# 12

# Maps and digital cartography

## 12.1 Introduction

Cartographers have long recognised the influence that maps have on the shaping of spatial consciousness (Monmonier 1991; Wood 1992; Lewis and Wigen 1997). The purpose of this chapter is to explore the way maps, whether paper or digital, may be used to present spatial information and to highlight some design principles to maximise their effectiveness at this task. In doing so we describe a range of mapping techniques appropriate for the different sorts of data routinely handled by archaeologists. We also consider some major cartographic principles and design conventions that help make maps effective communication devices, and discuss the growing importance of the Internet and interactive mapping for the publication of spatial data.

## 12.2 Designing an effective map

As defined in Chapter 2, maps are traditionally divided into two categories: *topographic* and *thematic*. The former term describes maps that contain general information about features of the Earth's surface, whereas thematic maps are limited to single subjects, such as soils, geology, historic places, or some other single class of phenomena. Both types of map must contain some basic pieces of information so that the reader is able to comprehend and contextualise the data that is being presented. The most basic of these, without which a map is difficult if not impossible to understand, are: (i) a title; (ii) a scale; (iii) a legend and (iv) an orientation device, such as a north arrow (Table 12.1).

There are other items that may need to be included on a map in certain circumstances. The most important of these is reference information about the coordinate system used to create the map, and how the grid system relates to what is being depicted. Maps produced by national mapping agencies will always contain information about the coordinate system (as described in Chapter 2). This often takes the form of a few lines of text in the bottom left or right of the map describing the point of origin of the grid and the coordinate system (e.g. UK National Grid), and the ellipsoid that has been used (e.g. WGS84). This information is necessary for computing transformations between different mapping systems, and it can also be of use in archaeological contexts when attempting to relate data collected from a GPS receiver with existing topographic maps. Coordinate information, such as how the grid was established and the location of the 0, 0 datum, is also useful when

Table 12.1 *Essential map items*

| Item | Description |
|---|---|
| Title | It cannot be assumed that common sense is a sufficient replacement for a title. For topographic maps, the title must provide the geographical context. For thematic maps, the title should identify the class of object or objects. Contour lines, for example, do not always represent elevation; they may represent temperature, rainfall or some other form of trend surface. |
| Scale | It is impossible to determine the scale of a map from visual assessment alone. Scales should either be given in easily multiplied linear units (1, 2, 5, 10, 100, etc.) or as an absolute scale (e.g. 1 : 25 000). In most cases, the latter style is more useful as it permits the reader to calculate approximate distances using a ruler. Many GIS and CAD systems have a facility for allowing absolute scales to be added to maps by automatically calculating the mathematical relationship between a map's geographical extent and the size of the printed version. As publishers may change the size of a map to fit the available space in a report or book, absolute scales will need to be recalculated. For this reason, despite being less useful, linear scales are often preferred. |
| Legend | This defines the thematic classification of the map. Legends, like the phenomena they represent, may either be continuous or discrete. In the case of the former, it is necessary to break the variables into categories or 'bins'. Some GIS programs create data bins that do not lend themselves to easy interpretation, and these therefore need to be changed manually. The number of legend categories used to define discrete data will ultimately be influenced by the number of objects there are in the class; however, it is worth keeping in mind that it is difficult to distinguish between large numbers of categories. |
| Orientation | A device to orientate the reader, usually in the form of a north arrow or grid overlay is essential. Although this in itself doesn't necessarily make the map more understandable, it does permit the reader to orientate the map and place it within a geospatial framework. |

presenting large-scale data, such as plans of an archaeological excavation or field survey.

Information defining how the data were collected may also be of use and should be stored as associated *metadata*. Metadata transforms a map into a more complete record of the spatial information. For example, maps showing geophysical data, such as soil resistivity, should contain, in addition to the information described in the previous paragraph, short descriptions of the equipment used and the conditions under which the data were collected. Chapter 13 describes geospatial metadata standards in further detail, including tools for the recording of this information.

## 12.3 Map design

One of the disadvantages of the type of mapping facilities included in GIS software is that the resulting maps often do not adhere to basic cartographic design principles (Dent 1999, p. 6). Successful communication of spatial information requires at least some understanding of these principles. Although we are not advocating an approach that emphases style over content, it is necessary to be aware that design plays an important part in the effective presentation of spatial data. Cartographers have recognised this for some time, and have grouped issues of map design into three areas: (i) those related to object arrangement, (ii) those related to visual impact and (iii) those related to comprehension.

Object arrangement is an important component of map design and helps ensure proper balance and focus of attention. Automated map production is a common element in many GIS packages, and can significantly reduce the amount of time spent preparing maps. Unfortunately, automated mapping can never quite reach the skill of a good cartographer, and maps produced using the built-in functions of GIS packages often require substantial editing. General problems of these systems include poor arrangement and sizing of basic elements: titles are often inappropriately large or small, labels are incorrectly placed, scales are in unsuitable units, north arrows are too large and ornate. Fortunately, these can be manually edited, although specialised vector graphic packages offer more opportunities for cartographic manipulation.

Visual impact plays an equally important role in map communication. For example, the upper map in Fig. 12.1 shows a map of Thrace in which there are few visual aids to help distinguish between the mainland, islands and sea. The lower map in the same figure corrects this by using polygon shading, which immediately provides a mechanism for visually distinguishing between features. Colours may also help readers distinguish between map features, but the non-judicial use of colour can create maps that become unintelligible rainbows of information.

Humans have a limited ability to deal with complex classifications of data, so progressive shading or the use of different colours may help in highlighting differences between object classes. Alternatively, it is sometimes worth using higher-level categories to make complicated data more comprehensible. For example, an excavated archaeological site may have 20 different types of features and these could be grouped into fewer numbers of larger categories (e.g. hearth and ash deposits, pits and constructional features) each with their own distinctive colour ramp (e.g. reds, blues and greens). In cases where three or more categories of information need to be communicated, it may be preferable to use a separate map for each category.

## 12.4 Thematic mapping techniques

Thematic mapping often requires the use of specialised mapping techniques to convey information properly, of which there are five basic types: (i) the choropleth map, (ii) the continuous distribution map, (iii) the proportional symbol map, (iv) the dot density map and (v) the isarithmic map. Most GIS programs are capable of producing all of these map types.

