Archaeo-Geophysics – Mapping The Magnetic, Resistive and Electromagnetic Past

A geophysical study of Indigenous Earth Mounds at Calperum Nature Reserve, South Australia

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Declaration of Candidate

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in an any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in text.

Signature………..

Abstract

Earth mounds are an abundant archaeological site type within the Riverland region of South Australia, Victoria and New South Wales. Within the Riverland region this site type has been understudied compared with the earth mounds of Victoria and New South Wales. This thesis represents the first archaeo-geophysical study of its kind, not only within this region, but Australia wide where there has been little research on cultural mounded features. Those few studies that have been conducted have not gone beyond just identifying the location of the feature.

The main goal of this research is to determine if geophysical techniques can provide information about earth mounds and associated features in order to answer archaeological questions about them and the population that built them. The research is important as the geophysical methodologies presented will guide future geophysical research on earth mounds. It will demonstrate what and how much archaeological information can be derived from each of the geophysical techniques and their respective relative effectiveness's.

In order to provide some insight into the cultural activity occuring at these sites a section of Hunchee Creek within Calperum Station was chosen to conduct an extensive geophysical research program. Three separate geophysical methods were chosen to non-invasively and non-destructively survey the interior and surrounding subsurface in order to answer archaeological questions. They were resistivity, magnetics and GPR, and each site was topographically surveyed and aerial imagery was acquired by drone and georeferenced to provide a high degree of spatial accuracy.

The detection of buried earth ovens within the mounds and surface scatters of heating elements deflating from the top of the mounds suggest that these site were re-use cooking

facilities. Magnetic responses from four suspected earth ovens when compared to two partially uncovered ovens containing clay balls were found to be of similar magnitudes. This would suggest that all mounds earth ovens still buried in situ are composed of the same material. The GPR and resistivity survyes were able to determine the earth mounds lateral, vertical extents and stratigraphy. This information provided an insight into site use size, re-use, and frequency. The geophysics data quadrants were topographically surveyed and combined with other Flinders University students' archaeological survey data which led to a combined archaeological interpretation methodolgy approach that others conducting similar studies should adopt in the future.

Further geophysical research will be required in the future to see if the trends within this small section of Hunchee Creek are regionally and inter-state consistent.

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Dedication

I dedicate this to my GPR colleague and friend Professor Larry Conyers ‘who got me into all of this archeo-geophysics mess’…and for that I’ll be forever grateful…

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Glossary of Terms

Apparent resistivity	The mean resistivity value of the ground as measured by an electrode array, including any non-uniformity of the soil and of any objects within it.
Curie Temperature	Reversible point above which ferromagnetic or ferromagnetic materials become paramagnetic.
Drift	The change in absolute error over time.
Dipole	Two equal magnetic poles of opposite sign separated by a short distance, in effect a bar magnet.
Gradiometer	Any instrument that records differences in a measured property between two sensors set at a fixed distance apart, rather than the total value of the property measured using a single sensor. This configuration is usually encountered in magnetometers.
Hyperbola fitting	Typically a post processing method that uses point-source hyperbolas, generated from buried objects such as pipes, rocks or tree roots in the ground to determine the velocity of radar wave energy.
Induced magnetisation	Magnetism of un-magnetised magnetic material induced by a nearby magnetic field.

Iteration	A repetition of a mathematical, computational procedure applied to resistivity data as a means of obtaining closer approximates to the estimated subsurface resistivity.
Magnetic moment	A measure of a material's tendency to align with a magnetic field.
Magnetic Susceptibility	Degree of magnetisation of a material in response to an applied magnetic field.
Paramagnetic	A material very weakly attracted by the poles of a magnet.
Pseudo-section	A sequence of earth resistance measurements made along the same surface base-line with different electrode separations and arranged to depict an approximate vertical profile of the variation of electrical resistance with depth.
Flux	The rate of flow of fluid, particles or energy through a given surface.
Flux density	The amount of magnetic, electric or other flux passing through a unit area.
Magnetic domains	A region in which the magnetic fields of atoms are grouped together and aligned in the same orientation.
Magnetic flux	Magnetic flux is a measurement of the total magnetic field which passes through a given area.
Susceptibility	A materials response to an applied field.

Thermo-remanent magnetisation	A persistent, permanent, magnetisation acquired by certain magnetic minerals after they have been heated above a threshold temperature and cooled in an ambient magnetic field.
WGS84	An Earth centred, earth fixed terrestrial reference system and geodetic datum.

Chapter 1: Introduction

The identification and analysis of earth mounds has been a focus of academic researchers as well as commercial archaeologists and heritage managers for over 30 years (Coutts et al. 1979; Coutts et al. 1976; Martin 2006; Westell and Wood 2014). Earth mounds are important as they provide evidence for past economic practices, social organisation, settlement patterns and cooking practices through time (Martin 2006:3).

Numerous investigations using various archaeological techniques have been conducted in Australia, but without the ability to 'look into' the deposit non-invasively and non-destructively (Martin 2006, Westell and Wood 2014, Klaver 1998, Balme and Beck 1996). Previous geophysical research on Australian earth mounds and hearths has shown that various geophysical techniques could be used for the initial detection and classification of hearth features based on their geophysical responses (Fanning et al. 2009; Moffat et al. 2008; Stanley and Green 1976). However these studies are simply focused on locating hearths rather than using the geophysical data to propose and answer archaeological questions relating to Indigenous land and resource use, or site formation processes. Australian archaeology lacks a robust methodology for the geophysical investigation of earth mounds. Much of the past research conducted in Australia has been pilot studies with recommendations for further research but very few of these studies have been reinvestigated (Fanning et al. 2009; Moffat et al. 2008; Stanley and Green 1976). This research will take into account past research and will also utilise various techniques over the same mounded feature to determine what level of information can be 'gleaned' from each of the techniques to answer archaeological questions about those features.

Conducted as a small component of a larger research program in collaboration with Flinders University Archaeology Department and the River Murray and Mallee Aboriginal Corporation (RMMAC), the research is situated within Calperum Station Environmental Reserve, 15 kilometres north of Renmark in the Riverland region of South Australia (Figure 1). The research site is located at Hunchee Creek which is 8.5km from the Calperum Station homestead and site office (Headquarters) (Figure 1). Calperum Station is a pastoral lease comprising of 242,800 hectares of mostly open Mallee bushland and Murray River floodplains. The station is managed by the Australian Landscape Trust under contract to the Director of National Parks (Australian Government – Department of the Environment and Energy 2017).

Figure 1: Location map – Calperum Station and the study area Hunchee Creek (aerial image from google earth).

Hunchee Creek is a mosaic of beautiful floodplain features but upon closer inspection there is an abundance of cultural features amongst its floodplain landforms. A common cultural feature encountered is earth mounds. Earth mounds are the refuse and rake outs from repeated cooking events that have occurred multiple times at that particular location. The heating element within these mounds was an earth oven, which in this region is usually constructed from fist sized clay balls or rocks that were heated to cook food (Beveridge 1889:33 in Coutts et al. 1976:6).

Research question and aims

This study focuses on a geophysical survey and data analysis of earth mounds along a section of Hunchee Creek located within Calperum Station in the Riverland region of South Australia. In particular, it adopts the view that geophysics is useful for imaging and mapping buried features that would have been an active part of the lives of the late Holocene population which inhabited this area (Westell and Wood 2014; Fanning et al. 2009; Moffat et al. 2008; Stanley and Green 1976).

The primary research question is:

- Can geophysical techniques provide information about the location, extent and stratigraphy of earth mounds and so assist with answering archaeological questions about their development and use?

In order to address this research question it will be necessary to also address the following aims:

- Assess the relative effectiveness of ground penetrating radar (GPR), gradiometry and resistivity in mapping and defining stratigraphy of earth mound sites in this region of the MDB.
- Determine if geophysics can differentiate between earth mounds containing relatively intact heat element material and those that do not.

- Determine if geophysical techniques can differentiate between natural and culturally manufactured mounds, even when they have little topographic expression.
- Determine if responses from geophysical datasets can infer or answer archaeological questions relating to site use choice, frequency, and re-use.
- Analyse the distribution and morphology of earth mounds and associated earth oven features, as revealed via geophysical techniques, for what they reveal about past Aboriginal societies choice of cooking sites/earth oven sites.

Significance

This research project is the first time the applicability of geophysical techniques to studying earth mounds has been rigorously tested and contributes to the development of a robust methodology for understanding these features and developing a deeper understanding of past Aboriginal cooking practices.

This research will also assist in providing a greater level of understanding of how Aboriginal people utilised the Hunchee Creek region in the past. This research is part of a larger project which has been run under the guidance and assistance of the River Murray and Mallee Aboriginal Corporation (RMMAC). These research findings will be of significance to RMMAC members as they will provide an insight into the past behaviour and land use practices of their people that traditional forms of archaeology cannot.

This research also outlines a methodology for future geophysical investigation of earth mounds and associated features. Continued improvements after the completion of this research with regard to survey methodologies will provide a greater level of survey accuracy and success which will provide for better management strategies and monitoring of these deposits for their future protection.

Thesis Outline

Chapters two and three situate this research project in relation to previous archaeological and geophysical studies of earth mounds and associated features. This previous research will be discussed from both Australian and international contexts, with the success or shortcomings of previous studies used to guide this research.

Chapter four outlines information relating to local and regional geology and geomorphology. This information is important to aid in the interpretation of the geophysical data in order to determine what features are beneath the ground and whether they are likely naturally formed or the result of human occupation.

Chapter five presents the research methods, including an overview of the equipment deployed for this research and also the associated field procedures and theory behind how each instrument operates.

Chapter six presents the results from some preliminary field testing conducted in 2016 and then presents data from the magnetics, ground penetrating radar and resistivity surveys conducted in 2017.

Chapter seven is a discussion about the results from the magnetics, ground penetrating radar and resistivity surveys and what information has been derived from each of these data sets.

Chapter eight concludes the thesis by re-addressing each of the research aims and the conclusions presented at the end of the discussion of results. Limitations of the research will be re-addressed and recommendations for future research in the area of earth mound geophysics will be discussed.

Chapter 2. Earth Mounds in archaeology

This chapter sets out to provide an overview of previous archaeological research on earth mound sites both in Australia and internationally. Initially this chapter will define earth mounds within an Australian context investigating previous research to outline key attributes, typologies, chronology, stratigraphy and distributions of mounds within different regions of the Murray Darling Basin. A brief review of research on international earth mounds will be presented in order to contextualise work conducted in Australia. This includes a review of key explanatory models and theories relating to the inception and proliferation of earth mounds in Australia during the mid- to Late Holocene.

What are earth mounds?

Earth mounds are an artificial landform, circular or elliptical, containing but not limited to heat retainers, ash, charcoal, faunal remains, stone tools, and occasionally burials (Balme and Beck 1996:39; Beveridge 1889:28; Martin 2006:9; Mitchell 1938:80; Sullivan and Buchan 1980; Westell and Wood 2014:33). The mound itself is believed to be the result of repeated earth oven cooking and oven-rake out events, which have gradually accumulated over centuries of occupation (Coutts et al. 1976:6). Mounds were used for a variety of purposes including cooking, as living platforms, as foundations for substantial dwellings and as part of large scale eel–trapping complexes (Pressland 1980:90-92 in Williams 1988:129). Mounds can appear in the landscape as isolated features or in clusters (Williams 1988:128).

Martin (2006) and Klaver (1998) argue that earth mounds have a wider range of possible functions and that they can be further subdivided based on their use. Martin (2006:12) defines earth mounds as mounded cultural deposits which can grade into other site types over time such as exposed pit ovens, non-mounded ashy deposits, mounded deposits that have been previously been lived on, and mounds formed from collapsed huts (Martin 2006:13; Frankel 1991:83). Klaver (1998:132) has taken the approach of defining mound sites on the basis of their constituent components and characterising them as a result of a range of likely formation activities. Such sites are classified as ground oven structures, small pit ovens, multiple pit ovens, oven mounds, ashy sediment accumulations, disturbed oven deposits, charcoal and ash concentrations, excavated pits, and utilised natural mounds. Both Klaver (1998:114) and Martin (2006:11) refer holistically to this type of feature as 'mounded cultural deposits' as they believe this to be a more appropriate 'general descriptor.'

Earth mound distribution across Australia

Earth mounds have been recorded on the northern Adelaide Plains, on some coastal plains in northern Australia, and also throughout the Murray-Darling system (Brockwell 2001:1-10; 2006:47; Westell and Wood 2014; Littleton et al. 2013). Earth mounds can differ locally and regionally but generally are all associated with riverine environments, floodplains and seasonal wetlands (Westell and Wood 2014:30).

Extensive research on earth mounds has been conducted throughout parts of the Murray Darling Basin, including in western and north western Victoria (Coutts et al 1979, 1976, Williams 1988), central Victoria (Buchan 1980, Frankel 1991), northern New South Wales, south central New South Wales (Martin 2006, Klaver 1998) western New South Wales (Pardoe 2003), the central Murray region, Murray region of South Australia (Westell and Wood 2014) and the Adelaide Plains (Littleton et al. 2013, Draper 1992).

Generally earth mounds are located in floodplain environments in close proximity to carbohydrate rich wetland plants such as *Typha Sp. rhizome, Triglochin procera and*

Bolboschoenus caldwelli and medianus which have been argued by archaeologists to have been cooked in them (Martin 2006:162). Some mound sites are located on elevated areas within the floodplain and appear to have been selected to deal with seasonal flooding events.

Figure 2: Typha Spp. In Ral Ral Creek, Calperum Station. Photographer: M. Morrison September 2015.

Westell and Wood (2014:30) have reviewed mound distribution and function on a regional scale within South Australia. They propose that there are some distinct differences in the societal role of mounds between those occurring within the Riverland and the northern Adelaide Plains. Mounds of the Adelaide Plains tend more to be grouped around residential nodes, located at wells and extending along the boundary between alluvial and estuarine habitats. Westell and Wood (2014:31) also argue that these types of mounds may have provided some sort of engineering solution to a landscape prone to flooding. Alternatively the Riverland mounds were used more routinely as processing sites that were distinct from formal occupation areas (Westell and Wood 2014:31). In South Australia, larger mound structures have been selectively used as cemeteries such as on the Adelaide Plains, however in the Riverland region this is not common (Littleton et.al. 2013:38-51, Westell and Wood 2014:31).

Earth Mound Stratigraphy

Earth mound stratigraphy has been extensively researched in south eastern Australia, with numerous excavations in multiple areas within the Murray Darling Basin (Coutts et al. 1976, Martin 2006, Frankel 1991). Stratigraphic layering within mounds can vary greatly with some mounds having one to two layers and others having as many as twelve (Martin 2006; Coutts 1976; Klaver 1998:172). It is often the case that mound stratigraphy has been damaged by post contact disturbance such as from farming and rabbit burrowing (Martin 2006:115; Coutts et al. 1976:3). The stratigraphic layering of earth mounds can contain charcoal, burnt clay or stone heat retainers, faunal remains, mollusc shells, lithics and in some regions burials.

Coutts et al. (1976:3) describes Western Victorian mounds as generally artificial, irregular features that have quite often been subject to both prehistoric and post contact interference. This interference is also evident in other regions as excavation data show an upper portion of the excavation containing layers that have been disturbed by animal burrowing or practices relating to vegetation clearance for farming (Coutts et al. 1976:3; Martin 2006:115; Klaver 1998). Excavation by Coutts et al. (1976:24) indicated that the mounds often contained two horizons, one being a black occupation horizon and the other being a red buckshot horizon with a diffuse intermediate zone with multiple layers. These layers contained ash layers, charcoal, burnt clay and unburnt animal bones, cooking places and human burials (Coutts et al. 1976:24, Frankel 1991:83). Distinguishing boundaries in mounds can be difficult because many of the materials within the mound have been derived from the same source and/or have undergone lengthy reworking (Coutts et al. 1979:38).

Two mounds were excavated and thoroughly analysed in the Hay Plain region by Martin (2006) one named Ravensworth 3 with dimensions of 112m x 70m and the other Tchelery 1 with dimensions of 130m x 80m. Each mound was a substantial cultural feature with a depth from surface to base of the deposit being 1.78m and 1.6m deep respectively (Martin 2006: 115-143). Both mounds had a complex stratigraphy with individual layers ranging from 5cm to 50cm thick containing varying percentages of earth oven related materials. The stratigraphy of Ravensworth 3 was poorly defined, although ten stratigraphic layers could be differentiated. From the surface of the deposit to 0.8m depth rabbits had burrowed through the deposit, within the excavation other cultural features were detected such as two hearths, ashy lenses, and both aquatic and non-aquatic faunal assemblages. Tchelery 1 mound contained twelve thin layers with differing percentages of hearth material from the surface of the deposit to the end. The deposit contained faunal assemblages, charcoal and ash layers and much like Ravensworth 3 clusters of in-situ earth ovens toward the bottom of the deposit. The last layer of the deposit was a hard basement layer believed to have been the floor of a hut containing an infilled basin shaped pit (Figure3) (Martin 2006:143).

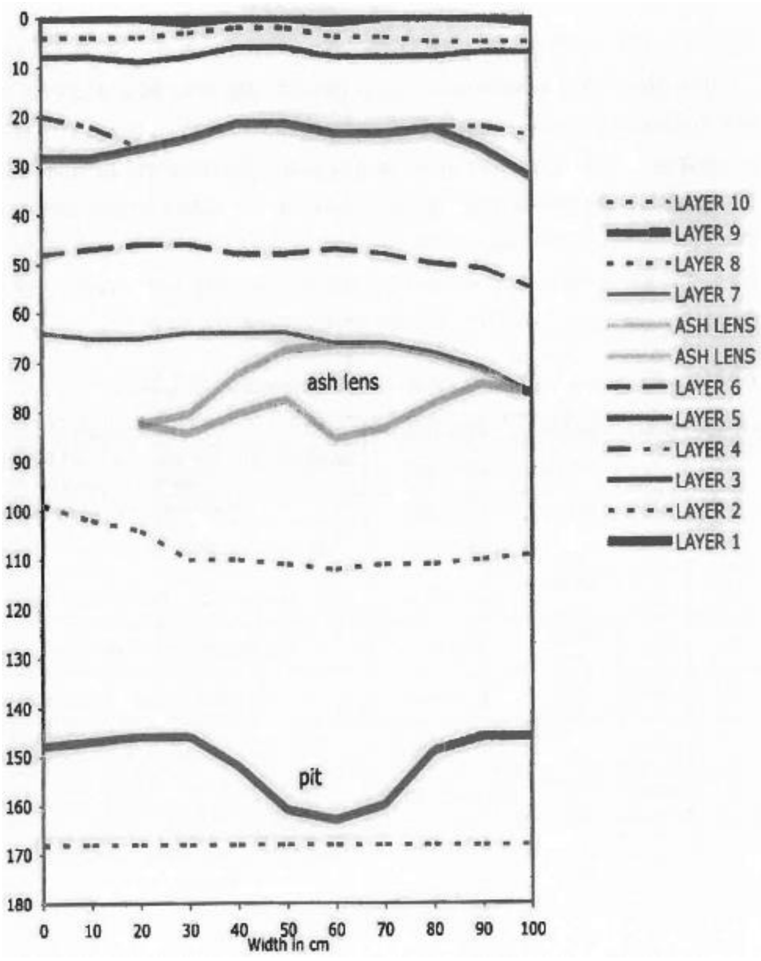


Figure 3: Ravensworth 3 earth mound stratigraphy (From Martin 2006:116)

Radiocarbon dates were taken through the deposit of each of the mounds to determine the ages of each layer within the stratigraphic sequence. Ravensworth returned dates at the surface of 4292 - 4064 cal BP (85.2% probability range) and at the bottom of the deposit of 4827 - 4409 cal BP (95.4% probability range). Tcherlery returned dates of 4440 - 4225 cal BP (90.2% probability range) at the top of the deposit and 5316 - 4437 cal BP (95.4% probability range) at the base (Martin 2006:171).

Klaver (1998:143) excavated mounds in the Murrumbidgee region to determine their stratigraphy, chronology and composition, investigating sites at Colombo Creek, Cooey Point Lagoon and Mt Galore. Mound sites excavated at these locations tended to be small raised circular features containing 4 to10 stratigraphic layers of varying thickness. The mound sites in this region were variable with upper layers in some cases being destroyed by burrowing animals. Some sites contained primarily ashy layers or ashy deposits and heat retainers in varying proportions. In one particular site near Cooey Point Lagoon, the bottom of the excavation was a sterile natural silty clay layer in which a pit had been cut, the base of the pit was found to be covered with a sheet of carbonised bark. The bark marked the boundary between the 'natural ground' and the cultural deposits above. Heat retainers were concentrated within the base of this pit. This layer indicated that the initial use of the site was planned as an earth oven and the earth oven (Klaver 1998:172).

In summary, excavations of earth mound sites within the MDB indicate that stratigraphy can be complex and variable. Picking stratigraphic boundaries in mounds can be difficult (Coutts et al. 1979:38). Stratigraphic layers within mounds also contained differing degrees of heating elements which can provide some clue as to site use intensity and site re-use intensity. Layers devoid of cultural material can potentially indicate a period of non-utilisation. A general theme in the excavation data of all studies discussed is that animals quite often burrow into the deposit as deep as 1m, destroying anything in-situ. In a number of cases, there is evidence of oven pits being cut into the natural substrates of mound deposits, or compacted basal layer within the stratigraphic sequence. Such situations provide evidence as to the primary function of the site when it was first created.

Earth Mound Chronology

Radiocarbon dates (calibrated) collected across Australia indicate the presence of earth mounds occurring in different locations from 5500 years ago until quite recently (Brockwell 2006:118). The oldest coastal/estuarine mounds have been recorded in northern Australia on the South Alligator River in western Arnhem Land which have been dated to 5472 - 4963 cal BP (94.7% probability range) (Brockwell 2006:118). Most south eastern Australia mounds are younger than this, however the Tchelery 1 mound on the Hay Plain is almost as old with a date of 4440 - 4225 cal BP (90.2% probability range) (Martin 2006:96). The majority of dates within the Murray Darling Basin have returned dates from 3400 - 1700 cal BP (92.1% probability range) (Figure 4) (Balme and Beck 1996, Coutts et al. 1977, Klaver 1998, Martin 2006, Westell and Wood 2014).

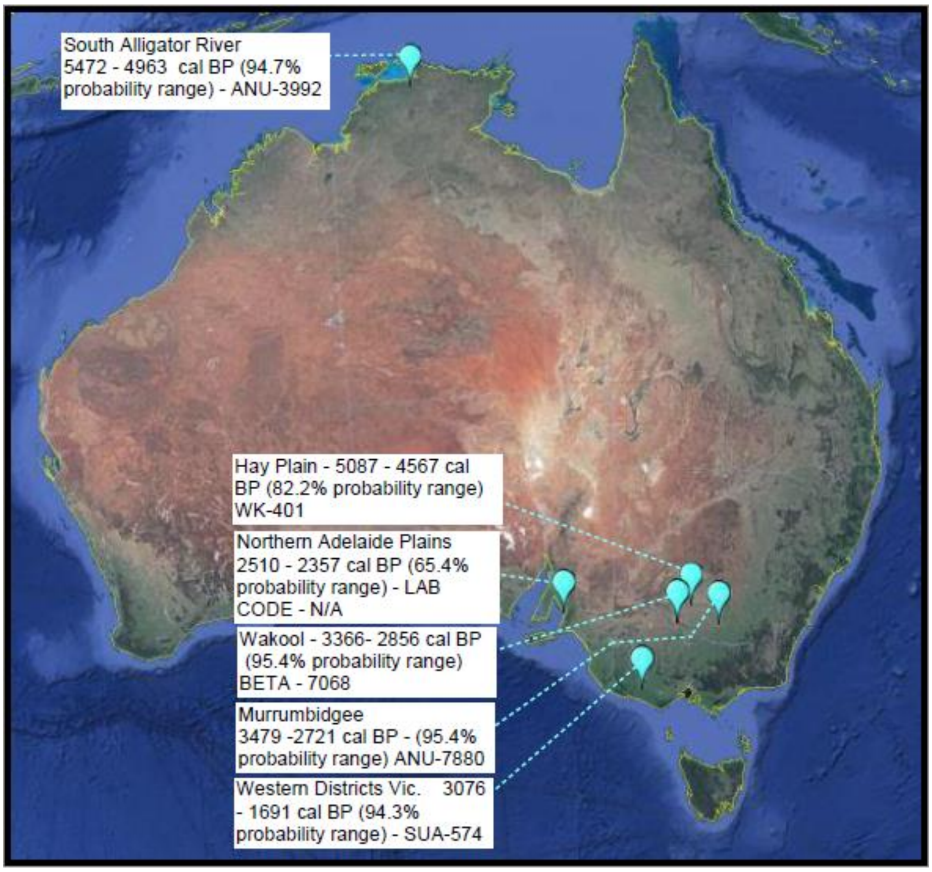


Figure 4: Map displaying the oldest radiocarbon dated earth mounds around Australia.

Interpretations of Mound Sites

In different regions across Australia the heating element of earth ovens can vary depending on what materials were available (Klaver 1998:19). For example Aboriginal people in various areas of south-eastern Australia used clay as heat elements for their ovens (Coutts 1979:87), Aboriginal people in Arnhem Land used chunks of termite mound (Mulvaney 1975:152) and in the western districts of Victoria rocks were used (Coutts et al. 1976 in Klaver 1998:53). However different types of heating element were not necessarily region specific, their geographic variation was based more on availability at the time and in some areas more than one type of heating element was used (Klaver 1998:19, Coutts 1979:87, Mulvaney 1975:152). It is the refuse from the earth oven cooking process that is the primary fabric of many mound deposits (Sullivan and Buchan 1980:87). Earth ovens are not just specific to Australia, as ovens or slight variations of this type of technology can be found on other continents and islands in both the south and northern hemispheres (Martin 2006: 72-73, Klaver 1998:22-29, Black and Thoms 2014:203-226).

Earth ovens and associated features are important cultural features as they can confirm the identification of activity areas, settlement patterns, and when excavated, provide a key source of datable carbon, faunal and floral samples and stone and other artefacts. These features also provide information relating to landscape use, mobility, resource scheduling, feasting, gender, and population changes (Black and Thoms 2014:204).

International distribution and typologies

Earth mounds can be found in different forms around the world such as the Neolithic mounds of the UK known as tumuli, tells of Syria, and terps of the Netherlands. While such earth mound features are related to cultural activity, none are directly related to cooking practices (Carver et al. 2014).

Earth mounds containing earth oven technology can also be found archaeologically around the globe throughout parts of Europe and Great Britain, Japan, Bismarck Archipelago, North America, South America, the Pacific Islands, Papua New Guinea, Samoa and New Zealand. Both British, Northern European and North American earth ovens have similar chronological patterns beginning around 4500BP and intensifying around 2000BP (Martin 2006:73, Thoms 2009). Much like Australia the advent and proliferation of cooking related earth mounds on other continents and islands is an indicator of dietary changes and human evolution as a result of increased consumption of fat and easier to chew meat in cold environments and of complex carbohydrates in temperate settings (Leach et al. 2006). From an North American perspective Black and Thoms (2014:205) refer to an earth oven as a layered cooking arrangement of fire, heated rocks or clay, food, green plant packing materials, and sediment designed to bake food in moist heat (Figure 5)(Black and Thoms 2014:205).

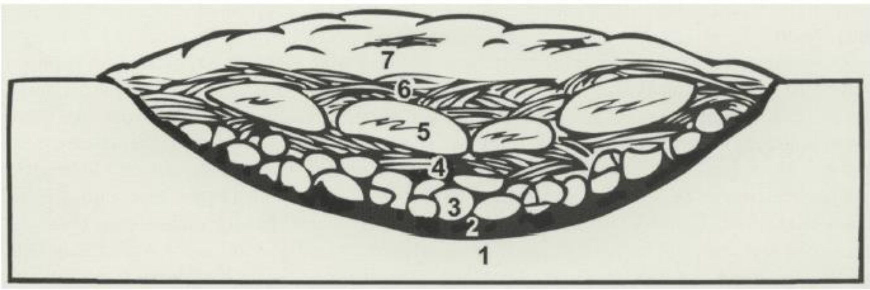


Figure 5*: a cross section of an earth oven, from Black and Thoms (2014:205) as can be seen the earth oven diagram shows 7 layers. 1.prepared surface(oven pit), 2. Fire (reduced to ashes and glowing coals by the time the oven is sealed), 3. Layer of red-hot rocks (heating element), 4. Lower layer of green plant material (packing), 5. Food layer, 6. Upper layer of packing, and 7. Earthen cap.*

Black and Thoms (2014:209) found that earth ovens were specialised plant processing facilities in many of the temperate and subtropical North American areas whereas they found that they were also used to process meats as well as plants in the more northern areas of the US.

Earth ovens and change in Holocene Australia

Two of the most accepted theories to account for population growth and changing behaviours throughout the Holocene are intensification and climate change (Lourandos

1988, 1985; Williams et. al 2010). Earth mounds are relevant in this debate as they are one of many indicators of cultural change that occurred 2000-5500 years ago (Lourandos 1988 :158). Mounds are important as they appear as a new site type for this period and indicate the habitation of marginal wetland environments, large scale food production and the exploitation of new food types and generally a more sedentary lifestyle (Lourandos 1985: 400).

Lourandos (1983:86-87, 1997:216-218) developed the theory of 'intensification' to explain the changes that hunter gatherer society experienced in the past 2000-5500 years. These changes involved intensifying of food production, population growth and an increase in sedentary behaviour. The main premise behind Lourandos' intensification model is that social and economic factors are the agents more responsible for change in a population rather than environmental, ecological, or technological factors. Lourandos (1988:150) discusses that social relations are viewed as the 'solutions to problems brought about by other factors' such as environment and demography (Lourandos 1988:150). Therefore according to this model, environment and demography provide the 'stress' to the population whereas social relations is the agent for change that combats that 'stress', therefore environment and demography are not the determining factor. Lourandos (1988:150) argues that intergroup relations, specifically feasting, ritual and exchange provides the context for change rather than domestic level production. Within these societies competition takes place for resources, spouses, exchange partners and information. Lourandos (1988:150) states 'that incentives then exist for increasing production beyond normal subsistence levels, to produce a surplus and/or control local resource productivity in order to meet or exceed social obligations.'

Lourandos' model was based on regional research conducted in the western districts of Victoria but was applicable to Holocene social transitions occurring continent wide during this period (Lourandos 1997). Lourandos (1988) makes a comparison to support his model with the peoples of Highland New Guinea as their society is similarly characterized by elaborate festivals, ceremonial occasions, exchange systems, and social conflict. In order to meet the demands of such social occasions surpluses (pig, yams etc.) are produced. A surplus of yams would be required to support these pig herds. The Australian equivalents of social occasion foods were eels, cereals, cycads and anything cooked in earth ovens thus the communal foods of Australia were in some ways as Lourandos (1988:157) states 'the functional equivalent of the New Guinea pig'. Earth mounds are the remnants of these social occasions where people lived and where communal foods were prepared, cooked and consumed.

Lourandos (1980:259) believes that population densities were not stable throughout the Holocene and that these changes can be explained by changes in energy harnessing techniques of which he believes mounds were instrumental.

Williams et. al (2010:831) propose that the catalyst for cultural change throughout the Holocene to Aboriginal people in Australia was due to changes in climatic conditions brought about by an increased El Nino-Southern Oscillation activity (ENSO). As a result of these climatic shifts, the early Holocene is characterised by higher than normal temperatures and rainfall (a thermal and precipitation maximum). In response this resulted in a greater abundance and availability of resources across Australia. Archaeological records then show an expansion of hunter gatherer settlement across the majority of the continent (Williams et al. 2015:106). This resource abundance in the early to mid-Holocene resulted in a longer patch residence time, low level food production and population growth (Williams et al. 2015:12, Bickford 2005:201). Mid-Holocene populations began to fill the continent restricting the movement of people between productive patches. This resulted in technological investment in more complex resource procurement such as in the use of earth ovens to make the inedible, edible (Williams et al. 2015:12, 106). In the mid to late Holocene the ENSO intensified in strength and frequency, drier and more variable conditions were experienced across Australia (Williams et al. 2010:832). The changing state and amplitude of the ENSO circulation placed environmental stresses on prehistoric populations in Australia. These stresses were due to an increase in aridity resulting in more intensive use of littoral resources (Luebbers 1978). The Late Holocene behaviours of Aboriginal people shows a general proliferation of technological investment, increasing territorialism and regional differentiation and greater use of marginal patches (Williams et al. 2015:12). These behaviours are seen to be a response to population packing which constrained mobility and resulted in broadening of the diet and greater control over resources (Black and Thoms 2014:206). These stresses on populations resulted in technological innovation specifically in regard to lower calorific food resources such as plant processing of which earth oven technology played a major role in the past 2000 years (Williams et al. 2015:106, Williams et al. 2010:832, Lourandos 1983, 1987, 1988).

Factors contributing to site destruction and potential pitfalls in researching earth mounds

Frankel's (1991:77) research has identified that an initial challenge with studying mounds is that they are often poorly preserved due to being 'generally softer and looser' than the surrounding soil and prone to erosion and animal burrowing's (Frankel 1991:77, Coutts et al.

1976, Coutts et al. 1979, Klaver 1998, Martin 2006). Fanning et al. (2005:16) has identified erosion, bioturbation, vandalism and damage from domestic livestock as a potential threat to this kind of deposit also.

Preslands (1977:91) research reveals that one must be careful when characterizing these features as past cooking and processing facilities. This is because not all mounds contain earth ovens and can easily be miss-identified if heat retainer material is not visible. Another potential pitfall identified by Sullivan and Buchan (1980:84) can be the confusing of earth mound deposits with the deposits left from previous bushfires in the form of burnt tree mounds.

Summary

Earth mounds are typically associated with riverine, floodplain and seasonal wetlands (Westell and Wood 2014:30) in multiple locations around Australia such as the Adelaide Plains, coastal plains in northern Australia and the riverine environments of south eastern Australia (Brockwell 2001:1-10, 2006:47, Westell and Wood 2014, Littleton et al. 2013). The structure and form of mounds can be extremely complex and variable, and it can be difficult to identify internal stratigraphic boundaries. Stratigraphic layering within mound deposits can contain differing degrees of earth oven material which can provide some clues as to site use intensity and site re-use intensity. Earth mounds are indicators of cultural change that occurred between 2000 and 5500 thousand years ago and there are differing theories as to the agents for this change such as social and economic and/or being climatic factors. Historically mounds are important as they appear as a new site type for this period and indicate the habitation of marginal wetland environments, large scale food production and the exploitation of new food types and generally a more sedentary lifestyle (Lourandos

1985:400). Earth mounds are the direct archaeological evidence/ remnants of the intensifying of food production and are specifically evidence of the past strategic use of marginal wetlands (Lourandos 1988:158).

Chapter 3. Earth mounds in geophysics

This chapter will provide an overview of previous geophysical research conducted on earth mound sites and similar cultural features. Initially Australian studies will be discussed followed by international examples.

Geophysical earth mound surveys conducted within Australia

Geophysical techniques have been infrequently applied in Australian archaeology, as reviewed by Lowe (2012). Moffat et al. (2008:60) attributes this underutilisation of geophysics in Australian indigenous archaeology to 'Australian archaeologists being reluctant to embrace these techniques because of their perceived high cost (both equipment and specialist staff) and the subtle nature of subsurface Indigenous sites as geophysical targets'.

This study is significant as no one has conducted research using geophysical instruments to map earth mounds in Australia. However there has been a small amount of work done on fire affected archaeological features which provides an analogue for this research.

The first emergence of geophysics in Australian Aboriginal archaeology occurred in 1975 with John Stanley and Ronald Green. Stanley and Green's (1976:51-56) research involved determining whether magnetics could detect hearths and shell middens. This work demonstrated that magnetometry was suitable for locating hearth and midden features in Australia by creating their own test plot containing a hearth which they manufactured, lit and later surveyed. The research was successful as the constructed hearth was easily identified (Figure 6). The study also involved comparing two types of magnetometers, a proton procession magnetometer and an alkali vapour magnetometer. This part of the study determined that the proton procession magnetometer being the older, cheaper less sensitive technology was much slower at surveying the area and could not provide the resolution that the newer technology could. This study illustrated that incorrect selection of instrumentation which is unable to achieve sub nT readings and fast sampling rates will limit the spatial detail with which an area can be readily mapped (Stanley and Green 1976:53).

