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Model metadata report for Glasgow Geothermal Energy Research Field Site bedrock model

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Model metadata report for Glasgow Geothermal Energy Research Field Site bedrock model

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Keywords

3D model, UKGEOS, Glasgow, geothermal, coal mines.

National Grid Reference

SW corner 260000,660850
Centre point 262500,662925
NE corner 265000,665000

Map

Sheet NS66SW, 1:10 000 scale, Rutherglen

Bibliographical reference

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Summary

This report describes the creation of a 3D geological model developed by the British Geological Survey (BGS) for the UK Geoenergy Observatories (UKGEOS) Glasgow Geothermal Energy Research Field Site (GGERFS). The model represents the bedrock geology, fault network, and underground mine workings. The model has been used to aid borehole prognosis and initial hydrogeological modelling.

The 3D geological model described here uses subsurface data held prior to the construction of the Observatory and represents our 'pre-drill' understanding of the bedrock and mine geometry. The pre-drill superficial deposits model is also available and is described in Arkley (2018).

1 Introduction

The Glasgow Geothermal Energy Research Field Site bedrock model described here updates the larger Central Glasgow v2 bedrock model (Monaghan et al., 2014) which itself builds on earlier Central Glasgow bedrock models (Monaghan and Pouliquen, 2009; Arkley et al., 2013). This revision was undertaken as part of the UK Geoenergy Observatories (UKGEOS) Project.

Intended Usage: This model was created to aid borehole prognoses, borehole drilling planning and to represent the best pre-drill understanding of the geology and mine workings in 3D.

The revisions to the model from previous Central Glasgow models include:

- The conversion of the model from GOCAD to SKUA-GOCAD 18 (here referred to simply as 'SKUA'). Users should note that SKUA models the tops of geological horizons rather than the bases.
- Additional coal seams have been included in the model. Horizons representing the Glasgow Main Coal, Humph Coal, Glasgow Splint Coal, Virgin Coal, Airdrie Blackband Coal, and Airdrie Virtuewell Coal were added to the existing surfaces representing the Glasgow Upper Coal, Glasgow Ell Coal, and Kiltongue Coal.
- The model also includes the base of the Scottish Coal Measures Group (base of the Scottish Lower Coal Measures Formation (LCMS).

The base of the model was set to -500 m OD and the top is 50 m OD. The area of this model was reduced down to focus on the Glasgow Geothermal Energy Research Field Site (GGERFS). The XY extent of the model is from 260000 660850 to 265000 665000, and fits mostly within the Rutherglen 1:10 000 Geology Series Map Sheet (NS66SW; British Geological Survey, 2007). The GGERFS bedrock model is suitable for use at scales between 1:10 000 and 1:50 000. The grid resolution of the exported model is 50m.

2 Modelled Surfaces/Volumes

The model contains 13 boundaries which define 12 geological units. All units were considered to be conformable apart from the base Quaternary unconformity termed rockhead (base of superficial deposits). The stratigraphic column used in the model can be seen in Figure 1.

Below is a list of the modelled surfaces with the name in the model and the equivalent BGS Lexicon code in brackets or surface name:

- Topo = Central Glasgow digital terrain model (DTM; 50 m resolution)
- Rockhead = Quaternary unconformity, base of superficial deposits
- TopMiddleCoalMeasuresFormation = base of Scottish Upper Coal Measures Formation (UCMS)
- GlasgowUpperCoal = Glasgow Upper coal (GU)
- GlasgowEllCoal = Glasgow Ell coal (GE)
- GlasgowMainCoal = Glasgow Main coal (GMA)
- HumphCoal = Humph coal (HUC)
- GlasgowSplintCoal = Glasgow Splint coal (GSP)
- VirginCoal = Virgin coal (VI)

- AirdrieBlackBandCoal = Airdrie Black Band coal (ABBC)
- AirdrieVirtuewellCoal = Airdrie Virtuewell coal (AV)
- KiltongueCoal = Kiltongue coal (KILC)
- BaseLowerCoalMeasures = base of Lower Coal Measures (LCMS)

