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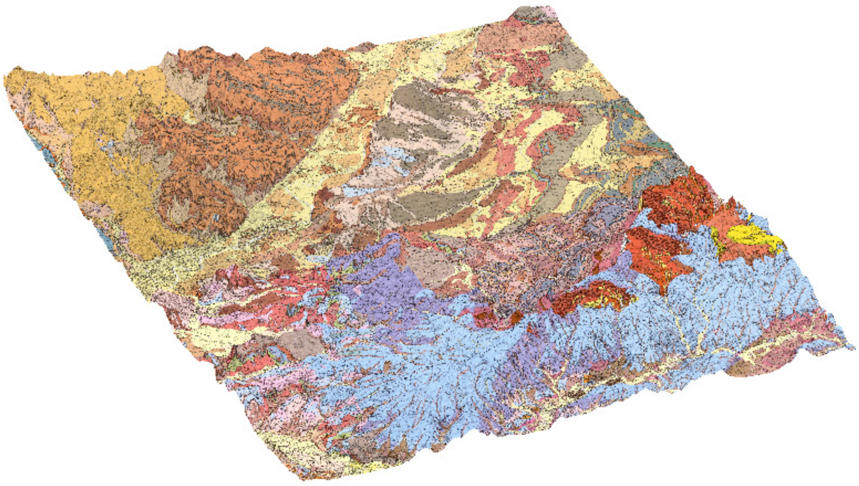
A guide to the construction of the DGSM Nottingham Melton Lithoframe 250K model

DGSM Programme

Internal Report IR/05/071



BRITISH GEOLOGICAL SURVEY

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A guide to the construction of the DGSM Nottingham Melton Lithoframe 250K model

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Front cover

DTM draped by the 50K Nottingham and Melton geological map sheets

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Summary

This report describes the rationale behind the construction of the Nottingham Melton Lithoframe 250K GOCAD model. This work was carried out between April 2001-March 2005, as part of the Nottingham Melton DGSM-UK project (E1362S96 Task 06). This model comprises the area of the combined Nottingham and Melton 50K geological map sheets.

1 Introduction

The purpose of this report is to briefly describe the process carried out to construct the GOCAD model for the area of the combined Nottingham and Melton geological sheets. This work was carried out between April 2001-March 2005, as part of the DGSM-UK project (E1362S96 Task 06). The purpose of the model was to resolve the deep structure of the Widmerpool Half Graben, an important Carboniferous sedimentary basin. This report assumes that the reader has some knowledge of the main types of modelling software and does not give a detailed guide to the use of such software.

Note: The work was carried out before the Lithoframe concept was firmly established, and hence the area covered by the model (30x40 km) does not conform to that now held for a Lithoframe 250K model (suggested tile size of 100 x 100 km) (see S. Mathers & A Monaghan powerpoint presentation). Nevertheless, other elements such as its depth, the use of seismic and deep boreholes and the degree of stratigraphic resolution do conform to the Lithoframe 250K scale concept and hence it is at this scale that this model is considered appropriate.

Building models within BGS has evolved considerably since the inception of the DGSM. The Nottingham Melton project was carried out at the same time as the DGSM-Framework, one remit of which was to specify the standards to construct a DGSM. Hence many of the procedures (e.g. some Best Practice documents) were not in place at the time that some of the procedures described here took place and hence any non-conformance to these procedures probably results from their lack of availability at the time.

2 Project Planning

At the start of the project a Project Plan was prepared. At this point the project tasks and deliverables were defined. These are outlined for the Nottingham Melton project in the project final report. Best Practice procedures as defined by the DGSM project were to be followed during the project.

3 General Methodology

3.1 DEFINING THE MODEL AREA

For this model the area of the combined Nottingham (126) and Melton (142) 50K geological sheets was chosen: The extent of the model is as follows:

Min. Eastings: 454000
Max. Eastings: 484000
Min. Northings: 315000
Max. Northings: 355000

It is recommended that a fringe around the area of at least 1 km is chosen in order to reduce the edge effects associated with surface modelling. Cropping of the model to the true project area after modelling is finished will produce a cleaner looking model. This will have resource implications for data capture but will also help with future modelling of adjacent tiles.

3.1.1 Standard Stratigraphic Markers

The Standard Stratigraphic Model (SSM) defines the level of detail that is expected in a suite of models for a region, that are designed to be consistent in resolution, depth and applicability. The SSM consists of a series of modelled surfaces that are defined for a given programme or set of projects, taking into account survey area and depth, scale and resolution. The SSMs are defined by identifying the key stratigraphic marker surfaces that provide consistent, widespread and well-defined features at outcrop, in boreholes and from other survey responses. For this project the major seismic surfaces and major stratigraphic surfaces at group level were chosen for the model. These are:

- DTM
- Rockhead
- Top Mercia Mudstone Group
- Top Sherwood Sandstone Group
- Top Variscan unconformity
- Base Warwickshire Group
- Top Deep Hard Coal
- Top Namurian
- Top Dinantian
- Top Caledonian Unconformity
- Faults

3.2 DATA SELECTION AND PREPARATION

Identification of datasets and digital capture of relevant datasets needs to be done early in the project lifecycle. The data selected to construct models must be described by standard metadata, so that features shown in a model can be tracked back to the data on which it is based. In general, this will mean that the data are held in corporate databases that have been subjected to documented reduction and validation.

