GROUND-PENETRATING RADAR FOR URBAN ARCHAEOLOGICAL MAPPING

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ABSTRACT

Urban settings, which are one of the most challenging areas for archaeological near-surface geophysical mapping, can benefit from the use of ground-penetrating radar. The GPR method has the ability to focus energy downward and therefore can potentially map buried features within the clutter of pipes, trenches and other typical urban materials. In addition, GPR can map buried stratigraphy in three-dimensions, which allows stratigraphic analysis of buried deposits. When amplitude slice-maps are produced in various horizontal levels in the ground they can show changes in land usage by building period, making GPR maps analogous to excavation levels over many depths used in traditional archaeological excavations.

INTRODUCTION

Ground-penetrating radar is a near-surface geophysical technique that allows archaeologists to discover and map buried archaeological features in ways not possible using traditional field methods. It can be an especially appropriate tool when working in urban settings, as it is not greatly affected by buried or surface metal and other cultural disturbances. In addition GPR transmits energy into the ground in a more focused way than other active near-surface geophysical methods, and can therefore evaluate buried materials directly adjacent to walls, open trenches and is not appreciably affected by nearby buildings and vehicles.

A growing community of archaeologists has been incorporating ground-penetrating radar (GPR) as a routine field procedure in cluttered urban settings for many years (Conyers, 2004; Conyers and Goodman, 1997; Gaffney and Gater, 2003). Their maps and images act as primary data that can be used to guide the placement of excavations, or to define sensitive areas containing cultural remains to avoid. These are especially important goals in urban archaeology where cultural resource management (CRM) goals are often tied to the evaluation of buried cultural deposits prior to beginning construction projects.

The GPR method has recently become so accurate that the possibility now exists to evaluate grids both large and small in some spatially constricted settings. The resulting GPR maps often show buried utilities as well as previous excavation disturbances, while still producing images of relatively undisturbed stratigraphy as well as un-disturbed archaeological materials in between. Often GPR maps can be directly compared to historic drawings, maps and photos as a way to compare historic records to what still remains in the ground. Most importantly, the GPR method can gather a great deal of information about the near-surface in a totally non-destructive way, allowing relatively large areas with buried remains to be studied efficiently and accurately, while at the same time preserving and protecting them when necessary.

THE GPR METHOD

Ground-penetrating radar (GPR) is a geophysical method that can accurately map the spatial extent of near-surface objects and archaeological features or changes in soil media and ultimately produce images of those materials. Radar waves are propagated in distinct pulses from a surface antenna, reflected off buried objects, features, bedding contacts, or soil units, and detected back at the source by a receiving antenna. As radar pulses are transmitted through various materials on their way to the buried target feature, their velocity changes depending on the physical and chemical properties of the material through which they travel (Conyers, 2004; Conyers and Goodman, 1997). The greater the contrast in electrical and to some extent magnetic properties between two materials at a subsurface interface (resulting in a stronger reflected signal) the greater amplitude of the reflected waves. When the travel times of energy pulses are measured, and their velocity through the ground is known, then distance (or depth in the ground) can be accurately measured to produce a three-dimensional data set (Conyers and Lucius, 1996). Each time a radar pulse traverses a material with a different composition or water saturation, the velocity changes and a portion of the radar energy is reflected back to the surface, to be recorded at the receiving antenna. The remaining energy continues to pass into the ground to be further reflected, until it finally dissipates with depth.

The success of GPR surveys is to a great extent dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial, surface topography, and vegetation. It is not a geophysical method that can be immediately applied to any subsurface problem, although with thoughtful modifications in acquisition and data processing methodology, GPR can be adapted to many differing site conditions. Although radar-wave penetration and the ability to reflect energy back to the surface is often enhanced in a dry environment, moist soils can still transmit and reflect radar energy, and GPR surveys can sometimes yield meaningful data even in totally saturated clay-rich soils. Often completely water saturated ground will drastically slow radar wave velocity, but not attenuate the signal, if the material is not electrically conductive.

GPR DATA COLLECTION

To produce reflection profiles the two-way travel time and the amplitude and wavelength of the reflected radar waves derived from pulses generated at the antenna are amplified, processed, and recorded for immediate viewing or later post-acquisition processing and display. Most often this primary display is in the form of two-dimensional profiles. During acquisition of field data, the radar-transmission process is repeated many times per second as the antennas are pulled along the ground surface or moved in steps. Distance along each line is recorded for accurate placement of all reflections in space within a surveyed grid. Reflection profiles are usually spaced between 50 and 100 centimeters apart in a grid, but recent research has shown that greater resolution is almost always a function of a more densely spaced grid (Goodman et al., 2004, Neubauer et al., 2002).

