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ORIGINAL PAPER

Geophysical and archaeological investigations of Baker's Flat, a nineteenth century historic Irish site in South Australia

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Abstract

The Irish settlement of Baker's Flat, located in the rural heart of South Australia near the town of Kapunda, was occupied from the mid-nineteenth century for about 90 years. Although little archaeological work has been carried out in Australia specifically on Irish communities, Baker's Flat is of particular interest because it potentially operated as a traditional Irish clachan, an informal clustering of farm dwellings and outbuildings, and home in this instance to the Irish immigrants who worked in the nearby copper mine. The site was cleared for farming purposes in the 1950s, and little recordation of the dwellings and settlement exist today, aside from a single 1890s map. Owing to the demolition and landscape modification, it was unclear whether any intact subsurface deposits still existed. Therefore, this site was ideal for deploying two geophysical methods, ground-penetrating radar (GPR) and magnetic gradiometry, to assess the presence of subsurface remains and explore the spatial layout of the site. Our results, when compared with those obtained from surface surveys and targeted archaeological excavation, revealed numerous subsurface features and helped to confirm that Baker's Flat was built in the style of a traditional Irish clachan. This study also demonstrated that magnetic gradiometer was the better geophysical method for mapping this settlement as the nature of the geology (shallow bedrock) and construction of the houses (built within the bedrock) limited the utility of GPR.

Keywords Australia historical archaeology · Baker's Flat · Historic Irish site · Magnetic gradiometry · GPR

Introduction

The British colonisation of Australia has been described as 'one of the longest-range mass migrations in human history' with large numbers of people relocated from one end of the world to the other (Connah 1988, p. 4). This was not always by their choice; the penal colonies of New South Wales, Van Diemen's Land (Tasmania) and Queensland received large numbers of transported convicts. Primarily originating from Britain and Ireland, the new settlers, whether convict or free, were required to adapt to new and very different environmental and material conditions.

The archaeology of these migrant communities has been addressed by many researchers (see, for example, Crook and Murray 2006; Crook et al. 2015; Godden Mackay Heritage Consultants 1999; Karskens 2003; Lawrence and Davies 2018; Lydon 1993; Mayne 2006; Mayne and Murray 1999; Murray and Mayne 2003; Winter et al. 2016). When examining such settlement, it is apparent that British convicts, soldiers and settlers dominated early colonial society, but it is important to note, however, that the British themselves were not homogenous. The Scottish, Welsh, Cornish and English cherished their own distinct identities, and the Irish, coming from Britain's first and oft-times most troublesome colony, hardly identified as British at all.

The archaeology of the Irish in Australia has been somewhat overlooked. Some Australian archaeological studies have focused on working-class, urban areas that had Irish inhabitants, but without a specific focus on the Irish as an

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ethnic group (for example, Godden Mackay Heritage Consultants 1999; Mayne 2006; Mayne and Murray 1999). With regard to the archaeology of the Irish specifically in rural Australia, all the known studies focus on South Australia—Ashley's (2009) thesis on displacement and resettlement of post-Famine Irish migrants in the rural township of Pekina, Arthure's (2014, 2015, 2017) work on the Baker's Flat community and McEgan's (2019) study of Irish graves in the mid-north of the state. In historical research, where more attention has been given to the rural Irish (for example, Campbell 1991, 1995; Doyle 1996; Reid and Kelson 2010), the focus has been mainly on the eastern Australian states, rather than on South Australia (Campbell 2002, p. 61–62).

And South Australia is different. Unlike the Australian states that originated as penal settlements for the unwanted of the British Empire, South Australia was established as a colony of free settlers, without the supposed 'stain' of convictism. This occurred within the context of a particular set of conditions that impacted on those Irish migrants who made their way there. These included the deliberate transplantation of British societal systems, conspicuous capitalism in the form of land speculation and mining, and a much lower proportion of Irish people in the population compared with other migrant groups. Historians have asserted that South Australia was the least Irish of the nineteenth century Australian settlements (Fitzpatrick 2005, p. 282; Richards 1991, p. 216), having 'the smallest percentage of Irish of all the colonies' (Sendziuk and Foster 2018, p. 66).

The effect of the small Irish presence, combined with a tendency to see them as just another group of British migrants, has rendered the Irish almost invisible in the landscape and written histories. This has certainly been the case for the Irish of this study, those who lived at Baker's Flat, Kapunda. In Kapunda's early days (1842–1855), settlers originated mainly from England, Wales, Cornwall, Germany and Ireland. The English arrived first, with capital to invest, and quickly assumed control of the pastoral, commercial and civic sectors. The Cornish and Welsh, with skills in mining, smelting and mine engineering, were in demand at the copper mine. The early Germans took up farms at Bethel, about 10 km west of Kapunda. This left the Irish, who mostly worked as labourers in the copper mine.

Kapunda was not Australia's only mining town. Archaeological work has been carried out on several nineteenth and early twentieth century mining settlements across Australia. These include Mate's (2013) study of a mine and township as an integrated landscape at Mount Shamrock, Queensland, the work by Lawrence and Davies (2015) on the effects of Cornish mining practices on the landscape of goldfield regions, Fleming's (2016) meta-analysis of the global and local contexts of three Western Australian goldfield sites, and Prangnell and Quirk's (2009) investigation of community attitudes towards children in the small Queensland gold mining town of Paradise. Overseas, several historians have looked at the Irish in mining communities: Cowman (2006) considered how a small community was able to develop mining expertise in a copper mine on the south coast of Ireland, Emmons (1990) focused on the large Irish population in the copper mining town of Butte, Montana and their central role in running the town, and Mulligan Jr (2015) explored how the Irish in Michigan's Copper Country used social and benevolent societies to help maintain their identity. Interestingly, the Irish in Montana and Michigan differed from other migrant Irish communities (see, for example, Brighton 2008, 2011; Linn 2010; Rotman 2010) in that they were primarily skilled workers, with a significant proportion of them being experienced copper miners (Emmons 1990; Mulligan Jr, 2015, p. 110–111).

Despite the broader interest in Australia historical archaeology, as discussed by Lowe (2012), few geophysical studies have been conducted on such sites and, to date, less than a handful have been completed with the goal of systematically mapping sites on a larger-scale (though see, for example, Gibbs and Gojak 2009; Hall and Yelf 1993; Lowe et al. 2018; Ranson and Egloff 1988). Exceptions include a comprehensive study that examined a significant convict settlement, the Port Arthur site (c.1830) in Tasmania using ground-penetrating radar (GPR), magnetometry, electrical resistivity and electromagnetic induction (see Links 2008). Investigations were completed on the areas of Settlement Hill, Penitentiary Complex and Isle of the Dead (1.34 ha surveyed), with the aim of detecting and characterising buried structural features associated with residential and administrative buildings from the penal period. Situated on Jurassic dolerite (which has a range of magnetic signatures), the underlying material at Port Arthur consisted of sandy topsoils underlain by acidic sands. This study found the value of geophysical methods for detecting archaeological features to be variable, especially magnetometry due to magnetic dolerite which interfered with the signal, and concluded that GPR and electrical resistivity were the best instruments for detecting walls, gravel surfaces, fill and structures at depths from 1 to 6 cm below the surface (Links 2008). A second study found magnetic gradiometry to be successful in mapping an early European cottage site in Gippsland, Victoria (Brooks et al. 2009). The site had experienced 140 years of agricultural activity, and the survey aimed to quickly and efficiently assess the nature of the surviving archaeology on a site that had been repeatedly ploughed. Focusing on an area measuring 2.47 ha, Brooks et al. (2009) found several anomalies associated with the site, including pits and a possible structure at a depth of around 10 cm. A more recent study completed by Lowe et al. (2018) over a ~ 1 ha site successfully located late nineteenth century buildings associated with a Native Mounted Police (NMP) Camp in Cape York Peninsula, Queensland, using GPR which easily detected building floors constructed from 'ant bed' (aka termite mound) although no superstructure remained at the ground surface. Excavations of the anomalies determined them to be highly compact floors with some gravel at depths of 5–10 cm.

Globally, trialling geophysical methods for mapping early settlements and their associated landscapes has proven to be very successful (Jordan 2009). Much of this success has to do with recent technological improvements in geophysical instrumentation. In many cases, high-resolution magnetic gradiometry has revealed that large settlement sites (> 2.5 ha) can be mapped efficiently and quickly, thus advancing the level of data acquisition overall (Gaffney et al. 2000). This is especially true in Europe, where large subsurface architectural features spanning the Neolithic to Roman periods are still present (Darvill et al. 2013; Donati and Sarris 2016; Keay et al. 2009). More importantly, recent studies have shown that high-resolution GPR using a multi-channel antenna system is equally successful in large-scale mapping (Trinks et al. 2018).

Informed by the success of such techniques and methodology elsewhere, the goal of this study was to conduct a large-scale geophysical survey on an early colonial settlement in Australia using high-resolution gradiometry and GPR to address questions about its spatial layout. The study site was Baker's Flat near Kapunda, South Australia (SA) (Fig. 1), the location of a large Irish settlement occupied from the mid-nineteenth century through to the early twentieth century. Fleeing the Great Famine of 1845–1850 in Ireland, the Irish

