Ground Penetrating Radar
Archeological Report

Ground-penetrating radar mapping in the search for graves
Higgs Beach area, Key West, Florida

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Introduction

Ten grids of ground-penetrating radar (GPR) data were collected in various areas to the north and on Higgs Beach along the south coast of Key West, Florida in November, 2010. The purpose of this study was to search for graves of various ages (Malcolm 2010) that might still exist in this area, in preparation for a re-development of the general area and possible relocation of Atlantic Blvd. The area studied were agreed on jointly by William Horn, Corey Malcolm, Johnny King and myself prior to beginning the surveys, and modified somewhat during the data acquisition as preliminary results were available and we were able to assess what areas needed to be tested further. Corey Malcolm and C. Michael Nalepa were involved in all data collection.

A GSSI SIR-3000 GPR system was used for all collection with 400 MHz antennas and a survey wheel for distance calibration. All reflection profiles were collected with a 40 nanosecond time window (equal to about 2 meters depth or 6 feet in the ground). Reflection traces were collected with 30 per meter along transects. Recorded amplitudes were gained automatically at each location were data were collected depending on the materials in the ground. Profiles were spaced 1 meter apart except for Grids 3 and 9 which had 50 cm profile spacing for greater subsurface resolution.

Figure 1: GPR system used in collection was the GSSI SIR-3000 system, 400 MHz antenna (orange box) and an attached survey wheel for distance calibration.

All data were saved to disk and then processed into profiles and horizontal amplitude slice-maps. In Table 1 are the profiles collected within each grid.

Table 1: Grid locations and profiles in each

Grid	Location	Reflection profile files
1	Higgs Beach between fort and bandstand	1-51
2	Small grid E. of Higgs Beach north of bike trail	52-84
3	High resolution grid within Grid 2	85-97
4	North of Atlantic Blvd. south of small dog park	98-108
5	Small dog park	109-131
6	Picnic area west of dog parks	132-183
7	Southern edge of big dog park	184-194
8	Western edge of small area in big dog park	195-205
9	Re-do of small dog park in high resolution	206-256
10	North of hand ball courts	257-269

The GPR Method

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 where it is recorded as digital wave forms on a computer in the main system (Conyers 2004). As radar energy moves through various materials, the velocity of the waves changes depending on the physical and chemical properties of the material through which they are traveling (Conyers 2004). When travel times of energy pulses are measured, and their velocity through the ground is known, distance (or depth in the ground) can also be accurately measured (Conyers and Lucius 1996), making GPR a powerful method for many historic and archaeological applications. The greater the contrast in electrical (and to some extent magnetic) properties between two materials at a buried interface, the stronger the reflected signal, and therefore the greater the amplitude of reflected waves (Conyers 2004). In grave mapping, reflections are usually created from the tops of caskets, void spaces that exist in the burial, burial goods and the discontinuities between the natural strata and soils and the homogeneous fill within the burial trenches.

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 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 this project the 400 MHz antennas were used, which produced data of good resolution at depths up to about 2 meters (6 feet) and resolved features as small as about 20 cm in dimension, which was quite good for resolving burials and many other features in the ground.

Reflection data were collected in transects spaced either 1 meter or 50 cm apart depending on the resolution necessary. Reflections obtained from within the ground were collected every 3.3 cm apart in these linear transects, within grids. All reflection data were first analyzed in two-dimensions to determine the nature of subsurface reflections, their wavelength, depth of penetration, amount and nature of background interference, and the velocity of radar energy in the ground. These reflection profiles were looked at first, and often buried features were visible in real-time on the radar computer screen during collection (Figure 1). When reflection data from field profiles were especially noisy, they were filtered later before the final products were produced for this report. Noise usually comes in the form of electromagnetic radio interference from radio, TV and cell phone transmissions. The radar antennas used for this project are within the frequency bands of these other transmissions, and therefore filtering was necessary.

In all cases the two-dimensional reflection profiles were not sufficient to show the aerial extent and origin of important reflections in the ground. This was especially true when dealing with many graves in a small area, and with other large buried features. Using a method called amplitude slice-mapping, however, the changes in reflections along and in between profiles were compared, gridded, and mapped spatially to produce images of reflection amplitude changes over an area at various depths in the ground (horizontal levels). When this was done, the layout of complex burials and other materials in the ground became visible (Conyers 2004). In amplitude slice maps colors of the rainbow are placed on the range of amplitudes with red being strong reflections (high amplitudes) and blue little or no reflection. Slices were produced at various depths, depending on the nature of reflections and the types of features to be visualized in each grid. Approximate depths of each slice are shown on each individual map. The amplitude slice maps are analogous to arbitrary horizontal excavation levels in standards archaeological studies.

In reflection profiles two-dimensional slices through the ground from the surface (at the top) to depth were produced, which are analogous to looking at features in the wall of a trench. In these images time was placed on the left axis, measured as the two way travel time that radar waves took to travel from the antenna, into the ground, and back to the antenna (measured in nanoseconds). Velocities were calculated for this area and in general each 5 nanoseconds in two-way travel time are equal to approximately 40 cm depth in the ground. There are some variations in velocity across the area of study, but the changes were minor and therefore this velocity-depth correction was used throughout. In the reflection profiles black and white colors are showing very high amplitude reflections and shades of gray are the low amplitude areas.

Grid 1: Higgs Beach between fort and bandstand

In this grid many complex bedrock features were visible including what might be an old sea wall, inland from the present wall, and cut and fill features from many erosion events from storms. The bedrock can be seen as high reflections (Figure 2) and the beach sand as more horizontally layered lower amplitude reflections. Walls are visible as distinct hyperbolic reflections.

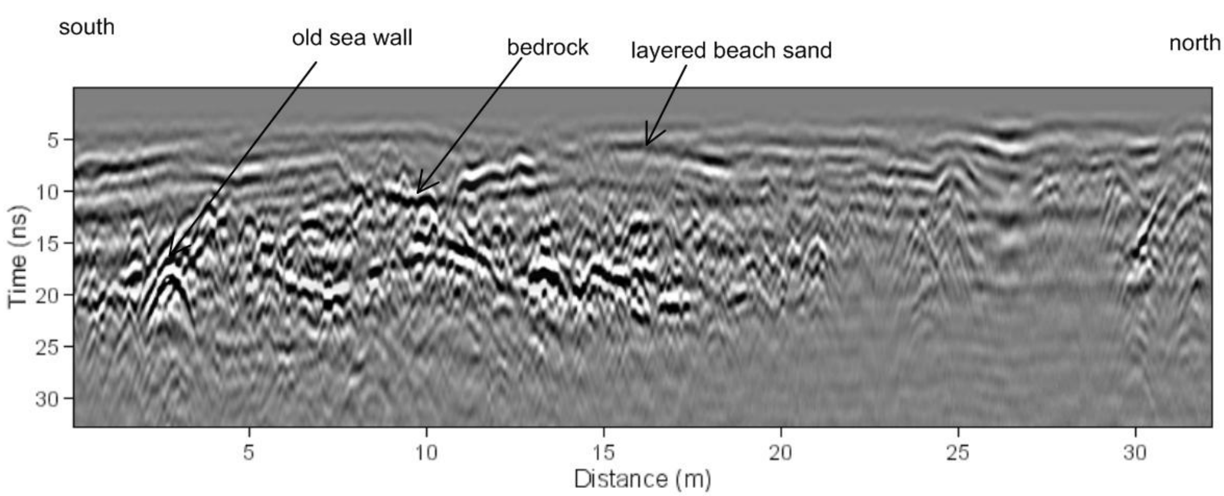

Figure 2: Reflection profile across the beach showing bedrock and beach sand reflections.

No graves were visible in the beach sand, and it is unlikely any still exist after all the erosion from hurricane flooding and placement of sand back on the beach, which Johnny King noted had occurred often. Many of these erosion channels and bedrock ledges and knobs are visible beneath the sand (Figure 3).

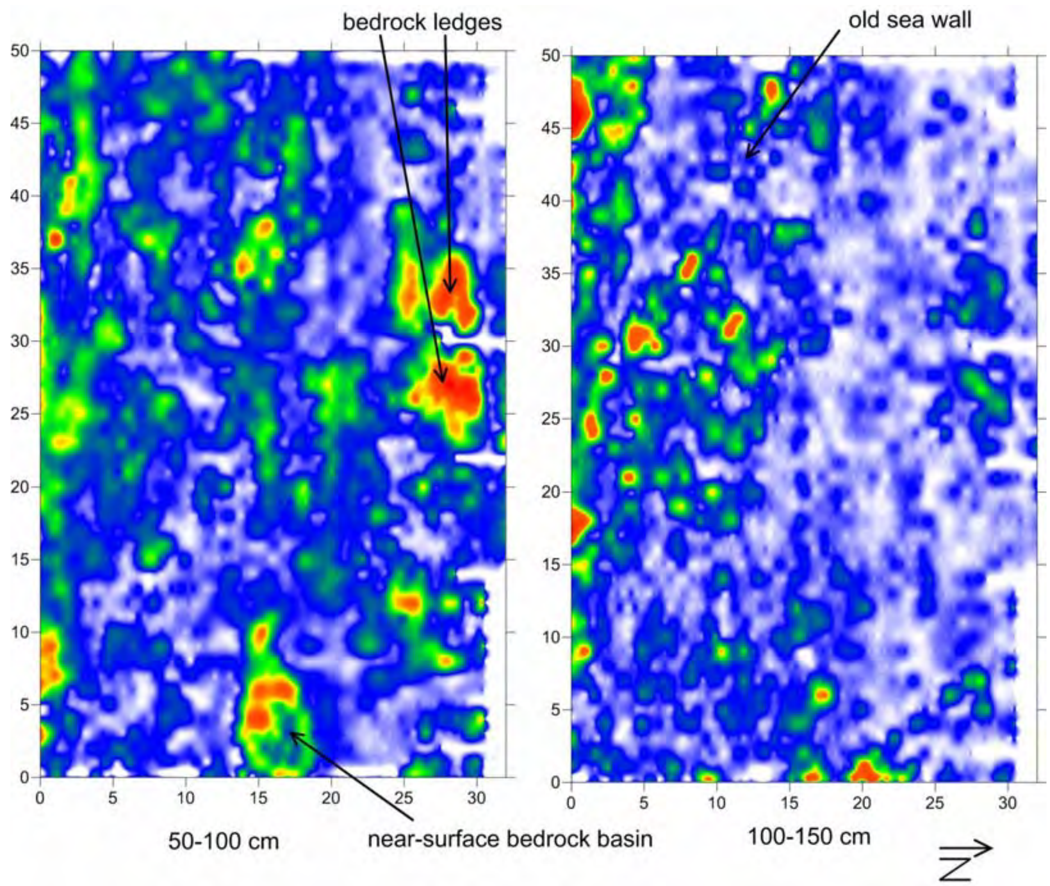

Figure 3: Amplitude slice maps of the area of Higgs Beach between the fort and the bandstand showing bedrock features and a possible old sea wall.

