was found that all surveys had a small amount of survey wheel slippage, producing some error in the horizontal placement of reflection traces, which was greatest when the antenna was pulled over surface irregularities and in and out of holes in the bedrock.

Reflection data were processed into vertical reflection profiles, where reflection amplitudes were re-gained to enhance subtle changes in layers and features, and all traces in all profiles had a background removal filter applied to remove extraneous noise (Conyers 2004: 123). All GPR reflection profiles processed in this manner showed a distinctive reflection produced from bedrock as well as variations within the sediment package above. Each was interpreted in two-dimensions and correlated with what was known from excavations to hold significant buried materials. Reflection profiles that illustrate significant buried features in each of the grids collected will be discussed in detail below.

Chamber 1 Grid

Eleven reflection profiles were collected near the cave mouth (files 15-25) within a grid that was 8x5 meters in maximum dimension (Figs. 17-22). The northernmost profile (file 15) was collected as close to the northern wall of the cave as possible and its 0,0 origin tied to the datum in the southeast corner of excavation square B9. Transects were oriented parallel to the excavation grid already in place and all were oriented from west to east (after alternate profiles collected in a zig-zag fashion were reversed). For all transects the first 2-3 meters on the western edge of the cave were collected over exposed bedrock, and therefore those

portions of the profiles were of no use in mapping changes in sediments or variations in the bedrock surface itself. No topographic map of the cave surface was available at the time, and therefore profiles were not corrected for elevation variations, although it was recognized that there was up to 20-25 cm of variation in elevation along some transects due to the uneven surface of the cave floor.

Reflection profile 15, the northernmost profile collected very close to the northern wall of the cave, shows a distinct bedrock reflection at about 18-20 nanoseconds depth in the middle of the profile (Fig. 18). The area of known burials within the sediment package overlying bedrock is not at all distinct in this profile, but in general the area appears to have a few reflection anomalies, perhaps associated with skeletal material. This profile demonstrates how indistinct human remains can be using the 400 MHz antennas, as they do not have the resolution capable of distinguishing small bones within a fine-grained matrix. A feature similar to the skeleton area is located between about 5 and 6 meters on this profile, whose origin is not known, but could be additional skeletal materials (Fig. 18).

Profile 16 (just 50 cm south of profile 15) also shows the general area of skeletal materials as a high amplitude reflection (Fig. 19), but it is also indistinct with regard to the materials known to exist in this area from excavations. The Iron Age structure is visible as a high amplitude reflection in the uppermost portions of the profile. One interesting break in the bedrock, which is quite narrow (about 20-30 cm diameter at most) can be seen in this reflection profile, which is likely a HBH similar to those exposed on the bedrock near the mouth of the cave and which were excavated from under the sediment cover during the 2006 season. This bedrock feature was not immediately visible during the initial interpretation of this data set (Fig. 19). The narrow HBH is visible only as a break in the bedrock reflection and its depth cannot be determined as radar energy was attenuated within this narrow hole. Its location, and other similar bedrock breaks, visible in other reflection profiles are shown in Fig. 17.

Similar bedrock features are visible in profile 17 below (Fig. 20). In this reflection profile the areas of skeletons and associated rocks and artifacts can be seen as high amplitude reflections, but with little definition of individual objects. The Iron Age structure between 6 and 7 meters is also visible, with a distinct reflection hyperbola at about 10 nanoseconds (50 cm depth), which was likely produced from a buried rock below this structure.

It does not appear that the skeletal materials (as least as defined by high amplitude reflections) continue this far eastward in the cave. But they are indistinct at best, where they are known to exist, so this supposition cannot be made using GPR analysis alone.

Little of interest was visible in the remaining profiles in this grid (files 18-25). Those reflection profiles showed layered sediment, which could contain skeletal materials and small objects, which were only poorly resolved using the 400 MHz antennas. No bedrock features were visible in those profiles (Fig. 21).

