From Seabed to Computer Screen—digital mapping of submerged and shipwreck sites

Bill Jeffery,
Maritime Archaeologist, Queensland Museum

Introduction

This paper describes a process in which the mapping and interpretation of a shipwreck site (HMS *Pandora)* and part of a submerged breakwater (in Myall Lake) were implemented. It considers the process that was carried out underwater and how three separate computer programs were used to try and achieve the required results.

It is the first—and far from exhaustive report of this process. The work has only just commenced in the use of these programs and it is hoped that this report will stimulate further work. Of course, all processes need a goal to strive for. The goal for this work was the accurate 3D digital recording of a shipwreck site and the excavated artefacts, and the ways in which this information could be interpreted to allow for analysis by the archaeologist and presentation to the public.

The paper considers the steps required in transferring the 3D information found on a site to the computer. This includes:

> measuring the distances and depths of a number of control points and analysing this data through the *Site Surveyor* program to compute X, Y and Z coordinates of these points;
>
> using the X, Y and Z coordinates of these control points to 'control' the orientation of stereo photographs, so as to produce 3D digital data on all the information contained in the photographs through the *VirtuoZo* photogrammetric program;
>
> importing this 3D digital data into the *MicroStation/J* program to enable 3D models to be compiled, viewed and analysed.

The sites investigated

Two sites were investigated. The first was the *Pandora* historic shipwreck. The *Pandora* was a 24-gun, Porcupine class 6th rate frigate built in 1778-1779 at Deptford, United Kingdom. The vessel sunk while trying to negotiate the outer edge of the Great Barrier Reef while on a voyage back to the UK with 14 of the mutineers from the *Bounty*. The history of the ship and the shipwreck site can be found in McKay & Coleman (1992) and Gesner (1991)

The *Pandora* shipwreck site is located about 200 kilometres east of the Australian mainland and south east of Thursday Island, which is located off the most northern tip of Cape York, in Queensland and situated in 30-35 metres of water.

The 1999 season's work on the *Pandora* was the ninth season of surveying and excavation of the site (Jeffery, 2000). This year saw the focus of the stern excavation in the Officers' Store, a 1.95 x 1.15 x 1.73 metres storeroom located on the starboard side of the platform deck (Figure 1).

The second site was at Neranie Point in Myall Lake, located on the NSW mid-north coast (Figure 2). This site consists of a breakwater built up to protect the droghers that loaded timber from the timber mill that operated there from 1873 to 1907. The breakwater consists of timber off-cuts and it initially extended for 150 metres out into the lake. Casuarina trees have colonised a higher portion of the breakwater and today a small 30 metre section of the breakwater extends out into the lake to a depth of three metres (Nutley, 1999).

This site was chosen in which to further investigate the use of the recording systems because of its heritage significance, ease of access, fair visibility, shallow depth and lack of interference from the weather. The site was also chosen because of the difficulty in obtaining reliable photographs on the *Pandora* site.

Surveying process

Pandora

There is no obvious evidence of the Officers' Store on the seabed. Concreted cannons, a pump wheel and other concretions—material from the decks above--are the only evidences of the remains of the *Pandora* on the seabed. The work on the *Pandora* therefore entails excavation of the 0.5 to 1 metre sediments to uncover the substantial and well preserved timber structure and the material used and stored there.

The location of the Officers' Store was calculated through information gained in previous excavations—and deduced to be within grids 107 and 109. (A theoretical network of two metre square grids had been laid over the whole site and numbered, see figure 3). It was considered appropriate to begin the excavation in grid 90, ie. part of the Captain's Store and work into the Officers' Store.

With this in mind, an area of seabed corresponding to these grids was delineated and a network of posts established around the area. The posts were to act as control points from which to measure the ship's structure and the other material (artefacts) related to the stores and fittings of the ship. These posts were placed randomly and not at the intersections of the grids as was done in previous seasons, for example at 20,10 (X=20 metres, Y=10 metres). The reason for this was that the delineation of grid intersections was found to be flawed and inaccurate. This season saw the involvement of a High Precision Acoustic Surveying System (HPASS) a system set up by the National Centre of Excellence in Maritime Archaeology, Western Australian Museum (Green, J. and Duncan, A., 1999) to accurately determine the X, Y and Z coordinates of these points.

The network of eight control points formed an elliptical shape around the area to be excavated. This allowed for the use of any four points that formed a square or rectangle and provided for good angles of intersection—hence a good fix--on the structure and artefacts. In an ideal world it would be possible to get X, Y and Z coordinates from three distances, but the underwater environment is a not an ideal world, so the fourth distance allows for greater accuracy using a "best fit" estimate of the point.

As the excavation went deeper however, these points had to be supplemented with control points (three more) within the excavation area, to enable four measured distances from four different points. This meant however that the good geometry for a position fix was compromised. Wherever a post was used as a control point from which to measure the ship's structure and/or artefacts, a four metre section of a fibreglass tape was fixed to the top of the post through an eye-bolt bolted onto a cap.

The computation of the X, Y and Z coordinates of the control points was determined through the measurements made by the acoustic system, and the tape measures and depth gauges, and interrogated by the *Site Surveyor* program. The coordinates of the recovered artefacts were computed through the *Web for Windows* computer program, which is connected to the Queensland shipwreck artefact database.

Myall Lake

Given the shallow depth of this site an area encompassing timber off-cuts of about 4 metres x 3 metres was chosen to record and photograph. The timber off-cuts were of various dimensions and orientation and they were thought to be a reasonable representation of material found on a shipwreck site and other submerged heritage sites (Figure 4).

Five points were marked outside of the area to be photographed and they were used to measure to 15 points within the area that were to act as control points for the photogrammetry. A computer depth gauge measured the depths of each point to within 0.1 metre. *Site Surveyor* was again used to provide X, Y and Z coordinates of all-the points.

Summary of the surveying process

The success of the surveying process to record 3D data on the *Pandora* and the Myall Lake sites was varied. On the Myall Lake site, it was achieved simply and effectively, and to within an accuracy of about 5mm (pers. comm. P. Holt) however the *Pandora* has some mixed results, providing both good and bad 3D coordinates. The reasons have to do with the quality of the implementation of the surveying in the field and not the computer program *Site Surveyor*.

The distances measured in the field on the *Pandora* site were implemented with both an acoustic system and by using simple tape measures. The depths were measured through pressure measurements as part of the acoustic system and also with diver computer depth gauges. The use of the two systems on the *Pandora* site means that some worthwhile 3D data is being obtained, however the quality of this data is not as good as expected or as good as the Myall Lake data. The Myall Lake site is a very shallow, small site in comparison, and the surveying was carried out by three people in total, over a short period of time.

In regard to the surveying on the *Pandora* it was the first time this acoustic system (HPASS) was used at this depth and it may be some time before the final, reliable coordinates will be obtained due to the ongoing testing with the salinity and temperature factors and the interrogation of the data in the software used to convert the acoustic signals and the depths. The diver operated surveying using the four tapes and a computer depth gauge employed about 14 divers for a period of 20 days at a depth of 30-35 metres. Both of these systems need to be further developed to ensure more reliable results.

However, the *Site Surveyor* program worked very well in computing the 3D coordinates of the control points. The Myall Lake data is the best to show and is illustrated in figure 5. In brief, the program needs:

> at least four external control points that form a set of braced quadrilaterals;
>
> baseline measurements from each of the four external control points to each artefact/ship structural point (the distances should be less than 15 metres);
>
> depth measurements of every point.

Site Surveyor has the ability to 'adjust' the positions of the points to calculate the statistically best estimate for the position of the points given the measurements available. It includes quality measures for the positions calculated by the adjustment that is needed for any true survey. The adjustments carried out by *Site Surveyor* is through the 'least-squares' adjustment technique, ie the sum of the squares of the observational residuals must be minimised. Given that *Site Surveyor* program uses more that three measurements to compute the position of a point, it uses a system of adjustments of all the measurements to provide a 'best fit' for the points.

For each of the measurements the expected standard deviation, ie. the precision of the measurements must be stated. The value of the standard deviation is based on knowledge about the measurement process and experience. The standard deviations of all points are shown as error ellipses. These ellipses can be regarded as a two-dimensional equivalent of standard deviation. These ellipses are also known as confidence ellipses as there is a certain level of confidence that a point can be found in the area of its error ellipse. *Site Surveyor* presents ellipses with a 95% confidence limit. An error ellipse should be as circular as possible, any which is more than twice as wide as they are high need work. The unit variance—driven more or less by the standard error—should be at or near the value one, which will indicate that the error ellipse is correct (pers. comm, P. Holt).

The overall accuracy of the survey can be specified, it needs to be realistic and achievable. The three values that need to be specified are the RMS of the Residuals, the maximum position error, and the maximum allowed depth error.

The size of the residual alone is not always a precise indicator when checking measurements for blunders. A better test quantity in this case is the residual divided by its standard deviation, or the 'w' test. This is a good guide to blunders, ie. bad measurements. Measurements with large 'w' values can be set to be ignored and the network adjusted again to gain an acceptable accuracy of the survey.

Another, better value that should be looked at in gaining an idea of the accuracy of the position of the points is the geometric error. On its own the RMS of the residuals will provide a quality figure on how well the measurements fit together but not the precision (position errors) of the computed points. With a small value for the geometric error and a small acceptable RMS of the residuals (less than 50 mm), the survey is complete.

For further information on *Site Surveyor* see http://www.threeh.demon.co.uk

Photogrammetry process

The next step in the mapping process was to use the few points with X, Y and Z values to control the photogrammetry in order to obtain digital coordinate information of any point within the overlapping section of the photographs.

The photogrammetric process is usually carried out above water with a metric camera, sometimes using a pair of cameras, called stereo photogrammetry, although one camera can be used. Photogrammetry is the process of obtaining reliable three-dimensional information of the subject photographed. A metric camera is one where the geometry of the camera and lens is well known and documented, is. the focal length is accurately known, and fiducial marks that appear on the film can be used to accurately orientate and scale the film.

A non-metric camera is one where this information is not known to the accuracy required, although it is possible to determine accurately the focal length of, and have fiducial marks placed within a non-metric camera. The type used in this project was the non-metric camera (Nikonos 5 with a 1 5mm lens). A similar camera with fiducial marks shown on the film was also used.

The aim was to test the use of the computer program *VirtuoZo* in recording and analysing the *Pandora* structure and the Myall Lake material. The *VirtuoZo* system is a digital photogrammetric suite that accepts scanned stereo photography as input and produces ortho-rectified images, digital terrain models and contour maps (Zhang, 1996). The following procedures relate to the requirements for *VirtuoZo* and how this was implemented on the *Pandora* and the Myall Lake site. As has already been stated, each overlapping pair of photographs need to be controlled in scale and orientation, and this is normally achieved through the use of control points with known X, Y and Z values appearing in the overlapping area (normally 60% of each photograph).

Requirements/set up procedures for *VirtuoZo* (from *VirtuoZo* http://www.*VirtuoZo*)

1. Convert the slides (used in this case) or "positives" to digital format using a scanning resolution of 25 micron or 0.025mm (1000 DPI) on a mid range or low range office scanner. Better scanning results can be obtained from a photogrammetric quality scanner, at a greater cost.

2. Enter control into *VirtuoZo* and convert the working units to mm. *(VirtuoZo* works well with whole units rather than fractions of a unit.)

3. Set up *VirtuoZo* procedure to run as a non-metric data source.

4. Perform Relative and Absolute orientations. Relative orientation generates common points identifiable on the stereo overlap for each image. This allows the images to be properly merged together to provide a 3D stereo image. Absolute orientation ties this 3D stereo image into a real world coordinate system.

5. Create the epipolar images and match. The Epipolar resampling creates two new images from the original images for the stereo pair and aligns the rows of pixels to remove any Y parallax existing in the original images. These epipolar images are essential for viewing the model in stereo.

The match process removes any X parallax between the newly created epipolar images and creates a grid of pegs over the model that will fall on common pixels on each of the epipolar images. If the contrast between the images is good the majority of these pegs will appear to be sitting on the ground when the model is viewed in stereo.

6. Digitise "break lines" in *MicroStation* (digital drawing program). A “break line” is simply a line indicating a change of grade. i.e. the top of a bank and bottom of a bank. This forces the Digital Terrain Model (DTM) to triangulate up to the change of grade and not to create triangles over the change of grade (pers. com. T. Parker, *VirtuoZo*)

7. Digitise objects in *MicroStation.*

Outcomes

A digital 3D rectified image

Contour plans

Ortho-images

Pandora

It was considered that photogrammetry of the timber structure should be the main focus and after several weeks excavation the Officers' and the Captain's Stores had been cleared. Following the installation of a number of control points on the timber structure and their coordination using the acoustic surveying system, photography was attempted in two different manners—both using a pair of cameras.

The first way was using the cameras mounted 50 cm apart and free-swimming across the area to be photographed. The control points were not utilised in this method for scaling; two 50 cm metal bars mounted at right angles were used. These photographs were more suitable for the compilation of a 2D photomosaic not using digital photogrammetric techniques.

The second method utilised two cameras mounted one metre apart on a metal bar that was fixed to the top of a camera tower. The base of the camera tower was two metres square and the cameras were about two metres off the ship's structure/sea bed.

Unfortunately, the photographs taken during the 1999 *Pandora* season were of poor quality. The presence of thousands of bait fish and larger fish, and the often poor visibility reduced the definition in the photographs to a level where *VirtuoZo* could not operate (Figure 6).

It was possible though to test the program on some photographs taken of the *Pandora* site in 1986, using the same camera tower (Figure 7). The good definition in these photographs allowed the system to select the same points in each photograph and produce a 3D rectified image of an area of the ship's timbers. The base of the tower was marked with points that were coordinated and the cameras had fiducial marks shown on the images. This allowed for interior and absolute orientations to be carried out which greatly assisted in the production of the 3D image. Two drawbacks to the image produced were that because the control points did not vary in the Z (height) plane, the resulting height data lacks accuracy; and because of the poor definition in the 'sand' areas, no image matches could be made between photographs resulting in inconsistent 3D information and imaging (Figure 8).

Myall Lake

Unlike the *Pandora* site, the selected area to be photographed was based on a random view of the timber off-cuts. An area of timber was chosen that had a certain amount of depth (Z) and that would allow for the development of two stereo models, thus testing the mosaicing aspects of the *VirtuoZo* program. The depth of the water—about 2 metres—and the poor visibility—about 5 metres—did not provide ideal conditions, and the photographs were taken on the surface by a diver in a free swimming mode. Transparencies as well as black and white film was used.

The control points consisted of a yellow, circular plastic material of about 10 cm in diameter and nailed to the timber. A different numeral on each of the points differentiated them. They were placed throughout the area so as to provide what was thought to be a good coverage in the X, Y and Z dimensions (Figure 9).

VirtuoZo programmers compiled the following report on the Myall Lake photogrammetry.

A 3D image was obtained by using *VirtuoZo*. Outlined here are the problems encountered and a suggested way of correcting them (Anon, 1999).

Perceived Problems:

Murky water and photography hindered the resultant match, to some degree;
Poor identification of control points, glare and size resulted in a poor absolute orientation;
The artificial light source resulted in a large amount of glare from the control circles. [No artificial light source was used, this was as a result of the reflective nature of the colour of the circles and the shallow depth of water];
The ground control points (GCP's) were too concentrated within the photography;
The two photographs-left and right images used to create the model were not in the same plane. The right hand photograph was lower than the left-hand photo. This resulted in a poor match result for that particular pair of photographs. [The two Nikonos 5 cameras with 15 mm lens's were mounted onto a metal bar, 50 cm apart and could well have moved during the photography].

Possible Solutions (not in any particular order):

Try taking sets of stereo pairs from different perspectives, in order to pick up breaklines that do not appear on the stereo pairs;
A small dot in the centre of the control circles is necessary to get a better absolute orientation result. The dots need to be visible in the photography; [Dots—nails were placed in the centre of the circle, but because of the flaring of the control circles, they could not be seen];
A well-distributed number of control points would have given a better result;
The use of a 35mm metric camera could be used to obtain a better result, this would cut down on the amount of control needed;
Try to estimate the height of the camera above the object being photographed, for each stereo pair;
The model or two overlapping photographs need to be in the same plane. A camera frame, with two cameras could possibly be used, to ensure stability of the two overlapping photos.

Conclusions

VirtuoZo is a very powerful photogrammetric program that works very well with good quality photographs. While the software programmers performed all the analysis of the data, it was considered that after reasonable training, non-photogrammetric specialists could implement the work.

It was considered the following points need to be carefully addressed in any future work with this program:

use only good quality (high resolution) large format photographs;
the use of a metric camera with known focal length and fiducials marks--in *VirtuoZo* the cameras must have the same calibration, therefore one camera only should be used (pers. com. T. Parker, *VirtuoZo);*
the accurate delineation of six (when using a metric camera) and eight (when using a non metric camera) control points spread out throughout the whole X, Y and Z range in the overlap parts of the stereo photographs.

While the computer hardware required to run *VirtuoZo is* not excessive, it does require a set-up that would be considered a high end machine. This combined with the cost of the software could make it out of the reach of agencies / museums that have small budgets. One of the great attractions of the program was its capability to perform automatic matching—auto-correlation--of similar points in the 3D model and the subsequent ease in producing contour plans and rectified images. Because of the poorer definition that accompanies many underwater photographs it is not possible to use this automatic process and therefore it gets back to the operator performing the matching manually.

A program such as *Virtual Mapper,* which is 10% of the cost and can run on any average PC is something to consider. This program was not used as part of this test but subsequently the Myall Lake photographs are being analysed by this program. A report on this work and the *Pandora* photographs already investigated by *Virtual Mapper* will be the subject of a separate report.

MicroStationJ

The promotional literature (http://www.bentley.com/products/mstation/j) on this program describes it as:

> Micro Station/J is a professional enterprise engineering modelling software that provides for integrated modelling with engineering and business applications. It is designed for large-scale collaborative engineering across the Intemet or Intranets and supports the entire life cycle of products and assets, from conception to construction and deployment. It incorporates high performance 2D and 3D modelling functionality such as associative 2D drafting, 3D solid modelling photorealistic visualisation and animation. Data can be published in a variety of formats such as CGM, SVR and VRML.

MicroStation has had some application in the graphical representation of the remains of heritage items, such as the Navajo dwellings in New Mexico. A theodolite, digital camera and line drawings were used to draw and render the remains of a dwelling which may be used in the future for virtual tours of a Navajo pueblito (Smith, 1997).

The aim of the *Pandora*/Myall Lake project was for *VirtuoZo* to provide a DXF of the *Pandora* and / or Myall Lake site and for *MicroStationJ* to render it into a solid 3D model. *VirtuoZo* did provide a DXF from *1986 Pandora* stereo pair of photographs but this was not proceeded with. Some of the 1999 data from the *Pandora* had been provided to *CADStation Solutions*—the Brisbane agents for *MicroStation* http://www.cadstation.com.au and as this project was deemed a priority for the developing *Pandora* display, the DXF was put aside.

The project that was proceeded with however does show the potential of the *MicroStationJ* program. The section of the Officers' Store that was uncovered during the 1999 excavation was carefully measured during the season and a plan and section was drawn up (Figure 10). This graphical information was presented to *CADStation Solutions* together with the X, Y and Z coordinates for every 50 cm on the seabed over the 50 metre by 20 metre area. A 3D solid, digital, rendered model was produced of the seabed and the structure of the ship in this area.

In addition, a small number of the recovered artefacts (Figure 11) where placed in context with the ship's structure in the 3D digital model. It is possible to place all the artefacts in the exact positions in which they were found and to be able to view and interrogate each of them. This has great potential for the archaeologists to be able to analyse a large number of artefacts in context with the ship's structure *insitu*—518 artefacts were recovered from the Officers' Store in 1999--a situation that is very difficult using more conventional drawing techniques. This application has some exciting possibilities, particularly as it will be feasible to link *MicroStation* with the text information from the Access database while viewing and rotating the artefact.

The following text was compiled by Jackson Shu of *CADStation Solutions*

Modelling the wreck of the *Pandora*

The three-dimensional model of the wreck of *Pandora* was created by using existing drawings and photographs of the wreckage site. The two-dimensional drawings were electronically scanned. one of the wreckage in elevation and one in plan. The scanned drawings were then brought into *MicroStationJ* and scaled 1:1, matching the actual dimensions of the wreck. The profiles of the wooden members were created by tracing the scanned drawing. The profiles were then extruded into three- dimensional objects by comparing the objects thickness in elevation and in plan. The cannon was modelled based a drawing of the original cannon which was also scanned and brought in *MicroStation*. A text table of the XYZ coordinates of the sea bed was used to generate a three- dimensional digital terrain model of the seabed using *MicroStation* J and Civil Pack, which is a Civil Engineering module for *MicroStation*. The model of the wreck was then place onto the seabed using known coordinates. The artefacts were also modelled using the electronically scanned images and profiles were then created by tracing over the photographs using *MicroStation*.

Once everything was in place spat/ally, materials were mapped to the surfaces of the three-dimensional model creating a realistic representation of the wreckage. The material images were taken from digital photographs of actually material such wood, sand and rust. The materials fur the artefacts came from the actual digital images of the artefacts. The models can be viewed from any angle and individual objects can also viewed by themselves. Digital fly-though.

animations of were produced of the site showing the area around the wreckage. The models was also translated to VRML which can be posted to a web site allowing viewer the explore the site in 3D, using their internet browsers.

The advantages of creating a three- dimensional *MicroStation* model of the wreckage is more than visual.

Inherent accuracy of *MicroStation* CAD platform allows extremely accurate documentation of all aspects of an archaeological site. Two-dimensional survey maps can be produced and also two-dimensional drawing of the wreckage and other artefacts can also be generated. Any new findings can be quickly add and updated.

The resulting 3D models were put into VRML and AVI formats but files can be edited and saved in many formats including TIFF, JPEG which are shown in figures 12-15. The VRMLs and AVIs can be seen on the Museum of Tropical Queensland's *Shipwrecks and You* display in Townsville, and possibly on the Queensland Museum's webpage http://www.qm.qld.gov.au/culture/culturewelcome.html

Conclusions

This work produced some 3D digital models that can be used by the archaeologist to assist in the analysis of a shipwreck site and it is in a form that can provide informative interpretive material to the general public.

It has been possible to get to this point using a combination of a computer surveying program, a computer drawing program and conventional underwater surveying using measuring tapes. It is worth noting that it is not always required to use only computer aided programs for the underwater surveying, such as photogrammetry to get to this outcome. The advantage of photogrammetry is that it is quick in the field and it captures considerable digital information that can be analysed in the laboratory. However, it is not always possible to get good clear water or the right conditions to use photogrammetry.

If it had been reliant on the photogrammetry to obtain the necessary information to produce the 3D model of the Officers' Store on the *Pandora* site, it would not have been obtained. Given the expense to implement such field work and that this project was a major outcome required, it is crucial that the data be obtained by whatever means, and this was accomplished.

VirtuoZo is a powerful but expensive program. Cheaper and possibly as effective programs such as *Virtual Mapper* and *Photomodeler* need to be tested under the same conditions. Another drawback for photogrammetry is that photogrammetrists/operators need to identify the material during the laboratory mapping and this can be difficult if they have little appreciation of the subject (MacNeill, R. & Bennett, C., 1992). This is not normally the case using conventional underwater surveying where the archaeologist is identifying and mapping the material *insitu*. The drawback to this process is the time and human resources it needs.

Before commencing a project, the outcomes required need to be considered and the appropriate surveying and drawing processes used. Photogrammetry will provide accurate 3D plans and visualisations and this could be the required outcome. A surveying process incorporating *Site Surveyor* and *VirtuoZo* (or substitute) could therefore be suitable. If however, accurate 3D digital models need to be produced, that will allow for virtual dives for the archaeologist and the general public to view and analyse what was found, including the thousands of artefacts concentrated in small areas, then a drawing program such as *MicroStation* is required in addition to *Site Surveyor*, but not necessarily with *VirtuoZo*.

The ideal would be for an integration of these programs, resulting in photo-realistic 3D digital visualisations in a virtual world that can be viewed whenever and however possible.

Acknowledgments

I would like to thank the following people for their help during the compilation of this work. Peter Gesner for his initiation of the project; Viv Moran for her surveying of the *Pandora* shipwreck site (in addition to other participants of the 1999 *Pandora* field work season); David Nutley and Tim Smith for their assistance with the Myall Lake field work; Peter Holt from *3H Consulting* with regard to the *Site Surveyor* program; Luke Constant and Tim Parker from *VirtuoZo* for their numerous discussions and assistance with the production of the rectified images (Figure 9); Andrew Musgrave and Jackson Shu from *CADStation Solutions* with regard to

the production of the 3D rendered models, images (Figures 12-15) and text, and their very useful advice on the use of *MicroStation*.

References

Anon, 1999 Report on Myall Lake Project and Results from *VirtuoZo*. Unpublished Report, *VirtuoZo*, Brisbane.

Gesner, P., 1991 *Pandora An archaeological perspective* Queensland Museum

Green, J. and Duncan, A., 1999 Report on the 1998 evaluation trials of the High Precision Acoustic Surveying System (HPASS) *International Journal of Nautical Archaeology* (1999) 28.1: 85-93

Jeffery, B., 2000 *Report on the 1999 season archaeology of the stern of HMS Pandora* Unpublished report for the Queensland Museum, Brisbane

McKay, J., 8 Coleman, R., 1992 *The 24-Gun Frigate Pandora 1779* Anatomy of the ship series. Conway Maritime Press

MacNeill, R. & Bennett, C., 1992 *Final Report: Sydney Cove Photogrammetry* Unpublished report for the Tasmanian Department of Primary Industries, Water and Environment, Hobart

Nutley, D., 1999 *Photogrammetric Survey Trial, Myall Lakes* Unpublished report for the NSW Heritage Office, Sydney

Smith, S., 1997, Documenting Dinetah. *MicroStation Manager.* Madison, USA

Zhang J., Zhang Z., Shen W., 8 Wang Z., 1996 The *VirtuoZo* Digital Photogrammetric system and its theoretical foundation and key algorithms. *Proceedings of the XVIII International Symposium of Photogrammetry and Remote Sensing,* Vienna.

Captions for Figures

Figure1	The Officers' Store located on the platform deck, starboard side (Courtesy of drawing by John McKay).
Figure 2	Location of the Myall Lake site.
Figure 3	The network of grids over the *Pandora* wrecksite (courtesy of the Queensland Museum).
Figure 4	The timber offcuts in Myall Lake—photo D. Nutley **Slide**
Figure 5	The plot of the Myall Lake control points—from *Site Surveyor.*
Figure 6	The Officers' Store on the seabed **Possible slide or digital capture from Video??**
Figure 7	The right photograph of a stereo-pair showing a section of some stern timbers.
Figure 8	3D rectified image of a 2 metre section of the *Pandora* shipwreck
Figure 9	The control points on the Myall Lake timbers—photo by B. Jeffery. **Slide**
Figure 10	Plan and Section of the *Pandora* Officers' Store—drawing by B. Jeffery
Figure 11	A spruce jar recovered from the adjacent Captain's Store and used in the modelling of the jars shown in the 3D models. Photo by G. Cranitch **Slide**