24 Total Geological History: a web-based modelling approach to the anticipation, observation and understanding of site conditions

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24.1 The Context

The concern is with the effective use of computers to assist site investigation where subsurface conditions must be predicted. It deals with qualitative rather than quantitative aspects of investigation, utilising the numerous case histories which suggest that failure to anticipate leads to failure to observe and understand. Following Fookes et al. (2000) it is argued that the geological model is the key to predicting subsurface conditions.

Technology offers investigators help in developing the model for their site. However, the approach advocated here is reflective rather than deterministic. This leads towards ideas contained in the knowledge management literature rather than expert systems. It also raises communication issues.

The result is a web-based approach designed to help users identify the geological and geomorphological processes that have produced the present conditions. The identification of these processes generate a list of subsurface conditions that are most likely to exist and which the subsequent detailed investigation should seek to locate.

The aim is to guide the cross-disciplinary research agenda for geological modelling and computer science. The issues raised and the language used are specific to workers in these fields. In this context, ‘technology’ refers to information and communications technology; ‘web-based’ is used as an abbreviation for those technologies which are generally associated with the world wide web, even though they may be used on a stand-alone computer.

24.2 Total geological history

The mechanics used by geotechnical engineers are largely based on the concept of an isotropic homogeneous continuum. In practice geological materials are often irregularly arranged and highly variable. This variability gives rise to uncertainty and presents a serious risk to building and civil engineering construction.

Ground conditions at any site are a product of its total geological and geomorphological history (Fookes 1997). To understand this history, it is necessary to develop a site specific geological model based on consideration of the regional and local geological and geomorphological conditions (Fookes et al., 2001). Development of the model begins during the initial desk study. How far the model can be developed at this stage depends on what published information and local knowledge is available. Even when detailed maps are available, interpretation is dependent on a fundamental understanding of the regional and local geology. The model may be refined throughout the investigation even though much of the geology will be known in the early stages of the investigation. As Figure 1 indicates, the main geotechnical data acquisition will take place in the later phases of the investigation and should be informed by the geological model.

24.3 Initial models

The model approach uses three sets of initial models first presented by Fookes et al. (2000):

- **Ten global scale tectonic models**. These cover large areas (typically many tens to hundreds of kilometres) and set the scene for anticipating the regional structure and rocks of the area.
- **Seventeen local (or site scale) geological models** (typically covering kilometres to tens of kilometres across). These relate to the rock forming environments and to tectonic and diagenetic changes
- **Eight local (or site scale) geomorphological models.** These relate to current and recent past climates (i.e. Tertiary and Quaternary Ages).

24.4 Case history: Emerson Green

A simple example illustrates both the importance of understanding the geology and the roll of the initial models. A 50 m section of cut slope for the A4174 Avon Ring Road at Emerson Green, north-east of Bristol (UK) failed in February 1999, about 8 years after construction (Figure 2).

The old UK 6-inches to 1-mile geological survey map ST67NE (i.e. 1:10,560 scale) shows a complex pattern of outcrops in this area from the Upper Coal Measures (near the top of the Carboniferous). These were extensively folded and faulted during the Variscan (Armorican) tectonic disturbances. The ground above the slip plane is ~~a~~ in highly weathered silty MUDSTONE dipping at 20° to the east, parallel to the slip surface shown in Figure 2. Below the slip plane and outcropping to the north is SANDSTONE. Both rock types are described on the site investigation report dated September 1989. The mudstone is described as “very stiff brown silty CLAY with many sub-angular mudstone lithorelicts to coarse gravel size”. The angle of friction for the more weathered material above was said to be 22° with a cohesion intercept of 34 kPa. The cohesion intercept suggests this was a peak strength rather than a critical state strength, which did not fit well with the highly fractured nature of the mudstone. The designers clearly relied on this because the slopes were constructed at 26°. The original site investigation report provided no indication that a model of the geology had informed the geotechnical data acquisition.

24.4.1 Developing a site specific model for Emerson Green

The approach to developing a site specific model for Emerson Green began with the published set of initial geological and geomorphological models (see Section 2.1). After consideration of all the models, one or more of these models will be identified to represent the particular site.

The geological model for open folds and joints shown in Figure 3 (from Fookes et al., 2001, Figure 3.12) anticipates the failure mechanism where weak mudstone overlies sandstone with a fold axis nearly parallel to the road. The intraformational shear (bed over bed slip) has reduced the shear strength below the peak value and possibly as low as its residual strength. There is a clearly defined shear surface in the mudstone just above the sandstone. Tests on clay from this band showed the residual angle of friction to be about 17°. The slip did not happen at the time the road was constructed because the excavation reduced the total stress and hence set up negative pore water pressure. This negative pore water pressure dissipated over time, leading to failure several years after construction.

