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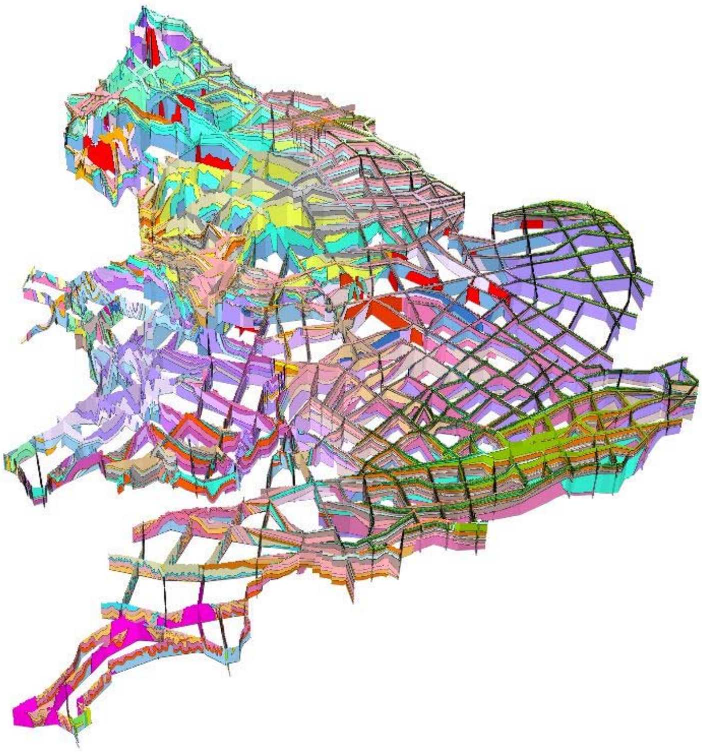
The construction of a bedrock geology model for England and Wales.

Geology and Regional Geophysics Programme

BGS Open Report OR/14/039



BRITISH GEOLOGICAL SURVEY

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The construction of a bedrock geology model for England and Wales.

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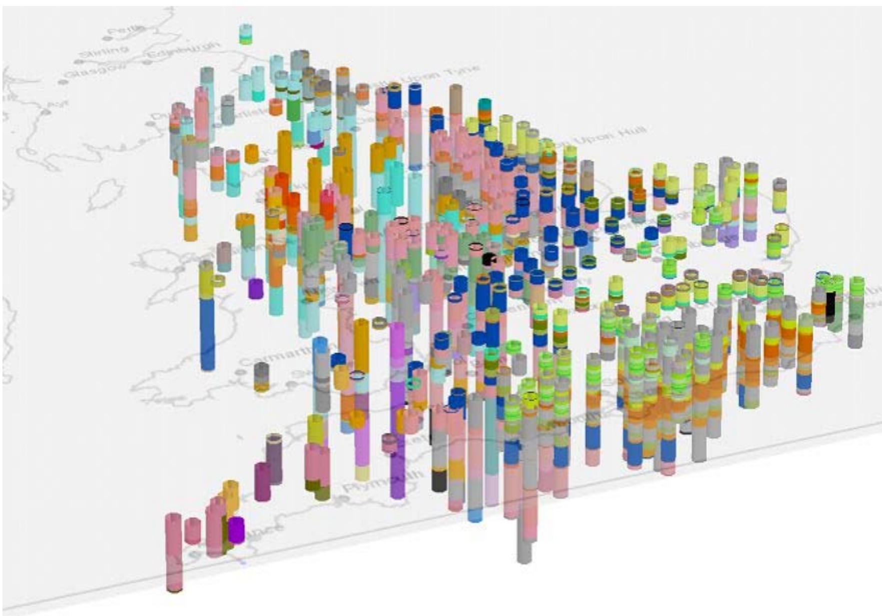

Keyworth, Nottingham British Geological Survey 2014

Keywords: 3D Model, Cross-sections, bedrock geology, England, Wales

Front cover The England and Wales bedrock model

Frontispiece The coded borehole sticks that inform the model

Bibliographical reference

MATHERS, S.J., TERRINGTON, R.L, WATERS, C.N. & THORPE, S. 2014 The construction of a bedrock geology model for England and Wales. *British Geological Survey Open Report*, OR/14/039. 23pp.

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

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Executive Summary

Government policy for the long-term management of the UK's higher-activity radioactive waste is geological disposal as outlined in the 2008 Managing Radioactive Waste Safely (MRWS) White Paper. The Government remains firmly committed to this policy and continues to hold the view that the best means of selecting a site for a geological disposal facility (GDF) is an approach based on voluntarism and partnership.

Feedback from a wide range of stakeholders has indicated that a robust presentation of what is known, and what is not known, about the geology of any prospective area is needed at an early stage in the MRWS process. The existing BGS GB3D model provides the only nationally consistent representation of the bedrock geology of Great Britain to depths of at least 1km. The links between this dataset and the underpinning geological evidence needed to be strengthened and rigorous peer review performed to enable an enhanced dataset to inform the MRWS process.

So the objective of this study was to further develop the GB3D model in England and Wales by the incorporation of about 300 deep boreholes into the existing framework of cross-sections, re-route some sections to incorporate the borehole data and provide additional sections to densify the network in order to produce a robust, verifiable and defensible dataset.

The appropriate applications for the revised model are for general and geoscience education to illustrate the national and regional bedrock geology of England and Wales to a depth of at least 1

km with an intended resolution of use in the 1:250 000 to 1:1Million 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 GB3D_v2014 supersedes the earlier 2012 version for England and Wales. The Scottish portion of the model remains unchanged except in the Borders area where editing was required to ensure consistency with the new interpretation in Northern England. The new dataset is a wholly owned BGS product and as with its forerunner it is freely available from the BGS website http://bgs.ac.uk as downloads in a variety of formats.

This dataset has been extensively peer reviewed and is now intended to act as a resource to inform the MRWS process.

1 Background to the study

The Government remains firmly committed to geological disposal as the right policy for the long-term safe and secure management of higher-activity radioactive waste, and continues to hold the view that the best means of selecting a site for a geological disposal facility (GDF) is an approach based on voluntarism and partnership.

In line with Secretary of State Edward Davey’s written Ministerial statement of 31 January 2013, Government has been considering what lessons can be learned from the experiences of the MRWS programme in West Cumbria and elsewhere.

