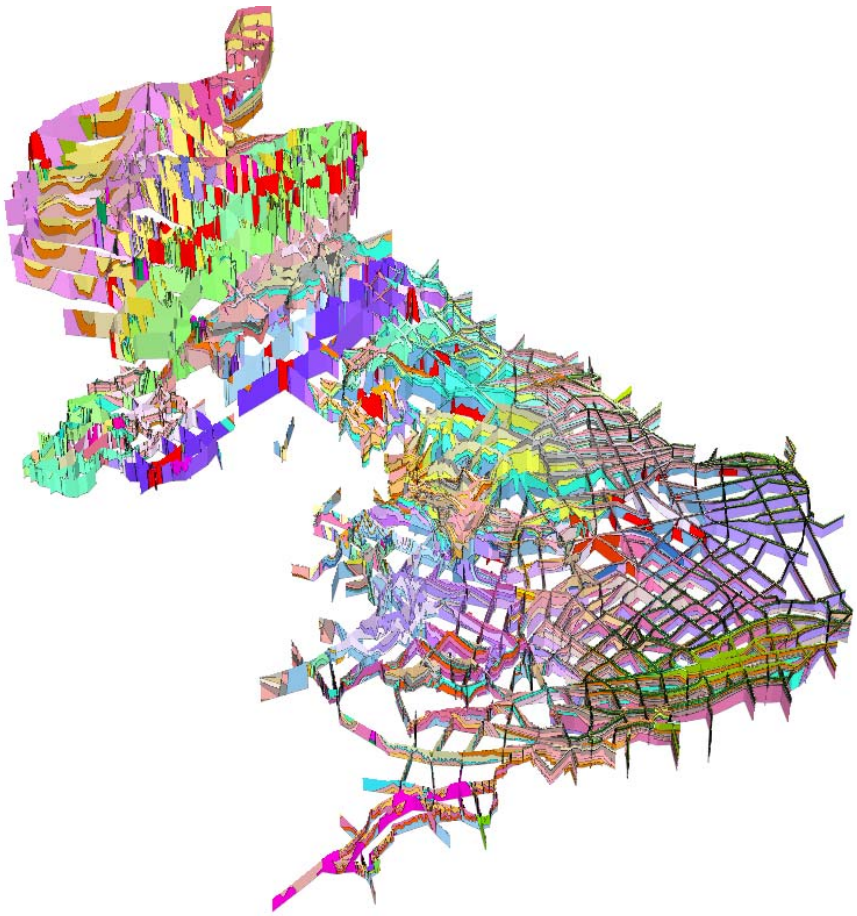
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The construction of a bedrock geology model for the UK: UK3D_v2015.

Geology and Regional Geophysics and Energy and Waste Programmes

BGS Open Report OR/15/069



BRITISH GEOLOGICAL SURVEY

GEOLOGY AND REGIONAL GEOPHYSICS AND ENERGY AND WASTE PROGRAMMES
BGS OPEN REPORT OR/15/069

The construction of a bedrock geology model for the UK: UK3D_v2015

C.N. Waters, R. L. Terrington, M. R. Cooper, R. J. Raine & S. Thorpe

.

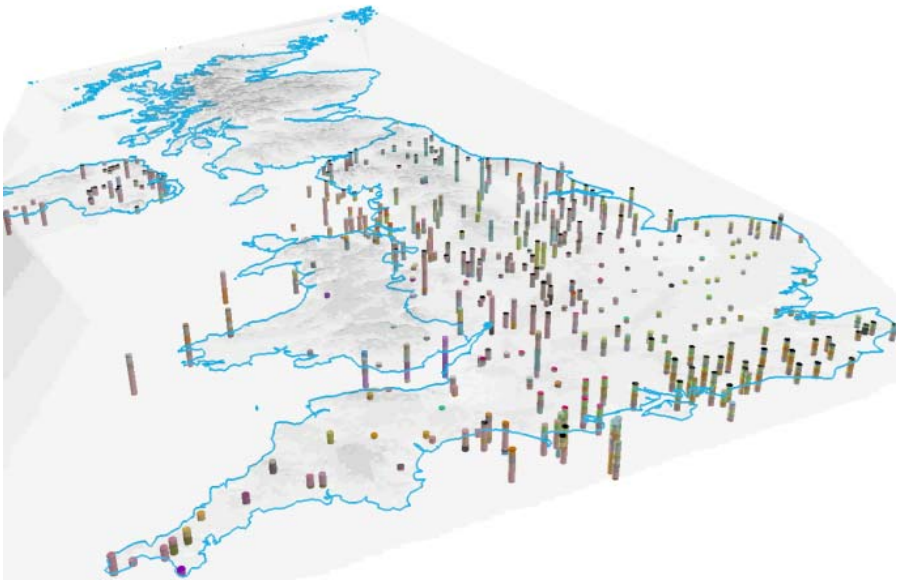
Keywords: 3D Model, Cross-sections, bedrock geology, United Kingdom

Front cover The UK3D_v2015 bedrock model

Frontispiece The coded borehole sticks that inform the UK3D_v2015 model

Bibliographical reference

WATERS, C. N. TERRINGTON, R., COOPER, M. R., RAINE, R. B. & THORPE, S. 2015. The construction of a bedrock geology model for the UK: UK3D_v2015. *British Geological Survey Report*, *OR/15/069* 22*pp*.



Keyworth, Nottingham British Geological Survey 2015

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488

email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683

email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270

Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501

www.nerc.ac.uk

Website www.bgs.ac.uk

Shop online at www.geologyshop.com

Contents

Executive Summary

This report is available for download on the BGS UK3D web page to allow the reader to better understand the context and development of UK3D, a national network, or ‘fence diagram model’, of bedrock geology cross-sections. It also explains the development of the metadata underpinning the model and therefore supports use and understanding of UK3D.

The pre-existing BGS GB3D model provided the only nationally consistent representation of the bedrock geology of Great Britain to depths of at least 1 km. The latest version of this model was released in 2014 as the GB3D_v2014 and accompanying report (Mathers et al. 2014b).

However, the existing GB3D_v2014 model lacked equivalent scale presentation of a fence diagram model for Northern Ireland. It was recognised that in order to provide comparable geological information across the United Kingdom it was necessary to upgrade the model to a UK3D fence diagram model incorporating Northern Ireland, with rigorous peer review performed to enable an enhanced dataset.

The objective of this study was therefore to further develop the GB3D model, outlined by Mathers et al. (2014a and b), into a UK3D model by the incorporation of 36 deep boreholes and a framework of 15 cross-sections for Northern Ireland.

The appropriate applications for the revised model are for geoscience communication and education to illustrate the national and regional bedrock geology of the United Kingdom to a depth of at least 1 km with an intended resolution of use in the 1:250 000 to 1:1 million scale range. Limitations inherent in the model preclude such applications as detailed geological assessments, resource-reserve estimation and exploration, and any representation or use outside the intended resolution range.

The new model produced by this study UK3D_v2015 supersedes the earlier 2014 version for England and Wales, for which areas of the fence diagrams remain the same. The Scottish portion of the model remains unchanged from the earlier 2012 version. The new dataset is a wholly owned BGS product and as with its forerunners it is freely available from the BGS website http://bgs.ac.uk as downloads in a variety of formats.

1 Background to the study

The pre-existing GB3D model provided the only nationally consistent representation of the bedrock geology of Great Britain to depths of at least 1 km. The latest version of this model was released in 2014 as the GB3D_v2014 and accompanying report (Mathers et al. 2014b).

However, the existing GB3D_v2014 model lacked equivalent scale presentation of a fence diagram model for Northern Ireland. It was recognised that in order to provide comparable geological information across the United Kingdom it was necessary to upgrade the model to a UK3D_v2015 fence diagram model incorporating Northern Ireland, with rigorous peer review performed to enable an enhanced dataset.

The scope of this latest phase of work was as follows:

- develop revisions to the national Geological Vertical Section (GVS), the summary of the geological succession displayed in the model, to incorporate lithostratigraphical units at the 1:625 000 scale resolution for Northern Ireland;
- identifying about 40 publicly available deep boreholes which represent the geological structure of Northern Ireland and have been adequately classified using stratigraphic picks corresponding to the resolution of the UK3D model;
- produce 15 cross sections, a total of 1707.5 kms length, to incorporate these deep boreholes, geological map data and other available datasets;
- assembling detailed metadata and compiling legacy metadata on sources utilised in the construction of the UK3D cross-sections in Northern Ireland.

2 Evolution of the national bedrock model

The initial build covered England and Wales (Figure 1) and was funded by the Environment Agency of England and Wales (EA) in 2009-10 (Schofield et al. 2012). In 2010-12 BGS funded the extension of the network of sections to Scotland, whilst additional infill sections were added in England and Wales and cross-sections were aligned along the coast to give the overall model the familiar boundary of the British coastline. Sections in northern Scotland were continued

across the Minch to the Outer Hebrides and similarly to Orkney, but the coverage was not extended at the time to include Shetland or Northern Ireland.

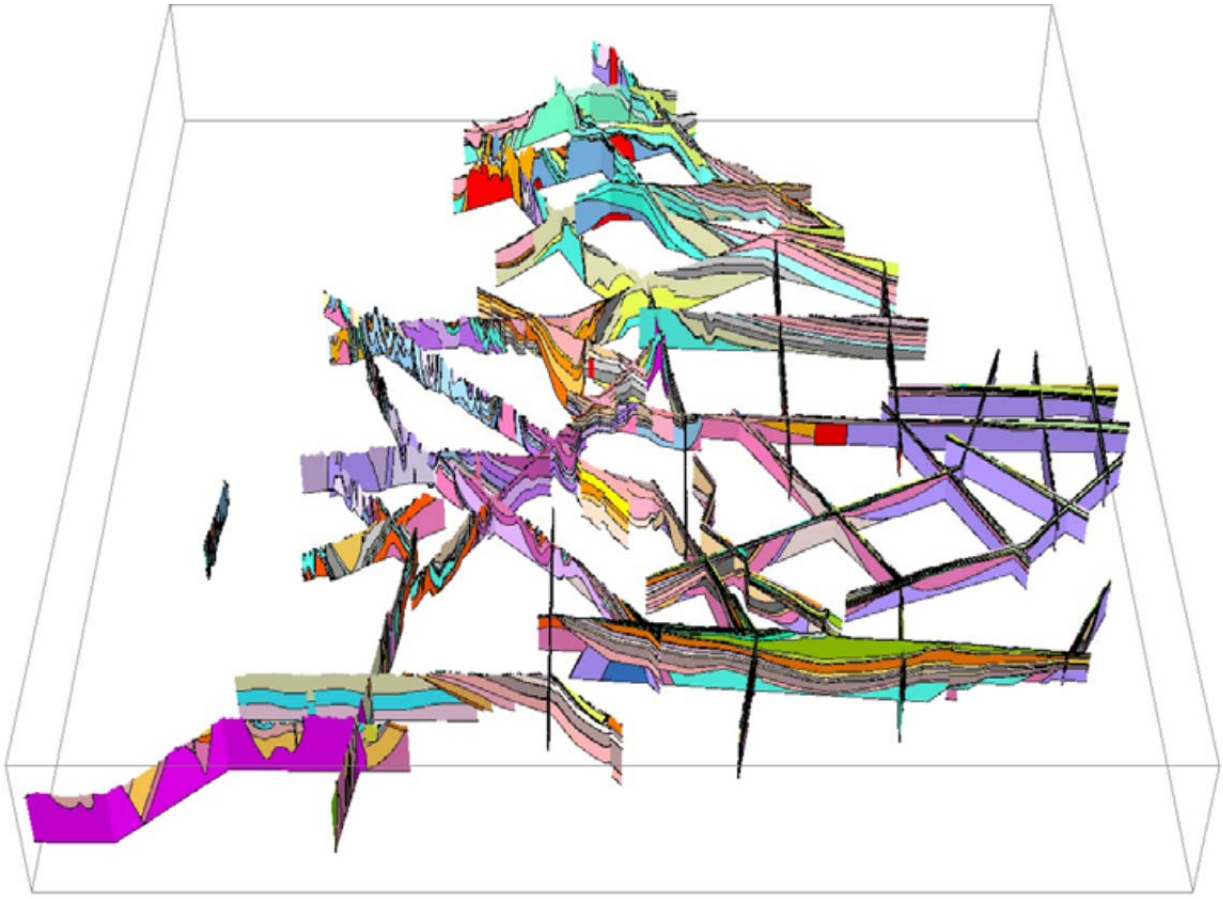


Figure 1. The initial fence diagram for England and Wales as delivered to the EA in 2010 (from Schofield et al. 2012).