### 12.4.1 *The choropleth map*

The choropleth map is the best way to depict the distribution of data classes in well-defined areas (called *enumeration units*). Choropleth maps do three things

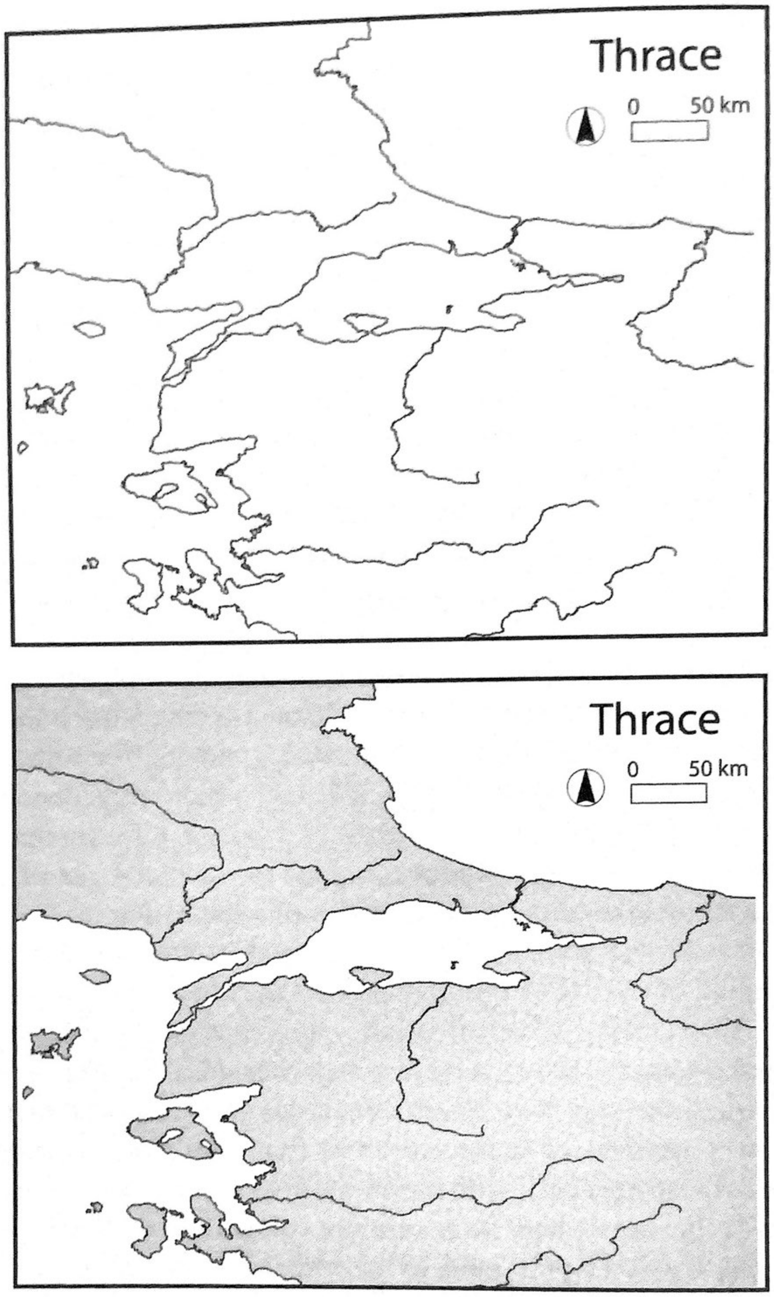
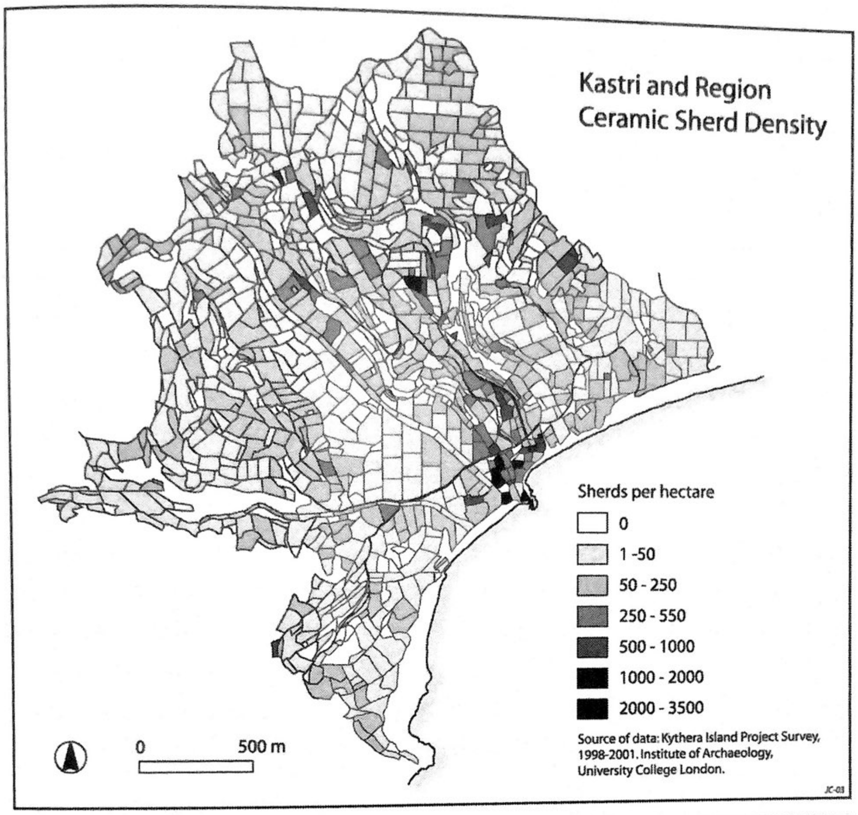



Fig. 12.1 The absence of polygon shading in the upper map makes it difficult to distinguish between the mainland, islands, rivers and sea. The addition of a polygon fill in the lower map allows these features to be more easily distinguished.

very effectively: (i) they show a quantitative or qualitative value associated with a geographical area, (ii) they give the reader a sense of the patterning of the mapped variables over a larger area and (iii) they provide a basis for comparing other values mapped using the same geographical boundaries (Dent 1999, p. 140). For example, the upper map in Fig. 12.2 shows the density of pottery sherds per survey unit (i.e. number of sherds/unit area). This form of mapping provides a means for determining the density of each unit in the survey map and, at the same



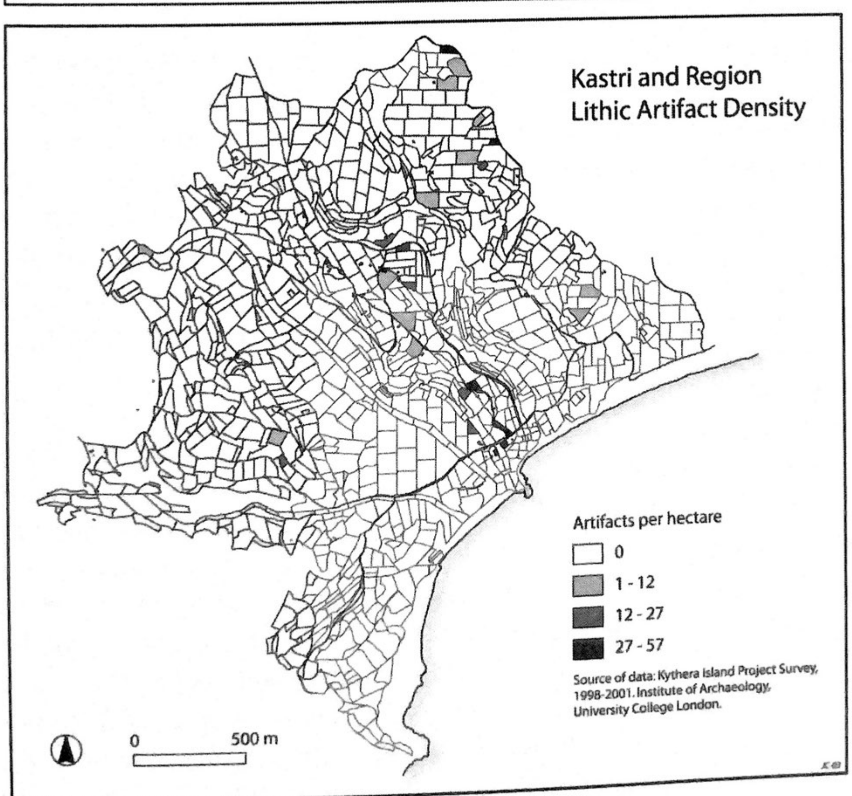




Fig. 12.2 Choropleth mapping using quantitative data. Source: Kythera Island Project. Used with permission.

