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Metadata report for the East Midlands region of the Pennine Basin 1:250 000 resolution geological model

Geology and Regional Geophysics Programme

Open Report OR/14/026

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND REGIONAL GEOPHYSICS PROGRAMME

OPEN REPORT OR/14/026

Metadata report for the East Midlands region of the Pennine Basin 1:250 000 resolution geological model

A G Hulbert, R L Terrington

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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

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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
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Summary

This report describes the East Midlands region of the Pennine Basin 1:250 000 model data and workflow. The model is based on the faults and surface contour plots in the map appendix of the following subsurface memoir:

Pharaoh, T C, Vincent, C J, Bentham, M S, Hulbert, A G, Waters, C N, and Smith N J P. 2011. The structure and evolution of the East Midlands region of the Pennine Basin. Subsurface Memoir of the British Geological Survey. 143pp

1 Modelled volume, purpose and scale

Figure 1: Modelled area (in red) Topological Map - Ordnance Survey data © Crown copyright and database right 2014.

This is a faulted GOCAD® regional model extending onshore across Nottinghamshire, Lincolnshire, Leicestershire, Cambridgeshire and parts of Norfolk (Figure 1). The model was constructed from digital data compiled for the East Midlands Subsurface Memoir (Pharoah et al., 2011). The results of the study are contained in the 1:625 000 scale structure contour, preserved thickness and subcrop maps (Figures 2 and 3) that accompany the Subsurface Memoir, so the data and model generated is regional to national in scale.

The model was developed as part of the Regional UK Lithoframe Programme, the aim of which was to convert the structural data interpreted in the subsurface memoirs into 3D models. Other models in this series include the Craven Basin, the Northumberland-Solway Basin, the south-west Pennine Basin and Weald Basin models. The East Midlands model provides an understanding of the regional bedrock structure in Eastern Central England (particularly for the Carboniferous rocks) and extends from +250 to -4 400m OD.

As the East Midlands Model was derived from digital data compiled for the Regional Subsurface Memoir series, tasks such as drawing seismic interpretation to well control have already been performed. This document describes the process of creating a GOCAD® model from derived digital contour data.