Feedback from a wide range of stakeholders has indicated that a robust presentation of what is known and what is not known about the geology of any area wishing to learn more about the MRWS process will be needed at an early stage in the process. The BGS GB3D fence diagram model provides the only nationally consistent representation of the bedrock geology of England and Wales to depths of at least 1km. It is recognised that the links between this dataset and the underpinning geological evidence would need to be strengthened and rigorous peer review performed to enable an enhanced GB3D dataset for England and Wales to inform the MRWS process.

The scope of the work was as follows:

- Identifying about 300 publicly available deep boreholes which represent the geological structure of England and Wales and have been adequately classified using stratigraphic picks corresponding to the resolution of the GB3D model;
- Adjusting segments of the existing GB3D cross-sections and producing further cross-sections to incorporate these deep boreholes. In addition a few more sections would be

constructed in previously poorly represented regions or areas where the geology is extremely diverse.

- Assembling detailed metadata and compiling legacy metadata on sources utilised in the construction of the GB3D cross-sections in particular including underpinning higher-resolution 3D models.

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 has not been extended at present to include Shetland or Northern Ireland.

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 fracking on aquifers (Mathers et al. 2012a). The final model produced was the GB3D_v2012 dataset (Figures 2 and 3). 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.

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; 2014) and in this report.

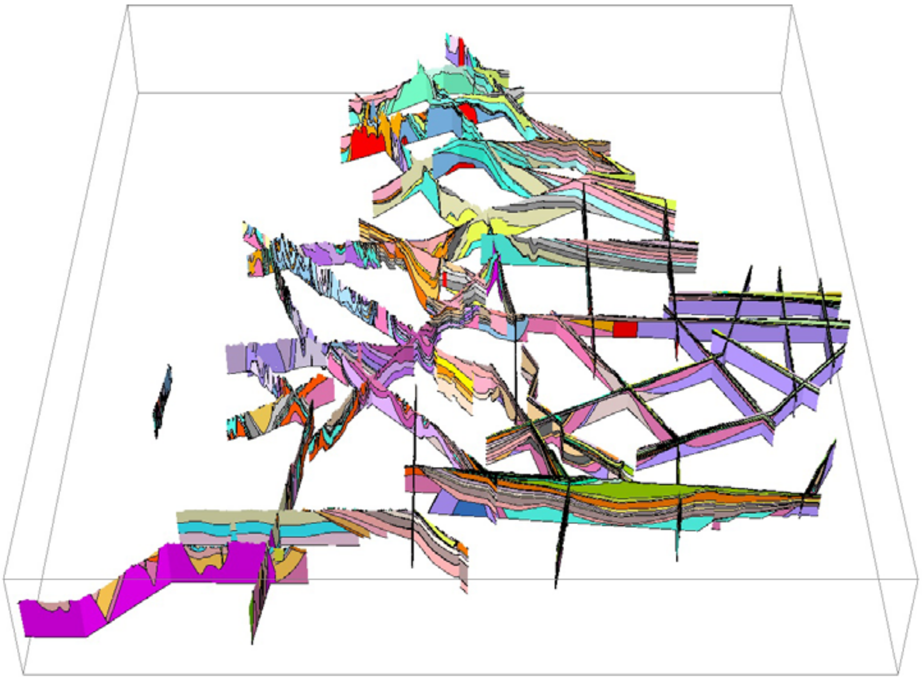


Figure 1. The initial fence diagram for England and Wales as delivered to the EA in 2010 (from Schofield et al. 2012)

Figure 2. The completed network of cross-sections for the GB3D_v2012 dataset

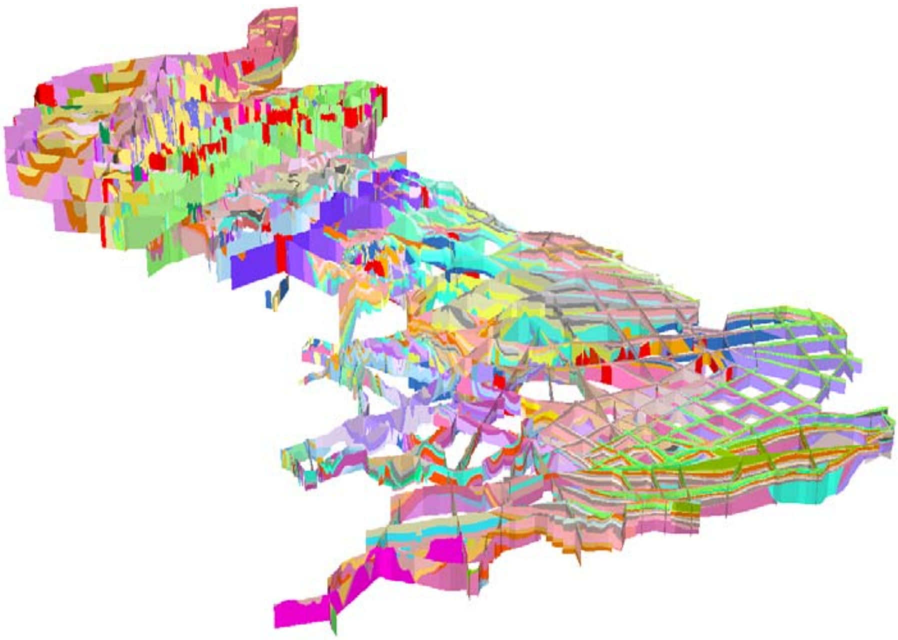


Figure 3. The completed GB3D_v2012 model from the southwest

This study extends 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 (see Figure 4).

Figure 4 Sections in England and Wales included in GB3D_v2012 release (red), those segments retained for the new GB3D_2014 model (yellow) and the completed framework including the new sections for GB3D_2014 (green). Note the section alignments for Scotland remained throughout as in Figure 2.

3 Datasets used in the model

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

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 comprising 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 the Isle of Man SRTM (Shuttle Radar Topography Mission data) data at 75 m resolution.

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 5). This data is held by BGS as ESRI shape files.

Figure 5. Printed version of the BGS 1:625 000 scale bedrock geological map data published as two mapsheets.

Some of the detail on these mapsheets 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 geology portrayed on these mapsheets is described in two accompanying booklets (Jackson, 2008; Stone, 2008).

Within the cross-sections the two principle 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 EA.

