The Journal of the Anthropological Society of South Australia is the official publication of the Anthropological Society of South Australia. It is a refereed journal that has been published since 1963. A list of recent peer reviewers can be found on the Society’s website http://www.anthropologysocietysa.com. The journal primarily provides a forum for researchers of Indigenous Australian anthropology, archaeology, history and linguistics although broader topics related to all of these disciplines may also be included.

Contributions accepted include: articles (5000-8000 words), short reports (1000-3000 words), obituaries (500-2000 words), thesis abstracts (200-500 words) and book reviews (500-2000 words). Notes to contributors are available through the Society’s website.

Should you wish to submit a paper to the journal please direct your enquiries to the secretary of the Anthropological Society of South Australia (current contact details can be found on the Society's website).

The journal is free for current members of the Anthropological Society of South Australia. Subscription application/renewal forms are also available through the Society’s website.

**Anthropological Society of South Australia Committee**

President: Dr Keryn Walshe (South Australian Museum)
Secretary (Webmaster): Dr Amy Roberts (Flinders University)
Treasurer: Mr Tom Gara (Native Title Section – Crown Solicitor’s Office – South Australia)
Councillor: Professor Peter Sutton (University of Adelaide/South Australian Museum)
Councillor: Dr Alice Gorman (Flinders University)
Councillor: Mr Chris Nobbs (South Australian Museum)
Councillor: Dr Janelle White (University of South Australia)

**Journal of the Anthropological Society of South Australia Editorial Advisory Board**

The Editorial Advisory Board consists of members the Anthropological Society of South Australia committee as well as the following specialists:
Professor Lester-Irabinna Rigney (Wiltj Yerlo, University of Adelaide)
Professor Jane Lydon (University of Western Australia)
Dr Paul Monaghan (University of Adelaide)
Dr David Martin (Australian National University)
Dr Natalie Franklin (Flinders University/University of Queensland)
Professor Robert Layton (Durham University)
Professor George Nicholas (Simon Fraser University)
Dr Stephen Loring (Smithsonian Institution)

The views expressed in this journal are not necessarily those of the Anthropological Society of South Australia or the Editors.

© Anthropological Society of South Australia 2014

ISSN1034-4438
# Table of Contents

**Editorial**  
*Amy Roberts*  

## Articles

Fighting Over the Heritage of South Australia’s Great Salt Lakes  
*Kim McCaul*  

An Introduction to Earthen Mound Sites in South Australia  
*Craig Westell and Vivienne Wood*  

Some Signs and Markers Employed by the Adnyamathanha of the Northern Flinders Ranges, South Australia  
*Bob Ellis*  

Three Scales: GIS, GPS and Digital Site and Data Recording Technology in Archaeological Salvage at Olympic Dam in Arid South Australia  
*Marjorie Sullivan, Peter Hiscock and Philip Hughes*  

The Need to Have Understood Your Local Geology: Nature and Sources of Materials Used to Manufacture Stone Artefacts at Olympic Dam, South Australia  
*Philip Hughes, Marjorie Sullivan, Peter Hiscock and Angela Neyland*  

An Investigation of the Use of Australites (Tektites) at Olympic Dam, South Australia  
*Barbara Rowland*  

## Short Reports

Filming at Cape Keerweer, Queensland, 1977  
*Peter Sutton*
THREE SCALES: GIS, GPS AND DIGITAL SITE AND DATA RECORDING TECHNOLOGY IN ARCHAEOLOGICAL SALVAGE AT OLYMPIC DAM IN ARID SOUTH AUSTRALIA

Marjorie Sullivan¹,², Peter Hiscock³ and Philip Hughes¹,⁴

¹Huonbrook Environment & Heritage Pty Ltd, PO Box 97 Moruya, NSW 2537, Australia
²Department of Archaeology, School of Philosophical and Historical Inquiry, Faculty of Arts and Social Sciences, The University of Sydney, NSW 2006, Australia
³Tom Austen Brown Professor of Australian Archaeology (as above)
⁴Department of Archaeology, Flinders University, SA 5001, Australia

Abstract

In a research and salvage study over ca 600km² of gibber and sandridge desert in arid northern South Australia, mobile digital geographic information system (GIS) technology was used to record a very large number of surface sites – mainly concentrations of stone artefacts. The records were stored in a GIS with landform information and height data, and were used: (1) To test a previously-developed model for the region which predicted that site distribution could be related to specific landscape patterns; (2) To identify sites for more intensive study during a follow-up salvage phase; and (3) To test explanations of the pattern of site characteristics and distribution, based on this large sample of open sites. This involved collecting and using digital data at several scales. Salvage phase excavations and detailed analyses at a much finer scale were related back to the broader scale survey information. As well as contributing new information to the archaeology of arid Australia, the study has demonstrated that mobile GIS is very effective for mapping large numbers of archaeological sites over an extensive survey area with high data intensities, for immediate analysis, and to provide a framework for subsequent detailed site and artefact analyses. Examples used include analysis of broad scale survey information, identification and description of salvage processes, linking regional dGPS and specific site data, and analysing intra-site variations in artefact distribution.
Introduction