In 2012 additional funding from the EA enabled a few further sections to be inserted in England and Wales, whilst many others were deepened in key sedimentary basins with potential shale gas source rocks. This was part of a project to design a risk screening tool for the possible impact of shale gas activities on aquifers (Mathers et al. 2012a). The final model produced was the GB3D_v2012 dataset (Figure 2). This model covered the onshore area of Great Britain (England, Scotland and Wales) and the Isle of Man and comprised 121 cross-sections with a total linear length exceeding 20,000 km, built to depths varying between 1.5 and 6 km.

In 2014 funding from Radioactive Waste Management Directorate (RWMD) resulted in two significant advances in the development of the GB3D model. Firstly, a study extended the GB3D_v2012 dataset by the incorporation of a few additional sections in England and Wales and the extension and realignment of many sections to include 305 deep stratigraphic boreholes (Mathers et al. 2014b). Subsequently, there was a study to provide a nearshore extension of the fence diagram at least 20 km offshore (Figure 3), with an additional 46 sections and 32 key offshore wells. The updated GB3D model was released in February 2015, accompanied by brief accounts of the regional geology of England, Wales and Northern Ireland, also funded by RWM Ltd., which were published in 2014 and are available for download at http://www.bgs.ac.uk/research/ukgeology/regionalGeology/home.html .

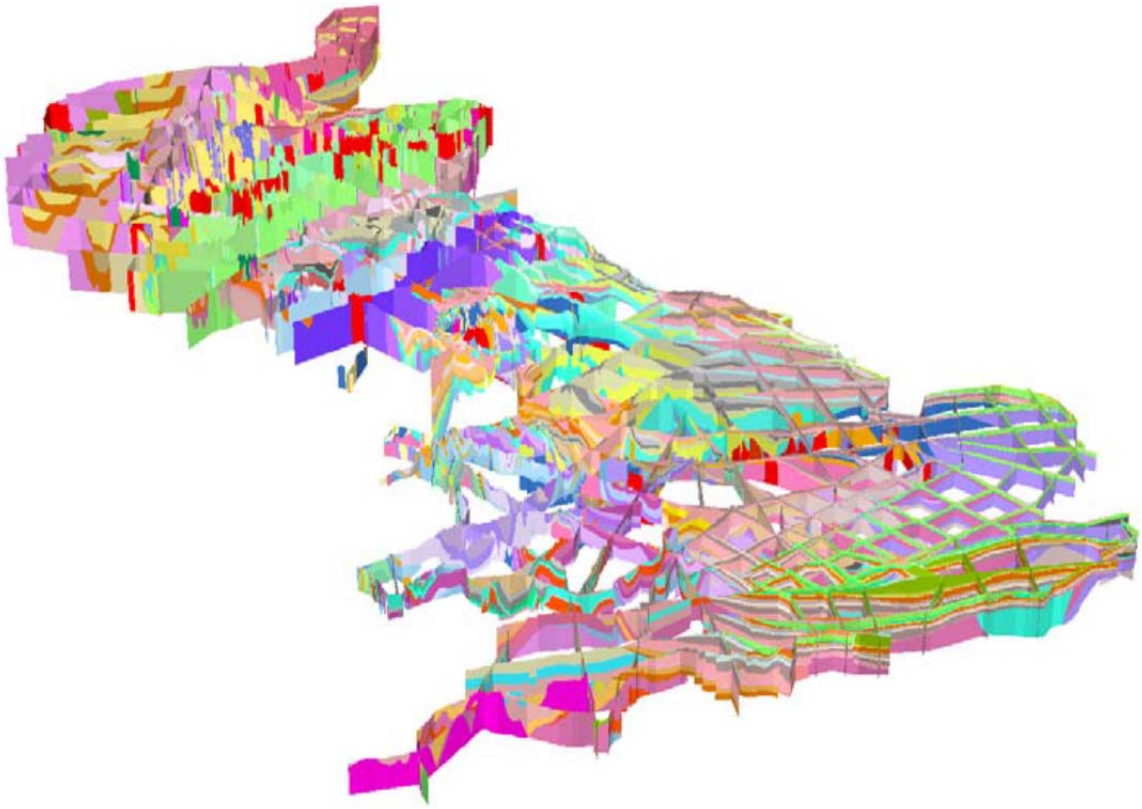


Figure 2. The completed GB3D_v2012 model for Great Britain from the southwest.

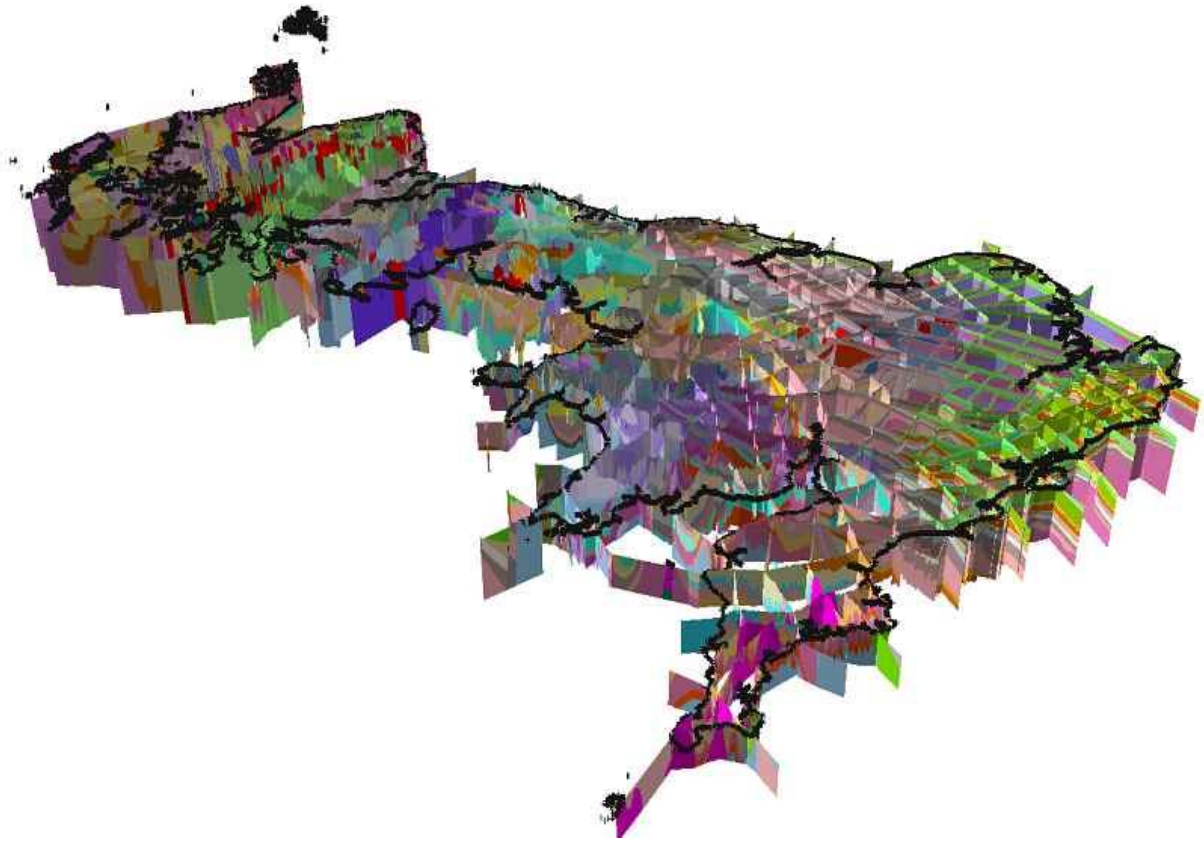


Figure 3. The completed GB3D_v2014 model for Great Britain from the southwest showing an increased density of sections and the nearshore extension.

The current study, funded by RWM Ltd, extends the fence diagram model to Northern Ireland and its surrounding nearshore area, to provide a network of subsurface information comparable to England and Wales, released as UK3D_v2015.

At all stages the model has been constructed using the Geological Surveying and Investigation in 3D software (Kessler & Mathers, 2004; Kessler et al. 2009). The methodology and sources used in the construction of the GB3D dataset have been thoroughly documented by Mathers et al. (2012b; 2014a and b) and in this report.

3 Datasets used in the UK3D_v2015 Model

The underpinning evidence base for the model is now described in terms of the data types.

3.1 DIGITAL TERRAIN MODEL

The Digital Terrain Model (DTM) was initially prepared in 2009-10 from the licensed national NextMap 5 m coverage, and sub-sampled with a variable grid spacing of 250 m along buffered section alignments and 2500 m in intervening areas. This was then replaced in 2011 with an overall NextMap coverage sub-sampled to 500 m due to the increase in the number of sections. This dataset also includes for the Isle of Man and Northern Ireland SRTM (Shuttle Radar Topography Mission data) data at 75 m resolution for the former and 30 m resolution for the latter, subsampled to 250 m. The SRTM data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov. The DTM was updated for the current version to include the DigBath 250 bathymetry dataset (http://www.bgs.ac.uk/products/digbath250/home.html), which was used to extend the coverage to a minimum of 25 km offshore, subsampled to 500 m.

3.2 GEOLOGICAL MAP DATA

Throughout the various stages of construction the model has been built to be broadly compatible with the geological linework of the BGS 1:625 000 scale bedrock mapsheets, UK North and South (BGS 2007a; 2007b; Figure 4). Higher resolution map data has been considered where greater stratigraphical or structural detail was required. For offshore areas, the nearest equivalent dataset is the bedrock theme of DigRock250 http://www.bgs.ac.uk/products/offshore/DigRock250.html a 1:250 000-scale digital map dataset. All of these map data are held by BGS as ESRI shape files.

Some of the detail on these map sheets of faulting, minor intrusions and lithological variations within units was not included in the cross-sections. The same stratigraphical schema was however followed and some 341 units including intrusions and metamorphic suites were distinguished in the GB3D_v2012 version. The extension to the nearshore and particularly the current development of the model in Northern Ireland has increased the number of units to 445 in the UK3D_v2015 model. The geology portrayed on these mapsheets is described in two accompanying booklets (Jackson, 2008; Stone, 2008).

Within the cross-sections the two principal groundwater aquifers of England and Wales, the Chalk Group and the Sherwood Sandstone Group, contain additional stratigraphic detail mainly to formation level, where resolvable, at the request of the Environment Agency.