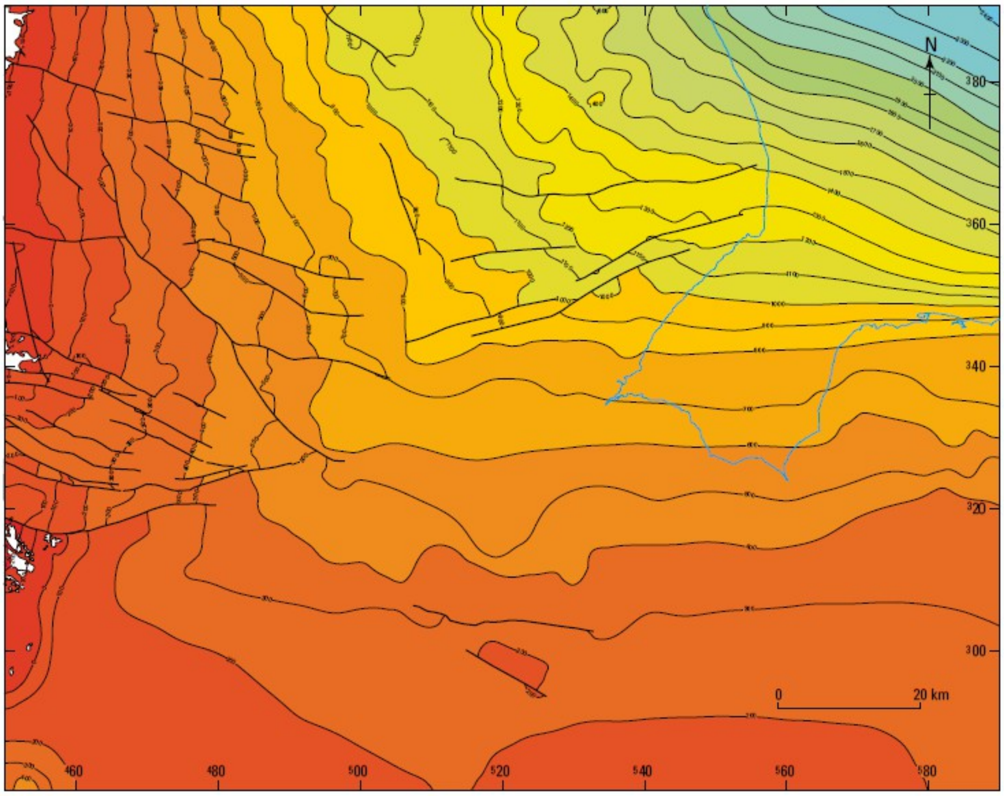

Figure 2: Example structural contour map of the Variscan Unconformity from the East Midlands Subsurface Memoir from Pharaoh *et al* (2011)

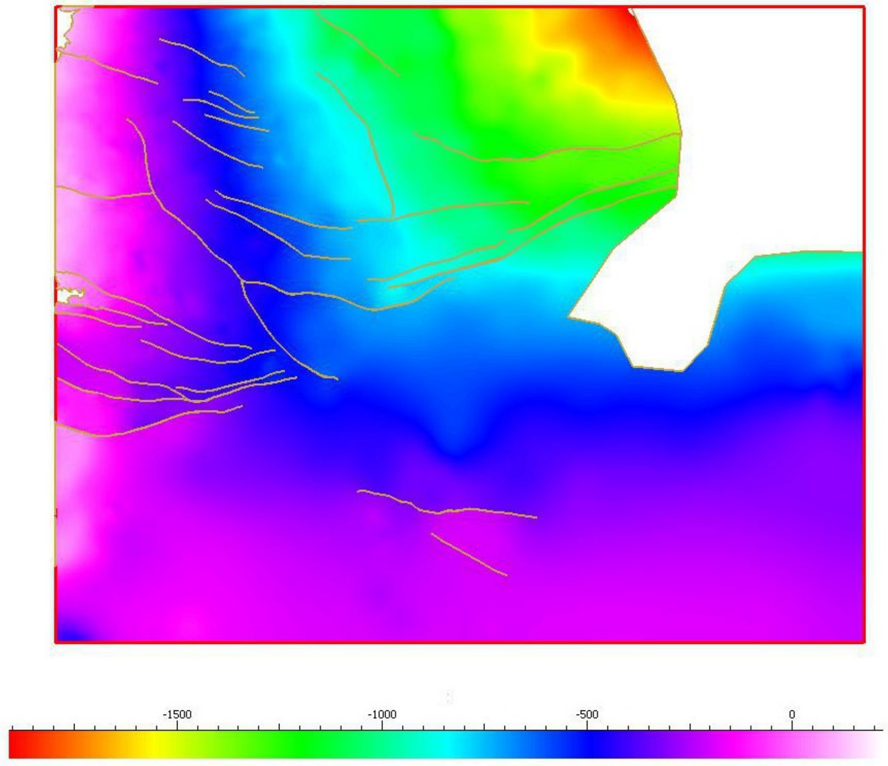

Figure 3: Modelled Variscan Unconformity surface (depth range in metres)

2 Modelled surfaces/volumes

The surfaces were generated from the structural depth contour plots. Well control was *not* directly used.

Surfaces modelled are (numbers relate to stratigraphic order):

