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Title: Mapping unmarked graves with ground penetrating radar at the Walkerville Wesleyan cemetery, Adelaide

Authors: Ian Moffat, John Linsell, Anthea Vella, Belinda Duke, Jarrad Kowlessar, John Gareth Griffith and Allison Down

A Ground Penetrating Radar (GPR) survey was undertaken to map unmarked graves within the historic Walkerville Wesleyan Cemetery in Adelaide. The survey revealed 168 probable graves, 20 possible graves and 68 additional graves containing more than one interment. Our results demonstrate the utility of geophysical methods, specifically GPR, as a non invasive tool for managing the cultural heritage of cemetery sites and suggest that this method could play a more significant role in Australian archaeology.

Abbreviations: GPR: Ground Penetrating Radar; RTK GNSS: Real-time Kinematic Global Navigation Satellite System

Introduction

The Walkerville Wesleyan Cemetery is a historic cemetery opened in 1849 and located approximately 3.5 km northeast of the Adelaide CBD. This is one of the earliest village cemeteries in Adelaide, which historical research suggests has been the location of 3,785 burials in 1,008 plots (McDougall and Vines 2012). The cemetery fell into disuse in the late 20th century. Only 1,158 individual burials in 324 plots are marked at the site.

Walkerville Wesleyan Cemetery has a trapezoidal shape with maximum dimensions of approximately 130_60 m, and broadly slopes to the south. The site is underlain by Quaternary sediments (Thompson 1969) and has brown solonised soil (Taylor et al. 1989). There are a moderate number of trees within the survey area, and a large number of surface features within the site including marked graves, garden beds, seats, a rotunda and a bitumen path. A fence surrounds the site, which is a substantial sandstone wall on the northern and southern boundaries.

Methods

Ground Penetrating Radar (GPR) is a geophysical technique that uses high-frequency electromagnetic waves to non-invasively acquire information about the subsurface. The geophysical detection of burials for forensic and archaeological investigations has accumulated a voluminous literature summarised by Moffat (2015), Conyers (2006) and Ruffell and McKinley (2005). Most of the geophysical surveys undertaken to map graves in Australia were performed as commercial projects but a number of studies have been published (Bladon et al. 2011; Lowe et al. 2014; Marshallsay et al. 2012; Moffat et al. 2010; Moffat et al. 2016; Powell

2004; Stanger and Roe 2007; Sutton and Conyers 2013; Wallis et al. 2008; summarised by Lowe 2012). Cemetery studies more broadly are widespread in Australian archaeology and utilise a plethora of techniques including surface survey (Littleton and Allen 2007; Muller 2015; Ward et al. 1989), excavation (Lowe and Mackay 1992; Pitt et al. 2017), bioarchaeology (Anson 2004) and isotope geochemistry (Owen and Casey 2017; Pate 1998, 2000). These studies can contribute significant information about many aspects of these sites but are, with the exception of excavation (which is invasive, expensive and often not in keeping with community wishes (Wallis et al. 2008)), unable to verify the number of unmarked graves.

