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# Using a three-dimensional digitiser and CAD software to record and reconstruct a Bronze Age fissure burial

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## 19.1. Archaeological background

The project to be described has its origin in a multi-disciplinary investigation of several caves in the Torbryan Valley, Devon, undertaken by the British Museum's Department of Prehistoric and Romano-British Antiquities between 1989 and 1992. The objective was to examine the archaeology of the Late Glacial (*c.* 12,500 BP) and Early Postglacial periods (to *c.* 4,500 BP) in the valley. This was not only a period of major change in human behaviour from nomadic hunter-gathering to sedentary farming lifestyles, it was also one of considerable environmental change associated with the end of the last glaciation (Roberts 1992; Roberts forthcoming). This paper will concentrate on the application of 3D digitisers in the field. Bronze Age specialists wishing to have a clearer understanding of the archaeology should refer to the papers by Roberts cited above.

The Torbryan caves lie along the flanks of a miniature gorge in the Devonian limestone, with eight caves and several fissures. Tornewton Cave was partly excavated by J. L. Widger between 1870 and 1890 (Widger 1892), and the work was later continued by Sutcliffe and Zeuner from 1944. It has yielded one of the most complete sequence of stratified deposits found in a British cave, and it is the only known locality where deposits of Wolstonian and Last Glaciation age are separated by an interglacial stratum with hippopotamus. The lowest fossiliferous layer with cold fauna, including reindeer and wolverine, is attributed to the penultimate (Wolstonian) glaciation; at the time it was occupied by bears, but the fact that it also has a sparse Upper Palaeolithic industry shows that man was also on the scene. Above is a Last Interglacial horizon with a few remains of hippopotamus narrow-nosed rhinoceros, red and fallow deer; hyenas then used it as a den. Finally there is a series of strata of cold fauna believed to belong to the Last Glaciation (Sutcliffe & Zeuner 1962).

When humans appeared on the scene, they used caves and rock shelters as temporary habitations, as industrial sites, as places of refuge in time of political unrest, and occasionally for burying the dead. These temporary uses of caves extend from the Upper Palaeolithic, through the Mesolithic, Neolithic, Bronze Age, Iron Age, Romano-British and even later times.

In 1990, on-site spatial analysis of the distribution of finds from one of the caves indicated that some human bones and pottery originated from the plateau on top of the limestone cliff overlooking the caves. An exploratory excavation in 1991 revealed a large parallel-sided rift which contained quantities of human bone from two skeletons located underneath large limestone boulders and in front of an artificially constructed dry stone wall. The feature was recognised as a "fissure burial", a rare and poorly understood form of later prehistoric mortuary activity previously unknown in the region. A radiocarbon date provided by the British Museum showed that the burials were of Middle Bronze Age date (BM-2826: 3230 ± 35 BP). This result was unexpected since there had been no other indication of activity in the valley during this period, and also because fissure burials in general had been assumed to be of Late Neolithic date.

The discovery offered an opportunity for conducting the first modern research excavation of a burial of this type in Britain, and a project to examine the feature was established to run concurrently with the final four week season of the existing project. The aim was to excavate the known burial area completely and to remove the standing wall in order to determine the potential extent of mortuary activity in the fissure. Information was to be gathered relating to the construction of the burial feature, the nature of the naturally accumulating sediment in which it was located, and taphonomic processes affecting the burials, as well as details of the human skeletal remains and their association with artefactual and environmental data.

## 19.2. The plan for recording the fissure burial

In order to realise these archaeological objectives, the best approach seemed to be to obtain accurate three-dimensional locational measurements for every object in the burial area, including the limestone blocks, and enter the co-ordinates into a computer for validation and analysis. Using appropriate modelling software, a three-dimensional reconstruction of the complete burial area could be generated at the post-excavation stage. It was decided that recording six points from every object would provide the minimum information necessary for reconstructing each object's size, approximate shape, location and orientation within the burial area.

An Electronic Distance Measurement device (EDM) was already in use for all positional recording, linked to a field computer system which gave immediate access to three-dimensional information about finds as they were excavated. However, since the burial area lay within a narrow limestone rift only a metre wide at its maximum, there were considerable logistical difficulties in recording its excavation. Chief among these was the impossibility of using the EDM for detailed recording, beyond fixing points with known co-ordinates in the exposed part of the rift wall. Traditional manual recording strategies were also deemed impractical owing to the space restrictions and the nature of the rift itself. No more than two people could work in the fissure at any time, and the safe and effective use of standard planning equipment would have been very difficult and time consuming. The loose scree matrix of the burial and wall would also have been dangerous to excavate using traditional methods. It was therefore considered that the safest and most efficient procedure was for each object to be recorded as it was removed from the burial area.

