METHODS OF SURVEYING IN ARCHAEOLOGY DEMONSTRATED AT THE TANG EMPERORS' MAUSOLEUMS

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ABSTRACT:

The eighteen mausoleums of the Tang Emperors (A.D. 618 - 907), scattered over an area of about 5 000 km^2 in the vicinity of Xi'an, the capital of the Province of Shaanxi, in the People's Republic of China, are presently documented in a joint Chinese-German project. The scales of the plans and maps to be produced extend from 1 : 2.5 to 1 : 1 Million. Consequently, a large variety of surveying methods is used, including close-range photogrammetry, tacheometry, GPS measurements, and remote sensing. For this reason, the purpose of this paper is not only a report about the specific project but also a review of possible solutions when geometric and topographic information has to be surveyed and visualized in archaeology.

KURZFASSUNG:

Die achtzehn Mausoleen der Tang-Kaiser (618 - 907 n. Chr.), die über einen Bereich von ungefähr 5 000 km^2 verstreut in der Nähe von Xi'an, der Hauptstadt der Provinz Shaanxi, in der Volksrepublik China liegen, werden gegenwärtig in einem gemeinsamen chinesisch-deutschen Projekt dokumentiert. Die Maßstäbe der zu erstellenden Pläne und Karten reichen von 1 : 2.5 bis 1 : 1 Million. Es werden verschiedene Meßmethoden wie Nahbereichsphotogrammetrie, Tachymetrie, GPS-Verfahren und Fernerkundung eingesetzt. Daher ist die vorliegende Veröffentlichung nicht nur ein Bericht über dieses spezielle Projekt, sondern auch eine Übersicht über verschiedene mögliche Methoden zur Aufnahme und Darstellung geometrischer und topographischer Informationen in archäologischen Aufgabenstellungen.

1. THE TANG EMPERORS' MAUSOLEUMS

1.1 Original Condition

The emperors of the Chinese Tang Dynasty (A.D. 618 - 907) went to great expenses for the construction of their mausoleums (ASIM, 1993). The actual funeral chamber was excavated at the end of a tunnel dug into the ground or a mountain slope. It was surrounded by a large wall with towers and four gates. More than life-sized stone sculptures representing human figures and animals were erected outside the gate areas. As a rule, the procession way leading to the south gate consists of two columns and about thirty of those sculptures. Every mausoleum was equipped with several buildings.

The mausoleum wall can easily have a total circumference of 10 km. Including the stone sculptures located outside the wall region, the immediate area of one Tang mausoleum may comprise 15 km^2. Furthermore, attendant tombs of nobles, court officials, and generals are spread over the country in the vicinity of the mausoleums. The total number of the Tang emperors' mausoleums is 18. Together with many hundreds of attendant tombs they are scattered over an area of about 5 000 km^2 in the vicinity of Xi'an, the capital of the Province of Shaanxi, in the People's Republic of China.

1.2 Present Condition

The ancient walls and temples, having been constructed of tamped loess, have vanished. Their location can be ascertained, however, since many of the baked roofing tiles can still be found. The ruins of the towers and gates are recognizable as mounds rising about 5 metres above the surrounding area. They have a very similar appearance as the numerous *tumuli* of the attendant tombs, which can reach elevations of 20 m, however. Many of the stone sculptures are still *in situ* and in good condition, others are fallen over, or broken to pieces. The funeral chambers are not accessible. Possibly they have been robbed in earlier times. It is not intended to open any of the funeral chambers in the near future.

1.3 The Documentation Project

The Tang emperors' mausoleums were added to UNESCO's list of World Heritage Sites. Since only very few mausoleums had been documented in the past (SONG and YAO, 1990), an effort was started in 1993 to do a complete documentation. This is carried out in a joint venture between archaeologists of the *Shaanxi Archaeological Institute* (Xi'an, P.R. China), and the *Römisch- Germanisches*

Zentralmuseum (Mainz, Germany). The authors of this paper, both from the *Fachbereich Geoinformatik und Vermessung (Department of Geoinformatics and Surveying)* at the *Fachhochschule Mainz* (Germany), joined the project being responsible for all geometric und topographic aspects of the documentation. An average of about forty plans and maps is necessary for the documentation of just one single mausoleum. Up to date, the survey of four of the eighteen mausoleums has been completed and made available for publication.

