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Digital geological map production in the United Kingdom—more than just a cartographic exercise

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Geological maps produced by national geological surveys have changed little since 1815. Such maps have many disadvantages however. They are time-limited statements, constrained by the extent of data and understanding of geological processes. With the ever-increasing volumes of new data, the need to rapidly update geological maps has become pressing. In the BGS this need has led to the creation of digital, spatially related geological databases which offer the potential to generate customised geological maps with improved clarity, consistency and quality over traditional map series.

The prime advantage is an ability to capture and link the spatial and non-spatial geological data and attributes from maps and other sources. A production system for 1:10 000-scale digital geological maps is now operational and the production of thematic maps at this scale is being investigated. A 1: 50 000 scale map series is planned. Although there have been technical and personnel difficulties, a system to provide geological information tailored to the user's individual requirements, is well advanced.

Introduction

Since its creation in 1835 as the Geological Survey of England and Wales, the organisation known today as the British Geological Survey has experienced many changes of title. As presently constituted, the Survey is a component body of the Natural Environment Research Council, one of six Research Councils in the United Kingdom charged with responsibility for administering and funding scientific research.

The Survey is funded from three principal sources in almost equal amounts: by a block grant from Government via the NERC, the so-called Science Budget; through commissions awarded competitively by departments of state to undertake geological work in support of policy; and from contract work for the newly privatised utilities, regulatory bodies, industry and commerce.

The Survey's mission is to maintain and to keep up-to-date the geological map of the UK. This activity, which forms the Core Programme funded by the Science Budget, is approved and monitored by a Programme Board which includes representatives of the major users of geological information. The profile of the work programme is shown at Table 1.

A 15-year programme to bring the geological mapping of the UK up to a modern standard was begun in 1990. Surveying is usually undertaken at a scale of 1:10 000 and the mapping is summarised in 1:50 000-scale colour printed maps supported by descriptive mem-

oirs. The Programme Board has set a annual publication target of an average of 21 1:50 000-scale maps and 15 memoirs.

Geological maps

Geologists have traditionally summarised their work in map form. In the United Kingdom, one of the first geologists to do so was William Smith, the Father of English geology who, in 1815, published his 1:313 800-scale map of England and Wales. Smith, a civil engineer, was concerned to establish the practical application of his geological observations and interpretations. His maps record the practical use of the various rock formations, for example as sources of building stone, coal, brick clay and so on.

The simplicity of Smith's maps has been lost as geological theory and understanding have developed. As the information base and expertise have expanded, geologists increasingly have included more-detailed interpretations of the geology. Often, this results in complex maps which are intelligible only to professional geoscientists. As a result, geological information is not readily available, in an easy-to-understand form, to many others who need it.

Recognising this, within the last decade there has been a radical change to the map products required by some of the Survey's major customers. New series of maps illustrating one or more themes of interest to planners, developers and other potential users have been prepared. These 'applied' or 'environmental' geological maps at 1:25 000-scale were first developed in the Fife Region of Scotland based on the Glenrothes area. (Nickless, 1982; 1986) and included topics listed at Table 2.

Geological maps show the distribution of rock types and their relationships, but it is essential to understand that they are two-dimensional representations of three-dimensional structures—the uppermost part of the Earth's crust. Geological maps are thus not merely portrayals of surface features, they are also interpretations of rock-structures at depth. There is a second significant distinction between topographic and geological maps. Although the topographic map is subject to limitations of scale, measurement and projection, and becomes outdated by man-made and natural modifications to the land surface, it is based on direct observation. In contrast, the geological map attempts to represent what is largely unseen. It is

Table 1 The Core Programme of the British Geological Survey.

The programme comprises a series of long-term strategic survey and monitoring activities. There are six elements:

- onshore geological mapping;
- offshore geological mapping;
- geochemical surveys;
- geophysical surveys;
- hydrogeological and geotechnical surveys, and
- National Geosciences Information Service, whose role is to draw together and disseminate the Survey data.

Table 2 Environmental geology maps relating to Ordnance Survey sheet 20 (based on Glenrothes in the Fife Region of Scotland).

