

# RECORDING AND MODELLING AN ABORIGINAL CAVE PAINTING : WITH OR WITHOUT LASER SCANNING?

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## Commission V

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### ABSTRACT:

There are many compelling arguments, worldwide, for the recording of indigenous art sites which are endangered by “people pressures”. The Baiame cave painting in the Hunter Valley of Australia (lat. 33 S, Long 151 E) is one such site. Traditional methods for recording rock art sites are reviewed from the perspective of archaeologists, indigenous peoples, the general public and surveyors/photogrammetrists. Needs and expectations of these diverse groups can range from approximate sketches to 3-D computer models and animations. Previously a laser scanner was used in conjunction with digital photography to produce a realistic 3-D model of the Baiame cave (El-Hakim *et al.*, 2004). Some simple surveying measurements were needed to ‘tie’ the spectral information on the cave wall to the digital elevation model (DEM) defined by the laser scanning. A second attempt at modelling the same cave has recently been undertaken using surveyed control points, digital photography and automated image correlation software commercially available with the Leica Photogrammetric System to produce a DEM and orthophotography. The relative merits of both approaches are discussed and the implications arising from their adoption outlined. The output of such a 3-D processes are reviewed with respect to the present and possible future expectations of users.

### 1. RECORDING ARCHAEOLOGICAL DETAIL

This discussion will concentrate on the common methods and techniques used in Australia to record rock art including both petroglyphs (rock engravings) and pictographs (cave painting) sites. There are three main methods of recording rock art currently in normal use today:

- drawing, (includes rubbing over the surface)
- tracing, (includes using grid squares) and
- photography (Stanbury and Clegg, 1990).

Although of increasing sophistication, all suffer from a series of limitations. Free hand drawing or sketching is simple and easy to conduct in the field but provides only a two dimensional record and is generally inaccurate (Brayer *et al.*, 1998). Direct rubbing using paper or tracing on plastic sheets is commonly adopted but the method creates large volumes of media which have to be photographically reduced for more efficient storage. It is also invasive, requiring the physical touching of the art and requires extensive field time (Taçon, 2004). The placing of a grid over the object and transferring detail one square at a time solves the physical reduction problem directly, but again requires time and patience in the field and inaccuracies are inevitably introduced.

The use of photography remains universal, particularly for simple recording and qualitative use. The extraction of quantitative data from photographs is less common and Clogg *et al.*, (2000) review the use of image processing of scanned imagery. In that study a digital filter and simple thresholding

methods are used to identify pictographs from the surrounding rock surface using spectral information alone.

The idea of recording rock art in 3-D is not new and indeed sophisticated optical methods to derive surface topography have been developed (e.g. Bertani, *et al.*, 1995). Although highly accurate, such systems are expensive and not practicable for fieldwork or for recording large objects. Laser scanning is one technology which has also demonstrated potential for rock art recording (Boehler, 2001), particularly when combined with imaging. El-Hakim *et al.*, (2004) merged spatial data derived using a laser scanner with spectral data obtained using a cheap digital camera to generate a virtual model of an aboriginal pictograph site at the Baiame cave in NSW, Australia (lat. 33 S, long. 151 E). The merging of the image and spatial data proved time consuming, although the latest generation of scanners which include an inbuilt imaging sensor should resolve this problem as the relationship between the laser scanner and the imaging device should be known *a priori*.

However, all current laser scanners remain bulky, expensive and require some expertise to operate. Ogleby (2004) presented a futuristic 20-year prediction and suggested the development of a combined Terra-pixel imaging and laser scanning device with limitless storage. His so-called “Ridjigital” may be the archaeologist’s recording panacea for the future, but there is a need now for equipment and a methodology to record rock art cheaply, easily, and without expert personnel in the field. Various solutions based upon the use of photogrammetry have been suggested, *by photogrammetrists*, as having great potential for many years, but none have reached fruition to the stage where they have been actively adopted by archaeologists.

## 2. RECORDING : NEEDS AND EXPECTATIONS

The fundamental question which all surveyors or photogrammetrists need to ask before any survey is “What does the user require?” This is particularly true for recording archaeological detail where the requirements are often quite foreign to the standard types of mapping undertaken by surveyors. This paper asks “Is it counter-productive to spend time and energy to produce a 3-D model and fly-through animation when all that the client required was a sketch to indicate approximate shape and size in 2-D only?”