Structural contour plots

The structure contour plots (e.g. Figure 6) utilised to inform the cross-section construction are mainly derived from the BGS Subsurface Memoir and 50K 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 together with a record of which individual sections utilised each of these sources (see Section 6 below).

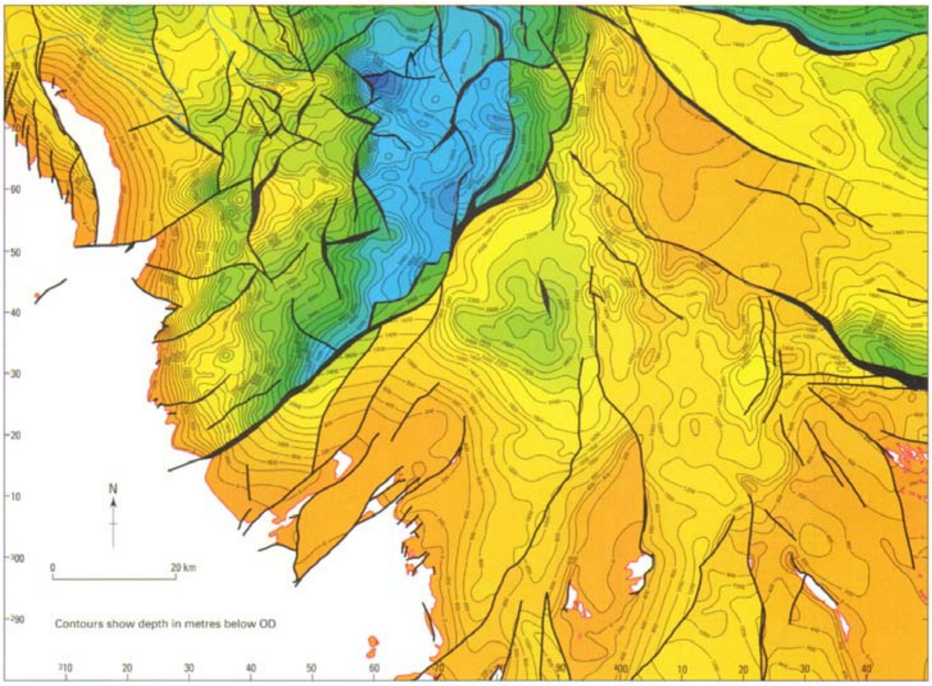


Figure 6. Depth to Caledonian unconformity for the south-west Pennine Basin and adjacent area (from Smith et al. 2005). Contours are in 200 m intervals and are offset by geological faults, shown as black lines where they intersect the unconformity. OS topography © Crown Copyright

BGS 1:50 000 Mapsheet Cross-Sections

The existing BGS 1:50 000 scale mapsheet series contains cross-sections that are held as 3D shapefiles. These were imported into the model workspace as short intersecting segments to guide construction of the GB3D cross-sections. In the GSI3D software section drawing window they are displayed as colour-coded cross ticks or arrows (Figure 7). Data from about 130 individual 1:50 000 scale cross-sections were utilised; these are listed in the section tracker database against the individual sections that they inform (see Section 6 below).

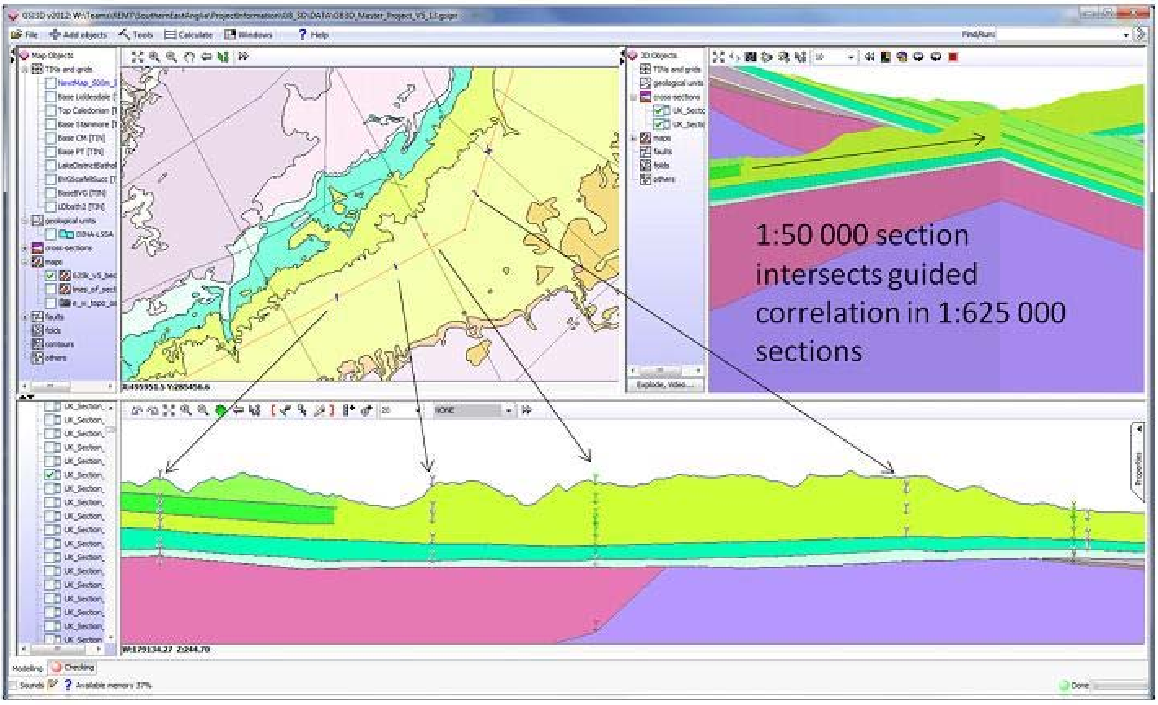


Figure 7. Section shown in green in the map view (upper left) and under construction in section view (below) showing cross ticks from 1:50 000 section intersections as guides (below). Notice the higher resolution stratigraphy available from in the 1: 50 000 section in the 3D view (upper right). NEXTMap Britain elevation data from Intermap Technologies.

Legacy BGS 3D Model Data

Existing 3D Geological Framework Models were used in GB3D cross-section construction to guide the geologist's interpretations. Figure 8 shows the distribution of models used. A shapefile with attribute information about each of these models is stored in the BGS Geoscience Data Index (GDI), at present this database is only available internally to BGS staff.

