Electrical Resistivity Surveys of Mock Clandestine Graves in Outdoor Forensic Laboratories

M. Horn, Louisiana Geological Survey, Louisiana State University, Baton Rouge, LA

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Abstract

Electrical resistivity surveys using dipole arrays over mock human graves at two outdoor forensic research facilities produce inversion model profiles with unnatural resistivity anomalies overprinting subsurface geology. The anomalies are interpreted to represent the contamination of the subsurface by a plume of fluid generated by the decomposition process. Anomaly patterns in two of the profiles suggest that decomposition fluid may fractionate at an early stage into a mobile, electrically conductive component and a viscous resistive component. The results also demonstrate relationships between array electrode spacing, anomaly resolution, and depth of investigation. Recommendations are made for continued tests over existing graves and for frequent surveys over a small number of new intact and isolated graves to address hypothetical questions raised by this study.

Introduction

Near-surface geophysical field surveys have been applied, with various degrees of success, to problems within the geological anthropological interface. In particular, measurement of electrical properties of the substrate (electrometry) has been used in the search for unmarked cemetery graves and, more recently, in the search and analysis of clandestine or criminal graves (Jones, 2008; Hansen et al, 2014; Pringle et al, 2016). In these settings, human decomposition contamination of the soil and subsoil, in addition to any incorporated materials, will alter the electrical properties in and around the grave shaft, making the feature detectable by electrical methods.

This study applies field electrometric techniques to mock clandestine graves at a pair of outdoor forensic research facilities (Figure 1). In these controlled environments, cadavers are placed outdoors to decompose for studies in taphonomy and osteology, while incidentally functioning as experiments in ecology and criminology. The specimens are ordinarily placed on the ground surface exposed to microbial and insect scavenging in direct atmospheric conditions and enclosed by fencing and wire cages to limit scattering of remains by larger scavengers. Some specimens are buried in grave shafts of 0.5 – 1.0 m in depth to enhance degradation by soil-borne insects and microbes and function as proxies for criminal burials. A smaller number are buried in deep graves to study anaerobic decomposition and adipocere formation. Most specimens are deposited nude, although some may be clothed or wrapped in sheathing in order to mimic criminal disposal or to modify the decomposition process. Few specimens are embalmed prior to emplacement.

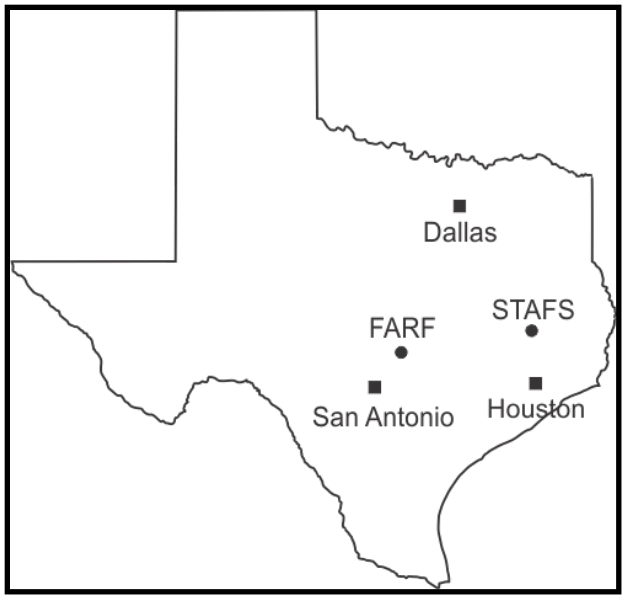

Figure 1. Location map of two outdoor anthropology forensic research facilities used in this study: STAFS in southeastern and FARF in south-central Texas.

Early-stage bloating terminates with purging and the release of decomposition fluid that immediately enters the soil and subsoil. This mélange of organic and inorganic compounds permeates the substrate as a plume, transferring contaminants that remain as a residue after the aqueous component diminishes by evaporation or continued permeation. For specimens that decompose at the ground surface, the ground surface area of residuum contaminant is referred to as the 'decomposition island'. In this discussion, 'decomposition plume' refers to a three-dimensional region of subsurface contamination that originates from decomposing remains.

The primary goal of the present study is to develop geo-electrical field techniques that will yield quantitative imagery (tomography) of decomposition contaminant plumes, to test geophysical search techniques for human graves, and to analyze contaminant plume migration and evolution, all without disturbing graves. While graves are of primary interest in this study, contaminant plumes from surface specimens can also be resolved by geo-electrical data. Abrief description of the geo-electrical method is first presented, followed by a summary of controlling parameters specific to the study sites and field measurement. The results of the measurements are then detailed, interpreted, and summarized with recommendations for future study.

Electrical resistivity survey method

An electrical survey over the ground surface produces an image of spatial variations of electrical properties in the substrate that can be interpreted in terms of lithology and soil chemistry: mineralogy, organic content, porosity, and interstitial moisture and contamination (Telford et al, 1990; Ward, 1990;

Seladji et al, 2010; Reynolds, 2011). Hence, the electrical anomaly field can be interpreted in terms of natural or man-made features, making the technique useful in the search for underground objects or geological field relations without, or as a precursor to, excavation.

An electrical resistivity survey is performed along the ground surface using a set of electrodes wired to an electrometer that imparts an electric current and measures differences in voltage response. Opposing electrical currents, positive and negative, imposed by one pair of electrodes generates voltage and current fields in the entire subsurface. The voltage drop measured between a second pair of electrodes divided by the magnitude of the current gives the Ohmic electrical resistance. Electrical resistance values are then converted to electrical resistivity, an intensive material property, based upon the relative configuration of the electrodes and the distances between them.

The four electrodes involved in resistance measurement can be arbitrarily arranged at the ground surface but in practice they are positioned according to one of a small number of geometrically simple arrays (Telford et al, 1990; Milsom and Eriksen, 2011; Reynolds, 2011). For exploration and analysis of human graves, this study used dipole arrays to produce two-dimensional cross-section models (profiles) of the subsurface. In dipole arrays used for profiling, potential electrode pairs are sequentially spaced along a linear transect either with the two current electrodes positioned on the same transect (dipole-dipole) or with only one current electrode there (pole-dipole) and the opposing current electrode placed a large distance from the array. The profile dataset is built by advancing the array an incremental distance, the 'data spacing', along the transect (Figure 2). Unpublished trials by the author demonstrate that the dipole-dipole array more effectively resolves subsurface features whereas the pole-dipole array slightly extends the depth of investigation and is most useful for highly conductive substrates.

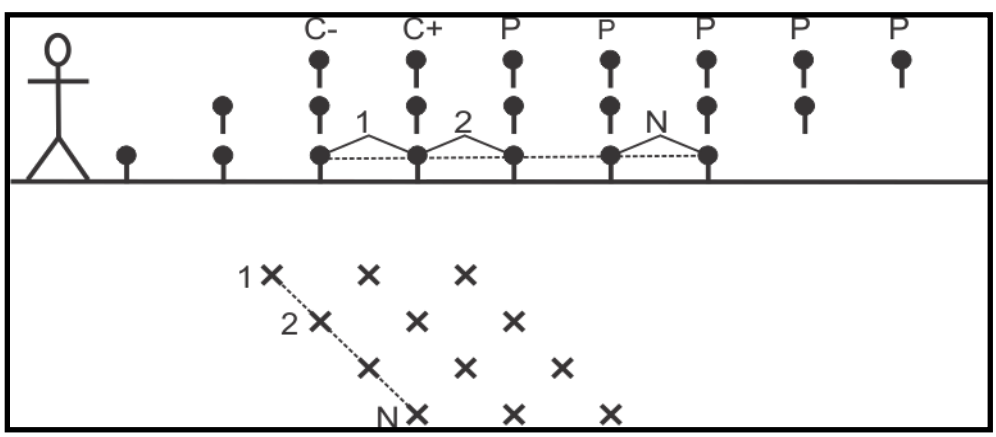

Figure 2. Schematic diagram of dipole–dipole array deployment. Stick-and-balls represent current (C) and potential (P) electrodes, integers refer to uniformly spaced potential electrode pairs, and 'x' marks data point locations plotted in the model subsurface. After readings are obtained from the N potential electrode pairs, the array is advanced an incremental distance called 'data spacing'.

