

Bellshill GOCAD[™] bedrock modelling (Clyde Project); NS75NW, NS76NW and NS75SW

Landscape and Geology Scotland Programme Internal Report IR/09/068



BRITISH GEOLOGICAL SURVEY

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Front cover Image of complete Bellshill GOCADTM 3D bedrock model.

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Bellshill GOCAD[™] bedrock modelling (Clyde Project); NS75NW, NS76NW & NS75SW

M McCormac

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) that describes how the Bellshill (Clyde catchment) GOCADTM bedrock model was made. This report is a contribution to the Glasgow and Clyde Basin Cross-cutting Super-project.

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Summary

This report is the published product of a study by the British Geological Survey (BGS) that describes how the Bellshill (Clyde Catchment) GOCADTM bedrock model was made. It is for BGS purposes and is a contribution to the Glasgow and Clyde Basin Cross-cutting Super-project. The report covers the data, constraints, geology, modelling process and outputs of the work. It should be used to understand the model in conjunction with the BGS model metadata and relevant sections of the GOCADTM software operations manual.

In addition to adopting best-practice procedures recommended in previous Clyde modelling (Monaghan & Pouliquen, 2009) this study has utilised recent updates to the GOCADTM software, most notably use of the Cross-section facility in modelling surfaces otherwise poorly constrained by observed data points. Consideration is given to the limitations of the current model, the potential for refinement of the model and for possible improvements to BGS modelling methodology.



Figure 1 Screen shot of GOCADTM 3D viewer showing oblique view of the complete model

1 Introduction

The task (BGS Project code E2008S71; Task1) called for creation of a 3 dimensional block model of selected Carboniferous stratigraphic horizons and faults in an area east of the Glasgow conurbation. The core study area covers three contiguous 10k standard geology sheets NS75NW, NS76NW and NS76SW (outlined on Figure 1), but the study included an ample margin (full area of Fig 1) to aid links with existing modelling work, west of the site (Monaghan & Pouliquen, 2009) and future work in adjacent areas.

The full National Grid coordinates of the model limits are Easting 270000 to 275000, Northing 655000 to 670000 and a depth cut-off of 2500 m below OD. The town of Bellshill, sited centrally, was adopted as title name for the study area and model.

The current version of GOCADTM (version 2.5.2) was used to create and fault the modelled surfaces. BGS proprietary software such as the intranet borehole recall routine (http://intranet/projects/dgsm/dataaccess/sddbsst_start.htm) and the 'DataPortal' were used to source the raw datasets and ArcGIS[®] (version 9.3) and Microsoft[®] Excel 2007 used to image, manipulate and prepare the data for import to GOCADTM.

The data and modelling files are organised in W:\RSS\Teams\Clyde_Basin\Data\Bedrockmapsandmodels\Bellshill\

ARC_OBJECTS includes the Bellshill project GIS and shapefiles for outcrops, project limits, faults and mining data

DATASETS Includes folders for raw data files of boreholes, map-lines and polygons and mining data

GOCAD[™] Contains the various versions of the GOCAD[™] model – the final clipped version is Bellshill_model2009_V1.prj

MASTERDATASET Contains the GOCADTM surfaces and pointsets exported from the final model, including faults and surfaces clipped at rockhead

Horizon Name	Map and model horizon mnemonic
Rockhead surface	RHEM
Scottish Middle Coal Measures Formation, Glasgow Ell Coal	GE
Base of the Scottish Lower Coal Measures Formation	bsLCMS
Base of the Upper Limestone Formation or Index Limestone	bsULGS
Limestone Coal Formation, Meiklehill Main Coal	MEM
Base of the Lower Limestone Formation	bsLLGS

The horizons selected for the model were, in descending order;

Table 1 Horizon name and mnemonic used in the model and in project file naming protocol.

2 General geology

Scottish Coal Measures Group rocks crop out over all but the north-west part of the study area where the Passage Formation and top part of the Upper Limestone Formation come to crop (Figure 2). Dolerite sills cut the Passage Formation but are only a minor local component of the Scottish Coal Measures Group of the study area. The coal seam stratigraphy of the Scottish Lower and Middle Coal Measures formations are well documented and correlated with the regional western Midland Valley succession (Forsyth, et al. 1996, Hall, et al. 1998, Brown, et al. 1999). However, the Scottish Upper Coal Measures Formation, which dominate the southern part of the study area have no mapped internal stratigraphy and lateral thickness variation may only be estimated from subsurface dips and fault throws.