GPR DATA INTERPRETATION

Standard two-dimensional images can be used for most basic data interpretation, but analysis can be tedious if many profiles are included in the database. This is especially true in urban settings that have seen multiple periods of construction, renovation or destruction and then re-development, producing a complex series of stratigraphic layers, most of which contain artifacts and the remains of prior building episodes. As GPR is a three-dimensional geophysical tool, the origins of each reflection in each profile as well as each stratigraphic layer must sometimes be defined before accurate and meaningful subsurface maps can be produced. This kind of analysis is often only possible with a good deal of interpretive experience, because the primary goal of most GPR urban surveys is to identify the size, shape, depth and location of all buried cultural remains and related stratigraphy. A more sophisticated method of GPR processing is amplitude slice-mapping, which creates maps of reflected wave amplitude differences in discreet horizontal slices within a grid (Conyers, 2004; Conyers et al., 2002; Goodman et al., 1998; Goodman et al., 2004; Leckebusch, 2003). In complexly layered urban settings that contain roughly horizontal layers of material a series of maps that show the spatial distribution of the amplitudes of reflected waves in well defined layers can be important because each map is potentially an indicator of meaningful subsurface changes in lithology or other physical properties. If those amplitude changes can be related to important buried features and stratigraphy, then location of those changes can be used to reconstruct the subsurface in three-dimensions. Areas of low amplitude waves usually indicate uniform matrix material or soils while those of high amplitude denote areas of high subsurface contrast such as buried archaeological features, voids or important stratigraphic changes.

EXAMPLES OF GPR MAPS AND IMAGES FROM URBAN ENVIRONMENTS

Often in complexly layered urban sites, where more deeply buried horizons usually contain materials of greater age, horizontal GPR amplitude maps can illustrate dramatic building changes over time. In this way the deeper slices will show older building activities, while the shallow slices more recent. This was demonstrated at a historic site in Albany, New York, USA, where fire-insurance maps of the city were available showing the location of buildings present on town lots at specific time periods, going back to 1857. These maps showed dramatic building, demolition and re-development episodes over a period of only 150 years. All buried materials from each construction episode are now located under a paved parking lot. Amplitude slice-maps were constructed in 25 centimeter depth slices (after radar travel times were corrected for velocity), and images of the buried architectural features visible in the GPR amplitude maps were compared to the historic lot maps (Figure 1). The slice from 50-75 centimeter depth shows building foundations whose location compared almost exactly to domestic structures and a large kiln that were present in 1890. In progressively deeper slices, those 1890 buildings were still visible, but deeper foundations from older structures were also visible in the slice in the 150-175 centimeter depth (Figure 1). When the locations of those features were compared to the oldest historic maps from 1857, no correlation was found to any mapped structures. The deeper GPR amplitude maps were therefore producing images of buildings that were present prior to the construction of any extant maps of the city. The shallower slices and their structural remains correlated almost perfectly with the most recent fire insurance maps.

