Geoscience after IT: Part B

Benefits for geoscience from information technology, and an example from geological mapping of the need for a broad view

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Abstract - Information technology can lead to more efficient, versatile and less costly ways of supplying and using information. The familiar paper journals and books of the geoscience literature are being supplemented, and some supplanted, by electronic versions offering new facilities. Geoscience repositories gain efficiency and flexibility in storage, management, access and presentation of data. Global standards help communication, sharing of facilities, integration of ideas, collaboration and delegation of decisions. An example from geological mapping illustrates how a broad view of computer methods leads, not just to better ways of delivering the same product, but to more fundamental improvements in expressing, sharing and generalizing the geologists' conceptual models. Familiarity with existing systems can blind us to their shortcomings: familiar methods may hide assumptions that are no longer relevant. The example suggests that maps, reports and supporting evidence can be linked by hypertext in a tightly connected model. Targeted distribution of appropriate, up-to-date information can replace the high-cost scattergun approach of conventional publication. This leads to a tentative identification of user needs.

Key Words - Electronic publication, global standards, digital cartography, conceptual model, user requirement.

1. The geoscience literature

Greater efficiency often shows up as reduced cost. Some figures, quoted by a fact-finding mission of the European Commission (Goldfinger, 1996), therefore deserve some thought. They refer to the costs of a banking transaction, such as paying a bill or cashing a check, in the USA. Using a full service branch, a typical cost was \$1.07; using telephone services \$0.54; using Automated Teller Machine full service \$0.27; using Personal Computer banking \$0.015; and using the Internet World Wide Web \$0.01. The authors point out that non-banking organizations, such as supermarket chains, can enter the banking field at low cost through the Web and can cherry-pick desirable customers from the traditional banks.

The costs are spectacularly reduced by removing the need to rely on manual records, the buildings to house them and staff to run them. Customers can control the transactions through an automated process from their own desktops. No routine support is needed from the supplier. Although some customers may pine for the marble halls and the human touch, the inconvenience of going to the bank and lining up for service is avoided. It is not difficult to draw analogies with obtaining geological information through the Internet, as opposed to purchasing traditional publications or visiting libraries or archives. Customers bear the small cost of printing the information on their own desktop printers, but have the opportunity to review it first on screen and benefit from the rapid delivery.

There has been wide discussion of the consequences of information technology for scholarly publication. Useful entry points are the work of Varian (1994) on the future of electronic journals, and the bibliography maintained by Bailey (1996). Odlyzko (1994, 1996) quotes some figures which give an idea of the scale of the costs. The number of publications in earth sciences has for some time been doubling every 8 years. Commercial publishers see a new journal as successful with as few as 300 paid subscriptions. Harvard University spends some $58 million a year on all its libraries. Subscription costs are about one third of total library costs, much of the remaining cost being associated with storing and managing books, serials and catalogs that are duplicated in numerous other libraries. To publish a scientific article in mathematics, Odlyzko estimates the research costs at $20 000, preparing and reviewing the paper another $5 000, and publication costs $4 000. The average number of readers for each article is about 20 (possibly less in geoscience). He suggests that if library users were asked to cover the publication costs by putting $200 into a meter in order to read one article in detail, or $20 to skim the contents, readership might fall. Instead, the costs are almost entirely concealed from the user.

High-energy theoretical physics is one area where new delivery systems are in place. Within a year of Ginsparg (1996) introducing a system, most communication of pre-prints in that field moved from paper to electronic communication. The main benefits are convenience, immediate worldwide availability, and the opportunity to comment and discuss.

