

# Clyde Regional Bedrock Model (Phase I) methodological report -BGS project document

Responsive Surveys Scotland, Geology and Landscape Scotland Internal Report IR/09/070



#### BRITISH GEOLOGICAL SURVEY

## RESPONSIVE SURVEYS SCOTLAND, GEOLOGY AND LANDSCAPE SCOTLAND INTERNAL REPORT IR/09/070

# Clyde Regional Bedrock Model (Phase I) methodological report -BGS project document

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# Foreword

This report is a published product of a study by the British Geological Survey (BGS) in 2008. It describes in detail how the Clyde regional bedrock model was made. This report is a contribution to the Glasgow and Clyde Basin Cross-cutting Super-project,

# Acknowledgements

A large number of individuals from the Glasgow and Clyde Basin Cross-cutting Superproject, have contributed to the project. This assistance has been received at all stages of the study. Of the many individuals who have contributed to the project we would particularly like to thank the following:

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## Summary

This report describes in detail how the Clyde Regional Bedrock Model (Phase I) was made in February to October 2008, using GOCAD<sup>TM</sup> structural workflow v 2.1.6 for modelling. It is for BGS purposes. 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

(http://intranet/scripts/dgsm/ida/isometadata/dgsm\_index.cfm?DATASET\_ID=13605071 &focus=DatasetDetail).

This report is a contribution to the Glasgow and Clyde Basin Cross-cutting Super-project,



Figure 1. Purple rectangle defines model area, though only the area in green incorporates all available borehole and mining data. Bedrock map extracted from DiGMap 50k, faults in black, coal seams in blue, Coal Measures strata in grey, Upper Limestone Formation in pale blue, Limestone Coal Formation strata in beige. Igneous intrusions in green. Clyde Plateau Volcanic Formation in red/pink/orange. Each map square is 5\*5km.

## 1 Introduction

Phae I of the Clyde Regional Bedrock Model as described here was created to form an overview of the subsurface geological structure over a 30\*25 km area around the Glasgow area/River Clyde catchment. The model approximates to the Lithoframe 50k specification (<u>http://intranet/projects/dgsm/lithoframe50.html</u>) but with fewer formations. The model will be stored in the GLOS/GSF with metadata and released subject to approval of the technical and geological content. This report was drafted by A Monaghan and G Pouliquen in 2008 and has been edited and finalised with minor additions by DJD Lawrence in 2009. Confidence (uncertainty) information for the model and discussion of how the model contributes to understanding of the geological structure will be incoporated in a separate report in 2010.

## 1.1 OVERVIEW OF MODEL

#### 1.1.1 Model volume

The model coordinates are 240000,655000 to 270000, 680000 covering 750 km<sup>2</sup> on the 1:10,000 map sheets NS66, NS56, NS57, NS47, NS65NW/NE, NS55NE/NW, NS46, NS57SW/SE (Figure 1). However note that the models are only reliable in the 425 km<sup>2</sup> area of NS56, NS66, NS55NE/NW, NS57SW/SE, NS47 and NS65NW, because it is only in these areas that systematic borehole and mining data capture had been completed at the time of modelling.

The modelled surfaces extend to c.-1.2 km depth, with the largest faults projected down to -2 km.

The model covers almost all the urban area of Glasgow as well as the peri-urban and rural fringes.

#### **1.1.2** Summary of the bedrock geology

The bedrock geology beneath the regional area shown in Figure 1 comprises Upper Carboniferous Coal Measures and Clackmannan Group strata (Figure 2) and Lower Carboniferous Strathclyde Group strata including the Clyde Plateau Volcanic Formation. The late Visean-Westphalian Clackmannan and Coal Measures group strata have been modelled where they exist today within the Kilsyth Trough. The majority of these strata comprise fluvio-deltaic to shallow marine facies consisting of cyclical units of argillaceous rock, sandstone, coal and limestone. The Coal Measures are present in the western part of the area only in an open, easterly-plunging syncline. The MEM coal horizon modelled in the LSC crops out in a broad curve across the central part of the area, though it is folded into roughly North-northeast trending structures which are dissected by east-west trending normal faults. The lithostratigraphy is primarily identified from interpretation of borehole records using the established BGS Carboniferous lithostratigraphic framework, lithostratigraphic and biostratigraphic markers (Browne et al., 1999; Hall et al., 1998; Figure 3). The Visean Clyde Plateau Volcanic and other formations of the Strathclyde Group form the high topography surrounding the modelled area, these strata are often fault bounded. There was not enough data to model a horizon of the Strathclyde Group.