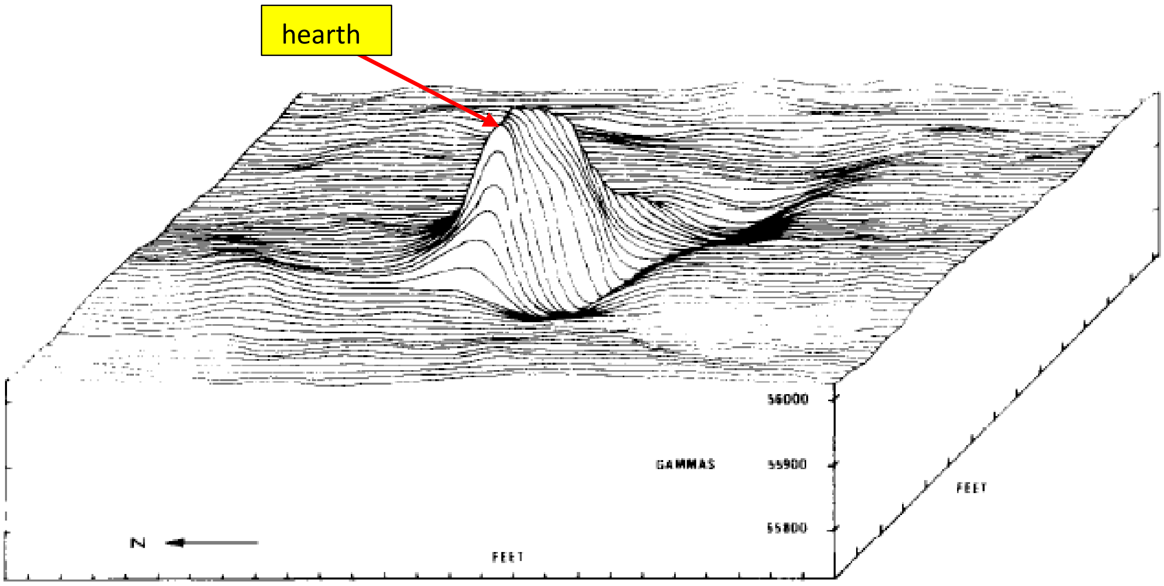


Figure 6: An isometric presentation of the total magnetic field plotted 0.5m above a camp fire hearth created by Stanley and Green as a test case. The data set is in gammas which is an older order of measurement to nano-tesla, however 1 gamma = 1 nano-tesla. Remanent magnetism parallel to the Earth's field was induced in the ferromagnetic minerals in the soil beneath the fire (From Stanley and Green 1976:56).

Clarke and Barbetti (1982) conducted some of the initial geophysics on hearths in the Willandra Lakes region. They were among the first to use palaeomagnetics to determine if hearth stones had been moved after their use which they believed may have indicated reuse and potentially indicated their function. They determined that the hearthstones were a variety of compositions including termite nest and carbonate nodules. They also noticed that the termite nest had two or more components of magnetisation whereas the carbonate nodules had many indicating that many had moved appreciably. The termite nest only having one magnetic component appears to have been left in situ after use and believed to have not been worth retrieving. This maybe because they were only an efficient heat retainers first time around. The different hearth/heat retainers indicated that these hearth/heat retainer types found in similar areas may have had different functions (Clarke and Barbetti 1982:149).

Williams and Gillieson (1987:128) did some of the first research in Australia on magnetic soil enhancement in southwestern Victoria. They used both soil chemistry and magnetics to clarify the function of activity areas on open archaeological sites (Williams and Gillieson 1987:133). Within their study area three areas containing mound complexes were studied at Caramut, Bessiebelle and Mt William. All of these sites were thought to be artificial features made within the last 2000 years by heaping of the surrounding soil and believed to be used as cooking and camping places. Samples were both surveyed with both field colorimeters to determine phosphorus and nitrogen levels associated with human occupation and also a portable magnetic susceptibility meter to determine magnetic susceptibility. Phosphorus and nitrogen levels can be used to detect human and food residues and additions to the soil which come from human refuse and waste especially from organic discard derived from bone, meat, fish and plants and ash from fires amongst other sources (Holliday and Gartner 2006:301; Hassan 1981). At all three sites Williams and Gillieson (1987:129) found that high readings of nitrogen and phosphorus related to hut site, cooking pit and hearth locations were substantially higher than those for surrounding off-site topsoils. The Caramut mound was composed of basaltic clays which returned the highest readings compared with that of Bessiebelle and Mt William which were sandy loams which do not retain soil nutrients as effectively as clays (Williams and Gilleson 1987:132). Samples from both Bessiebelle and Mt

William were also less magnetically enhanced than the Caramut site. The lack of enhancement was due to the sandy soil which was believed to be poor in magnetic minerals compared with that of the basaltic clay. They discovered that enhanced magnetic signal may persist for between 1000-2000 years. Williams and Gillieson (1987:134) found that the use of ratios of magnetic parameters provided the ability to identify hearth and cooking pit features where organic remains and charcoal were sparse. This research indicates that clay containing magnetic minerals and with an ability to retain nutrients can assist in the preservation of chemical constituents and magnetic properties of past occupied archaeological sites allowing them to be detectable long after they were constructed (Williams and Gillieson 1987).

Moffat et al. (2008:60-63) conducted a geophysical study to identify Aboriginal open sites, particularly hearth and midden sites in northwest Queensland. The study utilised both magnetics and electromagnetic methods, unfortunately the magnetics did not detect any hearth or midden features, however the electromagnetic survey did detect a burial. Unfortunately it was the choice of instrumentation and data acquisition methodology which potentially resulted in the research not being successful. The magnetometer used for the research was a proton precession magnetometer whereby the total magnetic field was measured; unfortunately the background noise could have potentially 'masked' the subtle features within the dataset collected as the instrumentation was only sensitive to 1nT. The studies unsuitable line spacing was one another factor contributing to the unsuccessful detection of known hearths and associated features. The survey utilised a line spacing of 1m when a line spacing of 10-20cm would have been more appropriate (Moffat et al. 2008). There were also issues with spatial accuracy as an uncorrected GPS system was used; this resulted in errors to do with navigation and also data acquisition positioning accuracy. The study found that sub-metre GPS or more appropriate (but more costly) differential GPS would have been more suitable for detecting features of this type (Moffat et.al. 2008).

Fanning et al. (2009) conducted a pilot study to confirm surface hearths detected during a reconnaissance survey using gradiometery. The hearths were identified and then categorised as buried, partially exposed, intact, disturbed, scattered and remnant based on a visual inspection. Readings from hearths from each category were collected and were compared with the site background reading to assess their respective magnitude. The magnitude of the magnetic response was considerably higher for in situ hearths compared to those that had substantially deflated. The study only assessed the presence and magnitude of the magnetic response from known hearths rather than attempting to locate them. The results do indicate that the instrumentation was suitable for detecting a significant response from the hearths surveyed which were all surface deposits (Fanning et al. 2009:21-22).

There has been very little research conducted using the electrical technique and GPR to map Australian earth mounds and earth ovens. This may be because magnetics is more suited to detecting this type of anomaly, being a quicker technique to deploy and the sensor is more suited to detecting earth oven material which has been magnetically enhanced. These techniques may have not been trialled over these features in Australia as countries that have been using archaeological geophysics for some time such as the UK have deemed them untested, unsuitable or unlikely to work for this type of application (English Heritage: 2008:14).

Similar geophysical research

GPR research has been conducted on other similar types of cultural landforms such as middens and the methodologies from these studies are applicable to this research. Kenady et al. (2018:538) have conducted work on a shell mound in northern Australia to delineate the extent and internal structure of a large late Holocene buried shell matrix site at Thundiy, Bentick Island. A pilot project was also conducted in the same area as Kenady et al. (2018) project whereby magnetic susceptibility surveys and excavations were conducted at three anthropogenic shell mounds on Mornington Island, Gulf of Carpentaria, Australia. The results were compared to assess site integrity and to determine whether magnetic signatures were related to cultural or natural site formation processes (Rosendahl 2014:21).

Lowe et al. (2016) conducted some of the first research on magnetic enhancement of deposits within the Pleistocene rockshelter Gledswood Shelter 1 in interior northern Queensland. Samples were taken every 5cm throughout the deposit and later measured with a Bartington Instruments MS2B sensor. The magnetics survey indicated samples that were weakly magnetic and were culturally sterile layers (Lowe et al 2016:224). The research also involved offsite burning experiments, and the data from these experiments indicated that natural fires do alter the soil temperature and mineralogy to the same extents as hearths. This indicated the increase in magnetic susceptibility of sediments in the shelter was not the result of natural bush fires but that as a result of human occupation. This research was the first of its kind to define the presence of humans at an archaeological rockshelter site in Australia (Lowe et al. 2016:226).

Summary

There have been no geophysical studies done on earth mounds containing earth ovens in Australia. Limited geophysical work has been done on shell mounds and other fire altered archaeological features. This limited research demonstrates that the methods deployed for this research should have been theoretically successful as these studies were undertaken in a similar context.

With the exception of the last three studies discussed very few of the past Australian archaeological geophysics studies go beyond being able to provide information about the location and extents of these sites, none appear to dissect the data in order to go beyond this. All studies tend to use 'the conventional methods' for looking for fire altered features, though the Moffat et al. (2008) is an exception to this. Very few of these Australian studies link geophysics to archaeology to answer questions, many are pilot studies with findings and recommendations for further research but very few of these studies are ever reinvestigated.

International research

There are many studies conducted internationally utilising GPR and Magnetics for the detection and study of kilns and hearth features particularly in the USA and the UK (e.g. Conyers 2009, 2011, 2012, 2013 2016, 2018, Kvamme 2003, Oswin 2009, Gafney and Gater 2010, Aspinal et al. 2009, Campana et al. 2008, Scheiber et al. 2010, Slater et al. 2000, Sternberg and McGill 1995, McGill 1990). There are few examples of these techniques being used to investigate earth mounds containing earth ovens similar to those studied here. Previous GPR studies in the American south west (Conyers 2012, 2011, 2018 Sternberg and McGill 1995, McGill 1990) are most relevant to this research.

There has been numerous published studies conducted in the use of magnetics to map hearths (Figure 7) and tipi rings (stone rings) across the US and UK (Jones and Munson 2005, Ezel et al. 1965, Scheiber et al. 2010, Slater et al. 2000) but only one recent publication by Conyers (2018) using magnetics and specifically a gradiometer system and GPR to map earth mounds containing earth ovens.

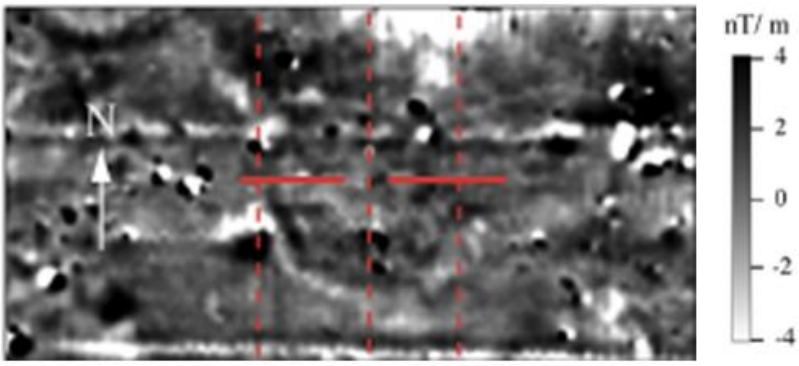


Figure 7: Gradiometer dataset containing a hearth, cross hairs delineate the centre of the hearth which is circular in shape (this is a plan view of the dataset). The amplitude bar relates directly to the shades of the magnetics accompanying data set, readings are expressed in nano-tesla (From Matney 2014:319).

Research published on the use of the electrical method to investigate earth mounds containing earth ovens does not appear to exist. The technique has been used in other archaeological contexts such as to investigate burial mounds and tombs (Tonkov 2008, Tsokas et al. 1994, Henry et al. 2014). ERT is also useful for mapping stratigraphic boundaries; it has environmental engineering applications such as being able to map heavy metal pollution and even mining applications such as mapping sulphide deposits (Reynolds 2011:330-330). The technique has been deployed to detect hearths in settlements throughout the US and the UK and many published studies have proven that these features are detectable by this method albeit being very subtle targets (Gibbons 1990, Matney et al. 2014, Schmidt 2013) (Figure 8).

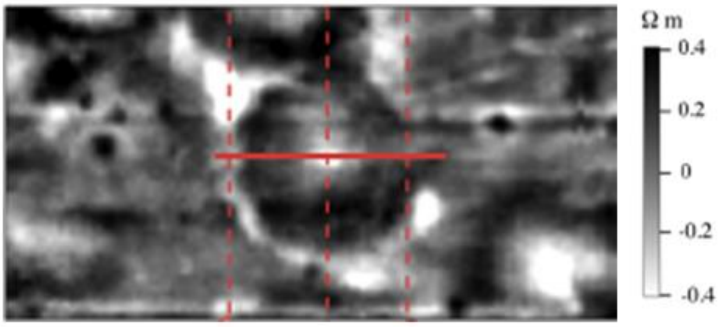


Figure 8: Resistivity survey over a hearth, the intersection of the solid line and middle dashed line delineates the centre of the hearth, the feature is circular in shape, note the subtle responses from the feature (plan view of dataset). The amplitude bar scale relates directly to the dataset and is expressed in Ohms (From Matney 2014:319).

Conyers (2012:154) and Sternberg and Mcgill (1995:215-216) have successfully mapped horno's (Native American earth oven or roasting pit) throughout the American south-west (Figure 9); they found that heat retainers within the horno's can provide good radar reflections as heat from the firing events bakes the oven bottoms creating a surface that retains water. This results in a dielectric contrast to the surrounding soil and that contrast is something that GPR detects effectively. Conyers (2012:154) discusses a survey he conducted at a facility called University Ruin in Tucson over a suspected horno.

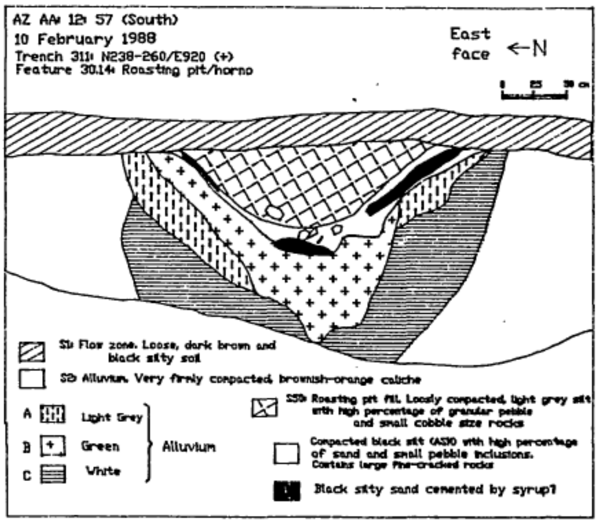
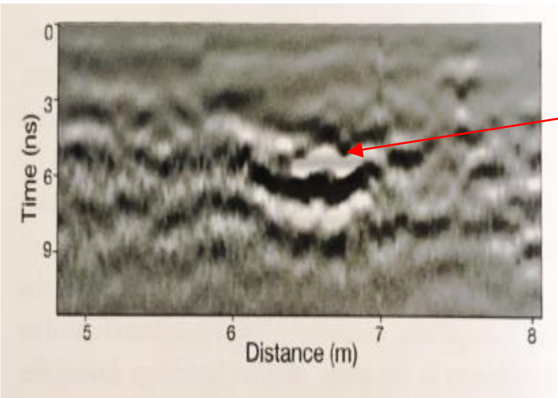


Figure 9: Cross section of a typical horno of the American south-west (roasting pit) (From Sternberg and McGill 1995:216).

When the GPR target was excavated a number of fire cracked stones were sitting on the top of the burned layer. Conyers (2012:154) found that these stones were not readily visible in the reflection profiles with the 400 MHz antenna however the burned baked layers beneath were easily detected and were more distinctly seen in amplitude slices created from multiple two dimensional profiles (Figure 10 and 11). Conyers (2012:155) believes that the heat retainers of the oven are unlikely to be detected with a 400 MHz antenna but the baked areas beneath will be readily mapped on most occasions.



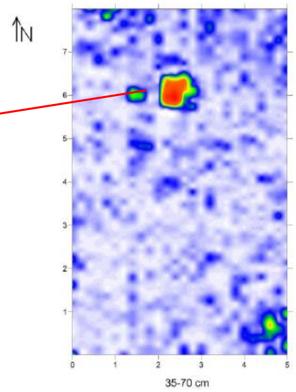


Figure 10 (left): a two dimensional profile containing a Hohokam horno (earth oven) note individual heating elements cannot be seen, however the baked base layer can be easily seen.

Figure 11 (right): an example of a horizontal amplitude slice map showing a Hohokam horno (earth oven) in a 35-70cm depth slice; the strong reflections of the horno are coloured red and yellow and the areas of weak or no reflections are in blue (From Conyers 2011).

Conyer's choice of frequency is in agreement with Sternberg and Mcgills' (1995:219) research whereby they tested the effectiveness of two separate antenna frequencies over a horno to see which frequency detected the feature most effectively. The two antennas used were a 100MHz and 500MHz antenna; responses from the 500MHz were much more distinctive than the 100MHz (Figure 12). According to Sternberg and McGill (1995:219) this was most likely because the shards and rocks within the horno were of a size capable of reflecting 500MHz signals in contrast to Conyer's study whereby they may have not been. The signals from the 100MHz were only capable of highlighting the larger structure of the pit, both Conyers (2012) and Sternberg and McGill (1995) appear to be in agreement that the choice of frequency of antenna is vitally important in effectively detecting these cultural features. When an appropriate frequency of antenna is chosen information relating to more than just the features location can be derived from the data set.

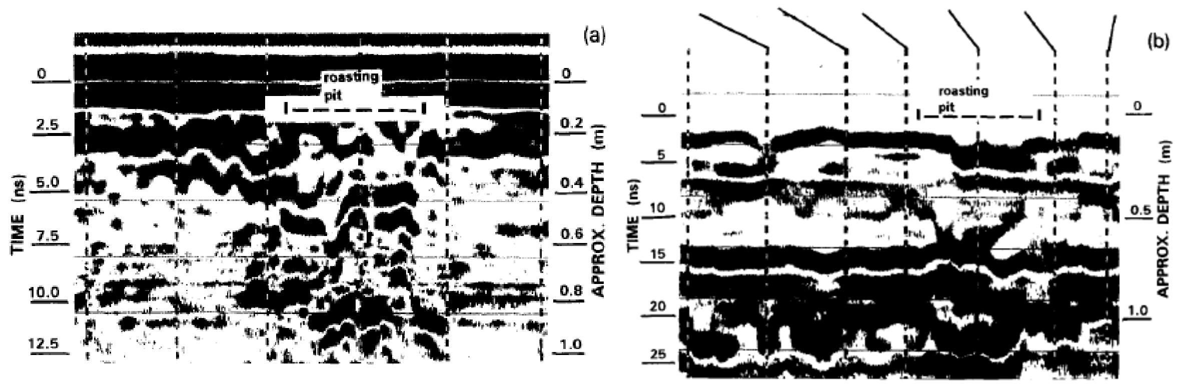


Figure 12: (a) A horno (roasting pit) recorded by a 500MHz system by Sternberg and McGill (1995: 215) (b) is the same horno recorded by a 100MHz system. A considerable loss of resolution can be seen in the 100Mhz dataset compared with that of the 500MHz. Dashed lines in the data set indicate 1m intervals.

Conyers (2018) has developed a new approach to detect fire altered archaeological features within complicated GPR 2D profiles by linking both datasets together and cross-correlating between them. This was achieved by acquiring datasets using each method over the exact same location. The datasets can then be linked, one above the other (Figure 13). A joint analysis can then be undertaken, GPR cannot detect fire altered material and magnetics cannot provide a 2D representation of features to indicate depth. However GPR can indicate subsurface depth and magnetics can indicate the location of fire altered features. When used in conjunction with each other Conyers (2018) found that the position of fire altered archaeological features could be illustrated in the 2D magnetics datasets and related to GPR datasets beneath whereby the GPR method could also indicate a depth to the feature. This became useful for Conyers (2018) in complicated GPR datasets with multiple responses in an around the fire altered feature and picking the feature from just the GPR data was impossible. This linked dual technique method of interpretation provided much more confidence in Conyers (2018) interpretations on many recent projects.

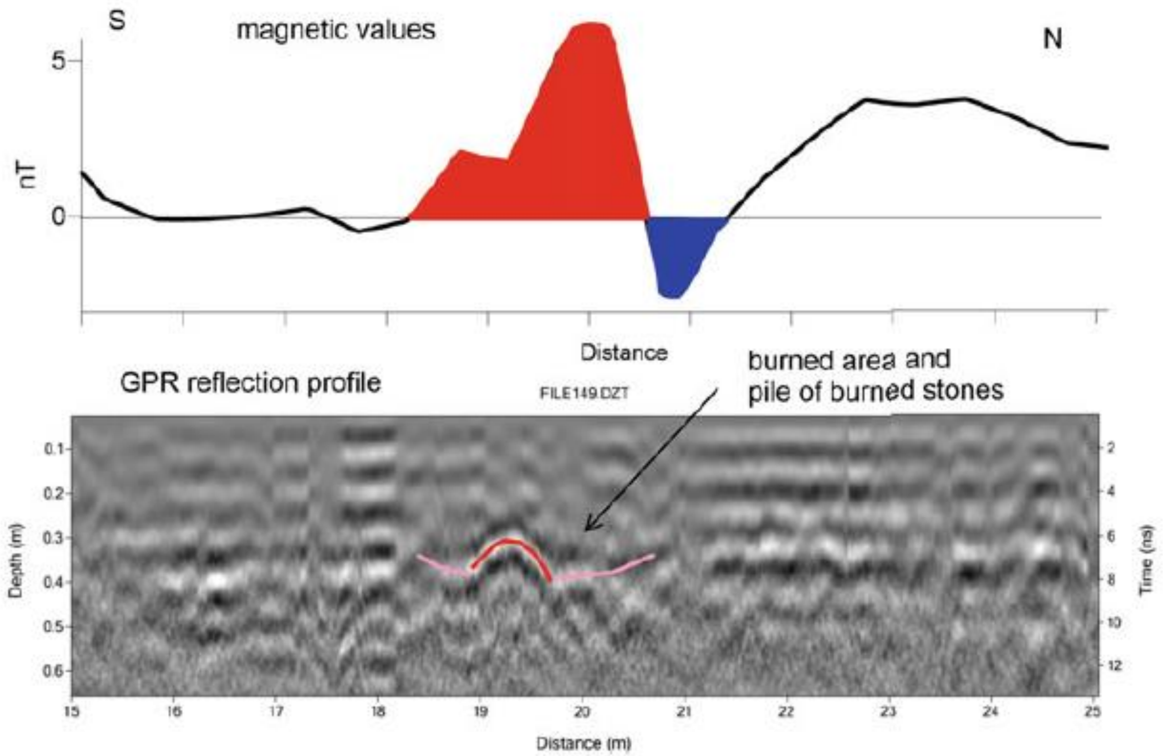


Figure 13: Combined 2D GPR profile and 2D magnetics profile interpretation approach, the dataset indicates a burned area with a pile of stones from an earth oven (Conyers 2018:99).

Summary

Australian Indigenous archaeology lacks a robust methodology for the successful detection of earth ovens and associated features with geophysical instrumentation. Many of the studies researched for this literature review have aims relating primarily to the detection of middens, mounds and hearths. None appear to address what other information can be ‘gleaned’ from the geophysical data sets other than the initial identification/location of the feature. This research hopes to bridge the gap between archaeology and geophysics by using geophysics to answer archaeological questions about the cultural features being mapped rather than just their initial detection. This research hopes to build on Fanning et al. (2009) findings by actually using a fluxgate gradiometer to accurately locate and map buried cooking features such as hearths or earth ovens still in situ and through their detection and mapping answer archaeological questions.

Chapter 4. The study area

In order to conduct and interpret archaeological geophysical surveys successfully it is imperative to understand the area's geomorphology, geology and soil types (Oswin 2009: 103). This is because geophysics is a discipline that identifies contrasts between the target and the surrounding subsurface. If there is no contrast there will be no definable response. (Clark 1990:125; Gafney and Gater 2010:55).

Regional geomorphology

The research area is situated in a section of an anabranch system attached to the Murray River near Renmark and comprising of Hunchee Creek and Little Hunchee Island (Figure 1). The surrounding areas of this anabranch system are comprised of the main active Murray River channel, flood plains, sand sheets, billabongs and periodic flooding lakes. The Murray River at Calperum Station has been the route of the river in its last two stages from the late Pleistocene to Holocene (Department for Environment and Heritage 2000:15), whereby there was an ancestral river and the modern river that can be seen today (Gill 1973:24-25, 49). The modern stages of the Murray River are much less active in even in peak flow compared with the older stages of the river. This more active phase can be interpreted based on the characteristics of fluvial sediments which are interspersed in a complex mosaic with small islands of old landforms in the modern floodplain (Gill 1973:24-25).

At present there has been no detailed geomorphic mapping of the Calperum floodplain, though wider regional studies have been conducted by Thompson (1975) and Gill (1973). Their respective research has been patchy and as a result low resolution and difficult to relate to the research location in a geomorphic context. At this present time there is a comprehensive geomorphic research project being undertaken within the Calperum

Floodplain by Flinders University, however the results are unpublished as it is still in progress (Westell in Prep).

To date the most relevant geomorphic research in the region has been conducted by Prendergast et al. (2009). This research will be used as a comparative framework to describe the land units at the site of this research as they are applicable and correspond with the land units of Prendergasts research. These systems are situated within 50km of this studies' research location and so are a suitable analog for the Calperum Station region. The section of Hunchee Creek where the research was conducted has morphological similarities consistent with land systems created to characterise land units in the Central Murray Valley, north Western Victoria (Prendergast 2009:59). Prendergast (2009) defined five of these land systems to categorise differing regional land units, describing them sequentially from south to north from highest to lowest elevation (Figure 14). The cross section provided shows a broad chronological sequence of the land units (Figure 15) (Prendergast 2009:58).

The land systems surrounding Hunchee Lagoon are the Mulcra Island Land System and the Murray Land Systems. The Mulcra Island System is 1-2m above the Murray Land System and 1m below the Lindsay Land System (Figure 14). The system is comprised of floodplain, palaeomeander scrolls and billabongs. The dominant process for the creating of this system has been fluvial with sediments of medium grey gilgai clay and fine medium overbank clays (Prendergast 2009:59). Vegetation within this system is dominated by Black Box (*E. largiflorens*), Lignum (*M. florulenta*) and Red Gum (*E. camaldulensis*) and some grasses (Predergast 2009:59). This system encompasses the proximal portions of the floodplain at Hunchee Creek, an area which contains approximately 50% of the geophysical survey grids.

The Murray Land System is comprised of the River Murray and its active floodplain, located below the Mulcra Island System. Flood plains, river channels and billabongs dominate this system. The dominant process for the creation of the Murray Land System is also fluvial with sediments of mostly compacted light grey medium clays. The dominant vegetation of this land system is Red Gum *(E. camaldulensis*) (Predergast 2009:59), which are especially prevalent on the banks of the Hunchee Creek anabranch. The other half of the geophysics survey grids fall within this system.

Figure 14: Prendergasts' (2009:57) land systems map of the Murray River region from the SA border to the left of the map into Victoria (Figure removed due to copyright restrictions).

Figure 15: Schematic southeast to northwest cross section generated from a-a' from Figure 14 (From Prendergast 2009:57); the vertical scale in the cross-section is exaggerated (Figure removed due to copyright restrictions).

Site geology

Gill (1973:7-8) has conducted the only geological analysis near Calperum Station, at Chowilla Dam 31km away.

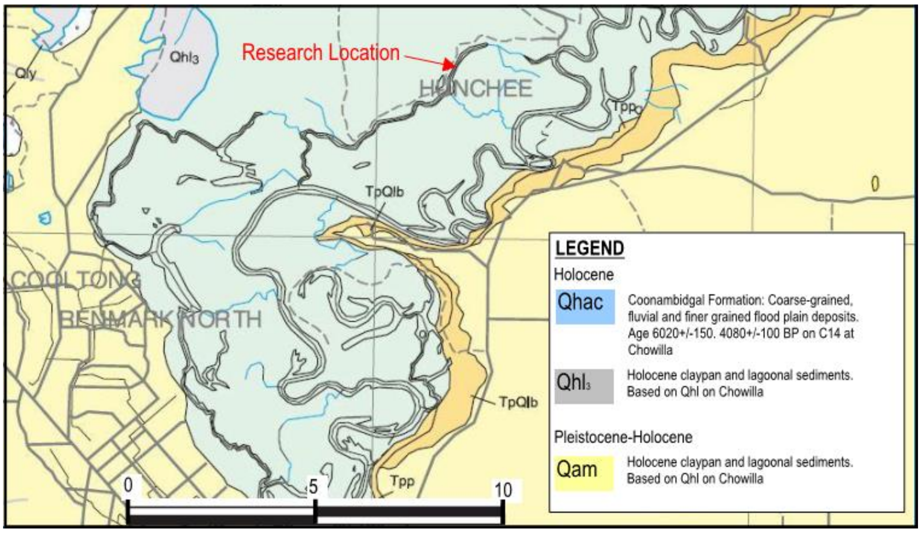


Figure 16: regional geological map of the Hunchee Creek region adapted (SARIG 2018).

The geology of Hunchee Creek is dominated by three main units which are depositional in origin (Table 1). The shallowest unit is the Coonambidgal Formation which is directly below the modern sediments of the MDB within this region (Figure 16).

Table 1: A summary of the geological units from Chowilla Dam but applicable to the research site, (this table has been adapted from Geoscience Australia – Australian Stratigraphic Units Database 2018, ***http://www.ga.gov.au/data-pubs/datastandards/stratigraphic-units***).

Formation Name	**Description**	**Rank**	**Event**	**Maximum thickness**	**Min. Age**	**Max Age**
Coonambidgal Formation	Alluvial floodplain and fan deposits, channel sands and clay playettes; clay, silt and fine to coarse grained sand, gravel.	Formation beds	deposition	8m	Holocene	Pleistocene
Blanchetown Clay	Laminated greenish-grey and red-brown clay and silty clay, locally calcareous and gypsiferous; minor interbedded quartz sand, ostracod sand; contains calcareous, gypsiferous and siliceous nodules.	Formation, beds	deposition	20m	Early Pleistocene - 1.2MA	Early Pleistocene – 2.4MA
Loxton/Parrilla Sands	Unconsolidated to weakly cemented yellow-brown fine to coarse well-sorted quartz sand, sandstone, interstitial white kaolinitic or gibbsite clay matrix towards top; composite sand sheet deposited in strand plain and fluvial environments	Formation, beds	deposition	15m	Early Pliocene	Late Miocene

The Blanchetown Clay is below the Coonambidgal Formation and the thickest of the deposits. The Loxton/Parilla Sands are the deepest and oldest of the deposits (Gill 1973:8; Worthy and Pledge 2007:110). All deposits are composed of clays, sands and gravels typical of a depositional environment. These deposits being covered by modern sediments did not influence the geophysical results.

Site soil types

At this time there has been no published research on soil classification for Calperum Station. The only source available at the time of this research was 'Nature Maps' a South Australian government website which broadly outlines regional soils (Government of South Australia 2018, http://spatialwebapps.environment.sa.gov.au/naturemaps/?viewer=naturemaps).

The soils present were brown/grey cracking clays, presumably modern floodplain sediments (Figure 17).

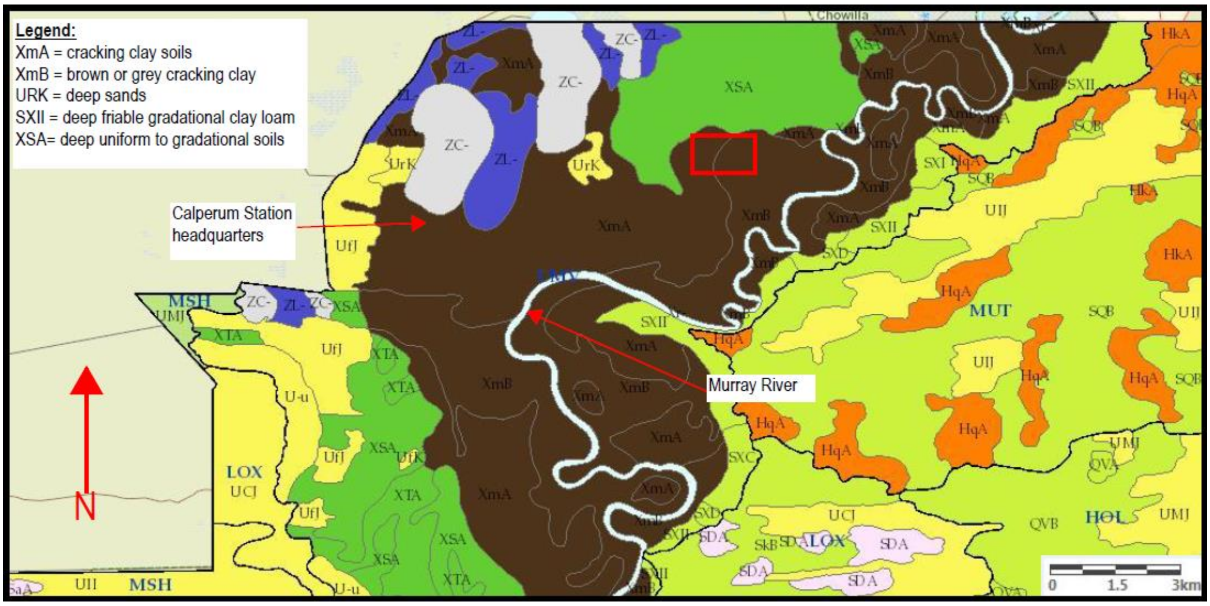


Figure 17: Site soil types of the research area and region, the study area is located within the red box (Map adapted from 'Nature Maps' – Government of South Australia website 2018 http://spatialwebapps.environment.sa.gov.au/naturemaps/?viewer=naturemaps).

Historical context and archaeology

The research area is located within a portion of the former First Peoples of the River Murray and Mallee Native Title Claim which incorporates a number of narrower Aboriginal groupings that existed prior to European arrival (Tindale 1974; Berndt and Berndt 1993). The portion the research area is located in was determined via consent with the rights and interests managed by RMMAC. According to Tindale's (1974:211) notes the study area falls within the boundaries of the Erawirung also referred to as the Jirau (Tindale 1974:211) or the Yirau (Berndt and Berndt 1993)(Figure 18). Tindale's (1974:211) accounts identify

Erawirung as a small group. Within their lands were two chert stone mines which they are known for being the custodians of and the products from which were used for trading with neighbouring groups (Tindale 1974, 1981; Woolmer 1976 in Clarke 2009: 156).Other descriptions of cultural boundaries also exist within ethnohistorical and anthropological literature however a detailed exposition is beyond the scope of this study.

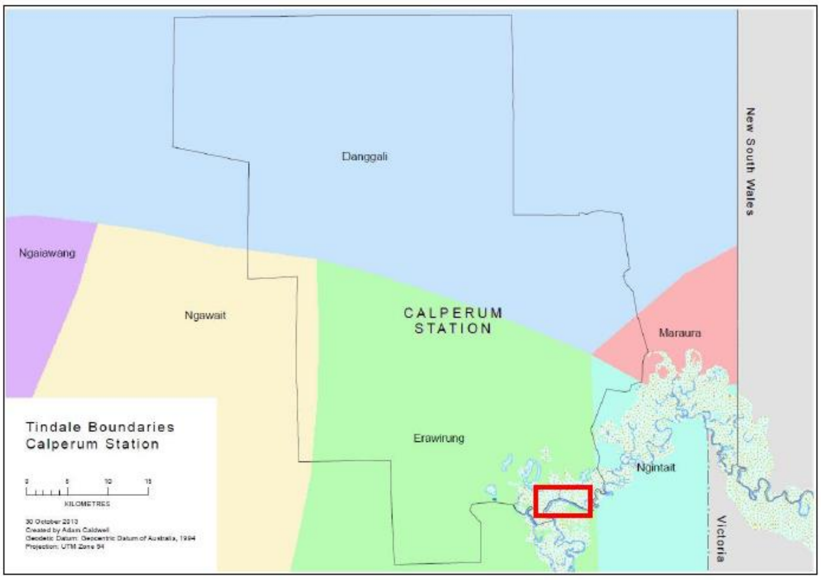


Figure 18: Tribal boundaries map of Calperum Station and surrounding regions originally created by Tindale (1974), Hunchee Creek is located within the red box (Caldwell 2014:4 in Threadgold 2017: 16).

Past archaeological surveys of the Murray River valley between the towns of Renmark and Mildura have located burials, artefact scatters, quarries, scarred trees and earth mounds and middens (Threadgold 2017; Caldwell 2017; Jones 2016; Westell and Wood 2014). The research locations is abundant with markers of past cultural activity.

To date there have been two local archaeological studies of the Hunchee Creek precinct and surrounding areas conducted by Jones (2016) and Threadgold (2017) as part of an integrated research program run by Flinders University. Threadgold (2017) has conducted the first detailed study of surface stone artefacts associated with earth mounds in the

Riverland district of the Murray River. An interesting finding of Threadgold's (2017:115) research was that there was a very low or absence of stone arefacts on the Calperum Station mounds suggesting that they were unlikely used for camping. Threadgold (2017) found this to be in direct contrast to Klaver's (2008) and Martin's (2006) research whereby the mounds contained artefacts on and throughout the deposit.

Jones (2016; Jones et al. 2017) is the other to have conducted archaeological research in the area however his research was on the structure and function of the mounds themselves compared with the mounds of other regions. Jones (2017:56) found that Calperums mounds shared similarities with the ashy deposits of the Menindee Lakes region albeit having a higher and more contained structure.

Summary

The Hunchee Creek research area is rich in archaeology of the Erawirung people, evidence of their past cultural activities can be seen in the landscape as scarred trees, artefact scatters, burials, quarries, earth mounds and middens (Tindale 1974, Woolmer 1976, Jones 2015, Threadgold 2017).