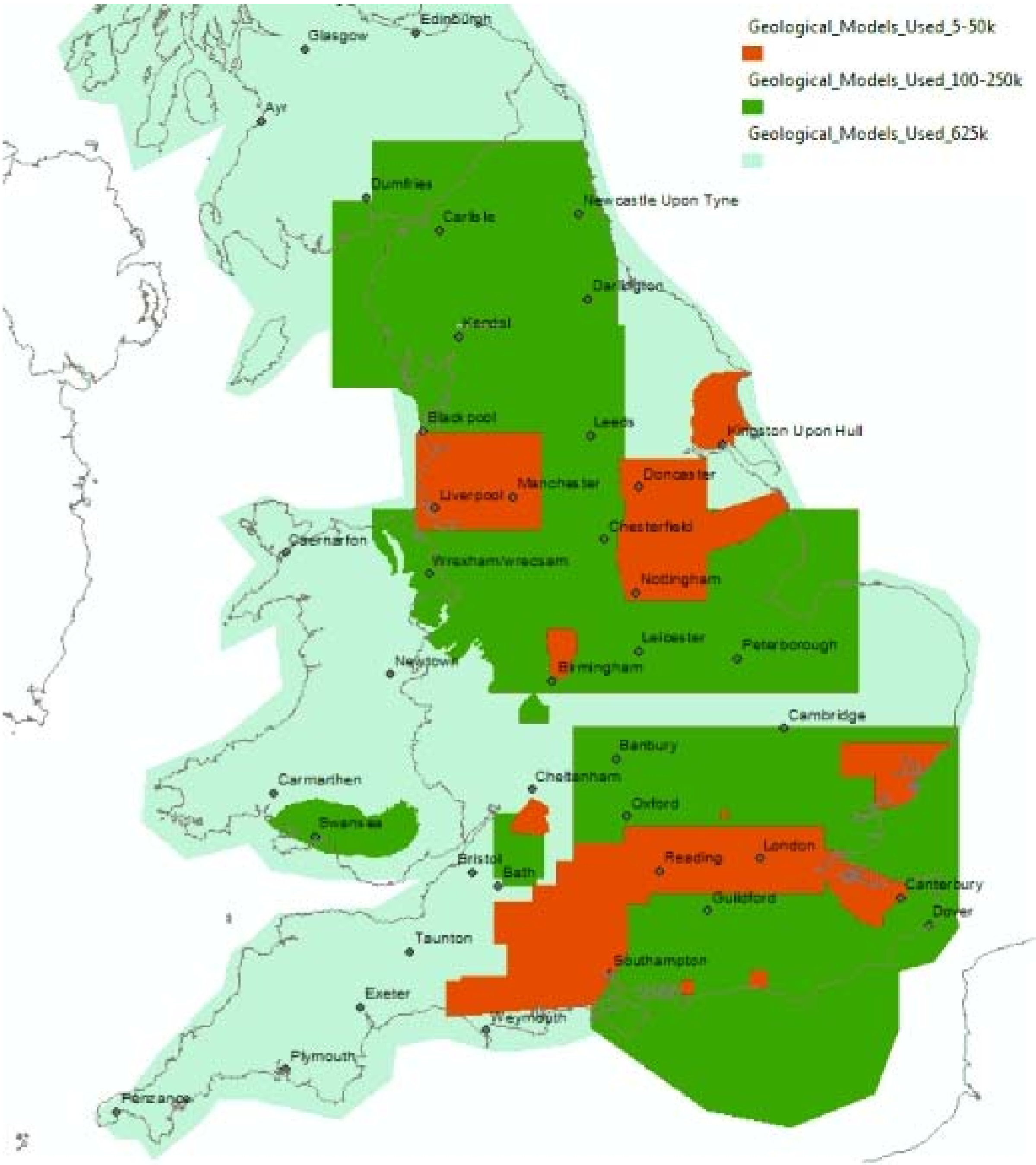


Figure 8. BGS 3D geological framework models in green show regional and basin-scale low-resolution models whereas the red areas contain more detailed higher resolution shallower models. Red areas enclosed within larger green polygons contain models of both types. The 625k resolution model with national coverage is GB3D.

The 3D model data is sliced along the lines of the GB3D cross-sections and is displayed as a series of colour-coded traces in a raster back-drop in the GSI3D section construction window (Figure 9) 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 9).

