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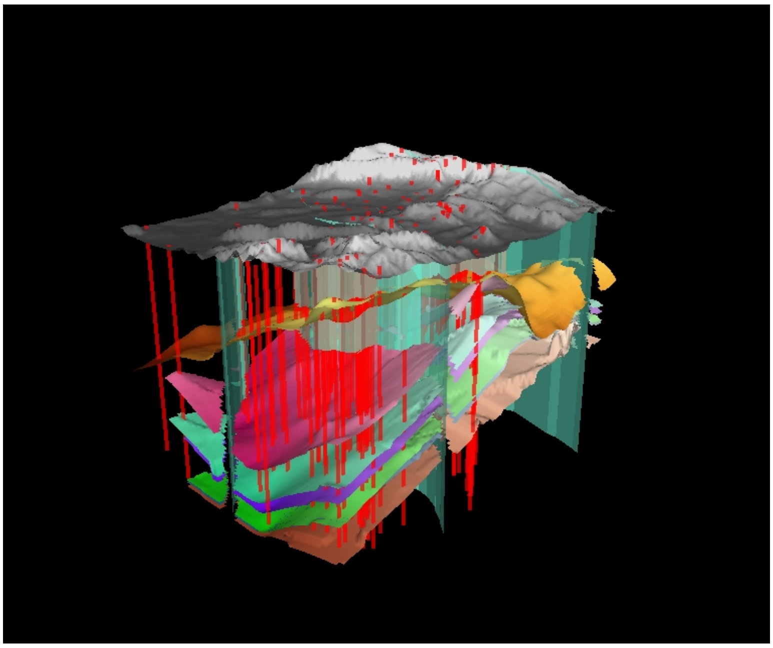
Modelling of coal seams in the Nottingham-Melton area: methodology and specifications

Digital Geoscience Spatial Model Programme

Internal Report IR/05/057



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/05/057

Modelling of coal seams in the Nottingham-Melton area: methodology and specifications

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Key words

Nottingham; Melton; DGSM; Surfer; Westphalian; Belvoir

Front cover

ArcScene visualisation of coal seams in the Nottingham-Melton area

Bibliographical reference

SHEPPARD, T. H. 2005. Modelling of coal seams in the Nottingham-Melton area: Methodology and Specifications. *British Geological Survey Internal Report*, IR/05/057. 20pp.

Keyworth, Nottingham British Geological Survey 2005

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) of the subsurface geology of the Nottingham-Melton district. It describes the production of 3D models of coal seams in the Langsettian and Duckmantian of the district from borehole, mining and seismic datasets.

All file pathways refer to the datasets and models archived on the enclosed CD-ROM. Model parameters are highlighted in green boxes.

Contents

Summary

3D models of coal seams in the Langsettian and Duckmantian of the Nottingham-Melton district were gerenerated from 1) borehole, 2) mining and 3) seismic datasets. The surfaces were produced by Kriging interpolation of data points using Golden Software's SURFER package. Surfaces derived from borehole data were a) interpolated, taking account of fault lines; b) recalculated to avoid intersections, c) blanked to remove intersections with the Variscan unconformity, d) blanked to remove intersections with fault lines. Surfaces derived from seismic data were regenerated from previously interpolated dataset, whilst surfaces derived from mining data were treated in the same manner as the borehole dataset. Composite models, taking into account borehole, seismic and mining data, were generated for three of the six coals examined. All models were exported to ArcScene and GoCad for visualisation and GLOS storage, and to xyz ASCII for storage in the GSF.

1 Introduction

This work was carried out in February 2005 as part of the Nottingham-Melton DGSM project, E1362S96 Task 06. A Gocad model for the entire area covered by the Nottingham (126) and Melton (142) geological sheets was already available. However, a significant coal-related dataset was still available to the project and had been relatively under-utilised. This dataset included a set of MS Access tables generated by PhD research (Sheppard 2003), Coal Authority mine plan data and data on the Deep Hard seam, generated by a previous BGS Deep Geology Group project (Holliday et al. 1984) and by more recent seismic interpretation as part of the Nottingham-Melton project. The work aimed to close this loophole and provide stratigraphic data for use in the Gocad models.

2 Data Preparation

Following PhD research a set of MS Access tables exists for depths to, and thickness of Westphalian A coal seams in the Melton area (Vale of Belvoir Coalfield). The objective of this work was to utilise and expand this dataset, to make it corporately available by uploading to Borehole_Geology and, by incorporating with other datasets, to produce a number of gridded surfaces that would compliment, and add richness and detail, to Gocad models previously constructed for the Nottingham-Melton area. It was decided that modelling of the Top Hard, Deep Main/Deep Hard, Parkgate, Yard, Blackshale and Kilburn coals in the Nottingham-Melton DGSM project area would be undertaken, using a) borehole data, b) seismic data, and c) mining data.

3 Workflow

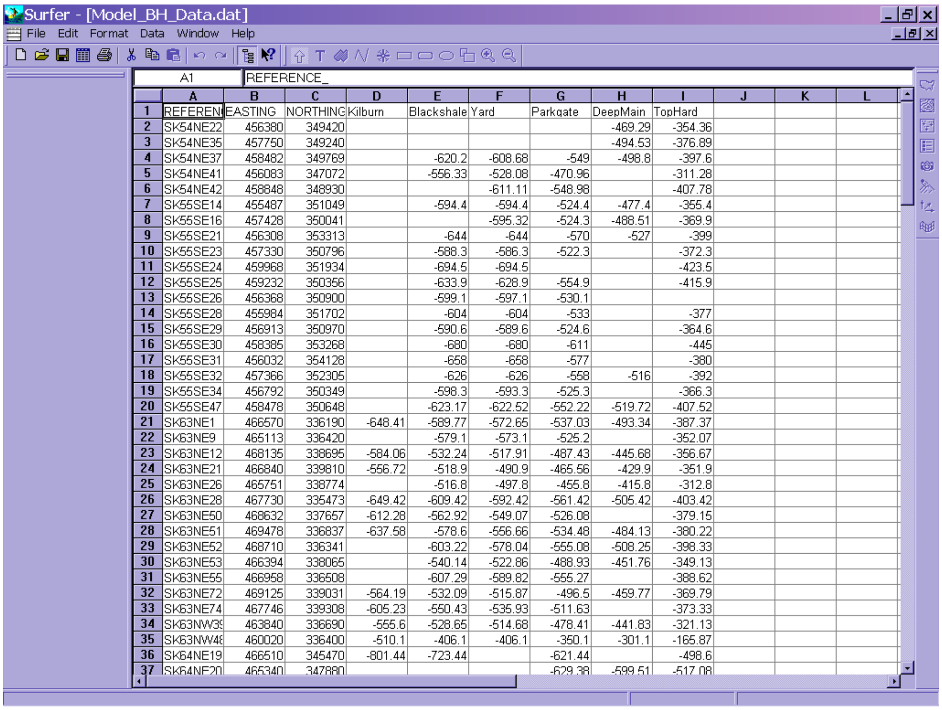
See Appendix 1.

