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Abstract: In most Latin American countries there are significant numbers of missing people and forced disappearances, 68,000 alone currently in Colombia. Successful detection of shallow buried human remains by forensic search teams is difficult in varying terrain and climates. This research has created three simulated clandestine burial styles at two different depths commonly encountered in Latin America to gain knowledge of optimum forensic geophysics detection techniques. Repeated monitoring of the graves post-burial was undertaken by ground penetrating radar. Radar survey 2D profile results show reasonable detection of ½ clothed pig cadavers up to 19 weeks of burial, with decreasing confidence after this time. Simulated burials using skeletonised human remains were not able to be imaged after 19 weeks of burial, with beheaded and burnt human remains not being able to be detected throughout the survey period. Horizontal radar time slices showed good early results up to 19 weeks of burial as more area was covered and bi-directional surveys were collected, but these decreased in amplitude over time. Deeper burials were all harder to image than shallower ones. Analysis of excavated soil found soil moisture content almost double compared to those reported from temperate climate studies. Vegetation variations over the simulated graves were also noted which would provide promising indicators for grave detection.

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*Title Page (with authors and addresses)

Preliminary results of sequential monitoring of simulated clandestine graves in Colombia, South America, using ground penetrating radar and botany

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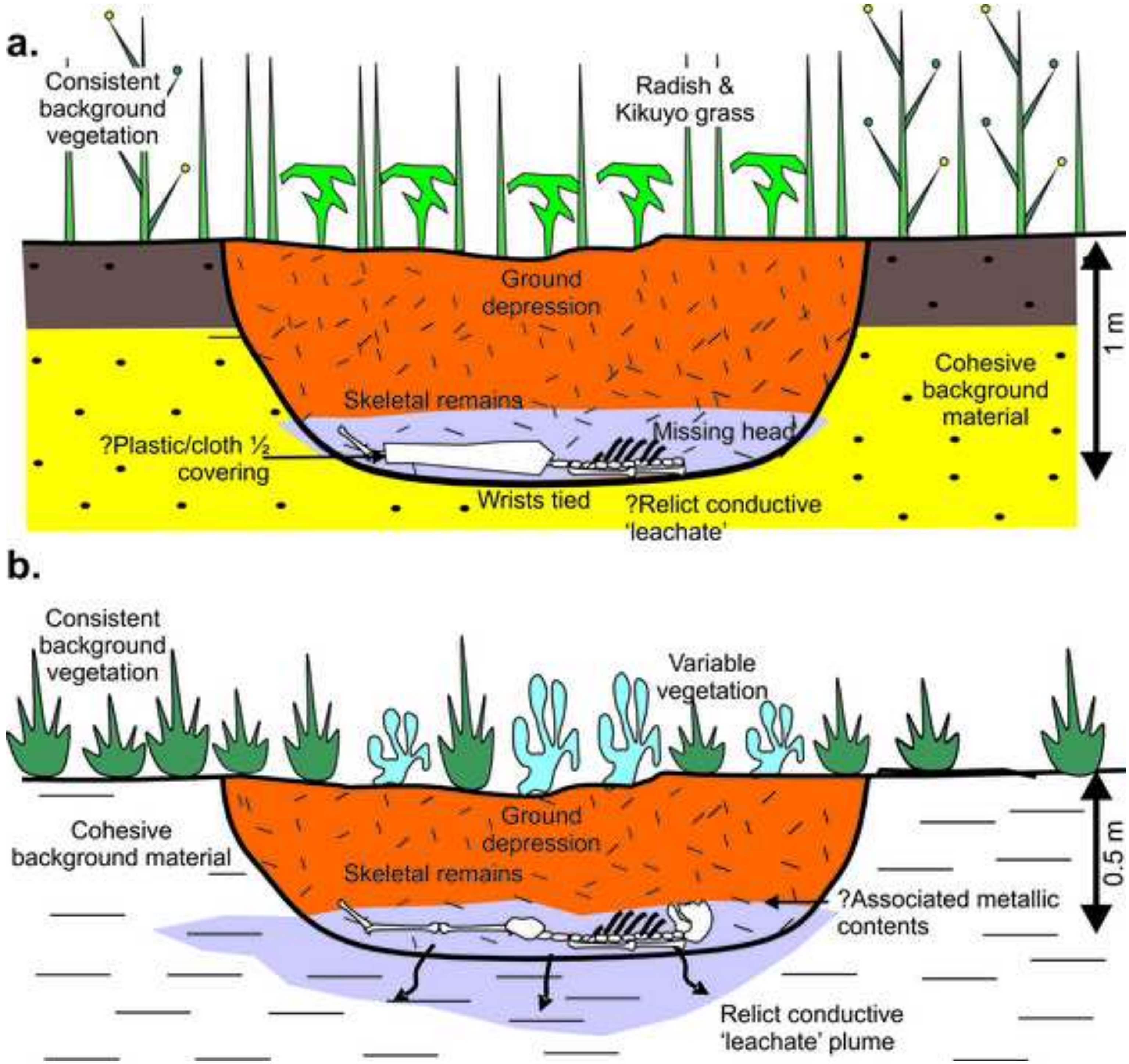
Graphical Abstract (for review)



***Highlights (for review)**

- Thousands of people currently missing in Latin America that may be buried
- This study created simulated clandestine graves and monitored for 48 weeks
- GPR 2D profiles imaged ½ clothed pig cadaver up to 19 weeks, poor thereafter
- GPR time-slices good for all up to 19 weeks; progressively poorer thereafter
- Botanical secondary succession species over graves observed and identified

Abstract

In most Latin American countries there are significant numbers of missing people and forced disappearances, 68,000 alone currently in Colombia. Successful detection of shallow buried human remains by forensic search teams is difficult in varying terrain and climates. This research has created three simulated clandestine burial styles at two different depths commonly encountered in Latin America to gain knowledge of optimum forensic geophysics detection techniques. Repeated monitoring of the graves post-burial was undertaken by ground penetrating radar. Radar survey 2D profile results show reasonable detection of ½ clothed pig cadavers up to 19 weeks of burial, with decreasing confidence after this time. Simulated burials using skeletonised human remains were not able to be imaged after 19 weeks of burial, with beheaded and burnt human remains not being able to be detected throughout the survey period. Horizontal radar time slices showed good early results up to 19 weeks of burial as more area was covered and bi-directional surveys were collected, but these decreased in amplitude over time. Deeper burials were all harder to image than shallower ones. Analysis of excavated soil found soil moisture content almost double compared to those reported from temperate climate studies. Vegetation variations over the simulated graves were also noted which would provide promising indicators for grave detection.