Over the last decade Australian archaeologists have become increasingly involved in large-scale development projects and large area archaeological surveys. There have been concurrent improvements in technology that have enabled archaeologists to create very large data-sets that relate to both site surveys and detailed site investigations. A major challenge in these settings is to articulate and integrate those very large amounts of data of different types and at different physical and/or spatial scales and articulate them to enhance archaeological knowledge.

For the past seven years we have undertaken an extensive archaeological salvage and research program, and our experiences in selecting and applying information collection and management processes to articulate and integrate data sets at three different scales are explained here. The theme of the project is the nature of forager land-use in an arid high-risk environment, and the explanation of chronological change in patterns of occupation, resource use and technology. The theme of this discussion is methodological, specifically the application of GIS and associated digital technologies, with a focus on: (1) The intensive site survey and recording stage; (2) The physical salvage of information involving field collection of archaeological materials, and laboratory cataloguing and measuring; and (3) The analytical framework in which the findings of broad scale field investigations and detailed laboratory measurements were linked to provide data in formats ready for interrogation. The goal was to acquire information that would address current research questions and (hopefully) many that will be asked in the future.

The work reported on here commenced in 2007 (see Hughes et al. 2011), and there have been significant improvements in the technologies available since then that would simplify a similar project commencing now, including systems built on Android mobile communication devices with internet storage of data, such as the Federated Archaeological Information Management Systems (FAIMS) described by Ross et al. (2013). Such systems are based on simple and readily accessible recording equipment but one aim of a project like FAIMS is to make data widely available to other archaeologists, and many commercial clients want better assurance of data
confidentiality than such systems provide at this time. Large well-funded projects might prefer to choose a system such as that described here, and the principles and fundamental processes of that system remain valid and applicable regardless of the technological platforms chosen.

All Australian States, many Commonwealth agencies, and all large resource extraction companies now use geographic information systems (GIS) with cadastral or other position information as a mapping base. Site data overlays, including heritage information, are incorporated to variable extents in such systems, as tools to guide land-use management decisions. Such integrated systems have also been used widely for survey and salvage projects in the United States and Europe (Bevan and Connolly 2004; McPherron and Dibble 2003; Tripcevich 2004a, 2004b) but with a few exceptions (the use of GIS for example by Holdaway and Fanning [2010] and Holdaway et al. [2013]), even when sites have been recorded digitally, GIS technology has not been applied widely in that way in broad scale archaeological projects in Australia. Clearly such systems do not justify the input costs/effort where few sites are likely to be recorded or where the work involves small projects in widely separated geographic areas but they are useful in other situations.

**Broad Scale Archaeological Survey**

In 2007 a proposed expansion of the Olympic Dam mine (Figure 1) in arid northern South Australia triggered the need for an intensive large scale archaeological survey over a ~515km$^2$ area (Figure 2), to be completed by the end of 2009. On the basis of 30 years of experience in the area it was acknowledged there would be a very large number of sites to be recorded so a decision was made in the planning stage (see Hughes et al. 2011) to use hand-held computer/GIS technology and digital site records rather than written site recording methods.
Figure 1 Olympic Dam location map.
The decision in 2007 to use a mobile GIS has been described by Marwick et al. (2013) and was based on four advantages over paper-based systems of the numerous benefits recognised then e.g., by Tripcevich (2004a, 2004b):

- Mobile GIS is most efficient when data collection is intensive, i.e., many sites/person/day.
- A highly structured digital recording system minimises recording errors and eliminates the potential for errors and the time-costs of transcribing data from field notes or recording sheets into a computer. An additional related advantage is that data are stored in a form that makes them immediately available for spatial or statistical analyses, and interim reporting.
- There was a mining company GIS already in use, and although no direct access to that system was available for this study, digital datasets or shapefiles, including fence and road locations, previously surveyed areas and recorded sites, good quality recent air photography and terrain units that covered all of the survey area were able to be transferred from it. Some thematic maps had been digitised, other environmental and heritage data were able to be digitised and stored as shapefiles. While paper maps can provide this information, and may be easier to read than a small screen in bright sun, a mobile GIS gives immediate context awareness, enables a user to determine location relative to other features, and automates calculations such as distance, direction and area.
- Mobile GIS is most effective on large multi-year projects where the time and expense of setup and training is offset by fieldworkers becoming increasingly efficient with the technology.
In addition to these considerations, the Olympic Dam salvage program had multiple other stakeholders, including Indigenous groups, company executives, government authorities, and the digital field data could be shared immediately from a server GIS.

