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Stonehenge — Mapping the Stones

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6.1 The background

It is little wonder that the vision of Stonehenge, rising out of the topography of Salisbury Plain, in southern England, has long since been a source of fascination and mystique to many a visitor. Even though the ravages of 5000 years, through several remodellings and the unfortunate 'vandalism' of previous visitors and owners to the surrounding landscape, have left the present day site bearing only a slight resemblance to that originally intended, there is still a feeling of awe and amazement within its construction that never ceases to fade. The designation of the area, by UNESCO, as a World Heritage site stands witness to this fact but it does not hide the view shared by many throughout Britain that the present site, and its facilities for the thousands of visitors, are unsatisfactory for such a world famous monument.

Even though the surrounding area is one of the richest prehistoric landscapes in the whole of Europe, it is the stones themselves that appear to capture everyone's imagination and each year draw thousands of tourists to the area. Every year new theories are put forward as to the precise origin of the monument, how it was constructed and how it was used. Its alignment with the rising of the midsummer sun has long been thought to be a temple to some religious belief. Many theories like this have looked at the relationships of the stones with astronomical alignments. Survey in its various forms, such as topographical and hand measurement, has therefore been crucial to any detailed analysis. Many of these theories, however, have made basic assumptions about the original builders and designers of the structure, such as their individual heights, which would have affected their actual view of the stones as they were being constructed and aligned with any possible astronomical significance. The surveys used have always, therefore, concentrated on recording the positions of the stones simply at ground level, but in reality it is the complex arrangement of stone shapes visible at 'normal' eye level that is really required within any detailed study.

Also, as the exterior faces of the remaining stones are themselves the only remaining evidence we have of the way the builders set about their original task of construction, it is equally important to record in detail the faces of each remaining stone as they presently stand today. With the requirement to view these faces from any angle, and the additional use of variable lighting conditions to highlight the complexity of the surface formations themselves. Such analysis really needs the benefit of being computerised.

Even though there is a wide range of survey material currently existing on the site as a whole, including aerial photography and topographic survey both generated at various scales over the last decade (Figs. 6.1–6.3), very little of this material covers the actual stones themselves in any degree of detail. The material that is available on the stones, such as historic prints from the 19th century and more recent hand survey from 1974, are not typically produced in a suitable format for detailed interrogation upon a computer.

It is with this thought, therefore, that the then regional Inspector and Head of Historic Branch for the South West region of English Heritage, Mr Brian Davison, set out in late 1993 to investigate the feasibility of generating such a detailed record and survey of the remaining stones themselves Hawkes (1994). This survey was to form another stage in the programme of survey, that had been jointly developed by the region and the then Head of Survey Mr Ross Dallas during the late 1980s and had previously included such items as low level aerial photography and detailed topographic survey around the stones themselves. It would also fit into the carefully considered rolling programme of data capture, data enhancement and public dissemination that is deemed necessary for such a prominent historic monument.

6.2 The project

The initial aims of this project, as originally set out by Brian Davison, were twofold. Firstly an accurate and complete photographic based archive of every visible external face of every stone, within the main monument complex, would be generated. This would provide a unique and invaluable record of the condition of every stone, as viewed at the time of photography, which would be invaluable not only for those wishing to conserve the monument but for those wishing to

Figure 6.1: Aerial view of the stone circle at Stonehenge.

analyze it in detail as well. Having this level of detail available for a particular period in time would permit any slow deterioration in the stones condition, that would normally have gone unnoticed, to be accurately monitored as well as providing photographic data for use in any in-depth analysis of the lichen colonies that are particularly prevalent on a number of the stones and apparently capable of providing fresh information on the history of the monument.

Secondly, a full set of accurate three dimensional survey data would be generated from the initial photography record, with each external stone face not only tied accurately to its 'neighbour' but also accurately related to the surrounding landscape through the use of the site coordinate system. To allow their anticipated use both by conservators and researchers alike these data *had to be* be available on a conventional PC *and* be accessible from within a standard CAD (Computer Aided Draughting) platform, such as AUTOCAD.

After contemplating the techniques available to generate this data, ranging from scanning 3D laser-heads to simple photography and taped measurement, photogrammetry—the art, science, and technology of making measurements from photographs—was chosen by Brian Davison to fulfil these primary aims because of its unique ability to both provide a high quality stereo-photographic record of the monument *and* to generate accurate three dimensional measurements from these over-lapping images.