Earth Interactions (Hepner et al., 1998), the on-line journal of the American Geophysical Union, the American Meteorological Society and the Association of American Geographers, offered a different rationale. It was launched for scientific rather than economic reasons. “The problem with you publishers is you think you add value. Well, you don’t. You force me to reduce the information in my scientific papers so that they will fit on a flat printed page.” The journal articles are refereed rapidly by e-mail and published on the Web. They offer such features as hyperlinks, animation, virtual reality, links to large datasets in external archives, “live mathematics”, interactive 3-D display, forward references (that is, to later citations of the paper), linked comments and replies, and corrigenda. It is intended to become financially self-supporting and the editors believe that: “the availability of authenticated peer-reviewed scientific articles for future scientists requires an income stream from the users. Furthermore, the marketplace will help to sort out the useful from the chaff.” After an initial subsidized trial period, the editors expect to obtain revenue from author and subscription charges, similar to their print journals. Their preparation costs (as opposed to publication and library costs) are at least as high as for a print journal.

Odlyzko (1996) suggests that the major displacement of conventional publication will occur between 2000 and 2010. When it happens, he expects the change to be abrupt. The kudos of publication in electronic journals must then match that of their printed counterparts. Computer-mediated communication is likely to replace much print publication because of the lower publication and library costs, and because of the improved representation of scientific findings, increased flexibility and ease of use. IT promises quicker access to more appropriate and up-to-date information at lower cost. Alongside the development of new methods that take full advantage of these opportunities, the **backlog** or **legacy** information (existing documents from earlier technology) must remain an integral part of the changing information system. As described in part L, section 3, much printed literature is also available as an electronic copy.

2. Managing a knowledge base

Technical journals are concerned with publishing self-contained articles on a wide range of topics. Commercial and state organizations, such as oil companies or geological surveys, have a different objective - systematically collecting and maintaining geoscience information to support specific activities. This calls for a different approach to IT. The British Geological Survey (BGS) is an example of a medium-sized survey. “The BGS is the UK's foremost supplier of geoscience solutions and is active in areas such as land-use planning, waste disposal, hydrocarbons exploration, civil engineering, minerals extraction, contaminated land, seismic and geohazard evaluation and understanding climate change” (BGS, 1998). A primary concern of BGS is therefore the management of a comprehensive knowledge base for a well-defined geographical and subject area.

BGS currently prepares and publishes a comprehensive set of geoscience maps and reports for the UK and surrounding seas, largely the results of its own surveys. Extensive archives of supporting information are held for consultation, including much information of variable quality from external sources. The archives take many forms, such as data files, field notes, borehole records, logs, charts, photographs, videos, sketches, thin sections, fossil specimens, satellite and aircraft imagery, references to external sources of information, including papers, sources of expert advice, and so on. In addition to the publications, many of the archived records are publicly accessible for inspection on site.

The integrated collection of linked information can be handled more efficiently with IT. Low-cost storage in computer databases makes it possible to archive and index information, including some results of field survey, in a readily accessible form. The indexes support off-site searching of the archive. Compound electronic documents combine text and map information, and link it to images illustrating detail and pointers to additional evidence. Flexible retrieval and presentation can provide output customized for a wide range of users (see J 1.8), as in Fig. 1. A well-structured database with full metadata (H 3) is a basis for publication on demand. Knowledge, however, still remains largely in the heads of experts. They must understand the users’ needs, as well as the content and structure of the information, to interactively control selection and output. As customers are best placed to understand their own requirements, the system should in time offer them direct access.