A possible approach to locational recording was to record points by triangulation, using three tape measures fixed to known points on the fissure walls. This would, however, have failed to address the most critical problems of the very large number of measurements to be taken within a three week period, and the fact that the data collected would then need to be entered manually (with considerable potential for transcription errors) into a computer, for validation, analysis and graphical display.

A more satisfactory solution would be to employ an electronic digitising device capable of recording, in computer-readable form, the three-dimensional co-ordinates of the tip of a hand-held stylus touched on significant parts of material immediately before it was removed from the burial. Morlan *et al* (1984), Jefferson (1989) and Reilly and Walter (1987) all describe applications of such devices in archaeological situations, but their use has not been widespread. It seemed that the "3SPACE Tracker" used by Reilly and Walter could satisfy the recording requirements at Torbryan, and an approach was made to the IBM UK Scientific Centre, who kindly agreed to lend it to the British Museum for the duration of the 1992 excavation season.

Following a period of familiarisation with the equipment, and some bench experiments, it was felt that subject to some modifications and enhancements to the driving software the device could satisfy the requirements for recording the burial, and the decision to proceed with the project was taken. To our knowledge, this was to be the first time an archaeological feature of this complexity would be recorded with a three-dimensional digitiser. We therefore felt it was important that, as well as aiming at a post-excavation graphical reconstruction of the burial, we should also evaluate the equipment and the methodology of recording adopted. This would allow us to highlight problems for other potential users of such equipment, and perhaps make recommendations for improvements in recording procedure.

A research plan was formulated along the following lines:

1. Pre-excavation phase
   - Carry out modifications and enhancements to the existing digitiser software (which had been written for the Sutton Hoo project) and test the revised version. The changes made are discussed below.
   - Train appropriate personnel from the excavation team in the use of the equipment and software.
2. Excavation phase
   - Carry out the excavation of the fissure burial, using the digitiser to record the disposition of the material before it is removed. The digitiser is to be powered from a portable generator, and connected to an 80286 laptop computer, where co-ordinates will be stored. This computer will carry simple graphics software, allowing a certain amount of visual checking of the co-ordinates.
3. Post-excavation phase
   - Transfer the co-ordinate data to a more powerful 80486-DX computer at the British Museum. Assess the magnitude of different types of error using the SPSS/PC statistics package, and look for evidence of any directional bias in the errors.
   - Write software to model the content of the fissure burial in three dimensions, using the facilities of the AutoCAD package. The reasons for choosing AutoCAD, and details of the modelling program are given below.
   - Assess the outcome of the project from both archaeological and methodological viewpoints, and make any future recommendations.

## 19.3. The 3SPACE-Tracker and associated software

### 19.3.1. Background

The "3SPACE-Tracker" (hereafter referred to as the Tracker) was first used in an archaeological situation in 1985 to record the outline of a "sandman" skeleton at Sutton Hoo (Reilly and Walter 1987). Some three thousand co-ordinates were recorded from a latex rubber cast of one of the skeletons, and the data was processed at IBM's UK Scientific Centre to generate shaded-surface reconstructions and wire-frame animations (Reilly 1988). The Tracker, as used at Sutton Hoo and Torbryan, comprises a System Unit, a source and a sensor (Fig. 19.1), although up to two sources and four sensors can be attached.

The System Unit is mains powered and connects via an RS232 interface to a PC, from which it is controlled by driving software. The source generates a low-frequency electromagnetic field which is detected by the sensor. When the System Unit is requested to take a reading, it returns six parameters to the controlling PC, representing the $x$, $y$ and $z$ co-ordinates of the sensor, and three angular measures describing the sensor's orientation in three planes. All measurements are relative to a frame of reference centred on the source.

Some technical specifications for the Tracker are given as an appendix.

| | *Dataset* | *df* | $\sigma_x$ | $\sigma_y$ | $\sigma_z$ | *RMS* |
|---|---|---|---|---|---|---|
| I | Main dataset excl. points 22-24; different points, different source positions | 196 | 1.8 | 1.5 | 1.7 | 1.7 |
| II | Points 22-24; different points, different source positions | 18 | 27 | 18 | 9 | 19 |
| III | Replicates on points 77, 10, 11; same source positions | 6 | 0.7 | 1.0 | 0.7 | 0.8 |
| IV | Replicates on points 10, 11, 17, 19, 21; same source positions | 5 | 2.1 | 2.1 | 2.6 | 2.3 |

*Figure 19.1: The 3SPACE Tracker, showing the System Unit with source (above) and sensor (below) attached. The sensor is mounted on a perspex stylus for use.*

### 19.3.2. Limitations of the Tracker

The Tracker should not be used near large metallic objects which could distort the magnetic field. In practice, small objects such as coins and drawing pins do not appear to affect its accuracy significantly. To maintain full accuracy, the sensor should only be positioned no more than 75cm from the source. Readings can be obtained up to about 150cm from the source, but accuracy falls off rapidly beyond 75cm. Furthermore, the sensor must be located only within a known hemisphere centred on the source. By default, this is the hemisphere lying in the positive $x$ direction, although this can be changed by issuing an appropriate command to the Tracker. Straying into the opposite hemisphere can give a sudden discontinuity in the co-ordinates returned, because the sensor cannot distinguish the state of the magnetic field at a given point and at its mirror image in the opposite hemisphere.