This survey technique was not actually new to the region. It was successfully used in 1967, in collaboration with University College London, within the context of the production of detailed contour drawings of the carvings that had earlier been accidentally found on stone 53 by Professor Atkinson in the early 1950s (Atkinson 1968). More recently it has been used within the national recording programme on monuments principally in the care of English Heritage, providing accurate line drawing information that forms the basis both for any proposed archaeological analysis and any works restoration planning documents.

Since 1991 English Heritage has been fortunate enough to have a dedicated in-house unit that collectively has a wealth of experience gained in this architectural application of photogrammetry, being the leading national authority on, and practitioners of, the technique for well over 25 years (Fig. 6.4). The Unit and Brian Davison had previously investigated the possible application of photogrammetry in providing a detailed record of the monument with some initial trials, during 1989, upon stones 30 and 101, located within the outer ring of Sarsen stones (Fig. 6.5).

Although this original data was never completely processed into drawings, it did provide Brian Davison and the Unit with some basic photogrammetric material on which to carry out initial tests on the suitability of the technique for the project. From this it was concluded that the traditional method of simply tracing around the stones, as used within the typical architectural survey of a traditional stone elevation, *would not* record the complex stone surfaces in sufficient detail. With very little in terms of sharp edges and features to directly trace round, an alterna-

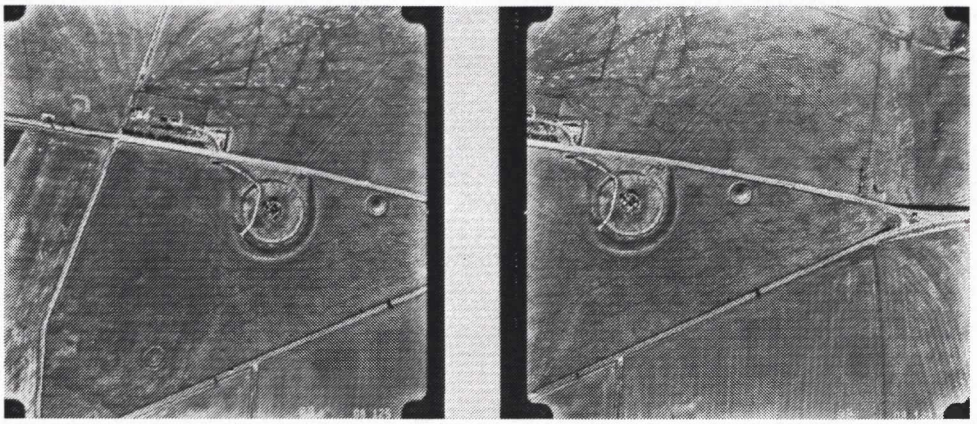

Figure 6.2: 1:3000 scale stereo pair of the stone circle (Photography by BKS Surveys Ltd.)