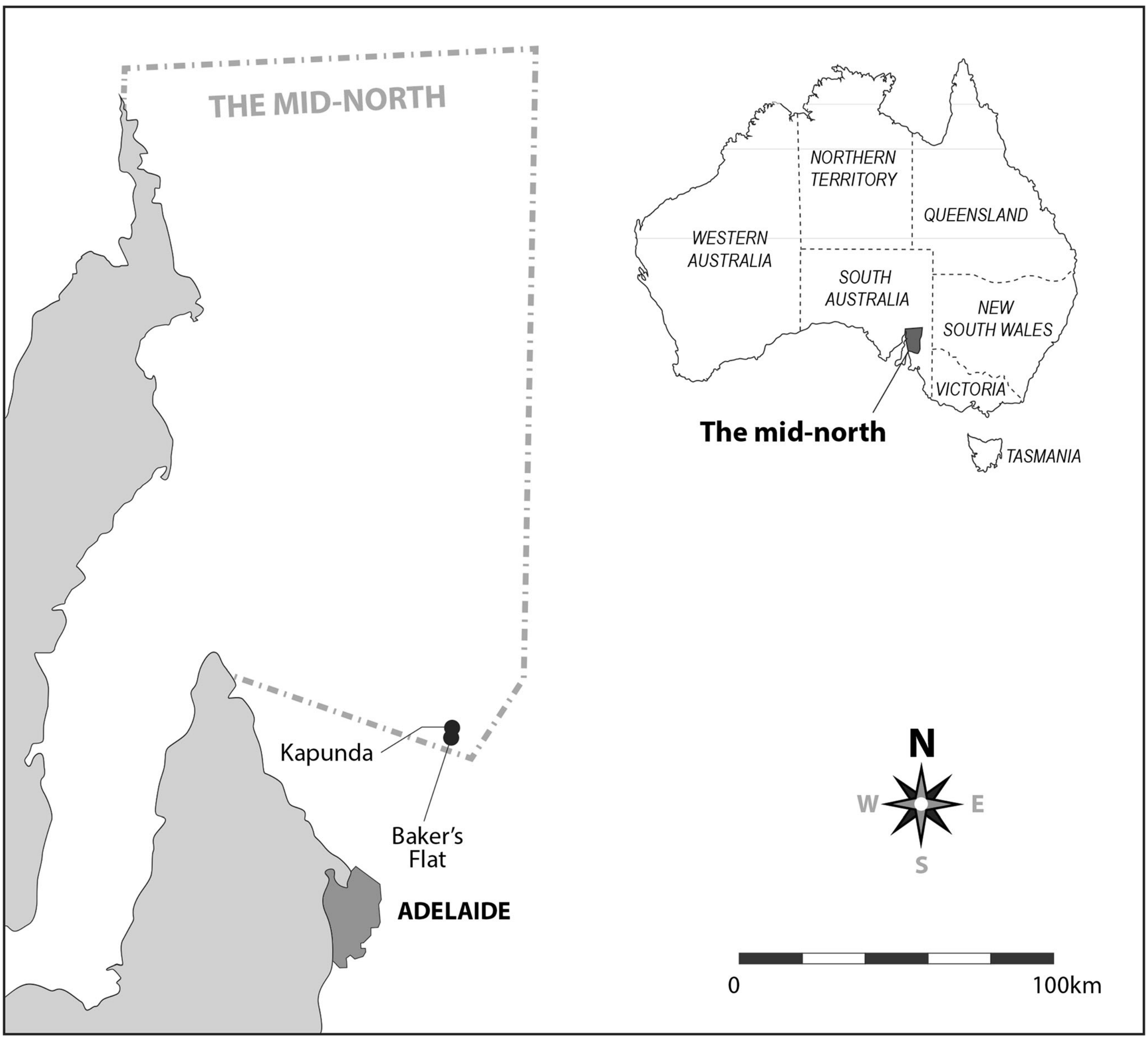

Fig. 1 Location of the Baker's Flat site in South Australia (Map: Heather Burke)

were drawn to Baker's Flat because of employment available to them at a nearby copper mine, especially after 1854 when the mine introduced steam technology that enabled deeper workings (Drew 2017, p. 38). Unlike the skilled Irish miners who found work in the American copper mines, the Irish of Baker's Flat are only ever described in the literature as labourers. However, a significant factor at Baker's Flat is that it essentially operated as a closed Irish community that controlled a large area of land allowing traditions and customs to be maintained, specifically, the clachan settlement style (Arthure 2014, 2015, 2017).

Although hundreds of Irish people lived at Baker's Flat over 90 years, there is little documentation about the community even in local and regional histories. A collection of stories about Kapunda, published in 1929, established a narrative about Baker's Flat as a 'lawless little community' of haphazard hovels and unrestrained flocks of geese, whose members were 'quick to resent any attempted interferences' (Tilbrook 1929, p. 31–32). This account set the scene for how Baker's Flat came to be described in subsequent histories: as a hotchpotch collection of rough shelters and small wattle-and-daub thatched cottages without fences (Charlton 1971, p. 18; Nicol 1983, p. 14). These short notations are the only published accounts relating to Baker's Flat, with the exception of newspaper accounts which inevitably focused on newsworthy incidents such as fights, public drunkenness, and land disputes. By the 1950s, when the remains of any houses were demolished to facilitate farming, the Baker's Flat community had, in effect, disappeared from both local memory and the landscape.

Recent archaeological work by Arthure (2014, 2015, 2017), however, has indicated that Baker's Flat is highly significant. The community appears to have adhered to a traditional Irish settlement model known as a *clachan*. Clachans dominated the rural landscape of nineteenth century Ireland, taking the form of clusters of up to 30–40 farmhouses and outbuildings grouped together without any formal plan (Johnson 1958, p. 554; Johnston 2007; Whelan 2011, p. 86–87). They were associated with a land management system called *rundale*, an arrangement where the land was farmed communally (Evans 1939; Johnson 1958, p. 556; Whelan 2011, p. 86–87). By the late nineteenth century, clachans had all but disappeared from Ireland, a consequence of deaths, emigration, evictions, and land clearances following the Great Famine (Ó Síocháin 2015, p. 9–10). The Baker's Flat settlement is the first time that a possible clachan has been identified in Australia and, as such, is of considerable significance. Of particular interest for this study, therefore, was to determine, as much as possible, information about the spatial layout of the site in respect to it conforming to a clachan. Archaeological investigations were undertaken after the survey to test some of the geophysical results.

Material features of a clachan

The predominant feature of an Irish clachan is the clustered nature of its dwellings and outbuildings; additionally, there were often strong kinship ties between the occupying families (Johnson 1958, p. 554; Whelan 2011, p. 86). The associated farming system of rundale involved an infield-outfield-commonage method of farming ideally suited for making the best use of marginal land. The infield comprised the best land and was used to grow food such as oats or potatoes, with each clachan family allocated a particular strip of land according to their needs (Whelan 2011, p. 86–87). At the edge of the permanently cultivated infield was an area of an outfield, generally of poorer land and used as required to grow additional potatoes. The remainder of the land was treated as commonage, common grazing land, where each family could graze their cattle and other livestock (Feehan 2003, p. 115; Whelan 2011, p. 86–87). Described as a 'sophisticated response to specific ecological conditions' (Whelan 2011, p. 89), it was an effective fit for settings where there were limited technology and funds but an abundant source of labour. The amount of land that could be controlled was key, with the average clachan settlement being about the size of an Irish townland (Feehan 2003, p. 115; Whelan 2011, p. 86), the latter being small sections of land, based on ancient territorial divisions. Whilst, on average, townlands cover about 300 acres (121 ha) (Andrews 2002, p. 13–14), they can vary widely in size from one or two acres to, occasionally, several thousand. The Baker's Flat land is about 60 ha and would have been familiar enough in area for Irish settlers to recognise that they had enough land to contemplate a clachan system. There are no indications in the documented histories or records that the Irish of Baker's Flat deliberately set out to establish a clachan there. Given that it was such a common settlement pattern at the time they left Ireland, it may well be that they just continued doing what they had always done or been familiar with and that it emerged organically. The critical factor, however, is that they had access to and control of a large section of land, something which eluded those who settled in the cities or large towns.

The second major feature of the clachan is its adherence to traditional Irish vernacular architecture. As such, typically stone houses are built to a single-storey oblong plan, are one room deep with rooms that open into the next without a central hallway, have steeply sloped thatched roofs, and windows and the doorway in the front wall (Aalen 1966, p. 47; Danaher 1978, p. 9, 11–12; Gailey 1984, p. 8; O'Reilly 2011, p. 193, 197, 203). Even the poorest one-roomed cabins in nineteenth century Ireland would have adhered to this form, except that mud rather than stone would have been the primary construction material (Danaher 1978, p. 30; O'Reilly 2011, p. 199). On average, the depth of a vernacular house could be between 3 and 4 m, and the length from 5.5–14 m (Ó Danachair 1955/

Fig. 2 A series of photos taken by John Kauffmann, published in the *Christmas Observer*, 13 December 1906, Adelaide depicting Baker's Flat houses in 1906 (Photo: Susan Arthure, from a copy held at the Kapunda Historical Society Museum)

1956, p. 78–80, 1964, p. 62–67; O'Reilly 2011, p. 197). Although all the buildings on Baker's Flat are now either reduced to rubble or wiped entirely from the landscape, photographs dating from 1906 (Fig. 2) illustrate that at least some of the dwellings adhered to traditional vernacular characteristics. Further, oral testimonies collected in 1975 concurred that the houses on Baker's Flat were mainly constructed as 'two or three rooms in a row' (Townsend 1975) or four rooms in a straight line (O'Brien 1975), and that the walls were made either of clay (Townsend 1975) or pug [clay] and stone (O'Brien 1975). A further testimony described how a house site was generally selected on a slope which was then dug out to make a level floor; the clay that was removed was used for the walls, and the rooms were positioned end-to-end (Beanland 1975).

As noted earlier, in Ireland the clachan had all but disappeared by the end of the nineteenth century (Ó Síocháin 2015, p. 9–10; Whelan 2011, p. 96–103). However, in the heart of SA, 16,000 km from Ireland, all the indications are that there was a clachan operating on Baker's Flat. Accounts in nineteenth century court records and newspapers highlight cooperative decision-making and land management practices consistent with rundale (see, for example, *Kapunda Herald* 1894a, 1894b; Supreme Court of SA 1892). The 1906 photographs (Fig. 2) depict houses conforming to the Irish vernacular tradition, and an 1893 survey map (Fig. 3) shows a cluster of buildings on the site in the north-west quadrant, consistent with a clachan arrangement. However, although building outlines are shown on the 1893 map, it is difficult to postulate fully whether these structures were domestic or agricultural, and there is no indication if all the buildings on the site were mapped. When this map is superimposed onto a modern aerial image, one can see some errors and skewness in regard to the site's dimensions and physical layout, indicating that this survey has its limitations. Hence, it was proposed to implement near-surface geophysics on the site, to be followed by an archaeological excavation that would test the results. It was hypothesised that the geophysical survey could reveal the original footprints of houses or enclosures that could then be tested through excavation.

The study site

The Baker's Flat site is located 75 km north of Adelaide, the state capital of SA, Australia, and 1 km south of the regional town of Kapunda (see Fig. 1). Today, it consists of a privately owned field that is farmed using a rotation of sheep grazing and grain crops. The site is located on a slight hill that gently slopes south to the Light River, an ephemeral watercourse with areas of permanent groundwater.

The site is situated on the Adelaidean Tapley Hill Formation, a feldspathic dolomitic siltstone containing secondary copper carbonates, oxides and sulphides (URS Australia 2015). It was the discovery of the secondary copper carbonates that led to the establishment of one of SA's earliest mines, the nearby Kapunda Copper Mine which operated from 1844 to 1878.[1] The Adelaidean Tapley Hill Formation is part of the Western Plateau Division physiographic region,

[1] The Kapunda Copper Mine was Australia's first successful metal mine and in recognition of its historical significance was inscribed on the SA Heritage Register in 1987.

