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Digital terrain modelling and three-dimensional surface graphics for landscape and site analysis in archaeology and regional planning

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16.1 Introduction

The use of two- and three-dimensional skeletal graphics in archaeological research is now well established. Less common is the use of three-dimensional terrain models as a backcloth onto which archaeological and environmental phenomena are plotted. This paper discusses the potential application of Digital Terrain Models (DTM) and surface graphics to archaeological and landscape analysis. The paper considers possible linkages between Geographic Information System (GIS) design and three dimensional surface graphics for both archaeological research and county planning requirements.

16.2 Digital terrain models

Surface modelling is the process of reproducing a physical or artificially created surface by means of a mathematical expression (Petrie & Kennie 1986). The term DTM refers to a particular subset of surface modelling which represents the surface features of a landscape through the modelling of altitude data. The term DTM was originally coined by Miller & LaFlamme 1958, though other terms, such as Digital Elevation Model (DEM), are occasionally used in the literature (Burrough 1986). These models generate a smooth continuously varying surface defined by mathematical functions. These techniques have found obvious applications in reproducing topographic surfaces though surfaces can be generated for almost any data which possess a Z attribute, such as a density value or a resistivity reading, and an X, Y coordinate. Representative surfaces can be achieved in two-dimensional form by the construction of isolines or contours joining points of equal value generated by interpolative algorithms. Such surfaces, however, do not have the visual impact or interpretative value of three dimensional images, nor may they be easily modelled or undergo numerical analysis.

It is not the intention of this paper to discuss in detail the techniques involved in the construction of DTM but the models do contain certain generic properties. The surfaces generated are usually based on irregularly spaced data scattered across the area of investigation, though the data may occasionally occur in a regular grid form. These techniques seek to interpolate a series of unknown surface values from a (usually more limited) number of known values. One of the requirements of a successful model is that the interpolation error should be minimised.

Two approaches are generally used to fit a mathematically continuous surface to what may be complex surface forms. The first, and perhaps the easiest, approach is based on the collection or arrangement of data into a regular grid structure to form an altitude matrix. This regularity can be based on square, rectangular or hexagonal structures, and a number of interpolative techniques exist to generate a regular grid structure from randomly located data. In this form, however, the data rarely reflect the characteristics of the original surface. Nor does uniform sampling of this type necessarily reflect the complexity of the original surface. Surface areas which are uniform or exhibit little variation are sampled at the same intensity as areas which may be considerably more complex. Differing complexity in relief therefore can only be captured by changing the size of grid and this can lead to considerable data redundancy. This disadvantage may be partially overcome by progressive sampling. The interpolative functions generate heights at regular intervals based on the average values of nearest-point neighbours occurring within a specified radius. These are usually weighted to reflect the effect of distance decay. Alternatively a polynomial surface may be generated through the random points, the so-called global method (Petrie & Kennie 1986), and grid values interpolated from this surface. A third, patchwise, approach divides the area into regular patches of equal size with separate low-order functions generated for each patch and these are subsequently joined.

The second approach uses the irregularly distributed data points to generate a triangular network of tiles of irregular size, shape and orientation (Petrie & Kennie 1986). Here the irregular node values are used to construct a continuous sequence of connected equilateral triangles into which the surface is divided. The generation of these triangular facets or tiles may be based either on the Delauney triangulation principle which is associated with the construction of Thiessen polygons (McCullagh 1986) or the radial sweep algorithm of Mirante & Weingarten 1982. The triangulated irregular network (TIN) approach is increasingly used because it reduces the problem of data redundancy, provides for better slope computation and facilitates the incorporation of sudden breaks of slope (Sibson 1986).

16.3 Data input

The type of mathematical algorithm used to generate a surface depends heavily on the form in which the height data occur. Altitude information can be obtained from a number of sources. These may consist of actual ground survey; the stereoscopic interpretation of aerial photographs; sonar or radar scanning devices; existing map information converted to digital form via the use of digitisers or semi-automatic line-following scanners; or from already-existing digital information such as that provided by the Ordnance Survey in increasingly greater quantities. The data must be registered to a common co-ordinate system, particularly if they are required to interface with other spatial data as stored in a GIS.