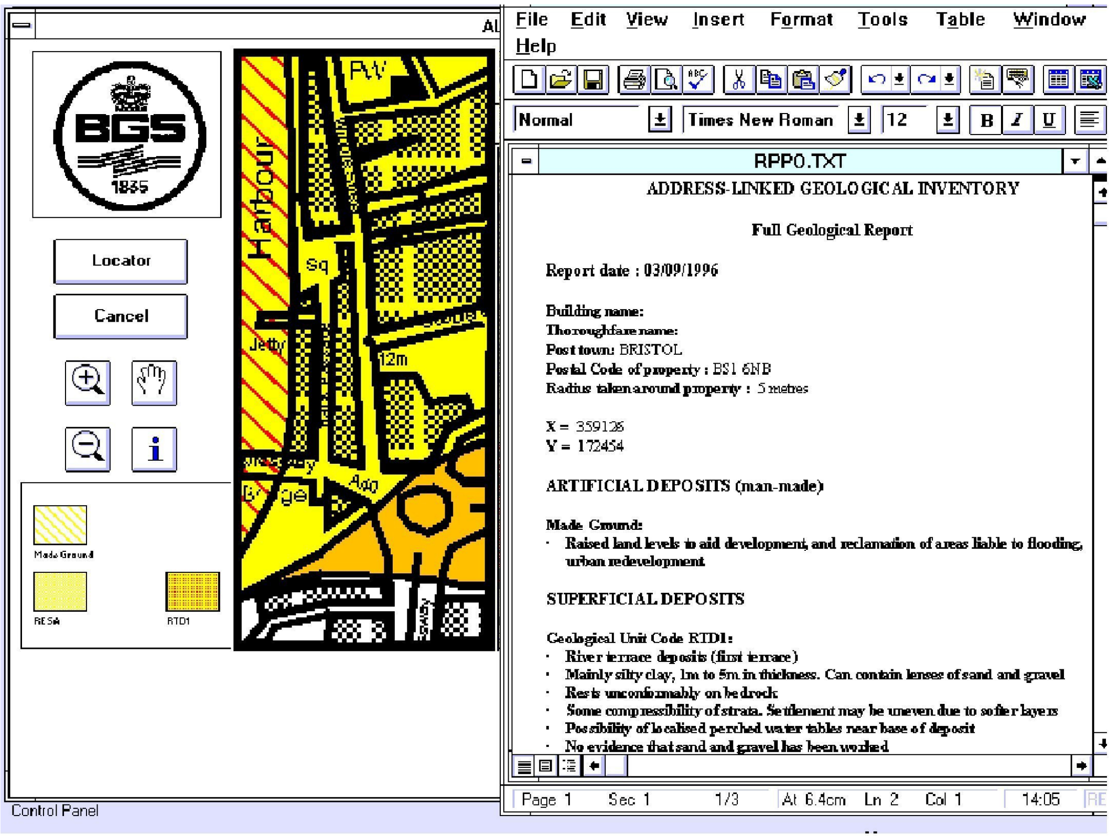


Fig. 1. Printed compound electronic document. Geological information relevant to the potential purchaser of a property is assembled in the BGS Address-Linked Geological Inventory. It is retrieved from various databases and GIS. The material is then edited, and provided to the customer on screen or on paper. A small section of an online report is shown here. British Geological Survey ©NERC. All rights reserved. Base map reproduced by kind permission of Ordnance Survey © Crown Copyright NC/99/225. More at: http://www.bgs.ac.uk/bgs/w3/see/SERVICES.HTM

3. Sharing information

IT should simplify the sharing of information. Yet a computer user may need to learn new techniques for every new application or change to the system. Even within an organization, different groups may tend to work independently, selecting their own computing tools and their own structure and format for storing data. Users may spend more time transforming data than solving geoscience problems. Sharing data between organizations adds further complexity.

A cross section of oil companies addressed this issue by creating the Petrotechnical Open Software Corporation (POSC) as a not-for-profit corporation in 1990. "The standards and open systems environment to be facilitated by POSC represent a maturing of the industry that frees companies from worrying about the integration of their computer systems and lets them concentrate on areas of added value" (POSC, 1993). Although specifically addressing the requirements of the Exploration and Production business, it adopts existing standards where possible, developed further as necessary. It makes decisions through an open process supported by technical arguments, not commercial or special interests. Its work is made available to all, and is relevant to a wide area of geoscience. In addition to POSC, there are many other activities and groups promoting standards in related areas. The short-term costs of standardization cannot always be justified by putative long-term gains, and many standards have been superseded before being widely adopted. Nevertheless, the implementation of standards and better links through the Internet are gradually overcoming the artificial barriers to communication.

The oil industry is establishing shared computer repositories where any of the subscribing companies can access the data. Because they are run by specialists, the repositories provide better and more secure facilities. Because they are collaborative ventures, they reduce duplication of effort in systems development, data collection and storage. Because the data meet agreed standards, they can readily be retrieved and analyzed by the subscribers. The quoted savings are immense.