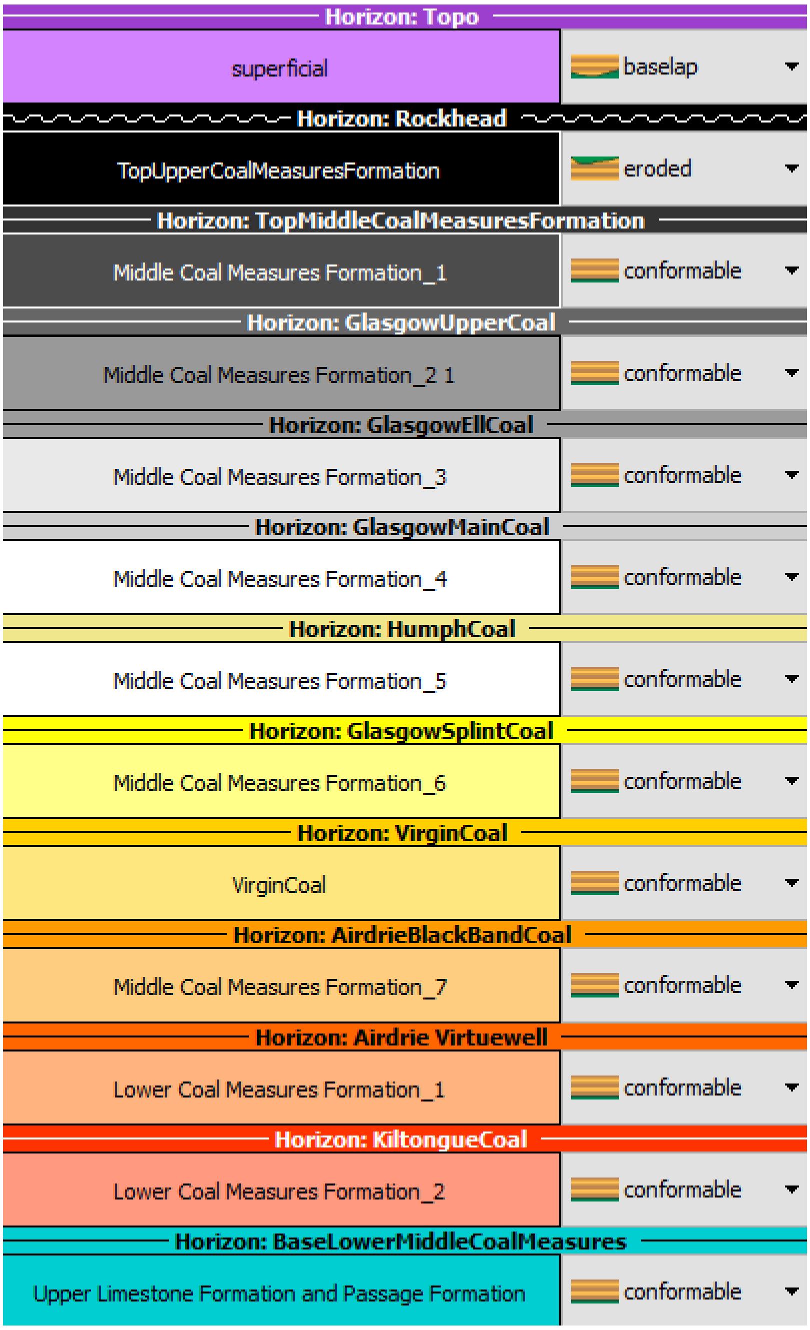

Figure 1 Stratigraphic column showing the modelled surfaces.

3 Modelled Faults

Faults generated from the GOCAD surfaces of the Central Glasgow v2 model (Monaghan, et al., 2014) and were input in to the SKUA workflow as top and base lines derived from the original GOCAD surfaces. Fault dips and subsurface locations were derived from mine plan information (where present) and taken from the 1:10 000 scale geological map (BGS, 2007). Figure 2 shows the faults that were included in the model.

Within the model area, faults the have previously be modelled by Monaghan et al. (2014) have retained their designated name (for example, f14, f15, f23). Slight changes were made to previous fault interpretations so that fault geometries better fit with faults identified in mine abandonment plans.