Grid 2: Small grid E. of Higgs Beach north of bike trail

This small grid immediately located a number of graves in its eastern portion, which we noticed on the system computer screen during collection. They appear to be intact coffins with void spaces, which are much different than most of the other graves that we located elsewhere in this study. Other interesting objects are also visible in this area behind the fort, which no doubt complicate things (Figure 4). There is also a large artifact scatter located directly next to the fort, which Corey Malcom excavated in the past when the restroom was being constructed. The realization that the material used to make the bike trails is very attenuating to radar was also first discovered during collection of the data in this grid. This problem was encountered in other areas as well. Johnny King was not able to help us with the chemistry of this material, which must be very electrically conductive and destroys much of the radar energy that attempts to pass through it. A more detailed grid of data was produced in this same area (Grid 3), where the details of the burials are much more apparent.

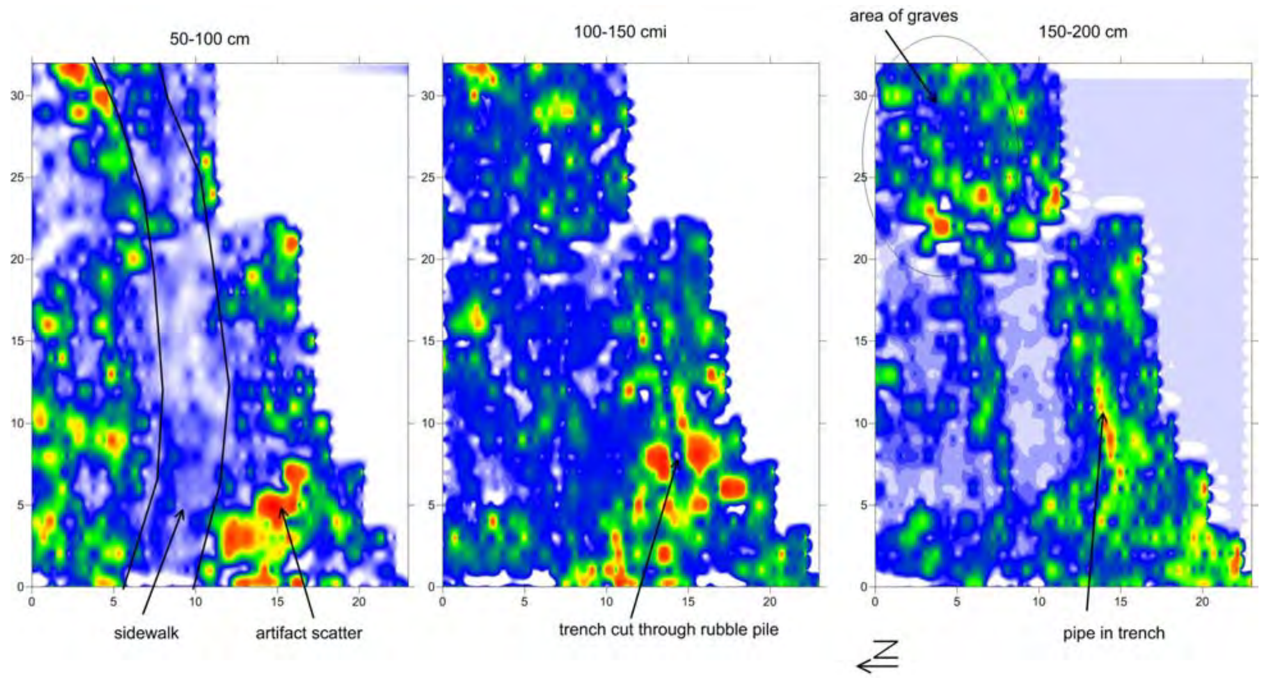

Figure 4: Amplitude slice maps just north of the fort showing the artifact scatter, an area of graves, and a few pipes. The sidewalk destroys all energy that attempts of penetrate it.

Grid 3: High resolution grid within Grid 2

The graves discovered during the acquisition of Grid 2 were re-surveyed with profiles spaced 50 cm apart and oriented north-south. Individual caskets were apparent, some of which still have void spaces in them, which are highly reflective (Figure 5).

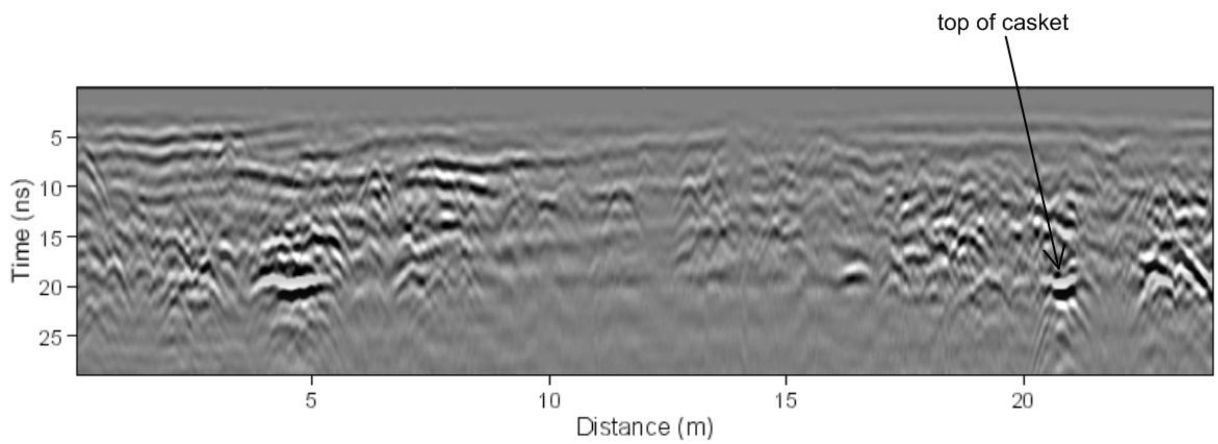

Figure 5: Reflection profile showing a casket, which likely contains a void space, producing a very high amplitude reflection.

Other graves in this grid are more subtle, which are likely less formal burials, or contain caskets that have collapsed and have no void spaces to reflect energy (Figure 6). One large complex feature is also visible in this grid, whose origin is not known (Figures 6 and 7).

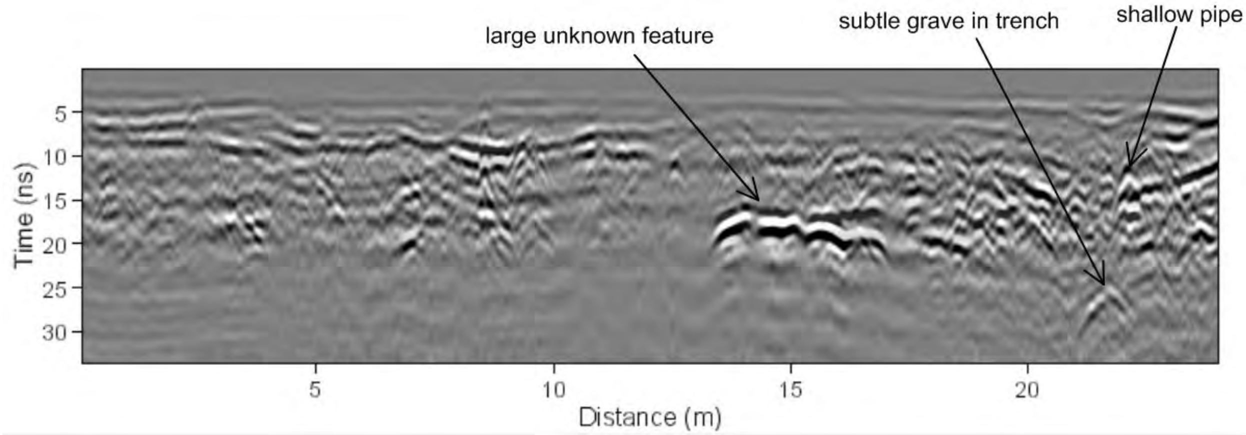

Figure 6: Reflection profile showing a subtle grave in a trench, and a large unknown feature, which may be related to activities that occurred at the fort, or the military barracks that were once located in this area.

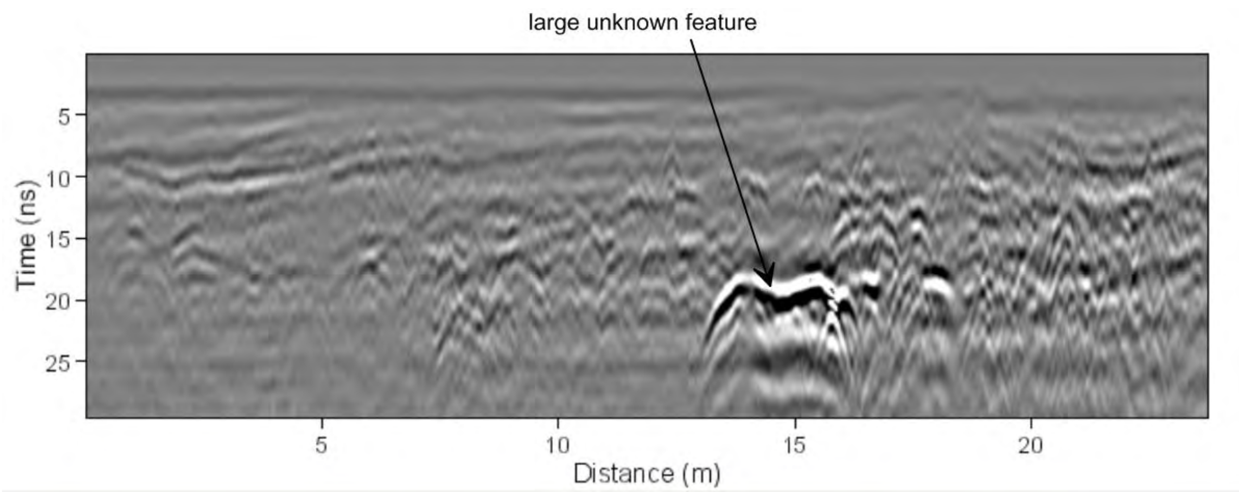

Figure 7: The same unknown feature visible in Figure 6, which is highly reflective, and contains objects within or under it.