Dipole array electrode spacing is ordinarily uniform, other than to circumvent an obstacle, and the spacing selection depends upon objective requirements. Greater electrode spacing provides information from greater depth but with concomitant loss of resolution of subsurface features. For example, a dipole array spacing of 1.0 m has a depth of investigation of about 2.3 m and spatial resolution of 1.0 m, while a 0.5-m array spacing senses down to only about 1.3 m deep but resolves half-meter features. This is a significant issue in profiling of human graves that have horizontal dimensions of about 1.0 x 2.0 m and depth range from 0.5 to 2.0 m. One objective of this study is to compare the electrical tomography models from different array spacings over mock clandestine graves less than one meter deep.

The tomographic imagery is produced by processing the profile data with a computational algorithm that estimates subsurface variations of electrical resistivity (Loke, 2014). This inversion process essentially generates a hypothetical distribution of electrical resistivity values in the subsurface that would produce the electrical resistance readings measured at the surface. The result is a model profile or image of electrical resistivity anomalies that can be interpreted in terms of spatial variations in subsurface lithology and soil chemistry, and by extension, geologic and anthropogenic features, such as sediment layering, soil development, contaminant plumes, and human remains.

Study Site Locations and Characteristics

Electrical profiling was performed with dipole electrical arrays over known graves and surface decomposition islands at two outdoor forensic research facilities in southeastern and south-central Texas (Figure 1). The Southeastern Texas Applied Forensic Sciences (STAFS) facility is located near Huntsville, Texas, and operated by the College of Criminal Justice at Sam Houston State University. The Forensic Anthropology Research Facility (FARF) is located near San Marcos, Texas, and operated by the Dept. of Anthropology, Texas State University.

Interpretation of electrical anomalies in the subsurface requires a familiarity with lithology of the naturally occurring host bedrock* of a site. (*The geological term 'bedrock' refers to a naturally occurring subsoil assemblage of minerals and rock fragments that is not necessarily consolidated, as is ordinarily implied by the term 'rock.') Interstitial moisture, lithology (mineral components, porosity, permeability), and sedimentary layering and structures affect electrical resistivity, serving as a basis for interpreting geological features in electric tomography (Telford et al, 1990; Ward, 1990; Seladji et al, 2010; Reynolds, 2011). Of the common rock forming minerals, clays, metallic oxides, and metallic sulfides are electrically conductive while carbonates, sulfates, and non-clay silicates are resistive. Independent of mineralogy, moisture increases the conductivity of bedrock and soil depending upon the salinity of the moisture and upon the porosity and permeability of the host. Conversely, organic materials

and compounds increase the overall resistivity of soil. Layering of lithology and/or moisture content are interpreted from electrical resistivity variations appearing as horizontal or sub-horizontal spatial trends, while localized concentrations of minerals, moisture, and contaminants are expressed as isolated anomalies incongruent with the layered or uniform host.

Absent a detailed geological study of the STAFS and FARF sites, bedrock lithology can be obtained from published geological maps and reports. The STAFS facility is situated on bedrock of nonconsolidated calcareous fine sand and mud of the lowermost Fleming formation (Miocene) (Shelby et al, 1968). No grave shafts were observed at STAFS during this study, but nearby ravines expose bedrock lithology that fits published descriptions. The site is situated within the high flood stage surface of an intermittent stream, possibly resulting in bedrock at the facility being capped by a veneer of fine sand and silt derived from a nearby Fleming source while retaining a similarity in exposure appearance.

TSU FARF is situated at the summit of a modern meander divide of shallow-dipping Edwards limestone (Cretaceous) (Barnes, 1974). During one visit to FARF, an unused empty grave shaft, approximately 1.0 m deep, was observed exposing nonconsolidated breccia of half decimeter and smaller clasts of locally derived limestone set in a matrix of red and rust-red clay-rich mud. In-situ Edwards limestone bedrock was not exposed in the shaft. In addition, half-meter weathered limestone boulders are loosely concentrated near the study site. These observations and the ease of grave digging at the facility, suggest that FARF grave shafts are within a nonconsolidated gravel veneer similar to remnants of localized alluvial fans of late-Pleistocenee age bearing alteration components (red clay) derived from pre-Cambrian basement of the Llano Uplift, exposed some 80 km to the northwest (Barnes, 1974).

Electrical Resistivity Profiles and Interpretations

Geo-electrical profiles were performed over five sets of graves at the two facilities using dipole arrays (Table 1). The graves at each profile location are aligned in rows with the long axes of the grave shafts perpendicular to the row line. With few exceptions, buried remains were of nude, non-embalmed adult cadavers placed outstretched in individual, shallow (< 0.5 m) grave shafts. Electrical profile transects were aligned along the average axis of the grave row to insure that measurements were made over cadaver centroids. Most profiling arrays were dipole–dipole with 0.5-meter electrode spacing; two exceptions for comparison were one dipole-dipole with 1.0-m spacing and one pole-dipole with 0.5-m spacing.

STAFS

Electrical profiles were performed over graves in three separate areas of the STAFS facility: Area 1A–Sec. VII, Area 1A–Sec. XI, and Area 2B (Table 1; Figure 3). Transects in Area 1A–Sec. VII and Area 2B also intersected the decomposition islands of nude cadaver specimens laid outstretched at the surface. At the time of field measurements, these surface sites were distinguished by the presence of disarticulated bones, some bearing residual soft tissue, indicating an advanced, or virtually complete, stage of decomposition.

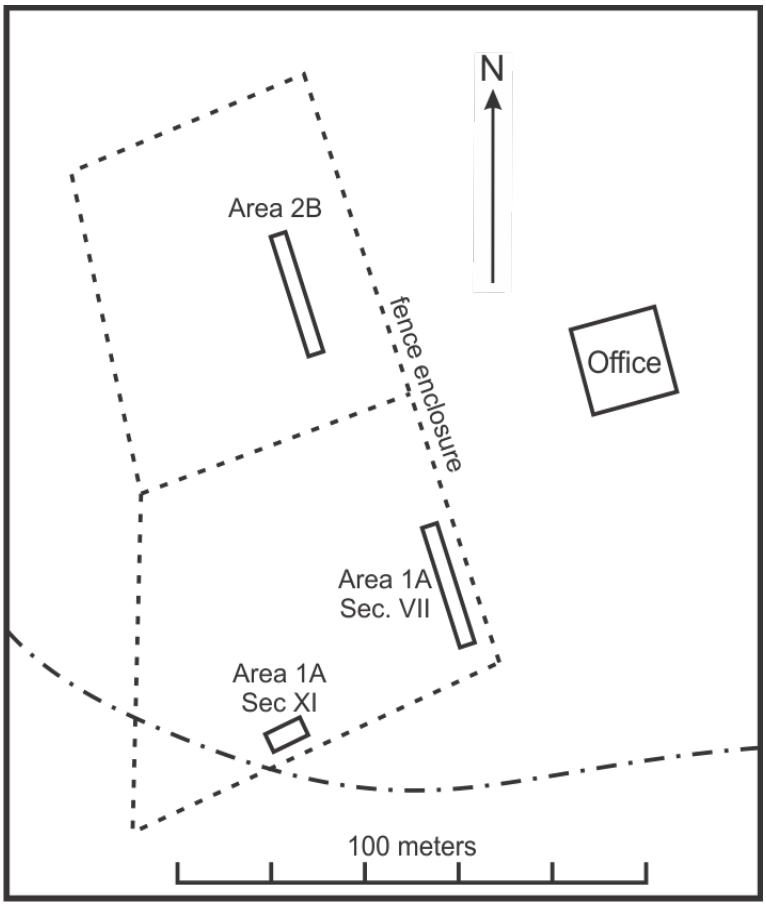

Figure 3. Map of STAFS facility showing locations of electrical profile sites. Dash-dot curve represents a ravine near the fenced experiment area.