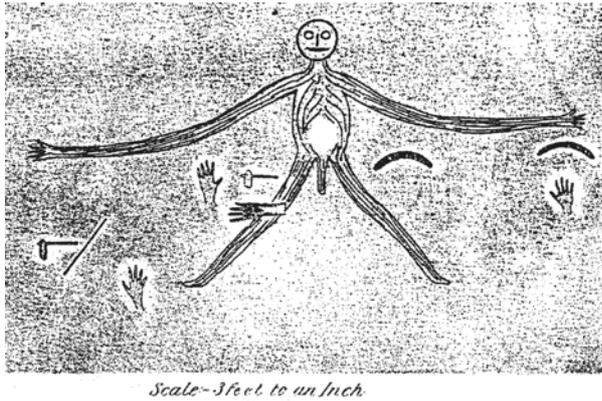


Figure 1. Traditional 19th Century recording of the Baiame cave painting (from Mathews, 1893)

Figure 1 shows a surveyor’s sketch used to record the Baiame Cave some 110 years ago (Mathews, 1893). Some contemporary products are shown in Figures 2 and 3. In Figure 2 all that was required was a 2-D sketch showing petroglyphs at the Bulgandry site near Gosford, New South Wales, Australia. The recording is used as the basis of an A4-sized folded brochure for the general public who have access to the site via a boardwalk.

Apart from the sketch of the site, the brochure provides a brief history of the local indigenous tribe and it is distributed freely by the National Parks and Wildlife Service. The same brochure is used by the local Land Council of indigenous people as a basis on which some of their tribal stories, legends and traditional culture can be introduced. Although this is not at the cutting edge of what surveyors and photogrammetrists in the 21<sup>st</sup> century can produce, it seems to be all that is *presently* required.

Figure 3 shows the type of detail survey one would associate with a surveyor’s plan, including a coarse representation of the third dimension as spot heights and contour lines. While this overall site is well-defined by this plan, information which scientists may require such as width/depth of grooves, nearby local topography, rock colour, granularity, site vegetation, etc. is not available. Obviously some form of incorporation of photography into the site surveys is essential for that type of detail. Should that extension of information be a computer animated 3-D walk-through? What is the role of the recorder of such a site?

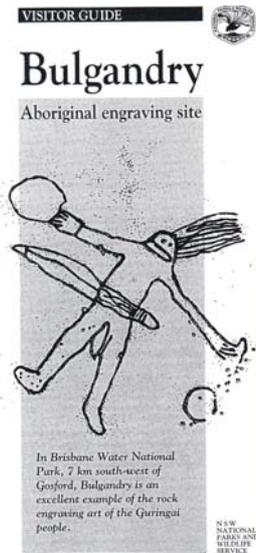


Figure 2. Visitor guide with explanatory notes of petroglyphs, Bulgandry, New South Wales.

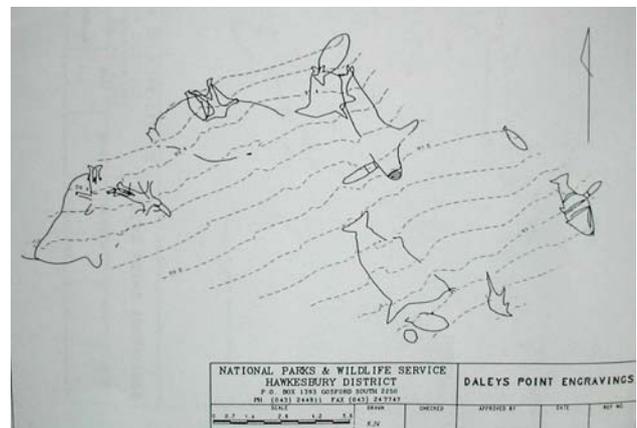


Figure 3. A detailed survey plan of a petroglyph recording site, New South Wales.