The amplitude maps of this grid show the location of the large object, and many graves in the eastern portion of the grid (Figure 8). The graves appear to be oriented north-south, which is interesting and puzzling. My experience in other cemeteries indicate that most Christian burials are east-west oriented. But the African graves discovered to the east of the fort (Conyers and Malcom 2002) were also oriented north-south, which perhaps indicates that there is something different with burial orientations in Key West.

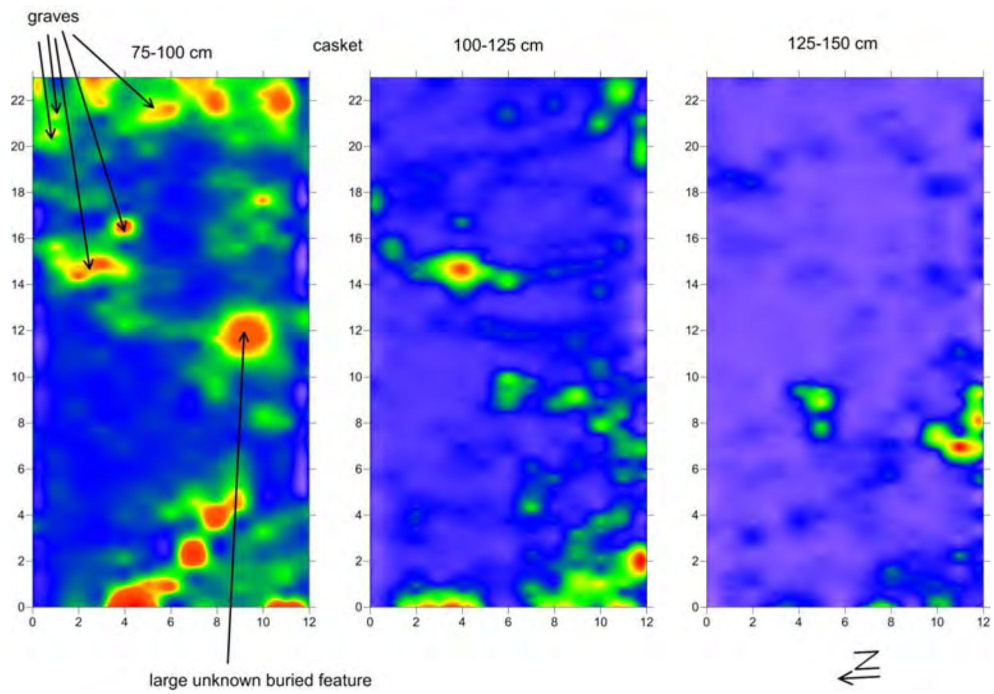

Figure 8: Amplitude slice-maps showing the large unknown object and the graves within this high resolution grid.

Grid 4: North of Atlantic Blvd. south of small dog park

This small grid showed a number of graves that are similar to those found in Grid 3. They appear to be caskets, some of which have intact void spaces (Figure 9). The ground in this grid is full of other objects as well, which make the reflections somewhat cluttered. I suspects the busy nature of these data is related to the proximity to the barracks that used to exist in this general area and a variety of surface trash or other objects that accumulated.

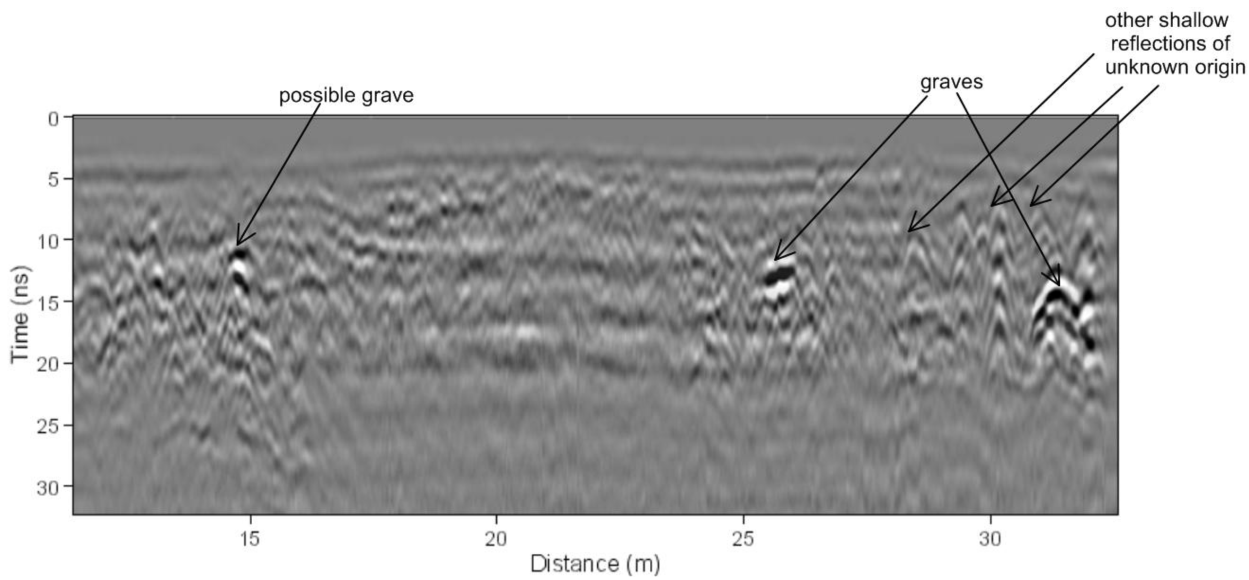

Figure 9: Reflection profile showing a few graves in Grid 4, but many other reflections of unknown origin, probably related to trash that accumulated in proximity to the fort and the historic barracks.

The amplitude slice-maps show the location of the graves in this grid, but also many other small reflections, which are likely trash that accumulated in this area related to the barracks, the fort, or road and bike trail building activities (Figure 10).

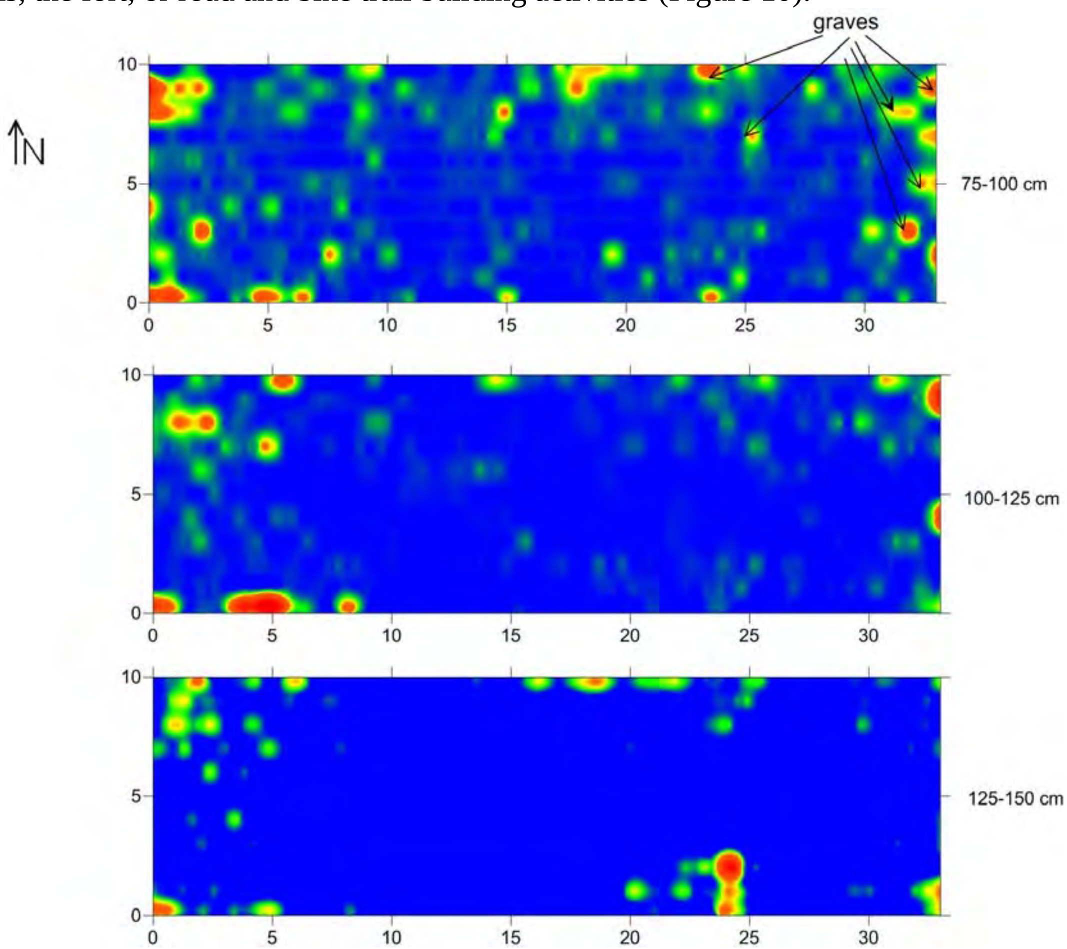

Figure 10: Amplitude slice maps of Grid 4 showing some graves and other debris that produces small reflections in the shallowest slices illustrated.