Rockhead

01 Top Cornbrash

02 Top Penarth Group

03 Top Sherwood Sandstone Group

04 Variscan Unconformity

05 Top Hard Coal

06 Subcrenatum Marine Band (Top Namurian)

07 Top Dinantian

08 Top Asbian

09 Top Tournasian

10 Caledonian Unconformity

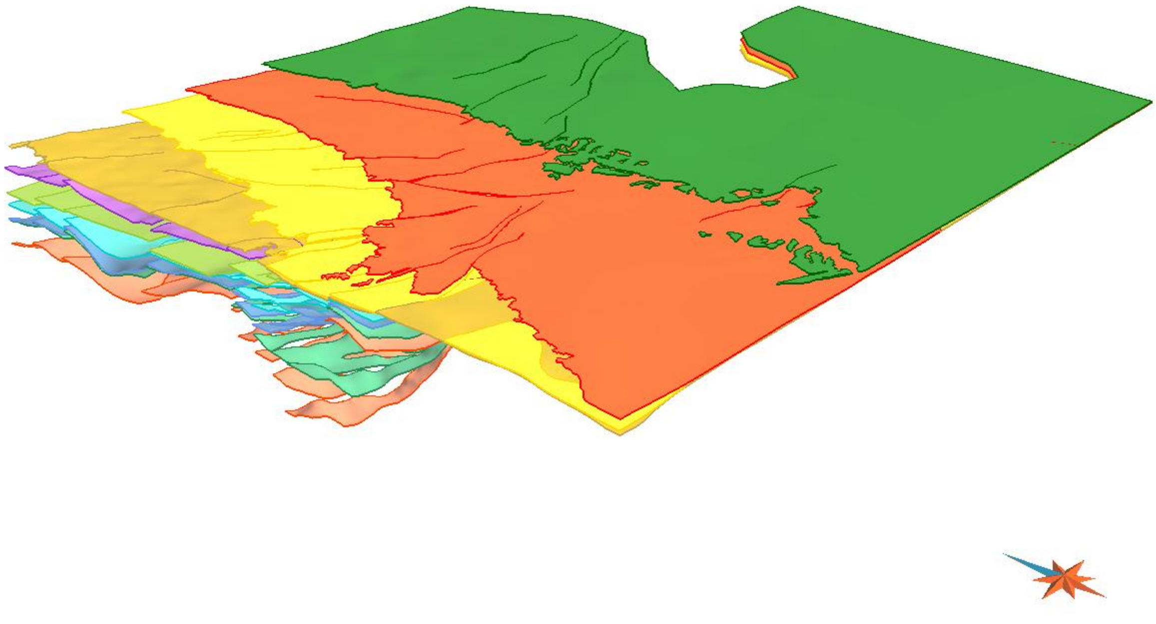

Figure 4: Image of modelled surfaces viewed from the South-West.

The figure below summarises the general stratigraphy from Pharaoh *et al* (2011):