time, provides information about the variability of the density in the study area. The lower map in the same figure shows the density of lithic artefacts (i.e. number of lithic artefacts/unit area). As both maps share the same enumeration units, it is easy to compare the distribution patterns of the two materials. Quantitative or qualitative data can be used for choropleth mapping. In the case of the former, the data must either be a total (such as the number of artefacts) or a ratio (such as the number of artefacts divided by the area of the enumeration unit). Unless the enumeration units are identical in area, ratio values are the more useful measure.

In both quantitative and qualitative forms of choropleth mapping, the underlying assumption is that the data are spread evenly throughout the enumeration unit. In some cases this assumption cannot easily be justified, yet this form of representation may still be the most appropriate mapping technique. In the previous map of pottery sherd distribution, for example, the artefacts cannot be assumed to be evenly distributed within each survey unit. This issue has been addressed by Lock *et al.* (1999) who suggest that choropleth maps bring major disadvantages to the representation of artefact distributions. Some concession to intra-enumeration-unit variability can be made by mapping a measure of the variability itself, using one of a variety of statistical measures that express the variability in a distribution of numbers. One simple measure is the *coefficient of variation*, which is the standard deviation divided by the mean. For example, Fig. 12.3 maps intra-unit variability for each enumeration unit for the ceramic sherd data in Fig. 12.2.

### Standardising and normalising data

As noted, the choropleth technique works best with quantitative data when presented as a ratio and, most often, this will be a ratio of the data value to the area of the enumeration unit (i.e. a density). This standardises the data so that variability is not dependent on the size of the collection unit. Alternative ratio calculations can also be used to 'normalise' the data allowing disparate data to be compared on equal terms. For example, an observed value, such as a sherd count, could be used to normalise the distribution of another artefact category thus showing new values as a proportion to number of sherds recovered in that enumeration unit.

### Determining class ranges

A major issue with choropleth mapping is categorising data values. Classes, or 'bins', are used to simplify patterns and make data easier to comprehend. Classification of data will invariably lead to generalisation and a loss of detail, but conventional cartographic theory, on the basis of experimentation, suggests that readers cannot distinguish between more than 11 grey-tone classes, and Dent (1999, p. 143) makes the recommendation that no more than 6 classes should be used. The classification method needs to be carefully controlled in order for it to be comprehensible. Some GIS programs use classification algorithms to determine the optimum number of classes, although user-intervention is often required. As described in Chapter 7, there are five basic approaches to numeric classifications for the

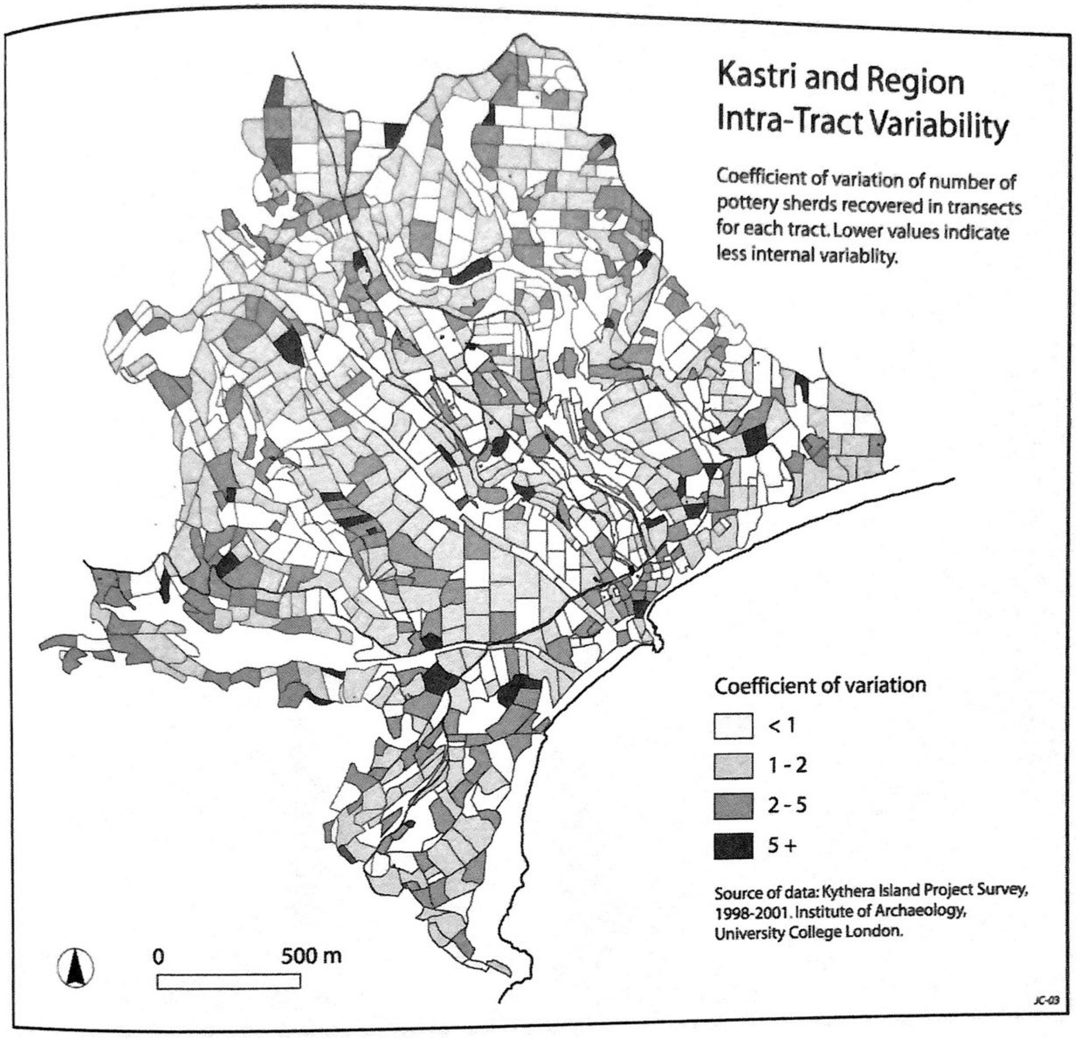



Fig. 12.3 Mapping enumeration-unit variability. Source: Kythera Island Project. Used with permission.

purposes of choropleth mapping: equal interval, natural break, standard deviation, quantile and equal area. As we previously explained, it is important to be aware of the structure of your data before choosing one of these methods (e.g. which of the four 'idealised' distributions it resembles in Fig. 7.15). This will help you choose the most appropriate classification method although you may need to edit the class ranges manually to present a more comprehensible picture of the data.