Grid 5: Small dog park

This grid in the small dog park immediately located a number of graves and what appears to be a "pit" that is filled with objects (Figure 11). So many graves were visible in this grid during collection that it was decided to collect an additional higher resolution grid (Grid 9) to better identify the burial features (Figure 12).

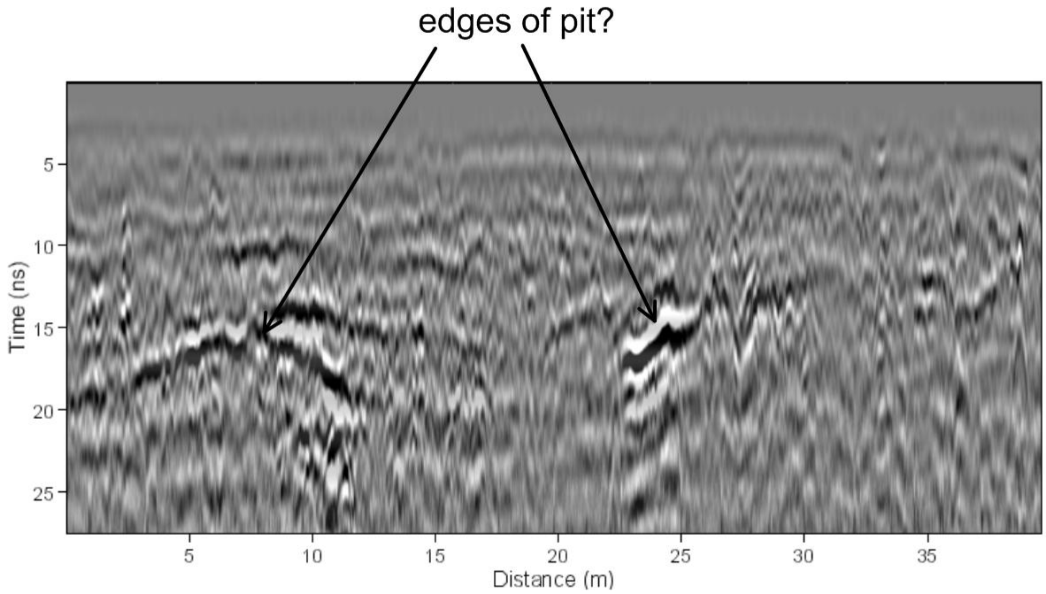

Figure 11: Reflection profile showing the edges of a pit within Grids 5 and 9 in the small dog park.

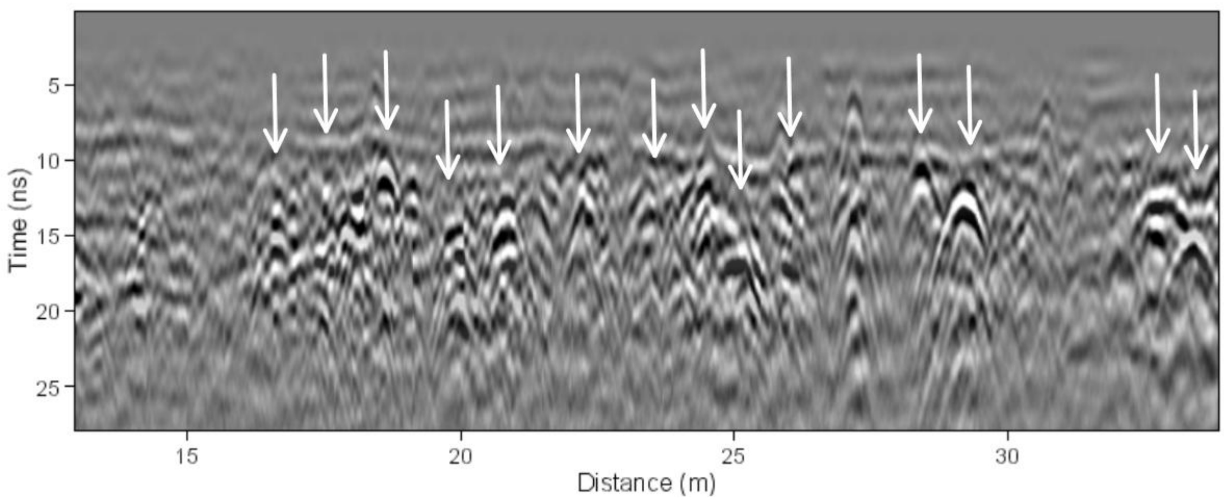

Figure 12: Reflection profile showing all the graves in this area, shown as distinct hyperbolic reflections and identified by arrows. This area has deeper bedrock than other areas mapped in the area, which is likely why there is such a concentration of graves, as the digging was much easier.

Where bedrock was closer to the surface, no graves are seen (Figure 13), indicating why graves are found in such a high concentration within the small dog park grids.

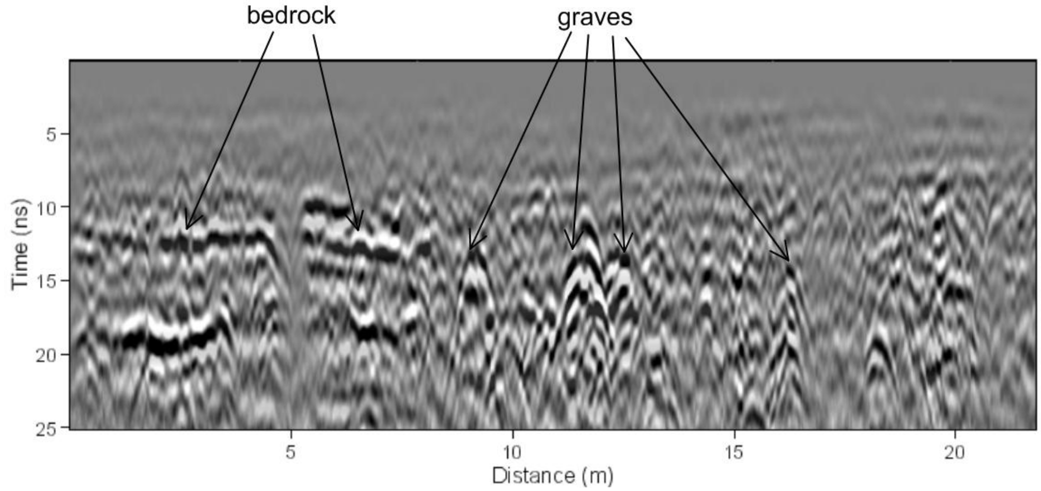

Figure 13: Reflection profile showing that when bedrock is near the surface, there were no graves dug, and areas with bedrock much deeper contain many burials.

The amplitude slice maps show a general area of graves, but because profiles were spaced only a meter apart, they are not easily identified (Figure 14). The bedrock areas near the surface can be easily identified by the red areas on the maps.

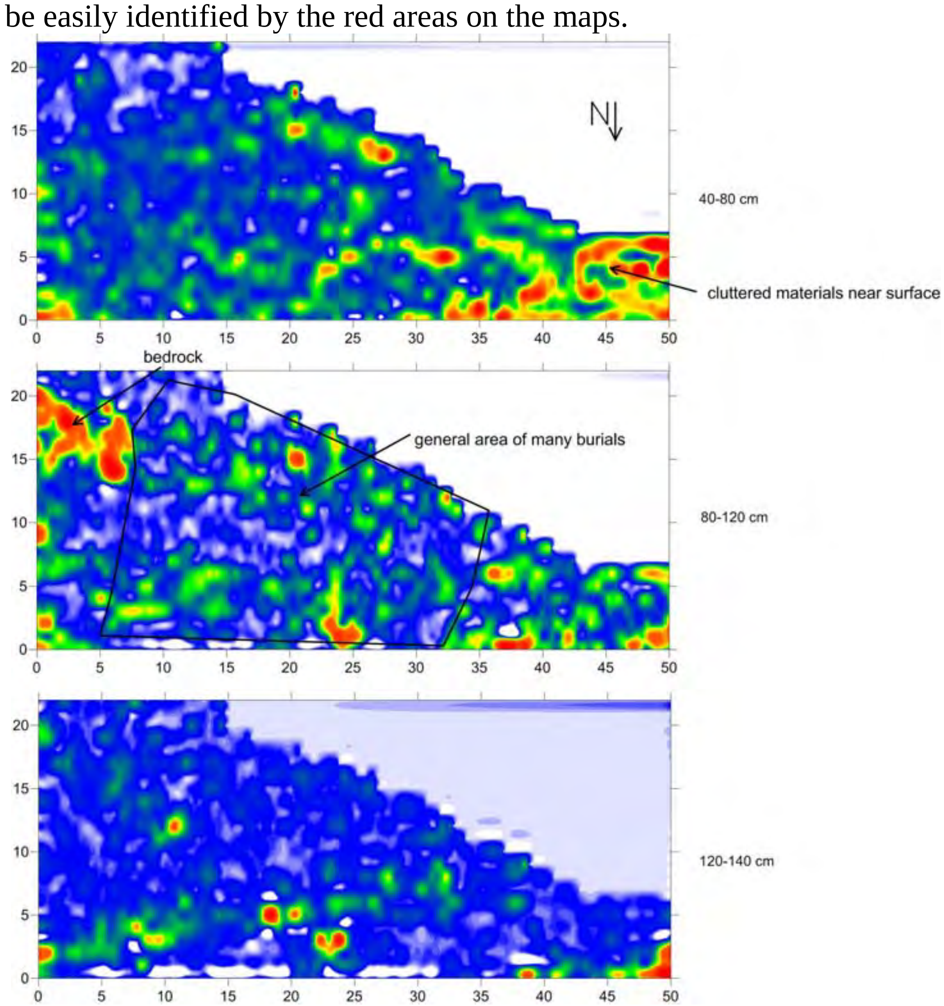

Figure 14: Amplitude slice-maps of Grid 5 showing the general area of graves in the small dog park, and the bedrock near the surface.

Grid 6: Picnic area west of dog parks

No graves were found in this large grid, but some other interesting features that help with an understanding this complex area in general. In general bedrock is close to the surface throughout the grid, which has been cut into to lay pipes (Figure 15). Other interesting features are of unknown origin, and could be related to the barracks that were located in this area.