4 Data Preparation

Borehole Data is derived from NGDC borehole records. For the Langsettian (Westphalian A) coals of the Melton area, a pre-existing MS Access database was utilised, derived by PhD research (see Sheppard 2003), whilst the Duckmantian (Westphalian B) Top Hard Coal was databased in Excel. For the Nottingham area, all SOBI boreholes over 600m in length were databased in MS Excel for all specified coals. Only tops data was collected for the Top Hard, Deep Main/Deep Hard, Parkgate, Yard, Blackshale and Kilburn coals in the Nottingham-Melton area. In addition, it was later found necessary to database a further borehole subset in the West Bridgford area, where the Pennine Coal Measures Group is present at relatively shallow depths and the structure could not be satisfactorily resolved by relying only on the >600m dataset. The Access and Excel datasets have subsequently been uploaded into Borehole_Geology. A limited number of boreholes with erroneous readings were removed after preliminary modelling.

The entire borehole dataset (197 records) was then converted, via Excel, to an ascii text .dat file, which is Surfer’s xyz data format,

..\Surfer_model\Borehole_model\Model_BH_Data.dat.



	A	B	C	D	E	F	G	H	I	J	K	L
1	REFEREN	EASTING	NORTHING	Kilburn	Blackshale	Yard	Parkgate	DeepMain	TopHard			
2	SK54NE22	456380	349420					-469.29	-354.36			
3	SK54NE35	457750	349240					-494.53	-376.89			
4	SK54NE37	458482	349769		-620.2	-608.68	-549	-498.8	-397.6			
5	SK54NE41	456083	347072		-556.33	-528.08	-470.96		-311.28			
6	SK54NE42	458848	348930			-611.11	-548.98		-407.78			
7	SK55SE14	455487	351049		-594.4	-594.4	-524.4	-477.4	-355.4			
8	SK55SE16	457428	350041			-595.32	-524.3	-488.51	-369.9			
9	SK55SE21	456308	353313		-644	-644	-570	-527	-399			
10	SK55SE23	457330	350796		-588.3	-586.3	-522.3		-372.3			
11	SK55SE24	459968	351934		-694.5	-694.5			-423.5			
12	SK55SE25	459232	350356		-633.9	-628.9	-554.9		-415.9			
13	SK55SE26	456368	350900		-599.1	-597.1	-530.1					
14	SK55SE28	455984	351702		-604	-604	-533		-377			
15	SK55SE29	456913	350970		-590.6	-589.6	-524.6		-364.6			
16	SK55SE30	458385	353268		-680	-680	-611		-445			
17	SK55SE31	456032	354128		-658	-658	-577		-380			
18	SK55SE32	457366	352305		-626	-626	-558	-516	-392			
19	SK55SE34	456792	350349		-598.3	-593.3	-525.3		-366.3			
20	SK55SE47	458478	350648		-623.17	-622.52	-552.22	-519.72	-407.52			
21	SK63NE1	466570	336190	-648.41	-589.77	-572.65	-537.03	-493.34	-387.37			
22	SK63NE9	465113	336420		-579.1	-573.1	-525.2		-352.07			
23	SK63NE12	468135	338695	-584.06	-532.24	-517.91	-487.43	-445.68	-356.67			
24	SK63NE21	466840	339810	-556.72	-518.9	-490.9	-465.56	-429.9	-351.9			
25	SK63NE26	465751	338774		-516.8	-497.8	-455.8	-415.8	-312.8			
26	SK63NE28	467730	335473	-649.42	-609.42	-592.42	-561.42	-505.42	-403.42			
27	SK63NE50	468632	337657	-612.28	-562.92	-549.07	-526.08		-379.15			
28	SK63NE51	469478	336837	-637.58	-578.6	-556.66	-534.48	-484.13	-380.22			
29	SK63NE52	468710	336341		-603.22	-578.04	-555.08	-508.25	-398.33			
30	SK63NE53	466394	338065		-540.14	-522.86	-488.93	-451.76	-349.13			
31	SK63NE55	466958	336508		-607.29	-589.82	-555.27		-388.62			
32	SK63NE72	469125	339031	-564.19	-532.09	-515.87	-496.5	-459.77	-369.79			
33	SK63NE74	467746	339308	-605.23	-550.43	-535.93	-511.63		-373.33			
34	SK63NW3	463840	336690	-555.6	-528.65	-514.68	-478.41	-441.83	-321.13			
35	SK63NW4	460020	336400	-510.1	-406.1	-406.1	-350.1	-301.1	-165.87			
36	SK64NE19	466510	345470	-801.44	-723.44		-621.44		-498.6			
37	SK64NE20	465340	347880				-629.38	-599.51	-517.08			

Model_BH_Data.dat in Surfer

Seismic data was supplied by the Nottingham-Melton DGSM project. It comprises two gridded surfaces for the Deep Hard Coal (one derived by Holliday et al. 1984 and a revised version generated by M. Bentham, T Pharaoh & C Vincent for the DGSM project), and a surface for the base Permian (UVAR), also generated by Bentham Vincent & Pharoah. The 1984 version of the Deep Hard and UVAR data was supplied as an asci xyz of grid-nodes at 250m. The revised Deep Hard was supplied as grid-node xyz at 1km spacing. These were all converted to .dat xyz for use in surfer:

..\Surfer_model\Seismic_model\UVAR\Notts_Melton_UVAR.dat

..\Surfer_model\Seismic_model\Deep_Hard\Notts_Melton_DeepHard.dat

(original 250m Deep Hard, from Gill Norton)

..\Surfer_model\Seismic_model\Revised_Deep_Hard\Revised_DeepHard.dat

(revised 1km Deep Hard, from Chris Royles).

