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LINKS BETWEEN MAP DATABASE SYSTEMS FROM DIFFERENT SCALES

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DIGITAL MAP PRODUCTION IMPLEMENTATION PROJECT

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SUMMARY

The results of BGS geological survey are mostly recorded on 1:10 000 scale maps, and published at 1:50 000 and smaller scales. The maps are generalised by removal of detail, smoothing lines and adjusting to fit the new base map. Digital map production still requires the delivery of traditional maps, in order to be consistent with past publications and to retain the customer base. But, while the map is unrivalled for presentation, new methods for data collection, storage, manipulation and retrieval are available in a digital environment. Constraints imposed by fixed scales and the need to fit specific base maps must eventually be overcome. Meantime, it is desirable to distinguish clearly between the needs of the scientific database and purely cartographic requirements, which may be transitory. It is recommended that as far as practicable, the scientific data from all scales should be held in a single database. Records for various ranges of generalisation should be distinct, and should have precise counterparts at each scale, where possible derived from the survey scale by algorithm. Stratigraphical relationships are involved in generalisation, and must be available as part of the database. Version control is vital to continuous revision, but made particularly complex by the need to update generalised maps.

1 - INTRODUCTION

1.1 Purpose

This report was prepared by a Working Group addressing Task 4, Objective C of the BGS Digital Map Production Implementation (DMPI) project, namely *to consider the current and potential links between those aspects of the 1:10 000 and 1:50 000 scale geological map production system which are concerned with digital data capture and the resultant databases.*

It sets out some background considerations and makes recommendations concerning the relationships of the different scales of map within a digital environment. The views expressed are not necessarily those of the DMPI project, nor of BGS.

1.2 Approach

Two approaches could be taken to the issues arising from map scales in DMPI. One is to look at the existing map products, and consider how computer methods could be used to produce them more efficiently. With this approach, little more than minor enhancement of the automated methods already used in the drawing offices would be needed. It would fail, however, to meet the requirements of the BGS strategy. A more radical approach has therefore been followed. Taking the requirements of the strategy as the starting point, the implications in terms of useful products and working practices are considered. These in turn determine the nature of the information repository - the database, geographical information system (GIS), metadata, and associated information. The 1:10 000 and 1:50 000 scale maps can be seen as initially the primary products of this repository, which must therefore be designed with their production principally, but not exclusively, in mind.

This approach inevitably means discussion of several issues which underpin the long-term success or otherwise of the activity, even if on a short-term view they appear irrelevant. The justification for the DMPI project, and much other work on information systems, lies in the medium to long term benefits. They could be put at risk if the wrong short-term expedients were to be adopted. Unless significant changes to the geologist's work pattern can be contemplated (see section 3.6), the second approach will fail, efforts would be better concentrated on the first approach mentioned above, and the conclusions of this report would be irrelevant.

1.3 Strategy

The strategy for BGS digital mapping is set out by Allen (1991). UK-wide digital coverage of 1:50 000 maps is targetted for the year 2005. Digitization at 1:10 000 scale will be selective but extensive, and in many areas will be followed by continuous revision - defined as the process of keeping the map database under constant review. For both scales, the database should be seamless within defined areas. The purposes of the database are mainly scientific, and it is expected to provide the basic data for 3-D modelling later in this decade. Future developments in cartography may allow the production of revised 1:50 000 maps directly from the scientific database. Facilities to generate thematic maps from the 1:10 000 data are planned for April 1993.

The strategy cannot be fully implemented now because in some areas the technology is not yet available, or is not at present sufficiently robust for a production system (see 3.4). Nevertheless, the strategy is crucial in considering the links between different scales.

2 - THE PRESENT SITUATION

2.1 Geological map scales

The British Geological Survey presents its map information at a number of scales, principally 1:10 000 and 1:50 000. The former is the survey scale, that is the scale at which the information is normally recorded on a field slip during survey by the BGS geologist. Additional information is recorded at the same time in a field notebook. As described elsewhere (see Rathbone and Walsby, 1989), a fair drawn copy of the map is prepared. A master copy (the standard) of the 1:10 000 sheet is generally archived and made available for inspection by the public. Occasional copies may be made on request. In contrast to the survey scale, some 2000 to 3000 copies of each 1:50 000 map are printed.

In response to specific requirements, maps may be produced at other scales, notably 1:25 000, but in relatively small numbers. Geological information for the UK and surrounding seas is further simplified and presented at 1:250 000, 1:625 000 and 1:1 000 000 scales. Geochemical, tectonic, geophysical or other data are also presented at small scales, in some cases in combination with geological data. These small scale maps may have print runs of several thousand copies.

The user requirement for the various scales is under investigation as part of the DMPI project, and the findings of this report must be reviewed in the light of their conclusions. Allen (1991) makes the following distinction. "The scientific requirements of geophysical modellers, geochemists and hydrogeologists are best met at 1:50 000 or smaller scales. Maps at 1:10 000 scale are required by external users such as planners, mineral extractive industry, construction industry and utilities, but are used internally either to answer an enquiry from an external source or for detailed scientific analysis including modelling. They are the principal reference medium within BGS and, as such, must be maintained at a high level of accuracy and reliability."

