From geological maps to models – finally capturing the geologists' vision.

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Geologists investigate the earth in order to understand its evolution and form and to work out the arrangement of the rocks beneath our feet. During a survey or investigation the geologist continuously develops a model in his/her mind of the concealed structures and arrangement of geological units taking into account knowledge of the processes that have led to their development. The purpose of the geological map is to then display the knowledge and information gathered about the surface and sub-surface conditions to a wide range of users.

The ultimate challenge, or principal difficulty, for the geological surveyors has always been to depict a three dimensional system through a two dimensional media, traditionally on paper, and in recent years in Geographical Information Systems (GIS). A key aide to solve the inherent problem of showing a 3-D object in 2-D is the use of cross-sections, these are effectively vertical or inclined geological maps, illustrating the order and arrangement of units at depth – just as slicing of cake reveals its internal structure.

In his ground-breaking 1815 geological map of England, Wales and southern Scotland William Smith illustrated the geological sequence and basic 3-D structure with what at first sight appears to be a single geological section drawn west-east through Britain (see Fig. 1). The detail and his annotation however reveals that this was not a single section drawn along a line or corridor but it was schematic to show the relationships that are present in a series of transects or sections through the country running from the north and west where the outcrops of the oldest rocks are found in Wales, the Lake District and Southern Scotland south-eastwards to the youngest strata in the London Basin

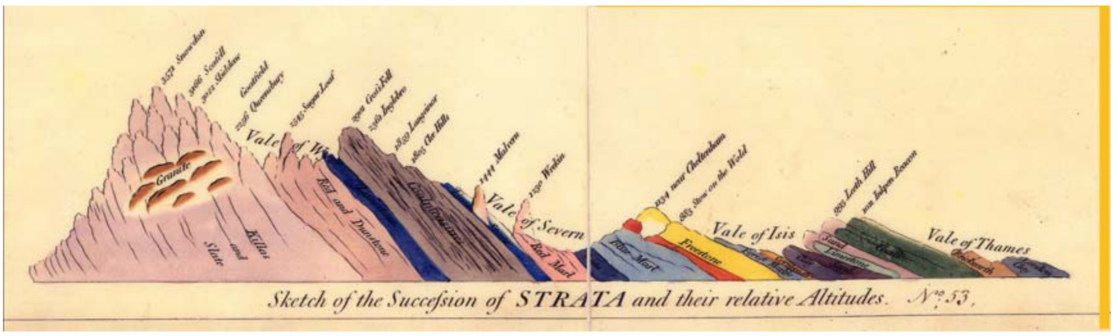

Fig. 1 William Smith's original section from his 1815 map

At this early stage in the development of geology Smith was already addressing the need to show the third dimension as well as the surface arrangement of units. Over time more refined section drawing resulted in outputs such as fence diagrams, ribbon diagrams and block diagrams to show the 3-D structure, while contoured surfaces were used to show the nature 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, the British Geological Survey (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 at scales up to 1:50 000 (DiGMapGB see Geoscientist Vol.13, No.2).

In the last 2 decades the advancement in the processing power of PCs has enabled scientists to create 3-D models of geological structures. First these were simple meshed surfaces of which perspective views could be obtained whereas today they are solid models of highly complex structural features or entire sedimentary basins. We are moving from a mapping to a modelling culture, and this should be seen as a natural progression.

However to-date, these models have tended in BGS and elsewhere to be commissioned as isolated projects to solve specific problems or evaluate resources. As such they do not fulfil the remit of a national geological survey - to **provide systematic, consistent, information and knowledge on the geology of the entire country**.

User surveys of geological maps have demonstrated an overwhelming demand for more detailed information of the shallow sub-surface, dominated in many parts of the country by Quaternary and artificial ground. However the data paucity and the relative disorder of deposits at shallow depth has frequently led to this key requirement being largely ignored by the geological 3-D modelling community who have received funding to concentrate their efforts on the petroleum and metallic minerals sectors.

Recent work in BGS in conjunction with Hans-Georg Sobisch, a geoscientist and software programmer currently based at the University of Cologne, has begun to demonstrate the feasibility of producing systematic 3-D geological models of the near-surface. These use Dr Sobisch's emerging software tool and methodology - Geological Surveying and Investigation in 3-D (GSI3D) that he has developed over the last decade, partly in collaboration with the NLfB (Lower Saxony Geological Survey).

In simple terms, GSI3D utilizes a Digital Terrain Model, geological surface linework and downhole borehole data to enable the geologist to construct regularly spaced intersecting cross sections by correlating boreholes and the outcrops-subcrops of units to produce a geological fence diagram of the area (Fig 2a-c). 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 (Fig 2d-f).

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. For example, something seen in sediments at the margin of a glacier in Iceland might well influence the way a geologist draws the base of a till unit on a geological section in Scotland; whilst the erosive power of a river in flood might inspire the geologist to draw a scoured base to a braided river deposit.

BGS has produced paper maps for 170 years and these often require another geologist to understand them fully; the originators' spatial ideas, models and concepts have never been captured, and so, to-date, have been lost to the science and to the users. The consequential loss of recorded knowledge has been enormous, but thankfully, the tools are now at hand to solve this problem.