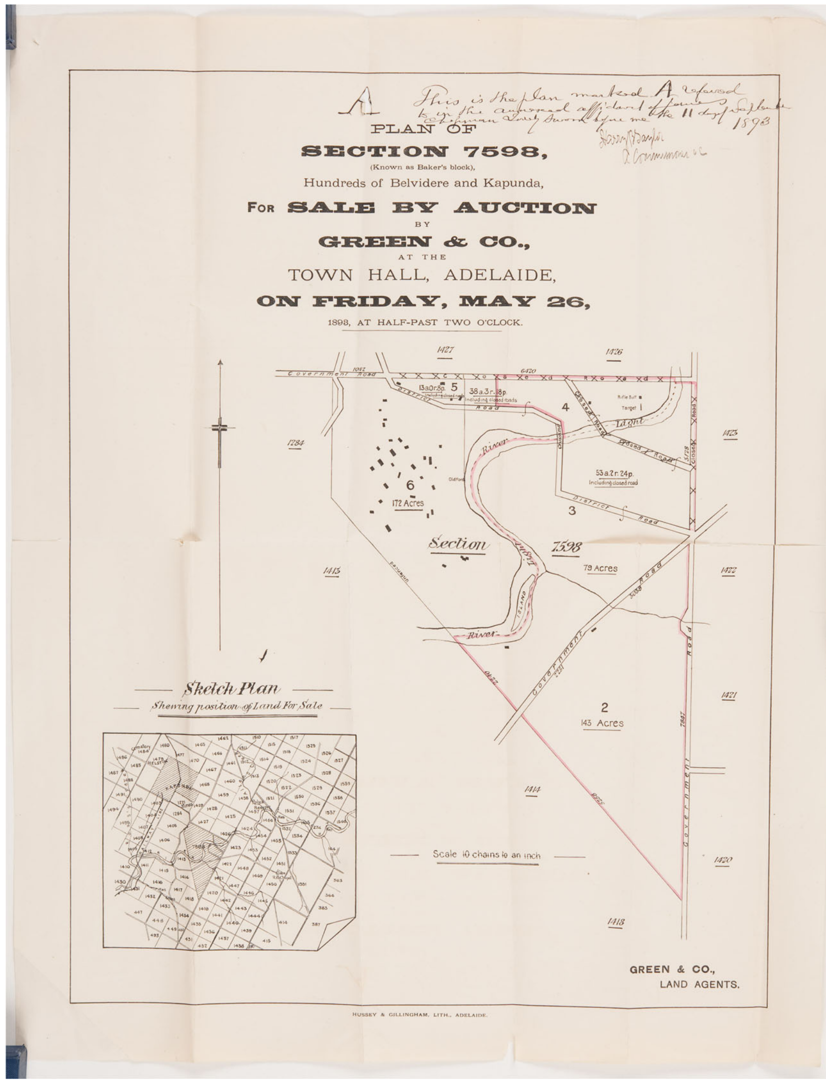

Fig. 3 1893 map of the Baker's Flat site (Supreme Court of South Australia 1892)

comprised of shield blocks and intracratonic basins, plains, plateaus, ranges, and dune fields.

The sediments in this area are classified as Red Chromosols, which are sandy loam to clay loam sediments overlying a red-brown well-structured clay (Isbell and NCST 2016). These sediments are soft carbonates that form from the weathered siltstone or sandstone Proterozoic sediments that comprise the underlying bedrock; locally these are defined as calcrete—a type of limestone occurring near the soil surface. The deposits are typically yellowish red fine sandy clays near the surface, underlain by dark reddish-brown clays with siltstone or sandstone fragments. Underlying those is a dark reddish brown very calcareous clay with a high percentage of siltstone or sandstone fragments.

When Europeans first arrived in the Kapunda region, following the establishment of the SA colony in 1836, the land and vegetation were deemed suitable for grazing large flocks of sheep (Charlton 1971, p. 6–7). After 1844, any existing trees were cut down and used for building or fuel in the copper mine. Today, vegetation on the site consists of tall grasses used for sheep grazing, annual grain crops, and several large pepper trees (*Schinus ariera*, syn. *S. molle*). In SA, pepper trees are useful indicators of colonial occupation; an introduced species, they were planted for shade and shelter from the 1850s onwards (Jones and Payne 1998, p. 39–41).

Only two surveys are known to have been carried out on Baker's Flat prior to this study: an 1893 survey resulting in a map prepared for the proposed sale of the land (see Fig. 3) and a 2013 pedestrian survey (Arthure 2014). There are no structures now remaining on Baker's Flat, although the landowner has confirmed that rubble heaps on the site documented in 2013 are the remains of buildings and that they remain in their original locations (D. Hampel pers. comm. December 2012). When the 2013 results are superimposed on the 1893 map, they reveal that most of the rubble heaps and artefact scatters are closely associated with the cluster of buildings recorded in 1893, though two outlier rubble heaps were also located near the southern boundary (Fig. 4). The 'dance floor' on the

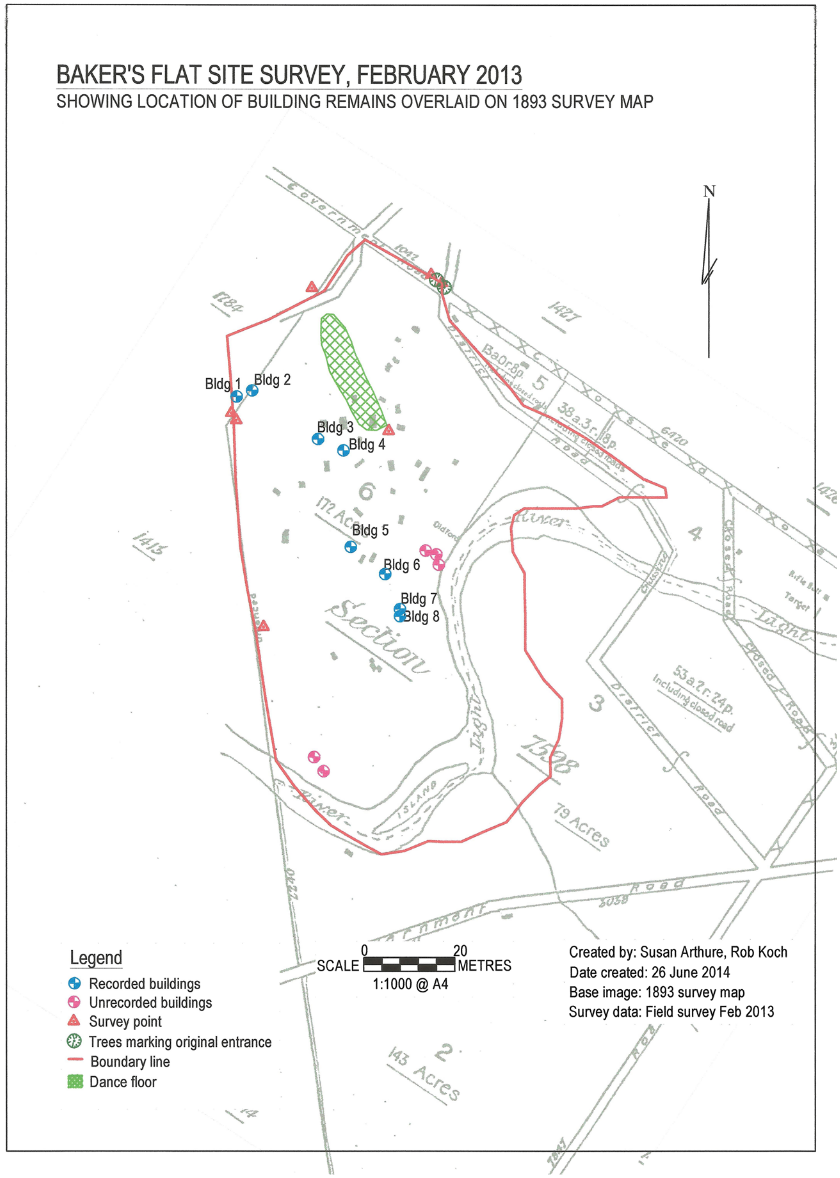

Fig. 4 The 2013 field survey results superimposed on the 1893 map

eastern side of Baker's Flat is a highly compacted area of land, known locally as the spot where the Irish settlers gathered to dance and socialise. It was described in 1936 as 'the virgin soil, flat and smooth, and hard as cement from the thousands of feet that gaily "kept the time" to the piper's or fiddler's tune' (Maloney 1936, p. 29) and later, in an oral testimony, as a 'hard patch of earth, and fires kept going to liven the scene' (Beanland 1975). The 2013 pedestrian survey, which had covered an area of 26 ha, found dense surface scatters of ceramics and glass west of this area, indicative of habitation (Arthure 2014, 2015). The pedestrian survey did not provide evidence for other buried archaeological features or offer a detailed understanding of the site's spatial layout. However, it was useful for identifying settlement indicators, and this evidence was used to locate the area for the geophysical investigation.

Methodology

Geophysical survey

Both GPR and high-resolution magnetic gradiometry were used to carry out the geophysical surveys at Baker's Flat. Magnetometry is a passive method meaning that it does not transmit anything into the ground, and instead, measures the strength or alteration of the Earth's magnetic field across an area (Aspinall et al. 2008; Clark 1996; Gaffney and Gater 2003; Kvamme 2003; Witten 2006). Magnetic gradiometry was assessed as being particularly suitable for the Baker's Flat survey because it can be used to cover large open areas rapidly. It was anticipated that the gradiometer would locate iron-rich material such as burnt features, metal, or particular soils.

GPR works by transmitting electromagnetic energy in the form of radar waves into the ground (Bevan 1998; Conyers 2009, 2012). When the wave encounters a different material in the soil (such as air voids, stone or a material with different moisture content), a reflection occurs, sending part of the wave back to the surface, where it is received and recorded. GPR was selected 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 identify any buried stone foundations such as might be associated with buildings, pathways or fences, or pits dug into the ground.

Owing to the large size of the Baker's Flat settlement (approximately 60 ha), the time (5 days) available for the survey, and some minor access restrictions (the site is located on a working farm), it was deemed most useful to establish just one large geophysical survey grid on the site. This 100 × 240 m (2.4 ha) grid was placed over an area that contained at least one bulldozed structure, one pepper tree and the area believed to be part of the dance floor (Fig. 5).