Due to a lack of previous research pertaining to geological and soil data a regional interpretation of both has been proposed for this chapter. The site is dominated by brown and grey cracking clays presumably Blanchetown clays in their origin. Their magnetic susceptibility was not known prior to this research which justified some preliminary field research to determine this and to ascertain if certain geophysical methods would work. From this testing three methods were deemed most suitable for use within the research program.

Chapter 5. Methods

The three types of technique used for this project were magnetics, resistivity and GPR, all of which have been used extensively across the world to non-destructively map archaeological features (Gaffney and Gater 2010:13). Magnetics is a technique whereby the spatial variations and contrast in the magnetic properties of the subsurface are investigated (Oswin 2009:46-47). The technique is effective in the detection of fire related features such as kilns, furnaces and hearths (English Heritage 2008:14). GPR is a technique that involves the transmitting of high frequency radar pulses into the subsurface in order to detect buried objects and stratigraphic boundaries (Conyers 2013:2). Resistivity is a technique whereby electrodes are installed into the ground, connected to a meter via cabling in order to measure local variations in the resistance of the subsurface. The technique is useful for the mapping of ditches, pits, foundations and stratigraphic boundaries (Gaffney and Gater 2010: 26; English Heritage 2008:14).

Flinders University Ethics Approval

This research is part of a larger project which has been run under the guidance and assistance of the River Murray and Mallee Aboriginal Corporation (RMMAC) whom represents the Indigenous groups of the South Australian Riverland.

Flinders University research projects that may impact Indigenous communities requires approval from the Flinders University Social and Behavioural Research Ethics Committee (SBREC). The approval for this project was granted on 11 November 2016, as project number 6,618. RMMAC cultural advisors were present during all field activities to ensure all work was culturally appropriate and that protocols were followed. In accordance with the wishes of RMMAC and under the provisions of the *Aboriginal Heritage Act 1988* (SA), all field work on this project was non-invasive and non-destructive. No archaeological site coordinates were to be disclosed in any future publications which also included this thesis. Approvals were provided for the undertaking of resistivity surveys by RMMAC and Aboriginal Affairs and Reconciliation in the Government of South Australia (appendix six).

Overview of selected geophysical techniques

Applied geophysics as defined by Milsom and Eriksen (2011:1) is the 'mapping of the subsurface through the remote measurement of its physical properties.' The success of any geophysical method relies on there being some kind of measurable contrast between the physical properties of the target and the surrounding medium (Milsom and Eriksen 2011:1). These properties are: density, elasticity, magnetic susceptibility, electrical conductivity and radioactivity. However in many cases not all equipment is suited to one particular purpose, therefore a combination of methods have been employed on this project. The methods that were used were: magnetics, resistivity and ground penetrating radar.

Table 2: Geophysical Techniques used for this research - the different geophysical techniques are broken up into two classes of sensor being either 'active' or 'passive'. 'Passive' methods use naturally occurring fields such as the earth's magnetic field of which the observer has no control in the detection of variations caused by geological or anthropogenic features. Alternatively 'active' methods involve generating signals in order to induce a measurable response associated with a target. The observer can control the level of energy input into the ground and also measure variations in energy transmissibility over distance and time (adapted from Milsom and Eriksen 2011: 3-4).

Technique	**Passive/ Active**	**Physical Property Utilised**	**Source/ Signal**	**Equipment used**	**Processing software used**
Magnetics	Passive	Magnetic susceptibly/ remanence	Earth's magnetic field	Bartington Grad601 dual sensor gradiometer	Terrasurveyor – DW Consulting
Resistivity Imaging/ Sounding	Active	Electrical resistivity	DC electric current	ZZ Resistivity Imaging Pty. Ltd. FlashRes resistivity IP meter	RES3DINV - GEOTOMO

Ground Penetrating Radar	Active	Dielectric properties (permittivity)	Pulsed or step frequency microwave EM (50-2000MHz)	Geophysical Survey Systems Inc. (GSSI) SIR3000 with 400MHz antenna	RADAN - GSSI

Topographic Survey

An RTK GPS (Leica Icon GPS 60) was used for all topographic survey. This had a spatial precision on coordinate data of ±25mm, and the device was set to prevent the capture of coordinate data where this exceeded ±0.5m threshold. Spot heights were recorded around the site in a grid pattern to build a digital terrain model. This is required because responses from geophysical targets can be influenced by topography. The amount of fill over an anomaly can influence the amplitude of the response. Therefore being able to link topography to geophysical datasets can provide a higher degree of confidence with interpretation (Oswin 2009:60-71, 118).

The only geophysical instrument on the project that was used with GPS integration was the gradiometer. Only data collected for the initial phase of field research was collected in the instrument's GPS mode not the instruments pre-set grid mode. In GPS mode coordinates were acquired from a Hemisphere GPS which was built-in to the field computer that was connected to the gradiometer system (Bartington 2012), with an estimated spatial precision of ± 5m. Coordinates acquired and recorded were outputted in WGS84 coordinate system.

Magnetics – Theory, instrumentation and survey preparation/calibration

Theory – Thermo-remanent magnetization at the atomic level

Kilns and fire related archaeological features were some of the first archaeological features surveyed with magnetometers because it became known that these features acquire a high thermo-remanent magnetization (TRM) during their firing (Aspinall et al. 2009:21). Within natural clays rich in iron oxides, neighbouring magnetic domains (refer glossary) are almost randomly orientated and under normal conditions the earth's magnetic field are too weak to produce significant alignment in them and therefore their induced magnetization (refer glossary) is relatively weak. However when these minerals are heated above their Curie temperatures (refer glossary) the minerals themselves lose their magnetic order and become paramagnetic (refer glossary), and as a result their individual magnetic moments can readily align with the ambient magnetic flux density (refer glossary). Once the material has cooled below its Curie temperature, magnetic order re-occurs and the domains form around the newly aligned magnetic moments. It is due to this consistent alignment that the overall TRM is high and creates a significant contrast between the heated feature, acting as a strong bar magnet aligned with the earth's field at the time of firing and the surrounding soil (Aspinall et al. 2009:21).

Another way topsoil can be magnetically enhanced by burning is known as the Le Borgne effect. This can occur when a soil contains the very common weakly magnetic, iron oxide hematite. The Borgne effect occurs by the burning of vegetation in surface fires which is sufficient enough to exclude oxygen, thereby producing a reducing atmosphere. A heat of 200^{o}C under these conditions is enough to reduce hematite in topsoil to magnetite. When the fires subside, oxygen becomes available the magnetite cools and then re-oxidises as maghemite, leading to a permanently enhanced magnetic susceptibility of the subsoil (Aspinal et al. 2008:24). This form of subsoil enhancement is also detectable with magnetometers (Aspinal et al. 2008:26).

Instrumentation

The instrument used on this project to acquire magnetic data is a fluxgate gradiometer manufactured by Bartington Instruments in the UK. The model to be used is a Grad 601 dual sensor system (Figure 19), the system is comprised of two tubes (sensors) mounted on a frame which has a central control box that acts as a control panel and data logger (Bartington 2012).

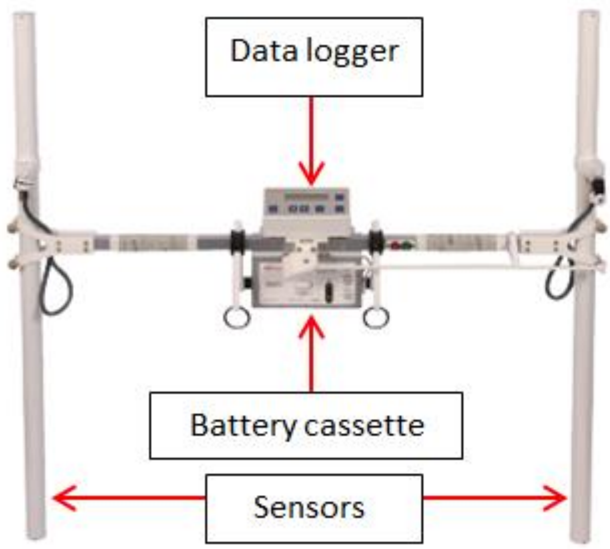


Figure 19: Bartington Grad601 – Dual Sensor Gradiometer (Bartington 2012).

Each of the sensors is comprised of two short wires called toroids which act as cores for primary coils wound closely around them so that the windings are in a series but opposing directions. In the absence of any external field the passing of an alternating current of between 2-5 kHz frequencies will produce equal and opposite fluxes in the two cores. A secondary coil wound around the pair therefore encompasses zero resultant magnetic flux.

By the laws of electromagnetic induction, any changing flux passing through the common secondary coil induces an alternating voltage in it equal to the rate of change with time (time gradient) of the magnetic flux. Since no resultant flux is passing there is no voltage induced in the secondary coil. However when the presence of an external steady field is encountered along the cores' axis it produces an output voltage proportional to the magnitude of that field (Aspinall et al. 2009:34). This configuration involves two sensors housed at a fixed distance from one another and one above the other (Figure 19). The vertical separation is 1m between sensors for this particular system, the sensors are relatively close together and as a result are affected equally by the earth's magnetic field and on occasion deep broad geological sources which are not of interest in an archaeological survey (Bartington 2012:4). These unwanted signals are filtered out when subtracting the two readings, this type of gradiometer configuration forms an inherent spatial high pass filter making the system more sensitive to sought after archaeological signals (Aspinall et al. 2009:33).

Survey preparation

Prior to the magnetometer surveys a metal detector survey was conducted over each of the survey areas using an X-Terra 705 metal detector manufactured by Minelab. This was to mark buried modern ferrous objects onsite which could be confused with cultural features in the magnetics surveys. A concrete pipe was located within the survey area which the metal detector survey confirmed contained metal reinforcing. Once all of the metal detector surveys were completed the fluxgate magnetometer surveys were undertaken.

The gradiometer system used on this project had a noise level (sensitivity) of c.0.1nT so very weak changes in magnetic susceptibility could be detected. This type of instrumentation was extremely sensitive to magnetic fields therefore all field personnel were asked to remove all metal from their person when near the sensors (Gaffney and Gator 2010).

The pre-set grid size chosen off the instrument was 20m x 20m with a lines spacing of 0.25m and a sample rate of 8 samples per meter.

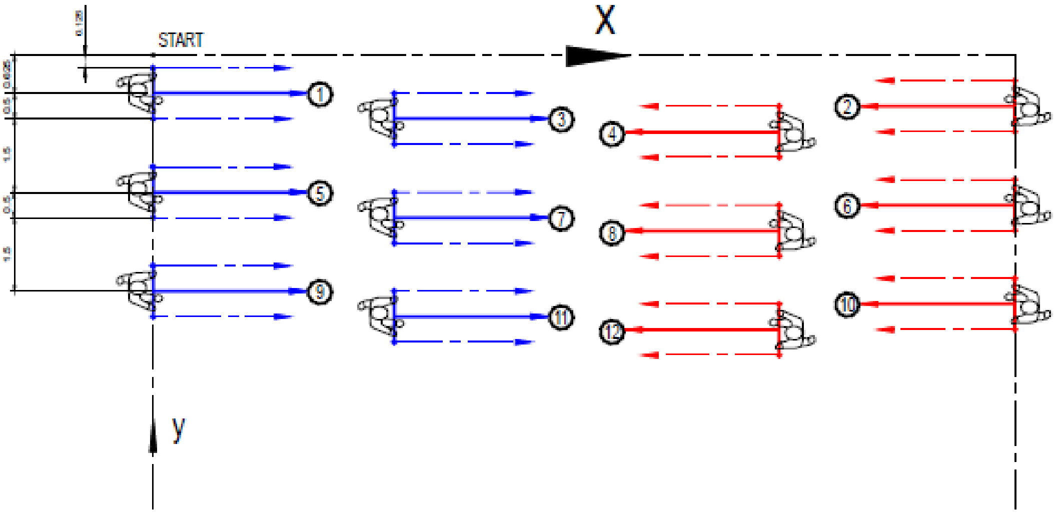


Figure 20: Grid configuration when instrument was set to grid mode to get maximum resolution – diagram is illustrating data acquisition at 4 lines per meter (0.25m spacing) and in zig zag configuration (Bartington 2012).

Instrument Calibration

The instrument was calibrated in non-magnetic area after a warm up period of 15 minutes following the manufacturer's instructions (Bartington 2012).

Ground Penetrating Radar – theory, instrumentation and survey preparation/calibration

Theory

Ground penetrating radar data is acquired by reflecting pulses of radar energy produced from an antenna typically run across the surface of the ground. This antenna generates waves of various wavelengths that propagate downward, and these waves spread as they move into the ground like a cone which is a function of the materials through which they pass through (Conyers 2013:47). As the transmitted waves travel through the ground they are reflected from buried objects and stratigraphic interfaces. These reflected waves travel back to the ground surface to be detected and recorded by a receiving antenna. This two way travel time of the signal from the transmitting antenna into the ground and then back to the receiving antenna is measured in nanoseconds (Conyers 2016:5). In order for a reflection to occur propagating radar waves travelling through the ground must experience an abrupt velocity change. This occurs when radar waves pass across contact boundaries of very different materials in the ground, for example the interface between sand and clay horizons. It is this abrupt velocity change at a boundary which causes the generation of a reflected wave that can travel back to the ground surface and to the receiving antenna from the reflection interface where they are displayed for interpretation and recorded (Figure 21). If buried interfaces are orientated in such a way to reflect radar waves away from the receiving antenna on the ground surface, then these surfaces will not be recorded and will be invisible to the GPR technique (Conyers 2013:107).

In order to determine correct depths of GPR targets within datasets one must have an understanding of the relative dielectric permittivity of the subsurface being investigated. Relative dielectric permittivity (RDP) also known as dielectric constant, and according to Conyers (2013:48) ‘takes into account the electrical and magnetic properties of buried materials and is a measure of the ability of a material to store a charge from an applied electromagnetic field and then transmit that energy’. RDP is a general measurement of how well radar energy will be transmitted to depth, therefore the velocity of the propagating wave and its strength are measured (Conyers 2013:48). RDP affects wave speeds as it refers to the density of bound electric charges in a material and the ability of a GPR wave to displace these charges. The higher the density of bound electric charges the higher the RDP, therefore a wave will move slower in a material with a high RDP and faster in material with a lower RDP (Bigman 2018:27). For example if a GPR wave is transmitted through two materials of the exact same thickness, one with a high RDP and the other a low RDP, the wave will take the longest to travel through the material with a high RDP compared with that of the low RDP (Bigman 2018:27). This is important because depths in GPR data are calculated in two way travel time of the radar waves being transmitted and an understanding of the velocities of these waves allows for more accurate depth estimates (Table 3). For this project an RDP of 8 was calculated using a velocity analysis processing technique called hyperbola fitting (refer to glossary) in a GPR post processing software called GPR Viewer.

Table 3: Relative dielectric permittivity's of materials and their corresponding average wave velocities (From Bigman 2018:28 – used with permission).

Material	Approximate Range RDP	Average Velocity (m/ns)
Air	1	0.3
Ice/Permafrost	2-3	0.17
Crude Oil	2-3	0.17
Asphalt	2-4	0.15
Dry Sand	3-6	0.15
Limestone	4-8	0.12
Concrete	4-10	0.12
Silt	5-30	0.07
Clay	5-40	0.05
Water	81	0.033

Typically GPR reflections/anomalies are classed as either planar or hyperbolic whereby for example a rock or pipe would be classed as a hyperbolic reflection and a clay floor would be classed as a planar reflection. An earth oven within a GPR data set could contain both types of reflections depending on its size.

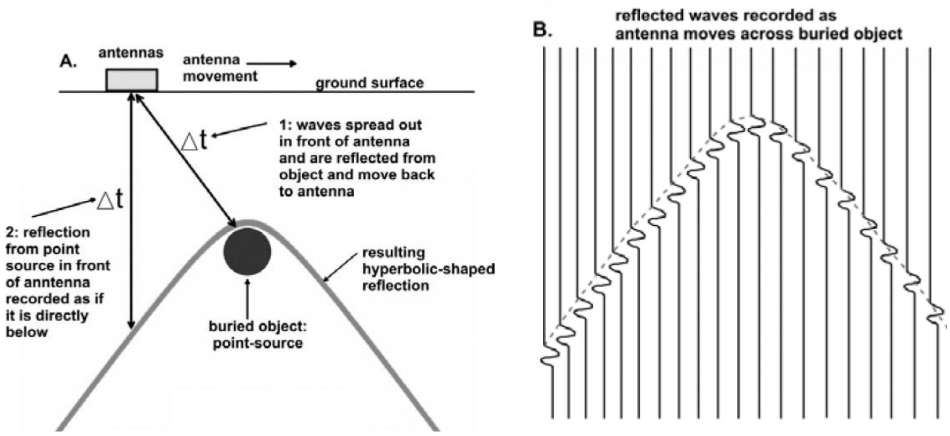


Figure 21: The conical projection of radar energy into the ground will allow radar energy to travel in an oblique direction to a buried point source (1) as seen in (A). The two-way travel time (t) is recorded and plotted in depth directly below the antenna where it was recorded (2). When many such reflections are recorded as the surface antennas move toward and then away from a buried object, the result is a reflection hyperbola (3), when all traces are view in succession, as seen in (B) (Conyers 2013:61).

Instrumentation

The ground penetrating radar system that was used on this project was a GSSI SIR3000 with a 400 MHz antenna. The system used was comprised of a control unit (a field computer) which was used to set survey parameters and store and display data. An antenna was used to transmit and receive signal which was then recorded by the control unit and both were linked via a control cable. The encoder wheel was attached to the survey cart and mounted against one of the cart's wheels. This was to enable it to turn with the cart wheel and calculate distance in real time as the system was pushed forward. The encoder wheel was attached to the system's antenna by way of a cable and both information from the antenna and encoder wheel travel up the main cable to be displayed and stored on the system's control unit screen and internal hard drive respectively.

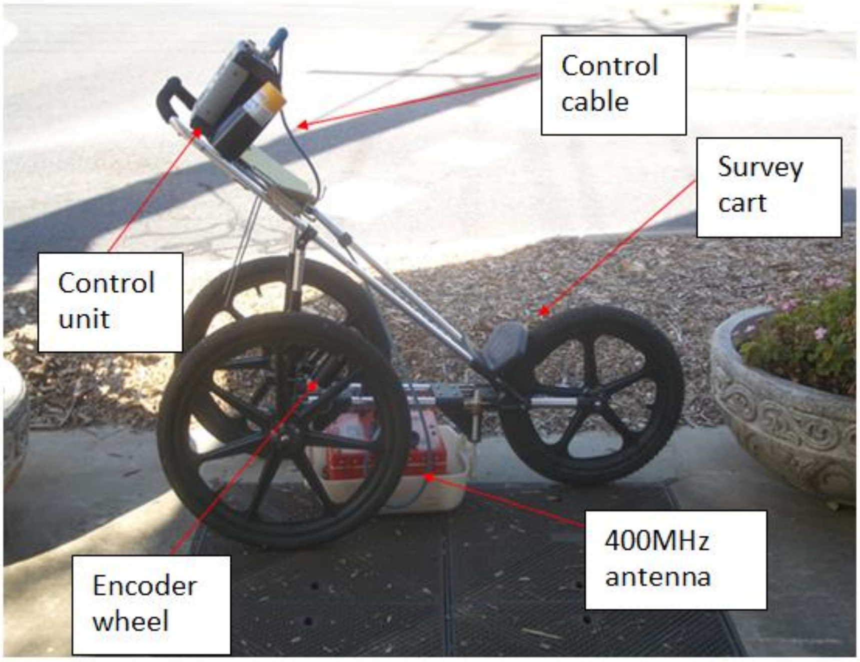


Figure 22: A Geographical Survey Systems Inc. (GSSI) Ground Penetrating Radar System used on this project.

Survey preparation/Calibration

After the magnetic survey had identified areas of interest these areas were gridded for GPR survey. This involved clearing the area of branches and any refuse that could be moved without causing any disruption to the surface of the ground. This was supervised by RMMAC members working on the project. The removal of such materials allowed for better antenna coupling (antenna to ground surface contact). The area was pegged as a square by way of measuring tapes and the GPR survey grid was scanned in both x and y directions at 500mm increments. Scan alignment was kept straight by way of measuring tapes stretched on each of the grid's edges and a rope stretched from measuring tape to measuring tape.

Instrument Calibration

Prior to survey the survey wheel (encoder wheel) was calibrated against a measuring tape.

Resistivity – theory, instrumentation and survey preparation/calibration

Theory

A basic description of electrical resistance survey theory devised by Schmidt (2013:7) 'is that buried archaeological features alter the flow of an electrical current that is injected into the ground electrodes and that the effect of these changed currents can be measured at the surface'. To explain the full physics of earth resistance is well beyond this thesis, however, the basic practice of measuring earth resistance for archaeological prospecting is that a current (amperage) is passed through the ground via electrodes (metal spikes/pegs in this surveys case). The resulting potential difference (voltage) is recorded and from these two quantities earth resistance (resistance) is calculated (Schmidt 2013:107). The unit measurement for calculating resistance is Ohms (Schmidt 2013:10). High resistance features in soil of uniform resistivity will cause current injected to be forced to flow around a high resistance feature. This results in the current finding longer and easier paths through the subsurface upsetting its regular pattern. Current density in the vicinity of the feature are reduced increasing the potential gradient and it is this gradient which is sampled by the potential electrodes. Therefore in this case V (voltage) is increased so V/I = R (V being voltage, I being current in amps and R being resistance) is increased resulting in positive anomalies in a line of readings. Alternatively a low resistance archaeological feature such as an infilled moist ditch will result in an easy path which attracts current. This lowers the potential gradient in and around the feature resulting in negative anomalies (Clark 2001: 37).

In terms of interpreting resistance data one must have an understanding of the relationship between what is injected (electrical current), what is measured (electrical potential) and what causes these changes (electrical resistivity) in order to pick potential features as archaeological (Schmidt 2013:7). When considering earth resistance as a technique for archaeological prospecting one must determine whether there is a resistivity contrast between the archaeological target and the surrounding soil matrix. As permission was not granted for excavation at the time of this field work, assumptions had to be made as to the site's soil conditions. Inferences were made as to whether the clay heating elements and mound itself would appear as resistive or conductive features. In principal the clay soil will be more conductive than the sandy clay loam soils of the earth mound therefore the mound's vertical and lateral extents should be detectable. The strength of responses from subsurface earth ovens may depend on if the clay heating elements are intact or have broken up. If there are air gaps around the clay heating elements which are no longer intact this will produce a resistive response (as air is highly resistive), however if the heating elements intact and there are no air gaps this will presumably result in a conductive response.

Instrumentation

The resistivity unit used on this project was a 64 channel resistivity/IP meter manufactured by ZZ Resistivity Imaging Pty Ltd. The system had the ability to combine all specified acquisition arrays together and collect data in a single run which is more efficient using less time than older conventional systems. The system was set to acquire one array after the other without having to move electrodes on that particular survey line. The system provided a real time read out of current and voltage measurements allowing adjustments in the field for optimum results (ZZ Resistivity Imaging Pty Ltd 2017).

Figure 23: The resistivity system used on this project (left) and one of 64 electrodes used to transmit voltage into the ground (right).

Survey preparation/Calibration

Only one earth mound was surveyed at the Hunchee Creek site using the electrical method due to time constrains. An existing grid surveyed by both gradiometer and GPR was chosen to run this electrical survey for comparative purposes. Electrode lines were run in a north-south orientation with 2m line spacing. A total of 64 electrodes were installed into the ground surface to approximately 100mm with an electrode spacing 0.5m. A salty water solution was poured over each electrode before the acquisition of each survey line in order to aid in the conductivity from electrode to soil interface. A total of seven survey lines were collected over the mound and multiple arrays were run automatically one after the other. Unfortunately the resistivity meter kept malfunctioning throughout the survey whilst collecting all of the arrays on the system. Therefore it was decided to record only the Wenner array and the dipole-dipole array to expedite the survey.

Wenner Array

The Wenner array consists of four operational collinear equally spaced electrodes at any one time along the electrode line. The inner two electrodes are the receiver electrodes (potential electrodes) whilst the outer two electrodes are the source electrodes (current electrodes). The array expands about the midpoint whist maintaining an equivalent spacing between each electrode (Figure 24). The Wenner array was utilised due to its suitability for the reconstruction of resistivity variations of and between layers (Milsom and Eriksen 2011: 131). All electrodes were installed in a straight line and were set by the resistivity meter to take readings at preselected logarithmic spacings along the electrode line. It was believed that the preselected smaller line spacings would provide sufficient shallow resolution and the larger spacings would provide the deeper resolution of the mound site. The minimum horizontal resolution that could be achieved with this array was 0.5m.

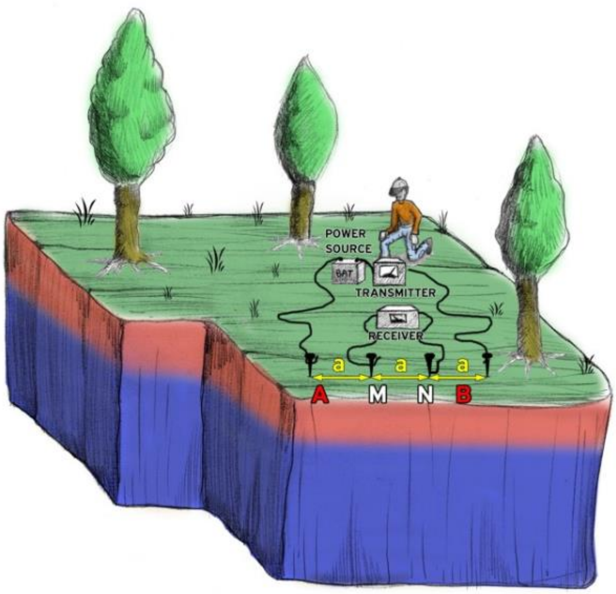


Figure 24: The Wenner array survey configuration, a = electrode spacing, A + B = current electrodes, M + N = potential electrodes. The four electrodes A, M, N and are equally spaced along a straight line (diagram created by Kleanthis Simyrdanis).

Dipole-Dipole Array

The dipole-dipole array is composed of two sets of electrodes, the source (current) and receiver (potential) electrodes. The aim of the dipole-dipole array is to maintain an equal distance for both the current and the potential electrodes (a=spacing)(Figure 25). For this array the distance between the current and potential electrodes is an integer multiple of ‘a’. As the distance between current and potential electrodes increase so does the depth of investigation as the current path gets deeper with the current and potential electrode separation. The dipole-dipole array was utilised due to its suitability for detecting vertical resistivity variations and lateral resolution of steep boundaries (e.g. targets in the same burial depth) (Milsom and Eriksen 2011:131). All electrodes were installed in a straight line and were set by the resistivity meter to take readings at preselected logarithmic spacings along the electrode line. It was believed that the preselected smaller line spacings would provide sufficient shallow resolution and the larger spacings would provide the deeper resolution of the mound site. The minimum horizontal resolution that could be achieved with this array was 0.5m.

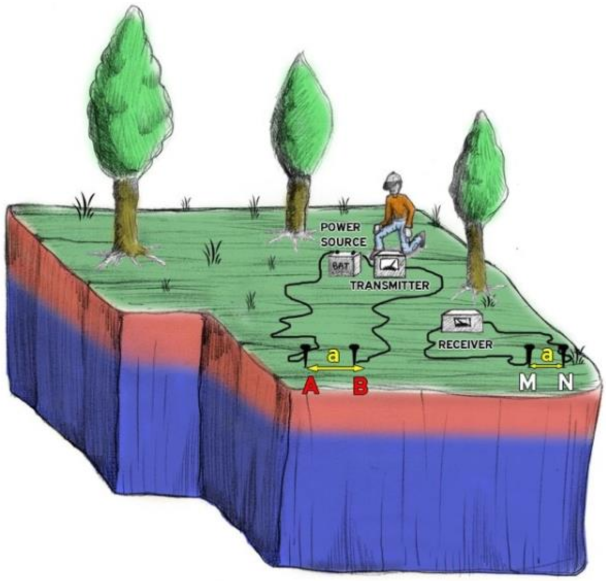


Figure 25: dipole-dipole array survey configuration, a = electrode spacing, A + B = current electrodes, M + N = potential electrodes. The distance between the current electrode 'A' and 'B' (current dipole) and the distance between the potential electrodes 'M' and 'N' (measuring dipole) information from different depths is obtained by changing the distance from A+B and M+N from one another along the electrode line (diagram created by Kleanthis Simyrdanis).

Data Processing and Analysis

Radan – (GPR)

Radan is a ground penetrating radar post processing software created by the manufacturer of the system used on this project, Geophysical Survey Systems Inc. (GSSI). The version used on this project contained both a 2D module and 3D module. Individual 2D profiles were post processed and then used to compile 3D datasets for further analysis The post processing involved a time zero correction (to adjust the surface of the ground to the first response within the dataset, a background removal filter (to remove unwanted horizontal bands within the data), and a gain restoration (to turn up amplitudes that were low to make the subtle features in the data more noticeable (Geophysical Survey Systems Inc. 2012).

Post Processing – GPR Data

Time 0 Correction

A time 0 correction was applied in order to indicate the ground surface within each radargram and 3D model. This is a fundamental correction that must be applied for accurate depth calculations. It is done by setting the ground surface to the first response in the GPR data not the beginning of the transmission which it is usually set at (GSSI 2012).

Background Removal

A background removal filter was applied to remove bands of ringing noise in the data. These bands are the result of low frequency 'noise' such as inherent instrument noise like 'antenna ringing'. This noise can mask subtle low to mid amplitude responses in the radar data therefore needed to be eliminated (GSSI 2012).

Migration and dual profile interpretation

An issue with GPR is that the radar's antenna radiates energy with a wide beamwidth pattern detecting things that are several feet away. As a consequence, objects with finite dimensions will appear as 'hyerbolic' reflectors in the digital dataset. Therefore the anomaly is detected well before and after where it sits in 'real life' space. Deeper objects can be obscured by numerous shallow objects that appear as encroaching hyperbolic reflectors on nearby hyperbolic reflectors. A challenge with interpreting the 3D GPR data set was trying to determine if responses detected within the same area as the magnetics dataset indicated magnetically susceptible material as cultural features or if they were tree roots. In an attempt to differentiate between the two types of feature, migration was used to 'collapse' all of the point source hyperbolic reflections back to their point source. It was hoped this would make the responses more clear as hyperbolic reflections from the un-migrated data were moulding into one another often resulting in one large or multiple linked reflections (GSSI 2012). To further improve interpretation of the GPR profiles, magnetic 2D profiles were combined with them in order to determine where the magnetic features were present in the GPR data

GPR Viewer

GPR viewer is a GPR software package created by Larry Conyers (Denver University) and Jeff Lucius (USGS) in 2016. It was used to view manipulate and process GPR reflection data. On this project this software was used to determine mound lateral and vertical extents and also to determine a correct RDP for accurate depth calculations.

GPR Process

GPR Process is a program written by Jeff Lucius (USGS) and Larry Conyers (Denver University) for the production of amplitude slice maps from GPR reflection profiles from standard rectilinear grids. It was used in this research for use in conjunction with Surfer15 to display and analyse 3D amplitude slice maps.

TerraSurveyor and Surfer (Magnetics Data)

Terrasurveyor is a post processing software package created by D.W. Consulting designed for the downloading, assembling, enhancing and publishing of geophysical data from a range of geophysical instruments. The software allows for different views of the data, including a shade, trace, delta, 3D relief, relief, spreadsheet and publish views of the data. For this project magnetics data collected both in GPS mode and grid mode were post-processed using this software. Datasets from both grid mode and gps mode acquisitions were processed and interpreted in 2D shade and 3D views (D.W. Consulting 2013). The final

2D datasets for interpretation and display were created in Terrasurveyor. The final composition and display of 3D datasets were created in Golden Software's Surfer15 program which is a gridding and mapping program. Surfer15 was chosen for final 3D outputs for display for no other reason than its outputs of 3D data were more visually appealing than Terrasurveyors'. Surfer15 was also used to import geo-referenced aerial imagery into in order to overlay all geophysical data and archaeological data into one combined data set. This provided information as to where all geophysical responses and artefacts were spatially situated and a combined map could be created by tracing around those features. This allowed for a multi-discipline site interpretation (Figure 26).

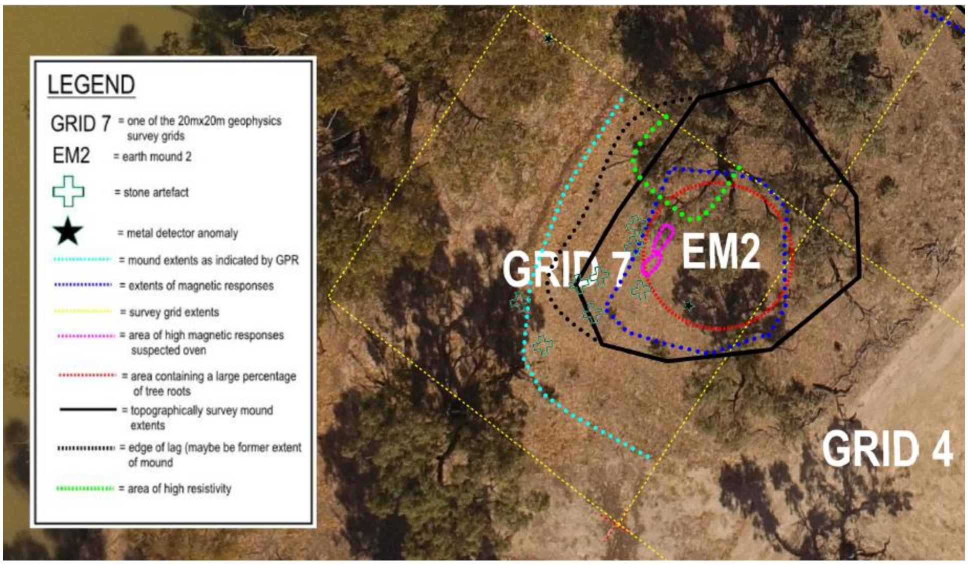


Figure 26: a map constructed in Surfer15 by tracing all of the geophysical anomalies of interest which were overlayed over the map, these geophysical layers have been turned off to just show what has been traced. This data is combined with another georeferenced archaeological survey which led to a combined inter-disciplinary interpretation approach.

Post Processing – Magnetics Data

The magnetic data was processed to eliminate striping and also to remove a feature within the data that was masking more subtle features.

Elimination of striped data

Data collected in grid mode was destriped (also known as zero median traverse) which is a processing technique for removing 'stripiness' from the data inherent in data collected in a zig-zag configuration with magnetic instruments (DW Consulting 2013:69). These effects can be the result of directional effects, operator's habit (not being free of magnetic material when surveying), instrument setup and drift (Figure 27).

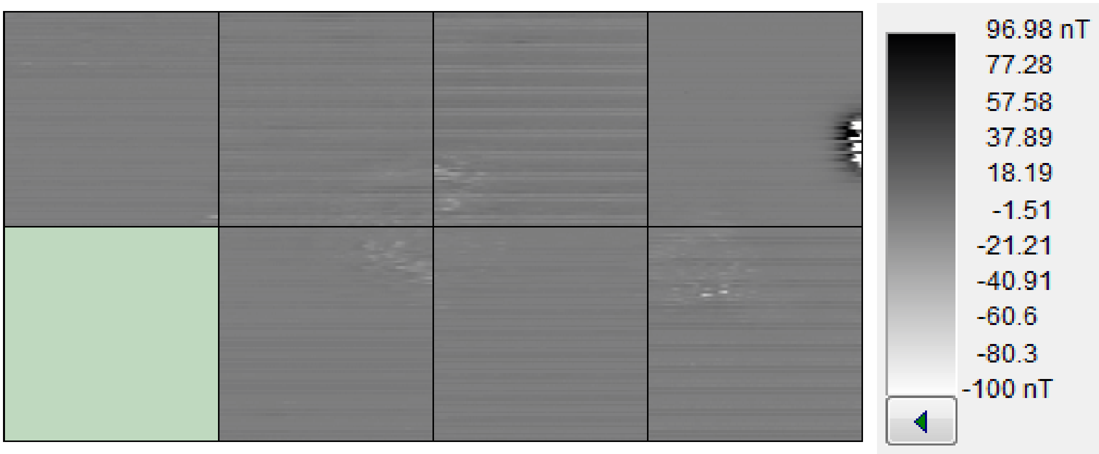


Figure 27: Seven combined magnetics datasets, processing was required to remove the stipes and also the high responses from the stormwater pipe in the top right grid square.

In order to remove the stripes from the dataset the processing function determines the median response of each grid or traverse and then subtracts that value from each data point in the current layer. The end result is stripes being removed from the dataset (Figure 28).

