Geophysical Prospection for Late Holocene Burials in Coastal Environments: Possibilities and Problems from a Pilot Study in South Australia

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Geophysical techniques have been widely employed for the noninvasive location of burial sites in archaeological and forensic investigations. This approach has met with varying degrees of success, depending on factors such as equipment choice, survey methodology, burial type, and geological setting. This paper reports the results of a multitechnique geophysical survey carried out immediately prior to the salvage excavation of two Indigenous burials from an eolian dune in coastal South Australia. Ground-penetrating radar was not successful in defining the location of the burials owing to the disturbed nature of the local stratigraphy. Magnetic field intensity and apparent magnetic susceptibility surveys identified discrete anomalies that coincided with the location of skeletal material revealed during excavation, which we hypothesize to be due to burning or ochre use during funerary practices. Despite the spatial association of these features, subsequent laboratory analyses of the mineralogy and magnetic properties of sediments collected from the site failed to find a definite cause of the anomalies. Nevertheless, the association between them and the primary interment locations has implications for archaeological surveys carried out in the Australian coastal zone, as it highlights the potential of magnetic field intensity and apparent magnetic susceptibility geophysical techniques undertaken with a more refined survey methodology to afford a noninvasive, culturally appropriate means through which to detect Indigenous burials. This approach may prove particularly useful in areas with disturbed stratigraphy where ground-penetrating radar is less effective. © 2010 Wiley Periodicals, Inc.

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INTRODUCTION

The location of unmarked subsurface burials presents a challenge to the archaeologist or forensic investigator as these features are often not apparent on the surface, are usually constrained in their geographic extent, and are difficult to detect through conventional minimally invasive investigation methods such as cadaver dogs, probing, or investigation of A-horizon disturbance (Killam, 1990; Owsley, 1995). This situation is exacerbated by widespread sensitivity toward the direct investigation of human remains, a concern that is particularly poignant for many Indigenous Australian communities, who consider that the disturbance of their ancestors can have dangerous consequences (e.g., Hemming, 2000). Despite this cultural disinclination to disturb burials, various processes such as the encroachment of development and changing patterns of erosion mean that it is often an inevitable and unavoidable occurrence. When this happens, it often requires a rapid response to put appropriate mitigation procedures in place (for a discussion of reburial issues see Wallis et al., 2008). Clearly, this is best avoided, and so the ability to determine the location of skeletal material with confidence through noninvasive techniques, prior to unavoidable disturbance, affords Indigenous communities the opportunity to develop mitigation or reburial strategies in a timely, well-considered manner.

In this paper we present a case study in which geophysical techniques were used to locate buried Indigenous skeletal remains in a coastal site where erosion had commenced and hence urgent excavation, reinterment, and site rehabilitation was required. The success of these methods in determining that the burials are associated with distinct geophysical anomalies (though whose origins are not well understood at this time) indicates the potential for them to be used in similar situations elsewhere.

THE GEOPHYSICAL LOCATION OF BURIALS

Geophysical survey techniques have long been recognized as a useful tool for the location of buried human remains, based on their ability to image the subsurface by measuring a variety of physical properties (Bevan, 1991; Buck, 2003; Davenport, 2001; France et al., 1992; Powell, 2004; Ruffell & McKinley, 2005). Of the various methods available, ground-penetrating radar (GPR) has proven to be the most consistently successful (France et al., 1992), usually when there are clear areas of dislocated stratigraphy or where interment involves a coffin. In some specific circumstances the skeletal material itself can be detected (e.g., Schultz, 2007), although this is rare.

Other techniques that have been used with varying degrees of success for subsurface burial detection include magnetometry, electromagnetic induction (EMI), and direct current resistivity. Magnetometry, either in single-sensor or gradiometer mode, has a long history of use in European and North American archaeology (e.g., Abbott & Frederick, 1990; Black & Johnston, 1962). Fire has been a particular target of magnetometer investigations as it has been demonstrated to create magnetic anomalies, either through the enhancement of soil magnetic susceptibility (Dalan

& Banerjee, 1998; Weston, 2002), the contribution of wood ash (McClean & Kean, 1993; Peters, Church, & Mitchell, 2001), or from both mechanisms (Linford & Canti, 2001). It therefore follows that if burial traditions involved an aspect of fire (such as smoking the burial pit or cremation of the body itself), magnetometry may be of assistance in identifying interment locations. An additional application of magnetic methods for the location of burials is through the identification of disturbance to the magnetic properties of the soil stratigraphy (Nobes, 1999:363). However, we consider this unlikely in the case study presented, owing to the relatively homogenous sandy nature of the substrate.

EMI is capable of detecting a wide range of features including soil type, sediment type, bedrock location, or the presence of cultural material (Kvamme, 2003). The EMI technique can locate burials through either the detection of metallic grave goods or metal within the interment “vessel,” or through changes to soil conductivity caused by the burial and associated sedimentary disturbance, as well as theoretically by detecting the actual skeletal remains themselves, though the latter is unlikely in most situations (Nobes, 2000:716; Nobes & Tyndall, 1995:266).

Direct current resistivity has also been used with some success to locate burials contained within a coffin (Powell, 2004), where it can identify contrasts between the resistivity of the substrate and the grave fill or the coffin cavity. Direct current resistivity should also have application in circumstances where burials are not contained in a coffin, by detecting the contrast in resistivity between the disturbed ground of the grave fill and the surrounding undisturbed stratigraphy.

Typically, the geophysical survey of burial sites has been driven by a forensic aim (Schultz, 2007), although the location of all types of burials is also a valid and urgent concern for archaeologists, city and town councils, Indigenous communities, and other local community heritage groups. In Australia, published geophysical surveys of cemeteries and burial sites, even those of non-Indigenous origin, have been extremely restricted to date, with the notable exception of Stanger and Roe (2007). Exacerbating this deficiency, most archaeological investigations of Australian Indigenous burial sites were conducted prior to the 1980s, when geophysical survey techniques were rarely utilized (e.g., Haglund, 1976; Pretty, 1977; Stirling, 1911; Thorne & Macumber, 1972). Since Indigenous communities gained greater control over their heritage in the 1980s, far fewer archaeological investigations of Indigenous burial sites have been carried out. Consequently, even fewer geophysical surveys of Indigenous burials have been attempted, let alone ground-truthed (though see NSW NPWS, 2003, for a summary). Given the sensitivity of Indigenous burial sites (e.g., Bell, 1998; Hemming, 2000) and the greater control communities now exert over if, when, and how such sites are investigated, noninvasive geophysical techniques potentially afford a culturally appropriate means by which to continue research into burials without causing disturbance to them, thereby satisfying both researchers’ and community desires (cf. Wallis et al., 2008).