2. METHODS OF SURVEYING IN ARCHAEOLOGY

2.1 Commonly Used Methods

Archaeological research covers many different activities. Here, we shall concentrate on one problem only, that is the measurement of geometric shapes of objects and topography, and their representation in graphical form. The difficult - and thus interesting - aspect of archaeological surveying projects is caused by the large variety of possible objects and their sizes.

In many cases we have objects ranging from some millimetres to some metres and buildings or excavations ranging from some metres to some hundred metres. Hence, the resulting documents will have scales between about 1 : 1 to 1 : 1 000. This kind of documentation is usually done by the archaeologists themselves. Drawings are created in direct view of the object with the aid of simple instrumentation, such as rulers, measuring tapes, and spirit levels. Photographs, not indended for photogrammetric treatment, complete this kind of documentation.

For larger areas or topographic surfaces tacheometric equipment is used occasionally. Close range photogrammetry has successfully been used for many archaeological tasks but still must be considered a rare technique when set into relation to the large number of projects accomplished without.

2.2 Possible Methods

In figure 1 possible techniques for surveying are arranged according to the scale of the final document which in turn is a function of object size and possible representation of details. A distinction is made between methods observing point after point and methods recording a complete area in a comparatively short time. All these methods are suitable for archeaological applications. In many cases, they are not considered, however. A major reason for neglecting modern methods is the fact that specially trained personell and costly technical equipment are needed. Nevertheless, the renunciation of modern surveying possibilities may result in an unnecessary high consumation of time and money.

Simple measurement methods will most likely not be sufficent if

- the objects have rather complicated shapes
- time is an important factor on site
- the objects are very small or very large.

In these cases, surveyors and/or photogrammetrists should join the archaeological teams and put their knowledge into practice. The Tang project has shown that a combined approach yields good results for moderate cost and within a reasonable amount of time.

MAPPING OF AREAS	••••••••REMOTE•SENS.•SAT.•• •••PHOT.•AIRPLANE••• ••LOW•ALT.•PHOT.•• •••••CLOSE•RANGE•PHOT.•••• •••••LASER•SCANNER•••••
MAPPING OF SINGLE POINTS	••••••••GLOBAL•POS.•SYSTEM• •••TACHEOMETRY•••••••••• ••SIMPLE•MEASUREMENTS••••••
SCALE 1 :	1 10 100 1 000 10 000 100 000 1 Mill
CORRESPONDING OBJECTS IN THE TANG PROJECT	S C U L P T U R E S: T O P O G R A P H Y: + Detail + Tower Mounds Complete + + + + Mounds of *tumuli* + Tunnel Entrance + Gate Areas + Procession Way + Mausoleum Mausoleum incl. Attendant Tombs + Group of Mausoleums + All Mausoleums + Shaanxi Province +

Figure 1: Surveying methods in archaeology and their applications in the Tang project

3. METHODS CONSIDERED IN THE TANG PROJECT

3.1 Remote Sensing

A large area has to be investigated for the Tang project. Detailed surveys have to be carried out in the immediate areas of the mausoleums. Nevertheless, there is a certain interest in the areas inbetween the different sites and the neighbouring regions.

The mausoleums have been erected at sites that were carefully selected based on geomantic considerations. Geomancy (*feng shui*, 风水) applies certain rules for the construction of tombs and buildings. Some are relatively easy to understand, such as the requirement of a mountain towards the north which is believed to protect from evil influences, or the presence of water in a certain direction, others are of more esoteric nature and can supposedly only be recognized by experienced geomancers. Since research in this matter is part of the project, maps including elevation information are needed. This has been achieved by images, DEMs, and perspective views from SPOT data. The potential of these products, although well known in the remote sensing community, is not yet known everywhere in archaeology.