3.2.1 Seismic Data

As a result of the extensive exploration for oil and coal in the area there exists a large legacy of 2D seismic coverage (Fig. 1). T. Pharaoh arranged for the purchase of 2D digital seismic data from Lynx UKOGL. This data was purchased and held under licence from UK Onshore Geophysical Library (UKOGL). The licencing conditions under which BGS hold the data forbid display of the actual seismic data to third parties (i.e. anybody outside BGS), and our agreement with UKOGL is that interpretations derived from the data must be ‘published’ with acknowledgement to UKOGL, before their use in commercial ventures can be considered. Approximately 160 lines, covering about 1100 line km, were available to the project. The SEGY format seismic data was loaded onto PC for interpretation using Landmark GeoGraphix software. For loading 2D seismic data of varying vintage or from different seismic surveys or data provider such as were available for this study, it is recommended the GeoGraphix ‘single line loader' is used. After loading, each line should then be loaded into SeisVision using the ‘seismic data manager’. In SeisVision each line should be checked to ensure it has been loaded using the same datum shift, the line hasn’t been reversed and that the SEGY file is not corrupted. Where paper copies of the lines are available they should be used to check the loaded digital data, particularly reference datum and correspondence to Common Mid-Point (cmp) location. Best practice guidelines and checklist reports (written by Bentham et al.) are available for further details.

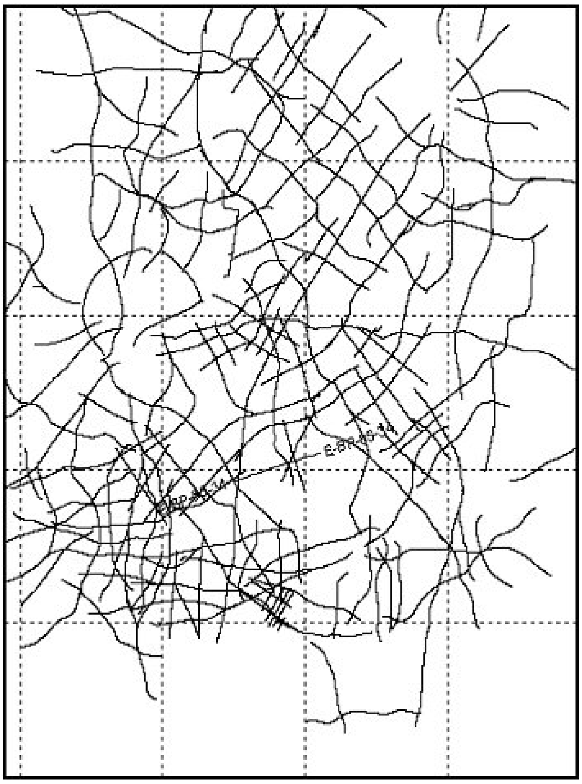

Figure 1. Seismic coverage in the Nottingham Melton project area.

Stratigraphic surfaces (tops) picked by the seismic interpretation were:

- MMG: Mercia Mudstone Group
- SSG: Sherwood Sandstone Group
- ROX: Roxby Formation (Permian)
- UVAR: Variscan Unconformity
- CAMB: Cambriense Marine Band
- THC: Top Hard Coal
- DHC: Deep Hard Coal
- MG: Millstone Grit
- DIN: Dinantian
- UCAL: Caledonian Unconformity
- Faults

In SeisVision each horizon was gridded in time, velocity and then converted to depth, using a grid spacing of 1000 m. Of the tops specified above, depth converted grids for all surfaces except CAMB and THC were produced. For the deeper surfaces there was poor well control to carry out an accurate depth conversion. The grids were then converted into GeoAtlas layers. Using

GeoAtlas, the horizons (as xyz grid node data) and contours were exported as ASCII files using the export ASCII files function. Faults were named numerically and range from F01-F70. The faults were also exported, but note that fault names are not retained when the data is extracted. It is therefore important to mark up fault names on a paper copy map of each horizon and use these maps to identify the relevant faults when working in GOCAD. This is a fiddly and inconvenient process but appears to be the only sensible way to assist correlation of faults in GOCAD and other modelling packages. The seismic project data are archived on PC kwp151195.

3.2.2 Coal Authority Digital Mine Plan Data

Mine plan data for the Nottingham Melton area was initially available as 1:2500 scale paper plans showing the extent of mining per seam, underground roadways, faults and contours on seams. These plans would require scanning and digitising to be of use for modelling. However, digital abandoned mine plan data for 8 worked seams was kindly supplied by the Coal Authority. It comprised:

- Polygons of the extent of working panels as DXF format files. These are z attributed.
- Spot heights (xyz) along roadways (point data), supplied as comma separated value (CSV) text files.
- Seam level contours (xyz) as DXF files. These are interpolations based on the spot heights.

Note: Faults are not included in these datasets. The DXF and CSV files can be easily imported into GOCAD, forming curves and points respectively.

3.2.3 Borehole data

A search of the SOBI database revealed over 7400 boreholes in the area, of which over 2500 were >30 m in length. Of these, only c.750 had any geological data associated with them in Borehole_Geology. Hence there was a requirement to carry out a significant borehole databasing exercise. The following bases were databased:

- Lias Group *
- Penarth Group
- Mercia Mudstone Group *
- Sherwood Sandstone Group
- Permian * = Variscan unconformity
- Cambriense Marine Band = Base Upper Coal Measures
- Aegiranum Marine Band
- High Hazles Coal
- Top Hard Coal *
- Vanderbeckei Marine Band = Base Middle Coal Measures
- Deep Hard Coal *
- Parkgate Coal
- Blackshale Coal
- Subcrenatum Marine Band * = Base Lower Coal Measures
- Eometabilinguis Marine Band
- Namurian (= top Carboniferous Limestone) *
- Top Early Palaeozoic Basement *