Most geophysical studies aiming to locate burials in Australia have been carried out on an ad hoc basis as locations for survey arise opportunistically, ignoring the effects that variations in geology (Doolittle & Collins, 1995) and burial properties (Powell, 2004) have on the nature of the geophysical response. These factors conspire to mean that anomalies "that are identified by remote sensing cannot be definitely equated with human remains with current technologies" (Powell, 2004:88), indicating that further baseline research on the application of this technology is required.

Environmental magnetic measurements may address this situation by allowing the quantification of the potential of a magnetic signal to be associated with a burial. This method of analysis provides information on four basic categories of magnetic mineral properties: (1) magnetic mineral abundance; (2) ease of magnetization, which is often related to magnetic mineral grain size; (3) stability, which is often linked to magnetic oxide composition (i.e., canted antiferrimagnetic to ferrimagnetic relative abundance); and (4) magnetic grain interaction (Maher, Thompson, & Hounslow, 1999). These measurements provide a variety of data to assist in the study of archaeological contexts, with magnetic susceptibility being widely used alongside conventional magnetometry survey techniques (Dalan, 2007; Dalan & Banerjee, 1998). Magnetic measurements on soils can respond to burning events, through soil heating (Linford & Canti, 2001; Marshall, 1998; Weston, 2002) and also through the magnetically enhanced remains of the burnt materials (Church, Peters, & Batt, 2007; Hounslow & Chepstow-Lusty, 2002; Peters, Church, & Mitchell, 2001). In both these situations, new magnetic minerals can also be produced during the burning process. Post-burial decay of bodies and other organic materials also has the potential ability to enhance the natural processes of magnetite formation in soils (Linford, 2004; Weston, 2002).

An opportunity to more systematically test the applicability of geophysical and geochemical techniques to the identification of Indigenous burials in a coastal geological context became available in late 2006, when members of the Ngarrindjeri community requested that archaeologists carry out a salvage excavation and reburial of at least one individual eroding from the lower reaches of an eolian sand dune. After discussions about potential benefits and future applications, it was agreed that a geophysical survey could precede the excavation. If a positive relationship could be established between geophysical anomalies and known burial locations, it would build confidence in the adoption of such techniques for the location of burials where the opportunity to ground-truth the results was absent. The primary aim of this pilot study was thus to determine if known Indigenous burials in coastal sand dunes in southern Australia resulted in sufficient changes to the physical properties of the burial medium so as to be detectable using geophysical techniques.

Ngarrindjeri *Ruwe* and Burial Practices

The study was conducted within the *ruwe* (country) of the Ngarrindjeri people, an area extending across the lower Murray River, around Lakes Alexandrina and Albert, down the tidal barrier lagoon of the Coorong and west through the southern Fleurieu Peninsula south of Adelaide in South Australia (Figure 1). Ngarrindjeri *ruwe* provides abundant riverine, coastal, and estuarine resources, supporting some of the highest population densities in Australia at the time of European invasion (Jenkin, 1979). The high population figures of Ngarrindjeri *ruwe* (and further upstream along the Murray River) translate into large numbers of burials, which are typically located