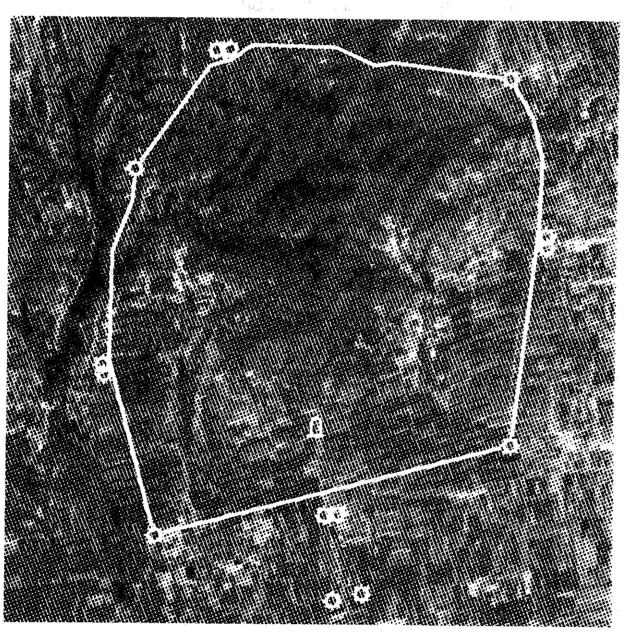

Figure 2: Jingling mausoleum, 1 : 50 000

Originally, unprocessed SPOT P scenes were used for orientation in the field. Lateron, these scenes were georeferenced with the aid of GPS control points and resampled to the specific Tang project map projection. In the meantime, an improved version is available, adding color from a simple classification based on SPOT XS data. Also, vector overlays can be added, showing the basic components of archaeological interest (mausoleum walls, towers, stone sculptures and monuments, attendant tombs), and topographic information (access roads, contours). Since all this information is kept in different files in the same data base, it can be combined as it is needed for scientific investigations, publications, exhibitions, or information for tourists when the sites are made accessible to the public. As an example, figure 2 shows the Jingling mausoleum area with all information of archaeological significance overlaid from the vector database derived from tacheometric surveys.

With DEMs from SPOT images, improved and checked by the local tacheometric surveys, all products mentioned above can be overlaid with contour lines and/or shown in any perspective desired. In addition, a short movie has been produced, showing a virtual flight over the area. Information about aspect and slope can be extracted and used for research in geomancy. Since most mausoleums are in areas where steep mountain slopes rise from the loess planes of the Wei river, all presentations showing three dimensions are quite impressive. Figure 3 shows Qiaoling mausoleum as seen from the south.

In the case of the Tang project, only few details of archaeological interest can be found in the images. As mentioned above, the buildings have vanished. Since the material used, loess, is the same as the surrounding soil, no difference in appearance can be found. Even in the field, investigations can only be made by lowering drill holes, and judging the density of the loess material. One important exception are the various mounds, however. Most of the ancient towers of the mausoleum walls and gates are still visible as mounds. As an average, they have a more or less circular base of 10 - 20 metres in diameter and they rise about 5 m above the surrounding area. Some additional tower sites are located far outside the mausoleums towards the south. In SPOT imagery the mounds deriving from towers can only be detected in very few cases. This is not really a problem since these objects are all found in the field surveys because of their predictable location.