16.4 Applications

DTM fulfil a number of applications for many users. Some of these uses have found outlet within archaeology. One of the primary applications has been in the generation of images representing landforms and these have been particularly valuable for interpretative purposes. DTM permit the image to be rotated and viewed from a variety of viewpoints and have the facility to change the perspective as required. The vertical scale may be exaggerated or diminished relative to the *X* and *Y* scale so that the reproduced landscape may be emphasised or de-emphasised accordingly. The ability to take cross-sections through a terrain and undertake volume estimation are further

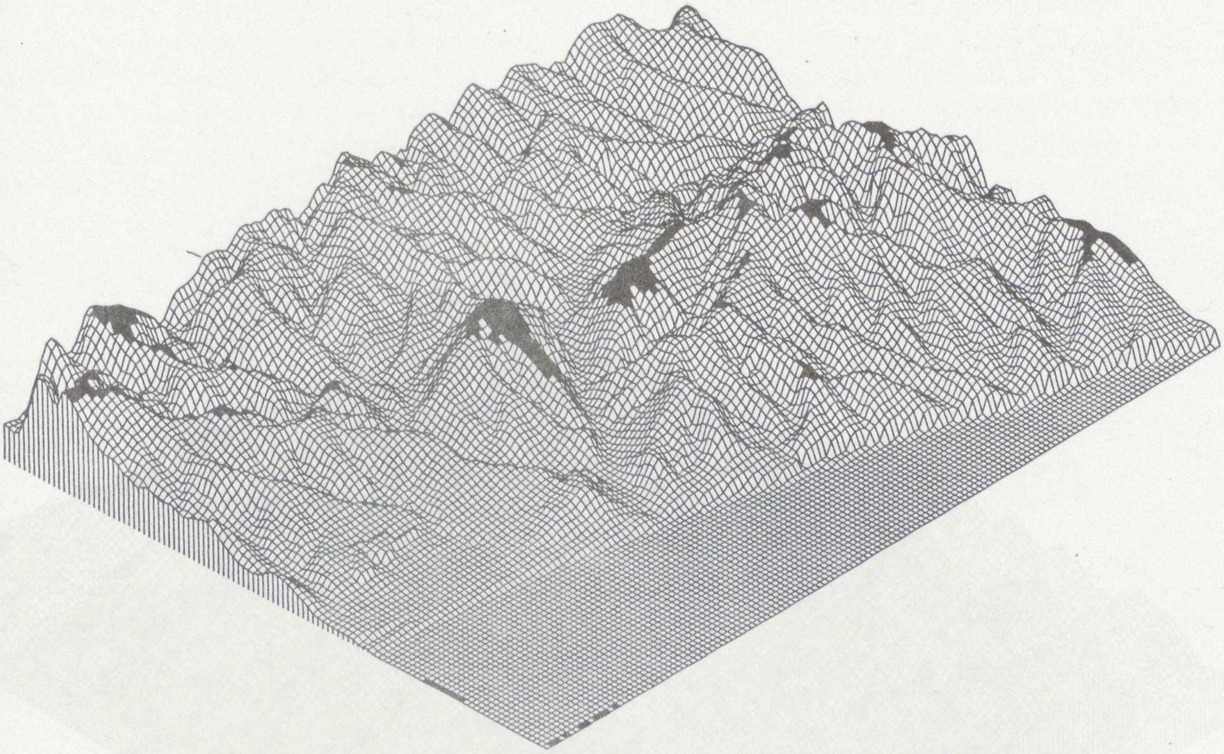

Fig. 16.1: Clay with flint

utilities of such models.

A major use of DTM has been to create viewlines and determine the extent of intervisibility between sites. Similarly slope, aspect and solar radiation intensity values can be calculated from the model and displayed on the image for numerous uses. Contours may also be generated and watersheds determined. Besides military usage many applications exist in environmental studies, in communications, recreation studies, landscape planning and, as this paper suggests, within archaeology.

