Integration of ground-penetrating radar and magnetic data to better understand complex buried archaeology

Lawrence B Conyers[(1)]

[(1)]Department of Anthropology, University of Denver, Denver, Colorado, USA

lconyers@du.edu

Introduction

Geophysical archaeologists have long relied on an analysis from multiple geophysical sensors to provide an interpretation of buried archaeological features and their surrounding matrix. Sometimes this is done by "data fusion" (Kvamme 2006) but often relies on a direct comparison of maps produced by different datasets (Piro *et al.* 2000), with a visual analysis of features or anomalies that appear to exist (or not) in a study area. While this can often be informative, a comparison of ground-penetrating radar (GPR) reflection features with those obtained by magnetic gradiometry are often not spatially comparable or indeed do they overlap at all, and are actually exhibiting properties of the ground that are very different both locally and regionally. While producing images of very different variables of the ground, the two datasets (GPR and gradiometry) are actually quite comparable and informative, but not when directly "matched up" in space. A few examples are given below where surveys of one method were complemented and enhanced with specific analyses of the other.

Ground-penetrating radar has the ability to view geological and archaeological units in three-dimensions that show the boundaries between layered materials in the ground with differences in relative dielectric permittivity (RDP) (Conyers 2013). The differences in RDP are almost wholly the product of differences in porosity and permeability of layers, and therefore their ability to retain or shed water (Conyers 2012). These differences in units can be viewed in reflection profiles and those profiles then re-sampled and mapped in slices, in order to show the distribution of important units in the ground (Conyers 2016a).

Magnetic gradiometry is measuring the differences in the magnetic susceptibility of units in the ground or their thermo-remnant magnetism (Aspinall *et al.* 2009; Fassbinder 2015). Those factors that affect the readings obtained by the modification of the earth's magnetic field by buried materials over space are very different than those obtained by GPR. Magnetic readings are also constrained by an inability to differentiate depth, while they are also modified by the depth of the materials in the ground, their geometry and the magnetic field orientation at different locations on the surface of the earth.

These very different factors that influence the way GPR and magnetic images are created need not be a constraining factor, as often GPR profiles and maps can be used to visualize buried features and stratigraphy in three-dimensions, and then their magnetic "signatures" can be used to understand their constituents. However, any direct correlation of GPR and magnetic gradiometry maps will often be disappointing, as they are displaying very different spatial locations of buried materials (Conyers 2016b).

Hollister Site, Connecticut, USA

In the Connecticut River Valley of New England a 17th century Colonial farming community was discovered using geophysics and excavated in the summer of 2016. This farmstead was founded soon after the Massachusetts Bay Colony by the earliest Pilgrims from England to the New World, and contains artefacts from both those earliest colonists and the indigenous tribes, with whom they apparently had amicable relations (at least for a time). This site was hypothesized by a surface scatter of pottery and other artefacts that suggested an occupation existed somewhere in the area. The landowners are also direct descendants of these earliest colonialists, and retained a verbal and partial written history of where their ancestors may have lived long ago.

The GPR slice from about 50-75 cm depth over a large area shows a complex series of reflections with very high amplitude, which were generated from glacial till and post-glacial fluvial units (Fig. 1), which are the "bedrock" in this area, below any cultural layers. On those deposits a soil was formed when the nearby Connecticut River degraded to its present level sometime in the Holocene, and produced a fill terrace. It was on this surface that the living surface on which Indian peoples and the Colonialists constructed their dwellings and other structures. The cellars of buildings, Indian people's pit structures, wells and possible storage pits, which were filled by fine-grained sand from post-abandonment flood episodes, are visible in the GPR slice. They can be seen as white areas of no radar reflection produced by a uniform fill sediment, with the surrounding stratigraphic units being very high amplitude (Fig. 2). In contrast, the magnetic map (Fig. 1) shows a large number of recent metal objects near the surface, none of which help in understanding the buried buildings. If only the magnetic map had been produced in this area, there would have been no discovery of the important buried features below.