Off-the-shelf GPS-enabled mobile GIS-fitted hand-held computers (details in Appendix 1) were used by a team with limited prior experience in GIS or digital data capture to walk over and survey the 515km² and record more than 16,000 open archaeological sites. The landscape consists of ancient stony tableland surfaces partly overlain by fields of longitudinal east-west dunes. Many of the interdunal swales and extensive plains are covered by gibber gravels and cobbles. The area lies within the driest part of Australia, rainfall <200mm annually, and surface water sources are ephemeral small lakes, pans and canegrass swamps with no connected drainage lines. Vegetation patterns were determined by the presence or absence of sand, gibber surfaces and water bodies (Badman 1999), so there are long-term stable relationships between the landscape units, and plant and animal resources.

Archaeological work in arid Australia has emphasised the relationship between site locations and exploitable resources or landscape features (e.g., Barton 2003; Hughes and Hiscock 2005; Napton and Greathouse 1996; Smith 2013; Veth 1993). Surface stone artefact concentrations are the most abundant type of site and are reliable indicators of past human activities. As a result of previous survey work in the Olympic Dam region over about 30 years, a model predicting and explaining archaeological site type and location in relation to landscape had been developed and was described by Hughes et al. (2011). That model is summarised in Table 1.

During the 2007-2009 survey phase teams of archaeologists and Aboriginal trainees walked across the entire area shown in Figure 2, with transect intervals that ensured good surface visibility guided by the predictive model. During this stage the team recorded more than 16,000 archaeological sites, with more than 1,000 additional sites in the Arid Recovery Reserve recorded as part of the salvage program in 2012-2013.
Table 1 Summarised model of relationships between landform types/geology and archaeological sites used in the Olympic Dam archaeology program.

<table>
<thead>
<tr>
<th>Landform type</th>
<th>Model prediction/explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tableland 2 Dissected tableland</td>
<td>Sites infrequent, quarries and knapping floors. Any isolated dunes contain rich diverse artefact scatters.</td>
</tr>
<tr>
<td>3 Drainage depressions</td>
<td>Sites infrequent, except on sand dunes around large moisture-holding depressions that were focal points for occupation. Such sites are large with high artefact densities and diversity.</td>
</tr>
<tr>
<td>4 Widely spaced dunes &lt;30% of landsurface</td>
<td>Medium to large sites, medium to high artefact densities and diversity. Concentrated around interdunal pans. Richest sites on dunes where pans and silcrete outcrops occur.</td>
</tr>
<tr>
<td>5 Moderately spaced dunes 30-60% of landsurface</td>
<td>As for landform type 4, but sites less frequent, less rich reflecting less common occurrence of pans and outcrops of raw material, due to increased sand cover.</td>
</tr>
<tr>
<td>6 Closely spaced dunes 60%-&gt;80% of landsurface</td>
<td>Sites very infrequent because of almost continuous sand cover, absence of surface water and stone sources, difficulty in traversing these landscapes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geological regime</th>
<th>Description</th>
<th>Material for artefact manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Quaternary Dune fields and clay pans</td>
<td>No materials exposed</td>
</tr>
<tr>
<td>Czs</td>
<td>Tertiary Silicified ancient beachridges</td>
<td>Main source of silcrete</td>
</tr>
<tr>
<td>K</td>
<td>Cretaceous Deeply weathered siltstones, shales, sandstones; extensive deposits of ice-rafted pebbles, cobbles, boulders, predominantly quartzite</td>
<td>Main source of quartzite chert and quartz from ice-rafted rocks, silcrete from silicified weathered sediments</td>
</tr>
<tr>
<td>A</td>
<td>Cambrian Andamooka Limestone</td>
<td>Main source of chert</td>
</tr>
<tr>
<td>P</td>
<td>Precambrian Simmons Member - Arcoona Quartzite</td>
<td>Not suitable for flaking, source of grinding and hearthstones</td>
</tr>
</tbody>
</table>