1. Introduction

In many South American countries there are significant numbers of people missing and those who have been subjected to forced disappearances [1]. For example, in Colombia there are currently ~68,000 people missing, of which it has been estimated that ~20,800 are forced disappearances [2]. Discovered clandestine graves of victims have been reported to be isolated [3,4] , co-mingled and mass burials [5], and in a variety of burial styles, depths below ground level and depositional environments [3-5]. Such numbers of victims has been reported elsewhere globally, for example, in 19th Century Irish mass burials [6], USA race riot victims [7], Spanish Civil War mass burials [8,9], World War Two burials [10,11], in post-WW2 Polish repression mass burials [12], the Northern Ireland 'Troubles' mostly isolated burials [13], the 1990s Balkan wars mass burials [14,15], and sadly in active civil wars with both isolated and mass burials [16].

Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere [17,18], with best practice suggesting a phased approach, moving from large-scale remote sensing methods [19] down to initial ground reconnaissance [20] and control studies before full searches are initiated [21,22). These full searches have also involved a variety of methods, including forensic geomorphology [20], forensic botany [23,24] and entomology [25, 26], scent-trained search dogs [27,28], physical probing [29-31], thanatochemistry [32-34] and near-surface geophysics [35-42].

Recent 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 [35,43-54].

Although forensic research has been undertaken in the fields of forensic entomology [55,56], anthropology [57] and osteology [58] in Latin America, there has been limited geophysical research to assist forensic search teams with the successful detection of both isolated and mass burials of human victims, although a pilot study has shown promise [59]. The paper aims are to *firstly* detail the several simulated clandestine graves that were established in the test site; these were deliberately created to be those typically encountered by forensic search teams in rural Latin America and specifically Colombia. *Secondly* the results of GPR sequential monitoring over the simulated clandestine graves over nine months will be detailed and compared to other studies. *Thirdly* and finally the results of simple 'grave' soil moisture content analysis and surface botanical variations observed will also be documented.

2. Material and Methods

2.1 Study site

The chosen controlled test site was situated in land owned by the National University of Colombia ~14 km north of the capital city of Bogotá (Fig. 1a). The study site was in a rural neo-tropical environment that had cleared dense vegetation that was typical of those encountered away from coastal areas in Colombia (Fig. 1b). The site was situated ~2,500 m above sea level. Geologically the site is underlain by fluvio-lacustrine terrace of the Sabana Formation of Middle and Late Pleistocene age. The local soil type is an andisol from lacustrine sediments and volcanic ash (Fig. 1c), with an organic topsoil horizon - ~5 cm to 60 cm thick and a red clay-rich loam beneath.

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 ºC and annual rainfall rates of between 500 mm – 1,000 mm per year [60 www.marengo.unal.edu.co].

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 [44-50,51,52,54], comprising similar chemical compositions, body size, tissue:body fat ratios and skin/hair types to humans [61]. Human remains were also able to be used in Colombia in this research, to represent clandestine graves which had been emplaced long enough for human remains to be skeletonised. The time frame that this would occur would typically be months to years post-burial, depending on local climate, soil type and other variables described elsewhere [17].

Resolution 8430 of the Ministry of Health Act (1993) and the National Charter for the Protection of Animals (1989) covered biomedical research for humans and animals respectively in Colombia (Ministry of Health, 1993). The same resolution provided recommendation on the dignity of human remains which was followed; human remains for this project were donated by the Colombian Association of Forensic Anthropology (ACAF) after a historical archaeological rescue. Best practice was also followed on the use of animals, namely non-conscious, minimal numbers and also minimizing any animal pain and discomfort [62]. The National University of Colombia Faculty of Science ethics committee had also approved the project.

Eight simulated clandestine graves were excavated on 19th June 2013. For each grave, the overlying vegetation was removed and *c.* 2 m x 2 m holes were dug in a regular pattern (Fig. 2a) as other researchers have undertaken [46-52]. Soil from both the top and main andisol soil were taken from all graves for analysis. Four graves were dug to ~0.8 m below ground level (bgl) and four dug to ~1.2 m bgl respectively, these depths have been commonly encountered in discovered clandestine graves in Colombia (see Table 1 for details). Note these were deeper than the average 0.5 m burial depths bgl reported in the U.S. [63] and UK [64]. Two simulated graves (Pig1/2) had freshly dispatched (electrocuted and bled <6 h before burial) ~70 kg domestic pig carcasses emplaced in the centre ,with them both having their lower half wrapped with cloth and the other wrapped with plastic as this was a common burial scenario in Colombia [65]. A further two graves (Cont1/2) were empty acting as control and were refilled by the excavated soil. The next two graves (Skel1/2) contained skeletonised human remains together with various small arms shell casings and the final two graves (Burnt1/2) contained beheaded and burnt skeletonised human remains as these burial style scenarios are also common in Colombia [66]. All graves with contents were then refilled with excavated soil back to ground level.

2.3 Ground penetrating radar data collection and processing

Repeat GPR survey datasets were collected within the survey area (Fig. 2a) at *c.* 1-monthly intervals after burial (Table 2). Most published forensic case studies using GPR use medium (200-500 MHz) dominant frequency antennae (e.g. [6,37,42]) and seems to be judged optimal by others monitoring simulated clandestine burials (e.g. [44,49,52]), thus 250 MHz dominant frequency shielded bistatic antennae were used by MALA acquisition equipment in this study. The 20 m x 10 m survey grid was GPR surveyed on both north-south and east-west oriented, 0.25 m spaced, parallel survey lines with 0.02 m radar trace spacings throughout using a 30 ns time window, which should penetrate to a depth of 1.60 m bgl.