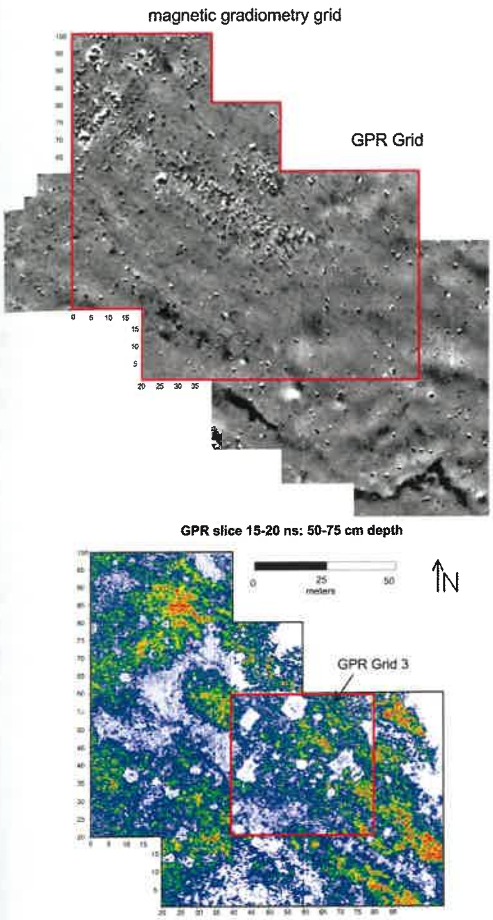

Figure 1: Magnetic gradiometry and GPR images from a large area in Connecticut, with the magnetic map showing mostly surface scatters of metal objects. The GPR slice shows many buried house cellars and other features built on this historic landscape now buried below recent alluvium. Grid 3 outline on the GPR map is shown in detail in Figure 2.

While the cellars are visible in the GPR slice maps, the magnetic map of this area appears to be mostly worthless. But it provides important information that can be used to interpret the GPR images. Many GPR reflection profiles were visualized, and the corresponding magnetic values were taken directly from the gridded magnetic readings used to produce the map (Fig. 3). They were then compared directly along multiple profiles in order to understand the magnetic properties of features and layers visible with GPR. When this is done the cellars are quite visible in profile, and the magnetic readings show that the material that filled in the cellars (and likely artefacts and burned material directly on their floors) display high magnetic readings. This provides evidence that there was likely a burning event, either intentionally or accidentally, at the time this community was abandoned and the cellars will filled with burned objects large enough to be visible in the GPR profiles (Fig. 3) and many smaller objects not visible with GPR, which have high thermo-remnant magnetism.

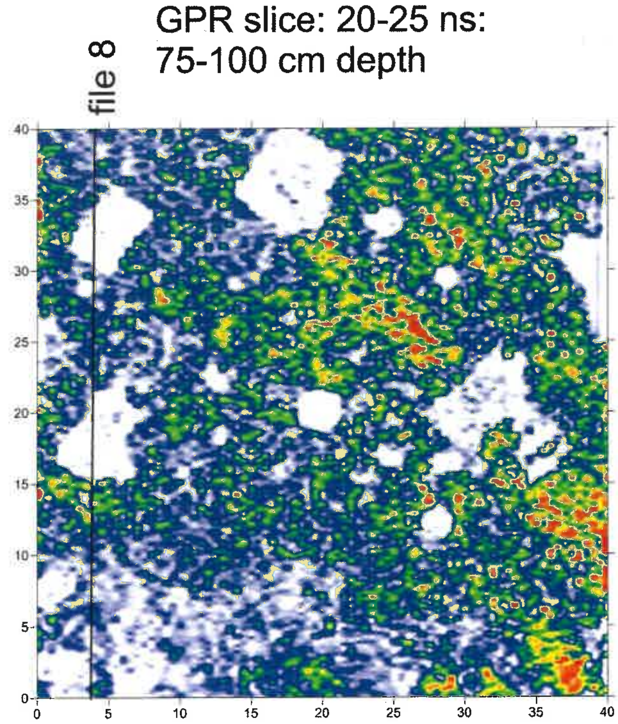

Figure 2: Grid 3 GPR amplitude map showing the cellars of historic buildings in white, with some storage pits and wells in the circular forms.

