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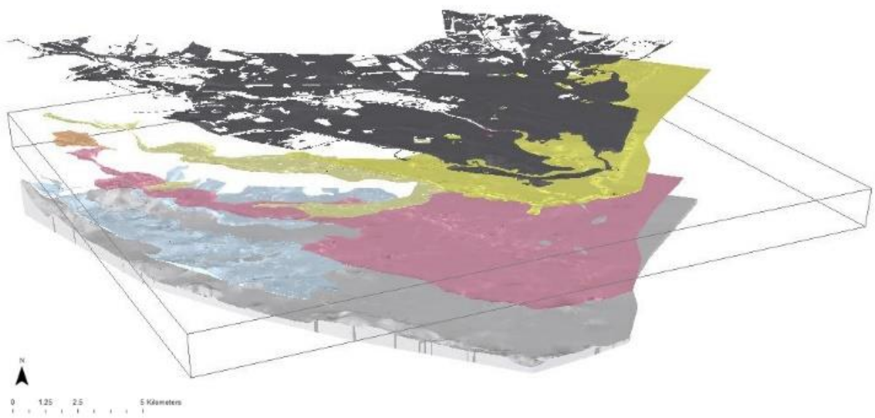
Metadata report for the Cardiff superficial deposits 3D geological model

Minerals and Waste Programme

Open Report OR/16/031



BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

OPEN REPORT OR/16/031

Model metadata report for Cardiff Superficial Deposits

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Burke, H. F.

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Map

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Exploded view of Cardiff superficial deposits model, looking from the south.

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Summary

The objective of this work was to assemble a geological framework model and calculated surfaces for the superficial deposits for the city of Cardiff. The model has a number of purposes:

- To investigate the superficial deposits within the city of Cardiff and surrounding area.
- To provide a communication tool to present the geological understanding of the superficial deposits of the area.
- To provide information on the subsurface distribution and thickness of the main superficial deposits (principally Till, Glaciofluvial Deposits, Alluvium and Tidal Flat Deposits) of Cardiff to inform a project which is presently investigating the potential for shallow geothermal energy in the city of Cardiff (BGS, 2018).

A series of 340 cross-sections have been constructed to form a fence diagram using Geological Surveying and Investigation in 3D (GSI3D) software. The sections cover much of the most densely populated areas of the city and include an area of boreholes, presently being investigated to evaluate the potential for ground source heat in part of the city. Geologists' knowledge has been applied to incorporate subsurface data (1330 boreholes from a total of 3090 boreholes within the project area) and surface geological mapping to provide an interpretation of the geological succession, utilising BGS 1:50 000 and 1:10 000 scale geological maps.

1 Modelled volume, purpose and scale

The geological model of Cardiff was developed to investigate the superficial deposits of the area and to produce calculated surfaces for the modelled units. The model was constructed using GSI3D software and the calculated surfaces can be exported from GSI3D for use in other software packages to produce data on the distribution, thickness and volume for a range of modelled units, particularly the Glaciofluvial Sheet Deposits which are considered to be the principal aquifer for water and ground source heat potential in the city (*Pers comm* D Boon).

1.1 PROJECT AREA

The extent of the model includes much of the most densely populated and developed urban area of the city of Cardiff. The area also includes the site of an InnovateUK funded technical feasibility study (Project number 102214) into the use of thermally enhanced shallow urban groundwater for ground source heat recovery (BGS, 2018), and is intended to inform ongoing investigation into that topic.

Figure 1 shows the extent of the Cardiff model area outlined in red. This is part of an InnovateUK technical feasibility study area, outlined in black and red. A network of monitoring boreholes is represented by the yellow dots. The background is a 5m cell size NEXTMap Britain Digital Elevation Model from Intermap Technologies.

