07-02

GPR Survey at Casa Grande Ruins National Monument 2007

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OBJECTIVES:

The purpose of this project was to test the effectiveness of minimally invasive testing techniques to confirm previously excavated features and to identify new features within Compound A at Casa Grande Ruins National Monument (CAGR). This project provided an opportunity for CAGR staff to work with Soil Scientists from the United States Department of Agriculture (USDA), technical specialists from the NPS Intermountain Region Geographic Resources office, and archeologists from other agencies. It also enabled park staff to identify and obtain copies of the final project reports for all previous CAGR research related to Ground Penetrating Radar (GPR) and excavations in Compound A. With enhanced technological applications, knowledge and expertise, new GPR data was collected within unexcavated areas of Compound A. Features that were identified in two previously backfilled excavations (Steen, 1963, Beckwith, 2006) were used to compare known features to the digitally processed, three dimensional results of the newly derived GPR data.

The successes of minimally invasive subsurface testing techniques rely upon both cultural and environmental factors, making the effectiveness of each technique site specific. Thus, this project plays a preliminary role within the larger management approach for CAGR. It funded the planning, implementation, analysis and reporting for a GPR survey within Compound A. All field work was completed during the period of March 12-23, 2007. The remainder of this project was spent on planning, analysis, archival research and report writing. It explored the use of GPR as a tool to confirm the presence of known features and obtain new subsurface data needed to identify newly discovered features. This new data will be combined with data generated through other projects that utilize Electromagnetic Induction (EMI), Light Detection and Ranging laser scans of building elevations (LIDAR), multi-spectral aerial photography, and magnetometer surveys both within the current park boundaries and in lands that are proposed for park expansion. Three dimensional (3D) applications for GPR, EMI and LIDAR data will be used to identify subsurface archeological features, answer questions of materials suitability for minimally invasive testing methods, and identify methods for converting raw data into GIS programs for later use in predictive modeling applications. Research conducted during this project will be incorporated with data obtained from other projects to provide CAGR with digital files that will further the parks research goals, condition monitoring, and resource interpretation.

Due to exceptional support from the archeological community, and with written permission from the granting agency (Western National Parks Association), savings on labor and travel budget items were reallocated to purchase computer equipment with hardware capability suitable for this type of data processing. Thus, in addition to generating new data regarding the location of archeological features in Compound A, this project brought the park closer to fulfilling cultural resource management objectives for archeological research and site management.

PARTICIPANTS:

The following people participated in and/or consulted on this project:

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EQUIPMENT:

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] The SIR System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate. The 200, 400, and 900 MHz antennas were used in this investigation. However, the 900 MHz antenna malfunctioned and produced high levels of background noise and no meaningful signal. This antenna was returned to the manufacturer for repairs and maintenance. The 200 and 400 MHz antennas provided similar penetration depths in the soils at CAGR. In electrically conductive soils, radar energy is effectively dissipated at relatively shallow soil depths regardless of antenna frequency (Lucius and Powers, 1997). The higher-frequency, 400 MHz antenna provided superior resolution and became the antenna of choice for the GPR investigations discussed in this report.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[2] Each radar record was submitted to the following processing procedures: setting the initial pulse to time zero, color transformation, marker editing, distance normalization, horizontal stacking, and background removal. For each grid site, the processed radar records were combined into a three-dimensional pseudo-image using the 3D QuickDraw for RADAN Windows NT software (Geophysical Survey Systems, Inc).[2] Initially, processed radar pseudo-images were migrated and the gain adjusted for display purposes. However, migration did not improve interpretations and many of the pseudo-images shown in this report represent non-migrated data. Once processed, arbitrary cross sections and time-slices were viewed and selected images attached to this report.

Electromagnetic induction surveys of two compounds were conducted with an EM38 meter (Geonics Limited, Mississauga, Ontario).[2] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 1998).

Geonics' DAS70 Data Acquisition System was used with the EM38 meter to record and store both apparent conductivity (EC_a) and position data.[2] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS).[2] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered. The NAV38 and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.[2]

PRINCIPLES OF OPERATION:

<u>Ground-Penetrating Radar:</u>

Ground-penetrating radar is an impulse radar system that has been specially designed for shallow, subsurface investigations. This system operates by transmitting short pulses of very high and ultra high frequency electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of different dielectric permittivity (E_r), a portion of the energy is reflected back to a receiving antenna. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a video screen and stored on a hard disk for future playback, processing, and/or printing.