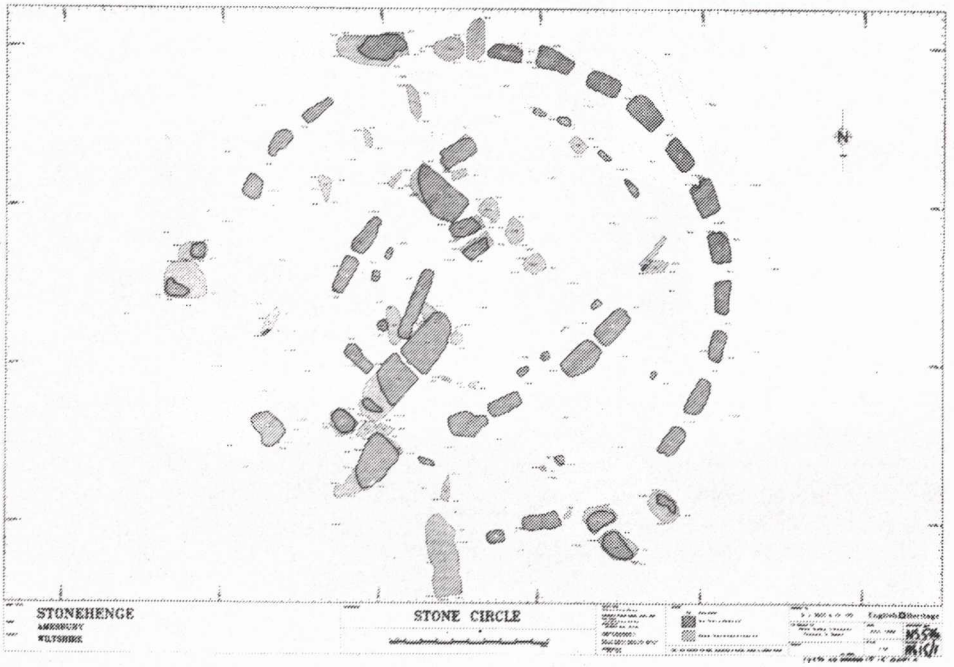

Figure 6.3: 1:50 scale topographic survey of stone circle. (Survey by M. J. Rees and Co. Ltd.)

tive approach was required to map the stone surfaces themselves and produce a grid of 3D points across each face that would hopefully represent the undulations and hollows that exist in these complex features. After initial trials a grid spacing of 2cm was subsequently chosen that would satisfactorily illustrate the relief on each stone face, being a compromise between level of surface detail representation and actual computer file size. This would produce the 3D model that is commonly referred to these days as a DEM (Digital Elevation Model).

6.3 The survey

6.3.1 The fieldwork

A typical photogrammetric survey comprises two basic processes: the site based fieldwork and the office-based plotting or processing work. The fieldwork can itself be subdivided into two further processes: the acquisition of the stereophotography of the object to be surveyed, using purpose built metric cameras (Fig. 6.6), and the measurement of precise survey observations using a total station theodolite to targets previously fixed to the object (Fig. 6.7).

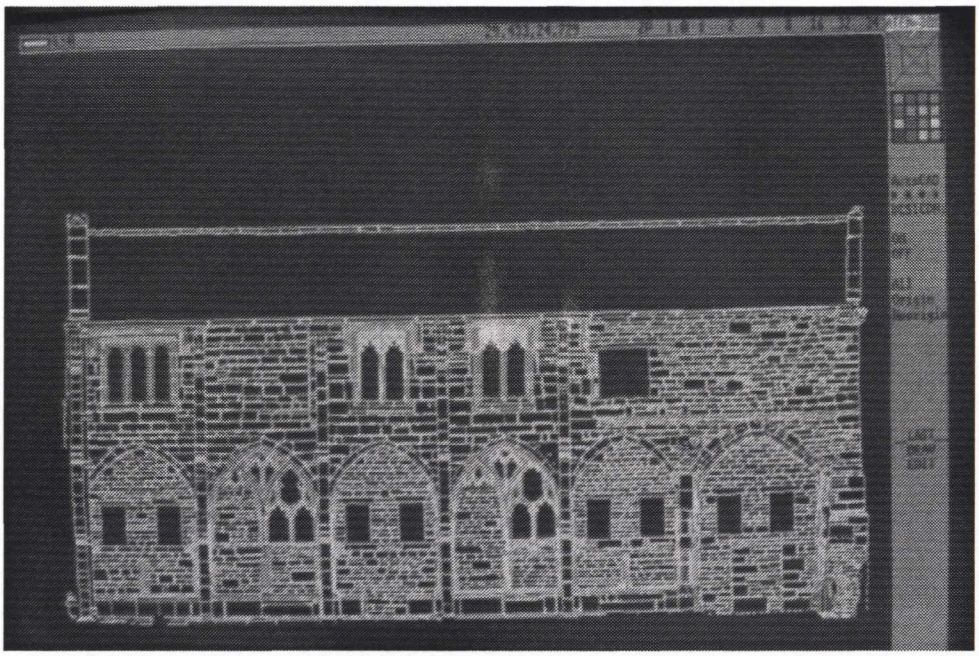

Figure 6.4: 1:50 scale photogrammetric drawing of Muchelney Abbey, Somerset.