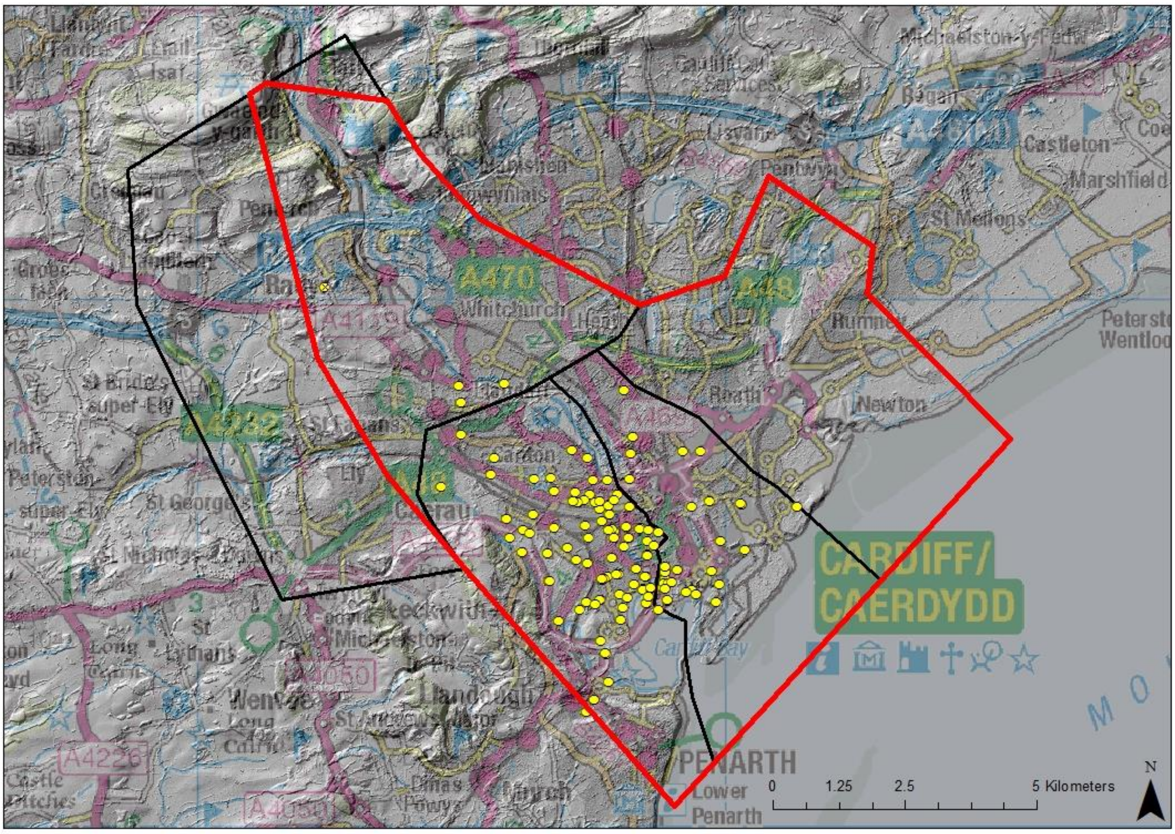


Figure 1 Extent of the InnovateUK, technical feasibility study area (black and red polygons combined). Groundwater monitoring boreholes are shown in yellow. Contains Ordnance Survey data © Crown Copyright and database rights 2020. Ordnance Survey Licence no. 100021290

2 Modelled surfaces/volumes

This section describes the superficial units considered in the construction of this model with a brief overview of their lithological properties. Also described is the rationale on which units were included or excluded from the model.

2.1 BRIEF OVERVIEW OF SUPERFICIAL GEOLOGY

During the Late Devensian, glaciers thought to have originated in the Brecon Beacons and Fforest Fawr uplands, flowed south across the south Wales coalfield to emerge onto the Vale of Glamorgan. The glaciers, at their bedrock-ice interface, deposited consolidated lodgement tills. The composition of these tills reflects the bedrock geology over which the glacier flowed. The rock unit lithologies have imparted a sandy and gravelly character to the tills of the Cardiff area.

During its retreat, morainic Hummocky Glacial Deposits were left behind at the ice margins, and are indicative of glacier ice stagnation. Hummocky Glacial Deposits have a distinctive egg box like topography, with a chaotic lithology and structure. Fans, terraces and spreads of glaciofluvial sand and gravel were deposited from meltwater streams, which reworked and redeposited the tills during deglaciation. Small lenses of Glaciolacustrine Deposits locally formed in ice dammed lakes and ponds.

Within the Cardiff area, the surface extent of Devensian deposits is limited to the north of a line running from St Nicholas, close to Culverhouse Cross, north of Leckwith extending south-eastwards to the coast. The sediments are part of a larger area of gravelly glacial deposits that skirt the rim of the coalfield from Swansea Bay to the west of Newport, defining the southern limit of the Late Devensian Glaciation in the region (Charlesworth, 1929).

During the Holocene, Alluvium and Tidal Flat Deposits were laid down in river valleys and the Severn Estuary as river systems including the Ely, Taff and Rhymney became superimposed upon the pre-existing relief. A rapid post-glacial sea-level rise led to the flooding of the lower reaches of river valleys. Peat accumulated in hollows with restricted drainage and head formed in response to the downslope movement of eroded material under the influence of periglacial climatic conditions (Kendall, 2015 and Waters and Lawrence, 1987).

2.2 LITHOLOGICAL DESCRIPTION OF SUPERFICIAL DEPOSITS IN THE CARDIFF DISTRICT

The following lithological descriptions are summarised from the memoir for the Cardiff district (Waters and Lawrence, 1987) and are presented here to illustrate the character superficial deposits in the modelled area:

Till: In the Cardiff district, the dominant glacial deposit is gravelly till with lenses of sand and gravel. The till has a variable composition ranging from stiff, stony, silty clay to clayey gravel. Gravel grade material is usually pebble to cobble sized. The matrix consists of variable mixtures of sand, silt and clay. Lenses of sand and gravel comprise grey to buff sands and sandy pebble-cobble gravels. The sands are commonly laminated or cross bedded when seen in exposures.

Glaciofluvial Sheet Deposits: Clayey sandy pebble-cobble gravels with thin beds of gravel which are matrix free. Glaciofluvial sheet deposits are often overlain by very fine clayey sand/silt and may be cryoturbated in their upper parts. Glaciofluvial deposits can be bedded or cross bedded.

Tidal Flat Deposits: In the memoir these deposits are referred to as Estuarine Alluvium and mainly comprise blue clay with very subordinate silts, sands and gravels. Peat is commonly present at the base and scattered thin peats are found throughout. Interbeds of sand and gravel are noted in borehole logs.

Alluvium: This is a variable deposit associated with the major rivers and streams. It commonly comprises clay, sand and gravel. Typically, alluvial deposits can be parallel and cross stratified.