Conclusions

In this case, while the GPR amplitude maps and reflection profiles were more than sufficient to map this buried Colonial farmstead, the magnetic information provides important additional information on the nature of the materials visible with GPR. The magnetic map, when viewed alone, is not helpful at mapping this buried site, but within those data are important values that when extracted and compared to the GPR profiles, tell a good deal. This is one example of GPR mapping being very important in the interpretation of this site with magnetic data playing a secondary but still important role. There are many other examples, which I have analyzed from elsewhere in the world where the magnetic maps are much more illustrative than the GPR, but once those images are produced they can direct the interpreter to look at the GPR in greater detail. The key to this kind of "data fusion" is that the two methods are often not directly compatible but parts of each dataset can be used together with great benefit. This can be a iterative process with both GPR and magnetic data analyzed, re-imaged and then interpreted again as data are extracted and compared. Magnetically-visible features can often be put into correct three-dimensional space using the GPR, or the GPR features visible in profiles or maps can be further interpreted with magnetic analysis. This deliberate merging of information then produces a much more holistic interpretation.

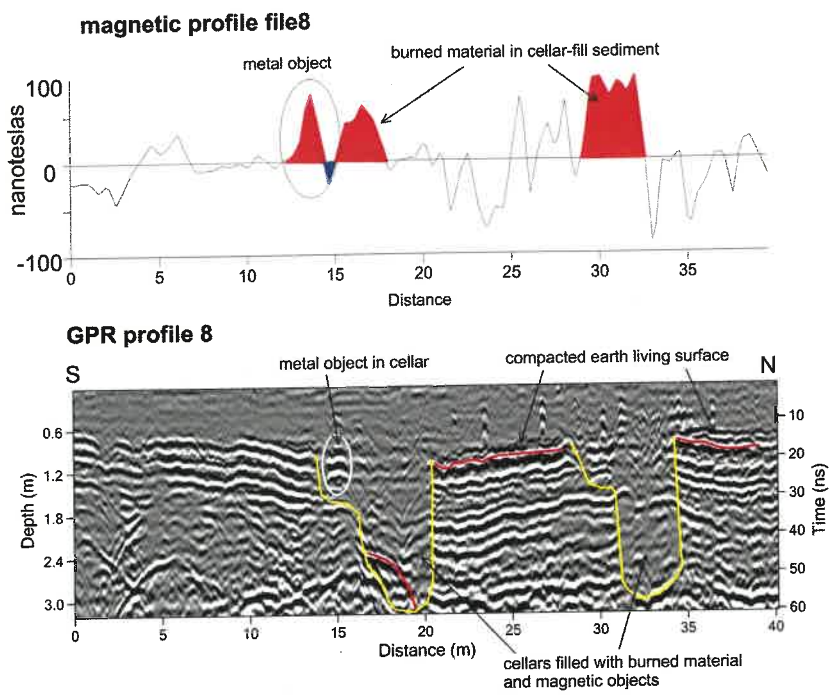

Figure 3: GPR reflection profile 8 (location in Figure 2) showing the incised cellars that were dug into the surrounding strata. The magnetic readings that correspond to this GPR profile show the types of material that filled in the cellars.

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Acknowledgements

Very many thanks to Maeve Herrick and Jasmine Saxon for lending me their fabulous dataset from Connecticut for this analysis. Also to David Wilbourn of Terrasurveyor for magnetic data corrections and processing. Ken Kvamme and Jarrod Burks were also helpful in magnetic data interpretation.