There are other gains. The standards create a larger single market and so justify higher investments in developing applications software. The consistency of data collected to uniform standards pays dividends in such areas as quantitative analysis, visualization and database management (see parts F, G, H). Standard procedures and content also simplify project planning. Effort can be put into genuinely new investigations rather than reinventing and documenting old ideas. Global standards (L 6) simplify exchange of data across boundaries of discipline, organization and place.

IT means that scientists can themselves prepare documents, such as letters, memorandums and reports. This includes keyboard entry, preparing and inserting diagrams, selecting content and layout by inspection on screen, and reusing earlier work in new contexts (C). A computer template prepared by a graphic designer can ensure a uniform house style. In an academic community, lecture notes, student appraisals, and examples can be accessed more widely and more readily.

Project management is also helped by computer communication. Larger groups can collaborate effectively through rapid dissemination of planning documents, schedules and progress reports. Fewer layers of management are needed, because the information is available to all (M 3.1). Potentially, improved sharing of information offers more freedom of action to individuals, with more intelligence at their fingertips. Many of the benefits of IT are missed, however, if they are sought in too narrow a context, as the following example of geological mapping illustrates.

4. The need for a broad view

An **information system** is a means of recording ideas and sharing information. Geoscientists, for excellent reasons, tend to take their information system for granted, and may consequently give little thought to a basic need for improvement. Modern information technology, appropriately applied, makes the system more effective and efficient. There are many examples of computer applications that make a valuable contribution to part of the geoscience information system. To gain the full benefits, however, it is necessary to look at the system as a whole. Analysis of a system generally starts with a specification of the user requirement, but this can prove hard to tie down. For example, a study that I shall now describe began with a small, familiar part of the system and ended by pointing to some unrecognized requirements.

It was my privilege, many years ago, to study some fine examples of conventional geological maps. The maps are informative, attractive, accurate. The organization which produced them strives to respond to customer demands. My objective was to learn by comparison how the poor daubs then coming off the computer printer might be improved. With modern technology, the aim must be not just an imitation, but a better product. To detect areas of possible improvement, it may help to consider how information was transformed during the process of mapping.

The information available to the geologists as they strode across the landscape, hammers at the ready, is very different to that which reached the final published map on which they signed their names. The geology, in its infinite diversity, has been reduced to areas with uniform colors corresponding to a small set of mappable units. This categorization of **objects**, that is the things or entities of interest in the current context, is a basic part (taxonomy) of the scientific method (J 2.1). Objects with similar attributes are grouped into named **classes** (grass, sheep, rocks), thus enabling one to make general statements about them and codify one's expectations about their properties and behavior. Not only can we talk about them, but in this case, can also show the distribution of classes of geological objects on a map. A dual statement is being made: the rocks designated on the map by a specific color have been identified as belonging to a particular formation; the formation comprises in part the rocks at the locations shown by the appropriate color on the map. We need to consider next, however, how adequately the map reflects the ideas in the minds of the surveyors.

4.1 Extending the language

We generally know more than we are able to express and share with others. Where technology allows us to express ideas in new ways, it can improve our ability to understand and share knowledge. The depiction of geology on the map is subject to cartographic constraints. Thicknesses of lines are chosen to be legible, boundaries are moved apart to be distinct, lines smoothed to avoid visual clutter, and so on. These are secondary to the interpretation in the field, which must surely have involved aspects, such as consideration of three-dimensional processes, which cannot be shown on the map. The geologists can therefore be said to have developed a **conceptual model** - a formalized mental image giving a simplified view of relevant aspects of the real world. The full conceptual model exists only in the minds of the authors, and must be further simplified for representation on the map.

The completed map is a permanent, shareable, public record of the authors' ideas. However, it necessarily imposes **physical constraints** on the representation of the conceptual model. The technical limitations of pen and paper are significant. Lines of even thickness and areas of uniform color are easily drawn, but artistic genius is needed to accurately depict our imperfect view of diversity, ambiguity and uncertainty. The limitations of our skills and tools force us to reduce the complexity of nature to a few mappable units.