* also picked by the seismic interpretation task

During this project a database of the stratigraphic surfaces listed previously was created in MS Excel and later uploaded into Borehole_Geology. Whilst it is clearly better to input the data directly into Borehole_Geology (using, for example, an Access interface such as the one designed by K Lawrie), on this occasion there were clear reasons for initially inputting the data into Excel. During this project a geologically untrained, temporary member of staff (Mr A. Arora) was tasked with the input of data. Apart from the correct recognition of stratigraphy, some of the other factors that data inputters need to be aware of include the need to correct for different datum surfaces (e.g. rotary table, Kelly Bushing, GL), metric versus imperial measurements, underground (mining) boreholes that go up (upbores) rather than down (downbores), underground (mining) boreholes that have both upbore and downbore sections, boreholes that use a mining datum (typically 10,00 ft below OD), the use of old stratigraphy in the written logs – hence the need to convert old stratigraphy into their more recent form from the written logs and the need to carry out interpretations of geophysical log data where boreholes are not fully cored. Hence it was considered sensible to collect the data in Excel rather than input directly into Borehole_Geology and run the risk of needing to continually correct the corporate database. The complexity of borehole data entry was new to the temporary staff member and it was felt important to maintain control and QC the data prior to uploading. Once this was carried out the data was uploaded into Borehole_Geology using the NSJ interpreter code and the NM Content Code to identify project and level of coding.

A best practice has been established by A. Kingdon as a result of this databasing activity (see: http://kwntsdgsm1/scripts/bestpractice/screen3.cfm?index_title=Recording%20stratigraphic%20information%20from%20borehole%20data%20for%20the%20DGSM&index_identifier=48&index_version=1.1). A large amount of staff time and effort was expended creating and checking the digital borehole dataset. Databasing is a crucial and time consuming part of the process of creating a DGSM and it is recommended that geologists carry out this task. Whilst databasing can be viewed simplistically as a data inputting job, it is clear that any models constructed using this data will ultimately depend on the quality of this initial work.

3.2.4 Borehole geophysical log data

Borehole geophysical log data was available to the project and represents an important record of the downhole geology, particularly as most deep boreholes are not fully cored. Hence it was essential to carry out a geophysical log interpretation exercise. Many geophysical logs were already present in the BGS Digital log data arcvive system, however, 42 logs were present on tapes requiring specialist reading and loading into Wellog and 41 were present as paper logs (Table 1). These were digitised using the software Jodphurs and loaded into Wellog as ASCII data. As a result of this acquisition exercise, 160 geophysically logged boreholes were available to the project. Of these 115 were examined in detail and stratigraphic surfaces from these were entered directly into Borehole_Geology.

For any given stratigraphic surface there will always be differences between a geophysical log derived depth and a cored or driller's depth. Normal convention has it that the geophysical log depth takes precedence. Borehole_Geology allows the input of geophysical log derived depths but this results in more than one depth entered per surface leading to confusion amongst users as to how the data was derived and which depth is correct. Currently, the only place in Borehole_Geology to store information regarding whether the data is a geophysical log derived depth or a driller's depth is in the 'Comments' field. Hence it is recommended that a new field be created in Borehole_Geology to accommodate this requirement. Borehole stratigraphic surfaces picked during this exercise were identified in Borehole_Geology by the insertion of "Geophysical log interpretation" in the Comments field.

3.2.5 DTM

During the life of the project various DTM's were available, e.g. CEH, NEXTMap. The NEXTMap DTM undoubtedly gives the best resolution, but manipulating this in GOCAD proved problematical as it constitutes a large points based dataset. The NEXTMap DTM was selected for use, sub-sampled at 625 m grid spacing. This was the value suggested when the data was extracted from the data portal. The performance considerations are critical to decisions regarding the size and resolution of the GOCAD model to be constructed as rapid manipulation of the model is essential to allow proper visualisation and efficient editing. It is likely that size/resolution of model which can practically be built in GOCAD will be closely tied to computer performance. Caution should be exercised to avoid making models which are too large, have too high resolution or contain too many elements as subsequent users of the models/surfaces may not have access to as high-specification computers. Subsequently, a bitmap image (jpeg) of 250K geology and 625K topography was extracted from the data portal and was draped on the NEXTmap topography using the GOCAD texture facility.

3.2.6 DigMap

DigMap 250K and 50K data were available for the entire Nottingham Melton area and 10K is also available for parts of the Melton Mowbray sheet. However, for this model DigMap250K lines were used for the stratigraphic linework and DigMap50K lines were used for the faults. There were problems associated with this approach, specifically that in places these datasets don't match. There were mismatches between where the fault traces at 50k scale and the stratigraphic outcrop linework at 250k. The obvious solution to this would be to use compatible scale outcrop and fault linework, but the 50K stratigraphic linework produces an extremely large dataset in GOCAD which is not easy to handle. Hence the 250K outcrop linework was used. 250k fault traces are incomplete across the area and would not have allowed full correlation between faults identified seismically at depth and surface crop. Even this proved problematical to use and had to be filtered with a minimum segment length of 50m.

3.2.7 Other datasets

The rockhead model as produced by R Lawley et al. was used. Other models were also available for use in the main GOCAD model. These included the Saltby Volcanic Formation Vulcan model, produced by S. Dumpleton, extra coal surfaces produced in Surfer by H. Sheppard and a GSI-3D model of superficial deposits in the River Wreake area, produced by R. Terrington. These were imported into the project. Reports of best practices are available describing the methodology used for this (see http://kwntsdgsm1/scripts/bestpractice/screen1.cfm).

4 Modelling

The area of the combined Nottingham-Melton Lithoframe 250K model covers approximately 1100 sq km and was constructed in Earth Decision Science GOCAD Software, Version 2.0.8 (Figure 2). The model incorporates all the seismically derived surfaces and faults, NextMap DTM, DigMap outcrop linework at 250K, DigMap fault linework at 50K and all databased boreholes. Some incrop and subcrop linework was derived from published work. Ten surfaces have been modelled and combined with DigMap linework. 58 seismically resolvable faults have been matched up with their surface expressions (where they reach the surface) and modelled. The lowermost modelled surface is the Top Caledonian Unconformity; in places this reaches depths of about 4.6 km. It is recommended that the model is not viewed with a vertical resolution greater than x5.