Figure 2 1:50k DiGMap map of the bedrock and fault geology of the study area (outlined). Trace of major faults used in the model shown in red, with names.

The general pattern of faulting is a crosscutting set of east-west and northwest – southeast trending faults which define a set of consistently southwest dipping tilted blocks, dropping to a structural low in the hanging wall of the Bothwell Fault (Figure 2). All but 4 of the modelled faults throw to the north or northeast and mining plans, where available, show all to be inclined planes in the range $30-60^{\circ}$.



Figure 3. Modelled surface for base Lower Limestone Formation horizon, illustrating general structural configuration of the study area.

3 Modelling: data preparation

The bedrock model was constructed from borehole, mine plan, 10k map outcrop, generalised vertical sections and interpreted cross-section data. Interpreted and validated borehole stratigraphy were entered by Tony Irving (AAMI) to the BGS corporate database BGS. Borehole-Geology.

The borehole data were recalled from the database using the form http://intranet/projects/dgsm/dataaccess/sddbsst_start.htm which obtains point X,Y,Z values of the base of specified stratigraphic horizons, relative to OD. The selected interpreter was AAMI with TMCM listed second. The raw data files were examined and edited so that only boreholes that reached the base of the relevant formation were utilised. The spread of borehole data across the area was very variable (Figure 3), from closely-spaced site investigations to boreholes more than a kilometre apart. Borehole sites (Figure 4) are concentrated along trunk road developments, industrial and domestic building schemes and where coal workings are at a shallow depth. Boreholes proving a significant penetration of the modelled section (red and purple symbols on Figure 4) are sparely distributed across the study area. Only a single borehole penetrates close to the base of the modelled succession in the southern part of the area (NS75NW-68, marked yellow cross on Figure 4).



Figure 4. ArcMAP[®] view of the study area illustrating the borehole coverage and density Borehole locations in black, 0-25 m penetration, largely proving Quaternary deposits. Borehole locations in green, 25-115 m penetration, largely proving strata at rockhead and shallow bedrock section. Borehole locations in red, 115-375 m penetration, moderate to deep boreholes giving full sections through the Coal Measures or deeper strata. Borehole locations in purple, 375 to >2000 m penetration, deep boreholes providing regionally important Carboniferous sections.

The main source of mining data was from 1:10,000 scale coal-seam atlases compiled for previous BGS coalfield studies. Where not available, data have been captured from mine abandonment plans through the expert services of Bill McLean and Sandy Henderson.

In all cases the geo-referenced and datum-corrected seam elevation map sheets were digitised by CartoGIS, providing ArcMAP[®] shapefiles for direct import to GOCADTM. (Figure 4).



Figure 5. ArcMAP[®] view of the study area illustrating the elevation control point coverage derived from mine plans for the Glasgow Ell Coal (green points) and the Meiklehill Main Coal (red points). Known extent of Glasgow Ell workings in pink, Meiklehill Main in blue

Mining data points and structure contours were supplied as ArcGIS[®] line and point shapefiles. The mining dataset also provided valuable data on subsurface faulting and therefore on dips of faults.

No edits were made to the mining dataset at the collation stage but a few out of range points had almost certainly been referred to the wrong datum level and were deleted.

The GE coal seam outcrop and base Scottish Lower Coal Measures Formation (LCMS) horizon boundaries (the only 2 horizons coming to outcrop within the study area) formed essential point-sets to constrain the model outcrop. The outcrop lines were digitized off the DigMap 10k tile scans in ArcMAP[®], along with extent polygons for each model geological surface. The surface traces of the selected faults were similarly captured. The shapefiles were then imported directly into GOCADTM.

GOCADTM tends to split imported ArcGIS[®] shapefiles into numerous, often duplicated, 'parts' which have to be merged manually to form a set of clean, continuous lines and closed curves for each horizon. The node spacing on the outline curves and fault traces is an important controlling factor on the surface triangulated mesh density and interpolation processing. The GOCADTM 'filter' and 'densify' tools were used to adjust the node spacing. A spacing of 300 m had been suggested from previous modelling but a closer spacing (100 m) was selected here to avoid undue loss of detail on the outcrop line.