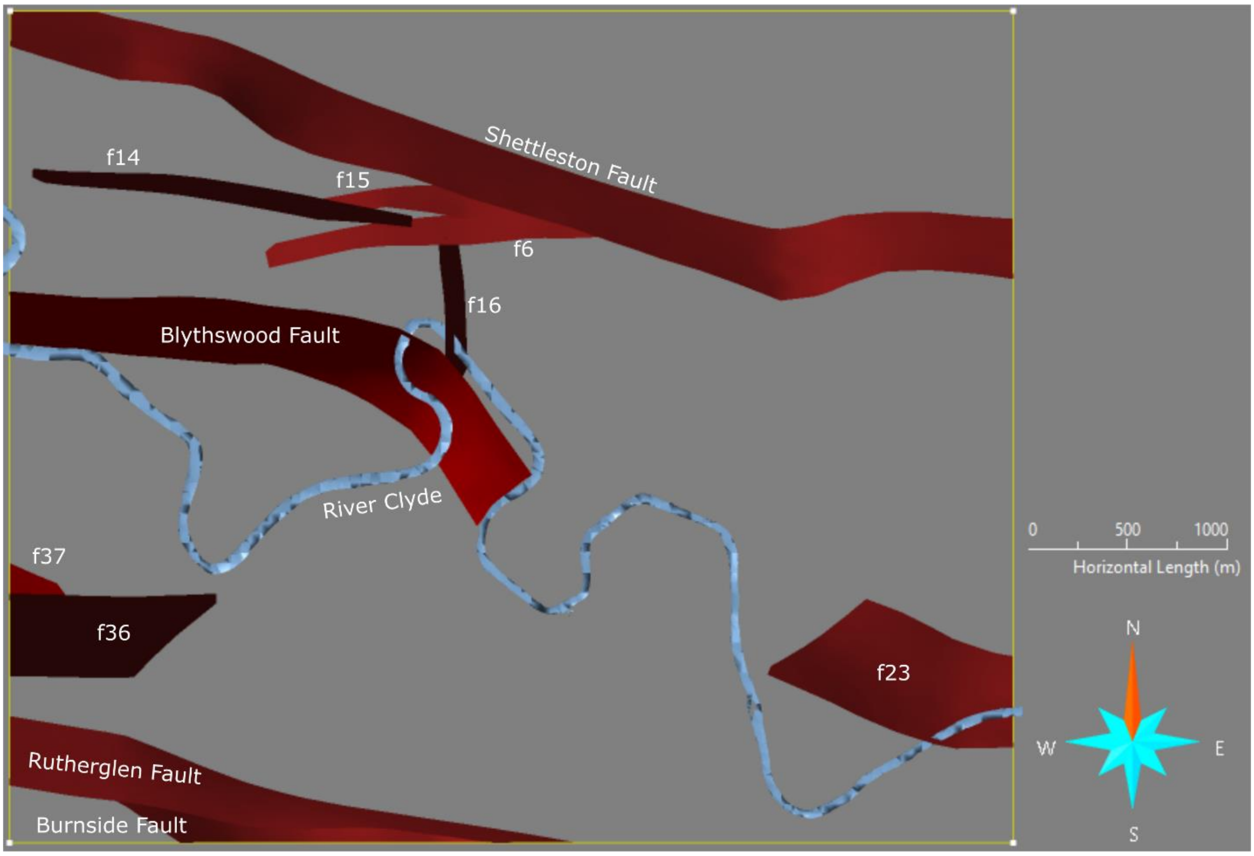

Figure 2 Modelled faults within the GGERFS study area. Note the truncation of many of the faults by the model extent boundary. River Clyde is shown for geographic reference.

4 Model Workflow

The standard SKUA-GOCAD version 18 'Structure and Stratigraphy' (SnS) workflow was used to create a volumetric model.

The workflow consists of:

- Data compilation and creation of a stratigraphic column (Figure 1)
- Fault modelling including the creation of a fault network and fault blocks (Figure 2)
- Modelling the horizons (Table 1)
- Creation of the geological grids – 3D meshes (Figure 4)

The model was then checked (Table 2), amended, and exported in various formats (Table 3).

Outside of the SnS workflow, manual techniques have been used to model manmade features such as mine workings, shafts, and underground roadways. The mined workings were modelled by creating triangulated surfaces (Tsurfs) from the model's geological horizons of the coal seams and ‘stencilling’ out the mine abandonment plan extents using the GIS shape files of the mine workings.

5 Model Datasets

Table 1 lists the datasets that were used in the construction of the modelled horizons. Not all input data available was used in the modelling process, for example a subset of borehole data was excluded. This is due to inconsistencies resulting from the complexity of the rockhead surface used in the 1:10 000 scale bedrock map compared to the modelled surface used here, and to new borehole data interpreted since the 1:10 000 scale bedrock map was updated.