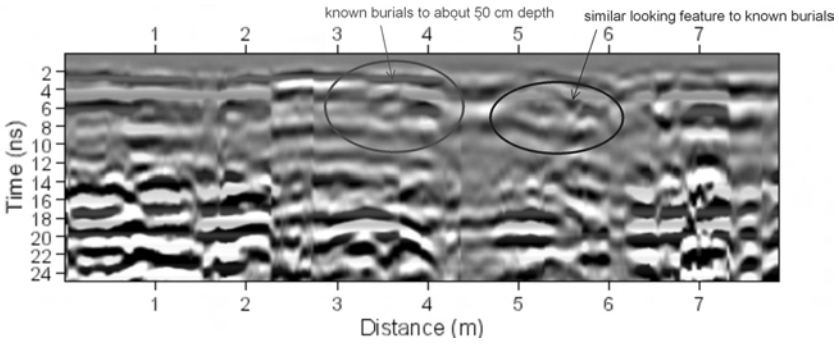

Figure 18. Reflection profile 15 showing the location of skeletal materials excavated in 2006. Bedrock is the high amplitude reflection at about 18 ns from 2.2 - 7 meters.

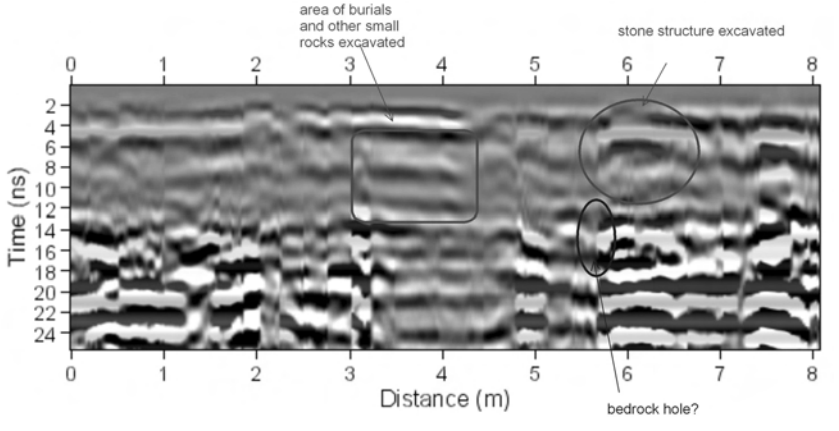

Figure 19. Profile 16 showing the Iron Age structure and a HBH visible as a break in the bedrock reflection.

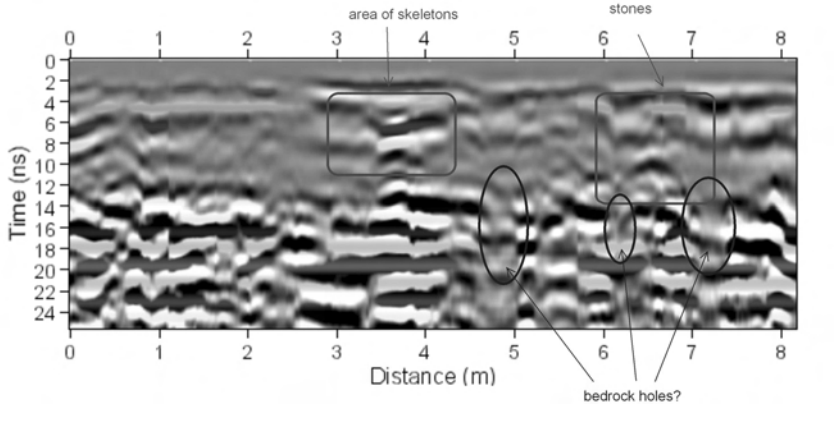

Figure 20. Profile 17 showing additional HBHs, stones near the surface, and a larger rock at depth.