Due to the anticipated size of this fieldwork operation and the requirement to ideally take each photograph in perfect overcast weather conditions, thus enhancing its function as an archival record, it was decided to sub-contract this important initial stage of the project to a suitable commercial survey company rather than tie up the limited personnel resources of the Photogrammetric Unit itself for a long period. Therefore in November 1993 The Downland Partnership, based in Wiltshire, England, were commissioned by English Heritage to carry out this important initial task. Due to the particularly bad weather conditions encountered over this winter period and the difficulty encountered in bringing onto site a portable hydraulic lift, essential for the photography of the upper surfaces of stones and lintels, the site work was not to be completed until March 1994.

The package of data, comprising 671 stereophotographs taken in both black and white and colour (Fig. 6.9), and the 1482 target observations, all held in 15 archive albums, was eventually delivered to the offices of English Heritage in London in April 1994.

6.3.2 The processing work

As mentioned earlier the stones forming the monument display complex surfaces rather than precise edges which is partly due to the work of the stone mason and partly that of time and decay. Therefore the traditional method of generating line based drawings, involving the manual tracing of a measuring mark around the edges of the required detail within a 'traditional' analytical photogrammetric plotting machine (Fig. 6.9) would not provide the required level of 3D DEM data.

Even though these machines have regularly been used by commercial survey companies to manually produce similar grids of 3D topographic data, known as DTMs, the large number of points to be generated on the stones within a relatively short timescale, which equated to approximately 50,000 points for each of the larger stones, would take a very long time indeed to generate using only manual methods. It was therefore decided that all the photographic data would be processed using a Digital Photogrammetric Workstation, which in 1994 was the latest technological advance to become available to the photogrammetrist.

This 'state-of-the-art' technology, which has its foundations in military applications, comprises a high powered computer workstation such as a Silicon Graphics or Sun Sparkstation, a TV monitor capable of displaying a realtime 3D image, a pair of 3D viewing spectacles and the all important image processing software. Once scanned into a digital format this machine could then automatically interrogate the stereophotography taken and, together with the survey control data, provide the required grid of points across each stone face in the form of the DEM. Each point would have accurate three dimensional coordinates related directly to the site coordinate system.

Once again, due to the size of the project, it was decided to commission this processing work to an outside consultant. Therefore in February 1994 LTG Services of London were commissioned to carry out the post processing work. In collaboration with Leica, the well known manufacturer of survey equipment based in Switzerland, an Helava DPW750 Digital Photogrammetric Workstation (Fig. 6.10) and a DSW100 High Resolution Scanner were both hired for a period of two months to allow the staff of LTG Services time

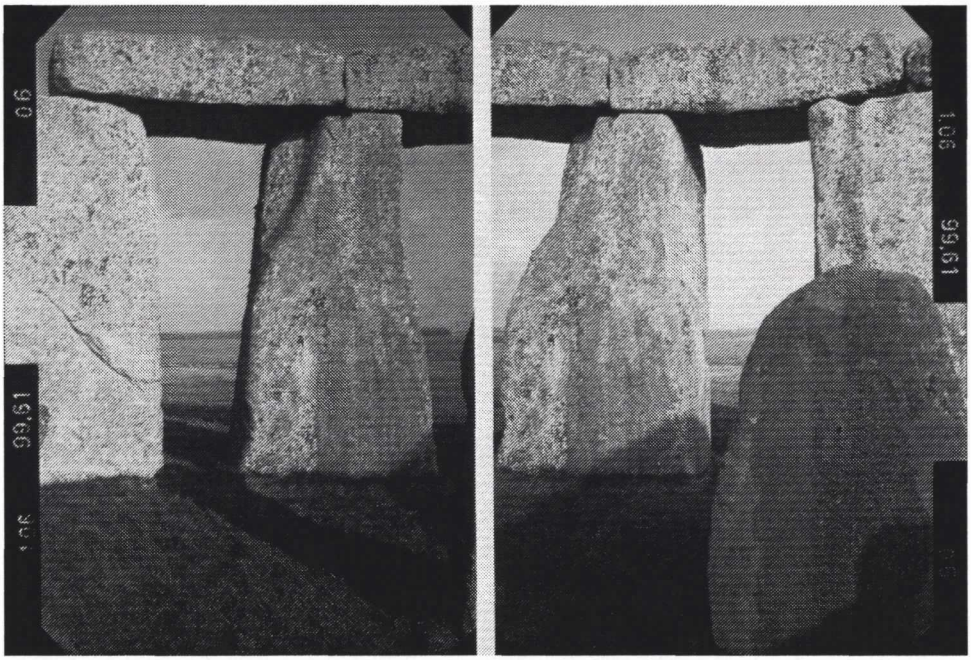

Figure 6.5: Stereopair of stone 30 from 1989.