The variety of scales reflects the amount of detail required by the user. The presence of a mine shaft or a small buried river channel could be of vital significance when considering the construction of an office building, but is irrelevant in, say, explaining a gravity anomaly. The smaller scale maps therefore present the regional picture, uncluttered and unobscured by local detail. As it is inevitable that only a small number of users will be interested in any specific small area, conventional publication of 1:10 000 scale maps is not justified. An objective of the DMPI project is to ensure that, even if only a few copies are made, they can be of good cartographic quality. This involves digital representation of the data, and raises the question of whether the same data could be reused in smaller-scale maps (see 6.0). As background, the conventional procedures for preparing 1:50 000 from 1:10 000 geological maps will now be described.

2.2 Preparation of smaller-scale maps

The field geologist is concerned with developing, recording and communicating his interpretation of the geology. In the field, he may relate his interpretation to visible topographic features. He records them, however, in relation, not to the real topography, but to a topographic map, which is a representation of the topography prepared separately by an Ordnance Survey (OS) surveyor with other and wider objectives in mind. In the conventional approach, the link between the two maps is essential, because OS maps are generally accepted as a means of correlating spatial datasets in the UK. Thus, a town planner or a soil scientist would have no difficulty in relating the geology to their own observations, by overlaying maps which have the same OS base. The precise match of geology to topography in these circumstances could be vital.

At present, the vast majority of the traditional geological maps prepared by BGS come from surveys based on 1:10 000, or the earlier 1:10 560, Ordnance Survey maps. The exact procedures to be followed in preparing smaller-scale maps are not formalised, and may be carried out entirely by cartographic draughtsmen, but the following description is reasonably typical.

When all the 1:10 000 scale quarter-sheets (5 km square) for a particular 1:50 000 map have been fair drawn by the geologist, they are assembled and checked to ensure that lines and areas match across sheet edges. The quarter-sheets are photo reduced to 1:50 000 scale, and the geologist indicates changes to be made in transferring to the 1:50 000 base map. This involves omitting lines and areas of secondary importance. For example, only a few of a set of closely spaced coal seams or dykes in a dyke swarm would be included, and minor stratigraphical units would be combined. The geologist's assistant, or a draughtsman, traces the remaining lines from the reduced 1:10 000 maps on to a single plastic overlay, on the back of which 1:50 000 topography has been dye-lined. Small crenulations in the lines are smoothed, to avoid giving an unattractive and possibly misleading visual impression.

Geological lines and points are adjusted where necessary on the smaller scale map, to ensure that they retain the same position relative to topographic features, for two reasons. One is that, for example, an outcrop to the south of a road at one scale should not appear to the north of it at another scale. A second reason is to ensure that the geometry implied by the intersection of geological lines and the land surface is correct. For example, planar, gently dipping surfaces must intersect contours and streams accurately, if the correct conclusions are to be drawn about their structure. Thus, formation boundaries might be shown veeing into the centre of a river on both scales, even if the depicted position of the river changed owing to OS generalisation of the topography.

Working from the symbols that identify the stratigraphical units on the monochrome 1:10 000 geology, the geologist or his assistant colours each area of the map and produces an initial table explaining the colours and symbols. The result is carefully checked by the geologist, and amended if necessary.

It is then the task of Cartographic Services to prepare a draft copy of the 1:50 000 geological map, based on the 1:10 000 fair-drawn sheets and the geologist's coloured compilation on the 1:50 000 base. Material for the map margins, including cross-sections, diagrams, explanations, text descriptions, bibliographical material, authorisation and disclaimers, is added by the geologist and Cartographic Services.

At one time, the reproduction material was manually prepared for publication by the Ordnance Survey on behalf of BGS. However, this process has now been automated, and instead of the laborious procedures of cutting and pulling colour masks, the lines of the geological map are digitised, and the classification of areas is indicated to the computer by codes attached to seed points near the centre of each area. The code indicates the stratigraphical classification of the area, but is also an indication of the colour by which it should be shown on the printed map. Line data are similarly coded to indicate the line style and colour. This work is all done in-house, and the resulting information is sent by tape to an external cartographic bureau. From the information on tape, a computer calculates the density of screening required for each colour in the printing process. Films are prepared automatically on a laser plotter, and from them printing plates are prepared.

When new geological information is obtained, this is held on file, and the survey scale maps are brought up to date at long intervals, at which time the accumulated information is reviewed and, if need be, the area resurveyed. The consequent long delays in making map information available are described by Rathbone and Walsby (1989). The 1:50 000 maps are revised, from the 1:10 000 maps, at intervals of several, possibly many, years.

In a number of cases, 1:50 000 maps are revised independently of the 1:10 000 map. This may be because the revision is based on external information, such as mapping by research students in the Scottish Highlands. In other cases, lack of time may prevent full revision, with the result that changes are not reflected at the so-called survey scale. In recent years, priority has been given to the production of the 1:50 000 maps, to the extent that some survey scale maps have been regarded as working documents, for the geologist's own use.

2.3 Associated data

The map is a medium of communication and its ability to store information is constrained by its display format. Associated details are therefore held in field notebooks and in various record collections, registers, reports and other documents. Much relevant information, such as site investigation reports, cores, samples and specimens, comes from outside sources and is curated by the Information Services Group. Other information on such topics as palaeontology, petrology and mineralogy may be held by specialist groups. All these repositories of information - geological and topographical maps at different scales, and the related records - are updated independently by different groups at different frequencies and times.