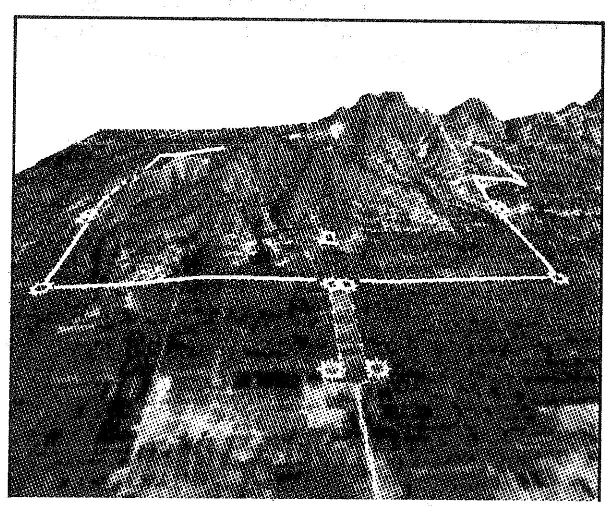

Figure 3: Qiaoling mausoleum, perspective view

As far as the mounds of the attendant tombs are concerned, the matter is somewhat different. More than one hundred of those satellite tombs may belong to one mausoleum. Also, tombs erected by earlier or later dynasties may be encountered. Their locations have not yet been documented with sufficient completeness and accuracy. A systematic search using remote sensing tools is useful. This is also promising since many tomb mounds are larger than the tower mounds, with diameters in the range of 20 to about 60 metres and corresponding elevations.

Efforts have been made to produce maps by digital image processing showing the probability of the presence of such mounds based on geometric and radiometric information from SPOT images:

- sunny side and shadow side (SPOT P)
- multispectral signature (SPOT XS; mounds are usually overgrown with sparse vegetation and surrounded by wheat fields)
- parallaxe anomalities (SPOT P stereo).

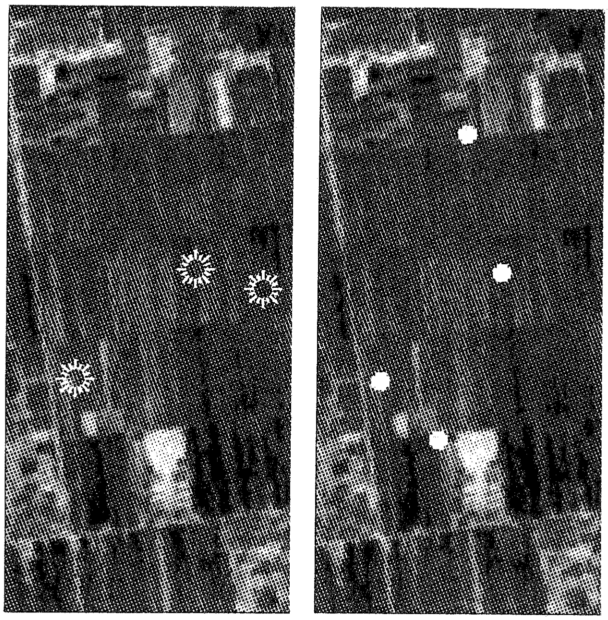

Figure 4: Location of tomb mounds, 1 : 25 000. Left: Tumuli from field survey. Right: Predicted locations from SPOT data. Two tombs were detected correctly, one of smaller size was missed. Two misinterpretations occur, one being a mound of no archaeological significance.

Parameters and thresholds have to be checked very carefully in this approach, taking into account the time of day and the time of year when the specific image was taken. Since the procedures show good results for large mounds (see figure 4), it can be derived that it will work well for smaller structures, too, as soon as imagery of higher resolution, such as MOMS-02, will be available.

3.2 GPS-Measurements

Measurements with handheld GPS receivers can yield accuracies better than 1 metre when postprocessed with the appropriate software. Since the Tang project could not be connected to the local horizontal control network, these measurements are used to introduce a common coordinate system for all surveys. An equirectangular map projection with true scale along the center parallel was chosen. Since orientation is a main matter of interest, all maps can thus be drawn with orientation to true north. The unfavourable linear distorsions of the projection are of less influence since the area of interest is mainly extending from west to east. Elevation control can be achieved using spot elevations from topographic maps, whereas orientation is derived from observations of the polar star.

GPS locating is very helpful for coordinating objects, mainly attendant tombs and isolated findings, that are too far apart to be connected by tacheometric measurements. They are also used for the determination of control points and training areas for the remote sensing procedures.