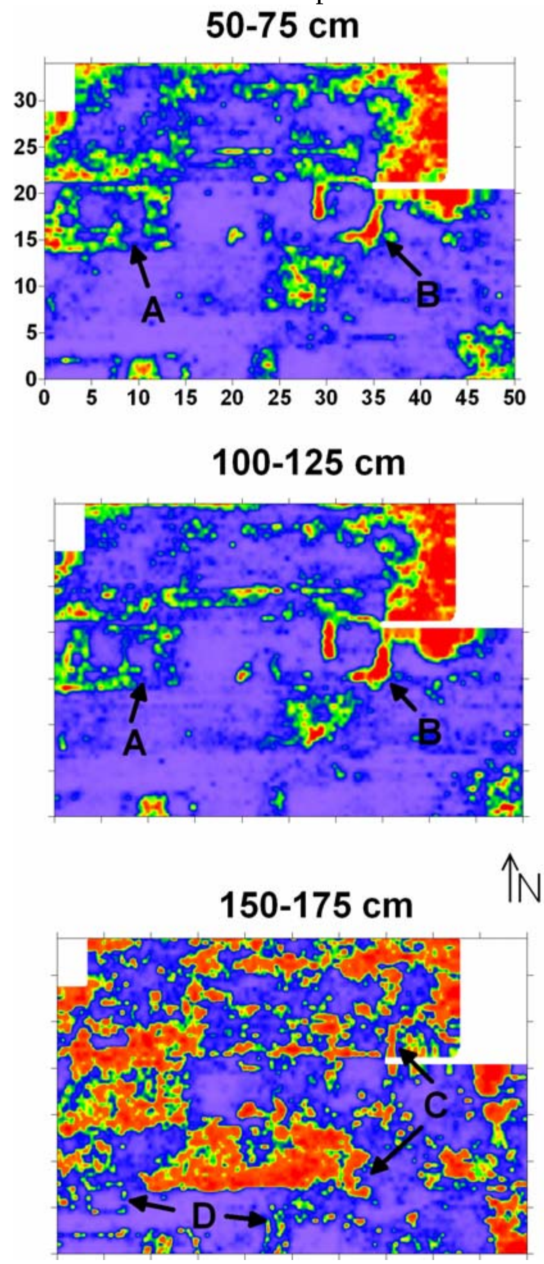

Figure 1: Amplitude slice-maps of an historic site in Albany, New York, preserved under a parking lot. Grid dimensions are in meters. The two slices illustrate very different preserved architecture at different depths. When the shallow slice from 50-75 centimeters is compared to the 1890 fire insurance maps, there is good correlation with what was known. Red and yellow areas are high amplitude reflections while blue are little or no reflection amplitudes. The deeper slice is showing smaller buildings from pre-

1857. A and B are known historic structures. C and D in the deeper slice are previously unknown older structures.

In this example from historic New York the horizontal amplitude slice-maps can be a way to not only map building locations over time, but when integrated with enough other information such as historic maps and artifacts from excavations, their function as well. The changing make up of historic neighborhoods can potentially be determined using these GPR amplitude maps, each of which is from a specific time period, if the sequential amplitude slices are roughly comparable to time periods. In this way GPR images can be much more than just a tool for finding and mapping buried features, but also a database from which to study social change and a wealth of other historic and anthropological questions.

A similar situation to the Albany project was undertaken in a parking lot in downtown Santa Fe, New Mexico where archaeological excavation trenches had found evidence of pre-Spanish occupation, perhaps the original "Pueblo of Santa Fe", thought to exist in this general area prior to the arrival of the Spanish in the early 17^{th} century. This study is a good example of the type of precision possible with GPR, in what would be considered an extraordinarily "cluttered" urban environment where excavation trenches, buried utility pipes and large areas of bulldozer disturbance exist in a small area. The area actually appeared so hopelessly disturbed that there was initially given little hope of success in finding any intact cultural remains.

Amplitude slice-mapping quickly produced images of the ground, but high amplitude reflections from the large amount of buried metal pipes, rubble from various constructions activities, and the back-fill from recent trenching obscured much of the images. A very simple amplitude filter, which removed only those values greater than one standard deviation above the mean, left the medium and low amplitude values, producing a map that was much more readily interpretable (Figure 2). An image of the parking lot from about 20-40 cm below the pavement surface showed the remains of a well preserved circular kiva wall amidst the noise and clutter. Kivas are semi-circular subterranean rooms that were used for ceremonial as well as domestic activities by the ancient Puebloan people, and are still used by their descendants that live in the area (Conyers and Cameron, 1998). In this study it is doubtful that any other near-surface method would have been capable of this degree of resolution, especially given the complexity of the area.

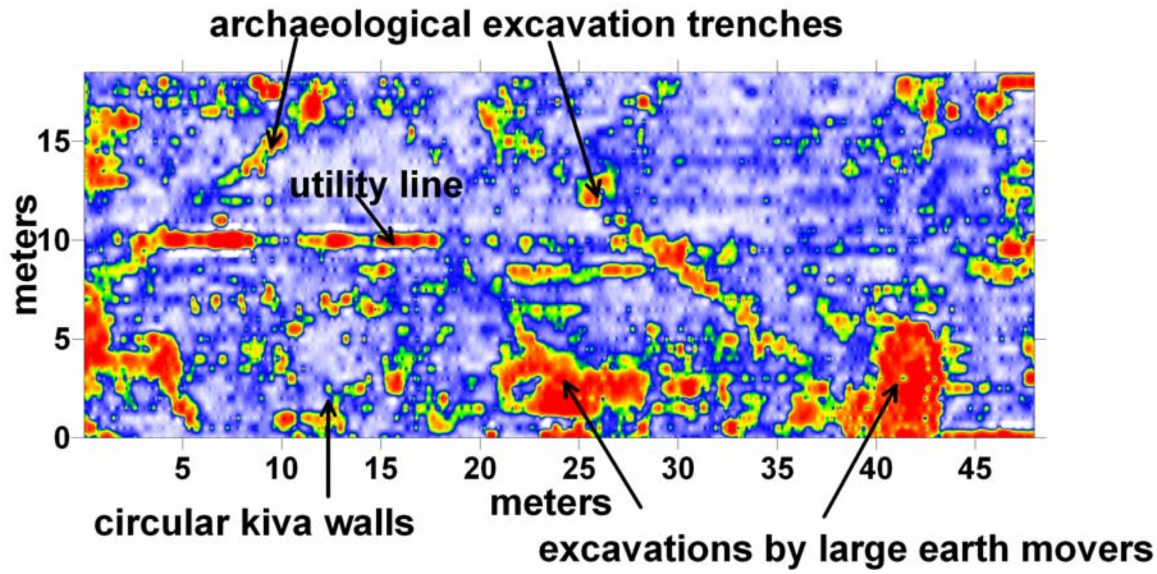

Figure 2: Amplitude slice-map from 50-75 cm depth in a parking lot in Santa Fe, New Mexico, showing urban clutter with one circular kiva preserved. Red and yellow areas are high amplitude reflections while blue are little or no reflection amplitudes.