Table 1 Data used to create SKUA model horizons.

Horizon	RH	MCMS	GU	GE	GMA	HUC	GSP	VI	ABBC	AV	KILC	LCMS
Map crop outlines		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mine working levels			✓	✓	✓	✓	✓	✓	✓	✓	✓	
Borehole markers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Borehole points	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note that borehole markers and points have been extracted from BGS’s borehole database that includes stratigraphic interpretations.

5.1 BOREHOLE DATA

Borehole data was recalled using the ‘BGS Magpie’ application in Access 2016 linked to the BGS corporate Borehole Geology database. This data provides stratigraphic boundaries representing the top or base of known coals or formations, interpreted by various BGS geologists. The Magpie application selects the deepest instance of any particular stratigraphic boundary in individual boreholes. The borehole interpreters selected in this order of preference were, Anthony Irving (AAMI), Alison Monaghan (ALS), Eileen Callaghan (ECAL), Timothy McCormick (TMCM), and David Low (DJLO).

The borehole data was checked and edited to include only markers recording the base of the stratigraphic interval or interest/top of the underlying interval. These XYZ borehole data points were loaded to SKUA as either borehole data points, or ‘well markers’ for boreholes constraining the greatest number of stratigraphic boundaries.

5.2 MINING DATA

Mine working levels (XYZ points) from digitised mine abandonment plans were used to constrain the 3D geometry of coal seam horizons.

Mine working levels were included in the SKUA workflow as ‘picks’, meaning that they guide the modelled horizons in the same manner as seismic data. That is, if there is a mismatch between a borehole marker and modelled interval thicknesses, the mine working level will not be honoured exactly.

The GIS files detailing the extent of the mine workings are separated into two classes, recorded mine workings and probable mine workings. Probable, unrecorded mine workings have been interpreted by a BGS staff member who was an ex-mining surveyor and is based on the presence of workings proved in boreholes, shafts, adjacent workings indicated on adjacent abandonment plans, and coal subcrop position at rockhead. The presence and extent of the probable mine workings is therefore uncertain.

Where faults cut through worked coal seams, the mine abandonment plan data are able to guide the location of fault planes at depth, as these are reflected as gaps in the mine plan (Figure 3), and occasionally recorded as a fault with downthrow direction and size of throw.

5.3 MAP DATA

The geological map subcrop lines from the 1:10 000 bedrock map was included for all applicable units. The data was taken from BGS (2007) and projected onto the modelled rockhead surface.

The SKUA workflow determined that some of the markers on the boreholes were inconsistent and were excluded from the modelling. This is likely because the thickness of the units in these boreholes is at variance with surrounding boreholes, or the boreholes intersect modelled faults but have no fault recorded in the borehole record.

6 Model Limitations

6.1 GENERAL

- The SKUA workflow uses a thickness model to calculate horizons to ensure a minimum separation and prevent crossovers. Thicknesses from boreholes which penetrate the most horizons are prioritised. Inconsistent data is then ignored, meaning that there could be important data points excluded and that the model does not fully capture the true lithological variability.
- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations. Therefore, geological modelling is an empirical approach.
- It is important to note that this 3D geological model represents an individual interpretation of the data available; other interpretations may be valid and multiple models can be produced with the same data.
- Borehole start heights are obtained from the original records, Ordnance Survey mapping or a digital terrain model. Where borehole start heights look unreasonable, they are checked and amended if necessary in the index file. In some cases, the borehole start height may be different from the ground surface, if for example, the ground surface has been raised or lowered since the borehole was drilled, or if the borehole was not originally drilled at the ground surface.
- The full complexity of the geology may not be represented by the model due to the spatial distribution of the data points at the time of model construction and other limitations including those set out elsewhere in this report.
- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. boreholes locations, elevations, etc.). Any raw data considered when building geological models may have been transcribed from analogue to digital format. Such processes are subjected to quality control to ensure reliability; however undetected errors may exist. Borehole locations are obtained from borehole records or site plans.
- The geological map linework in the model files may be modified during the modelling process to remove detail or modify the interpretation where new data is available. Hence, in some cases, faults or geological units that are shown in the BGS approved digital geological map data (DiGMapGB) may not appear in or perfectly match the geological

model or vice versa. Modelled units are coloured differently to the equivalent units in the published geological maps.
- Borehole coding (including observations and interpretations) was captured in a corporate database before the commencement of modelling and any lithostratigraphic interpretations may have been re-interpreted in the context of other evidence during cross-section drawing and modelling, resulting in a mismatch between BGS databases and modelled interpretations.