Once the 2D GPR profiles were acquired by the RadExplorer™ data collection software, they were downloaded and imported into RADAN v6.6 data processing software. For each profile, standard sequential processing steps were undertaken to optimize image quality, namely; (i) DC removal; (ii) time-zero adjustment to make all traces consistent, this adjustment eliminates the time zero; (iii) 2D spatial filtering; (iv) bandpass filtering to reduce noise; (v) amplitude correction to boost deeper reflection amplitudes, and; (vi) deconvolution. Once completed and with all GPR 2D profiles having their known spatial position added, horizontal time-slices of the GPR data were generated for each repeat GPR survey.

2.4 Vegetation data collection

Botanical plants that grew on the graves during the first 3 months after burial were collected, in order to identify following the protocol of the National Herbarium of the Universidad Nacional de Colombia [67].

3. Results

3.1. Ground penetrating radar

Selected GPR 250 MHz 2D profiles acquired through the survey period are shown in Figure 3 (see Fig. 2a for respective profile locations). The simulated modern clandestine grave with pigs as murder victim analogues at both 0.8 m bgl (Pig1) and 1.2 m bgl (Pig2) were generally imaged throughout the survey period as good to poor ½ hyperbolic reflection events but became progressively less clearly defined after 38 weeks of burial (Fig. 3). The simulated empty control graves were poorly imaged as areas of loss of signal continuity (Fig. 3). The simulated historic clandestine graves with skeletonized remains at both 0.8 m bgl (Skel1) and 1.2 m bgl (Skel2showed low amplitude ½ hyperbolic reflection events up to 19 weeks post-burial, but was not able to be imaged after this time (Fig.3). The simulated historic clandestine graves with beheaded and burnt skeletonized remains were not able to be imaged throughout the survey period, with perhaps some loss of radar signal continuity at this location on each respective 2D profile (Fig. 3).

The GPR 250 MHz horizontal time slices generated from the 250 MHz 2D profiles generally showed surprisingly good results for the respective four, fifteen and nineteen weeks after burial time slices (Fig. 4a-c), with discrete square-shaped anomalies of high radar amplitudes present in all time slices that could be mostly correlated to all the respective simulated clandestine burial positions. However, these target locations had progressively reducing radar signal amplitudes for the successive twenty-two, thirty-three and thirty-eight week datasets (Fig. 4d-f), with only the shallow simulated clandestine burials, and in particular the simulated modern burial with ½ clothed pig cadaver, being clearly identifiable throughout the survey period (Fig. 4).

3.2. Grave soil moisture content

The excavated soil from the simulated clandestine graves were analysed following standard procedures [47] and found that the top soil moisture content varied between 0.426 – 0.476 (0.438 average) with the main 'grave' soil varied between 0.558 – 0.717 (0.643 av.). These soil moisture values were almost double those reported by authors in more temperate climate studies (e.g. [47]).

3.3. Forensic botany

After four weeks of burial, surface botanical vegetation was observed to be predominantly kikuyo grass between the simulated clandestine graves (Fig. 5a). After eight weeks of burial, *Brassicaceae* (wild radish) predominates over the simulated clandestine graves (Fig. 5b). After sixteen weeks of burial, lush *Raphanus raphanistrum* vegetation was observed over all graves (Fig. 5c) with kikuyu grass between the graves (Fig. 5d).

4. Discussion

This is the first published forensic geophysical research conducted over simulated clandestine graves in Latin America and thus has allowed some basic questions posed by forensic search teams to be addressed and indeed compared to other forensic research and case studies.

Firstly detail the several simulated clandestine grave that were established in a test site that were typically encountered by forensic search teams in rural Latin America and specifically Colombia. From this and other studies (e.g. [3-5]), it has been documented that murder victims in clandestine graves in Latin America are often ½ clothed. Other authors have noted that victims in discovered clandestine graves were either naked or fully clothed/wrapped in plastic (e.g. see [63,64]). Not having the body wrapped may allow greater access by insects and thus forensic entomology may prove more useful in Latin America as other researchers have started to document (e.g. 55-57]). Having murder victim's remains beheaded and burnt, whilst common in Latin America, is not common elsewhere, but nonetheless is important to be included for comparative purposes for forensic search teams. This study also used human remains which is still relatively unusual in geophysical monitoring of simulated grave control studies.

Secondly the results of GPR sequential monitoring over these simulated clandestine graves over 9 months will be detailed and compared to other studies.

For the 2D profiles, *firstly the simulated modern clandestine graves with pigs* as murder victim analogues generally showed variable gpr survey results, with subtle half hyperbolic reflection events which had progressively less signal amplitudes for the longer post-burial survey dates (see Pig 1/2 in Fig. 3). This was in contrast to other simulated burial studies in similar depositional environments and soil types that evidenced clothing/wrapping generally provides a good radar reflective surface and hence good quality GPR hyperbolic reflectors could be obtained (e.g. see [51,52]. This could be due to the plastic covering not being fully over the pig unlike other studies (e.g. [51,52]). However, bulk ground electrical resistivity techniques may be useful for forensic search teams to employ in these scenarios, as decomposition fluids are highly conductive and will not be trapped within victim clothes so will be a useful geophysical target (see [52]). Note however that the conductivity of decompositional fluids has been shown to be temporally highly variable and it is currently thought that surveys should be optimally conducted one to two years post-burial [69]. *Secondly the simulated empty control graves* were not able to be imaged throughout the survey period, although there was a loss of signal continuity observed at this location throughout the survey period (see Cont1/2 in Fig. 3). This agrees with other studies (see, e.g. [51,52]) where the soil disturbance present in control graves becomes progressively harder to image post-emplacement. *Thirdly the simulated historic clandestine graves with skeletonised remains* were poorly imaged in gpr surveys in 2D profiles up to nineteen weeks post-burial, but were not able to be identified after this time period (see Skel1/2 in Fig. 3). It was suggested that the small size of the skeletonized remains, the depth of burial and relatively small contrast of dielectric permittivity between the human remains and the surrounding soil which make such target locations difficult to identify using this technique. This has also been observed in historic unmarked human burials in graveyards and cemeteries (see [70-71]). However it was felt important to simulate as it was a common burial scenario in Latin America and there are no published simulated burial geophysical monitoring studies using human remains. Finally the *simulated historic clandestine graves with beheaded and burnt human remains* were not able to be imaged by gpr surveys in 2D profiles throughout the survey period and were worse than the purely skeletonised remains (see burnt1/2 in Fig. 3). This was thought due to the smallest geophysical target, the depth of burial and relatively small contrast of dielectric permittivity between the human remains and the surrounding soil. It is suggested that perhaps magnetic geophysical methods may be useful to detect such burnt human remains as [68] successfully located Anglo-Saxon remains using this method and [72] shows magnetic susceptibility was a good detection technique to detect various simulated forensic targets although this has not been undertaken in this study.