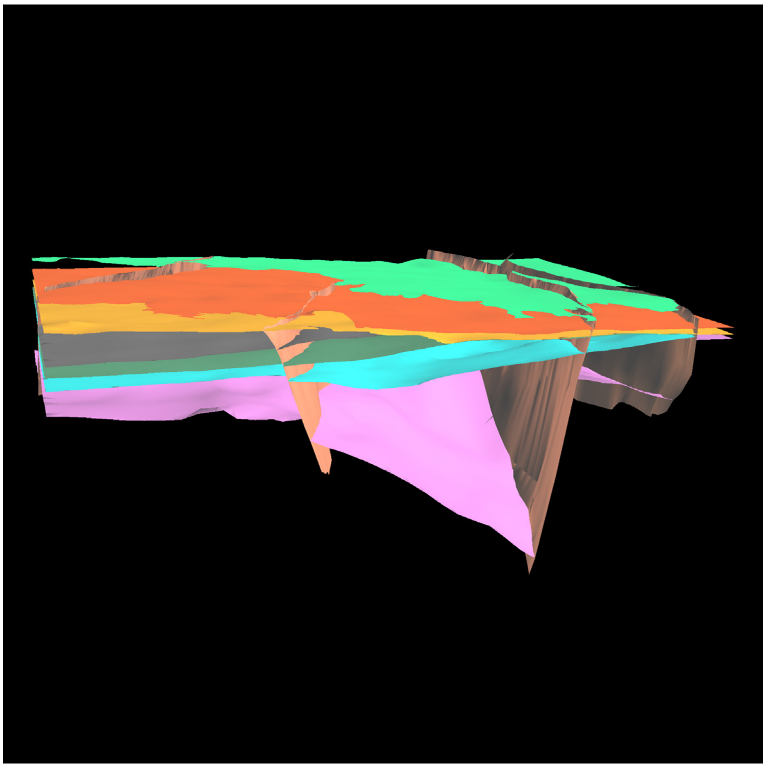

Figure 2. GOCAD model to show the thickening of the Carboniferous succession into the Widmerpool Basin.

The lowermost (magenta) surface represents the top of the Caledonian basement, the light blue surface forms the top of the Dinantian (Lower Carboniferous), dark green is Top Namurian, grey is Top Deep Hard Coal, orange is top Sherwood Sandstone Group and light green is the top of the Mercia Mudstone Group. Although visually simple, this model results from an extensive and detailed evaluation of both seismic and borehole data in the area. There is a major fault on the right side of the model (Normanton Hills Fault) and clearly shows that the basin is a half graben feature. In the basin centre the Dinantian is up to 3.5km in thickness.

4.1 SURFACE MODELLING

The expectation of building the model was to produce surfaces as the primary output. GOCAD produces surfaces by triangulation; these can then be modified (interpolated) by the Discrete

Smooth Interpolation (DSI) method, which is an iterative method. The goal of the DSI method is to create a smooth result. The purpose of this stage was to create continuous surfaces representing the main SSMs. These units are Caledonian Unconformity, Top Dinantian, Top Namurian, Top Deep Hard Coal, Base Warwickshire Group, Variscan Unconformity, Top Sherwood Sandstone Group, Top Mercia Mudstone Group, Rockhead and DTM. All modelled surfaces except the DTM and Rockhead were constructed by combining all the seismically derived surfaces, filtered DigMap outcrop linework at 250K (where applicable) and all databased boreholes. Top Roxby was also included at an earlier stage in the modelling but it was later omitted due to inconsistencies in picking the horizon in both boreholes and seismic data.

The basic procedure followed is outlined below:

- The NEXTMap DTM was extracted via the Data Portal and imported into GOCAD as an ascii grid. A triangulated surface was then created from the grid nodes.
- A raster image (in jpeg format) of DigMap 250K geology and OS 625K topography was extracted from the GDI and draped on the NEXTmap topography.
- The rockhead surface was created from a combination of 1 km grid rockhead supplied by B. Napier and the NextMap DTM. In places the rockhead lies above the DTM. Where this was the case the DTM surface was used.
- Initially the borehole data was extracted from Borehole_Geology using an *SQL* query. Subsequently an intranet application was built to provide this information via the DGSM Data Portal and it is recommended to use this application. The Portal is the recommended route for data extraction though it cannot deal with large areas with large numbers of boreholes and a 'tile' approach may be required. There were many boreholes that lacked start heights and, as GOCAD requires OD based z values, the extracted dataset needed editing before it could be of use for modelling.
- GeoGraphix does not readily export data. It allows depth converted grids to be exported to GeoAtlas, then ascii xyz data for the depth converted grids can be created. The time picks on the seismic lines cannot be exported. The depth converted grids have nodes that do not overlap vertically with nodes from other depth converted surfaces.
- Depth converted seismic grid data were imported into GOCAD and triangulated to produce surfaces.
- Mine plan data was imported into GOCAD. DXF data were imported as curves and CSV format files as point sets.
- The DigMap 250K linework was imported as curves and registered to the topographic triangulation.
- The surfaces were then fitted to the borehole and mine plan data as derived from Borehole_Geology. The DSI was run to fit the geometry of the seismically derived surface with boreholes acting as control nodes. Where crossovers between surfaces occurred, a minimum thickness was specified to remove the errors.
- The extent of the surfaces were limited to the DigMap 250K croplines where applicable.
- Subsurface extents of units were derived from boreholes and/or project area.
- In places the seismic grid for MMG, top UVAR and SSG overlapped the DigMap linework, i.e. the seismic grid appeared to suggest continuation of the geology above the DTM. This resulted from not specifying the edge of the seismic grid accurately. Hence where data points from seismic grid were outside cropline or obviously at incorrect depth (as a result of processing), datapoints were edited manually.