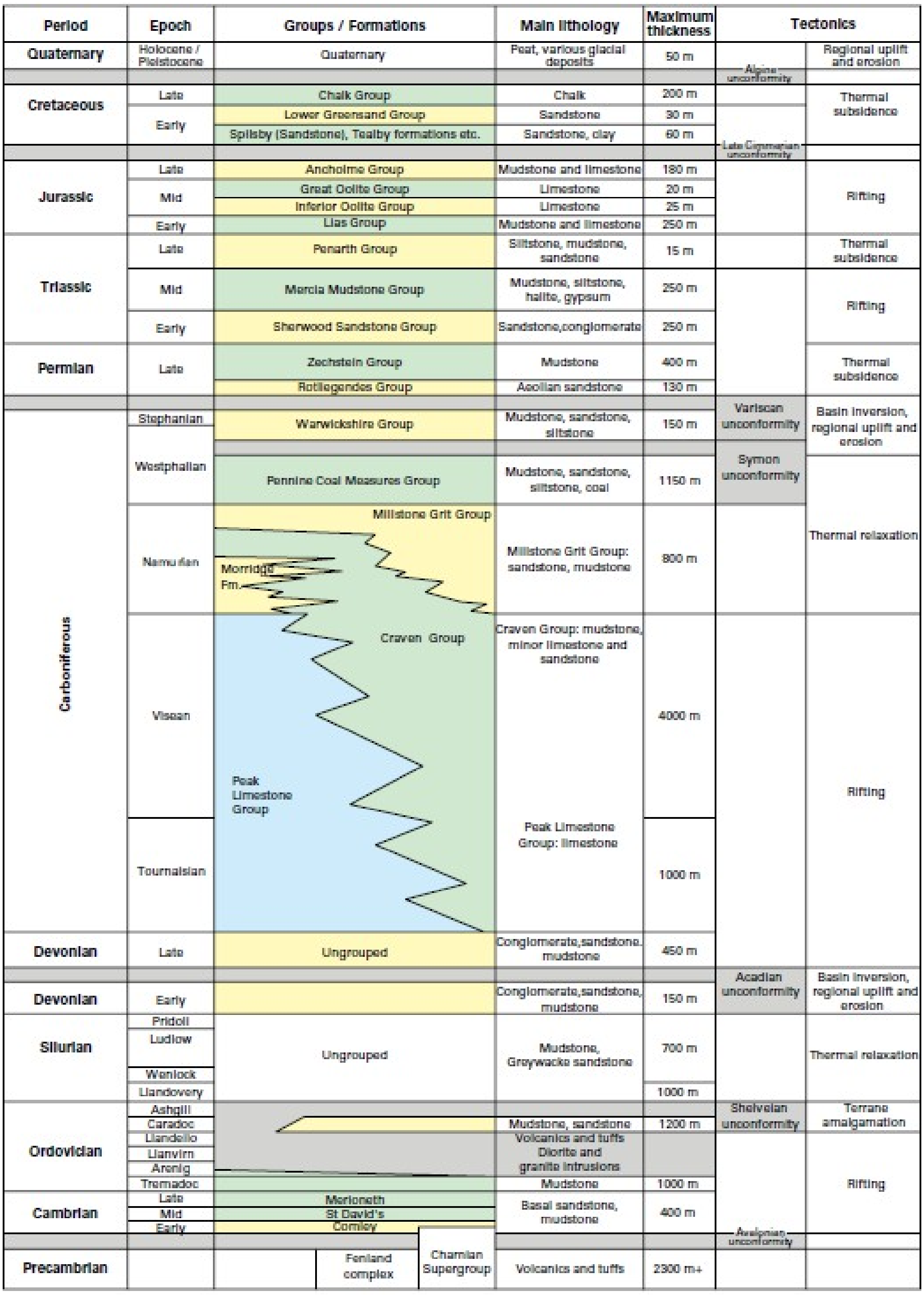

Figure 5: Summary of the stratigraphy, geological and tectonic events for the East Midlands region of the Pennine Basin

3 Modelled faults

All of the faults used in the construction of the model were sourced from the East Midlands Basin Subsurface Memoir (Pharoah et al., 2011). These were digitised per surface as ESRI polyline shapefiles as part of the Regional UK Lithoframe programme. As the model was regional in nature, an initial filtering of the faults was applied to ensure that only those that had significant throw/displacement (generally >100 m) were used for the surface construction.

One method of filtering was to select faults that had a length of greater than 10 000 m (a value arrived at by experimentation), as it is recognised that the greater the length of the fault (in 2D space) the greater the throw/displacement (Young-Seog and Sanderson, 2005). By selecting faults over 10 000 m, many of the faults with throws of greater than 100 m are used in the modelling phase.

For shorter faults, finding those that had significant displacement and were worthy of inclusion in the model was a case of manual inspection. This was achieved by taking all of the faults that had a length shorter than 10 000 m, and examining the contour values across and within a buffered distance (usually either 250 or 500 m) in order to estimate the change in elevation across the fault. From the results of this, faults that were less than 10 000 m in length but were found to have a throw greater than 100 m were selected for use in the project.

The total distribution of faults modelled can be seen in Figure 6.

