Moisture and Soil Differences as Related to the Spatial Accuracy of GPR Amplitude Maps at Two Archaeological Test Sites

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At many archaeological sites containing subtle buried features the distribution and retention of moisture can often be a dominant factor that determines whether reflected waves of sufficient amplitude can detect these features and be potentially mapped using GPR. A number of tests were performed at two archaeological tests sites in Illinois and Washington, where conditions varied dramatically with respect to soil types and moisture content. Amplitude maps produced from data collected in both sandy and clayey ground during both wet and dry ground conditions demonstrates that some types of cultural remains in these soils are visible in one condition or the other, but not always both. Hard packed or baked surfaces and buried wood artifacts will often either pool or retain water and sometimes be visible only when the ground is wet. Other features that are more visible in dry conditions can become obscured by differentially retained water in wet ground conditions, depending on material surrounding them. Laboratory measurements of soil samples from these sites show how sensitive many material types are to minor moisture changes, producing dramatically different reflected wave amplitudes with only small variations in water content. These findings can be used as a guide to the efficacy of GPR in different soils and moisture conditions.

Key words: Archaeological features, soil moisture, amplitude maps

I. Introduction

Moisture changes and the distribution of water in the ground has long been understood to be one of the dominant, if not controlling, factor influencing GPR propagation and reflection from buried interfaces. In most archaeological contexts there is often little is known about the nature of buried cultural and geological materials in the ground and therefore the genesis of many reflections is often a subject of conjecture. An understanding of how reflections are produced in certain conditions is therefore crucial. In addition many archaeological geophysicists have noted dramatic differences in amplitude maps and the nature of reflections in profiles at the same site when reflection data are collected during different ground moisture conditions. These variations are sometimes noticeable seasonally or even diurnally. Sometimes these variations occur more dramatically in sandy soils, and at other times in clay-rich ground. In order to quantify some of the potential variables related to water changes in the ground that can potentially influence the resolution of GPR amplitude maps, reflection data were collected at two archaeological test sites in the USA during different conditions and with different GPR systems and antennas. At both test sites buried cultural features similar to those encountered in some U.S. archaeological contexts were constructed and artifacts of known composition and dimension were placed on, within and in association with them to simulate buried archaeological sites [1]. All constructed features were then surveyed in three-dimensions prior to re-burial and the soil was compacted and re-planted in ground cover to mimic the original conditions.

Archaeological features constructed at these test sites ranged from burned and compacted house floors to storage cisterns, earth ovens, hearths and simulated burials, with a variety of metal, wood and ceramic objects placed in association with them. The test site in Illinois is buried by moist silty clay and the site in Washington is covered by dry wind blown sand. At the Illinois site the buried features range in depth from 30 to 60 cm below the ground surface and at the Washington site between 50 and 150 cm.

Reflection data were collected at both sites with 3 different radar systems, producing different 49 grids of reflection data. Each grid was conducted over the same features using different collection methods, such as survey wheels, continuous data collection and step acquisition. Profiles were also collected with various transect spacing and orientations. These grids of data were collected at both test sites when the ground was very dry and again when water saturated. Soil samples were taken at each from the pertinent depths and laboratory measurements were made of their various chemical and physical properties including clay types and relative dielectric permittivity. Soil water saturation measurements were also made in the field at the time each grid of data was collected.

Each GPR reflection database was then processed into amplitude slice maps using various slicing, gridding and interpolation parameters. The results of those maps (more than 120 different iterations) were velocity corrected and compared to the known depths of features and objects in the ground.

The spatial extent of the known features and objects was then compared to the amplitude maps produced from the GPR reflection data to determine which had the best spatial correlation between the known features and the GPR amplitude maps using statistical correlations in a GIS program. A comparison of all the GPR amplitude maps to the known location of features indicates that moisture retention, as well as the distribution of water along and near these buried materials is one of the dominant factors in the production of reflection amplitudes. This varied dramatically depending on whether the soil was sandy or clay-rich. Some buried features produced low amplitude reflections that were all but invisible in amplitude maps when the ground was dry but produced distinct reflections at buried interfaces when water was retained or pooled on them. Laboratory measurements of the soils at each site indicates that very large changes in relative dielectric permittivity can be produced with only very small moisture changes, indicating that water and its retention is controlling the visibility of many buried archaeological features in these varying ground conditions.