The elevation data for the rockhead surface (RHEM) was downloaded as an ASCII grid from the DGSM intranet dataportal and a surface created manually within GOCADTM. Fault and horizon outcrop line elevation (Z) values were obtained from this grid by vertical projection (Curve Menu – Property – Transfer property – Transfer property vertically) Figure 6.

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Figure 6. Transfer of elevation values from rockhead surface to outcrop or fault-trace lines

The primary geological surface control data of borehole intercepts, outcrop elevation and underground mining elevations were merged into single pointset files, one for each surface, from which a first pass at horizon creation in the GOCADTM Workflow could follow (Figure 9).

4 Fault modelling

The criteria for selection of faults for modelling was followed from previous work (Monaghan & Pouliquen, 2009) only faults with throws greater than about 70 m were selected. All faults were assumed to have a constant dip of 60° except the Bothwell Park Fault, shown at outcrop to have a dip of 40° . The recorded or calculated vertical displacements and general direction of throw of the selected faults are tabulated below (Table 1).

The surface traces were taken largely unmodified from the scanned 10k standards. However, a degree of simplification was used where fault terminations involved a plethora of minor crosscuts, such as at the eastern end of the Shettleston Fault, or to ensure a clean compartmentalisation of the model, such as at the link between the Airdrie and Gartsherrie faults (Figure 1).

Fault Name	Vertical offset	Direction of downthrow (Azimuth in GOCAD TM Workflow)
Airdrie	60–110 m	N –NE
Bothwell	90–110 m	N
Bothwell Park	60–90 m	NE
Braidenhill	80 m	Ν
Braidhurst	150 m	W
Chapelhall	c. 200 m	N
Chryston	90 m	SW
Comedie	59–230 m	S
Dechmont	500+ m?	N–E
Garnkirk	100 m	S
Gartsherrie	90–210 m	NE
Heathfield	80–175 m	Ν
Muirhead	100–145 m	SW
Newhouse	c. 200 m	N–NE
New Stevenston	110 m	NE
Shettleston	90–c. 200 m	Ν
Viewpark	60 m	NW
Whistleberry	70–120 m	N (40°)

Table 2 Name, vertical offset and direction of throw of faults selected for modelling.

The creation of model fault planes from the surface traces was carried out in the GOCADTM Workflow and needed little intervention other than to check the down-throw directions, which are

set automatically, and reset as necessary.

With many faults having multiple intersections, the fault to fault contact process was carried out on a pair by pair basis. The Check Fault Contact graphic dialogue (Figure 7) was of particular value to check or set contact types.

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🔽 0 Ambigue	ous contacts					
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6	BothwellPark 🔻		whistebeny	Fuillea		
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8			NewStevenston	Full Tear	•	
9			Bothwell	Branch	-	
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11	Chapelhall 🗸 🔻					
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Figure 7. Editable table of fault intersection hierarchy in the GOCADTM Workflow

Manual intervention was required in a number of instances, especially at triple or low angle intersections. In the case of the Bothwell Park/Bothwell Fault intersection, which merge together rather than cut, a clean contact proved difficult to create and the Bothwell Park Fault was remodelled to subtend a higher intersection angle. The most problematic contact was the close intersection, at depth, of the Heathfield, Muirhead, Airdrie and Gartsherrie Faults. It was decided to simplify the intersection by truncating the Heathfield fault at about -1000 m depth. However, this caused a problem with modelling the lowest stratigraphic horizon (base Lower Limestone Formation (LLGS) later in the Workflow process. The Heathfield fault plane surface was manually re-extended to satisfy the intersection.

5 Horizon modelling

For modelling purposes, the vertical interval between horizons of interest were taken from the 10k standard GVS's for NS75NW, NS76NW & NS75SW

These values compared well with borehole data in the north of the study area, though there is evidence of marked thinning of the pre-Coal Measures succession towards the south (see para 8.2).

All primary data available per horizon were loaded to the GOCADTM Workflow (Figure 9) and first pass surfaces generated using the outline strategy parameters illustrated in Figure 8, ensuring the surface was fitted exactly to the given outline curve.