Compared with other geophysical techniques, GPR provides high resolution images of the subsurface. The effective use of GPR is highly site specific and is interpreter dependent. Ground-penetrating radar does not work equally well in all soils. Soils having high electrical conductivity rapidly dissipate the radar's energy, restrict penetration depths, and create low signal to noise ratios, which impair image quality and interpretability. The performance of GPR is dependent upon the electrical conductivity of soils. In highly conductive soils, the use of GPR is inappropriate. Use of GPR has been most successful in areas of sandy or coarse-loamy soils. Generally, observation depths range from 5 to 30 m in sandy soils, 1 to 5 m in loamy soils, and less than 0.6 m in clayey soils.

GPR measures the time that is required for electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, stratigraphic layer, buried artifact) and back. The two-way travel time is a function of the velocity of signal propagation (v), which is inversely proportional to relative dielectric permittivity as shown in Equation [1] (Daniels, 2004):

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

$$\sqrt{E_r} = c/v \qquad [1]$$

where c represents the velocity of light in a vacuum (0.2998 m/ns). E_r can range from 1 (air) to 80 (water). The relationship between depth (d), two-way travel time (t) and velocity of propagation (v), is shown in Equation [2] (Daniels, 2004):

$$d = vt/2 \qquad [2]$$

Based on a known depth to a buried reflector, calculated values of E_r (for the upper 1 m of the soil) ranged from about 3.3 with the 200 MHz antenna to 4.5 with the 400 MHz antenna. Accordingly, dielectric permittivities of 3.3 and 4.5 were used in this study, yielding propagation velocities (v) of 0.141 and 0.164 m/ns, respectively. However, considerable spatial variability in soil material and compaction exists within each site. As this spatial variability introduces errors into depth calculations, depth estimates are regarded as close approximations.

SURVEY PROCEDURES:

To collect data required for the construction of 3D GPR pseudo-images, survey grids were established. Each grid was constructed using two equal length and parallel lines, which formed the opposing sides of a rectangular area. Along these parallel axes, survey flags were inserted into the ground at a uniform spacing of 25, 50 or 100 cm (grid interval), and a reference line was stretched between matching survey flags on opposing sides of the grid using a distance-graduated rope (see Figure 1). GPR traverses were conducted along this reference line. An antenna was towed on the soil surface along the graduated rope and, as it passed each 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially displaced (a uniform distance of 25, 50 or 100 cm) to the next pair of survey flags to repeat the process.

SURVEY SITE:

CAGR occupies 472.5 acres at the north end of Coolidge, in western Pinal County, Arizona. Most of the site is in native range and consists mainly of creosote bush, cacti, mesquite, annual weeds and grasses. A majority of survey sites are located within a delineation of Coolidge sandy loam (soil map unit 11; http://websoilsurvey.nrcs.usda.gov/app/). The very deep, well drained Coolidge soil formed in alluvium. Typically, Coolidge soil has a calcic horizon within depths of 14 to 40 inches (http://soildatamart.nrcs.usda.gov/). The surface layer contains about 5 to 10 % clay. The clay content of the subsoil ranges from 20 to 30 %. In the subsoil, salinity and SAR (sodium absorption ratio) can range from 0 to 4 mmhos/cm and from 0 to 13, respectively. In the substratum, salinity and SAR can range from 4 to 8 mmhos/cm and from 13 to 40, respectively. Because of the presence of soluble salts, Coolidge soil is considered generally unsuited to deep exploration with GPR. The very deep, well drained Laveen soils formed in alluvium. Laveen soil is similar, but contains slightly more clay than Coolidge soil. Table 1 lists the taxonomic classifications of these soils.

Table 1. Taxonomic Classifications of Soil Mapped at Casa Grande Ruins National Monument

Soil Series	Taxonomic classification
Coolidge	Coarse-loamy, mixed, superactive, hyperthermic Typic Haplocalcids
Laveen	Coarse-loamy, mixed, superactive, hyperthermic Typic Haplocalcids

All grid sites located in Compound A were significantly compacted by pedestrian foot traffic. The grid site located within Compound C (Arizona State Site Number AZ AA:002:006) was less disturbed and less compacted by visitor traffic. Figure 1 shows the locations of all GPR grids and transect sites within CAGR. Also shown in this figure are the locations of buried and exposed structural walls. The Global Positioning System (GPS) coordinates for each grid location were collected with a Trimble Geo XT GPS Unit with a minimum of 30 positions for each point. The location of each point was saved as a shapefile in ESRI ArchGIS 9. Details regarding the accuracy of these point locations are stored in the metadata associated with that file.

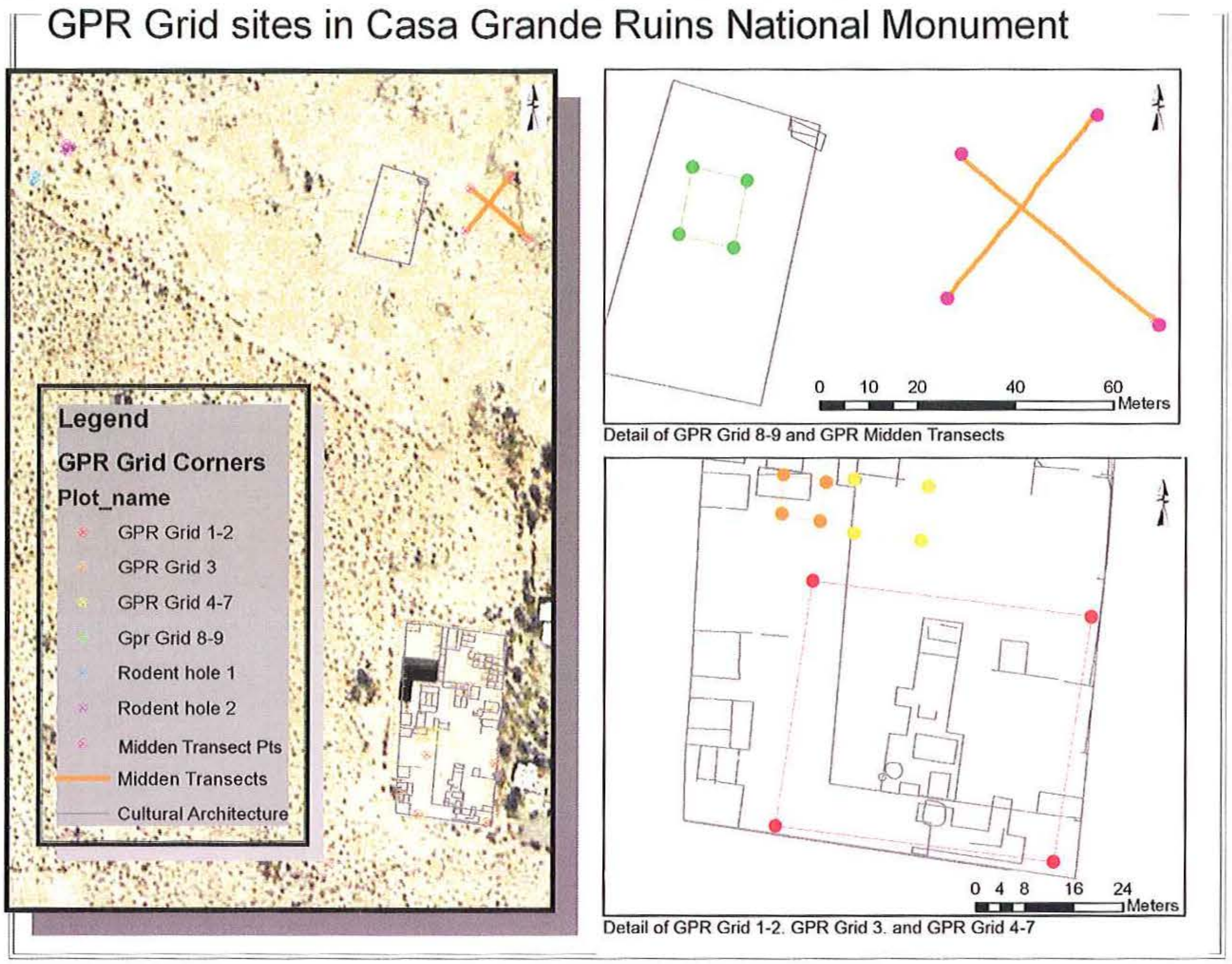

Figure 1. Locations of the GPR grid and transect sites within CAGR. This image was prepared by Eric Drummond (GIS Analysis, NPS, Lakewood, CO).

RESULTS:

Grid Site 1:

Figure 2 illustrates a portion of the radar record that was collected along the first 12.5 m of the Y = 40-m traverse line in Grid Site 1. This radar record has been migrated to compress hyperbolas and reduce diffraction tails caused by point reflectors. A horizontal high pass filter has been used to remove system noise. On the radar record shown in Figure 3, a high amplitude point reflector is evident to the immediate left of "A," at a depth of about 50 cm. A second point reflector is evident below and slightly offset to the right of reflector "A" at a depth of about 75 cm. The multiple ringing of this reflector suggests a metallic object. These reflectors help to confirm that the 400 MHz antenna can profile to a depth of at least 75 cm and can detect contrasting features in areas of Coolidge soil.

These two subsurface reflectors are presumed to represent historic cultural features associated with the 1910 construction of former Superintendent Frank Pinkley's residence. This structure was constructed above the unexcavated prehistoric remains of many rooms within Compound A. This structure is noted in the park Master Plans from 1932, 1935 and 1941. It was remodeled in 1937 to facilitate office space for the Southwestern Monuments headquarters and demolished four years later (Clemensen, 1992).

Also evident on the radar record shown in Figure 3, are a weakly contrasting subsurface feature to the left of "B" and an area of less contrasting (dense) surface soil materials around "C." Difference in density and compaction between buried and partially buried caliche walls and enveloping soil materials were expected to be manifested on radar records. These features (B and C in Figure 3), while not highly contrasting and noticeable, could represent the expression of buried caliche walls. If so, these features are difficult to discern and identify on 2D radar records.

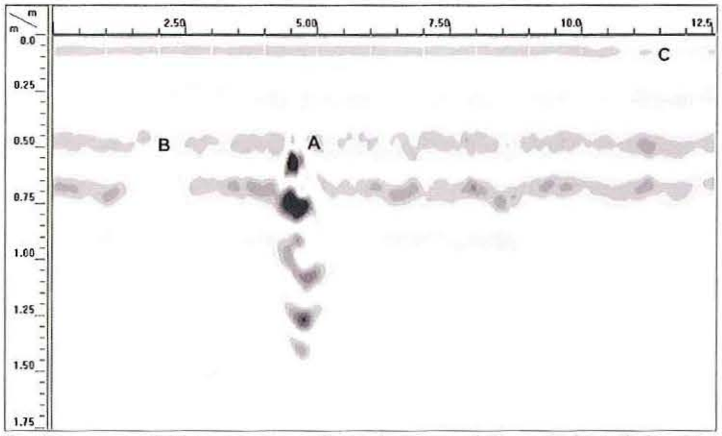

Figure 2. A representative portion of a radar record from Grid I (Line X = 40 m) showing both strongly (A) and weakly (B) expressed point reflectors and an area of contrasting surface soil materials (C).

The ground within Compound A is highly compacted. This compaction would reduce density and moisture differences between the caliche walls and the heavily foot trafficked soil materials. As a consequence, in areas of compacted surface soil materials, buried walls would be poorly manifested and difficult to discern on 2D radar records. Similar experiences are reported by Conyers and Cameron (1998) for a prehistoric Chacoan road in Utah.

The 2D radar records from this grid site revealed numerous subsurface reflectors that varied in size, depth, and reflected signal amplitudes. Most of these reflectors undoubtedly represented buried cultural items, and some possibly represent structural walls associated with the Hohokam culture. The location of subsurface reflectors has been plotted and some patterning has been revealed. Yet, without intensive exploratory excavations the full meanings of these objects remain unclear.

Figure 3 contains two sets (upper and lower) of time-sliced images from Grid Site 1. The two set of plots are for different depths with each set containing two identical plots (one annotated the other not). In Figure 8, the plots on the right have been annotated. These 3D cube images are considered pseudo-sections of the grid area as the vertical scale merely approximates the depth of subsurface features. The upper two plots are horizontal time-slice images made at the 50 cm soil depth. The lower two plots are horizontal time-slice images made at the 100 cm soil depth. The thickness of each slice is about 32 cm. In each plot, north is to the left. To create these images, the maximum reflected wave amplitude method was used. Depths are based on a constant propagation velocity of 0.141 m/ns.

In an attempt to detect subtle subsurface features, the radar data set from this grid site was submitted to Hilbert magnitude transformations (both phase and frequency information) and spatial filtration, but to no avail. The use of these processing techniques did not enhance the imaging of subtle features nor improve interpretations. The plots shown in Figure 3 have been subjected to very little processing and have not been migrated.

In the plots shown in Figure 3, along most of the southern boundary (right-hand plot margin) of this site, a comparatively distinct zone has been enclosed by a green-colored rectangle. This zone appears to contain relatively few subsurface reflectors and is therefore assumed to consist of fairly homogenous materials. This fairly homogenous and unremarkable zone has been identified with the letter "A." This area is noticeable in both the 50 and 100 cm depth-sliced images. It appears to extend across the southern portion of the grid from about Y = 8 m to Y = 46 m, and from X= 31 and 32 m, to X = 40 m. This represents a likely area for habitation and buried structural elements. While nothing exceptional is evident in this zone, and perhaps a stretch of the imagination, a "*wall-like*" feature appears to extend in an east to west (from top to bottom of plots) direction along its northern border (X = 31 to 32 m).

Additional features, believed to be associated with the site of the former residence, have been enclosed in a green-colored rectangle, which has been identified with the letter "B". This area contains a collage of both high and low amplitude reflections that are believed to represent historic artifacts. Also apparent in these plots is a conspicuous, high-amplitude, linear feature, "C", that is located in the northeast corner of the grid area. This linear feature extends in a southwesterly direction towards the site of the former residence and may represent a buried utility or drain line. Other linear features have been identified in the upper and lower, right-hand plots with green-colored lines. As none of these features appear to persist with depth, it is unlikely that they represent buried walls.

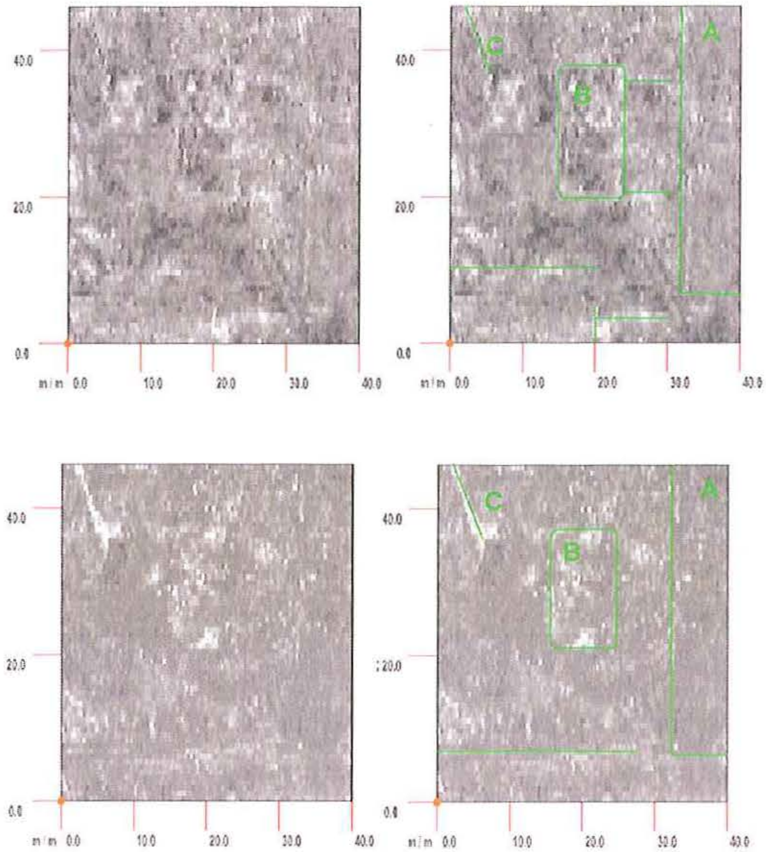

Figure 3. Two sets of time-sliced images from Grid Site 1, Compound A.
Horizontal time-slice images for depths of 50 cm (upper plots) and 100 cm (lower plots).
The thickness of each slice is 32 cm. In each plot, North is to the left.

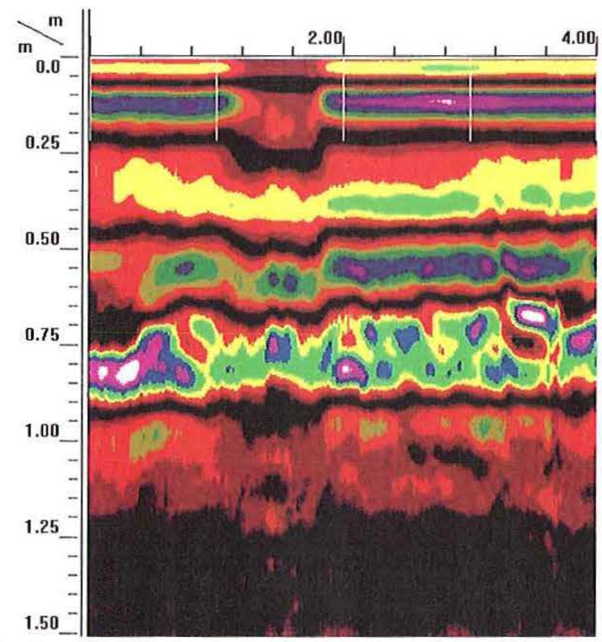

Figure 4. The disruption of surface and near-surface reflections and
the faint indentation on this radar record indicates the location of the
partially-exposed, buried wall in Grid Site 3.

Grid Site 2:

This slightly smaller survey area was located within Grid Site 1. Radar traverses were conducted in an east to west direction, which is orthogonal to the direction conducted in the survey of Grid Site 1. As the orientation of buried structural features and archaeological remains is unpredictable, two GPR surveys of a site in orthogonal directions are often recommended (Lualdi et al., 2006; Dabas et al., 2000). However, this places additional demands on resources and greater burdens on the positional accuracy of the two radar data sets. Thus, the positional accuracy achieved in the surveys of Grid Sites 1 & 2 was not combined into a single 3D representation. Instead, two models were developed and evaluated to search for any discrepancies within the two data sets. The radar data from the survey of Grid Site 2 were comparable to the data collected from the survey of Grid Site 1 and did not provide any additional information on the location and identification of buried structural walls within the compound.

Grid Site 3:

This very small grid site contained an exposed buried wall which was profiled with GPR. (See figure 4.) Knowing the location of the wall, conducting radar traverses at very slow speeds of advance, and the use of signal processing techniques greatly improved the recognition of this feature on radar records. However, even with these measures the partially exposed, buried wall was not evident on all radar records.

A range-gained and color-enhanced radar record clearly shows the location of the partially-exposed, buried wall located between the 1 and 2 m distance marks. This feature was not initially evident on the processed radar record. Color transformations, color table and range gain adjustments were needed to "*bring out*" this feature on this radar record. Though repeatedly passed over with the 400 MHz antenna, even with these display and processing options, the low amplitude and unremarkable reflective characteristics of this partially-exposed, buried wall made it indistinguishable on many of the radar records. In areas of compacted soil materials, such as founded in the heavily foot trafficked areas of Compound A, caliche walls are very difficult to distinguish on radar records.

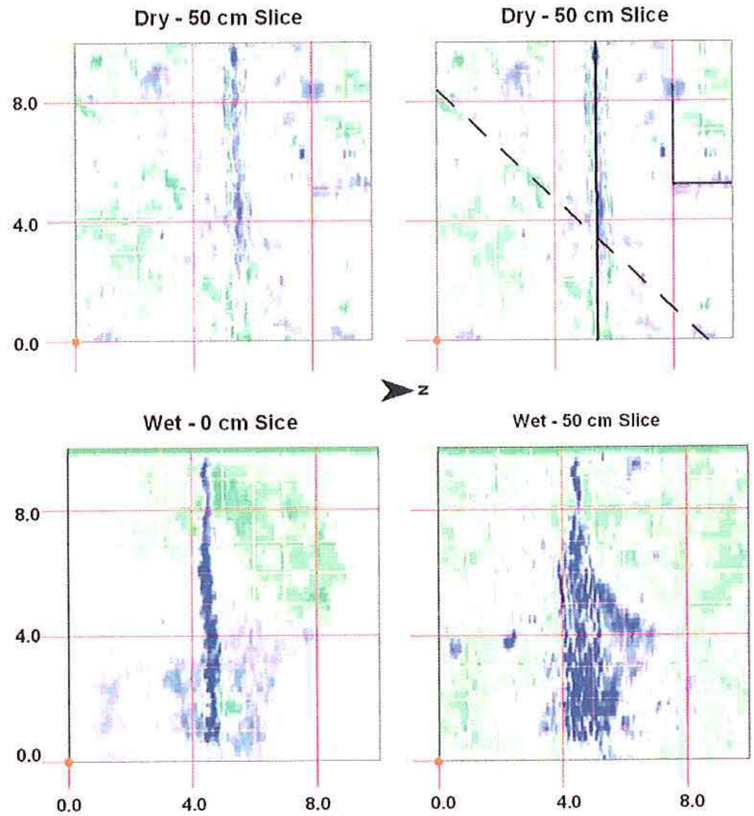

Figure 5. Time-sliced images collected with the 400 MHz antenna from Grid Site 4 (upper plots) under dry conditions and Grid Site 5 (lower plots) under moist conditions.

Grid Site 4 thru 7:

Conyer and Cameron (1998) reported that the floors of pit structures visible on radar records under dry conditions were not evident under wet conditions. Unwanted, high amplitude reflections, which were caused by pockets of soil materials with higher water contents, masked the floors on radar records. In general, masonry that is dry, homogenous and in good condition has been found to provide more favorable radar targets than masonry that is inhomogeneous, rubble, or with higher conductivity (Colla and Maierhofer, 2000). In addition, differences in moisture content and signal velocity have been used with GPR to map zones of potential archaeological interest (Pipan et al., 1999).

Figure 5 shows different time-slice images of the grid area. Each plot represents a pseudo-image of the radar data collected at this grid site with the 400 MHz antenna. The two upper plots are identical time-sliced maps that were collected under dry conditions. The slice is 0.34 m thick and was made at a depth of 50 cm. The upper right-hand plot has been underscored with line segments representing buried utility lines and potential structural walls. In each plot, the location of a modern utility line that bisects the site from east to west is clearly expressed by a high amplitude linear reflector that occurs at approximately X = 5.3 m. This feature has been highlighted with a solid, black line in the upper right-hand plot.

Overlying this feature, naturally deposited fill materials were noticeably less dense than the adjoining, highly compacted soil materials. In the upper plots of Figure 5, a very faint, linear reflection pattern extends across the site from southwest to northeast. This feature has been emphasized with a segmented, black line in the upper right-hand plot. In the upper right-hand corner of the upper plots, spatial signal amplitude patterns suggest the presence of buried wall structures. Though the reflections are rather indistinct and blurred, the locations of possible buried walls have been indicated in the upper right-hand plot.

The lower two plots represent pseudo images of the radar data, which were collected with the 400 MHz antenna under moist conditions (a sprinkler was run across the site for several hours). These time-slice images are 0.34 m thick and represent horizontal slices made at depths of 0.00 (lower, left-hand plot) and 0.50 m (lower, right-hand plot). In each plot, the location of a modern utility line that bisects the site from east to west is clearly expressed by a linear pattern of high amplitude reflections that occurs at approximately X = 4.8 m. This utility line was installed to provide electricity to the Great House for public safety during evening events. It was replaced with conduit to supply electricity to the upgraded security system in 2006 (Beckwith and Carr, 2006). The difference in the location of this feature on the plots of the two surveys (see upper and lower plots in Figure 5) is attributed to antenna offset caused by conducting the radar traverses on different sides of the survey flags.

The buried utility line is more pronounced in the lower plots of Figure 5. The soil materials overlying this refilled trench are less compacted, more permeable, and have higher water content than adjoining soil materials. While the wetted area is discernible in the lower plots, the structural features inferred in the upper plots have been obscured by the addition of water. In areas of compacted soil materials, buried, prehistoric caliche walls of the Hohokam culture are similar to surrounding soil materials and represent poor radar reflectors. Conducting surveys under wetter soil conditions masked what little evidence there was of these structures on radar records.

Grid Sites 8 and 9:

Compound C represents a relatively undisturbed and less trafficked area. Two surveys (one with the 400 MHz and one with the 200 MHz antennas) were conducted on what appeared to be a central courtyard in an attempt to locate buried structural walls. As with the other grid sites, the depth of penetration of the 200 and 400 MHz antennas were comparable. Because the resolution of the 400 MHz antenna was superior to that of the 200 MHz antenna, the 400 MHz continued to be the antenna of choice.

Figure 12 contains two time-slice images of the radar data collected with the 400 Hz antenna at the grid site. These time-slice images are 0.32 m thick and were made at depths of 50 (left-hand plot) and 100 cm (right-hand plot). These plots are relatively unremarkable, with no well-defined linear features. These plots contain few persistent, higher amplitude reflectors that could represent buried archaeological features. In the 100 cm depth slice image, two areas containing more depth-enduring, high amplitude reflections have been labeled "A" and "B". These reflectors represent the most promising sites for artifact concentrations and their appearances suggest possible wall structures. At Grid Sites 8 and 9, if buried wall structures exist, these features are no more discernible in this setting than in the more trafficked and compacted soil setting found within Compound A.

Middens:

Archeological middens consist of cultural deposits that may accumulate for several generations during extended site occupations. Middens are known to contain discarded artifacts, food debris and sometimes human burials. Most middens within Casa Grande Ruins National Monument form easily identifiable mounds whose surfaces are littered with sherds and lithics. Figure 6 is a portion of a radar record that was collected with the 400 MHz antenna over a midden mound. The radar record shown in Figure 13 has been *terrain corrected* based on rough calculation of the elevation at each of the equally spaced (3 m) reference marks. *Terrain correction* or *surface normalization* corrects the radar record for changes in elevation and, in this example, improves interpretations and the association of subsurface reflectors with the midden mound. Across the midden, the 400 MHz antenna provided a penetration depth of about 1.0 m. Within the midden, a larger number of higher-amplitude point reflectors are evident suggesting concentrations of buried artifacts (see Figure 6).

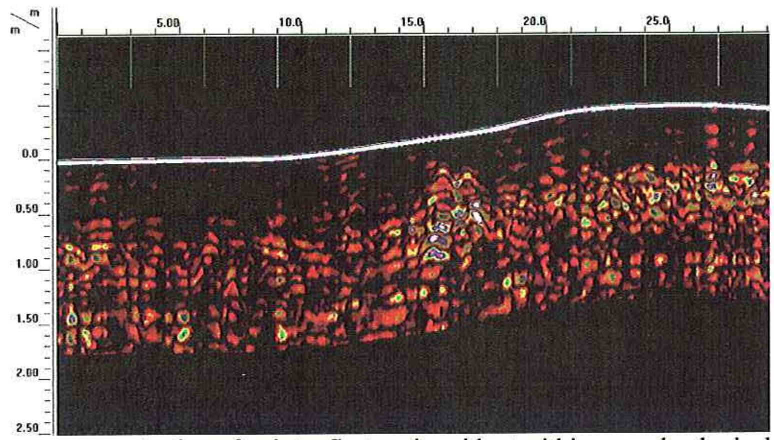

Figure 6. A greater concentration of point reflectors is evident within an archeological midden.

CONCLUSIONS:

This project tested the effectiveness of GPR as a minimally invasive method for identifying subsurface archeological features within CAGR. Both the 200 and 400 MHz GPR antenna provided comparable penetration depths (about 1 m). Differences in surface moisture content of soils within the survey grids did not alter the results of GPR survey data. The soils within Compound A have been significantly compacted by foot traffic and other forms of public visitation over the past 100 years. This visitor impact limited our success for using GPR to identify prehistoric features within such a highly visited site. However, this project did provide useful data for park management and visitor interpretation of cultural resources at CAGR.

A total of nine grids and two transects were surveyed using GPR. Seven of these grids were located within architectural Compound A. Many buried caliche walls do not sufficiently contrast with the surrounding soil materials in dielectric properties to produce strong and easily identifiable reflections on radar records. Various data processing techniques and display options were utilized to make these features more discernible on 2D radar records and 3D pseudo-images. Archival records were consulted to determine the location of previous historic uses within the architectural compound and records from previous excavations were consulted. Excavation records were compared with the results of this GPR survey in order to identify the signature of known prehistoric, architectural features. Once identified, GPR data was re-assessed to identify similar signatures where prehistoric architecture was not previously known to exist. Both historic and prehistoric architectural features were identified within Compound A, but the historic component was much easier to discern from the GPR data.

GPR survey data was collected within two additional grids and two transect lines within Compound C to assess how visitor induced soil compaction affects the accuracy of GPR readings. Survey of these grids did identify areas where more traditional archeological testing is recommended, but no clear definition could be established to identify new walls within the architectural boundaries of Compound C.

Due to good preservation within the current boundaries of CAGR, most archeological sites are readily identified according to geometry, surface elevation, surface soil coloration and artifact density. Determinations of site layout and indications of archeological feature type are more difficult to make without employing traditional methods of archeological excavation. This difficulty is even more pronounced for sites located beneath a historic plow zone. CAGR is pursuing an expansion of the park boundaries to include lands that are currently under commercial cultivation. Excavations conducted on properties adjacent to the current boundaries of CAGR have produced a wealth of archeological data and preliminary surface surveys have already identified numerous sites worthy of preservation just beyond the monument boundaries (Craig, 2001; Beckwith, 2007; Rice, 2002). It is likely that additional subsurface resources are yet to be discovered beneath the historic plow zone of adjacent properties. Minimally invasive techniques may be a rapid reconnaissance tool to identify the location of subsurface archeological features within the lands proposed for park expansion. Further testing of minimally invasive subsurface testing techniques such as GPR, EMI, multi-spectral LIDAR imagery, and Magnetometer Surveys are recommended.

This project refined our understanding of the limitations of GPR at CAGR, while providing data that enhanced our knowledge of architectural features within Compound A. This data will be incorporated into the research goals for the park, the management planning for archeological site preservation, and enhance public understanding of the impressive cultural resources at CAGR. The successes of this project owe credit to the Western National Parks Association for their generous grant and members of the archeological community who donated their expertise, labor, and time to complete this project.

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