Finally, GPS can be used to support or derive DEMs for small scales (see 3.3).

3.3 Aerial Photogrammetry

Photogrammetry using airplane platforms is a most valuable tool for archaeological surveying in scales between about 1 : 50 000 and 1 : 1 000. On the other hand, it must be understood that many countries are reluctant to make aerial photographs publicly available. Since this is the case in many places with an extensive archaeological heritage, this is a common problem to solve for archaeologists.

The availability of satellite imagery of ever improving resolution will sooner or later overcome this problem. In the meantime, other methods have to replace photogrammetry. In the Tang project, a map 1 : 5 000 with contour lines is produced for every mausoleum, covering an area of 5 to 15 km^2. Elevation differences of up to 600 m are encountered within such an area. For the first mausoleums, an electronic tacheometer has been used. This is a very time-consuming method, however, and demands considerable physical fitness from the personell. Considering that accuracy demands are not extreme for the job, GPS methods with sub-metre accuracy as mentioned above can replace tacheometry. While it is still necessary to walk through the terrain, it is no longer needed to have visibility (hidden valleys, dust!) between the observed point and a fixed point. An other possible solution, the derivation of the DEM from satellite imagery has proven to be too inaccurate for this scale with SPOT data. Again, the availability of images of higher resolution may solve this problem in the near future.

Low altidude photogrammetry from platforms like kites, balloons, and model airplanes or helicopters, has proven useful for large scale mapping in many archaeological projects, and should always be considered. In the Tang project, no useful application has been found yet.

3.4 Tacheometry

The basic set of maps for the documentation of one mausoleum consists of the mausoleum map 1 : 5 000 (mentioned above), a map 1 : 1 000 showing the southern procession way with the stone figures and the south gate, three maps 1 : 500 for the other three gates, a map 1 : 200 for the tunnel entrance of the burial chamber, and ten to twenty maps 1 : 100 with two profiles each for the mounds of the towers. If attendant tombs are present, they are mapped in the same way as the tower mounds, although smaller scales (1 : 200, 1 : 500) may be used for larger structures. All maps have dense contour lines to visualize terrain irregularities that may be present. Locations of drill holes are mapped in the larger scales. All findings of significance are mapped; a special numbering system makes sure they can be connected to the photographic and text documents created by the archaeologists. This will be helpful, too, when work on a GIS for the Tang emperor's mausoleums will be started.

All mapping in the scales mentioned is accomplished with the aid of an electronic total station. Data is recorded onto an integrated exchangeable data memory and transferred to a laptop every evening. Plans, including contour lines, are produced with a common CAD system.

3.5 Simple Measurements

Since technical equipment of various kind is readily available in the field, simple hand measurements are used only for small objects of very simply geometry such as stone blocks. Hand drawings of stone sculptures of consideral artistic and geometric quality (figures 6 and 7) are created by a Chinese expert.

3.6 Close Range Photogrammetry

Stone sculptures carved from limestone decorate all Tang mausoleums. Considering that they have been standing in the open air for more than thousand years, many of them are in a comparatively good condition. All sculptures are photographed by the archaeologists. Close range photogrammetry is applied to selected figures only. Three methods are used. A complete digital object model (DOM) is derived for some objects. Vector drawings showing one or more views are used in other cases. For less important objects, simple stereo models are photographed; the films are stored to make later plotting possible, if desired.

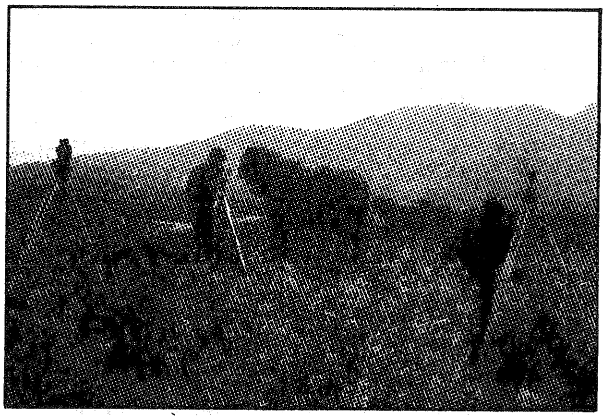

Figure 5: Documentation of a stone sculpture.