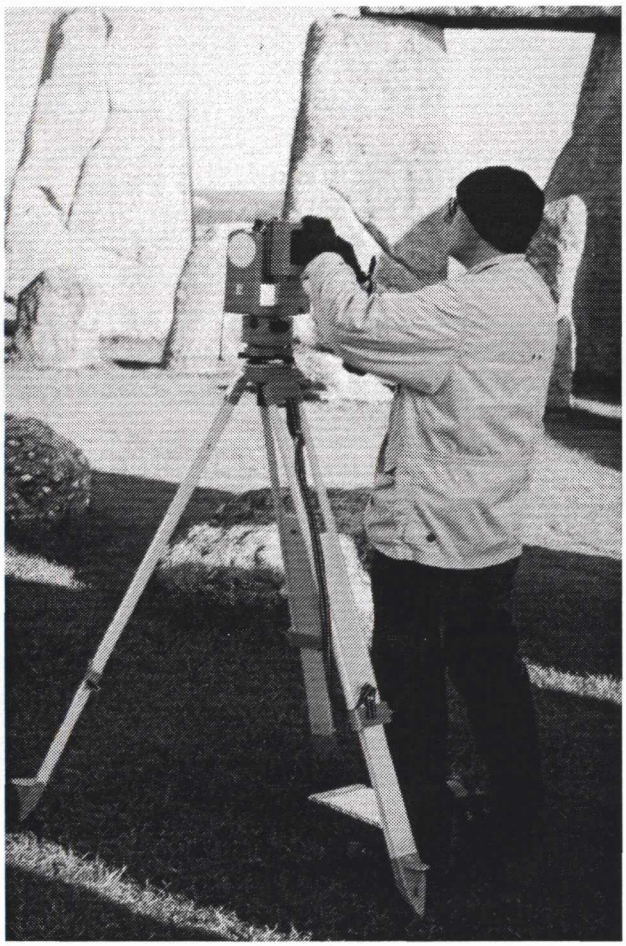

Figure 6.6: Wild P31 metric camera in use at Stonehenge.

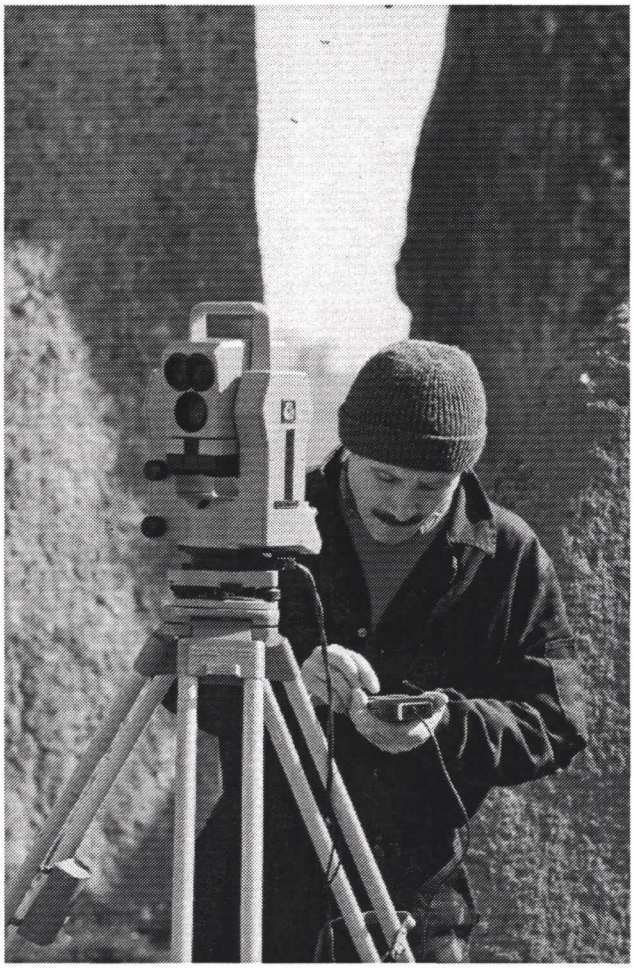

Figure 6.7: Total Station Theodolite in use at Stonehenge (Photograph by David Stevens).