An evaluation exercise part-way through the survey stage (Marwick et al. 2013) showed immediate archaeological returns from the investment in mobile GIS. It demonstrated that the digital data were suitable for immediate analysis, and confirmed the hypothesis based on previous observations that people were sensitive to relatively small variations in the desert landscape and altered the nature and density of their activities in response to small-scale environmental differences. It highlighted patterns of gradation in the distribution of archaeological sites and established a basis for subsequent and more sophisticated GIS analyses which would both allow better interpretation of prehistoric behaviour and quantify responsiveness to the differences in the economic potential of dissimilar landscapes.
The extensive survey area, the intensive level of survey and the large numbers of archaeological sites meant that observation of human choices and behaviour could be obtained at a very high spatial resolution. Objective landscape classification (described by Hughes et al. 2011) made it possible to quantify landscape diversity in the study area at a high spatial resolution and reduced false associations that could result from less precise environmental mapping. Large datasets were established, and site patterns were able to be quantified and explained rapidly, using GIS tools.

The Middle Scale: On-site Work at Salvage Sites

Following survey, negotiations between BHP Billiton, the three traditional land owning groups, the consulting group (HEH) and government agencies, resulted in a decision to undertake archaeological salvage work with an explicit research focus at ~150 sites which represented the range of site types recorded, were in clusters distributed across the study area, and focused on a range of archaeological questions as outlined by Hughes et al. (2011). The salvage stage ran from July 2010 through to July 2013.

Three field salvage methods were applied and the protocols for each method were defined and followed closely. The most common approach was that applied to artefact concentrations, placing a 1m\(^2\) grid across selected parts of the assemblage and undertaking surface and shallow subsurface collection of cultural material (stone artefacts and manuports) from that grid. In most sites selected squares were also test-excavated to ~1m depth. Total stations (electronic theodolite integrated with an electronic distance meter (EDM) to measure distance along a slope) were used to plot clusters and scatters of artefacts, some topographic or environmental features and grid square corners.

The other methods applied to multiple knapping floors and hearths used a total station for piece-plotting the locations and disposition of individual artefacts. The methods varied depending on the research purpose. In one very large site comprising multiple knapping floors and an exploitable silcrete source, several points and lines of orientation were plotted for each artefact. In studies of knapping features on chert and...
quartzite and of hearthstone distribution around cooking hearth sites, piece-plotting with the total station resulted in sets of point data.

At the outset of the salvage stage it was apparent that since the site records had been transferred immediately to a digital storage format, and site spatial data could similarly be transferred from the total station to a digital database, it would be logical to also digitise artefact collection, cataloguing, measurement and analysis. All notes and acquisition information taken in the field were therefore recorded directly and stored on netbook computers. Netbooks were also used with the software program FieldGenius (FG) to manipulate the total stations. Barcode scanners and bar-coded labels were used for all artefact bags, with date, site, grid-square and spit information incorporated. During subsequent cataloguing, measuring and analysis steps, barcoding and separate bagging was extended to include artefact type, raw material, implement information and storage box information. It is noted that better directly-programmable instruments have since become available that simplify barcoding and associated labelling processes. Automating the labelling process provided numerous benefits – it saved many hours of writing labels, it avoided many practical problems encountered when labelling bags in wet or windy conditions, it avoided transcription errors, enabled checking as bags and artefacts were listed, weighed and deposited after each day’s fieldwork, allowed for rapid searching of artefact databases by site, spit, type or raw material. It also enabled subsequent measurement data to be linked directly to the catalogue.

Over 1 million objects were catalogued in this way, more than half of which were flaked stone artefacts. From about half of the 150 sites salvaged, additional artefact measurement and analysis was undertaken, artefact density maps were drawn, and relationships between site and artefact variables were investigated – all directly from the data stored in the digital site files. The digital systems used at this middle scale were effective for re-locating stored artefact assemblages and efficient, allowing for immediate analyses through ArcGIS, selected databases or statistical packages.
Fine-scale: Site Data and the Need for a Protocol for Processing Survey Data

About half the sites underwent further artefact analyses in the laboratory. An artefact measurement protocol using a Lotus Approach database was established by Peter Hiscock, Oliver Macgregor and Angela Neyland and four levels of measurement of artefacts were defined to facilitate different levels of analysis for different assemblages to address different questions. Computer-linked calliper and weight measurements with photograph file numbers were entered directly into the artefact database linked through the site numbers to other site data in the GIS. On selected assemblages rock compression measures and colorimeter data were added to the database. In situations where refitting enabled core or nodule reconstruction, the sequence was recorded using a computer-linked 3D laser scanner. At the end of the measurement stage all artefact data could be related back to the position of the artefact in the landscape.