- Surfaces were fitted to previous geological work such as section lines on map sheets by assessing offsets for major faults, and approximating thicknesses of units.
- The construction of horizon surfaces is relatively straightforward, but was complicated by problems with trying to honour all the data points (i.e. depth converted seismic grid, borehole and mine plan). It was found that there was some overlap between some of the deeper stratigraphic surface, particularly the UCAL, DIN and MG.
- It was clear that the seismic depth conversion (derived using borehole sonic logs in the GeoGraphix software package) contained errors for some of the deeper stratigraphic surfaces (top UCAL, top DIN, top NMRN) as the grids overlapped in places. The UCAL in particular was far too shallow – some parts of the base of the Widmerpool half-graben appearing to be at depths in the region of 2700 m below OD whereas depth converted sections of Fraser and Gawthorpe (1990) have the base of the half-graben at depths of 4500 – 5000 m below OD. This was due to the depth conversion being based on too few boreholes. After re-checking of horizon depths in boreholes, which revealed a number significant errors, the top DIN and top NMRN were 'adjusted to Wellmarkers' in GOCAD. The top UCAL was not adjusted to wellmarkers due to insufficient boreholes. A time grid, exported from GeoGraphix, was depth converted using a constant which allowed the grid to match the profile of Fraser and Gawthorpe (1990).
- To remove crossovers from surfaces, minimum thicknesses were specified for some units. These included 1 m thickness between rockhead and DTM; 10 m between SSG and underlying units, 25 m thickness of Namurian and 20 m for the Deep Hard.
- The surfaces were originally modelled using seismic data from a wider area than the final model. Surfaces were then clipped to the model extents. This was carried out to eliminate major edge effects.
- The DTM was used to limit the uppermost position of the stratigraphic units.
- The whole process was iterative i.e., an initial surface would be created and then inspected for anomalies. For example, these might be derived from rogue points derived from seismic gridding procedures or incorrect picking of borehole intersections. Data points were then deleted or moved after an assessment of their validity. A new surface would be created and re-inspected. Through this process, a continuous dialogue between the modeller and geologists familiar to the structure and stratigraphy is recommended so that issues can be resolved early in the modelling process.

4.2 FAULT MODELLING

In the GOCAD model it was desirable to model the interpreted fault surfaces as independent entities, for instance so that the surfaces can be projected to ground surface. The source data for the fault modelling were:

- Fault traces derived from the Landmark GeoGraphix software. Fault traces were exported from GeoGraphix according to horizon in numerical order, i.e., DIN1, DIN2, DIN3 etc from Dinantian. Note: DIN1 does not necessarily mean it is Fault 1, therefore all fault intercepts have been renamed to include the fault name (F1, F2 etc).
- DigMap surface faults at 50K.
- Throws on major faults were interpreted from geological knowledge of the area such as memoirs and sections on geological maps.

GeoGraphix does not export faults name, i.e. during export the names are lost. Faults had to be rebuilt in GOCAD by creating a points set for each fault where it crossed each successive stratigraphic surface, then building a surface for the fault in GOCAD using the points. This was time consuming as there were about 70 faults exported from GeoGraphix. Also, GeoGraphix cannot deal effectively with a fault that has been inverted, i.e. has sections of net extension and sections with net compression. This can be overcome by picking each as separate faults. The fault modelling is complicated by the fact that depth converted picks on the faults are not output from the seismic interpretation package, so a relatively involved procedure must be gone through in order to obtain a model of each fault surface. This procedure is as follows:

1. Rename all faults output from GeoGraphix to include fault name, but retain GeoGraphix designation for future reference. Fault labelling followed the convention established by the seismic interpretation task. i.e. numerical, Fault_01, 02 etc.
2. Check all faults by name to verify that all the horizons are in the correct location.
3. Create a points set from all the horizons for each fault.
4. Data points for fault intersections from seismic data, particularly from the Top Dinantian surface, often lay outside the envelope from other surfaces. This probably resulted from incorrect depth conversion and hence the generation of spurious xy points. Where this was the case these were not included in surface creation.
5. Create a convex hull from the points set for each fault. The convex hull is a line which should enclose all data points (i.e. a border) and provides the extent for a first fault surface. Densify the convex hull, and ensure that the convex hull honours all the data points.
6. Create a new surface from the convex hull.
7. Use DSI: The fault points sets for each horizon are used as control points to warp the surface to fit data points. This forms the main fault surface.
8. Clearly not all faults extend to the surface but in order to try to match up the seismically derived faults with their possible surface expression, fault surfaces at depth were compared to DigMap 50K traces. Where a modelled fault has an obvious expression at surface, this is added to the points set for the fault and remodelled. In places this created problems with the fault modelling because there was a mismatch between the DigMap fault linework and the seismically derived fault surface – this expressed itself as a bend or kink in the fault (see Fig. 3). Upon further investigation it was found that the fault at surface was hidden beneath drift and its inferred position was picked as part of an earlier analogue (i.e. paper-based) seismic interpretation phase.
9. Another problem that was encountered whilst matching surface fault expressions with the seismically picked faults was that some seismically picked faults appeared to cross from one DigMap fault to an adjacent one. Shotpoint locations, marking the positions of the seismic lines, were imported into GOCAD. These showed that typically these differences resulted from gaps in seismic coverage and can probably be linked to difficulties in correlating faults between successive, widely spaced 2D seismic lines.
10. In some cases, segments of major faults have been picked seismically, but other segments are not included. If a fault appears to have an obvious extension at surface, linking the two seismic segments then the fault is modelled as continuous between the two segments.
11. Some faults surfaces have a pronounced ‘corrugated’ appearance in places (Fig. 3). This is particularly evident on faults F1, 4, 7, 8, 13,14, 15, 20, 21, 25, 28, 32, 37, 40, 46, 47,