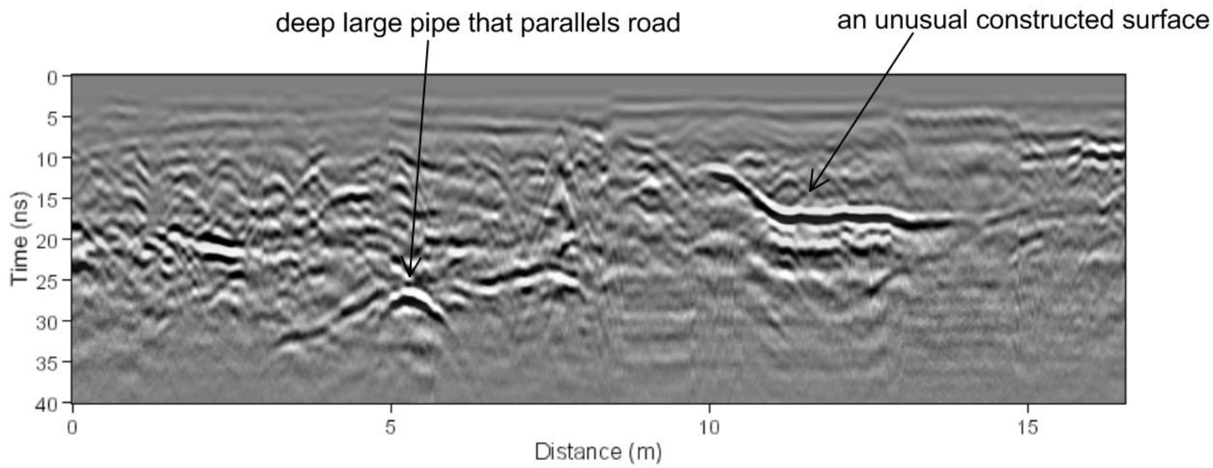

Figure 15: Reflection profile showing a deep pipe and a constructed surface of unknown origin, perhaps related to the historic barracks.

In much of the grid bedrock is very close to the surface and produces a very distinct reflection, which is sometimes very flat, and other times undulating (Figure 16).

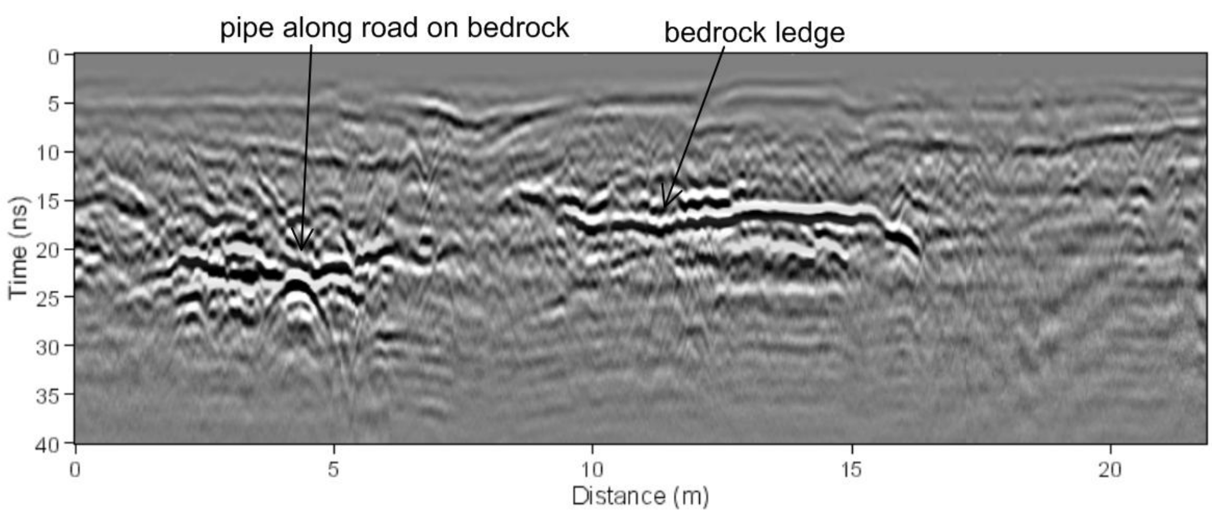

Figure 16: Reflection profile showing a buried pipe and complex bedrock reflections common in Grid 6.

In places horizontal reflections are visible filling in what was an undulating ground surface, likely produced from flooding during hurricanes. The sand fill is visible as low amplitude horizontal reflections (Figure 17).

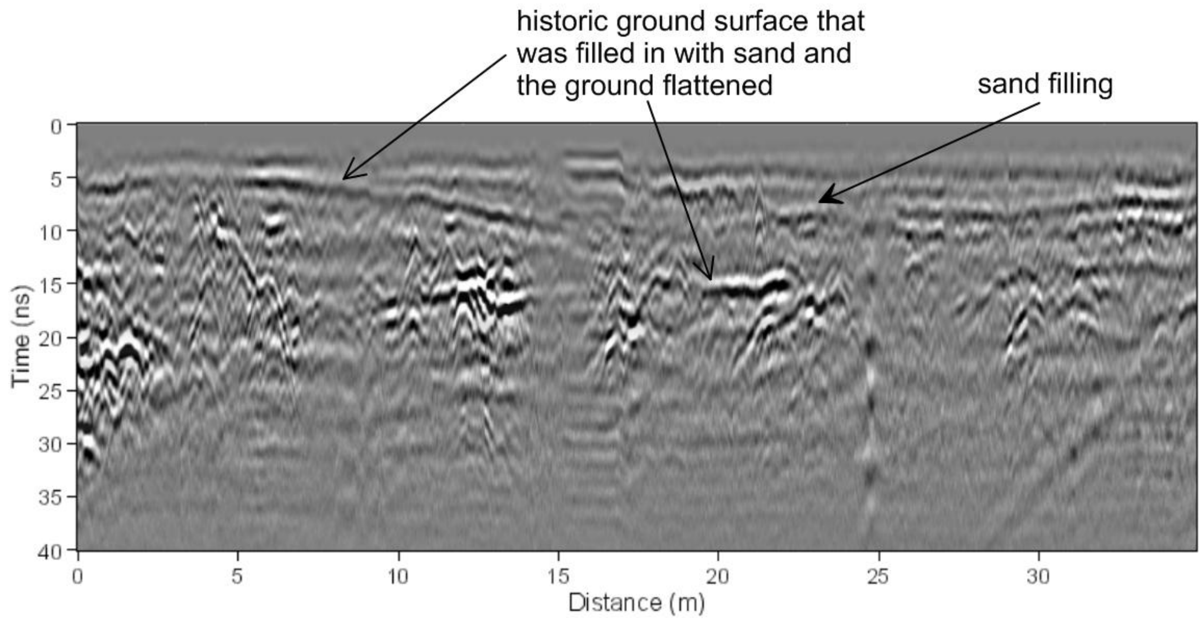

Figure 17: Reflection profile showing the sand filling that was used to level the area after channeling from flooding during past storms.

In places the bedrock is severely channeled, creating an undulating buried bedrock surface (Figure 18).

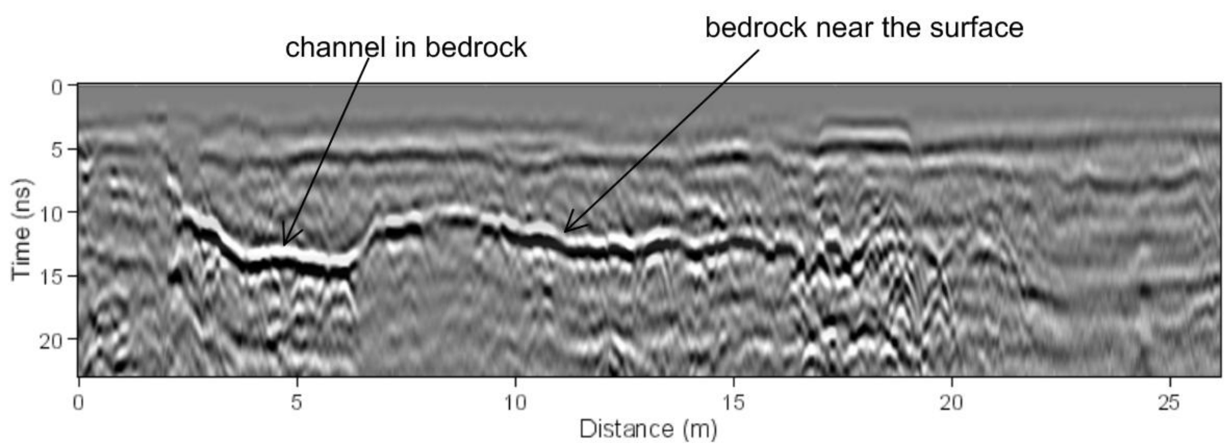

Figure 18: Reflection profile showing channeling in the bedrock.

The amplitude slice maps are complex, but potentially interesting. In a shallow slice a square feature is visible, which might be the remains of a foundation from the barracks (Figure 19). Other visible features in this grid are related to bedrock ledges and knobs that are now buried by sand to level the present ground surface.