2.4 Quality aspects

No previous documentation of the procedures to be followed in preparing small-scale geological maps could be found. This suggests that the procedures are pragmatic, based on the individual characteristics of each area and each map. Scientific and cartographic considerations both play a part in deciding on the map content, and compromises between the two may be necessary. Consistency and quality are difficult to maintain in these circumstances. Quality is controlled and assured by the approval process, in which the Project Leader, Group Manager and Programme Manager approve each map before it is passed for publication. The control may extend back to the survey-scale material, on a less formal basis.

3 - THE STATE OF THE TECHNOLOGY

3.1 Towards a digital system

Major changes to the map production system are planned, with the data held as a seamless database from which maps can be directly produced. Although the objectives are appropriate, the technology for production implementation is not immediately available, and cannot be developed by BGS. Some of the technical problems have been alluded to in the data analysis and other project documents (Bain and Giles, 1991). It may be timely to consider the ideal system which could meet these requirements, taking the project strategy at its face value. The constraints of present-day practices and technology, and how they may be overcome by likely future developments will then be considered. Future developments bear on current planning, because the half-life of data now being collected is many times greater than that of the software and hardware on which it depends. Data collection and entry, which will account for most of the cost of this project, is thus providing a resource which may for the most part be used with systems which do not yet exist. The implications for working practices in BGS may be more significant than the computing considerations.

There are a number of improvements to the present system that might be sought from a computer database. One is a closer link between the information depicted on the digital map and the supporting information held in other databases. A second is the ability to keep the information up to date, and to generate on demand maps and other presentations from the latest information. A third is to maintain consistency of information between presentations at different scales or levels of detail. A fourth is to overcome the artificial breaks imposed by map sheet boundaries. To achieve these improvements, there is a need for a structure which ensures that when individual items are modified, the changes are consistent with the rest of the database.

All these features are implied by the requirement for a seamless, continuously updated database. They are reasonable and logical user requirements. Unfortunately, a production system with these characteristics is beyond the reach of available technology. Accepting them as a real requirement, it is necessary to look at what is possible now, what future developments are in hand, and how to make the most of existing technology while positioning the longer term strategy to take advantage of new developments when the time is right.

3.2 Computing developments

In the May 1992 issue of *Computers and Geosciences*, there are three articles by suppliers of large GIS systems which are relevant to BGS planning. One (Morehouse, 1992) describes a well-established hybrid technique for storing spatial data within a file structure with links to attributes held in a relational database. This is the approach adopted in the three main GIS systems currently in use in BGS. Arc/Info archives the information as a set of tiles, which provides acceptable performance, but as Chrisman (1990) points out elsewhere, although technically necessary at this stage, the approach must be superseded in due course to meet the requirements of seamlessness. Two other papers (Herring, 1992 and Batty, 1992) point out the limitations of the hybrid database approach, which does not offer the flexibility and the potential for distributed computing of a relational database. Their proposed solutions involve incorporating spatial data as a component of the relational database, and extending the query language (SQL) to accommodate the requirements of a GIS. This approach, however, is controversial, and it has been suggested that the complex knowledge-based structure, typical of geological and other GIS, cannot be adequately represented within the simple rules-based structure which a relational database requires (Worboys et al, 1990).

In this area of active research, the systems already in use within BGS seem to be as appropriate as any available alternative, and more robust than most. Their current limitations must therefore be accepted, but continuing developments can be expected over the next few years, introducing greater flexibility as GIS are included in a windowed open systems environment, and providing more database features as an integral part of the GIS.

Looking further ahead, there is an underlying concern that more than a hundred of years of investment have trapped the geological surveying process in an unsuitable technology, (Loudon, 1992). The GIS community are pursuing developments which must influence the process of geological mapping (see, however, 3.6). For example, Goodchild (1992) asks:- *Is the traditional approach to geological field mapping the most* *appropriate if the eventual objective is a digital 3-d representation of the subsurface?* He goes on to indicate that:- *We need better methods for dealing with the world as a set of overlapping continua, instead of forcing the world into the mould of rigidly bounded objects.* From that viewpoint, current efforts in digital cartography may be superseded by a more radical change of mapping procedures, even before the present remapping of the UK is complete.

An interesting development is the attempt by the Petrotechnical Open Software Corporation (POSC, 1992) to set standards for a software integration platform, which may lead to recording geological data, including map data, within a framework of globally accepted standards. Their deliberations provide a forum for bringing together the efforts of providers of geological information, such as BGS, and the commercial suppliers of hardware and software.

Present efforts in the field of digital cartography face rapid change, and a flexible approach is essential. There are external pressures, and consequent opportunities, to change the paradigm of geological survey. Unless our present efforts in digital cartography succeed in building a bridge from the past to the future, they will have been in vain. Developments in computing technology are a possible guide to the organisation of the information system, and hence the scientific activity, within a digital framework.

3.3 The ideal database

Ideally, data within a database are integrated in such a way that when one item is changed, the cross-references to all related items take the change into account. Thus a bank might note the change of address of a customer, and all his bank accounts, standing orders, and so on, would access the amended address. If the customer's address were held separately for each application, then there is a probability that some of the required changes would be forgotten. Control of redundancy (duplicated information) helps to avoid this risk by holding each address once only, cross-referenced from each point where it may be required. Maintaining the correct cross-references (referential integrity) depends on careful data modelling and database design.