As an additional example of how GPR maps can quickly determine the extent of remains in the ground from what are known buildings comes from Angel Island, California. This area once held the immigrant processing center for people coming to the U.S.A. in the late 19^{th} and early 20^{th} century, primarily from Japan and China. Detailed plans exist in the building records of one of the large wood-frame buildings from this time. Today the area is a California State Park, with only a few buildings standing from this time period. When the GPR amplitude maps were overlain on the floor plans of one of the buildings that were known to have stood in this area (Figure 3), it was found that only two basement areas still had intact structural remains. The remainder of the building had been destroyed and removed from the site. In this case the GPR maps could quickly locate the specific areas where archaeological materials still exist for study. The great disparity between what was there less than a hundred years ago, and what still exists today was dramatically illustrated using GPR mapping.

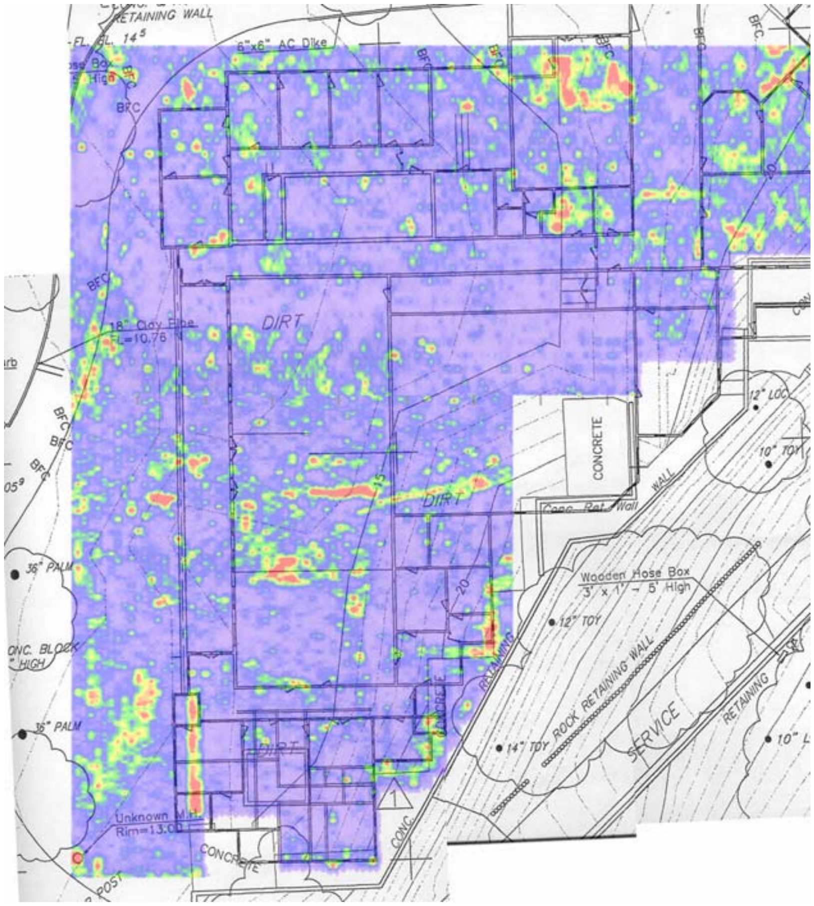

Figure 3: GPR amplitude slice-map from 75-100 cm depth at Angel Island, California. Superimposed on the GPR map is a plan of the original building in this area. Total GPR amplitude slice map grid dimensions are 50x50 meters. Only a few foundation walls and three areas of basement walls are still preserved from the original structure as high amplitude red, yellow and green reflections.

CONCLUSION

Ground-penetrating radar has the unique ability of near-surface geophysical methods to produce three-dimensional maps and images of buried architecture and other associated cultural features in urban settings. Three-dimensional maps of amplitude changes can define physical and chemical changes in the ground that are related to buried materials of importance, even in the most cluttered of urban environments. This is possible because the GPR method has the ability to very precisely show these changes in a three-dimensional "cube" of reflection data, where the clutter can be discriminated from the archaeological features of interest.

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