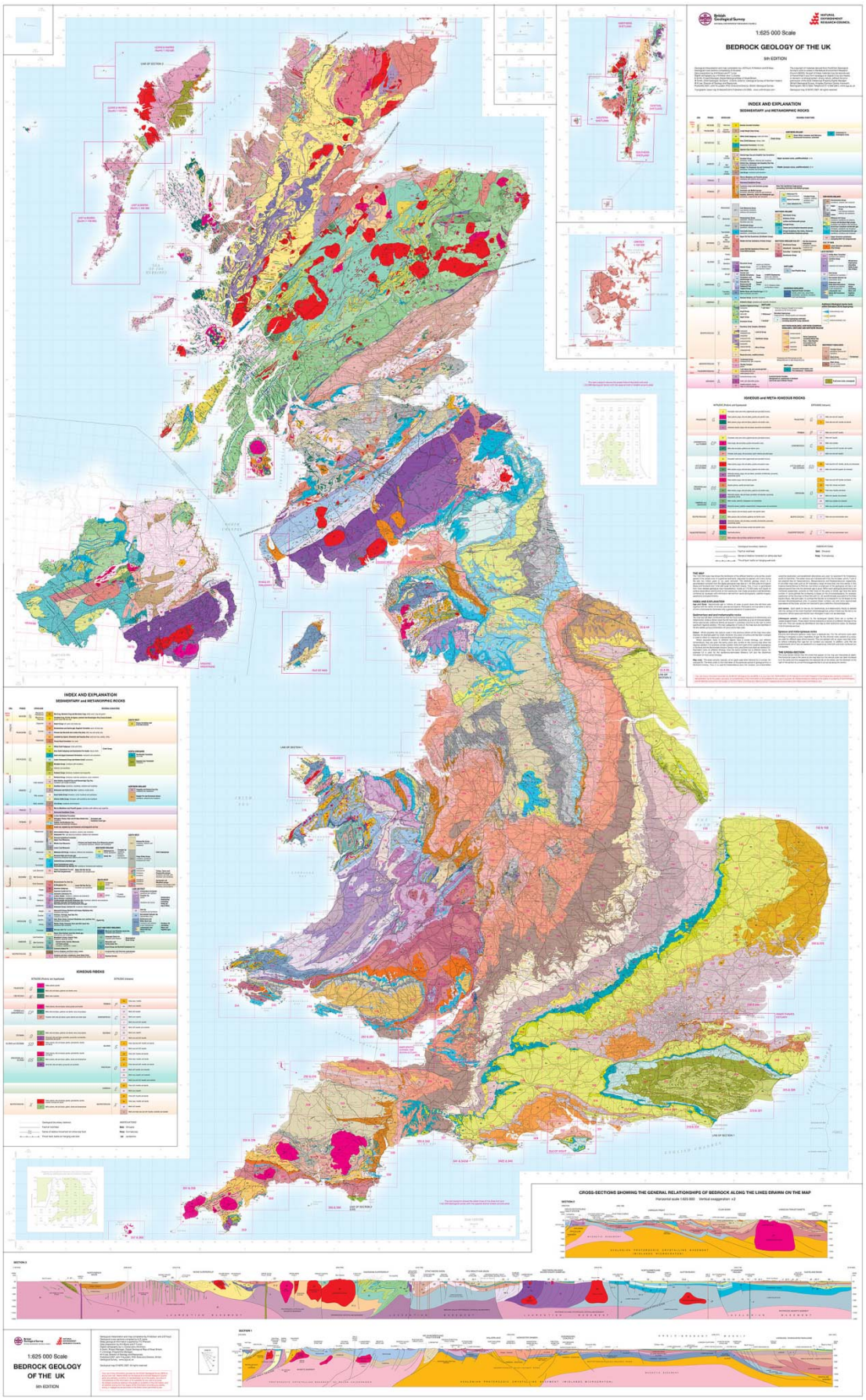


Figure 4. Printed version of the BGS 1:625 000 scale bedrock geological data combined from the two component mapsheets.

3.3 STRUCTURAL CONTOUR PLOTS AT REGIONAL SCALE

The structure contour plots (e.g. Figure 5) that were utilised to inform the cross-section construction are mainly derived from the BGS Subsurface Memoir and 1:50 000 scale Sheet Memoir series together with the published scientific literature. They in turn comprise syntheses of available deep borehole logs and interpreted seismic data for key stratigraphic surfaces and unconformities. These sources are listed in the 'section tracker database' (described in Section 5 below) together with a record of the individual sections that utilised each of these sources. No equivalent of the regional structural contours derived from subsurface memoirs was available for the Northern Ireland extension of the model.

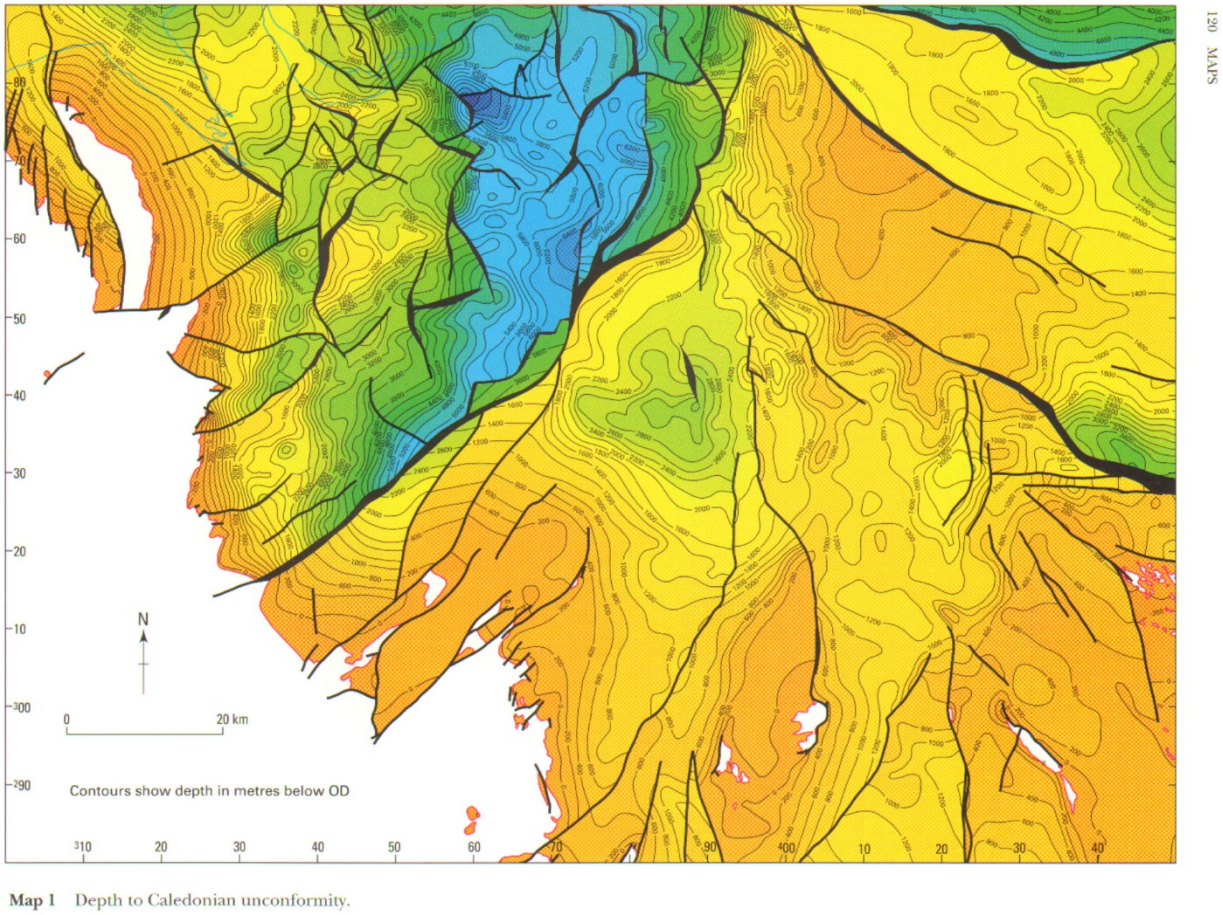


Figure 5. Depth to Caledonian unconformity for the south-west Pennine Basin and adjacent area (from Smith, et al. 2005). Contours are in 200 m intervals and are offset by geological faults, shown as black lines where they intersect the unconformity.

3.4 1:50 000 MAP SHEET CROSS-SECTIONS

The existing BGS 1:50 000 scale mapsheet series contains cross-sections that are held as scale-true 3D shapefiles. These were imported into the model workspace as short intersecting segments to guide construction of the UK3D cross-sections (currently these cross-sections are crossed by UK3D sections at 469 locations). In the GSI3D software section drawing window they were displayed as colour-coded cross ticks or arrows (Figure 6). Data from about 130 individual 1:50 000 scale cross-sections were utilised, although none were used in Northern Ireland extension.

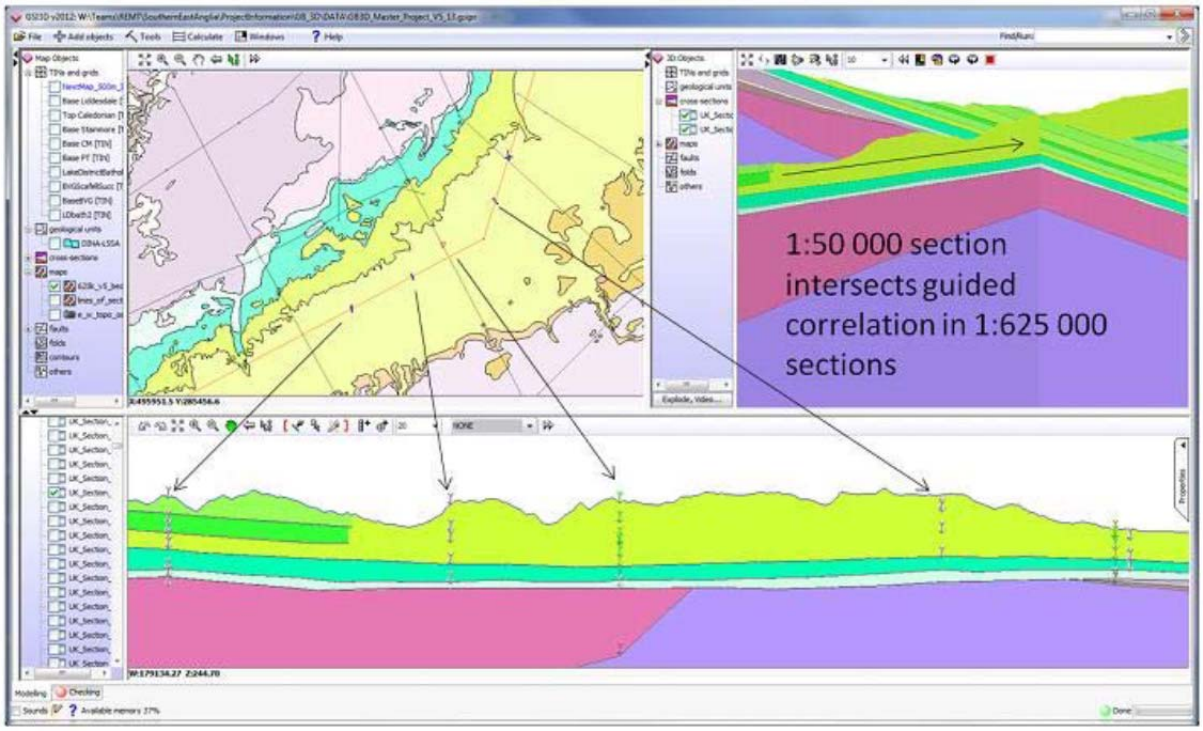


Figure 6. Section shown in green in the map view (upper left) and under construction in section view (below) showing cross ticks from 1:50 000 section intersections as guides (below). Notice the higher resolution stratigraphy available from in the 1: 50 000 section in the 3D view (upper right). NEXTMap Britain elevation data from Intermap Technologies.