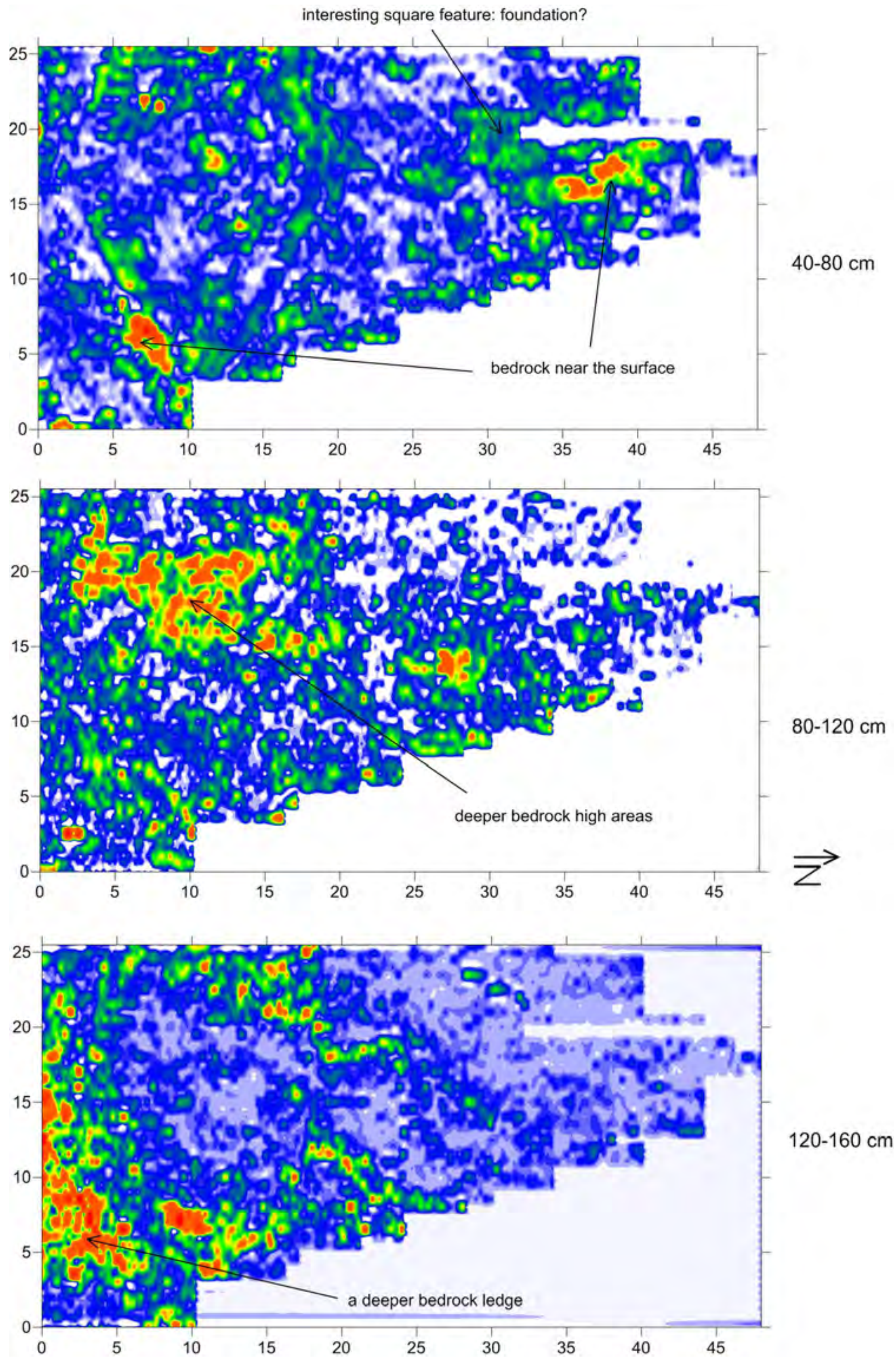

Figure 19: Amplitude slice maps of Grid 6 showing many bedrock features and one square feature, which is likely a building foundation in the 40-80 cm slice.

Grid 7: Southern edge of big dog park

Bedrock is very close to the surface in this area and no graves were found. The lack of graves in this area north of the small dog park is likely related to bedrock being located near the surface (Figure 20). One distinct incision is visible, likely a trench for a pipe, which is no longer in the ground.

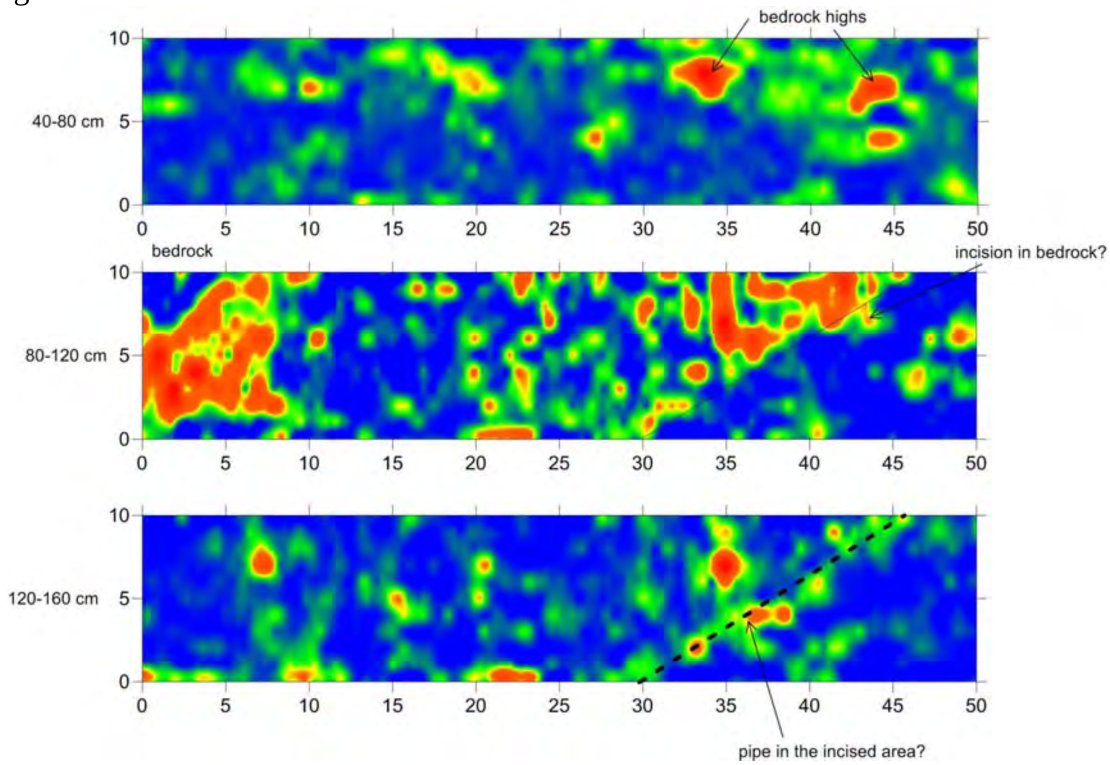

Figure 20: Amplitude slice maps of Grid 7 showing bedrock features near the surface.

Grid 8: Western edge of big dog park

A few graves were found in this grid to the west of the small dog park along the north-south fence separating the large and small dog parks. One very unusual buried object was also found in this grid (Figure 21) of unknown origin.

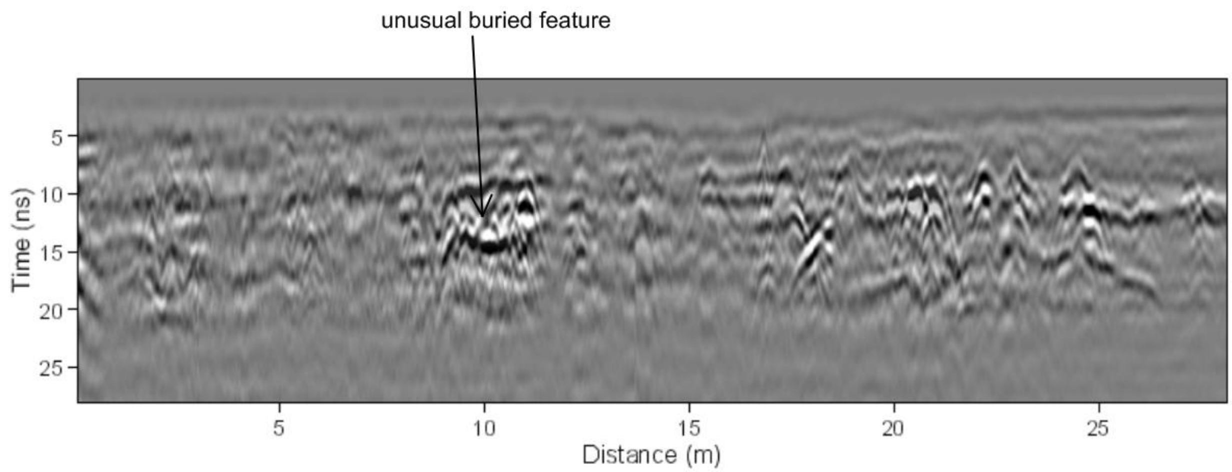

Figure 21: Reflection profile showing a large unusual object found in Grid 8.

In much of this grid bedrock is very close to the surface and only a few graves are found in the easternmost portion of the grid along the fence separating this area from the small dog park (Figure 22).

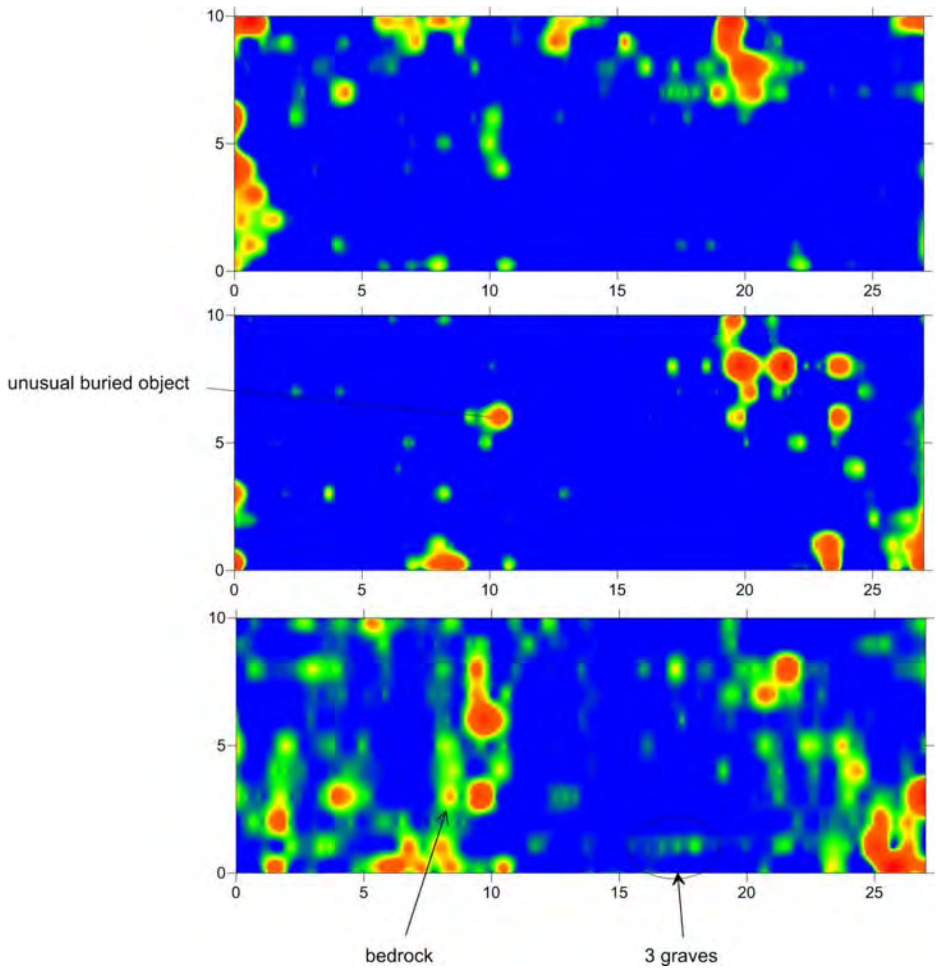

Figure 22: Amplitude slice maps of Grid 8 showing a few graves along the fence, and an unusual object (Figure 21) in the middle of the grid.