24.5 Geological Environment Matrix (GEM)

The conceptual precursor for the Total Geological History model was the Geological Environment Matrix (GEM) presented by Fookes (1997). Understanding GEM helps towards understanding the initial models. Both GEM and the initial models are based on the premise that the geology of a particular location is the sum of its history including:

- Formation and alteration, including faulting and folding
- Modification by geological activities including igneous intrusion and metamorphism
- Surface and near surface influences including marine and glacial processes.

GEM presents this as a matrix, One axis is divided into four principal rock-forming environments; each is subdivided into sub-environments. The other axis is divided into five rock modifying environments, each again subdivided. The two axes are presented as columns in Table 1 for reasons of space.

Fookes suggests further subdivisions to create sub-sub-environments (e.g. Bb1, reverse faults, Bb2 normal faults). For each sub-sub-environment there should be a table detailing both the geological and the engineering features plus associated key words, appropriate site investigation procedures and cross-references to other sub-sub-environments which may be associated with this one.

These tables were seen as an *aide mémoire* to assist experienced geologists develop site-specific models of the total geology. The risk that these tables may become too detailed and cumbersome is acknowledged. The geological environment matrix is important because it led to the development of the initial Total geology models.

The initial models provide a better way to communicate the information contained in GEM. Figure 3 illustrates one of the initial geological models, the full set can be found at http://www.uwe.ac.uk/geocal/totalgeolgy. The models work because they represent real systems in their entirety; engineers and geologists can identify with them from direct experience.

24.5.1 Digital data

Fookes (1997, First Glossop Lecture, page 398) suggested that GEM was likely to benefit from computerisation and mentioned database software and keyword searches. When the Total Geology models were created, it was clear that they were suited to presentation in a computer based system. The computerised version discussed here uses world web technologies: DHTML and JavaScript. Currently it does not depend on web server technologies (e.g. CGI scripts) and can be run from a CD on a standalone computer. The reasons for this approach are presented below. What follows applies specifically to the process of developing a site specific geological model.

Attention is drawn to the words of Evert Hoek (1999, Second Glossop Lecture): "The three-dimensional block drawings and sections included in the written version of the first Glossop Lecture, prepared by Mr G Pettifer, are miniature masterpieces of geological art. If only such drawings were available on all construction sites. … Help for artistically challenged geologists is on the way in the form of computer generated three-dimensional models."

24.5.2 Knowledge based systems

Standard texts on Artificial Intelligence (AI) contain examples of games such as chess and tic-tac-toe, but not football. Klein and Methlie (1995) describe chess and tic-tac-toe as *formal systems*. They are characterised by three essential features:

- They are token manipulation games
- They are digital in the sense that a token is either in a square or not
- There are a finite number of legal moves.

Such games can be solved by effective search procedures because the problem is well structured and the domain knowledge is limited and easily available. These procedures do not work for unstructured real world problems, such as the design of a bridge, *where there is no single correct answer*.

Predicting subsurface conditions is a comparatively well structured problem. The site defines the problem boundaries and the domain knowledge of engineering geology changes relatively slowly. Several systems have been developed (e.g. Toll, 1995). They are characterised by the following limitations:

- The output is deterministic (e.g. number and location of exploration points, methods of sampling, and types of in situ tests; Oliphant et al., 1966)
- The input required to describe the site exceeds the generated output
- Interpretation of subsurface conditions is characterised by straight lines between data points
- The total domain knowledge contained within each system is small compared with the domain knowledge in a single text book.

The deterministic nature of such systems gives rise to the danger that users may relinquish responsibility to the machine and the output will not be rigorously checked. However, this danger should be balanced against the need to process the ever increasing volume of information available.

24.5.3 Data base systems

Knowledge based systems sit at one end of a technological spectrum, the other end being a database containing all available relevant information. There are two problems with the database: (a) knowing what you are looking for and (b) knowing how to find it.

Figure 4 uses a 2 x 2 matrix to divided questions into four types. It is presented here to highlight the problem of knowing what you are looking for. The top row contains those questions we are aware of while the bottom row relates to questions we have not thought about. To use a database you must first think of a question. Expert systems attempt to prompt users to ask questions they may not have thought about. Of course, whether you think of the question or not, you may already know the answer.