69. These faults required remodelling using the raw data points to try to produce a smoothed surface.

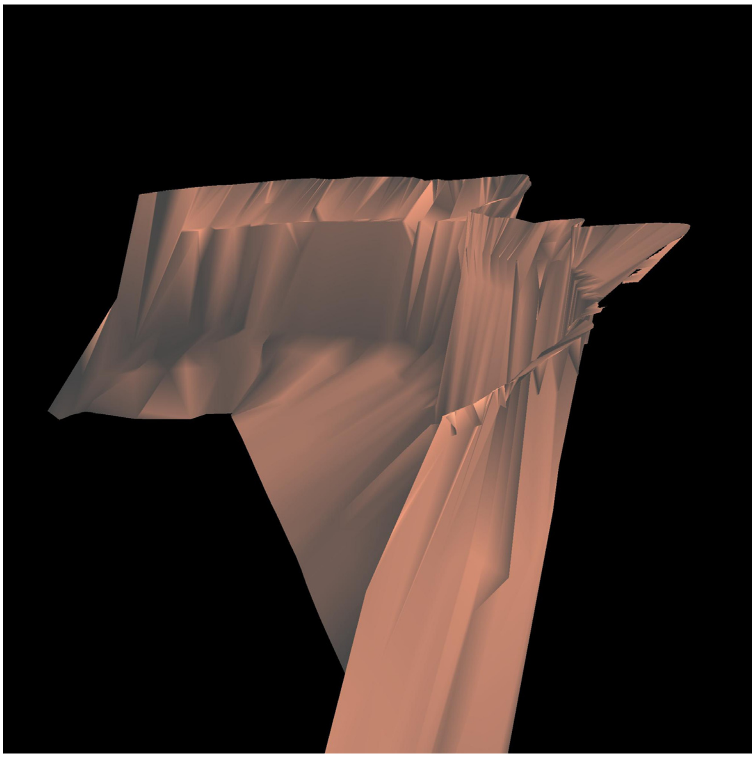

Figure 2. Normanton Hills Fault in the GOCAD model.

Note the steep bend in the fault at it reaches the surface DTM (not shown). The vertical exaggeration is x1. The fault is created by generating a surface using the seismic data and honouring the DigMap 50K surface linework for the fault. The fault is one of the major faults in the area and is well constrained seismically. Hence the bend is likely to be a function of a slight mismatch between the inferred surface position of the fault and its seismic position. The vertical distance of the mismatch is typically in the order of about 400 m. A slightly corrugated effect can also be seen along the fault surface. The lower part of the fault is listric in form.

The lower parts of the Foston-Eakring (Fault 21) and Normanton Hills (Fault 1) faults can be seen on seismic sections to be listric in form. Hence the deeper parts of these faults were made to curve appropriately using points on the Caledonian Unconformity (Fig. 3).

Stratigraphic surfaces were then cut and offset by faults. This is time consuming, hence only major faults were done, i.e. where the known displacement is > 50m over a wide area. Surfaces were cut by 4 main faults: Normanton Hills (Fault-01), Cinderhill (Fault_10), Foston-Eakring (Fault_21) and the Sileby Fault (Fault_47). Also, not all stratigraphic surfaces were cut by these faults if the displacement was < 50m. The following GOCAD commands were used:

1. Cut stratigraphic surfaces with faults using 'Cut By Surfaces'. Do not 'build constraints' and do not 'beautify'.
2. Delete intervening triangles individually.
3. It may be necessary to attach constraints to a stratigraphic surface to fit with surface or curve on that surface.

DigMap 50K faults that do not appear to coincide with seismically resolvable faults were simply modelled as vertical, using the Fault Construction wizard. These are treated in the following way:

1. Compare DigMap faults with fault traces picked for modelled faults.
2. Delete faults traces previously picked for modelling. Modelled fault traces are grouped in DigMap_nonvertical.
3. Limit faults to the area of interest.
4. Use fault wizard to create vertical faults down to an aribitrary 200 m below sea level and up to 220 m above sea level. Use a minimum segment length of 10 m and no maximum segment length.
5. Cut fault surfaces by DTM (using ‘Cut by Surface’ command).
6. Use ‘Surface Edit Parts Remove’ selection to remove parts above DTM.
7. Group these vertical faults together to make display easier.

4.3 INTEGRATION OF OTHER DATASETS

There were 3 ‘models’ that were integrated into the main GOCAD model. These were the GSI-3D model of the superficial deposits of the River Wreake, the Vulcan model of the Saltby Volcanic Formation and the extra coal surfaces modelled in Surfer. The import of the GSI-3D model was relatively straightforward, as the triangulation files produced by GSI-3D are easily imported into GOCAD. To carry out this, triangulations were exported from GSI-3D as .ts file format, copied across to the relevant folder and opened as an object in GOCAD. Note: these are grids converted to triangulations.

A Best Practice Report (see http://kwntsdgsm1/scripts/bestpractice/screen1.cfm) describing the methodology for importing Vulcan files into GOCAD has been written by Steve Dumpleton and Gill Norton. In summary the procedure is as follows:

1. Export triangulations from Vulcan as 3D dxf (ensure 3d box is checked). Import dxf into GOCAD.
2. Vulcan to GOCAD block models. Export block model as ascii file, but use “model to csv” rather than “export ascii”. Use import raw data columns based data in GOCAD. Call the litho_code column the “name”. GOCAD imports each set of blocks attributed to a lith code as a single pointsets.

To import Surfer files into GOCAD, firstly they need to be converted from the surfer grid format to Arc-compatible ascii format using a ‘grid convert’ utility, which is freeware from Geospatial Designs. This creates Zmap grids that can be readily imported into GOCAD using ‘File-Import Objects-Landmark-Zmap-Ascii Grid as a 2D grid’ command. A BGS report has been written by H. Sheppard describing this procedure (see IR/05/057).