### 12.4.2 *Maps of continuous distribution*

Continuous distribution maps are used to display information about continuously varying quantitative data rather than discrete data. Maps of continuous distributions are similar in many ways to choropleth maps because they display values within an enumeration unit, within which the value is assumed to be representative. The major difference is that in maps of continuous distribution, the enumeration units are typically equal shapes and sizes (usually raster pixels, although other shapes such as hexagons can also be used) whereas choropleth maps may use different shaped

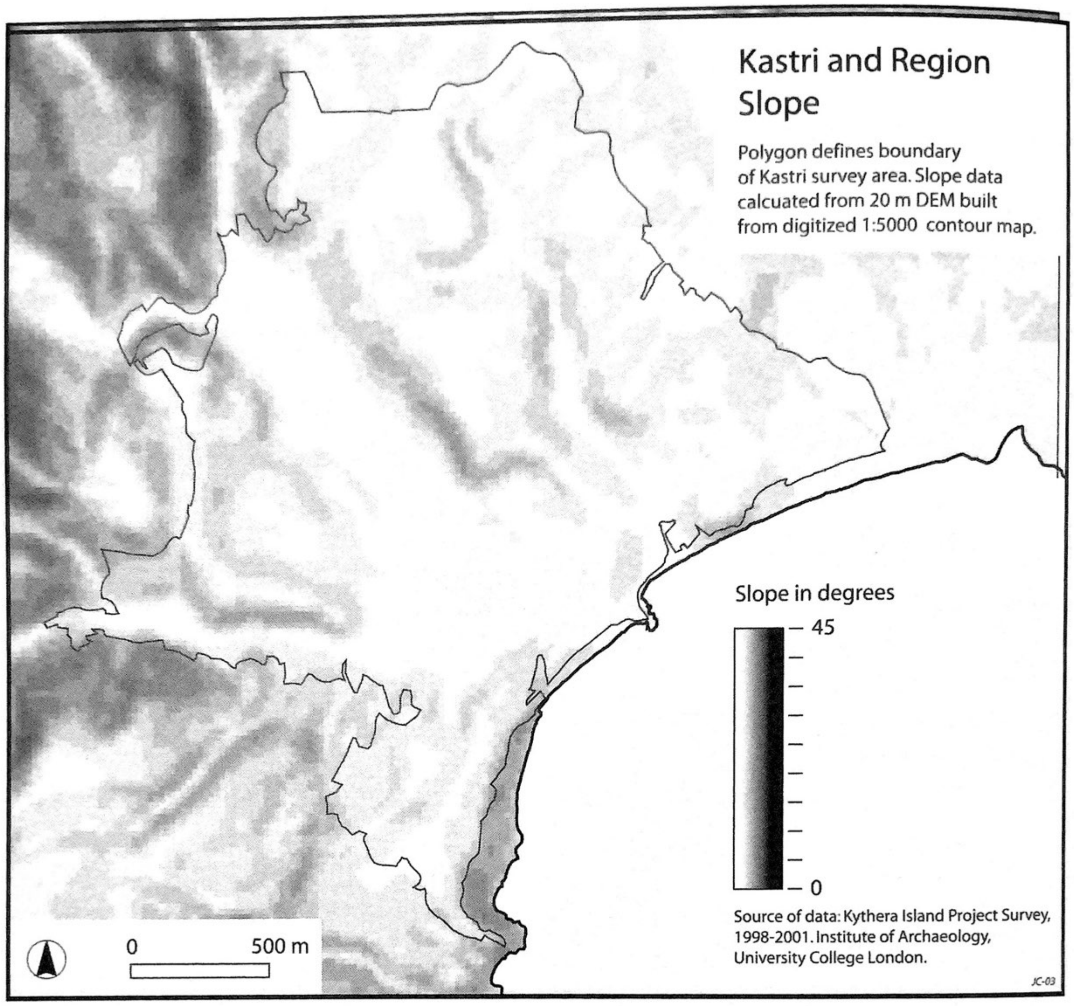



Fig. 12.4 Continuous distribution mapping: slope values. Source: Kythera Island Project. Used with permission.

polygons. The visualisation framework for maps of continuous distribution is also different, in that values are best represented using a ramped (or smooth) scale rather than discrete classes. The smooth gradation from the highest and lowest values also enhances the idea that the data being displayed are continuous in nature. Several colours can potentially be used in a colour 'ramp', for example a transition from green to yellow to red, to show changing elevation, temperature or rainfall values. Colour ramping can result in dramatic visual effects for continuously distributed data such as elevation. If done injudiciously, such as ramping between more than three or four colours, it can interfere with the interpretation of data patterning. Some data, such as slope values, are often better represented using a single ramped colour.

Figure 12.4 shows a map of slope values for the same study area used in the previous figures. In this case, the data categories are not individually identifiable; rather, an impression of a continuously varying surface is maintained by the use of