24.6 A middle course

Davison (1998) explored a middle course between knowledge-based systems and databases. Such systems invite the user to provide project specific data, which is used to test the relevance of information held by the system. There are three outcomes to such a test:

- some information is clearly irrelevant and should not be displayed
- some information is clearly relevant and should be displayed
- insufficient data has been supplied to determine the relevance.

In the third case it may be appropriate to provide additional guidance to help the user determine the relevance.

The Web provides a convenient vehicle for such a system. The key elements are:

- A well structured information system
- A collapsible menu which exposes details as they are required
- Form elements to enable users to enter site specific information
- Rules which determine what to expose and what to hide.

The Geological Environment Matrix provided the initial information structure in this case. The ~~total geology~~Total Geology initial geological and geomorphological models provide the user interface.

24.6.1 Codifying knowledge

Figure 5 highlights knowledge states that may be taken for granted when seeking to develop computer systems to support site investigation. Fookes (1997) takes the total geological model approach to the third, externalised expression, stage. GEM applies a standardised scheme to this, so beginning the process of codification. The ~~total geology~~Total Geology initial models presented by Fookes et al. (2000) take codification one stage further. The computerised version described here is a first attempt at digital representation; future evolution and refinement is expected.

24.6.2 The role of case histories

The knowledge management literature has things to say about the role of story telling. Shum (2000) argues that the significance of stories, in a business context, lies not in their ability to preserve ‘true accounts’ of what happened in the past, but in their use as a vehicle by which an organisation preserves its collective memory and reasons about its current situation. We use case histories to preserve our collective memory and demonstrate the relevance of rules and procedure that have been distilled from experience. Fookes et al. (2000) provided 31 case histories linked to their models. These case histories are included in the computerised version and cross-referenced to the models.

24.6.3 Navigation

Navigation is important because the models are cross-referenced and linked to case studies. As the Geological Environment Matrix suggests, keywords will become increasingly important as the system develops. Web technology has something to offer in terms of hypertext links and text searches, but the argument is not one sided. The thumb is a remarkably useful device for flicking backwards and forwards between pages; and it is relatively easy to remove the staples from a document and view several pages at once. Few have the means to use several computer screens at once.

24.6.4 Communication issues

Communication issues may make or break a World Wide Web application. First consider screen resolution because there is a wish to display at least three components simultaneously (Figure 6). The first component is an annotated diagram. Simple conversion to one of the web graphic file formats makes the annotations unreadable (to overcome this, the annotations were removed from the diagrams and superimposed using the positioning properties in HTML4). The second component is the commentary, which is associated with each model, and the third component is a navigational aid. Although some browsers have a 'full screen' option, normally about 16% of the screen area is devoted to browser controls. White space is necessary to enhance readability but the way it is measured varies. The reader is invited to estimate the proportion of the screen layout in Figure 6 devoted to prime content. The design involves a judgement about what constitutes prime content. For comparison, Nielsen (2000) presents a number of typical commercial web pages in which the prime content occupies between 14 % and 20% of the display.

Writing for the World Wide Web requires a different style from that used for academic papers. Reading is 25% slower from a computer screen (Nielsen, 2000) and few enjoy reading long passages on-line. The result is a different reading style. Readers scan information and tend to skip text that extends beyond a single screen. Nielsen and others recommend the inverse pyramid style of writing (conclusion first), simple paragraph and sentence styles, sub-heading and bullet points where appropriate.

Despite such difficulties, an estimated 20 million people in the UK spend on average of 5hr 10min per month surfing the web (http://209.249.142.57/uk/web/NRpublicreports.usagemonthly). Few of these 20 million are interested in the predictions of subsurface conditions. However, the Web offers a means or reaching a wider audience. Where the Web is used for technical material, a common motive is the transfer of printing costs from provider to recipient; this is especially true of product support information. In other cases the Web is used to reduce delivery times and enable frequent updates.

24.7 A solution

The objectives of a digitally-based Total Geological History are:

1. to increase awareness of the need for a cognitive model of the total geological environment before the detailed investigation begins,
2. to provide a framework to help site investigation develop the model for a particular site.

These objectives dictate three target groups:

1. students
2. practising site investigation practitioners
3. project sponsors and managers

The primary design objectives are to:

1. explain the significance of the total geological environment
2. assist users identify which sub-environments apply to a particular site
3. help users develop a list of features anticipated by the sub-environments
4. clarify the significance of the anticipated features using case histories
5. provide appropriate background information
6. tread a middle course between prescriptive guidance (as some knowledge-based systems) and totally open information system
7. provide maximum accessibility

24.7.1 Interface design

The first objective suggests a World Wide Web approach. Two other factors support this decision. The first factor is the reduction in the interface development effort; this frequently exceeds 50% of the workload for traditional software. The second factor, also related to the user interface, is more important but less immediately obvious. It relates to the sixth design objective.