Mining Data was supplied by the Coal Authority for use by the Nottingham-Melton DGSM project. It comprises ESRI point shapeflies of seam level readings from subsurface measurement of the Blackshale, Deep Hard, and Top Hard, together with a small dataset for the combined Deep Hard/Piper. A further dataset, labelled 'Deep Main' was also provided, with elevations way above the expected level of the Langsettian Deep Main Coal. This is probably a mis-labelled dataset for workings in the Bolsovian (Westphalian C) High Main Coal. These datasets were also found, on inspection, to contain a significant number of erroneous readings. Thus the shapefile was edited in Arc 3.2 and erroneous data removed, the shapefile attribute table then being exported as an xyz text file and converted to .dat format by, and for use in, Surfer.

..\Surfer_model\Mining_model\Blackshale\Blackshale_seamlevels.dat

..\Surfer_model\Mining_model\DeepHard\DeepHard_Seamlevels.dat

..\Surfer_model\Mining_model\DeepHard_Piper\DeepHard_Piper_Seamlevels.dat

..\Surfer_model\Mining_model\DeepMain\DeepMain_Seamlevels.dat

..\Surfer_model\Mining_model\TopHard\TopHard_Seamlevels.dat

5 Surfer modelling

5.1 BOREHOLE MODELS

Raw models were created in Surfer via a kriging interpolation of the borehole dataset Model_BH_Data.dat using the Surfer Grid | data tool. The raw Kriged surfaces each have the following parameters:

Data range: Xmin 455000 Xmax 483000 Ymin 320000 Ymax 355000

Cell size: 350m

Model faults: The surfaces were kriged with simplified fault data derived from DigMap 50. The seismically-derived fault linework for Nottingham (126) and Melton (142) sheets was redigitised in ArcView 3.2 to produce a simplified (low number of vertices) polyline shapefile representing the Foston-Eakring, Harlequin, Cinderhill, Normanton Hills and Sileby faults.

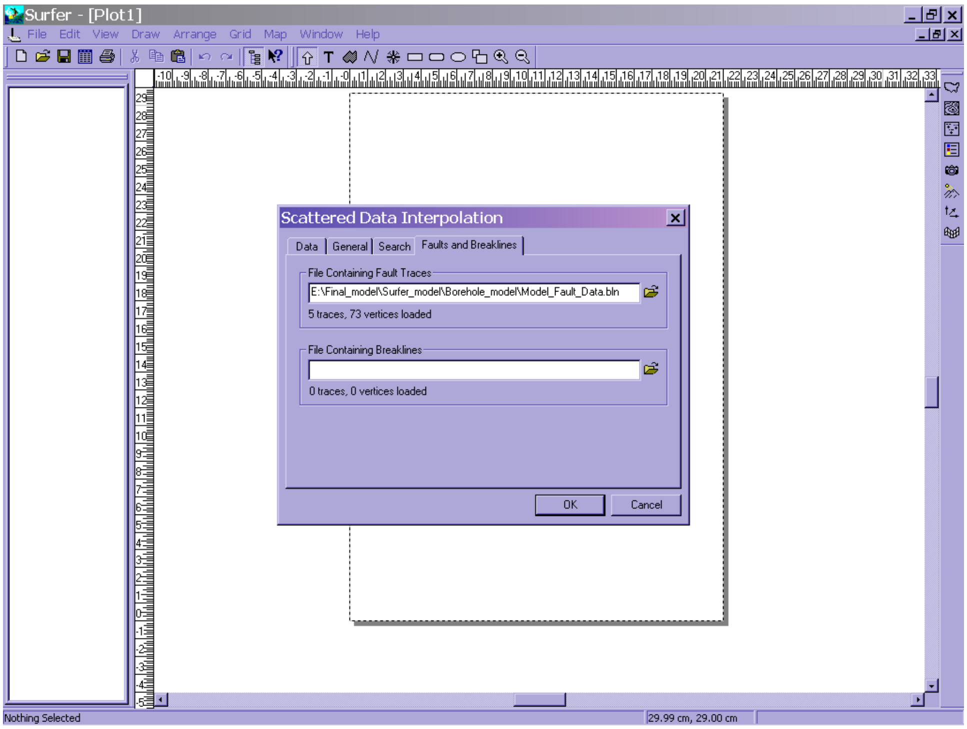
..\Components\Features\Model_Faults.shp.

This shapefile was converted to 3D and then to ascii xyz in Arcview using a free avenue script downloaded from esri.com ArcScripts archive,

..\Components\Features\3d2ascii.ave.

This ascii xyz polyline data was then converted to Surfer Blanking line (.bln) format in Surfer for use during interpolation:

\Surfer_model\Borehole_model\Model_fault_data.bln.



Loading the model fault data into Surfer's Kriging interpolator.