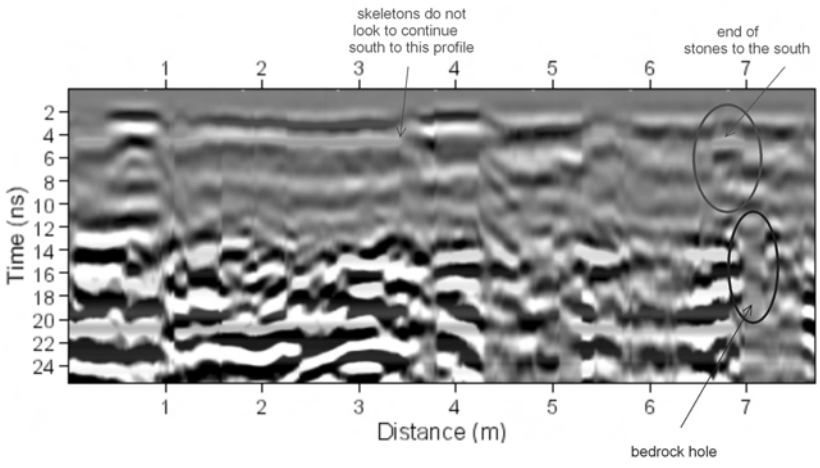

Figure 21. Profile 18 showing the distinct HBH that truncates the horizontally layered sediment in the cave. It is filled with sediment of a different type and continues to the bedrock floor of the cave. Additional HBHs within the bedrock are also visible.

Back of Cave: Chimney Grid

All the GPR reflection profiles collected within the chamber below the chimney at the rear of the cave showed a distinct bedrock surface between 90 and 120 cm depth (about 18-22 nanoseconds), with sediment layers on top (Fig. 22). These five profiles were numbered 26-30 and all were 5 meters in length. No structures, truncation features or large rocks of any sort were visible with the 400 MHz antennas. The sediment layers in this recessed area of the cave appear to slope to the north, suggesting there was some accumulation of sediment into the cave sometime in the past as the cave floor was covered with material washed in from the chimney above.

Terrace Grid

Fourteen GPR reflection profiles were collected in this grid along the sloping terrace in front of the cave (Figs. 23-25). Bedrock was exposed just to the south of the grid and also to the south along the steep slope on the margin of the terrace. It was not known how deep the preserved sediment might be on this slope at the time the GPR data were collected. It was presumed that the bedrock surface buried by sediment would contain features such as were visible in exposures nearby. Possible walls or other features on bedrock were also hypothesized to exist under the sediment cover. The grid of reflection profiles consisted of lines of differing length in order to cover as much of the area as possible (Fig. 23).

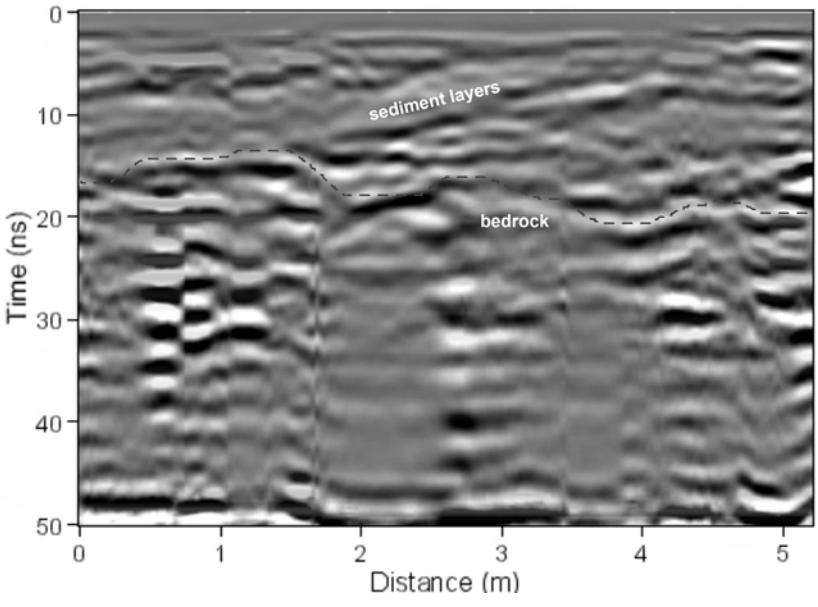

Figure 22. Profile 27 illustrating bedrock at 18-20 ns with sloping sediment layers above.