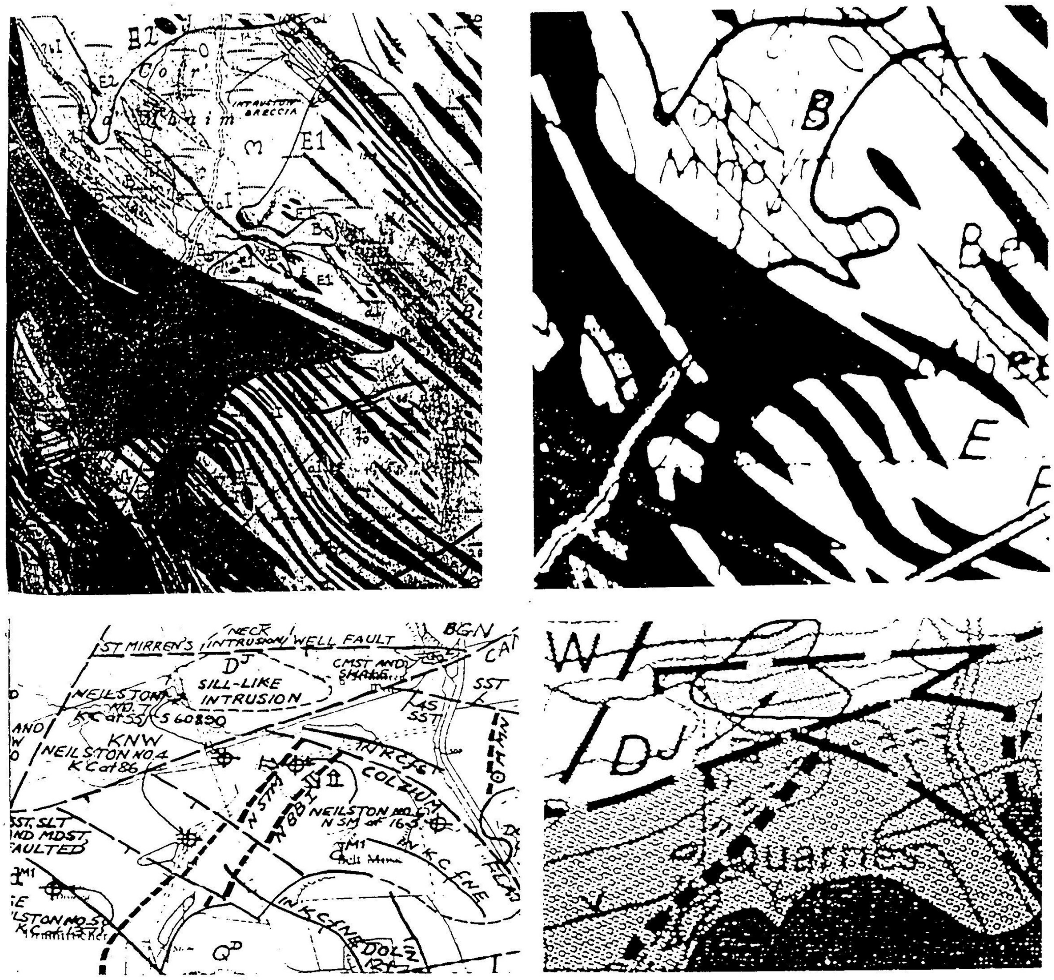
Our mental images of objects are strongly influenced by their representation. Make a careful schematic drawing of a fossil, and it may be easier to remember the drawing than details of the original specimen. Draw firm boundaries on a map and they affect your view of the geology. The rock bodies are three-dimensional, and can be fully understood only in terms of the processes by which they originated and developed through geological time. The map is two-dimensional, supplemented by cross-sections, indications of the geometry such as orientation measurements (strike and dip), intersections with the topography, and possibly contours on a subsurface horizon. We have a view of the vertical relationships along the lines of cross-sections, with a rather hazier view in between. Ink marks on static, two-dimensional paper cannot represent satisfactorily a complex sequence of three-dimensional units and their spatial relationships, far less their origin and structural history.