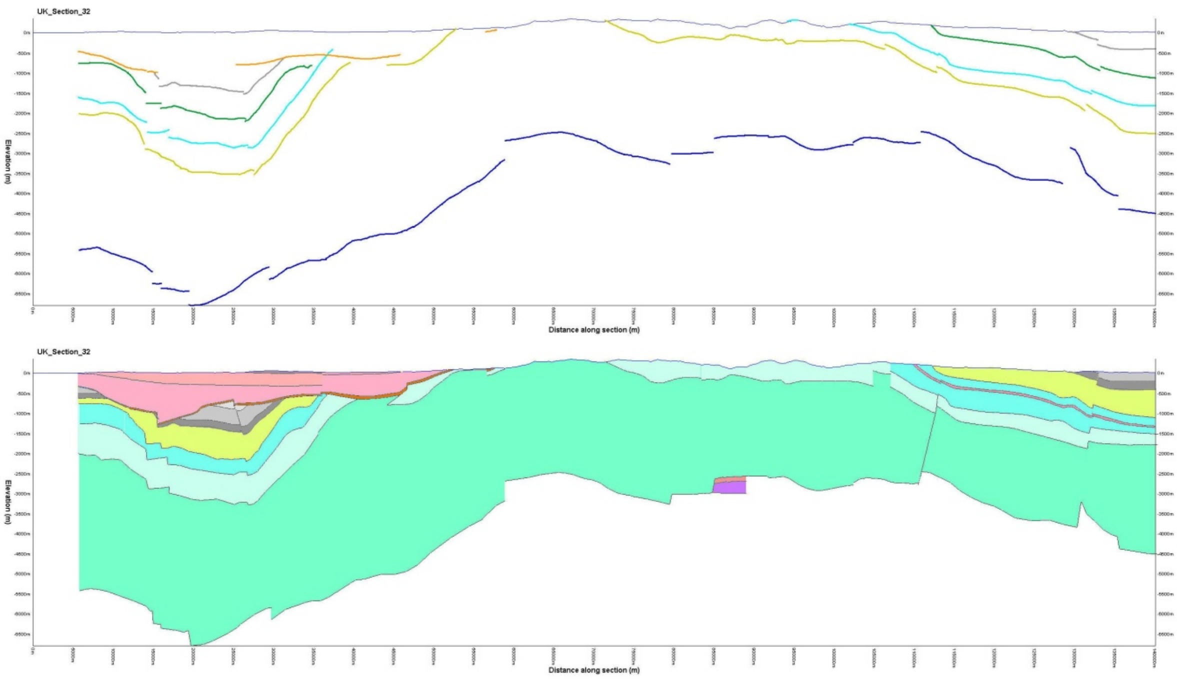


Figure 9. Attributed surfaces based on the Northumberland-Solway study (Chadwick et al. 1995) displayed along the line of a GB3D section (above), the constructed section is shown below. Note that faults are shown as offsets in the stratigraphic surfaces. The colour schema for units in the two panels is not unified. NEXTMap Britain elevation data from Intermap Technologies.

Slices through BGS 250K 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 50K resolution GSI3D models, mainly located in the London Basin and southern East Anglia-Essex were also utilised (Figure 9). These 50K 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 GB3D cross-section are systematically recorded.

4 Boreholes

The principal aim of this recent phase of GB3D construction (2013-14) was the incorporation of 314 deep boreholes to produce an enhanced model for England and Wales. BGS holds records of several thousand deep (>250m) boreholes so it was necessary to select a representative subset of these to incorporate into the model.

Quotas were allocated to each regional area based on the region size, geological complexity and in some cases data availability. A selection of non-confidential publicly available boreholes were 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 initial BGS borehole selection was presented, region by region, to the NDA and their independent peer review panel and agreement was reached on the 314 boreholes to be used (Figure 10, 11) and the revised section alignments (Figure 4).

The distribution of boreholes (Figure 10, 11) 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.

The selected boreholes were classified using the stratigraphic schema of the 1:625 000 scale mapsheets, in many cases existing 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**

