Digital 3D Geological Models – the geological maps of the future

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Background

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. 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)

BGS has recently captured and published national coverage of geological map data as 2-D digital maps of Britain (DiGMapGB) at 1:50,000 scale. (Jackson & Green, 2003).

From 2000, the next major challenge facing BGS has been to begin the translation of their 2D geological map outputs into fully interactive digital 3D geological models of the subsurface. One of the main areas in which this translation has occurred already is in the Ipswich-Sudbury area of East Anglia.

The LithoFrame Concept

These digital 3D models are called LithoFrames and it is envisaged that they 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.

BGS aspires to construct models at scales comparable to its principle map outputs, i.e 1 Million, 1: 250 000, 1:50 000 and 1: 10 000. The intention is that the traditional map at the appropriate scale will form the surface cap of the model. Small scale regional and national models will extend to much greater depth than the more detailed larger scale versions.

Central to the LithoFrame concept is that the varied resolutions of LithoFrame are consistent with each other so that collectively they form a seamless transition from general national model to a detailed site specific one. The definition of highest order Stratigraphic units should be defined first and included in all models of a higher resolution. So in Figure 1 the major stratigraphic boundaries selected for LithoFrame 250 are applied to the higher resolution LithoFrame 50 and 10 models which are thus constrained to a common structure within which progressively more detail is nested.

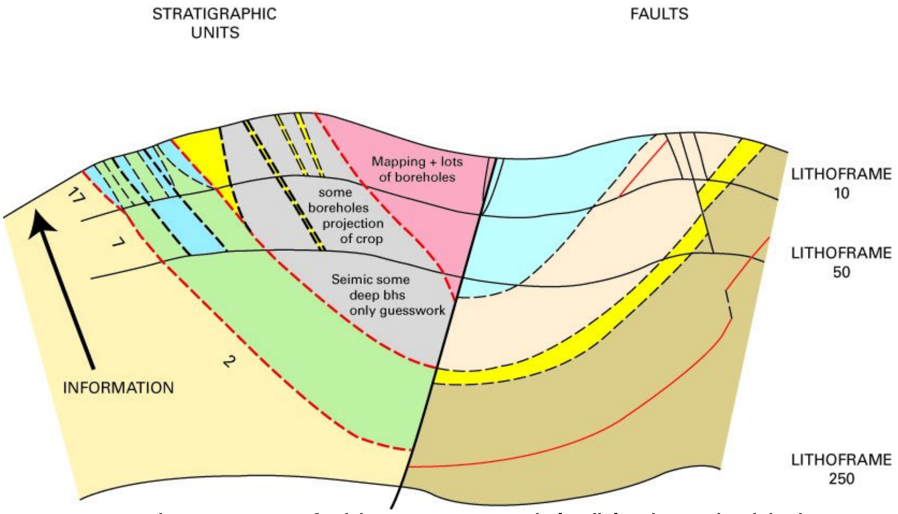

Figure 1 Nested structure of LithoFrame models (black and white)

Table 1 Main parameters of the proposed LithoFrame resolutions

	LithoFrame1M	**LithoFrame250**	**LithoFrame50**	**LithoFrame10**
Proposed coverage (long term)	Entire onshore and UKContinental Shelf	Entire onshore and UK Continental Shelf .	Onshore UK	Major Urban and development areas. Areas of complex near-surface, classic geology and research interest
Tile Size	Single tile	100 x 100 Km	20 x 20 Km	5-10 x 5-10 Km
Resolution of grid output	1Km	500m	100 –200m	50-100m
Depth	50km	5 - 10km	1-2KKm	100- 200m or base of superficial deposits if deeper
Uses	Visualisation National/international Collaboration, Education, Public understanding of science	Visualisation Popular science, overviews for the energy sector, deep structural studies .	Analysis Standard Systematic output Coal, Petroleum, Aggregates bulk minerals aquifers , land-use planning, major infrastructure.	Detailed Analysis and problem solving. Site specific/detailed studies of all kinds, detailed planning,
Datasets	Geological linework DIGMAP625 Deep Seismic lines national-regional magnetic and gravity data, very deep boreholes	Geological linework DIGMAP250 Seismic lines and regional magnetic and gravity data, deep boreholes.	Geological linework DIGMAP50 Seismic lines, boreholes, deep mining data	Geological linework DIGMAP10 All boreholes and mining data
Commercial potential	Low, popular publications, atlases	Modest, contextual models for energy , water and environment sectors	Moderate-High the standard product for the geoscientist and allied professions	Very high, detailed models to resolve problems and deliver geoscience solutions

GSI3D and the Subsurface Viewer

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.

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.