Peat: A diachronous basal peat is commonly present at the base of the tidal flat deposits as well as occurring as scattered thin layers. This basal peat is well developed beneath the former East Moors Steelworks site but is rarely present beneath the estuaries. Two higher peats are recorded in boreholes. Peat is also recorded as accumulating in kettle-holes within areas of till deposits.

Glaciolacustrine Deposits: Laminated clays occur in lenses throughout the till and hummocky glacial deposits. Glaciolacustrine deposits also typically contain silts.

Hummocky (Moundy) Glacial Deposits: Glacial sand and gravel deposits of the Cardiff memoir are here referred to as hummocky glacial deposits. These comprise a heterogeneous, largely unbedded admixture of sandy pebble-cobble gravel with lenses of locally pebbly sand, laminated clay and gravelly till. (Waters and Laurence, 1987 and Kendall, 2015).

2.3 MODELLED UNITS

During the development of the model it became apparent that it was not practical to model all of the units defined on the Cardiff district 1:50 000 geological map (BGS, 1989). Some units were omitted because it was not always possible to identify them from the descriptions in borehole records, or because their subsurface distributions are not laterally extensive enough. Table 1 lists the mapped geological units in the area and shows which were actually modelled. The cell colour of the unit name corresponds with images of the model later in this report (units that have not been modelled are uncoloured).

Table 1 List of Superficial Deposits considered in the creation of the model

Name	**LEX-RCS**	**Description**	**Comments**	**Modelled?**
Made Ground	MGR-FILLU	Made Ground	Defining areas of made or infilled ground.	**Yes** – see discussion below
Soil	SOIL-UNKNOWN	Soil	Not used in final model	No – not laterally continuous
Tidal Flat Deposits	TFD-XCZ	Tidal Flat Deposits	Mainly comprises blue clay with subordinate silts, sands and gravels and peats	**Yes**
Basal Tidal Flat Gravels	TFD-V	Basal Tidal Flat Gravels	Basal gravel described in Waters and Lawrence (1987)	No – not readily distinguishable in logs
Peat	PEAT-P	Peat		No – not laterally continuous
Alluvium	ALV-XSCZV	Alluvium	A variable deposit, associated with major streams and rivers, commonly comprising clay, sand and gravel	**Yes**
River Terrace Deposits	RTDU-XSV	River Terrace Deposits		No – none in the modelled area
Glaciofluvial Sheet Deposits	GFSD-XVSC	Glaciofluvial Sheet Deposits	Glaciofluvial sheet deposits, comprising clayey, sandy, pebble-cobble gravels with thin beds of gravel which are matrix free	**Yes**
Hummocky Glacial Deposits	HMGD-XSV	Hummocky Glacial Deposits	Comprising glacial sand and gravel deposits	No. This units was included to match the units defined on the Cardiff Maps but was not modelled
Till	TILL-DMTN	Till	Composition ranges from stiff, stony, silty clay to clayey gravel. Lenses of sand and gravel	**Yes**
Bedrock	ROCK-UKNOWN	Undifferentiated Bedrock		**Yes** – the bedrock has been used to define the base of the model and provides a cut-off point at -50m AOD. No inference of the type or lithology of the bedrock has been made, and therefore it has been given a grey colour
Peat_lens_base	PEAT-P	Peat Lens Base		No – not laterally continuous
Peat_lens_2_base	PEAT-P	Peat Lens Base		No – not laterally continuous
Peat_lens_3_base	PEAT-P	Peat Lens Base		No, but small lenses exist in the central area

Name	LEX-RCS	Description	Comments	Modelled?
GLLD_lens_base	GLLD-CZ	Glaciolacustrine Deposits Base		No – not laterally continuous
HMGD_lens_base	HMGD-XSV	Hummocky Glacial Deposits Base		No – not laterally continuous

GSI3D workflow and methodology was used for all modelled geological units (Kessler and Mathers, 2004). However, modelling artificial ground in this way was problematic because of its patchy distribution on the corresponding geological maps. This was exacerbated by difficulties in matching artificial ground recorded in borehole logs to mapped artificial ground. Artificial ground mapping on BGS maps traditionally focuses on modifications to the landscape, such as quarries and railway embankments, and not the wider 'urban blanket' recorded in boreholes.

Ordnance Survey VectorMap data was used to create shape files for buildings, roads, railways, excavated waterways, docks, and green space (Table 2). These shape files were buffered and cross checked with the existing artificial ground layer. They were then merged, dissolved and clipped to the Cardiff project area and any polygons smaller than 10,000 m^2 were removed. A made ground guideline was created in the cross sections by reducing the DTM by 1.5m. This value is considered to be representative of typical made ground thickness in urbanised areas; the average thickness of made ground recorded in the study area is ~1.9 m (n=1210), however the dataset includes boreholes penetrating locally thicker deposits associated with road and rail infrastructure and former industrial sites (the maximum thickness of made ground recorded in the boreholes used is 12.7m). Local knowledge and Ordnance Survey Open Data were used to inform decision making where mapped made ground did not agree with the borehole logs.

Table 2 Ordnance Survey Open Data themes that define the extent of made ground in the model and the buffer distance used

Theme from OS Open Data	Buffer distance
Urban regions	10m
A roads	10m
B roads	10m
Primary roads	10m
Minor roads	10m
Motorways	10m
Railways	10m

3 Model datasets

This section describes the Digital Terrain Model (DTM), borehole logs and digital geological map data used to constrain the model.