The effect of these limitations in practice is that to survey a sizeable area, such as the fissure at Torbryan, the source has to be moved regularly as the excavation progresses, and at each move some care has to be taken that the source is orientated appropriately.

### 19.3.3. The Tracker's associated software

When used for digitising, the sensor is mounted on a pointed perspex stylus (visible in Fig. 19.1), the tip of which is touched on to the point whose co-ordinates are sought. When a reading is taken, it is of course the position and orientation of the sensor that is measured, not that of the stylus tip. Provided, however, that the "sensor to stylus tip" vector is known, the position of the stylus tip can be calculated by the driving software. This vector need only be determined once, or until such time as the geometry of the stylus is altered. A C program called CALIBRATE has been written, which takes a series of readings while the user moves the sensor into different positions but keeping the stylus tip on one spot. The sensor therefore describes points on the surface of a sphere centred on the stylus tip. Since the position and orientation of the sensor is known

```
/* Reference points for RELOCATE */
  1    -0.4765     2.7693    -1.5067    s16
  2    -0.5123     3.0377    -1.5712    s35
  3    -0.3494     3.0721    -1.4277    s32
/* fauna 330 rib frag*/
  6    -0.9347     2.8662    -1.8669    a
  7    -0.9896     2.8831    -1.8522    b
  8    -0.9612     2.8696    -1.8558    c
  9    -0.9579     2.8806    -1.8656    d
 10    -0.9569     2.8760    -1.8592    e
 11    -0.9591     2.8747    -1.8625    f
/* fauna 331 rin frag */
 12    -0.9077     2.8711    -1.8673    a
 13    -0.8898     2.8908    -1.8719    b
 14    -0.8971     2.8817    -1.8734    c
 15    -0.8935     2.8743    -1.8658    d
 16    -0.8959     2.8786    -1.8666    e
 17    -0.8972     2.8759    -1.8711    f
/* stone 341 */
         .           .          .
         .           .          .
```

*Figure 19.2: A sample of data recorded by the Tracker. The first three lines of co-ordinates are reference points used by the RELOCATE program. The two groups of six points are recordings of two bone fragments.*

for each reading, the required vector can be calculated, and is stored in a file for later use by the digitising program.

The digitising program (a C program called DIGITIZ) has a simple function. In essence, it waits until the user presses a key on the PC, takes a reading from the Tracker's sensor, calculates the corresponding position of the stylus tip, and writes a line of text to a file on the PC which contains the $x$, $y$ and $z$ co-ordinates. This process is repeated until the user chooses to stop the program. For use at Torbryan, a few enhancements were added to DIGITIZ, the most important of which allowed the user to type in a sequence of characters to be appended to the line containing the co-ordinates, allowing the user to "label" an individual reading. A second modification allowed a whole line of text to be inserted between readings, in order to label groups of points. These facilities were used to pass information to the modelling software describing where the data for each excavated object began and ended, and to identify the object itself. A sample of some data recorded by the Tracker appears in Fig. 19.2.

A third C program called RELOCATE was written to allow sets of co-ordinates to be transposed from one frame of reference to another. It has been mentioned already that the source had to be moved frequently as excavation progressed into the fissure. The frame of reference for the readings, being centred on the source, consequently changed as well. RELOCATE allows co-ordinates recorded when the source has moved from position 1 (say) to position 2 to be transformed into the frame of reference of position 1. This is illustrated schematically in Fig. 19.3.

The only requirement is that *both* source positions have had a set of three "reference points" recorded, and that these two sets are non-coplanar. These co-ordinates are used to calculate the required transformation matrix. Where many source positions are involved, the co-ordinates can then "mosaiced" together until all are expressed relative to a common frame of reference, which in this case was the

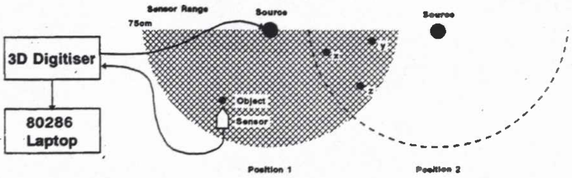


*Figure 19.3: Schematic illustration of movement of the source to an adjacent position. The reference points x, y and z, which are used by RELOCATE, must be recorded under both source positions. The shaded area indicates the range within which accurate readings are possible under source position 1.*

*Figure 19.4: The Tracker in use at Torbryan to record reference points on the edge of the fissure. (Photograph : Cath Price).*

excavation's site co-ordinate system. A fixed set of some sixty points were marked along the length of the fissure on the rock. Suitable triplets of points were selected at each movement of the source as reference points for RELOCATE. Some of these were in positions that could be surveyed using an EDM, and thus tied in to the site co-ordinate system. Fig. 19.4 shows the Tracker being used to record reference points on the side of the fissure.