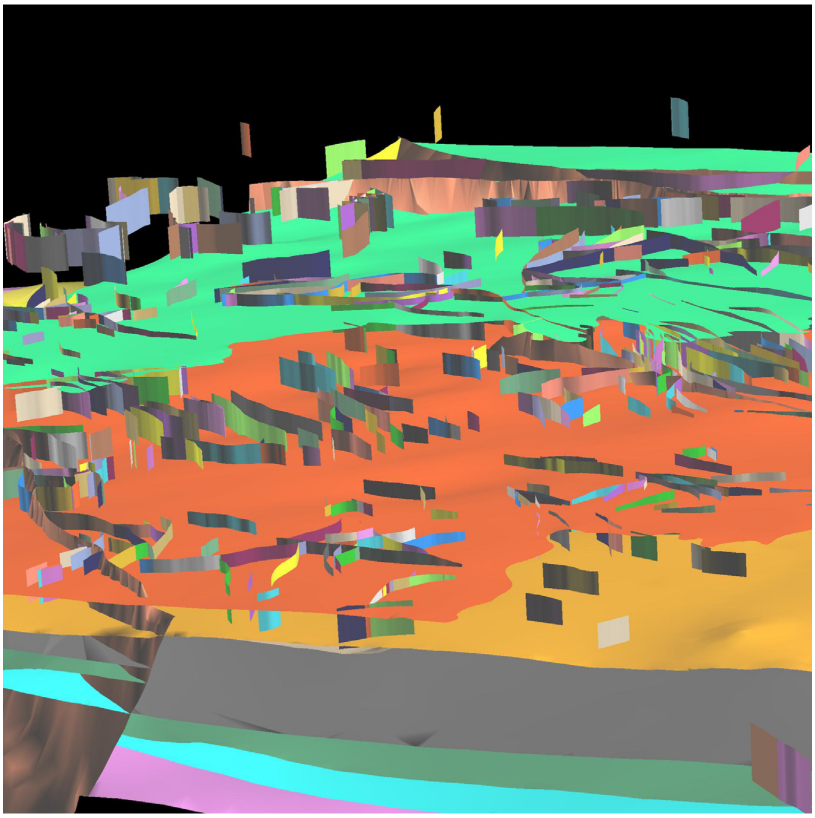

Figure 4. DigMap 50K faults modelled as vertical structures.

5 Model validation, metadata and archiving

The model was examined in detail by K. Ambrose (KAM). A number of comments related to the overall presentation of the model and are easily dealt with e.g. such as the use of a scale bar, the use of a GVS summary log, the need for a transparent topographic layer with grid lines to enable a proper positional check of the data. Other comments included:

- The models should have a surface geology layer and the relevant surfaces must relate to this layer. *Response:* Agreed; DigMap250k was draped on topography.
- It would be useful to have the ability to infill a given stratigraphic unit and to be able to look at cross sections/slices through the model. *Response:* A 3D block model can be built if required to give this functionality, but was outside the scope of this project.
- The Deep Hard subcrop surface is wrong in places and needs modifying. *Response*: To correct this, technical reports were supplied by KAM showing the position of the subcrop of the Deep Hard Coal. This linework was digitised and imported into GOCAD and the old surface limited to this new linework.
- None of the faults in 'Surface' match with those in the 'Vertical_faults_from_DigMap_to_200m_depth' group. The grouping of the DigMap vertical faults contains some different faults, all of which appear to match with the individual faults apart from one or two irregularities in the fault surface trace. *Response*: There is obviously some confusion as to what these faults represent. The faults in the

'Vertical_faults_from_DigMap_to_200m_depth' group represent the remainder of the faults that have no obvious seismic expression. In the absence of any seismic data to constrain them further they have all been modelled simply as vertical faults that terminate at a depth of 200 m.

- The geological maps have to be the starting point for this model and all layers must relate to them. This only affects two surfaces (top MMG and top SSG) but **all** faults used in the model must relate to the surface; seismic data should then be used to refine the faults and to show those that are beneath superficial deposits. During compilation of the Melton Sheet Standards, considerable time was spent looking at seismic data and attempting to fit surface faults to it. Thus the match between the two should generally be good. Borehole intersections should form the basis for all the surfaces modelled, again refined using seismic data for areas of poor borehole control. The density of deep boreholes over most of this area should be sufficient to define the surfaces very well. *Response*: Agreed. Seismic data was integrated with the surface position of the faults.
- Top_Dinantian surface – This cross cuts both the top_mg and top_dhc surfaces in several places and gets too close to the top_uvar in places. *Response*: The DIN surface that KAM initially inspected was incorrect; the revised surface is now in a position that does not cross MG and DHC. This surface has proved problematical to model due to poor borehole control to constrain the seismic depth conversion. It has been revised to take in these comments but attention is still needed in this matter and T. Pharaoh proposes to look again at the depth conversion as part of the East Midlands project.
- The Eakring – Foston Fault (Fault_21), is just about represented as a reverse fault but it is not very convincing, appearing to be nearer vertical. The fault profile as shown on the Nottingham Sheet cross section shows a very low hade to this fault at depth that does not come out at all on the model. *Response*: The modelled fault is listric in form but at high values of vertical exaggeration (>5) it appears straight. Hence it is recommended to keep the vertical exaggeration at or below this value.
- The mid ridge corresponds to three fault planes (10, 20, 28) but no fault is indicated on the model. This would appear to be the Cinderhill Fault forming the northern boundary to the Widmerpool Half Graben This fault system should have a southerly downthrow but this is not clear and it appears to be vertical. *Response*: It would appear that the Cinderhill Fault represents more of a flexure than a major fault. Surfaces have only been cut by 4 main faults: Normanton Hills (Fault-01), Cinderhill (Fault_10), Foston-Eakring (Fault_21) and the Sileby Fault (Fault_47).
- The Normanton Hills Fault is very poorly represented with no fault shown and the model not even showing a clear ridge. *Response*: This is a major fault in the model.
- The Widmerpool half graben is not well displayed as a half graben profile but this may be a true representation at this time. *Response*: This comment must relate to the later Carboniferous and earlier surfaces as the model clearly shows it is a half graben during the Lower Carboniferous.
- Where are the Melton Mowbray and Rempstone granites? *Response*: These were not modelled.
- Some obviously spurious data points affect some of the surfaces, e.g. Top UCAL.

