Journal of Applied Geophysics 135 (2016) 232–242

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Geophysical and botanical monitoring of simulated graves in a tropical rainforest, Colombia, South America

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ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form 29 September 2016
Accepted 2 October 2016
Available online 05 October 2016

Keywords:
Forensic geophysics
Clandestine grave
Ground penetrating radar
Magnetic susceptibilty
Conductivity
Resistivity

ABSTRACT

In most Latin American countries there are significant numbers of missing people and forced disappearances, currently ~80,000 only in Colombia. Successful detection of shallow buried human remains by forensic search teams is currently difficult in varying terrain and climates. Within this research we built four simulated clandestine burial styles in tropical rainforests, as this is a common scenario and depositional environment encountered in Latin America, to gain knowledge of optimum forensic geophysics detection techniques. The results of geophysically monitoring these burials using ground penetrating radar, magnetic susceptibility, bulk ground conductivity and electrical resistivity are presented from one to forty three weeks post-burial. Radar survey results with both the 250 MHz and 500 MHz frequency antennae showed good detection of modern simulated burials on 2D profiles and horizontal time slices but poor detection on the other simulated graves. Magnetic susceptibility, bulk ground conductivity and electrical resistivity results were generally poor at detecting the simulated targets. Observations of botanical variations on the test site show rapid regrowth of *Malvaceae* and *Petiveria alliacea* vegetation over all burials that are common in these forests, which can make detection more difficult.

1. Introduction

In many South American countries there are significant numbers of people missing and those who have been subjected to forced disappearances (www.desaparecidos.org). For example, in Colombia there are currently ~80,000 people missing, of which it has been estimated that ~24,000 are forced disappearances (www.medicinalegal.gov.co). Discovered clandestine graves of victims have been reported to be isolated (Solla and Işcan, 2001; Işcan et al., 2005), co-mingled and mass burials (Varas and Leiva, 2012), and in a variety of burial styles, depths below ground level and depositional environments (Solla and Işcan, 2001; Işcan et al., 2005; Varas and Leiva, 2012). Such numbers of victims has been reported elsewhere globally, for example, in 19th Century Irish mass burials (Ruffell et al., 2009), USA race riot victims (Witten et al., 2000), Spanish Civil War mass burials (Ríoz et al., 2010; Ríoz et al., 2012; Fernandez-Alvarez et al., 2016), World War Two burials (Fiedler et al., 2009, Ossokoswki et al., 2013), in post-WW2 Polish repression mass burials (Szleszkowski et al., 2014), the Northern Ireland 'Troubles' mostly isolated burials (www.iclvr.ie), the 1990s Balkan wars mass burials (Brown, 2006), and sadly in active civil wars with both isolated and mass burials (www.syriahr.com).

Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere (Pringle et al., 2012a; Parker et al., 2010), with best practice suggesting a phased approach, moving from large-scale remote sensing methods (Kalacska et al., 2009) down to initial ground reconnaissance (Ruffell and McKinley, 2014) and control studies before full searches are initiated (Harrison and Donnelly, 2009; Larson et al., 2011). These full searches have also involved a variety of methods, including forensic geomorphology (Ruffell and McKinley, 2014), forensic botany (Aquila et al., 2014) and entomology (Amendt et al., 2007), scent-trained search dogs (Lasseter et al., 2003;), physical probing (Ruffell, 2005a;), thanatochemistry (Vass et al., 2008;) and near-surface geophysics (France et al., 1992; Nobes, 2000; Ruffell, 2005b; Pringle and Jervis, 2010a; Novo et al., 2011).

Recent forensic geophysical research using simulated clandestine graves have found optimal detection methods and configurations are highly variable, depending upon a host of factors, the most important deemed to be time since burial, burial style, local soil type, vegetation and climate (France et al., 1992; Pringle et al., 2008; Jervis et al., 2009; Schultz and Martin, 2011; Pringle et al., 2012a; Schultz and Martin, 2012; Pringle et al., 2012b; Ruffell et al., 2014; Pringle et al., 2015a, 2015b; Pringle et al., 2016). As reported in Molina et al. (2015) and Molina et al. (2016), there has been little research to-date in South America using controlled test experiments to determine optimal

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http://dx.doi.org/10.1016/j.jappgeo.2016.10.002
0926-9851/

geophysical search technique(s) and equipment configuration(s). This is critical as South America will have different burial conditions to other controlled work, including soil types, climate and vegetation, which will affect geophysical detection.

Ground penetrating radar (GPR) is one of the most popularly-used geophysical equipment in the search for evidence buried in the ground by judicial authorities technical and police worldwide (Pringle et al., 2012a). GPR has been successful in numerous controlled experiments (France et al., 1992; Pringle et al., 2008; Jervis et al., 2009; Schultz and Martin, 2011; Pringle et al., 2012a; Schultz and Martin, 2012; Pringle et al., 2012b; Ruffell et al., 2014; Molina et al., 2015; Pringle et al., 2016;), and criminal cases (Ruffell, 2005b; Pringle et al., 2008; Ruffell et al., 2014), but it has been suggested that in some cases it has been used based on past successes and without consideration of local depositional conditions (Jervis et al., 2009). GPR has not been successful in locating graves in all conditions (Ríoz et al., 2010), in saline soils (Pringle et al., 2012b) rich in wet clay (Pringle and Jervis, 2010a) or drawbacks in its implementation (Pringle et al., 2012c).