The sedimentary rocks are cut by Late Carboniferous igneous intrusive sills and they are faulted and folded. The Dechmont Fault is a major structure running through the area; it trends NW and downthrows Coal Measures to the northeast against Clackmannan Group strata (Figure 1). The east-northeast trending Milngavie-Kilsyth Fault and the Dechmont Fault together define a triangular-shaped basin of Upper Carboniferous strata. Within this the most common larger faults are roughly east–west trending (e.g. Shettleston and Comedie). Fault patterns are quite complex, commonly either intersecting or tipping out within the modelled area. To the southwest of the Dechmont-Great Dyke-Blythswood faults some more distinctly northeast trending faults are present (e.g. Paisley Ruck). The Dechmont structure appears to divide two Midland Valley Upper Carboniferous structural styles – northeast trending half-graben/graben block and basin to the west (e.g. Ayrshire) and north-northeast trending growth folds to the east (e.g. Central Coalfield and Fife).

One of the main aims of modelling was to examine whether the growth of faults and folds through time fits in with current understanding of the regional geological structure. This can be summarised as

- 1. Upper Devonian/lowermost Carboniferous extension on northeast and eastwest structures before Clyde Plateau Volcanic eruption (extensional basin)
- 2. Dextral strike-slip during and after Clyde Plateau Volcaanic eruption up to Westphalian C times, likely occurring in pulses. Allied extension on north-east to east trending faults and growth anticlines/synclines on north-northeast trends
- 3. Latest Carboniferous fold tightening and Variscan unconformity, which is

4. cut by very latest Carboniferous and early Permian east–west faults and dykes (see Monaghan and Parrish, 2006 or Underhill et al., 2008 for more details).

In summary, strike-slip to extensional tectonism is thought to have been active during the Visean–Westphalian when the strata modelled here were deposited (Read, 1988; Rippon et al., 1996), so stratal thickening and thinning across fault and fold structures is expected.

Rockhead unconformity			
Glasgow Ell Coal (GE)	Worked coal in Middle Coal Measures		
Base Lower Coal Measures (LCMS)	=Base CMSC=LOMB		
Base Upper Limestone Formation (ULGS) = Index Limestone (ILS)			
Meiklehill Main Coal (MEM)	= Upper Possil Coal URP (where splits) = Cowglen Sclutty CSCO=Lochinch Cherry LCHC=Garscube Davy (no Lexicon code)=Cadder Main (no Lexicon code). Worked coal in Limestone Coal Formation.		
Hurlet Coal (HURC) or Hurlet Limestone (HUR) = Base Lower Limestone Formation (LLGS)	Worked coal – Base Clackmannan group		

## **1.1.3 Faults and surfaces**

#### Table 1Summary of modelled surfaces.

The worked coals were chosen for the level of XYZ information available from mine abandonment plans. GE is one of the most extensively worked coals in the Middle Coal Measures and MEM is extensively worked within the Limestone Coal Formation (Figure 3; whereas KDG is not extensively worked in the eastern side of the area).

Major faults with throws >100 m, or with significantly long traces and throws >50 m were modelled in the first instance (Figure 4). These corresponded with the 'principal' fault structures shown in figures in the Glasgow, Airdrie and Hamilton memoirs within or bounding the LLGS–UCMS sedimentary rocks (i.e. faults within the Clyde Plateau Volcanic Formation (CPV) were not modelled as the CPV was not to be modelled). Based on these criteria, 27 faults were modelled:

Balmore, Barrhead, Blythswood (=GreatDyke), CMW, Campsie, Cardonald, Clarkston, Comedie, Crookston, Dechmont, GS, Garnkirk, Gleniffer, Hilton St Flannan, KT, Lenzie, Lunloch-Muirhead, Milngavie-Kilsyth, Paisley Ruck, Pollock, Possil, Priesthill, Rutherglen, Scotstoun, Shettleston, F46 and f47, Robroyston (f49)



Figure 2 Summary stratigraphy of the modelled Carboniferous strata in the Glasgow area. Coal name codes (e.g. GE) referred to in text above.