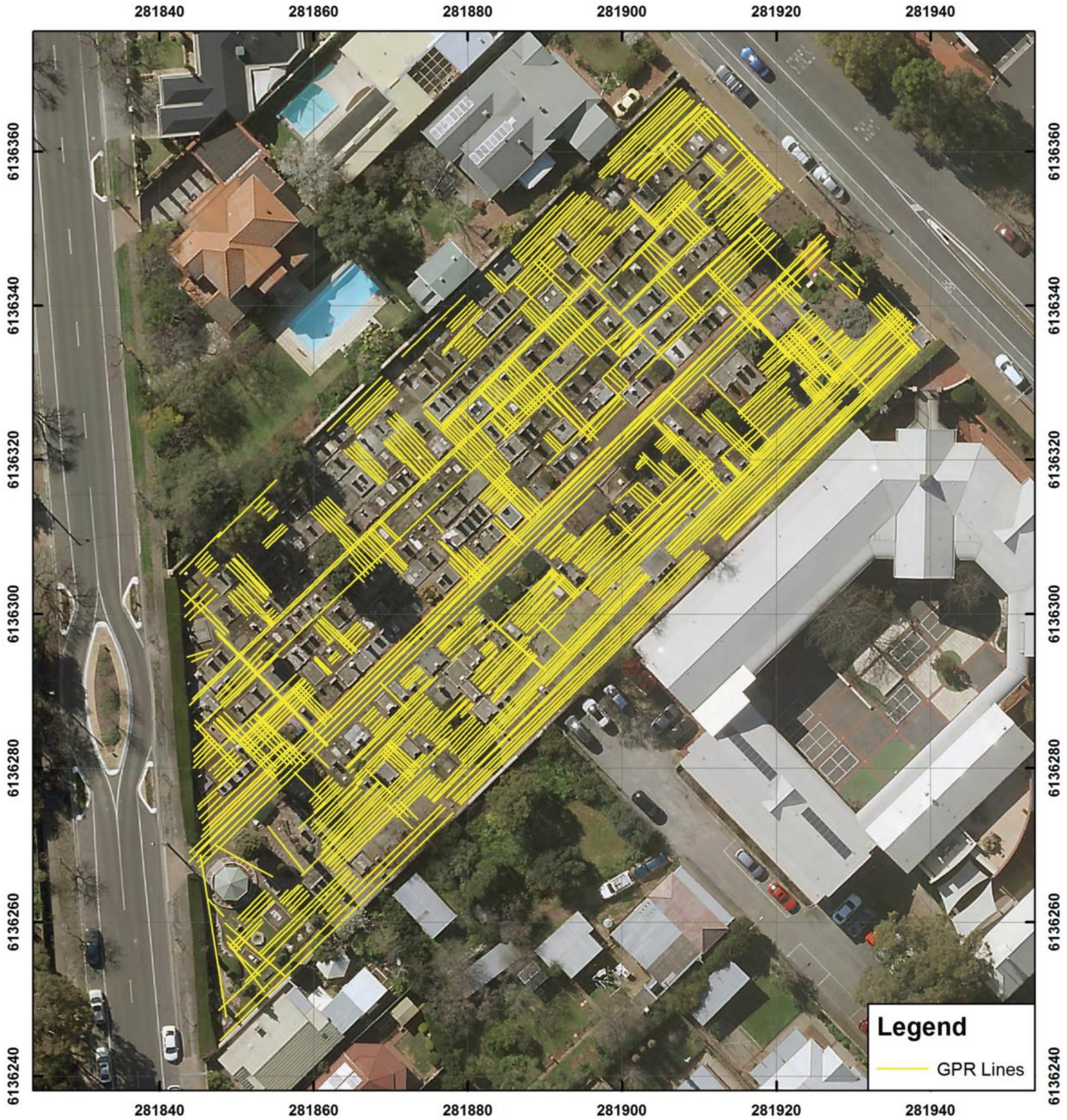

Figure 1. GPR line locations (n¼647) at Walkerville Wesleyan Cemetery.

The survey at the Walkerville Wesleyan Cemetery used GPR lines (647 in total, shown in Figure 1) placed in opportunistic locations and orientations between surface features (largely extant grave markers). Where possible, GPR lines were placed approximately parallel, with a 0.5m spacing between adjacent lines. Lines were stopped at surface obstacles and a new line started on the other side of the feature. The location of the start and finish of each line was collected using a CHC x91þ RTK GNSS (Real-time Kinematic Global Navigation Satellite System) unit mounted over the centre of the GPR antenna. Surface features were recorded using a high-resolution digital elevation model and georectified orthophoto created using an ITW Ultrafoil 15 aerial photography kite with a Canon S100 camera running a CHDK script taking photographs every 3 seconds that were processed using Agisoft Photoscan Professional.

The survey was conducted using a Malå X3M GPR with a shielded 500MHz antenna. Data were collected using a sample frequency of 10,755 MHz, a time window of 66 ns, 712 samples, trace increment of 0.020m and 2 stacks. Data were processed using ReflexW software using a sequence involving move start time, Butterworth bandpass, background removal, running average, energy decay and a timecut filter.

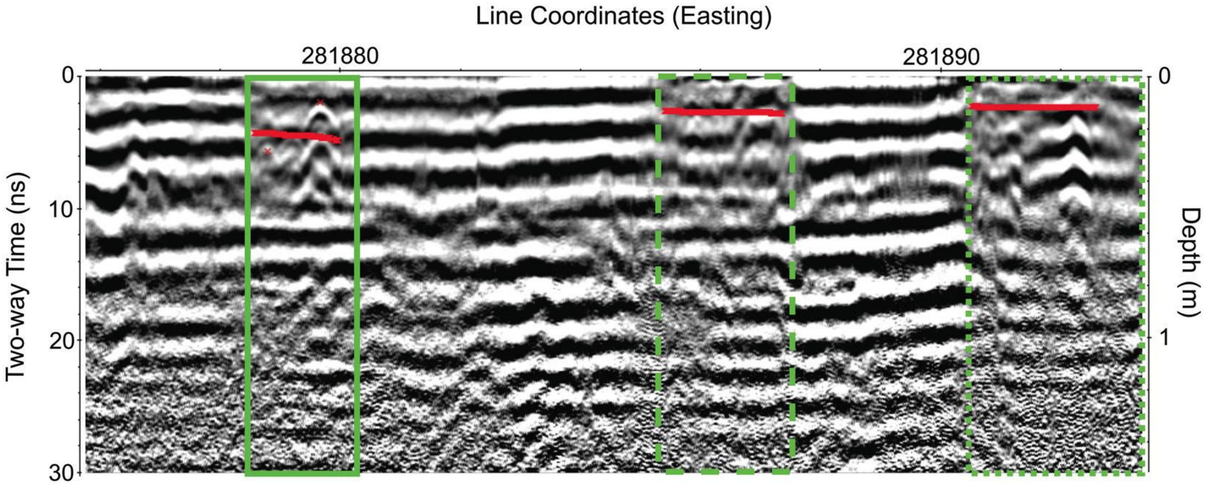

Figure 2. A section of GPR Line 125 from Walkerville Wesleyan Cemetery with picks shown on the image in red and interpreted probable, possible and multiple graves shown in solid, dashed and dotted green, respectively.

