1. BACKGROUND

BGS has stopped its systematic onshore geological surveying programme and the litho-printing of geological maps will cease after a final batch of completed maps are published. In future BGS will undertake integrated mapping and 3D modelling in user defined target areas considering all our available geospatial data (map, boreholes, geophysics etc) assessed in a single 3D workspace. The output will be 3D geological framework models that capture the understanding and interpretation of the survey geologist and honour all available data at the time. As well as building new models in these strategic areas, BGS is collating all existing models assembled over the last 25 years into a common framework to produce a multi-scaled National Geological Model of Britain (Mathers, 2011) comprising crustal, bedrock and Quaternary themes (http://www.bgs.ac.uk/research/UKGeology/nationalgeologicalmodel/home.html). Different to the traditional geological map, the national model will not be completed at any specific scale, but at every point in the model there may be a different geological resolution available, depending on the purpose of the original model or the strategic national need for subsurface information.

2. MODELLING SOFTWARE & WORKFLOWS

Over the last 30 years BGS has developed a strong capability in 3D geological modelling using a variety of methodologies and modelling software to produce geological framework models varying in resolution from national to site-specific. Currently BGS uses the following main software packages: 1) GOCAD/SKUA are mainly deployed to produce models of structurally complex and faulted bedrock geology drawing on datasets including seismic profiles and cubes, regional geophysical patterns, deep boreholes and surface geological surveying; 2) GSI3D is mainly deployed to model superficial, artificial and layer-cake bedrock geology to shallow depths (c.500m) through the use of cross-sections (Kessler, Mathers & Sobisch, 2009). The intuitive approach of the GSI3D software means that all our investigative geologists can use this package and it comprises an effective front end for the assembly of cross-sections of complex geology and fault network that can then be exported to the other more mathematically grounded packages for model calculation; 3) Petrel is increasingly used as our tool of choice for flow modelling but is not generally used for geological framework model construction.

In combination these packages enable the BGS to model almost all of Britain's geology at any resolution and evaluate all types of geoscience data in the production of these geological 3D framework models. In golf one needs a suite of tools (clubs) to play an effective round, the same holds for geological modelling. So imaginative and increasingly sophisticated workflows are now being used for many projects involving data exchange between packages and exploiting the strengths of the individual software methodologies (Kearsey et al. 2012). Interoperability, as ever, remains paramount.

Outputs from the modelling process are many and varied, they include screen grabs of models and 3D PDFs (Figure 1) used to illustrate reports, derived maps highlighting particular geological situations and answering particular user-defined questions, grids and tins for use in GIS systems. The models are also the delivered as fully attributed 3D block models using our bespoke Viewer-Browser, the LithoFrame Viewer. Using another BGS product, Geovisionary, 3D models and their components can be placed in a dynamic fly-through setting to demonstrate the interrelationship between terrain, surface geology and the sub-surface infrastructure.
Figure 1. Screen grab of the Assynt culmination 3D model produced using the latest 3D PDF technology. The model is available as a free download from: http://www.bgs.ac.uk/research/ukgeology/assyntCulmination.html

3. THE MODELS
The National Geological Model has the following properties.

1. geospatially correct representation
2. scalar independence and varied resolution
3. national in coverage, seamless onshore and in time offshore

Existing datasets for incorporation include BGS's digital geological linework at all scales (the surface layer), sub-surface, offshore and survey memoirs, reports and published literature containing useful contour and isopach maps, together with existing framework models and surfaces and geophysical data. The assembly of the framework models is also underpinned by key corporate databases, dictionaries and lexicons for boreholes, stratigraphic and rock terminology. A national sequence of lithostratigraphic units has also been developed. Framework model construction also relies on licenced national digital terrain and bathymetric models of ever improving resolution, air photography and remotely sensed imagery.

NATIONAL CRUSTAL MODEL
The national crustal model grew out of an initial collaborative study between the geological surveys of Britain, Northern Ireland and Ireland to construct a deep model of the Caledonian orogenic belt (Leslie et al. 2013). The model (Figure 2) clearly shows the tectonic grain of the orogenic belt and its division into distinct terranes separated by major bounding fault structures. Work is underway to extend this model southwards to include England. The model was constructed as a fence diagram in GSI3D but it is intended to migrate the dataset to GOCAD in order to calculate a full, but simple, 3D block model. For further details on the development of this model please contact Graham Leslie agle@bgs.ac.uk.