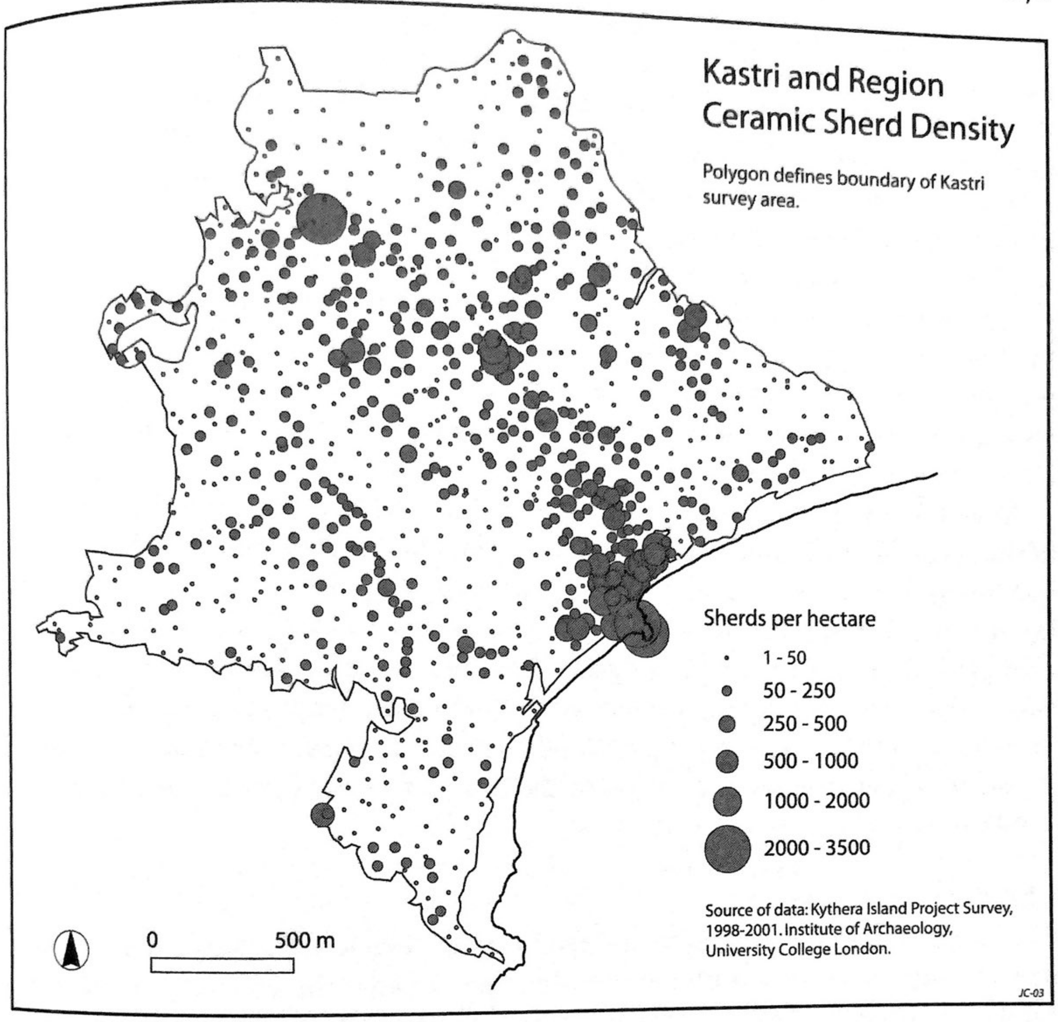



Fig. 12.5 Ceramic density variability mapped as proportional symbols. Source: Kythera Island Project. Used with permission.

ramped legend. It is important to emphasise that continuous distribution maps are not limited to environmental phenomena; they can be used effectively to show the distribution of a wide range of data. To cite one recent example, the mapping of fluted point distribution using continuous distribution techniques has been used to help understand the expansion of Palaeoindians (Steele *et al.* 1998; Anderson and Faught 2000).

### 12.4.3 *The proportional symbol map*

Proportional symbol maps are possibly the most popular form of thematic map devised. This is largely because of the fundamentally simple idea behind the technique of using the size of a symbol (typically circles, although squares, triangles or other shapes are also used) to represent the quantity of a phenomenon at a specific place on a map. Figure 12.5 shows a map of pottery sherd densities using proportional symbols.

Simple though this technique may be, there are some issues that need to be taken into account when creating proportional symbol maps, particularly with regards to the selection of the symbol and the manner in which the grading is calculated. Circles are traditionally the preferred shape because they can be easily scaled and related to a precise position on a map, but most programs offer a range of alternative symbols that may be more suited to the type of data that is being mapped. A major problem with complex shapes, however, is the difficulty they present for assessing scalar differences. Experiments have demonstrated that people both over- and underestimate the size of circles depending on the size of the neighbouring circles. The relative sizes of squares are most accurately estimated, although squares can create a rectangularity in maps that can distract from the data (Dent 1999, pp. 179–180).

Most GIS programs possess automatic scaling features for determining the size of the symbols in relation to their associated class ranges. Formulae for determining symbol size have been developed in cartography (e.g. Dent 1999, pp. 177–183), but it is unclear to what extent this has been adopted in GIS. Examination of the size grading in most systems suggests that it is based on linear calculations, so some user intervention may be needed for effective communication. Depending on whether circles, squares or some other shape is used, sizes may need to be adjusted to give a better impression of the differences between larger and smaller symbols.

### 12.4.4 *The dot-density map*

The rise of GIS-led cartographic production has seen a decline in the use of dot-density maps, which is unfortunate because they are an extremely useful and powerful way to present information about density values. Dot-density mapping is based on a simple premise: each dot represents a consistent unit of data, so that the total number of dots within an enumeration area equals the total data value. The map in Fig. 12.6 depicts ceramic distribution in the study area using this technique. As can be seen, this provides a very good impression of the underlying spatial structure of the distribution, although not the precise values for each enumeration unit, which is better represented by choropleth mapping. Additionally, as the dots are placed randomly within the enumeration unit, they do not show the specific location of the phenomena. This may appear rather limited compared to a map which shows the location of the units, but Fig. 12.6 arguably provides a better sense of the density variability than a simple choropleth map.

The effectiveness of this sort of mapping is based partly on the value of the dots, partly on the size of the dots and partly on how the dots are placed within the enumeration unit. If the dot value is too low or the dot size is too large, the map soon becomes crowded to such an extent that dots bleed into each other. Conversely, if the dot value is too high or the size too small, the map is too sparsely populated and any underlying spatial pattern is difficult or impossible to detect. To avoid creating a false sense of patterning, the dots also need to be randomly placed within their