The inversion model profiles STAFS–01, -04, and -05 are shown color contoured in Figure 5. Marker stake positions and specimen IDs are shown as they appeared at the time the surveys were performed. Relative positions of the profile images in sub-figures (a) and (b) indicate that the origin (x = 0.0 m) of transect -01 was positioned approximately 0.25 m south of the origin for profiles -04 and -05. In the color image, yellow to red shadings represent areas of relatively high electrical resistivity while green-to-blue shadings represent conductive areas. The bar scale is in log10 of resistivity values, so dark red (3.0), for example, represents an electrical resistivity value of 10**3 = 1000 ohm-m. All three model profiles in Figure 5 are color contoured according to the same bar scale.

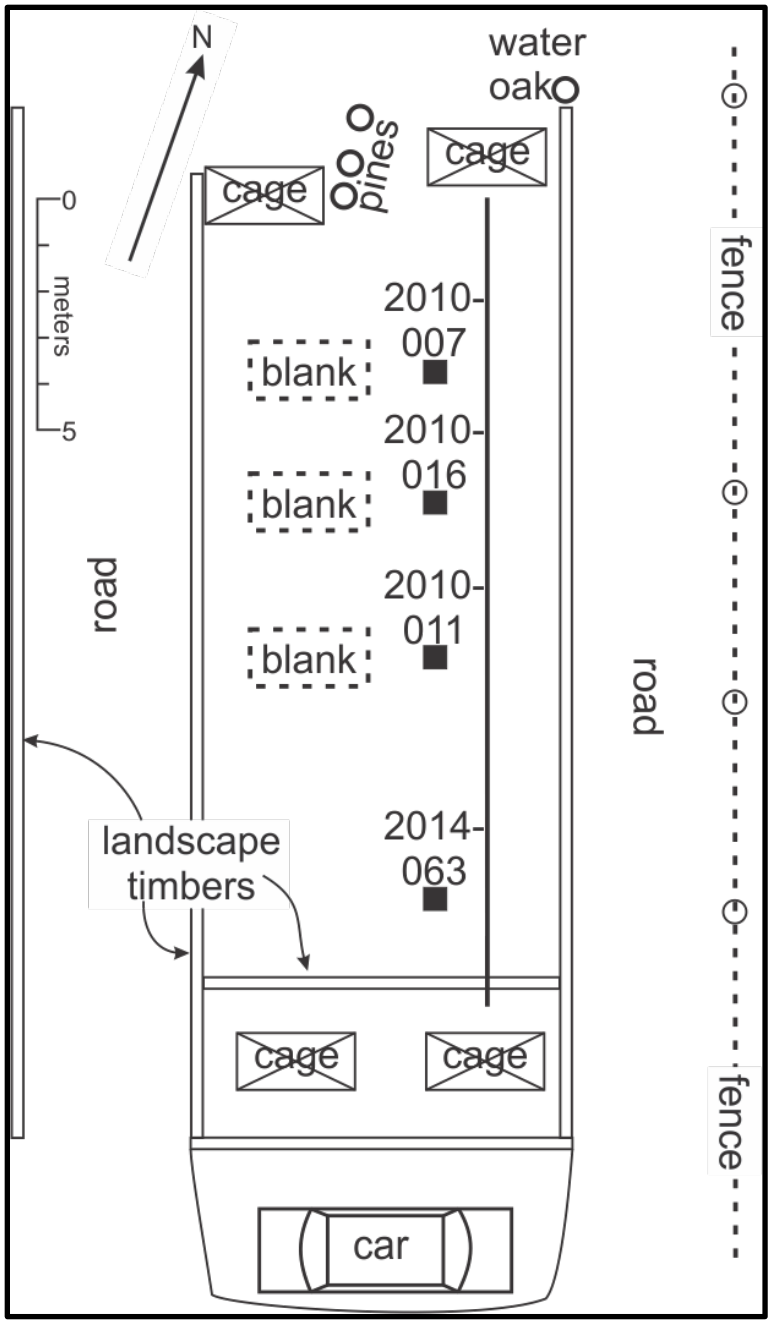

Figure 4. Map of graves and related landmarks of STAFS Area 1A, Sec. VII in December 2016. Heavy line locates transect for STAFS–01, -04, and -05. Solid squares locate grave markers with specimen ID's. Cages enclose surface specimens. In March 2017, specimens were positioned atop 'blank' graves.

The inversion models consistently show regions of relatively high electrical resistivity associated with locations of human decomposition both at the surface and in the subsurface. The lack of a distinct resistivity anomaly associated with specimen 2014-063 is an exception, but at the time of field measurements (Winter 2016–17) there was significant uncertainty about the location of that specimen. An

isolated resistive anomaly consistent with the deep, plastic-wrapped specimen is clearly resolved in profiles -01 (x = 7.0–8.25 m) and -04 (x = 7.5–8.75 m), implying that the marker stake was incorrectly positioned about 2.0 m to the south. This inaccuracy further implies that marker stakes 2010-007 and 2010-016 may have also been mis-positioned. In any case, these results show that contamination of soil by human decomposition, either by the fluid plume itself or, more likely its residue, increases the electrical resistivity of the contaminated soil and subsoil.