Consistency in the database must be maintained while the data are being updated (update control). For example, if a bank official updates a customer's address, at the same time as another official is recording that the original account is to be changed to a joint account, precautions are needed to ensure that both operations are completed in the correct sequence, and not in parallel.

For efficiency, it can be desirable to maintain a distributed database, so that the account information is held on a computer in the customer's local branch, but is accessible when required from the head office or elsewhere.

The full history of each bank account (version control) is needed, giving the balance after each transaction, and relating this to other recorded events. For example, the balance at the time when the account changed from single to joint ownership must be known.

Finally, the system must be designed to offer acceptable performance. Delays of several minutes in verifying a customer's balance would be unacceptable.

3.4 The geological database

The strategy (Allen, 1991), and steps already taken within the DMPI Project, imply that features similar to those just described in the banking example, are sought in the geological and cartographical database. The characteristics of the data, however, make it difficult to reproduce the features of the conventional database. It is necessary to consider each aspect in turn, as there are important implications.

If the Ordnance Survey correct the position of a river at a point on a 1:10 000 scale topographic map, it could mean that locational records for a fossil specimen, a borehole and a geological boundary, which had been sited on a river bank on the original map, should be revised. This might or might not have effects on a Drift thickness map, and perhaps would alter the stratigraphical classification of an area on the map. Even if the Ordnance Survey did not make corresponding changes to the 1:50 000 map, some, but not all, of the changes could be reflected in the 1:50 000 scale geology. If, however, the change were due, not to error, but to the river changing its course, then the topographic base should be changed, but none of the other amendments would be appropriate. Background knowledge (not available to the computer) is needed to make the correct decisions. A database design to handle automatically all the knock-on effects of altering one item in the database is difficult to achieve, and is not attained in the current data models.

In a conventional database, updating data involves a transaction which lasts a fraction of a second. The records in question are locked until the update is complete, thus ensuring that conflicting changes are not made. Modifications to a geological database require a longer time-scale. For example, a new housing development might lead to changes in the geological maps, the borehole records, geotechnical data and the topographic maps. The opportunity for confusion is clear, in terms of, say, geotechnical tests being added for a borehole which had not yet been recorded, and boreholes being sited on roads which had not yet been mapped. On a shorter time-scale, there is a risk that an update to the database is only partially completed. For example, a line might be added to a GIS, when, owing to computer failure, the attributes of the line did not reach the database. References to the new line are thus lost, possibly creating serious errors in resulting maps which are difficult to detect.

As very large volumes of data are required to represent map data, there is a need to keep the data near the point where they are most used. The data must therefore be distributed. Even with simple relational databases, the technology to maintain a fully distributed database is not yet robust. With the hybrid database currently required for cartographic data, they may never be developed. A less satisfactory alternative is a set of databases where each office can fully access only the data held locally.

For scientific and legal reasons, past interpretations and data must be on record as well as the current view. It would not be acceptable for BGS to publish information which external users took as the basis for, say, planning the construction of a motorway, or writing a scientific paper, and for that information then to be overwritten on the computer and erased from the record. Each change to the database, has therefore to be time stamped, and the earlier version retained and accessible, but clearly marked as superseded. On the existing limited BGS database, version control is not a problem. However, Newell et al (1992) warn that, in contrast to a pilot study:- *the situation in a production environment is just the opposite: a complex data-model, a large number of users, concurrent activities, and a large investment in the creation of the database. The problem of version management could dominate all database activities in a production system and yet not manifest itself at all in a pilot project.*

Graphical and cartographical data do not fit readily into conventional database structures. In order to give reasonable response times, a GIS is generally designed with a hybrid data structure, with the geometric data (such as points, lines and areas) held in one structure, with their own data management facilities, cross-referenced to their attributes, held in a relational database and operated on by a relational database management system. Acceptable response times from the computer are thus obtained at the expense of retaining much information outside the database management system. The full features of database management cannot be expected in these circumstances.

At present, standards for transferring complex data structures between systems are under active debate, world-wide. The location of points and lines can be transferred between GIS, such as Intergraph MGE and Arc/Info. Relationships among points and lines, including the definition of closed areas, can be re-established, after transfer, with difficulty. However, the links between the spatial entities and their attributes are lost when the data are moved from one GIS to another, and in consequence, the information is effectively locked into a single system. Procedures to overcome this are not available in BGS, and much more work in this area is required. A consequence is that digital cartography products cannot at present be made readily available to users outside the original system.

It should be pointed out that the problems outlined are not just consequences of computer technology. At a technical level, solutions will no doubt be found, and are indeed in prototype form now. Computer technology makes faster communication of information possible, and will make new solutions possible. Rather, the problems are deeply embedded in current work practices. It is therefore necessary to review existing procedures, and consider how the information system tackles these issues without computers.

3.5 The existing system

The primary means by which earlier technology handles the problems outlined above is by partitioning published information into quite large discrete documents (maps, papers, memoirs, etc.), representing many man-years of effort. Many identical copies of each document are distributed and stored. Thus many copies of a map may be printed, without revision for several years after publication. The geology on the map is locked irrevocably to a specific topographic base by overprinting. However, since the topographic map is itself revised on a long cycle, users are likely to be able to relate other information, such as planning data, by overlaying information from the same or a similar map. Other records, such as borehole logs, are handled as informal data which are archived and can be copied or consulted at the records centre, but are not necessarily consistent with other sources of information.