16.5 DTM and surface information

Of major interest to this paper is the creation of terrain models which then act as a backcloth against which archaeological site data and thematic information such as soil, land use, and vegetation cover may be displayed. This involves generating a three-dimensional terrain image onto which spatial information is plotted. Two-dimensional plots form the basis of much data recorded in archaeology but the use of three-dimensional images have immediate display and interpretative benefits as the accompanying figures indicate (Figs. 16.1–16.5).

In one sense plotting archaeological information on a terrain image in this way is the equivalent of graphically displaying in three dimensions a bivariate relationship consisting of site information and altitude. Necessarily hidden line removal remains operative with the

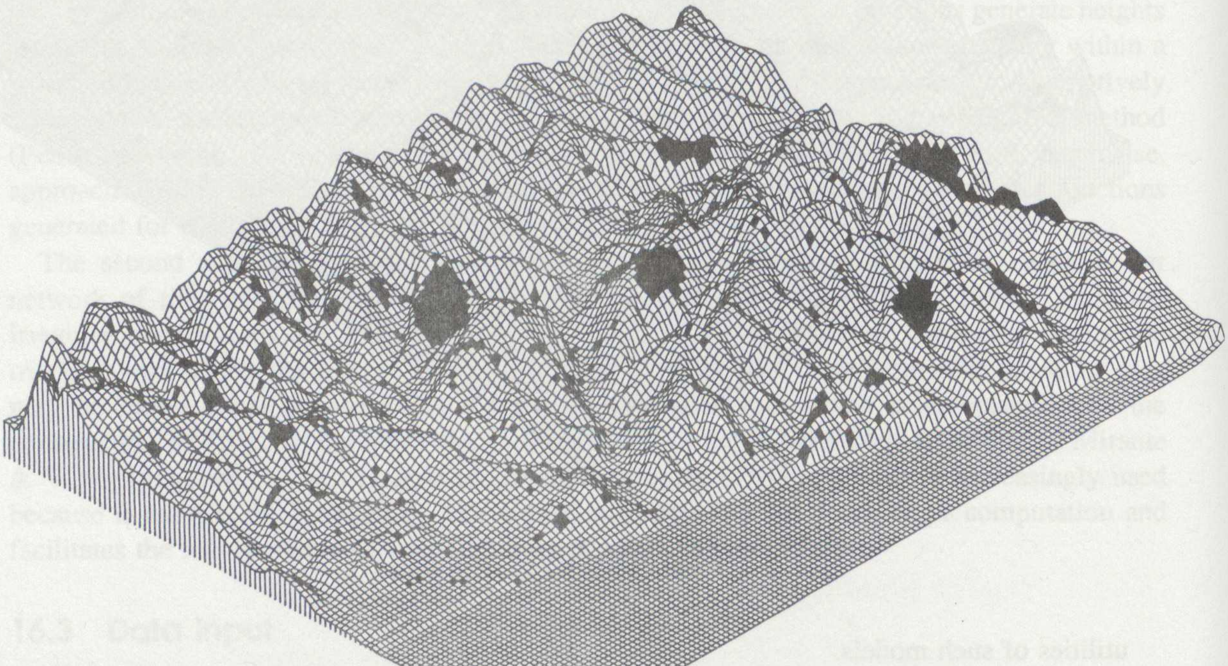

Fig. 16.2: All archaeological sites

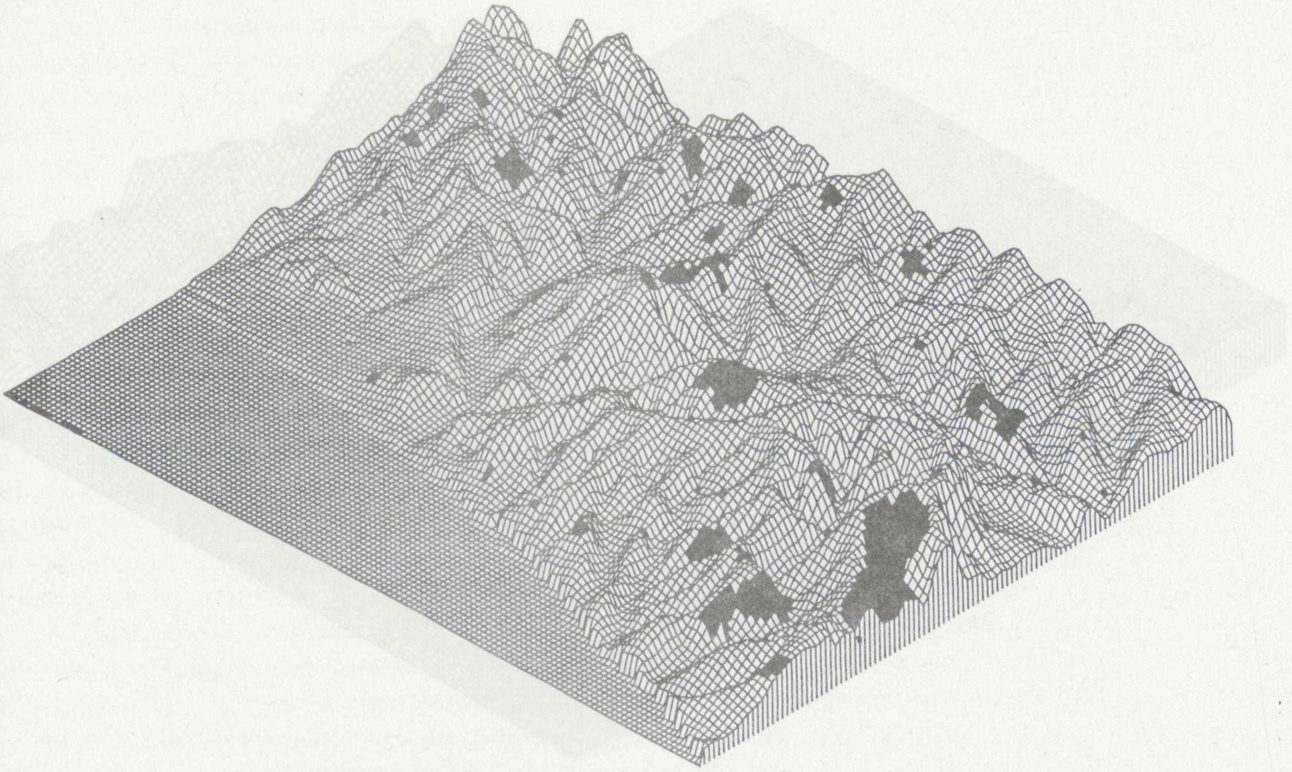

Fig. 16.3: Early Iron Age sites

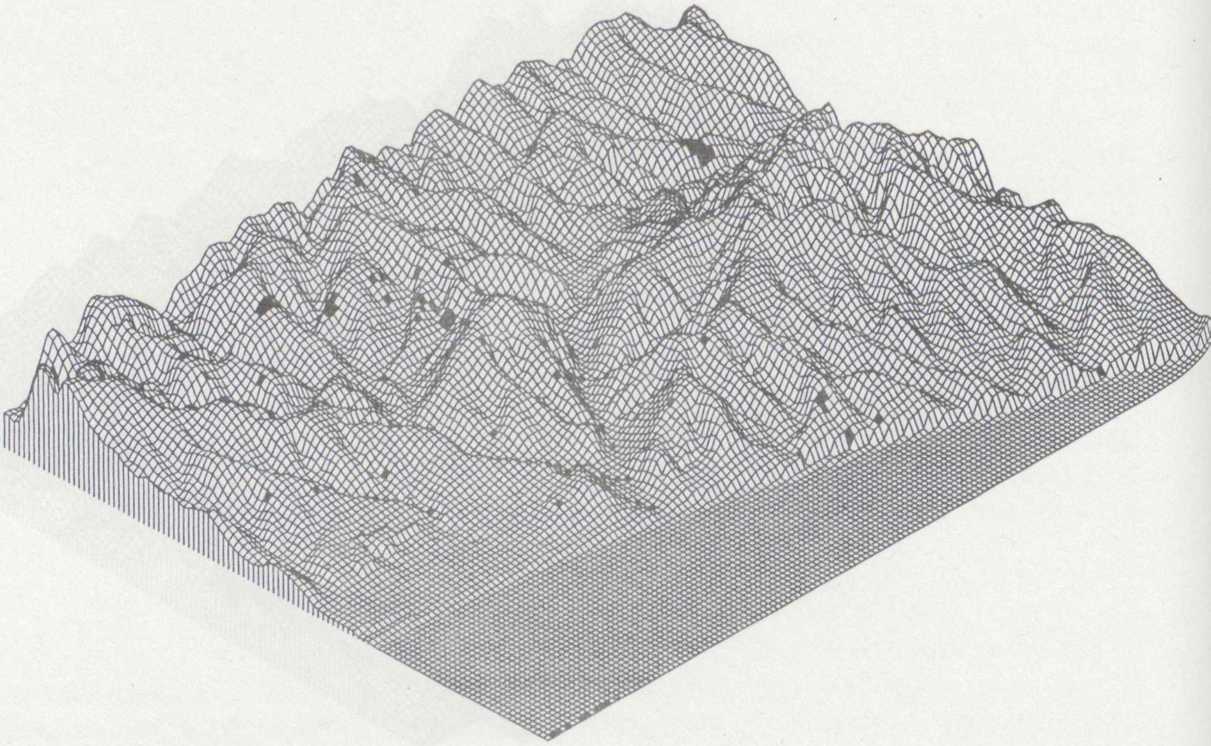

Fig. 16.4: Roman sites

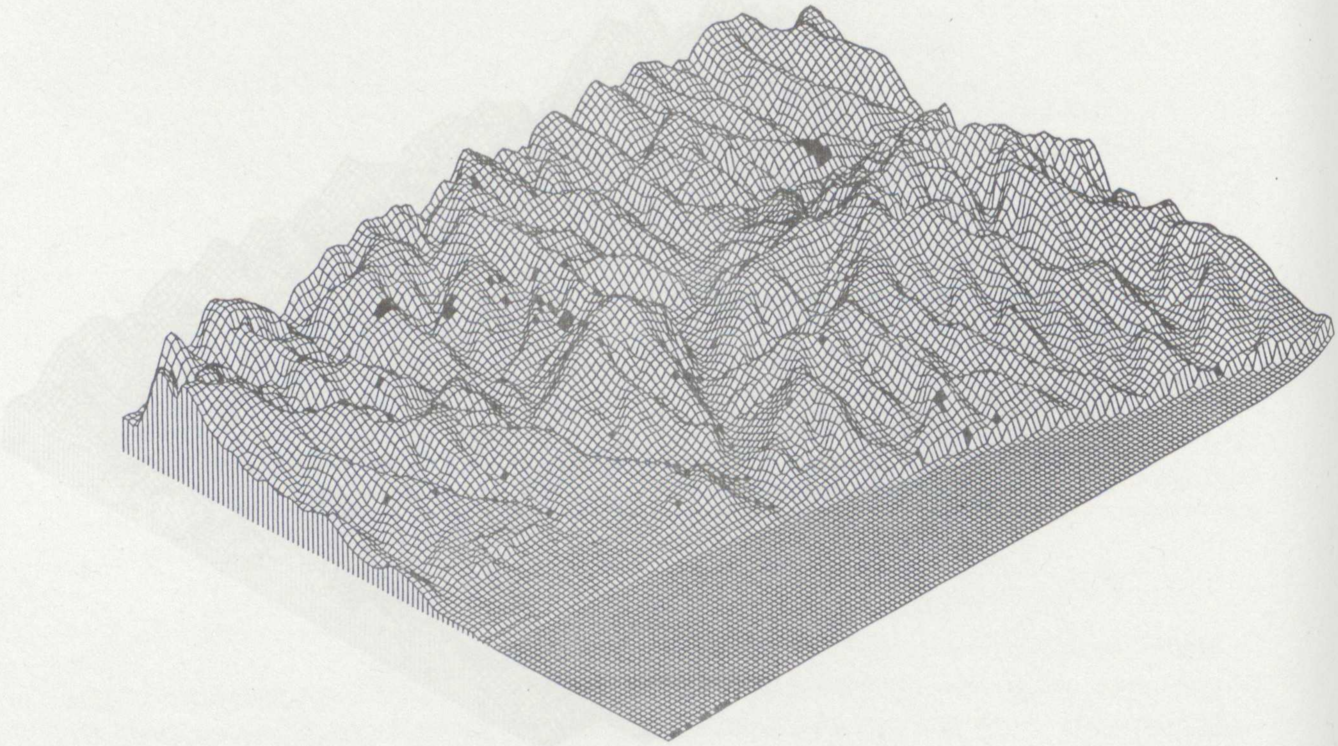

Fig. 16.4: Roman sites

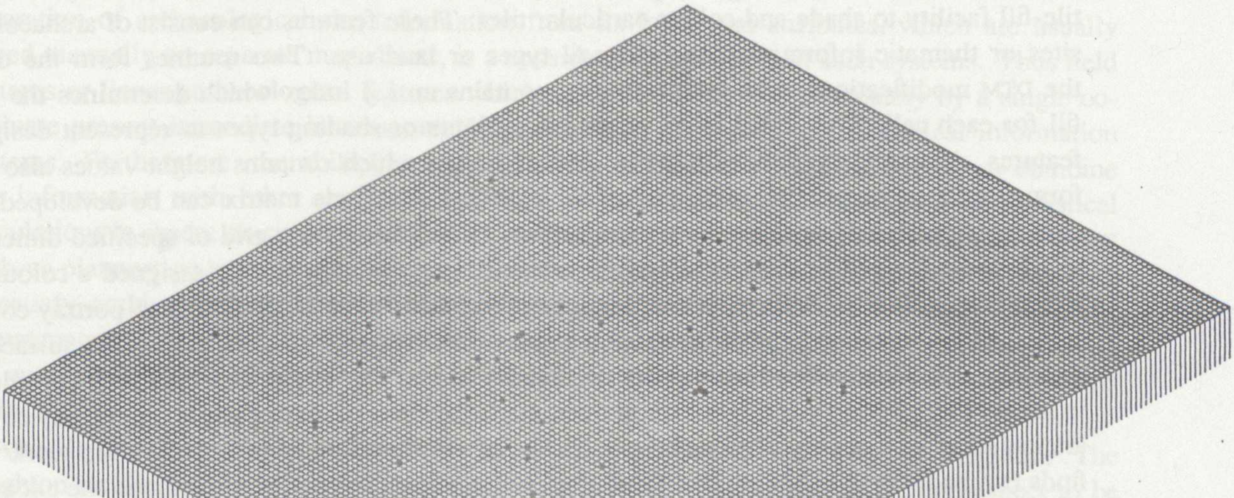