3.5 LEGACY BGS 3D MODEL DATA

Existing 3D Geological Framework Models were used in UK3D_v2015 cross-section construction to guide the geologists' interpretations. Figure 7 shows the distribution of BGS models, including many that were considered in the development of UK3D_v2015.

The 3D model data is sliced along the lines of the UK3D_v2015 cross-sections and is displayed as a series of colour-coded traces in a raster back-drop in the GSI3D section construction window (Figure 8) so that the geologist could use it as a guide. In some areas poor model calculation is evident, particularly near to the ground surface where published map data has greater veracity, and in such cases the geologist chose to override the model information (Figure 8).

Slices through BGS 1:250 000 scale resolution GOCAD models based on the BGS subsurface memoir series of sedimentary basins in Northumberland-Solway, East Midlands, Southwest Pennines, Craven and Weald contributed much useful detail. In addition more detailed 1:50 000 scale resolution GSI3D models, mainly located in the London Basin and southern East Anglia-Essex were also utilised (Figure 7). These 1:50 000 scale GSI3D models are in the main shallow and so they only contribute information on the uppermost bedrock units. Details of the data utilised in the construction of these various models are contained in the separate reports and metadata documentation for the individual models. Where multiple resolution models were available the highest resolution model was usually preferred to guide the interpretation unless this was known to be less reliable. In the section tracker database (see below at Section 6) the models utilised in the construction of the individual UK3D_v2015 cross-section are systematically recorded.

In Northern Ireland, a crustal-scale model of the north of Ireland (Leslie et al. 2013), built as part of the Tellus Project (GSNI 2013), was used initially to guide construction of the UK3D_v2015

sections. The low resolution of this model however prohibited use of any depth picks in the new sections produced for this project.

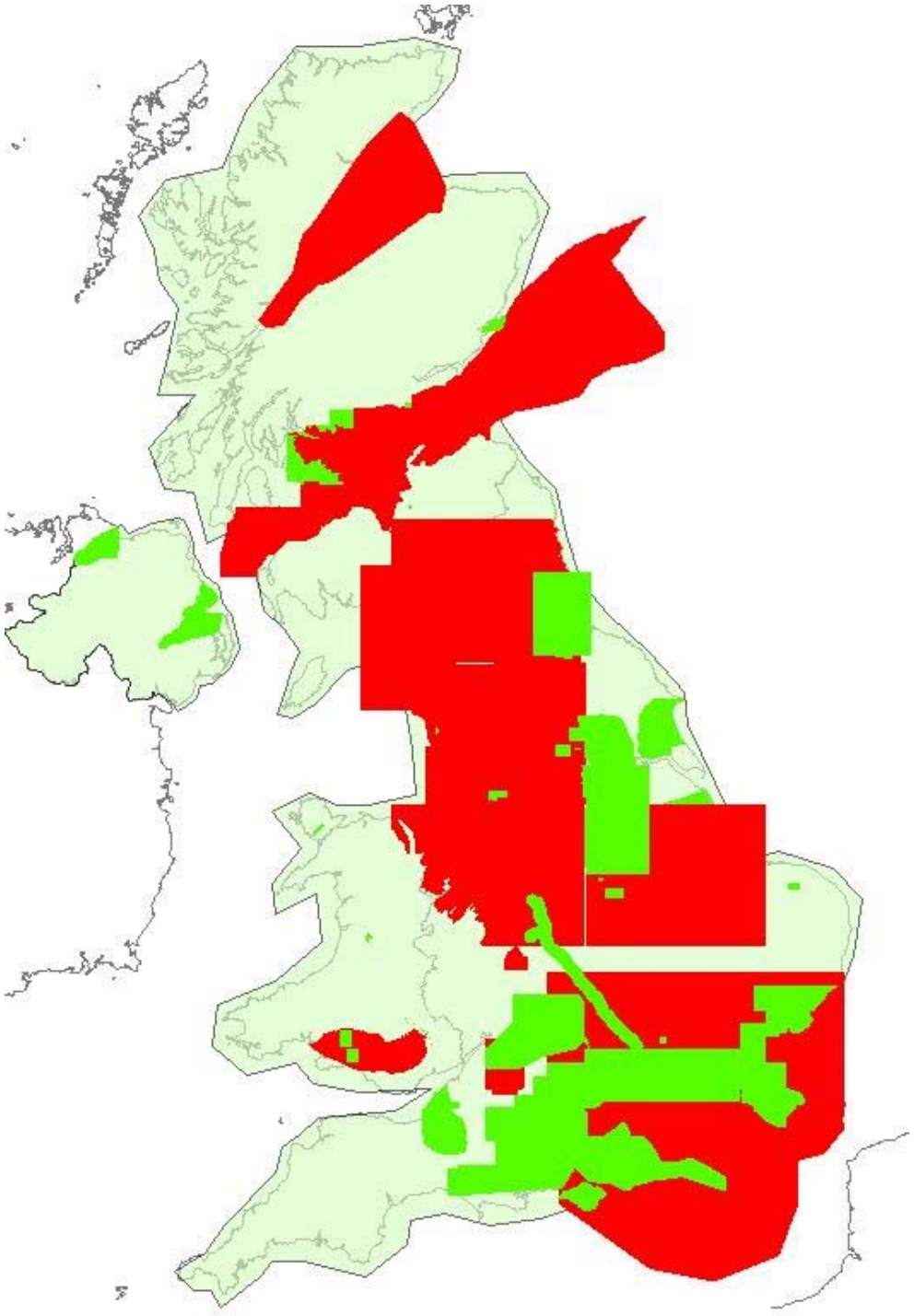


Figure 7. BGS 3D geological framework models at 2016, red shows regional and basin-scale models whereas the green areas contain more detailed shallower models, some of which include Quaternary models that were not incorporated in UK3D_v2015. Green areas enclosed within larger red polygons usually contain models of both types. The 1:625 000 scale resolution model with national coverage (pale green) is UK3D_v2015.

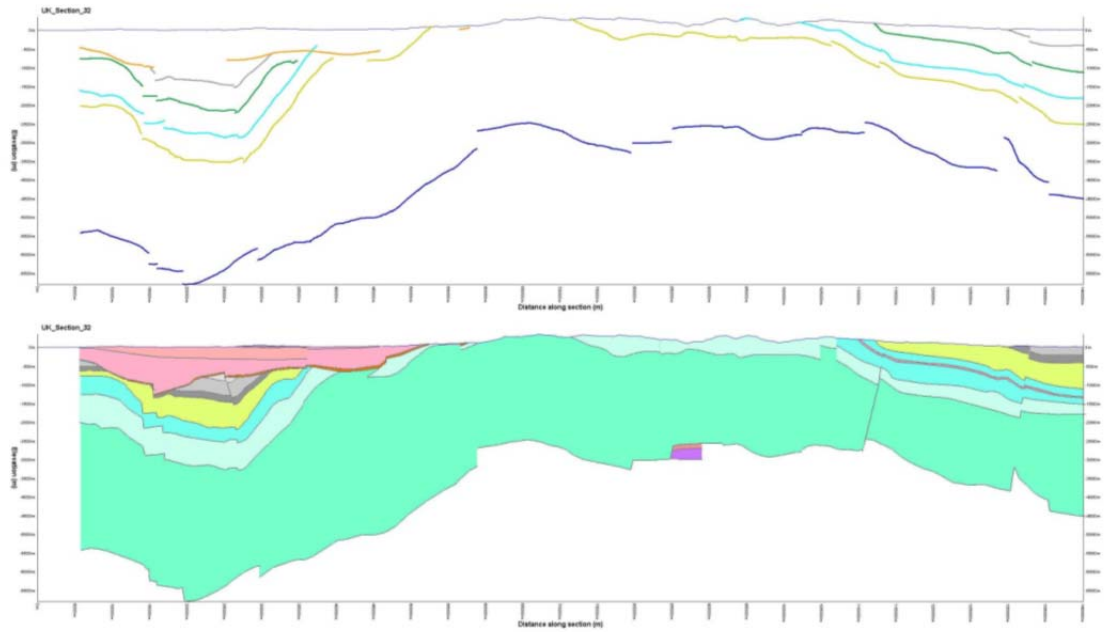


Figure 8. Attributed surfaces based on the Northumberland-Solway study (Chadwick et al. 1995) displayed along the line of an UK3D_v2015 section (above), the constructed section is shown below. Note that faults are shown as offsets in the stratigraphic surfaces. The colour schema for units in the two panels is not unified. NEXTMap Britain elevation data from Intermap Technologies.

3.6 BOREHOLES

An important aim of recent phases of construction of GB3D_v2014 and UK3D_v2015 was the incorporation of 372 deep boreholes to produce an enhanced model for England, Wales and Northern Ireland. This provides demonstrable 'tie-in' of the UK3D sections to key data points provided by the boreholes and hence enforces model confidence. BGS holds records of several thousand deep (>250 m in length) boreholes so it was necessary to select a representative subset of these to incorporate into the model.

A selection of non-confidential publicly available boreholes was chosen based on the need to achieve a good distribution of boreholes, utilize the deepest boreholes available, and include boreholes showing well-developed rock sequences. Boreholes with published interpretations were given preference. The final BGS borehole selection was used to guide section alignments.

The distribution of boreholes (Figures 9, 10) nevertheless remains uneven due to the variable data availability. This in turn reflects the regional geology and the presence or absence of economic drivers for the drilling of deep boreholes. So, for example, there are very few deep boreholes in Mid Wales, the Lake District and north Essex where all the available data were used. In contrast, several areas contain a wealth of deep borehole data such as Central and Eastern England making the selection of representative boreholes more difficult. In Northern Ireland most of the deep boreholes are present in Co. Antrim, around Lough Neagh and in Co. Fermanagh, with very few deep boreholes present elsewhere.

The selected boreholes were classified using the stratigraphic schema of the 1:625 000 scale mapsheets, in many cases existing BGS interpretations were simply accepted and copied across from the internal BGS Stratigraphic Surfaces and Borehole Geology databases. In other cases the boreholes were re-evaluated and a new interpretation was established. A comprehensive MsExcel spreadsheet of the boreholes was produced, giving their BGS Single Onshore Borehole Index (SOBI) name and number, their grid references and start height (Figure 11). This table comprises the GSI3D borehole index *.bid file. The downhole log spreadsheet identifies the units present identified by the BGS Lexicon codes and lithologies following the BGS Rock

Classification Scheme, each contains the depth from the start height to the base of the unit. This comprises the GSI3D borehole log *.blg file shown in Figure 12.