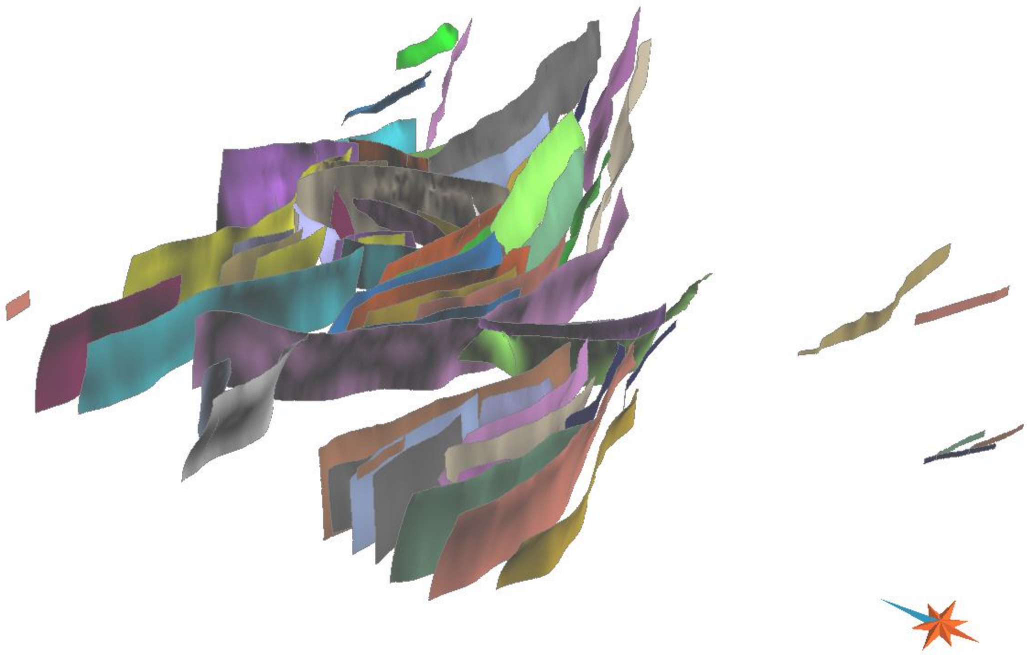

Figure 6: Distribution of the modelled faults for the East Midlands Model

Two types of faults were produced using the Structural Modelling Workflow in GOCAD®. Some of the faults were produced using the fault sticks method (whereby fault cuts at individual surfaces were combined to produce a fault surface) and the rest used the Fault Centre Line method (a single fault line at a particular level, with a fault dip and direction applied). For both types of faults generated, fault contacts were modelled where individual faults were crossed or truncated by other faults in the model

3.1 FAULT STICKS

1. Each surface was calculated using the digitised contours to give a raw unfaulted surface.
2. The fault traces generated were draped onto their respective surface.
3. Faults were grouped by their fault location – meaning each draped fault trace that corresponded with an individual fault was extracted to a new fault curve object - further filtering could be undertaken at this point, as not all draped fault cuts were necessarily required to produce an aesthetically pleasing fault object (Figure 6).
4. The grouped fault traces were allocated a *Fault Stick* data type in GOCAD® and put through the Structural Modelling Workflow for generating a fault surface. Manual editing of the fault surface was sometimes necessary to smooth out any spikes or anomalous data.

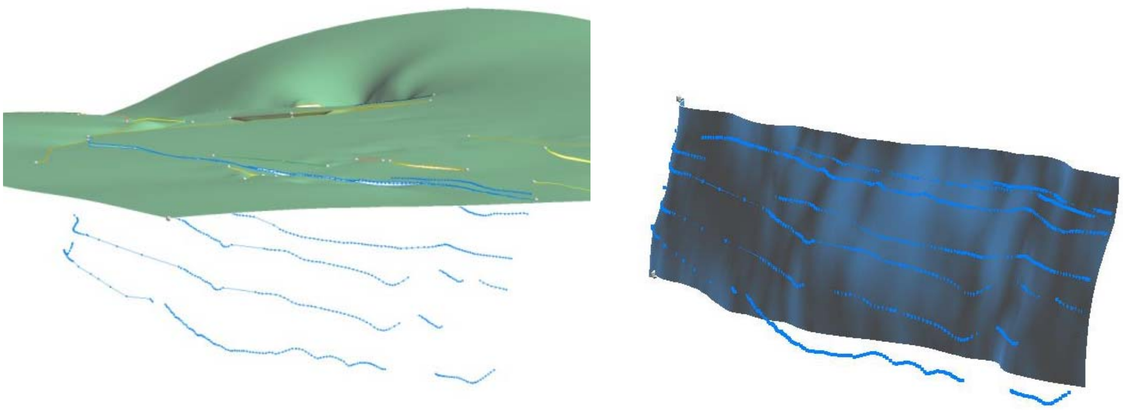

Figure 7: Example from the Northumberland-Solway Model showing the construction of a fault surface (the Closehouse-Lunedale fault) from fault sticks (right image in blue) and the interaction of the fault with the Permo-Trias surface prior to faulting (in green) from Terrington *et al* (2013).