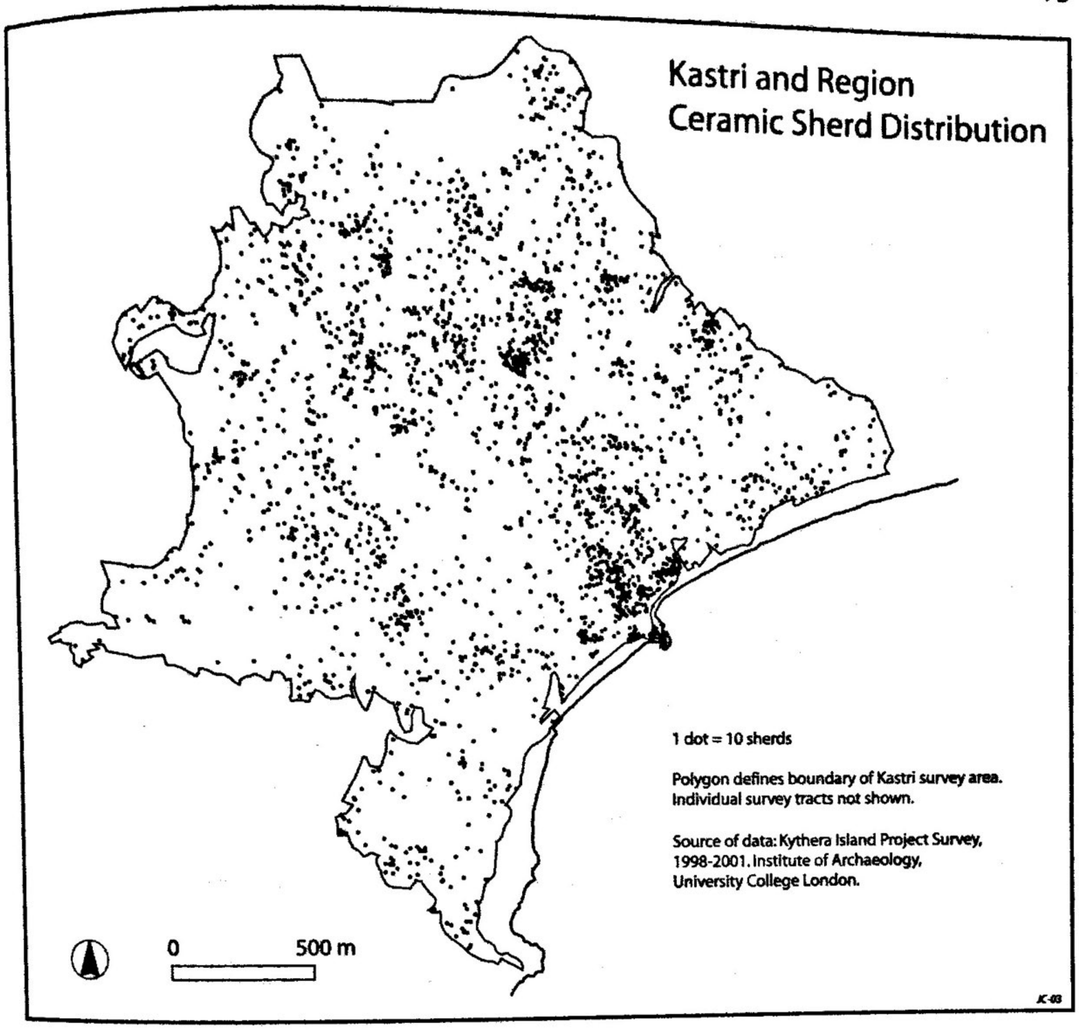



Fig. 12.6 Ceramic distribution as a dot-density map. Source: Kythera Island Project. Used with permission.

enumeration areas; any tendency to cluster within this space can undermine the very purpose of this type of mapping.

### 12.4.5 *The isarithmic map*

Isarithmic maps are used to portray three-dimensional surfaces (volumes) using line symbols referred to as *isolines*. This form of mapping is most recognisable when it is used to show variations in elevation using contour lines. The technique is, of course, not limited to showing elevation, and can be used to represent any expression of volume – or data that can be conceived as a volumetric – such as temperature or rainfall. The technique can be divided into two separate forms depending on the underlying data: *isometric mapping* and *isoplethic mapping*. The former term is used to describe data that are collected as points, whereas the latter term is used for data that occur over geographical areas (Dent 1999, p. 191). Examples of isometric maps used by archaeologists include elevation, rainfall and other environmental data

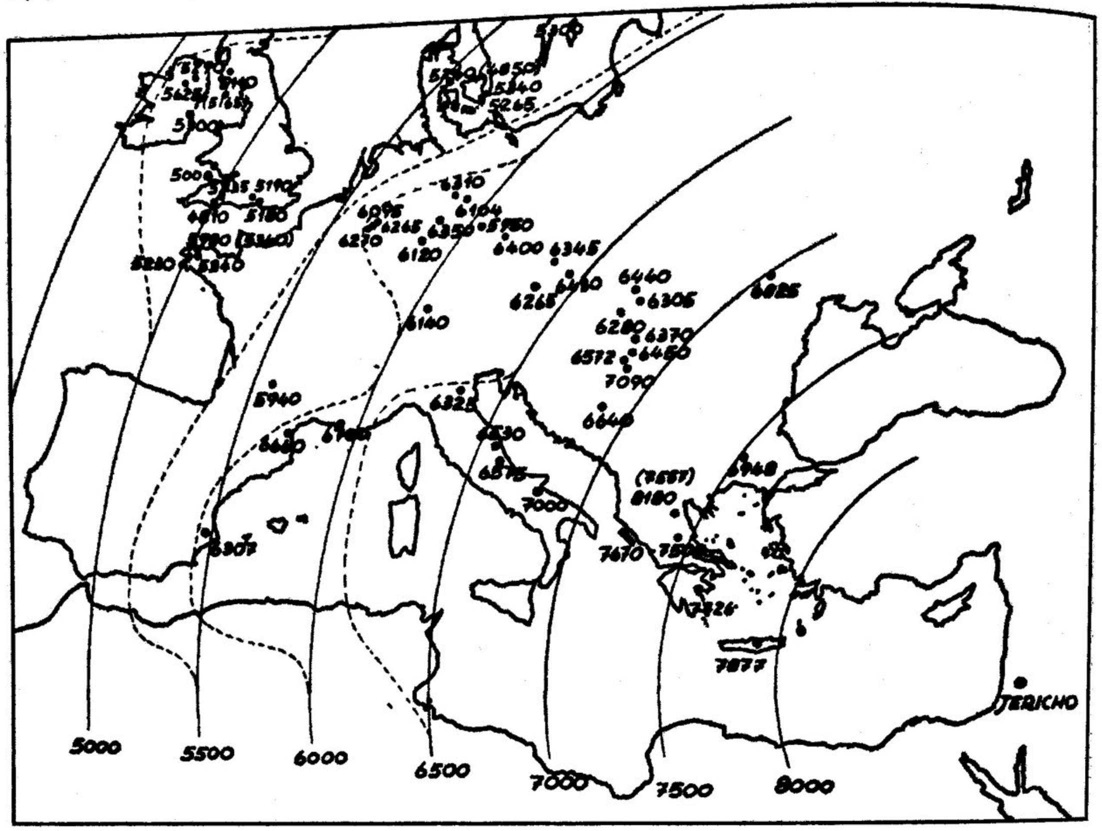



Fig. 12.7 Isochronic mapping of the spread of Neolithic farming, with dates in years BP (from Ammerman and Cavalli-Sforza 1971, p. 685). Dashed lines are expected regional variations. Reproduced with the permission of Blackwell Publishing. See Gkiasta *et al.* (2003) for more recent spatial modelling of the Neolithic radiocarbon record.

that have been collected by recording instruments or field observations. Isarithmic techniques have also been used to construct maps such as that in Fig. 12.7, which depicts the spread of Neolithic expansion in Europe using *isochrons*, where the locations and dates of Early Neolithic sites form the underlying point data (Ammerman and Cavalli-Sforza 1971).

In contrast, isoplethic techniques are used to depict spatial variability of data that have been collected in enumeration units, for example population density per square kilometre or the number of pottery sherds per hectare as shown in Fig. 12.8. Although the method of construction is similar to isometric maps, isoplethic mapping ultimately hides the scale of the collection unit. This is acceptable for truly continuous data (as this can often be found in the map documentation), but may cause confusion for quasi-continuous datasets as used in Fig. 12.8. For this reason, isoplethic maps are less suited for data collected in enumeration units, which are better mapped using choropleths.