Details of the BGS Lexicon can be found at: **https://www.bgs.ac.uk/lexicon /**
For the Rock Classification Scheme at: **http://www.bgs.ac.uk/bgsrcs/**
and the SOBI database at: **http://www.bgs.ac.uk/products/onshore/sobi.html**

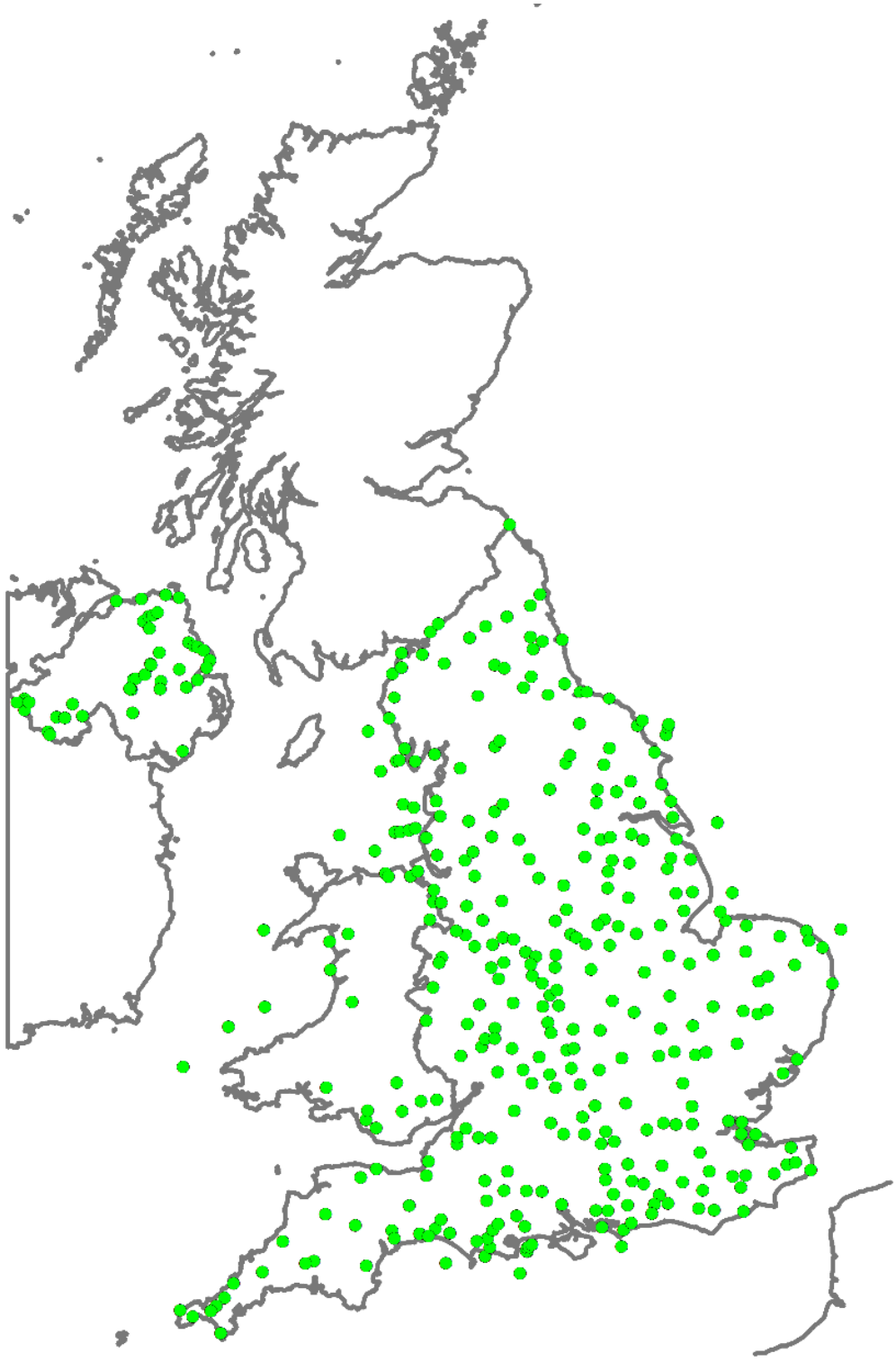


Figure 9. Locations of the 372 boreholes used in the UK3D_v2015 dataset.

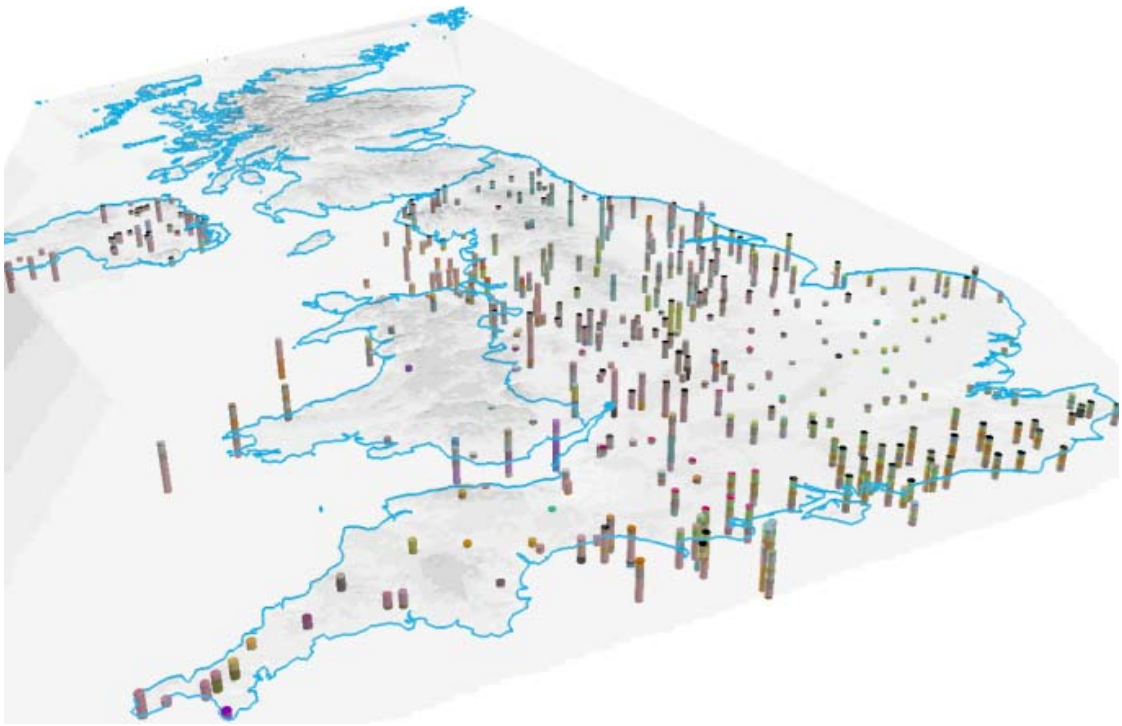


Figure 10. The classified borehole sticks showing stratigraphic interpretations. DTM source is described in section 3.1.

Borehole_Name	BNG_EASTING	BNG_NORTHING	START_HEIGHT	BGS_ID	REGNO
(FENNY STRATFORD) BLETCHLEY STATION	486840	233770	79.2	352236	SP83SE207
A.R.C.W. PENZANCE 3	146770	29280	8.79	644895	SW42NE1
ABBEY MILLS 1 GREENFIELD	319490	377570	15.24	140638	SJ17NE1
ACKLINGTON STATION	422103	601533	40.84	703110	NU20SW53
ALDBROUGH 1	525900	436900	17.68	1.6E+07	TA23NE7
ALFOLD 1	504337	134437	60.35	570473	TQ03SW5
ALLENHEADS 1	386041	545385	406.6	611505	NY84NE4
ALPORT 1	413612	391055	283.5	195972	SK19SW1
ALREWAS 1	418636	314067	51.5	194227	SK11SE7
APLEY BARN	434370	210660	85.1	320043	SP31SW3
ARCHERBECK	341568	578152	82	631058	NY47NW14
ASHDOWN 2	551070	129240	178.43	624146	TQ52NW12
ASHINGTON 1	512750	118230	26.43	578054	TQ11NW25
ASHOUR 1	556400	144239	81.4	1097251	TQ54SE67
ASHTON PARK	356330	171460	18.29	388665	ST57SE73
ASHWELL 1	528600	239000	59.4	534348	TL23NE1
ASKERN 1	456507	415008	7.62	116406	SE51NE1
ASTON TIRROLD	455790	187220	54	418808	SU58NE42
BACTON 2	633390	334490	15.5	518613	TG33SW1
BAGGERIDGE 5 PENN	389250	296540	132.01	275725	SO89NE6
BANK END MARYPORT	305130	538460	7.62	651388	NY03NE3
BARFORD	428300	262000	64.9	316625	SP26SE95
BARROCK PARK	346131	546596	95.93	639560	NY44NE28
BASSINGHAM 1	492080	360598	16.62	250736	SK96SW16
BATH ROAD 2 HARMONDSWORTH	506830	177130	25.9	573856	TQ07NE28
BATSFORD LOWER LEMINGTON	421500	234700	115.8	315500	SP23SW3
BAXTERS COPSE 1	491496	117731	76.5	434555	SU91NW10
BECKERMONDS SCAR	386362	480167	337	32882	SD88SE1
BECKINGHAM 1	479204	390351	4.77	240156	SK79SE4
BECKLEES	335166	571578	35.25	634007	NY37SE3
BECKTON GAS WORKS 4	542800	181650	3.81	946648	TQ48SW34

Figure 11. Extract from the Master MsExcel spreadsheet of the boreholes (*.bid) listing, from left to right, their name, start position in x and y, in British National Grid, elevation (z) in m relative to O.D., their unique BGS record id, and their BGS borehole registration number (SOBI database).