At this finest scale, the level at which artefact characteristics and distributions needed to be analysed, it remained important to retain accurate spatial information. It was noted above that during the salvage collection/excavation stage, site grids, excavation pits and local topographic features had been mapped using a total station and customised mapping software (in this instance FG). All 17,000(+) sites in the study area were ‘georeferenced’ i.e., they had been recorded at locations assigned by the GPS-enabled hand-held computers and the coordinates (X and Y or easting and northing components) in a standard map projection for this area (MGA1994 Zone 53) and stored in a master ArcGIS file (which was also backed-up in the off-site BHP Billiton system).

To look at intra-site variation – which covers a major proportion of artefact analysis and archaeological interpretation – it is not necessary to know the exact spatial relationships between sites, nor to know the exact position in space, especially its elevation for most artefacts. Traditionally archaeologists have used automatic levels, theodolites, reducing tachymeters and recently total stations to plot artefact or sedimentary structural positions precisely, in three dimensions. It is less common to find precise spatial links between sites, or between sites and
landscape elements, and commonly researchers assign an 'arbitrary datum' based on a contour or spot height from a relevant topographic map for the height (elevation or z) coordinate.

Several researchers in this program are continuing investigations that link artefact information to specific landscape settings. The study extended across an area of 30 x 20km and it was necessary to be able to link site patterns, regional slopes, and associations between site elements and landscape units. We needed to link the survey data covering >17,000 sites with the positions of individual artefacts on dune and swale or plain surfaces within each of the 150 sites salvaged. The technique for linking the sites to incorporate them into a single three-dimensional database – also linked to Australian primary survey points – was to undertake differential GPS (dGPS) surveys of all the salvage sites (where elevation at each GPS reading is determined accurately by comparison with a fixed survey point). BHP Billiton supported this dGPS survey, and two mine surveyors – happily both geographers with an excellent understanding of landscape elements and interested in the disposition of archaeological material across the landscape – undertook this work during mine survey 'downtimes'. A senior archaeologist accompanied the dGPS surveyors to ensure key archaeological features were plotted, and artefact scatter boundaries and site grids were marked. Across some of the area LiDAR imagery was available, and where that could be used only a couple of dGPS field survey points were needed to establish elevation. As a by-product, this program also provided an opportunity for the surveyors to compare LiDAR image interpretations with detailed field data for a few sites where both data sets were available.
The Need to Merge Two Survey Datasets

During the salvage fieldwork phase the Olympic Dam program operated with two spatial data sets (as described below) with different characteristics and containing different sets of information. To answer many of the archaeological research questions posed at the outset of the program those data sets needed to be integrated. For each salvage site there were two different sets of geodetic survey (spatial) data, inherently not designed to be merged.

The FG (total station) site data – which are stored by that software as a layer - included points and lines: grid square corners, artefact locations as points and/or lines (for piece-plotted sites), site control points, feature boundaries and at some sites other environmental features such as trees, eroded/disturbed areas. The internal accuracy of the FG data was ~2-5mm (not accounting for human error), and the data points were controlled by the theodolite geometry i.e., the projection was local to the site. In most circumstances Easting=0m, Northing=0m and a height value assigned arbitrarily marked the point where the total station was first located at each site.

The dGPS site data – stored as layers of points – included site control points, topographic features, position of site grids, artefact scatter boundaries, selected landscape features. The internal accuracy of these data was ~ 20mm.

Angela Neyland (in prep.) in consultation with BHP Billiton surveyor, Rebecca Tayler, established a protocol for merging the two spatial datasets, based on the characteristics of the two systems and the data collected in this study based on the following factors:

- The control points were the data in common between the datasets.
- The FG data were more accurate on a large scale (locally) than the dGPS.
- The projection of the dGPS data more closely reflects reality than do the FG data.
- The data included both point and line fields/layer types.
- The FG data included a relative (local) projection which incorporated an elevation value. Data point values may be positive or negative numbers and when transforming FG data to a 'real-world' projection to link with the dGPS data the + or – value, which depended on the arbitrary elevation value assigned at the site, determined the digital elevation value in the merged data.
The Need to Preserve Data Accuracy

The fieldwork exploited the high level of accuracy of a total station to record artefacts in a very fine-grained level of detail, and recorded the position of the site grid squares. It was essential to preserve that level of accuracy.

In order to bring the FG and dGPS data together it was necessary to georeference the FG data in three dimensions. ArcGIS offers several methods of georeferencing data sets. Some of these methods were not suitable as they would have skewed, warped and/or scaled the data in order to make them fit the guide (in this situation the dGPS control points).