## 3. PAST USE OF PHOTOGRAMMETRY FOR ARCHAEOLOGICAL AND ROCK ART RECORDING

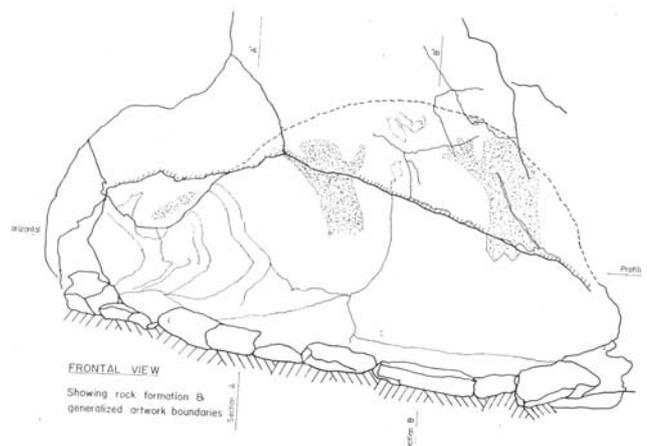


Figure 4. Traditional photogrammetric recording of a cave, Gosford region, New South Wales in early 1980’s. (after Olgeby and Rivett, 1985).

In Australia, in a series of related projects, Rivett (1979) and Ogleby & Rivett (1985) demonstrated the benefits of photogrammetry for recording rock art, particularly pictographs. Fieldwork was conducted at a series of sites around Australia, and their “*Handbook of Photogrammetry*” (Ogleby & Rivett, 1985) was a key text of its day describing how to conduct a photogrammetric survey for field archaeology. Figures 4 and 5 show examples of their work for the photogrammetric recording of a cave in the early 1980’s. The difficulty for a non-surveying expert to interpret such plans must not be overlooked.

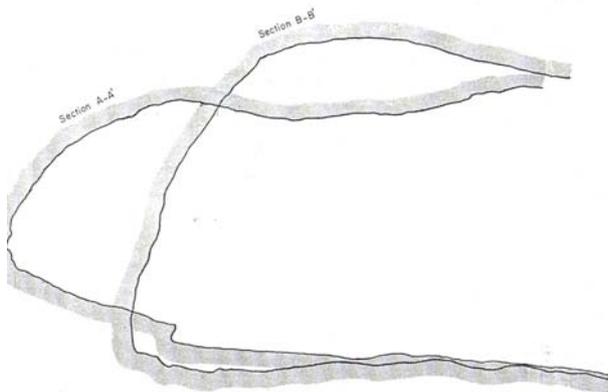


Figure 5. Traditional photogrammetry used to depict profiles or sections of the cave in Figure 4.

These plans were produced on large sheets of paper (A1 size) as a sequence of sub-plans and cross-sections. Of course, this was done prior to the availability of digital photogrammetry, but it represents the type of ‘user-unfriendly’ product which many archaeologists associate with photogrammetry. Despite these reservations, their recording was much more comprehensive and less invasive than the present-day “norm” which may still be a copying or tracing on a plastic overlay (see Figures 6, 7 and 8) or a simple photographic record with a scale bar and no allowance made for tilt or relief distortion.

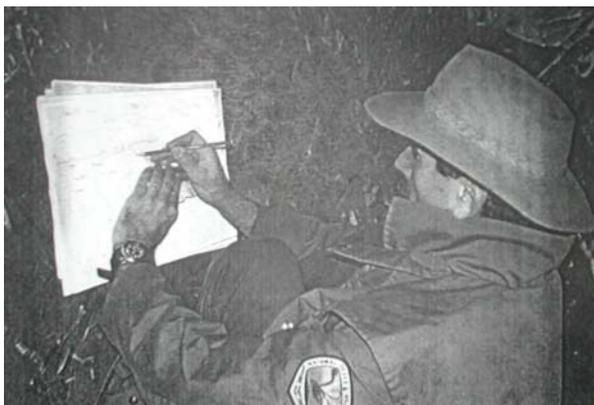


Figure 6. Recording a pictograph by “eye” copying. National Parks and Wildlife Service, 1992.