Borehole_Name	EASTING	NORTHING	StartHt	Base_of_Unit	Lithostrat	Lithology	Description	LEX_ROCK	CONTENT_CO	Interpreter	BGS_ID	RegionID_f	Red	Green	Blue	RGB
(FENNY STRATFORD) BLETCHLEY STATION	486840.0	233770.0	79.2	45.1	KLOX	MDSS	No Boge log, aka Fer	KLOX-MDSS	Null	Null	352236	Region12_13	117	148	0	38005
(FENNY STRATFORD) BLETCHLEY STATION	486840.0	233770.0	79.2	68.6	GOG	SLAR	Chipping Norton lst a	GOG-SLAR	Null	Null	352236	Region12_13	176	201	84	5556656
(FENNY STRATFORD) BLETCHLEY STATION	486840.0	233770.0	79.2	124.0	LI	MSLS	Bottom in Mid Lias	LI-MSLS	Null	Null	352236	Region12_13	0	84	201	13194240
(FENNY STRATFORD) BLETCHLEY STATION	486840.0	233770.0	79.2	125.0	UIIO	GN	TD Granite Age unkn	UIIO-GN	Null	Null	352236	Region12_13	201	0	117	7667913
A.R.C.W. PENZANCE 3	146770.0	29280.0	8.8	232.0	UDEV	MDSS	NULL	UDEV-MDSS	Null	RICHAS	644895	Region08	237	148	176	11572461
A.R.C.W. PENZANCE 3	146770.0	29280.0	8.8	300.2	DEV	HBSCH	NULL	DEV-HBSCH	Null	RICHAS	644895	Region08	237	117	148	9729517
ABBEY MILLS 1 GREENFIELD	319490.0	377570.0	15.2	21.3	SUPD	DRFTU	Null	SUPD-DRFTU	G3	PRWI	140638	Region18	255	255	255	16777215
ABBEY MILLS 1 GREENFIELD	319490.0	377570.0	15.2	57.3	PSLCM	MSCI	base defined by G. S	PSLCM-MSCI	G3	PRWI	140638	Region18	148	148	148	9737364
ABBEY MILLS 1 GREENFIELD	319490.0	377570.0	15.2	288.0	MG	MDSS	Includes G. Cumbrier	MG-MDSS	G3	PRWI	140638	Region18	237	176	0	45293
ABBEY MILLS 1 GREENFIELD	319490.0	377570.0	15.2	301.1	BHCR	MDCH	Null	BHCR-MDCH	G3	PRWI	140638	Region18	237	255	84	5570541
ABBEY MILLS 1 GREENFIELD	319490.0	377570.0	15.2	363.9	DINA	LMST	Null	DINA-LMST	G3	PRWI	140638	Region18	176	255	255	16777136
ACKLINGTON STATION	422103.0	601533.0	40.8	19.8	DRIFT	DRIFT	NULL	DRIFT-DRIFT	Null	DMILL	703110	Region07	0	0	0	0
ACKLINGTON STATION	422103.0	601533.0	40.8	66.2	PSLCM	MSCI	NULL	PSLCM-MSCI	Null	DMILL	703110	Region07	148	148	148	9737364
ACKLINGTON STATION	422103.0	601533.0	40.8	84.9	MG	MDSS	NULL	MG-MDSS	Null	DMILL	703110	Region07	237	176	0	45293
ACKLINGTON STATION	422103.0	601533.0	40.8	452.3	SMGP	LSSM	NULL	SMGP-LSSM	Null	DMILL	703110	Region07	176	201	201	13224368
ACKLINGTON STATION	422103.0	601533.0	40.8	563.0	AG	LSSA	NULL	AG-LSSA	Null	DMILL	703110	Region07	176	255	255	16777136
ALDBROUGH 1	525900.0	436900.0	17.7	45.7	DRFT	DRFTU	Null	DRFT-DRFTU	G3	JFORD	15627300	Region09	0	0	0	0
ALDBROUGH 1	525900.0	436900.0	17.7	530.4	CK	CHLK	Null	CK-CHLK	G3	JFORD	15627300	Region09	237	255	117	7733229
ALDBROUGH 1	525900.0	436900.0	17.7	553.2	HUCK	CHLK	Red Chalk Formation	HUCK-CHLK	G3	JFORD	15627300	Region09	117	201	0	51573
ALDBROUGH 1	525900.0	436900.0	17.7	600.5	CA	SDST	ie LOCR = lower creta	CA-SDST	G3	JFORD	15627300	Region09	54	255	117	7733046
ALDBROUGH 1	525900.0	436900.0	17.7	722.7	LI	UNKN	NB. no Upper / Middl	LI-UNKN	G3	JFORD	15627300	Region09	0	84	201	13194240
ALDBROUGH 1	525900.0	436900.0	17.7	741.6	PNG	UNKN	Null	PNG-UNKN	G3	JFORD	15627300	Region09	237	117	84	5535213
ALDBROUGH 1	525900.0	436900.0	17.7	923.5	MMG	UNKN	Null	MMG-UNKN	G3	JFORD	15627300	Region09	255	176	176	11579647
ALDBROUGH 1	525900.0	436900.0	17.7	1524.6	SSG	UNKN	Null	SSG-UNKN	G3	JFORD	15627300	Region09	255	176	201	13218047
ALDBROUGH 1	525900.0	436900.0	17.7	1643.2	ROX	UNKN	Lower Bunter Shale,	ROX-UNKN	G3	JFORD	15627300	Region09	255	176	148	9744639
ALDBROUGH 1	525900.0	436900.0	17.7	1714.2	BTH	UNKN	ie ZG	BTH-UNKN	G3	JFORD	15627300	Region09	54	255	224	14745398
ALDBROUGH 1	525900.0	436900.0	17.7	1940.1	EDT	UNKN	ie ZG	EDT-UNKN	G3	JFORD	15627300	Region09	255	117	0	30207
ALFOLD 1	504337.0	134437.0	60.4	5.2	Null	UNKN	Null	Null-UNKN	P	TMCM	570473	Region14_15	10	10	10	657930
ALFOLD 1	504337.0	134437.0	60.4	254.5	WC	MDST	Null	WC-MDST	P	TMCM	570473	Region14_15	201	224	148	9756873
ALFOLD 1	504337.0	134437.0	60.4	382.2	UTW	SDST	Null	UTW-SDST	P	TMCM	570473	Region14_15	237	237	54	3599853
ALFOLD 1	504337.0	134437.0	60.4	411.5	GRC	CAMDST	Null	GRC-CAMDST	P	TMCM	570473	Region14_15	117	201	84	5556597
ALFOLD 1	504337.0	134437.0	60.4	448.1	LTW	SDST	Null	LTW-SDST	P	TMCM	570473	Region14_15	237	201	117	7719405
ALFOLD 1	504337.0	134437.0	60.4	578.8	WDC	MDST	Null	WDC-MDST	P	TMCM	570473	Region14_15	148	148	84	5543060
ALFOLD 1	504337.0	134437.0	60.4	724.2	ASD	SDST	Null	ASD-SDST	P	TMCM	570473	Region14_15	117	176	237	15577205
ALFOLD 1	504337.0	134437.0	60.4	781.5	DSB	MDST	Null	DSB-MDST	P	TMCM	570473	Region14_15	50	50	50	3289650
ALFOLD 1	504337.0	134437.0	60.4	1121.4	LPB	CAMDST	Null	LPB-CAMDST	P	TMCM	570473	Region14_15	237	176	54	3584237
ALFOLD 1	504337.0	134437.0	60.4	1199.1	PL	SDST	Null	PL-SDST	P	TMCM	570473	Region14_15	255	176	0	45311
ALFOLD 1	504337.0	134437.0	60.4	1255.8	KC	CAMDST	Null	KC-CAMDST	P	TMCM	570473	Region14_15	237	117	0	30189

Figure 12. Extract from the downhole interpretation file (*blg) showing multiple entries for each borehole, key columns include no. 5 giving depth from the borehole start height in metres to the base of a unit, columns nos. 6 and 7 giving the BGS Lexicon and lithology codes, and column no.11 giving the initials of the interpreter.

3.7 GEOPHYSICAL DATA

Seismic data have not been used directly in the construction of the fence diagram however this source has been extensively utilised in the production of the various BGS 250K resolution GOCAD models based on the BGS subsurface memoirs (Figure 7). Where multiple resolution models were available the highest resolution model was used to guide the interpretation unless it was known to be less reliable.

In Northern Ireland, recently acquired, regional scale, high resolution, Tellus geophysical data sets (GSNI 2013) were used to improve the geological accuracy of the sections. The data proved particularly useful in the location of poorly exposed faults and to delimit the extent of concealed Palaeogene sills. In addition, regional gravity (Reay 2004) was used to constrain significant thickness variations associated with buried Permo-Triassic basins.

4 Model workflow

A standard GSI3D workflow (Kessler & Mathers 2004; Kessler et al. 2009) was followed for the construction of the cross-sections. The full network of section lines for UK3D_v2015 is shown in Figure 13. Construction of cross-sections is performed in the GSI3D section window. This displays all the required information including the topography along the section, the bedrock geology at surface or rockhead, boreholes, intersections of crossing sections with the intercepts for individual units, surface traces from existing models displayed as raster backdrops. Structure contour maps are displayed in the GSI3D map window which is dynamically linked to the section window.

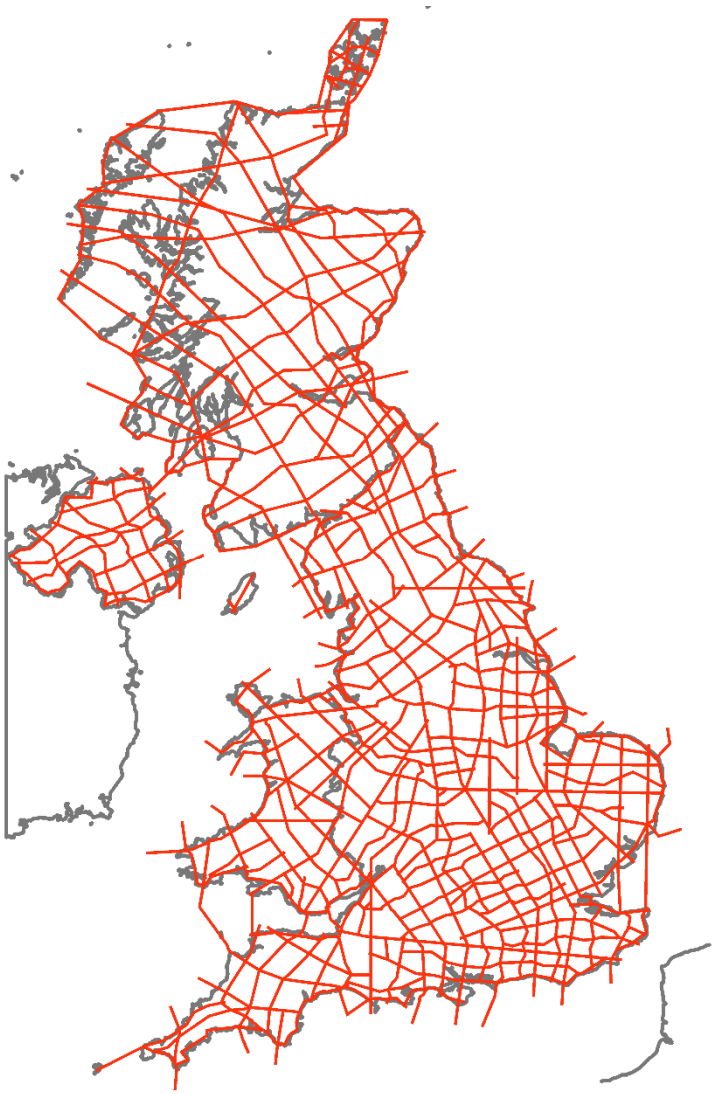


Figure 13. The completed network of cross-sections for the UK3D_v2015 dataset.

The geological units are normally constructed as unit base lines drawn in order going down the stratigraphic stack. The sections progressively colour up as the units are added.

Workspaces for section construction, including the alignments of all the revised, new and existing cross-sections, were prepared by the BGS data management team. Existing sections were cut and terminated at regional boundaries utilising a specially developed tool for use in GSI3D. Each regional geologist(s) then completed construction of their allocated set of cross-sections and checked them for internal consistency. The interpretations where then reviewed along the boundaries of regions by pairs of geologists to produce a consistent agreed interpretation from which a master dataset was compiled. The entire model was then reviewed for stratigraphic cohesion and consistency.

Geologists responsible for individual regions are listed in Table 1. The regional areas are shown in Figure 14 for which regional descriptions are available for regions 7−20 for download from http://www.bgs.ac.uk/research/ukgeology/regionalGeology/home.html. These geological summaries are intended to inform the general public of the geology in each of the regions covered by the model.