For the horizontal time slice datasets, these were surprisingly good up to nineteen weeks post-burial, with all burial positions being able to be identified in contrast to the 2D profile results (Figs. 3/4). These good early monitoring time slice results could be argued to be due to gpr imaging the replaced disturbed soil in the simulated graves rather than the burial targets themselves as [51] observed in a similar soil type. However, there the imaged anomalies in subsequent time slice datasets were generally poor, with only the shallow burial with the modern simulated clandestine grave with ½ clothed pig cadaver being reasonably well defined (Fig. 4d-f). These latter results were most likely due to soil compaction reducing the dielectric permittivity contrast of the grave soils versus the background soil environment, as well as the relatively small physical size of the buried simulated targets making them more difficult to image. However note the importance of collecting 2D GPR profiles of suspected burial sites in both north-south and east-west orientations and the rural nature of the controlled test site environment that made the time slices image the simulated targets a lot better than simply analyzing individual 2D GPR profiles alone. This would also be important in geophysical surveys to locate unmarked burials in graveyards, burial grounds and cemeteries if time allowed as most radar surveys only collect 2D profiles in one orientation (e.g. see [70]).

Thirdly the results of simple 'grave' soil moisture content analysis and surface botanical variations observed will be documented. Simple analysis of excavated 'grave' soil indicated high (>50%) soil moisture content that was around double from that reported from temperate climate studies (e.g. [47]). This may have important implications for the rate of decomposition, it has been widely reported that decomposition rates increase with temperature (e.g. see [73]) but not that of soil moisture content, this may prove of interest for further research. Rainfall rate variation between control test sites has shown to be important variable of measured conductivity values of decompositional fluids (see [69]). The observed variations in surface botanical vegetation of Kikuyu grass, *Brassicaceae* and *Raphanus raphanistrum* (see Fig. 5) indicated the secondary succession where primary vegetation had been replaced by the burials. These secondary vegetation succession variations have been observed in other environments, for example, *Imperata* grasslands in South-East Asia [74], grasses and *Asphodel* herbaceous perennials in semi-arid Mediterranean countries [75], and *Urtica* Nettle annuals and early flowering perennials in Western European countries [76]. These will be important potential investigatory sites for forensic search teams to identify in this depositional environment, especially where the post-burial date is short and less than 9 months like this study.

A schematic figure (Fig. 6) summarises the typical clandestine burial scenario encountered in Latin America and contrasts this with those shown in temperate northern hemisphere climates for the readers information.

5. Conclusions

Simulated clandestine graves commonly encountered in Latin America have been created on a control test sites outside of Bogota, Colombia. These have included using ½ clothed pig cadavers as 'fresh' graves, historic graves using donated skeletonised human remains and beheaded and burnt donated skeletonised human remains.

Sequential monitoring of the simulated clandestine graves over 9 months by 250 MHz GPR on 2D profiles showed that the pig cadavers could be imaged up to 7 months after burial, but the skeletonised remains were poorly imaged and the beheaded and burnt remains were poorly detected throughout the survey period, most probably due to a weak dielectric permittivity contrast between the skeletal remains and the surrounding soil. In contrast, the horizontal time slices showed generally good imaging of all of the simulated clandestine graves, probably due to a combination of the contrast between the disturbed grave soil and the background rural environment and the 2D GPR profiles being collected in both orientations over the survey area.

Soil moisture contents of over 50% were observed in the simulated clandestine graves and may be an important variable that has not been reported elsewhere. The secondary succession surface vegetation variations documented will prove very useful for forensic botanists searching for clandestine graves that are less than 1 year old in such depositional environments.

Observations of the botanical species variations of secondary succession over the simulated clandestine graves have been identified in such rural Latin American environments and should prove to be important to identify for forensic search teams to identify potential burial site(s).

Further work should extend the sequential GPR monitoring period to several years post-burial in order to give forensic investigators databases to compare their results to and perhaps see if the observed temporal changes continue. It is also suggested that magnetic surveys be undertaken to determine if this technique could resolve the beheaded and burnt human remains. ‘Grave’ soil should also be extracted and analyzed to determine if human-specific compounds could be detected and, if so, could be used in this environment as an additional complementary forensic search detection tool.

6. Role of the funding source

There was no involvement of any funding sources with this project.

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9. Figure Captions:

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.

Fig. 2. **a**. Plan-view of control test site showing positions of eight simulated clandestine graves (annotated) with top row depths ~0.8 m and bottom row ~1.2 m below ground level (bgl). Selected 2D GPR profile lines and orientations also shown. **b**. simulated clandestine grave with ½ clothed domestic pig cadaver. **c**. simulated clandestine empty grave for control. **d**. simulated clandestine grave with skeletonised human remains and bullet casings. **e**. simulated clandestine grave with beheaded and burnt skeletonised human remains. See text for details.