The magnetic gradiometer data were collected using a Bartington Instruments Fluxgate Grad601-2. This instrument utilises four magnetometers—two pairs stacked vertically 1 m apart to provide a measure of the magnetic gradient at each measuring station. Whilst it would have been ideal to survey with an eight magnetometer system, such a system was not available to us, and the Bartington has a demonstrated track record for collecting high-resolution data. Gradiometers allow for the recording of very subtle (0.1 nT) fluctuations in the local magnetic field. The instrument was set up to record data eight times per meter with 0.5 m spaced survey transects (16 samples/m^2). Data were downloaded and processed using

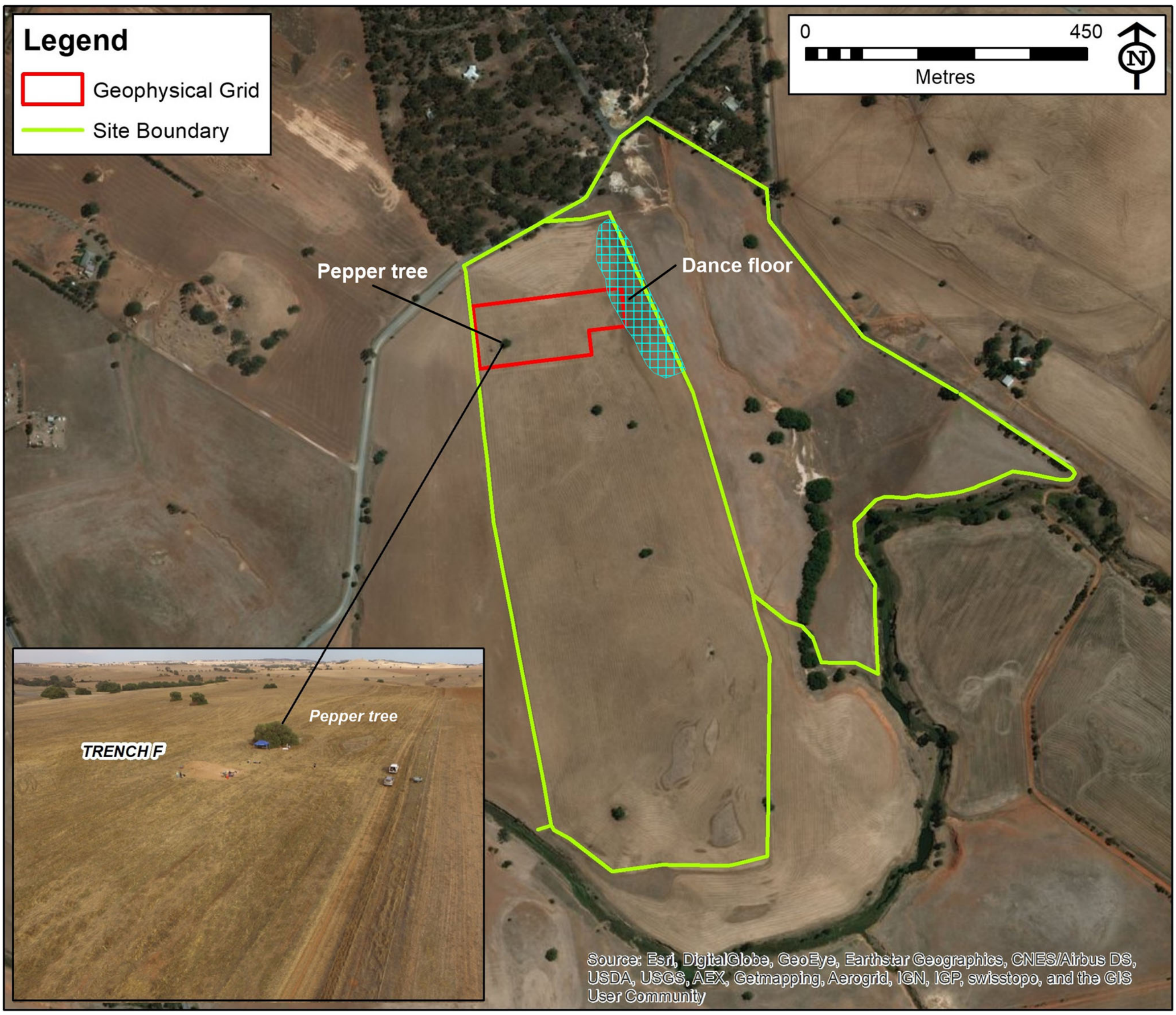

Fig. 5 Aerial view showing the geophysical survey area at the Baker's Flat Site with inset of drone view of the site looking approximately south. Note the pepper tree, near the western edge of the site

TerraSurveyor version 3.0.25.1. Processing was limited to destriping to remove abnormal high/low readings, high-pass filtering and interpolation to equalise pixel size to 0.125 m by 0.125 m. The processed data were exported and imported into ESRI ArcGIS 10.6.1 for cartography.

A Geophysical Survey Systems, Inc. (GSSI) SIR-3000, 400 MHz antenna and a model 620 survey wheel were 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 1 m due to time constraints, although 0.50 m spacing would have been preferable. Using GPR-SLICE v7.0, data were processed (time zero correction, background removal and bandpass filter) and converted into amplitude slice-maps and reflection profiles. A constant velocity (m/nS) model was used with an average velocity of 0.093 m/nS in the hyperbola search menu. The hyperbola fitting function to estimate the relative dielectric permittivity, which is calculated from the two-way travel time to depth, was used to make the time slices and provide an estimated depth of the data (Goodman and Piro 2013; Jacob and Urban 2015). These depth estimates generated in the software were then compared to those from the excavations to create the amplitude slice-maps. For the GPR, an overlay analysis computed in GPR-SLICE (see Goodman and Piro 2013) using depths from 15–40 cm was created to highlight the anomalies across the site with depth. This helps in the interpretation of the reflection features as the amplitude slice levels are overlaid to show the strongest reflectors at specified depths.

Laboratory analyses of slag

Two slag samples collected near the area reported to have been the dance floor and where numerous slag samples were found on the surface, were measured to understand their magnetic characterisation particularly in relation to the construction of the site (e.g. floors and social spaces) and how this might affect the magnetic gradiometer results. All magnetic characterisation methods were conducted at the Institute for Rock Magnetism at the University of Minnesota. Low-field susceptibility (χ) was measured on a Magnon susceptibility meter using a 300 A/m field at two frequencies (465 and 4650 Hz). Each measurement was repeated four to five times so that error could be quantified using a standard deviation. This was followed by the temperature dependence of low-field susceptibility on an AGICO MFK 1-FA susceptibility meter using a 300 A/m field at 976 Hz. The natural remanent magnetisation (NRM) of the slag samples were also measured on a 2G Enterprises 755 cryogenic rock magnetometer operated inside a magnetically shielded room with a background field of < 200 nT. Primary hysteresis loops and backfield remanence acquisition curves were collected using a Princeton Measurements Corporation alternating gradient magnetometer (AGM). Hysteresis loops were analysed using the protocol of Jackson and Solheid (2010) and are useful tools for constraining average magnetic domain behaviours within a sample and concentration of magnetic minerals.

Results

Geophysics

The gradiometer data reveal numerous positive and negative response magnetic anomalies in the survey area (Fig. 6a). Figure 6b has been annotated to show the predictive interpretation of anomaly types before the area was ground-truthed by

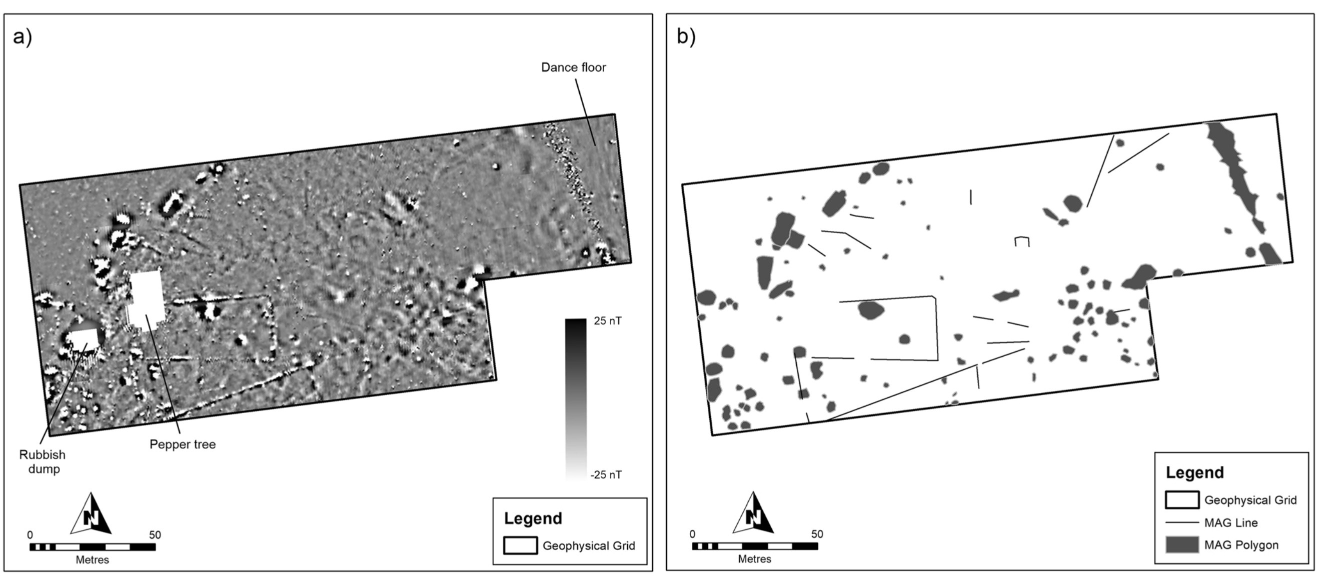

Fig. 6 **a** Magnetic gradiometer map with black representing a positive magnetic gradient and white a negative gradient without highlighted anomalies and **b** interpretation of anomalies, including potential houses and enclosures

excavation, particularly high magnetic monopoles of interest (grey polygons) and linear architectural features (black line). Several large ovoid to rectangular dipoles (i.e. both positive and negative responses) were visible in the north-west part of the grid, forming rectilinear patterns reminiscent of structures. These anomalies were approximately 10 m long and 5 m wide, consistent with the size and shape of a traditional Irish vernacular house. Other anomalies are shown as linear dipoles that appear to form enclosures or walls. These run along the central and southern ends of the survey grid. An extended linear cluster of smaller dipoles is visible in the north-east section of the grid in addition to a cluster of high response ovoid monopoles in the south-east. These monopoles range in size from 1–3 m in diameter and appear to be situated directly south-west of an area that contains less magnetic variation compared to the rest of the surveyed area. This is the place reported to have been used as a dance floor and gathering area.

The GPR data did not reveal any rectilinear-shaped high amplitude reflections that could be indicative of buildings (Fig. 7a). Most reflections appeared as irregularly-shaped strong reflections with no visible patterning (Fig. 7b); however, a few of the linear high amplitude reflections correlated well to anomalies detected in the gradiometer (Fig. 6). The GPR did detect one feature that was not visible in the gradiometer data, and this was the large circular high amplitude reflection apparent in the south-central part of the survey area. As with the gradiometer results, there appears to be less variation in the data in the upper layers of the GPR data in the area of the reported dance floor (Fig. 8a). Around 35 cm below surface, we see the reflections starting to increase, and this continues to about 65–70 cm below surface.

Archaeological excavations and comparison of geophysical results

Following the geophysical survey, archaeological excavations on Baker's Flat took place in April 2016 and April 2017, at the end of a dry Australian summer. Since the magnetic gradiometer data appeared to display the site layout better than the GPR, the former was used to assist in identifying areas for targeted excavations. Seven areas of interest (AOI) were outlined in areas that contained apparent cultural anomalies, especially those that appeared to be houses and enclosures (Fig. 8b).