Figure 6.8: Stereopair of stone 3.

Figure 6.9: Leica SD2000 Analytical Photogrammetric Plotting Machine

to process the 350 stereomodels that had been taken.

However by the end of the commission to LTG and the hire period of the workstation from Leica in April 1994, it was evident that not all the models would be successfully processed into DEMs. In addition it was found that some of the edges of the stones had not been fully processed and 'gaps' in the data coverage were noticeable due to the lack of suitable oblique stereophotographic cover. This latter point necessitated a further period of fieldwork in March 1995, by the staff of the Photogrammetric Unit themselves, to provide suitable coverage of such edges. After in-house checking and transformation of the processed data into AUTOCAD drawing files, taken from the initial data provided by LTG, it was deemed essential to hire a further digital workstation to complete this initial phase of DEM production.

Hence in association with Carl Zeiss, a manufacturer of survey equipment based in Germany, the Phodis ST30 Digital Photogrammetric Workstation (Fig. 6.11) was hired from July to October 1995, located in the Photogrammetric Units' own offices in London and operated by its own personnel. This was used to process the remaining models and infill any of the larger gaps visible in the existing data along some of the stone edges.

6.4 Conclusion of the project

The current status of the project is that the majority of the 350 stereomodels have now been fully processed into AUTOCAD drawing files and combined together to form complete 3D surface images of each stone (Fig. 6.12).

Some of the minor faces upon the smaller stones still remain to be processed although it has been found that reverting to manual DEM processing upon the Units own analytical plotting machines is still more economic than using the automated systems for such small areas of processing.

It is anticipated that once all the processing and formatting of the DEM data is completed, during this year, the 3D drawing files can then be safely archived onto a suitable medium, such as DAT tape or CD-ROM and provided to the regions, as originally intended. In addition the archive of monochrome and colour stereophotographic images has been separated out to be safely stored away in separate locations, such as the new regional English Heritage office for Stonehenge itself in Amesbury. Even though a number of problems have been encountered that have collectively helped to delay the final completion of the project, photogrammetry, and the new equipment used, has proved itself very capable indeed of providing the level of detail required and is hence being considered for other projects within English Heritage. Even though the regional teams are still presently unable to directly utilise the 3D drawing files generated, they and the new managers of the monument can rest assured that a very detailed record of these important stones now exists in a format that can be easily used by both conservators and scholars alike.

6.5 Future uses of the data

At the inception of this project in 1993 it was felt that the data that would be generated, including the set of stereophotographs themselves, would have numerous other applications that could go well beyond the original aims of the project. The basic 3D data, for instance, is suitable for further computer rendering including the draping of the photographic image itself over the 3D framework. Within the last year developments in the 3D graphics capability of basic personal computers have enabled the true interaction between operator and image to step ever nearer the virtual sense and it is with this advance that the 3D survey data generated from this project is finding an additional use.

As has been well documented and reported in the national media English Heritage has embarked during 1996 upon developing *Virtual Stonehenge*, a virtual reality model of the monument and its surroundings that will include both the stones and the vast area surrounding the monument which will be capable of running on the latest personal computers. The initial stages of creating this model have already been commissioned by English Heritage to VR Solutions Ltd of Salford near Manchester, an external company specialising in this type of work, together with funding from Intel, the well known manufacturer of computer processing chips.

The 3D data generated by this project has proved to be an integral part in developing the accurate framework that the virtual model requires prior to rendering, draping of photographic images and final interactive viewing. By utilising existing survey material and processing the recent colour aerial stereophotography that was taken of the site last year, using the latest Leica Helava digital photogrammetric workstation to generate new 3D DTM computer data, the photogrammetric technique has also proved fundamental in generating the accurate three dimensional topographic map data for the all important stones to be fitted into. It is now anticipated that another mapping project will be required to continue this work.