Figure 8. Horizon modelling strategy choices in the GOCADTM Workflow

	Feature Boundary Type	Data Type 🔺		Horizons	Data Type Options
eLOMS_r/epourve	Not Defined	K Interpretation lines		🖶 belishil_bsLCMS_v6	
shil_biLCMS_main_extrit	Not Defined	K Interpretation lines		belichil_biLCMS_V7	68 PointsSet
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Iseams40utput	Not Defined	K Interpretation lines		belishil_GE_A3	6 PointsSet
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Figure 9 Horizon data selection screen in the GOCADTM Workflow

5.1 DEEP HORIZON INTERPRETED CONTROL POINTS

Deep surfaces with little or no borehole or mining control can be generated from a well-controlled, or 'reference' horizon, by vertical transfer of depth properties by a constant amount. This presents an easy option for closely spaced horizons, and was largely used to generate the bsULGS surface from the MEM horizon, 20 m above. However, with horizon separation of greater than 50 m the intersections with dipping fault surfaces are laterally shifted to such a degree as to require extensive editing to afford a tidy fit.

In previous Midland Valley coalfield modelling, interpreted control points were introduced into the model by hand placement of individual points. New to GOCADTM, the cross-section tool proved an efficient method of introducing interpreted point sets, while avoiding overshoot at fault contacts. The tool is accessed from the CrossSection folder in the main Objects table of contents. Right-click – New – From Digitized Polyline allowing a line of section to be drawn across the model in the 3D viewer. On completion, a vertical plane of section is automatically created and a new window opened displaying the plane of section with the intercepting surfaces and fault planes shown as coloured lines (Figure 10). This window has a suite of editing tools allowing complete or partial remodelling of selected horizon and/or fault plane intercept lines. The edited lines are densified, if needed, then converted to control-points for the relevant horizon (Points – New – From Curves) and the horizon re-modelled in the Workflow.

A grid of 12 cross-section lines was found adequate to control the data-less bsLLGS horizon, along with refining the horizon-fault contacts. The higher, partially controlled surfaces benefitted from the addition of 6–7 sections.



Figure 10. GOCADTM 2D cross-section window displaying modelled fault and horizons intersection lines and editing toolbars. The poorly constrained lowest (bsLLGS) horizon is clearly in need of refitting to the fault planes

5.2 GLASGOW ELL COAL (GE)

The GE horizon has the most extensive control dataset and consists of a main area underlying most of NS75NW and NS76SW, and three outliers cropping out in the footwalls of the Heathfield, Gartsherrie and Airdrie faults, across the southern part of NS76NW. The horizon has an extensive control-data set giving a high degree of relative confidence to the modelled surface, over much of the area. The exception is the area of deep burial in the hanging wall of the Dechmont and Bothwell faults.

5.3 BASE SCOTTISH LOWER COAL MEASURES FORMATION (BSLCMS)

Control points on this horizon were confined on, or close to, the outcrop. Only a single borehole intercept is available in the south-east corner of NS76NW. To improve the control of the surface it was decided to use the outcrop lines of six of the main Coal Measures coal seams, assigning the averaged height of the respective coals above the base of the Coal Measures as depth property (Table 3).

Coal Seams	Metres above base Coal Measures
Glasgow Ell (GE)	204
Glasgow Splint (GSP)	154
Airdrie Virtuewell (AV)	114
Kiltongue (KILC)	80
Lower Drumgray (LDC)	52
Coatbridge Balmoral (COBC)	24

Table 3. Coal seam names, lexicon codes and averaged vertical height above base, selectedfor modelling the base Scottish Lower Coal Measures Formation horizon.

This procedure extended the control on the horizon to all but the south and west of the study area. However, it has the limitation that any inconsistencies in the mapped coal seams will be transferred to the modelled surface, and/or any detail mapped in the coal seams will be transferred to the modelled surface, where in reality the detail, or different detail, may exist. No allowance was made for the error introduced by the dip of the strata, which is proportional to the cosine of the dip. Up to a dip of 10° the error is 1% of the interval thickness, within modelling tolerance, but at 25° the error rises to 10% and a correction would be required to maintain the fidelity of the control data set.