It can be imagined from the above that the huge number of co-ordinates recorded at Torbryan, the frequent change of source position, and the need to record reference points

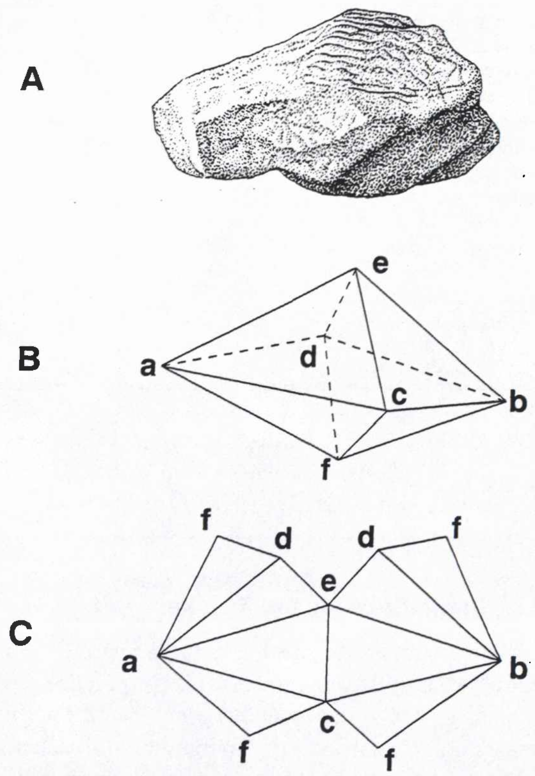


*Figure 19.5: Digitising an object and reconstructing it with AutoCAD. A shows a typical stone. B shows the six points recorded and the octahedral polyface mesh as reconstructed by AutoCAD. C shows the octahedron in "unfolded" form.*

for use by RELOCATE, demanded a highly organised procedure for storing and naming the various co-ordinate files.

## 19.4. Modelling the fissure burial with AutoCAD

Autodesk's AutoCAD package (Version 12) was chosen as the environment in which to model the burial for a variety of reasons. It was already available on an 80486-DX computer within the British Museum's Department of Scientific Research, where it was being evaluated for other archaeological projects. It was clear from this that it had the sort of facilities for viewing, zooming and panning in three dimensions that would be of great value in interpreting the necessarily complex reconstruction of the burial. It provides other aids to interpretation: the ability to assign graphical entities to different "layers" whose contents can be displayed in different colours or switched on and off independently; hidden line removal for clarifying drawings containing many overlapping objects; the ability to impart a highly three-dimensional impression by surface rendering. Drawings can be exported in a variety of formats, suitable as input to desk-top publishing packages.

From the outset a formalised schematic reconstruction of the burial, rather than a realistic one, was the objective. The aim was to allow the spatial disposition of broad groups of material to be easily distinguished within an environ-

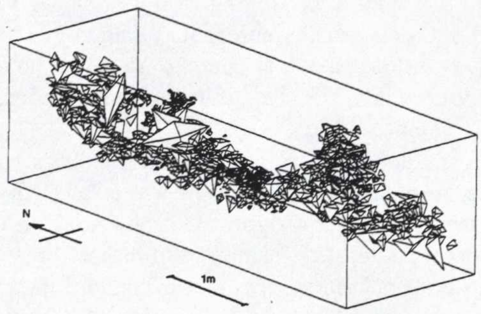


*Figure 19.6: An oblique view of a reconstruction of the burial, with hidden lines removed. Objects shown include stones, human and animal bones, flint and charcoal.*

ment offering facilities for easily changing the user's three-dimensional viewpoint. Given the time available, it would not have been feasible to digitise objects in such a way that every one could be identified in the reconstruction. As a compromise, the six points recorded on each object were chosen to span, roughly speaking, the full extent of the object in three dimensions. This suggested that each object be modelled as a (non-regular) octahedron with vertices corresponding to the six recorded points. Figs. 19.5A and 19.5B illustrate the concept.