Digital object models (DOM) give a full representation of an object. The data could be used to reconstruct or duplicate the complete object. Most stereo plotter software packages have modules to facilitate measurements. Nevertheless, the measurements are time-consuming and very boring. When complete sculptures are documented, the DOM has to be put together from several views of the object. The idea to derive DOMs for three-dimensional closed objects by the way of automatic stereo correlation was investigated. The results are published in a separate paper (Boochs and Heinz, 1996).

Vector plans scaled 1 : 10 are needed for the more important sculptures. A front view is essential. In most cases, a side view is added, but up to four views can occur. Those are derived from stereo models which are taken with a 6 cm x 6 cm réseau camera. A 120 mm lens is used in order to minimize hidden object regions. Stereo models have to be taken from positions above and to the left and right of the figure to make sure that all outlines are visible in the models. This results in six to twelve stereo models per view. Control points are drawn on adhesive tape which is fixed to the stone surface. The coordinates of those points are derived by intersections observed from a conveniantly placed baseline with the total station. A common setup is shown in figure 5.

An analytical stereo plotter is used to digitize the stereo models directly into a CAD system. If the stereo models are photographed in the proper way, the outlines of the objects can be drawn with good results. Also, drawings of object parts showing sharp edges do not cause any problems. The representation of all other details, such as faces or the drapery of robes is very dependent on the interpretation of the operator. As a rule, the results lead to arguments between the archaeologist (*"the expression of the face in the drawing is different from the original"*) and the photogrammetrist (*"why do you want to map things which cannot be objectified?"*). A rather long revision process usually leads to a compromise accepted by both sides.