One of the reasons that photogrammetry has not been more widely adopted in the past has been the costs, particularly access to the equipment and skilled labour involved in preparing relevant drawings (Rosenfeld, 1988). Specialized metric cameras were originally required and they needed to be calibrated to enable accurate data to be derived. Traditional

instrumentation also enforced strict geometric constraints upon imagery that could be used and also required conventional two dimensional plans to be produced. All derived spatial data had to be reduced and plotted to an average or mean plane, introducing artificial scale distortions into the plotted data (Ogleby & Rivett, 1985).



Figure 7. Recording a pictograph by tracing onto plastic sheeting, Wollemi National Park, 2004



Figure 8. Tracing a petroglyph in the field onto foil (Stanbury and Clegg, 1990).

More recently, Ogleby (1999) has continued to demonstrate the benefits of photogrammetry to a wider archeological audience, including the Ayutthaya temple in Thailand (1999) and the Olympiad (Ogleby, 2000). In these two examples, an important final product has been the virtual model, enabling the visualization of the site from any perspective.

#### 4. INTERNATIONAL COMMITTEE FOR ARCHITECTURAL PHOTOGRAMMETRY (CIPA)

The International Committee for Architectural Photogrammetry (CIPA) is one of the international committees of ICOMOS (International Council on Monuments and Sites) established in collaboration with ISPRS (International Society of Photogrammetry and Remote Sensing). Its remit is to improve surveying methods to record cultural monuments and photogrammetry has been an important focus for development.

One of the important principles CIPA has adopted and tried to promulgate has been the “3x3” method of image acquisition (Herbig & Waldhausl, 1997). This technique promotes a simple, yet scientifically-based scheme to acquire photography which will allow later photogrammetric measurement. The

principles include 3 geometrical rules (control, base/distance ratio, normal photography); 3 photographic rules (constant camera geometry, soft illumination, film type); and 3 organisational rules (sketches, care, checks).

It is disappointing that these principles and photogrammetric methods are not more widely adopted. Indeed, one of the tasks identified by CIPA is to “Bridge the Gap” (Letellier, 2001) between the information user and the information provider. It is recognized (Palumbo and Ogleby, 2004) that the impediment preventing wider adoption of photogrammetry to rock art recording is the unavailability of a cheap, portable, automated and easy to use systems. It is believed that work described in this paper provide a significant step towards to achieving that objective.

## 5. RECORDING THE BAIAME CAVE

### 5.1 With Laser Scanner



Figure 9. Using a Laser Scanner at the Baiame Cave, New South Wales.

The Baiame Cave in the Hunter Valley of New South Wales (lat. 33 S, long. 151 E) is typical of the rock ‘overhang’ type of cave which is found throughout much of the mountainous sandstone region of eastern Australia. (see Figure 9) A 3-D recording of the Baiame cave was carried out by El-Hakim et.al (2004). The technique used is summarized in Figure 10.

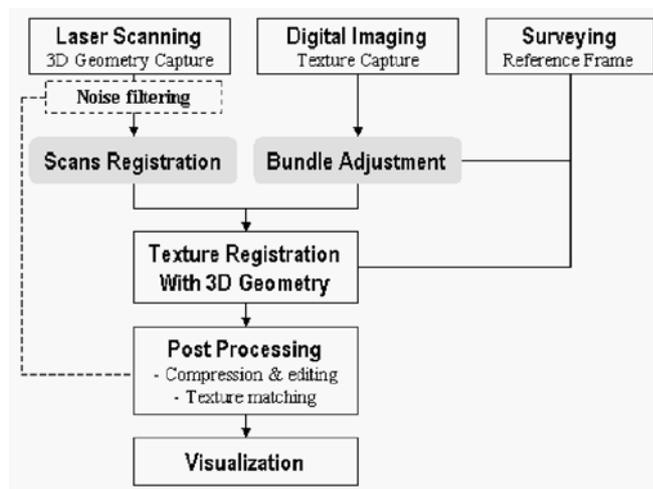


Figure 10. Recording the Baiame Cave with a Laser Scanner

As can be seen in Figure 9, 3-D geometry was captured with a laser scanner and a digital camera was used to record the spectral texture of the pictograph. A total station was used to “tie” both sets of data together by measuring the coordinates of points which were discernable in both sets of data. These points were located on both textural and geometric discontinuities.

