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Title: A geophysical analysis of Aboriginal earth mounds in the Murray River Valley, South Australia

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Earth mounds are common archaeological features in some regions of Australia, particularly within the Murray-Darling Basin. These features are generally considered to have formed via the repeated use of earth oven cooking methods employed by Aboriginal people during the mid- to late-Holocene. This study assesses the relative effectiveness of key geophysical methods including magnetometry, groundpenetrating radar (GPR) and electrical resistivity tomography (ERT) in mapping, and determining the stratigraphy of earth mound sites. Three earth mounds adjacent to Hunchee Creek, on Calperum Station in South Australia's Riverland region, were chosen to conduct a comparative trial of these methods. This research demonstrated that geophysics can be used to both locate mounds and provide information as to deposit thickness and size. Individual ovens within mounds can also be located. This suggests a greater potential role for geophysics in understanding the Holocene archaeological record in Australia.

Introduction

In Australia, earth mound sites have been reported in a select number of provinces: coastal and sub-coastal localities in the tropical north (Brockwell, 2006), throughout the Murray-Darling Basin (MDB) and in the southeast of the country (Balme & Beck, 1996; Coutts, Witter, McIlwraith, & Frank, 1976; Martin, 2011; Westell & Wood, 2014; Williams, 1988). Based on excavations to date, mounds are a mid- to late-Holocene phenomenon, with those in the southeast younger than approximately 4 ka (Martin, 2011). These features are important for understanding the character and chronology of past lifeways of Indigenous peoples as they provide evidence of past economies, settlement patterns and food preparation practices through time. The apparent sudden emergence of mounds in the mid- to late-Holocene has been attributed to a number of different causes. Lourandos (1980, 1985, 86–87, 1988, 150, 1997, 216–218), for instance, considered that the appearance of new site types, such as earth mounds, was the result of socio-demographic changes including population growth and increased sedentism, as well as an associated need to enhance food production through the use of more labour-intensive food-production systems. More recently, Williams et al. (2010, 831; Williams, Ulm, Turney, Rohde, & White, 2015a; Williams et al., 2015b) similarly argued that mounds represent evidence of a suite of economic and socio-demographic changes, but unlike Lourandos, proposed that demographic packing and changing climatic conditions brought about by the El Niño Southern Oscillation (ENSO) climate system triggered economic and, in turn, archaeological shifts.

Regional surveys and excavations indicate that many mounds are the accumulated remains of multiple earth ovens (also ground ovens; see Black & Thoms, 2014) that used local clay as a heating element on which vegetable foods and/or game were cooked (Martin, 2011). This model is supported by the presence of ash, charcoal, and baked heat retainers on the surface or at the margins of mound sites. Where excavations have occurred, the model is supported by the identification of *in situ* oven features (Coutts et al., 1976; Martin, 2011). However, as Jones, Morrison, Roberts and the River Murray and Mallee Aboriginal Corporation (2017, 23) noted (see also Klaver, 1998), excavations have not been conducted in all regions and there is a diversity of site types associated with earth oven cookery methods including ‘ashy deposits’ (Type 1) (see also Pardoe, 2003); low, incipient mounds (Type 2); and discrete oven mounds (Type 3). One key hypothesis for Type 1 to Type 3 mounds is that they were constructed primarily to process the underground storage organs of wetland monocots such as *Typha* spp. (Jones et al., 2017; Martin, 2011; Westell & Wood, 2014), a major staple in some parts of the MDB. A fourth type – domestic mounds – are less common, and as Williams (1988) and Coutts et al. (1976) demonstrated, such sites did involve the use of earth oven technology, but their primary purpose was as a dry elevated platform upon which shelters and huts were constructed; burials were placed; and food preparation, consumption, and other activities occurred. Examples of such sites have also been identified in the northern Adelaide Plains region of South Australia (Littleton, Walshe, & Hodges, 2013; Westell & Wood, 2014), though these have been subject to limited research to date.

Figure 1 Location map – Calperum Station and the Hunchee Creek research location

This research is concerned with applying a suite of geophysical methods to identify and characterize oven mound features in the MDB. A key limitation in earth mound research in Australia has been distinguishing anthropogenic and naturally occurring mound features (Sullivan & Buchan, 1980; Williams, 1994). Non-anthropogenic mounds are occasionally found near active channels where floodplain drainage and sheet wash have removed adjacent sediment from levees or as shadow bars where sediment has accumulated around large trees (Sullivan & Buchan, 1980; Williams, 1994). While the occurrence of cultural materials, such as clay heat retainers, stone artefacts or faunal material can aid in the identification of earth

mounds, these are not always obvious – particularly where lenses of flood sediment have been deposited across mounds, obscuring surface deposits of cultural material. Excavation provides much more certainty, though it is inappropriate as a reconnaissance technique on both ethical and logistical grounds. Given this, our research sought to assess a range of relatively non-invasive geophysical techniques for distinguishing anthropogenic and natural earth mounds, identifying possible features within them and determining their stratigraphy.

To date there have been few other published geophysical investigations of Australian earth mounds. Early exploratory work by Elliot (1980) used magnetometry to attempt to identify cooking pits in two mound sites in Victoria, and while results were inconclusive in this regard, the technique was found to be valuable for distinguishing between anthropogenic and natural earth mound features. More recently, Conyers, St Pierre, Sutton, and Walker (2018) demonstrated the utility of combined ground-penetrating radar (GPR) and magnetics survey to investigate the interior features within six earth mound sites recorded near Mapoon in north-eastern Australia. These mounds are not a good analogue for those found in the MDB as they occur in fundamentally different landscapes, are much taller (4 m in some cases), are composed primarily of sand, and are not thought to be associated with earth-oven cooking. Earlier geophysical research on heat retainer hearths, however, has shown that various geophysical techniques could be used for the initial detection and classification of anthropogenically burnt features (Fanning, Holdaway, & Phillips, 2009; Moffat, Wallis, Beale, & Kynuna, 2008; Stanley & Green, 1976).

Methods

The research site selected for this study is located on the floodplain to the north of the Murray River some 8.5 km from the Calperum Station headquarters (Figure 1) near Renmark, South Australia. Initial surveys (Jones et al., 2017; Thredgold, Roberts and the River Murray and Mallee Aboriginal Corporation, 2017) identified 27 probable mounds distributed across sampled portions of the floodplain, with 15 of these located on Hunchee Creek and an associated billabong (oxbow lake). Geophysical investigations targeted two mounds on a levee adjacent to the creek (EM1 and EM2), and a third mound to the north (EM3). These were selected because of the excavation potential of EM2, the tallest mound site in this area, with others included for comparative purposes.

Magnetometry was used primarily to verify that the relatively subtle topographic variations identified visually as earth mounds did in fact show evidence of burning, recognizable via magnetic enhancement (Linford & Canti, 2001). While natural processes can potentially generate magnetic enhancement (e.g. burning of the lower bole of large trees, baking the surrounding sediment), magnetically enhanced sediments across a mound are considered here to be highly diagnostic of anthropogenic processes. GPR and electrical resistivity tomography (ERT) were applied as a means of mapping the stratigraphy, particularly the contact between the base of the mound and the underlying levee deposits. All data were positioned based on their grid corners using a Trimble R10 GNSS antenna that received base station corrections via the mobile network. All sites were photographed aerially using both an Event 38 E384 and DJI Phantom 3 UAV which was used to create georectified orthophotos and digital elevation models (DEMs) with Agisoft Photoscan Professional.

A total of eight grids were surveyed with a gradiometer, seven of which were connected (Figure 2) and one was collected in a different area (Figure 3). GPR and ERT data were also collected in Grid 7, which contains EM2.

Magnetometer data were acquired using a Bartington Grad 601 dual sensor fluxgate gradiometer. Data were collected in $20\text{ m} \times 20\text{ m}$ grids with a line spacing of 0.25 m and a sample rate of eight samples per metre. Before field acquisition commenced, a metal detector survey was conducted over the site in order to detect any modern ferrous material that might mask subtler readings. Magnetics data were processed in Terrasurveyor where they were destaggered, de-striped, and the mask function was used to remove unwanted responses from a stormwater pipe containing metal reinforcing that was detected in Grid 4 (Figure 2).

Figure 2 Location of Grids 1 to 7, each grid is $20\text{ m} \times 20\text{ m}$ – aerial photography by drone

Figure 3 Location of Grid 8 – aerial photography by drone

GPR data were collected using a GSSI SIR3000 with a 400 MHz antenna mounted on a survey cart in a 20 m × 20 m grid with a line spacing of 0.5 m. GPR data were processed in GPR Viewer using a time 0 correction, a background removal filter and a topographic correction. Both profiles and amplitude slice maps of the GPR data were utilised for interpretation. Relative dielectric permittivity was calculated using a velocity analysis conducted through hyperbola fitting using GPR Viewer which was used for depth correction.

ERT data were collected using a FlashRES-Universal 64 channel resistivity/IP meter collecting Wenner and dipole–dipole arrays. ERT surveys were run in a north–south orientation with 2 m line and 0.5 m electrode spacing. A saline solution was poured over each electrode before the acquisition of each survey line to reduce the contact resistance. Despite this, contact resistance remained high (up to several thousand Ω) due to the dry soil. ERT data were exported and filtered using ZZ RdatacheckU64 software and converted to an appropriate format for inversion using the flashres2res2dinv script. Data were inverted into resistivity inverse model sections using Res2DINV software using a L1 norm (robust) inversion least-squares method where the absolute difference between the measured and calculated apparent resistivity values is used. After two-dimensional (2D) processing was complete the data were then loaded into RES3DINV in order to generate a three-dimensional (3D) dataset, which was sliced at a number of depths parallel to the ground surface.

Figure 4 The main magnetics survey grid dataset, Grids 1 to 7 are $20\text{ m} \times 20\text{ m}$ grids collected with 0.25 m line spacing. The scale of readings in nanoteslas to the right of the main survey grid correspond to the colour of the readings in the dataset

Figure 5 Peak responses from EM2. a and EM2.b, displayed in a twodimensional magnetics profile. Profile alignment is delineated by the red dashed line in Figure 4 from point A (0 m) to point B (20 m). Distance is expressed in metres on the bottom of the profile and readings are expressed in nanoteslas on the lefthand side of the profile

Figure 6 The 20 m × 20 m magnetic dataset of Grid 8 – the colours within the dataset coincide with colour scale to the right of the dataset; readings are expressed in nanoteslas

Results

Magnetometer surveys

Magnetometry showed that all three earth mounds have anomalous magnetism (−3 nT to −9 nT) over their entire area (Figures 4–7). Within the individual earth mounds a number of discrete high amplitude (−13.52 nT to −52.95 nT) features were located which are interpreted from the magnetics data as indicating *in situ* discrete heating elements (Table 1). Another similar feature (S1.a) was located approximately 10 m from EM3 in Grid 8. These features appeared as strong negative responses within the magnetic datasets due to their location in the Southern Hemisphere (Aspinall, Gaffney, & Schmidt, 2009). These anomalies are interpreted here as individual earth ovens because of their discrete size and their similarity in amplitude to hearth features located in other studies (Aspinall et al., 2009; Fanning et al., 2009; Gaffney & Gater, 2010). None of these features responded to the metal detector survey.

GPR surveys

EM2 in Grid 7 was the only mound to be surveyed with GPR. The GPR data revealed a high amplitude reflector under this mound, which was interpreted to be the contact between the base of the mound and the underlying levee due to its elevation in comparison to the surrounding landscape. Mapping of this feature allows the maximum mound thickness to be determined as

0.3 m and the lateral extents as 13 m × 15 m. No other stratigraphic features could be discerned within the mound with the GPR. This was potentially due to the shallow nature of the site, as excavations by Coutts, Henderson, and Fullagar (1979) noted that smaller mounds often have a homogeneous stratigraphy. The deposit returned numerous point-source hyperbolic responses of varying amplitude (Figures 8 and 9). These features are tentatively interpreted as being a combination of heating elements and tree roots. In contrast to the 2D profiles no useful data were obtained from the 3D amplitude slices, presumably because of the subtle amplitude contrast between the earth mound and the surrounding material.

To address difficulties in determining the cause of point-source hyperbolic responses on EM2, an additional analysis was performed using the method of Conyers et al. (2018) of cross-correlation of both magnetics and GPR 2D profiles. This provided a means of comparing magnetic anomalies interpreted as discrete hearths and/or heating elements with GPR hyperbolic responses in the same location. The alignment of these 2D magnetic and GPR profiles and suspected earth ovens were displayed in a combined interpretation map (Figure 10).

Table 1 Peak responses from features interpreted as individual earth ovens within all of the magnetics survey grids

Heating element ID	Response size	Peak response
EM2.a	1 m × 0.5 m	−51.42 nT
EM2.b	0.8 m × 0.5 m	−52.95 nT
EM3.a	0.5 m × 0.3 m	−20.69 nT
EM3.b	0.5 m × 0.2 m	−13.51 nT
S1.a	0.7 m × 0.5 m	−33.04 nT

Figure 7 Peak response from a partially exposed earth oven S1.a composed of clay from Grid 8. Profile alignment is delineated by the red line from point A (0 m) to point B (20 m) in Figure 6. Units: x-axis, in metres; y-axis, in Nanoteslas

Feature EM2.a (Figure 10), which is interpreted as an *in situ* hearth based on its elevated magnetic response, was detected at 14.5 m within GPR profile 69 (x-axis) and 6.2 m within

GPR profile 10 (y-axis) (Figures 11 and 12) at a depth of 0.17 m. EM2.b was detected at 13.8 m within GPR profile 13 (y-axis) but was invisible in GPR profile 70 (x-axis). The depth of the suspected earth oven within both profiles was 0.13 m. The combination of GPR and magnetics provides the opportunity to accurately determine the depths of individual intact buried hearths providing useful data for excavation planning.

ERT survey

The seven survey lines using dipole–dipole array ERT inverse model sections across Grid 7 (which includes EM2) produced resistivity values that vary from 0.10 to 150 Ω m. The survey identified a resistive surface layer approximately 0.3 m thick with resistivity values of 60 to 150 Ω m; this stratigraphic unit was detected from lines one to six from 15 to 27 m along these lines (which broadly corresponds to the location of EM2) but was not present in line seven which is located adjacent to the mound (Figures 13). A number of additional features with elevated resistivity, particularly between 0 and 10 m along the profiles, are present on all survey lines however these are believed to be from poor ground coupling/installation of the electrodes due to large trees (*Eucalyptus camaldulensis*) and their shallow roots on the edge of the riverbank.

The Wenner array survey also identified a resistive feature from 16 to 23 m in line one which has a resistivity of 60 to 150 Ω m (Figure 14). This feature was not present in other lines. As with the dipole–dipole results, a number of discrete high resistivity features are present on the survey lines that we attribute to tree roots. Root mean square (RMS) errors for both the dipole–dipole and Wenner surveys are high (> 20%) which we attribute to the high contact resistance measurements.

Figure 8 Two-dimensional ground-penetrating radar (GPR) profile 17 topographically corrected and annotated, mound extents and depth were derived from all other profiles in this manner

Figure 9 Two-dimensional ground-penetrating radar (GPR) profile 69 topographically corrected and annotated, mound extents and depth were derived from all other profiles in this manner

Figure 10 Combined location of ground-penetrating radar (GPR) and magnetics profiles and alignment map over Grid 7

Figure 11 Ground-penetrating radar (GPR) profile 69 and corresponding two-dimensional magnetics profile over the interpreted *in situ* hearth feature EM2.a – their alignment and location are depicted in Figure 10 by the red arrow from A (0 m) to B (20 m)

Figure 12 Ground-penetrating radar (GPR) profile 10 and corresponding two-dimensional magnetics profile – their alignment and location are depicted in Figure 10 by the yellow arrow from C (0 m) to D (20 m)

Figure 13 Dipole-dipole array inverse model resistivity section of electrode line one, the first line of the survey grid which goes through the centre of EM2

Figure 14 Wenner array inverse model resistivity section of electrode line one, the first line of the survey grid which goes through the centre of EM2

Figure 15 Main survey location grids displayed containing geophysical anomalies and archaeological artefacts, generated for a combined method site interpretation

Figure 16 Grid 8 combined survey map

Discussion

All survey results were incorporated into two plans (Figures 15 and 16) and illustrate a broad agreement between the mound's lateral extents defined by topographic survey, magnetometry and (where available) GPR. Importantly, no two methods provide a precise alignment.

The GPR and the topographically surveyed extent of the mound show the best agreement for EM2 while magnetics and, to a greater degree, ERT show smaller lateral extents. The restricted distribution of this feature in the ERT data is probably an artefact of the coarse line spacing (2 m) of the survey. In contrast, the disparity between the magnetics and GPR/topographic data may suggest that the mound is not composed entirely of burnt material but was constructed on top of an existing topographic high, likely part of the underlying levee.

In the case of EM1 and EM3, the magnetics and topographic survey show a feature of approximately the same size but marginally offset in location. The slightly greater geographic extent of feature S1 suggests burnt material may exist in the subsurface away from where it is exposed on the surface.

Overall, this research has confirmed that magnetometry is the most reliable technique for identifying discrete earth mounds and individual earth oven features during non-invasive investigations. These features present as broad areas with slightly depressed magnetic gradient values (-3 nT to -9 nT) or discrete areas with a significantly elevated or depressed magnetic gradient (-52.95 nT or -13.51 nT, respectively). This combination of features within a single earth mound echoes the excavation results of Martin (2006, 151) who found both intact hearths and disseminated burnt material in mound sites. GPR is most useful for delineating the vertical extent of mounds and, when used in conjunction with magnetics, is able to provide depth information to 2D magnetic targets. ERT showed some promise in defining the location and

extent of mounds. However, abundant tree roots in the survey area created a number of resistive anomalies which limited the value of the technique for mapping mound extents. Had this technique been deployed on mound sites where tree roots had less impact a more successful result delineating mound extents may have been more likely. The survey was also hampered by a relatively coarse electrode spacing relative to the thin topographic expression of these earth mounds which means that the detection of these features is based on a limited number of data points, particularly given the comparative poor spatial resolution of the Wenner array (Dahlin & Zhou, 2004). High RMS errors attributed to the elevated contact resistance of the study area also suggest that the inversion data may not be robust. Future surveys in the region will trial the use of smaller electrode spacing, a higher frequency antenna, and electromagnetic induction instruments to see if these can further enhance the utility of geophysics for earth mound investigations.

This study, while principally focussed on trialling the potential role for geophysical techniques to make a contribution to understanding the distribution and stratigraphy of earth mounds in general, was also able to provide important new information about the study area at Huncree Creek. Magnetometry validated that the three earth mounds identified by field survey on the basis of topography and tested with geophysics are all comprised almost entirely of burnt material. This validates our field survey methodology and suggests that the other mound features identified without geophysics in the Huncree Creek region and Calperum Station more generally are accurate designations. The combined results of the GPR and magnetic survey also suggest that these features contain a number of *in situ* hearths that would be of interest for excavation to obtain samples for dating and palaeodietary studies. Finally, the thin stratigraphy of these mounds, as revealed by ERT and GPR, supports our interpretation that these are thin accumulations of sediment probably accumulated mainly through anthropogenic activities rather than being geological features that have been repurposed to use as mounds.

Conclusions

This research further demonstrates the value of geophysics for landscape archaeology in the Australian context, particularly for noninvasively investigating the lateral and vertical dimensions of mound features, and identifying *in situ* earth oven features. The magnetic method proved to be most effective for locating earth mounds and finding individual earth ovens within them. GPR was most effective for determining mound depth and lateral dimensions, although it was unable to determine any internal stratigraphy. This is likely due to the shallow depth of mound features investigated here, and so the technique may be more valuable to use on larger mound features with well-defined stratigraphy. ERT showed some promise, but overlapping resistivity values between the earth mound sediments and poor ground coupling caused by tree roots made defining these features difficult.

Overall, this research suggests a vital role for geophysical methods within the investigation of earth mounds in Australia. Fanning et al. (2009) noted that exposed heat-retainer hearth features are a continually diminishing resource of both cultural and archaeological importance, an observation that is replicated in our study area. Surveys of the floodplain in the study area reveal a landscape with many examples of partially or fully deflated deposits of earth oven material, indicating processes of site loss on a large scale. Importantly, such features are of high significance to Aboriginal Traditional Owners and so large-scale reconnaissance excavation programmes are inappropriate. The use of geophysical techniques to locate, map and define the stratigraphy of these features will allow these important archaeological features to be studied in a non-invasive and culturally appropriate manner, and can potentially support

more strategic and low-impact investigations of mounds, for example, enabling archaeologists to excavate specific features of interest, such as intact ground ovens. While debate about ground oven cookery techniques and earth mound function will continue, it is clear that discrete hearths are a key component of mound features (see also Martin, 2011) and thus further application of geophysical methods can generate new insights on mound formation and use, and thus contribute to debates on purported changes in Aboriginal lifeways in Australia through the midto late-Holocene.

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Conflict of Interests

The authors declare no conflict of interest.

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