Search specifications: for each interpolation the kriging interpolator was set to use the following search parameters:

Sectors: 4

Maximum number of data points per sector: 6

Minimum acceptable number of data points in all sectors (node blanked if fewer): 4

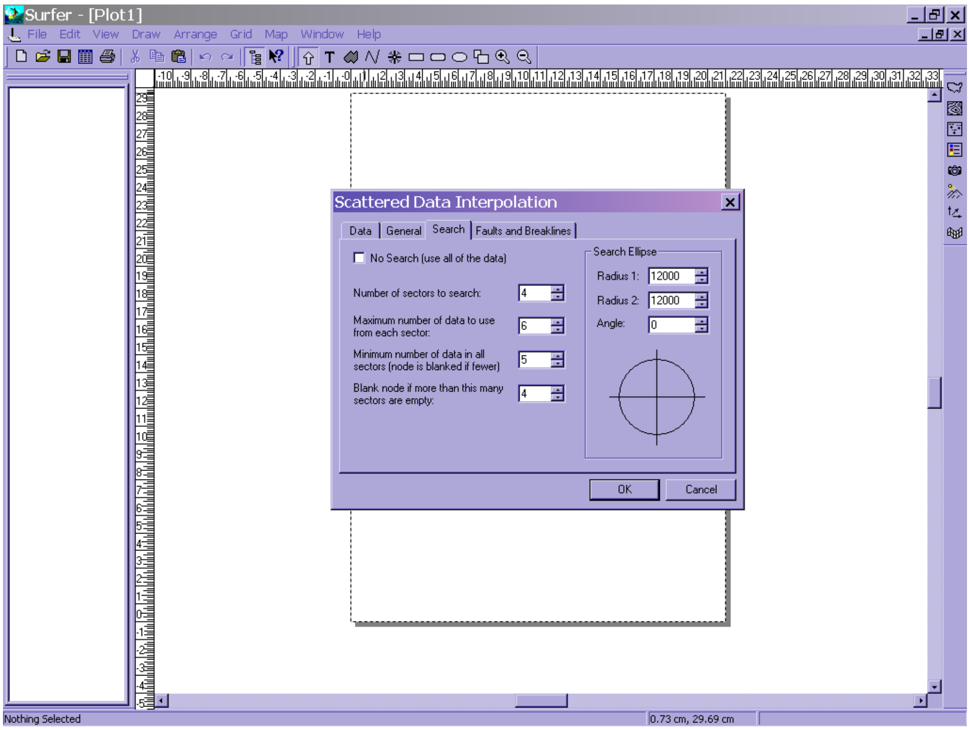
Node blanked if more than this number of sectors are empty: 4

Search radius was varied inversely according to data density, which was greater for coals higher in the stratigraphic succession. Search radius was as follows:

Kilburn: 18900m search radius

Blackshale through to Top Hard: 12000m search radius

This sector search is generous, allowing grid nodes to be populated even in areas of relatively little data. Areas where data is far too scarce for reasonable interpolation are blanked, e.g. north side of Foston-Eakring fault: Borehole SK85SW/48 is too far from other boreholes for reasonable interpolation (outside search radius), and in all grids has been blanked.



Specifying search parameters in Surfer's Kriging interpolator

The raw kriged surfaces are saved as:

..\Surfer_model\Borehole_model\TopHard_raw.grd

..\Surfer_model\Borehole_model\DeepMain_raw.grd

..\Surfer_model\Borehole_model\Parkgate_raw.grd

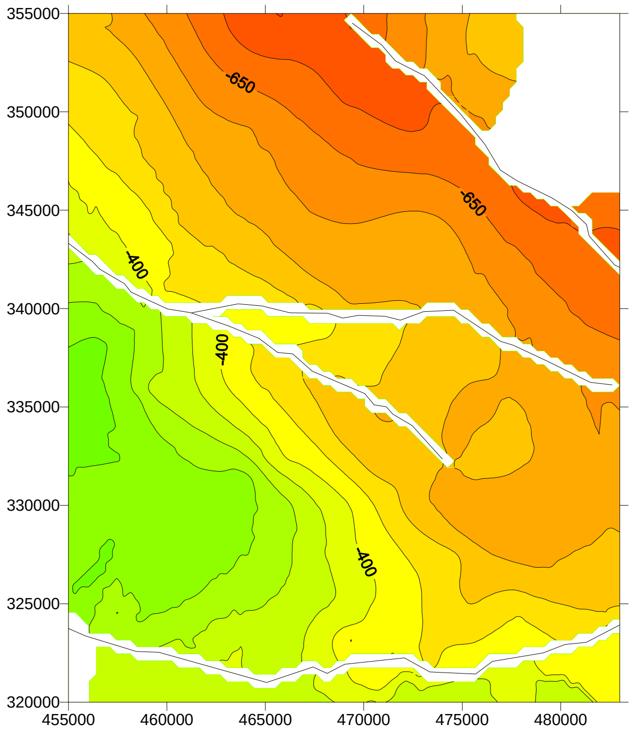
..\Surfer_model\Borehole_model\Yard_raw.grd

..\Surfer_model\Borehole_model\Blackshale_raw.grd

..\Surfer_model\Borehole_model\Kilburn_raw.grd

The surfaces are in Surfer's proprietary .grd grid format and can be plotted in Surfer using a common colour-level file for the model,

..\Surfer_model\Borehole_model\model_levels.lvl.



Raw surface for the Deep Main Coal, coloured using model level file.

For each surface, an interpolation report, recording data statistics and Kriging parameters, was automatically created by Surfer in rich-text (.rtf) format. These reports are stored as follows,

..\Surfer_model\Borehole_model\Interpolation_reports\TopHard.rtf

..\Surfer_model\Borehole_model\Interpolation_reports\DeepMain.rtf

..\Surfer_model\Borehole_model\Interpolation_reports\Parkgate.rtf

..\Surfer_model\Borehole_model\Interpolation_reports\Yard.rtf

..\Surfer_model\Borehole_model\Interpolation_reports\Blackshale.rtf

..\Surfer_model\Borehole_model\Interpolation_reports\Kilburn.rtf

Because the Kriging interpolator is able to interpolate beyond the limits of the dataset, the raw grids were all expected (and found) to have false intersections. Therefore, constrained grids were produced in order to properly stack the surfaces. For any two given seams, the minimum spacing recorded in any borehole (minimum real spacing) was determined by importing Model_BH_Data.dat into Excel and calculating the minimum interval between surfaces in the dataset. Interval spacings were as follows:

Top Hard-Deep Main: 38.8m

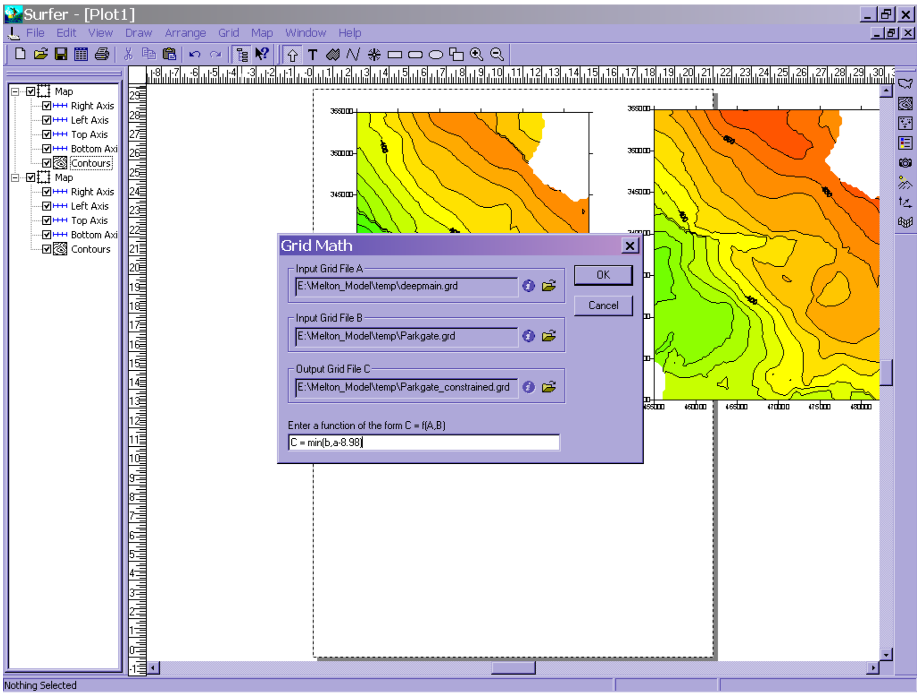
Deep Main-Parkgate: 8.98m

Parkgate-Yard: 10.57m

Yard-Blackshale: in some boreholes, the two coals are united. However, the minimum spacing for those boreholes where the coals are found separately was 0.65m.

Blackshale-Kilburn: 15.92m

One surface must act as the ‘reference’ surface against which all others are constrained. Because more boreholes encountered the Deep Main Seam than any other, this was chosen as the reference surface. The grids for coals below the Deep Main were thus successively constrained: raw Deep Main used to constrain raw Parkgate, the constrained Parkgate used to constrain raw Yard, and so on. In each case, the grids were constrained by using the Grid | Math tool in surfer, which allows mathematical formulae to be applied to each cell in one or two grids (Grids A and B) with each cell value of a third grid, grid C, being the product of that formula as applied to corresponding cells in grids A & B (note that all grids must therefore be the same size).



Grid math in surfer, with the raw Parkgate surface being constrained by the Deep Main surface

Grids were constrained according to the formula :

c = min(b,a-x)

Where a = upper (constraining) surface, b = lower (raw) surface, c = product (constrained) grid, and x = minimum interval value (as above).

Because the Top Hard is above the constraining surface (Deep Main), it was constrained according to the formula:

c = max(a,b+38.8)

where a = Top Hard, b = Deep Main and 38.8 is the minimum interval value.

Constrained grids are saved as:

..\Surfer_model\Borehole_model\Tophard_constrained.grd

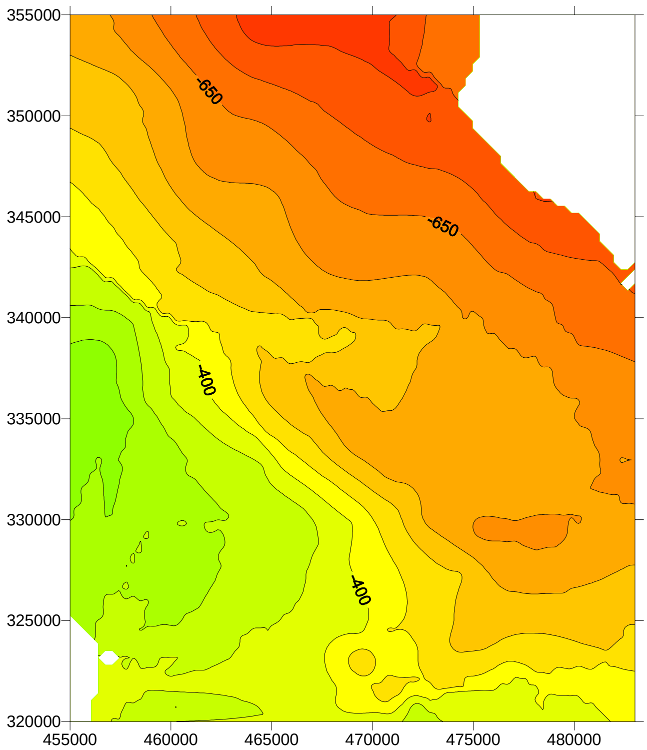
..\Surfer_model\Borehole_model\DeepMain_ constrained.grd

..\Surfer_model\Borehole_model\Parkgate_ constrained.grd

..\Surfer_model\Borehole_model\Yard_ constrained.grd

..\Surfer_model\Borehole_model\Blackshale_ constrained.grd

..\Surfer_model\Borehole_model\Kilburn_ constrained.grd



Constrained surface for the Parkgate Coal

Thirdly, because the surfaces were gridded against faults with a blanking value along the line of the fault, the constrained grids (which do not retain the blanked fault lines after being processed using Grid | Math) were blanked in order to allow faults to pass through the surfaces when visualised in 3D using ArcScene. In order to do this, a set of polygons were produced for each fault (Foston-Eakring, Harlequin, Sileby, Cinderhill, Normanton Hills) by digitising a polyline within Surfer and saving the file as a Surfer blanking (.bln) file. The fault blanking files are:

..\Surfer_model\Borehole_model\Blanking_files\Foston-Eakring.bln

..\Surfer_model\Borehole_model\Blanking_files\Cinderhill.bln

..\Surfer_model\Borehole_model\Blanking_files\Harlequin.bln

..\Surfer_model\Borehole_model\Blanking_files\Normanton.bln

..\Surfer_model\Borehole_model\Blanking_files\Sileby.bln

Blanked grids are saved as:

..\Surfer_model\Borehole_model\Tophard_blanked.grd

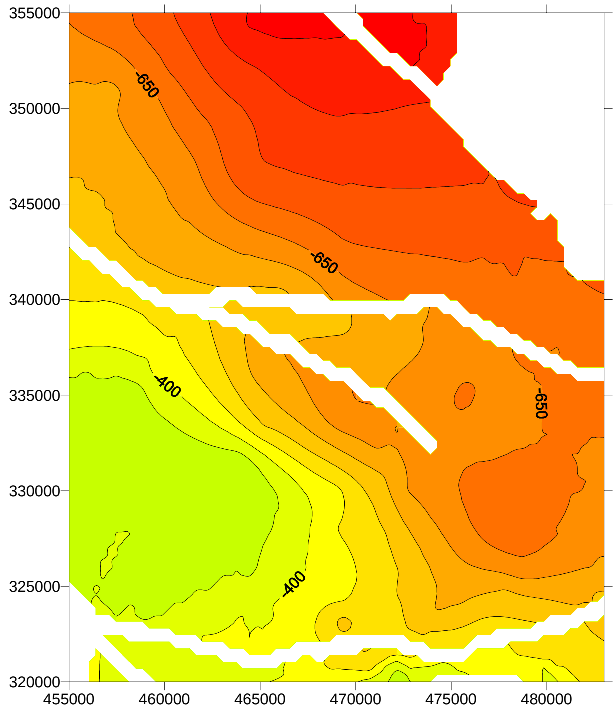
..\Surfer_model\Borehole_model\DeepMain_blanked.grd

..\Surfer_model\Borehole_model\Parkgate_blanked.grd

..\Surfer_model\Borehole_model\Yard_blanked.grd

..\Surfer_model\Borehole_model\Blackshale_blanked.grd

..\Surfer_model\Borehole_model\Kilburn_blanked.grd



Blanked grid of the Blackshale Seam

Finally, the grids were expected to have real intersections with the Base Permian unconformity (UVAR) surface, which cuts down into the Westphalian stratigraphy in the southern part of the project area. In order to model this intersection, a grid of the UVAR surface was prepared by kriging interpolation of the raw Nottingham-Melton UVAR xyz data

..\Surfer_model\Seismic_model\UVAR\Notts_Melton_UVAR.dat

with the following parameters:

Data range: Xmin 455000 Xmax 483000 Ymin 320000 Ymax 355000

Cell size: 350m

Search Sectors: 4

Maximum number of data points per sector: 6

Minimum acceptable number of data points in all sectors (node blanked if fewer): 4

Node blanked if more than this number of sectors are empty: 4

Radius: 250m

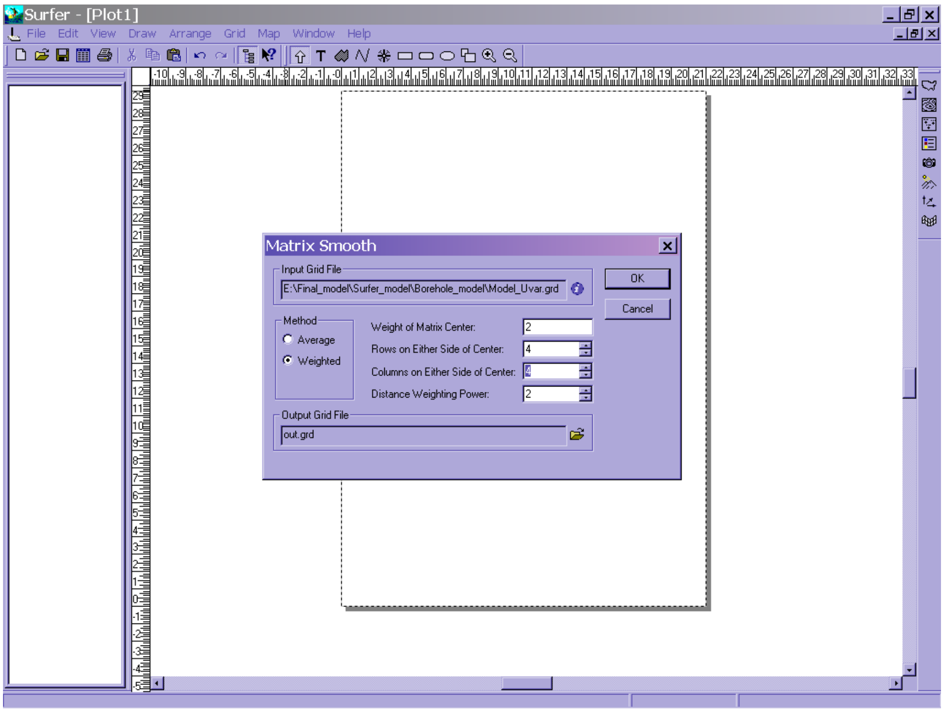
This kriged surface was then smoothed using the Surfer Grid | Matrix smooth tool. The smooth was a weighted smooth with the following parameters:

Weight of matrix centre: 2

Rows either side: 4

Columns either side: 4

Distance weighting power: 2



Matrix smooth in Surfer

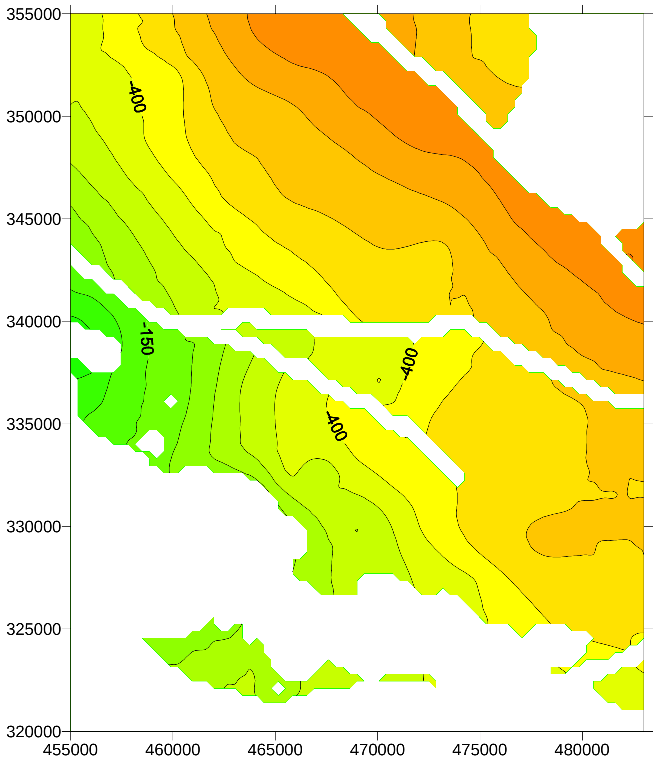
The resultant surface is

..\Surfer_model\Borehole_model\Model_Uvar.grd.