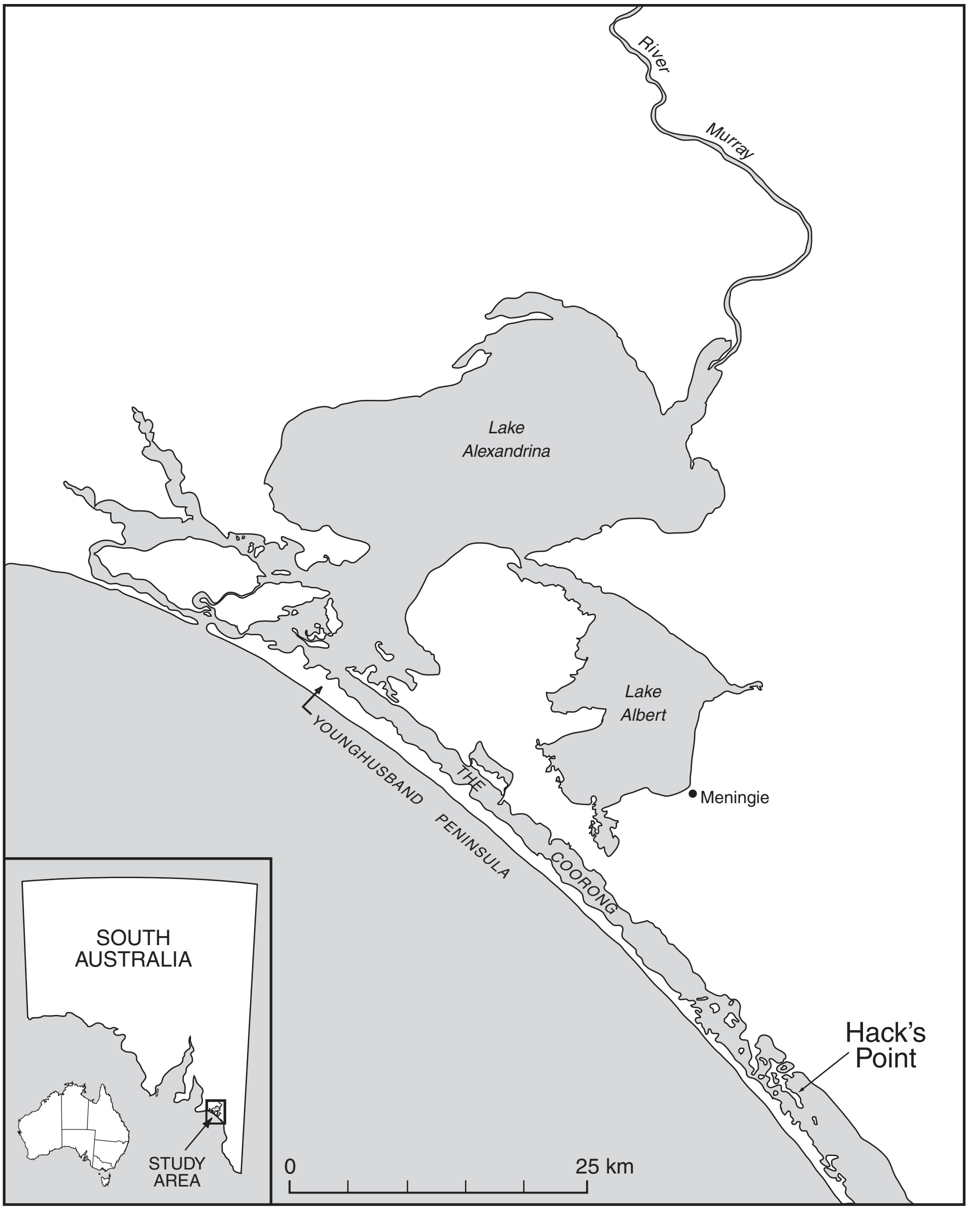

Figure 1. Map showing the location of the Hack's Point study area, South Australia.

in the unconsolidated sands of the extensive contemporary and relict dune systems of the region (e.g., Littleton, 1999, 2007; Pardoe, 1988; Pretty, 1977). Such sites are of high cultural significance, providing "contemporary Ngarrindjeri people with a physical and spiritual connection with their ancestors and their 'country'" (Hemming, 2000:63).

Of particular interest for the purposes of this study are the ceremonial aspects of the Ngarrindjeri burial process, especially the role of fire and use of ochre. Accounts dating back to the mid-1800s have described in detail such practices, particularly the construction of burial platforms to smoke and dry the "red ochre covered" body prior to burial (e.g., Bell, 1998; Berndt, Berndt, & Stanton, 1993:273; Hemming, Jones, & Clarke, 1989; Taplin, 1879). These ceremonies could continue for up to three months, leading to a long residence time for discrete burial related fires. The association of charcoal (Wallis, Hemming, & Wilson 2006) and ochre (South Australian Aboriginal Heritage Register, unpublished data) with burials in the region are supported by archaeological investigations. This close association of burials with both fire and ochre suggested it might be possible to use magnetic techniques to detect Ngarrindjeri burial sites.

The Study Site: The Hack's Point Burial Complex

The study was undertaken at the Hack's Point burial complex, located at the southern end of a small promontory jutting into the lagoonal waters of the Coorong (see Figure 1). Geologically the region is dominated by the interplay between eolian and coastal processes, leading to convoluted spatial and temporal relationships between geomorphic units. Of direct relevance to this study, two generations of eolian dunes are present: older, lithified dunes representing the previous sea level highstand, nestled among which are a much younger generation of Holocene-aged dunes relating to the current sea level (Bourman et al., 2000; Von der Borch, 1974). The study site is situated on the northern side of one of these Holocene-aged sand dunes, which is lightly vegetated by *Acacia*, she-oaks, and an array of annual herbs and grasses.

The site includes at least two individuals, one of which was already extensively exposed through erosion, thereby instigating the necessity of the salvage excavation. The existence of at least one additional burial in the vicinity was strongly suspected based on the presence of a second cranial (brow ridge) fragment also exposed through erosion (see Figure 2). Also nearby were the remains of a collapsed platform, such as may have been used for either the smoking or display of the body after death as part of traditional burial rites.

Methodology

Field-Based Geophysical Investigations

A grid measuring 8 × 3 m was established over the area of interest using an automatic level and measuring tapes to facilitate the accurate location of data points. The geophysical techniques used for this investigation included ground-penetrating radar (GPR), electromagnetic induction (EMI), and single-sensor proton precession

