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Long-term sequential monitoring of controlled graves representing common burial scenarios with ground penetrating radar: Years 2 and 3

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ABSTRACT

Geophysical techniques such as ground-penetrating radar (GPR) have been successfully used for forensic searches to locate clandestine graves and physical evidence. However, additional controlled research is needed to fully understand the applicability of this technology when searching for clandestine graves in various environments, soil types, and for longer periods of time post-burial. The purpose of this study was to determine the applicability of GPR for detecting controlled graves in a Spodosol representing multiple burial scenarios for Years 2 and 3 of a three-year monitoring period. Objectives included determining how different burial scenarios are factors in producing a distinctive anomalous response; determining how different GPR imagery options (2D reflection profiles and horizontal time slices) can provide increased visibility of the burials; and comparing GPR imagery between 500 MHz and 250 MHz dominant frequency antennae. The research site contained a grid with eight graves representing common forensic burial scenarios in a Spodosol, a common soil type of Florida, with six graves containing a pig carcass (*Sus scrofa*). Burial scenarios with grave items (a deep grave with a layer of rocks over the carcass and a carcass wrapped in a tarpaulin) produced a more distinctive response with clearer target reflections over the duration of the monitoring period compared to naked carcasses. Months with increased precipitation were also found to produce clearer target reflections than drier months, particularly during Year 3 when many grave scenarios that were not previously visible became visible after increased seasonal rainfall. Overall, the 250 MHz dominant frequency antenna imagery was more favorable than the 500 MHz. While detection of a simulated grave may be difficult to detect over time, long term detection of a grave in a Spodosol may be possible if the disturbed spodic horizon is detected. Furthermore, while grave visibility increased with the 2D reflection profiles, particularly with the 250 MHz antenna, the combination of both imagery options is recommended when evaluating GPR data during a search for a clandestine grave.

1. Introduction

Forensic investigators will generally incorporate a variety of methods as part of an interdisciplinary protocol when searching for clandestine graves and physical evidence associated with criminal activity. With the growing interest in the field of forensic geoscience (Davenport, 2001a; Fenning and Donnelly, 2004; Pye and Croft, 2004; Ruffell and McKinley, 2005; Morgan and Bull, 2007; Pye, 2007; Schultz, 2007a; Ruffell et al., 2009a; Schultz and Martin, 2012; Ruffell and McKinley, 2014), the use of geophysical tools as part of a multidisciplinary search protocol have become accepted search methods by criminal investigators. While early geophysical research concluded that ground-penetrating radar (GPR) was the most important geophysical tool for delineating forensic graves (France et al., 1992; France et al., 1997), more recently, it has been shown with controlled research that electrical resistivity is an important geophysical tool for forensic grave detection in certain soils that may limit the effectiveness of GPR (Jervis et al., 2009a; Jervis et al., 2009b; Pringle et al., 2012a; Pringle et al., 2016).

There are a number advantages when incorporating geophysical tools, including GPR, as part of a multidisciplinary search protocol for clandestine graves and buried evidence. First, and foremost, GPR is a non-invasive, or non-destructive, search tool that does not produce surface damage (Schultz, 2007a; Schultz and Dupras, 2008; Dupras et al., 2012; Schultz, 2012). Therefore, the context of potential buried evidence is preserved. In addition, if site characteristics are appropriate for this equipment, it is normally used to highlight smaller anomalous areas across a much larger survey area. Investigators can then focus

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follow-up testing over the smaller areas, that can include invasive methods, to confirm detection of a buried target, or to clear an area thought to contain a buried body or evidence so that additional searching can be directed elsewhere (Ruffell, 2005; Schultz, 2007a; Schultz and Dupras, 2008; Billinger, 2009; Ruffell et al., 2009a; Dupras et al., 2012; Schultz, 2012).

The application of geophysical tools for forensic applications requires experience searching for objects and disturbances in the near surface. As a result, controlled research involving sequential monitoring of graves has been invaluable for investigators to gain experience using this equipment for forensic applications as well as for determining optimum detection technique(s) and equipment configuration(s) (see France et al., 1992; France et al., 1997; Freeland et al., 2003; Powell, 2004; Cheetham, 2005; Schultz et al., 2006; Schultz, 2008; Jervis et al., 2009a; Jervis et al., 2009b; Schultz and Martin, 2011; Pringle et al., 2012a; Pringle et al., 2012b; Schultz and Martin, 2012; Ruffell et al., 2014; Molina et al., 2016). This research often consists of burying pig carcasses (*Sus scrofa*) as proxies for human bodies and to sequentially monitor and detect graves for a length of time post-burial, while controlling a number of grave variables; these variables include burial depth, soil type, dominant frequency antenna type, postmortem interval (PMI), carcass size, as well as the actual burial scenario, such as naked or wrapped carcasses (Schultz et al., 2006; Schultz, 2008; Jervis et al., 2009a; Pringle et al., 2012a; Schultz and Martin, 2012; Molina et al., 2016; Pringle et al., 2016). This research has been useful for determining the applicability of these technologies for detection of graves in various soils and scenarios; and as a result, GPR is now routinely used to clear areas and to successfully locate clandestine burials of homicide victims (e.g. Nobes, 2000; Davenport, 2001a; Davenport, 2001b; Schultz, 2007a; Dupras et al., 2012).