The processed GPR data were interpreted using a pre-specified interpretation scheme, which included identifying individual hyperbolas (symmetrical cone shaped reflections from features with a high contrast in dielectric permittivity, such as metal), stratigraphic breaks, and subsurface disturbances. Graves were interpreted on the basis of multiple adjacent stratigraphic breaks that were recognised as abrupt changes in reflector amplitude in the shallow (<0.5m depth) subsurface, as shown in Figure 2. These features were interpreted to represent disturbance of the A horizon of the soil profile due to the digging and subsequent refilling of the grave shaft. This is a much more robust methodology for the detection of unmarked graves than the widely used method of attempting to locate skeletal material or coffins directly using hyperbola picking, as explained in more detail in Moffat (2015).

Where stratigraphic breaks were located in multiple adjacent GPR lines and their spatial extent corresponded to the approximate size (_1 _ _2m) of an adult coffin these features were interpreted to represent an unmarked burial. In the case where only a single GPR line was able to be collected in an area (i.e. where surface features were too close together to allow a second line) graves may be interpreted based on a stratigraphic break observed from a single line. The methodology used was unable to image burials which contain multiple coffins in a single burial plot and the method used had a lower limit of size recognition of about 1_2m; smaller graves were not included in the results.

The degree of confidence of the interpretation of these data is reflected by classifying the unmarked graves as probable or possible (as discussed in Moffat et al. 2016). Features which are classified as probable unmarked graves have sub-surface disturbance with dimensions of approximately 2m _ 1m and an orientation that corresponds to the rows of marked graves on the surface. Features identified as possible unmarked graves have a different shape or orientation or are found in unexpected parts of the cemetery (such as under the current path bisecting the site). This approach is similar to the RAG (red, amber, green) method of unmarked grave identification (Donnelly and Harrison 2013; Ruffell and McAllister 2015). However, the classification of graves at the Walkerville Wesleyan Cemetery is entirely based on the spatial properties of the geophysical anomalies rather than including consideration of surface features such as headstones or topographic anomalies.

Results

The survey revealed a total of 256 subsurface interments including 168 probable graves, 20 possible graves and 68 areas with multiple burials, as shown in Figure 3.

Unmarked graves are located in nearly all areas where the ground surface was not obstructed by surface features such as trees or graves in the northern portion of the cemetery. The distribution of graves (both marked and unmarked) is less dense in the southern part. GPR identified a number of features (the largest being _28_2m) with a total area of _894m2 that are interpreted as containing multiple graves. We are unable to distinguish individual burials in these areas, but, assuming an average grave area of 2m2 based on the approximate dimensions of an adult coffin, these features probably contain at least 447 burials. On that basis, the GPR survey has accounted for 635 unmarked grave plots in total, which, combined with the 324 currently marked plots, suggests that a total of 959 of 1008 plots identified from historical research have been located (McDougall and Vines 2012).

Figure 3. Unmarked grave locations at the Walkerville Wesleyan Cemetery.

Discussion

A relatively well-understood and researched cemetery in an urban area such as Walkerville is probably the least likely location for finding unmarked graves with geophysics. Cemeteries that are poorly studied and have poor spatial definition (often in rural areas) are more likely to contain unmarked graves, and so geophysics has even more potential to help understand these sites. That we were able to locate at least 256 graves in this study speaks to a critical need for this approach to be adopted far more widely as part of cemetery investigations.

Another critical outcome of the survey is demonstrating the importance of high-quality positioning and site-recording techniques in undertaking geophysical surveys on cemetery sites that have a complex mosaic of surface features. The convoluted nature of the portions of this site that are not obstructed by surface features is illustrated by the map of GPR line locations in Figure 1. Emplacing surveys of this spatial complexity in a timely fashion is only possible using survey-grade positioning, such as RTK GNSS or total station, and is not feasible using the historically conventional approach of emplacing rectangular grids using measuring tapes (such has been employed in all previous published geophysical survey projects mapping graves in Australia other than Moffat et al. 2016). Combining these data with a high-resolution georectified orthophoto (which can be created using a unmanned aerial vehicle, kite or pole) provides the opportunity to evaluate the position of the unmarked graves with reference to surface features and produce a visual, easy-to-understand data product in spatially complicated survey areas.

Conclusions

At least 256 individual unmarked graves were located at the Walkerville Wesleyan Cemetery in Adelaide using GPR. These included 168 probable and 20 possible unmarked graves. Sixty-eight additional areas where multiple graves are likely to be present have been mapped, which contain an estimated total of 447 individual burials.

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ORCID

Ian Moffat http://orcid.org/0000-0002-2171-7145
Anthea Vella http://orcid.org/0000-0001-6562-3135
Belinda Duke https://orcid.org/0000-0002-4300-9596

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