Before methods for determining the placement of isolines were integrated into many common GIS packages, isarithmic mapping was a technically demanding

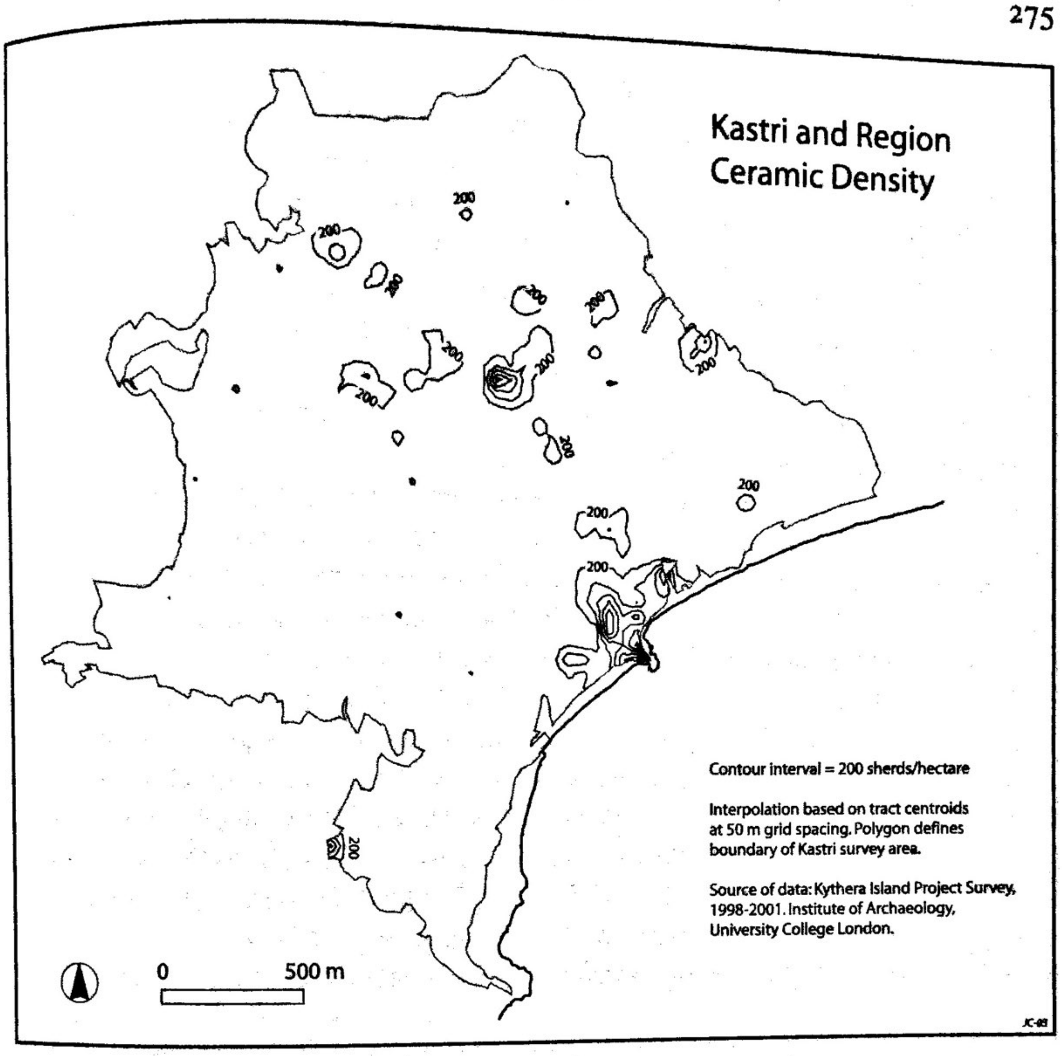



Fig. 12.8 Isoplethic mapping of pottery density. The base data are identical to that used to construct the maps in Figs. 12.2, 12.5 and 12.6. Source: Kythera Island Project. Used with permission.

exercise. Conceptually, the process can be equated to inserting a horizontal plane through a three-dimensional surface at a set value, and recording the line of intersection. In practice, this process could be approximated by 'threading' a line through an array of data values and then smoothing the line. This, of course, assumes that the data array contains values that match the intervals of the lines. If this is not the case, then data values will have to be estimated through the process of ***interpolation*** (as described in Chapter 6).

Isarithmic mapping is subject to the same sorts of errors that have been described previously; errors in data collection may produce faulty base data, improper interpolation algorithm might result in inaccuracies, edge effects can cause spurious results towards the borders of the distribution, the map may be improperly drawn and the finished map itself may be improperly interpreted by the reader. The use of

GIS for map generation does not necessarily mean that a map will be appropriately drawn, so some care also needs to be taken to make certain that the source information is both clearly and properly presented. There are some design strategies that can be used to assist this, such as making isolines appear dominant on a map by using heavier weighted lines than used for other map data, and making certain that the isoline labels are legible and orientated towards the user. Automated labelling of isolines, or other spatial objects, is not handled very well by GIS and the use of more sophisticated third-party automated labelling facilities or, alternatively, manually placing labels, will ensure greater legibility.

## 12.5 Internet mapping

As the use of the Internet and other forms of electronic dissemination of archaeological data increase, so does interest in presenting map data in such a way that it can take advantage of the interactive and hypertext facilities that multimedia authoring languages offer. Electronic publication has also changed the style of publication by providing the reader with more options to navigate text and data in non-linear ways, and to create their own interpretations of the evidence.

Hodder (1999, pp. 117–128) has discussed the impact of global information systems on archaeology and, in a lively debate, Hodder (1997) and Hassan (1997) also discuss the implications arising from Hodder's celebration of the erosion of the authority of authorship that has been seen as an implication of digital publication. Similar implications arising from digital publication of spatial information can be proposed: providing users with interactive access to complete spatial datasets – and thus the ability to create, interrogate and analyse subsets of this information – challenges the authority of the cartographer and presents opportunities for alternative interpretations. Standards for Internet GIS, or 'Web GIS' as it is also called, are still emerging (Smith *et al.* 2002; Peng and Tsou 2003); the development of technologies for interactive Internet mapping is consequently a relatively new enterprise in the rapid rise of GIS technologies, but is one that has the potential to bring GIS to a much wider non-specialist audience.

Archaeologists have been early users of this technology as it provides a logical extension of the traditional published site report to a more interactive and interpretable format. Facilities that permit hyperlinks between data tables, descriptions and related maps can increase the effectiveness of maps as communication media. A good example is the development of a 'Web-CD' for the West Heslerton Project (Powlesland 1998) described in Chapter 3. Another is the York Archaeological Trust's publication of 41–49 Walmgate (Macnab 2003), where within a web browser users are able to navigate at will between maps and data with ease: large-scale maps are hyperlinked to smaller-scale plans of individual burials and features, which are linked to data tables describing the contents and artefacts. These in turn are hyperlinked to Harris matrixes, the cells of which are linked back to other maps. This provides the reader with near-seamless movement between spatial data description and synthesis, providing a more integrated site report than the traditional, paper-based, linear model.

While hypertext and hypermaps provide exciting avenues for the publication of archaeological information, they are dependent on predefined links between data that the user is then free to navigate. Fully 'interactive mapping', on the other hand, involves a different set of tools that mimic the functions of standalone GIS delivered via the Internet and accessed by a browser. This type of mapping involves an element of free navigation within and between maps and spatial datasets, including standard facilities like changing the scale and level of generalisation, panning and moving across maps, and enabling and disabling map themes (Cartwright *et al.* 2001). Many commercial GIS packages now offer the ability to distribute GIS data and GIS functionality over the Internet. When linked to a 'geolibrary' (Goodchild 1998) offering searchable access to spatial datasets, the potential for more exploratory analysis of spatial data relationships is increased. Some of the more common proprietary Web GIS platforms include ESRI's ArcIMS[1] and Internet Map Server (IMS),[2] and MapInfo's MapXtreme[3] software. Using these programs, it is possible to distribute GIS data from dynamic servers to users via web browsers, extending the user-base of spatial information to non-GIS specialists.