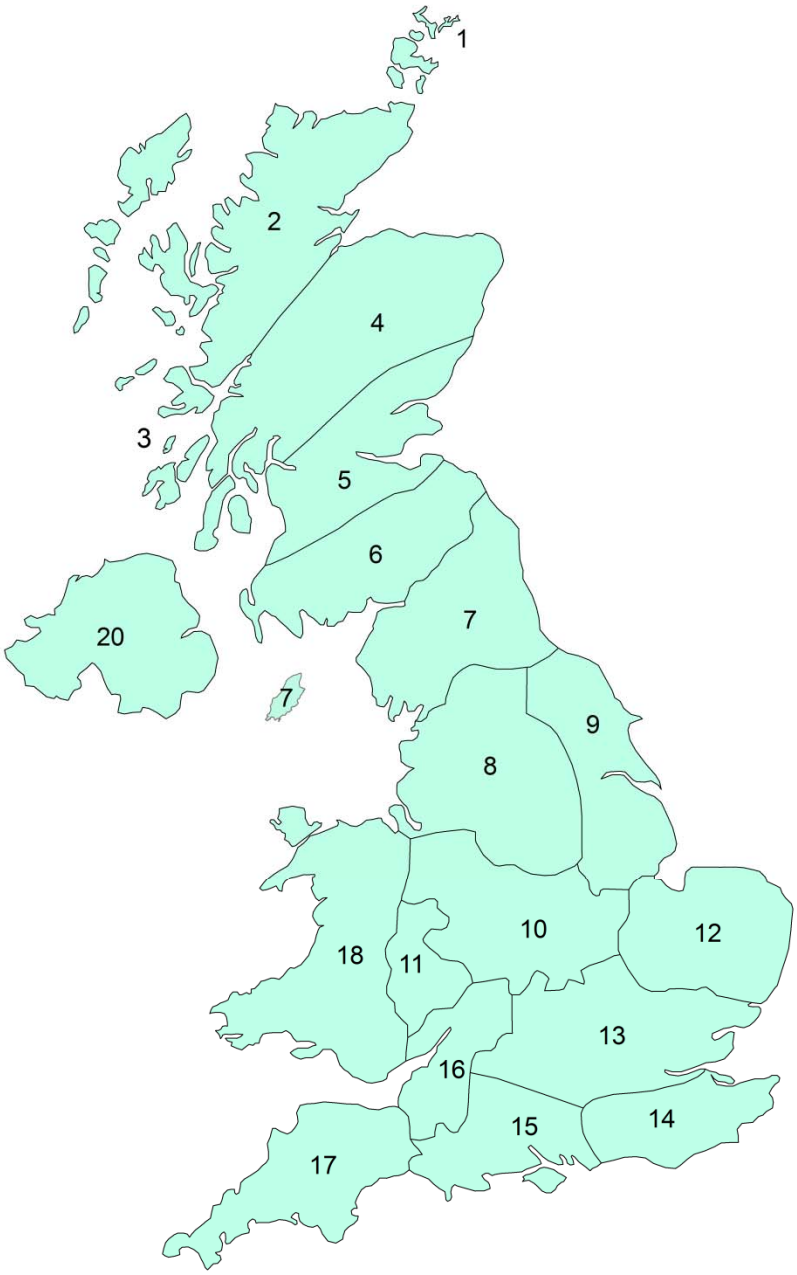


Figure 14. Areas based on the BGS Regional Guide Series for which regional summaries of the geology have been produced. No regional summaries were produced for Scotland (regions 1−6).

The revised model produced by this study is shown in Figure 15 and comprises part of the new UK3D_v2015 dataset. The dataset is freely available in a variety of formats from the BGS website at:
http://www.bgs.ac.uk/research/ukgeology/nationalGeologicalModel/GB3D.html

Table 1. QA roles and regional geologists for the areas in Figure 14.

Number	Region	Geologist(s)
1	Orkney & Shetland	Orkneys included in Northern Highlands
2	Northern Highlands	Hugh Barron / Clive Auton / Graham Leslie
3	Tertiary Volcanic Districts	Included in Northern Highlands
4	Grampian Highlands	Graham Leslie
5	Midland Valley of Scotland	Graham Leslie / Mike McCormac
6	South of Scotland	Graham Leslie / Mike McCormac
7	Northern England	David Millward / Colin Waters
8	Pennines & adjacent areas	Colin Waters
9	Eastern England	Jon Ford / John Powell
10	Central England	Mark Barron
11	Welsh Borders	Oliver Wakefield
12	East Anglia	Steve Mathers
13	London-Thames	Steve Mathers
14	Weald	Peter Hopson
15	Hampshire Basin	Peter Hopson
16	Bristol & Gloucester	Mark Barron
17	South West England	Richard Haslam / Poul Strange
18	North Wales and South Wales (combined)	David Schofield / Phil Wilby
20	Northern Ireland	Mark Cooper / Robert Raine
	Stratigraphic review	Colin Waters / Mark Barron / Peter Hopson / Steve Mathers
	England-Scotland border review	Colin Waters / David Millward
	QA and sign-off	Steve Mathers (England & Wales) Colin Waters (Northern Ireland) Diarmad Campbell (Scotland)

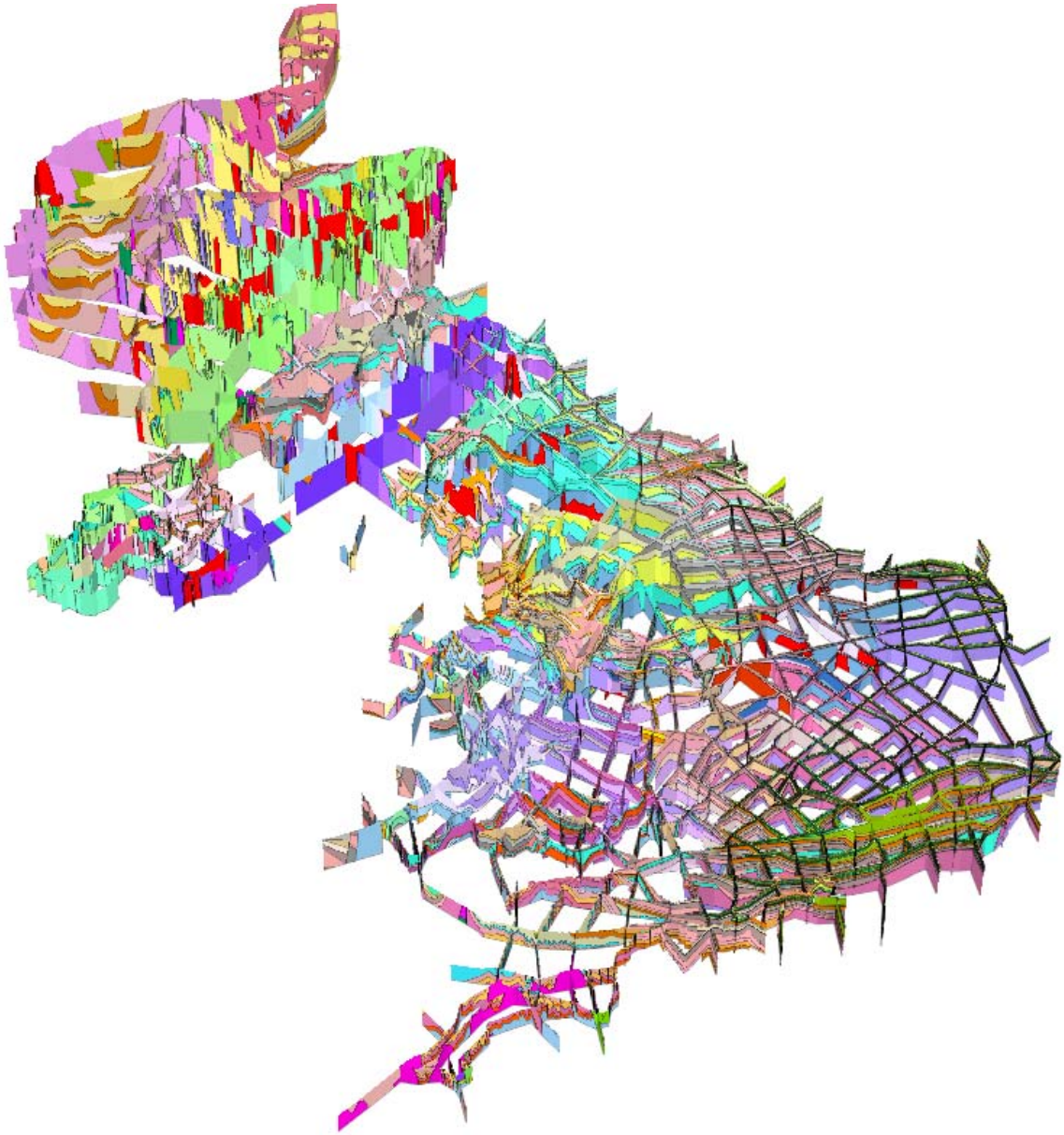


Figure 15. The revised cross–section framework included in the UK3D_v2015 dataset.

5 Metadata

Data sources consulted and decisions made in section construction were recorded in the specially designed Cross-Section Metadata Recording Database using MsAccess (Figures 16-18). This was formerly known as the GB3D Section Tracker (Mathers et al. 2014a and b). Figure 16 shows the main input form where all metadata details are held. Figure 17 shows a close up example of the diary entries (total over 3752) made for each individual cross-section, and Figure 18 shows part of the extensive list of data sources consulted. The sources were recorded section by section. There are 988 individual sources cited in this database including existing models, cross-sections, structural contour maps, scientific papers and BGS reports. The database also records the QA and approval decisions section by section.

The database was dynamically updated and was utilised by all the participating geologists simultaneously. It can be made available as required as an MsAccess database.

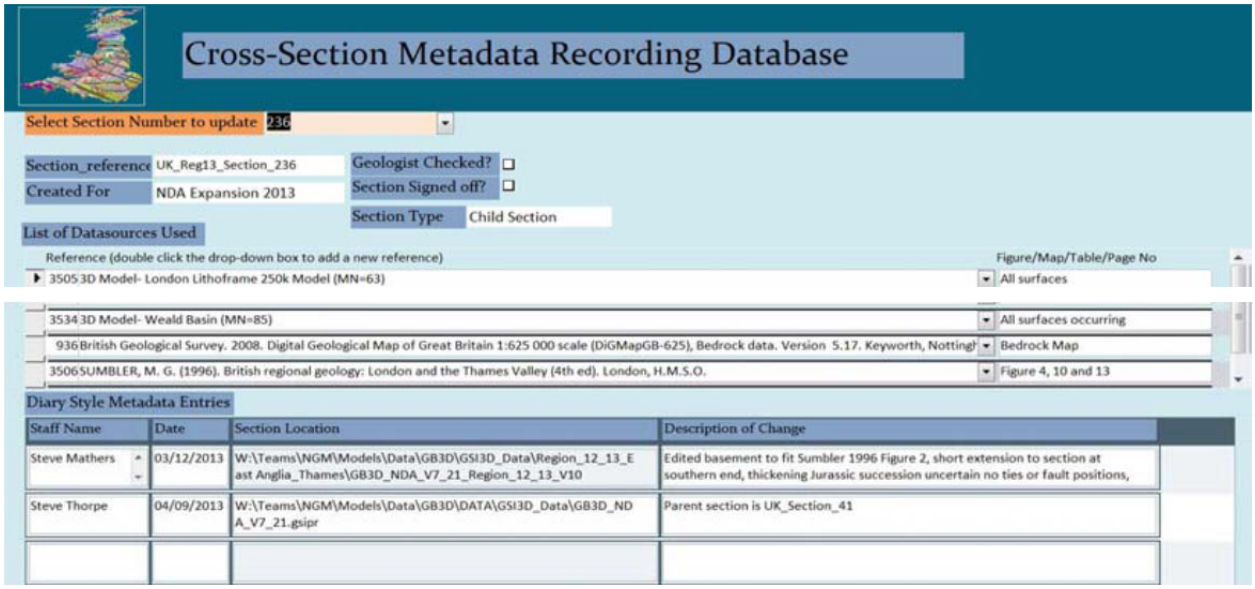


Figure 16. Cross-Section Metadata Recording Database main input form.