A map at a uniform scale cannot accommodate the variation of information density on the ground. For example, the geological information for a map sheet may be limited to a few good coastal exposures with little solid geology exposed inland. A map which fully reflected this would have a thin zone of illegible clutter relieving the blank monotony of the rest of the sheet. If the main objective of surveyors in the field is to produce a map, therefore, they may give limited attention to the detail of good exposures, knowing that there is no room to show the results on the map. Again, the physical limitations of the medium influence the conceptual model, and thus the investigational procedure.

The ink marks on the map depict formalized symbols, such as stratigraphic codes, which do not imitate the appearance of the original objects, and patterns, such as formation boundaries, which are miniaturized versions of patterns on the ground, or, rather, in the geologists' conceptual model. The process of moving from observation in the field to representation on a map involves **generalization**, that is, showing the salient features, possibly in a simplified form, and removing unnecessary detail (see Buttenfield and McMaster, 1991). When a smaller-scale map is produced for the same area, the original map is again generalized. The latter process can be readily studied with the aid of an enlarging photocopier. Fig. 2 indicates differences between features drawn at the scale of the original survey at 1:10 000 and as shown on the published map at 1:50 000. This may also throw light on the generalization during field mapping and the aspects of the real world that are conserved during that process.

The dike swarms or the coal seams in Fig. 2 are obviously exaggerated in thickness for legibility, and thus are not a true scaled reduction. Their exact numbers (actual or observed) are not shown, although variations in numbers may be reflected in some way, and it is possible that the spacing or relative spacing is also indicated. Their orientation is probably represented, and in a few cases their continuity and even variation in thickness, but not their length. An intricate pattern has been carefully displayed. Its exact meaning, however, is not immediately obvious.

Generalization resembles statistical **sampling** (F 3), in which a small number of items are selected to represent a larger whole. Generalization also reduces a large amount of information to a more manageable quantity that throws light on the overall situation. Here, the requirement is to be able to draw conclusions about the geology from the map. Statisticians insist that in order to arrive at statistically valid conclusions an appropriate sampling scheme must be followed and explained to the user (see Davis, 1973). The map in some ways resembles a sample, but what was the sampling procedure? Take, for example, a symbol showing the orientation of bedding in Fig. 2. It may be representative of the orientation within either a particular area, or within an outcrop, or a horizon, or a pattern of folding. It may be a random sample, a typical value, a particularly significant value, or selected haphazardly. It may refer to an area the size of a field notebook, or it may not. Certainly it is not a measurement from which one could confidently draw quantitative conclusions. Lines on the map show formation boundaries and the positions of faults. But it is seldom clear where the geologists observed their presence, or inferred it from landscape features, and where they were required simply in order to complete the geologists' reconstruction. Despite the large scientific investment which the map represents, its content needs cautious interpretation. Nevertheless, despite the absence of any recognizable sampling scheme, it is possible to learn much about the geology from a geological map.



(A) (B)

Fig. 2. Map generalization . A: fragments of maps (on the left) at survey scale of 1:10 000. B: maps for the same areas (on the right) generalized for publication at 1:50 000, enlarged here to the same scale for comparison. The amount of information is progressively reduced during observation, recording, abstracting and reading. This generalization process can be observed in action during scale reduction of a map. In the upper example (BGS Sheet 44W, Eastern Mull) geometrical properties of the dike swarm include average orientation, lenticularity, variation in density, dimensions and spacing. Some of these at least were affected by generalization. In the lower example of scale change (BGS Sheet 31W, Airdrie) minor faults were removed, coals seams selected, and the orientation of the coal seam adjusted to remove the effect of minor faulting. Presumably similar faults and coal seams exist that were too small to show at survey scale. British Geological Survey ©NERC. All rights reserved. Base maps reproduced by kind permission of Ordnance Survey © Crown Copyright NC/99/225. More examples in: BGS Technical Report WO/94/3

Perhaps the map is not an attempt at a precise geometrical depiction, but rather is telling a story which geologists have been trained to understand. It is not difficult to imagine geologists in the field developing their own conceptual model, and using a pre-existing map to check it against earlier observations and align their ideas with those of their predecessors. Geologists who could themselves have done the earlier work, know that particular marks are made under specific circumstances. By an intuitive process they could put themselves in the authors' shoes, project themselves into the authors' minds and visualize the conceptual model that lay behind the depiction on the map.