Web GIS has been extended by the definition of a markup language called Scalable Vector Graphics (SVG), which offers considerable improvement on HTML. Previously, maps accessed by web browsers had to be in raster formats and user interactivity was enabled by predefined hyperlinks, or by Java scripting which provided some degree of interactivity. SVG is a new non-proprietary grammar that extends the utility of XML and establishes a standard for describing two-dimensional vector graphics. Introductory guides to XML and SVG can be found in Ray and McIntosh (2002) and Eisenberg (2002). Although SVG only provides a mechanism for the creation of vector graphics (and their integration with raster images) it nevertheless offers a major enhancement to HTML by enabling the combination of raster and vector graphics in ways not previously possible. Adobe Illustrator[4] will export files as SVG, and extensions to several common GIS packages have been developed that enable the publication of map data using SVG, such as SVGMapper[5] for ESRI's ArcView, Map2SVG[6] for MapInfo Professional and GeoMedia WebMap[7] for Intergraph. A Web GIS application using SVG is shown in Fig. 12.9, which allows mouse-over querying of archaeological contexts from an excavation (Macnab 2003). Verhoeven (2003) has also described the application of SVG to interactive mapping of archaeological data from a Mesopotamian survey project.

[1] www.esri.com/software/arcims/. [2] www.esri.com/software/internetmaps/.
[3] www.mapinfo.com/. [4] www.adobe.com/svg/. [5] www.svgmapper.com/.
[6] www.gis-news.de/svg/map2svg.htm. [7] http://imgs.intergraph.com/gmwm/.

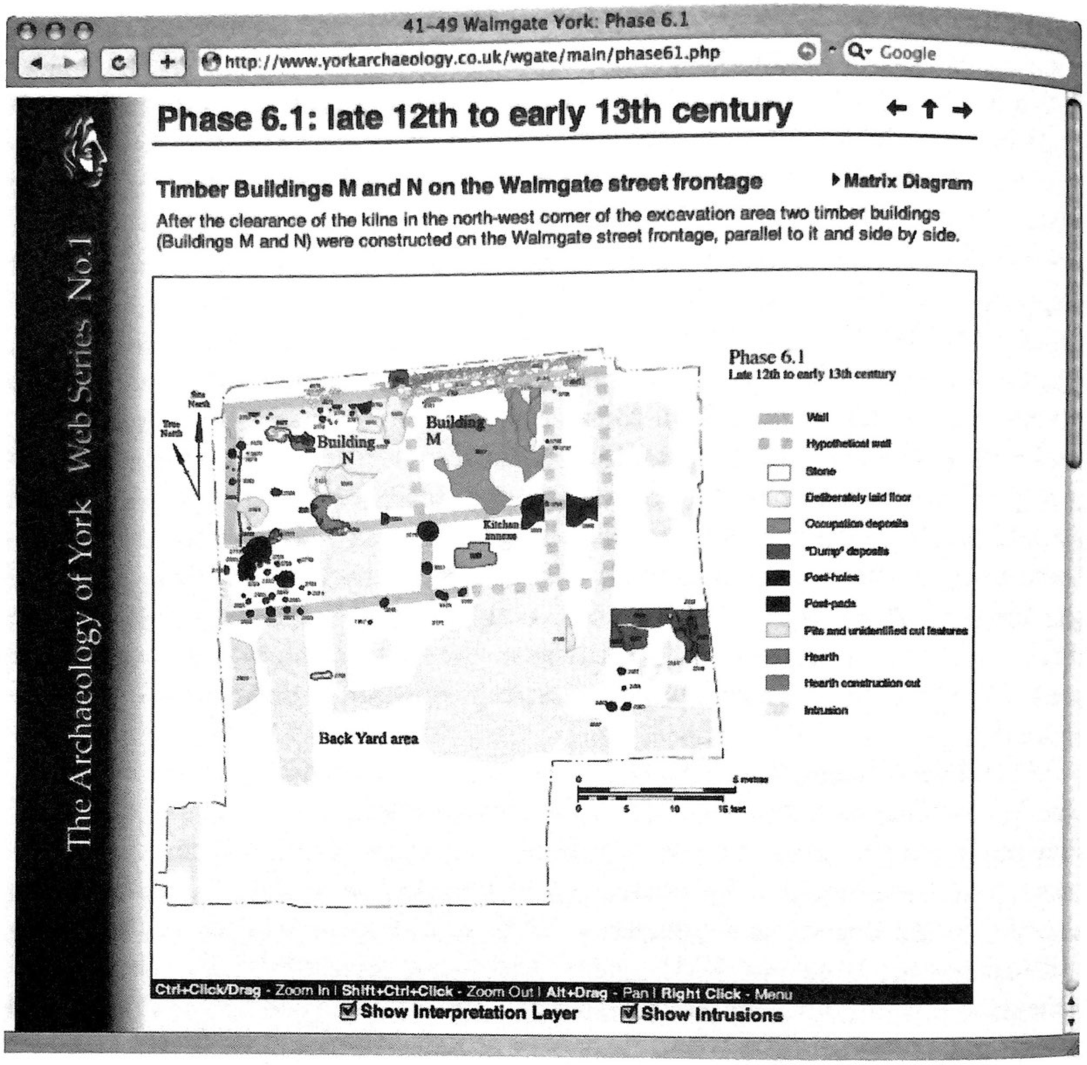



Fig. 12.9 An SVG map of late twelfth to early thirteenth century phases at Walmgate, York (Macnab 2003). Clicking on a given context pulls up a context description with links to photos and the stratigraphic matrix. The map can be zoomed and panned and thus provides many of the functions of GIS via a web browser. The system was built by Mike Rains using MySQL, PHP and Apache. Data and interface copyright ©York Archaeological Trust. Reproduced with permission.

## 12.6 Conclusion

Maps are wonderfully communicative documents that are able to hold and express a vast amount of spatial data that would otherwise be impossible to convey efficiently. A basic understanding of cartographic principles is extremely important for the effective use of maps, and the techniques described in this chapter will fulfil the mapping needs of most archaeological users of GIS. As is clear from the previous section, however, digital publication requires both a new set of skills and a rethinking of how data can be made available to the public. Although there will be a place for the traditional paper map in the future of GIS, and traditional map design is still a vital skill, Internet mapping will increasingly come to dominate GIS and will transform the mapping techniques that cartographers have come to rely on. The growing importance of the Internet as a primary vehicle for data dissemination, the sharing of map data between users in different countries and the provision of tools for the interrogation of map data within Internet browsers, are all part of this trend. In our opinion, this will continue to the stage when dynamic digital maps will become the primary vehicle with which users interact and explore archaeological datasets.