In the past, most software was *procedural* and characterised by flow charts. A flow chart has a start point, one or more end points and a number of decision points which determine which path the user takes. Web browsers are *event driven*. The software waits passively for the user to press a key or click a mouse button, each event triggers a related action. The freedom that is provided by the event driven web browser interface counterbalances the system designers' natural tendency to produce a prescriptive system.

Figure 7 shows two commercial web-based information systems targeted at professional software developers. These are noticeably different to the on-line help associated with software aimed at a wider market. These examples have been presented here to draw attention to some aspects of the ‘tTotal gGeology’ screen layout shown in Figure 6.

The first common feature is a hierarchical menu that communicates the structure of the knowledge base and aids browsing. In all three cases, the menu collapses to show only the section (chapter) heading and opens to reveal the sub sections. The structure is important because it help users to discover answers to questions they had not thought to ask (Figure 5: unasked question). Associated with the menu (contents) is an index and search facility. An initial search through the commentaries in the total geology models found 1004 words. An initial cull reduced this to 703 keywords; the current search facility is based on these words. Work continues to refine this list and provide links to the case histories.

The second common feature in Figure 7 is a plain uncluttered appearance. This contrasts with the common use of textured backgrounds and bold colours to appeal to mass audiences. The ‘tTotal gTeology’ use of a textured background is under review.

24.7.2 Content

The prototype version of the computer-based system was a simple restructuring of Fookes et al. (2000). The current version separates the models (part 1) from the background information (part 2). A separate introduction attempts to explain the significance of the total geological environment.

The models are divided into three groups with the global tectonic models providing the setting for the other two groups of models. The site scale geomorphological and geological models have annotations and key descriptions to form the basis for the check lists, since it is these models which provide the initial basic conceptual picture of the local potential conditions.

Figure 8 shows some of the check boxes used to select particular models and generate the output. At this stage of development, the output is simply the commentary associated with the selected models.

Figure 9 shows the case history output for the two models selected in Figure 8. While Figure 8 uses a screen shot to show graphical elements, Figure 9 was produced by copying and pasting text; a standard simple procedure that enables users to reformat the output to suit their purpose.

24.8 Summary

1. Site investigation needs to develop a site-specific conceptual model of the ground before the detailed investigation begins. The model helps anticipates the ground conditions and therefore reduces the risk of investigators failing to observe and understand.
2. The geological environment matrix provides a framework for building such a conceptual model. The sub-environments with this matrix have been developed

into a set of global and site scale models, in providing the starting point for a site-specific model.

3. The approach advocated here is reflective rather than deterministic. It also seeks to prompt the user to challenge assumptions and provides a check list to ensure all realistic possibilities are considered.
4. World Wide Web technologies offer a middle course between ‘procedural’ prescriptive systems on the one hand and open ‘databases’ on the other. Such a middle course raises questions which may have been overlooked; at the same time it limits the danger of excessive reliance on the computer software.
5. The ‘tTotal gTeology’ web-site is being developed with many presentational factors in mind. A paper-based approach has much to commend it, compared with computer screens, and printout facilities are being designed into the system.
6. The current system continues to be developed to add new features (e.g. index and search facilities) and to restructure the existing content to improve navigation and make it easier to read on a computer screen.

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See also: Ten Mistakes in Web Design http://www.useit.com/alertbox/9605.html