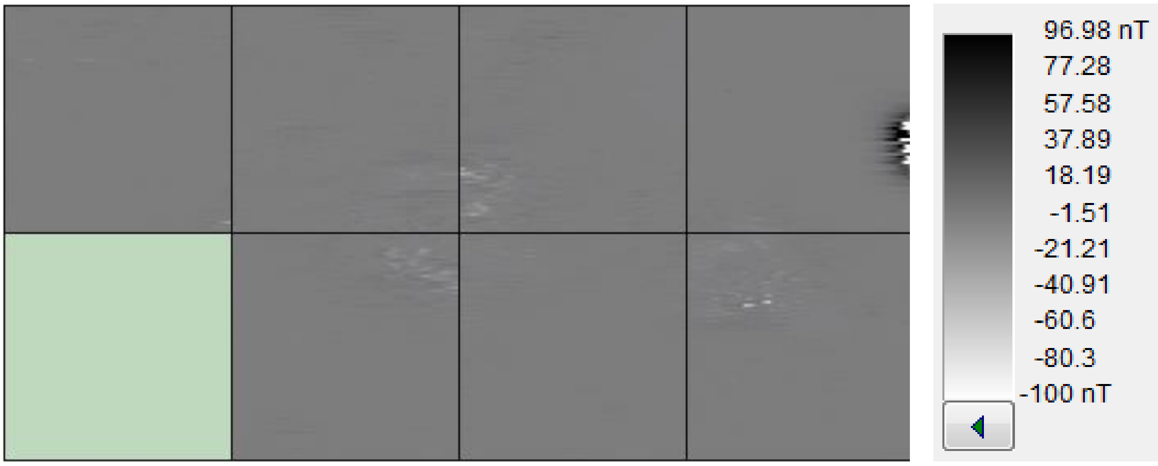


Figure 28: Magnetics dataset after the 'destripe' function has been applied. Responses from the concrete pipe in the top right corner grid are masking more subtle responses.

Elimination of unwanted modern responses

Within the main magnetics dataset a concrete pipe running under the roadway was detected (Figure 28), the pipe was highly magnetic and strong responses were recorded before traversing over the pipe. The pipe must have contained metal reinforcing as readings were consistent with responses experienced from metallic objects i.e 100nT+. This is problematic for data interpretation when an unwanted object such as this is detected as the post processing software assigns a colour scale to the responses recorded within that particular survey. Should a very high reading be experienced the scale set can be very 'coarse' and very subtle readings may not be assigned their own respective specific colours and hence are averaged out of the data set, effectively becoming invisible. In order to rectify this issue the pipe had to be removed from the dataset. Within the post processing software the 'mask' command was used to remove the responses from the stormwater pipe. This command involves selecting the area of the unwanted responses by drawing a shape around it. Once this was placed correctly, all data within the area selected are then eliminated from the survey (Figure 29) (DW Consulting 2013:85). The data is replotted according to the highest and lowest responses recorded, for example (Figure 28) before processing the data was plotted at +96.98 to -100nT and after the feature was removed (Figure 29) was plotted at 9.61nT to -52.95. As a result the features in the dataset exhibiting subtle/ lower responses became more visible.

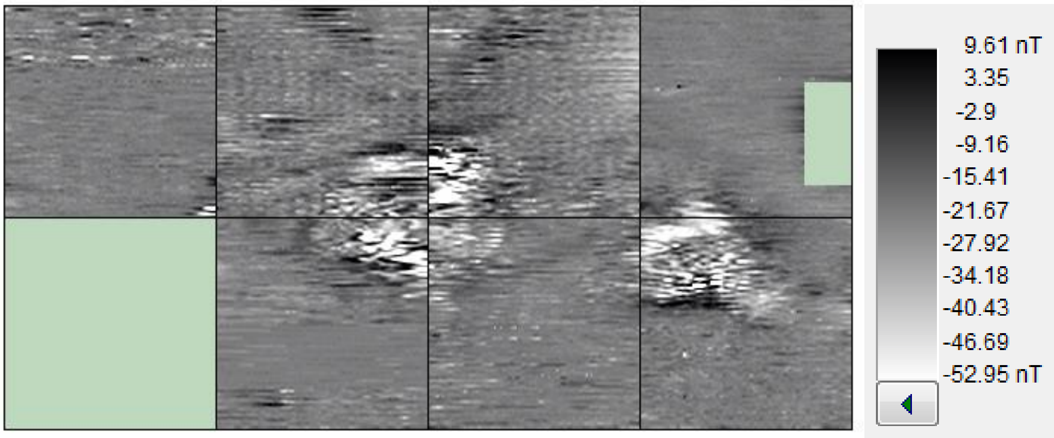


Figure 29: The dataset after the 'mask' function has been applied, in the top right grid of the dataset the stormwater pipe has been removed resulting in other more subtle features becoming visible. Adjacent to the dataset is the colour scale of the data which is expressed in nano-tesla.

Resistivity software – RES2D and RES3D

Before any post processing was done in any of the resistivity post processing packages, the lines of data were imported into excel as a spreadsheet and readings were graphed. This was required to identify spurious readings that were 'outliers' and were at random intervals. Readings were plotted from spreadsheet form to a scatterplot and readings that were orders of magnitude away from the main data group within the scatter plot were eliminated. This process could be described as a very crude form of low pass filter. After this filtering was complete, resulting data were loaded into the resistivity post processing software. There were two software packages used to process and display the resistivity data for this project both manufactured by Geotomo one being RES2DINV and the other RES3DINV. Firstly the data was imported into RES2DINV in order to process and display the resistivity data from each of the seven lines and pseudo-sections of apparent resistivity were created. However to improve the interpretability of the data an inversion was conducted. An inversion is a computer processing technique whereby pseudo-sections of apparent resistivity (appropriately scaled earth resistance measurement values) are converted into actual depth sections of estimated subsurface resistivity.

The inversion algorithm works by initially subdividing ground in the dataset into as many layers as there are individual measuring points in the sounding curve. The bottom of each layer is assumed to lie at a depth equivalent to the electrode separation used for the measurement, and its resistivity is temporarily set to the respective apparent resistivity. This leads to a preliminary model for the layered earth and its respective values. The software then calculates the resulting sounding curve that would be measured over such a set of layers which is known as forward modelling. These results will be different from the actual measurements; this first attempt is only a crude approximation, the software then adjusts the model's resistivity's to reduce this error. The sounding curve is then calculated again and resistivities further adjusted. That process is iterated until a set of resistivity values have been found that lead to a satisfactory match between calculated and measured sounding curves. This process of finding soil parameters that match the geophysical measurements is known as an inversion (Schmidt 2013:75-76). This inversion process results in the conversion of measured results into estimated soil property values, which is then replotted in a final pseudo-section (Figure 30). These final pseudo-sections provided a cross-section of the survey lines in order to obtain an estimation of the depth to features within the mound and to investigate the mounds stratigraphic sequences (Noel and Xu 1991 in Gaffney and Gater 2010:60).

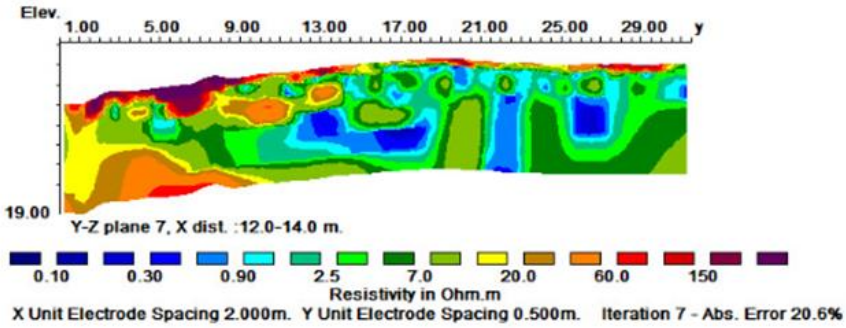


Figure 30: An example of a pseudo-section after the inversion process, the data was collected over one of the earth mounds on this project. Readings are expressed in Ohms, colours in the pseudo-section correspond to the colour scale below, this data has been topographically corrected.

In order to allow a spatially correct interpretation of the ERT data, elevations from an RTK topographic survey were recorded over the entire site and every electrodes position was recorded. This was required for the resistivity survey as the site was not flat and would be required in order to place features in their correct orientation within the pseudo-sections and inversion slices. These elevations from the survey data were loaded into RESDINV and elevations were assigned to the dataset (Figure 30). After 2D processing was complete the data was then loaded into RES3DINV in order to generate a 3D dataset from the seven lines of resistivity which were collected). Resistivity maps also known as inversion slices were the result (Figure 31). The software generated multiple horizontal slices of the dataset at differing levels from the surface of the mound to 5m deep. However most inversion slices past 2m in depth were ignored as the deposit was very unlikely to be that deep and the target area of these surveys was likely to be in the first meter of soil.

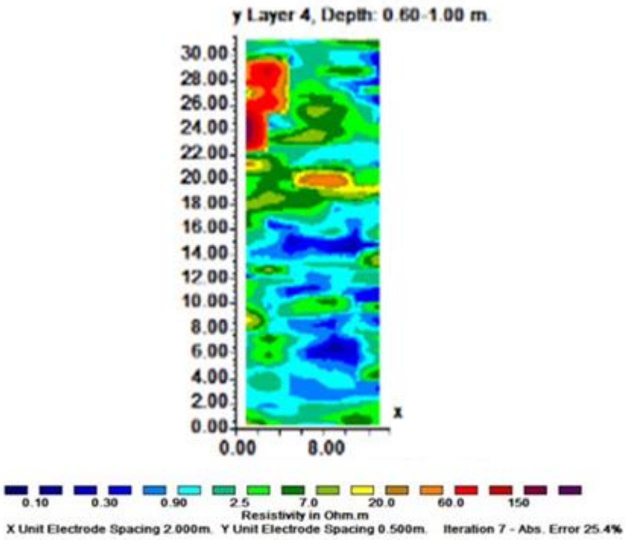


Figure 31: An example of a 3D inversion slice from the Wenner Array dataset collected over one of the mounds, resistivity is expressed in ohms per metre in a colour scale below the dataset. The depth of the slice has been take from 0.6m to 1.0m.

Data acquisition limitations

The main limitation of the project was the inability to ground truth all anomalies detected. Unearthing of earth mound material leads to the mounds degradation (Fanning et al. 2005:21) and this was why unearthing every suspected earth mound was out of the question. However not being able to ground truth all suspected anomalies resulted in much inferred geophysical interpretation. For example GRP, magnetics and resistivity are unable to accurately determine whether the heating elements in an earth oven are rocks or clay, non-invasively, therefore inferences were made when it came to the interpretation of these features.

Limitations in relation to GPR acquisition were uneven terrain, rocks, tufts of grass etc. these can cause poor antenna to ground surface coupling, resulting in difficult to interpret reflection profiles with differing amplitudes of waves, none of which are actually reflecting off real subsurface anomalies (Conyers 2013:76). Care was given to make note of areas of poor coupling by marking the area in the dataset by way of the systems ‘mark’ function and taking thorough field notes.

Limitations in relation to magnetic data acquisition result from unwanted readings from modern metallic anomalies such as modern camp rubbish, metal fences, gates, nails, etc. which may in turn mask the subtle readings of wanted indigenous buried features in close proximity (Gafney and Gater 2010). In the magnetic surveys the only unwanted anomaly of this kind was a stormwater pipe with reinforcing and two smaller responses that were found with metal detector in two survey grids. Another limitation in relation to magnetic data acquisition was the bouncing up and down of the sensors whilst traversing lines. If the sensors are not always held upright and at a constant level from the ground surface readings can fluctuate very slightly during the acquisition process. This can be extremely problematic if the targets sought after are very subtle and can be ‘masked’ by readings resulting from sensor movement. This type of error was experienced in heavily vegetated areas.

The resistivity instrument malfunctioned on several occasions during acquisition over several days which delayed the survey and resulted in only seven lines being acquired. However the data acquired for this research was not affected by any of these malfunctions. The system was collecting a Schlumberger, dipole-dipole, Wenner and ZZ’s own array one after the other automatically. After some trouble shooting it became apparent that the instrument was malfunctioning during the Schlumberger and/or ZZ array which were the most time intensive. It was decided to stop collecting these two arrays as the malfunctions were wasting too much time. The dipole-dipole and Wenner arrays did not cause the instrumentation to malfunction and were confirmed to be collected until the acquisition time ran out on the last day of field work. It was decide that the Wenner array would provide the horizontal resolution required and the dipole-dipole array would provide the vertical resolution required.

Another limitation was the inability to install electrodes to the desired depths in some locations near and around the end of the riverbank. The end of the riverbank was populated with gum trees with roots on and just under the surface which made the installation of the electrodes extremely challenging. This led to high resistivity readings due to poor contact with the soil and these areas of high resistivity were discounted as cultural features.

Chapter 6. Geophysical Results

This chapter presents the results from this study which includes some preliminary field testing conducted in 2016 and a more comprehensive field research phase conducted in 2017 at Hunchee Creek. A total of eight grids were acquired with gradiometer, seven of which were connected and one was collected in a different area. A total of one 3D ground penetrating radar grid was collected and two long traverses were collected along the baseline of the main gradiometer combined grid. A total of seven lines of resistivity data were collected over an earth mound suspected of containing possible buried heat retainer material in order to produce an ERT (Electrical Resistance Tomography) dataset. The survey area contained three features recorded as earth mounds, with two of the mounds with heat retainer material scattered across the surface (Jones et al. 2017).

Initial phase of fieldwork

Prior to this thesis research some preliminary field work was conducted in order to determine if some of the geophysical instrumentation selected would be suitable for the detection of earth ovens in this particular environment of the Murray Darling Basin. Due to time constraints not all instruments were deployed and it was decided that the magnetic technique was most likely to succeed and could collect the most data in the smallest amount of time. Two locations were selected, one at Hunchee Creek (Survey Site 1) and one at a dune system (Survey Site 2) 700m north of the Calperum Station Homestead (Figure 32). Both were different site types, Hunchee Creek was a section of riverbank and floodplain and the other was a dune system a few hundred meters away from the nearest waterway. Both areas selected had suspected in-situ earth ovens present, the area surveyed at Hunchee Creek had earth mounds present which were suspected to have come from earth oven origins while the sand dune site had partially and fully submerged earth ovens deflating from a dune system. The magnetic technique was deployed to determine if these features were different enough from their surrounding environment to be detectable.

Figure 32: Location map of Survey Site 1 (Hunchee Creek) and Survey Site 2 (Dune System).

Survey Site 1

The earth mound surveyed at Hunchee Creek (Survey Site 1) later to become grid seven in the 2017 fieldwork) had very poor surface expression, contained no surface scatters of heat retainer material and was less than 250mm in elevation from natural ground. The magnetic survey detected a difference in magnetic susceptibility compared with the surrounding area over a section of river bank potentially indicating repeated past burning events associated with the use of earth oven technology (Figure 33). Within the right hand corner of the dataset an almost round area of strong magnetic readings can be seen indicating an area of suspected burning.

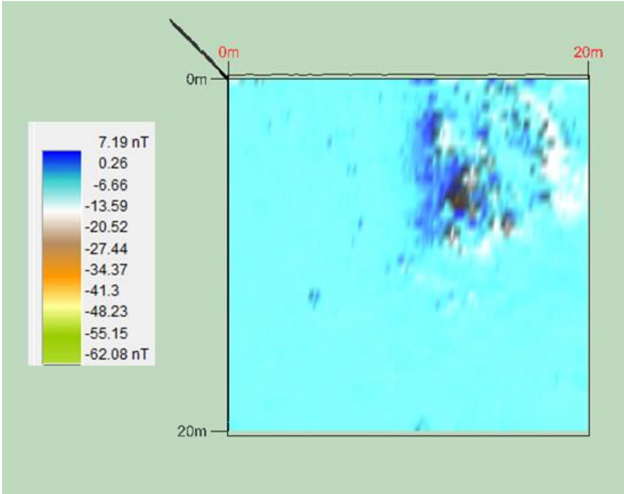


Figure 33: Magnetic Dataset collected over a mound at Hunchee Creek (Site Survey 1).

The Hunchee Creek survey was conducted with the gradiometer set to grid mode as there were too many trees to run the instrument in GPS mode as the instrument needs a clear view of the sky for optimal positioning.

Survey Site 2

A dune system near Calperum Station had earth ovens partially buried and deflating out of the dunes which had definite magnetic signatures. However it was noticed that the fully deflated earth oven material (Figure 34) provided very low and sometimes no magnetic reading at all compared with those that were partially deflated and more in-situ.

Figure 34: Fully deflated earth oven within the surveyed area of Site Survey 2, this feature provided readings of the same amplitude as the surrounding soil.

A theory for this is that the in-situ elements of the heating elements magnetic moments are all still aligned whereas the deflated elements are not and magnetic moments are no longer aligned resulting in low to nil magnetic readings above or below the background level (Aspinal et al. 2009:22). Two partially deflated earth ovens were clearly seen in Survey Site 2. Two buried anomalies were detected within the area surveyed of similar amplitude to those which were partially submerged (Figure 35).

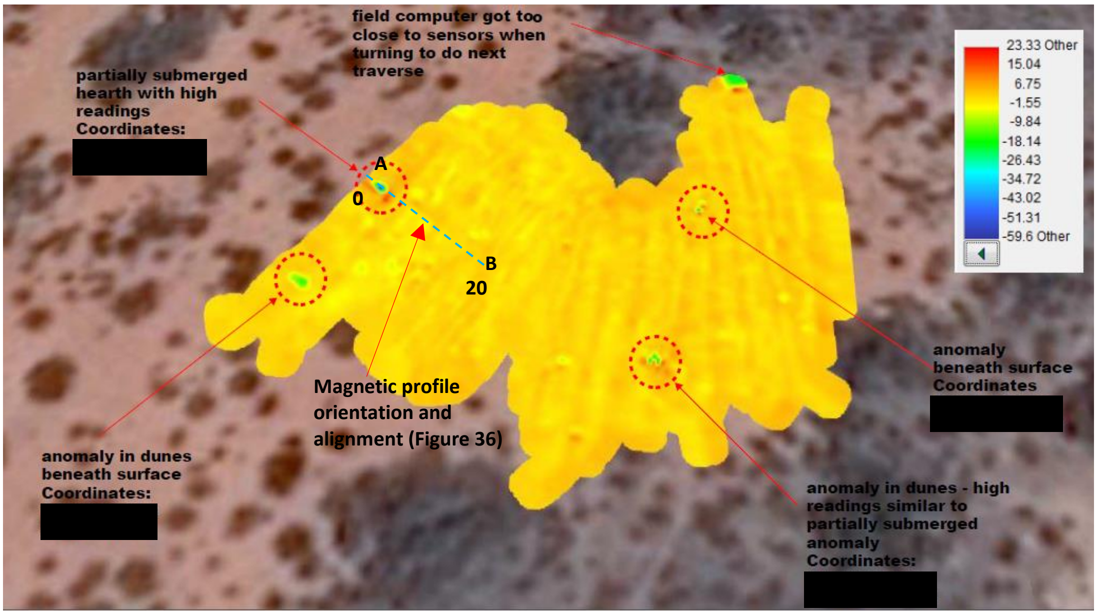


Figure 35: Dataset collected over partially submerged and suspected submerged earth oven over a dune system near the Calperum Station Homestead. The system was set to 'GPS mode as there was little tree cover onsite and satellites could be used for positioning by the system negating the need for grids to be set up for data acquisition.

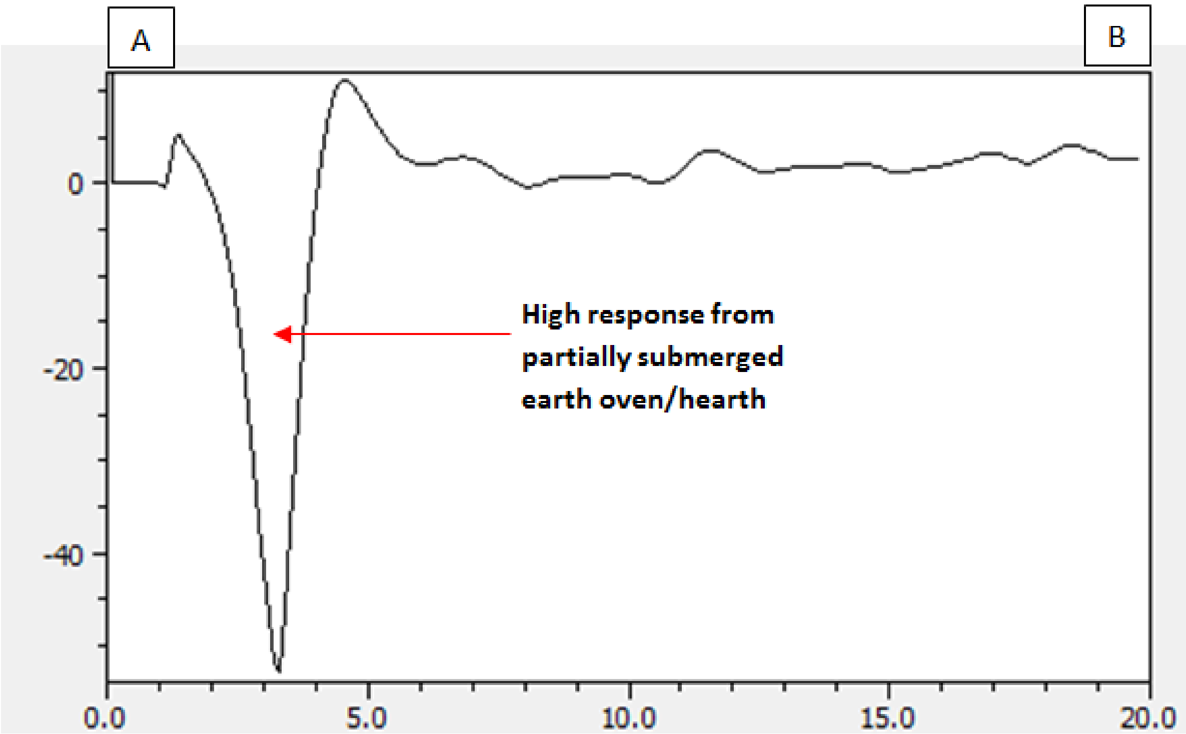


Figure 36: High response from partially submerged oven from the sand dune survey (survey site 2), displayed in a 2D magnetics profile. Profile alignment is delineated by the light blue dashed line in figure 35 from point A (0m) to point B (20m). Distance is expressed in meters on the bottom of the profile and readings are expressed in nT on the left hand side of the profile.

Figure 37: (left) partially buried earth oven in dunes with high readings from Survey Site 2 magnetics dataset (right) a closer view of the oven and exposed heating elements some of which were rocks and clay balls.

The two buried anomalies are believed to be buried in-situ earth ovens, this survey was conducted using the instrumentation in GPS mode as the area was reasonably clear of trees and a clear line of site to the sky was obtained through out all of the survey.

Summary

This preliminary field work provided justification for future phases of research, the magnetic technique clearly identified areas of burning on both survey sites. The surveys identified partially submerged and also fully submerged (suspected) heating elements. The research at this phase had already gone further than Fanning's (2005) heat retainer surface gradiometer studies by mapping both what was on the surface as well as below. The successful detection of these features allowed for the planning of future magnetics, GPR and resistivity surveys in the next phase of field work. It was decided to focus all following field work on a section of Hunchee Creek containing three earth mounds close together. Two of these mounds had the remnants of clay heating elements across their surface while the other had none. Stone artefacts were also found on and around this group of mounds proving it a place of previous cultural activity and worthy of an intensive phase of survey.

Main phase of fieldwork

Topographic Survey

Surface depths were recorded around the site at random locations in order to build a digital terrain model. This was to digitally produce an accurate map of elevation for the site, which assisted in interpretation of the geophysical data. This assisted in the interpretation of magnetics and resistivity data by indicating areas of higher elevation which could in turn explain areas of lower response that may have more overburden hence the lower response and in the inverse for the opposite. The area where the surveyed earth mounds are located gently slopes down to the river bank with elevation changes from 19.6m from the top of the surveyed mounds to 17.1m at the river's edge (Figure 38).

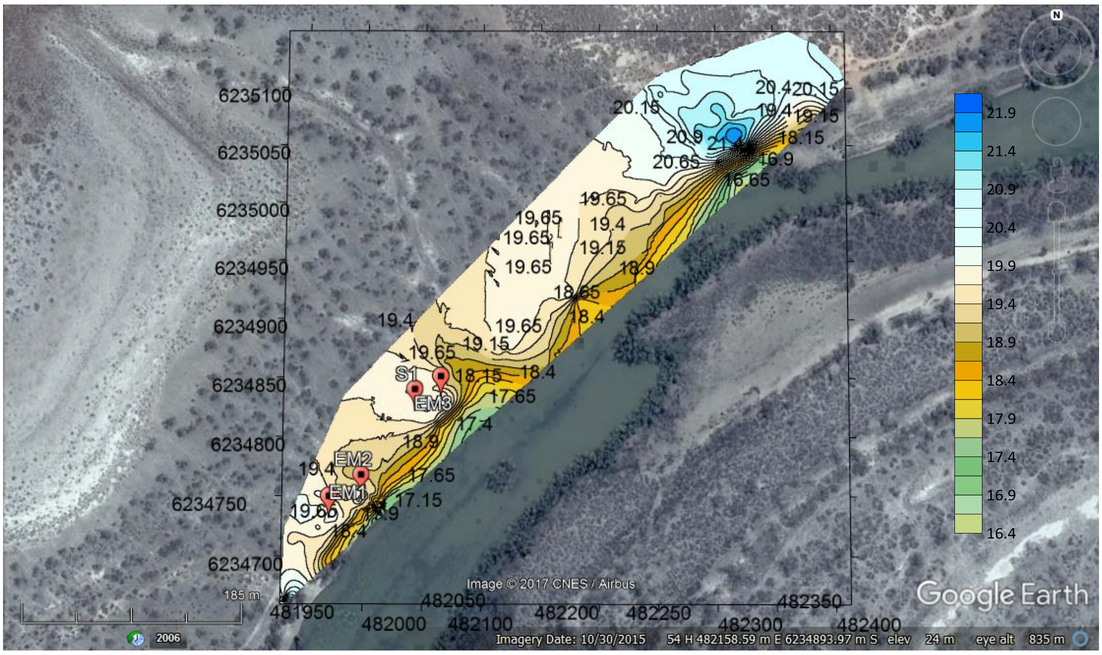


Figure 38: Digital elevation model of the whole site along Hunchee Creek – refer to Appendix 1 for a high resolution representation of this dataset – northing is displayed on the left hand axis and eastings along the bottom axis, scale is expressed in AHD meters (Australian Height Datum) meters.

It became apparent in the digital terrain model that all three earth mounds were situated at the very top of the riverbank and were some of the highest elevated areas within the survey area (Figure 38). Earth mound one had an elevation above sea level of 19.65m, EM2 had an elevation of 19.15, and EM3 19.9m. The river bank edge had an elevation of 17.15m which was the lowest point within the survey area and 19.9m being the highest. Therefore there was a difference of 2.75m from the highest to the lowest point within the survey area.

Survey Grid Locations

Two survey sites along a section of Hunchee Creek were surveyed using three different types of geophysical instrumentation. One of the survey sites contained seven survey grids whilst the other survey site contained one survey grid (Figure 39 and 40).

Survey Grid Configuration – Site 1

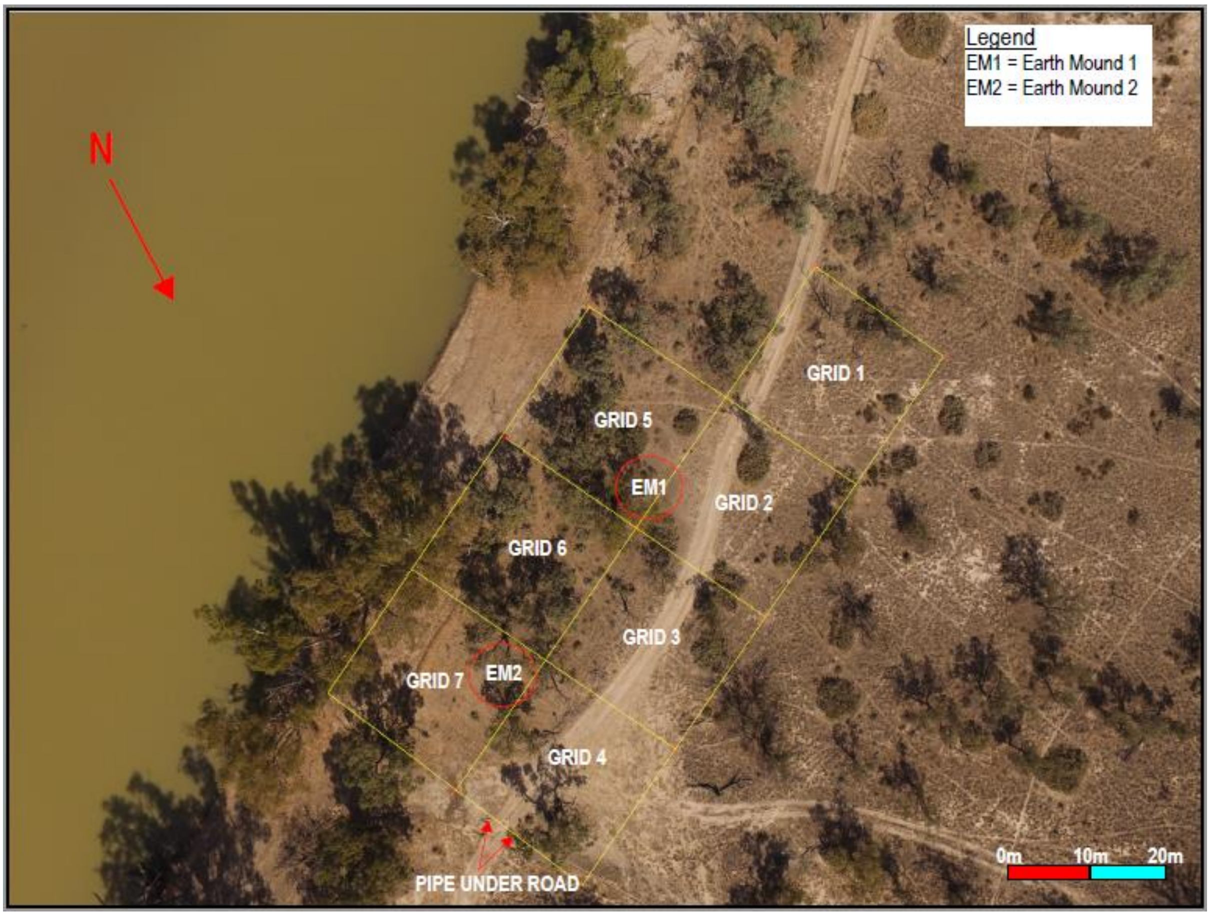


Figure 39: Location of grids one to seven, each grid is 20m x 20m – aerial photography by drone – photo courtesy of Dr Ian Moffat.

The placement of the main survey area was chosen at this location of Hunchee Creek as two earth mounds were located here. It was decided to conduct the survey over both mounds and the surrounding areas. One earth mound contained heating element surface scatters while the other did not. All grids collected were 20m x 20m and made up a composite of seven grids totalling 2800m^2. Grids one to seven were surveyed with the magnetic technique whilst only grid seven was surveyed by both GPR and ERT (Electrical Resistivity Tomography). The access road ran through grids one to four and the majority of grids contained vegetation that had to be surveyed around or over (Figure 39).

Survey Grid Configuration – Site 2

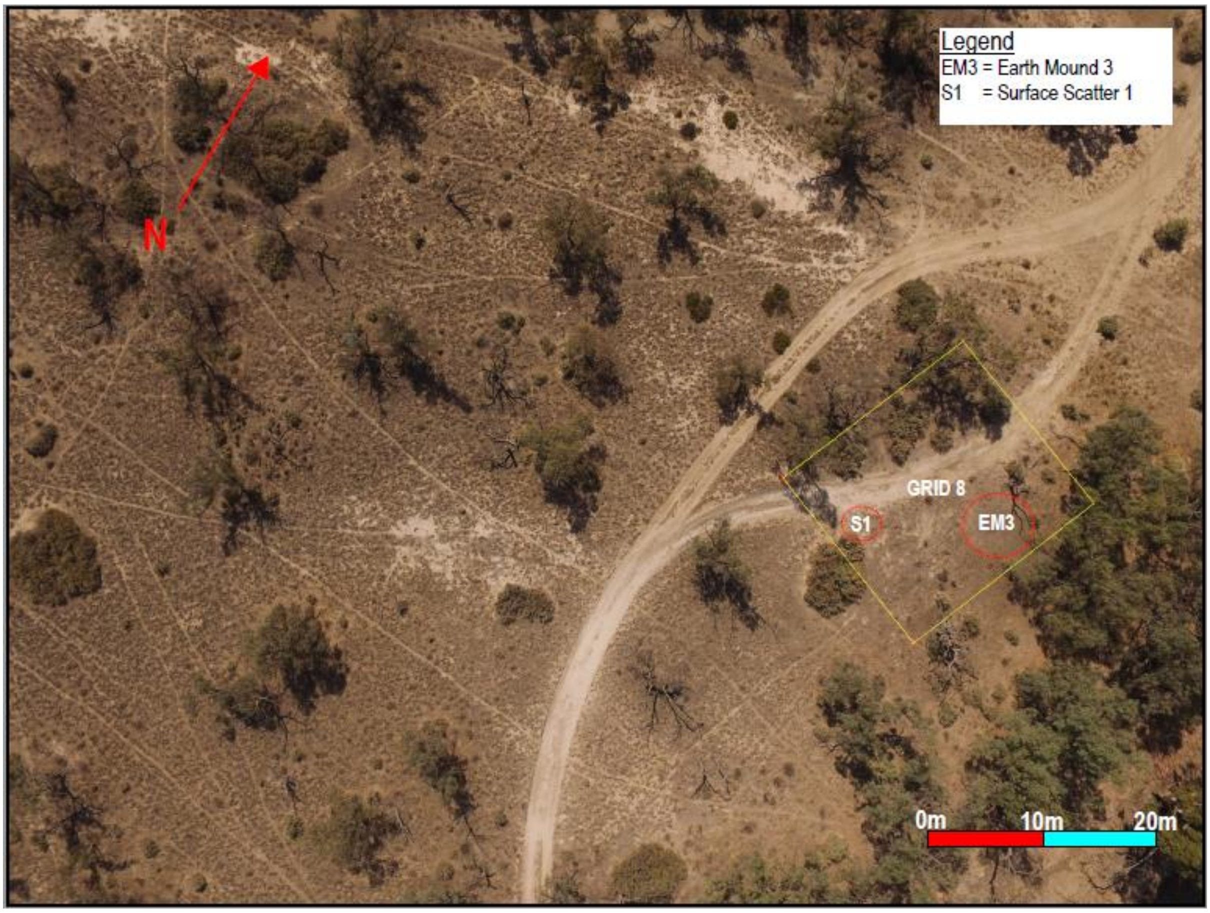


Figure 40: Location of grid eight - aerial photography by drone – photo courtesy of Dr Ian Moffat

Grid eight was placed over an earth mound that contained heat element surface scatters. A quarter of the grid contained vegetation that had to be surveyed around, while a section of unpaved track ran through the grid (Figure 40). Grid eight was 20m x 20m totalling 400m^2 and was only surveyed using the magnetic technique.

Magnetics Results

The magnetics survey was conducted over a section of Hunchee Creek encompassing the riverbank, the crest of the riverbank and the very beginning of the floodplain. The main access road ran through some of the magnetics grids. The survey area contained three earth mounds with two of them with heating element material scattered across the surface. Grids one to seven were all a part of the same survey area whereas grid eight was located north-east along the riverbank approximately 50m away.

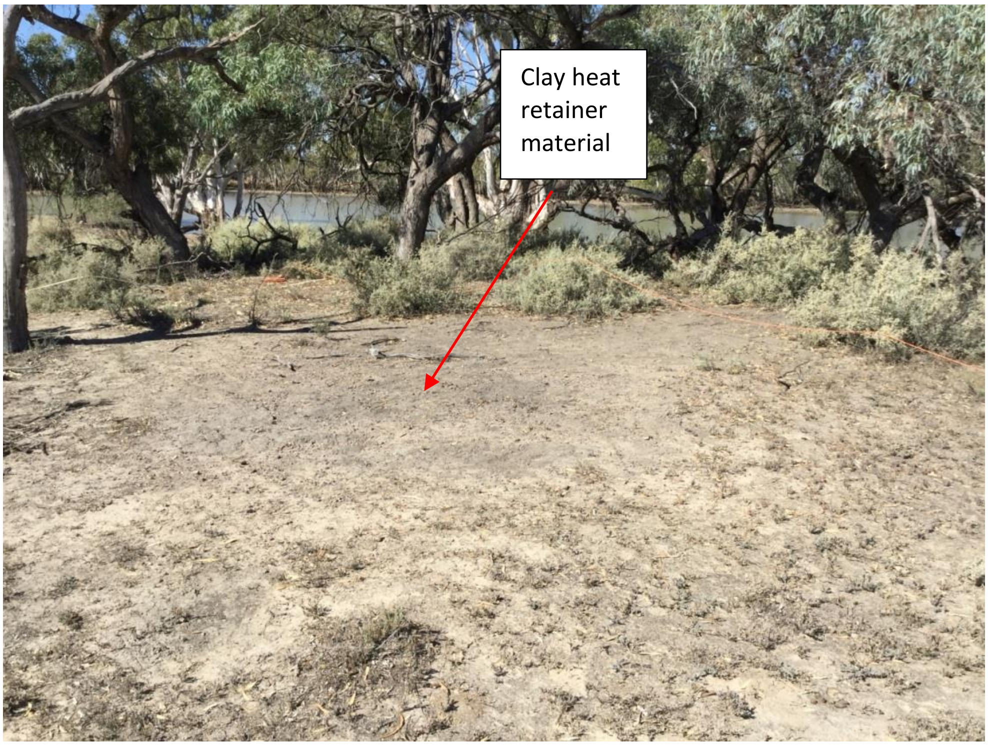


Figure 41: Earth Mound 1 - located within grid two and five of the main magnetics survey grid – abundant clay heating element material was detected scattered across the surface of the mound.