# Figure 3 (opposite) 3D faults included within the Clyde Regional Bedrock Model (Phase I), viewed from above. Where faults have been named, those names were used, otherwise faults were sequentially numbered. B Map view showing fault names. Note some fault segments have been joined or simplified during the modelling process.

Fault traces were selected from the DiGMap 50k dataset. In places picking the fault traces was difficult and in this case the 1:10,000 maps were used to identify named fault segments. Previous fault modelling e.g. for the East End Glasgow bedrock model was not used because it was at a different scale of 1:10,000.

For simplicity, fault dips were assumed to be 60° - values of 45–60° are given in the Airdrie memoir from mining information (Forsyth et al, 1996). Fault dips/positions were checked against mining information and consequently some faults' surfaces were locally adjusted during modelling. For example mining data points and contours on the MEM horizon within the northeast area of the model proved the Garnkirk Fault in a slightly differing subsurface location to that predicted by a 60° dipping fault.

## 1.1.4 Data file structure

The data and modelling files are organised on:

W:\RSS\Teams\Clyde\_Basin\Data\Bedrockmapsandmodels\Regionalmodel2007 as





Figure 4 Final model GE in green, base LCMS purple, base ULGS yellow, MEM dark blue and base LLGS light blue. Arrow is 25 km length, 2x vertical exaggeration, faults extend to -2 km.

## 2 Data entry, compilation and modifications

The Clyde Regional Bedrock Model (Phase I) was constructed from borehole, mine plan, map outcrop and interpreted data. This section documents the data types and records data modifications found to be necessary as a result of the modelling process. It also lists data points that were excluded from modelling but which could not be resolved in corporate datasets at this stage.

## 2.1 BOREHOLE DATA

Borehole data was entered to the BGS corporate database BGS.Borehole\_geology (or Bo\_Ge), nearly all by Tony Irving (AAMI). On some sheets (NS66SW,NS66NW, NS56SE), borehole entry and geological coding was checked by a geologist. Newer site investigation data had not been checked by a geologist and some required modification.

The borehole data were recalled Bo Ge the from using form http://intranet/projects/dgsm/dataaccess/sddbsst\_start.htm (Figure 5) which obtains the X,Y, Z relative to OD values of the base of particular stratigraphic horizons. The stratigraphic codes used are listed in Table 1. The preferred interpreter was always AAMI with TMCM listed second. The raw data files were examined closely and edited so that only boreholes that reached the base of a formation were used in the 'XYZ' data file which was loaded into GOCAD<sup>TM</sup>.

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#### Figure 5 The borehole recall form from the BGS Intranet

The spread of borehole data across the area was very variable from closely spaced site investigations, occasionally with multiple data entry points, to in extreme cases, boreholes more than a kilometre apart. Data points were inevitably concentrated around the outcrop of worked coals and were sparse on stratigraphic surfaces in deeper parts of the basin.

Most borehole data points have a reasonably good level of certainty. Boreholes with very bad records or very poorly known sites were not coded into the database. However, there can be uncertainty in geologically coding short, isolated site investigation boreholes, in a drillers record of a borehole (i.e. if not geologist examined) or sometimes in the siting of the borehole. However, these should result in errors in location being no greater than about 5-10 m in Z, and perhaps 20-50 m in term of XY.

# **2.1.1 Edits required to BGS.Borehole\_Geology and borehole exclusions from modelling**

Examination of the borehole Z values in GIS and in comparison with the map data allowed a first pass of edits/modifications to be required. Further edits became obvious when modelling commenced. A geologist checked data points that appeared potentially inaccurate for erroneous geological coding (e.g. coded as GU coal seam when in fact GE), erroneous siting of the borehole in BGS.SOBI, or an erroneous start height for the borehole in BGS.SOBI.

Table 2 lists edits that were required. Changes were made to Bo\_Ge, SOBI (i.e. any newly recalled data file should be up to date) and the modelling data files as appropriate.