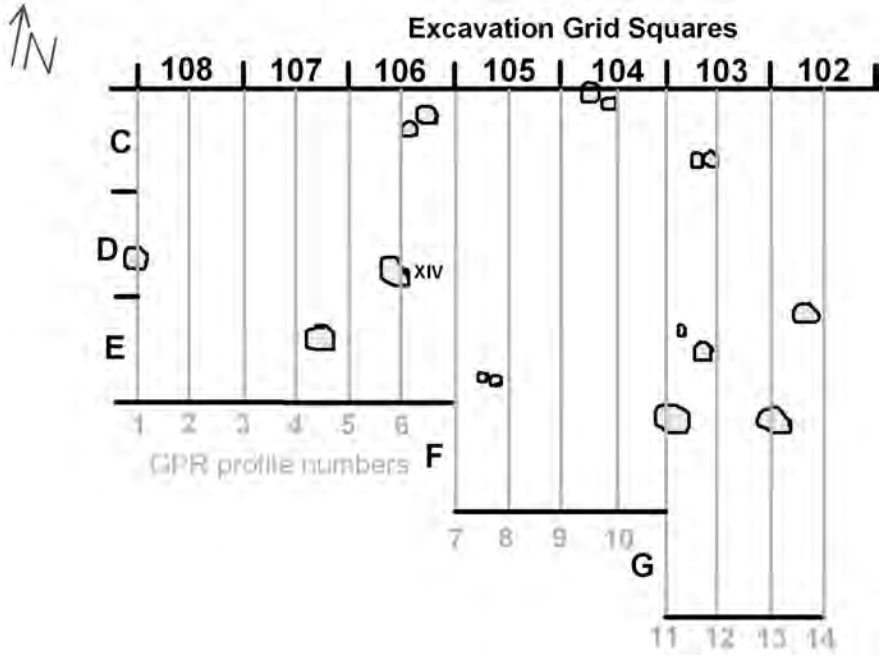

Figure 23. GPR Terrace grid showing reflection profile locations on the excavation grid with later exposed HBHs shaded.

High amplitude reflections that were hypothesized as walls were visible when the GPR reflection data were interpreted directly after their collection in July 2006. In light of the excavation results, these initial interpretations proved to be erroneous. Instead what was found was a complex bedrock surface that sloped down, as predicted. However, a noticeable raised bedrock ridge occurred in the middle part of the terrace, and then bedrock sloped downwards again to the south, which provided a "lip" to catch and preserve the sediment on the terrace (Fig. 24).

A GPR reflection profile along the northwestern portion of the grid shows this distinct ridge as a high amplitude reflection (Fig. 25). The bedrock reflection is also visible below the sediment cover. This same general configuration of bedrock was visible in all reflection profiles within the grid. As can be seen in Figure 24, the bedrock surface is very complex in this area, and a number of cracks and holes are visible. This complexity was also visible in the GPR reflection profiles. One interesting profile did show one of the HBHs, noted as XIV in GPR Figure 23. This HBH was quite visible on the bedrock surface (Fig. 25) at exactly the location shown in Figure 8, from which the annotations in Figure 23 were derived.

In general, these GPR reflection profiles on the terrace show some of the features that were later exposed in excavation, but most were quite complex. What were thought to be