Fig. 16.5: Neolithic sites with altitude set to zero

result that, depending upon the complexity of the terrain, not all information will be displayed. However, if the height matrix is set to zero, or a uniform height, then a complete isometric map of the data can be obtained in much the same form as traditional two-dimensional map plots (Fig. 16.5). A few software packages are currently available on the market which will perform this type of function. The cost of such systems however is an important factor. The results here are the outcome of development work funded by CADCENTRE of Cambridge who developed the GINO-F suite of graphics routines. The GINO-SURF three-dimensional graphics routines have been modified to produce terrain surface plots and have been tested using the Brighton archaeological site information system. In contrast to some systems which rely on changes in the colour of the grid lines which describe the terrain image to represent a surface feature, this system uses a tile-fill facility to shade and colour particular tiles. These features can consist of archaeological sites or thematic information such as soil types or land use. Two routines form the core of the DTM modifications. The ISOFIL routine contains an i, j index which determines the colour fill for each cell. This index is set to specific colours or shading types to represent designated features. A second routine calls for an altitude matrix which contains height values also in i, j form which are compatible with the colour index. The altitude matrix can be developed using data-to-grid conversion algorithms within GINO. Given therefore a grid of specified dimensions to which height information is allocated, each cell may be individually assigned a colour code to represent a surface feature. A major application of this work is the ability to portray complex spatial information and elevation data on a three-dimensional surface image. This surface may represent a landscape but this need not necessarily be so. The image may also vary considerably in scale. Thus some plots might extend over only a few tens of metres while others may cover an area as large as a county. The technique can be of use therefore for site excavation work where finds can be located and plotted in three-dimensional space. A series of layers in the excavation may then be created and displayed for comparison and interpretation of site evidence through archaeological time. Alternatively patterns or relationships between sites may be examined at the regional scale. The interfacing of this technique with a regional archaeological site database is discussed later in the paper. Environmental and explanatory information, such as the distribution of soils within an area, can be similarly displayed (Fig. 16.1). Such information may be plotted on its own or in conjunction with other archaeological information so that relationships may be examined visually. The interpretative and display requirements of professional users of archaeological information, including both researcher and planner, are clearly much enhanced when data are reproduced in such a graphical form. Displays of this type also have obvious potential to impart archaeological information to non-specialists who may be more able to interpret three-dimensional images than two-dimensional diagrams or maps. These plots may be seen therefore as providing greater ease of interpretation than either tables or maps.

