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Geophysical monitoring of simulated graves with resistivity, magnetic susceptibility, conductivity and GPR in Colombia, South America

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ABSTRACT

In most Latin American countries there are significant numbers of both missing people and forced disappearances, ~71,000 Colombia alone. Successful detection of buried human remains by forensic search teams can be difficult in varying terrain and climates. Three clandestine burials were simulated at two different depths commonly encountered in Latin America. In order to gain critical knowledge of optimum geophysical detection techniques, burials were monitored using: ground penetrating radar, magnetic susceptibility, bulk ground conductivity and electrical resistivity up to twenty-two months post-burial. Radar survey results showed good detection of modern 1/2 clothed pig cadavers throughout the survey period on 2D profiles, with the 250 MHz antennae judged optimal. Both skeletonised and decapitated and burnt human remains were poorly imaged on 2D profiles with loss in signal continuity observed throughout the survey period. Horizontal radar time slices showed good anomalies observed over targets, but these decreased in amplitude over the post-burial time. These were judged due to detecting disturbed grave soil rather than just the buried targets. Magnetic susceptibility and electrical resistivity were successful at target detection in contrast to bulk ground conductivity surveys which were unsuccessful. Deeper burials were all harder to image than shallower ones. Forensic geophysical surveys should be undertaken at suspected burial sites.

1. Introduction

In many South American countries there are significant numbers of people both missing and those who have been subjected to forced disappearances [1]. In Colombia there are currently ~71,000 people missing, of whom it has been estimated that ~21,000 are forced disappearances [2]. Clandestine grave victims discovered in South America have been reported to be isolated [3,4], co-mingled and mass burial styles [5], at different burial depths below ground level and in a variety of depositional environments [3–5]. Other relevant published case studies of atrocity victims have been reported, for example, in 19th Century Irish mass burials [6], USA race riot victims [7], Spanish Civil War mass burials [8–10], World War Two burials [11,12], in post-WW2 Polish repression mass burials [13], the Northern Ireland 'Troubles' albeit mostly isolated burials [14], the 1990s Balkan wars mass burials [15,16], and sadly in current civil wars with both isolated and mass burials [17].

Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere [18,19], with best practice suggesting a phased approach, moving from large-scale remote sensing methods [20] to initial site reconnaissance [21] and control studies before full ground searches are initiated [22,23]. These full searches have also involved a variety of methods, including forensic geomorphology [21], forensic botany [24,25] and entomology [26,27], scent-trained search dogs [28,29], physical probing [30–32], thanatochemistry from soil samples [33–35] and near-surface geophysical investigations [36–43].

Recent forensic geophysical research has used simulated clandestine graves to work out optimal detection methods and equipment configurations. Results have been found to be highly variable, depending upon a host of factors, the most important determined are time since burial, burial style, local soil type, vegetation and climate [36,44–56]. There has been little research in South America using controlled test experiments, with [57]

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reporting ground penetrating radar (GPR) results from monitoring controlled burials over a period of nine months. This paper presents results of GPR, surface magnetic susceptibility, bulk ground conductivity and electrical resistivity datasets from ten months to twenty-two months post-burial. Brief discussions on these techniques in forensic searches are now given.

GPR is one of the most popularly employed pieces of geophysical equipment being used in searches by professional search teams and practitioners [18]. GPR has been successful in detecting forensic targets in numerous controlled experiments [36,44–55,57] and criminal cases [40,41,46,55]. However it may not be optimal in all depositional conditions [8,47,48], which include saline soils [51], wet clay [42] or burial style [53].

Magnetic susceptibility is an emerging technique and measures materials that are susceptible to being magnetised, with measurements generating an AC magnetic field of low intensity, making both positive and negative susceptibilities [54]. This reading usually increases by combining magnetic minerals such as magnetite and ferromagnetic materials with manmade material [58]. The use of magnetic susceptibility for forensic purposes has been successful in buried target detection [59] in simulated environments [46,54,60], and to differentiate soil samples [61,62].

Bulk ground conductivity is a relatively quick field technique to measure relative changes in ground conductivity between targets and background readings by inducing an electro-magnetic current [18,63]. Although more widely used in environmental forensics [18,63], it has had mixed results in criminal searches [18,38,64,65]; controlled studies have determined that the depositional environments have been deemed to be very important, with searches in urban environments found to be particularly problematic for successful target detection [61,66]. Decompositional fluids have also been found to be detectable with this method but are temporally variable [56]. Electrical resistivity is the reciprocal of conductivity and has been widely used in environmental forensics [18,63], detection of clandestine graves [42], ancient burials [66–68] and in controlled experiments [36,39,46,48,51,53], however, major depositional environment variables can affect target detection, including soil moisture [69,70], soil type [18,70] and salinity [51].