Grid 9: Re-do of small dog park in high resolution

A high resolution grid of data was collected over the same area as covered in Grid 5, in the small dog park, where the possible pit and associated graves was found (Figure 14). This grid had profiles spaced 50 cm apart, and profiles were oriented north-south instead of the east-west orientation used in Grid 5. Many burials were again found in this grid, but they could be discerned more accurately. In addition an east-west oriented pipe that crosses the burials (and cuts some of these burials) was visible in the deepest slices (Figure 23).

The graves in this grid are found everywhere there is not bedrock near the surface. Bedrock close to the surface was no doubt the limiting factor in digging trenches deep enough to bury the dead. Everywhere in this grid, this is the case. Bedrock limits the burial depth to the north, east and west. The limits of burials to the south are not known, as the southern fence of the dog park, the bike trail and Atlantic Boulevard are found in that area and GPR surveying was impossible. It is likely that graves continue under the road in the direction where the African Cemetery is located, where burials were discovered in 2001 using similar GPR methods (Conyers and Malcom 2002).

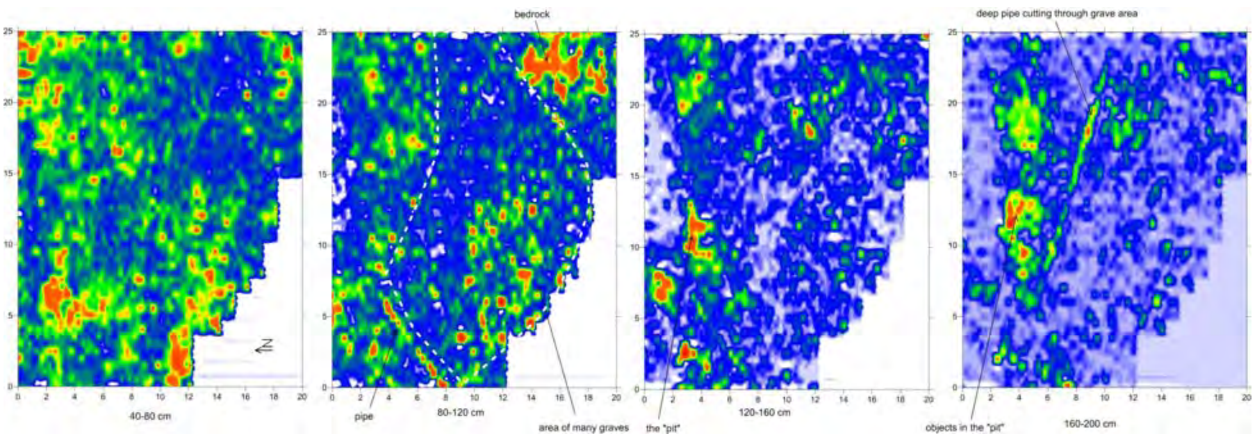

Figure 23: Amplitude slice maps of Grid 9 showing many graves in the white dashed outlined area in the second slice, the “pit” in slice 3, and the pipe crossing the area in the fourth slice.

A different look at “the pit” can be seen in many profiles in this grid (Figure 24). The pit is not a trench but instead a broad pit, which contains a number of reflective objects, whose origin is not known. The objects in the pit are jumbled, but little else can be said about them.

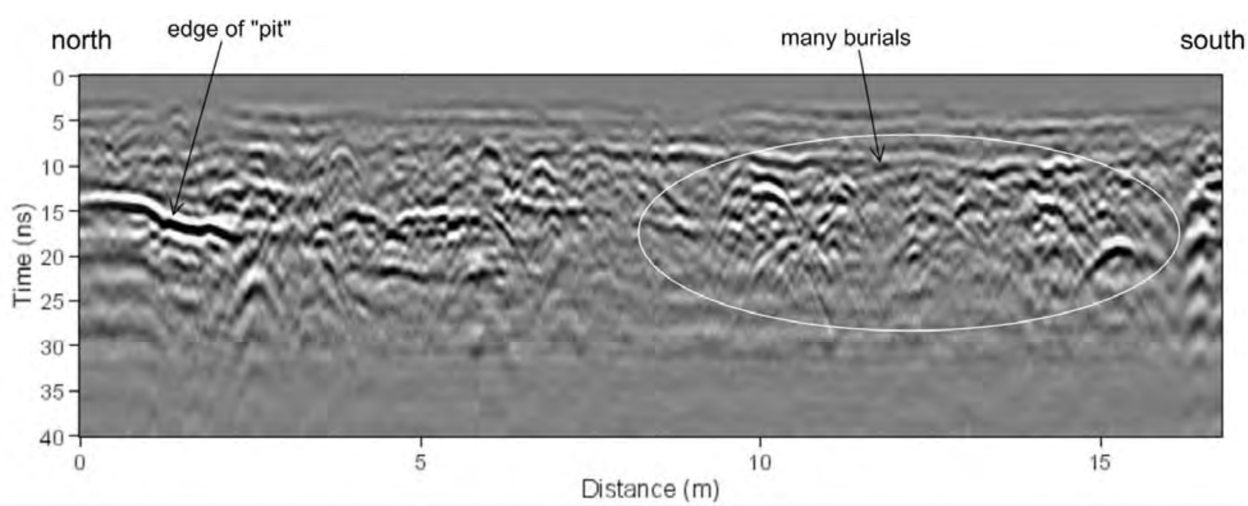

Figure 24: Reflection profile showing the north edge of the pit and burials located to the south.

A composite map, which is somewhat busy, but contains much information, is found in Figure 25. This image contains amplitudes from Grid 8 and 9, with crosses marking the most distinct graves. This image does not contain the slice showing the “pit”, but does have the individual graves located in more detail. In Figure 25 sixty-seven graves are marked, which were placed on this image based on amplitude signatures in the slice maps and also reflection hyperbolas visible in each of the two-dimensional profiles (eg. Figures 12, 13 and 24). Two pipes also cross this area, which cut some of the graves and likely exhumed bones and other burial remains when the trenches for them were excavated. In addition it appears that some of the graves were incised into preexisting burials, making this area very complex. If some of the burials were not within coffins or informal burials of other sorts they would also be more difficult to image using GPR. So I suspect there are many more burials in this area than the 67 that are marked in Figure 25.

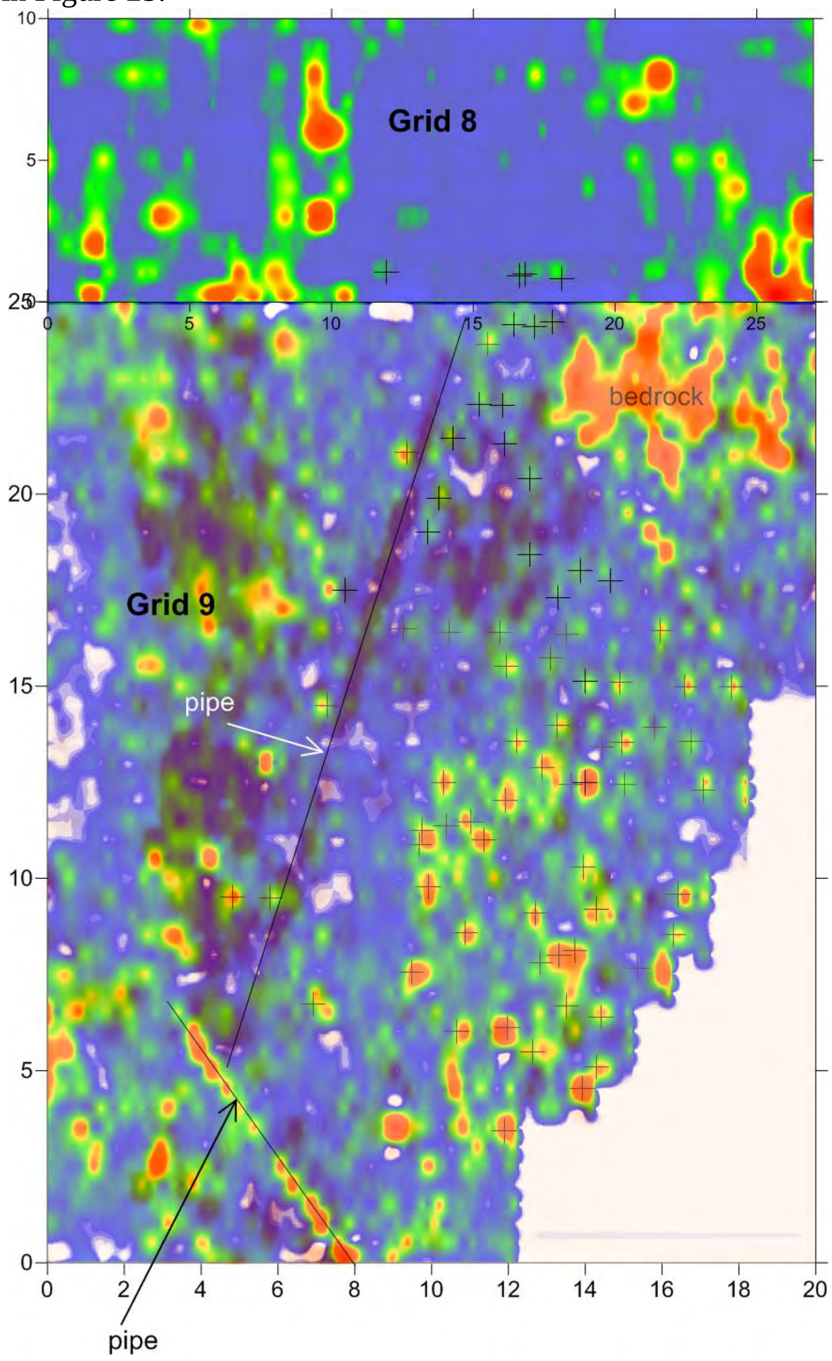

Figure 25: Composite amplitude maps of Grids 8 and 9 with crosses indicating the most distinct burials and the two most prominent pipes crossing the area.