A major technical determinant of this information system is the offset-litho printing process, and its ability to provide large numbers of high quality documents at reasonable cost. The setup costs for each print run are high, but marginal costs of additional copies are low. Thus a print run of several thousand documents costs little more than a run of a few dozen. The economic consequence is the need to communicate information with the smallest number of documents and as many copies of each document as the market can absorb. One inevitable result is an inflexible, crowded, presentation format. Another is that information is not only delayed by years in publication, but is based on other sources of information which were themselves years out of date. The overwhelming advantage is that the scientist or user need keep track of only a small number of large blocks of information. Within each document, the authors, editors and referees have already undertaken the daunting task of resolving internal conflicts. Indeed, a large part of many text documents is concerned with citing sources and weighing conflicting evidence.

3.6 Pragmatic solutions

There are definite limits to the extent to which innovation in BGS map production is acceptable. BGS must be less concerned with developing entirely new methods, than with ensuring that the immensely valuable information resource which it has built up over the years can be refurbished to be of continuing value in a new technical setting. The consistency and coherence of that information is one of its valuable features, and must be maintained. The existing information must therefore be placed within an electronic environment, from which existing map styles can be produced, but which also offers new possibilities and, if possible, the flexibility to accommodate future change.

Considerable effort has already gone into building up a BGS database, which is now part of the existing information resource. It was argued in the previous sections that the aim of providing a scientific database from which maps can be generated is entirely practicable, but that some necessary features are not yet robust enough for production purposes. At this stage, some short-term expedients may be necessary. For example, version control poses problems. While these are worked on, the only immediate necessity is to record external communication transactions, in other words to retain a copy of all maps published or supplied to customers. Depending on relative costs, this may be a paper map, or an archived copy of the plot file. This is feasible only until such time as the system is successful with a high degree of usage, thus full version control must be introduced as soon as practicable.

Difficulties will undoubtedly arise from the fact that the paper map is currently seen as the master copy of the information, which is approved and authorised. This must be regarded as a temporary situation, and procedures for quality assurance of the scientific database must be introduced. Retrospective quality assurance is difficult to achieve, and without it, the long term value of the digital record must be in doubt. Equally, it is difficult to provide quality criteria for a situation in flux. The work reviewed in earlier sections suggests that the full benefits of new technology will only be obtained after a period of trial and error, and there must therefore be a willingness to discard some laboriously compiled digital data.

More significant is the need to organise work in such a way that the long update cycle in a GIS does not cause confusion. A solution is to partition the database by area, and place control of updating and editing the data in the hands of a small group who are thoroughly familiar with the area and the state of their information. They are thus in a position, with the help of informal manual procedures, to supply the background knowledge on which operation of the GIS depends. It is arguable that at this stage, the group should also be aware of any access to their part of the database, so that they can issue warnings and give assistance as necessary. Geologists must be explicitly responsible for development and upkeep of the computer record of their data.

Some commercial organisations, notably oil companies, take the view that multidisciplinary teams should be organised on an area project basis, housed together in an open plan office, bringing together skills in, say, geology, geophysics, geochemistry, reservoir engineering, log analysis, cartography and database, working together on a shared multidisciplinary database. In these circumstances, the responsibility for the content of the local partition of the database resides with the team. Conformity with other teams is ensured by imposition of tightly defined corporate standards and data architecture. Continuous revision and resistance to innovation (see Peuquet and Bacastow, 1991) may in due course lead to a similar approach in BGS.

It is not clear to what extent the pattern of geological investigation has developed to fit the technology or vice versa, but it is evident that computer technology could free the information system from some technical constraints. Before that is feasible in practice, some existing assumptions have to be reconsidered.

4 - QUESTIONABLE ASSUMPTIONS

Existing procedures for geological map production were based on assumptions reflecting well-established technology, so familiar that little thought is given as to whether the assumptions are still valid. As the reason for digital cartography is to overcome deficiencies in earlier technology, assumptions which have a bearing on links between map scales must be reconsidered.

4.1 Medium is not the message

One assumption is that the map must be equated with the information portrayed on it. Three quite different functions: recording information during field "mapping", storing information in the archives, and communicating information to others, are all performed with nearly identical representations on similar, or even the same, documents. Computer methods mean that this need no longer be the case. As the scientific database is seen as central to the mapping activity, the three functions can be handled separately, each by the methods best suited to it. The hard-copy map remains unsurpassed for communication, but the benefits of digital storage are recognised. It follows that the information can be recorded during field surveying in any form which can readily produce the required digital record. Scale need no longer be defined for data capture.

4.2 Long print runs

A second assumption is rooted in the characteristics of offset-litho printing processes, considered in 3.5. The economics of the process dictate long print runs. It is therefore assumed that it is desirable to communicate as much information as possible with as few documents as possible. The present pattern of publication world-wide reflects this assumption, including the existence of standard OS map scales and sheet boundaries. The pattern, however, may soon be broken as the cost of one-off presentation of selected information from a database becomes increasingly competitive.

