The archaeological signature of ‘ant bed’ mound floors in the northern tropics of Australia: Case study on the Lower Laura (Boralga) Native Mounted Police Camp, Cape York Peninsula

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A B S T R A C T

Ant bed (also known as termite mound) floors were a common feature of historical buildings in colonial Australia, yet they are rarely identified in archaeological contexts. In this paper we present a case study of these features in buildings associated with a late nineteenth century Native Mounted Police camp in Cape York Peninsula, Queensland. Aboriginal colleagues reported the former existence of these floors in buildings at the site, though none could be seen at the contemporary ground surface. The question thus existed as to whether they were extant in subsurface contexts. Ground-penetrating radar revealed rectangular, high amplitude reflections in many parts of the site. Excavation demonstrated these features comprised stratigraphically discrete units that were highly compact, often with a substantial gravel component. Sediment analysis of the coarse-grained component has distinguished these floors from surrounding off-site samples. The level of compaction seen in the floors has significant implications for the retrieval of artefacts in such contexts since it prevents any objects from being integrated into the deposit. While the distribution of the practice of using ant beds for floors is unknown, it appears their use was common throughout Australia in the late 18th through the 19th and 20th centuries. Examination of the physical elements that make up these floors has provided a clearer idea of each floor's recorded history and use. We have also identified a methodology for examining ant bed floors in Australia and elsewhere that can be used anywhere that ant mounds occur and may have been a source of flooring material.

1. Introduction

In Australia there has been considerable historical research on the Native Mounted Police (NMP) (e.g. Bottoms, 2013; Richards, 2008), yet very few studies have examined the associated material culture of NMP camps or their organisation, layout and construction. Such camps were an integral part of Queensland’s frontier conflict during the 19th century, a time when a military style police force was used to eliminate Aboriginal resistance to white incursions. Despite some systematic steps towards understanding frontier conflict through archaeology (e.g. Barker, 2007; Cole, 2004; Litster and Wallis, 2011), little is understood about the built environment associated with police camps. Many such camps were short-lived and therefore quite temporary, meaning that construction was basic and could consist of as little as canvas tents or open-sided bough shelters. Even longer-term camps (the longest lasting 25–30 years) typically consisted only of simple timber and iron structures, often roofed and walled with bark or grass (and sometimes iron sheeting) that could be easily dismantled, sold and/or re-constructed elsewhere for both expedience and frugality. Given that more permanent structures were uncommon at NMP camps, it is hypothesised that many of their living surfaces were probably earthen floors.
explore some of the archaeological consequences of their use, including their geophysical and archaeological correlates.

The Boralga NMP camp, established by 1876, was one of the longest operating NMP camps. While no excavations had been carried out at the site before our work in 2016, two previous reports which noted the existence of ant bed floors at Boralga were informed by highly skilled Aboriginal trackers: Jerry Musgrave and George Musgrave, both Kuku Thaypan speakers and Traditional Owners of the area now known as Rinyirru National Park. They also had connections to the site itself through their employment in the Queensland Police Force and the cattle industry (Cole et al., 2002). In 1972, Jerry Musgrave, then the police tracker at Laura, guided Ernie Stephens of the Cairns Historical Society to Boralga (Stephens, 1972). Here they found ‘old yard posts to take rails. Beyond were the old posts and ant bed floors’ (Stephens, 1972:1). In a subsequent community archaeology project (1999–2000), Dr. George Musgrave (1920–2006), who succeeded his elder brother Jerry as the police tracker at Laura and was a master tracker known for his remarkable ability to read the ground, identified a raised flat area near the eroded southern approach to Boralga lagoon as the remains of an ant bed floor likely to mark the location of the trackers’ (troopers’) huts (Cole et al., 2002:142, Fig. 3F). The initial Boralga fieldwork was preceded by a controlled burn conducted by Dr. Musgrave and the Ang-Gnarra Rangers, and ground visibility was relatively high. Burning was not conducted prior to our 2016 survey, which failed to identify ant bed floors at the ground surface: thus geophysics seemed the most appropriate method for identifying and mapping these features.

Earthen floors are made from various admixtures and are consolidated to form a hard surface. In Australia, earthen floors were being used as early as 1797 and were described as being composed of “trampled earth or packed clay” (Freeland, 1968:13). Many of these floors contained clay as a primary constituent and were watered regularly to keep them hard and reduce the dust associated with them (Edey, 1981; Lewis, 2014; Sorensen, 1911). According to Chauncy (1855:23), “the floor may be raised a little about the level of the ground outside, and a strip of broad paling placed all around to keep it in. It may then be covered with a coating of small broken stone, earth and wood ashes, which if occasionally sprinkled with water, becomes, in the course of a short time, almost as hard and complete as stone”.

The best earthen floor was constructed from crushed ant or termite mounds,1 either trampled or puddled (i.e. crushed to a fine consistency, watered, and then beaten). Lewis (nd 3.06.04) noted what is possibly the earliest use of puddled ‘ant bed’ for flooring in Queensland in the 1850s. By the 1880s the use of this technique in building construction was well known in northern Australia (Lewis nd 3.06.03–3.06.04). In many ways, ant bed is a perfect flooring material, since the sediment is already very finely sorted and the insects produce excreta and saliva to bind the particles together. Historically, its durability and resilience made it particularly well suited to flooring kitchens, tennis courts, cricket pitches, dairies and smithies (“Eureka” 1935:10).