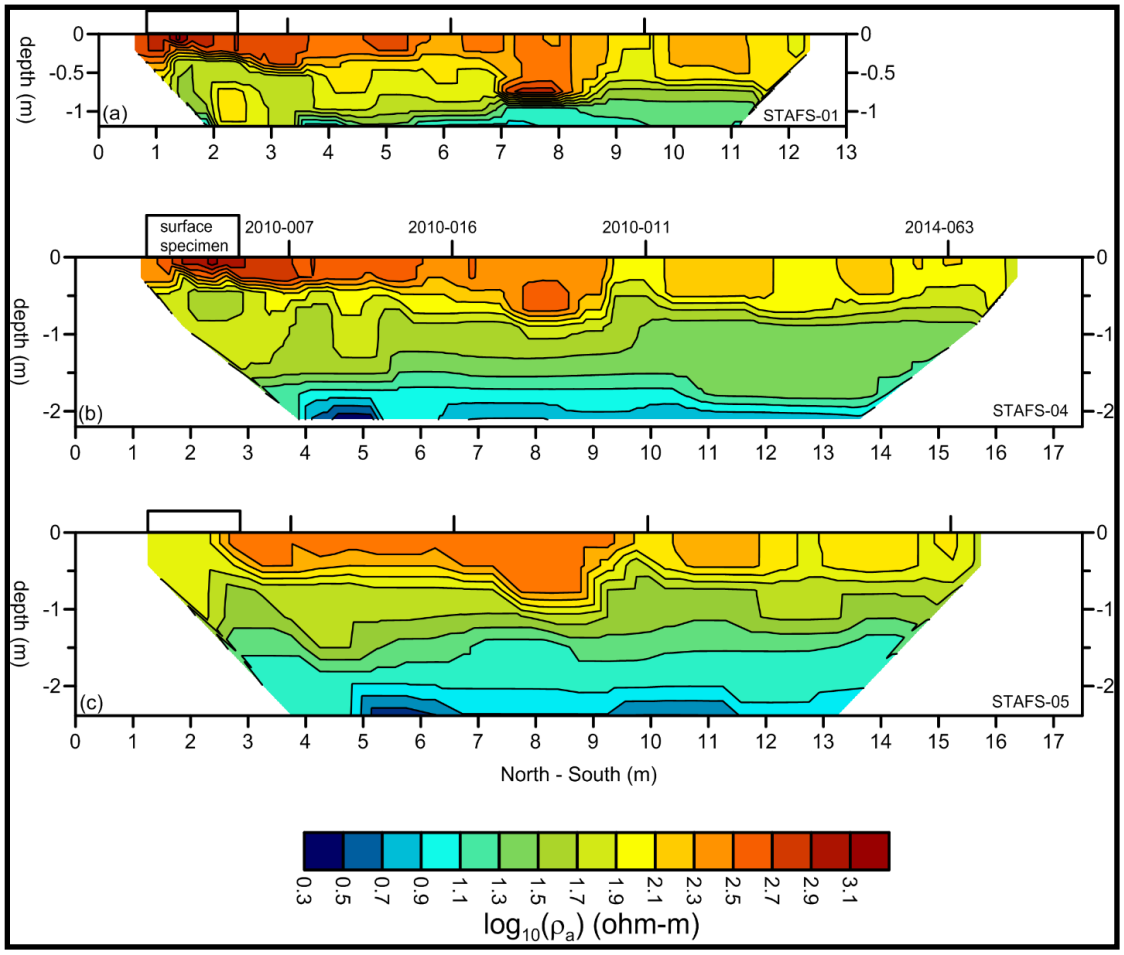

Figure 5. Color contour inversion models of profiles STAFS-01 (a), -04 (b), and -05 (c), with color bar scale of resistive (red) vs. conductive (blue) electrical resistivity values. Locations of surface specimen and grave marker stakes are indicated along the ground surface. 0.5 m spacing (a) produces higher resolution of resistivity anomalies while 1.0 m spacing (c) produces lower resolution but greater model depth. Dipole–dipole array, (a) a = 0.5 m, d = 0.5 m, N = 7, (b) a = 1.0 m, d = 0.5 m, N = 8, (c) a = 1.0 m, d = 1.0 m, N = 8.

The lowermost interval in all three profiles is relatively conductive (blue shading) and seems to define a layered sedimentary sequence, although the depth of the layering interface (blue vs. green shading) appears to vary with array electrode spacing: about 0.75–1.0 m depth in profile -01 vs. 1.0–1.5 m in profiles -04 and -05. Interpretations of geologic and anthropogenic features for the three profiles are shown in Figure 6. These interpretations are based on a general arrangement of naturally layered sediment

with surface-downward incursions of decomposition plumes recognized as vertically cross-cutting regions of anomalously high electrical resistivity. Because the marker stakes have been moved on one or more occasions, they are considered to provide only approximate locations of remains in the subsurface.

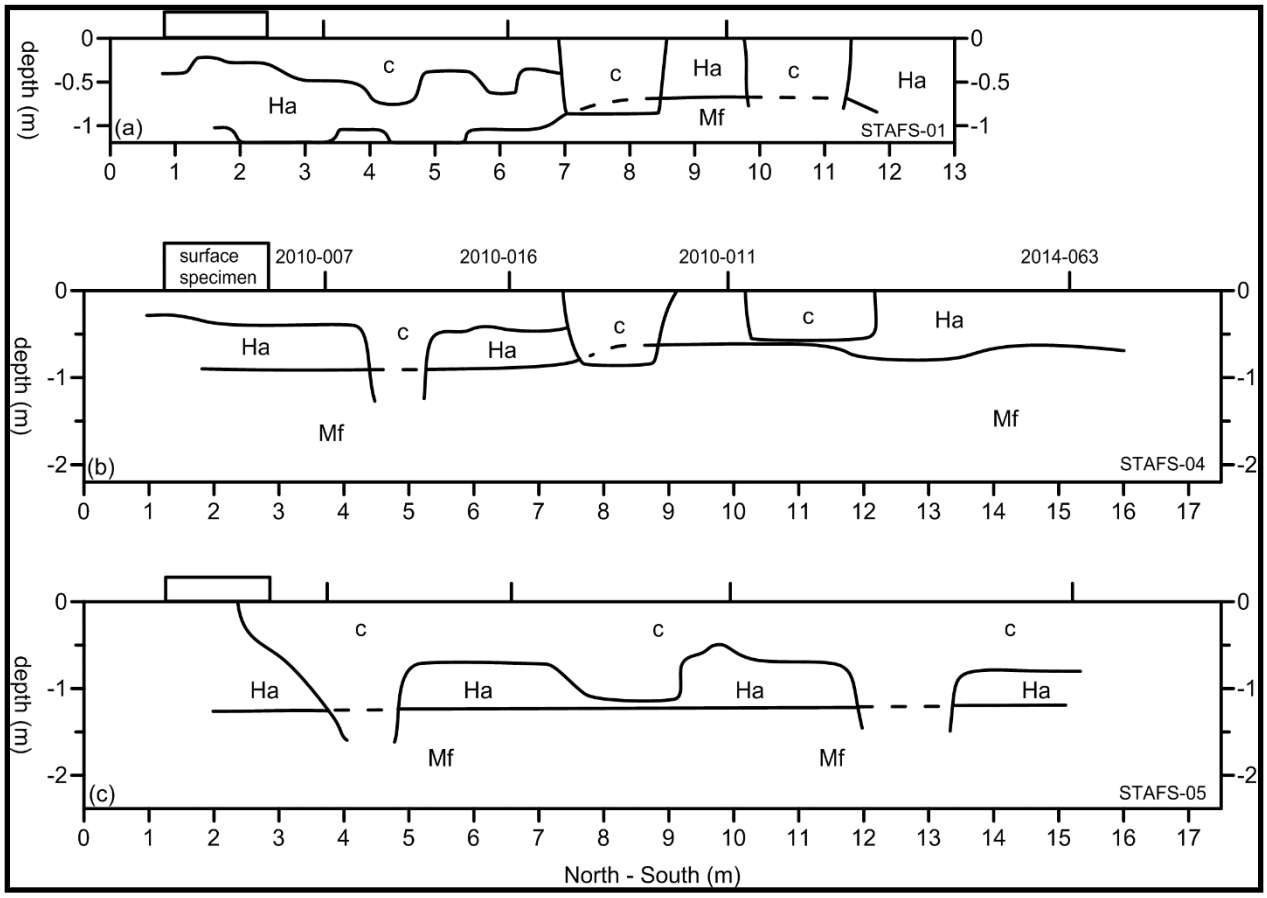

Figure 6. Line drawing interpretation of resistivity profiles of Figure 5. Soil contamination, 'c', due to decomposition fluids cross-cuts the natural layering of Miocene Fleming formation (Mf) and veneer of Holocene alluvial deposits 'Ha'. Grave shafts are implied at x = 4.3, 6.0, 8.0, and 11.0 m. The resistive anomaly at x = 3.0 m in (a) is interpreted as originating from the surface specimen at x = 2.0.

The difference in model results produced by three different array spacings is evident by comparing the three diagrams. Half-meter electrode and data spacing (profile -01) yield greater anomaly resolution, but its effective depth (~ 1.2 m) is only about half that produced by the 1.0-m spaced dipole array (profiles -04 and -05). A satisfactory degree of anomaly resolution and extended depth of investigation can be obtained with 1.0-m electrode spacing and 0.5-m data position spacing, albeit at the expense of quadrupling the measurement time.