4.3 Spatial correlation

A third assumption is that, in the UK, the Ordnance Survey topographic base map is the primary means by which spatial information from diverse sources is correlated. In fact, the geologist, like any other collector of spatial data, now has an increasing range of tools for fixing position in the field, including satellite and air-borne imagery, radionavigation and Global Positioning Systems, and local surveying assisted by laser range finders and electronic plane tables. Geographical information systems (GIS) are a powerful tool for combining and manipulating spatial datasets, including topographic data, but do so through geodetic coordinates, or through registration points, rather than through any of the various base maps to which individual datasets were referred.

4.4 Fixed scales

These assumptions have led to concentration on a small number of scales, each with a standard presentation of the topography, widely used for all spatial data. In turn, this leads to a fourth assumption, that geological map information should be related to a few fixed scales. There is little doubt that for the foreseeable future geological maps at 1:10 000 and 1:50 000 must be primary products of BGS. Market requirements and preservation of the customer base demand it. The function of the maps, however, is akin to that of a man with a red flag walking before a horseless carriage, namely, to maintain compatibility with an older technology.

Scale is a characteristic of the map on which information is presented - the ratio of the distance between two points on the ground and the distance between the two corresponding points on the map - and cannot be a property of the database. The corresponding characteristic of the data is their level of detail and their resolution - the minimum distance between two points on the ground which have distinct geographical locations in the database. Information must be held at different resolutions and levels of detail to avoid the problem mentioned earlier, of a regional view being cluttered with irrelevant detail. Three bands, from fine to coarse resolution, might be considered: local, regional and national. As suggested by Lowe, they could be used to prepare maps up to 1:25 000; over 1:25 000 and up to 1:100 000; and smaller than 1:100 000 scale.

4.5 Map and model

A fifth assumption is that the geology is directly related to the topographic map, rather than to the topography. With the incoming of GIS, topographic surveyors are reinterpreting their role, seeing a primary function in producing a digital landscape model, from which the secondary cartographic model is derived (see Barwinski and Kremers, 1992). Similarly, the primary concern of the geologist must be to produce a geological model, and its cartographic representation is a secondary concern. For example, it may be necessary to place a strike and dip symbol on the map where there is room to see it. The orientation measurements should be collected and recorded, however, with scientific, not cartographic, requirements in mind. In general, it is desirable to separate the scientific database from cartographic considerations at every scale.

4.6 Generalisation

A number of cartographic reasons are advanced for changes to the content of a map when the scale is reduced. The excessive detail obscures the important points. A highly crenulate line looks disproportionately thick when reduced in scale without smoothing. Text becomes unreadably small. Important lines, depicting say, roads or rivers, may be scarcely visible. Thus the process of reduction in scale involves omitting the less important features; enlarging text and exaggerating important lines; smoothing small crenulations; moving items to reduce local clutter, for example, moving road and river apart so that they do not overlap. It tends to be assumed that these changes are made in order to improve the ease of reading the map.

It is not impossible, however, that some of the rules of thumb used by the cartographer originated with technical constraints that no longer apply. For example, an excessively complex line would be difficult to handle in cutting and pulling masks. Examination of, say, satellite images of a complex river system, suggests that (in raster images at least) fine detail is no barrier to reading a map, provided that the detail is in tune with and reinforces the main pattern. The human eye is adept at cutting through detail, and using it to build up a broader picture. It is also possible that there are valid reasons for generalising a topographic map, such as the need to reduce the amount of text, which are irrelevant for the geology.

Within a computer environment there are different reasons for reducing detail, such as keeping data volume in check, and ensuring that a readable screen display can be prepared directly and therefore rapidly from the data.

5 - THE DESIGN OF THE DATABASE

5.1 General aspects

The terms data and database are used loosely in this report, to refer to interpretations as well as observational records, and to include information held within a GIS. Decisions about the database design depend on views on the effect of technology on the map preparation and production procedures, and on the present capability and future development of the technology. These have been considered in sections 3 and 4.

Preparation of a geological map involves data of many kinds. Some data are selected for scientific, some for cartographic purposes. Different data are appropriate to different scales of map. Some data appear on the face of the map. Some are considered during map preparation, but not shown in the final product. Some data were collected as a result of map preparation and recorded in field notebooks or elsewhere. Some data, such as site investigation reports, were collected for other purposes, and may or may not have been taken into account in preparing the map. At smaller scales, there are other datasets from geophysics and geochemistry, which are collected separately, but may relate to the geological map. There are therefore general issues of database design, which determine the setting in which the map data are held. They must be considered within the general framework of the BGS data architecture. On the other hand, map production must not be held up by delays and conflicting priorities elsewhere in the organisation. Therefore, the data architecture must provide for a self-contained partition of the database for map production, with clearly defined interfaces to the other database components.

To some extent this can be achieved on the current data models (Bain and Giles, 1991). There is a need to extend the data model to include the geometrical data held within the GIS. The POSC (1992) data model may be appropriate, and would also ensure that future requirements for 3-d modelling could be met. Consideration might also be given within the data model to subdividing the GIS into a number of coverages, each dealing with a specific theme. Examples are solid and drift geology, man-made deposits, mining, present-day topography, structural aspects, mineral resources, rockhead elevation, etc. This would have the advantages that thematic maps could be more readily prepared, and that it would be easier to select from the various themes to generate a well-balanced published map. Separate display of themes might help to overcome the feeling that data should be recorded only where there is room to display it on the map. Interrelationships between coverages could be recorded, so that if, say, a sand and gravel deposit lay directly on rockhead, or an outcrop was on the bank of a stream, the relationships could be recorded explicitly and maintained at various levels of generalisation.