Fig. 3. Sequential selected GPR 250 MHz 2D profiles taken over the simulated clandestine grave sites, showing; **a**. 4 weeks, **b**. 15 weeks, **c**. 19 weeks, **d**. 22 weeks, **e**. 33 weeks and, **f**. 38 weeks post-burial respectively. Buried simulated named grave (see Table 1 for detail) positions, burial depths bgl and any resulting ½ hyperbolic reflection events (arrows) are both marked (see text for details and Fig. 2a for location).

Fig. 4. Sequential GPR 250 MHz 2D horizontal time slice taken over the simulated clandestine grave sites, showing; **a**. 4 weeks, **b**. 15 weeks, **c**. 19 weeks, **d**. 22 weeks, **e**. 33 weeks and, **f**. 38 weeks post-burial respectively. Buried simulated named grave (see Table 1 for detail) positions and depths bgl shown at top (see text for details and Fig. 2a for location).

Fig. 5. Sequential photographs of surface botany over simulated clandestine graves. **a**. no vegetation after 4 weeks of burial. **b**. *Brassicaceae* (wild radish) preferentially growing over graves after 8 weeks of burial. **c**. lush vegetation (*Raphanus raphanistrum*) growing over simulated clandestine graves after 16 weeks of burial and **d**. kikuyo grass growing between simulated graves.

Fig. 6. Schematic annotated diagrams of a. typical clandestine grave encountered in a. Latin America and b. temperate northern hemisphere scenarios (modified from [17]).

10. Table captions

Table 1. Details of simulated clandestine graves emplaced at the test site with dimensions, contents and justifications all given. A1-D1 were emplaced ~0.8 m below ground level (bgl) and A2-D2 were emplaced at ~1.2 m bgl respectively (see Fig. 2 for location).

Table 2. Summary if geophysical data collected during this study. *Burial date was 19th June 2013. Accumulated degree day calculated from average daily temperature information (see text for details).

Figure1
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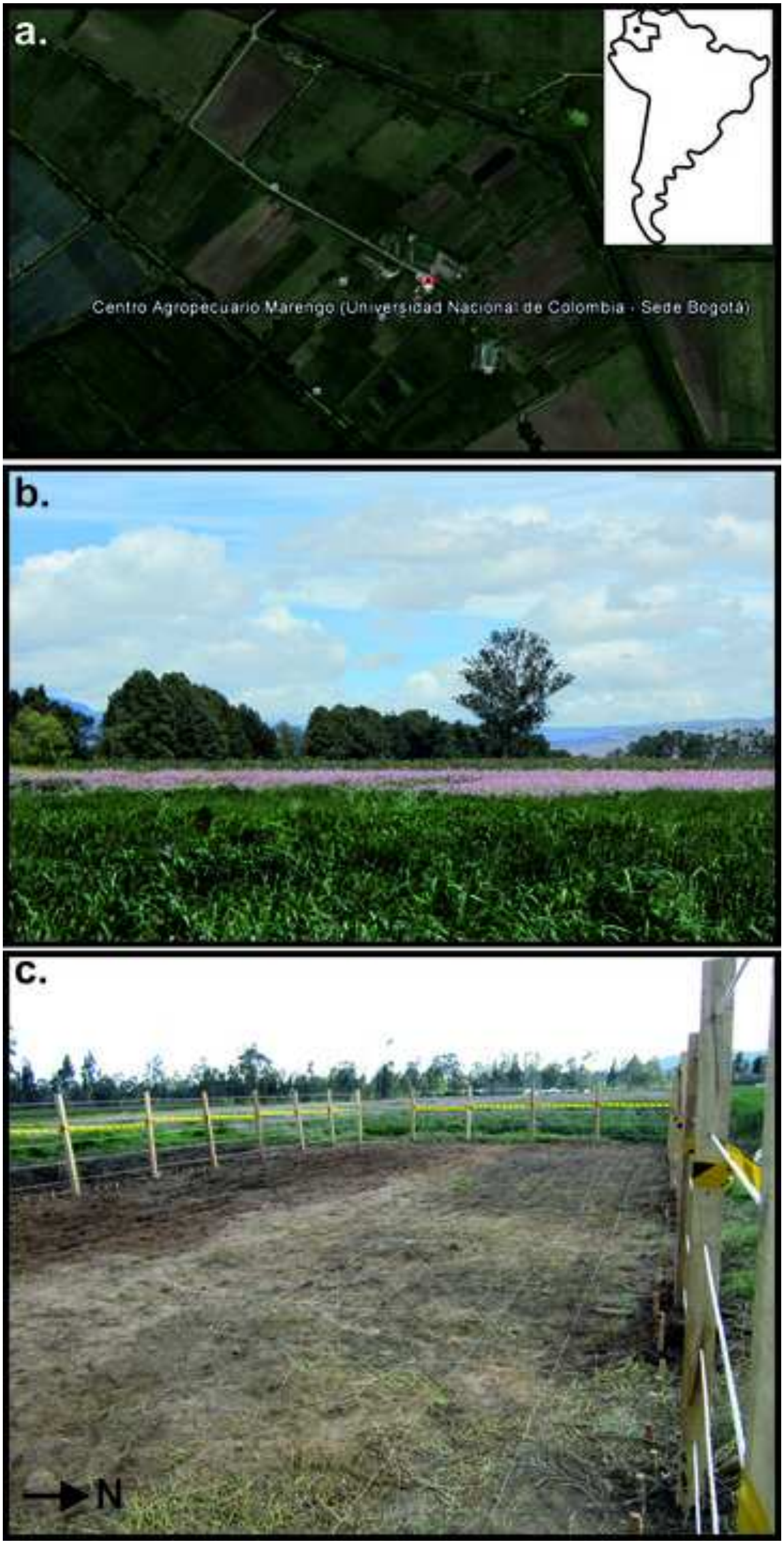