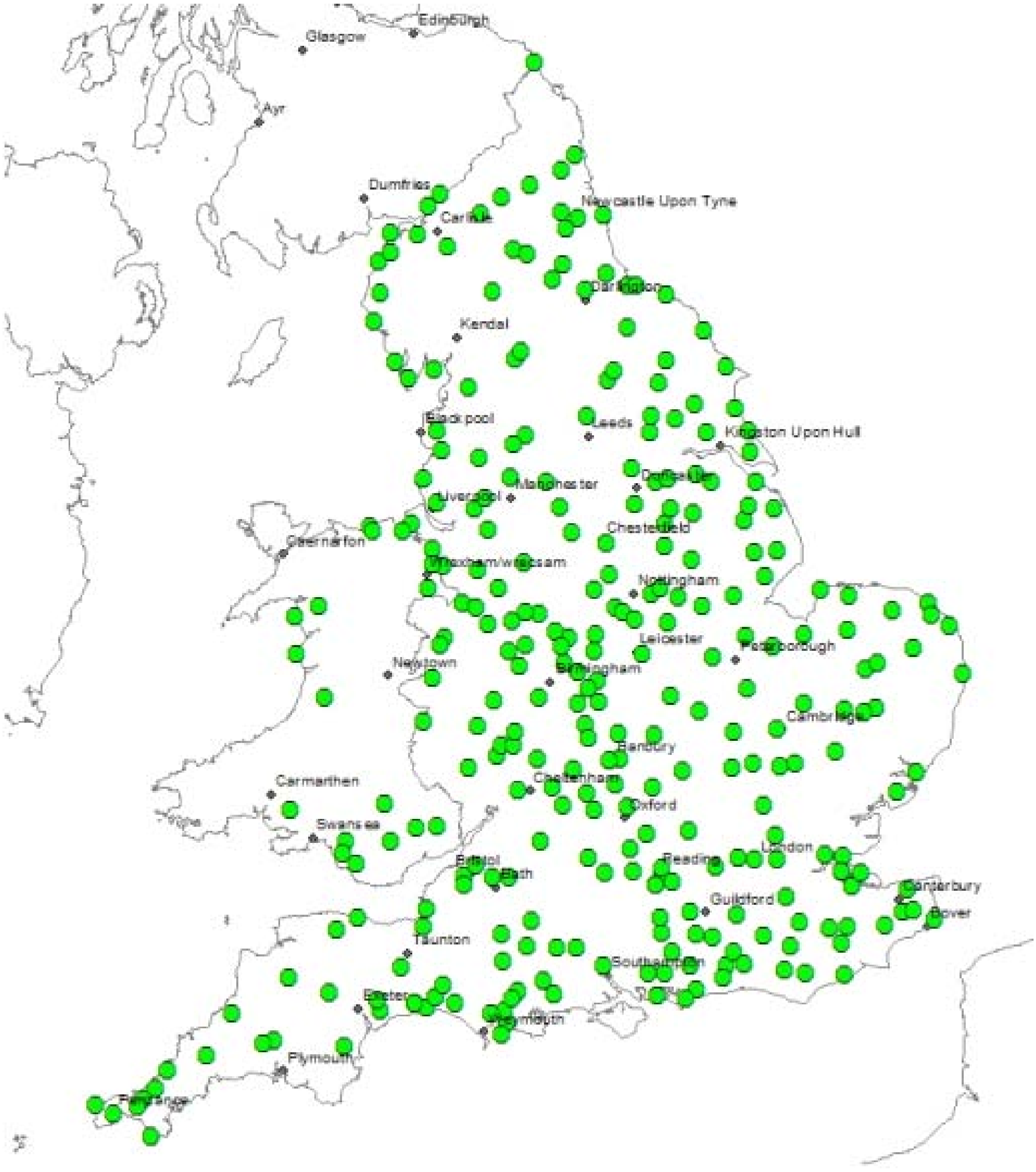


Figure 10 Locations of the 314 boreholes used in the GB3D_v2014 dataset

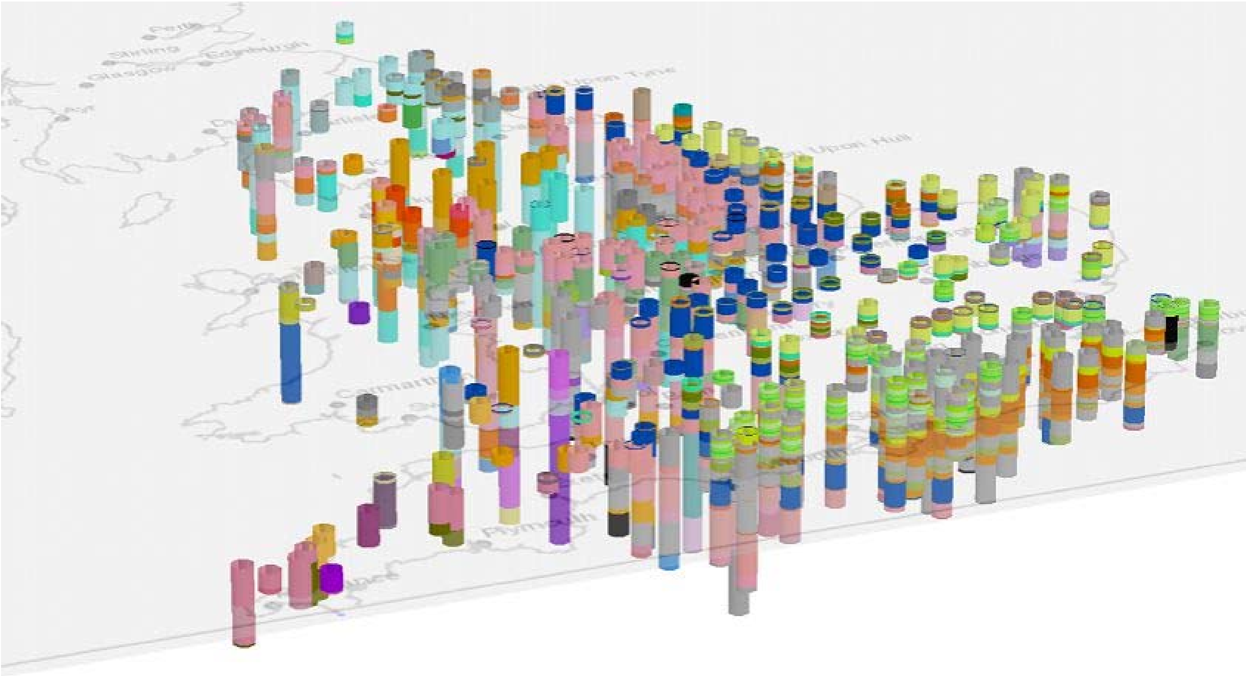


Figure 11 The classified borehole sticks

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 12 Master excel 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 Fen	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, t	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 13 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.

5 Model workflow

A standard GSI3D workflow (Kessler & Mathers 2004; Kessler et al. 2009) was followed for the construction of the cross-sections.

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.

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

Workspaces for section construction were prepared by the data management team including the alignments of all the revised, new and existing cross-sections. 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 as follows, units to base of Palaeogene by Steve Mathers, Cretaceous by Peter Hopson, Jurassic by Mark Barron, and all older units by Colin Waters. The entire dataset was then signed off by Steve Mathers as project manager. The checking and sign-off are also recorded in the section database.

Geologists responsible for individual regions are listed in Table 1 and the regional areas are shown in Figure 14.

The revision of the England-Scotland border area was finally completed and the new GB3D_V2014 dataset was compiled.

Figure 14 Areas based on the BGS Regional Guide Series

Table 1 Regional geologists, for the areas in Figure 14.

Region	**Geologist(s)**
Northern England	David Millward
Pennines & adjacent areas	Colin Waters
Eastern England	Jon Ford
Central England, and Bristol & Gloucester	Mark Barron
Welsh Borders	Oliver Wakefield
South West England	Richard Haslam
Wales	David Schofield, Phil Wilby
Hants Basin, and Weald	Peter Hopson
East Anglia, and London-Thames	Steve Mathers
Stratigraphic review	Colin Waters, Mark Barron, Peter Hopson, Steve Mathers
England-Scotland border review	Colin Waters, David Millward
QA and sign-off	Steve Mathers

The revised model produced by this study for England and Wales is shown in Figure 15 and comprises part of the new GB3D_v2014 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