See also: How Users Read on the Web http://www.useit.com/alertbox/9710a.html

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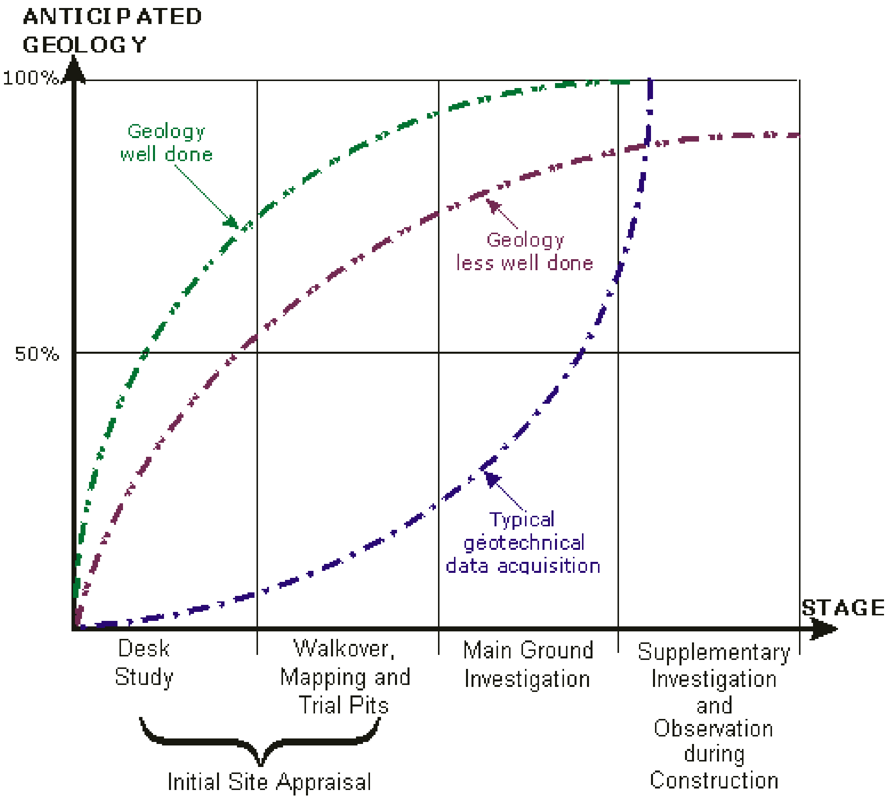


Figure 1. Site investigation stages, after Fookes et al. (2001).

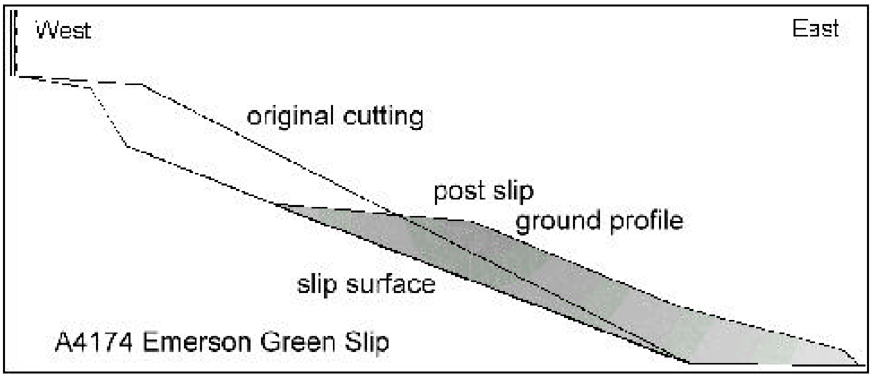


Figure 2. The Emerson Green slip.

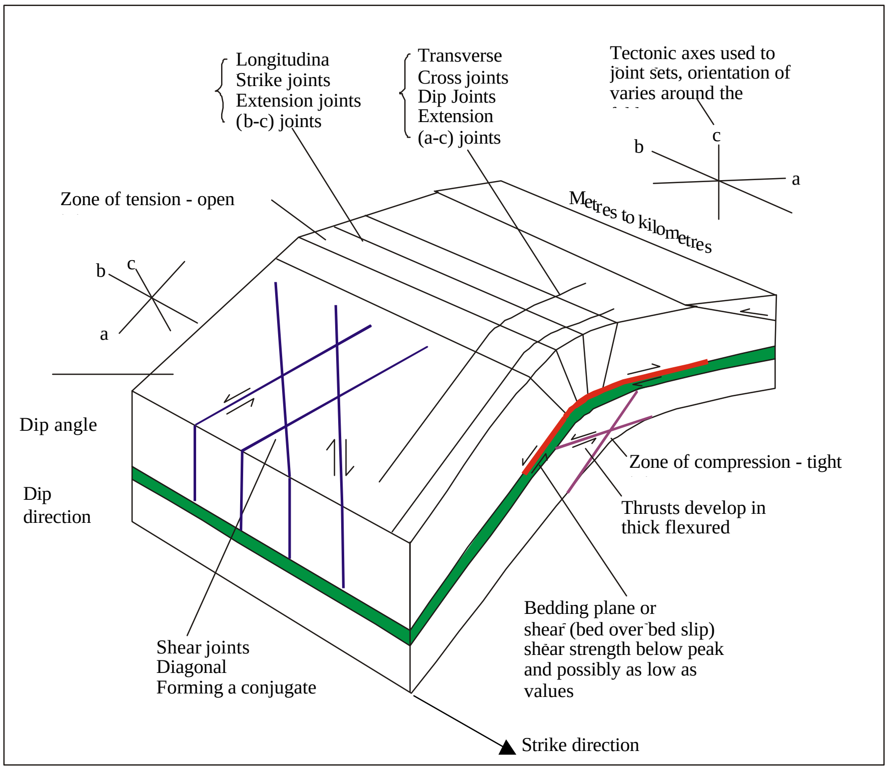


Figure 3: Geological model - structural - open folds and joints (after Fookes et al., 2001, figure 3.12).