3.1 DIGITAL TERRAIN MODEL

The DTM used for this Cardiff superficial model is derived from the OS Opendata Terrain-50 model at a 50m cell resolution.

3.2 BOREHOLE DATA

At the start of the project, a total of 4629 boreholes in the BGS Single Onshore Borehole Index (SOBI) were within the Cardiff model area (Section 1 and **Figure 1**). However, the majority of these boreholes had only geological rockhead defined, or no geological interpretation whatsoever in their associated record in the BGS Borehole Geology Database. Geological interpretations from borehole logs have to be manually entered into the Borehole Geology database. With so many boreholes needing to be entered before they could be used in the model a series of spatial queries was used to identify those that would be most useful:

- The boreholes in the project area were clipped to the DigMap50 (v7.22) superficial polygons. This identified 4149 boreholes that lie within mapped superficial deposits.
- These 4149 boreholes were compared to the BGS Rockhead Elevation Model (v2009). Only boreholes with drilled depths that exceed the thickness of superficial deposits according to the BGS Rockhead Elevation Model were selected because they are more likely to penetrate rockhead. This reduced the number of boreholes for consideration in the model to 2664.
- The project area was divided between a team of four geologists to build cross-sections and provide geological interpretation within their areas (Figure 2). Within each area, a team member designed a series of cross-section lines in ArcGIS, incorporating as many boreholes as possible to help characterise the subsurface distribution of the superficial deposits. The geological information in each borehole along these lines of section was entered into the BGS Borehole Geology database and incorporated into the 3D modelling software, ready to correlate the cross-sections. This process resulted in 1330 boreholes being captured into the corporate databases and used in the model.

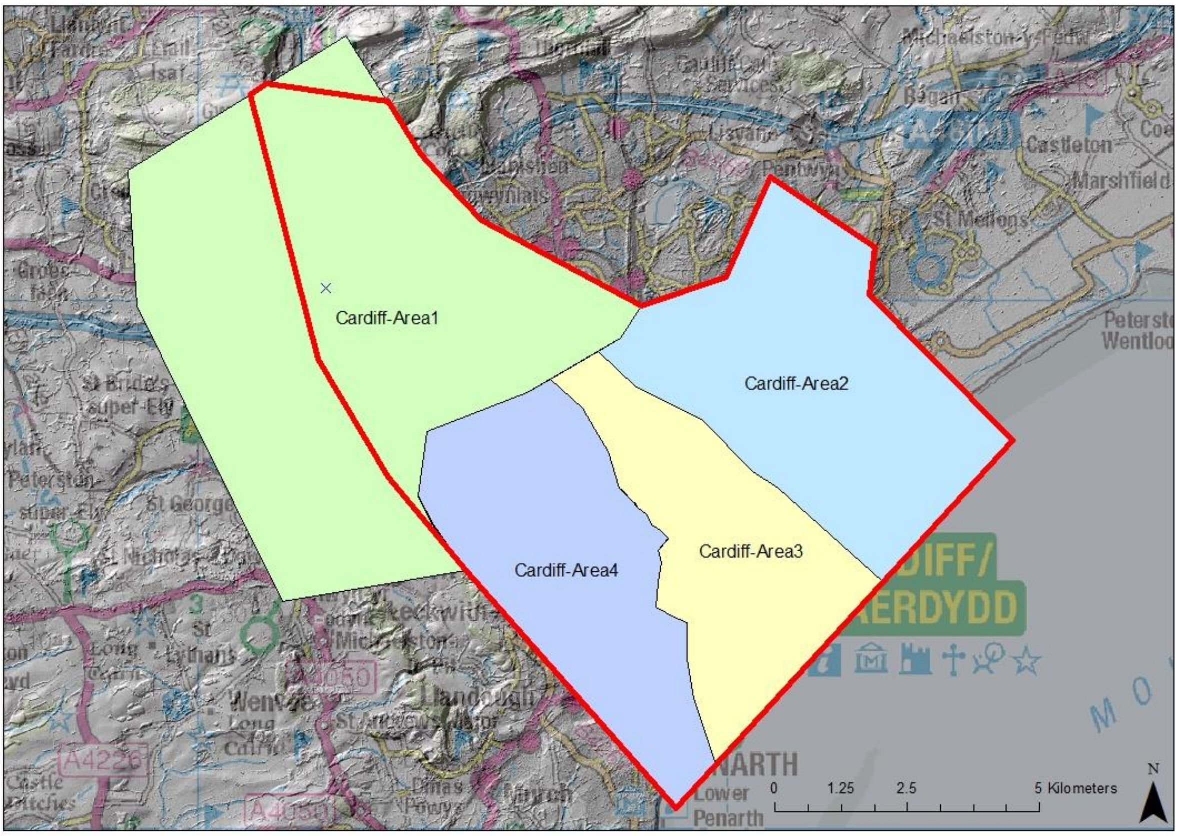


Figure 2 Modelling areas assigned to individual geologists. Contains NEXTMap Britain elevation data from Intermap Technologies and Ordnance Survey data © Crown Copyright and database rights 2020. Ordnance Survey Licence no. 100021290

3.3 GEOLOGICAL MAP DATA

The surface extent of superficial deposits used in the model is derived from the BGS DigMap50 dataset, based on 1:50 000 scale geological maps of the area. Most of the area is within the Cardiff district (BGS, 1989 and Waters and Lawrence, 1987) but also includes parts of the Bridgend sheet (BGS, 1989 and Wilson et al, 1990), the Newport sheet (BGS, 1969 and Squirrell and Downing, 1969) and the Pontypridd and Maesteg sheet (BGS, 1975 and Woodland and Evans, 1964).