As a result of these comments a number of aspects of the models were dealt with before acceptance. These include elimination of all overlapping surfaces and obvious rogue data points. Following correction of the model it was again reviewed by KAM and approved. It was then accepted and approved by the Project leader. The relevant Metadata was submitted to the Metadata manager and files were uploaded into the GSF and GLOS.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

FRASER, A.J. & GAWTHORPE, R.L. 1990. Tectono-stratigraphic development and hydrocarbon habitat of the Carboniferous in northern England. In: HARDMAN, R.F.P. & BROOKS, J. (eds) *Tectonic events responsible for Britain's oil and gas reserves*. Geological Society of London Special Publication, 50, 417-440.

BOREHOLE NAME	QS	No.	DIGITISED IN JODPHURS & LOADED INTO WELLOG	TAPES LOADED INTO WELLOG
ALL HOLLOWS	SK73NE	12		Y
ASFORDBY No.2	SK72SW	96		Y
ASFORDBY SITE No.1	SK72SW	81		Y
ASFORDBY SITE No.6	SK72SW	95		Y
ASH PLANTATION	SK72SW	93		Y
AYLESFORD COVERT	SK62SE	25		Y
BACK LANE	SK73SE	65		Y
BANK HILL	SK64NW	35		Y
BARKESTONE WOOD	SK73SE	57	Y	
BELVOIR 1	SK83SW	107	Y	
BOTTESFORD 1	SK73NE	1		Y
BOTTESFORD 2	SK83NW	8		Y
BOTTESFORD 3	SK73NE	2		Y
BOTTESFORD 4	SK73NE	3	Y	
BRACKENDALE FARM	SK63NE	72		Y
BROUGHTON HILL	SK72SW	109		Y
CALCROFTS CLOSE	SK83SW	104	Y	
CANAL FARM	SK72NW	2	Y	
CASTLE VIEW	SK72NW	9	Y	
COACHGAP FARM	SK73SW	4	Y	
CROXTON ABBEY	SK82NW	41	Y	
CROXTON BANKS	SK83SW	103	Y	
CROXTON KERRIAL	SK82NW	46	Y	
DENTON BRIDGE	SK83SE	530	Y	
DENTON LODGE	SK83SE	532	Y	
EADY FARM, BOTTESFORD	SK73NE	9	Y	
EASTWELL	SK72NE	40	Y	
EGYPT PLANTATION	SK82NE	424	Y	
ELSTON GRANGE	SK74NE	2	Y	
FALLOWS FARM	SK65SW	53		Y
FISHPONDS	SK72SW	101		Y
FOUNDRY	SK72SW	98		Y
FRANCE PLANTATION	SK83SE	541	Y	
FREEBY VIEW	SK72SE	10	Y	
GOADBY GORSE	SK72NE	46	Y	
GRANBY 1	SK73NE	4	Y	
GREAT PONTON 1	SK83SE	540	Y	
GREENWOODS BARN	SK83SW	108		Y
HAGG LANE	SK64NE	43		Y
HARBY EAST	SK73SE	56	Y	
HARSTON HALL	SK83SW	102	Y	
HARSTON ROAD	SK83SE	528	Y	
HAUL ROAD	SK72SW	84		Y
HOLWELL	SK72SW	75		Y
HOSE	SK72NW	3	Y	
IRONSTONE FARM	SK72SW	116		Y
LANESIDE	SK72SW	76		Y
LANGAR 1	SK73NW	4	Y	
LINDHURST COTTAGES	SK55NE	32		Y
LIONVILLE COTTAGES	SK72NE	42	Y	
LONG CLAWSON 2	SK72NW	13	Y	
MANOR HOUSE	SK72SW	87		Y
MELTON SPINNEY	SK72SE	9	Y	
ODD HOUSES	SK63SW	73		Y
OSIER BED	SK72SW	74		Y
PILLBOX No.1	SK72SW	91		Y
PIPELINE	SK72SW	85		Y
RACECOURSE FARM	SK72NW	8	Y	
REDMILE BRIDGE	SK73NE	11	Y	
ROMAN PLANTATION	SK83SE	529	Y	
SALTWAY	SK62SE	31		Y
SCALFORD 1	SK72SE	30	Y	
SCREVETON 1	SK74SW	1	Y	
SHEEP PENS	SK72SW	103		Y
SHELT HILL	SK64NW	34		Y
SHERRICLIFFE FARM	SK73SE	58	Y	
SHOBY SCHOLES	SK62SE	30		Y
STATHERN SOUTH	SK73SE	60	Y	
STEELWORKS	SK72SW	90		Y
STENWITH	SK83NW	11	Y	
STUD FARM	SK62SE	26		Y
SUBSTATION	SK72SW	80		Y
SYSONBY FARM	SK72SW	88		Y
TERRACE HILLS	SK83SW	101	Y	
THE CHASE	SK72SW	77		Y
THE PRIORY	SK62SE	29		Y
THORNEY PLANTATION	SK72SW	112		Y
TUNNEL	SK72SW	89		Y
UPLANDS FARM	SK72SW	107		Y
WALTHAM LANE	SK72NE	45	Y	

Table 1. List of geophysical logs acquired and uploaded into Wellog.