6.2 BEDROCK

- The mismatch data (Table 2) provides an overview of how well the modelled horizons intercept the borehole 'well markers'. Within the workflow, well markers can be fitted exactly, resulting in an overly 'dimpled' surface. The approach taken in this model was to allow some smoothing of horizons to best fit the majority of markers (minimising the mismatch) whilst giving a consistent geological model.
- The Glasgow Splint Coal and Virgin Coal are modelled very close together, and this is based on their relationship in the data. For example, they are commonly 4 m apart in the model. Clough et al. (1920) summaries that these two seams are occasionally united, and often close enough to form a single working.
- Towards the south-eastern corner, where the top of the Middle Coal Measures interacts with f23, the two slices of horizon differ notable from published interpretations. The two small patches are a result of a shallow dip interacting with a relatively bumpier rockhead horizon.

6.3 FAULTS

- Faults with less than 30 m of throw have not been modelled meaning that small-scale faulting is unrecognised in the data and may account for mismatch and model inaccuracies.

6.4 MINE WORKINGS

- The extent of mine abandonment plans suggests additional unmodelled minor faults at the intersection of Dechmont and Rutherglen faults (Figure 3) that have not been included in the model.

Some locations of probable mine workings correlate to locations where the corresponding seam is not modelled. This due to the model being a simplified representation of reality. Some areas of geological complexity (i.e. highly folded, faulted, or speculative interpretations), have been simplified in the modelling process.

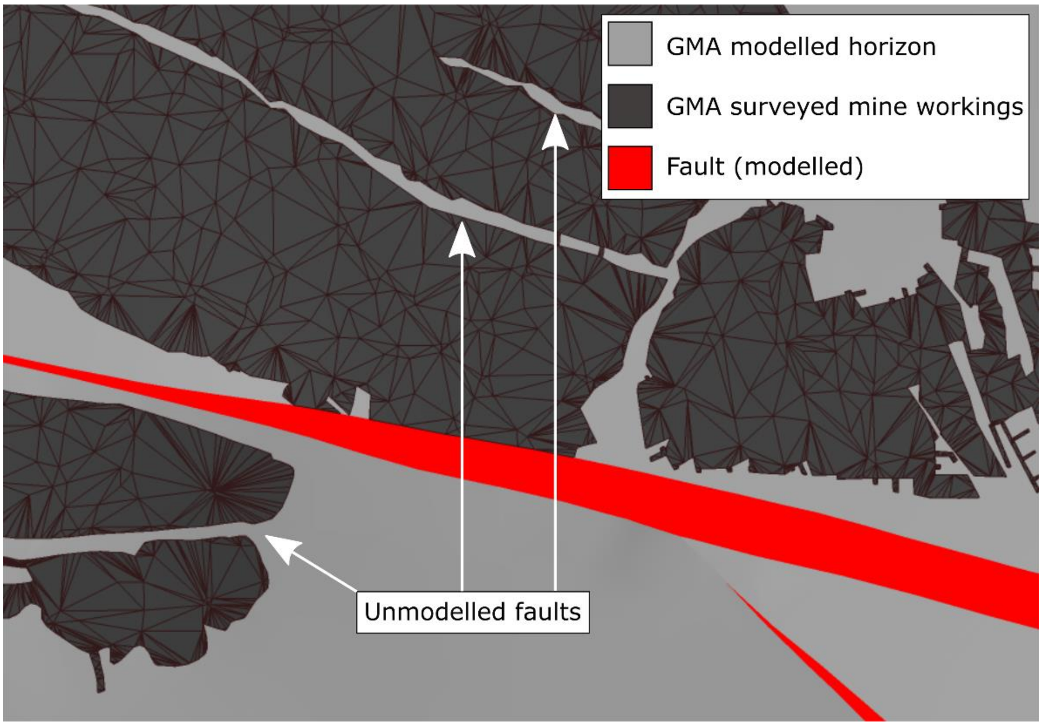

Figure 3 Glasgow Main Coal mine workings showing that there are unmodelled minor faults near the Rutherglen fault.