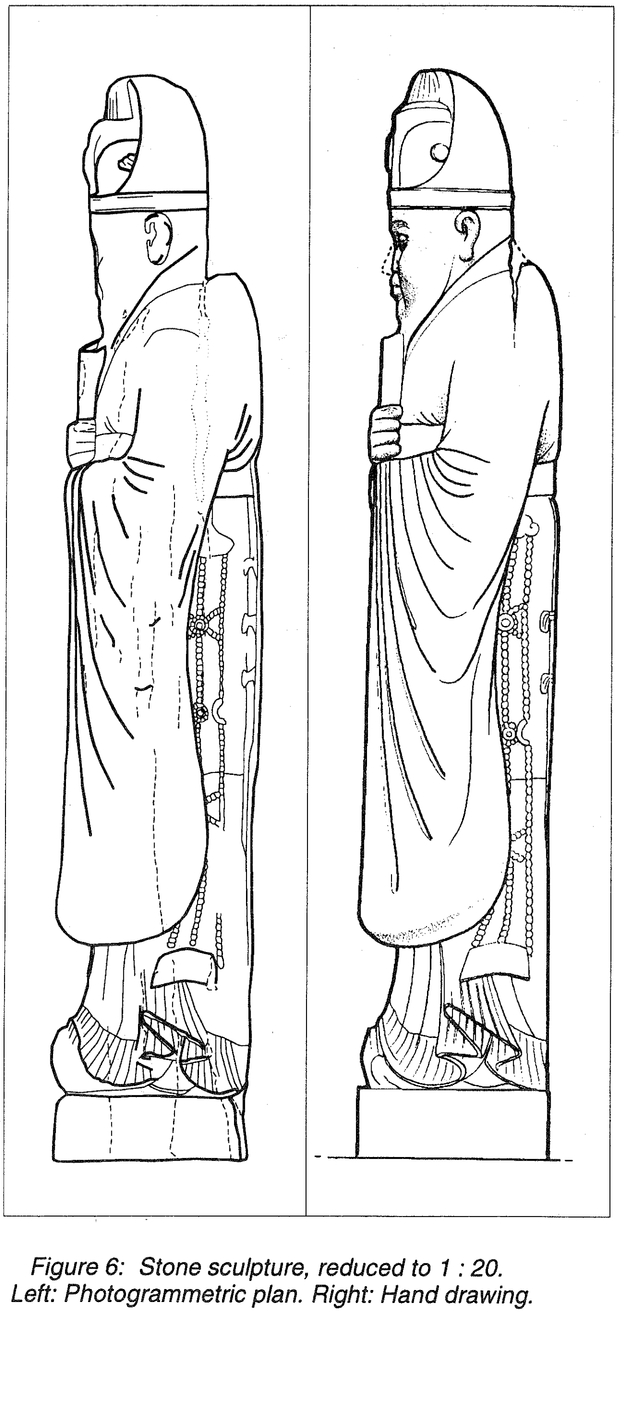

Figure 6: Stone sculpture, reduced to 1 : 20.
Left: Photogrammetric plan. Right: Hand drawing.

Since vector drawings from photogrammetric imagery are of great importance to archaeologists, we have thought of several ways of overcoming the obvious problems:

- Contour lines can give additional geometric information and improved perception (see figure 8, or a very fine example in SONG and YAO, 1990), but additional work is needed to draw the contour lines or to derive them from a DOM.

- If DOMs are available, a method might be developed to extract vectors from the slope information. If successful, this could lead to an automatic or semi-automatic procedure for the derivation of vector plans. With the exception of outlines and sharp edges, we could not yet formulate acceptable criteria for the presence of a vector line, however. Consider a drapery facing the observer. Which lines should be drawn? The line on the ridge, or in the depression, or the line where concave curvature changes to convex? Or all of those?

- DOMs can obviously be used for all kinds of perspectives and photorealistic representations. We have stopped our efforts shortly before getting a result showing a sculpture as it would appear on a photograph, asking ourselves why we do not use a good photograph in the first place.

- An artist, creating hand drawings, is more capable of giving an appropriate impression of an object by using hatching techniques and filling in supplements for details that have vanished. If enough identical points can be found, a transformation of the artists view to the exact geometry of the photogrammetric plot can show good results (figure 7). The transformation has to be observed very carefully, however, in order to avoid unnatural distortion.

In some cases, objects being partly destroyed still can be reconstructed graphically without any assumptions. Figure 9 shows a reconstructed column. The pedestal which is still *in situ* was plotted from stereo models. The shaft was added using hand measurements taken from the near-by fallen over object. From the capital of the column shown in figure 9, only one fragment showing one of the eight edges was found. The reconstruction of the missing parts was based on the photogrammetric plot of the fragment, making use of the the symmetry of the octogonal object. All procedures were carried out in the CAD system.

3.7 Laser Scanners

The development of laser scanners for close range applications (KLEINER and WEHR, 1993) may result in an alternative to photogrammetry as soon as these instruments are field reliable and have sufficient resolution. For further processing and visualization of the data the same problems as with photogrammtric DOMs are encountered.

4. CONCLUSIONS

A large variety of modern surveying techniques is available for archaeological projects. The Tang emperors' mausoleums survey may encourage more archaeologists to consider the new methods for their tasks.

Figure 7: Head of stone sculpture, reduced to about 1 : 12. Above: Photograph. Center: Overlay of photogrammetric plan (thin lines) and supplemented hand drawing. Bottom: Hand drawing transformed to photogrammetric plan.