Table 1 The geological environment matrix

Rock forming Environments

Principal environment	Main sub-environment	Key
Continental	Slopes	1.1
	Glacial	1.2
	Proglacial	1.3
	Periglacial	1.4
	Drylands	1.5
	Wetlands	1.6
	Lacustrine	1.7
	Fluvial	1.8
	Esturine	1.9
	Costal	1.10
Marine	Lagoonal	2.1
	Reef	2.2
	Shelf	2.3
	Cont. slope	2.4
	Abyssal	2.5
Igneous	Plutonic	3.1
	Intrusive	3.2
	Extrusive	3.3
	Pyroclastic	3.4
	Hydrothermal	3.5
Metamor- ~~phic~~ phic	Temperature	4.1
	Pressure	4.2
	Regional	4.3
	Auto	4.4

Rock modifying environments

Principal environment	Main sub-environment	Key
Burial	Compaction	Aa
	Diagenesis	Ab
	Metamorphism	Ac
Techtonic	Folding	Ba
	Faulting / shearing	Bb
	Metamorphism	Bc
Volcanic	Hydrothermal	Ca
	Baking	Cb
Weathering	Periglacial	Da
	Temperate	Db
	Dry tropical	Dc
	Wet tropical	Dd
Processes	Back wearing	Ea
	Down wearing	Eb
	Solution	Ec
	Subsidence	Ed
	Sea level change	Ee
	Earthquake	Ef

	..what we know	..what we don't know
We know…	**Answered questions:** We know that we know *e.g. desk study information*	**Unanswered questions:** We know that we don't know but we have ways to find out *e.g. results of planned investigation*
We don't know	**Unquestioned answers:** We don't know that we know *e.g. unquestioned assumptions*	**Unquestioned questions:** We don't know that we don't know *e.g. unimagined voids*