Figure2
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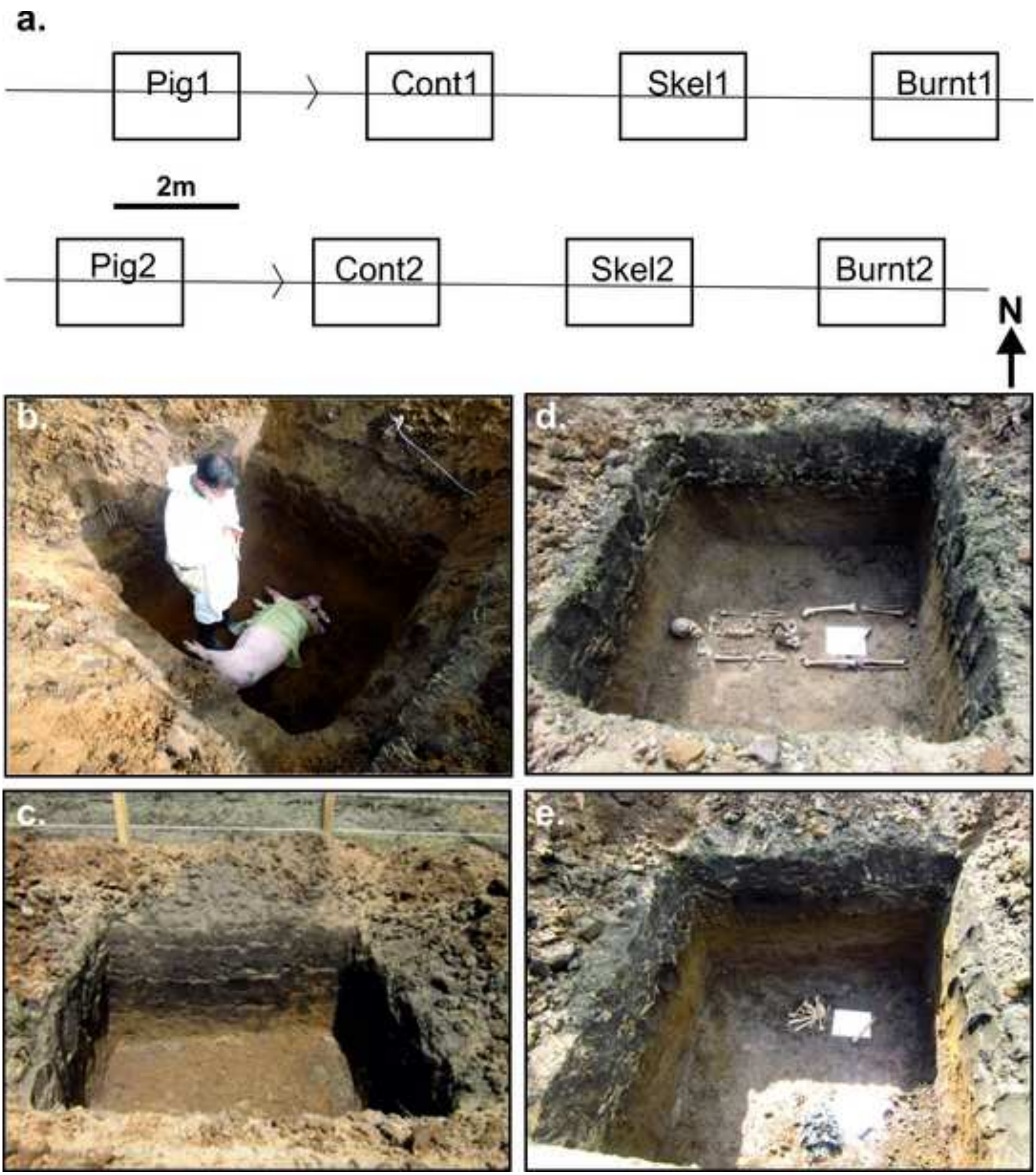

Figure3

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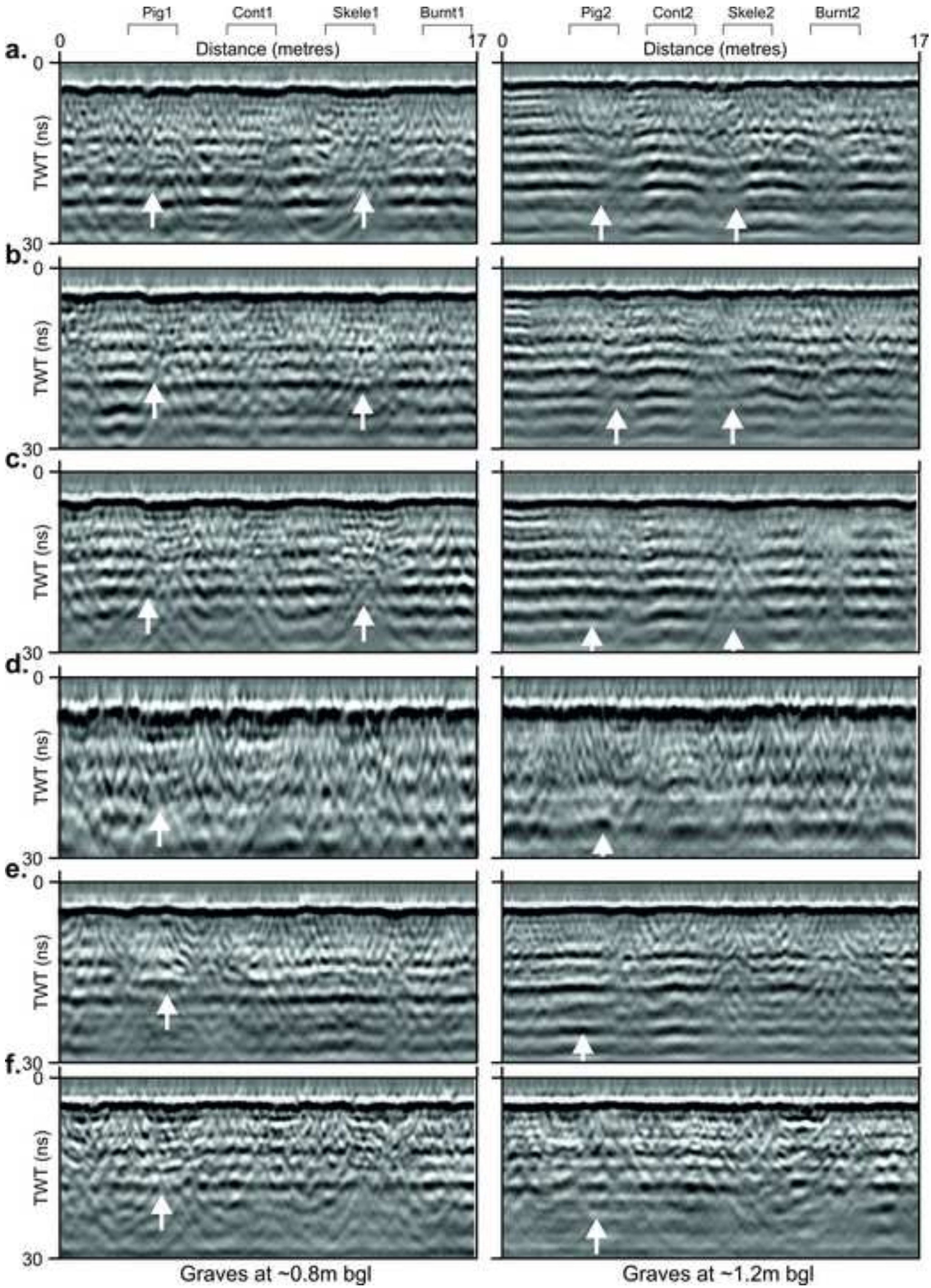