7 Model Quality Assurance

In order for a geological model to be approved for publication or delivery to a client a series of quality assurance (QA) checks are carried out. This includes visual examination of the modelled surfaces and fit to datasets. The modelled geological surfaces are checked for artefacts such as spikes and thickness anomalies. The naming convention of the modelled geological units is checked to ensure that recognised entries in the BGS Lexicon of Named Rock Units (http://www.bgs.ac.uk/lexicon/home.html) and the BGS Rock Classification Scheme (http://www.bgs.ac.uk/bgsrcs/) are used as far as possible.

Any issues found in the QA checking process are recorded and addressed before delivery/publication of the model.

8 Model Uncertainty

Input data and interpretations for geological modelling sometimes provide conflicting evidence regarding the location of horizons and geological features. During the modelling workflow, these conflicts are often flagged and options are available to resolve inconsistencies. Not all of these inconsistencies can be remedied so SKUA minimises errors to the input data.

SKUA takes borehole 'well markers' as the strongest guidance for the geometry of the subsurface. However due to the variable data density and local complexities in geology smaller than the modelled grid size, not all of the modelled horizons will perfectly match the input borehole markers. The difference between the modelled horizons and the borehole markers is shown in Table 2 below.

Table 2 Model error (mismatch) between surfaces and borehole markers.

	RH	MCMS	GU	GE	GMA	HUC	GSP	VI	ABBC	AV	KILC	LCMS
Minimum (m)	-13.1	-15.1	-23.2	-10.7	-12.0	-38.0	-3.9	-3.2	-7.7	-4.5	-6.7	-4.1
Average (m)	-0.9	-6.0	0.1	0.1	0.4	0.9	0.0	0.1	-0.6	0.5	0.1	0.0
Maximum (m)	14.6	-1.2	22.8	12.5	9.3	9.5	3.0	4.8	10.7	5.5	9.9	2.1

The average surface mismatch with borehole markers presented in Table 2 ranges from between negative 6 m up to positive 0.5 m. Visual inspection of markers with particularly large minimum or maximums reveals that these wells are often in close proximity to modelled faults. The modelled fault surfaces do not fully capture the complexity of fault zones and cannot replicate these zones perfectly.

SKUA has a feature to force horizon surfaces to match well markers exactly, however this process does not produce aesthetically pleasing results and does not improve the model overall.

No formal uncertainty analysis has been performed, but it is thought that uncertainty will be strongly influenced by data density (specifically, borehole density), as was shown by Monaghan et al. (2014; Figure 11).

9 Model Exports

The model's horizons, faults, mined seams (surveyed and probable), and roadways (coal and stone) have been exported to SKUA surfaces (.ts) as well as the GIS compatible ASCII grid format (.asc) (Table 3).

Table 3 Summary of model export types with typical file sizes.

Export type	File format	Approximate size
SKUA tsurf	.ts	~4 MB
ESRI ASCII grid (1 m x 1 m)	.asc	~200 MB
ESRI ASCII grid (5 m x 5 m)	.asc	~10 MB

The SKUA surfaces are created with irregular triangles of varying size from approximately 50 m wide in areas of low variability down to triangles approximately 1 m wide on curved edges or in mine workings. The ASCII exports on the other hand have uniform cell sizes of 1 m and 5 m, which generally captures the outline of horizons and the sometimes intricate survey outlines of worked mine seams. It is therefore important to remember that the resolution of the surfaces can be much higher than the resolution that the model was created for.

10 Model Images and Uses

This section illustrates the pre-drill model and various model exports.

The extent and connectedness of the mined underground coal seams, shafts and roadways are likely key hydrogeological pathways for the low temperature mine water geothermal Geoenergy Observatory (Figure 6).

This bedrock model and the superficial model of Arkley (2018) have been used to aid borehole prognoses before construction of the research facility. The models have also been used as the geological framework for initial hydrogeological modelling.