Figure 4. Knowing what we know

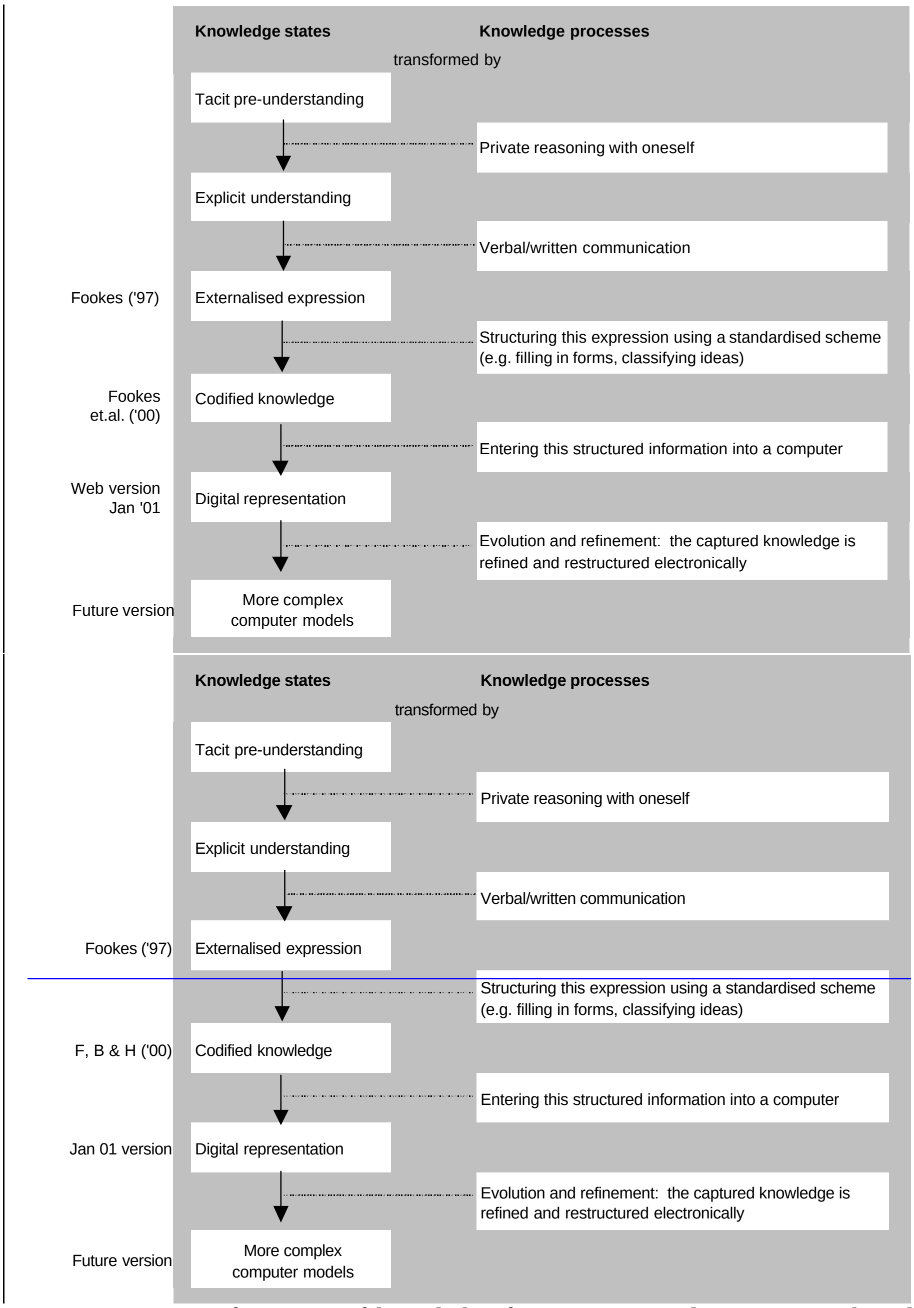


Figure 5. Transformation of knowledge from tacit to explicit computer-based knowledge (after Stahl, 1993)

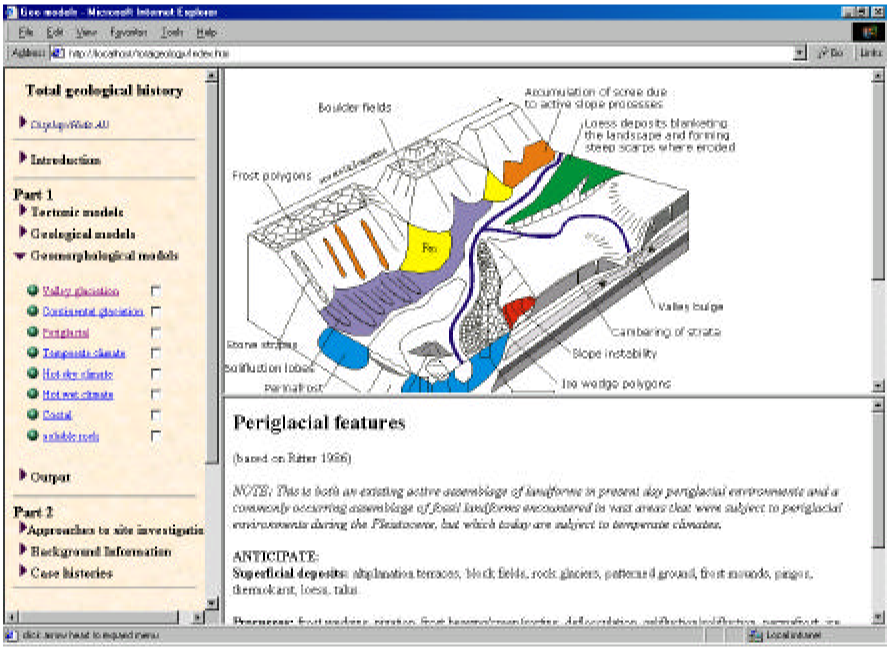
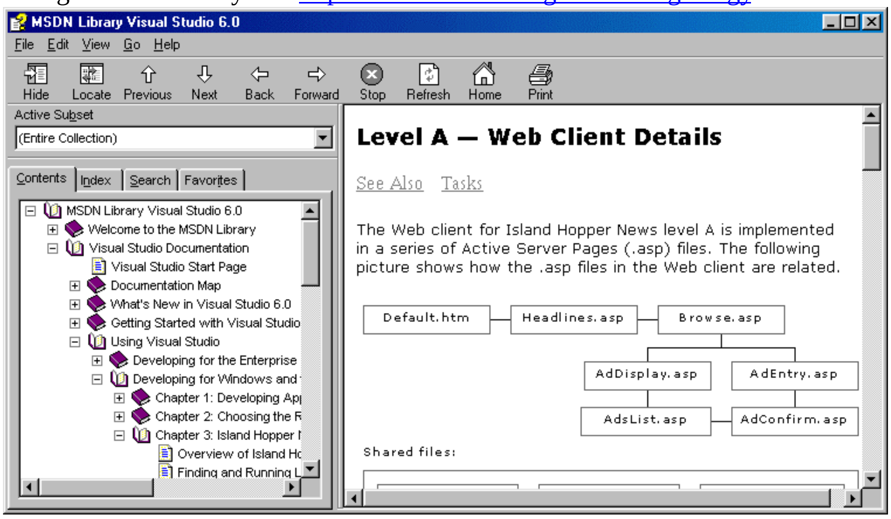