Coal seam surfaces were fitted to this uvar grid by blanking nodes which intersected with it. Again this was done using the Surfer Grid | Math tool, with formula:

c = if(a<b,1.70141e+38,b)

where c = the product grid intersected against Uvar, a = the smoothed Uvar surface Model_Uvar.grd, b = the coal seam surface to be blanked against Uvar, and 1.70141e+38 = Surfer's grid node blanking (NoData) value.



Top Hard seam, intersected against Uvar (large blanked area in south-west)

The intersected surfaces represent the finalised borehole model surfaces, and are found as:

..\Surfer_model\Borehole_model\Tophard_intersected.grd

..\Surfer_model\Borehole_model\DeepMain_ intersected.grd

..\Surfer_model\Borehole_model\Parkgate_ intersected.grd

..\Surfer_model\Borehole_model\Yard_ intersected.grd

..\Surfer_model\Borehole_model\Blackshale_ intersected.grd

..\Surfer_model\Borehole_model\Kilburn_ intersected.grd

5.2 SEISMIC MODELS

Notts-Melton_Uvar.dat and *Notts-Melton_DeepHard.dat* were kriged as follows:

Cell size: 300m

Search sectors: 4

Maximum number of data points per sector: 6

Minimum acceptable number of data points in all sectors (node blanked if fewer): 4

Node blanked if more than this number of sectors are empty: 4

Radius: 250m

Revised_DeepHard.dat was kriged to the same parameters except that a 12000m radius was used. No other processing was undertaken on these grids, which are stored as:

..\Surfer_model\Seismic_model\UVAR\Notts-Melton_Uvar.grd

..\Surfer_model\Seismic_model\DeepHard\Notts-Melton_DeepHard.grd

..\Surfer_model\Seismic_model\Revised_DeepHard\Revised_DeepHard.grd

5.3 MINING MODELS

Seam level .dat files were kriged as follows:

Blackshale & Deep Hard: search as for seismic models with radius at 1000m, model_faults.bln used for faulting; grid size 250m;

Combined Deep Hard/Piper: gridded at 10m with no faults and no search (dataset is less than a dozen points).

'Deep Main' and Top Hard: gridded at 150m with search and faults as for Blackshale and Deep Hard.

No other processing was undertaken on these grids, which are stored as:

..\Surfer_model\Mining_model\Blackshale\Blackshale.grd

..\Surfer_model\Mining_model\DeepHard\DeepHard.grd

..\Surfer_model\Mining_model\DeepHard_Piper\DeepHard_Piper.grd

..\Surfer_model\Mining_model\TopHard\TopHard.grd

..\Surfer_model\Mining_model\DeepMain\DeepMain.grd

5.4 COMPOSITE MODELS

Composite models:

..\Surfer_model\Composite_models

for the Top Hard and Blackshale Coals were generated by combining the xyz .dat format datasets for mining models and boreholes. In the case of the Deep Main, the revised Deep Hard seismic xyz data was also incorporated. Resultant *combined_xyz.dat* files were kriged with a search profile as for the borehole model surfaces, the only exception being that xmin was reduced to 454000 to take advantage of mining data outside the optimal borehole data distribution area and, because of the large spatial differences in data density between the combined datasets, it was not practical to use faults in the interpolation.

The grids were prepared with a 300m cell size and gridding reports are available,

..\Surfer_model\Composite_models\Gridding_reports

Deep Hard_raw.grd and *Blackshale_raw.grd* were then constrained to *Top-Hard_raw.grd* by the same mathematical operation as described for the borehole models above, and all surfaces intersected against the smoothed model Uvar surface *Uvar_for_composites.grd* (same as

Model_uvar.grd but with xmin at 454000) again as already described, to produce the fitted and final *fitted_intersected* grids respectively.

6 Grid Conversion

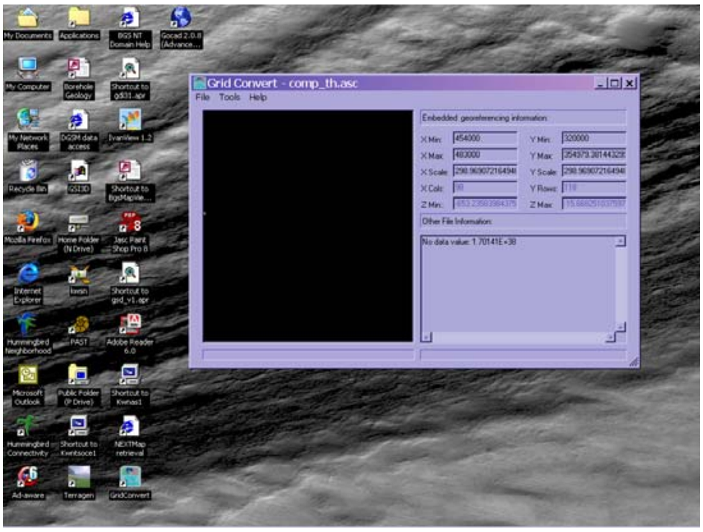
For visualisation in ArcScene, the final gridsets were converted from surfer .grd format to Arc-compatible ascii .asc format by a utility called 'grid convert', which is freeware from Geospatial Designs,

http://www.geospatialdesigns.com/gridconvert.htm

..\Surfer_model\Utilities\GridConvert.msi

Note that the application requires the dotNet environment to run

..\Surfer_model\Utilities\dotnetfx.exe



Grid Convert application

Borehole model: intersected grids as above in

\Surfer_model\Borehole_model

were converted to ascii grids in

\Arc_model\Borehole_models\ASCII

Seismic model: individual grids in subfolders of

\Surfer_model\Seismic_model

were converted to ascii grids in

\Arc_model\Seismic_models\ASCII

Mining model: individual grids in subfolders of

\Surfer_model\Mining_model

were converted to ascii grids in

\Arc_model\mining_models\ASCII.