If a "transparent" wire-frame reconstruction had been adequate, a series of twelve lines connecting the vertices would have sufficed — easily achieved with the AutoCAD "3DPOLY" command. However, views with hidden lines removed and surface rendered views cannot be generated from three-dimensional polylines, since AutoCAD requires more information about how the faces of the polyhedra are to be constructed from the vertices. AutoCAD's "PFACE" command accepts such extra information and allows the user to generate arbitrary "polyface meshes" of edge-connected polygonal faces. Eight faces, twelve edges and six vertices are involved in constructing an octahedron, and Figs. 19.5B and 19.5C show one, together with its "flattened out" form, to illustrate the method of construction.

The raw co-ordinate data from the Tracker requires some pre-processing before these solids can be generated, and AutoCAD's ADS (AutoCAD Development System) module allows the generation to take place under the control of a C program, which greatly simplifies the task. The C program was also designed to read the labels on the Tracker data (see Fig. 19.2) and use them to assign each reconstructed object to an appropriate "layer" (in the AutoCAD sense) using the "LAYER" command. Different classes of object (e.g. stones, bones, *etc.*) can thereafter be removed from or included in the reconstruction, or displayed in contrasting colours. It was also found to be of value to assign objects to different layers on the basis of object size. If, for example, "large stones" and "small stones" are assigned to different layers, small stones can be suppressed in simplified reconstructions. Fig. 19.6 shows an oblique view of a reconstruction showing all the fissure material recorded, with hidden lines removed.

A dBASE IV record was normally created for every significant artefact found at Torbryan, but it was not considered worthwhile to do this for every object in the burial

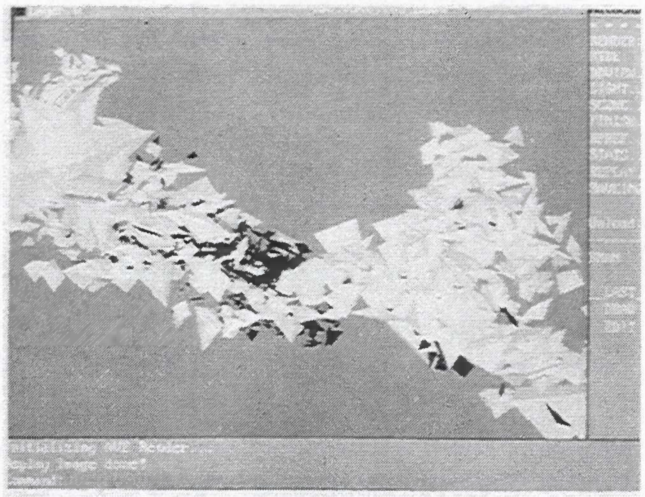

*Figure 19.7: A reconstruction of the central part of the burial, rendered with AutoCAD. The dark objects represent bone, the lighter ones stone.*

area. It should be pointed out, however, that Version 12 of AutoCAD provides an SQL interface to dBASE IV (and to other popular database packages) and that if such records had been created, much more wide-ranging and complex selection criteria could have been easily applied to determine the content and appearance of reconstruction drawings.

Rendering was used as another visualisation technique. AutoCAD has a reasonably sophisticated rendering module included as standard with Version 12, which allows imaginary light sources to be set up in the vicinity of the reconstruction, and the surfaces of each object to be shaded according to the incident light from the light sources and the shadows imparted by neighbouring objects. The shades of colour used are based on that specified for the layer to which the object belongs. With the display hardware available to us, this allowed only eight shades of each particular colour, but even this provided quite a realistic three-dimensional effect. Fig. 19.7 shows a simple monochrome rendering where dark objects represent bones and the lighter ones stones.

## 19.5. Error analysis

### 19.5.1. Preliminary work

An analysis of the errors in Tracker readings for the "reference points" was undertaken, with the aim of estimating the overall recording error likely to occur when the equipment was in daily use in the field, and looking for any evidence of directional bias. The reference points (see section 19.3.3 above) were fixed points chosen to span the burial area and used to transform measurements to a common frame of reference using the Relocate program. Each reference point was measured a number of times from different source positions and occasionally from the same source position. The slightly different co-ordinates obtained from each source position were the result of two factors: the measurement by the Tracker in local co-ordinates and the effect, through Relocate, of any other reference point measure-

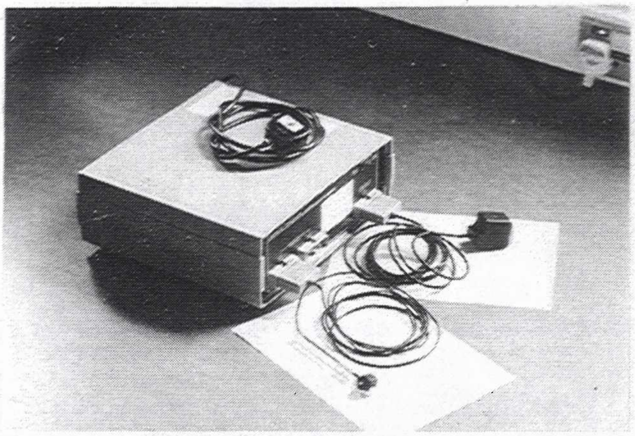

*Table 19.1: Tracker errors under various conditions. Note: errors quoted as ± σ in mm, based on analysis of variance; df denotes the degrees of freedom for the error; RMS denotes the root mean square.*

ments necessary to "daisy-chain" the local co-ordinates back to the main frame of reference.