Figure 6. screen layout : http://www.uwe.ac.uk/geocal/totalgeology



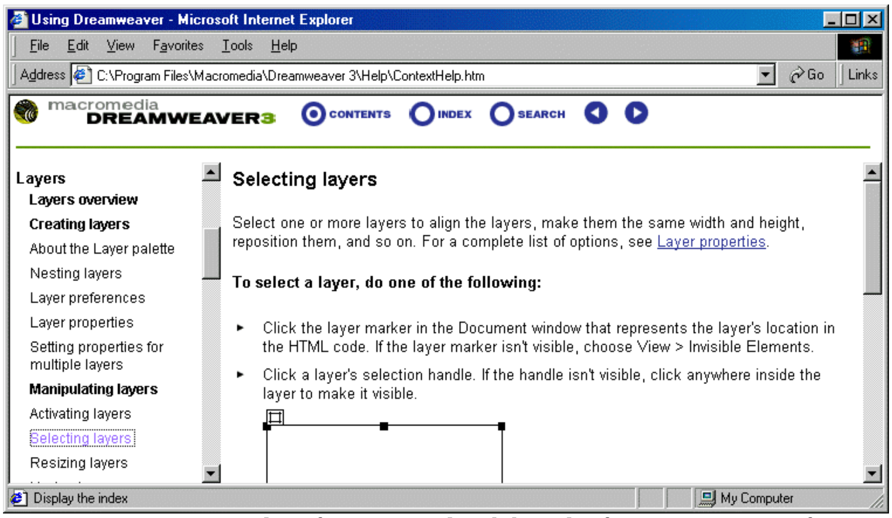


Figure 7. Two examples of commercial web based information systems for professional users.

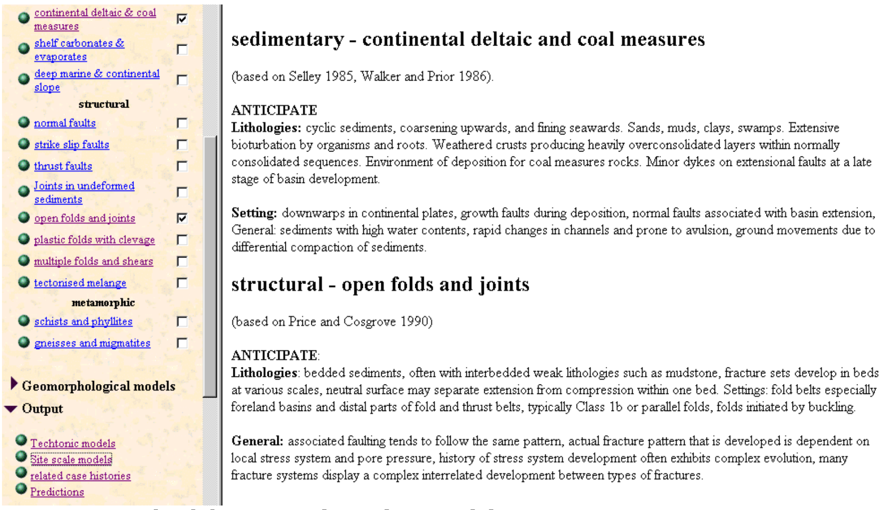


Figure 8. Check boxes used to select models.

Relevant case histories

sedimentary - continental deltaic and coal measures None found
structural - open folds and joints see cases (3), 10, 11
2 models selected

Case History 3: Goldau rock slide, Switzerland
Case History 10: Mangla Dam, Pakistan

Case History 11: Barrage de Castillon, France

Figure 9. Related case history output.