The Deep Hard/Piper grid, being extremely small, was not converted.

Composite model:

individual *fitted_intersected* grids in subfolders of

\Surfer_model\Composite_model

were converted to ascii grids in

\Arc_model\Composite_models\ASCII.

Grids were then converted from ascii to ESRI format using the 'import ascii to grid' tool in the Arc Toolbox application. The esri grids are found in the following folders:

\Arc_model\Borehole_models\ESRI,

\Arc_model\Seismic_models\ESRI,

\Arc_model\mining_models\ESRI,

\Arc_model\composite_models\ESRI.

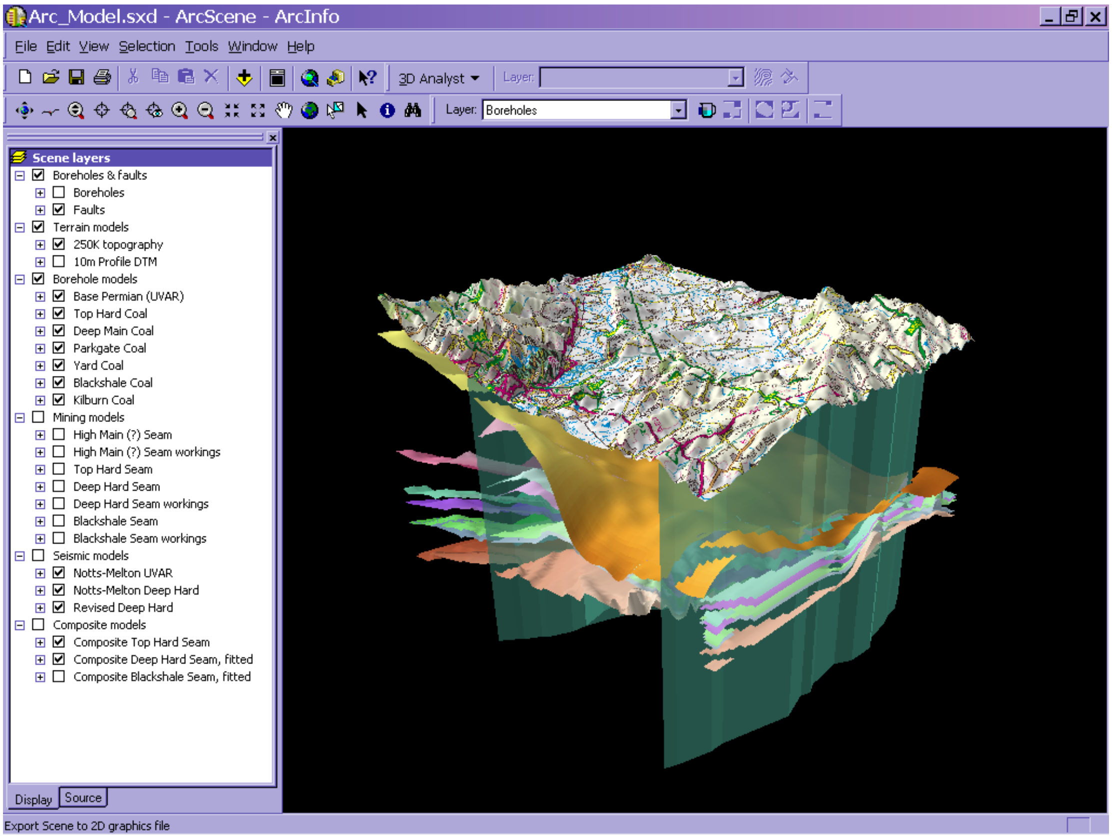
7 Visualisation and Model Build

All ESRI surfaces, as above, are loaded into an arcscene .sxd file where they can be viewed and compared in 3D,

..\Arc_model\arc_model.sxd.

In addition, the sxd model has topography (10m BGS Profile DTM, *\Components\dtm\dtm* and 250k colour topographic map, *\Components\topo\sk.tif*),

fault and borehole data (*\Components\features\model_faults.shp* and a borehole shapefile *\Components\features\model_boreholes.shp* generated from *Model_BH_Data.dat* and including seam depths relative to OD) and various shapefiles of mine plans associated with the mining seam level data.



ArcScene SXD Model

8 Export and Storage

All ESRI surfaces used as components in the .sxd model above were converted to Zmap .dat (not the same as a Surfer .dat) files for use in Notts-Melton DGSM GOCAD models. This was done using the Arc2Zmap Arc 8 macro (*\GOCAD_model\Arc2Zmap\arc2zmap.mxd*) provided by Bruce Napier. The grids found in *GOCAD_Model\Borehole_Models* are the same as the grids found in *Arc_Model\Borehole_Models\ESRI*, and the same relative relationship applies for the grids in *GOCAD_Model\Seismic_model*, *\Mining_Model*, *\Composite_Model.*

These Zmap Gocad grids represent the final products of the modelling exercise and have been archived in the GLOS.

Aditionally, all finalised surfer grids (identical to the Zmap grids above) have been exported to ascii xyz using GridConvert and are stored in the folder ..*\GSF_Models*. **These models have been archived in the GSF.**

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.

D. W. HOLLIDAY, J. M. ALLSOP, M. R. CLARKE, R. C. LAMB, G. A. KIRBY, W. J. ROWLEY, K. SMITH, N. J. P. SMITH & P. W. SWALLOW. 1984. Hydrocarbon prospectivity of the Carboniferous rocks of eastern England. BGS (Deep Geology Research Group) Report No. 84/4.

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Appendix 1

Project workflow: