The past, present and future of 3D Geology in BGS

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Introduction

In its role as a national geological survey the British Geological Survey (BGS) has produced paper maps of Britain's geology at a series of scales for the past 170 years. Over time these have become more detailed with the one-inch (1:63 360) scale being the benchmark in the mid 19^{th} Century up to today, where 1:10 000 is the scale of primary survey considered appropriate for modern needs over most of Britain's landscape. Geological maps often require another geologist to understand them fully; the surveyors' spatial ideas, models and concepts can never be properly represented in a 2D map output, and so, to-date, much knowledge has been lost to the science and to the users.

In 1815 William Smith was already addressing the need to present the third dimension of the geology as well as the surface arrangement of units. Over time, cross-section drawing became more refined, resulting in outputs such as fence diagrams, ribbon diagrams and block diagrams to reveal the 3D structure, while contoured surfaces were used to show the spatial position of individual horizons such as major unconformities or the thickness variations of units or sequences (isopach maps)

Today, nearly 200 years after Smith's first map was published, BGS has nearly finished the systematic survey of the geology of Britain at the large scale (predominantly 1:10 000) that is required for modern needs; in addition BGS has recently compiled and published all existing data as 2-D digital geological maps of Britain (DiGMapGB) at scales up to 1:50,000 (Jackson & Green, 2003).

From 2000, the next major challenge facing BGS and other national surveys has been to begin the translation of their traditional 2D geological map outputs into fully interactive 3D geological models of the subsurface.

Past 3D modelling in BGS – the long slog

In the last 3 decades the rapid evolution of computer processing power has enabled scientists to create 3D models of geological structures. Much of the impetus for these developments came form the hydrocarbon and metallic mineral exploration industries. First these were simple meshed surfaces, which could be visualised as perspective views, whereas today they are solid models of highly complex structural features or entire sedimentary basins. Individual geological units are now usually modelled as objects or volumes and can either be attributed for display with a multitude of applied and themed properties, or populated internally with measurements or properties using 3D pixels, or voxels.

BGS has been building geological models for about 20 years and as past research and experience has grown preferred software packages have emerged (see Smith *et al*. 2005)

At present BGS builds general deep regional models using GOCAD, a software tool particularly favoured by the oil industry, whilst a relative newcomer - Geological Survey and

Investigation in 3D (GSI3D) - is used to produce detailed systematic 3D geological models of the near-surface terrains characterised by artificial ground, superficial deposits and straightforward bedrock geology.

GOCAD is being developed through a research consortium based in Nancy and is distributed through Paradigm, a major provider of information solutions for the oil and gas industry. In BGS it has to date been used mainly for geological models at national and regional 1:1 Million and 1:250 000 scales. Data used are largely from deep exploration boreholes, 2D and 3D seismic profiles, regional geophysical surveys and published national tectonic atlases.

GSI3D has emerged over the last 5 years as a result of BGS collaboration with Dr Hans-Georg Sobisch, a geoscientist and software programmer and now proprietor of his own software company INSIGHT GmbH based in Cologne. As a result BGS is now using GSI3D to produce detailed systematic 3D models that incorporate all the usable data for a given area. Such models are tied to the published surface geological linework at either 1:10 000 or 1: 50 000 scale and have the advantage in the digital age of being dynamic - capable of instant revision as soon as new data become available.

Armed with these two software tools BGS is now embarking, though its new National Geoscience Framework programme, on a campaign to systematically build 3D models, at the four principal resolutions mentioned above. These models will be constructed across the entire country to standards developed from the last 5 years of research into systems and methods for 3D modelling. The products, known collectively as LithoFrame are described more fully on the BGS website. http://www.bgs.ac.uk/3dg

These LithoFrame models will be structured and attributed to meet the needs of a wide range of applied users, and ultimately, may take the place of the traditional geological map. However, this will only happen if the models are produced on a national scale, at realistic costs, and are made available and accessible to the user community

Tools for the job – GSI3D and the Subsurface Viewer

In this article we will focus on the contribution GSI3D as a software and methodology has made to the progress of geological modelling in BGS.

GSI3D was built with geological surveyors, their working environment and culture in mind. It has resulted in an intuitive, user-friendly working package that has gained widespread acceptance throughout BGS.

The software is programmed in JAVA, is very light-weight and can be run on any standard operating system. Its file import and export formats are open and extensible, and the main model file is written in Extensible Markup Language (XML). The software is directly compatible with GIS systems and other 3D packages such as GOCAD.

GSI3D works with the principle components of any geological survey: a terrain model, mapped geological linework, borehole and section data as well as geophysical data. Together the display of these datasets enables the geologist to construct regularly spaced intersecting cross sections by correlating between boreholes and the outcrops-subcrops of units to produce a geological fence diagram of the area (Fig 1C). Mathematical interpolation between the nodes along the sections and the limits of the units (outcrop plus subcrop) produces a solid model (Fig 1E) comprised of a series of stacked triangulated objects corresponding to each of the geological units present (Hinze *et al* 1999, Sobisch H.-G. 2000, Kessler & Mathers 2004).

In addition to the GSI3D modelling package, a stand-alone viewer is also available for the visualisation and simple analysis of geological models constructed using GSI3D and other software packages. The Subsurface Viewer provides a decision support system for users to resolve their problems based on the best available 3D understanding of the geology.

The analytical functionality at present allows the user to drill synthetic boreholes at any point, construct synthetic sections along specified lines or waypoints, slice the model horizontally at any required OD level, to strip off deposits from the model to produce uncovered models or to display only selected geological units. Individual model units can also be separated in 'exploded' views and enhanced 3D visualisation is possible using anaglyph images. Individual surfaces (tops, bases) can also be contoured at any desired interval. In summary the model cube can be sliced and diced at will to assess the geology. (Fig 1F-H) gives an example of the different views and analytical functions enabled in the Subsurface Viewer.

On www.bgs.ac.uk\free a sample download of a small 3D model from the Thurrock area in East London is available along with a user manual.

The need for, and benefits of, the added dimension

Models have a wide range of applications; they are suitable for interrogation using GIS-based analytical tools to produce thematic and bespoke outputs. These geological models are generic rather than themed and so have a thousand and one potential uses and users. (Kessler et al 2005)

Here we mention a few possibilities – such as enabling the thickness and volumes of aggregate resources or mineral deposits and their overburden to be contoured, and so derive thickness ratios to define cut-off points for exploration or extraction. For the hydrogeologist the combination of all impermeable layers in the stacked model can, for example, produce maps of total aquitard thickness and the degree of aquifer protection, so useful in groundwater recharge, pathway and pollution studies. Furthermore interrogation of the model at any given point will provide the user with an automated borehole prognosis for the site. Similarly, a vertical geological section can be generated along any specified course through the model for use in linear route planning or tunneling.

The most important beneficiaries of this step change of delivery of geological information will be the general public and in particular geoscience students and teachers. We envisage 3D models as shown in Figure 1 will become much more educationally informative than their forerunners… geological maps.

To-date the main commissioners of BGS-built near-surface models have been

- Local authorities such as Glasgow City Council wanting to examine ground conditions and inform planning decisions on proposed development

- Archaeological services such as those provided by the Museum of London and county heritage departments.

- Water companies including Yorkshire and Anglian Water to help with issues such as wetland management and pollutant pathways

- The Environment Agency and their consultants are the biggest single customers to-date for models, using them to help resolve issues of catchment management, aquifer protection and recharge, numerical modelling and flood protection.

We applaud the vision of these varied organisations and the impetus they have given to the development of a geological modelling capability at BGS.

A vision for the future

To-date the emphasis in BGS has been on the development of model construction methods and the definition of specifications for standard models. As the availability of models increases their potential to contribute to the understanding of the geological evolution of individual areas and whole regions will become more apparent. Just as hydrocarbon models have contributed significantly to the understanding of basin evolution and structure, the more detailed near-surface models will contribute increasingly to the following areas of geoscience.

- River Terrace chronology and floodplain evolution
- Archaeological preservation potential and land use change
- Soil science – spatial modelling of horizons and watertables
- Quaternary Science – e.g. understanding glacial history
- Palaeoenvironmental reconstructions and landscape evolution

The modelling process described in this article leads to the building of essentially lithostratigraphic models in this respect they mimic the geological map. These models form the building blocks of a geological survey, the Lithoframes. The *real* benefit of the models to the applied users is when models are attributed with measured properties.

To fulfil the BGS mission of a systematic nationwide survey of the 3D geology, the BGS will increasingly work in partnership with government and industry. The BGS relies heavily on data from external sources in the form of data from ground investigations as well as maps and plans from constructions. Business-to-business solutions with end users and common data exchange formats based on open standards will propagate the exchange of new data and, in return, delivery of updated models will add considerably to the value of ground investigation data collected by industry

Conclusion

Geology is an inherently three dimensional science, but the portrayal and communication of the Geologists' outputs was hampered for over a century and a half by the two dimensional nature of media such as paper and later GIS systems.
A good indication of the demand for the real 3rd dimension has been the exponential growth of commissions from government agencies and industrial partners for models to provide real solutions for real-life issues.