Ant and termite mounds are found throughout Australia. Termites initially form the mounds, but once they are abandoned they can be re-colonised by other ants, which means that mounds can be shared by different species. Unlike other species’ nests, termite mounds may be occupied for long periods, with their size increasing over time (Dostál et al., 2005). Termite mounds in far northern Australia are deemed ‘magnetic’ (Amietermes laurenensis) since they are very large (> 1.5 m) and aligned north to south to minimise exposure to the sun and keep the interior relatively cool (Grigg, 1973). They continue to be enlarged by the addition of thin layers of galleries on the surface. Texturally, these mounds are composed of a range of soil types, often having a different texture and structure to the surrounding sediment (Eldridge and Pickard, 1994). It has also been shown that ants can introduce foreign material, such as quartz grains, sandstone fragments, charcoal and twigs, to the mounds (Cowen et al., 1985).

While historical documentation on the construction of buildings at NMP camps is rare, ant bed may have been utilised on occasion. This material was certainly in use by the NMP at the Oak Park camp in 1880, near Gilberton (about 380 km south of Boralga), (Oak Park Daily Journal, 25 and 27 May 1880) and at the Musgrave camp in 1891 (about 130 km north of Boralga) (Musgrave Native Police Camp, part 1 1891). At the nearby historic Old Laura homestead complex (c1892), located 6 km north of Boralga, it was also documented that termite mounds were used and mixed with ox blood to make the floors; ‘the kitchen also had a dirt floor made from compacted termite mounds’ (NPSR, 2017). The Boralga site provided an excellent opportunity for assessing the value of geophysical survey for identifying ant bed floors, especially given the observations of Jerry Musgrave and George Musgrave at the site. A combination of ground-penetrating radar (GPR) and magnetic gradiometry was employed, followed by excavation of target areas, and subsequent geoarchaeological, magnetic susceptibility and soil chemistry analyses on sediment samples. Geoarchaeological studies have provided invaluable information on how natural resources may have influenced the construction of settlements and offer a way to connect the invisible to the visible (Rapp Jr. and Hill, 1998; Sampietro and Vattuone, 2005). Our study not only offered a way to understand part of Boralga’s built environment but also allowed the chance to evaluate other geophysical signatures created by the NMP at the site, which in turn provided insights into their past activities.

2. Boralga NMP camp

The Boralga NMP camp is located on the floodplain of the Laura River, at the southern extremity of Rinyirru National Park about 18 km downstream from the town of Laura on Cape York Peninsula, Australia (Fig. 1). It is situated within the Laura Basin, which contains dissected sandstone hillslopes and plateaux in the uplands, and residual alluvial sands derived from the sandstones in the lowlands (Biggs and Philip, 1995; Morgan et al., 1995). This is part of the Eastern Uplands Physiographic Region and includes uplands and coastal areas of the western part of the Cape York Peninsula, including the Great Escarpment. The uppermost part of this area is the Battle Camp Formation, which is characterised by a conglomerate of shaly sandstone and leached shale of the Lower Cretaceous age (Lucas and de Keyser, 1965). The Laura River Basin is a major feature in the peninsula’s hydrology and extends from the edge of the continental shelf into Princess Charlotte Bay to the east (Smart and Rasidi, 1979).

Soils on the Boralga site are primarily alluvial sands that tend to have a high clay content and are typically classified as hydrosols. The most common local soil type are Anbed Soils, these being deep redox hydrosols that are sourced from a mixture of metamorphic rocks and arkosic, rocks rich in quartz and feldspar, sediments (Biggs and Philip, 1995:42, 108). These soils occur on the alluvial plain — an area dotted with termite mounds today. The upper horizons are dark grey (10YR4/1) loamy fine sand with some organic matter, overlying a mottled greyish brown (10YR5/2) occasionally bleached loamy fine sand horizon. A mottled yellow-brown (10YR5/3) sandy clay loam underlies this, becoming more alkaline with depth, with soil pH ranging from 5.5–6.5. When the sediment is dry, it becomes very firm, and during the dry season, it is difficult to excavate the soil below 30 cm.

The Boralga NMP camp was established by 1876 close to the Laura Telegraph Station, the Laura River crossing and the Palmerville Track to the Palmer Goldfields. The camp operated until 1894, when it was closed and the buildings dismantled and their materials transported elsewhere for reuse (Cole, 2004; Cole et al., 2002). The only known historical plan of the site is Stanhope O’Connor’s 1877 ‘Plan of Police Reserve on the Laura River’, which shows an area of 238.5 acres, including a complex of six buildings, a ‘swamp’ and the Laura River. The

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1 Many species of both ants and termites construct mounds across Australia and it appears that any of them could be used for flooring, depending on local availability (see later in this paper for further explanation).
‘swamp’ is a permanent waterhole (lagoon) located directly north of where the buildings were situated, and is still present today.

According to a report by the Travelling Inspector (1894) to the Commissioner of Police, there were seven buildings on site when Boralga was closed: 1) the officer's quarters (consisting of six rooms and a kitchen); 2) the constable's quarters (two rooms and kitchen); 3) an office (with two spare rooms); 4) a store; 5) a saddle and forage room; 6) a shed used as a forge and for cart storage; and 7) ‘trackers quarters’. Both the 1877 plan and the 1894 report indicate seven buildings, or complexes of buildings, on site, although the archaeology revealed eight and those not in any arrangement that resembled the 1877 plan (Fig. 2). O'Connor's plan reflects a fairly standard layout for an NMP camp, since they contained replicable, essential elements: they were often arranged in a square or U-shape with the officer's quarters at the apex and an open space used as a parade ground in the centre. From the few plans that are labelled, the officer (Lieutenant or Sub-Inspector) was typically located closest to the road or entrance point, with the constable's (or sergeant's) quarters close by and the troopers' huts...
furthest away. This placed the white officers at the opposite end of the camp to the troopers, with the buildings around the edges of the parade ground between them serving mixed utilitarian (saddlery, forge, tool and cart storage) and domestic functions (ration, fowl house, meat house). Essential buildings were the various quarters, a store, saddlery and armoury. The square formation, hierarchical separation and organisation around a central parade ground are also fairly standard features of military layouts (for example in 19th century forts in the American mid-west [Miller, 2012]). NMP camps that are known from documentary sources to have conformed to such a plan include Musgrave, Diamantina, Cooper’s Plains, Carl Creek, Corella Creek, Barcoo, Glenroy and Waterview.

Why the physical buildings at Boralga do not conform to O’Connor’s plan is currently uncertain, although the 1877 plan is inaccurate in almost every respect (including scale, orientation and topographic features) and so cannot be relied upon as a faithful representation. It is also evident that the camp evolved throughout its 18 year history, and may have been used as a stock camp after it ceased to be an NMP camp. As such, there may well have been different iterations of architecture and layout over the life of the camp, and it is likely that buildings, equipment and materials changed according to resources, available staffing and seasons. For example, in 1881 Joseph Judge erected his own accommodation (Laura Police Station File, 2 May 1881), which is presumably the Constable’s cottage referred to in 1894. Of the seven buildings on site in 1894 an unspecified number (‘some’) were described as ‘new’ when the station closed, implying that more than one had been built relatively recently (Laura Police Station File, 23 June, 1894). Until the artefact analyses are complete, however, we are unable to speculate on the ages of specific buildings or how they might relate to different phases of use.

We have taken these changes into account in adapting the 1894 site plan to reflect the contemporary physical remains at the site (see Fig. 2). During a site visit in 1972 several old posts and bed floors were observed at the site (Stephens, 1973). Many posts from the various buildings were still present in 2002 when the site was revisited, and at least five main clusters of structural remains were identified, as well as two refuse areas (Cole et al., 2002: Fig. 3a). In 2016, when we visited the site for the currently reported study, eight separate structures were identified through a combination of archaeological and geophysical techniques.

3. Method: Geophysical survey

For the 2016 geophysical surveys at Boralga, both GPR and magnetic gradiometry were used to identify and map subsurface features and to help target areas for archaeological excavation. Magnetic gradiometry was chosen because it can cover large open areas rapidly and it was anticipated that iron-rich material, such as burnt features, metal or iron-rich soil, or refuse areas, would be present at the site. GPR was chosen because it provides spatial information both horizontally and vertically to produce a three-dimensional image of the subsurface. It was anticipated that GPR would be able to potentially identify buried stone foundations, floors, pathways, refuse areas and walls.

Four areas (GSA) where surface vegetation was minimal and/or where wooden posts were present (GSA 01–GSA 04) were geophysically surveyed (Fig. 3). While wooden posts were not present in GSA 04, a large amount of surface material indicated the potential for subsurface material to be present. Owing to heavy surface vegetation, four additional areas were surveyed using only gradiometer (GSA 05–GSA 08); only two of these areas (those containing wooden posts, GSA 07 and GSA 08) are discussed here. Survey grids ranged in size from $20 \times 20$ m, to $40 \times 80$ m. The total area surveyed was 1.08 ha.

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**Fig. 2.** Site map of the Boralga NMP camp superimposed with O’Connor’s 1877 ‘Plan of Police Reserve on the Laura River,’ which shows six large buildings (QSA A/44857) and Cole et al.’s (2002) site plan with five clusters of structural remains: E – constable’s quarters; F-G – troopers’ huts; H – shed, possibly a blacksmith’s forge; J – saddle shed; and S – officer’s quarters.
Magnetic gradiometer data were collected with a Bartington Instruments Grad601-2. The instrument was set up to record data eight times per meter with 0.5 m spaced survey transects (16 samples/m²). Data were downloaded and processed using TerraSurveyor version 3.0.33.6. Processing was limited to destriping to remove abnormal high/low readings and interpolation to equalise pixel size to 0.125 by 0.125 m. This was important due to the high presence of metal on the site. The processed data were exported and imported into ESRI ArcGIS 10.5.1 for cartography.

A Geophysical Survey Systems, Inc. (GSSI) SIR-3000, 400 MHz antenna and a model 620 survey wheel was used to collect the GPR data. Sixteen-bit data were collected with a 40 nS time window, 512 samples/scan and with 25 scans/m. Transects were spaced every 0.5 m. Using GPR-SLICE v7.0, data were processed (background removal, bandpass filter and regain) and converted into amplitude slice-maps. The hyperbola fitting function to estimate the velocity of the electromagnetic signal in a given volume of the medium was employed. This velocity was used to calculate the two-way travel time to get a depth estimate (following Goodman and Piro, 2013; Jacob and Urban, 2015). The excavations were then used to verify the depth estimates generated in the software.

**4. Geophysical results**

The processed GPR data reveals rectangular-shaped, high amplitude reflections in GSA 01–GSA 04. Their size, rectangular shape, intensity and location (i.e. directly adjacent to the wooden posts) indicated that these reflections reveal at least six compacted earth floors. Fig. 4a shows the processed data and amplitude slice-maps (from 5 to 30 cm) for Floors 1, 2, 3, 4, 6 and 8, and the interpretations before excavation (Fig. 4b). These buildings were defined by Cole et al. (2002) as the officer’s quarters (GSA 01, Floor 1), a troopers’ huts (GSA 02, Floors 2 and 3) and a shed, possibly a blacksmith’s forge (GSA 03, Floor 4) (see Fig. 2). At least two unidentified floors (GSA 04, Floor 6 and GSA 03, Floor 8) were also found, though the saddle shed (GSA 07, Floor 7) and constable’s quarters (GSA08, Floor 5) were not imaged by the GPR. The floors are visible as reflective planar surfaces in the reflection profiles and are similar in appearance to other historical earth floors (Conyers, 2012:116) (Fig. 5). All floors appeared around 5 cm below surface (bs) and continued to a depth of 10 cm bs. As shown in Fig. 5d, the sediment profile of the excavated ant bed confirms the reflective surfaces. Additional high amplitude reflections were also visible, forming irregular ovoid and linear patterns. Some of these are associated with tree roots (since many trees are present across the site), while others indicate eroded ant mounds.

Positive and negative response magnetic anomalies were visible in all the areas surveyed, but no floors were detected using the gradiometer (Fig. 6a). Magnetically, there was no definitive contrast between the floors and the surrounding natural soil except for GSA 04, which contained extremely high magnetic responses in the location of the high GPR reflection (top left corner of Fig. 6a). These anomalies were likely related to a large amount of surface metal observed in this location. Geophysical survey maps were annotated to show the predictive interpretation of anomaly types before being ground-truthed by excavation. The anomaly types included positive responses, which were often semi-circular to ovoid in shape containing higher magnetic signatures, and those for metal, which showed coupled positive and negative responses (Fig. 6b). While floors were not observed in the magnetic gradiometer data, other features, such as refuse areas, were, and these show up as positive magnetic responses. At least three of these were targeted for excavation (see Table 1).
Fig. 4. Amplitude slice-maps of all geophysical survey areas (GSA) at Boragla sliced from 5 to 30 cm (a). Areas with higher reflections denoted by yellow and red. Fig. 6 (b) shows several anomalies, including floors and ant mounds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 5. An isosurface rendering of GSA 01’s floor with transects A, B, and C (a). Reflection profiles for transect A (Profile 030), B (Profile 038) and C (Profile 047) showing the ant bed floor (b). A 3D image showing both the amplitude slice-map and reflection profile of the floor (c). Sediment profile of the excavated ant bed (red dashed lines) confirming the reflective planar surfaces (d). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
4.1. Summary results of excavations and correlation with geophysical data

Twenty 1 × 1 m trenches were excavated at Boralga (Fig. 7). While the geophysical data assisted in determining where to place most of the excavation trenches, other locations were determined through the presence of artefactual material on the surface (Trench 01) and archaeological features such as the fireplace and pebble surface (Trenches 05 and 09). Contexts, or stratigraphically-decayed archaeological features such as the presence of artefactual material on the surface (Trench 01) and archaeological features such as the fireplace and pebble surface (Trenches 05 and 09). Contexts, or stratigraphically-decayed layers, were used to record the different stratigraphic events within each trench and were based on textural and morphological characteristics. Each trench was assigned a new numerical context (e.g. Context 001 and Context 002) and was described using standard stratigraphic and archaeological techniques. For all trenches, Context 001 comprised the upper 2–5 cm top leaf litter, while Context 002 was the underlying layer.

Of the 20 trenches, five were placed in four different areas that were presumed to be ant bed floors based on the geophysical evidence (Trenches 02, 06, 08, 10 and 14) (see Table 1). Two trenches (Trenches 18 and 19) were also placed in an area that could not be mapped by the GPR but contained wooden posts and a slightly raised flat area resembling an ant bed floor (Fig. 7b).

The structural elements making up the hard floor surfaces were identified through the excavation. Most floors varied in thickness between 5 and 10 cm and were visible as strong GPR reflections (see Fig. 5b). Each floor contained a light yellow-brown (10YR6/4) to pale brown (10YR6/3), very compact, clay-rich deposit that was very hard to excavate, designated Context 002 and Context 003, respectively. Archaeologically these floors were identifiable via their high levels of compaction, and because at Boralga they also included a gravel conglomerate and were a different colour compared to the surrounding sediment (see Fig. 5d). Importantly, the high level of compaction in the floors had significant implications for the retrieval of artefacts, since it prevented any objects from being integrated into the deposit, unlike deposits beneath floorboards. Very few artefacts were retrieved from the five ant bed floors excavated at Boralga, including from around their edges where material might have been expected to have been swept during cleaning episodes.

Excavation of three trenches (Trenches 04, 07 and 16) placed in areas containing positive magnetic responses demonstrated that these anomalies were refuse areas (Fig. 7). The first was adjacent to the troopers’ huts in GSA 02 (Trench 07), the second in GSA 06 (Trench 04) and the third was located in GSA 07 (Trench 16). The magnitude, shape and location of the anomalies in GSA 02 and GSA 07 (near the wooden posts and floors), and in GSA 06 (found below surface finds) made them interesting targets to detect. The sediments in the excavated refuse areas were also very compact and rich in silty clay, organics and historical artefacts (primarily glass, ceramic, metal). All refuse areas, which were also defined as Context 002 in those trenches that contained them, were much darker in colour compared to the other sediments found during excavations, ranging from very dark greyish brown (10YR3/2) to dark greyish brown (10YR4/2). Their thickness varied from 5 to 20 cm. Except Trench 04, most of the refuse areas were located near (within 20 m of) the mapped floors detected by the GPR. Two looted refuse areas were also observed during the 2016 field season. One of these was located downslope from the main area of habitation (Trench 03), similar to Trench 04’s location. The second was located near the officer’s quarters; excavation was not undertaken at the latter as it had been heavily looted in the past.

The signatures of some archaeological features were detected by
Fig. 7. Locations of Trenches 01, 02, 06, 07 (GSA 02) and Trenches 13 and 14 (GSA 03) superimposed on the GPR (a) and magnetic gradiometer datasets (b). The same for Trenches 16, 18 and 19 (GSA 07) and Trench 10 (GSA 04) on the GPR (c) and magnetic gradiometer datasets (d). Location of Trenches 05, 08 and 09 (GSA 01) on the GPR (e) and magnetic gradiometer dataset (f).
both instruments at the site. For example, the large refuse area (Trench 07; GSA 02), located near the troopers’ huts, and the newly identified Floor 6 (Trench 10; GSA 04) were imaged by both instruments (Figs. 7a–8d). These anomalies show up as high amplitude GPR reflections and positive magnetic responses. In the case of the refuse area, this is attributed to both the compacted living surface of the troopers’ huts and their discarded (highly magnetic) rubbish. The material excavated included glass, ceramics, belt buckles, cartridgtes, flaked stone and animal bone. For Floor 6, these signatures represent another compacted floor surface and large quantities of metal artefacts (especially horseshoes) found on top and within them.

5. Methods: Laboratory analysis

It was important to examine the natural resources, such as the ant mound and control samples, to better understand the floors at Boralga and to explain their presence in the GPR results. The three excavated refuse areas were also measured to understand their magnetic signatures. Laboratory analyses consisted of particle size analysis, loss on ignition (LOI), which included the organic matter and CaCO$_3$ equivalent, and magnetic susceptibility. Twenty-one bulk sediment samples were analysed and included each context associated with the five excavated floors at Boralga (n = 10), in addition to samples (n = 2) collected from a known ant bed floor at one of the buildings, the meat house in the nearby Old Laura Homestead complex (Fig. 8a–b), an ant mound (n = 1) (Fig. 8c), three of the excavated refuse areas (n = 6), and natural/control samples (n = 2). These variables were used to help distinguish the relationships between the samples and to assess the hypothesis as to whether or not the floors were constructed from ant bed material.

A hydrometer analysis was completed to examine the fine-grained texture of each of the 21 samples since ant species are known to show a preference for finer particles to build their nests (Lee and Wood, 1971; Venn, 2008). First, the samples were sieved through a 2 mm sieve. After sieving, 30 g of sediment from each context was pretreated with Calgon (sodium hexametaphosphate; cf. Garrison, 2003:124) for 24 h. Samples were then mechanically agitated and poured into a tube with deionised water for 5 h. Hydrometer readings were taken at 1 min, 15 min, 45 min, 60 min, 120 min and 300 min to measure textural changes, such as clay, silt and sand content of the sediment (following Blair and McPherson, 1999). For the coarse particles, the dry sieving method involved drying and weighing 30 g of each sample. This was followed by ashing the samples for ~12 h in a muffle furnace at 900 °C to remove any moisture and measured. Each sample was then ashed for ~20 h at 500 °C to remove any organics and measured. Samples were then ashed for ~3 h at 900 °C to remove carbon dioxide (CO$_2$) from the carbonates and then measured, with the CaCO$_3$ calculated by dividing the CO$_2$ content by 0.44 (following Stein, 1989).

Magnetic susceptibility was used to help understand the magnetic character of the samples. The two dominant factors that determine magnetic susceptibility in sediments are the presence of iron oxides, which result from their parent material, and the degree to which these oxides have been enhanced by processes associated with human activity (i.e. fires) (see Lowe et al., 2016) or metal working (i.e. smelting) (see Powell et al., 2002). Several minerals contribute most to the magnetic character of archaeological sediments, and this includes hematite (α-Fe$_2$O$_3$), maghemite (Fe$_2$O$_3$), magnetite (Fe$_3$O$_4$) and goethite (α-FeOOH) (Evans and Heller, 2003). A range of mineral sizes can also form, varying from ultra-fine superparamagnetic (SP) grains (magnetic grain size < 0.03 μm), to fine stable single domain (SD) grains (0.03–0.1 μm), to pseudo single domain (PSD) grains (0.1–20 μm) (Dearing et al., 1996).

Low-field mass-normalised magnetic susceptibility readings (χ) were taken using a 300 A/m field oscillating at both low (460 Hz) and high (4600 Hz) frequencies to calculate the susceptibility and the percentage loss of the low-frequency value (χ$\text{fd%} = (\chi_{460Hz} - \chi_{4600Hz}) / \chi_{4600Hz} \times 100$) (after Dearing et al., 1996; Maher, 1986). In practice, the measurement of χ$\text{fd%}$ shows the contribution of ultra-fine SP grains (Dalan and Banerjee, 1998; Dearing et al., 1996; Maher, 1986). Increases in magnetic susceptibility in conjuction with χ$\text{fd%}$ potentially suggest an increase in the percentage of SP grains (Dearing et al., 1996), which are often found in burned or well-developed sediments. All samples were packed in small non-magnetic Althor P15 boxes (5.28 cm$^3$ volume). Magnetic susceptibility measurements were completed in the lab using the Bartington Instruments MS2B sensor. Repeat measurements were taken for each sample and averaged.

5.1. Results of laboratory analysis

When looking at the fine-grained particle size analysis, specifically the sand, silt and clay content, the texture of almost all 21 samples was between sandy loam to sandy clay loam (Fig. 9a, Table 2). The ant mound contained a low sand (61.4%) and silt (12.8%) fraction (compared to the other samples) and the highest fraction of clay (25.6%). All five excavated floors at Boralga, when the values were averaged, had the highest fractions of sand (70.4%), moderate clay (17.1%) fractions and a low silt fraction (12.2%). Floors 1, 3 and 6 contained more sand (> 70%), whereas Floors 4 and 7 contained more silt (> 10%) (see Table 2). All floors contained clay, with Floors 1, 3, 4, and 6 possessing the highest percentages (> 20%). At the nearby Old Laura Homestead,
The samples, when averaged, contained the lowest fraction of sand (60.3%), but high fractions of silt (18.1%) and clay (21.4%). The three refuse areas, when averaged, also contained similar percentages to the floors and natural/control samples, with sand being the highest (70.4%).

The coarse-grain particle sizes showed a slightly different outcome to the fine-grained component because the larger particles were sampled (Fig. 9b, Table 2). Again, all 21 samples, when averaged, contained a higher sand fraction overall and almost all contained a moderate percentage of very fine to fine sands (range from 31.7–56.1%). Interestingly, the five excavated floors at Boragla and the ant mound contained the highest fraction of coarser grains (medium to coarse sands and very fine coarse sands to fine gravel) and the lowest fraction of fine grains (clays, silts and very fine to fine sands) (Fig. 9b). In contrast, the refuse areas and natural/control samples contained the lowest amount of coarse grains and highest fraction of fine grains (Fig. 9b). Based on this analysis, the floors and ant mound are the most similar in terms of their particle sizes and account for the highly reflective values in the GPR data (Fig. 10). The Old Laura Homestead floor contained higher coarse and lower fine fractions than the refuse areas and natural/control samples, but less coarse material than the floors at Boragla. This indicates that less coarse material (i.e. gravel and small pebbles) was being used as a floor base. Almost all samples contained a moderate percentage of very fine to fine sands except Floor 7 (~14%). Similar to the fine-grained analyses, Floors 1, 3, 4 and 6 contained higher fractions of clays and silts (> 2%) in percentages that were similar to the Old Laura Homestead.

As part of the natural soil formation that occurs in the upper layers of a horizon, the natural/control sample, especially Context 001 from Trench 20, contained more organic matter than the ant mound and five excavated floors at Boragla (Fig. 9c, see Table 2). This was also the case for the CaCO₃ equivalent (Fig. 9d). Since the Old Laura Homestead was in use up to the 1950s and the sample came from the floor of the meat house building, where it was reported that ash was mixed with water to give the floor a grey-white appearance (NPSR, 2017); it was anticipated that the contents of the sample would be higher, and this was confirmed in both the organic matter (10.92%) content and CaCO₃ equivalent (1.62%) (see Context 001 for Old Laura, Table 2). In contrast, the ant mound at Boragla had a low percentage of organic matter (5.84%), as did the floors, which averaged 3.91%, apart from Floor 3, which was 8.51%. The CaCO₃ equivalent for the ant mound and Boragla floors was also low. For almost all samples there was a slight increase in CaCO₃ equivalent occurring in Context 002, indicating either dissolution of CaCO₃ because of increased water movement in the soil profile or the precipitation of carbonates (Birkeland, 1999). We note that, while these increases are subtle given the age of the deposits (< 150 years), they still provide information about the site's formation processes. The organic matter percentages in the three excavated refuse areas (ranging from 5 to 22%), when averaged (10.88%), had the highest percentage overall, yet CaCO₃ percentages were low (1.02%).

The low-field magnetic susceptibility (χ) data revealed that the natural/control samples were similar in magnitude only to Floor 3 from Boragla, the three excavated refuse areas (when values were averaged) and the Old Laura Homestead (ranging between 5.48 and
Table 2

Raw data values for the five excavated floors at Boralga, the three refuse areas, the floor at Old Laura, the ant mound and the natural/control sample.

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<th>GSA</th>
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<th>Orgastics (%)</th>
<th>CaCO3 equivalent (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
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AM = Ant mound.
OL = Old Laura homestead.
* Fine-grained analysis.
8.83 × 10⁻⁷ m³/kg) (Fig. 11a; Table 2). Boralga Floors 1, 4 and 7 have lower than average susceptibility values (< 1.96 × 10⁻⁷ m³/kg), which are similar to those measured on the ant mound. Only Floor 6 exhibited higher magnetic susceptibility readings, and this correlates well with the very positive magnetic gradiometer anomaly in GSA 04 (see Fig. 6b). The frequency dependence of susceptibility (χfd%) reveals that the magnetic grain sizes varied (Fig. 11b). Samples containing the highest percentages (7–10%) were found in Boralga Floor 1 (Context 001), Floors 4 and 7 (Context 002), the Old Laura Homestead (Context 002) and two of the three refuse areas (Trench 07 and 16). The remaining samples ranged between 3 and 5% in χfd%, yet Floor 6 and the other refuse area (Trench 04) contained the lowest percentages.
CaCO$_3$ either (Fig. 11d). However, when the samples are separated into the outcomes of the samples. As shown in Fig. 11c, there appears to be no correlation of magnetic susceptibility to the organic material. Regression analyses demonstrated that $\chi$ is not correlated to CaCO$_3$ either (Fig. 11d). However, when the samples are separated into clusters, a relationship between the parameters is visible. Those samples with average susceptibility values and high organic matter content are grouped in one area of the plot (i.e. Floor 3, natural/control sample, refuse area and Old Laura Homestead), while the Floor 6 samples plot on their own. The remaining samples that contain low susceptibilities and organic matter also plotted separately (i.e. Floors 1, 4, and 7, and the ant mound). The CaCO$_3$ plot is slightly different, in that both Floor 6 and the Old Laura Homestead samples plot on their own, and the remaining samples plot together, with the exception of the Old Laura samples, one of the refuse area and the natural/control samples.

6. Discussion

The application of geophysical methods in Australian archaeology is still rare, but steadily increasing (see Lowe, 2012). This study is one example of utilising geophysics to solve archaeological problems — in this case using GPR to distinguish culturally modified sediments such as ant bed floors from natural sediments. However, the application of magnetic gradiometry and magnetic susceptibility were also beneficial for understanding activity areas, such as refuse areas and areas where activities may have been taking place (i.e. metal working on Floor 6, see below). By generating hypotheses from the geophysical images and testing them archaeologically, we have provided insight into Boralga’s physical layout of the Boralga NMP camp. Based on historical documents and artefacts will provide further insights into the complex functional life of the Boralga camp. Based on the archaeological material to date and the geophysical results of GSA 04, we can suggest that the previously unidentified Floor 6 is highly likely to be a forge. In addition to the extremely high magnetic values found in both the magnetic gradiometer and magnetic susceptibility data, and high amplitude responses in the GPR data, many horseshoes were recovered from the excavations. This suggests that activities involving blacksmithing were likely taking place here. The role of a farrier was central to the maintenance and continuation of NMP camps, as the upkeep of horses was critical to the day-to-day operations of the force. A farrier’s work involved the heating and cooling of iron objects, which would, in turn, produce strongly magnetic material resulting in greater magnetic susceptibility (and other magnetic properties) (Dalan and Banerjee, 1998).

For Floor 3, the high organic content, an increase in magnetic susceptibility and the strong GPR reflection reinforced oral history evidence that this area contained the troopers’ huts. Organic matter and carbonate analysis are good indicators of activity and refuse areas, since human activities, and wastes from humans, plants and animals alter the human past, and this study has demonstrated that.

By analysing the physical elements of the geophysical signatures, we have been able to provide insights into the construction techniques and layout of the Boralga NMP camp. Based on historical documents and ethnographic sources (see Cole et al., 2002:140; Stephens, 1973:1) we had some idea that floors at the site were constructed from ant bed, though none were visible at the contemporary ground surface. Archaeologically, these features showed up in subsurface contexts as discrete, highly compacted units with a substantial gravel component. The particle size analysis for the fine-grained sediments of all five excavated floors has shown that almost all sediments sampled in this study are sandy loam in texture, with sand being the dominant texture throughout. However, the coarse-grained analyses revealed that the floors contained a substantial coarse fraction component, which was similar to the coarse fractions observed in ant mounds themselves. When we compare these coarse-grained results to the refuse areas and natural/control samples, we see that the patterns in the physical properties are different and that the refuse areas are more similar to the natural/control samples. This is to be expected, as the refuse areas were dug out of the natural material and likely back-filled with the same material after use. The magnetic susceptibility and LOI data were also good indicators that these floors were constructed from ant mounds specifically, as the values measured for the floors were similar to those measured for the ant mound.

It is the coarser fractions of these floors and ant mounds, as well as the compaction, that the GPR imaged at Boralga, not their magnetic signature as evidenced in the gradiometer data. All seven of the historically noted buildings at Boralga have been identified through this study, and possibly an eighth unmentioned building added. We have also learned that the constructed floors were not associated with specifically ranked personnel (i.e. officers versus troopers) and that all contained a similar texture throughout: highly compacted sandy loam followed by a coarse sand to fine gravel. What we have also observed is that some floors contain higher magnetic susceptibility values, such as Floor 6 and Floor 3, or more organics, such as Floor 3. Such observations can allow us to start hypothesising about the function and use of these buildings specifically.

While the overall goal was to identify ant bed signatures, our current analyses have enabled a very broad assessment of the function of particular buildings; current work in progress and analyses deriving from the artefacts will provide further insights into the complex functional life of the Boralga camp. It is most likely to be derived from Aboriginal troopers and their wives, rather than Europeans, whose refuse tended to include large quantities of ceramics and bones from introduced species such as cattle.

Other buildings, such as the officer’s quarters (Floor 1) and saddle shed (Floor 7), contained very low organic matter percentages and susceptibility values. Since in general earthen floors were watered regularly to prevent them from cracking (cf. Edey, 1981; Lewis, 2014; Sorensen, 1911), it is possible that the organics may have been flushed out. It is much more likely that different activities were taking place here. The unidentified Floor 6 may date to an earlier phase of the police camp, or a later iteration of it as a stock camp. Other activity areas, such
as the three excavated refuse areas, were also characterised as positive magnetic anomalies. Not only did magnetic susceptibility confirm an increase in susceptibility capable of producing the magnetic gradiometer anomaly, but the organic matter percentages also showed that these parameters were positively correlated, confirming activities involving refuse and discard.

Interestingly, the ant mound sample collected at Boralga contained the highest percentage of clays in the fine-grained analysis, and this is likely a characteristic feature of ant mound construction. Venn (2008), and Lee and Wood (1971) found that most ant species, when building their nests, show a preference for finer size particles and that many nests have a larger amount of clay than surrounding soils. This is because termites or ants bring materials to the surface, commonly from the mottled weathered zones (i.e. clay rich layers) (Birkeland, 1999).

This is evident in the Boralga ant mounds, as clay percentages were much higher than both the natural and floor samples. When compared to the Old Laura Homestead these percentages were more similar, which is largely a result of many fine organics and clays found in the homestead’s floor. However, since the outside of nests are constructed with excreta, plant remains and saliva (Lee and Wood, 1971), it is highly compact with moderate porosity (between 30 and 35%). When this highly compact, clay morphology is broken down the nests become more granular, containing a significant coarse grain component. It is probable that the process of making the ant bed floors at Boralga (crushing the samples, mixing them with other material and watering them after compaction) account for the lower clay percentages than those observed in the ant mounds. Such activities would deplete the clay and alter the existing crystalline clay structure which would result in lower percentages.

When we look at scale, which is another way of seeing the geophysical landscape, we can start to understand more than just the built environment (i.e. construction techniques)—we can also look at the microscopic and macroscopic relationships within it. This would include the spatial layout of each building, their sizes and relationships to one another and to other archaeological features such as the refuse areas, in addition to the buildings’ relationships to the lagoon and the Laura River. For example, the troopers’ huts were located away from the officer’s and constable’s quarters and closer to the waterhole. Interestingly, eight of ten culturally modified trees at the site (shown in Fig. 3b) are within 20–40 m of the troopers’ huts, leading us to speculate that it was the troopers who were making the modifications to these trees. On a microscopic scale, we can start to look at the relationships to other historic sites or police camps in the area. For example, we know that the nearby Old Laura Homestead and at least two other NMP camps, at Oak Park and Musgrave, used ant mound floors. This offers perspectives on time in the landscape, meaning that the use of ant bed floors was more common in the construction of buildings in this region in the late 18th through the 19th and 20th centuries. Scale is another way of looking at how we connect place and space, as well as the subsurface stories that lie waiting to be discovered (cf. Ferraby, 2017).

7. Conclusion

The interpretation of geophysical data is one way to think about buried archaeological features; testing them through a series of analyses helps us make sense of them and provides the best way for understanding them in terms of their function and use over time. In this case, Aboriginal knowledge of a site which is culturally and historically significant provided an impetus to study the archaeology of ant bed floors. Through this knowledge, we were able to map these floors using geophysical technologies and test our observations through archaeological and geoarchaeological analyses.

While the precise geographic distribution of the practice of using ant beds for floors is unstudied, it appears they were common throughout Australia in the 18th, 19th and 20th centuries. Examination of the physical elements that make up these floors has provided a clearer idea of each floor’s use. This study also has implication for studies of other historic sites in Australia and elsewhere, specifically for detecting past buildings where walls or structural supports such as timber are no longer visible or present, or on sites where ant bed floors may have been used. While the historical literature is still very sparse on its use, ant mounds are commonly found throughout the Australian landscape, making them a widespread suitable material for construction. We now also understand the geophysical signatures associated with these features, making it more viable to apply these technologies to other historical sites that may have utilised this material. Perhaps the next step would be to explore the distribution of ant mounds against the distribution of known ant bed floors in Australia.

Acknowledgements

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