NATIONAL BEDROCK MODEL
Construction of a national bedrock model began in 2009 with a commission from the Environment Agency of England and Wales (EA) to produce a simple fence diagram of 42 cross-sections for the onshore area of England and Wales extending to 1-1.5km depth. Subsequently sections were added by BGS to incorporate Scotland, insert bounding coastal sections and finally, with a second tranche of funding from the EA, many sections were deepened to capture the full vertical extent of potential shale gas sources. The model is available as a free download in varied formats from the BGS website http://www.bgs.ac.uk/research/ukgeology/nationalGeologicalModel/GB3D.html. The model GB3D_v2012 now comprises 121 sections with an aggregate length of over 22,000 km (Figure 3). The model adopts the geological classification and colour schema of the published BGS 625K scale bedrock geology maps. The component sections are also guided by various underpinning datasets, these include:
1. Existing regional 250K and tiled 50K resolution models (these in turn take into account seismic data, deep boreholes-wells, and regional geophysics),
2. Intercepts from BGS 1: 50K mapsheet cross sections,
3. Rasterised images of published maps (contoured surfaces, isopachs, subcrops), and cross sections, Surface Geology (625K bedrock linework)

Figure 2. Crustal fence diagram viewed from the southwest, sections are 15Km deep, fault planes in red.

Figure 3 The GB3D_V2012 Bedrock fence diagram of Great Britain. Vertical Exaggeration x15.
Utilising the 625K geological map and the cross sections the distributions of the 381 geological units in the model can be traced as shown in the example below (Figure 4). Distributions for key aquifers and potential shale gas sources have been compiled into a GIS to provide a risk screening tool for the EA to assess applications for shale gas exploration. The fence model can also be used to calculate low resolution 3D volumes for the youngest and structurally simplest bedrock units down to the base of the Permo-Trias. These have been used in regional and catchment scale hydrogeological modelling studies. Extracts from the fence model have also been utilised to communicate regional geology to the general public with respect to radioactive waste disposal and to illustrate BGS accounts of regional geology. A further phase of development of the fence is underway funded by the Nuclear Decommissioning Authority. This will key in 300 golden spike deep boreholes to enhance the model accuracy and provide a consistent national dataset to inform the public about regional geology in the context of the selection of a suitable site for location of a nuclear waste repository.

Figure 4. The Cretaceous Grey Chalk Sub group of southeast England. Left, outcrop and extent of correlation in GB3D_V2012 dataset, right, the distribution of the unit (outcrop plus subcrop) defined by the dataset in GSI3D.

NATIONAL QUATERNARY MODEL

Unlike the crustal and bedrock national models building an equivalent Quaternary version introduces certain difficulties:
1. Quaternary sediments tend to lack the extensive distributions of older geological units
2. Correlation is difficult or impossible over long distances and between regions or major catchments
3. Quaternary sediments are typically extremely variable in terms of their lithology

Therefore our approach to building a national Quaternary model is proceeding on the basis of constructing regional stratigraphies and consistent models that can be linked together for synthesis at a higher and often very fundamental level of classification (such as all the deposits of the last glaciation). This is a pragmatic approach and has been made more achievable by the recent production of a comprehensive stratigraphic classification and chart for the UK Quaternary (McMillan et al. 2005, Waters 2012).

Perhaps the most important output from the Quaternary model will be the production of an improved national model of the top bedrock-base Quaternary surface. This is of obvious importance in terms of engineering but also provides an important cap for bedrock modelling (Figure 5).
4. METADATA & QA

The increasing use of models and model data demands proper recording of metadata and the introduction of rigorous QA procedures. To-date in BGS this has not been undertaken in a properly structured or systematic way. The creation of the National Geological Model programme has endeavoured to rectify this situation through:
1. The establishment of corporate rules and guidance for modelling projects
2. The introduction of systematic QA procedures and checking of all new models
3. The recording of detailed metadata on model construction and in particular sources of data evaluated, geological rules and assumptions and decisions taken
4. The assembly of corporate databases to hold the above information.
5. The gathering of metadata and checking of legacy models.

5. REFERENCES