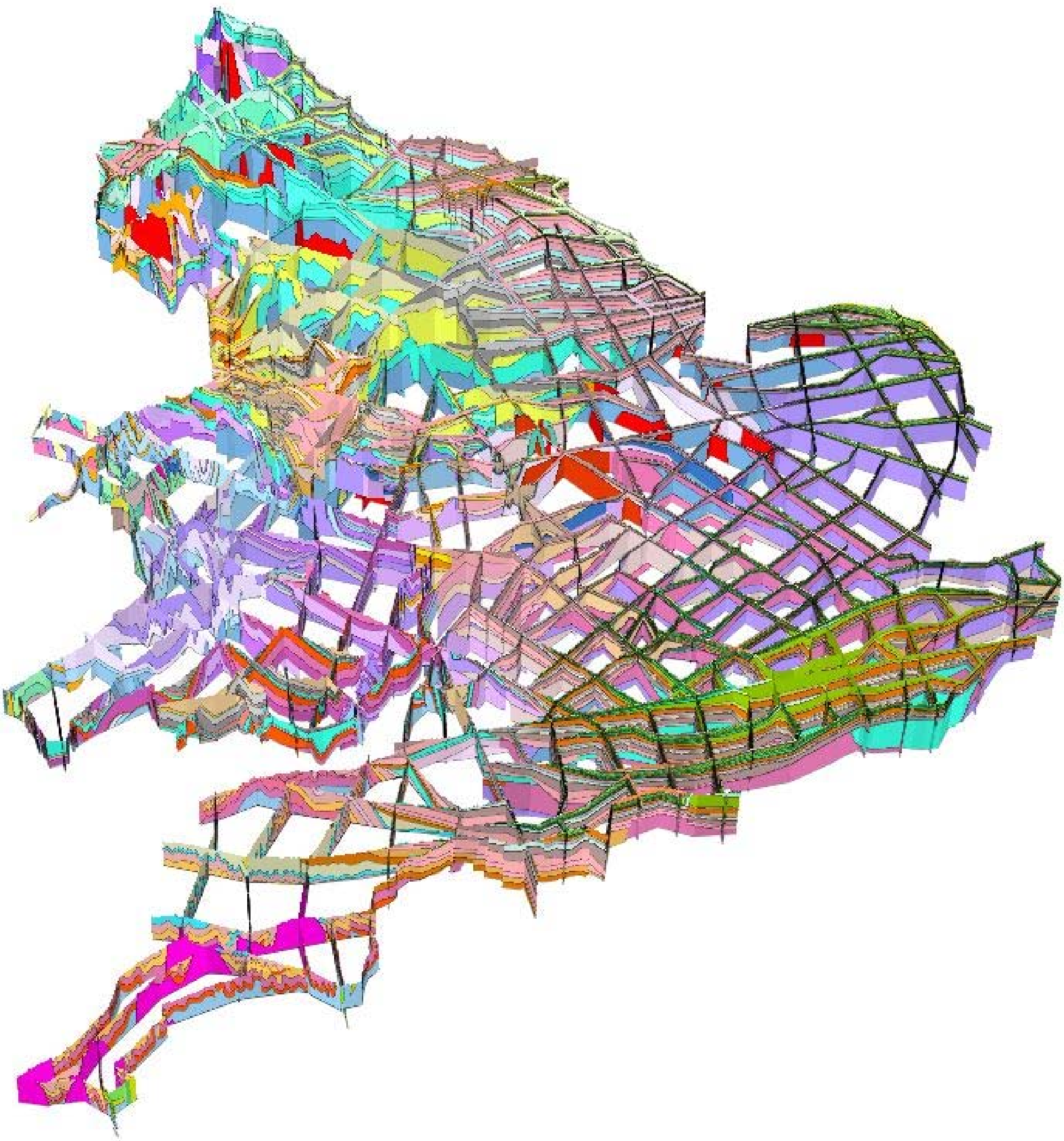


Figure 15 The revised cross–section framework for England and Wales included in the GB3D_v2014 dataset.

6 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. 2014). 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 2150) made for each individual cross-section, and Figure 18 shows part of the extensive list of sources consulted. The sources were recorded section by section, there are943 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 is dynamically updated and can be utilised by all the participating geologists simultaneously. It can be made available as required as an MSAccess database.

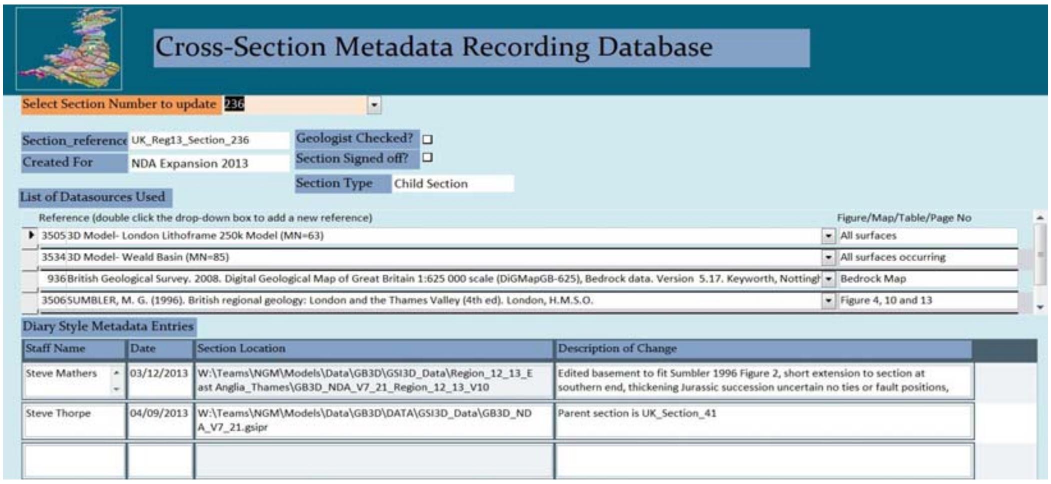
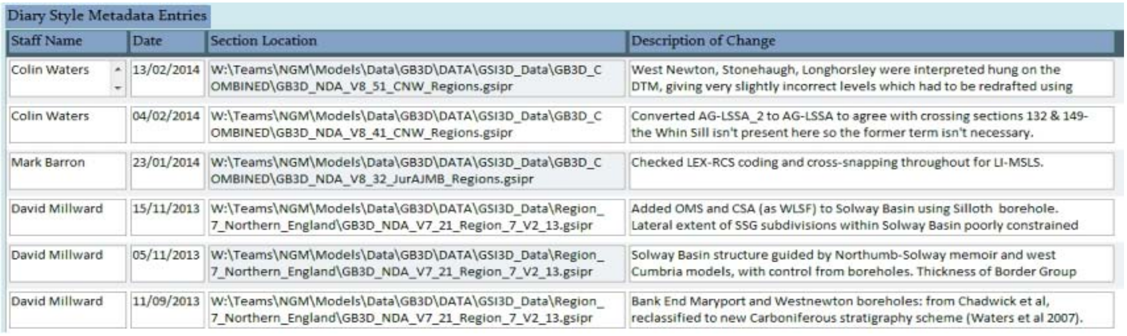


Figure 16 Cross-Section Metadata Recording Database main input form



Diary Style Metadata Entries

Staff Name	Date	Section Location	Description of Change
Colin Waters	13/02/2014	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\GB3D_COMBINED\GB3D_NDA_V8_51_CNW_Regions.gsipr	West Newton, Stonehaugh, Longhorsley were interpreted hung on the DTM, giving very slightly incorrect levels which had to be redrafted using
Colin Waters	04/02/2014	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\GB3D_COMBINED\GB3D_NDA_V8_41_CNW_Regions.gsipr	Converted AG-LSSA_2 to AG-LSSA to agree with crossing sections 132 & 149- the Whin Sill isn't present here so the former term isn't necessary.
Mark Barron	23/01/2014	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\GB3D_COMBINED\GB3D_NDA_V8_32_JurAJMB_Regions.gsipr	Checked LEX-RCS coding and cross-snapping throughout for LI-MSLS.
David Millward	15/11/2013	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\Region_7_Northern_England\GB3D_NDA_V7_21_Region_7_V2_13.gsipr	Added OMS and CSA (as WLSF) to Solway Basin using Silloth borehole. Lateral extent of SSG subdivisions within Solway Basin poorly constrained
David Millward	05/11/2013	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\Region_7_Northern_England\GB3D_NDA_V7_21_Region_7_V2_13.gsipr	Solway Basin structure guided by Northumb-Solway memoir and west Cumbria models, with control from boreholes. Thickness of Border Group
David Millward	11/09/2013	W:\Teams\NGM\Models\Data\GB3D\DATA\GSI3D_Data\Region_7_Northern_England\GB3D_NDA_V7_21_Region_7_V2_13.gsipr	Bank End Maryport and Westnewton boreholes: from Chadwick et al, reclassified to new Carboniferous stratigraphy scheme (Waters et al 2007).