STAFS Area 1A, Sec. XI. Profile STAFS–02 was measured over three buried specimens in this location (Figure 7; Table 1). The burial was conducted on a single occasion to mimic a mass grave in which three (nude) adults were closely spaced in a single pit of (nominal) 0.5-m depth. The electrical

profile transect was positioned at approximately waist level of the cadavers with sufficient length to traverse the neighboring subsurface at both ends of the grave. Three cages enclosing above-surface specimens were situated sufficiently near that one or more decomposition islands may have encroached upon the transect and impacted profile data.

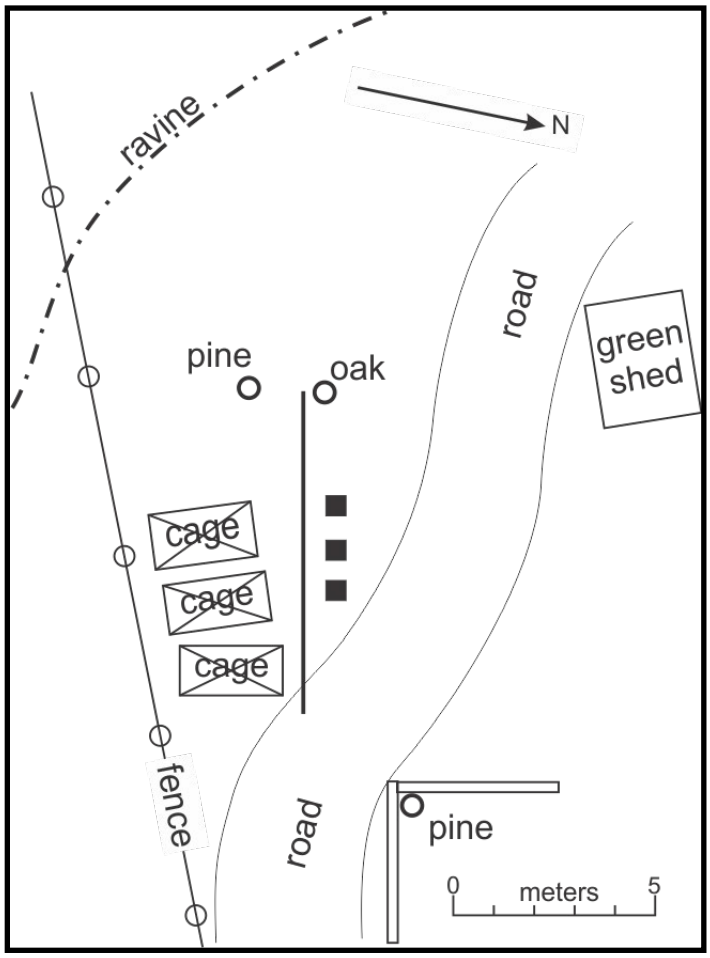

Figure 7. Map of mass grave and nearby landmarks of STAFS Area 1A, Sec. XI. Heavy solid line indicates transect STAFS–03. Solid squares locate grave marker stakes. Specimen IDs were not available.

The inversion model and interpretive images for the mass grave are shown in Figure 8 using the same color contour scale as in Figure 5. As in STAFS profiles -01, -04, and -05, high resistivity values occur in the upper 0.5 m of the subsurface, correlated with sites of human decomposition. In this case, two anomalies are isolated in the east and west ends of the profile rather than directly beneath the marker stakes. The easternmost resistive anomaly possibly originates from one of the decomposition cages immediately nearby, while the western anomaly perhaps represents a single decomposition fluid plume coalesced from three individual plumes that migrated westward upon encountering the permeability barrier of clay (blue shading) at the floor of the burial pit.

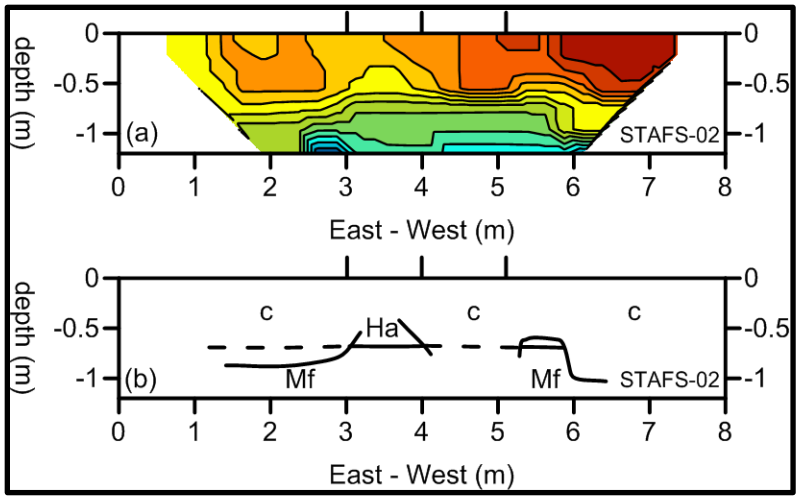

Figure 8. Color contour inversion model (a) of profile STAFS–02 over mass grave of three cadavers, and (b) interpretation diagram. Grave marker stakes are indicated by vertical line segments along the ground surface. Color bar scale as in Figure 5. 'c' indicates soil contamination by decomposition, 'Mf ' = Miocene Fleming formation, 'Ha' = Holocene alluvium. Dipole-dipole a = 0.5 m, d = 0.5 m, N = 7.

STAFS Area 2B. Profile STAFS–03 was measured in January 2017 using a 0.5 m dipole-dipole array (Table 1; Figure 9). All are original graves of nude adults interred over October–December 2014, two of which, 2013-030 and 2014-075, were embalmed prior to burial. The inversion result is color contoured in Figure 10(a) using the same bar scale as in Figures 5 and 8; the interpretation of resistivity boundaries is shown in Figure 10(b). In the following interpretations, as for Figures 5 and 8, it is assumed that the grave markers could be inaccurately located.

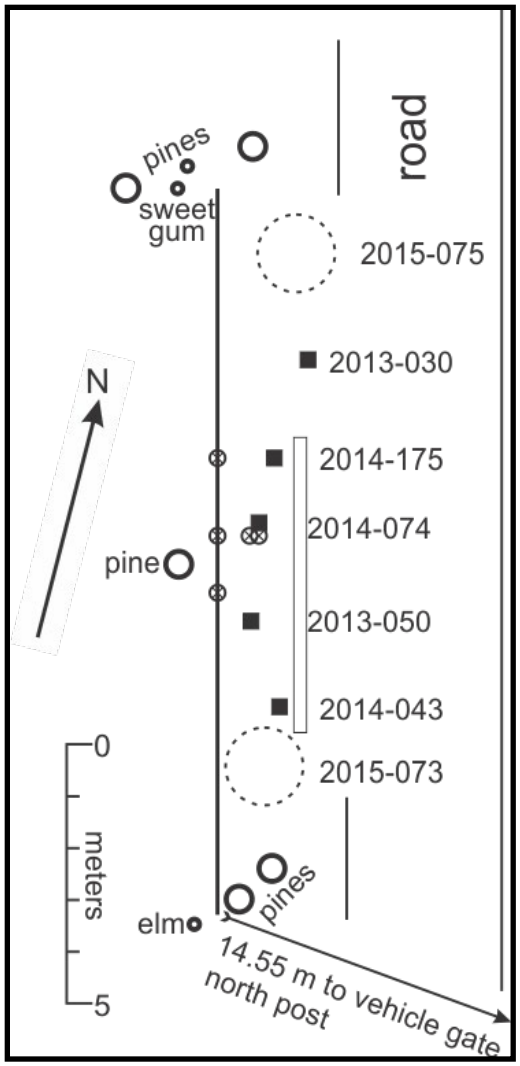

Figure 9. Map of profile STAFS-03 (heavy solid line), grave markers (solid squares), and related landmarks of STAFS Area 2B in their relative positions in January 2017. Graves and markers are separated from the gravel service road by a landscape timber (light rectangle). Dotted circles outline the remains of completely decomposed surface specimens. Small crossed circles indicate positions of soil samples collected by Texas A&M University (not discussed in this report).