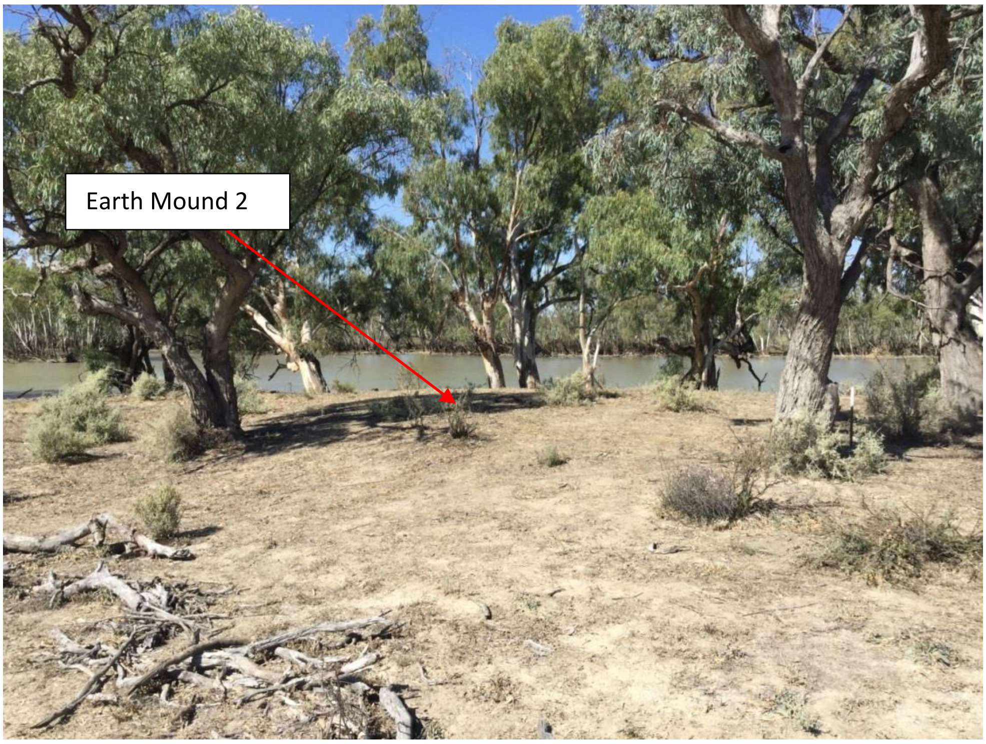


Figure 42: Earth Mound 2 - located within grid four and seven of the main magnetics survey grid – no clay heating element material was located on the surface at this location.

Magnetics – grids one to seven

Grids one to seven were 20m x 20m grids assembled within the post processing software. Within the composite of grids there were three main areas containing substantial amounts of magnetically susceptible material. One of the features located in grid four was a modern reinforced concrete pipe which was being used to direct water runoff under the roadway. The concrete stormwater pipe resulted in a dipolar responses meaning it had both a negative and positive component like a magnet. Readings ranged from +96.98nT to -100nT (Figure 43), this feature was of no interest to this survey and it was decided to remove it from the dataset.

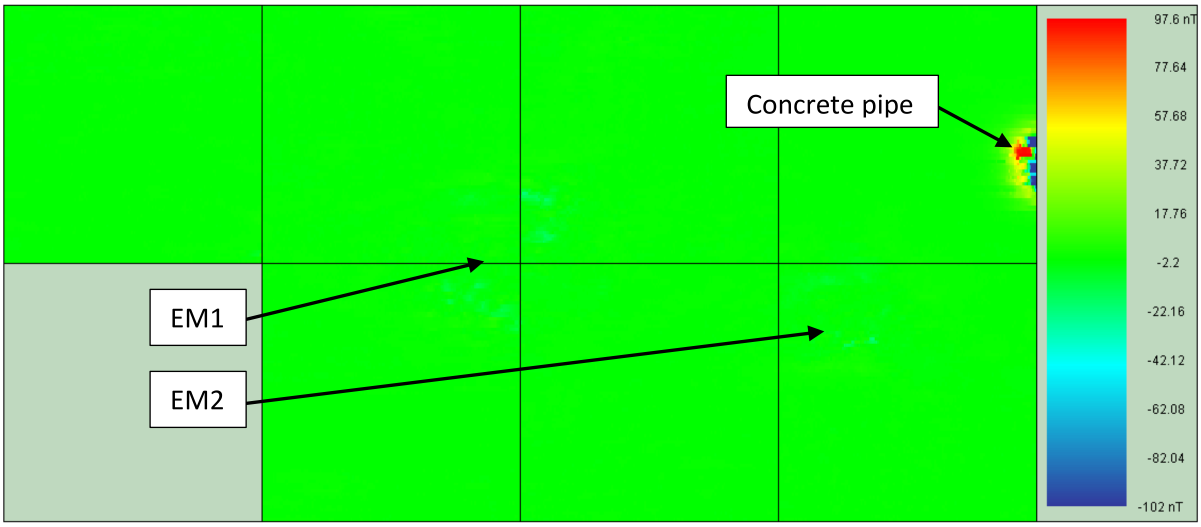


Figure 43: Grids one to seven – the high readings of the concrete pipe running under the road have resulted in EM1 and EM2 becoming virtually invisible, therefore the pipe needed to be eliminated from the dataset.

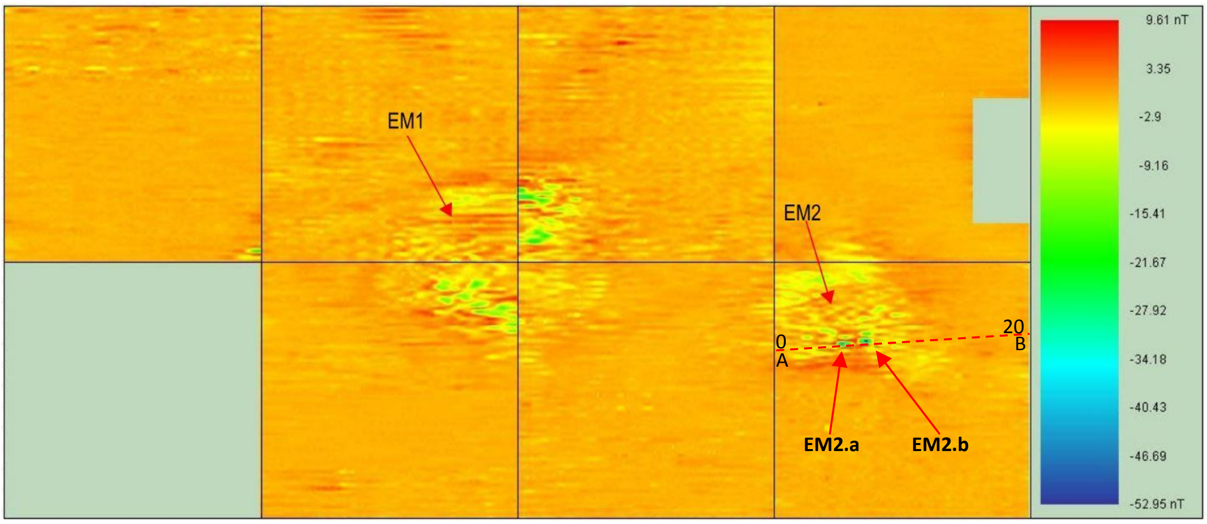


Figure 44: The main magnetics survey grid data set, grids one to seven are 20m x 20m grids collected with 0.25m line spacing. The scale of readings in nano-tesla to the right of the main survey grid corresponds to the colour of the readings in the dataset.

After the removal of the unwanted magnetic readings two other features became more visible exhibiting magnetic readings from +9.61nT to -52.95nT. These two major features exhibiting magnetic responses were located over EM1 and EM2. EM1 contained surface scatters of heating element material which would account for some of these magnetic readings whereas EM2 had no obvious surface features associated with burning. Both EM1 and EM2 exhibited responses both positive and negative however the negative readings were more abundant and of a higher magnitude with both mounds (Figure 44, 45 and 46). Grids one to four contained readings toward the northern edge of the main grid extents that may be the result of magnetic enhancement. These readings appear in areas with dense shrubbery so could also be the result of errors associated with sensors swinging when traversing this vegetation. Grid seven contained two locations which exhibited two strong negative responses which became labelled EM2a and EM2b (Figure 44 and Figure 45).

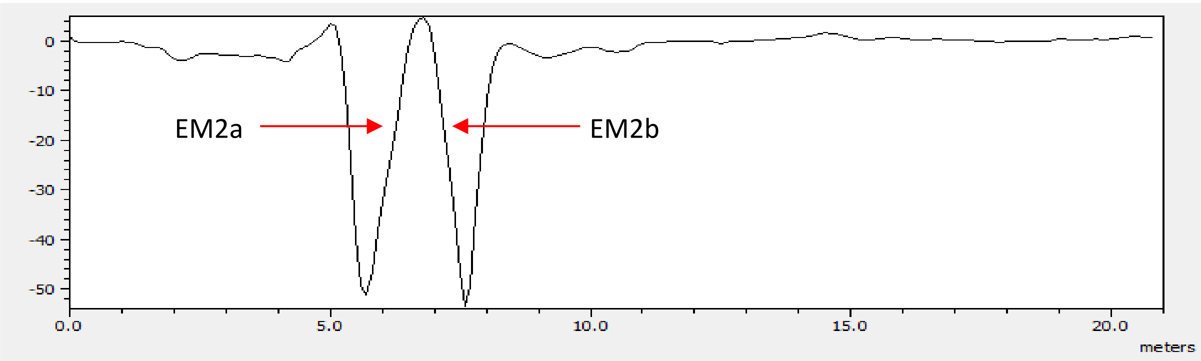


Figure 45: Peak responses from EM2.a and EM2.b, displayed in a 2D magnetics profile. Profile alignment is delineated by the red dashed line in figure 44 from point A (0m) to point B (20m). Distance is expressed in meters on the bottom of the profile and readings are expressed in nT on the left hand side of the profile.

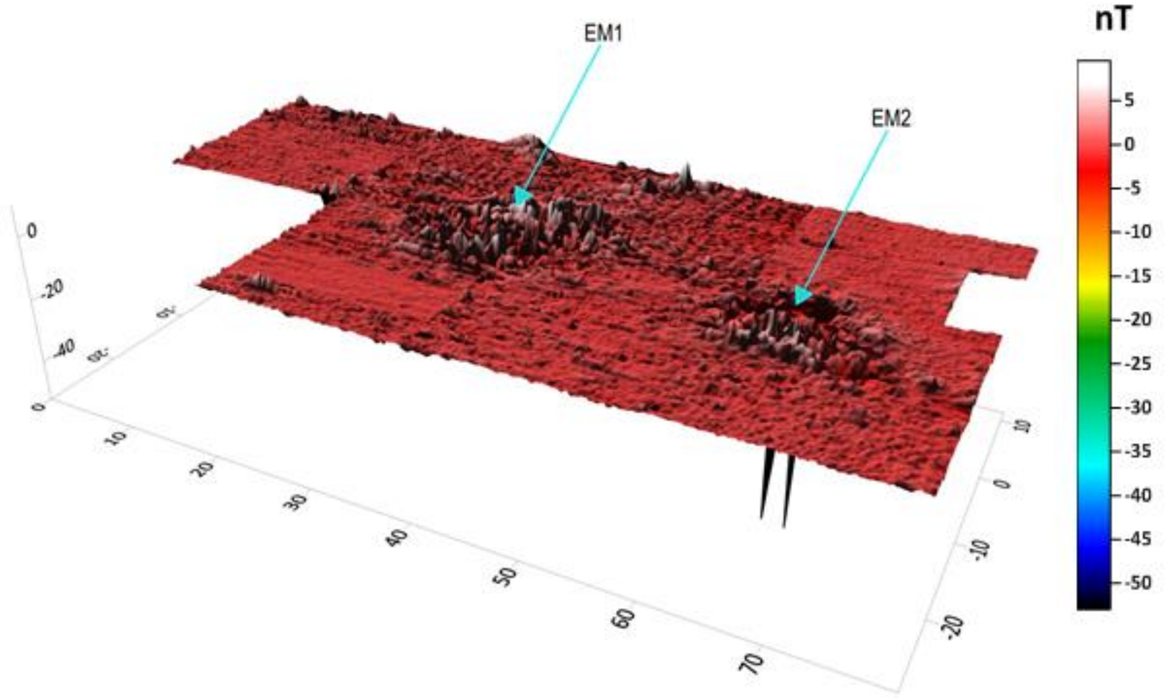


Figure 46: 3D isometric representation of the magnetics data from grids one to seven.

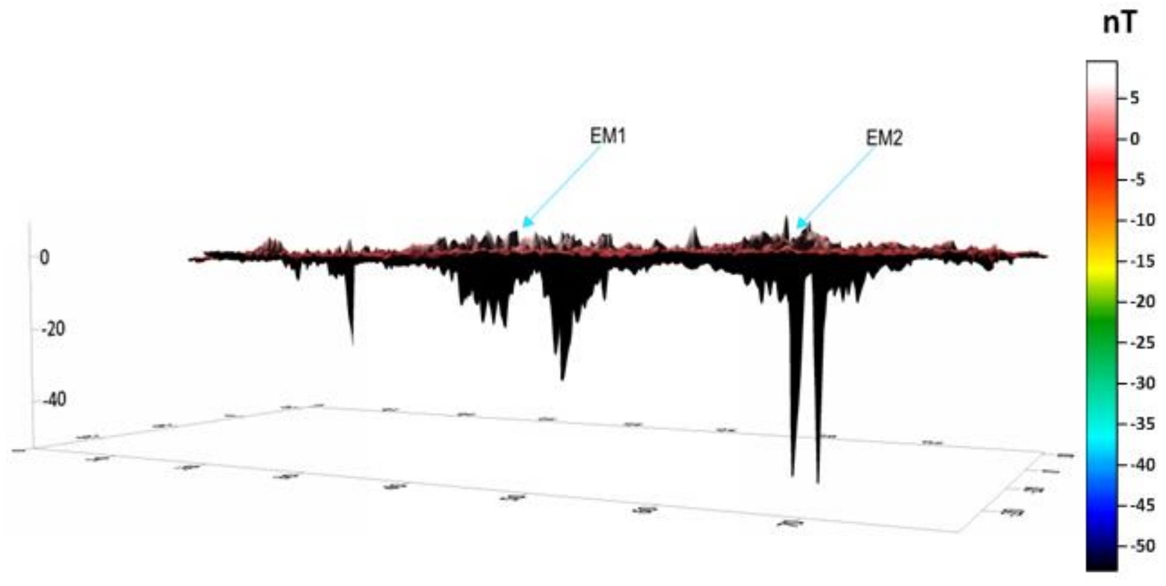


Figure 47: Side view of data from grids one to seven, the majority of magnetic responses are negative under earth mound one and two.

Magnetics – grid eight

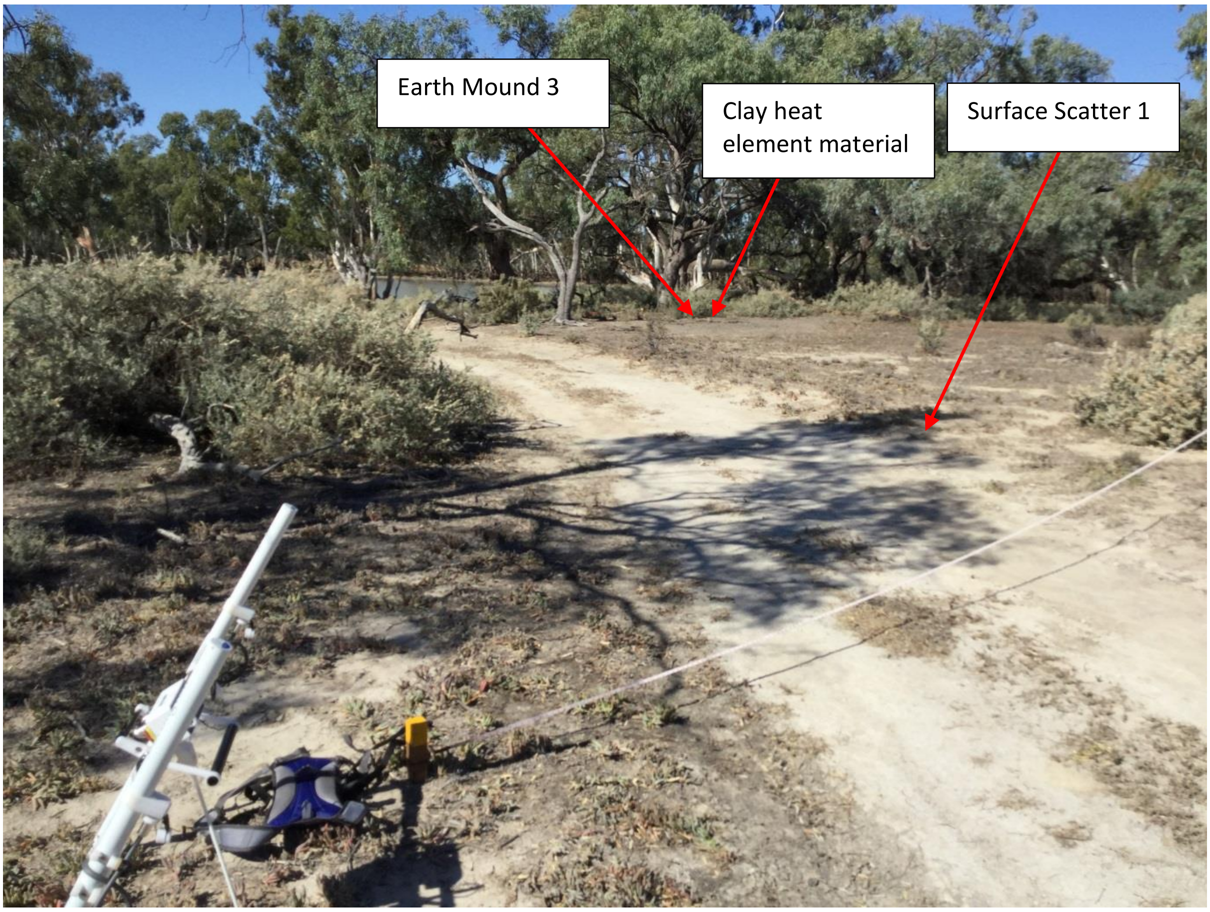


Figure 48: Grid eight is the single magnetics grid acquired separately from the main survey grid one to seven, the grid contained EM3, S1 and the access road.

Figure 49: A small subtle surface scatter of clay heating elements located within grid eight of the magnetics survey next to the access track (left). The surface scatter is not visibly obvious (right).

Grid eight was 20m x 20m and placed over an area adjacent to the riverbank bisected by an access track. One half of the grid was composed of the high side of the riverbank and the other was the beginning of the flat floodplain each separated by the access roadway. The area contained an earth mound in the south-eastern section of the grid with plentiful burnt clay pellets of differing sizes over the majority of the mound. The area toward the top of the riverbank had abundant trees which obstructed the survey whilst the beginning of the floodplain had patches of saltbush which had to be surveyed over. These obstacles within this data set do not appear to have been detrimental to the data collection. The magnetic responses over and around the earth mound and baked clay surface deposits were elevated. These features exhibited a negative response of between -0.12 to -33.04 nT (Figure 50).

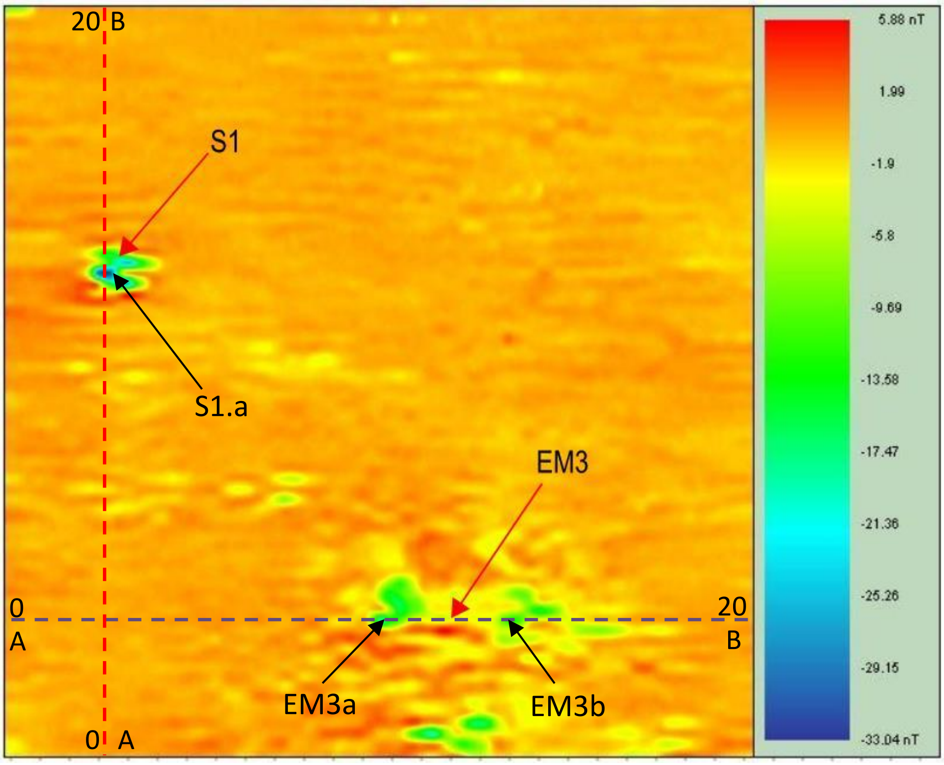


Figure 50: is the 20m x 20m magnetic dataset of grid eight the colours within the dataset coincide with colour scale to the right of the dataset; readings are expressed in nano-tesla.

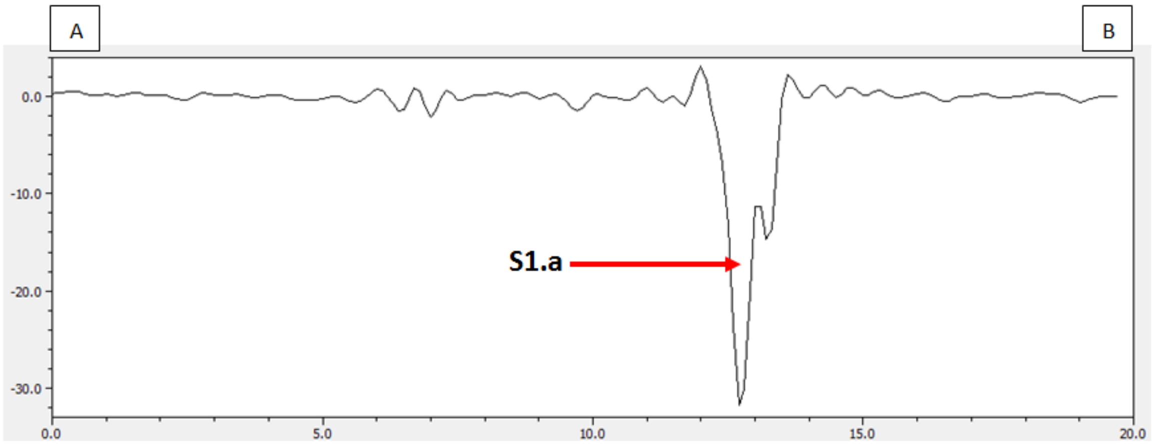


Figure 51: Peak response from a partially exposed earth oven composed of clay. Profile alignment is delineated by the red line from point A (0m) to point B (20m). Distance is expressed in meters on the bottom of the profile and readings are expressed in nT on the left hand side of the profile.

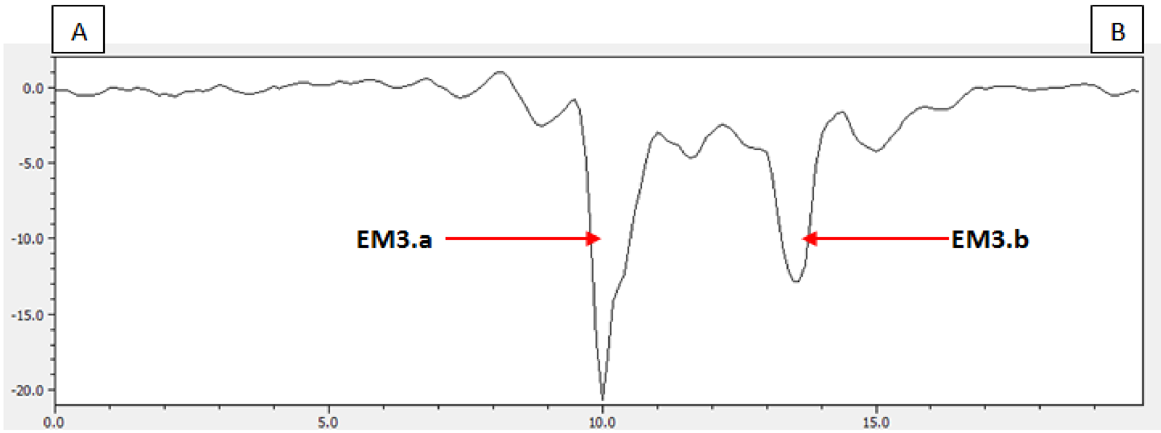


Figure 52: partially exposed earth oven composed of clay. Profile alignment is delineated by the purple line from point A (0m) to point B (20m). Distance is expressed in meters on the bottom of the profile and readings are expressed in nT on the left hand side of the profile.

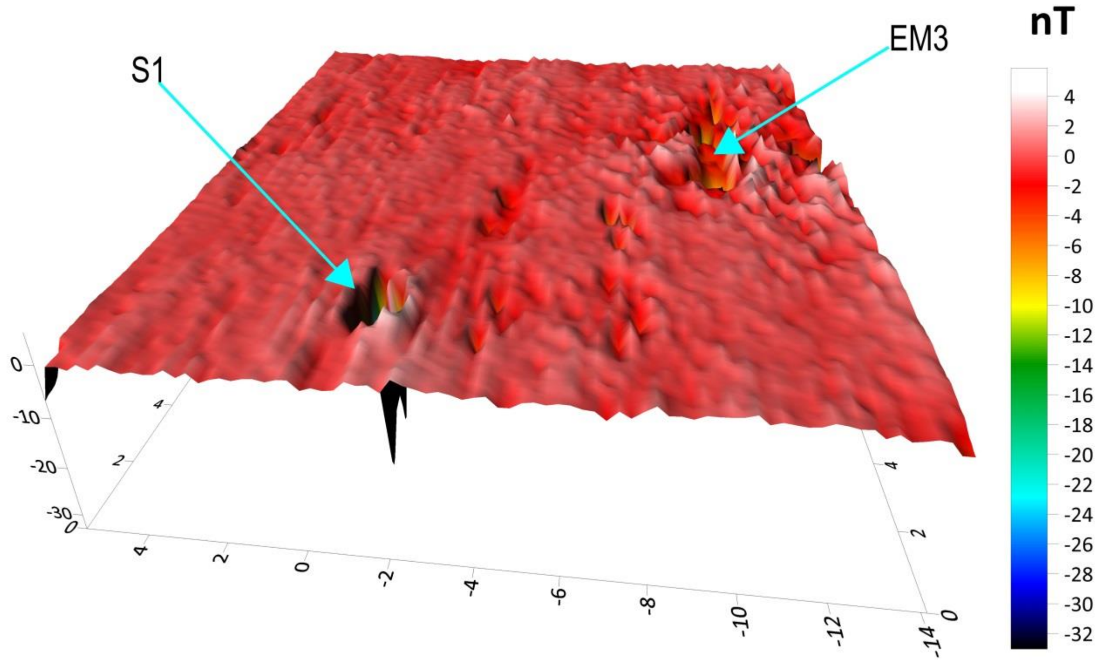


Figure 53: 3D isometric representation of the magnetics data from grid eight.

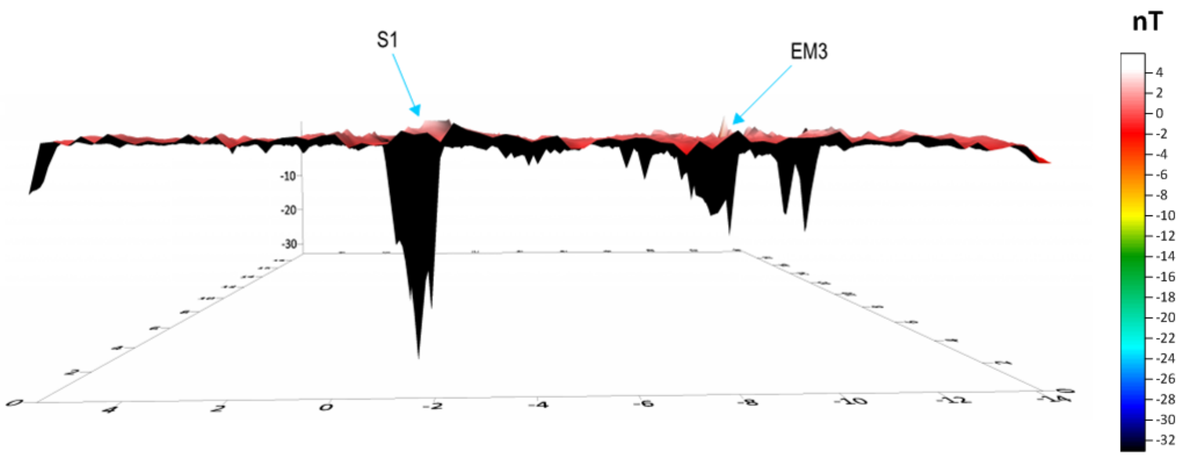


Figure 54: Side view of grid eight, the majority of magnetic readings are negative.

At the road edge substantial magnetic responses were detected over a discrete area. Upon further investigation a small surface scatter of burnt clay material was detected which was not observed during the initial survey (Figure 49 and 50). The responses for this magnetic feature ranged from -0.12nT to -33.04nT, which were significantly higher than those of the earth mound in this grid.

Peak responses and their sizes from each of the survey grids and dune survey were tabulated in order to determine if there were correlations in magnitude between these responses (Table 4).

Table 4: Peak responses from suspected earth ovens within all of the magnetics survey grids.

Heating element ID	Response size	Peak response in nano-tesla
EM2.a	1m x 0.5m	-51.42 nT
EM2.b	0.8m x 0.5m	-52.95 nT
EM3.a	0.5m x 0.3m	-20.69 nT
EM3.b	0.5 x 0.2m	-13.51nT
S1.a	0.7m x 0.5m	-33.04 nT
Dune survey	0.8m x 0.7m	-57.95 nT

All peak responses from each of the grids and dune survey were all negative. EM2.a, EM2.b, EM3.a, S1.a and the peak response from the partially submerged earth oven in the dune survey were all of very similar in magnitude.

Ground Penetrating Radar Results

3D Dataset collected over grid seven

A total of one grid was acquired over earth mound two (EM2), in both X and Y orientations in order to generate a 3D dataset. The 3D dataset was collected over EM2 as this mound had suspected buried heating element material within it which had been detected in an earlier preliminary magnetics survey in 2016. As grid seven contained EM2 and potential buried heating element material it was decided to run a 3D GPR survey over the same area for comparison purposes. The extents of the survey were the same as the magnetics survey 20m x 20m however a line spacing (spacing between profiles collected) was 0.5m therefore forty lines in two orientations were acquired (Figure 55).

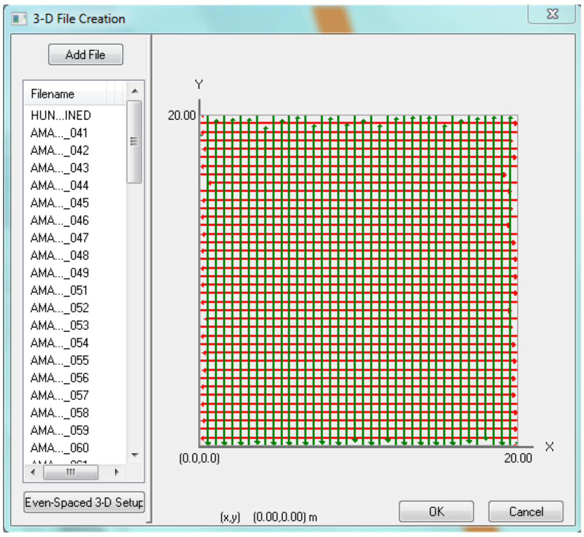


Figure 55: survey configuration conducted over grid seven, data was collected in a zig-zag configuration at 0.5m intervals totalling forty scans acquired in each orientation.

Point source hyperbolic reflections and stratigraphic layering was detected within the 2D profiles from the surface of each profile to 0.6m deep which is where penetration ceased. This was evident as inherent instrument noise overtook 'real' transmissions from the antenna and no more definitive hyperbolic, planar or stratigraphic layering could be deciphered from within the 2D profiles. The highest proportion of hyperbolic reflections were detected from the ground surface to 0.3m deep and the majority were detected within the north western section of the survey grid. Some reflections within the data are attributed to poor antenna coupling which is the result of traversing challenging vegetation. If what appeared to be mid to high amplitude planar reflections in the data beginning at the ground surface and remaining to the bottom of the profile they have been interpreted as unwanted coupling reflections/ responses. Having to traverse some vegetation be it trees, shrubs or ground covers within every geophysics grid was inevitable and much of the data contained varying amounts of hyperbolic reflections from tree roots.

Determining mound thickness and depth

Due to the subtle nature of responses from the mound to natural soil the 3D constructed dataset was unable to discriminate the extent and depth of the mound. Therefore 2D profiles from both x and y axis needed to be analysed to deduce extents and depth (Figures 57-60), this information was then tabulated (Appendix four and five) and plotted over a combined interpretation map (Figure 56).

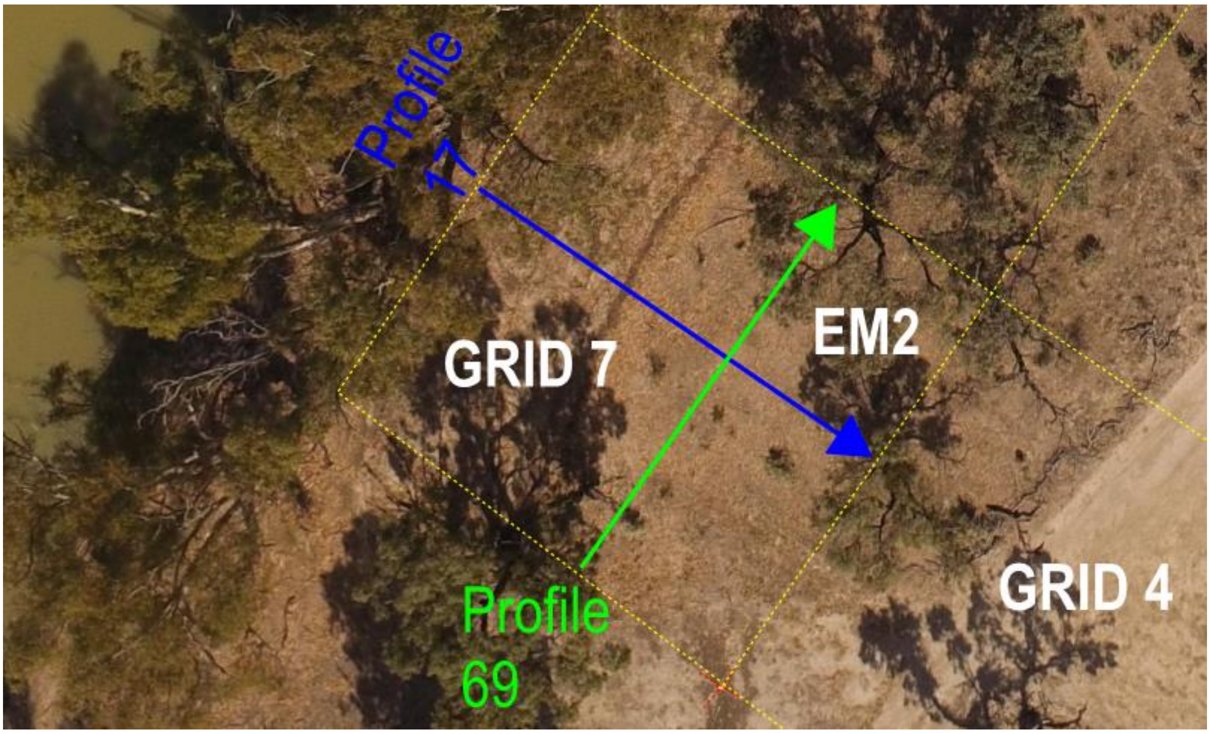


Figure 56: Map showing the alignment of profiles 17 and 69, eighty 2D profiles from both x and y axis were analysed and extents and depth tabulated in order to delineate the mound extents and mean depth.