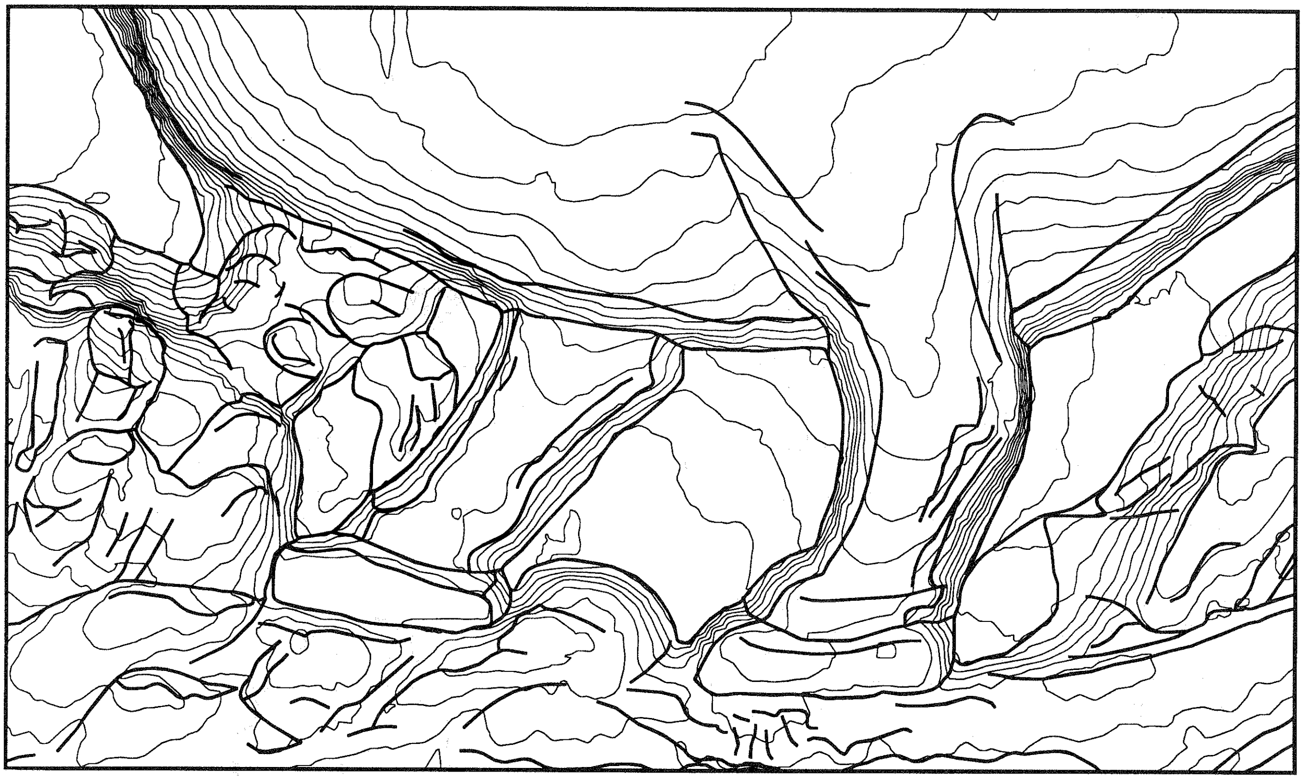

Figure 8: Cutting from a stone sculpture showing photogrammetric plan with overlay of contour lines from a DOM (Reduced from 1: 2.5 to 1 : 6).

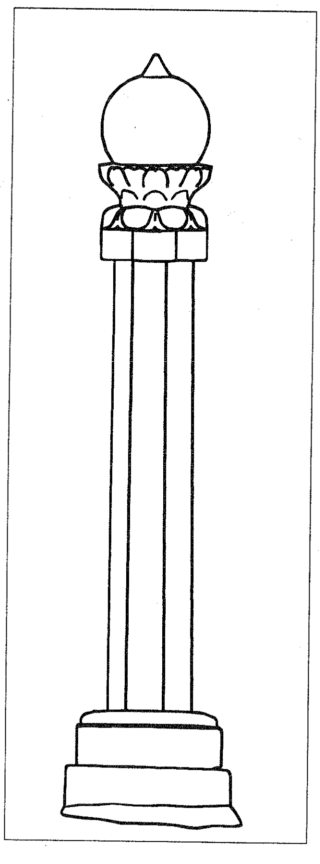

Figure 9: Column, reduced to about 1 : 80. Graphically reconstructed from broken parts.

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