4 Model workflow

The standard GSI3D workflow was used to create the 3D model. (Kessler and Mathers, 2004). Details specific to this model are given below:

- The model project area was based on the associated geothermal project area (BGS, 2018) and shape file approximating the geothermal project extent was brought into GSI3D project.
- A Digital Terrain Model was chosen and brought into the GSI3D workspace. This was the Ordnance Survey Terrain 50 with a 50m cell size, chosen because it is open source.
- Digital geological map data from the BGS DigMapGB-50 data set was used for modelling the surface extent of the superficial deposits.
- Boreholes were identified for inclusion in the project based on a methodology described in Section 3. The downhole information in these boreholes was coded into the BGS corporate database for use in the model.
- Generalised Vertical Sections were constructed based on units defined by Waters and Lawrence (1987) and in the 1:50 000 geological map for Cardiff (Kendall, 2015).
- A Made Ground layer was generated and imported into GSI3D (Section 2).
- The project area was divided into four areas (Figure 2) for four team members (RS Kendall, LR Williams, AM Patton and DI Schofield).
- A system of cross-sections was designed by each team member which incorporated as many boreholes as possible and in orientations considered to best define the subsurface structure (Figure 3).
- GSI3D was used to draw sections based on the design described above and utilising newly captured data from boreholes.
- “Envelopes” or coverages for each modelled unit were digitised to define the maximum extent of each deposit in the subsurface.
- Edge matching was undertaken between project areas to ensure consistency across project area.
- The model was calculated and checked for errors.
- The cross-sections were checked for errors.
- Geological surfaces were exported as ASCII data for use in other applications.

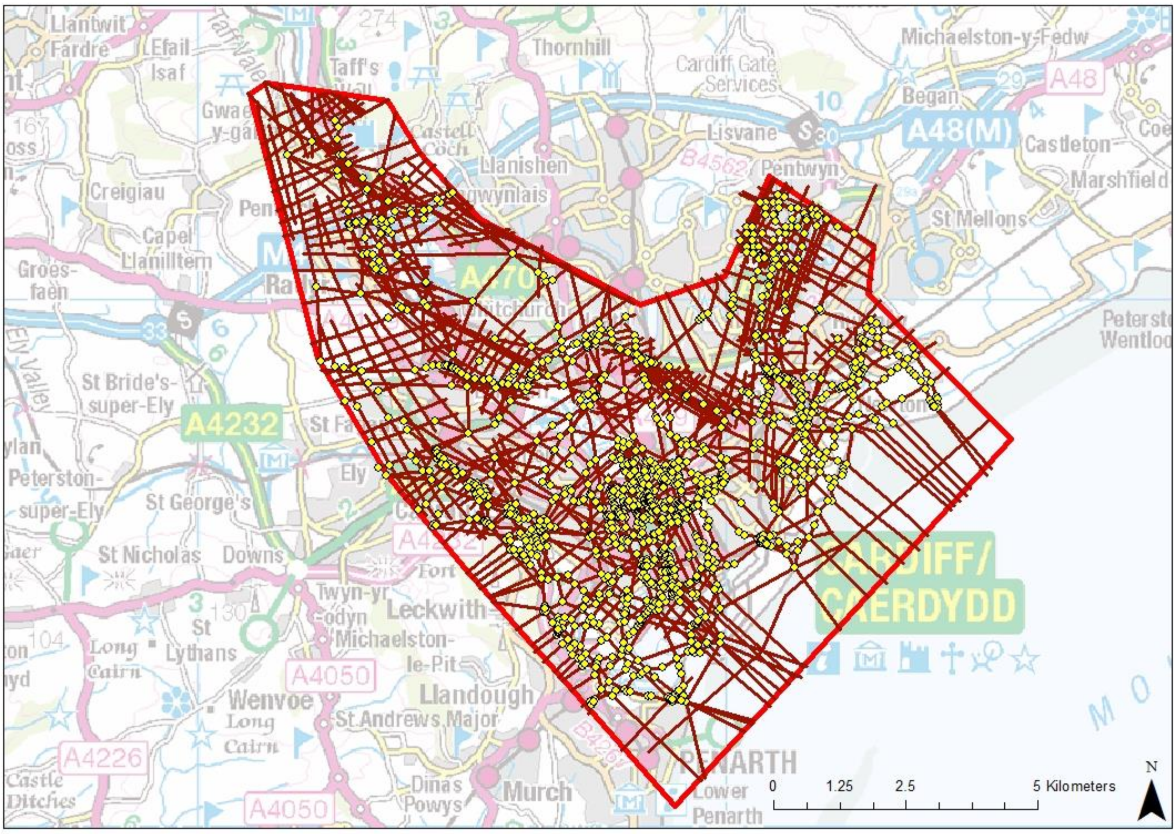


Figure 3 Distribution of cross-section lines (dark red) and the boreholes (yellow) used in the construction of the model. Contains Ordnance Survey data © Crown Copyright and database rights 2020. Ordnance Survey Licence no. 100021290

5 Model assumptions, geological rules used etc.

Our understanding of the superficial geology of Cardiff is based on the memoir for Cardiff (Waters and Lawrence, 1987). This publication was used to define conceptual rules for the relationships between the superficial deposits (Kendall, 2015). The oldest superficial deposit in the model area is assumed to be till. The till is overlain by glaciofluvial sheet deposits, which may cut into the till. The glaciofluvial sheet deposits are in turn cut out by modern floodplain alluvial deposits. In the southern part of Cardiff the Tidal Flat Deposits drape the Glaciofluvial Sheet Deposits and interdigitate with the modern alluvium. More detail on the geological setting can be found in Kendall (2015) and Waters and Lawrence (1987).