## 2.2 MAP DATA

Note that the bedrock map represents the outcrop (or subcrop) of stratigraphic horizons at rockhead i.e. very commonly buried beneath superficial deposits. Exposed outcrop of bedrock is rare. 1:10,000 and 1:50,000 scale digital map data were used in the bedrock model in several different ways:

- 1. Coal seam outcrop and base unit boundaries formed important point sets to constrain the model outcrop/extent. The line segments shapefiles selected by attributes in GIS were simplified using the ArcGIS<sup>®</sup> tool 'simplify' using point remove and a tolerance of 10 m. Line segments that were defined by only two data points had an additional vertex added in the centre so that the calculation in Gocad (which ignores data points close to faults) does not exclude this cropline data The shapefiles were then brought into GOCAD<sup>TM</sup>, filtered to a node spacing of 50 m and then densified to 500 m and Z values created by projection onto rockhead.
- 2. Outcrop polygons were created in ArcGIS<sup>®</sup> to form the outline curve which bounds the area covered by each geological surface. Some outcrop polygons contain 'holes'. The data were simplified using the ArcGIS<sup>®</sup> tool 'simplify' using point remove and a tolerance of 10 m. The shapefiles were then brought into GOCAD<sup>TM</sup>, filtered to a node spacing of 50 m and then densified to 500 m and Z values created by projection onto rockhead. Very small polygons of GE and ILS were not filtered and densified, to preserve their shape. Polygons were split into individual parts and holes ready for modelling as each surface created needs to be constrained by a curve with only one part).

3. The fault traces at outcrop to be modelled were selected from the map and loaded to  $GOCAD^{TM}$ .

Where available 1:10,000 scale data was used, if not 1:50,000 data was used and in some cases - such as parts of the MEM-URP-CSCO extent – no map line work existed and so geological interpretation was required using a standard thickness and the available borehole data. However, in the latter interpreted areas an error of  $\pm 150$  m in XY is quite possible.

Surface	Borehole ID	Resolution
	NS66NE bj 54	Underground – no start height, ignore
	NS66SW bj197	Underground – no start height, ignore
	NS57SE bj214	Underground – no start height, ignore
	NS66NE bj68	Section, ignore
MEM	NS56SW bj 534	TMCM interp of bh with MEM is wrong but cannot be changed
GE	NS56SE 693	Site is unclear and seems to be wrong, delete from file.
ILS	NS56NE 909/1	Site is unclear and seems to be wrong, delete from file.
URP	NS 56NW 620 and 621	URP interpreted way below crop by FC Black and correlation looks OK, but this is much higher than surrounding borehole stratigraphy and map outcrop of URPI. Also difficult to resolve with bj21 and 20 in which URP is quite deep and should be at crop according to map. Decided to keep outline polygon on URPI for now and not use the data points for BJ620, 621 – worth investigating whether the site is wrong.
HUR	NS66NW bj 2	site was wrong in recalled file and SOBI – it should be NS 6382 6966, corrected in data file.
URP/ILS	NS67NE bj 54	had the wrong site in SOBI, now changed to 267575,675975 sh=38m
	NS56SE bj 398/8, 523 and 1632	Deleted from the files. A small sliver of GE containing 3 boreholes is not modelled at 50k.

# Table 2 Record of checks and edits required to BGS SOBI and BGSborehole\_geology (Bo Ge) as a result of the modelling.



# Figure 6 Variable distribution of mining data spot heights (red) and contours (white) on the MEM coal.

The mining dataset also provided valuable data on subsurface faulting and therefore on dips of faults.

The various mining datums used meant that some cleaning/editing of the data was required. No simplification or decimation has been made. These data points have the highest confidence level as they were systematically surveyed in.

## 2.3 INTERPRETED GEOLOGICAL DATA

This falls into two categories – interpreted points added from a two cross-section interpretations on NS66SW and geological interpretations of fault-surface contacts, overlaps etc undertaken during modelling in GOCAD<sup>TM</sup>. The former interpreted data is a data file, the latter is geological knowledge that is incorporated in the model during the modelling process.

#### 2.4 ROCKHEAD SURFACE

A high resolution model of the rockhead surface interpreted from ongoing GSI3D modelling was not available for the whole area. Therefore the BGS RHEM model was downloaded from the data portal at 50 m grid resolution.

# 3 Modelling

#### 3.1 DATA AND MODEL FILES

Data files in GOCAD<sup>TM</sup> are merged from the borehole, mining and outcrop pointsets (e.g. Figure 7).