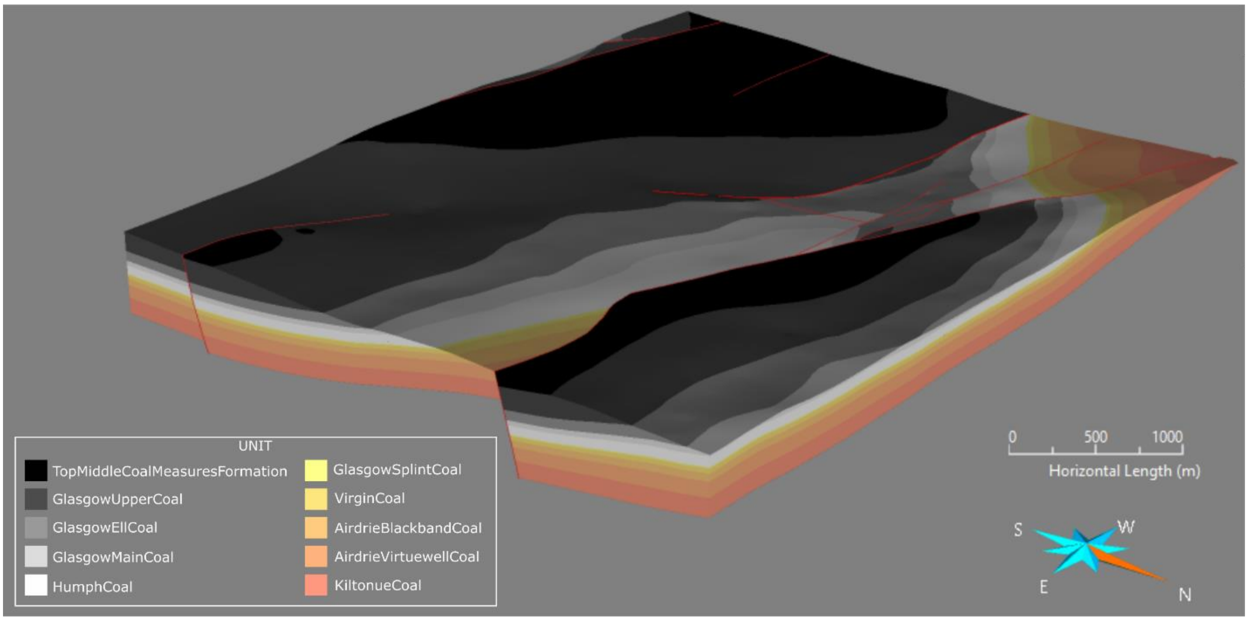

Figure 4 SKUA geological bedrock model, looking SW, vertical exaggeration X2. Top view on rockhead surface with superficial deposits removed.

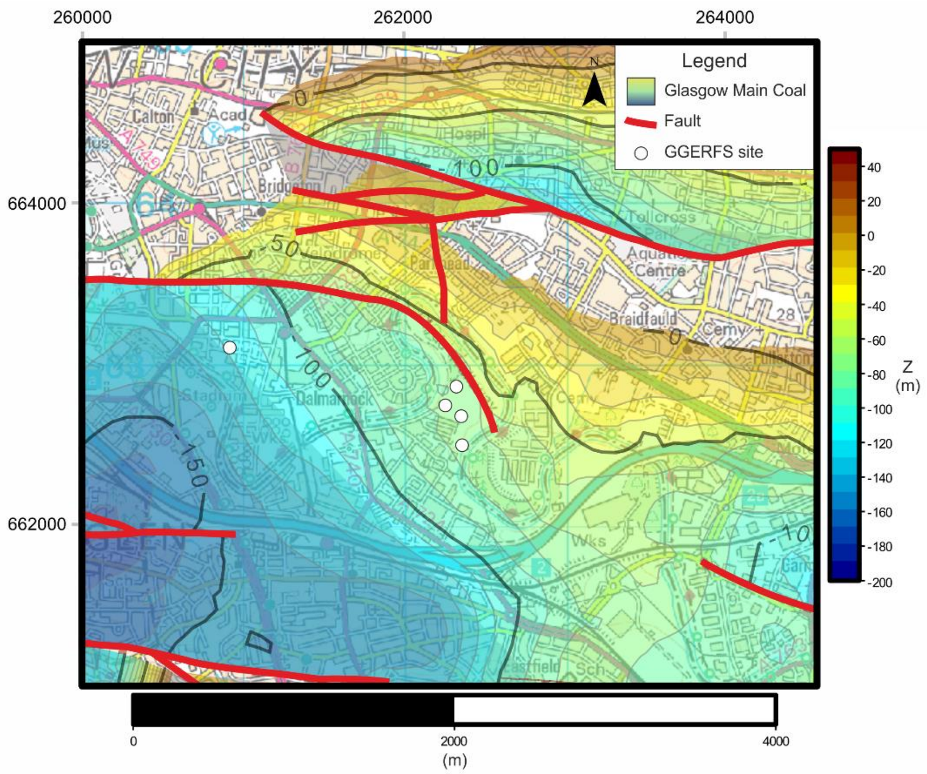

Figure 5 Contoured depth grid (m relative to Ordnance Datum) for the base of Glasgow Main Coal, horizon exported from the geological model showing the closed synclinal structure and variety of fault trends. Created using ArcGIS. Copyright © Esri. All rights reserved. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2019] Ordnance Survey [100021290 EUL].