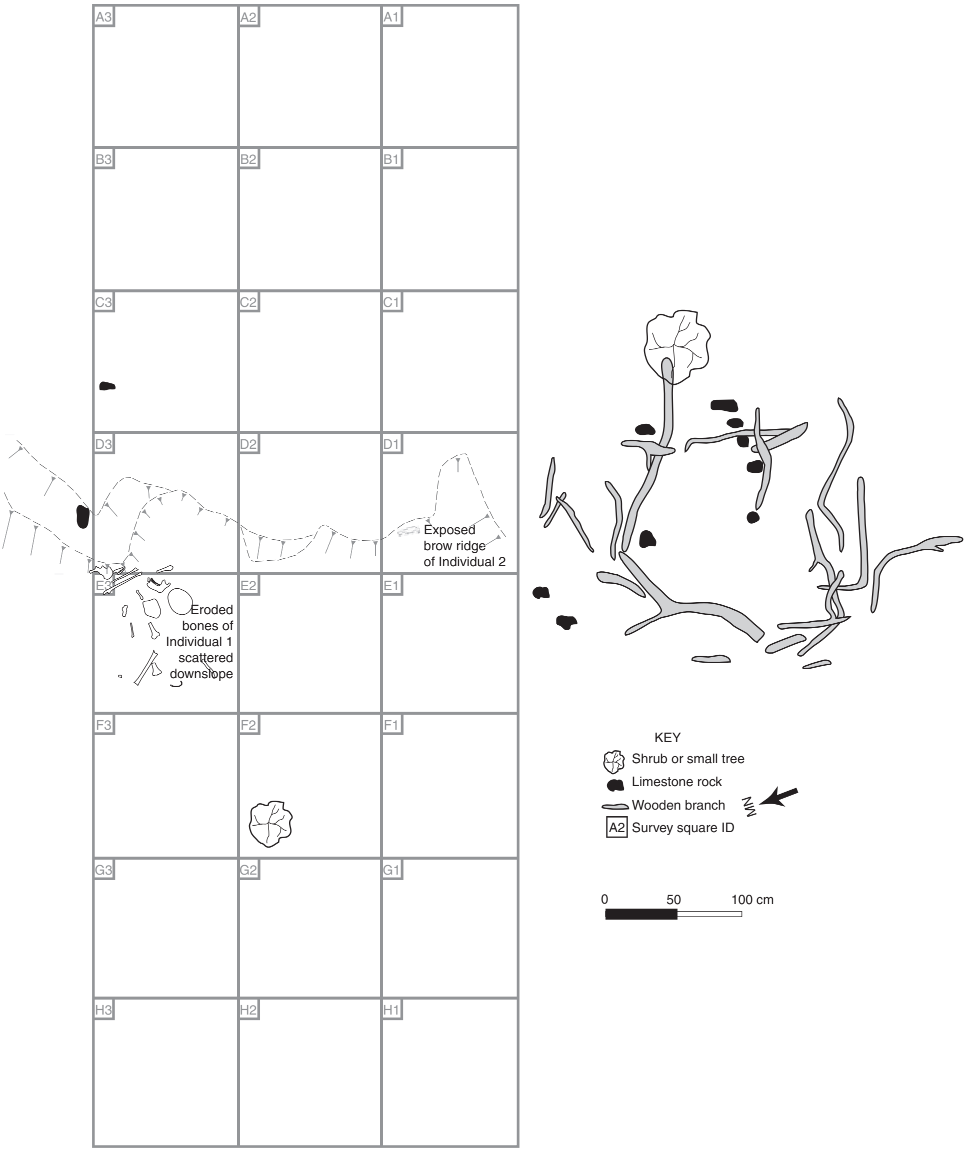

Figure 2. Site plan and survey grid over the Hack's Point burial complex, South Australia.

magnetometer. GPR was collected using a Mala/Ramac X3M with a 500-MHz antenna and a line spacing of 0.5 m. Magnetometer data were collected on 0.5-m survey lines and station spacings over the grid, using a Geometrics G-856 single-sensor proton precession magnetometer tuned to a background level of 59,000 nT. Data values varied from 59,751.4 nT to 59,777.3 nT with a range of 25 nT and a standard deviation of 4.05 nT. No diurnal correction was applied owing to the short duration (approximately 1 hr) of the survey, based on the findings of Silliman, Farnsworth, and Lightfoot (2000) that surveys of limited duration do not suffer from a significant reduction of data quality in its absence. EMI data were collected on the same grid using a Geophex Gem-2 instrument collecting in-phase and quadrature data for the frequencies 4075 Hz, 9875 Hz, 18,075 Hz, 24,975 Hz, and 41,375 Hz. Apparent magnetic susceptibility was calculated as a dimensionless value from the quadrature and in-phase response by WinGem v3 software based on the homogeneous half-space assumption, as described by Huang and Won (2000:33).

GPR data were processed using ReflexW using a processing flow including the following processing steps: subtract mean (dewow), energy decay, declipping, correct max phase, move start time, and background remove. The interpretation process was based on the assumption that any discontinuities in the stratigraphy or discrete hyperbolas were thought to represent a possible association with burials. This assumption would necessarily produce a large number of anomalies, which, however, would hopefully not miss features of interest. All collected magnetometer and EMI data were gridded with MagPick software using a spline interpolation (Smith & Wessel, 1990) with an X and Y interval of 0.25, a tension of 0.25 for 4000 iterations with a convergence limit of 0.1, using the highest and lowest data values as data limits. Data were displayed as a simple contour map with 250 nonequalized color points with overlain contours after the resolution was increased to an appropriate level for display using a bilinear function.

Excavation and Skeletal Analysis

The already established geophysical survey grid of 1 × 1 m squares (see Figure 2) was used as the basis for the subsequent excavations so the results could be easily compared to the identified geophysical anomalies. Survey squares in rows C, D, and E were identified as the priority for excavation owing to the presence of exposed bones and geophysical survey results. Survey squares in rows A and B were not excavated due to the absence of surface indications of bones, time constraints, the lack of geophysical anomalies (see Results section), and the general risk of destabilizing the site. Sixteen bulk sediment samples of ca. 1 kg were collected during excavation from the various sedimentary units encountered; these were used to carry out the X-ray diffraction and laboratory-based magnetic analysis described below (see Table I).

In keeping with community wishes, all bones recovered during the excavations were studied on site using methods outlined by Buikstra and Ubelaker (1994). Once analysis had been completed, the skeletal material was reinterred as close as possible to the original interment locations. A protective layer of sand-filled biodegradable bags was then positioned over the site to facilitate revegetation.

X-Ray Diffraction Analysis

X-ray diffraction of all samples was carried out with a Siemens D501 Bragg-Brentano diffractometer, equipped with a graphite monochromator and scintillation

Table I. Sediment samples.

Sample Number	Location	Excavation Trench	Date Collected	Unit
001	E4	HP1	06/01/07	Rabbit burrow fill
002	D3/E3	HP1	05/01/07	Associated with right tibia of Individual 1 in rabbit burrow
003	D3	HP1	05/01/07	Unit 1
004	F4	HP1	07/01/07	Unit 3
005	F4	HP1	07/01/07	Unit 2
006	C1	HP1	07/01/07	Unit 1
007	D3	HP1	05/01/07	Unit 1
008	D4	HP1	06/01/07	Unit 1, surface sample
009	C1	HP1	07/01/07	Unit 1, surface sample
010	E1	HP1	05/01/07	Associated with ribs of Individual 2
011	F4	HP1	06/01/07	Unit 1, surface sample
012	D2	HP1	04/01/07	Unit 1, 25 cm below surface
013	E1	HP1	06/01/07	Unit 1, damp sandy feature
014	F3	HP1	07/01/07	Unit 1, surface sample
015	D1	HP1	04/01/07	Unit 1, surface sample
016	E4	HP1	06/01/07	Unit 2

detector, using CuKα radiation. All samples were scanned from 2° to 70° 2θ, at a step width of 0.02° and a scan speed of 1°/minute.

Bulk sediment samples were analyzed using a bulk scan, as a mineral separate and as a magnetic fraction. The bulk scan subsamples of 2 g were milled in a McCrone Micronizing Mill in ethanol for 20 minutes, dried, and filled in a side packed sample holder. To obtain the mineral separate sample, 10 g of bulk sediment sample was suspended in an aqueous solution of sodium polytungstate with a specific density in the range of 2.81–2.89 g/cm^3. After 1 hr, the heavy minerals had settled out and were extracted from the bottom of the glass flask onto filter paper, washed with deionized water, and dried. They were hand-ground in acetone in an agate mortar and suspended onto a quartz low-background holder. For samples 4 and 10, a magnetic fraction was collected by drawing a magnet through sediment subsamples, generating a small sample of magnetic minerals. Mineral identification was performed with the program DiffracPlus Eva 10.0.