Element maps (basic data)	1	bore sites
	2	unconsolidated deposits
	3	lithology of the unconsolidated deposits
	4	engineering properties of the unconsolidated deposits
	5	thickness of the unconsolidated deposits
	6	depth to water in the unconsolidated deposits
	7	sand and gravel thickness
	8	bedrock geology
	9	bedrock lithology
	10	rockhead contours
	11	shallow undermining
	12	natural landslip potential
	13	opencast workings
	14	hardrock aggregate resources
	15	limestone resources
	16	brick and tile clay
	17	mudstone for brick-making
	18	hydrogeology
Derived maps (combining two or more elements)	19	underground storage potential within 100 m of the surface
	20	sand and gravel potential
	21	foundation conditions
	22	groundwater resources
Environmental potential maps (summary maps based on the element and derived maps)	A	development potential
	B	priority areas for on-site investigation
	C ¹	surface or near-surface resources with potential for opencast working
	C ²	buried resources which might be won by opencast working
	C ³	buried resources which might be won by pumping or mining

based on information revealed in natural and temporary sections such as cliffs, gullies or man-made excavations, and drill holes. It is thus an analysis of both surface and subsurface information available at the time of survey. In an area of few outcrops much may be conjecture, and new data from, for example, a new borehole or road cutting may alter dramatically the interpretation, and hence the map.

In the UK geological maps are often issued as two editions, *Solid*, showing the consolidated rocks, and *Drift*, the superficial, unconsolidated Quaternary and Recent deposits. Scales range from the largest at 1:10 000 (which have to date been released as monochrome paper dyeline/diazo prints) to the smaller at 1:50 000, 1:250 000 and 1:625 000 (reproduced by offset-lithography).

Geological maps produced by these conventional methods have their weaknesses. Like all 'fixed' paper products, they are inflexible. It is time-consuming to separate chosen elements, to change scale, to integrate other information or to vary the area covered. Despite the production of two editions, geological maps can be complex documents, a mixture of factual and interpretive detail, and when presented in monochrome may be very difficult to interpret. Arguably, the most significant weakness of maps, which are often based on the evaluation of only a few pieces of hard data, is the difficulty of updating and revising. As a national repository for geological data, the BGS acquires new information at a rapid rate but its maps are amended only infrequently. The desire to arrest this progressive obsolescence was a primary stimulus for the BGS to develop a digital system for the production of its 1:10 000-scale map series.

The overall objectives of the 1:10 000-scale digital map production system were thus:

- to establish a digital geological map database;
- to facilitate the continuous revision of maps by updating the digital database;
- to provide data in digital format to be integrated with other systems including internal and external modelling and Geographic Information Systems software;
- to produce high-quality (and readily understood) geological maps;
- to allow the generation of non-standard, customer-specific output and
- to ensure consistent standards of format and production.

The development of digital geological map production in the BGS was therefore not seen merely as an isolated cartographic exercise, designed simply to provide a digital facsimile of the conventional geological map. The intention was to capture the data contained within the map, the points, lines and polygons and their geological attributes, to create linked spatial and non-spatial databases and deliver a variety of digital and paper products.

Objectives

There was considerable geological computing expertise already available in the Survey to achieve these objectives. Digital geological map production had been attempted in the 1970s but the available hardware and software was insufficiently mature (Bickmore and Kelk, 1972; Rhind, 1973; Loudon and others, 1980). Throughout the 1980s, Computer-Aided Design (CAD) and Relational Database Management System were used in diverse projects across the BGS. In the late 1980s digital cartographic systems were being used in the preparation of several 1:50 000-scale maps and GIS was being investigated for the production of applied geological maps (Loudon and

Digital geological map production

Why do it?

Whilst an initial stimulus was an ambition to synthesize and update geological maps rapidly, the move to a digital system was also seen as an opportunity to create a digital geological map database as a primary BGS information

Figure 1 The structure and organisation of the project.

Mennim, 1987; Loudon and others, 1992; Loudon, 1992). The experience from these programmes was used to define the objectives and provided the basis for the development of a comprehensive operational requirement and contract specification for the hardware and software. In early 1991 a project team was assembled to implement the digital system.

The project required significant resources in terms of both capital and skills—in geology, cartography, systems analysis, database design and management, system design and procurement and GIS. A formal project management methodology was adopted to ensure effective co-ordination of a complex multi-disciplinary task. The project team was organised into a number of sub-projects co-ordinated by a Project Manager who in turn reported to a Project Management Board comprising three senior BGS managers (Figure 1).

Central to the project was the desire to create a digital map database. Consequently, the data structure (modelling) element of the project was considered fundamental. The database was designed at a conceptual level (the logical model, Figure 2) before any attempt was made to implement it on the chosen hardware and software. There were two reasons for this. Firstly, it was critical that the system met the specific BGS objectives. Secondly, it was crucial to maintain the scientific integrity of the data to allow future vendor independence, providing the potential to implement a system on other hardware and software platforms.