# Figure 7 Merged data file containing spot heights, outcrop lines and contours for MEM horizon

Horizon	Pointset	Surfaces
	$\label{eq:stars} $$ W:\Bedrockmapsandmodels \Regionalmodel2007\Gocad\MasterDataset\Datapoints\Revis ed_Feb2008 $$$	\\W:\Teams\RSS\Clyde_Basin\Data\Bedroc kmapsandmodels\Regionalmodel2007\Goca d\MasterDataset\Horizons_surfaces_revised 0208
GE	Reg_GE_bhshcrop_points.vs	baseGEcoal.ts
Base LCMS	Reg_baseLCMS_bhcrop_points.vs	baseLCMS.ts
ILS	Reg_ILSbaseULGS_bhcrop_points.vs	ILSbaseULGS.ts
MEM	Reg_MEM_bhcrop_points.vs	MEMURPcoal.ts
HUR	Reg_HURbaseLLGS_bhcrop_points.vs	HURbaseLLGS.ts

 Table 3 Location and names of merged data files and modelled surfaces.

## 3.2 MODEL BUILDING

The GOCAD<sup>TM</sup> structural workflow v 2.1.6 was used with a standard BGS methodology (e.g. see Monaghan & Pouliquen, 2009). For example, first pass modelled surfaces were created very quickly to identify and resolve spurious data points.

## **3.2.1 Fault surfaces**

The same process as described in Monaghan and Pouliquen (2009) was followed. In summary

1) Import all the faults interpreted from the 50k map as a shapefile into GOCAD<sup>TM</sup>

2) Each fault is made of parts which have to be merged in GOCAD<sup>TM</sup> (*Curve* > *Edit* > *Part* > *Merge selection*). At this stage, there might still be subtle gaps between the curves's parts in GIS which need to be bridged (*Node* > *bridge*).

3) Use '*filter segment degenerated*' and densify nodes, sampling to 25 m.

4) Project the faults' traces onto the Rockhead surface

5) Apply correction when necessary (i.e. translate faults points which are outside of the AOI = outside of the rockhead coverage, X=0, Y=0, Z=DZ of last point).

7) Within the workflow declare faults curves as fault centre line and define a dip  $(60^{\circ})$  and vertical extent (+500 m and -2000 m).

## **3.2.2 Edits required to fault surfaces**

Hilton St Flannan: the fault's surface has been altered to fit the mining data. The fault position should also be at borehole site at ILS Z value of -260 m. Thus, a pointset has been created with an isolated horizon point located on the northern side of the faulted horizon. This point has been slightly translated (X=0, Y=20, Z=0) north and the fault surface has been fitted to the point.

Garnkirk: the fault's surface has been fitted to the MEM/URP mining data, in this case the dip has been lowered from 60 to  $50^{\circ}$ ).

Lenzie: mining data points showed the fault at depth could locally differ from the surface trace by over 200 m.

Two methods have been used to edit fault surfaces.

In the first method, isolate the points which should belong to the fault's plan and simply do a *fit to pointset* to the existing fault's surface (Figure 8a). Additional smoothing might be required (*Surface > Interpolation > On Entire Surface*). Fix control nodes on the top and bottom borders of the fault so that they are not altered whilst fitting to pointset.

In the second method, isolate the mining points which belong to the fault's surface and include then in the fault pointset (Figure 8b). A trick for not loosing the feature in the data manager is to write over the existing pointset when creating the new one. To avoid re-building a rough surface around the new points it is better to delete the top and bottom rows around the newly added points (Fig 8b). Then use *Structural modeller* > *Fault Modelling* > *Edit Data* > *Fault Points* > *Update fault geometry*.

#### **3.2.3 Horizon surfaces**

The standard structural workflow methodology was used. Significant amounts of time were put into removing overlaps and in editing fault-horizon contacts.





Figure 8 8a Spot heights in black extracted from mining data and constraining the Lenzie Fault plan surface. 8b Deletion of the fault data around the mining data points before reinterpolation

## 4 Model use and limitations

#### 4.1 SCALE

The model is appropriate for use between 1:50,000–1; 250,000 scales. The intention is that the model be used to define regional scale subsurface structure. It is not meant for local or site specific studies.

## References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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