The first stage in the analysis was to calculate, using all the available measurements for a given point, the deviations from average for the point. These measurements consisted of both "replicates", i.e. readings of the same reference point taken using the same source position, and readings of the same reference points taken using different source positions. In addition to the main reference points some so-called "additional points" were also measured. These were meant to provide a cross-check and as a back-up in case any problems emerged with any of the main reference points.

Preliminary investigations of these deviations revealed three problems, as follows:

- i A particular source position (No.4) gave extreme results for several points measured from it (see triangles in Fig. 19.8A, described below). It was decided to omit these results from further error analysis, and to run RELOCATE again later to correct any object locations based on this source position.
- ii The "additional points" also tended to give rise to large errors. As these points had already been recognised as potentially unreliable they had not been used to locate objects (except in a very few cases). They were also omitted from the main error analysis.
- iii The errors associated with the measurements of points 22 to 25 were very high. For one or two results this was partly due to the unsatisfactory source position mentioned earlier, but it was also due to a cumulative error because of a mistake in setting up on the first day when experience in using the equipment was limited.

### 19.5.2. Summary of the error estimates

As discussed in i and ii above, the readings associated with the "additional points" and with the unsatisfactory source position were removed. The data was then divided into two. The first subset, comprising the bulk of the data and denoted I, represented data collected under normal conditions and the second, consisting of data relating to points 22 to 25 and denoted II, represented data collected under difficult conditions; see iii above. Point 25 was not considered in the error analysis because it was only measured from a single reference point.

Two smaller datasets of replicate readings were abstracted from dataset I: triplicates measured on each of three points (denoted III) and duplicates measured on each of five points (denoted IV). Since each dataset of replicates was measured under precisely the same conditions, i.e. from the same source position, they were considered to give an empirical test of the Tracker's quoted specifications.

The errors were estimated from analyses of variance of the relevant subset of the data. The summaries of the errors relating to each of these subsets is shown in Table 19.1. In the case of subset II only, positive correlations between deviations in the $x$, $y$ and $z$ directions were observed. This implies the possibility of a directional component in the error for these points.

Figs. 19.8A–19.8C show AutoCAD plots of the $x$–$y$ plane deviations from point averages for (A) all the data (including "additional points"), (B) the main dataset I and (C) the "problem" points of dataset II. The scales are indicated by circles of radius 50mm, 5mm, and 50mm respectively (using the mm units of the survey). The directional component for II is shown by the first principal component (defined in three-dimensional space but only shown here in the $x$–$y$ plane).

### 19.5.3. Discussion

The errors for the main dataset I (see Fig. 19.8B) are about the same in all directions and are normally distributed (with one outlier in the $x$ direction). The directional correlations are low and the root mean square error is ± 1.7mm. To attain this degree of precision, it is necessary to take care in setting-up the equipment: the inclusion of the "additional points" leads to deterioration in precision as a comparison of Figs. 19.8A and 19.8B.

Because some source positions were used for only one or two points one cannot always be sure whether excess variation is associated with the source position or the point being measured. Despite this confounding of the information from points and source positions, there was sufficient data to test the overall effect of changing positions, and this showed no statistically significant effect. However, since in practice it is always necessary to move the source, the best estimate of error under field conditions is the larger one derived from dataset I.

The errors for points 22 to 24 are very much worse than for the bulk of the data. Even if these points had not been suspect in advance they would have been evident immediately from the error analysis. This is an argument for inspecting the deviations from point averages on-site, as soon as they become available so that corrective action can be taken if necessary. Fig. 19.8C shows the magnitude of these errors. Fortunately these points were not used for the burial itself but only for the natural fill.