Unfortunately, there are limited published geophysical studies incorporating different burial scenarios involving bodies (humans and pig), including the utilization of an empty control grave, over a long term postmortem period of sequential monitoring for greater than one year. For example, while Schultz et al. (2006) and Schultz (2008) studied the effect of time for postmortem periods up to 21 months postburial using GPR to monitor small and large pig carcasses in two different soils types and two different depths, a comparison of wrapped and naked carcasses was not evaluated. More recently, Pringle et al. (2012a, 2016) is the only geophysical study that has reported results of continuous monitoring for a long-term time period of six years using resistivity and GPR. In this landmark research project, two graves with pig carcasses and an empty control grave were studied to evaluate the geophysical response over time for wrapped and naked pig carcasses (Pringle et al., 2012a; Pringle et al., 2016). Further, Schultz and Martin (2012) was the first study to evaluate the effect of numerous real-life burial scenarios by incorporating six graves with carcasses, including wrapped and naked scenarios, in addition to two empty control graves. However, the authors only reported the first year of continuous monitoring with GPR out of a three-year monitoring period. Since there has been minimal research evaluating the effect of grave detection representing long-term PMIs, it is integral to evaluate how various grave variables will affect detection of graves over long periods of time post-burial. The purpose of this controlled GPR study is to present Years 2 and 3 of the research project previously reported by Schultz and Martin (2012), which only included Year 1, and to discuss the trends observed over the entire three-year monitoring period. It is important to note that preliminary results for Year 2 were initially presented by Hawkins (2011); however, the GPR results for Year 2 were rescored and reimaged for this work.

Specific aims for this research include the following:

- compare GPR imagery characteristics using 2D reflection profiles and horizontal time slices for multiple burial scenarios containing domestic pig carcasses that represent real-life examples for Years 2 and 3 of a three-year sequential monitoring period post-burial;
- compare imagery using both the 500 MHz and 250 MHz dominant frequency antennae to evaluate which antenna provides clearer target reflections, or increased detection, of grave features, such as the decomposing/decomposed pig remains, disturbed soil, and items added to the grave for the different scenarios over time;
- and determine how a common soil type in Florida, a Spodosol, and increased soil moisture from rainfall affect the detection of multiple grave scenarios over time.

2. Materials and methods

2.1. Research site and data collection

As noted in the previous section, this project is an extended study with the results of Year 1 previously published. Additional information concerning the research site and the construction of the graves can be found in Schultz and Martin (2012). The research site was an open and flat field within a wooded area of the Deep Foundations and Geotechnical Research Site of the University of Central Florida campus located in Orlando, Orange County, Florida (Fig. 1). The climate in this area of Florida is a subtropical humid environment, and the field surface consisted of grass that was mowed periodically for data collection purposes. Six euthanized pig carcasses (approximately 41 kg to 45.5 kg) were used as proxies for human bodies and buried at a shallow (~0.5 m) or deep (~1.0 m) depth within 1 m by 1 m hand-dug graves. The carcasses were placed in the center of the grave with the snout towards the north wall of the grave and the back (dorsal aspect) towards the east wall of the grave. Construction of the graves was completed by placing the excavated matrix in the grave and then trampling down the matrix to refill the graves. Leftover matrix was removed from the research grid. It is important to note that the two control graves without pig carcasses were also hand-dug and refilled identically to the pig graves. A permanent grid (11 m by 22 m) was constructed containing the two control graves and six pig graves within two rows (Fig. 2 and Table 1). The graves simulated common forensic scenarios involving buried bodies (Fig. 3 and Table 1) (see Schultz and Martin, 2012):

1. a shallow, naked pig carcass with nothing added to the grave (1A);
2. a deep, naked pig carcass with nothing added to the grave (1B);
3. a deep pig carcass with 0.07 m^3 of granite river rocks placed over the carcass (1C);
4. a deep pig carcass wrapped in all-purpose, impermeable vinyl tarpaulin (1D);
5. a shallow control grave without a pig carcass (2A);
6. a deep control grave without a pig carcass (2B);
7. a deep pig carcass with 68.04 kg of calcitic and dolomite lime placed over the carcass (2C);
8. and a deep pig carcass wrapped in a 2–3 mm thick cotton blanket (2D).

The soil within the research grid are Spodosols classified as a Pomella series (Doolittle and Schellentrager, 1989). These are sandy soils containing a spodic horizon, which is a dark horizon made up of organic matter, as well as an accumulation of aluminum oxides that may contain iron (Brady and Weil, 2002). While the soil profile is described in Schultz and Martin (2012), it is important to note that there was a slight variation of the soil profile throughout the research grid (Fig. 3). Overall, the depth to the spodic horizon generally ranged from ~60 cm to ~85 cm for most graves within the research grid. Furthermore, the most notable change with the soil profile after constructing the graves was the disruption of the spodic horizon, visible as a gap in the detected horizon on the 2D reflection profiles, within the grave shafts.