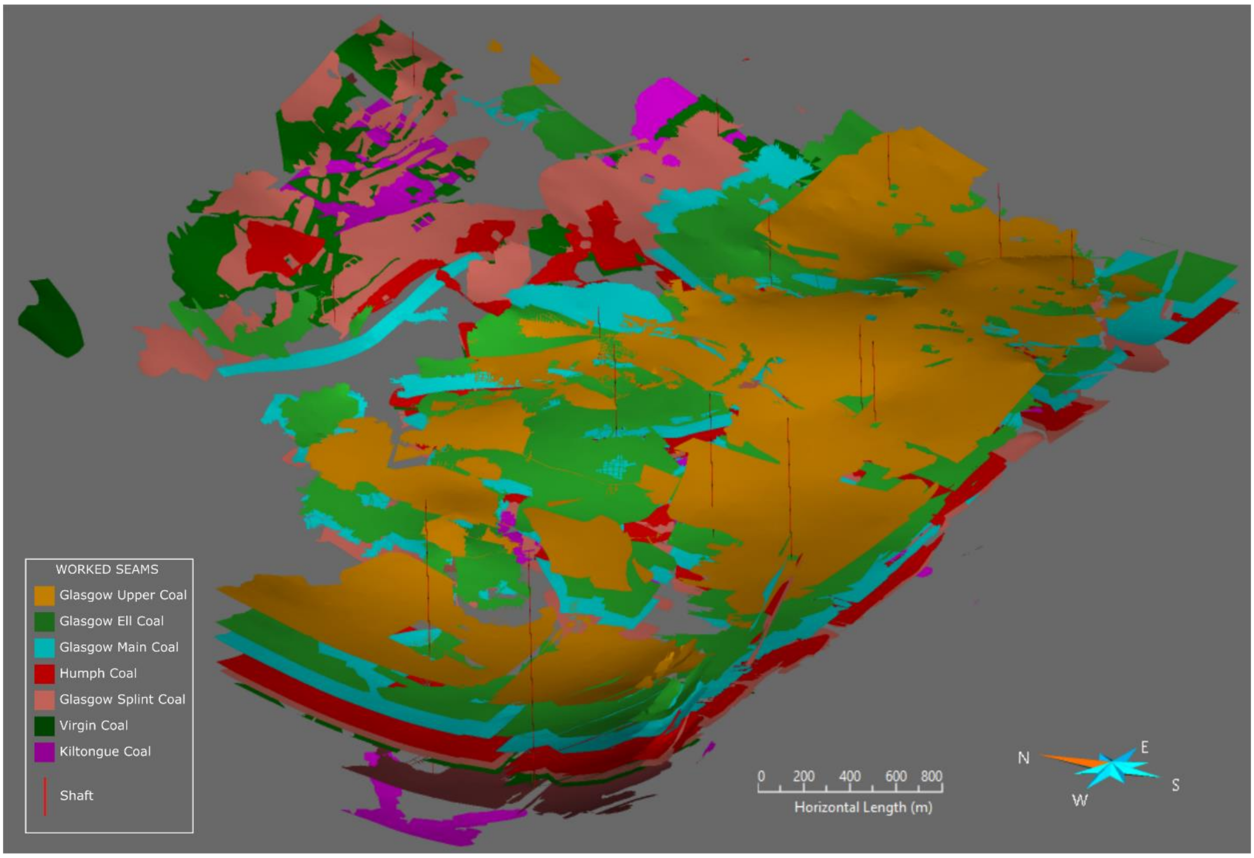

Figure 6 Isometric view from the east showing the extent and stack of recorded mine workings and shafts of the worked seams in the Scottish Coal Measures Group cut out of the geological model, to illustrate the extent and connectivity of the potential mine water geothermal resource.

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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: https://envirolib.apps.nerc.ac.uk/olibcgi.

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