3.2 FAULT CENTER LINES

If the fault trace only occurred on a single surface, or the fault heave over several surfaces was insignificant, the *fault centre line* data type was used in GOCAD® Structural Modelling workflow. The *fault centre line* allows the user to specify the elevations of the top and the base of the fault and the dip angle. The fault generated is a simple extrusion of the fault centre line. This fault type is often used where faults displace the outcrop (or subcrop).

3.3 FAULT CONTACT MODELLING

After fault construction, fault intersections need to be modelled and constraints built. This is normally done within the modelling workflow using the “Fault Contact Modelling” dialogue. This works well with relatively simple fault networks. For more complex networks or where individual faults may not always have the same vertical extents, manual construction of fault contacts and constraints produces a better model. To do this, we use the “cut by surfaces” method with the “build constraints” option selected. This fills the fault contact table in the same way that the workflow method does. The fault network for the East Midlands model was done in this way.

4 Model datasets

Digital Terrain Model (DTM)

Used as a reference dataset. The DTM source was NextMap at a 200 m cell size resolution. A surface was then created from extracted points. Optimisation was performed to produce more triangles in areas of more detail.

Borehole data

Boreholes used in the model have been extracted from the Stratigraphic Surfaces database. The surfaces described in this report are based on structural contour data from the memoir; they are warped to fit with the borehole data in the latter stages of the modelling process.

Map data

The map data were generated directly from the Subsurface Memoir (Pharoah et al., 2011) and cross-referenced with DigMap GB 1:50 000.

Mine plan data

No mine plan data were used directly in the modelling.

Seismic data

Seismic data were interpreted and used in the generation of the contour data in the Subsurface Memoir (Pharoah et al., 2011).

Geophysical data

Please see Pharaoh *et al* (2011)

4.1 GOCAD® OBJECTS

The following objects relate to the project specific data types within the GOCAD® project file. Each of the horizon datasets will have a pre-cursor number to identify it using the schema:

01 – Top Cornbrash

02 – Top Penarth Group

03 – Top Sherwood Sandstone Group

04 – Variscan Unconformity

05 – Top Hard Coal

06 – Subcrenatum Marine Band (Top Namurian)

07 – Top Dinantian

08 – Top Asbian

09 – Top Tournasian

10 – Caledonian Unconformity

4.1.1 Pointset – GOCAD® project

- Contains all of the structural contours, derived from the modelled surfaces, as points (e.g. 01_EastMidlands_Top_Cornbrash_Structure_Contour_points.vs)

4.1.2 Group - GOCAD® project

- EastMidlands_boreholes - data extracted from the SSD and used for surface fitting.
- EastMidlands_faults - contains all of the fault surfaces generated through the Structural Modelling workflow (e.g. EastMidlands_EMF001N_ts).
- EastMidlands_Raw_faults - contains the “grouped” fault data used for fault surface creation.
- EastMidlands_Raw_Data – contains the contour and crop data used for surface modelling and the “pre-grouped” fault cut data used for fault modelling

4.1.3 Surface - GOCAD® project

- Contains those surface horizons that have been clipped to the combined outcrop and subcrop for that horizon (01_EastMidlands_Top_Cornbrash_ts)
- Other datasets include the DTM derived from the NextMap DTM at 200m resolution

5 Model development log

W:\Teams\UKGF\RegionalLithoframe\Data\East_Midlands\gocad

East_Midlands_v0.gprj	DTM Construction Construction of initial horizon surfaces for fault sticks Z values.
East_Midlands_v0_1.gprj	Construction of fault objects prior to fault surface modelling.
East_Midlands_v1_1.gprj	Borehole data added, stratigraphic column built
East_Midlands_v1_5.gprj	All faults built, all contacts modelled.
East_Midlands_v2_0.gprj to East_Midlands_v2_10.gprj	Surface construction (including horizon/fault contact modelling, contact refinement, fitting surfaces to boreholes and removal of surface crossovers)
East_Midlands_v3_0.gprj to East_Midlands_v3_4.gprj	Final model editing Faults clipped by truncating surfaces Model clipped to coast Addition of geology and topological images for visualisation