5.2 Scale dependent aspects

The GIS is not tied to specific scales, and if important detail for a local area can be portrayed only at a larger scale than 1:10 000, that should not be a barrier to including it. Mine-plans, sketch maps from a field notebook, vertical sections and cross-sections could all be digitised and included in a GIS coverage. For cartographic reasons, only a small part of the information might be included in the published map. The fact that the GIS contains more complete and more up-to-date information gives additional market value, both to the GIS and to thematic maps prepared directly from it.

Data suitable for local, regional and national scales must be clearly distinguished for presentational purposes. Thus, data suitable for 1:10 000 and 1:50 000 maps would be labelled as such. It is neither necessary nor desirable to hold them in separate databases. With scale-dependent data, such as a formation boundary which was recorded on a 1:10 000 base map, and smoothed and adjusted to fit a 1:50 000 base, it is desirable to maintain links between corresponding items at both scales, to ensure that the lines refer to the same attributes, and to ensure that corrections at one scale are carried through to all others. Separate GIS coverages could be held for presentation at local, regional and national scales, all referring to the same database of attributes, one attribute being suitability for display at a particular map scale.

5.3 The structure of the information system

The information related to the digital map making activity could be regarded as a small set of databases connected through well-defined interfaces, but is better developed as part of a single database, linked through metadata and standards, partitioned into independent but related subsets. Many of the point data taken into account in the preparation of the map, can be, and often are, held in a relational database. This may include borehole information, samples and specimens, locations of mines, pits and quarries, and structural measurements such as bedding orientation. They are scale-free and independent of the map. There is a strong argument for ensuring that these data are stored in a relational database, and linked to the line and area data within a GIS. Although individual items could be cross-referenced to specific maps, the database as a whole would be independent of the cartographic activity.

For practical reasons, it may be desirable to distinguish the part of the database containing information which was examined and used by BGS field geologists in the course of arriving at the interpretation depicted on the map, from the record of data contributed to BGS and held by Information Services. The latter was collected for other objectives, and may not have been considered relevant or appropriate in the BGS mapping activity. Although useful in other contexts, it may conflict with, and should be clearly distinguished from, the BGS interpretation. The segments of the database are linked at index level.

6 - DATA CAPTURE AND GENERALISATION

As the scientific database is intended to be central to the DMPI activity, cartographic data should be drawn from the scientific database, and amended as necessary to provide the required maps. Derived maps and revised maps should refer back to the scientific database. Otherwise, cosmetic changes valid for one particular map would carry through to thematic maps and maps at other scales, where they are irrelevant and possibly misleading. While it is clearly necessary to select and amend data for map production, the resulting cartographic datasets should not be seen as part of the database. In the longer run, they might not even be stored after use.

At present, and for the immediate future, the roles of the cartographic and scientific datasets are reversed. The map information is presented to Cartographic Services on paper and is digitised there. Generalisation to smaller scales is carried out manually, and maps at various scales are digitised independently. Graphical characteristics are recorded and carefully checked, and geological attributes added to meet DMPI requirements. The primary objective is an efficient map production line. Use of the data within a GIS for scientific investigation is still on an experimental basis. After the production geological database is in place, the methods currently in use for digital cartography must be adapted for data entry to the scientific database, without disrupting map production.

The manual process of deriving smaller scale maps, described in 2.2, is clearly inefficient, as it involves repeated redrawing and rechecking of the same information by different groups. By analogy with word processing and desk-top publication, it might be expected that computer methods would make it possible to capture the information at an early stage, in a form which would allow a good quality of plotted output, and that thereafter changes could be made by editing and automatic redrawing, rather than by a manual copying process which is liable to introduce new errors. An analogy can be drawn with writing a paper in manuscript several times, having it typed, then retyped to correct errors but introducing new ones, and finally having it set in print, only to be corrected again in galley proof. A word processor allows the scientist to write, correct, amend and rearrange a document as often as required while gradually building on the original text, printing it whenever necessary, and eventually passing the digital copy to a typist or print-setter for final production without further keyboard work, and the inevitable introduction of new errors.

The cartographer, however, has a problem not faced by the typist, namely, the need to generalise. The task of generalising, adjusting and fitting the geology from the 1:10 000 to the 1:50 000 scale base is the cause of major expense and delay. The underlying objective is to simplify the representation of the geology so that the more significant features are not obscured by detail, while maintaining spatial relationships between the geology and the topography. Two reasons are advanced for the latter.

One is that, for example, an outcrop on the south of the road at one scale should not appear on the north of it at another. Within a GIS environment, this is unlikely to be seen as important, as data mapped at many scales and to varying degrees of accuracy are examined together as a routine matter. Even in the field, the user failing to find an indicated outcrop might be prepared to look across the road. The BGS map is explicitly not intended as a substitute for detailed site investigation.