Intuition, that is apprehending something without any intervening reasoning process, is vital to science. You could not have read this far without it. Human beings are skilled in intuition, computers are not. But that is not the end of the story. What geologists show on a map is an inextricable mixture of hard fact and interpretation. With computer support, the language of the map could be extended so that aspects of the geometry, for example, could be rigorously sampled in the field, and the three-dimensional structure could be recorded and tested for consistency. But this is pointless if the rigor is lost in the final portrayal. These issues are explored in more detail in part G. Meantime, the point is that there is a hidden requirement for users to free their ideas from the constraints of scale, dimensionality and cartographic representation imposed by the paper map; to develop multiple conceptual models more freely; and to express them more fully and rigorously in the shareable record. Modern information technology can extend the means of expression and communication, but must be used with caution and awareness of the likely consequences.

4.2 Connectivity and integration

Devising a solution to the narrow user requirement just outlined could have damaging and dangerous side-effects, like taking aspirin for the pain of a stomach ulcer. The geological map is a small part of recorded geoscience information. Changes to one part can have knock-on effects elsewhere. For example, to obtain an account of the geology, even of a mapped area, the user is likely to turn to a written report. Both map and report are expected to share the same conceptual model, and refer to the same objects and object classes (H 5). One cannot be modified without affecting the other.

The map and the report are separate documents, possibly prepared at different times. Small maps are likely to be included in the report, as well as diagrams providing graphical information that might more naturally be part of the map. Many maps, on the other hand, contain long text descriptions that could fit equally well into a report. There is thus no sharp distinction of content between map and text material. They are separated because the two widely different formats could not readily be printed as a single document. Cross-reference from report to map is by the tedious mechanism of grid coordinates, and references from map to report are likely to be confined to a brief bibliography referring to the map sheet as a whole. For obvious reasons, no conventional document contains references to items published later than itself. The connections between documents could clearly be improved.

To grasp the full significance of a geological interpretation, the user may have to visit the area and retrace the investigation. After all, in any science there should be the option of checking conclusions by reexamining the evidence. Even where field notes can be examined, however, there is little guidance to the precise reasoning behind the conclusions shown on the map or recorded in the report. Although providing an invaluable context, published maps and reports may lack the specific information which is required for a detailed study, and give little indication of where that detail can be found. Think, for example, of the civil engineer looking for records to assess the foundations of a large building. If borehole records exist, they may have been used as supporting evidence in making the map, but neither explicitly cited nor evaluated. Information technology should be able to offer better solutions to supporting, retracing and sharing the investigators' ideas.

A surprisingly large part of most scientific papers is a reworking of earlier published material, recast to explain or support the author's viewpoint, but involving a degree of repetition that might be unnecessary if the original sources were more accessible. A somewhat broader solution would therefore take advantage of the greater connectivity that GIS and hypermedia (E 4) can offer, and thus the ability to integrate information from many sources. Material from the map, the report, diagrams, the database, computer applications, video and still photography, external comments, references to previous work and access to expert opinion could all be incorporated in a fully connected hyperdocument, using simple and familiar tools for access from the desktop. It would be unwise, however, to embark on such a project without considering its long-term development and the means of disseminating the information.

4.3 Deliver and print

The economics of the offset-lithography printing process affect both text publications and maps. Preparing the reproduction material is complex and requires scarce skills, possibly resulting in long delays. The costs of setting up a print run are comparatively high. Subsequently, each additional copy within the print run costs little more than the paper and ink. Some thousands of high-quality copies may therefore be printed in a batch. Identical copies are bound, dispatched, documented and stored throughout the world, in public, private and personal libraries. Interlibrary exchange schemes are organized to mail copies if they are not available locally. All this is to reach the handful of users who may be interested. The printed product is a permanent snapshot of the author's ideas at a particular time. Revision is costly and therefore infrequent. The information is likely in consequence to be out of date.