Analysis of Environmental Magnetism

Magnetic susceptibility (χ) of the bulk sediment samples was measured in the laboratory using a Bartington MS2 susceptibility meter (Dearing, 1999). This was performed at two frequencies (470 Hz and 4700 Hz) to give the low frequency susceptibility (χ_{lf}) and the percentage frequency dependent susceptibility (%χ_{fd}). The χ_{lf} provides an indication of the total abundance of magnetic material (commonly magnetite), whereas the %χ_{fd} is an indication of the relative amount of superparamagnetic magnetite (i.e., grain size ca $<0.03\ \mu$m), commonly related to either sources of pedogenically enhanced topsoil (Dearing, 1999) or burning events. Anhysteretic remanent magnetizations (ARM) were applied using a DC field of 0.1 mT and an alternating field of 80 mT (Walden, 1999) and converted to susceptibility of ARM (χ_{ARM}). χ_{ARM} provides an indication of the relative abundance of single-domain grains of magnetite (i.e., grain size ca. 0.03 μm) and their degree of magnetic interaction (Maher, Thompson, & Hounslow, 1999). Following saturation isothermal remanent magnetization (SIRM) at 1000 mT (using a Newport electromagnet), back field IRMs were applied with a Molspin Ltd. Pulse magnetizer at 20, 50, 100, and 300 mT (Walden, 1999). The IRM values were converted to %bIRM$_{\text{field-interval}}$, which indicates the percentage of backfield IRM acquired over particular applied field intervals (e.g., %bIRM$_{0\text{-}20\,T}$). Ratios of χ_{lf}, χ_{ARM}, and IRM (or SIRM) provide various discriminators for the above four categories of magnetic proxies, and are detailed in Maher, Thompson, and Hounslow (1999) and Peters and Dekkers (2003). The S (-bIRM100$_{mT}$/SIRM) and L-ratio values (Liu et al., 2007) were also determined.

The measurement of *in situ* induced and remanent magnetism was not possible for this study as detailed laboratory-based magnetic analysis was not considered for this site until after it had been excavated and subsequently refilled. The authors consider that this method would make a worthwhile contribution to future studies of this type.

Results

Geophysical Survey

The magnetometer data show a discrete anomaly with elevated magnetic intensity (+15 nT) on the eastern edge of the survey area, coincident with the subsurface location of Individual 1. There is no anomaly coincident with the primary or secondary interment locations of Individual 2. The subtle nature of the magnetic field intensity response suggests that a gradiometer may have been a more appropriate choice for the targets encountered in this survey, although an instrument of this type was not available for this study.

The field-based apparent magnetic susceptibility data derived from the EMI for the 41,375 Hz frequency (indicative of our most shallow depth of investigation) shows an anomalous zone of elevated response coincident with the interment locations of both Individuals 1 and 2. All other frequencies plotted for EC and apparent magnetic susceptibility show no anomalies spatially consistent with burial locations. (See Figure 3.)

The GPR revealed a large number of anomalies (87 in total), which appeared as discrete hyperbolas or dislocations in reflectors. These anomalies were principally not related to the burials, probably reflecting bioturbation from such agents as rabbits, lizards, and vegetation. This appears to support the findings of Nobes (1999:363) that using a high antenna frequency for burial investigations can be ineffective. As the survey site has now been destroyed through excavation, we are unable to test