6 Software Used and Model workflow

6.1 SOFTWARE USED

- GOCAD® v2009
- ArcGIS 9.3
- MS Excel

6.2 MODEL WORKFLOW

The following workflow was used to generate the Northumberland-Solway Basin Model:

1. Compiled all raw data into a GIS:

W:\Teams\UKGF\RegionalLithoframe\Data\East_Midlands\EastMidlands.mxd

2. Imported all fault traces, outcrop data and structural contours for each horizon into GOCAD®.
3. Additional data added included the NextMap DTM (See Model Datasets Section 4)
4. A raw surface (uncut by faults at this stage) for each horizon was modelled using a combination of the structural contours and outcrop which had elevation values applied from the DTM surface data.
5. Every fault trace was draped onto its corresponding surface using the ‘Transfer Property by Vertical Projection’ tool and then following the methodology established in Sections 3.1 and 3.2, the fault plane was constructed.
6. Once all of the faults had been constructed, branch contacts were established between the faults using the manual ‘cut surfaces with constraints’ method.

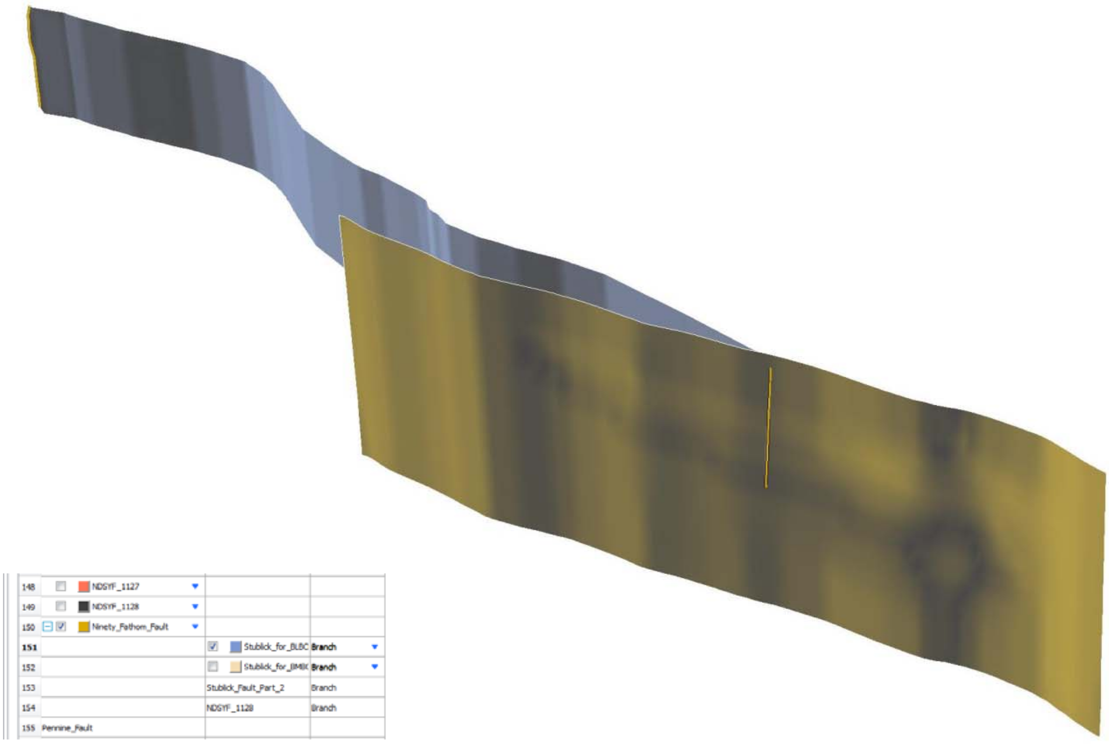

Figure 8: Example fault contact from the Northumberland-Solway Model between the Ninety Fathom fault (Main) and the Stublick fault (branch) from Terrington *et al* (2013)

7. The faults were then used to cut the raw surface horizons using the ‘Horizon-Fault Contact Modelling’ in the Structural Modelling workflow.
8. Fault contacts and surface horizons were either edited using the Structural Modelling workflow parameters or manually using the tools available in GOCAD®

7 Model limitations

The modelled surfaces were directly constructed from the structural contours from the East Midlands Subsurface Memoir and then warped to fit boreholes. This may result in the modelled surface not matching the original structure contours.