The control points recorded by the dGPS were very accurate in space but less accurate in relation to each other (as each was defined with reference to a distant point). The control point locations recorded in FG were more accurate in relation to each other. It was therefore necessary to use the dGPS control points as a guide in order to merge the FG data set into the dGPS set. The method needed to avoid stretching (‘rubber sheeting’) the FG data over the dGPS data, as that would have resulted in loss of accuracy of artefact locations. For the analyses planned to be undertaken on the data, in situations where the control points of the FG data and the dGPS data did not match perfectly, maintaining the FG internal accuracy was judged to be more important than exact control-point matching.

The protocol to merge the dGPS and FG data (Neyland in prep.) involved using selected file formats (see Appendix 2 for technical details) for several purposes: 1) To maintain links between data points and labels; 2) To merge compatible formats; 3) To retain the fine level of detail available from the total station data; 4) To georeference the data in three dimensions; and 5) To transfer this information into the ArcGIS system. This meant site maps at 0.2m contour intervals could be saved, and exported as high resolution .tif or .jpg files (e.g., Figure 3).
Figure 3 Site ODX_04443 in a blowout sloping to the southwest, on a high linear sand dune. Top image is an airphoto of the site with 500mm contours derived from LiDAR imagery superimposed on it. Lower image is the site map with 200mm contours drawn (by Katarina Sporcić, using Angela Neyland’s method) from the merged FG and dGPS data, with the excavation grids shown.
Discussion

Data collection with a mobile GIS enabled the survey team to collect a massive amount of data during survey fieldwork and to eliminate transcription time and error – benefits described previously by researchers such as McPherron and Dibble (2003) and Tripcevich (2004a, 2004b). The introduction of mobile GIS also increased the rate of site recording by more than four-fold when compared with the recording of >800 sites in region over 30 years, prior to 2007 (Marwick et al. 2013).

Of the four advantages that motivated our use of this system, our experience was that the critical advantage of a mobile GIS was its high efficiency when large amounts of data needed to be recorded rapidly (i.e., a large number of sites or artefacts to be recorded per person per day) and increased setup and troubleshooting time becomes a relatively small proportion of the overall data collection effort. For projects where the amount/density of data to be recorded is low, the gain in efficiency with a mobile GIS will be smaller and in such circumstances a paper and GPS system may be more efficient because of its negligible setup time and lower cost. About two months, or 8% of time, in this survey was spent on setup, mostly on creating and testing the recording forms. In the context of a three year survey in an area where it was known there would be many sites, this was an acceptable investment. Since 2009 this GIS-based recording system has been used with minor modifications in archaeological surveys of areas near Olympic Dam and as far afield as the Pilbara in WA, further improving the time and cost return of the original investment over a paper and GPS system.

As Marwick et al. (2013) noted, the Olympic Dam sites fell into a narrow range of site types and artefacts within them in repeated patterns that suited a systematic recording protocol. Projects that encounter high levels of variation, or cannot anticipate the kinds of data to be recorded, might benefit from freeform data capture rather than the tightly controlled data entry fields that were an important advantage for this survey. More flexible data entry and associated problems for analysis would need to be balanced against the enhanced uniformity and accuracy of tightly controlled data entry, defined value limits and automatic error checking.
It was also noted that the disruption to fieldwork when the mobile GIS system fails may be under-represented in the literature on mobile GIS in archaeology. Mobile GIS is a complex and flexible setup that replaces many pieces of equipment and if the handheld computer fails during a paperless survey fieldworkers are limited in the tasks they can perform. Recent mobile GIS equipment and software have become reliable and robust. Breakdowns can never be completely avoided however, and during the Olympic Dam survey their impacts were mitigated with multiple nightly data backups and keeping redundant functioning equipment on hand for immediate replacement of broken units so as to minimise delays caused by waiting for repairs. When the sites' database was ‘cleaned’ at the end of the survey stage, errors such as ‘9’ entered when values should have been ‘0’ and omissions of artefact data, were found to have occurred in fewer than 0.5% of the sites.

For all the other computer-based systems used in this program there are numerous alternative approaches and equipment that would achieve the same outputs. What is different in this study is the demonstrated ability to link data and derived information across the three scales, to articulate survey, field and analytical datasets, and to be able to integrate information based on survey patterns, artefact distributions on sites and artefact characteristics very simply.

Conclusions

Going digital allows for articulation across scales (for methods, approaches and types of data). This program involved in part a trialing and learning process, but a key lesson became apparent almost immediately – that it is not efficient to mix technologies, and once a decision has been made to embrace digital systems for one part of an integrated study, it commits the project to continue with such technology in other elements of the study if the disciplinary benefits of available technology are to be realised or enhanced.