A distinctive difference between this setting and that of other STAFS profiles is the depth (< 0.3 m) to the lower conductive interval (blue shading). In the absence of direct lithologic data, the conductive sediment can be interpreted as a clay-rich interval within the Fleming formation blanketed at this location either by a thin Holocene flood deposit or, perhaps equally likely, mantled by thin humus-rich, 'A' horizon soil.

High resistivity (~250–300 ohm-m) anomalies at shallow depth more or less correlate with grave markers and with each of two surface specimens, 2015-075 and 2015-073, located at the north and south ends of the transect. This consistent relationship suggests that the resistivity anomaly results from downward permeated decomposition fluid or its residue. Given the roughly equal age of the two surface

specimens, the larger outline of the anomaly beneath sample 2015–073 suggests more permeable soil and subsoil than beneath specimen -075.

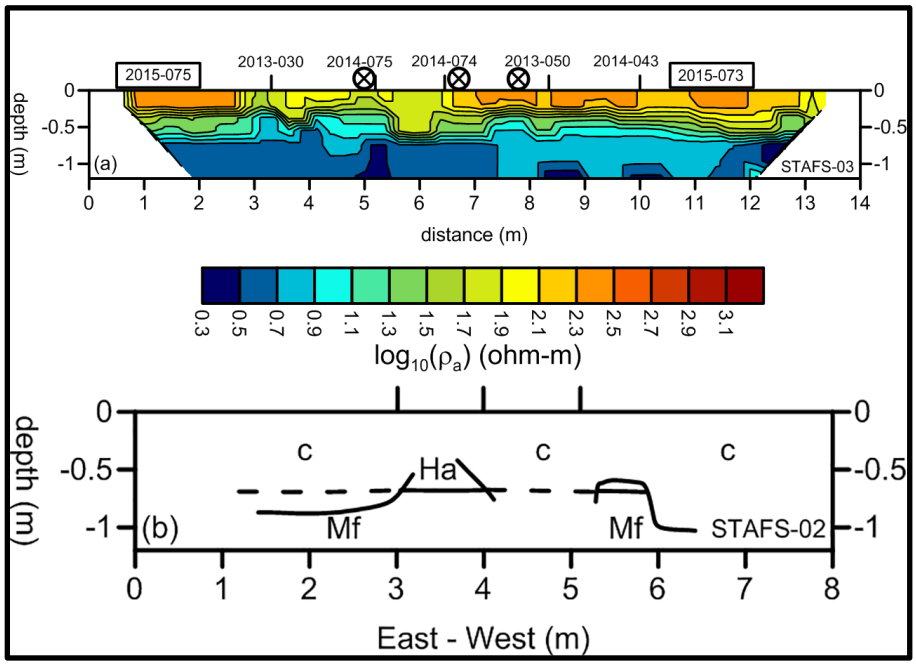

Figure 10. Color contour inversion model of profile STAFS–03 across graves and surface specimens (a) and interpretation (b). Color scale and interpretation annotations are as in Figures 5 and 8. Dipole–dipole, a = 0.5 m, d = 0.5 m, N = 7.

The markers for the two embalmed cadavers, 2013-030 and 2014-075, approximately correlate to a pair of downward lobate anomalies of relatively moderate resistivity (yellow-green) suggesting that the embalming medium may have been conductive or perhaps inhibited development of electrically resistive compounds in the decomposition fluid. Despite the burials being roughly the same age, specimens -043, -050, and -074 produced anomalies (200-300 ohm-m) of smaller size and depth than the embalmed specimens, alternatively suggesting that the embalming media may have reduced the viscosity of the decomposition fluid, resulting in broader dispersal into the subsurface.

FARF

Three dipole electrical profiles were performed at the FARF facility over two different areas and ages of graves (Table 1; Figure 11). Profiles FARF-01 and -02 were performed in October 2017 over a row of six graves and six blanks as part of a soil chemistry study (Baide, 2017; Figure 12(a)); both used a dipole-dipole array with electrode spacing 0.5 m, data spacing 0.5 m, and N = 8. Profile FARF-03 used a pole-dipole array with 0.5 m electrode spacing and N = 8 over a single 3 month old grave (Figure 12(b)) to permit comparison of grave age and array type. All graves were shallow (<0.5 m) burials of nude

adults in virgin shafts. Remains were not observed, but grave marker location accuracy was assumed from individual surface depressions of rectangular shape.

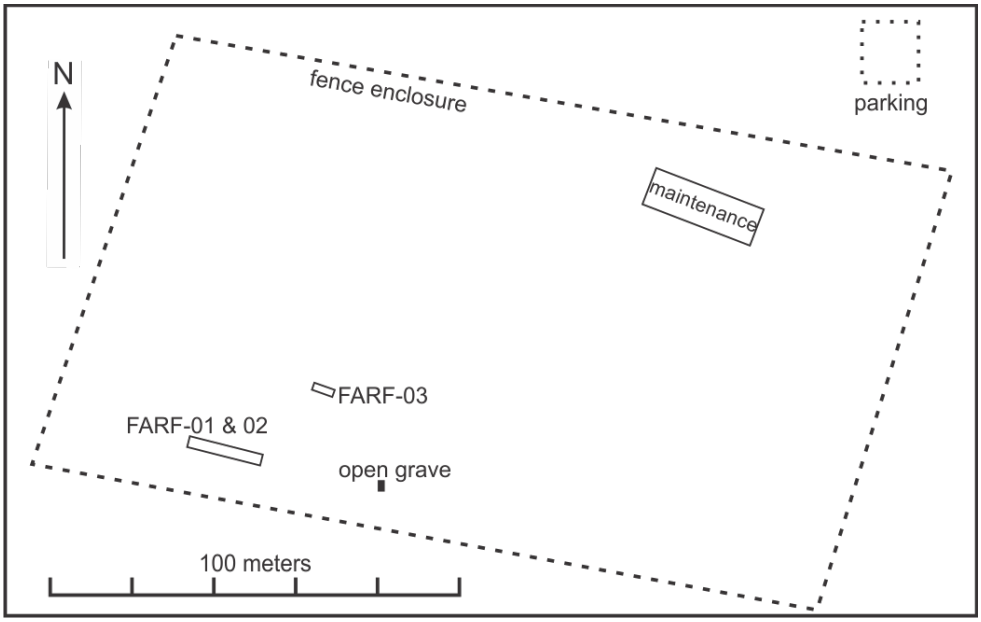

Figure 11. Map of FARF outdoor forensic facility showing transects FARF–01, -02, and -03, and an open virgin grave shaft at the time of the field study.