As part of the modelling process, crossovers may occur between the surfaces. Some of these are directly the result of contours overlapping in vertical space. These have been resolved wherever possible but still may exist in some places.

8 Model image

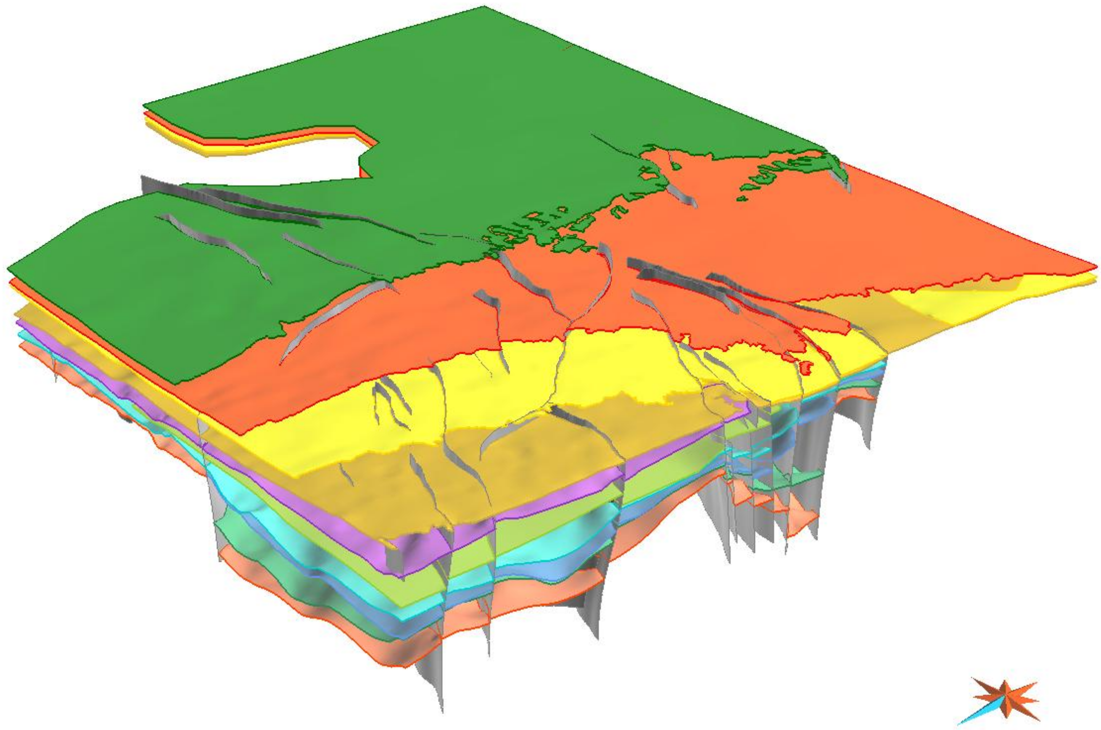

Figure 9: View of the final fault cut surfaces viewed from the North-East

9 References

PHAROAH, T C, VINCENT, C J, BENTHAM, M S, HULBERT, A G, WATERS, C N, and SMITH, N J P. 2011. The structure and evolution of the East Midlands region of the Pennine Basin. Subsurface Memoir edition. *British Geological Survey*, 143.

TERRINGTON, R L, and THORPE, S. 2013. Metadata report for the Northumberland and Solway Basin 1:250 000 geological model. *British Geological Survey*, OR/13/049 (British Geological Survey).

YOUNG-SEOG, K, and SANDERSON, D J. 2005. The relationship between displacement and length of faults: a review. *Earth Sciecne Reviews*, Vol. 68, 317-334.