Further control was obtained from a set of 6 cross-section lines using the overlying GE horizon as a guide.

bsULGS

No outcrop was present within the study area and there were only 8 borehole intercepts, thus modelling the surface rested largely on constant interval vertical projection from the closely underlying MEM coal.

MEM

The good mining-plan controlled surface is confined to the northern part of NS76NW so six cross-section lines were added to control the deeper surface area.

bsLLGS

With no control points at all, the surface was entirely modelled from twelve cross-section constructs.

6 Horizon to fault fitting

This process required extensive manual intervention. The GOCAD[™] Workflow fitting process was run using defaults, except a small data-exclusion distance (10–25 m) was set, to exclude

horizon control points impinging on the fault surface. All the fault-horizon contacts had to be edited. The main, and most effective, tool was the contact re-drawing tool (Figure 11), where the footwall and hanging wall contacts are redrawn to maintain the sense and magnitude of the fault throw along its length (Figure 11). This editing process could give rise to unrealistically sharp pull-up (or down) in adjacent parts of the horizon surface, and to compensate, regions were created around the fault and localised DSI interpolation applied.

In the case where fault and horizon mesh spacing was not closely matched in the preliminary modelling stages, parts of a horizon margin can project through, or stop short of, the fault surface. Though often only visible at large magnification, the horizons were manually re-cut to the fault surfaces, and any overlap slivers deleted.

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Figure 11. Horizon contact redrawing menu in the GOCADTM Workflow



Figure 12. Screen shot of GOCAD[™] 3D viewer Intersection line (in red) of the base Lower Coal Measures horizon with the Airdrie Fault. The footwall intersection will be redrawn to smooth the unrealistically sharp step in its profile. On the right, the surface appears to cross over a fault. This intersection will also be adjusted to maintain the fault throw along its length.

7 Modelling process limitations

- 1. The GOCADTM cross-section generation facility is new and the functions included with GOCADTM version 2.5.2 are different from the previous version 2.1.6. The facility is also prone to crash the application under certain conditions, such as when the data points are switched on during digitising.
- 2. A single borehole NS75NW-68 is the only deep bore in the southern part of the study area. The bore penetrates to 605.5 m below ground level, a little below the Top Hosie Limestone, the top of the Lower Limestone Formation. The Glasgow Ell Coal and the base Lower Coal Measures level are encountered at depths typical of the whole region. However, the Passage, Upper Limestone and Limestone Coal formations are all markedly thinner than the regional norms, while the MEM coal, or its equivalent, are not recognized in the section. Tony Irving confirmed that the borehole had been investigated palaeontologically and the stratigraphical assignments were reliable. However, the thinning could be explained by faulting within the section, not recorded in the log. With no other boreholes in the vicinity for comparison and validation, the borehole was excluded from the local control data set. If the sequence is truly a condensed one, it may be possible to remodel the deeper horizons in respect of data obtained in the future from the south and east of the study area. The key question is whether the thinning occurs progressively across the region or occurs in stepwise fashion across individual faults.
- 3. Simple geometrical calculation on fault/horizon intersections recorded on mine plans, that is fault-throw versus fault-hade, indicate fault dip-angles somewhat lower (down to 20°?) than the 40–60° assumed for the modelling. This may be real or may be due to coal seam working stopping short of the main fault plane, due to fault-proximal disturbance, or multiple fracturing along the fault zone. As modelling is carried out in future, it would be worth revisiting the fault geometry assumptions with reference to more mine plan data and/or seismic profile analysis.
- 4. Plans show mine workings in the Glasgow Ell Coal (GE) extending under virtually the whole area of NS75NW and 76SW, with outliers in NS76NW. However, apart from the extreme south-east corner, no elevation data have been extracted for NS75NW. Mine abandonment plans do show spot height and these data need to be captured. When the data become available the modelled surface will need to be updated. The data density for the Meiklehill Main coal is very good, but the coverage is confined to the northern third of NS76NW. Working extent polygons extend south into NS76SW, but again no mine elevation data has been captured.
- 5. Generalised underground gradients of seams were also noted, but so far it has not been found possible to utilise these data directly in the GOCADTM workflow

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: <u>http://geolib.bgs.ac.uk</u>.

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