Anomaly AOI02, excavated in 2016, was over a potential enclosure or walled area highlighted by linear dipoles in the gradiometer results. It is estimated that this feature might occur around 50–60 cm based on the sensitivity of the instrument and sensor spacing. Here, the results were inconclusive as the ground was so compacted that it could not be excavated using hand tools below a depth of 30 cm, at which point a hard and impenetrable red clay was encountered (5.5 pH, Munsell colour 7.5YR 4/3 Brown) congruent with the extremely dry state of the land. The soil profile was consistent throughout and contained very few artefacts. These factors, combined with the flat topography and information from the landowner about the import of topsoil in the 1950s, indicate that the excavation was unable to penetrate past the imported soil to the original top layer or bedrock. A further attempt in 2017 using a mechanical excavator was brought to an abrupt halt when the arm of the bucket snapped in the hard soil.

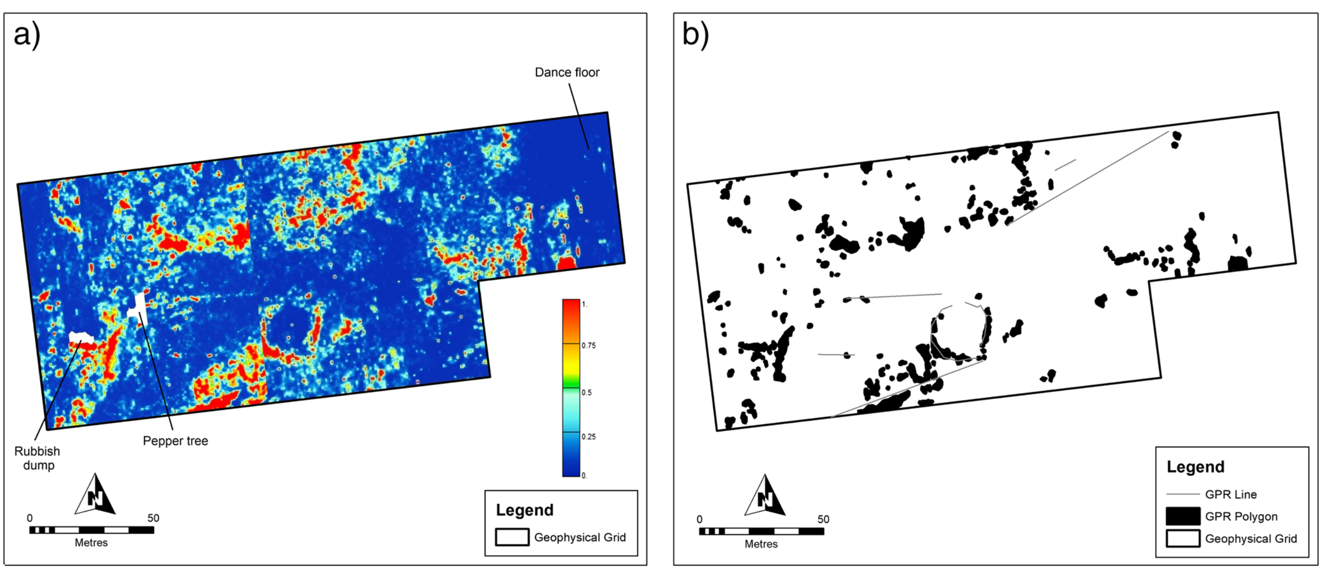

Fig. 7 **a** GPR amplitude slice-maps from 15 to 40 cm below surface showing areas with stronger reflection in yellow and red and **b** the interpretations of several anomalies, including a possible enclosure and circular feature

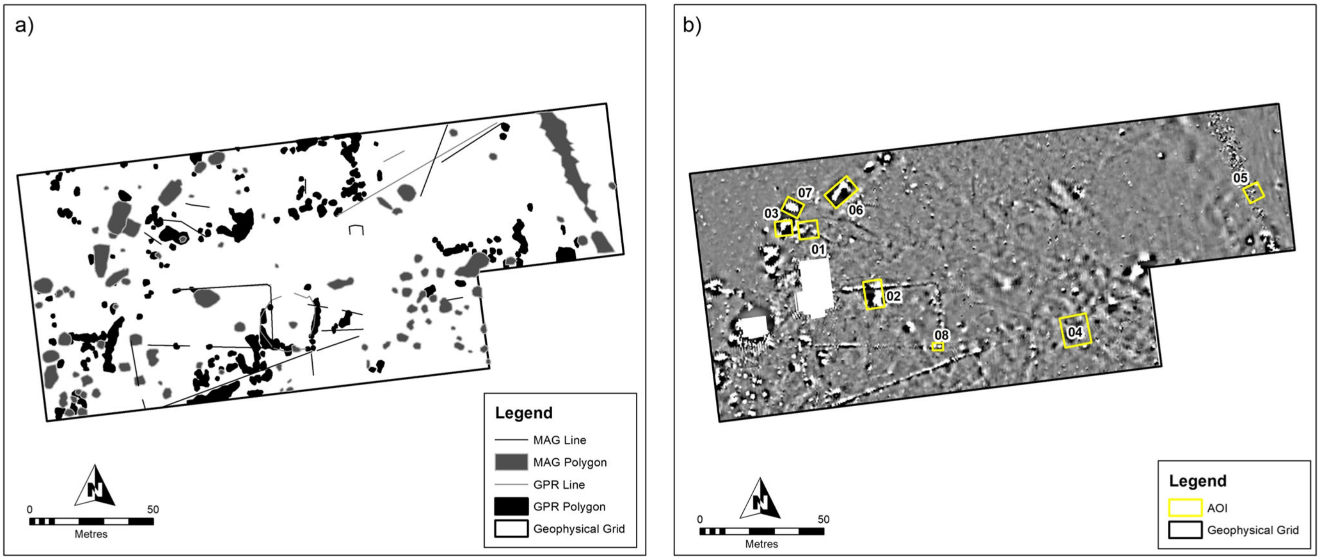

Fig. 8 **a** Overlay of GPR and gradiometer interpreted anomalies and **b** the seven areas of interest (AOI) that were identified for subsequent targeted excavations shown on gradiometer map

Based on the magnetic signatures (dipole) it is believed that this anomaly is a wall or fence containing metal.

The second area, covering AOI03 and AOI07 and excavated over both field seasons, was in the north-western section of the geophysical survey grid, close to the pepper tree and near building 2 recorded in the 2013 survey (see Fig. 4). In 2016, this area was opened as Trench A, and 27 m^2 was excavated, to a maximum depth of 75 cm. In 2017, the excavation was extended north as Trench F (highlighted in Fig. 9a) with 29 m^2 excavated to a maximum depth of 75 cm.

In 2016, based on the magnetic gradiometer indicators of several large ovoid to rectangular dipoles, it was suggested that a building would be uncovered at Trench A. It was hypothesised that this building would contain a floor area constructed of slag as per oral testimony collected from resident Mick O'Brien (1975) who described how he and his father carted 'skippings from the mine' to be used to make the floors on Baker's Flat. Slag when used properly, can be beneficial in a range of construction applications especially as an aggregate replacement and supplement in concrete (CIA 2003). A was laid out on a 7 m north-south/6 m east-west grid over AOI03.

Trench A was entirely excavated using hand tools. It was expected that the imported fill would extend to a maximum of 20 cm. However, it was much deeper than this in most of the excavated squares. Across the trench, at a depth of between 30 and 45 cm of fill, large metal fragments began to emerge, and further excavation revealed parts of metal bed frames, corrugated and flat iron sheeting, drawn wire, flattened tin cans and old metal tools tumbled throughout this context across more than 6 m^2 (3 m long and 2 m wide). It was these artefacts, rather than a slag floor, that were the cause of the large positive magnetic value recorded during the magnetometer survey.

Further, at the western edge of the Trench A excavation, a new context emerged, consisting of heavy white compacted clay that appeared to have been deliberately cut in a rounded-off shape; it subsequently became clear that this was a cavity dug into the hillside. It became obvious on further investigation that the structure being excavated was a 'dugout', where a low shelter wall had been dug into the bedrock, taking advantage of the slope of the land, with a floor extending eastwards from it (Fig. 9b). Regular depressions in the top surface of the wall are indicators of supports to accommodate a wall or thatched roof; several wooden railway sleepers and part of this roof, which had subsequently been covered with iron sheeting, were found collapsed in the centre of the building. In the hollow interior, below the metal, the occupation layer consisted of a floor with channels running east-west, and a cobbled path at the eastern edge constructed of cut stones including some slag pieces; the hundreds of glass and ceramic artefacts recovered are consistent with this being a domestic dwelling. Whilst these floors were difficult to detect in the GPR amplitude slices (Fig. 9c), they were more visible in the reflection profiles and showed up as strong planar reflections (Fig. 9d). These reflections are about 10 m long, the same length as the documented dwellings on the site and about 20 cm thick.

Excavations in the 2017 field season concentrated on Trench F, again situated over AOI07, which was 7 m long and 5 m wide, again on a north-south axis (Fig. 10a). The Trench F stratigraphy was very similar to that in Trench A, and the first 25 cm was excavated using a mechanical excavator. Following the removal of this fill, excavation continued with hand tools. The results were consistent with those from the previous year's excavations, with large amounts of corroded metal (bed frames, flat and corrugated iron sheeting, drawn

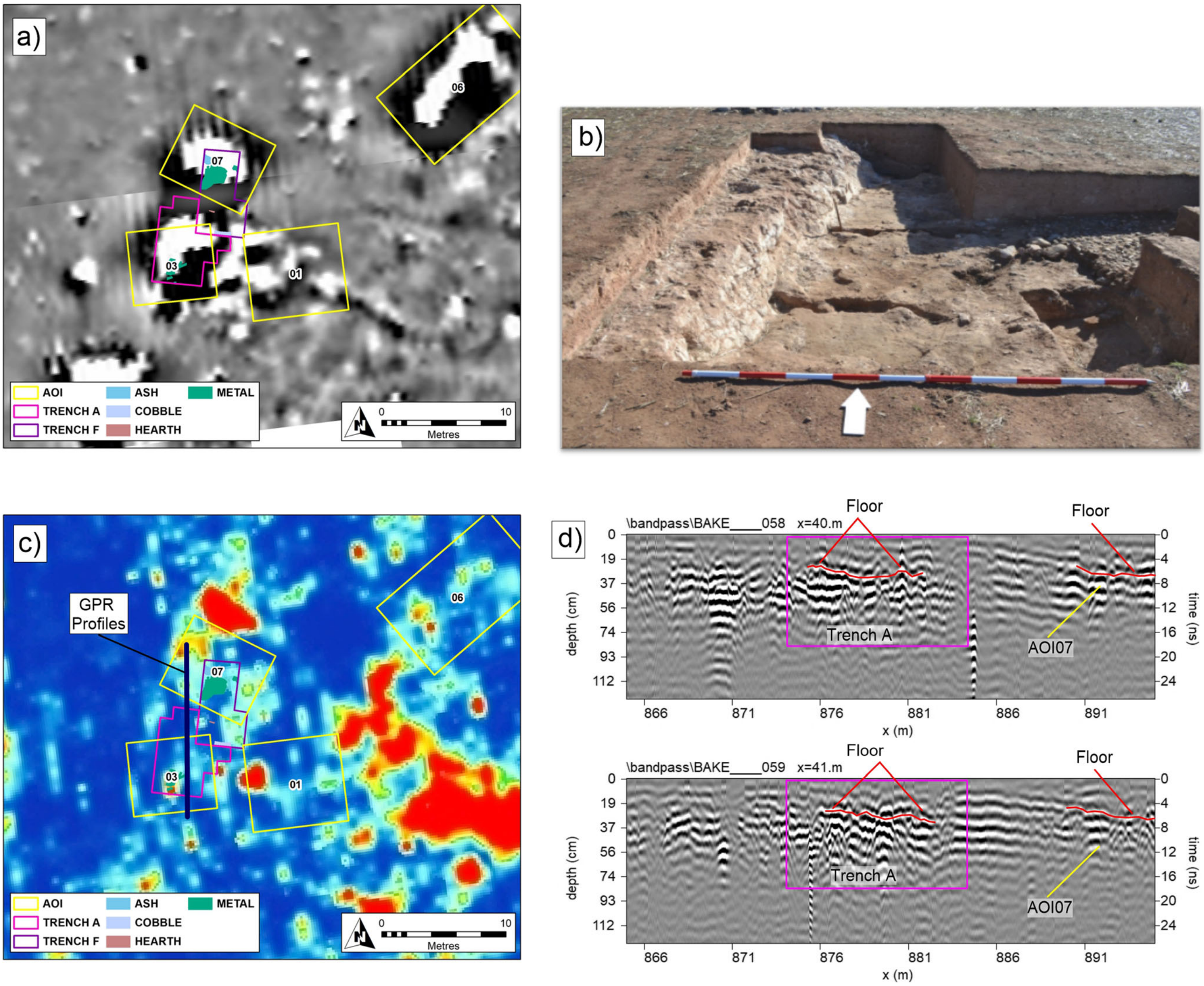

Fig. 9 **a** Gradiometer map is showing the location of Trenches A and F over the tested oblong magnetic anomalies in AOI03 and AOI07. **b** Photograph of Trench A during excavation. **c** Amplitude slice-map from 15–40 cm below surface showing location of Trenches A and F, and the GPR reflection profiles. **d** Reflection profiles 58 and 59 showing the floors in Trench A (red line) and the floor associated with the building in AOI07 (red line)

wire, and flattened tins) emerging from the interior of the dwelling at a depth of 30–45 cm below surface. The fill and metal covered the occupation layer, which emerged at a depth of 70–80 cm. Together Trenches A and F revealed a dugout dwelling that adheres to the oblong design of an Irish vernacular house and is consistent with the type of dwelling associated with a clachan. The gradiometer results revealed this oblong shape due to a large amount of metal infill inside the dwelling (see Fig. 10a), whilst the GPR reflections show the floors as strong planar reflections (Fig. 10b).

Whilst much of the surveyed site could not be tested archaeologically, we can still hypothesise what certain anomalies could represent. For example, the dance floor was reported to be in the eastern half of the survey area and due to the repeated trampling of the ground surface, consisted of highly compacted earth. Both the magnetic gradiometer and GPR results showed weaker responses in this area (Fig. 11). However, the GPR reflection profiles running through this area showed a strong planar reflection that occurred around 40 cm below surface, most likely imaging a hard-compacted soil layer. Whilst anomaly AOI02 could not be investigated due to the hard fill located above it, both instruments picked up this linear feature: the GPR as a high amplitude reflection and the gradiometer as a positive magnetic response (Fig. 12a). The reflection profile highlights this feature well, which occurs at ~30 cm below surface, extending to about 60 cm below surface (Fig. 12b). The nature of the large circular high amplitude GPR reflection defined as AOI08 is still unclear, but its shape strongly suggests it is of anthropogenic origin (Fig. 12c). It could be that these higher amplitudes are clay fill or a hard-compact layer as they have similar characteristics as other strong GPR reflections on site. Alternatively,

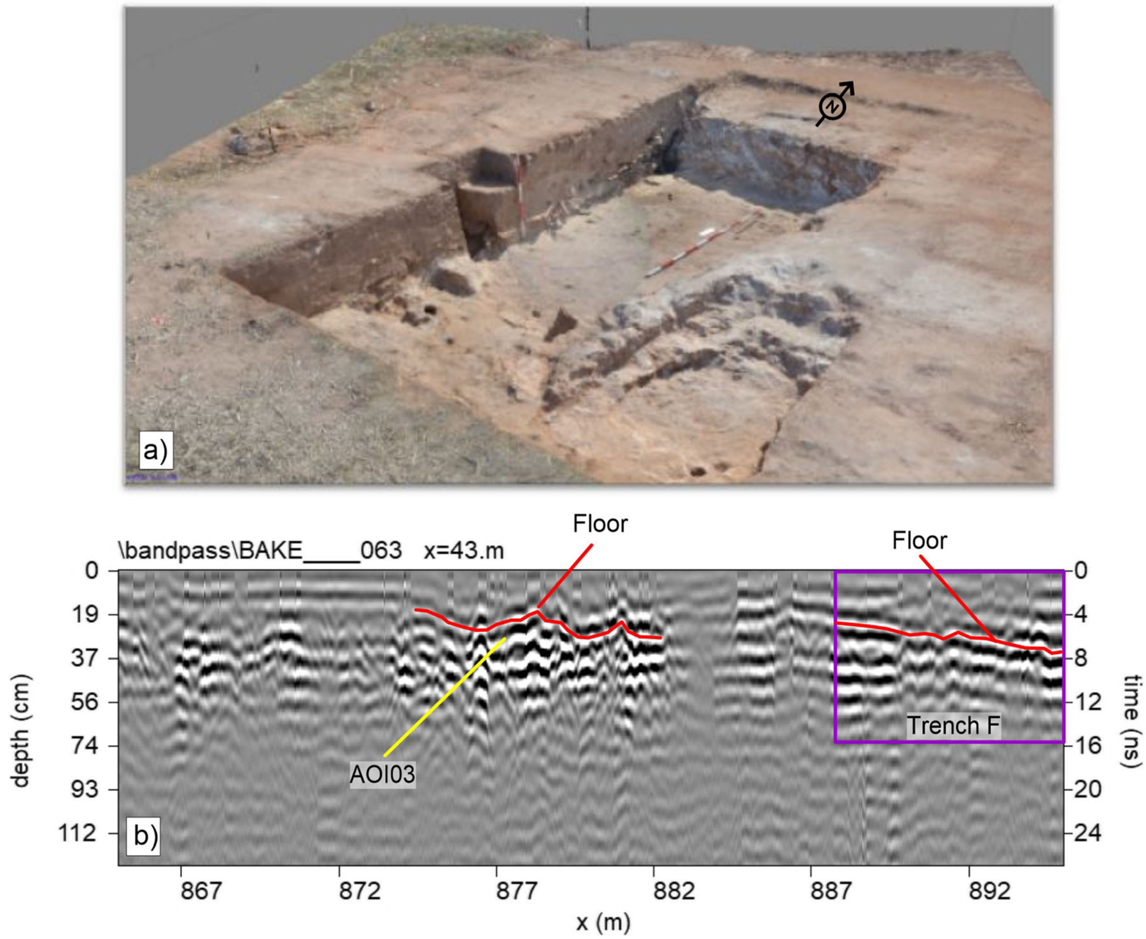

Fig. 10 **a** Photogrammetric image of Trench F excavations and **b** GPR reflection profile 63 showing the floors in Trench F (red line) and the floor associated with the building in AOI03 (red line)

it could be the removal of a hard layer as the material inside the circular feature is weaker (Fig. 12d).

The analysis of the excavated artefacts from Baker's Flat is ongoing as part of Arthure's PhD research. Early indications are that much of the material reflects consumer habits of the broader colonial Australian community of that time (see, for example, Crook 2000). One distinct element of the ceramic assemblage, however, that may indicate a degree of 'Irishness'

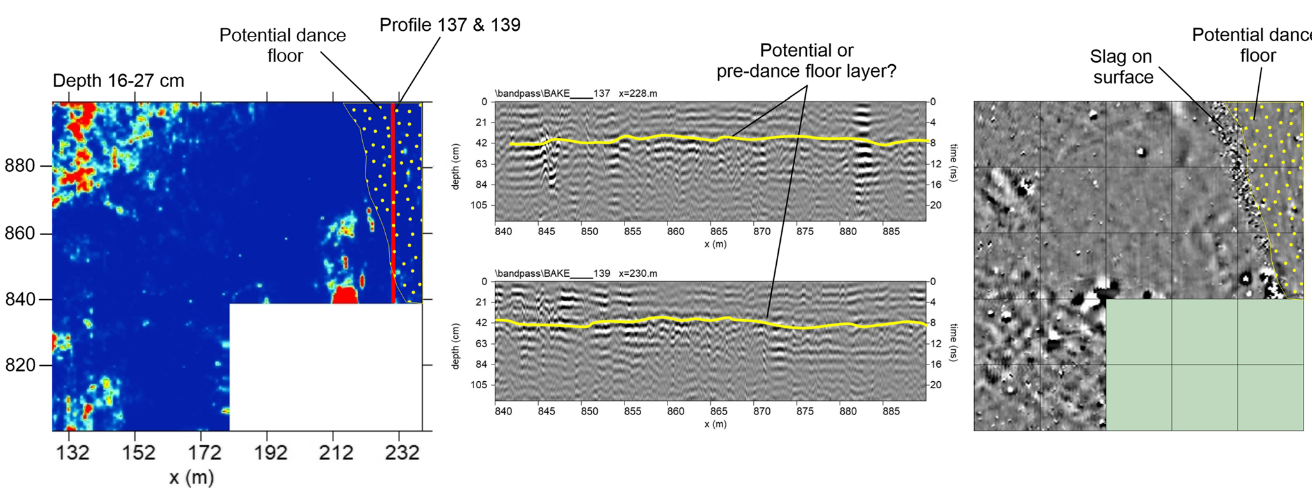

Fig. 11 (left) Amplitude slice-map of upper surface layers showing the location of reflection profiles 137 and 139 and the potential dance floor; (centre) two reflection profiles showing strong amplitude planar reflections (yellow line) presumably around 35–65 cm below surface; and (right) the gradiometer map of the potential dance floor and concentration of slag. Note grid squares in gradiometer map are 20 m

is the presence of a large variety of colours and patterns. This mismatching is consistent with data for the nineteenth century Irish poor in areas of rural Ireland (Orser 2010, p. 92–94) and urban United States (Brighton 2011, p. 41–44; Rotman 2012, p. 35–37). We note that the Australian experience is different from Ireland and the United States and, as Crook (2000, p. 23) has argued, there is an economic element involved: if crockery was being purchased in small quantities or piece by piece, as it could be afforded, a mismatch of colours and patterns was likely. Interpreting this as Irish is therefore necessarily speculative at this stage whilst the analysis is incomplete; it will be discussed in detail in Arthure's forthcoming thesis (Fig. 13).

The two samples of slag collected from the site that were analysed produced similar mass-normalised susceptibility and remanence values despite being almost three orders of magnitude difference in mass. Their susceptibility and remanence values are approximately two and three orders of magnitude than most vertic soils (Table 1).[2] Measurements of susceptibility as a function of temperature show that there is only one composition of magnetic mineral in the slag. Therefore, the bimodal coercivity mixture is likely to be due to two discrete grain size distributions. Electron microscopy of archaeological slag at other locations has shown that small samples can consist of agglutinates, where splattered droplets of molten slag harden into composites (Shaar et al. 2015). Different droplets would have similar compositions but may have experienced slightly different cooling histories, giving rise to different magnetic size distributions.

Discussion

The geophysical work completed on the Baker's Flat site has provided a more comprehensive understanding of the site and its spatial layout. Whilst both instruments detected subsurface cultural features, the gradiometer results proved to be more valuable for providing useful information about the settlement's layout, specifically the types of buried archaeological material present on the landscape. One reasoning for the absence of definable archaeological features in the GPR amplitude slice-maps was the notion that the occupants of Baker's Flat built their houses directly on top of and within the local bedrock (calcrete). Ethnohistorical sources reported this type of construction was taking place at the site, and the 2016 and 2017 excavations confirmed this. The fact that after the site was abandoned, the buildings were levelled and filled in with a different material to flatten and smooth the land surface in preparation for cropping had implications for both the geophysical survey and subsequent archaeological excavations. This infilling ranged in thickness from 25– 75 cm across the site, making it difficult not only to interpret the geophysical data but also to test several anomalies as evidenced with AOI02.

Areas that could be tested archaeologically revealed that the larger oblong magnetic anomalies were former buildings. Trenches A and F, interpreted as the inside of a dwelling/dugout, showed that the dwelling had been abandoned and the building itself collapsed. Some metal refuse was either left in situ or cleaned up from the surrounding vicinity and pushed inside, causing the large magnetic signatures that make up the oblong anomalies in this area. At about the same time that the metal refuse was pushed in, these dwellings had also been filled in with soil by the landowner to facilitate farming (D. Hampel pers. comm. 2012, 2017). These observations from the Trench A excavations allowed us to anticipate the findings in Trench F the following year. More importantly, the landowner was able to confirm that his father had levelled any remaining buildings on Baker's Flat in the 1950s and had brought in clean fill to level out the site, explaining why this context was so sterile. Any large items lying on the surface at that time, including sheets of flat and corrugated iron, metal bed frames and wheelbarrows, were tossed into the 'holes' of the dugouts and filled in. This accounts for the metal that was found on top of the occupation layer, and why the occupation layer is rich in artefacts such as ceramics, glass, metal and faunal remains but the layers above are rich only in metal.

[2] These relative differences have significant implications for magnetic gradiometry at archaeological sites. The Q value, or Koenigsberg ratio, is the ratio of a rock's remanent magnetisation (Mr), meaning the magnetic moment of substances when no magnetic field is applied to its induced magnetisation meaning the magnetic moment when a magnetic field is applied to a substance. In this study, we used the NRM intensity for measuring Mr. Since low Q value (< 0.5) samples are dominated by the induced magnetisation, their magnetic anomalies will appear as magnetic highs (positive) compared with more non-magnetic crusts. The amplitude of an induced anomaly increases with the magnetic mineral content. When Q values are > 2, the orientation of a sample's NRM becomes essential. When Q equals 5, the dominant remanence can lead to large negative anomalies, especially when the NRM vector is at an obtuse angle to the Earth's magnetic field direction. Assuming an ambient magnetic field intensity at Baker's Flat is 58 μT (46 A/m), the Koenigsberger ratio for the two samples is significantly greater than 2 (see Table 1). As such, their strong magnetic remanence will likely contribute towards elevated anomalies with respect to surrounding soil and sediment with lower Koenigsberger ratios. The average sediments Q values are between 0.02 and 10 (Hunt et al. 1995). Since Baker's Flat is less than 1000 years old, the remanence direction of the slag should be roughly parallel to the modern field, thereby generating large positive anomalies such as we see in the gradiometer map (see Fig. 6a).
The susceptibility as a function of temperature, which is good for detecting the magnetic minerals of the slag, was remarkably reversible on warming and cooling (Fig. 13a). The Curie temperature (Tc) was slightly higher during warming (471 °C) than during the cooling phase (463 °C). The slight decrease on cooling may be associated with partial oxidation of the assemblage or with the relaxation of confining pressure on the mineral grains embedded in the rapidly quenched silicate glass. These temperatures are lower than the Curie temperature of pure magnetite (580 °C) (Evans and Heller 2003; Thompson and Oldfield 1986) and are more consistent with magnetite partially substituted with metals such as Titanium (Ti), Chromium (Cr), or Magnesium (Mg).
The sample shows mostly a single domain-like behaviour with minor contributions from the pseudo-single domain (PSD) and multidomain (MD) magnetic grains (Dunlop 2002) (Fig. 13b). Magnetic domains are small regions in which the magnetisation is uniform within a sample, but the magnetisation vector with each region differs from that of its neighbours (Evans and Heller 2003). Plots of the back-field derivative of the data show two overlapping coercivity distributions with peaks near 30 and 75 mT (Fig. 13c).

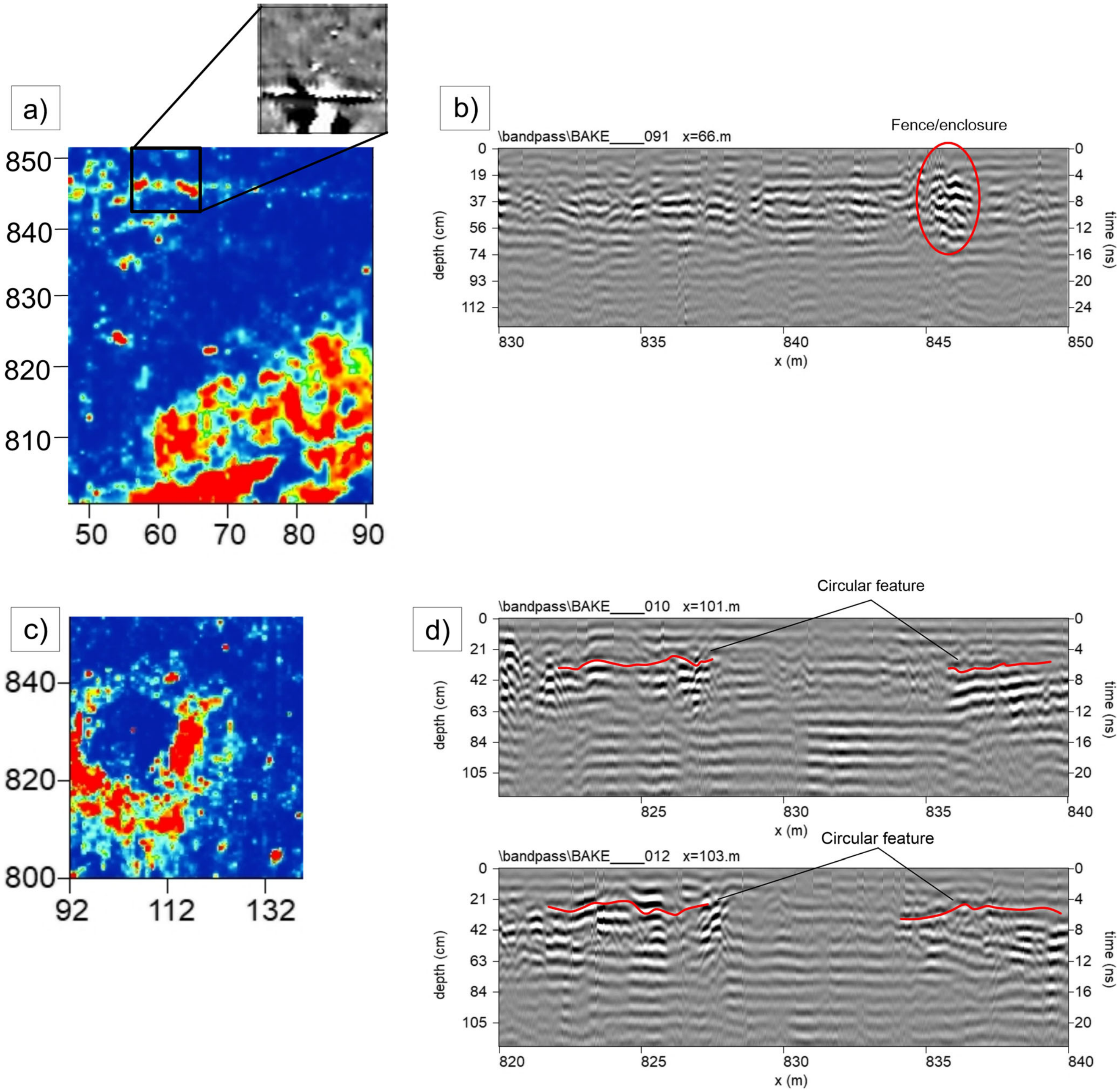

Fig. 12 Amplitude slice-map from 15 to 40 cm showing **a** the fence/enclosure with a 20 m grid inset of the gradiometer map and **b** reflection profile 91 displaying the fence/enclosure (red circle) presumably around 19–56 cm below surface. Amplitude slice-map of the large circular feature (**c**) and (**d**) reflection profiles 10 and 12 showing strong amplitude planar reflections (red lines) presumably around 20–45 cm below surface marking the boundary of the circular feature

The results of the magnetic gradiometer survey have also revealed what appears to be clearly defined zones or areas of habitation on the surveyed portion of Baker's Flat (Fig. 14). These areas reflect the use of the settlement for residential, farming, and social activities. Much of this information comes from the positive magnetic responses on this site. One piece of evidence is the use of slag, a material that was found throughout the site, especially a linear concentration that marked the boundary of the reported dance floor which created some of the anomalies detected. Another was the dumping of numerous metal artefacts into the houses when they were bulldozed and levelled, as part of the site's abandonment and later agricultural use. Other areas showing strong magnetic responses were the enclosures, the paths leading up to the buildings, isolated metal fragments and an area of potential campfires near the area of the dance floor. Weaker magnetic responses were also important, particularly the dance floor which also contained weaker GPR signals. Whilst only a small portion of the site was surveyed, it is clear that the geophysical results provide a more detailed representation of the site than

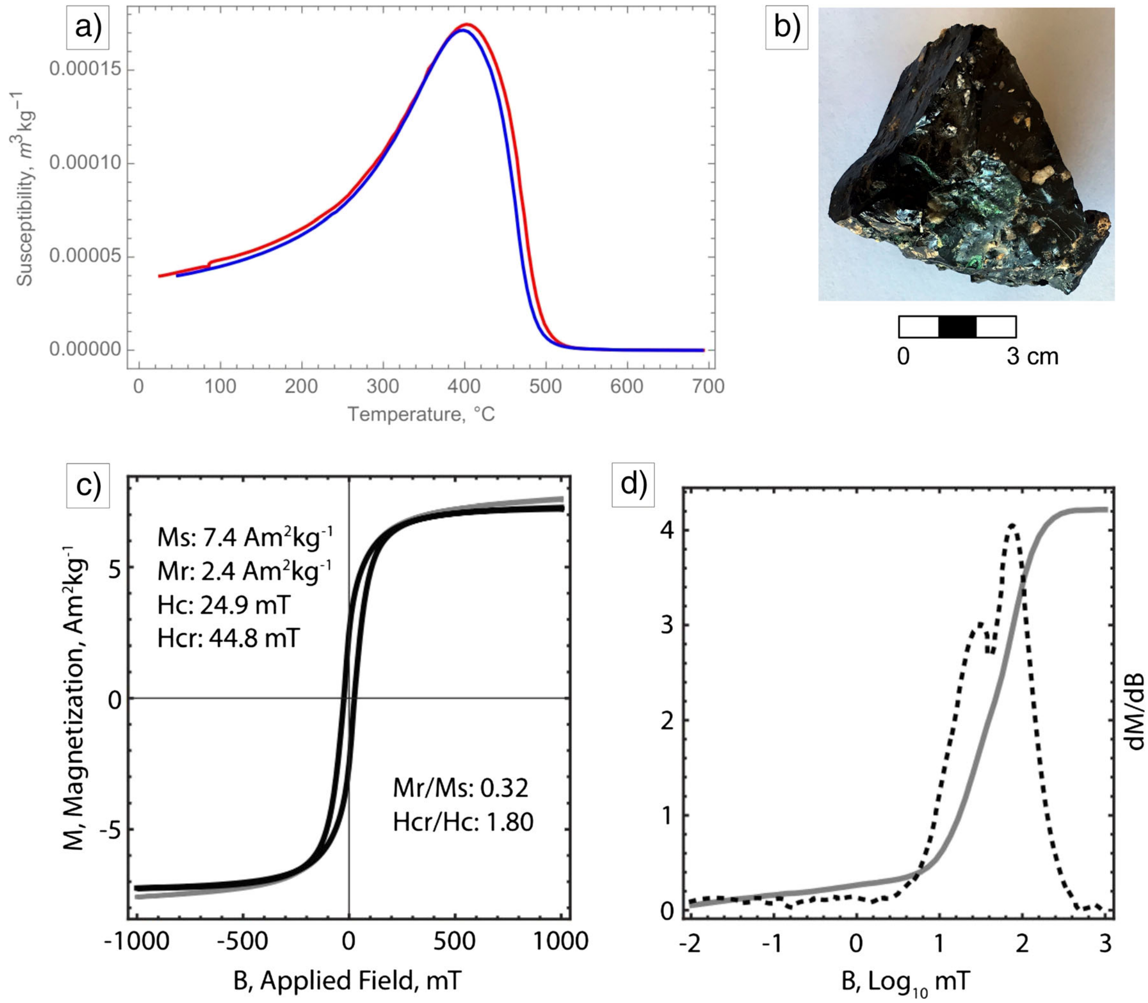

Fig. 13 **a** Temperature dependence of low-field susceptibility showing warming (red) and cooling (blue) for Slag 02. **b** Image of slag from the site; **c** hysteresis properties showing major hysteresis loop (grey) and the total ferrimagnetic induced magnetisation of Slag 02 (black); and **d** the rotated backfield data in grey and its derivative (dashed line)

the 1893 map which only showed a few buildings. This is a critical outcome when examining early European settlement sites in general, especially if historical plans are scarce.

Another key aspect of this study was the importance of taking into account oral testimony. Both recorded in the past and contemporary from the current landowner; this enabled us to gain a greater understanding of the changes that had occurred in the landscape. Oral testimony also provided evidence about the specific housing style of single-storey one-room-deep buildings. Archival records and photographic evidence provided information on the Irish style houses likely to have once been present, specifically their size and shape, and how they were constructed from local clay. Legal evidence revealed how the occupants were working and modifying the land through the cooperative farming practice of rundale, including the use of fences and enclosures. The geophysical results allowed for the mapping of subsurface features at the Baker's Flat site and the excavations provided a way to test them. The excavations proved some of the geophysical interpretations and provided information on the site's post-depositional processes which included infilling of new soil and levelling. It is also worth noting that despite the site

Table 1 Susceptibility and remanence properties of the two slag samples

Sample	Mass (g)	$\chi_{465\ Hz}$ ($\times 10^{-5}$ m^3 kg^{-1})	$\chi_{4650\ Hz}$ ($\times 10^{-5}$ m^3 kg^{-1})	χfd (%)	NRM (Am^2 kg^{-1})	Q
Slag 01	8.63	5.1 ± 0.1	4.7 ± 0.1	8.5	1.05×10^{-2}	4.5
Slag 02	0.01	5.8 ± 0.1	5.3 ± 1	7.8	4.57×10^{-2}	17.2

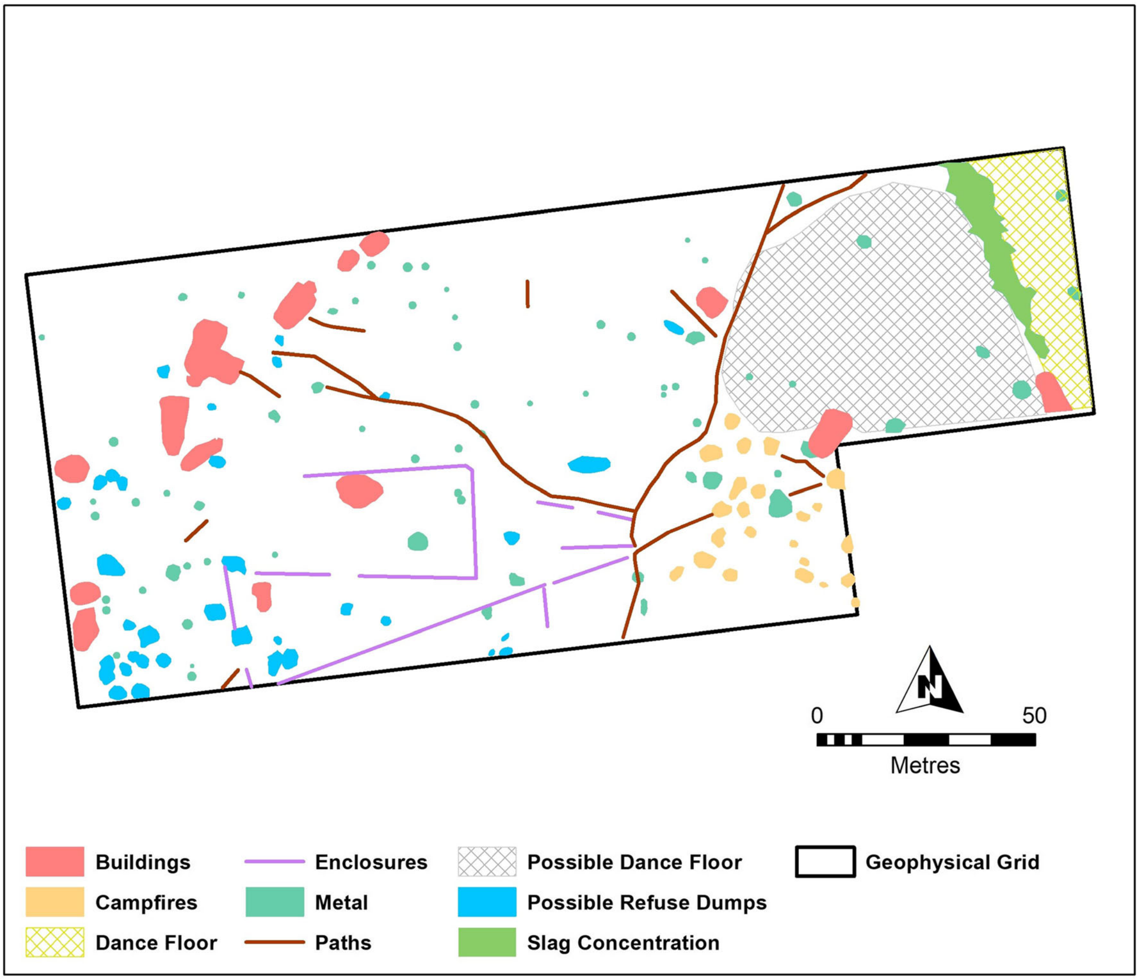

Fig. 14 Interpretation of Baker's Flat site based on the geophysical data. Note that areas marked as refuse dumps and campfires are extrapolated as such as they have not been ground-truthed

being bulldozed and levelled, we were still able to map features, an outcome that Brooks et al. (2009) also made in their study, despite decades of the site being ploughed.

We have also been able to link material culture and tradition in our study, through the use of archival and oral testimonies and archaeology, demonstrating that combined methodologies are imperative for effective interpretations (cf. Schlanger 1992, p. 92; Lawrence and Low 1990; Thompson et al. 2011, p. 197). The interpretive maps allow us to start postulating about the people of Baker's Flat, how they used their space and surrounding landscape, and how this use reflects the long-term occupation of one region (Ireland) and the migration of Irish cultural practices to another place (Australia). We can also start hypothesising about other trends on the site that we might expect to see if the rest of the site was surveyed with geophysics. For example, given that AOI03 and AOI07 correlated with a vernacular Irish house, we predict that the identification of similar geophysical signals elsewhere on the site will represent the same features—houses or buildings. If these patterns are in clusters, this clustering of 'houses' would mean a clachan, a tradition that is evident throughout the site, not just in the area we investigated.

Conclusion

This study has expanded our understanding of the built environment and the use of space on Baker's Flat in several key ways. Firstly, it provided a broad spectrum for understanding both the site's natural and cultural environment, making it possible to recognise the challenges in realising their formation processes and the geophysical interpretation. Targeted archaeological excavations helped in discerning some of these features where applicable. Secondly, we found magnetic gradiometer to be more effective than the GPR at discerning the site layout, particularly the location of houses as many of these houses were filled in with metal debris after being bulldozed in the 1950s. Thirdly, both instruments detected a fence/enclosure as well as weaker geophysical signals in the area rumoured to be a dance floor. Only the GPR identified a large circular feature, the interpretation of which remains elusive. Analysis of slag found on the eastern portion of the site showed that this material contributes to many of the positive magnetic responses seen here and that this material was used to border the dance floor arguably creating a bounded social space. This study has demonstrated that traditional construction styles in Europe were brought over and reproduced in Australia during the years of early colonial settlement, being preserved here even as they disappeared from their country of origin. To date, only one geophysical survey of this scale has been completed in Australia. This study not only demonstrated the success of geophysical applications for mapping early European settlements but also provided a wealth of information that can be tested with traditional archaeological methods and oral histories.

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