A second major use of DTM is that once the data are in digital form it is possible to model the height matrix to test any number of hypotheses. Such models have been used, for example, to ascertain the extent of flooding likely to ensue from certain environmental and climatic conditions being met. The power of such models in archaeology to recreate past landscapes and landforms is very attractive. Thus, based on the Selsey raised beach at 25 ft. OD, the sea level during the Ipswichian interglacial period may be recreated and the landform of the South Downs recreated. The same may be performed for a number of archaeological time periods and archaeological sites may be seen in the landscape context in which they originated. The extent of such change can be hypothesised and tested. Similarly the extent of soil erosion, for example, over a region may be explored using these approaches and again related to historical and archaeological evidence.

16.6 Interfacing archaeological information retrieval systems and DTM graphics

Some potentially interesting areas of investigation are possible when the above techniques are interfaced with archaeological or environmental information systems. Such techniques enable a host of complex spatial information stored in the database to be displayed. The need for computer-based archaeological information systems has attracted considerable attention in recent years and a number of digital information systems have been established. Very few, however, have been designed to take account of the spatial component of archaeological sites or associated environmental information beyond allocating a single co-ordinate to each site. The separation of archaeological site information from its locational attributes, which are usually stored manually on separate map sheets, is a considerable weakness of such systems. Thus field systems or linear archaeological features which cannot be described adequately by a single co-ordinate present immediate insurmountable problems in traditional archaeological information systems. Furthermore, the ability to interrogate the database with spatial queries or combine site information with other environmental data to seek relationships or undertake statistical calculations is absent on such systems. And yet this is a prime requirement of information users such as planners or researchers. The need for spatial data-handling capabilities in archaeology to satisfy archival, educational and research purposes and, importantly, to contribute to the management of the historic environment, is clear. These capabilities can be achieved through the application of techniques developed in the field of Geographic Information Systems (Harris 1986).

Altitude is just one of many variables stored on such a GIS established at Brighton. The Brighton archaeological site information system allows terrain models, slope, and aspect to be generated and linked directly to the archaeological and environmental elements of the database. Archaeological site information can be retrieved from the database according to specified time periods or type of site or according to combinations of archaeological, environmental, and spatial conditions. The information may then be analysed and the results output as tables or maps or, as this paper contends, combined with the production of three-dimensional terrain images as surface features. The portrayal of sites in association with topography is of considerable benefit in the display and interpretation of the data. It is intended to develop such a database for the South Downs in East Sussex, an archaeologically rich region, for which environmental information such as land use, agricultural land quality, urban development, planning and administrative zones, and altitude information have already been established in the database. As further 'levels' of information become available so they too will be incorporated within the database. Thus the availability of remotely sensed satellite imagery for particular areas would, after classification and georeferencing, enable these data to be plotted on the respective terrain image.

16.7 Conclusion

It is suggested that the ability to use DTM onto which surface information can be plotted has a number of beneficial applications in archaeology. Such techniques provide greatly enhanced graphical output to aid the visual representation of complex spatial data and to facilitate interpretation for both specialist and non-specialist. The ability to model the elevation or terrain information to recreate hypothetical surfaces, possibly past landforms, and to then place surface information on this image is a useful possibility. Certainly the true potential of such techniques become apparent when they are interfaced with extensive archaeological databases within a geographic information system.

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