The tender for the hardware and software was won by Intergraph (UK) Ltd and the equipment was installed in October 1991. A preliminary version of the system was implemented in April 1992 and the final system was ready for operational production in December of that year. The system is based on the concept that the spatial data are held within the cartographic/GIS system (Intergraph's Microstation and MGE) and are linked to non-spatial data and attributes held within the corporate Relational Database Management System (Oracle). By issuing queries against the linked databases it is possible to generate a variety of conventional geological maps or non-standard products.

A much simplified workflow, which omits quality control and map management stages may be summarised as follows.

- 1 The geologist prepares manuscript geologically attributed lines master and colour models.
- 2 Manuscript lines master and colour models approved by line management.
- 3 The cartographer digitises map, generates polygons and captures attributes.
- 4 Electrostatic plots of required editions generated; raster topography added at immediate pre-plot stage.
- 5 Plots approved by line management; plot files held for reproduction on demand.

The key has been to develop a system which is based on geological as opposed to cartographic attribution of the lines, points and areas on a map. Thus the system is not only capable of offering scale variation and site-centred mapping, but because the individual elements have been stored in a geologically structured way, they can be selected and combined at will in customised geological products. For example, it is possible to select the areas of fill and made-up ground in a particular region and to depict their coincidence with a particular underlying rock unit. The facility to select elements of the map and to plot them in colour makes the maps much clearer and more intelligible than their black and white dyeline predecessors. In digital form the map may be manipulated much more readily and the ability to edit and revise will allow the maps to be updated as new information becomes available. Of fundamental benefit is the capability to provide digital geological map data which can readily be integrated with other information by using a GIS or surface modelling software. Thus the system provides the BGS with the capability to handle the large volumes of data required to digitally produce some 14 of the 18 applied geological 'element' maps drawn manually for the Glenrothes project. It is also possible to integrate the socio-economic criteria necessary to generate the Environmental Potential maps (Table 2).

Issues arising from implementation

The introduction of routine production of 1:10 000-scale digital geological maps by BGS cartographic staff has involved the adoption of new skills and changes in long-established working practices. Initially, this met with some resistance from staff. In part, the transition to new working methods has been made easier by the introduction several years ago of digital techniques in place of scribing in map production. The new practices can therefore be regarded as a continued evolution of that process.

Nevertheless, it has taken time and effort to set the overall strategy and the longer-term vision of a map series derived from manipulating geologically attributed spatial data with other databases. It has been necessary to convince the cartographers to look beyond map production as an end in itself and to see themselves as an important part of a team engaged in database building. Some of the main issues in bridging the cultural change relate to this databasing content of the work and the need, for example, to assign geological codes (attribution) to graphic features; to formalise and standardise working practices; and to integrate cartographic and geological disciplines so that neither group works in isolation.

The work of building the geological map databases must not be seen in isolation but in the context of the Survey's total information strategy. The aim of the BGS has been to pursue an integrated, 'holistic' policy and it has expended considerable effort in

the last few years in identifying and cataloguing a data holding in excess of 750 individual datasets.

The introduction of a digital system also continues to meet with some resistance from field geologists many of whom, being fiercely independent and free-thinking by training, resent the introduction of the standard specifications and dictionaries necessary to ensure the success of a national map database. A more rigorous approach to quality control has been essential as geographic information systems are unsuited to the practice of using vague cartography to hide geological uncertainty. There has also been a failure to appreciate that

the versatility the system provides comes at a price and there is resentment of the increased effort needed to explicitly label the maps in order to build the database.

System and data management have proved to be very complex; provisional procedures are in place but a considerable amount of work remains to be done. Some of the more significant issues encountered are as follows.

- The designed system is an integrated operation which crosses BGS divisional boundaries; new standards and procedures for data management are being devised to replace pre-existing

Figure 2 The logical data (entity-relationship) model which is fundamental to the digital map production project. Each cell in the model represents a single entity. Symbols on the lines connecting cells show, in diagrammatic form, the relationships between different entities.

diverse (and often ad hoc) methods. The system requires close supervision and map managers have been appointed to ensure effective liaison between the geological and cartographic divisions.

- Problems arise because geological maps released by the BGS are regarded as authoritative documents which may be used in litigation. Conventionally, the master version of the paper map carried the approving signature of the Chief Geologist but it is difficult to retain this necessary formal approval procedure and yet exploit the flexible and dynamic virtues of a digital system. For the moment BGS has opted to take a magnetic archive copy of the database following Chief Geologist approval of an electrostatic plot of the map. The problem is, in essence, one of version control and archive management. This highlights the further difficulty of validating those parts of the database which are not graphically represented on the map. Checking these items will involve significant effort.
- The digital map system has been designed to provide access to, and display information held in BGS databases which lie outside the responsibility of the map production system (for example borehole and structural data). The independence of these databases means that effective procedures are necessary to ensure there is no conflict between the contents of the various databases and their graphic representation on the map face.