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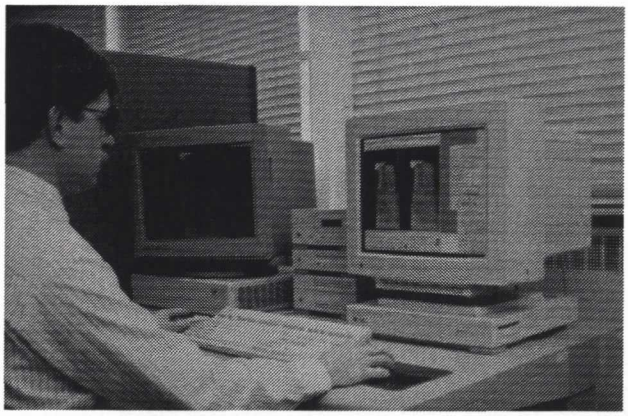

Figure 6.10: Leica Helava DPW750 Digital Photogrammetric Workstation (photograph by LTG Services).

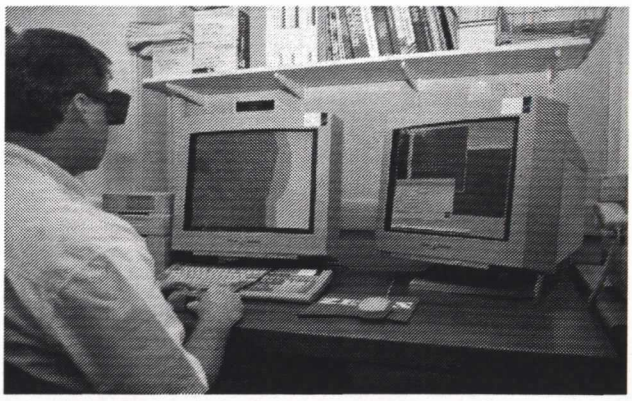

Figure 6.11: Zeiss Phodis ST30 Digital Photogrammetric Workstation

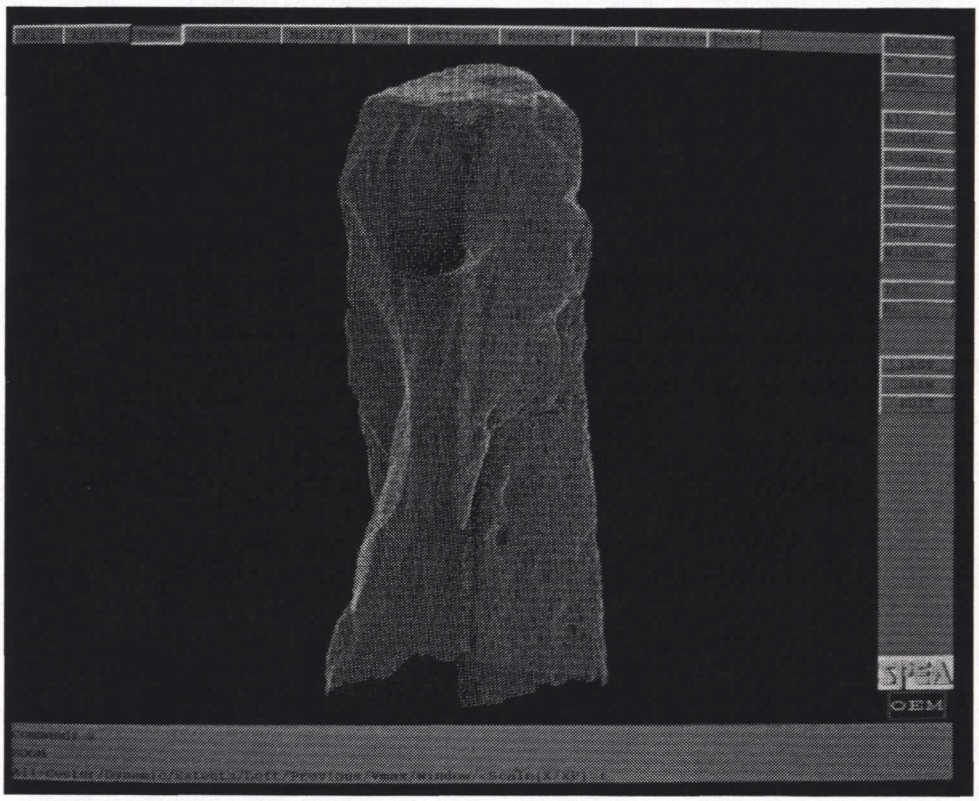

Figure 6.12: 3D DEM of stone 3 formatted for viewing within AUTOCAD.

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