Mobile GIS is a cost-effective approach, but only for large surveys or repeated work in a geographic area and on archaeological materials of a predictable nature. In the Olympic Dam salvage program substantial archaeological information was derived very efficiently from the use of mobile GIS.
technology and supporting laboratory and corporate systems, and by the implementation of compatible systems at finer scales in the overall program.

A key benefit is the immediacy of a GIS-based system. It provides a resource with which to ask research questions and link disparate information directly, and to compare information within and between sites or areas.

Undoubtedly McCoy and Ladefoged (2009) were correct in forecasting that mobile GIS and related spatial technologies will continue to change archaeology and contribute to its progress, but this discussion comes with some notes of caution from our experience in the Olympic Dam program:

- Digital survey methods applied at appropriate scales within an extensive, long-term program were effective, efficient and certainly worthwhile. Such methodology is not always appropriate however, and it cannot be assumed that 'generic' packages for recording sites, recording excavation results, or analysing excavated material will ever be available as such methods will need to be tailored to any specific project.
- The systems used were (and their more modern equivalents remain) expensive, and the institutional frameworks required to support the resultant datasets are expensive to acquire and maintain, and require specialised computing skills to be used effectively. For people working on small dispersed projects, or engaged primarily in small-scale one-off projects across different landscapes, such systems are (at this time) unlikely to be cost-effective. There is scope however for groups of consultants or researchers working in the same area to negotiate, establish a suitable system, and then to use it to exchange or integrate information.
- People establishing such a system need research questions to guide their choices about the configuration of a system to ensure it will be appropriate for their needs.
- Once a decision has been made to embrace digital technology for one part of an integrated study, for this to be efficient and effective requires a commitment to apply digital technology in other elements of the study. Then the disciplinary benefits of the technology can be realised or enhanced. Such a commitment must take into account at the outset the method by which the data or the system will be maintained once any specific project has been completed.
Acknowledgements

This work was undertaken in accordance with the Olympic Dam Agreement between BHP Billiton and the Aboriginal native title claimant groups under a contract with BHP Billiton that included research support. The project databases and catalogue information are stored in BHP Billiton’s corporate GIS and associated data management systems which provide a secure back-up for the systems that will go on being used at Olympic Dam and through the South Australian Museum. Special thanks are due to Ben Marwick who was dogged in establishing functional mobile GIS systems and protocols, to BHP Billiton mine surveyors Richard Wilkin and Rebecca Tayler, to Heather Leasor who established and maintained effective data management systems for the salvage program, to Amy Tabrett who found and established the hardware and software packages to ensure compatible systems, and to Angela Neyland who designed the procedures to link spatial data at three scales.

Appendix 1: Methods and Material Specifications (after Marwick et al. 2013)

The >17,000 sites were recorded using a mobile GIS based on the ESRI ArcMap 9.1 and ArcPad 7.1 platforms, some later upgraded to ArcGIS 10 and ArcPad 12 systems. The basic hardware and software used were similar to those described in previous studies (McPherron and Dibble 2003; Tripcevich 2004b), including ruggedised handheld computers (TDS Recon and Nomad, described by Clegg et al. [2006]) with a touchscreen interface and built-in GPS (Holux GM-270U and SiRFStar III) running Windows Mobile 6 operating system and ESRI ArcPad software. ESRI’s suite of programs is ubiquitous in the private sector and in higher education (http://www.gisjobs.com/survey_all/), and extensive support is available in online fora. The use of proprietary software made the cost of the system high, but although free and open-source alternatives are now available they remain more difficult to use and to build in data safety checks.
Although there is a variety of software for mobile GIS, ArcPad features that made it suitable for this use:

- Real-time capture and display of GPS data in NMEA format, display of detailed telemetry (e.g., speed, direction) and information about the quality of the data (number of satellites, position error) useful for navigation and coverage calculations during the survey.
- ArcPad can display position in context with other datasets through the standard convention of data layers to produce maps. Custom datasets included the location of tracks, fences, previously recorded sites, previously surveyed areas and aerial photography.
- ArcPad allows rapid input of field data into a database. Data files so created can be appended to a master record at the end of each day for rapid analysis, reporting and safe archiving.
- The extensive use of ArcPad in other industries and disciplines means there are numerous examples of customised ArcPad applications available at online support fora that were useful to adapt for the archaeological survey (cf. Tripcevich 2004b:19).