Magnetic susceptibility (ms) is an emerging forensic field technique. It works by passively measuring a sample or sample area in SI dimensionless units, the causes of which are complex (see Pringle et al., 2015b for background). The ms reading usually comprises a bulk value of the material present within the measured area; thus values are usually high when multiple magnetic minerals such as magnetite and ferromagnetic materials made by man, amongst others are present (Miller, 1996). The use of magnetic susceptibility for forensic purposes has been successful both in several simulated environments and with different buried targets (Milsom and Eriksen, 2011; Linford, 2004), Pringle et al., 2015b), to differentiate soil samples (Guedes et al., 2013), and to identify illegal dumped waste (Manrong et al., 2009), but is seldom used in forensic investigations.

Bulk ground conductivity Electro-Magnetic (EM) surveys are a quick active field technique to measure relative changes in ground conductivity between targets and background readings. The Slingram method works by inducing a primary electro-magnetic field in a transmitter coil and measuring any secondary ones produced from any conductive objects in a receiver coil, the instrument being sequentially moved between sample positions with the coils at a constant separation (see Reynolds, 2011; Thiesson et al., 2011 for background). Both EM fields can be measured, with targets detected as relatively high/low anomalies, compared to background values, depending if ferrous or non-ferrous materials are present (Pringle et al., 2012a). Although more widely used in environmental forensics (Reynolds, 2011) it has had mixed results in criminal searches (Nobes, 2000; Pringle et al., 2012a; Bigman, 2012), in controlled studies depositional environment is deemed very important, it was found to be problematic in urban environments (Pringle et al., 2008; Dick et al., 2015). Decompositional fluids have also been found to be temporally variable but could be detectable with this method (Pringle et al., 2015a). Electrical resistivity is the reciprocal of conductivity and has been widely used in environmental forensics (Reynolds, 2011), detection of clandestine graves (Pringle and Jervis, 2010a), ancient burials (Dick et al., 2015;) and in controlled experiments (France et al., 1992; Pringle et al., 2008; Jervis et al., 2009; Pringle et al., 2012b; Pringle et al., 2012c;); however major depositional environment variables can affect target detection, including soil moisture (Jervis and Pringle, 2014;) soil type (Pringle et al., 2012a;) and salinity (Pringle et al., 2012b).

The Molina et al. (2015) and Molina et al. (2016) papers report on geophysical monitoring results of simulated clandestine and historic burials in a rural depositional environment in Colombia. This paper provides a critical comparison of this study, also using simulated clandestine graves but in a tropical rainforest depositional environment in Colombia that is sadly an all too common burial discovery scenario in Latin America. The research aims were: *firstly*, to assess whether radar, surface magnetic susceptibility, bulk ground conductivity and electrical resistivity methods could detect the simulated graves, *secondly*, to determine if there was an optimal time for surveying post-burial and *thirdly*, to compare results to other studies, particularly other Latin American control burial studies.

2. Material and methods

2.1. Study site

The research site is located in a semi-rural area of the Experimental Farm Barcelona of the Los Llanos University, Colombia ~100 km east of the capital Bogota (Fig. 1a). The study site is in a semi-rural tropical densely vegetated environment that is typical of those encountered away from coastal areas in Colombia (Fig. 1b). The site is situated ~391 m above sea level. Geologically the site is underlain by alluvial rocks of Holocene age. The local soil type is a 50 cm thick sandy entisol composed of light brown alluvial sediments of fine grain size and isolated rock fragments.

The nearby University meteorological weather observation station was situated ~0.5 km from the test site, which continually recorded rainfall and temperature data. The site has an average temperature of 26 °C and annual rainfall averages of 3000 mm per year, with a dry period from December to March and a rainy period from April to November (IGAC, 2004). Climate data over the study period is shown in Fig. 2.

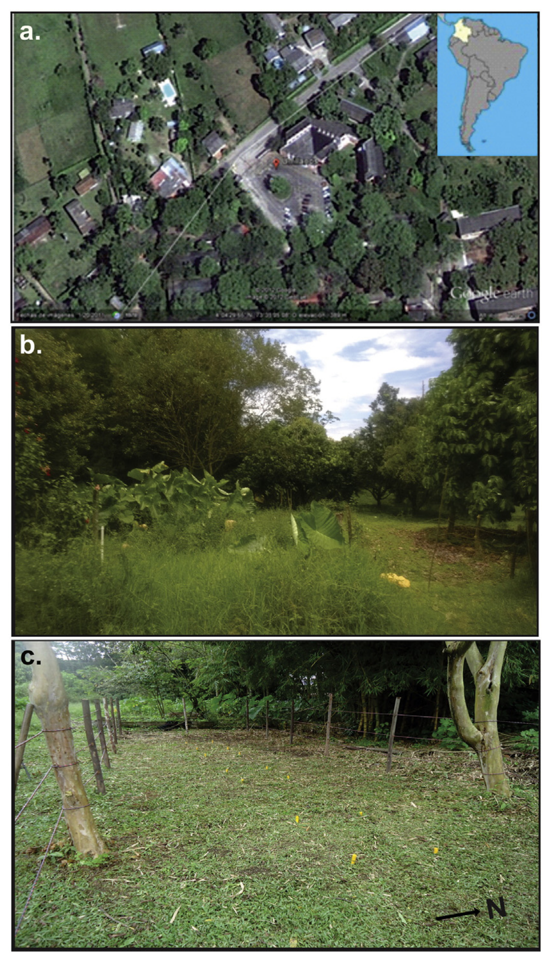

Fig. 1. (a) Aerial photograph at the University of Los Llanos, Colombia with location (inset). (b) General study site photograph of Experimental Farm Barcelona. (c) Fenced test site with orange stakes denoting grave position.