A second reason for maintaining spatial relationships is to ensure that the geometry implied by the intersection of geological lines and the land surface is correct. For example, planar, gently dipping surfaces must intersect contours and streams accurately, if the correct conclusions are to be drawn about the structure. There are a limited number of areas in which this is important, and it may be questioned whether the attention to detail is needed elsewhere. Within the GIS, it is highly desirable to separate the geometry from the base map. One possibility is to store three-dimensional geological lines in the GIS. Lines can be digitised in three dimensions with little extra effort if a suitable digital elevation model is available, retrospectively if the DEM cannot be obtained at the time of initial digitising. This preserves the geometry observed at survey scale.

If the smoothing of lines and surfaces can be specified by an algorithm, the results will be more consistent and predictable, and the task of updating the derived scale from the survey scale will be simplified. Where the map data are digitised separately at two scales, every effort should be made to retain a match between the individual entities. For example, a line segment at one scale should correspond, with the same start and end points, as the same segment after generalisation. This is essential if the original and smoothed lines are to share the same attributes, and to ensure that changes at one scale can be carried through to the derived data.

The 1:50 000 scale maps are in many cases digitised for printing purposes, and could provide a rapid means of building up the database. One danger is that the subsequent updating is likely to be done on the survey scale map, leading inevitably to problems in keeping the two scales in phase. Another difficulty is that the more detailed information is likely eventually to be required on the computer. The initial effort will then have been wasted, because, while it may prove possible to generalise data automatically, there is no prospect of doing the reverse. In areas where the 1:50 000 map is to be digitised without revising the 1:10 000 geology, then only the lines and areas appearing on the 1:50 000 map need be digitised, but ideally they should be digitised at 1:10 000 scale.

In those areas where the original survey did not relate to a 1:10 000 scale base map, the argument remains for digitising the required information from the scale at which subsequent updating will take place. The precise source of the data should of course be recorded in the metadata. If, for some reason, only the published scale is digitised, this should be seen as a temporary measure. The possibility of line segments and other small parts of the data being updated from larger scale maps must then be kept in mind in designing the data structure.

The other aspect of generalisation, which is the removal of areas, lines, points and symbols of secondary importance, can be made easier with computer support. Additional work is required on the digital representation of the stratigraphic table, with links to the map data, to provide a convenient means of selecting and combining stratigraphical units. The digital stratigraphic table is also required to give a consistent view of the spatial distribution of stratigraphical units across map-sheet boundaries, and to define the relationships among them. These are key items in the database as a whole, particularly for generalisation and for developing a seamless database. Much more work is required to bring this to a satisfactory state.

An immediate conclusion is that there are reasons to seek improvements in the method of generalisation, but that areas can be found where little generalisation is required. Adjustments which may be necessary for fitting data to a specific base map at reduced scale should not be reflected back into the scientific database, as this introduces an inaccuracy in the GIS environment, and delays availability of the data.

7 - CONCLUSIONS AND RECOMMENDATIONS

1. Context

1a. Data related to the geological map should be added to, and maintained within, a self-contained segment of the BGS geological database, conforming to the overall data architecture, metadata and standards (see 5.1, 5.3). Delays to map production because of this, however, would not be acceptable (6).

1b. The contents of the geological database must be maintained by geologists, preferably working in multidisciplinary teams. Their local and background knowledge is essential for maintaining consistency in the database and GIS for map production (3.6).

1c. The technology to support the full DMPI strategy is not available now (3.4). It can be expected to be available well within the currency of the data, and short-term expedients are possible in the meantime (3.6).

1d. The digital data, as well as the maps derived from them, should be seen as a marketable product (5.2).

2. Generalisation and data capture

2a. The data should be maintained at local, regional and national levels of generalisation, all held within a single database. The database is primarily for scientific purposes. No separate cartographic database should be developed, and maps at all publication scales should be derived from the scientific database. Maps should be available from the database to meet customer specifications, not just for a few fixed scales, tied to specific topographic base maps (6).

2b. Items, such as line segments, which exist at more than one level of detail, should share the same attributes and end points, so that both can be amended to reflect changes. Where one segment at a derived level includes many segments at survey scale, the many to one relationship should be exact and should be recorded in the database (6).

2c. Data for many scientific purposes, and for use in a GIS, should not be adjusted to match a specific base map. The required cartographic adjustments can be made at the time of map production, but only if they are really required. They should not be reflected back to the scientific database (6).

2d. Every effort should be made to automate the process of smoothing geological lines, areas and surfaces (6).

2e. Consideration should be given to storing some points, lines and areas in three dimensions, to preserve the geometry recorded at survey scale (6).

2f. As far as it is economically feasible, data should be captured at survey scale. Even where no 1:10 000 map is to be produced digitally, the elements to be included at 1:50 000 should preferably be digitised from the 1:10 000 map, generalised, and included in the database at both levels of detail (6).

3. Areas where additional work is needed

3a. Quality assurance procedures must be developed for the database (3.6).

3b. The current data model must be extended to take account of geometrical and GIS aspects, and to provide the framework for cross-relating data held at various levels of generalisation (5.1).

3c. Additional work is needed on the digital representation of the stratigraphical table, on which depends the procedures for selecting and combining map units, and for maintaining consistency between maps of different areas (6).

3d. Version control must be implemented in the database, before continuous revision can be attempted (3.4).

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