Grid 10: North of hand ball courts

The area north of the handball courts had a good deal of the material used for paving the bike trails remaining on the surface. This mystery material, which attenuates radar energy at the surface, precluded energy penetration deeper than a few inches in the ground (Figure 26). Even with those technical problems it is apparent that bedrock is located very close to the surface in this area, and therefore would not be an area suitable for burials. No burials that are at all similar to those found elsewhere in the other grids were found in this grid, and only reflections from bedrock near the surface (Figure 27).

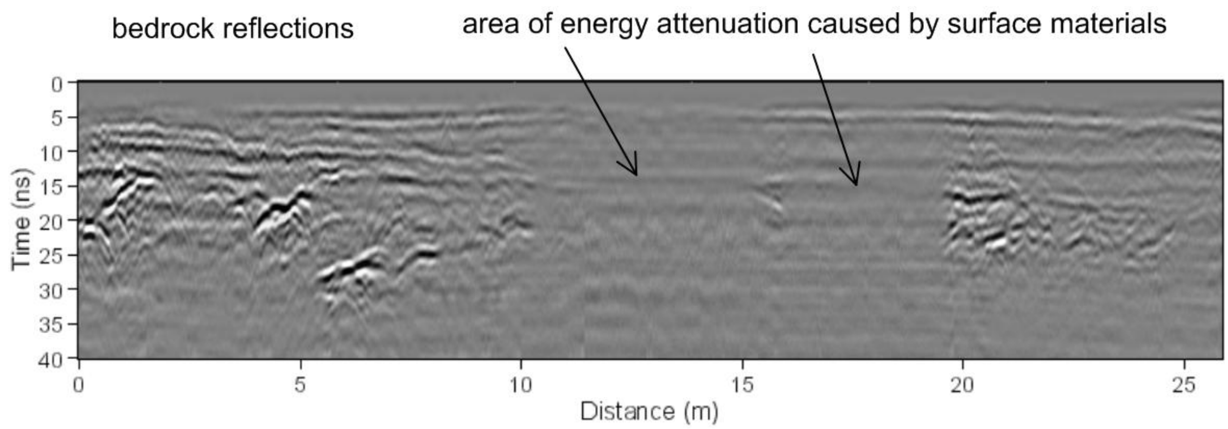

Figure 26: Reflection profile showing attenuation caused by paving materials stored on the surface.

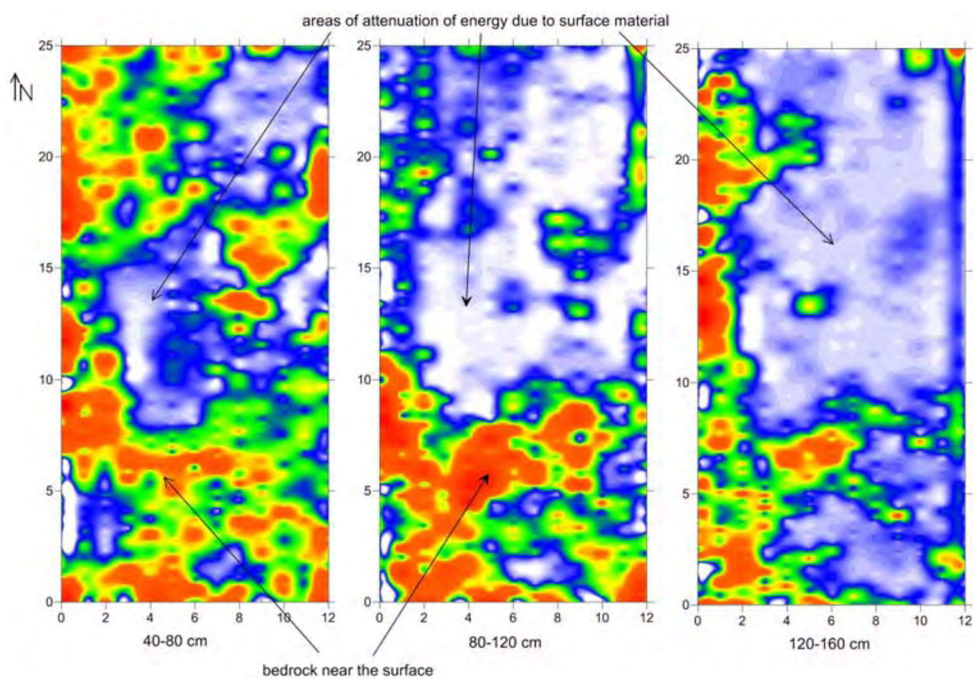

Figure 27: Amplitude slice maps of Grid 10 showing areas of attenuation and bedrock located very near the surface through the area surveyed.

Conclusions

Radar energy penetration and reflection was excellent throughout the area surveyed in the Higgs Beach area. Radar penetration was in excess of 2 meters (6 feet) throughout the area using the 400 MHz antennas. Bedrock reflections were the most common feature found in most grids and when bedrock was close to the surface (shallower than 1 meter: 3 feet) appears to have been the limiting factor in burials. The abundance of burials were found in potions of Grid 3, 4,5,8 and 9, which in all cases were in areas where bedrock was deeper than two meters below the ground (6 feet). An outline of the general areas of graves is found in Figure 28, which covers much of the small dog park and adjoining areas, and a small area in a grassy space adjacent to the bike trail west of the fort.

While GPR was excellent at mapping many graves in this area, it is likely that subtle graves exist, which did not produce significant reflections. No method exists to produce images of these kinds of subtle graves short of excavations. In addition graves likely exist under the bike trail and Atlantic Boulevard, which were not surveyed. A major undertaking to remove the asphalt and all other surface materials prior to surveying with GPR would be necessary to locate those areas, and it is probably best to work under the assumption that they are there, and be careful with all excavation operations in the area.

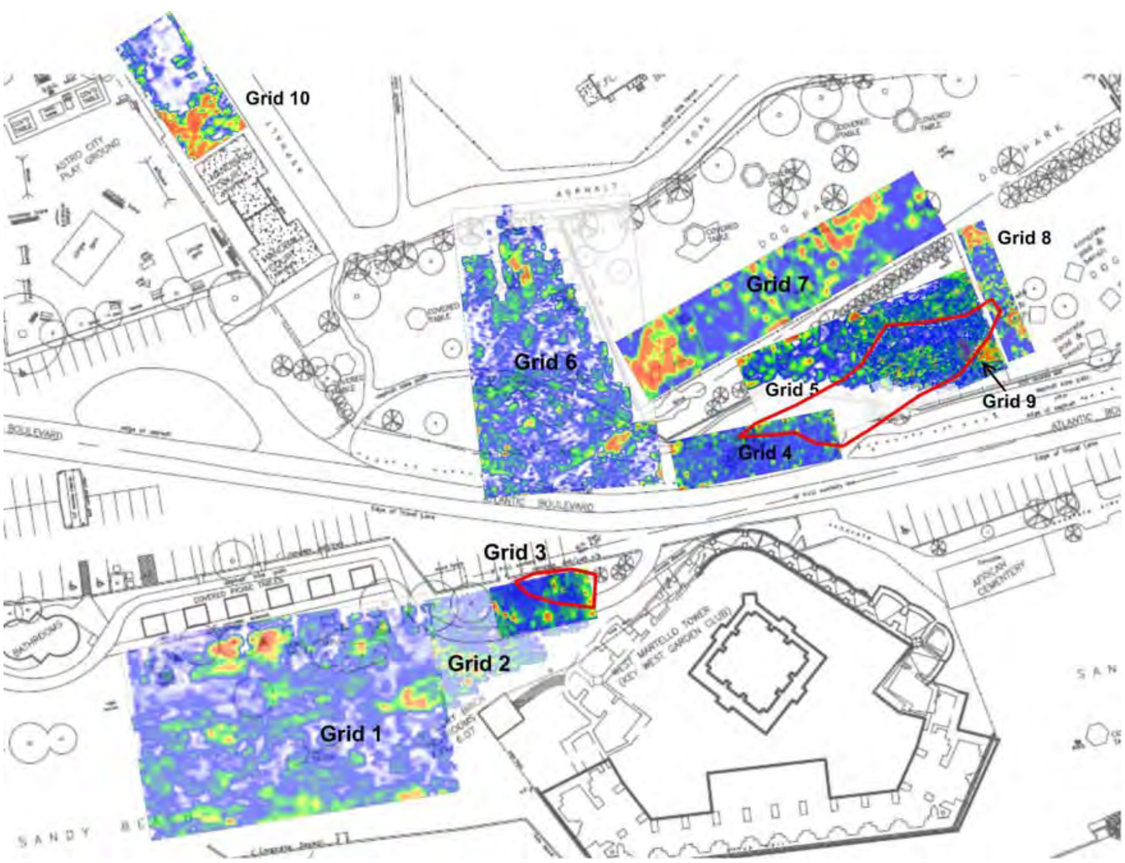

Figure 28: Composite base map of all grids with the areas where graves were identified shown in red.

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