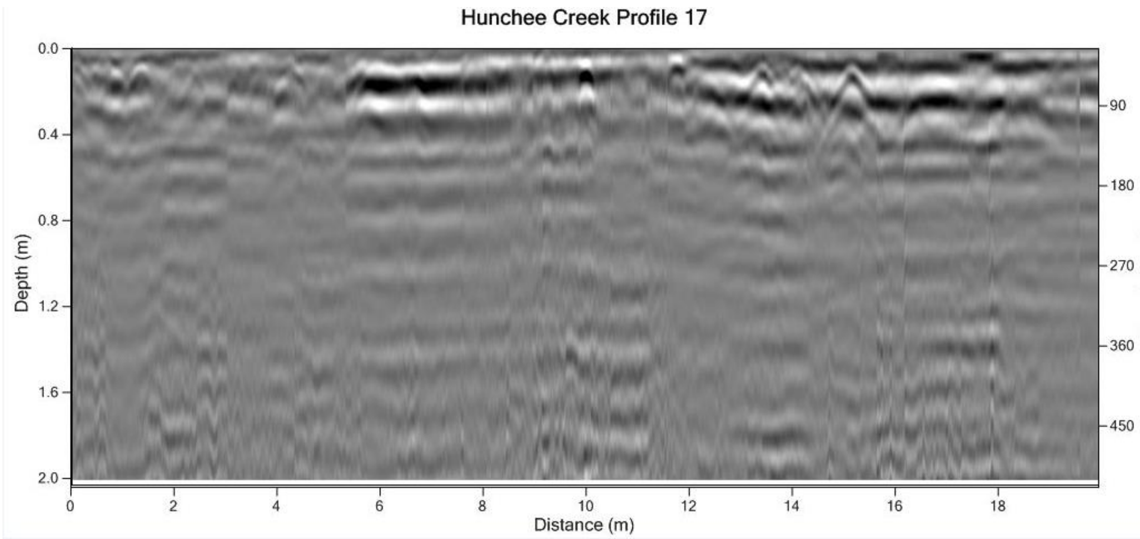


Figure 57: A 2D GPR profile 17 from the 3D dataset collected over grid seven, alignment depicted by the blue arrow in Figure 56, 0m is off the mound, the mound deposit starts at 10m and continues through to 20m.

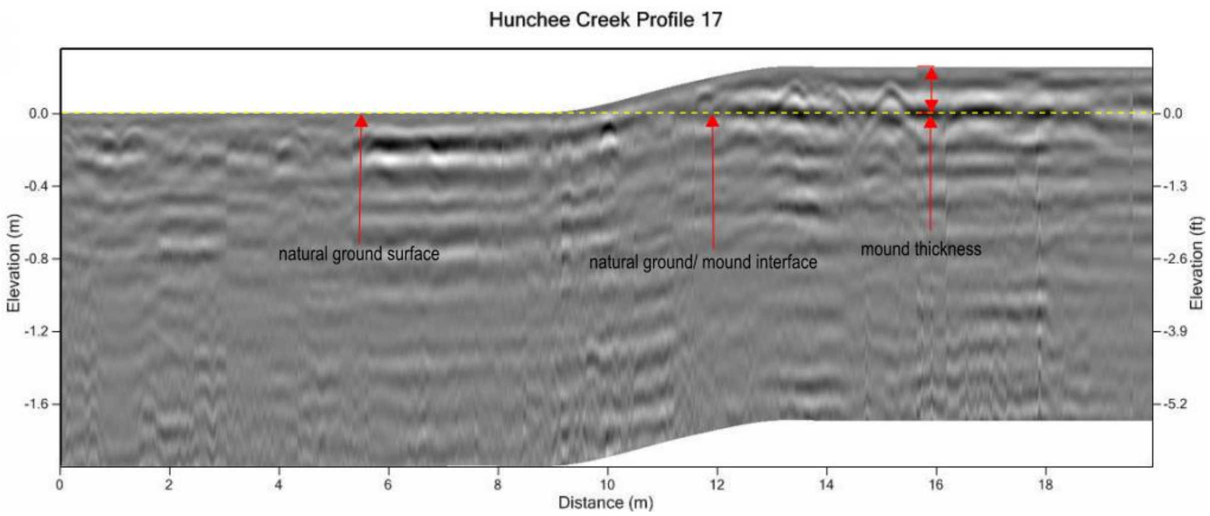


Figure 58: 2D GPR profile 17 topographically corrected and annotated, mound extents and depth were derived from all other profiles in this manner.

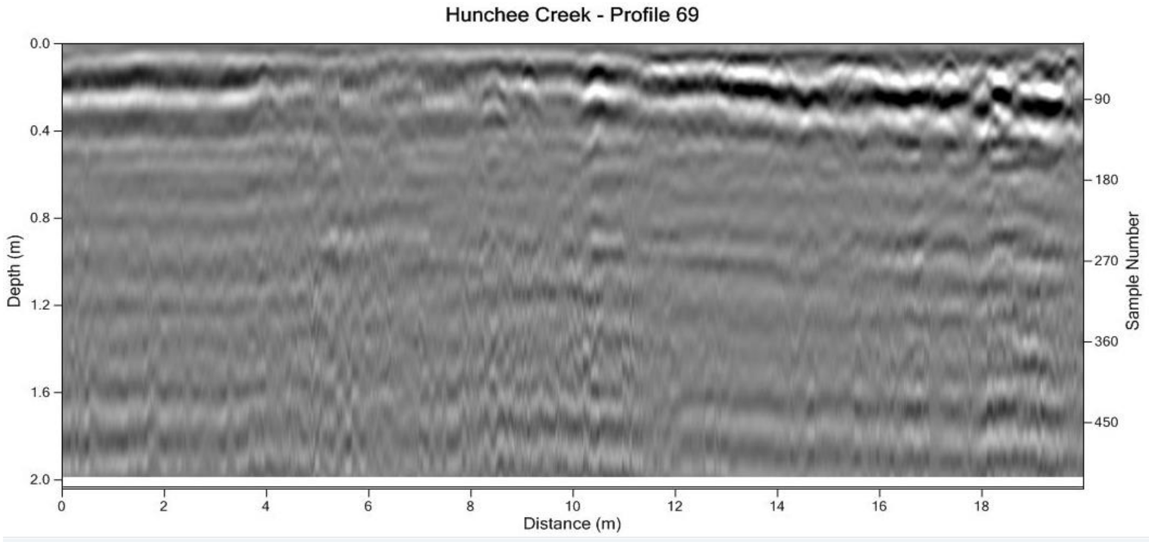


Figure 59*: A 2D GPR profile from the 3D dataset collected over grid seven, alignment depicted by the green arrow in Figure 56, 0m is off the mound, the mound deposit starts at 11m and continues through to 20m.*

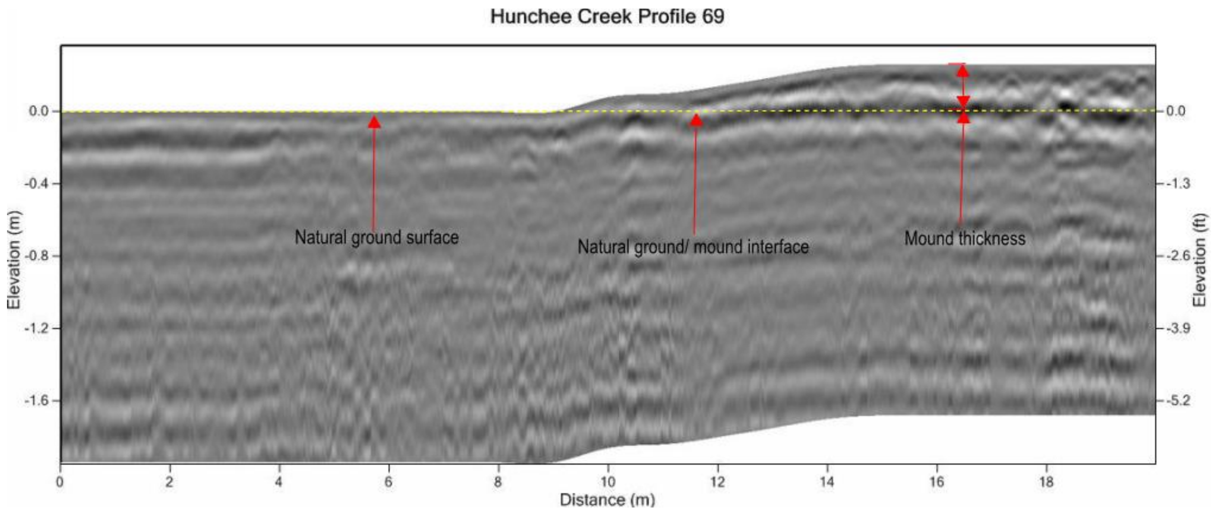


Figure 60: 2D GPR profile 69 topographically corrected and annotated, mound extents and depth were derived from all other profiles in this manner.

Magnetics and GPR combined

The combined 3D GPR data sets were extremely complicated with many reflections from tree roots and cultural material. A strategy was required to be able to analyse these results, which was to combine both the GPR and magnetics 2D profiles only over features of interest. This allowed for the determining of the location of magnetic material (2D magnetic data) and the depth of that material (2D GPR). The premise between the linking of the datasets is that the magnetics will show the location of a magnetic feature within GPR data which may not be able to be deciphered amongst other features around the feature of interest. As the location of the feature is then known a feature can be chosen and a depth ascertained in an otherwise congested location of GPR responses. Tree roots were the major contributor to this congestion. In order to construct linked 2D magnetics/GPR profiles each profile must be of the exact same length, in the same orientation and have been collected over the exact same area. This approach has been undertaken to target areas of high magnetic response namely EM2a and EM2b to confirm their location and deduce their depth.

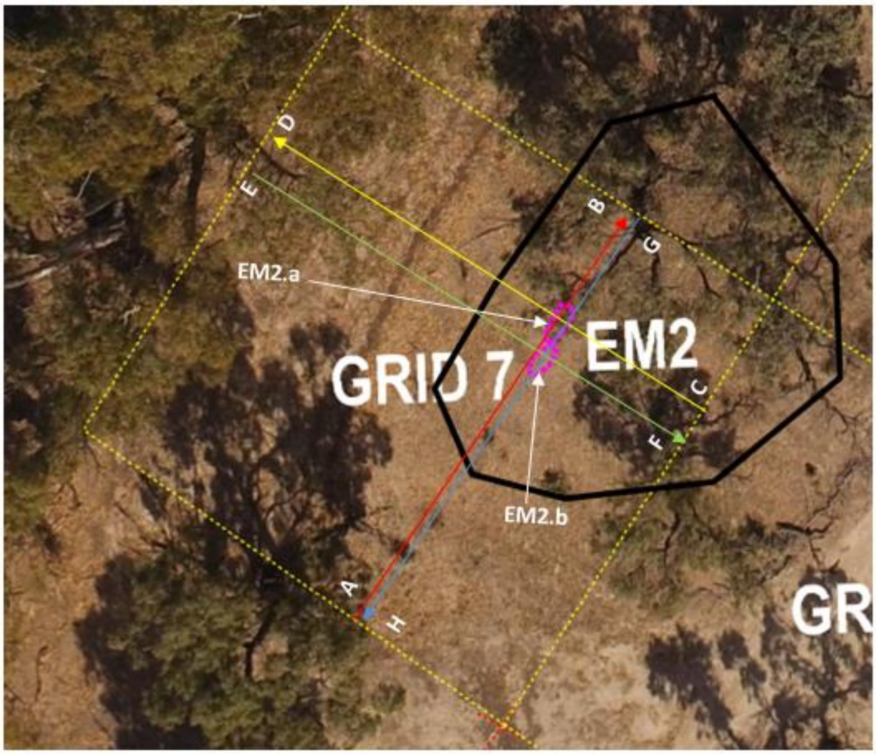


Figure 61: Combined GPR and Magnetics profiles location and alignment map over grid seven.

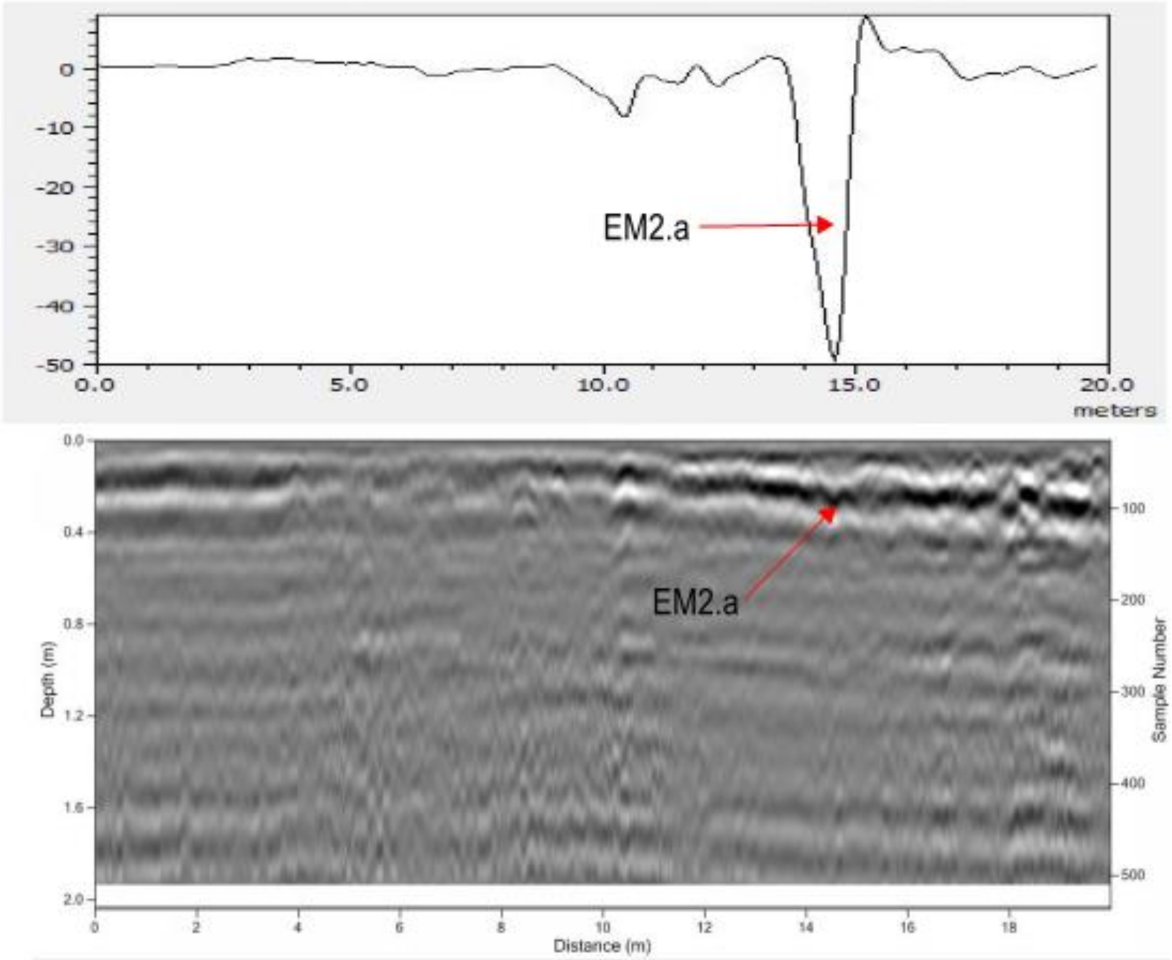


Figure 62: GPR profile 69 and corresponding 2D magnetics profile their alignment and location is depicted in Figure 61 by the red arrow from A (0) to B(20m).

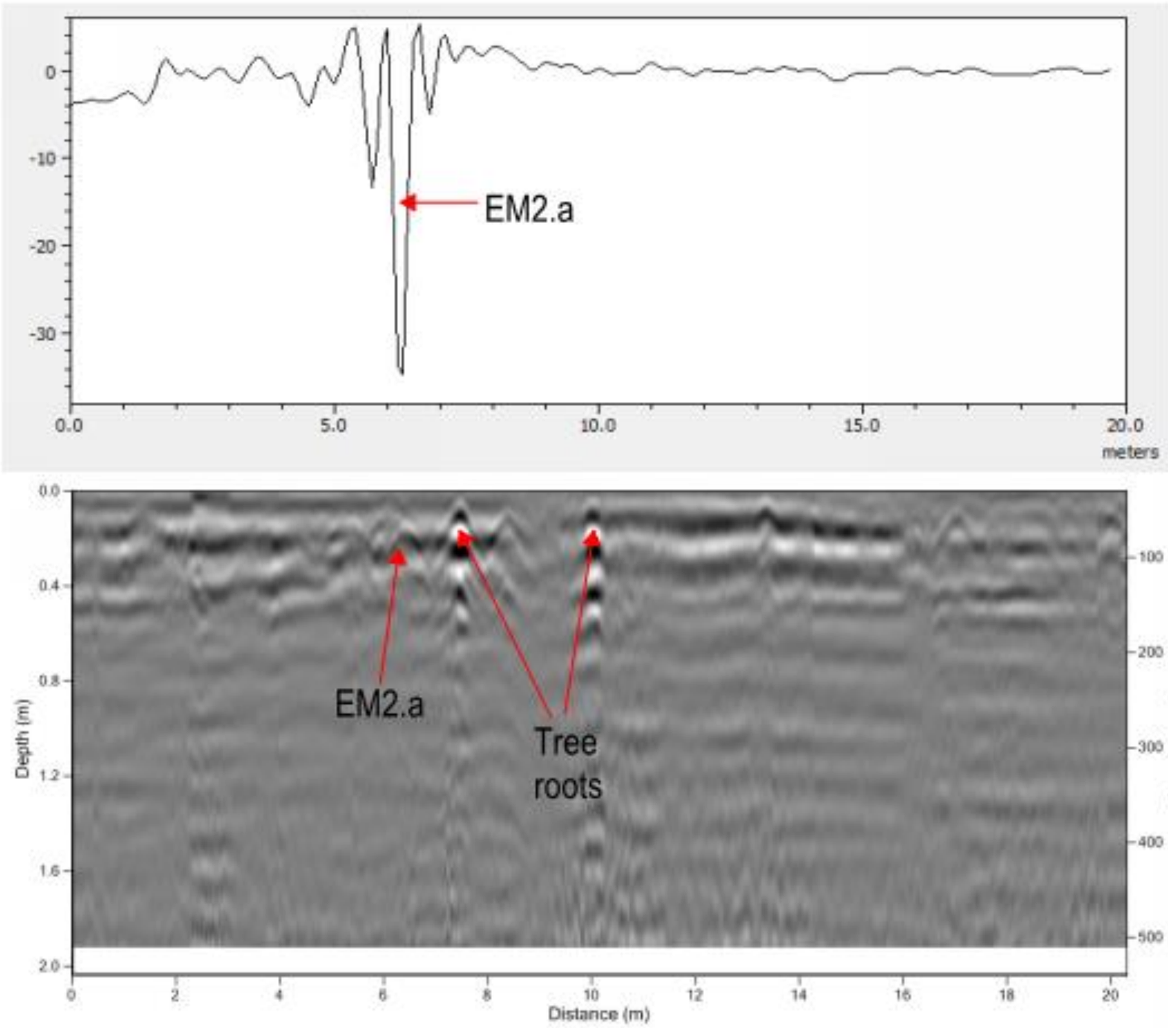


Figure 63: GPR profile 10 and corresponding 2D magnetics profile their alignment and location is depicted in Figure 61 by the yellow arrow from C (0) to D(20)m.

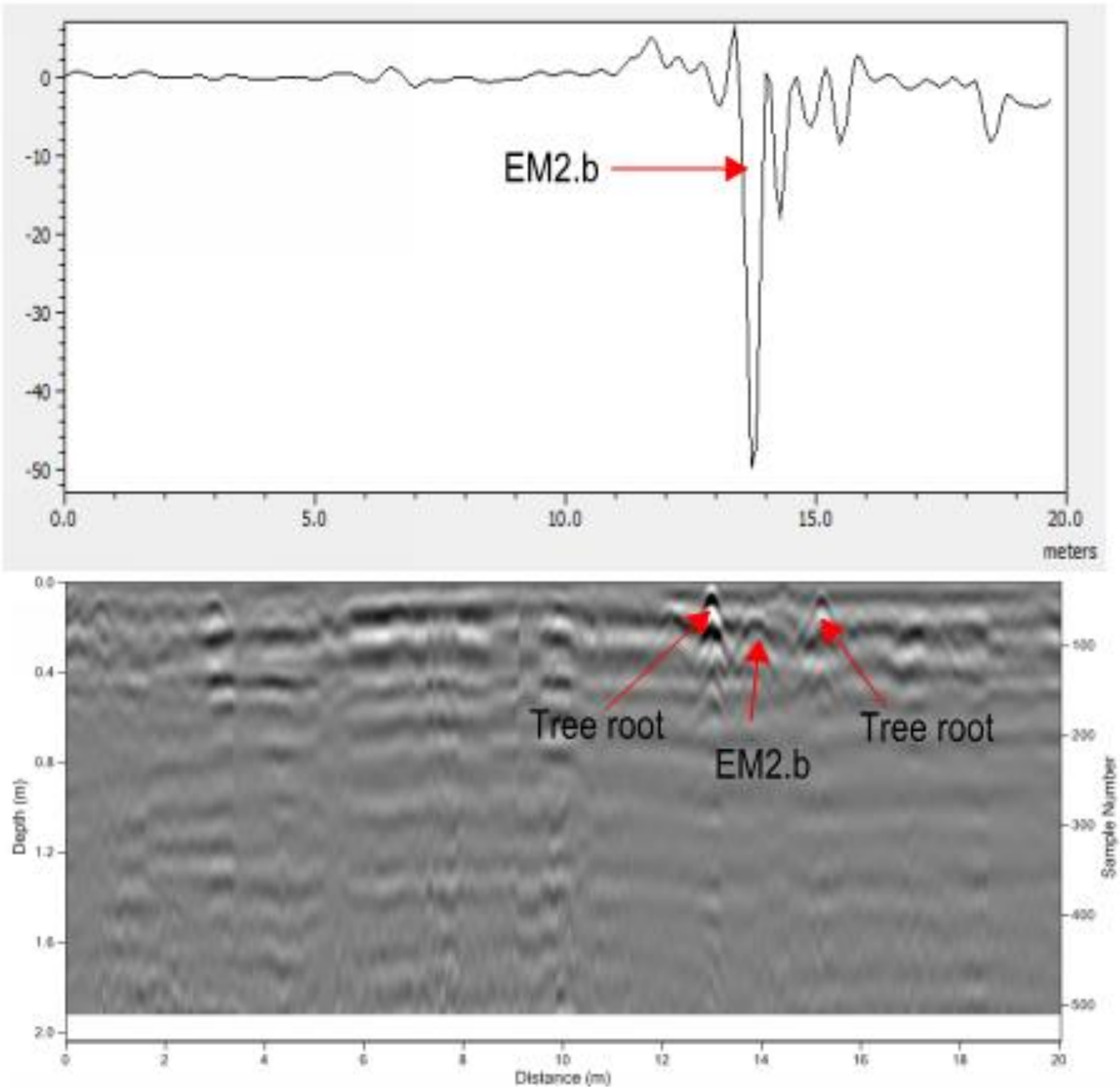


Figure 64: GPR profile 13 and corresponding 2D magnetics profile their alignment and location is depicted in Figure 61 by the green arrow from E (0) to F(20).

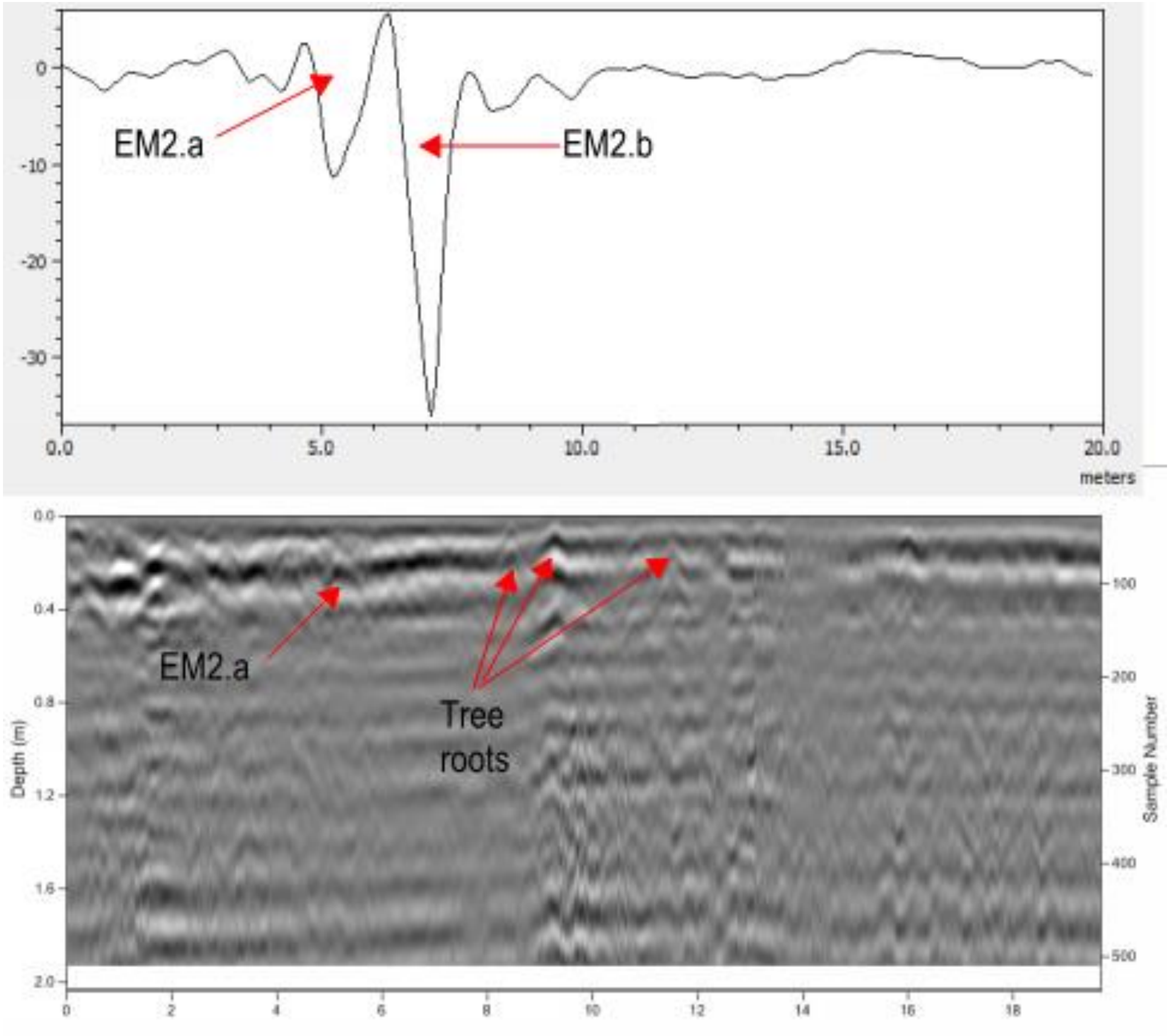


Figure 65: GPR profile 70 and corresponding 2D magnetics profile their alignment and location is depicted in Figure 61 by the blue arrow from G (0) to H (20m). EM2.a has been detected again in both the magnetics and GPR profiles. EM2.b has not been detected in the GPR profile.

Resistivity Results

A total of seven lines of resistivity data were collected over EM2 which is within grid seven of the magnetics dataset. These seven resistivity lines were collected over this location as there were suspected buried heating elements and intact ovens within this grid that had been detected during preliminary surveys. The lines were layed out in such a way as to encompass non-mounded areas and also the highest part of the mounded area in order to detect a contrast between the differing zones. For the first four lines all array configurations were run and recorded but unfortunately during line five the instrument started malfunctioning and stopped collection and recording. As time was running out on site it was decided to just run the dipole-dipole and Wenner arrays to save time and prevent the instrumentation from malfunctioning any further. This approach was successful and as a result seven complete lines of dipole-dipole and Wenner array data were acquired. Only results from these arrays will be discussed.

Electrode positions were recorded with RTK GPS and used to construct pseudo-sections (Figure 66 and 67) with correct elevations. From this topographic survey a digital elevation model was also constructed in order to cross-reference between the elevation model and the resistivity data.

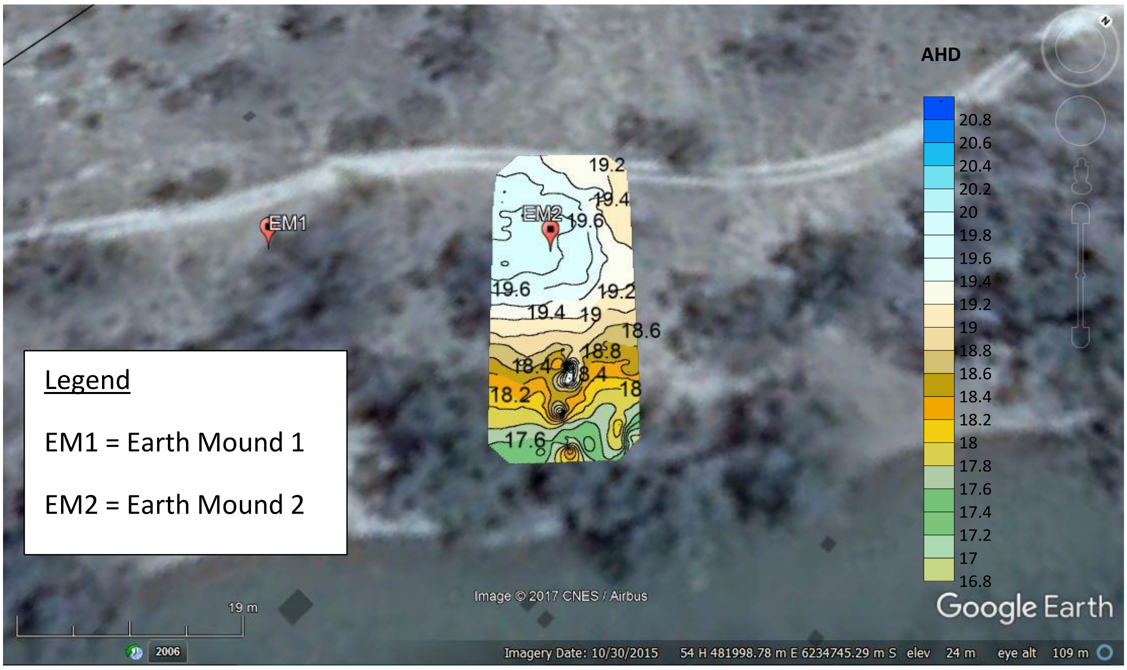


Figure 66: Digital elevation model constructed from topographically surveyed electrode positions, survey was located within grid seven – photo courtesy of google earth.

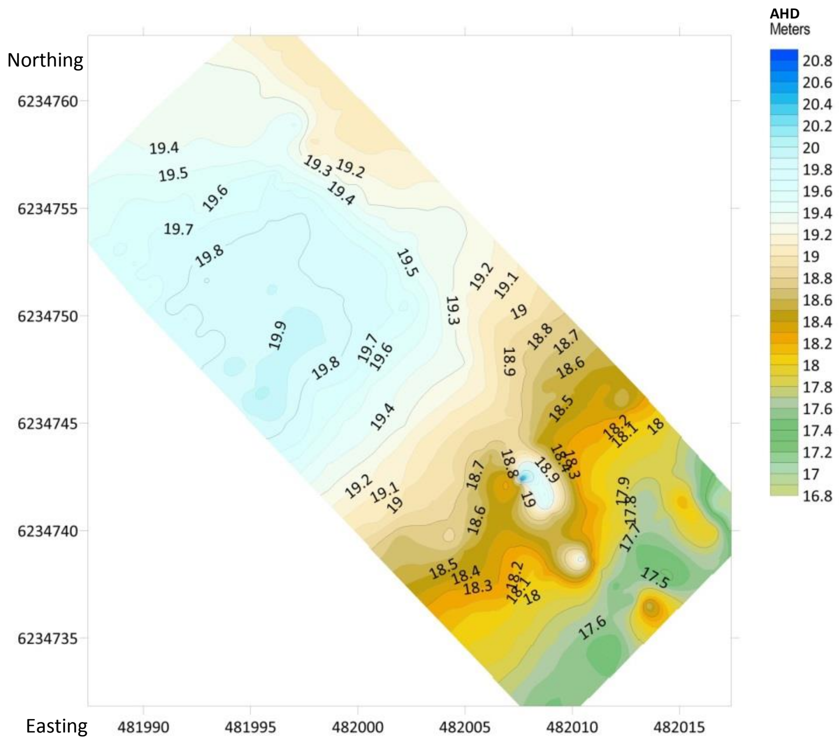


Figure 67: Digital elevation model constructed from topographically surveyed electrode positions, EM2 is at the highest elevation of 19.9m with elevations gently sloping down to the river's edge at 17.5m at its lowest level.

A total of seven dipole-dipole array and Wenner array pseudo-sections were outputted from the 2D post processing software. Data was also inputted into the 3D software used to generate a series of 3D inversion slices. In order to achieve the lowest percentage of RMS (root mean square) error possible, the dipole-dipole array data went through seven iterations and achieved an error percentage of 20.6%. The Wenner array data also went through seven iterations and achieved a percentage of error of 25.4%. Resistivity survey lines totalled 32m in length and spacing between the lines was 2m. A total of 14m was covered transversely over the mound and 32m longitudinally. As the earth mound at this location has an elevation less than 0.3m above natural ground any feature below 0.9m from the surface of the mound was not reported on as it is extremely unlikely that there is archaeological material below this level. The left hand side of the pseudo-section is the electrode nearest the river side of the grid and the right hand side of the pseudo-section is the electrode line nearest the access road.

Dipole-dipole and Wenner array pseudo-sections

All of the pseudo-sections generated from each of the arrays 7 electrode lines can be seen in the appendices section of this thesis (Appendix 2 and 3). All psudeo-sections have been topographically corrected in order to provide a more realistic representation of the data as it sits in space. Depth is expressed on the left hand side of the pseudo-section and distance is expressed in meters on the top of the psdeudosection. The colour logarithmic scale below the pseudo-section is expressed in Ohm meters and corresponds to the colours of the data set (Figure 68). The riverbank closest to the river edge is at 0m of the pseudo-sections and the end of the pseudo-section is at 32m which is located near the edge of the access road. Responses from more than 0.9m deep were unlikely to be cultural in origin at this site therefore only responses from the surface to 0.9m deep were analysed. Each individual pseudo-section was broken up into 0.3m depth zones vertically and corresponding zone 2m vertically. The resistivity responses from each pseudo-section were then tabulated (Tables 5 and 6).

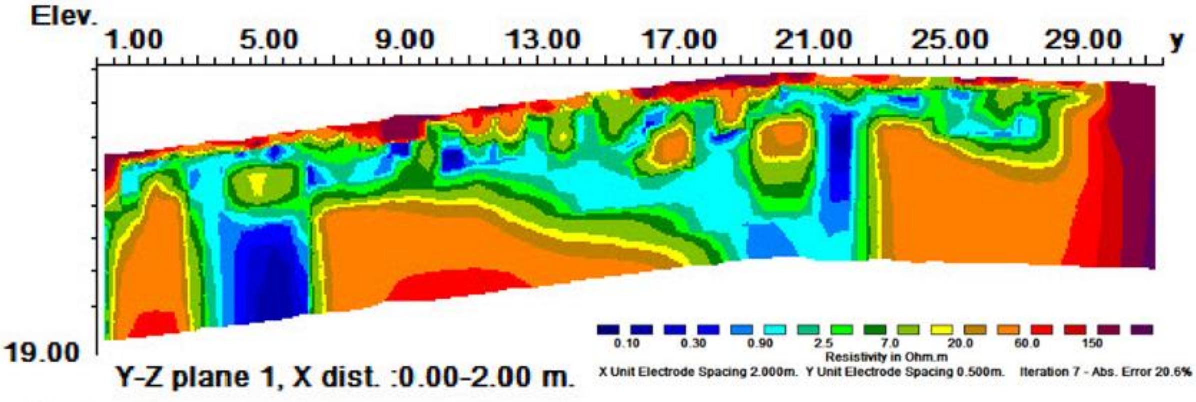


Figure 68: The first pseudo-section constructed from line one (beginning) of the dipole dipole array electrode line.

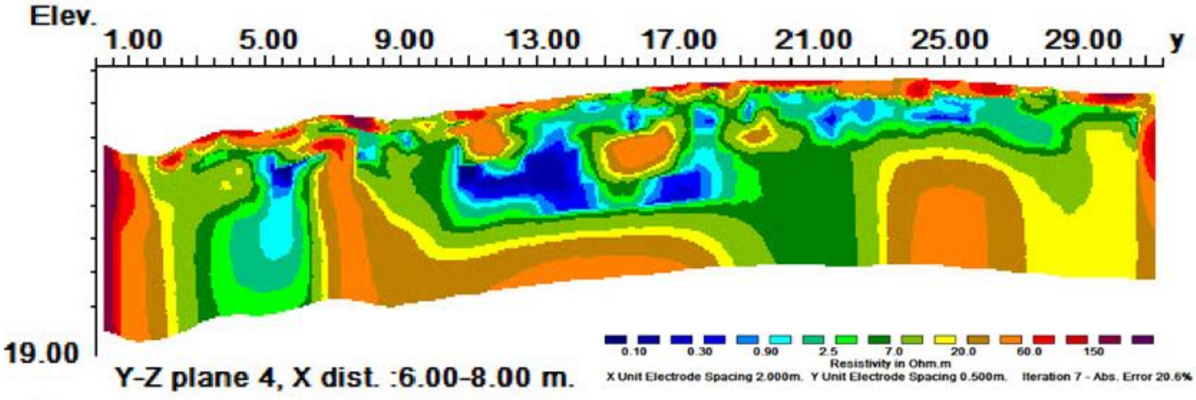


Figure 69: Dipole-dipole pseudo-section from the middle of the survey grid, electrode line 4.

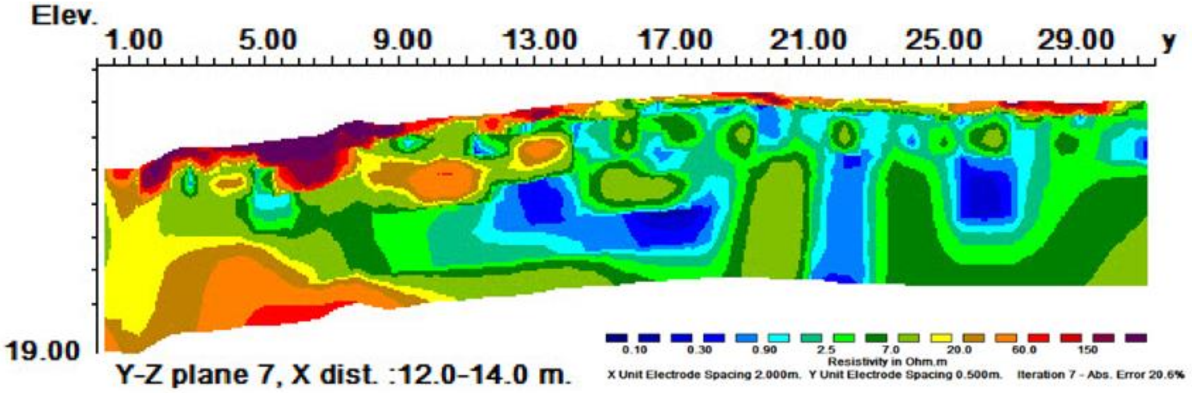


Figure 70: Dipole-dipole pseudo-section of the last electrode line of the survey, line 7.

Table 5: Summary of dipole-dipole readings from 0m – 0.3m, 0.3m -0.6m, 0.6m-0.9m deep, readings are in Ohm.m, cells coloured brown are the location of the mound along the electrode line recorded from the topographic survey, red cells are responses caused from tree roots (poor contacts), green cells are responses interpreted as underlying clay.

Pseudo-section	Depth m	0-2m	2-4m	4-6m	6-8m	8-10m	10-12m	12-14m	14-16m	16-18m	18-20m	20-22m	22-24m	24-26m	26-28m	28-30m	30-32m
1	0-0.3	150	60	20	20	150	60	60	7-20	60-150	150	60-150	20-60	7-20	150	60-150	150
1	0.3-0.6	60	20	60-150	60	150	20-150	60	7-20	60-150	150	60-150	20-60	7-20	150	60-150	150
1	0.6 -0.9	60	7	0.9-7	20-60	150	7-60	7	7	7	20-60	7	7	0.3 -7	2.5-7	0.9-7	150
2	0-0.3	60-150	60-150	60-150	60	20-60	20	60	7-20	20-60	60	150	20-60	7	20-60	20-60	150
2	0.3-0.6	7-20	7-20	.30-7	60	20-60	20-60	7-60	2.5-7	2.5-7	60	7-60	7-60	2.5-7	7	3-20	7
2	0.6 -0.9	60	.30-7	0.3-7	60	60	20-60	2.5-7	2.5-7	60	7-60	7-60	7-60	7-60	0.3-7	0.3-7	0.3-7
3	0-0.3	60-150	60-150	60-150	60-150	60-150	60	60-150	7-60	7-60	7-150	7-150	7-60	7-60	60-150	60-150	150
3	0.3-0.6	60-150	2.5-60	2.5-60	2.5-60	0.9-60	0.9-20	0.3-20	0.9-20	2.5-20	.30-60	.30-60	0.3-60	0.3-60	7-60	7	7
3	.60 -0.9	60-150	20	2.5-7	.90-7	.09-60	.30-60	.90-20	.30-7	.30-7	.30-7	.30-7	.30-.90	.30-.90.	.30-7	7	7
4	0-0.3	7-150	60-150	60	7-150	7-150	60	7-60	2.5-60	7-60	60-150	60	60	60	7-60	7-150	20-150
4	0.3-0.6	7-150	7-60	7-60	7-150	7-150	7-60	2.5-60	2.5-7	2.5-20	7-20	0.9-60	60	0.9-60	2.5-60	7-60	2.6-60
4	0.6 -0.9	7-150	2.5-7	.30-7	2.5-60	.90-7	7-60	2.5	.30-7	.90-7	.90-7	.90-7	.90-2.5	.90-2.5	.90-7	2.5-7	7-60
5	0-0.3	7-60	7-150	7-60	7-60	20-60	20-60	20-60	20-60	60	60	60	60	60	7-60	7-60	7-60
5	0.3-0.6	7-60	.90-60	7-60	7-60	7-60	7-60	7-150	.90-20	.90-20	2.5-20	2.5-20	.90-7	.90-20	.90-7	.90-20	.90-20
5	0.6 -0.9	7-20	.90-60	7-60	7-60	7-20	7-60	20-150	.90-20	.90-20	2.5-20	2.5-20	.90-7	.90-20	.90-7	.90-7	2.5-7
6	0-0.3	7-150	150	150	60-150	60-150	60-150	20-150	7-60	60-150	60-150	60-150	60-150	60	60	60	7-20
6	0.3-0.6	7-150	150	60-150	60-150	7-150	7-150	7-150	.30-7	.30-7	.30-7	.30-20	.30-7	.30-7	.30-7	7-20	2.5-7
6	0.6 -0.9	150	150	150	2.5-60	7-20	7-20	7-150	.30-7	.30-7	.30-7	.30-7	.90-7	.90-7	.90-7	.90-20	.30-7
7	0-0.3	20-150	150	150	150	60-150	7-60	20-150	7-60	7-20	20-150	7-150	7-20	7-60	60-150	60-150	2.5-60
7	0.3-0.6	20-150	60-150	60-150	150	.90-150	7-60	.90-60	.90-20	.90-20	.30-7	.30-7	.30-7	.90-7	.90-7	.90-7	.90-7
7	0.6 -0.9	20-150	.90-150	7-150	150	150-.90	.90-7	.30-20	.30-7	.90-7	.30-7	.30-7	.90-7	.90-7	.90-7	.90-7	.90-2.5

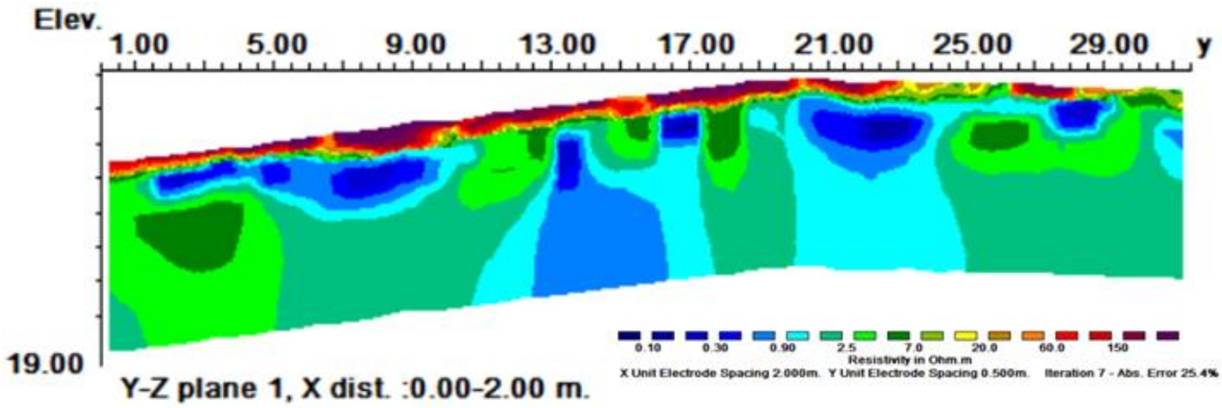


Figure 71: Wenner Array – pseudo-section of electrode line 1, the first line of the survey grid.

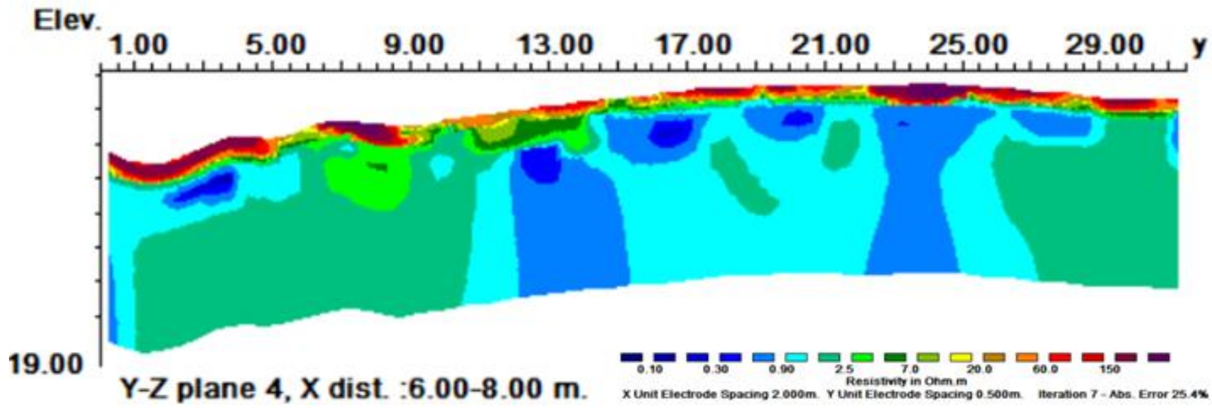


Figure 72: Wenner array pseudo-section, electrode line 4, the centre line of the survey grid.

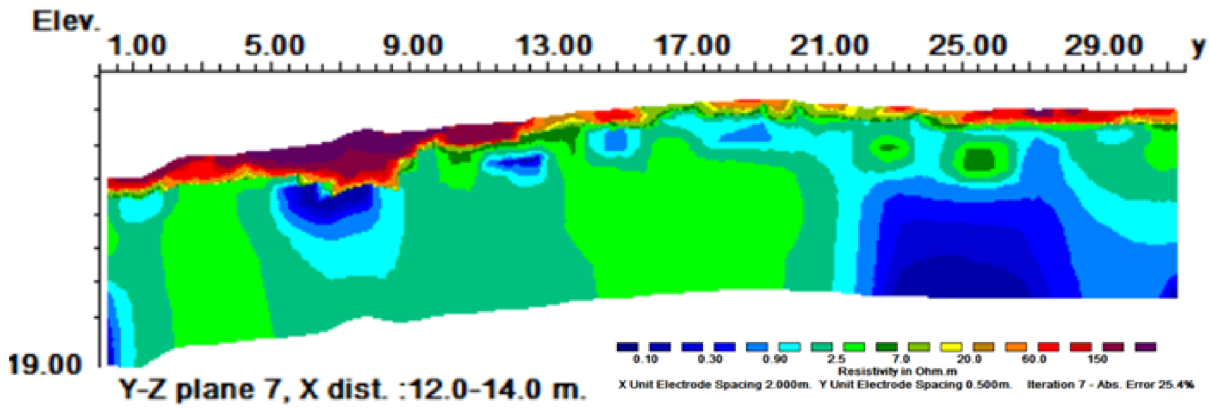


Figure 73: Wenner Array pseudo-section electrode line 7, the last line collected of the survey grid.

Table 6: Summary of Wenner array readings -0m – 0.3m, 0.3m -0.6m, 0.6m-0.9m deep, readings are in Ohm.m, cells coloured brown is the location of the mound along the electrode line recorded from the topographic survey, red cells are responses caused from tree roots (poor contacts), green cells are responses interpreted the underlying clay.

Pseudo-section	Depth m	0-2m	2-4m	4-6m	6-8m	8-10m	10-12m	12-14m	14-16m	16-18m	18-20m	20-22m	22-24m	24-26m	26-28m	28-30m	30-32m
1	0-0.3	60	60	150	150	150	150	150	60	150	150	150	20-60	7-20	150	20-60	7
1	0.3-0.6	60	60	60	60	150	60	60	60	60-150	150	60-150	60	7-20	150	20-60	7
1	0.6 - 0.9	2.5-7	.30-.90	.30-.90	.90-7	150	0.9-2.5	2.5-7	7	.30-7	.90	.90-2.5	.30-.90	.90-2.5	.30-.90	.30-2.5	2.5
2	0-0.3	60	150	150	150	150	60-150	60	20-60	60-150	60-150	60-150	60	60	60-150	20-60	20
2	0.3-0.6	60	60	150	60-150	150	60	60	60	60-150	60-150	60	60	60	60	60	20
2	0.6 - 0.9	2.5-7	.90-2.5	.90-2.5	.90-2.5	60	2.5-7	7`	.90-7	.90	2.5	.30-.90	.90-2.5	.90-7	.90-2.5	.90-2.5	2.5
3	0-0.3	150	150	60-150	150	60-150	60-150	150	7-60	60-150	60-150	60	60-150	60-150	60-150	60-150	60
3	0.3-0.6	60-150	20-150	2.5-150	150	60-150	20-150	60	7-60	60	60-150	20	7-20	7-20	7-60	60	20
3	0.6 - 0.9	2.5	2.5	2.5	2.5-7	2.5-7	2.5	2.5-7	.30-2.5	.90	.90-2.5	2.5	2.5	.90-2.5	.90-2.5	.90-7	2.5-7
4	0-0.3	150	150	60-150	150	150	150	60	7-60	7-20	150	60-150	60-150	150	60-150	20-150	60-150
4	0.3-0.6	60	60-150	60-150	150	7-150	60-150	60-150	7-60	7-60	150	60-150	60-150	60-150	20-60	20-60	60
4	0.6 - 0.9	.90	.90	2.5	2.5	2.5	2.5-7	7	.30-.90	.30-.90	.30-.90	.30-.90	.30-.90	.90	.30-.90	.30-2.5	.30-2.5
5	0-0.3	150	150	60-150	150	60-150	60-150	60-150	7-60	20-150	150	60-150	150	60-150	20-150	20-150	60-150
5	0.3-0.6	60	60	60	60	7-60	7-60	7-60	7	7-60	60	60-150	60-150	2.5-60	7-60	7-60	7-60
5	0.6 - 0.9	0.90-2.5	.90-2.5	.90-2.5	.90-2.5	2.5-7	7	7	.90-7	.30-.90	.30-.90	.30-2.5	.30-2.5	.30-2.5	.30-2.5	2.5	2.5-7
6	0-0.3	150	150	150	150	20-150	60-150	60-150	7	7-60	150	20-150	20-150	60-150	60	60-150	60
6	0.3-0.6	60	150	150	2.5-150	2.5-60	7-60	7-60	.90-2.5	.90-60	60	7-20	20-150	2.5-7	2.5-7	2.5-20	2.5-7
6	0.6 - 0.9	.90-7	60	60	60	2.5-7	2.5-7	2.5-7	.30-7	.30-.90	.30-.90	.30-7	.30-7	.90-7	2.5-7	.90-2.5	.90-2.5
7	0-0.3	150	60-150	150	150	150	150	20	60	7-60	7-60	7-60	20-60	60	60-150	60-150	60
7	0.3-0.6	60	60	150	150	150	7-60	2.5-7	7-60	.90-20	.90-7	2.5-20	.90-20	60	60	60	60
7	0.6 -	2.5-7	20-	20	60-	2.5-	7-60	.90-	.90-	.90-	.90-	2.5	.90-	2.5-	2.5	.90-	2.5-

	0.9		60		150	150		7	7	7	7		7	7		2.5	7

Electrical Resistivity Tomography (ERT) Results

A series of ERT depth slices were constructed for both arrays. Within this results section only the first three slices will be displayed from the ground surface to 0.6m deep. The complete set of slices reaching 5m+ can be viewed in Appendix 3. The riverbank closest to Hunchee Creek is at 0m of the depth slices and the end of the depth slices are at 32m which is located near the edge of the access road. Slice depth is expressed in meters at the top of the dataset and length and width are expressed in meters on the x and y axis of the slice. The colour logarithmic scale below the pseudo-section is expressed in Ohm meters and corresponds with the colours of the data set (Figure 74).

Dipole-dipole array depth slices

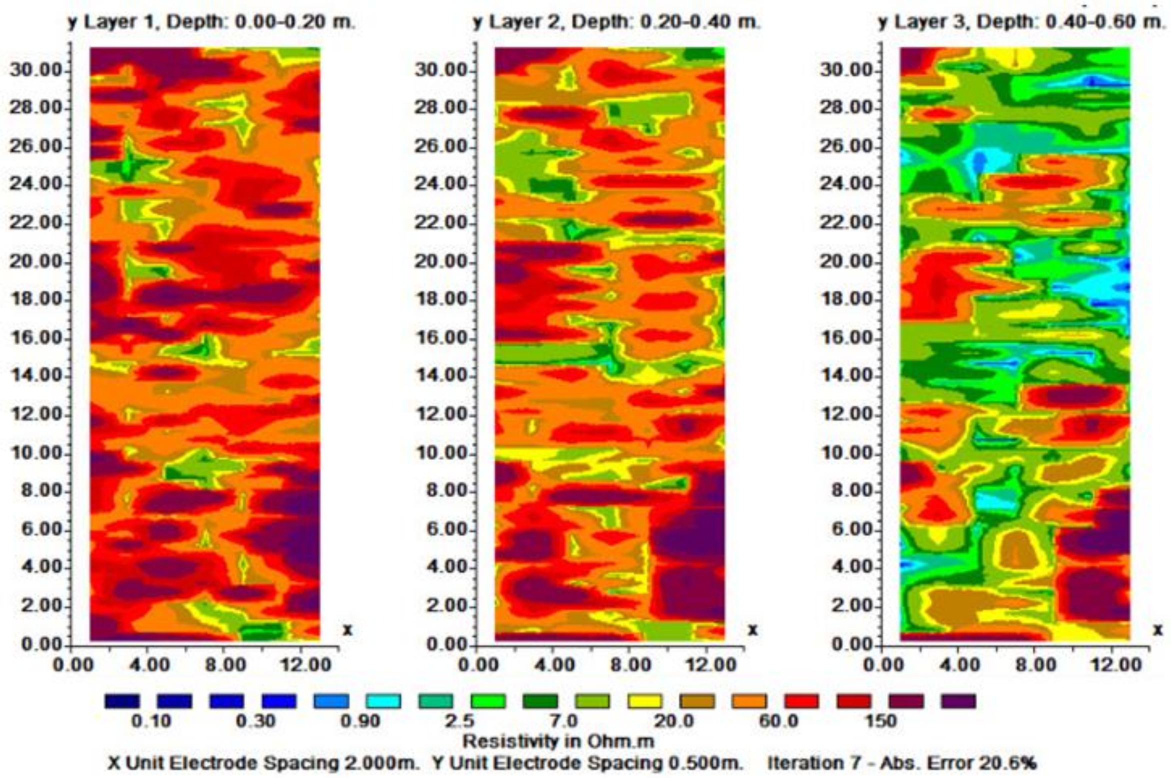


Figure 74: 3 Dipole-dipole array depth slices from the surface to 0.6m deep.

Wenner array depth slices

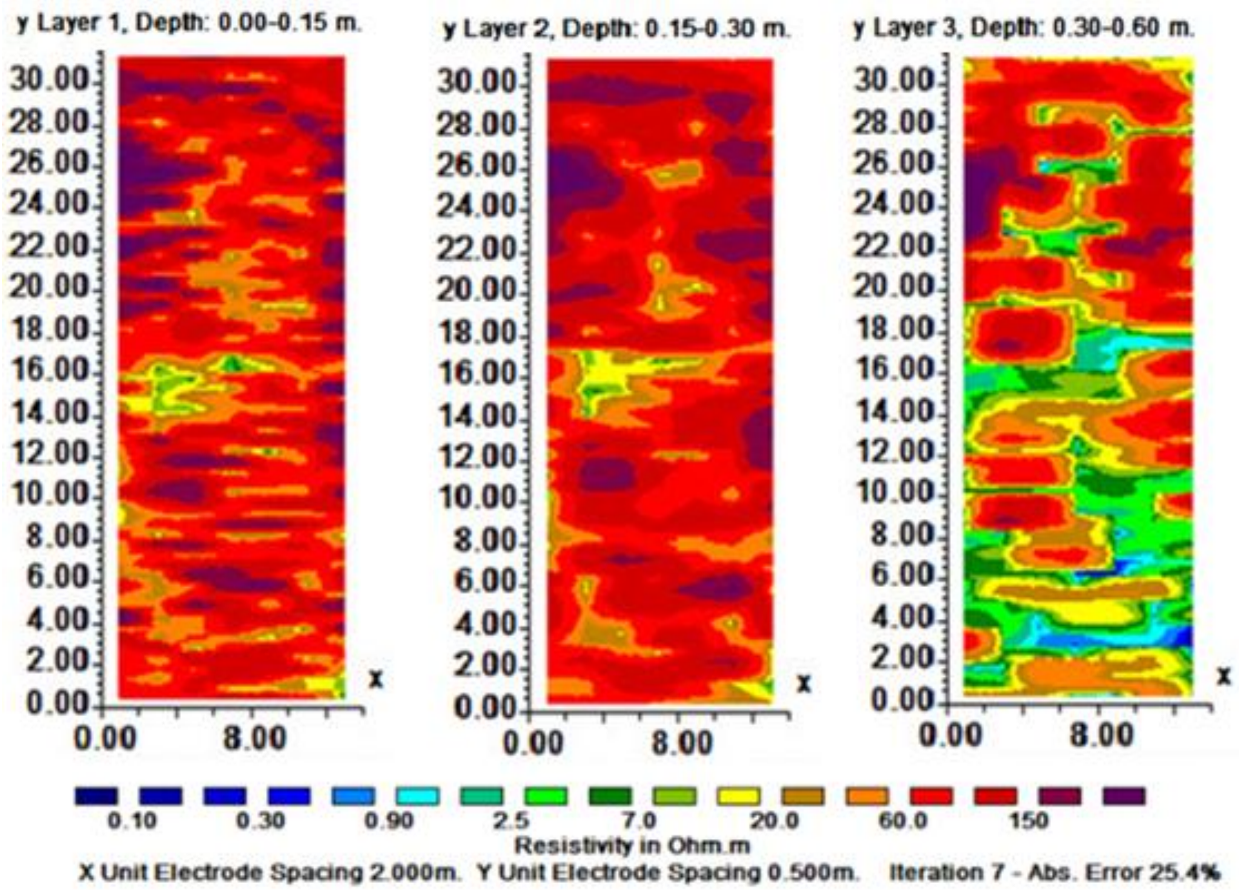


Figure 75: Three Wenner array depth slices from the surface to 0.6m deep.

Both the arrays show a resistive layer from the surface to between 0.3m - 0.6m deep. Below 0.6m deep in most zones the soil becomes less resistive from 150 Ohms to 0.9 Ohms a difference of 149.1 Ohms (Tables 5 and 6).

Combined Interpretation

All survey results were incorporated into two maps for a combined interpretation of all of the acquired data. The first map was generated over grids one to seven and second over grid eight. All data was geo-referenced and has been plotted where it sits in real space. Only grid one from the main survey area had no features of archaeological interest to discuss.

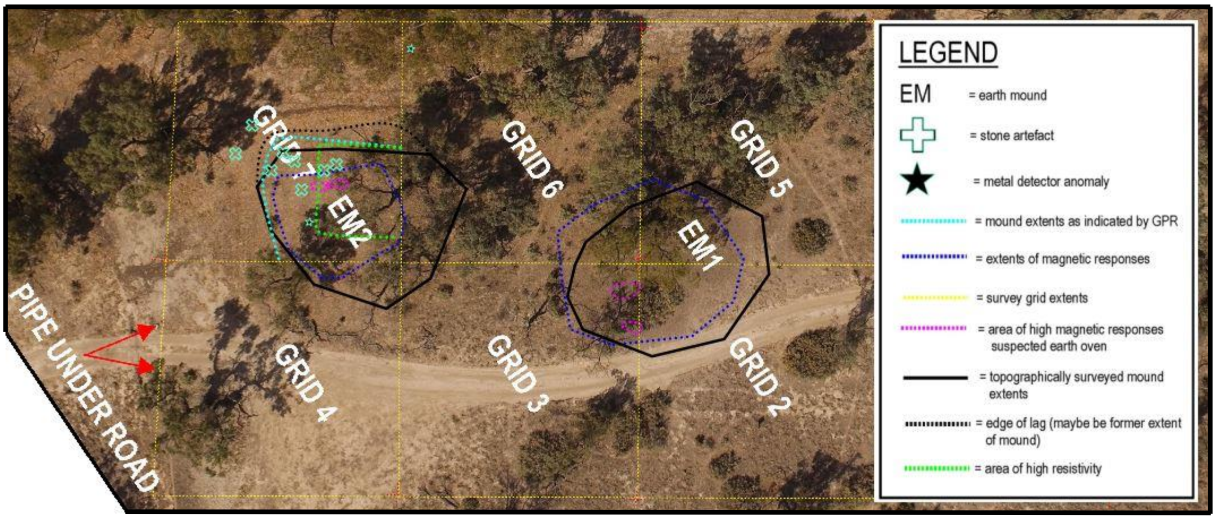


Figure 76: Main survey location grids displayed containing geophysical anomalies and archaeological artefacts, generated for a combined method site interpretation.

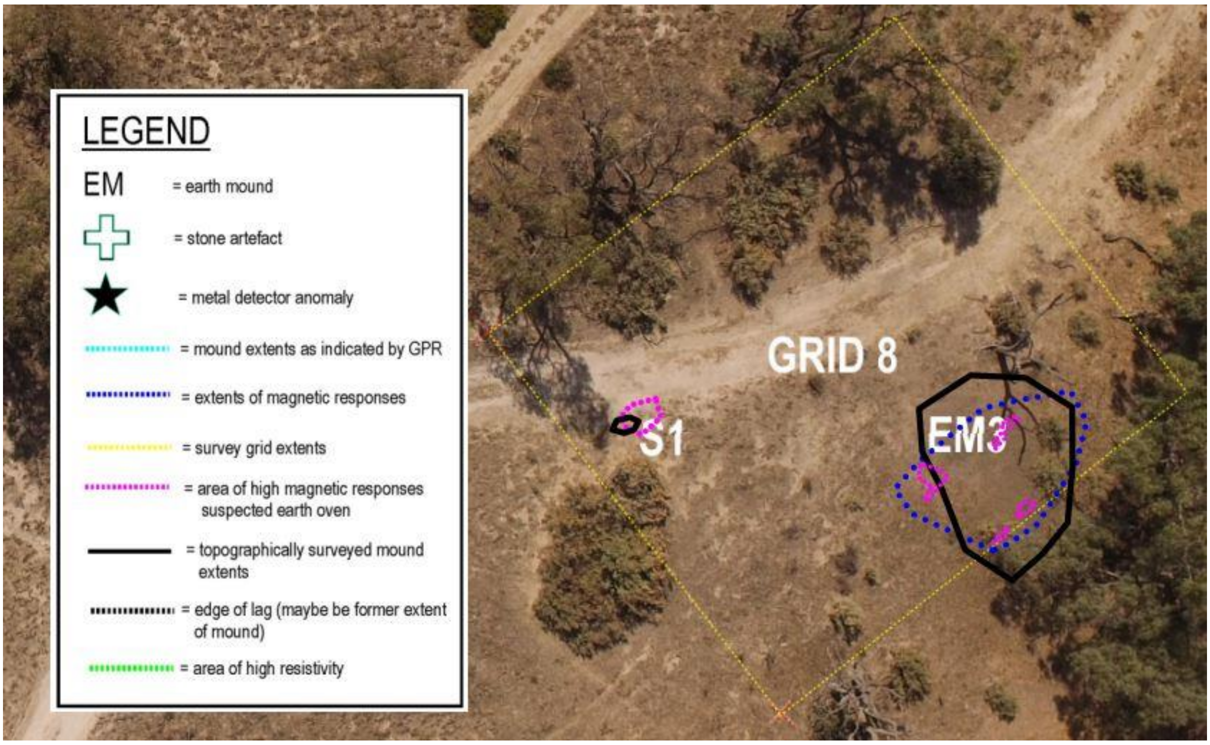


Figure 77: Grid 8 combined survey map

Grid Seven had all three intensive geophysics surveys conducted over it and a quick metal detector survey. The information from all geophysical methods was overlayed onto a geo-referenced aerial image of the research site (Figure 76 and 77). Two areas of high magnetic responses were detected as well an area within the topographically surveyed mound extents of elevated magnetic responses. Stone artefacts were only detected on this earth mound and topographically surveyed. Only the magnetics survey extended to other grids and that is why the mound extents as determined by GPR and resistivity don't go beyond grid seven.

Summary

The magnetic technique effectively determined whether the mounds investigated were cultural or naturally formed through the detection of fire altered material. The GPR technique effectively determined lateral and vertical extents of the mound whereas the resistivity was only able to determine the vertical extents of the sites topsoil. The amalgamation of all techniques into one combined dataset allowed for a combined interpretation approach which indicated where all features were situated in space on the research site.

The geophysical results presented here and what they mean archaeologically are to be discussed in the following chapter.

Chapter 7. Discussion of results

The principal aim of this study was to distinguish how effective geophysics was for the detection and mapping of earth mounds/earth ovens and associated features. This study has shown that cross-correlation between different geophysical methods and a joint approach between geophysical and archaeological survey combined into one dataset is the most effective way to interrogate an archaeological site in this context.

This chapter discusses the results obtained from the magnetics, ground penetrating radar and resistivity surveys conducted over a portion of Hunchee Creek. These surveys were conducted in order to address the research aims and primary research question introduced in chapter one.

As excavation was not possible at the time of this study the origins of responses from features beneath the ground could not be visually analysed. Therefore only inferences could be made as to what these responses were from.

Topographic survey

The topographic survey indicated that all three mounds were the highest elevated landforms within the survey site (Appendix 1). The mounds themselves are situated on the highest part of the riverbank. Within the survey area there is a total elevation difference of 2.75m from the highest surveyed area located at EM3 to the lowest being the edge of the riverbank and this elevation difference changes over less than 40m in most cases. This elevation change could best be described as a gentle slope from the top of the mound to the water's edge. Therefore it could be inferred that the locations of the three earth mounds surveyed were chosen due to their easy access to the water's edge. For reasons such as to collect clay required for making heat elements for ovens, and for hunting or foraging for food or other resources.

Magnetics Results

Only EM1 and EM3 contained surface scatters of heating element which gave some clue as to mound function. EM2 did not contain any sign of surface scatters of heating element material, its origins were suspected but no evidence could be visually detected. However after the gradiometer results were viewed it became quite obvious that it was not a natural deposit but was constructed through human occupation.

The peak responses from suspected earth ovens of EM2, EM3, S1 and a partially buried oven from the dune survey appeared as strong negative responses within the magnetic datasets (Table 4). The reason for this is the magnetic inclination of the earth's magnetic field at this location. Magnetic inclination or magnetic dip as it is also termed is the angle of the geomagnetic vector with the horizontal at a given location. It is defined to be positive when the field vector dips downward (Northern Hemisphere) and negative when the field vector dips upward (Southern Hemisphere) (Matzner 2001). Therefore positive values of inclination indicate that the magnetic field of the Earth is pointing downward at the point of measurement and negative values indicate this is pointing upward (Aspinal et al. 2009:63-65). This is because earth oven material and ovens themselves when magnetised can act as bar magnets buried in the ground. This 'magnet' is created as a result of the oven being fired and then aligns with the earth's magnetic field (thermo-remnant magnetization). The magnetic fields at this location are angled down as they converge at the pole, and in this part of the world is approximately sixty degrees. This means that magnetometers and gradiometers will detect the top end of the magnet more strongly than the 'bottom' end resulting in apparent lack of or reduced positive signal. This angle will also mean that the position of the signal on the ground will be offset more from the actual position of the feature. Therefore, care would be required when excavating such a feature.

Grid eight contained EM3 and a partially buried earth oven that was only detected during the gradiometer survey as it became evident when readings spiked when walking near it. It was not detected by others who visually surveyed the area. The heat element material that was on the surface was not responsible for the high readings recorded. However the surface material did exhibit a magnetic response but when held against the sensor was nowhere near as strong as when the sensor was held over the scatter on the ground. It was what was buried below that was exhibiting the larger negative readings as high as -33.04nT, which is a suspected in-situ earth oven. If so this magnetic feature would support Fanning's et al. (2009) findings whereby intact heat retainer elements produce stronger readings than those that have been scattered and are eroding away. Readings of this magnitude were also experienced over the nearby earth mound in grid eight which could mean there are also in-situ earth ovens beneath the surface. The surface scatter feature and what was below it in grid eight were very similar in their responses to the oven's detected in the preliminary surveys of sites one and two. Just like the ovens in the preliminary surveys the partially submerged earth oven was composed of clay balls which could be seen eroding from the ground and the surface around it contained burnt clay nodules also. The data shows that earth ovens composed of in-situ clay balls containing magnetic minerals such as the ones at Calperum exhibit a stronger response compared with that of the earth mound surface heating elements which are deflating from the deposit. Similar magnetic responses from a partially submerged earth oven composed of only clay when compared with other responses from other buried suspected earth ovens could indicate the use of only one type of heating element, clay. Suggesting that the population of this area exploited what was most plentiful and nearest to their cooking sites for constructing their ovens which presumably was clay from Hunchee Creek.

Ground Penetrating Radar (GPR) Results

A 3D grid was generated in order to determine the location of buried archaeological features and also to delineate the mound's lateral and vertical extents. 3D amplitude slice maps were outputted; however they were unable to highlight either of these features. This may have been because the abundance of high amplitude responses from tree roots masked the more subtle responses from the earth oven material. The extents of the mound were not visible in the amplitude slice maps because the transition between mound and surrounding soil did not have enough of a geophysical contrast. Therefore another strategy for processing the data was devised and this was to analyse each individual GPR profile to see if the mound's lateral and vertical extents could be detected. Before data processing the earth mound appeared as a dipping layer within the GPR data. Therefore when travelling up or down a mounds surface the GPR will image the layer getting thicker or thinner respectively (Figure 57 and 59). In order to determine correct mound thickness and determine where features sat correctly in space a topographic correction was applied to each profile. After analysing eighty topographically corrected profiles from both x and y axis of the survey grid mound extents and depths were recorded in a spreadsheet (Appendix 4 and 5). This data was then used to plot the extents of the mound as defined by GPR over a combined interpretation map. To determine correct depths within the data a velocity analysis was conducted through hyperbola fitting and a relative dielectric permittivity of eight was chosen and applied to each of the 2D profiles. After all profiles were adjusted an average thickness of the deposit was calculated to be 0.3m. After all profiles were topographically corrected and analysed mound lateral extents were determined to be 13m x 15m. The mound natural clay interface was the only obvious stratigraphy that the GPR could detect. There was no stratigraphic layering within the 0.3m deposit. The 0.3m deposit was full of point source hyperbolic responses of varying amplitude which were both heating element material and tree roots.

Determining earth oven locations and depths

All GPR data contained significant tree root activity which made detecting archaeological features within the deposit difficult. Therefore Conyer's (2018) method of cross-correlation of both magnetics and GPR 2D profiles was adopted for analysing 2D dataset to deduce potential earth oven locations and their depths. 2D GPR profiles and 2D magnetics over both EM2.a and EM2.b were combined in order to determine their respective depths and positions. Care was taken to pick their exact locations due to the magnetic inclination at this point on the earth's surface. EM2.a was detected at 14.5m within profile 69 (x axis) and 6.2m within profile 10 (y axis) (Figures 62-63). The depth of the earth oven within both profiles was 0.17m deep. EM2.b was detected at 13.8m within profile 13 (y axis) but was invisible to GPR in profile 70 (x axis) however EM2.a was still visible in both magnetic and GPR profiles on this line at 5.5m (Figures 64-65. The depth of the earth oven within both profiles was 0.13m deep.

Resistivity Results

Dipole-dipole array pseudo-section results

Resistivity readings in all seven dipole-dipole array pseudo-sections from the surface to the bottom of section contained resistivity readings from 0.10 to 150 ohms. The survey identified a resistive surface layer approximately 0.3m thick; this first layer is believed to be topsoil and also the soil of the earth mound deposit. Unfortunately the responses from this layer have not successfully highlighted the extents of the mound deposit located between 15m and 27m of the pseudo-sections (Table 5). This could be because both the mound soil and the topsoil of the site are not electrically dissimilar enough to be differentiated. The top layer seen in all data sets is composed of readings from 60 to 150 Ohms which when referring to Table 7 would indicate that the most probable soil type is a topsoil (Appendix 2). The readings of the second layer are consistent with clay, most likely grey gilgai clay however this is only speculative until excavation can be conducted. High resistive readings in pseudo-sections 4, 6, and 7 at between 0m and 5m are believed to be from poor ground coupling/installation of the electrodes due to large red gums and their shallow roots on the edge of the riverbank (Appendix 2). Therefore responses from these areas have been discounted.

Wenner array pseudo-section results

Resistivity readings in all seven Wenner array pseudo-sections from the surface to the bottom of the pseudo-section contained resistivity readings from 0.10 to 150 ohms. The Wenner array survey also identified a surface layer of the same depth that the dipole-dipole did. Unfortunately the responses from this layer have not successfully highlighted the extents of the mound deposit located between 15m and 27m of the pseudo-sections (Table

6). This could be because both the mound soil and the topsoil of the site are not electrically dissimilar enough to be differentiated. The top layer seen in all data sets is composed of readings from 60 to 150 Ohms which when referring to Table 7 would indicate that the most probable soil type is a topsoil (Appendix 2). Just like the dipole-dipole array the Wenner array displayed high resistive readings in pseudo-sections 4, 6, and 7 at between 0m and 5m are believed to be from poor ground coupling/ installation of the electrodes due to large red gums roots on the edge of the riverbank (Appendix 2).

Table 7: Electrical conductivity (EC) characteristics of some major soils and clays (Katsube et al. 2003).

Material	Soils and Clays	Electrical Resistivity (Ωm)	Electrical Conductivity (mS/m)
Soil Types	Clay (general term)	1 - 100	10 - 1000
	Loam	4 - 40	25 - 250
	Top Soil	40 - 200	5 - 25
	Clay-rich Soil	100 - 400	2.5 - 10
	Sandy Soil	400 - 4000	0.25 - 2.5
	Loose Sands	1000 - 10^5	0.01 - 1
Clay Type	Kaolinite	50 - 5000	0.2 - 20
	Montmorilonite	4 - 15	67 - 250

Summary of ERT results – dipole-dipole and Wenner array results

In both datasets from both arrays, high resistivity responses were detected in the lower half of the datasets near the river. Just like the pseudo-sections these can be attributed to poor coupling due to the numerous Red Gum roots in that area that prevented the electrodes from being installed to their optimum depths resulting in highly resistive readings. The ERT slices in both arrays datasets indicated a highly resistive layer from the surface to approximately 0.3m deep. This layer is consistent with the readings from Table 7 which indicates that this layer has the electrical properties of a topsoil. Below this layer readings in accordance with table 7 indicate a clay soil, which was what was expected at this location.

The ERT datasets have not been able to highlight the lateral or vertical extents of the mound.

A more favourable result may have occurred with a more appropriate survey design. It appears that electrode spacing was not conducive to detecting and mapping resistivity changes in the top 100-300mm of topsoil. It may have been appropriate to have had electrode line spacings at 0.5m or closer resulting in more resolution and less interpolation that the software was required to do in order to fill areas in between the electrode lines thereby producing a more realistic representation of the subsurface. A closer line spacing may have remedied this but would have quadrupled the field acquisition time which was not practical on this field work. The electrode spacing of 0.5m was not the most suitable for this type of application either based on the thickness of the deposit. Closer electrode spacing such as 0.1m would have provided more shallow resolution but reduced the penetration of the signal. This would not have been a problem as the deposit extents are inferred to be within the top metre of the dataset. The resitivity technique did successfully define a surface layer which does prove it has the ability to define layer interfaces. This in itself shows it could have the ability to decifer between mound deposit and the top soil surface layer. At the Hunchee Creek site the mound and the topsoil were not electrically different enough for the resistivity technique to detect a discernable contrast. This is why only one consistent layer can be seen running throughout the whole survey in all resistivity datasets.

Despite this, some novel information can been gleaned from the data. The resistivity survey has clearly mapped what is inferred to be a surface top soil and clay layer beneath. These layers were detectable as they were both electrically different enough to produce a noticeable response. It is proposed that the earth mound deposit is within the confines of the topsoil layer and has not been dug into the clay layer. The two layers were so electrically different if the deposit had been dug into the clay layer it would have been readily detectable. Therefore this would indicate that the mound deposit cannot be any deeper than 0.3m deep and a deposit thickness can be assumed. Therefore one might assume that this site has either had a lot of erosion taken place or it was not a heavily utilised processing site based on the thickness of the deposit. Additionally ERT has been useful on this project for the delineation of subsurface stratigraphic sequences which provided an understanding of site geology and soil type.

Multi-Discipline combined interpretation

Grid seven was the site of the most intensive survey of all of the research area. Magnetics, GPR and resistivity was conducted over it and interpreted results plotted over an aerial image acquired via drone (Figure 76). The metal detector survey only detected one anomaly within the grid which was 2.5m way the from the nearest high response from the magnetics survey. Therefore no modern magnetic material was influencing the responses from the high magnetic features detected that were suspected subsurface earth ovens. The lateral extents of the earth mound as defined by GPR coincided with the extents recorded by the topographic survey. This indicates that the mound does not extend beyond its surface distribution. The resistivity did detect a zone which could be thought to be mound but its extents did not correlate with any other of the data collected. Subsurface magnetic material was detected within the mound extents over a substantial portion of the mound. This would indicate that this mound has been used multiple times for cooking. Six of eight artefacts were topographically surveyed on the mound. This is the only mound they were detected on. Three artefacts were found on the mounds south-east edges the other three were found very close to the responses from the suspected earth ovens. These two features so close to one another indicates a high probability of the most of recent cultural cooking activity on the site.

Synthesis

Assessing the effectiveness of multiple techniques

This research has confirmed that magnetics is the most effective technique for initially identifying earth mounds and earth oven features during non-invasive investigations. GPR is most useful for delineating mound lateral and vertical extents and when used in conjunction with magnetics is able to provide depth information to 2D magnetics targets. This is achieved through cross correlation of both techniques' 2D profiles at the post processing phase. Resistivity was the slowest of the techniques to deploy and given the site conditions at Hunchee Creek was the least effective. This may have been due to a faulty survey design. Only the vertical extents of the topsoil could be delineated at this site but the lateral and vertical extents of the mound could not be confidently detected.

Identifying discrete earth ovens

This research demonstrates that magnetics can quickly and definitively differentiate between earth mounds containing intact earth ovens and those that do not. This was evident by the lower magnetic responses from the surface scatters of heating element material on the mound surface compared with the high responses from material that were buried and inferred to be in-situ earth ovens. The shape and magnitude of the responses from highly magnetic buried anomalies from all mounds surveyed matched an exposed earth oven containing in-situ clay heating elements from the sand dune survey. It is now quite probable that the buried magnetic features of similar readings are earth ovens containing similar sized clay balls as their heating elements. These geophysical responses support other research projects conducted by Flinders in the same area that show clay as the only heating element of earth ovens surveyed in this region. Presumably this is because rocks were not as readily available (Jones 2016; Threadgold 2017).

Distinguishing natural and cultural mounds

This study shows that geophysics can differentiate between natural and culturally manufactured mounds even when they have poor topographic expression. This can be achieved through the detection of magnetic responses which at this research site indicated the presence of earth ovens and heating element material which had been created as a result of human occupation.

Choice

The topographic survey indicating the position of the mound and the magnetics indicating the position of buried earth ovens within the mounds show that these archaeological features are located in close proximity to Hunchee Creek. This would simply indicate that the past population of this area chose to cook close to the water course. The artefact survey conducted by other Flinders students for their respective research indicated that very few artefacts were detected on the mounds surfaces (Jones 2016; Threadgold 2017). This would indicate past Aboriginal people in this area chose not to camp on these features but rather constructed them and left them to go to camp. There were no responses detected consistent with compacted living surfaces within the GPR or resistivity data therefore the geophysical data supports the archaeological data in this respect. These findings are also in agreement with Westell and Woods (2014:31) research which found mounds in this region were used as processing sites rather than formal occupation areas.

Frequency

GPR was able to define lateral and vertical extents of earth mound two (EM2); GPR defined the lateral extents as 13m x 15m. Based on a dielectric of eight determined an average deposit thickness of 0.3m. The ability of GPR to differentiate between stratigraphic sequences meant that deposit thickness could be determined and inferences could be made as to site use frequency. The thickness and a lack of stratigraphic boundaries within the deposit would indicate a site not heavily utilised and very unlikely used by a large group of people. This in comparison to some of the mounds Martin (2006:113) investigated on the Hay Plain which were over 1m thick which based on thickness presumably would have accommodated more people or were used on many more occasions by a similar amount of people. The magnetics shows that the site was used on multiple occasions. The magnetics detected only one suspected subsurface oven at EM3, two suspected ovens detected within EM2 and none within EM1. The magnetics did detect fire altered material over or within all of the mounds surveyed. This would indicate multiple site uses as the surface and subsurface scatters of heating elements as detected by the magnetics are the result of accumulated past earth oven rake outs. However this combination of raked out material and buried earth ovens is in line with what Martin (2006) found when excavating mounds. This indicated two different types of oven use, one where heating elements were raked from the pit ready for re-use and heating elements that were abandoned and left in-situ (Martin 2006:151).

Re-use

EM3 with surface scatters of heating elements above a suspected intact oven indicate past site reuse. Heating element material or intact earth ovens deeper in the deposit are older than the material above in most cases. Therefore anything on the surface is younger than what is buried. The magnetic responses covering most of the surface deposit indicates that these sites were re-use sites. The fact that intact earth ovens are buried and heating element material is deflating from the ground suggests that these sites were used over separate occasions. This was also demonstrated by Martins (2006) research on mounds however excavation was used to determine this rather than geophysics.

Choice of cooking sites/earth oven sites

The distribution and morphology of earth mounds and associated earth oven features as revealed via the geophysical techniques utilised have revealed that the past Aboriginal societies choice of cooking sites tended to be located in clusters along the edges of Hunchee Creek in this region. This is agreement with Williams (1988:128) research which found that mounds in the MDB tend to be isolated landforms or clusters. . This is supported also by two other archaeological surveys conducted within the Hunchee Creek precinct over a larger range than this research (Jones 2006; Threadgold 2017). The locations of mounds in this project show that being close to the water course was a preferred location for the construction of these features as opposed to the adjacent floodplain which is devoid of them. This is likely so as to be close to easy to gather wet clay from the creek for moulding into heating elements for the constructing of earth ovens. Also to be in close proximity to carbohydrate rich wetland plants and animals which archaeologists speculate may have been cooked with this form of technology (Martin 2006:162).

Chapter 8: Conclusion

This chapter summarises the thesis and the key results of this research. It considers limitations encountered and directions for further research in the future.

Geophysical investigations of earth mounds

This research demonstrates the value of geophysics for non-invasively investigating the internal stratigraphy of earth mounds, illustrating their lateral and vertical distribution extents, presence of earth oven material and intact earth oven features. Non-invasive methods are of extreme importance especially when earth mounds are a continual diminishing resource of both cultural and archaeological importance (Fanning et. al 2005: 21). However if geophysics is used effectively and sought after targets can be readily mapped, targeted excavation can occur. This is demonstrated by the results from EM2 where the mound itself had very little surface expression and no clay heating element material on the surface. Therefore how could one decipher whether it was a naturally formed or formed by human occupation? The magnetics answered this very quickly with such strong readings of magnetically susceptible material below the ground surface, presumably magnetised heating element material. This project has emphasized that geophysics for earth mound survey is more culturally appropriate, this is because archaeological excavation only provides a small window of information rather than an idea of subsurface distribution which all of the combined geophysical methods utilised on this project can provide. Resistivity and GPR have the ability to map lateral, vertical and stratigraphic distribution and layers throughout a deposit. Traditional excavation methods cannot achieve this without completely unearthing and destroying the entire deposit. The earth mounds of Hunchee Creek are mounds which have very poor topographic expression and many are difficult to identify and may be missed with the ‘untrained eye’. From a management point of view geophysics is extremely important in identifying and classifying these features as cultural or natural features. There is no other way archaeologists could non-invasively and non-destructively work out subsurface distribution of confirmed earth mounds with conventional archaeological methods alone.

It is hoped that the geophysics will assist and potentially alleviate the pitfalls in the characterization of these sites chosen for this research project. Due to some of the destructive processes mentioned above hearths and earth ovens and associated features are a diminishing resource and research done by Fanning et al. (2005:21) suggests that we have a limited time to study them before they disappear.

This research has shown the magnetic method to be the most effective for the initial detection of earth mounds and determining whether they are cultural features or natural landforms. GPR and the resistivity technique are effective for determining mound depth and lateral extents. The geophysics has shown that these mounds were utilised multiple times and the preferable location for their construction has been along the edges of the water course as opposed to the adjacent floodplain. Geophysical data sets devoid of responses that would indicate living surfaces and archaeological surveys with low numbers of artefacts have shown that these mound sites were not camped on. This research has proven that geophysics can provide information about the location, extent and stratigraphy of earth mounds and so assist in the answering of archaeological questions about their development and use.

Limitations

The opportunity to ground truth was not possible on this site to confirm that the anomalies being detected were mound structures, earth ovens or heating elements. Therefore inferences have been made as to the origins of geophysical responses recorded.

Only one 3D grid was collected on the research site due to time constraints, collecting data in a 3D configuration to generate amplitude slice maps and relate 2D profiles to them is the most thorough way to investigate the subsurface of a site. 3D GPR grids collected over every magnetics grid would have provided a greater level of detail of the subsurface. Being able to overlay each geophysical methods dataset as was done for grid seven would have provided a better understanding of where archaeological features were distributed onsite resulting in the research question and aims being addressed with a higher proportion of evidence.

A limitation with the resistivity survey was the electrode line spacing, 2m was too large a distance to correlate resistive responses from adjacent lines. As this distance was so large the software needed to interpolate data between these lines in order to build the 3D ERT slices. This could have resulted in features being incorrectly displayed; line spacing of 0.5m or less would have been more appropriate and would have provided a more accurate representation of the subsurface. However more than double the time allocated on this project would have been required to conduct such a survey. The spacing between electrodes is also something that would need to be reviewed. Electrode spacings of 0.5m did not provide enough detail of the first 100-300mm of the topsoil where it was suspected most of the cultural deposit would be at. An electrode spacing of less than 300mm would have been more appropriate. Due to time constraints only seven resistivity lines were collected which did not cover the entire mound and surrounding areas. More lines of data over and off the mounds surface would have provided clearer results.

Future directions/recommendations

Both the resistivity and GPR surveys have successfully been able to determine the depth of the deposit. The average depth of the deposit is 0.3 m deep which poses the question do these mounds with such poor topographic expression and being so shallow qualify as earth mounds at all? This compared to other sites around Australia mentioned in the literature review with mounds much larger. Pardoe (2003:44) proposes a different site type called ashy grey deposits, measuring 10-40cm, having a different colour to the surrounding sediments, and containing varying amounts of heat element material. GPR having determined the depth of the deposit the question is now able to be posed do these earth mounds of Hunchee Creek qualify as mounds? Or do they qualify as ashy deposits or are they something in between? More accurately categorising mound types in the future in my opinion should be something to be pursued.

In summary this research has demonstrated that the use of geophysics in archaeology is the only way to non-invasively investigate the inner construction of earth mounds. There is no other way but geophysics to determine the lateral and vertical distribution of earth mounds without invasive excavation. Non-invasive methods are of extreme importance especially when earth mounds are a continual diminishing resource of both cultural and archaeological importance (Fanning et. al 2005:21). Should excavation need to occur using primarily traditional excavation methods geophysics should be deployed 'first hand' in order to 'strategically' target sought after features to be uncovered by the excavation. This is not to say that traditional archaeological excavation methods now become defunct, but quite the opposite. They are to be used in conjunction with geophysics to minimise risk of degradation to the deposit.

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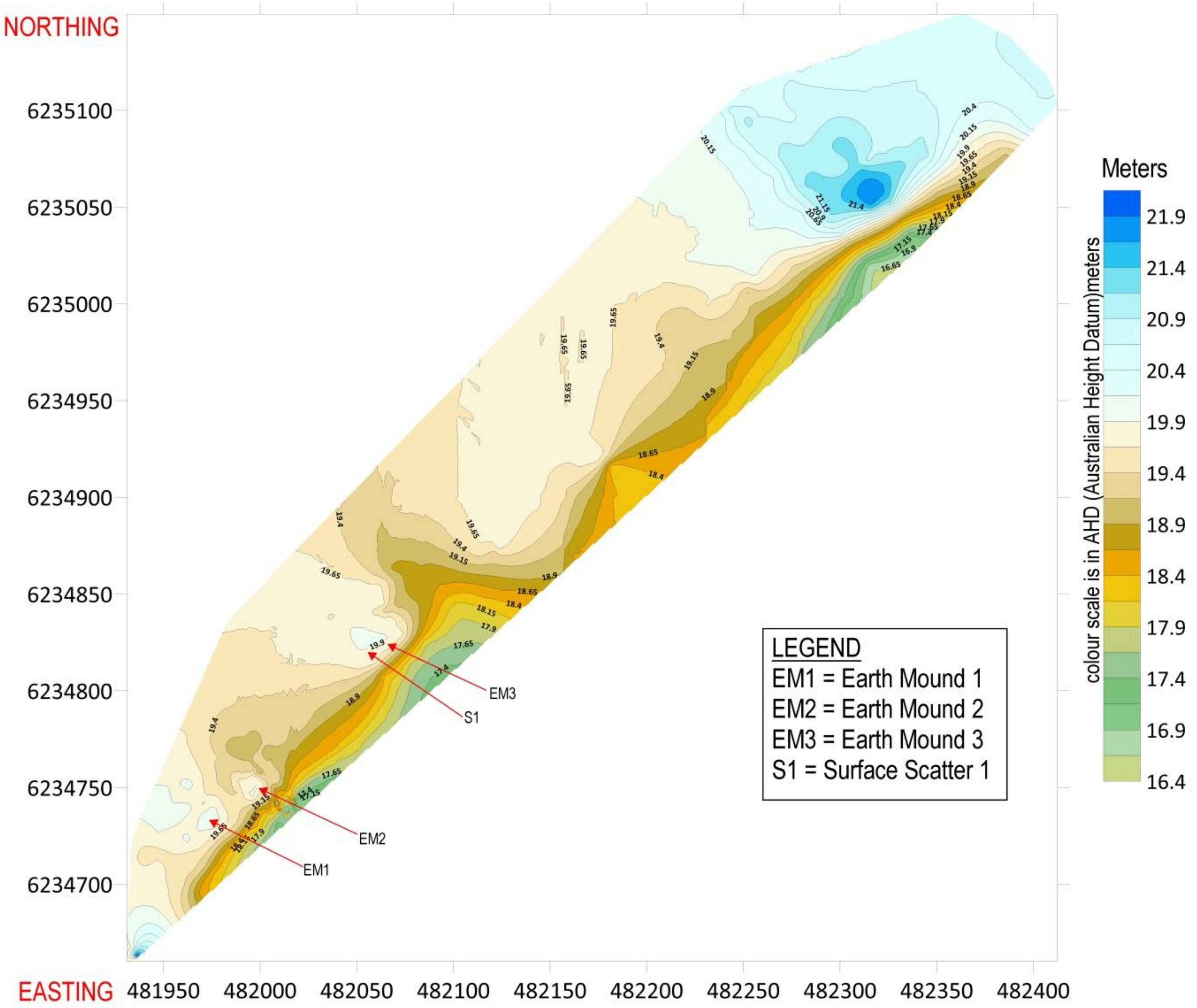
Appendices

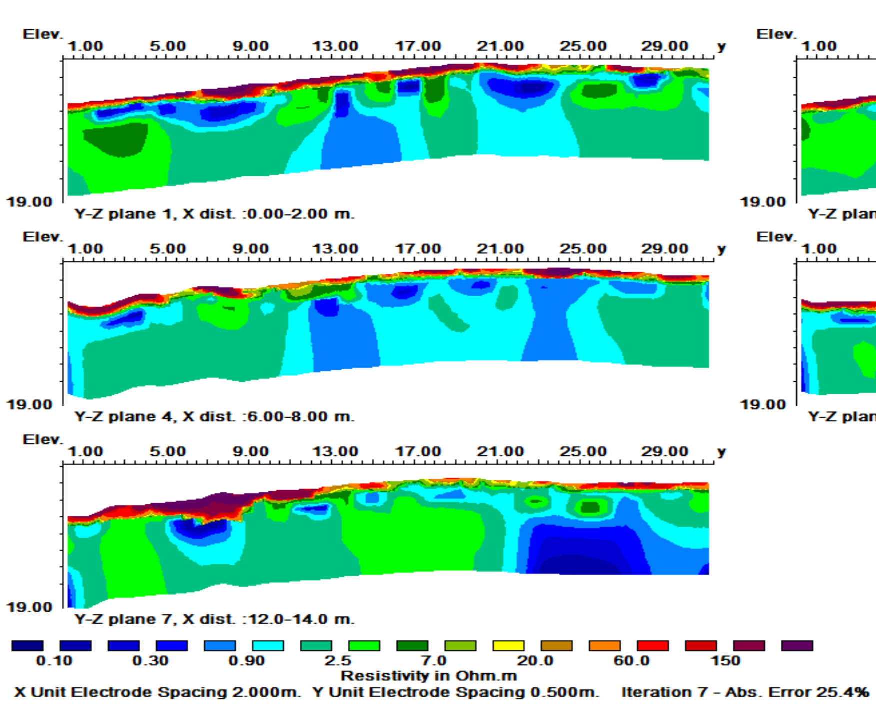
Appendix 1: Survey Data

Digital Terrain Model of a section of Hunchee Creek

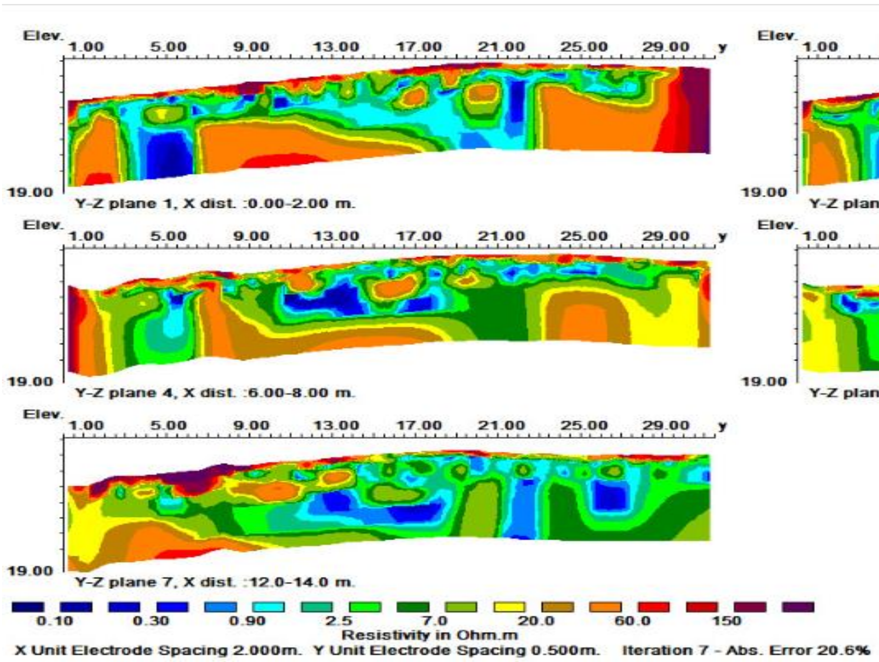


Appendix 2: Resistivity Data – Pseudo-sections

Complete resistivity datasets from grid seven



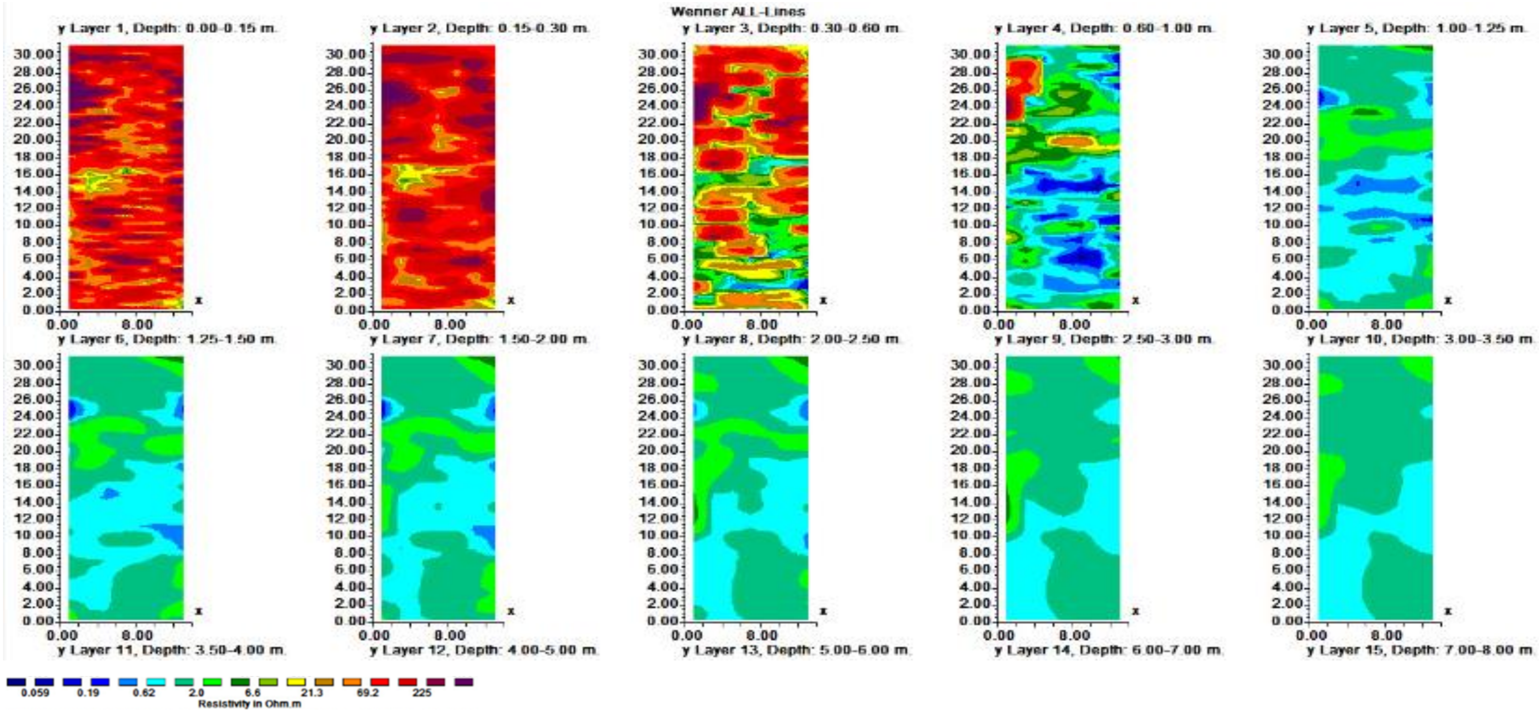
Above: Wenner Array Survey over grid 7 – topographically corrected



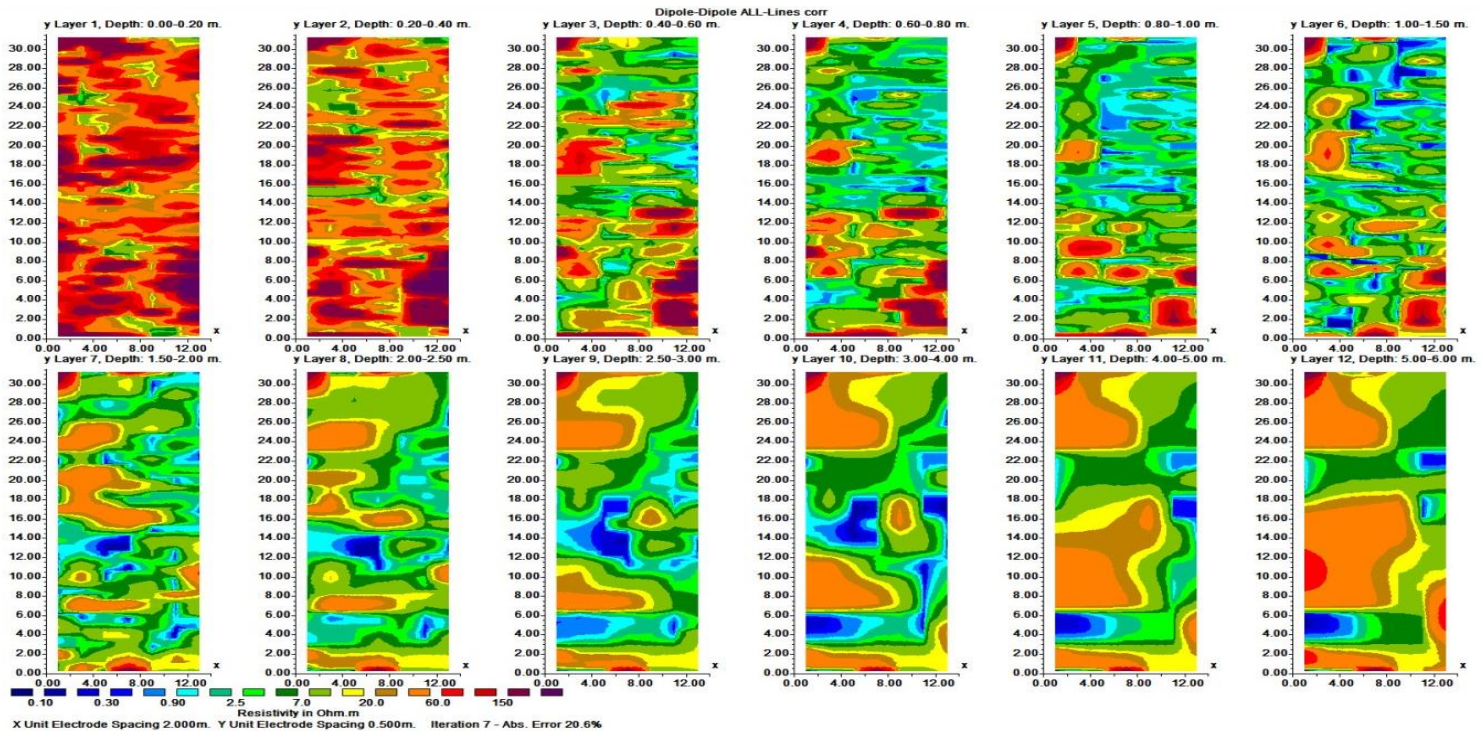
Above: Dipole Dipole Array Survey over grid 7 – topographically corrected

Appendix 3: Resistivity Data – ERT Slices

Complete resistivity datasets from grid seven



Above: ERT (Electrical Resistivity Tomography) Wenner Array formulated from lines 1-7



Above: ERT (Electrical Resistivity Tomography) Dipole-dipole Array formulated from lines 1-7

Appendix 4 - GPR Mound Extents – Table

Table: Formulated to determine earth mound extents from 80 GPR 2D profiles collected over grid seven, data collected in zig-zag formation

Mound Extents and Mean Depth					
Profile	**Start deposit**	**End deposit**	**Axis**	**Traverse**	**Depth (deepest part of deposit**
1	not detectable due to roots	not detectable due to roots	Y	N	not detectable due to roots
2	not detectable due to roots	not detectable due to roots	Y	S	not detectable due to roots
3	10.7	n/a	Y	N	0.4
4	10.79	n/a	Y	S	0.36
5	11	n/a	Y	N	0.38
6	10.7	n/a	Y	S	0.36
7	10.9	n/a	Y	N	0.45
8	10.75	n/a	Y	S	0.34
9	10.27	n/a	Y	N	0.35
10	10.15	n/a	Y	S	0.38
11	10.13	n/a	Y	N	0.4
12	10.13	n/a	Y	S	0.38
13	10.29	n/a	Y	N	0.31
14	10.29		Y	S	0.33
15	10		Y	N	0.34
16	10.3		Y	S	0.3
17	11.12		Y	N	0.31
18	10.06		Y	S	0.34
19	5.37		Y	N	0.24
20	12.27		Y	S	0.38
21	10.2		Y	N	0.35
22	10.2		Y	S	0.4
23	no deposit detected		Y	N	no deposit detected
24	no deposit detected		Y	S	no deposit detected
25	no deposit detected		Y	N	no deposit detected
26	no deposit detected		Y	S	no deposit detected
27	no deposit detected		Y	N	no deposit detected
28	no deposit detected		Y	S	no deposit detected
29	no deposit detected		Y	N	no deposit detected
30	no deposit detected		Y	S	no deposit detected
31	no deposit detected		Y	N	no deposit detected
32	no deposit detected		Y	S	no deposit detected
33	no deposit detected		Y	N	no deposit detected
34	no deposit detected		Y	S	no deposit detected
35	no deposit detected		Y	N	no deposit detected
36	no deposit detected		Y	S	no deposit detected
37	no deposit detected		Y	N	no deposit detected
38	no deposit detected		Y	S	no deposit detected
39	no deposit detected		Y	N	no deposit detected
40	no deposit detected		Y	S	no deposit detected
					0.355
					average depth

Appendix 5 - GPR Mound Extents – Table

Table: Formulated to determine earth mound extents from 80 GPR 2D profiles collected over grid seven, data collected in zig-zag formation

Mound Extents and Mean Depth					
Profile	Start deposit	End deposit	Axis	Traverse D	Depth (deepest part of deposit)
41	no deposit detected		X	E	no deposit detected
42	no deposit detected		X	W	no deposit detected
43	no deposit detected		X	E	no deposit detected
44	no deposit detected		X	W	no deposit detected
45	no deposit detected		X	E	no deposit detected
46	no deposit detected		X	W	no deposit detected
47	no deposit detected		X	E	no deposit detected
48	no deposit detected		X	W	no deposit detected
49	no deposit detected		X	E	no deposit detected
50	CORRUPT FILE	CORRUPT	FILE	CORRUPT	FILE
51	no deposit detected		X	W	no deposit detected
52	no deposit detected		X	E	no deposit detected
53	no deposit detected		X	W	no deposit detected
54	no deposit detected		X	E	no deposit detected
55	no deposit detected		X	W	no deposit detected
56	no deposit detected		X	E	no deposit detected
57	6.74		X	W	0.2
58	7.43		X	E	0.2
59	8.81		X	W	0.2
60	7.93		X	E	0.2
61	7.57		X	W	0.26
62	10.22		X	E	0.3
63	9.17		X	W	0.26
64	9.68		X	E	0.32
65	9.33		X	W	0.31
66	10.3		X	E	0.31
67	8.9		X	W	0.32
68	9.96		X	E	0.35
69	11.27		X	W	0.32
70	9.46		X	E	0.38
71	n/a		X	W	n/a
72	9.6		X	E	0.39
73	9.58		X	W	0.35
74	n/a		X	E	n/a
75	10.07		X	W	n/a
76	9.81		X	E	0.35
77	9.13		X	W	0.39
78	no deposit detected		X	E	no deposit detected
79	10.33		X	W	0.26
80	no deposit detected		X	E	no deposit detected
					0.298421
					average depth

Appendix 6 – Permission for resistivity survey

From: "Thomas, Roger (DSD-AAR)" <Roger.Thomas@sa.gov.au> **Date:** Thursday, 1 December 2016 at 5:08 PM **To:** Amy Roberts <amy.roberts@flinders.edu.au> **Cc:** "Van Wessem, Alexander (DSD-AAR)" <Alexander.VanWessem@sa.gov.au> **Subject:** Earth Mound Testing - RMMAC

Dear Amy,

I write in relation to your proposal to conduct resistivity testing, in collaboration with the River Murray and Mallee Aboriginal Corporation (RMMAC), on a number of earth mounds located at Calperum Station. Through recent correspondence with Alex van Wessem, Acting Principal Heritage Officer, you have furnished DSD-AAR with an overview of the nature of the proposed testing and outlined the extent to which RMMAC will be involved.

I refer to the attached letter from Sheryl Giles, RMMAC Chairperson, which you sent to DSD-AAR on 11 November 2016, in which permission is provided for yourself and your research team to conduct the proposed resistivity testing on earth mounds at Calperum Station. I note that the testing will be undertaken at the direction of RMMAC representatives (or a representative) who will be in attendance on the day.

In light of the attached letter, I acknowledge that the Traditional Owners for the Calperum Station area, as represented by RMMAC, are proposing to assist you in your research pursuant to Section 37 of the *Aboriginal Heritage Act 1988* (SA) which states that:

"[n]othing in this Act prevents Aboriginal people from doing anything in relation to Aboriginal sites, objects or remains in accordance with Aboriginal tradition"

Please ensure that the resistivity testing is undertaken in a manner which reduces the risk of damage to, disturbance of or interference with Aboriginal sites, objects or remains.

If you require any clarification on the content of this email, please do not hesitate to contact Alex van Wessem, Acting Principal Heritage Officer, on (08) 8226 7037 or by email at alex.vanwessem@sa.gov.au.

Kind Regards,

Roger Thomas

Manager

Aboriginal Heritage Team

Aboriginal Affairs and Reconciliation

Department of State Development

Phone: 08 8226 8902

Fax: 08 8226 8930

Email: roger.thomas@sa.gov.au