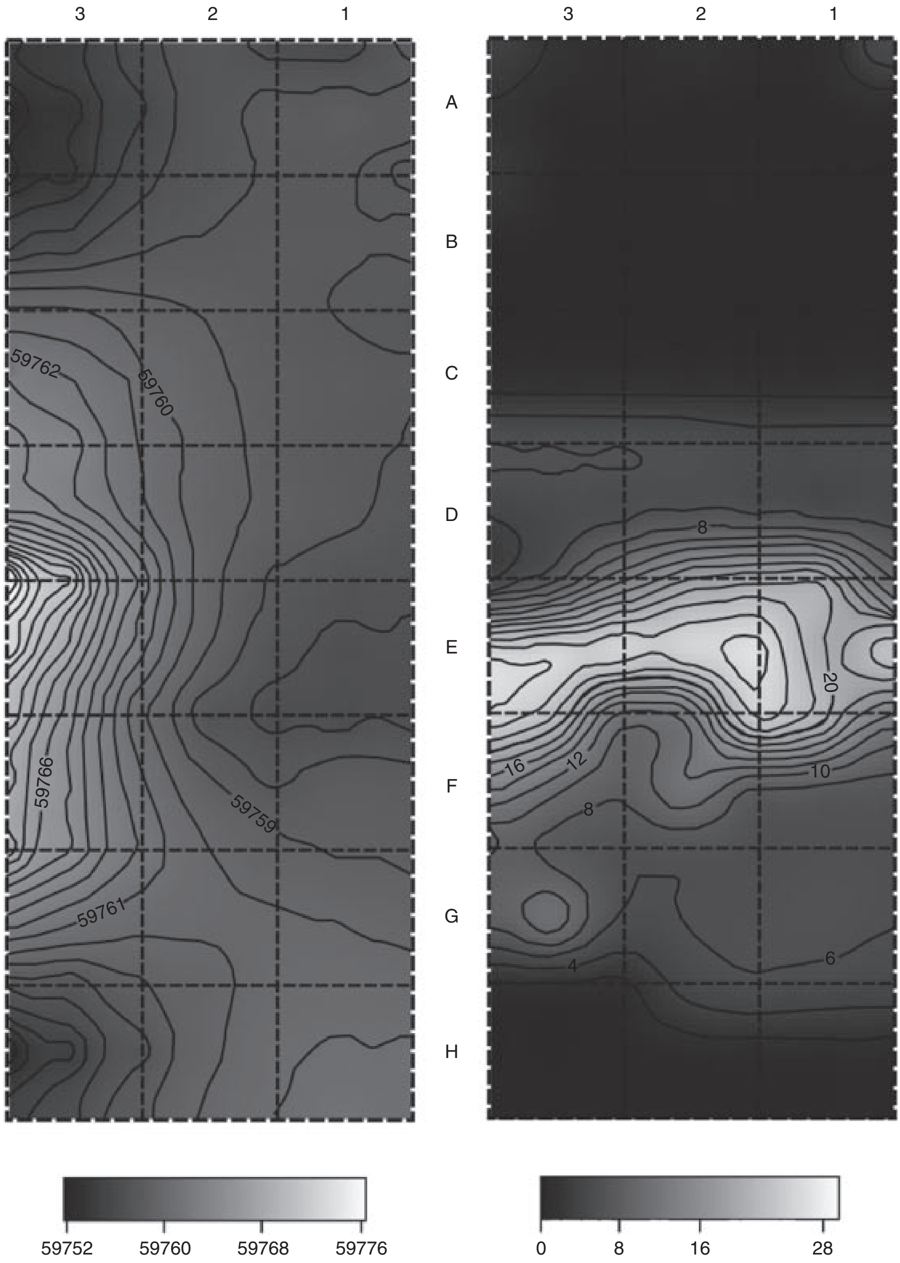

Figure 3. Geophysical survey results with magnetic intensity in nT (left) and apparent magnetic susceptibility derived from the 41,375 Hz electromagnetic induction data (right), Hack's Point, South Australia.

whether a lower antenna frequency would have been effective in this case; however, the authors intend to experiment with this in future trials in this area.

Site Stratigraphy

Excavation revealed the dune consisted of two main stratigraphic units, in addition to the grave fills. Unit 1 was a grayish-brown colored sand with the upper part approximately 5–10 cm thick, containing reasonable quantities of charcoal and decaying organics such as roots, twigs, leaves, and seeds, and below this level a further 30–40 cm had minimal quantities of organic materials present. Underneath Unit 1 was a second stratigraphic unit comprising a clean, finely sorted yellow sand that contained no organic detritus at all (Unit 2). The burials themselves were associated with a fine, grayish colored sand that had occasional small flecks of charcoal present (Unit 3). There was some evidence for a grave cut in the eastern wall of Square D3 associated with the excavation of Individual 1, although no such feature could be seen associated with Individual 2.

Interment Locations

The primary interment location of Individual 1 was known prior to survey or excavation as a result of the extensive erosion (see Figure 4). Excavation recovered almost all of the bones of this individual, with approximately half of them having been disturbed by taphonomic processes or human intervention from their original interment location. The remainder were found largely articulated and in an anatomically correct position, approximately 20–30 cm below the current sloping ground surface. The bone positioning suggests that this individual was buried lying on their back with the elbows flexed and confirms that the primary interment site was in the far northwestern corner of Square D3. A small sample of charcoal associated with the base of the grave of Individual 1 returned an age estimate of 2017 ± 35 B.P. (Wk-18512), with a calibrated 2 sigma age range between 1880 and 2060 B.P. cal.

Excavation indicated that the partial cranial fragment belonged to a second individual buried at the site (Figure 4), almost all the bones of which were also recovered. Of particular relevance for the geophysical survey results, this individual was associated with both a primary and secondary interment site. The primary interment site was demonstrated through excavation to occur along the western margin of the corner of Squares D1 and E1, as indicated by the presence of the articulated left shoulder and rib bones. Approximately 60 cm upslope (i.e., centrally in Square D1) was a secondary interment location, containing a bundle of non-articulated bones, including the right and left arms, right leg and pelvis, the mandible, and the right clavicle and scapula. The evidence suggests this secondary material may have eroded at some time in the past and then been quickly reburied. This proposition is supported by the bones' relatively good state of preservation, which otherwise would have rapidly deteriorated with exposure to the elements.

A detailed discussion of the skeletal analysis results is presented elsewhere (Niland, 2007; Niland, Domett, & Wallis, 2009) and will not be discussed further herein.

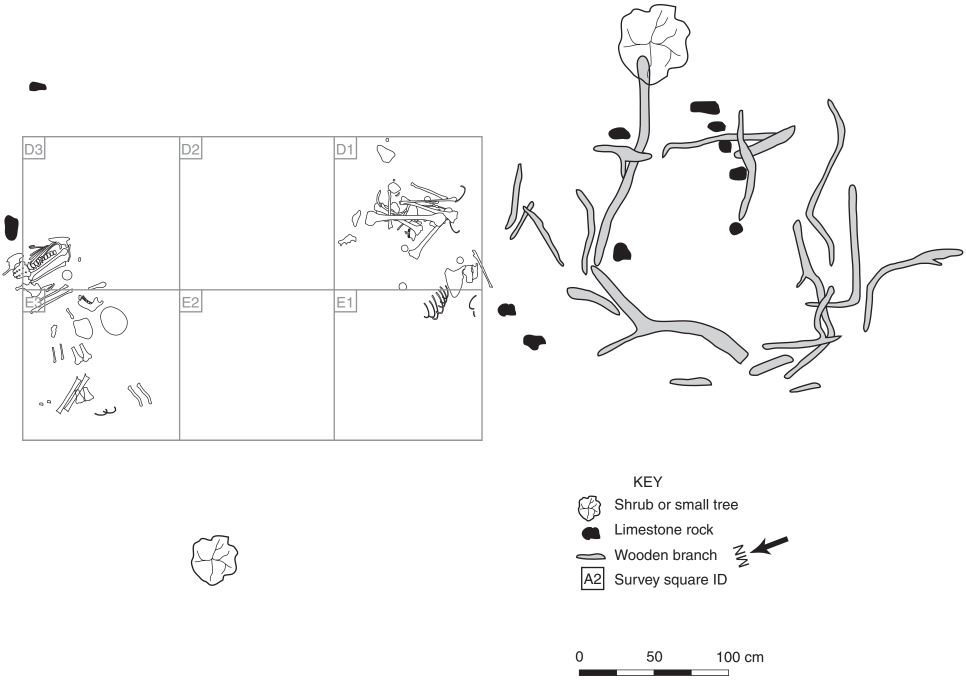

Figure 4. Detailed plan of Individuals 1 and 2, Hack's Point burial complex, South Australia.