FARF–01 & FARF-02. Transect FARF-01 was positioned at cadaver waist level through a row of six graves collinearly interspersed with six blanks: back-filled empty graves labeled 'controls' by FARF personnel. FARF–02 was positioned 3.0 m south and parallel to transect -01 to generate a baseline model profile of the undisturbed subsurface. The color contour inversion profiles and line drawing interpretations are shown in Figure 13. The patchwork appearance of disjointed conductive (blue) and mid-range resistive (yellow) anomalies through most of profiles 01 and 02 are consistent with the discontinuity of rock and mud components typically found as lenses in conglomeratic fan or colluvium deposits, suggesting this interval correlates with the nonconsolidated breccia exposed in the open shaft nearby. The conductive portions (blue) could correspond to relative concentrations of iron-rich clay vs. concentrations of (resistive) carbonate as limestone clasts and matrix precipitate. The relatively continuous and consistently resistive region at lower right in both diagrams is interpreted as Edwards limestone bedrock which lacks clay-rich layering, but subtle lateral variation within these anomalies may reflect moisture concentrated in vertical fractures associated with the surrounding Balcones fault system (Barnes, 1974).

As at STAFS, anomalies of relatively high resistivity (yellow-orange to red) are associated with decomposed remains, borne out by comparison between FARF model profiles -01 and -02. However, at this location, all but one (D31-2014) of the resistive contaminant plumes appear to be paired with an

immediately subjacent conductive region. While the conductive anomalies in these profiles can be interpreted as concentrations of iron-rich clay in the fan breccia, a purely coincidental association of grave shafts with clay-rich lenses seems improbable. Moreover, isolated meter scale conductive anomalies are lacking in the model profile along the baseline transect, FARF-02. These observations invite the hypothesis that these conductive anomalies could be the signatures of a conductive component of the decomposition fluid that fractionated as a mobile saline aqueous solution from the original decomposition fluid, separating from a less mobile, more resistive assemblage of organic compounds.

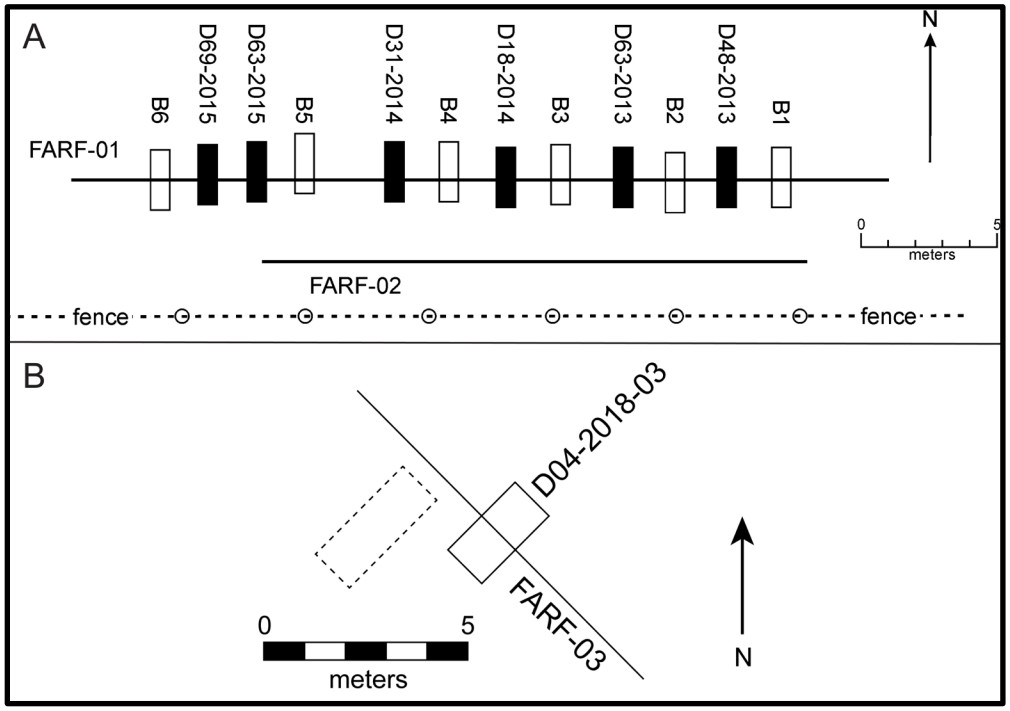

Figure 12. Maps of transects FARF–01 and –02 (a) and FARF–03 (b). In (a) transects are labelled and shown with heavy solid lines. Rectangles indicate grave shaft depressions in correctly scaled sizes, shapes, and positions. Filled rectangles with ID numbers indicate human graves, unfilled rectangles and 'B-' indicate blank or 'control' graves. Dotted rectangle in (b) is open grave from which remains had been removed prior to time of the survey.

FARF–03. The inversion model profile of FARF-03 is color contoured and interpreted in Figure 14 using the same bar scale as in Figure 13. A pole-dipole array, 0.5-m spacing, N = 8, and remote electrode ~ 20 m southwest was used to profile a relatively young (3 months) grave placed in mid-January 2018 (Table 1; Figure 12(b)). The interpretative diagram suggests the upper surface of Edwards limestone bedrock at 1.0–1.25 m depth overlain by muddy Pleistocene breccia. A high resistivity contaminant plume, enveloping and diverging from the remains proper, is mapped as a roughly conical shape settled on impermeable limestone bedrock, cradling a vertically eccentric conductive anomaly.

The conductive anomaly coincides with the region of back-fill, but its cause is unclear. The coincidence suggests the conductive anomaly is consistent with moist, clay-rich backfill. However,

because the back-fill lithology should be the same as the undisturbed host, a significant contrast in electrical resistivity is unexpected. Alternatively, perhaps some of the increase in conductivity could be attributed to early stage contamination by a fractionated conductive phase. This notion conflicts with interpretations of profile FARF–01 that identify the conductive anomaly in a position adjacent or subjacent to the resistive anomaly. However, burial FARF-03 is significantly younger (3 months vs. 2–4 years) allowing the possibility of relative movement of contaminant plumes shortly after purge.

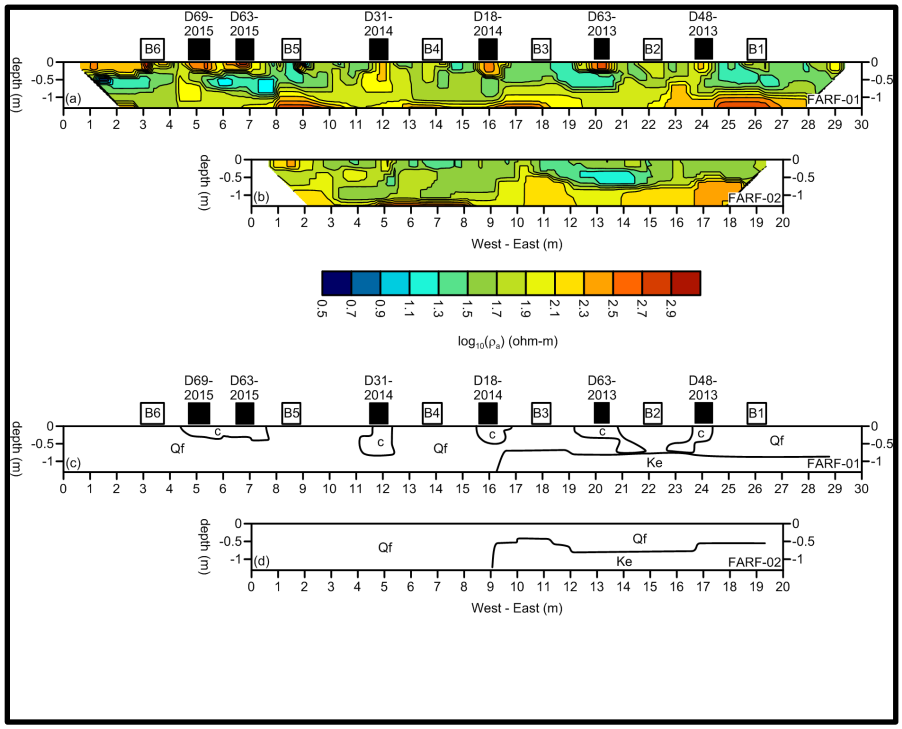

Figure 13. Color contour inversion models of profiles FARF–01 (a) and FARF–02 (b) and respective interpretations (c) & (d). Profile diagrams are shown in correct relative West – East positions. As in Figure 12, solid squares locate human graves, unfilled squares locate blank graves. In (a), high resistivity anomalies correlate to human graves. In (c) and (d), 'c' = contaminated soil/sediment, 'Ke' = Cretaceous Edwards limestone, 'Qf' = Quaternary (Pleistocene) alluvial fan material local breccia). Dipole–dipole, a = 0.5 m, d = 0.5 m, N = 8.