What we have witnessed in the past few exciting years in BGS is only the beginning of a paradigm shift in the way in which the geological sciences are communicated to the whole population: the old adage **a picture paints a thousand words** springs readily to mind!

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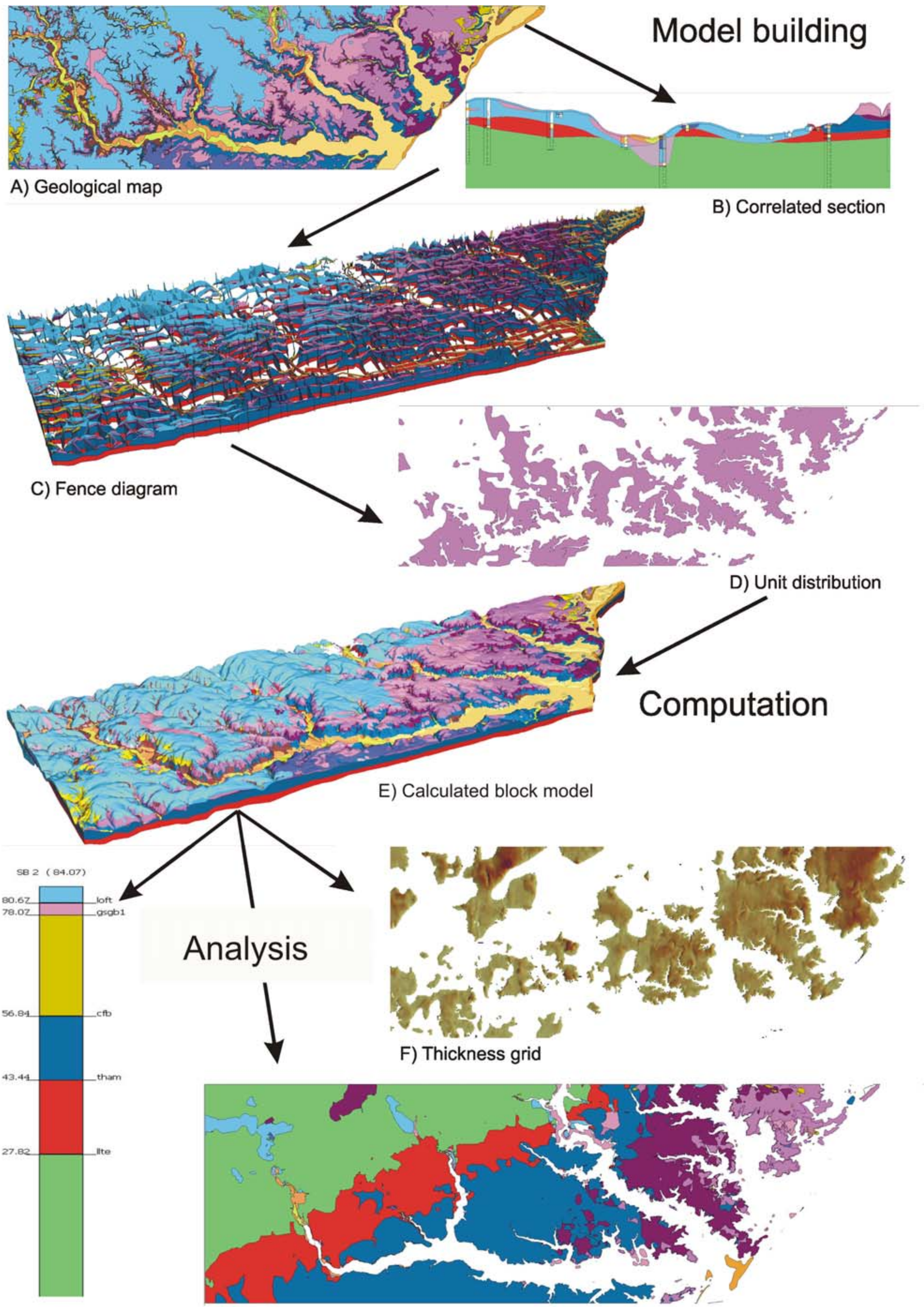

Figure 1. The model building workflow (1A-1E) in GSI3D and example analytical outputs (1F-H) that can be derived from the calculated model within the Subsurface Viewer. The model shown comprises some 1200 sq km of the Sudbury-Ipswich-Felixstowe area of southern East Anglia.