X-Ray Diffraction

A summary of the XRD results is provided in Tables II and III and described briefly below.

X-ray diffraction analysis of the bulk sediment samples show that quartz, K-feldspar, plagioclase, calcite, and clay are ubiquitous. Muscovite/illite are present in samples 2, 5, 7, 10, and 11, while trace amounts of aragonite are found in samples 6 and 15 and traces of gibbsite are found in sample 8. Variations in the mineralogy between the bulk samples seem unrelated to geophysical response, facies unit, or association with burials.

Quartz, tourmaline, hornblende, rutile, zircon, ilmenite, andalusite, anatase, sillimanite, and epidote are ubiquitous in mineral separates analyzed by XRD. Muscovite/illite is present in the mineral separates of all except sample 3. Calcite is present in mineral separates 4, 5, 10, 11, and 14. Kyanite is present in mineral separates 12, 14, 15, and 16. Romerite is present in mineral separates 6, 7, and 8. Monazite is present in mineral separate 5. Topaz is present in mineral separate 1.

The magnetic mineral separates collected from samples 4 and 10 both contained significant amounts of ilmenite but no other detectable magnetic mineral. These samples also contain nonmagnetic minerals (quartz, K-feldspar, plagioclase, calcite, and traces of muscovite and hornblende), which are likely to be contaminants in the magnetic separate.

Table II. X-ray diffraction bulk analysis samples.

Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Quartz	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
K-feldspar	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plagioclase	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Calcite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Clay	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Muscovite/illite		X			X		X			X	X					
Trace aragonite						X									X	
Trace gibbsite								X								

Table III. X-ray diffraction mineral separate samples.

Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Quartz	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tourmaline	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hornblende	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rutile	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Zircon	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ilmenite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Andalusite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Anatase	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sillimanite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Epidote	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Muscovite/illite	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Topaz	X															
Calcite				X	X					X	X			X		
Monazite					X											
Romerite						X	X	X								
Kyanite												X		X	X	X

In summary, the XRD results do not suggest a clear source for the magnetic field and magnetic susceptibility anomalies recorded in the field. It is possible that the anomalies may be a result of varying amounts (rather than a presence or absence) of ilmenite.

Environmental Magnetism

The magnetic analysis revealed an approximate twofold change in magnetic concentration parameters (χ_{lf}, SIRM, χ_{ARM}) in the sample set, with all magnetic concentration parameters being strongly intercorrelated (Table IV).

The largest concentration of magnetic minerals occurs in adjacent quadrants D2 (sample 6), C1 (samples 6 and 9), and D1 (sample 15). This concentration appears

Table IV. Magnetic properties of sediment samples.

Sample	$\chi_{\mathrm{lf}} \times 10^{-7}$ m^3 Kg^{-1}	%χ_{fd}	$\chi_{\mathrm{ARM}} \times 10^{-8}$ m^3 Kg^{-1}	SIRM $\times 10^{-5}$ Am^2 Kg^{-1}	S-Ratio	Hcr mT	%bIRM$_{0\text{-}20\,\mathrm{mT}}$	%bIRM$_{0.1\text{-}0.3\mathrm{T}}$	%bIRM$_{0.3\text{-}1\mathrm{T}}$	χ_{ARM} /SIRM $\times 10^{-3}$ mA^{-1}
1	0.66	6.7	29.7	44.9	0.77	20.5	57.1	8.8	2.8	0.66
2	0.72	9.0	33.4	47.5	0.47	17.5	55.5	25.1	1.6	0.70
3	0.52	6.7	21.9	38.3	0.65	18.4	46.6	11.6	5.9	0.57
4	0.68	8.8	31.4	50.0	0.71	18.9	52.1	10.3	4.3	0.63
5	0.71	9.8	33.1	42.4	0.72	17.7	54.4	9.9	4.0	0.78
6	0.82	8.4	41.2	54.5	0.82	17.8	58.8	6.8	2.2	0.76
7	0.72	7.8	35.1	48.6	0.83	16.7	58.6	8.6	0.0	0.72
8	0.68	7.1	32.8	46.7	0.78	21.4	56.2	8.4	2.9	0.70
9	0.97	8.5	48.6	66.8	0.83	19.2	60.0	8.2	0.5	0.73
10	0.78	5.8	35.9	53.2	0.71	18.0	54.4	9.2	5.3	0.67
11	0.70	8.8	31.8	49.1	0.69	18.4	52.9	11.1	4.5	0.65
12	0.87	7.3	38.2	63.4	0.74	19.0	52.5	8.4	4.7	0.60
13	0.59	7.6	27.4	39.4	0.64	18.6	48.7	10.4	7.5	0.70
14	0.63	8.4	29.3	42.6	0.71	17.0	53.8	9.5	5.1	0.69
15	0.82	9.6	40.8	56.9	0.75	17.0	56.6	7.0	5.5	0.72
16	0.57	8.4	24.9	40.0	0.57	20.9	47.7	10.0	11.7	0.62

to be a spatially related feature since it occurs throughout the stratigraphy at these locations and so might represent a burn site. Reasonably high $\%\chi_{fd}$ indicates reasonably high concentrations of superparamagnetic ferrimagnets, which may represent infiltration of some dust input from nearby topsoils, as the soils in the survey area are too immature for likely *in situ* development of superparamagnetic magnetite.

No elevated magnetic mineral concentrations appear to be associated with the magnetic intensity anomaly. There are also no consistent spatial or stratigraphic related changes in the magnetic grain size parameters over the site.

The magnetic minerals at the site are dominated by a low coercivity mineral, which may represent magnetite, evident by the generally low values of the $\%\mathrm{bIRM}_{0.3\text{-}1T}$. The χ_{ARM}/SIRM and χ_{ARM}/χ at $\sim 0.7 \times 10^{-3}\ \mathrm{mA}^{-1}$ and ~4.5, respectively, suggest a population of magnetite particles about 0.1 μm in size (Peters & Dekkers, 2003). However, the large acquisition (~55%) of backfield IRM at 20 mT (i.e., $\%\mathrm{bIRM}_{0\text{-}20\,mT}$) is not really supportive of this, suggesting that the coercivity of remanence (Hcr) is on average ~18 mT. Reconciliation of these two facts occurs if the magnetite has substantial Ti content. This may relate to the abundant ilmenite identified in the sand as the magnetite, which may be present as Ti-rich intergrowths within the ilmenite.