II. DATA COLLECTION AND PROCESSING

Reflection data were collected using GSSI SIR-10, 2000 and 3000 systems with paired 300, 400 and 900 MHz antennas. Data were collected at the Illinois test site when the ground was completely dry, and then again during and directly after a torrential rain storm that dropped more than 10 cm of rain in a 24 hour period. At the Washington site the sandy overburden material is almost always dry, as the climate is arid, and the sandy ground is highly permeable and therefore well drained. Reflection data there were collected during these normal dry conditions, and then again after the site was evenly flooded with more than 30 cm of water from a nearby fire hydrant for 2 days prior to data collection. Transect spacing at both sites ranged from 25 to 50 cm depending on the antennas used. All reflection data were frequency filtered and migrated, if necessary, before performing standard horizontal amplitude slicing [2]. All amplitude slice-maps were corrected for velocity, which varied considerably with the differing moisture conditions, to produce depth-slice maps corresponding to the depths of the known features for direct comparison.

Each amplitude map was constructed in 2 ns thick slices or less. A maximum 20 cm search radius was used (only in sequential reflections traces within each profile) to produce a spatial cube of relative amplitudes, with no interpolation between profiles, so that the integrity of the original reflection data could be maintained. Each time-slice map of relative amplitudes was then produced by gridding using the *Surfer 8* mapping and imaging program. In this process a 1 meter search radius or less was used, interpolating between and along profiles with a power of 4 (weighting the data closest to the center of the search radius) and smoothing the data at most at a factor of 1 or less. Image maps were then created for each slice that could be imported into GIS programs for spatial correlation and colors were assigned to the relative amplitudes of each map when the final images were created for viewing.

III. AMPLITUDE MAPS AND FEATURE COMPARISONS

At the test site in Illinois four contiguous house floors containing hearths, storage cisterns and burials within one floor are the targets (Figure 1). Three of the floors are composed of compacted clay derived from the local soil. One floor (the second from the left in Figure 1) is composed of the same material but was burned prior to burial, which made it very hard and impermeable (Figure 2).

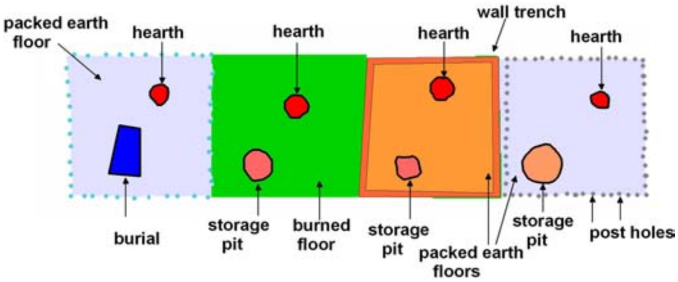

Figure 1: Model of the buried house floors at the Illinois test site with associated features.

Figure 2: Construction of the house floors at the Illinois test site after compaction and the burning of one. Storage pits and hearths are visible as circular darker features on the floors.

Amplitude maps of the house floors when the ground was dry showed the general outline of all four house floors, with some of the smaller storage pits and hearths visible as areas of higher amplitude (Figure 3). In general the resolution was good enough to be able to recognize the general outlines of the floors, but usually not the smaller features on or within them. This is probably because the soil used to construct the floors and associated features is made of the same material as the surrounding ground, and when conditions are dry, the slightly compacted (or burned) features differ only slightly in their amount of retained water from the overlying soil, and therefore do not physically or chemically contrast greatly. In these dry ground conditions there may actually be greater differences *within* the material making up the archaeological features than there is *between* these features and the overlying ground, producing reflection amplitude maps of the features themselves that are quite "noisy" and indistinct.

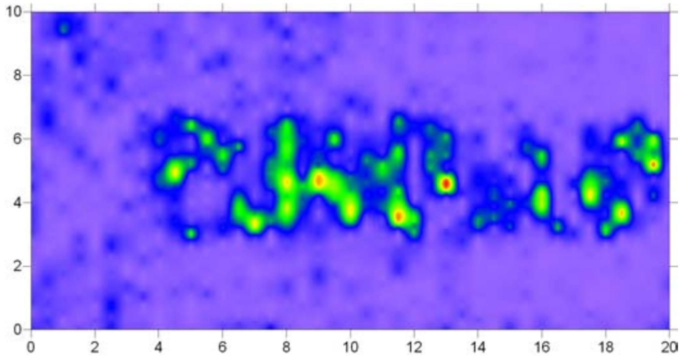

Figure 3: Amplitude map of the 400 MHz frequency reflection data over the house floors shown in Figure 1 when the ground was dry.

When the silty clay soil at the Illinois site was totally saturated the burned house floor became very distinct in the amplitude map, while the adjacent floors, composed of compacted soil much like the overburden became all but invisible (Figure 4). In these conditions the water that had percolated into the ground just a few hours before the data were collected appears to have been pooled on the burned floor, as it was impermeable, but not on the adjoining floor surfaces that are composed of essentially the same material as the overburden (with the only difference being minor compaction variations). In these wet conditions the un-burned floors and the overlying material were effectively "homogenized" and there was no distinct interface to reflect radar energy. During these wet conditions the only high amplitude reflections were produced at the upper interface between the burned clay floor and the overburden that were likely produced by pooled water along this hard impermeable surface (Figure 4).

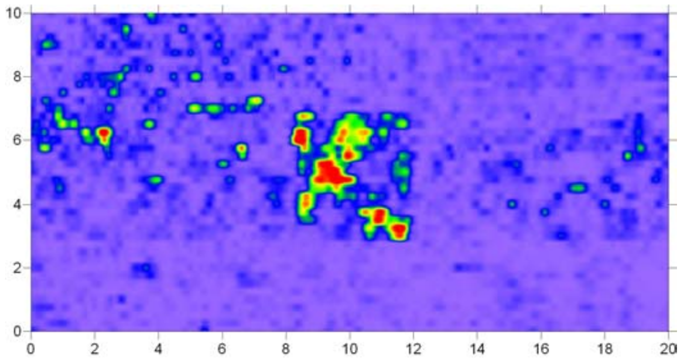

Figure 4: Amplitude maps of the Illinois house floors using the 400 MHz antenna when the ground was extremely wet.

A laboratory analysis of the soils from this site show how even a small amount of water added to the silty clay can dramatically affect its relative dielectric permittivity (RDP) and therefore reflectivity of radar energy. The clay-rich soils from various depths at the site were analyzed using a HP Network Analyzer [3]. In these tests when a small amount of water was added to each of the soil samples the overall RDP increased dramatically from 3 (when dry) to as high as about 10-15 with a small amount of added water (Figure 5). These measurements document how minor amounts of retained water pooled on (or perhaps within) certain archaeological features can dramatically change their RDP and therefore produce reflections with higher amplitudes along the buried interfaces that collect moisture.

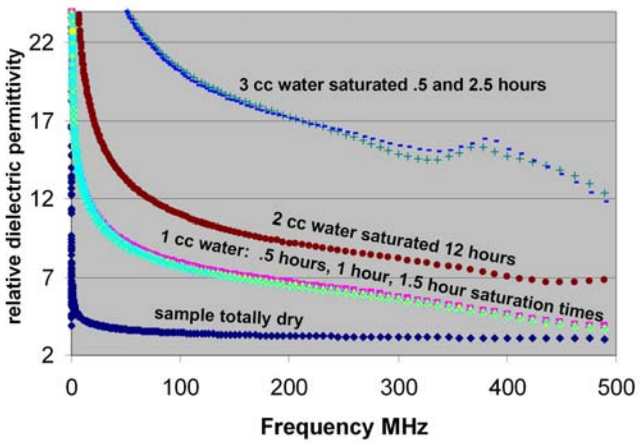

Figure 5: As small amounts of distilled water are added to a 13 cc silty clay sample from the Illinois site, and allowed to sit for varying amounts of time, the RDP increased dramatically.

At the test site in Washington a number of individual wood and metal objects as well as larger earthen, stone and brick features (Figure 6) were readily visible in amplitude maps (Figure 7). During dry ground conditions earthen and metal objects and features are compositionally different enough from the surrounding sandy soil to produce large velocity contrasts at their interfaces and resulting high amplitude reflections. The only significant buried feature not visible in the amplitude maps during dry soil conditions was a wooden foundation consisting of square beams 30 cm in diameter (Figure 8). The brick well and rock ring are highly visible in the amplitude maps, as were some pieces of modern trash. Those materials are all composed of material that differs greatly from the surrounding sandy soils, and distinct reflections from them would be expected. But the wooden beams when dry do not contrast physically or chemically from the surrounding sandy soil and therefore no reflections with amplitudes large enough to be visible were produced.

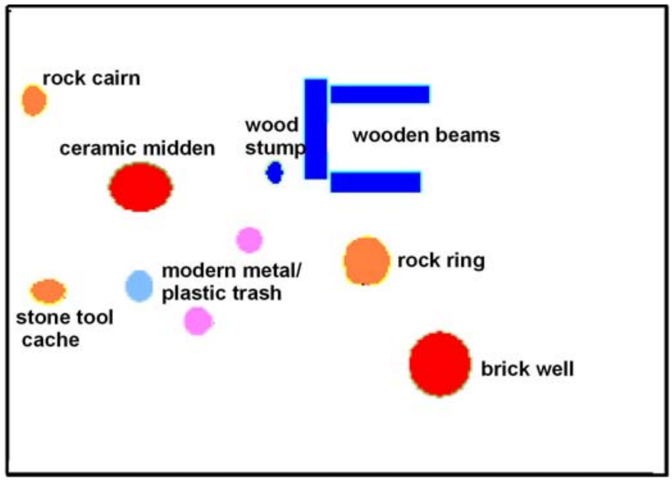

Figure 6: Washington test site where buried features are located about 1.5 meters below the surface.

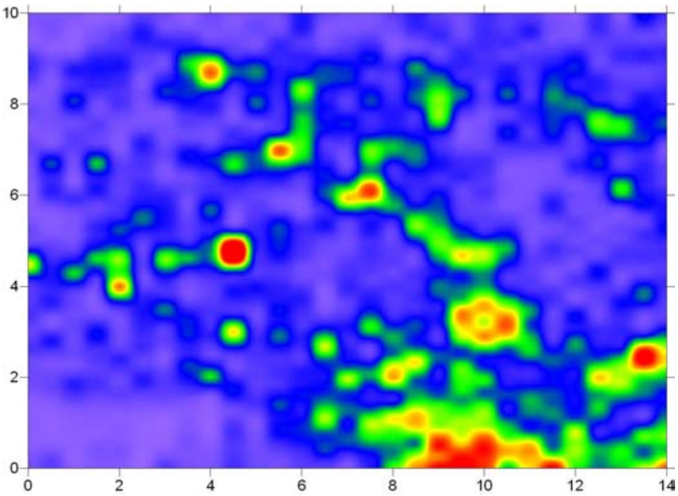

Figure 7: Amplitude map at the Washington test site from 1.5 meters depth. Data were collected when the ground was dry.

Figure 8: Washington test site just prior to burial showing the buried wooden beams modeled in Figure 6.

However, data collected just after the site had been soaked with water for 2 days showed a significantly different reflection amplitude picture. The resulting amplitude slice map produced through and just above the buried wooden beams shows very high amplitudes, probably because the wood had absorbed water in its pores while draining away in the surrounding sandy matrix (Figure 9). Many of the metal objects were still visible when the ground was wet, as would be expected, but other less reflective features produce reflections that appear distorted and otherwise obscure. It appears that these features are retaining or blocking the downward seepage of water in this sandy permeable soil, producing a series of complex reflections that are difficult to interpret. This differential retention of water in sandy soils has been noticed elsewhere when GPR data are collected soon after a rain or snow melt [4].

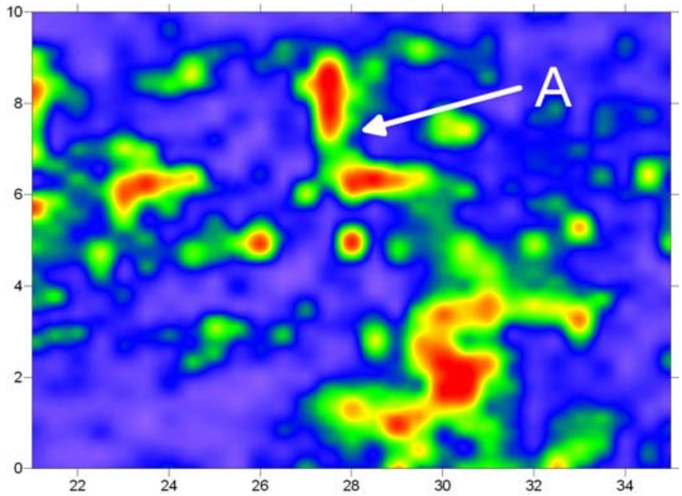

Figure 9: Amplitude map from 1.5 meters depth collected with ground was wet. The wooden beams at (A) are now visible.

IV. CONCLUSION

Differential water retention and distribution can significantly change the production and geometry of radar reflections produced from archaeological features in the ground. In clayey soils where the target features are also of the same clay, little contrast exists between the two when the ground is dry, and they are visible but indistinct. When these soils are wet, however, burned clay features will pool water on their surface and produce very distinct high amplitude reflections, while the unburned features are almost invisible. In sandy soils dry conditions are best for imaging most archaeological features and artifacts as they differ chemically and physically from the sandy matrix. But when that ground is wet, many difficult to interpret reflections can be produced from pools of differentially retained water around and above some buried features. Wooden features, however, produce very distinct reflections in wet conditions when the matrix is sand as they retain water in their pores and produce a distinct velocity contrast with the surrounding material.

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REFERENCES

[1] John Isaacson, R. Eric Hollinger, Darrell Gundrukm and Joyce Baird, "A Controlled Archaeological Test Site Facility in Illinois: Training and Research in Archaeophysics". Journal of Field Archaeology, vol. 26, pp. 227-236, 1999.

[2] Lawrence B. Conyers and Dean Goodman, Ground-penetrating Radar: An Introduction for Archaeologists. AltaMira Press, Walnut Creek, California, 1997.

[3] Timo Saarenketo, "Electrical properties of water in clay and silty soils", Journal of Applied Geophysics, vol. 40, pp. 73-88, 1998.

[4] Lawrence B. Conyers and Catherine Cameron, "Finding Buried Archaeological Features in the American Southwest: New Ground-penetrating radar techniques and three-dimensional computer mapping", Journal of Field Archaeology, vol. 25, pp 417-430, 1998.