The problems associated with dissemination and release of the digital map data are considerable because, in the UK, data are regarded as a tradeable commodity. It has proved difficult to reconcile a cost-recovery policy necessary to sustain research and map production while ensuring that the products are available to all at a fair and affordable price. Additionally the problems of policing copyright of digital data and controlling unauthorised digitisation of BGS map holdings cannot be understated. After long discussion a comprehensive charging structure is now in place. Multi-coloured electrostatic plots of 1:10 000 maps are replacing monochrome dye-line (diaz) copies and their price reflects the higher-quality product and the technology used to produce them. Digital data at 1:10 000, 1:50 000 and 1:250 000 scales are available in raster and vector formats. Raster data may be purchased outright but vector data are available only under licence.

The success of the development of digital mapping in the Survey and its adoption in production has depended on the commitment of senior management in identifying and protecting the project team from work conflicts, and providing the significant financial resources for the purchase of equipment and software. The project has drawn staff from many groups across the Survey, on average 8 man years per year over the last three years.

The time taken to produce a 1:10 000-scale map using digital methods is probably 5% greater than traditional methods. The advantage comes in the facility to readily update the map and to generate tailored and non-standard map products. The initial investment, as data are converted from paper to digital formats, is substantial but unavoidable. A small production team has been identified and targets set with the aim that, as digital map sales develop, the team should become self financing.

Although the potential of digital data in Geographic Information Systems is widely recognised, there has been, as yet, little expressed demand in the UK for a digital geological component. In part, this may reflect a failure on the part of the BGS to inform the potential client base. The strategy will be the continued use of market surveys to determine and meet customer need.

The future

Following implementation of the 1:10 000-scale system, the BGS has investigated the feasibility of extending the geologically attributed approach to its 1:50 000-scale series. This series is currently

produced by digital means but by a cartographically structured process. The advantages established for the 1:10 000-scale system retain their validity regardless of scale, and extension of a similar approach to the 1:50 000-scale series will more readily enable provision of national coverage of geologically attributed digital map data.

In the last two years, some members of the implementation team have concentrated on the digital production of non-standard (customized or thematic) geological maps. The BGS has considerable expertise in the conventional production of thematic or applied geological maps and sees the capability to generate these digitally as crucial to its future business. The production of map variants based on map face data alone—scale and area variation, element and selection and permutation—has been completed successfully. Work is well advanced on refining and automating the generation of maps from multiple datasets (i.e. map-face data integrated with other digital information—for instance borehole, geochemical, geophysical, mining and quarrying, environmental and planning data).

Under the aegis of the project, the BGS is also investigating two other systems. The first is a digital map compilation system for field geologists; using scanning and GIS technology to capture, and selectively vectorise, data from available sources. The second is a system for digital acquisition of data in the field. The feasibility of using pen-based systems for construction of the field map and notes in the field is being explored. A comprehensive user requirement has been developed and a pre-prototype trial has been conducted.

Although many of the maps produced in future will be ephemeral and customer specific, it is reasonable to assume that there will continue to be a demand for printed material. For the foreseeable future the Survey will continue to provide a coherent printed map cover for the UK at a scale of 1:50 000. However, the emphasis is changing to the underlying data and interpretation, and away from printed map products. Within this, the centrality of the databases is assuming overriding importance and the printed map will increasingly become regarded as peripheral by many users.

The development of the two-dimensional digital system is a significant advance on current conventional methods of disseminating geological map data. However, geology is a three-dimensional science and the long-term goal must be to develop a system to deliver a three-dimensional digital spatial models which can more fully, analyse and illustrate the reality of complex geological interrelationships.

The BGS intends to build on the advances made to date which reflect a structured approach to the construction of digital databases, an acceptance of an imposed data architecture, the commitment of both staff and financial resources to the project and its subsequent implementation in map production.

Over the coming year a number of digital map products will be made available under licence. A series of 1:10 000-scale maps have been released for north London and Glasgow. The 1:250 000-scale geological map of mainland Britain with cartographic attributes is also available. The aim is to provide this as a full geologically attributed dataset shortly. Work is in hand to release a number of 1:50 000-scale maps as digital files.

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