Figure4

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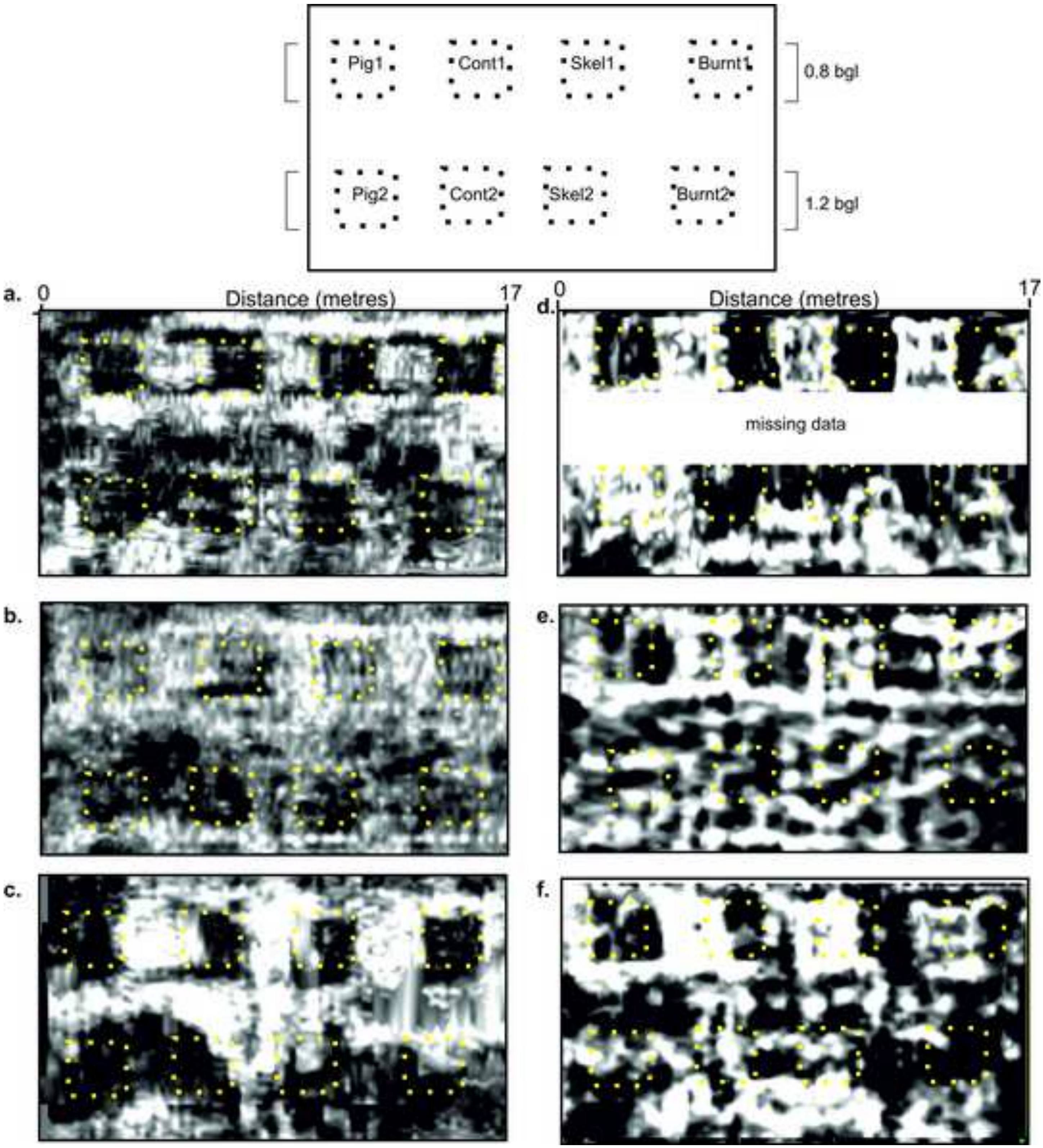