The ArcPad recording forms were designed using the open format Extensible Markup Language (XML 1.0) specification which has the advantages of being widely used, well-documented and editable with the most basic text editing software (e.g., forms can be edited directly on the PDAs in the field). The original paper recording forms that had been used in the region by (Hiscock and Hughes 1983) were revised and translated into XML to design ArcPad forms using ESRI’s ArcPad Studio program and a text editor. Where possible the data input options were constrained by drop-down menus, check boxes and radio buttons rather than allowing flexible but error-prone data input using text boxes. This helped speed data entry, standardised data collection, avoided invalid data and minimised data cleaning time. XML was also used for ArcPad configuration files to set communication variables between the GPS and the recording form (such as position averaging) and to limit the number of toolbar buttons displayed on the PDA screen, to maximise the map area.
In addition to the custom ArcPad recording form, scripts were written to calculate certain fields automatically based on entered data, check data input on the fly, prompt the user if certain conditions were not met and provide information to the user about what to do. ArcPad forms were scripted using VBScript, which like XML, is widely used, well-documented and editable using any text editor. VBScript and SQL were used to move the data from the PDA to a desktop computer, append data to a master database, update the mining company’s heritage dataset to ensure newly recorded sites could be protected, check for duplicates and assign unique identifiers to sites. GPS tracklog data were recorded constantly during survey and archived with ArcMap to prevent resurveying of the same area, to show survey coverage, and hence demonstrate the absence of sites from some parts of the landscape.

Sites located during the 2007-2009 surveys were recorded as single points into a point shapefile with co-ordinates averaged from ten positions captured by the GPS for reliability of site location with an estimated horizontal accuracy of 2m. Information about location, environmental context, size, number of artefacts, artefact raw materials, the presence and abundance of certain implement types, the presence of hearths and attributes of knapping floors was collected. In ongoing more focused surveys since 2009 in areas outside the original survey area, polygon shapefiles have been used to map the boundaries of sites, with a minimum of five positions averaged at each vertex to improve location accuracy. Although ArcPad allows for direct capture of digital images and other data input (e.g., measurements of stone artefacts from digital calipers), these were not relevant to the survey goals and these features were not used.
Appendix 2: Linking Data through Different File Formats (after Neyland in prep.)

The Olympic Dam program generated several different file types from FG, from the dGPS survey and those created in ArcGIS. Each has its own characteristics and some tools to align features are available only for a certain file format. These were:

- **Shapefiles** – GIS format files each containing data in the form of points, lines or polygons. While different shapefiles can be overlaid at one location they are not linked. If for instance a line shapefile that includes a boundary around a collection of points representing individual artefacts is moved, the point file will not follow, and the data will be irrevocably dissociated. Georeferencing the total station/FG data however involves moving line, point and polygon layers so they remain linked, to retain their data association/location. The main benefit of shapefiles is that they have a clear well-organised attribute table that will include the extra information such as labelling recorded when point data are collected, in addition to its location.

- **CSV Files** – point files only. In this study raw dGPS data were acquired from the surveyors in comma separated variable (CSV or string) format. From this digital elevation models and topographic maps can be created.

- **CAD Files** – are three dimensional. There are several computer aided drawing (CAD) file formats including .DXF and .DWG files, and what distinguishes them from other file types is that they are a collection of layers rather than a single layer, including linked layers for point features, line features and polygon features. ArcGIS tools can georeference whole CAD files, so if point features are moved the line and polygon features are also moved. While FG and other total station software is capable of exporting .DXF CAD files which can be added as a layer to ArcGIS, this separates all the text information into a separate ‘Annotation' layer which cannot be re-appended to the point and line layers, so that process renders site piece-plotting and grid plotting datasets virtually useless. It was therefore necessary to convert several shapefiles (line or point) into a single .DWG CAD file in which to georeference them, ensuring the text information was not stripped. The information was then stored in ArcGIS.

- **Topographic data** was recorded by the dGPS survey as a series of points able to be processed as a .DXF contour map suitable for making publishable images of sites but it is not adequate for any analysis of site data that requires elevation/differences in elevation as a variable. For such analyses is a digital elevation model (DEM) was needed. DEMs are a raster files from which contour maps or hillshade maps can be generated, and various analyses undertaken.

- **Rasters** are georeferenced grids or matrices of cells (pixels) useful for various analyses and easy to create using ArcGIS. The cell size can be selected, the smaller the cell or pixel the higher the resolution. The value in each cell is calculated during the creation of the raster and these can be representative of a selected attribute. A digital terrain model (DTM) is a raster in which the cell values are elevation.
• The nearest neighbour interpolation calculation was used to create a raster from a set of point data, averaging the values of the points nearest to a given cell. If the data are generally more widely spaced than the cell size chosen the results will be interpolated and the raster will create new inferred data calculated from the data available. If the point data are more closely spaced than the cell size chosen, the nearest neighbour calculation will be smoothing or generalising the data.

The process was automated for the Olympic Dam program by customised tools created by Angela Neyland.

References