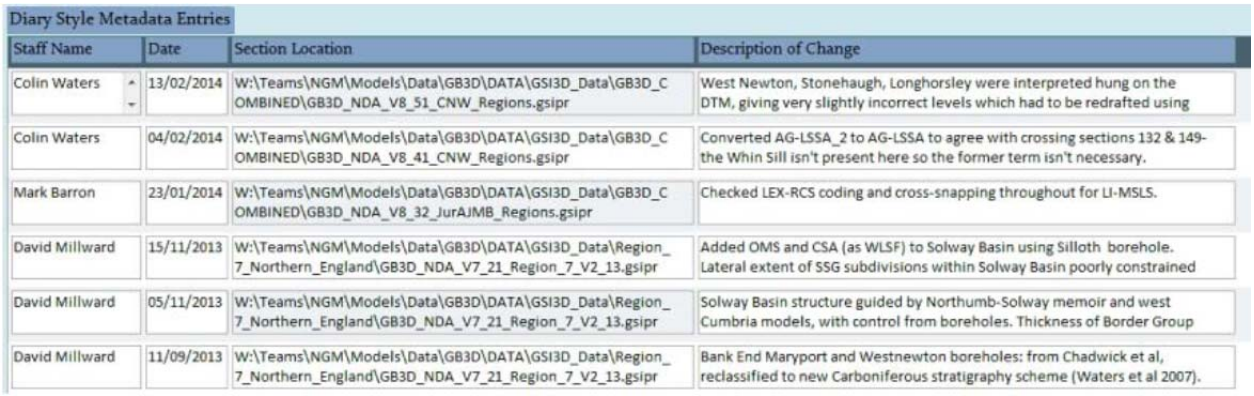


Figure 17. Example diary entries for one individual cross-section.

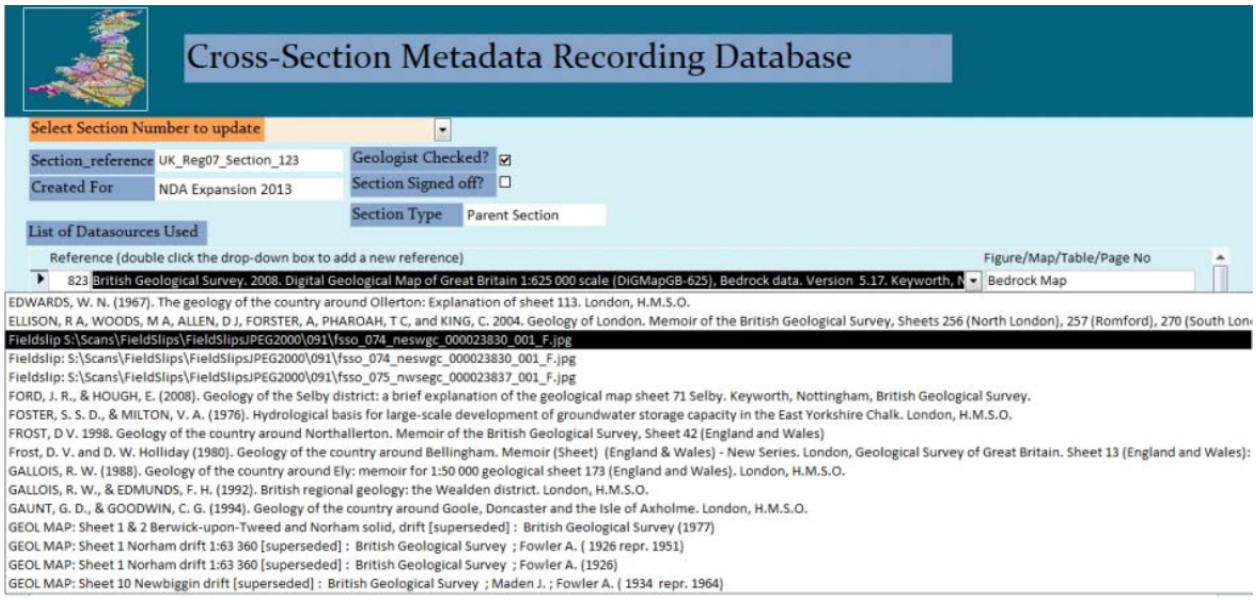


Figure 18. The sources used in individual section construction pull down list with 988 entries.

6 Model rules, use, limitations and uncertainty

6.1 MODEL RULES

- Wherever possible the 1: 625 000 scale bedrock geology linework and stratigraphy were adopted in the section construction. In practice it was necessary to simplify some of the detail in terms of minor intrusions, minor faults and lithological facies variations within individual units. In the nearshore area, where 1: 625 000 scale bedrock geology linework is not available, the 1:250 000 scale dataset was used. In Northern Ireland 1:10 000 scale bedrock linework was used locally to demonstrate the potential effects of faulting on the geometry of subsurface units.
- Significant faults are depicted as offsets of the stratigraphic units rather than as actual fault objects within the workspace.
- Superficial geology is excluded from the sections. This implies that where superficial deposits are present the bedrock unit floods up to the DTM (surface) in sections. In general the thickness of superficial deposits is insignificant at the intended model resolution.
- The depth cut off is variable depending on the nature of geology, it is generally 1.5 - 3 km but lies deeper where major aquifers and potential mineral or hydrocarbon sources are present within sedimentary basins.
- A false horizontal base at an arbitrary depth has been constructed for some units to provide a base for the section, these should not be interpreted as true bases for these units.
- Boreholes are hung from the given OD start height in most cases. Where a start height is not provided on the borehole log, the borehole was hung from the DTM.

6.2 USE OF THE MODEL

Appropriate applications for the UK3D_v2015 dataset include the following:

- geoscience communication and education to illustrate national and regional British geology (from the available download);
- illustrating national or regional bedrock geology overviews for scientific publications for widespread and/or non-specialist use e.g. radwaste (Powell et al. 2010), shale gas (Mathers et al. 2012a) with an intended resolution of use in the 1:250 000−1:1 million range;
- catchment-basin scale first-order calculated volumes of structurally simple stratified geological units performed in GSI3D and exported. These have been mainly used to-date for hydrogeological modelling;
- regional GIS projects including the extents (x,y) of individual geological units (generated for use in GIS from GSI3D).

6.3 LIMITATIONS

Limitations inherent in the UK3D_v2015 dataset preclude such applications as:

- detailed geological assessments of any kind, e.g. borehole, site or linear route prognosis;
- resource-reserve estimation and exploration of any kind;

- any representation or use outside the intended regional to national (1:250 000−1:1 million) resolution range.

6.4 MODEL UNCERTAINTY

With the exception of the 372 deep boreholes incorporated into the sections the model is not assessed in terms of uncertainty because it does not show the distribution of much of the other underpinning information including other boreholes, detailed surveys and seismic lines together with higher-resolution local and regional geological 3D models built using these primary datasets. The model was built using existing syntheses which themselves do not contain an assessment of uncertainty or metadata on data used and how it was interpreted.

7 Model availability

The dataset is provided as a free download in varied formats for educational and other not for profit uses. Further information about licensing the digital data for commercial usage is available on request from http://www.bgs.ac.uk/enquiries .

Since 2015 the UK3D_v2015 dataset has been served in various formats as free downloads from the BGS website:

http://www.bgs.ac.uk/research/ukgeology/NationalGeologicalModel/UKB3D.html

and the dataset for the completed GSI3D GB3D_V2012 model with a Data Object Identifier is available at:

http://www.bgs.ac.uk/research/ukgeology/nationalGeologicalModel/GB3D.html

The BGS LithoFrame Viewer version uses a calculated and encrypted GSI3D-built project workspace file. This viewer is a free browser for visualization of models and cross-sections. A good high-end graphics card, such as that used for gaming, is however essential for model visualization in this viewer.

Other formats are available for data visualization include 3D PDF, which can be read using Adobe Acrobat reader v6* onwards and KMZ for use in Google Earth (preferably v7* onwards) and fly-through movie files captured in the GeovisionaryTM software.

Downloads of correlation lines for the bases of some of the stratified and more continuous geological units (Pridoli and younger) are also available for the GOCAD and Petrel geological modelling packages.

The launch of the UK3D_V2015 datasets supplants the earlier version, it is available in the same formats at: http://bgs.ac.uk

8 References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

In recent years all NERC publications have been submitted for inclusion in the NERC Open Research Archive (NORA) details are at: nora.nerc.ac.uk/

British Geological Survey. 2007a. Bedrock Geology UK South 1:625,000 scale mapsheet 5th Edition.

British Geological Survey. 2007b. Bedrock Geology UK North 1:625,000scale mapsheet 5th Edition.

Chadwick, R.A., Holliday, D.W., Holloway, S. & Hulbert, A.G. 1995. The structure and evolution of the Northumberland-Solway Basin and adjacent areas. *Subsurface Memoir of the British Geological Survey*. (London: HMSO).

Geological Survey of Northern Ireland 2013. A guide to the Tellus data. Young, M. E. & Donald, A. W. (eds). Geological Survey of Northern Ireland, Belfast.

Jackson, A.A. 2008. Bedrock Geology UK South. British Geological Survey 84pp. ISBN 978 085272 586 3 http://nora.nerc.ac.uk/3708/

Kessler, H & Mathers S.J. 2004. Maps to models. *Geoscientist* 14/10 4-6. http://nora.nerc.ac.uk/983/

Kessler, H., Mathers, S.J. & H.-G. Sobisch. 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers & Geosciences*, 35, 1311–1321. http://dx.doi.org/10.1016/j.cageo.2008.04.005; http://nora.nerc.ac.uk/7207/1/Kessler_CG_GSI3D_article_final.pdf

Leslie, G., Cooper, M.R. & McConnell, B. 2013. Solid Achievement. *Geoscientist*, Feature Article, April, 10-15.

Mathers, S.J., Bloomfield, J.P Smith N J P & Terrington R. 2012a. iHydrogeology WP1: A revised geological fence diagram for England and Wales. *British Geological Survey Internal Report*, CR/12/056. 25pp.

Mathers, S,J., Terrington, R. L., Waters, C.N. & Leslie, A.G. 2012b. Model metadata report for GB3D National Bedrock Fence Diagram GB3D_v.2012. *British Geological Survey Open Report* OR/12/079 14pp. http://nora.nerc.ac.uk/20686/

Mathers, S.J., Terrington, R.L., Waters, C.N. & Leslie, A.G. 2014a. GB3D – a framework for the bedrock geology of Great Britain. Geoscience Data Journal 3,9.

http://onlinelibrary.wiley.com/doi/10.1002/gdj3.9/full

Mathers, S.J., Terrington, R.L., Waters, C.N. & Thorpe, S. 2014b. The construction of a bedrock geology model for England and Wales. *British Geological Survey Open Report*, OR/14/039. 23pp. http://nora.nerc.ac.uk/507670/

Powell, J.H., Waters, C.N., Millward, D, & Robins, N.S. 2010. Managing Radioactive Waste Safely: Initial Geological Unsuitability Screening of West Cumbria. British Geological Survey Research Report, CR/10/072. 73pp. http://nora.nerc.ac.uk/15505/

Reay, D. M. 2004. Geophysics and Concealed Geology. In: The Geology of Northern Ireland-Our Natural Foundation. Mitchell, W. I. (ed). Geological Survey of Northern Ireland, Belfast.

Schofield D I, Ambrose, K , Barron, A J M , Hopson, P M , Mathers, S J, Myers, A H, Waters, C N & Terrington, R L 2012. A geological fence diagram for England and Wales. BGS Open Report OR/12/081. http://nora.nerc.ac.uk/20480/

Smith, NJP, Kirby, GA, & Pharoah, TC. 2005. Structure and evolution of the south-west Pennine Basin and adjacent area. Subsurface Memoir of the British Geological Survey, 129pp.

Stone, P. 2008. Bedrock Geology UK North. British Geological Survey 88pp. ISBN 978 085272 585 6 http://nora.nerc.ac.uk/3709/