The geological map is complex and to the expert eye is full of information. But there is tension between the scientists' desire to record all their insights and the demands of the market place. Information to attract as many readers as possible may be included to justify the wide circulation, at the expense of clutter and complexity.

The end-user of the map may be an expert in another field with limited training in geology. Aspects of the geology may be important to the land-use planner zoning residential areas, the construction engineer planning a new highway route, the insurance agent concerned with geological risk to housing, the lawyer with a claim for ground-water pollution, the teacher explaining landforms, the company director financing mining development. All have their own requirements for specific geological information, which may or may not be available from the general map.

They need a simple presentation of the information including relevant detail but free of clutter. One approach to meeting such needs is to prepare many thematic maps for the same area, meeting a range of potential requirements. A result, however, is greatly increased publication costs. A solution is to print on demand extracts selected from a **geographic information system** (**GIS**), a computer-based system for handling map information (see Bonham-Carter, 1994). Parallel arguments could be made about text reports.

Because many maps are published to a standard set of scales, the geological map can be overlain on a light table to correlate it spatially with other maps showing for example topography, soils, or land use. Unfortunately, it may be difficult to find the maps, their sheet boundaries may not match, there may be many small discrepancies due to different series being revised at different times, and the map underneath is never easy to read. GIS offers a solution in principle, seldom achieved at present because of the lack of availability of digital maps.

The geological map has been taken as an example, but is a small part of the recorded information on geoscience. Text publications share many of the same deficiencies. The language in which the reports are expressed forces a particular pattern of thought, such as categorizing the diversity of nature in predetermined molds, which may not always be the best option. A report of any kind is expensive and laborious to produce. It therefore tends to present a rather tidy and self-contained account of its topic, omitting unsuccessful lines of investigation and details that may be informative but do not contribute to the main theme.

None of this implies incompetence, but rather that ways of working are influenced, perhaps controlled, by the available tools. Around these tools a major industry of intermediaries, such as publishers, printers, booksellers and librarians, has grown and cannot change overnight. Geoscientists are the beneficiaries of a huge legacy of information, recorded and greatly influenced by the technology of the time. Now, technology is moving on and the information industry is regrouping. It is feasible to hold information of many types under the control of the originators or their proxies, and to select and deliver it electronically worldwide when required, for local editing and printing of both images and text under the control of the user. In the words of the Xerox Corporation, *print-and-deliver* is giving way to *deliver-and-print*.

5. Towards a user requirement

There are incompatibilities and conflicts between the old and the new. Ways of thinking and ways of working that have been deeply ingrained over generations, may no longer be appropriate. We must consider not just the representation of existing data, but also the more effective representation of reality. We must bear in mind that new methods may bring risks of misunderstanding, which hidden features of conventional systems were designed to circumvent. The benefits we can expect from IT, and our objectives in using it, can be crystallized as a user requirement, a concept described in more detail in K 3. An apparently narrow user requirement, as in B 4.1, must be placed within its wider context. To the frustration of IT support staff, the user requirement tends to evolve as new methods are explored, and may be clear only after the work is complete.

In general terms, the user requirement identified so far is to share information more effectively and efficiently by:

- more complete and rigorous representation of conceptual models and their supporting evidence
- reduction of repetition by better links
- direct worldwide access to information that meets global standards
- more appropriate control of information by originators and users, with less reliance on intermediaries
- easier access to more rigorous analytical methods and visualization techniques
- a move from fixed paper documents, to a shared, dynamic knowledge base, from which users can selectively retrieve and print information

At this stage, I hope you agree at least on the need for geoscientists to arrive at an informed view of how we can best work with new information technology: informed by experience of the various tools that IT places at our disposal (parts C to H), and by insight into how we think and work within the geoscience information system (parts I to M).

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