Summary

This study shows foremost that evidence of soil contamination by human decomposition can be detected using electrical resistivity survey methods. Distinct resistive anomalies are found to correlate to human decomposition in shallow graves (< 1.0 m) and on the ground surface. The anomalies are interpreted to represent either the residue of permeated decomposition fluid or the fluid itself, and are fairly distinct in situations where the contaminated host sediment has not been disturbed. A general correlation of electrically resistive anomalies with human decomposition is consistent with results of a multi-year geophysical study with buried hogs (Jervis et al, 2009; Pringle et al, 2016).

This study also illustrates the difference in model results obtained from dipole arrays of different spacings. A dipole–dipole array with electrode and data spacing a = 0.5 m and N = 8 readings per array shift produces a high resolution image down to about a 1.2-m depth. A pole–dipole array of the same spacing produces information to a greater depth (~ 1.7 m) and in the same amount of field measurement time with slight resolution loss. Greater depth (~ 2.3 m) is reached with minimal loss of resolution using a 1.0-m dipole–dipole array with data spacing of 0.5 m and N = 8, but at the cost of quadrupling the measurement time over the same transect length.

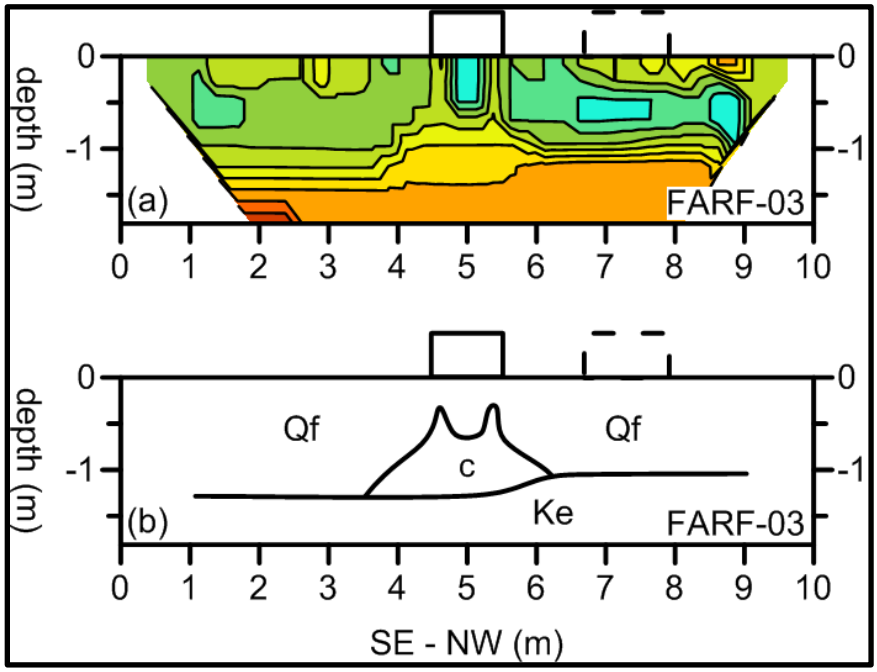

Figure 14. Color contour inversion model of profile FARF–03 (a) and interpretation (b). Color scale as in Figure 13. Profiled grave indicated with solid rectangle; nearby grave (to southwest – see Figure 12(b)) indicated by dashed rectangle. Annotations for (b) are as in Figures13(c) and (d).

Another goal of this study was to assess the effectiveness of electrical resistivity profiling as a search technique for unmarked graves. Half-meter spaced profiling produces excellent spatial resolution, but it is time economical as a search technique only in areas of a few meters' length or breadth. An area of quadruple-size scale can be timely addressed using an array with 1.0-m electrode and data spacing, but the technique is less economical over distances greater than about 30 m. Anomaly resolution is lower with the coarse array, but the STAFS profiles show that decomposition contamination is sufficiently resolved to guide subsequent higher resolution profiling, soil sampling, or exploratory digging.

Results from the FARF profiles hint at the notion that the original decomposition fluid mélange fractionates into conductive and resistive components during plume permeation. It is hypothesized that the conductive component is a relatively mobile saline aqueous solution, while the resistive phase perhaps

consists of insoluble compounds of such viscosity as to permeate only a short distance from the source. The data and models do not address whether contaminant permeation is episodic with rainfall or is a single event terminated by the loss of the original aqueous phase to evaporation. Testing this hypothesis and addressing these questions requires a time series of electrical tomography images that would presumably follow the evolution and migration of the decomposition plume (cf. Pringle et al, 2012). Such a data series can be constructed by a conceptually simple experiment in which periodic electrical surveys are performed over a single isolated grave or a small number of fresh graves widely spaced in virgin soil.

TABLE 1.

Data and Parameters of STAFS and FARF Electrical Resistivity Profiles

Profile	Location	Specimens (verbatim from marker)	Array	Length (m)	Depth (m)	Survey Date
STAFS-01	STAFS: Area 1A, Sec. VII	STAFS 2010-011; WF UA; 11-18-10 STAFS 2010-016; WF UA; 12-7-10 STAFS 2010-007; WM UA; 12-7-10	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 7	13.0	1.2	07 Dec., 2016
STAFS-02	STAFS: Area 1; Sec. XI	n/a	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 7	8.0	1.2	08 Dec., 2016
STAFS-03	STAFS: Area 2B	STAFS 2013-030 STAFS 2014-075 STAFS 2014-074 STAFS 2013-050 STAFS 2014-043	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 7	14.0	1.2	11-12 Jan., 2017
STAFS-04	STAFS: Area 1A, Sec. VII	STAFS 2010-011; WF UA; 11-18-10 STAFS 2010-016; WF UA; 12-7-10 STAFS 2010-007; WM UA; 12-7-10 STAFS 2014-063; BM; 9-19-14	dipole-dipole; a = 1.0 m, d = 0.5 m, N = 7	17.5	2.1	22-23 March, 2017
STAFS-05	STAFS: Area 1A, Sec. VII	STAFS 2010-011; WF UA; 11-18-10 STAFS 2010-016; WF UA; 12-7-10 STAFS 2010-007; WM UA; 12-7-10 STAFS 2014-063; BM; 9-19-14	dipole-dipole; a = 1.0 m, d = 1.0 m, N = 7	17.5	2.4	22-23 March, 2017

FARF-01	FARF	D48-2013 D63-2013 D18-2014 D31-2014 D63-2015 D69-2015 #1 - #6 CONTROL	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 8	30.0	1.2	26 Oct., 2017
FARF-02	(3.0 m south of FARF-01)	none (baseline profile)	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 8	20.0	1.2	27 Oct., 2017
FARF-03	FARF	D04-2018; 1-22-18	dipole-dipole; a = 0.5 m, d = 0.5 m, N = 8	10.0	1.6	19 April, 2018

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