What is now being produced at BGS using tools like GSI3D are interactive systematic 3-D models that incorporate all the usable data for a given area. Such models have the advantage in the digital age of being dynamic - capable of instant revision as soon as new data becomes available.

These 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. Here we mention a few possibilities – such as enabling the thickness and volumes of aggregate resources or mineral ore-bodies 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/customer with an automated borehole prognosis for the site. Similarly, a geological section can be generated along any specified slice through the model (horizontal as well as vertical), for use in linear route planning or tunneling, in other words the model can be sliced and diced as required.

These systematic models represent the building blocks of the 3-D architecture of Britain's geology. We are now ready, due to technological advances, to translate and extend William Smith's map fully into the third dimension to produce a solid model of Britain's geology.

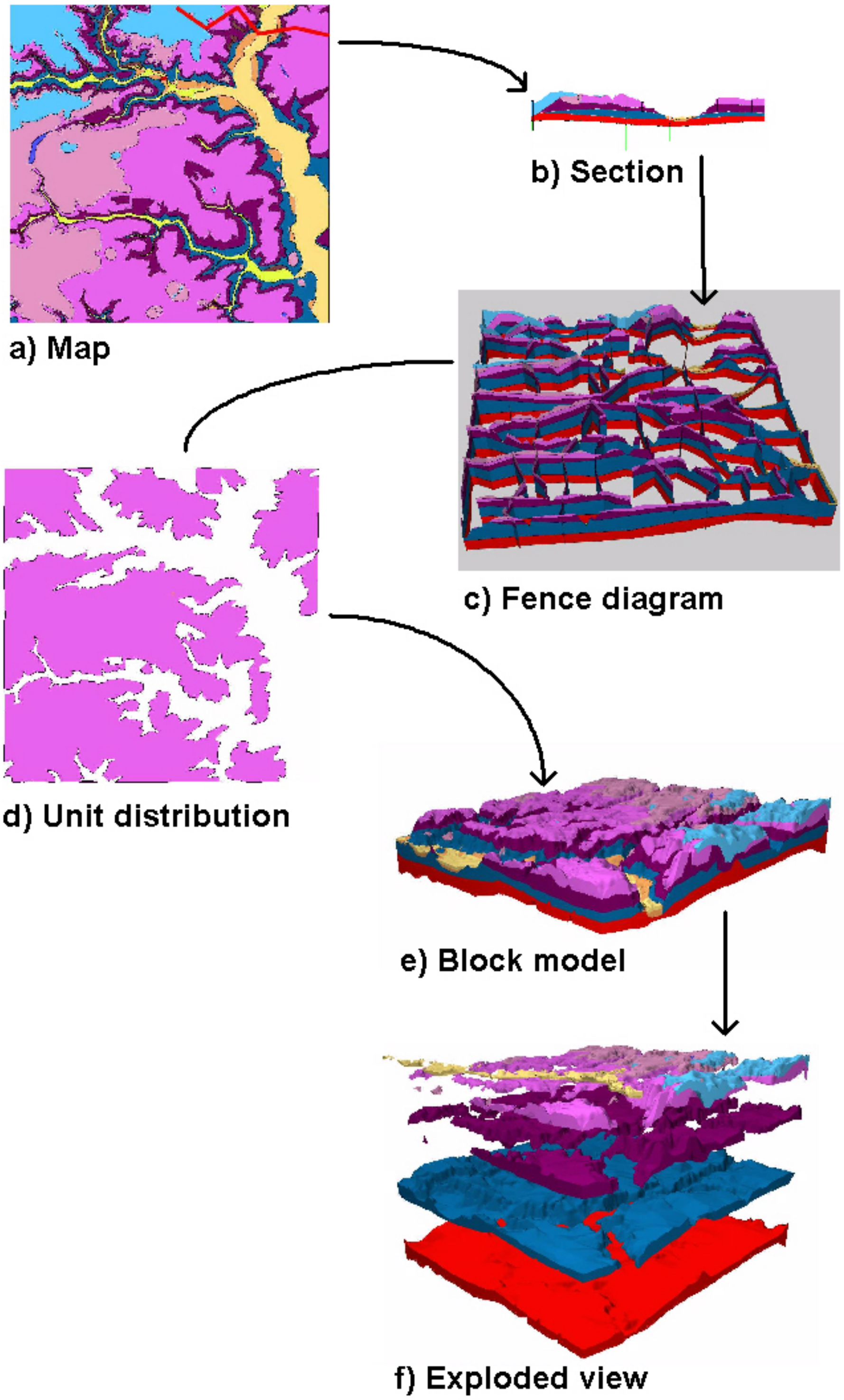

Fig 2a Geological map of 1:25.000 sheet TM24, Woodbridge, Suffolk;
Fig 2b Geological section from TM24;
Fig 2c Geological fence diagram of TM24;
Fig 2d Distribution (outcrop plus subcrop) of Quaternary Kesgrave Sand and Gravel deposit;
Fig. 2e Computed block model of TM24 viewed from the northeast
Fig. 2f Exploded detail of the block model revealing 3-D geometry of key units