Figure 17 Example diary entries for one individual cross-section

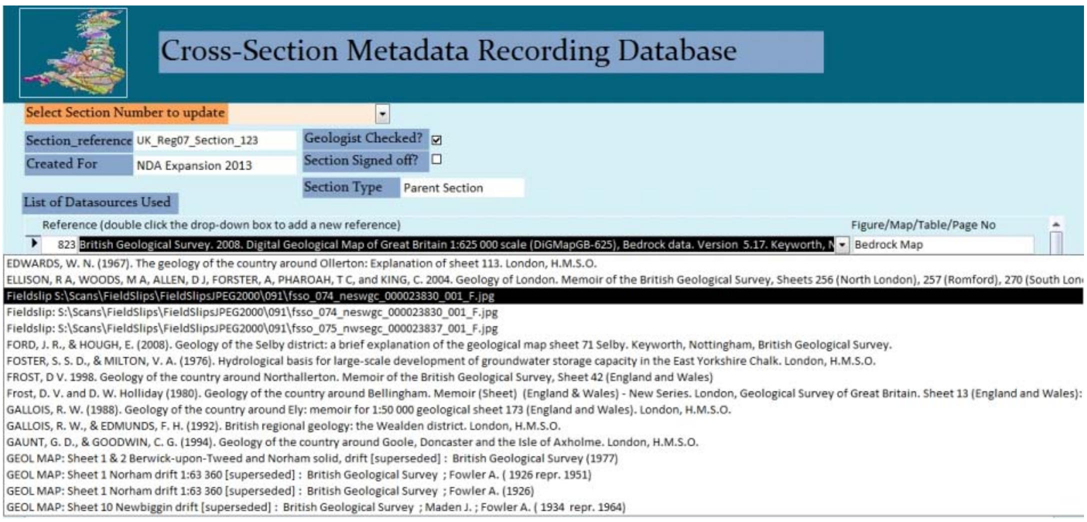


Figure 18 The sources used in individual section construction pull down list with 943 entries

7 Model rules, limitations and uncertainty

Model rules

- Wherever possible the 1: 625 000 scale bedrock geology linework and stratigraphy were adopted in the cross-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.
- Significant faults are depicted as offsets of the geology 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 thought to be present within sedimentary basins.
- A false horizontal base at an arbitrary depth has been constructed for some units to correspond to the base of the section, these should not be interpreted as true bases.
- 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.

Use of the model

Appropriate applications for the GB3D_v2014 dataset include the following:

- Illustration of national or regional bedrock geology for scientific publications and for public information and non specialist use e.g. Radwaste (Powell et al., 2010), Shale Gas (Mathers et al., 2012a). The intended resolution of use is 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). See example in Figure 19.

Limitations inherent in the GB3D_v2012 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 to 1:1 million) resolution range.

With the exception of the 314 deep boreholes incorporated into the sections the model is not easy to assess 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.

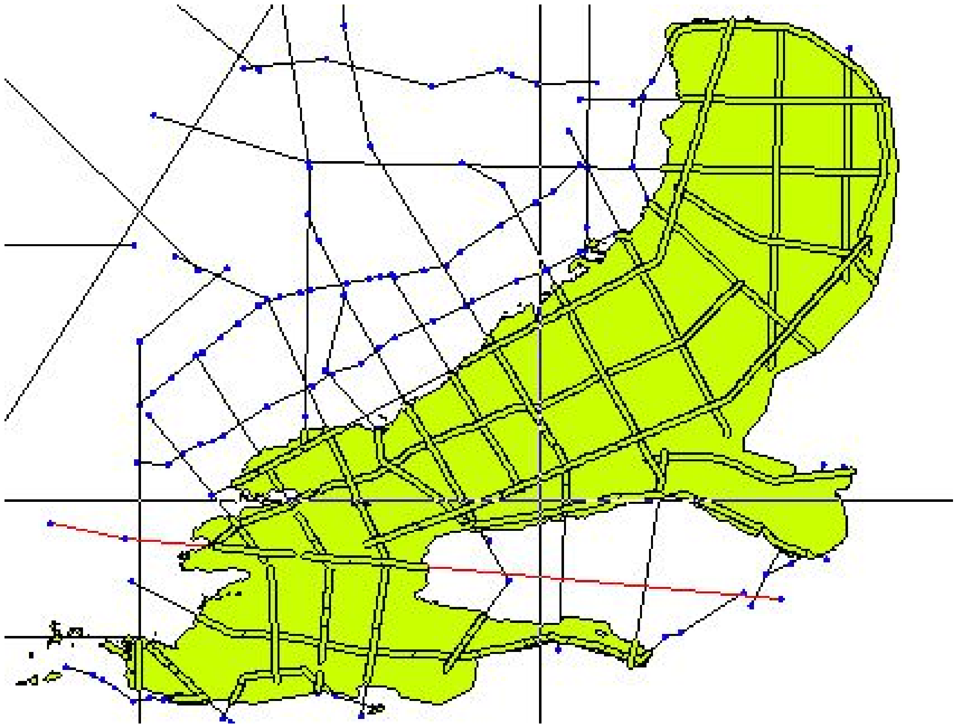


Figure 19. Distribution of the Grey Chalk Group derived from the information in the individual sections and the surface outcrop polygons enabling the construction of a full outcrop-subcrop distribution (a.k.a. coverage, envelope)

8 Model availability

Since December 2012 the GB3D_v2012 dataset has been served in varied forms as free downloads from the BGS website:

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

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

http://www.bgs.ac.uk/services/NGDC/citedData/catalogue/f60c6923-0bd2-4469-bc7a-9c0775453ac8.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 Geovisionary™ 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 GB3D_V2014 datasets supplants the earlier version, it is available in the same formats at: http://bgs.ac.uk

9 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/

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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/

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