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. Mathematical interpolation between the nodes along the sections and the limits of the units (outcrop plus subcrop) produces a solid model comprised of a series of stacked triangulated objects corresponding to each of the geological units present (Sobisch H.-G. 2000, Kessler & Mathers 2004).

Geologists draw their sections based on facts such as borehole logs linked (correlated) by intuition – the shape ‘looks right’ to a geologist. This ‘looks right’ element pulls on the modellers’ wealth of understanding of geological processes, examination of exposures and theoretical knowledge gathered over a career in geology.

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. Users do not need to invest in their own software in order to analyse models.

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.

On http://www.bgs.ac.uk/science/thamesgateway/3dModels.html a sample download of a small 3D Viewer model of the Thurrock area in East London is available along with a user manual.

GSI3D was designed for modelling the complex Quaternary and Tertiary sequences of the North German Plain. Its current capacity is limited to modelling superficial deposits and structurally simple bedrock environments. A 3 year BGS-funded research and development programme has just begun to extend the capability of the software to deal with more structurally complex bedrock environments with features such as reverse faulting, overfolded strata, cross-cutting intrusion and diapirs. Once completed the software should be capable of modelling almost all geological environments encountered in Britain's diverse geology.

The central tenet in this development is that the software remains intuitive and easy to use so that it can be rolled out to all investigative geologists within BGS and also marketed to other surveys and organisations. This will be ensured by the interactive and iterative approach between users and designers that has been a key feature of GSI3D development to-date.

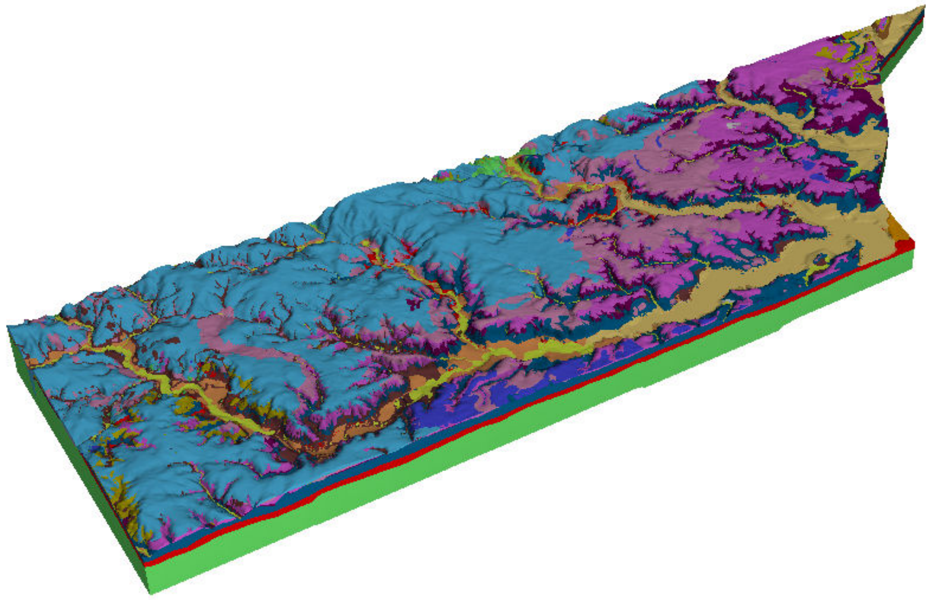

Figure 2 Block model of the Ipswich-Sudbury area down to the base of the Chalk group viewed from the southwest. (B & W caption)

Colour Plate X. Block model of the Ipswich-Sudbury area viewed from the southwest. The model extends down to the base of the Chalk Group (shown in green) and shows the regional sheet of Lowestoft Till (pale blue) in the north and west giving way to the sandy plateau of the south east underlain by the Glacial sand and Gravel, Kesgrave Sand and Gravel and Red Crag (shades of pink and purple). The area is dissected by the Gipping-Orwell, Deben and Stour drainage systems.

Model usage

The LithoFrame models have a wide range of applications; they are suitable for interrogation using GIS-based analytical tools to produce thematic and bespoke outputs. These 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.

However we envisage that 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.

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

- Local authority Planners
- Archaeologists and Heritage bodies
- Water supply companies
- The Environment Agency

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

Summary

Geology is an inherently three dimensional science, but the portrayal and communication of the Geologists' thoughts and outputs has been hampered for over a century and a half by the two dimensional nature of available media for dissemination (paper, GIS). We are now entering an era when 3D objects can be modelled routinely in 3D enabling visualisation and analysis. This is not just happening in Geology but in many other fields such as architecture and medical science.

Acknowledgments

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