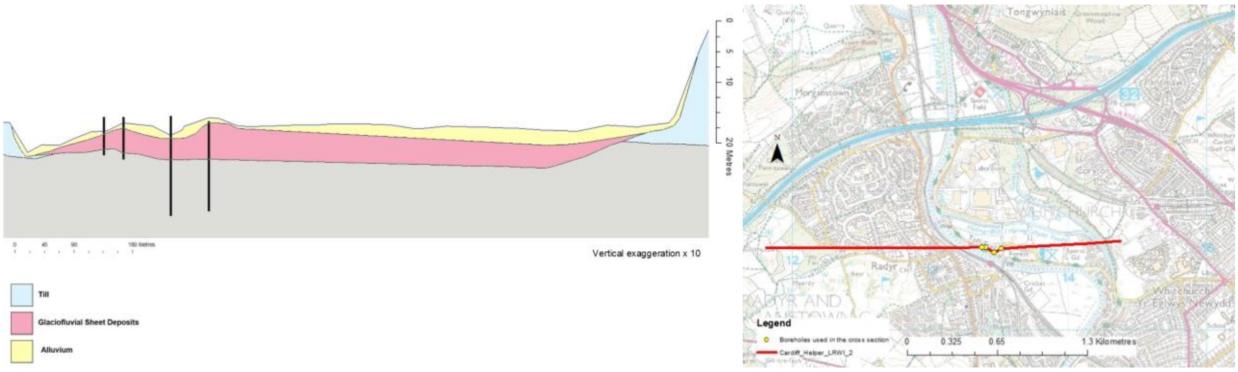
The maximum depth for the model is 50m below Ordnance Datum and the combined thickness of superficial deposits is less than 30m.

6 Model limitations

There are a number of limitations identified with this model which should be considered wherever the resulting surfaces are used in the future. These limitations and concerns are listed below:

- This model uses the Ordnance Survey Terrain 50 Digital Terrain Model (DTM) at the full resolution 50m cell size as its capping surface. This DTM was chosen because there are no restrictions on its use. However, this grid is relatively coarse when considering that the maximum thickness of superficial deposits in the area is less that 30m and commonly much thinner. Cardiff city centre has only very shallow topographical relief which is not accurately represented by this DTM. The DTM is also very ‘spiky’ in places.

- Most of the boreholes in this study area have no start height recorded, which has caused difficulties in defining the depths of unit boundaries. Where a start height is known, the interpreted geology has been used at the depths given in the log. Where there is no start height the borehole has been rendered to DTM in GSI3D. In some cases the start height has been ignored because it assumed that the contemporary ground surface is different to the present day DTM. In other cases, the borehole was drilled before any anthropogenic alteration of the ground surface occurred (such as building of a motorway embankment). These boreholes are accurate records of previous land surface and can be very useful. There are a number of identified problems which are caused by the use of this DTM:
    - The reported start height of the borehole may not match the present day ground surface, defined in the model by the DTM, which may introduce errors estimating the depth to the top and base surfaces for a unit.
    - The OSDTM 50m is spiky in nature, being a coarse grid. This has introduced errors for the start height of boreholes which are hung from it. In testing to see how significant this problem might be, the OSDTM 50m was compared to the bald-earth DTM (an in-house algorithm-refined DTM using NextMap as the base but with areas of woods removed). The result was that in some instances, the variability in start height can be greater than the thickness of the units or even the length of some boreholes. This results in an error factor of greater than 100% in places.
    - The spiky DTM also poses problems when trying to fit unit bases to a mapped geological boundary to the ground surface. In places, unit bases have to be deformed to accommodate the variability in the DTM. This is particularly obvious with alluvium, which runs up hills in some areas. Figure 4, shows cross-section *Cardiff_Helper_LRWI_2*, which runs west to east across the River Taff in the north of the model area. Alluvium follows the DTM up the eastern side of a valley in this cross-section.



4B

4A

Figure 4 Cross-section Cardiff_Helper_LRWI_2, which runs W-E across the River Taff. Alluvium is modelled to fit the DTM and climbs up the eastern side of the valley. 4A – cross section and 4B illustrates its position within the city of Cardiff. Contains Ordnance Survey data © Crown Copyright and database rights 2020. Ordnance Survey Licence no. 100021290

- Construction of made ground in cross-sections and envelopes is complex. It has been found that infilled or made ground is seen in boreholes where it is not mapped at the surface and vice versa. Because of this, a decision was made to define the extent of using published Ordnance Survey datasets (Section 2). Further enhancement of the made ground layer based on geological surface mapping and additional borehole data could be undertaken as part of future model development activities.