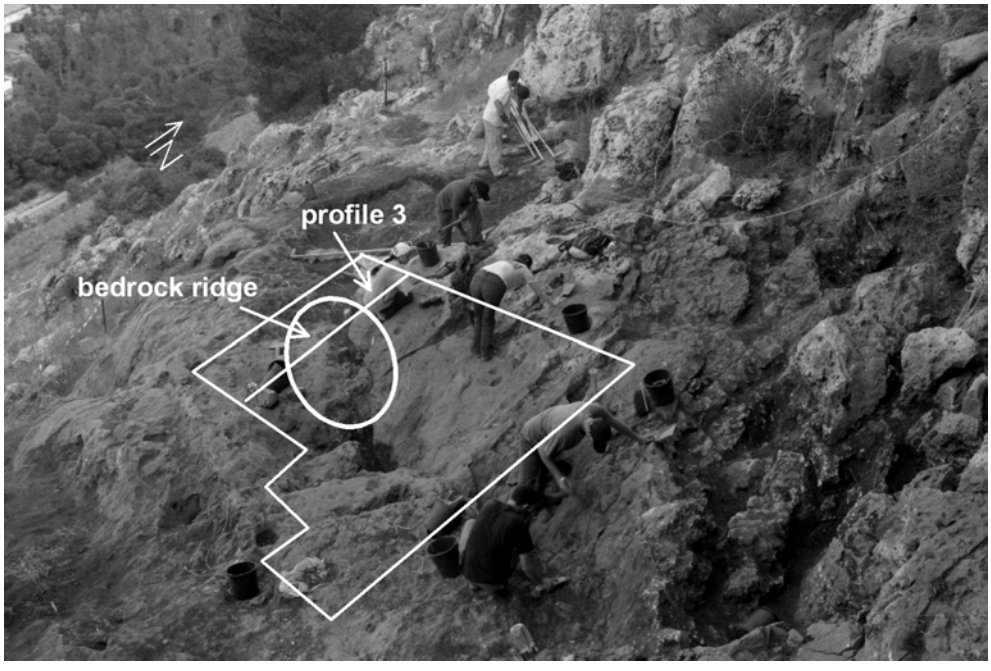

Figure 24. Photograph of the terrace after excavation (August 2006). A noticeable bedrock ridge is located in the western portion of the grid.

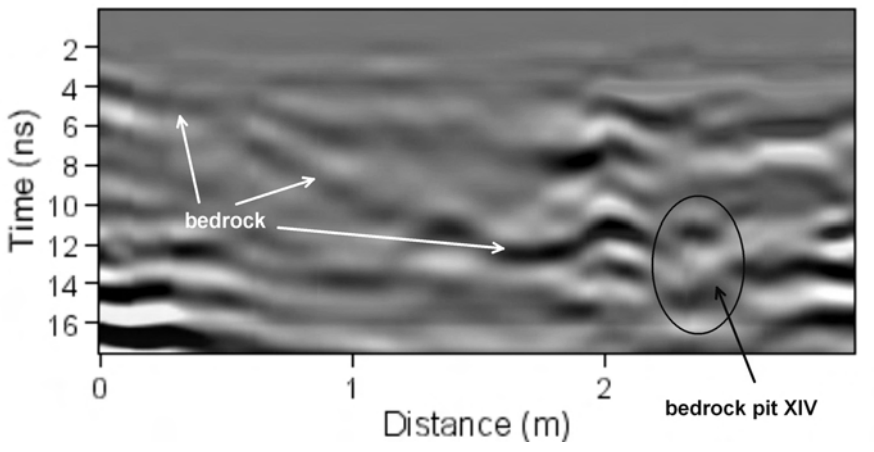

Figure 25. A HBH is visible in this profile as a subtle break in the bedrock reflection, just to the right of the high amplitude bedrock ridge at 2 meters.

walls in the initial interpretation turned out to be the bedrock ridge and other complexities in the bedrock below the sediment, many of which were later exposed and are visible in Figure 24.

Conclusions

Much of the analysis of the GPR reflection data collected at Raqefet Cave was done after a good deal of information about the subsequent excavations was available. This allowed features known to exist to be looked for in reflection profiles, and interpreted "after the fact". A direct correlation of the placement and size of those known objects, stratigraphy and bedrock mortars with the GPR reflections showed that some very subtle features, not visible during an initial analysis in July 2006, were in fact visible. For instance, the bedrock ridge on the terrace was initially interpreted in 2006 as a wall (which was one of our initial working hypothesis of possible features that might be found there). Only after excavation was this elevated feature determined to be a natural bedrock ridge. Also, the narrow HBHs visible in many profiles within the cave were overlooked in the initial analysis, as they were too small and subtle to have caught the eye.

The GPR reflection data collected both inside and outside the cave were in excellent quality, with a depth penetration of more than 2 meters and good resolution. The project suffered somewhat from an inability to correct profiles for surface topographic variations, but not so much that buried features were still not visible. The 400 MHz antennas provided a fairly high resolution of strata, objects and the bedrock surface, but still tended to blur the processed images somewhat. Future work of this sort would benefit from the use of a higher

frequency antenna system providing much greater resolution, but will necessitate a closer transect spacing. Those reservations aside, a number of interesting cave features were still visible in the GPR reflection profiles that remain to be uncovered including a large HBH(?) with at least two objects in it, and numerous small HBHs within the bedrock. Skeletal material and small associated stones and other objects could not be defined within the sediment matrix of about the same size and composition. Perhaps higher resolution data might better define these human remains.