The results for the two datasets of replicates are presented separately because the set of five duplicates appeared to be much more variable than the triplicates, and there

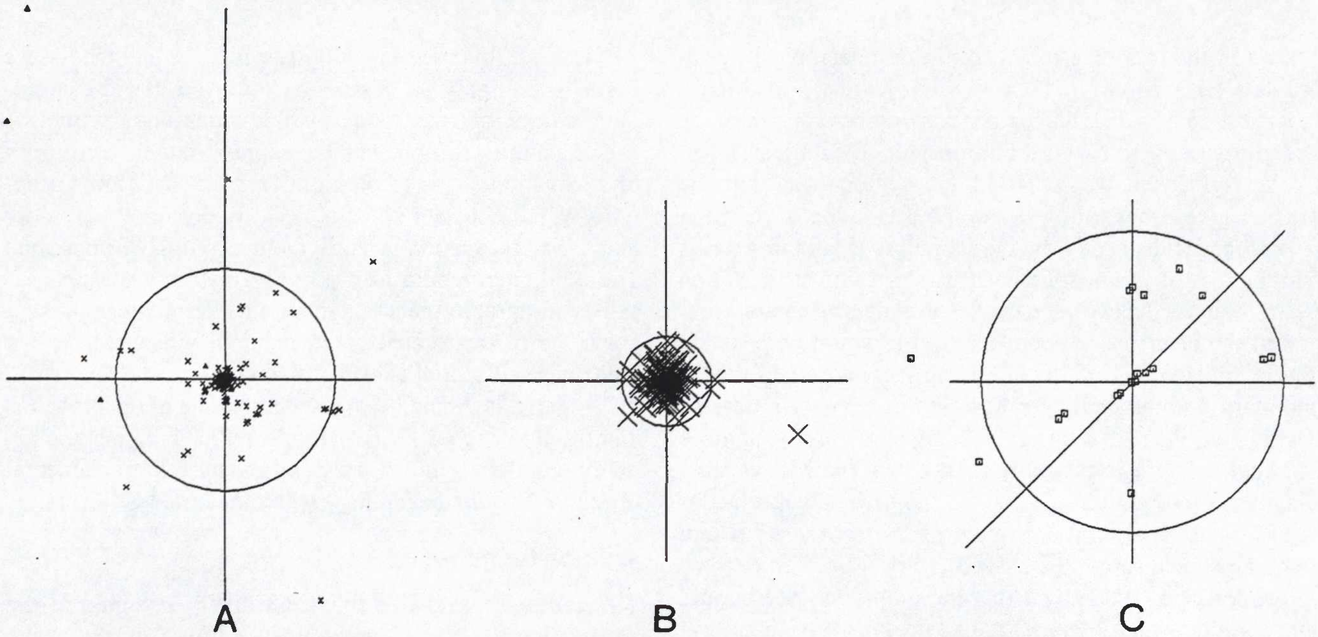


*Figure 19.8: Deviations from point averages for recorded points, using circles as indicators of scale. A shows all data, with triangles relating to readings taken with the unsatisfactory source position. B shows main data set I. C shows "problem" points 22–24. The radii of the circles are respectively 50mm, 5mm and 50mm, in field measurement units.*

was a particular problem with an aberrant *z* reading for one of them, probably because the equipment was slightly out-of-range. The overall RMS of 0.8mm for dataset III represents the precision under the best possible conditions.

### 19.5.4. Recommendations for monitoring and reduction of errors

On-site error analysis could help to identify specific problems as they occur. For this one would require to take several readings for each reference point, and at least five to be able to identify outliers. If the source positions could be applied to exactly the same number of points each time, then it would be easier to make a direct test of the consistency of a given source position. All source positions would need to be set up with the same degree of care, as the larger errors associated with the "additional points" show. A program to print out deviations from point averages and subsequently to identify any outliers would be helpful. On the basis of the current error estimates, deviations that were greater in absolute value than, say, 2mm could be flagged, with a double flag for those greater than 3mm. Plotting the deviations as in Fig. 19.8A, which was produced by AutoCAD, would also be useful both for indicating the general level of errors and also indicating any directional bias.

For the main dataset, the RMS error of 1.7mm suggests that, even allowing for the fact that RELOCATE has been applied, the Tracker is performing well within its stated accuracy. Although we have to accept that specific problems can lead to substantial deterioration in accuracy, prompt action should enable these to be corrected on site in most cases. There are nevertheless ways in which the overall accuracy might be improved. A digitiser with better accuracy is an obvious possibility. In fact, a newer model of the 3SPACE Tracker, called "FastTrack", has about three times better accuracy and is significantly cheaper. (Its specifications are given in the Appendix.) The specifications also appear to imply that it could achieve at least the same accuracy as the Tracker at a considerably greater distance from the source, so that the source would need to be moved less often. Apart from the more practical benefits of this, overall error would be reduced since every use of RELOCATE introduces additional error. This error could also be reduced by employing more than three reference points, but only at the expense of more digitising effort and added complexity of the RELOCATE program.