It is clear that the made ground generation methodology is not a perfect solution. Some areas of made ground may be omitted from the model as they are below the size limit used to delimit the coverage of the urban fabric and infrastructure, or where the made ground may be present that is not associated with modern urban/infrastructure features (e.g. in relation to historical developments and infrastructure). Equally there are large areas where the made ground polygon created is largely over-generalised.

The made ground layer is constructed using OSDTM 50m. Its accuracy is questioned because of the problems outlined above, namely its coarse grid and spiky nature.

- There are in excess of 3090 boreholes within the project area, and more data has been collected during the course of this project. The model uses 1330 boreholes. Inclusion of more interpreted borehole data would improve the model.
- Only limited field testing (mainly desk study) has been done to validate this model.
- Glaciofluvial sheet deposits and till often have very similar compositions as described in the borehole logs. Geological mapping was used to distinguish between them because it takes into account topographic features. In the subsurface however, a deposit described as 'till' or over consolidated is interpreted as till.
- At the start of the modelling process the project leader for the InnovateUK project (*pers comm* David Boon) for which this model has been created, requested that geological rockhead be used as opposed to engineering rockhead. This has led to some difficulties especially where deep weathering of the Mercia Mudstone Group facies is suspected. Where borehole logs record gravelly, pebbly or cobbly soils, beyond the estimated limit of till (See section 1) these deposits are classified as glaciofluvial sheet deposits. Further study of the effects of weathering on the Mercia Mudstone Group mudstones is needed to improve understanding of the distributions of weathered bedrock and glaciofluvial deposits in these areas.

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The 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.
- The full complexity of the geology may not be represented by the model due to the spatial distribution of the data 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. borehole 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.

7 Model QA

In order for a geological model to be approved for publication or delivery to a client a number of QA checks are carried out. This includes visual examination of the modelled cross-sections to ensure that they match each other at cross-section intersections and fit the borehole and geological map data used. The model calculation is checked to ensure that all units calculate to their full extent within the area of interest and 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 images

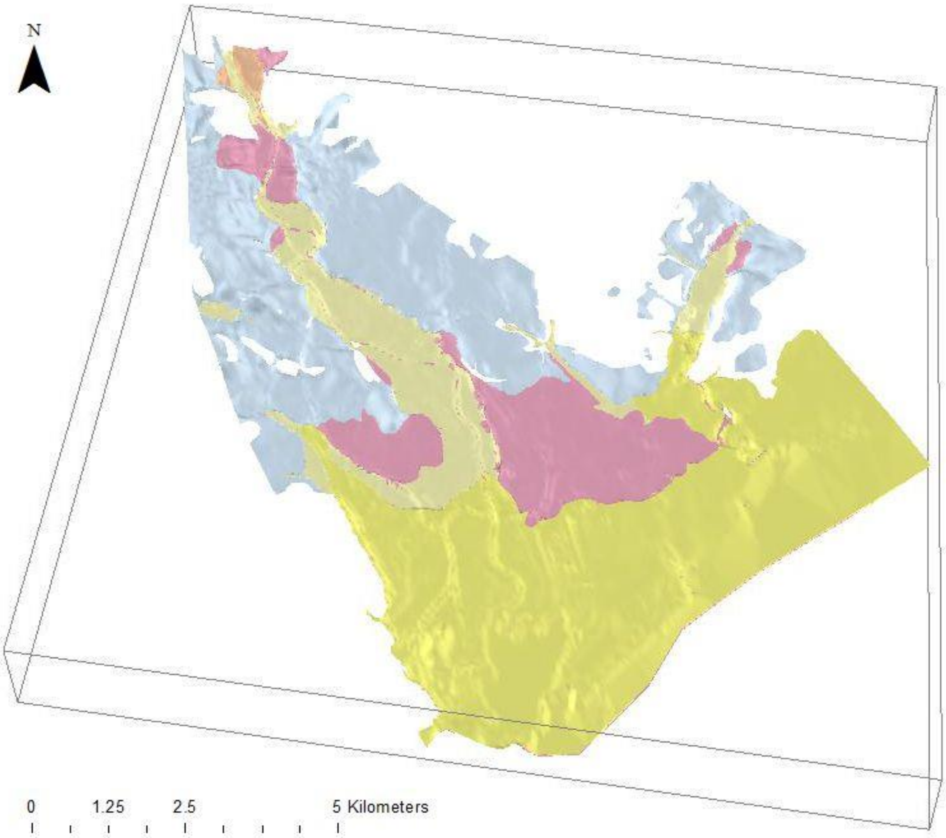


Figure 5 View of the model looking across the harbour to the north showing all modelled superficial deposit units (5 times vertical exaggeration; made ground not shown). Key as per Table 1.