This paper presents results of GPR, surface magnetic susceptibility, bulk ground conductivity and electrical resistivity surveys over controlled burials in Colombia, South America in a rural depositional environment, from ten months to twenty-two months post-burial. GPR results from zero to nine months post-burial were reported in [57]. The research aims were: *firstly*, to assess whether these 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.

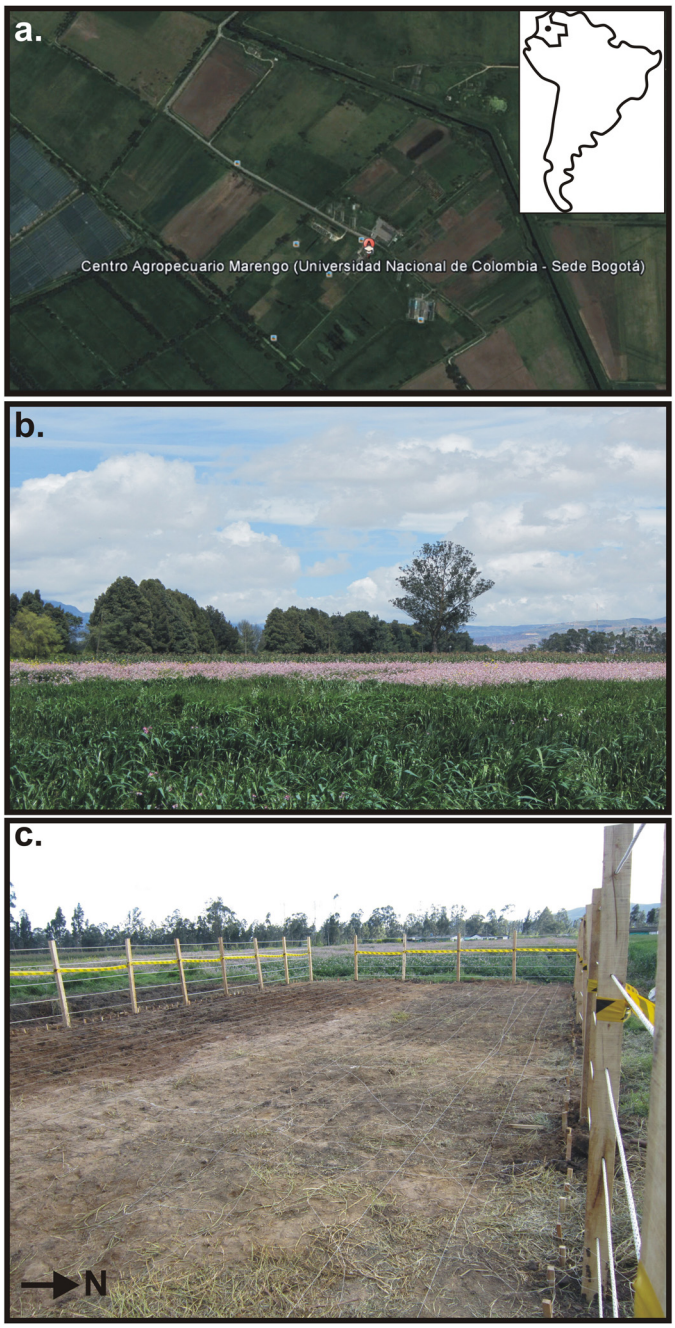

Fig. 1. (a) Aerial photograph of the Marengo Agricultural Center of the National University of Colombia with location (inset). (b) General site photograph. (c) Fenced test site with cleared vegetation photograph. Modified from [57].

2. Materials and methods

2.1. Study site

The experimental site is located in a rural area of the Marengo Agricultural Center of the National University of Colombia ~14 km north of the capital Bogota (Fig. 1a). The study site was in a rural neo-tropical environment with dense vegetation that was cleared, typical of those encountered away from coastal areas in Colombia (Fig. 1b). The site was situated ~2500 m above sea level. Geologically the site is underlain by fluvial-lacustrine deposits of the Sabana Formation of Middle and Late Pleistocene age. The local soil type is a red clay-rich andisol loam, formed from lacustrine sediments and volcanic ash (Fig. 1c), with an organic topsoil horizon ~5 cm to ~60 cm thick.

The Tibaitatá Centre for Agricultural research had a meteorological weather observation station ~1 km from the test site, which continually recorded rainfall and temperature data. The site was observed to have an average temperature of 14 °C and annual rainfall rates of between 500 mm and 1000 mm per year [71] with little seasonal variation as would be expected in this latitude.

2.2. Simulated graves

It was decided to use freshly dispatched domestic pig cadavers to simulate clandestine graves of murder victims as they are commonly used in such monitoring experiments [45–50], comprising similar chemical compositions, body size, tissue:body fat ratios and skin/hair types to humans [53]. The National Charter for the Protection of Animals (1989) covers biomedical use of animals in Colombia (Ministry of Health, 1993). For this study it was also