Figure5
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Figure6

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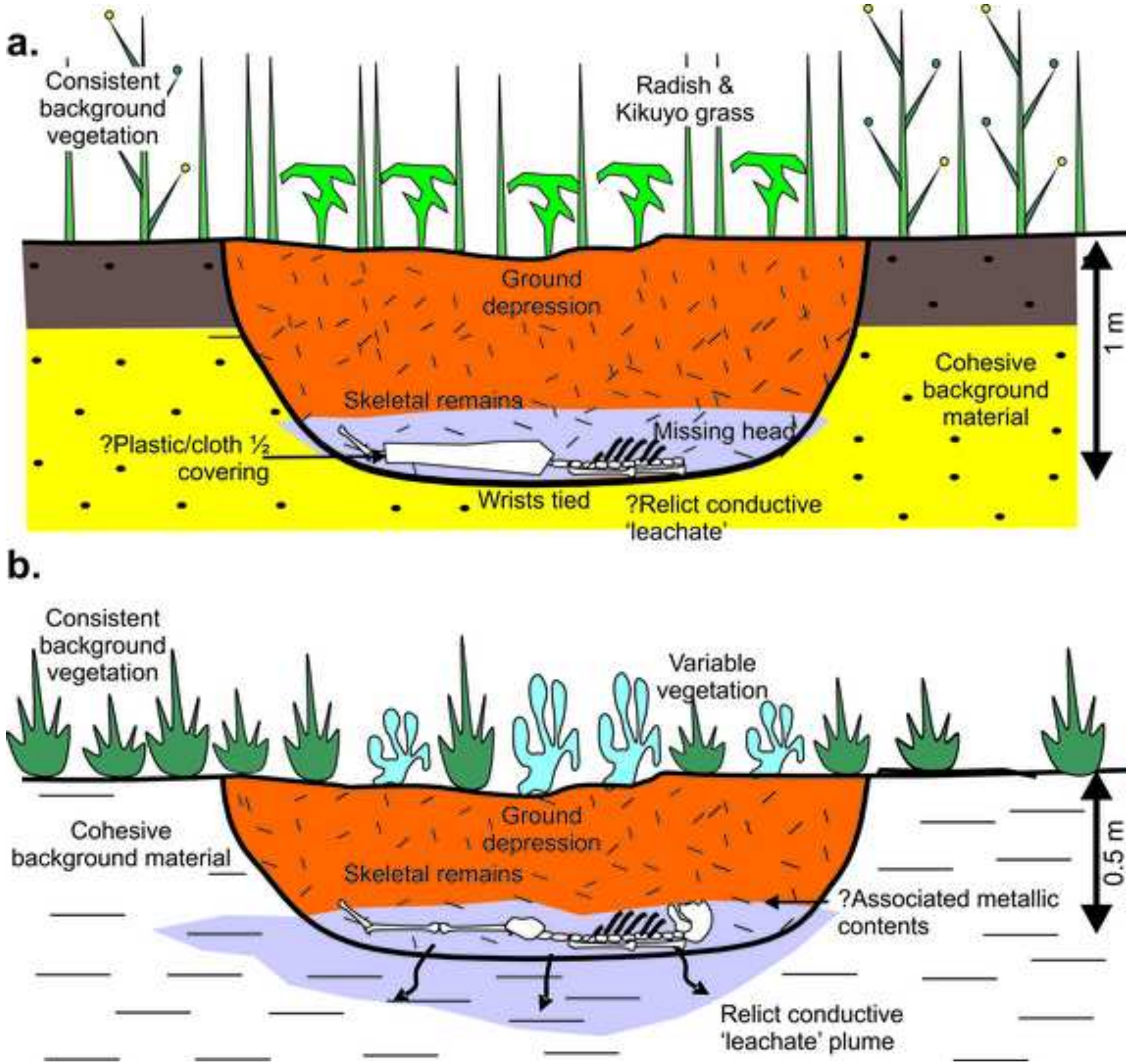

Grave no.	Dimensions	Contents	Description	Justification
A1/B1	2 m x 2 m x 0.8 m / 1.2 m	70kg domestic pig carcass freshly dispatched	Bottom half wrapped in cloth	Represents ½ clothed common scenario
A2/B2	2 m x 2 m x 0.8 m / 1.2 m	None	Dug and re-filled	Acted as control
A3/B3	2 m x 2 m x 0.8 m / 1.2 m	Skeletonised human remains with 6 x 9mm & 4 x 38mm bullet casings	Skeleton placed in dorsal extended position	Common homicide scenario
A4/D4	2 m x 2 m x 0.8 m / 1.2 m	Beheaded skeletonised and burnt human remains	Bones laid out anatomically correct	Common homicide scenario

Table 1. Details of simulated clandestine graves emplaced at the test site with dimensions, contents and justifications all given. A1-D1 were emplaced ~0.8 m below ground level (bgl) and A2-D2 were emplaced at ~1.2 m bgl respectively.

Survey date	Survey day after burial*	Accumulated degree day (ADD)
20/06/2013	1	22
03/07/2013	14	210
09/07/2013	20	303
15/07/2013	27	382
26/09/2013	100	1303
23/10/2013	127	1683
14/11/2013	149	1953
28/01/2014	224	3002
06/03/2014	261	3510

Table 2. Summary if geophysical data collected during this study. *Burial date was 19th June 2013. Accumulated degree day calculated from average daily temperature information (see text for details).

Optional e-only supplementary files

Click here to download Optional e-only supplementary files: graves_v4_with_TCs.docx

Response to Reviewer

We thank Reviewer 1 for their comments on the manuscript which have all been undertaken in full. They are listed in sequential order below, with a separate ms with 'Track Changes' supplied with the revision to clarify what changes have been undertaken from the original submission.

In reply to point 1 of R1, we agree that more discussion should be made to compare this study results to others; the discussion has been significantly expanded to reflect this.

In reply to point 2 of R1, more detail has been added to both the results and discussion sections to state why there were limited anomalies recorded in the gpr data from the various targets buried.

In reply to point 3 of R1, we agree that there should be more discussion on the 2D profile results, we have therefore added extra annotation to Figure 3 showing these and more description in both the relevant results and discussion sections.

In reply to point 4 of R1, we have labelled location, limits & features of the 3D time slices in Fig. 4 with additional description in the respective results and discussion sections.

In reply to point 5 of R1, we agree that the botanical variations observations are important. We have therefore added 'and botany' to the title and expanded a botanical paragraph in the discussion.

In reply to point 6 of R1, we agree that there are some minor grammatical errors which have been identified and corrected (see Track changes ms), particularly 'this paper aims to firstly' and ;first published geophysical research in Latin America' that were pointed out.

In reply to R1's final comments, Figure 3 has been removed as requested with subsequent figures renumbered.