The magnetic parameters ($\%\mathrm{bIRM}_{0.3\text{-}1T}$, S-ratio), indicating antiferrimagnetic high coercivity minerals (i.e., hematite and goethite), show no consistent spatial or stratigraphic changes. The highest value found of $\%\mathrm{bIRM}_{0.3\text{-}1T}$ is found in the base unit (sample 16, Table IV).

The sample associated with Individual 1 (sample 2) has the lowest S-ratio due to large amounts of IRM acquisition between 100 and 300 mT (i.e., larger $\%\mathrm{bIRM}_{0.1\text{-}03.T}$). Owing to the limited applied field range used (i.e., to >2 T would have been more suitable for detecting goethite), it is not clear if this relates to an increase in relatively soft hematite (but acquisition of IRM above 300 mT is limited) or to a population of very hard (acicular lamellae in ilmenite?) titanomagnetite particles. Further work on the material adjacent to the skeletal remains may help clarify the likelihood of ochre use in the burial rites.

The magnetic mineral measurements do not correspond particularly well to the magnetic anomaly detected, which suggests that the anomaly is not an induced anomaly from the bulk material at the site. However, it may be that the sediment sampling was not sufficiently dense near the anomaly to detect its source. The presence of a very small metallic object being the anomaly source seems unlikely, since excavation was meticulous. The most likely explanation is that the anomaly is the result of enhanced viscous remanence acquisition, most probably due to burning-related formation of very small magnetite grains (i.e., near the superparamagnetic/single-domain boundary), concentrated at the anomaly site.

Discussion

The results from the geophysical and geochemical investigations of the Hack's Point burial site present a tantalizing yet incomplete picture. There is a clear spatial relationship between the location of the magnetic field intensity and apparent magnetic susceptibility (at the 41,375 Hz frequency) anomalies detected in the field surveys and the location of skeletal material as demonstrated through excavation, in an environment where GPR proved to be ineffectual. This correlation suggests that funerary practices involving burning or ochre may have led to an increase in magnetic minerals associated with these features, yet the source of these magnetic anomalies based on X-ray diffraction and environmental magnetic analysis is not clear.

Laboratory analysis revealed an increased concentration of magnetic minerals in a spatially related feature in Squares D1, D2, and C1, which may indicate a burn site. Unfortunately, the location of the field-based geophysical anomalies and the laboratory identified magnetic anomalies are not coincident. This may be explained in several ways:

1. The magnetic field-measured anomalies may represent material not sampled in the laboratory program (i.e., burnt bone, small high-intensity burnt patches).
2. The magnetic intensity and field-based apparent magnetic susceptibility anomalies may be the results of an anomaly caused by enhanced (viscous?) remanence acquisition. One mechanism for this may relate to the formation (through burning) of superparamagnetic magnetite, with a restricted grain size distribution, which may not have been detected using the measurement frequencies on the Bartington meter (Eyre, 1997). These superparamagnetic magnetite particles may have an elevated response to the EMI frequency, which is some 10 times larger than that used on the Bartington meter, hence their detection by the apparent magnetic susceptibility field measurements.
3. The increased levels of magnetic mineral concentration in Squares D1, D2, and C1 were not of sufficient magnitude to produce a coincident field magnetic intensity or apparent magnetic susceptibility anomaly in the field surveys. This would suggest that the field anomalies have another source not sampled or characterized in the laboratory analysis.

The sediment sampling strategy was probably too widely spaced at this site to enable a definitive answer to this dilemma. In the future, we recommend a sediment sampling program in which all likely magnetically enhanced material is collected for mineralogical data analysis, for the successful resolution of this ambiguity on similar sites. Also it would be advantageous to sample all likely magnetically enhanced material including the bone. However, in this case this was not in keeping with the community's wishes in regard to the direct analysis of skeletal material.

We also suggest several improvements to the geophysical survey program to make the location of the anomalies easier. We suggest that for future surveys, significantly finer grid spacing, on the order of 0.25 m, be used to increase the spatial resolution of the geophysical data set. We also suggest the field-based use of a magnetic gradiometer and magnetic susceptibility instruments, in addition to the single-sensor magnetometer, electromagnetic induction, and ground-penetrating radar instruments used in this study. Additionally, the use of a lower frequency ground-penetrating radar antenna than the 500 Mhz used in this study (as discussed by Nobes, 1999) is recommended.

Summary

The study reported herein involved a multitechnique geophysical survey of a small area of eolian dune in the Coorong region of South Australia demonstrated through excavation to contain two buried individuals, with one dating to 1880–2060 B.P. cal.

Apparent magnetic susceptibility and magnetic field intensity surveys produced anomalies with a strong spatial correlation to buried skeletal material in the study area. We tentatively suggest that apparent magnetic susceptibility and magnetic intensity surveying might prove to be useful methods for locating burials within this and similar geomorphic environments.

Ground-penetrating radar and conductivity responses were not successful in locating the burials in the study area. Despite its wide application in the location of burials elsewhere, GPR failed because the complexity of the subsurface stratigraphy led to a high number of false positive responses, though there is no reason to believe that in a less disturbed context this technique should not produce similarly solid results, as has been the case elsewhere.

Laboratory-based environmental magnetic investigations yielded a significant spatially discrete increase in magnetic concentration parameters that cannot be correlated with the results from the field-based geophysical survey. A more systematic and detailed sampling strategy including the *in situ* sampling of induced and remanent magnetism will be adopted in future surveys to attempt to overcome this problem.

To conclude, despite some ambiguity as to their mineralogical cause, the strong spatial correlation between geophysical anomalies and interment locations suggests that magnetic intensity and apparent magnetic susceptibility techniques have a significant potential to make a contribution to the location of Indigenous burial locations. This includes sites where there is a high degree of stratigraphic complexity (which can render GPR ineffective) and where funerary practices involve burning and/or ochre use. This suggests that these techniques could play a significant role in allowing Indigenous peoples to locate their ancestors' communities in a culturally appropriate manner when the burials themselves may be threatened.

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