The surveyed control points which were used in the bundle adjustment to recover the locations of the camera stations, also improved the overall accuracy and limited error propagation. This occurred even when the geometric configuration of the images may have been less than optimal. Given that a somewhat unsuitable laser scanner of the long-range type was used for this project, and that the DEM needed some ‘massaging’ to overcome the laser scanner accuracy of approximately +/- 30mm, an overall accuracy of the final product of approximately +/- 10mm in each axis was considered excellent.

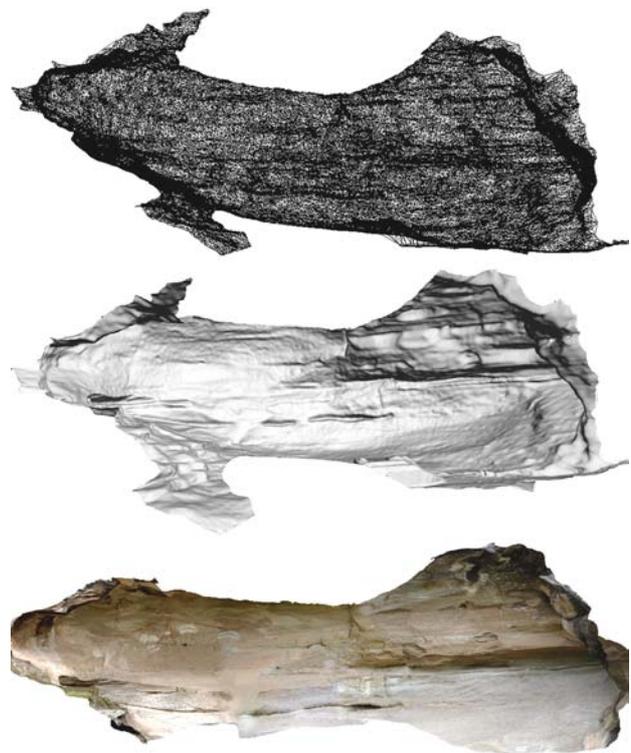


Figure 11. The 3-D Model generated with Laser Scanning.

The entire Baiame Cave was captured with the laser scanner (the pictograph is on the left-hand third of the cave). Figure 11 shows the triangular mesh, relief shading and then the addition of image texture. This has to be contrasted to Figure 13 where only the pictograph itself was the main subject of the image correlation. It could therefore be argued that a further advantage of the laser scanner is its ability to capture DEMs of large areas from a single set-up, unlike the image correlation method where each additional section requires a stereopair of images from the digital camera.

### 5.2 Without Laser Scanner

In late 2004, an opportunity to re-visit the Baiame cave and record it using only digital photogrammetry and a total station was available. On this occasion, the software package known as the Leica Photogrammetric Suite (LPS) was used to extract

3-D coordinates from stereoscopic pairs of images using the technique known as image correlation. LPS is a software module within the larger IMAGINE package distributed by Leica Geosystems.

The image correlation process needed some manual input in order to establish the spatial relationships that existed between the images. Once acceptable exterior orientation parameters had been determined it was possible to use the automated Digital Elevation Model (DEM) generation tool, which matches areas of textural detail on overlapping pairs, to extract a dense matrix of point elevations to represent the morphology of the rock surface.

The automated DEM generation tool uses an “hierarchical feature point matching” algorithm. The algorithm relies on the identification of unique localised texture in the imagery and past experience (Stojic *et al.*, 1997, and Chandler *et al.*, 2001) suggested that natural rock surfaces supplemented by painted art would create appropriate image texture for the algorithm to work effectively. Thousands of small features are identified on both images, their coordinates determined automatically and a regular grid of elevations generated through an interpolation process.

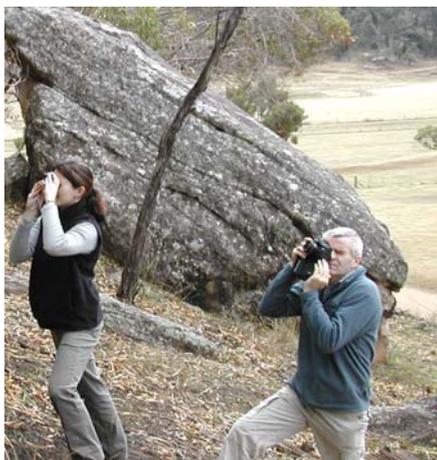


Figure 12. Photography with 6 Mega-pixel Kodak DCS460 (right) and a 3 Mega-pixel Nikon Coolpix camera (centre) at the Baiame Cave.

A 6 Mega-pixel Kodak DCS460 and a 3 Mega-pixel Nikon Coolpix camera were used to record the Baiame Cave, the Kodak being used to calculate the DEM and the Nikon providing the orthoimage. The Nikon was chosen for the orthoimage because of a better colour balance in the images on the cave wall. The DEM had a spacing of approximately 20 mm and an accuracy approaching 5 mm per stereopair. When the stereopairs were joined together, the accuracy reduced to approximately 10 mm due to a number of factors including the accuracy of the control points, unresolved components of camera calibration and slight inconsistencies with calculating the exact orientations of the camera positions.

The next step was the generation of an orthophotograph for the interior of the cave using the colour imagery which had been acquired. The real significance of the orthophoto is the removal of relief and tilt distortions providing an image with the qualities of a map. For example, horizontal distances between features can be directly scaled from the orthophotograph. Of

perhaps greater significance is the combination of the orthophotograph with the DEM, which allows the object to be analysed in three dimensions. In the IMAGINE software the DEM and orthophotograph can be loaded into a package called VirtualGIS which allows 3-D interrogation and inquiry and also enables the production of 3-D fly-through sequences. Various light models can be applied and different layers of data visualized from any perspective. See <http://snap.lut.ac.uk/Jim/baiame.avi> for the output product.



Figure 13. A Snapshot of the Orthophotograph and the DEM.

Given the accuracy analysis from the bundle adjustments and check points, *no firm conclusions are possible over which system is superior with regard to accuracy.* It is obvious, however, that there are some areas around the periphery of the model in Figure 13 where the automatic image correlation technique could only find points at a spacing greater than desirable. There are other factors apart from accuracy to consider in practical field situations and these are discussed below.

## 6. THE LASER SCANNER : STRENGTHS AND WEAKNESSES

There can no doubt that laser scanners will be a “tool of the future”. Their potential is immense, but, at the time of writing (late 2004), there are some key features to consider when used for cave art. These **negative factors** include:

- operational aspects such as size, bulk, power supply and difficulty of using a computer on site (see Figure 14)
- accuracy depending on the type of long- or short-range scanner
- difficulty of merging morphological and spectral datasets (DEM and images)
- cost of scanner (note that the photogrammetric software is not yet cheap enough to be readily accessible by non-expert photogrammetrists, but may only be 20% of the cost of a laser scanning system)
- integration of multiple scans from different locations

The most **positive** aspect of a laser scanner is the capacity to rapidly gather 3-D data at rates of 10,000 or more data points per second across most types of surfaces. This is extraordinary, compared to a motorized total station which can also achieve 3-D coverage over a pre-determined area but at a rate of only one point every 5 seconds.



Figure 14. A Laser Scanner in the Field Poses Logistic Problems.

## 7. IMAGE CORRELATION : STRENGTHS AND WEAKNESSES

The only modern surveying technique which can approach the speed of data capture of the laser scanner is automatic image correlation using digital photogrammetry. Rates of approximately 1000 points per minute are possible and the accuracy is similar. An added benefit of this photogrammetric procedure is that the photographic images required for the orthophoto generation are the same as those used to create the DEM. Compare this to the problem which can arise when trying to match digital camera images with a laser-scanned DEM to produce the textured surface. It can be a very difficult procedure combining data from different sources and lead to inaccuracies.

The **disadvantages** to using image correlation routines include the:

- need for some control points in order to determine the orientation of the camera stations – these typically require a total station to record the XYZ positions of some clearly definable spectral features, such as the tip of finger, end of a boomerang, etc. Such control points are also required if multiple laser scans have to be overlapped.
- difficulty, or even impossibility, of finding suitable points for automatic image correlation if the wall of the cave is of a uniform nature and does not possess a surface texture suited to this process (for example, a surface with uniform patches of colour will not permit image correlation)
- need for a suitable coordinate system. All the software modules with which the authors are acquainted, (including LPS used for this project) were designed for aerial photography and subsequent topographic map production. It is assumed, therefore, that the DEM surface will be close to horizontal and the photography taken looking vertically downwards. In a cave the reverse may be true if the artworks are on the ceiling. The coordinates of the control system must be rotated to meet this expectation before the software will operate. For artwork which occupies both the wall and then moves up across the ceiling (see Figure 15) there will be a need to construct DEMs piece-wise and then subsequently rotate them into a uniform system of coordinates, making certain that sufficient points have been observed in overlap areas of the DEMs.

- cost. As the image correlation software was designed for large aerial survey mapping projects, it is quite specialized for a small market and consequently expensive. However for research and non-commercial use, some manufacturers offer significant discounts.



Figure 15. Swinton's cave, Gosford, New South Wales. Note the pictographs are on the cave wall, ceiling and overhang, resulting in piece-wise construction of an overall DEM. The cave entrance is lower right.

Although image correlation has worked in the caves for the pictographs imaged to date, this technique has not always been successful for some type of petroglyphs. The areas for study in these engravings are the grooves in the rock surface. If recently re-touched to aid visualisation for tourists or for cultural reasons, these grooves may become devoid of natural texture. In such regions the image correlation algorithm will fail to find points of interest with sufficient local contrasting detail and so the DEM datapoints will not be generated in the very place they are most required.

## 8. CONCLUSIONS

There can be no doubt that for "total" 3-D recording of rock art, the creation of a DEM, generation of orthoimages, draping of those images over the DEM and production of fly-throughs, animations, etc. provides the basis for subsequent and non-intrusive scientific investigation. This is clearly the way to record a site for web-based delivery and the creation of virtual reality animation.

Photogrammetrists seem to be poorly aware of what the owners of the site really require. Will a simple plot on A4 paper of the main features be adequate for the site record? Can the cost of making a virtual 3-D model be justified? Likewise, do the archaeologists understand what can be provided by photogrammetrists?

A study of recording rock art in the archaeological literature would suggest that any educational process being undertaken by CIPA or similar organizations has not been accepted, understood, or even heard, by archaeological practitioners. Should the photogrammetrists try harder to convince their client that while a 3-D model may not be required at the moment, the opportunity to capture one should be taken as the archaeological feature must deteriorate with the passing of time?

The advent of laser scanning has created opportunities for modeling 3-D surfaces. The drawbacks with the equipment have been documented and the alternative technique of using digital image correlation software has been explored. The operational problems associated with bulkiness and portability of the laser scanner are removed by use of a digital camera, but an issue of cost and expertise remains. The cause for concern with the digital image correlation is whether there will be a texture on the surface which will enable image correlation to proceed. The authors' experience to date has been positive for pictographs and most natural petroglyphs. The technical skills required to manipulate a laser scanner in the field are countered by the office skills needed to operate the image correlation package, so personnel- and skill-wise, there is little to choose between methods. The skills needed to merge 3-D DEMs, drape images across them and create 3-D models and visualizations remain substantially the same.

No firm conclusions could be drawn from the results of the Baiame cave as to the 'best method', as both methodologies produced similar products with similar accuracies *in the area covered by the pictograph*. Away from the pictograph some image correlation difficulties resulted in the cave surface appearing unnaturally "blocky" ... there may be other situations where image correlation will simply not work at all due to the spectral texture of the cave walls.

The Baiame cave is a slightly unusual case as it is easily accessible by vehicle and so the problems associated with transporting a bulky laser scanner and power supply by manpower through mountainous terrain were not of concern.

*The challenge would seem to be one of educating potential archaeological users of the present and future scientific benefits of 3-D modeling, visualization and animation rather than being overly concerned with which method to adopt.*

Given the authors' experiences of the lack of awareness (total lack in most cases) in potential users of what can be achieved, and high-profile current projects still using traditional methods such as hand-tracings onto plastic sheets, it is the integration of 3-D suppliers with users which is our paramount concern.

It is the professional duty and social responsibility of photogrammetrists to promote the use of 3-D techniques for the recording of cultural objects so that their beauty and intricacy may be recognised and studied by others in the future.

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