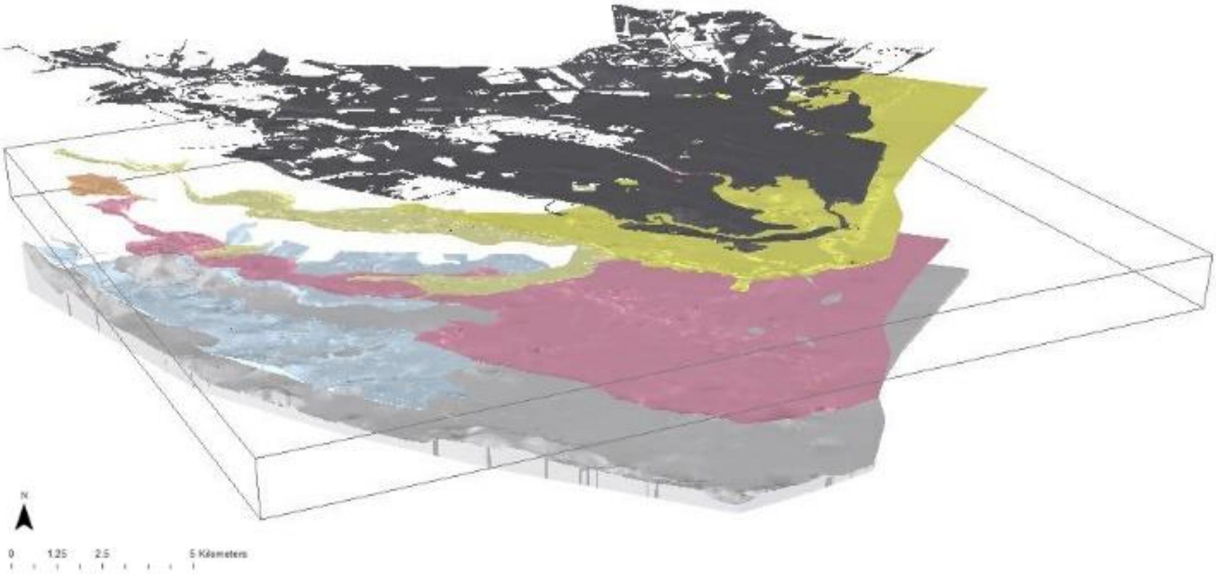


Figure 6 View of the exploded modelled superficial deposit units, viewed from the southwest corner looking eastwards. Key as per Table 1.

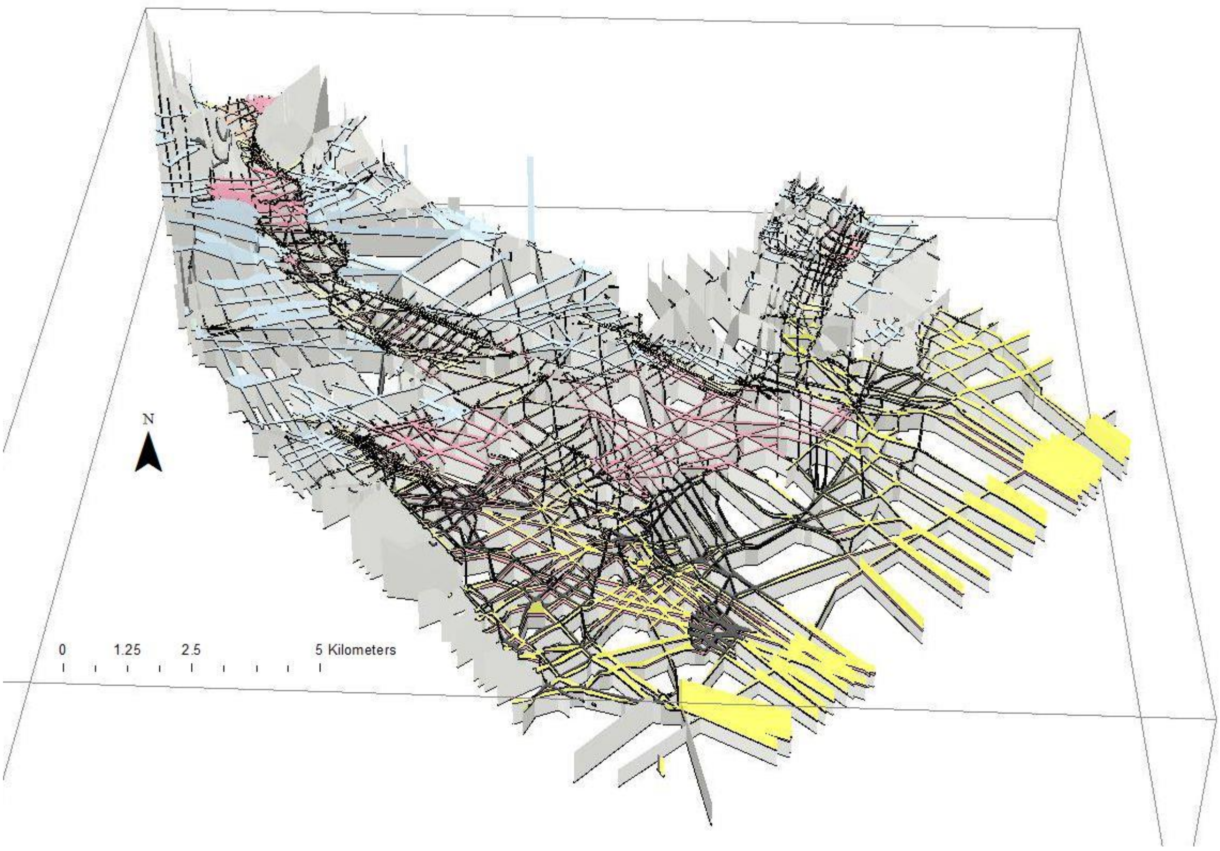


Figure 7 Figure 7 View of all cross-sections in 3D, looking across the harbour to the north. Key as per Table 1.

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

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