## 19.6. A retrospective assessment

### 19.6.1. Problems experienced and possible solutions

As a consequence of the speed and accuracy of the digitising equipment, it proved possible to investigate the fissure burial fully during a four week excavation season. Although practical problems were encountered in the field, they were minor compared to the benefits gained by the use of the equipment. The more significant problems are indicated below.

Initially we found the equipment to be slow to set up, but this was partly related to familiarity with the procedure, and the time decreased as the excavation progressed. A major improvement in the setting-up speed occurred after the transmitter was secured to a non-metallic cube with open base which facilitated mounting the source for use. It is recommended that an easily mountable pedestal is fitted to the source, or that a perspex tripod is developed for this purpose.

Problems resulting from voltage fluctuations in the generator used to power the Tracker occurred on a few occasions. These caused spates of multiple readings to be generated, but no damage was done to the Tracker, and fitting a voltage stabiliser would probably solve the problem. On one occasion the generator failed completely, resulting in the loss of all data from the currently open co-ordinate file. Modifying the digitising software to regularly post data to disk during a recording session would be straightforward, and would minimise such data loss.

A significant weakness of the system was that the Tracker gives no warning if a reading is taken beyond the recommended distance from the source, or if a reading strays into the opposite hemisphere. It was mentioned in section 19.3.2 that the Tracker is capable of changing the orientation of the hemisphere boundary, and it would be possible in principle to program the digitising software to move this boundary automatically to "follow" the sensor's current position, provided that this only changed gradually. A more practical solution is probably to give an audible warning when the sensor either approaches the hemisphere limit or moves out of the optimum range of the source, at which point the source should be moved.

A persistent worry was that the points recorded could not be validated until RELOCATE had been used to transform the co-ordinates to the site grid. If a major problem had occurred, it would probably not have been noticed until after the objects concerned had been lifted from the burial. A significant enhancement to the recording facilities would be the provision of software on the controlling PC to offer the user immediate visual feedback (in terms of site co-ordinates) as readings are taken. Wire-frame views of features could be built up as readings are taken, allowing an immediate choice of whether to gather more points and so improve the accuracy or realism of the result. Any errors could be corrected immediately. In effect, the software would combine the functions of RELOCATE with the simpler graphical facilities of a package such as AutoCAD. The suggestions made in section 19.5.4 relating to monitoring errors could also implemented within this software. Laptop computers are now quite powerful enough to support such an application.

### 19.6.2. The benefits

Despite the problems outlined above there were considerable benefits to using the digitiser system: the speed and accuracy of recording; the ability to work in otherwise inaccessible areas; the ability to recover information which it is not usually practical to record; that all data is read immediately to a computer with excavators' annotations appended.

The financial implications of the increased efficiency of using the digitiser should also be taken into account. With the help of the Tracker a complete Middle Bronze Age burial in a highly inaccessible location was excavated and recorded in four weeks, by three people, with a degree of detail and accuracy that has never before been possible. Furthermore, the data, which comprised over six thousand three-dimensional co-ordinates, were in a form that required only straightforward pre-processing before generating a complete graphical reconstruction with AutoCAD. Given the complexity of the feature recorded, the logistical problems of working in the fissure, and taking into account initial problems with familiarity with the equipment, it is estimated that using the digitiser took less than a quarter of the time of traditional recording methods.

Overall, the use of the digitiser in recording the fissure burial was highly successful and showed that the equipment can be of great value in field situations. While the use of a digitiser might well be inappropriate for a majority of excavations, it is to be highly recommended for situations where considerations of security or conservation demand that excavation be carried out as quickly as possible. The equipment could also prove valuable where complicated stratigraphy occurs, where site formation processes are to be reconstructed or, in general, where a need for computerised spatial analysis is foreseen.

Finally, it should be stressed that none of the problems identified in section 19.6.1 are insoluble, and most are actually quite straightforwardly addressed. No fundamental limitations of the technology were unearthed at Torbryan.

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## Appendix

Both devices described below are manufactured by Polhemus Navigation Sciences Division, McDonnell Douglas Electronics Co., PO Box 560, Colchester, Vermont 05446, USA.

*Specification of the 3SPACE Tracker*
Cost (in 1984): $9900 US; Static accuracy: 2.5mm RMS positional, 0.5° RMS angular; Resolution: 0.8mm positional, 0.1° angular; Range: 75cm from source for specified accuracy, 150cm (approx.) with reduced accuracy.

*Specification of FastTrak*
Cost (in 1993): $5750 US; Static accuracy: 0.8mm RMS positional; 0.15° RMS angular; Resolution: 0.0002mm per mm of source/sensor separation (positional); 0.025°angular; Range: 75cm from source for specified accuracy, 300cm (approx.) with reduced accuracy.

In the UK, FastTrak is available through TDS Cad-Graphics Ltd, Lower Phillips Road, Blackburn, Lancs, BB1 5TH.

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