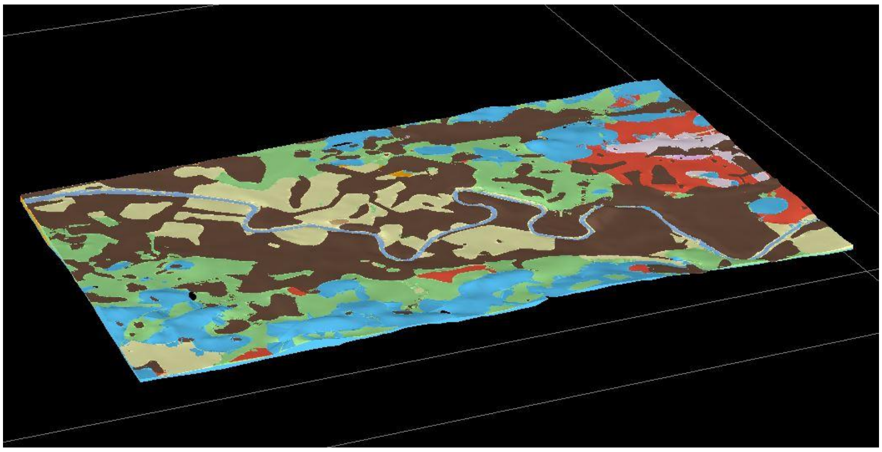
Model metadata report for the post-drill superficial deposits model, UK Geoenergy Observatory in Glasgow

UK GEOENERGY OBSERVATORIES PROGRAMME

Open Report OR/21/034



BRITISH GEOLOGICAL SURVEY

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Model metadata report for the post-drill superficial deposits model, UK Geoenergy Observatory in Glasgow

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Editor

A A Monaghan

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3D image of superficial deposits beneath the UKGEOS Glasgow area

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Glasgow City Council and Clyde Gateway Urban Regeneration Company have provided datasets and feedback on geological modelling over many years and are also thanked here.

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Summary

This report presents the metadata behind the post-drill superficial deposits 3D geological model data release, developed by the British Geological Survey (BGS), for the UK Geoenergy Observatory in Glasgow (UKGEOS). The site is located within the Clyde Gateway regeneration area of eastern Glasgow (Glasgow City Council) and Rutherglen (South Lanarkshire Council), central Scotland, UK.

The superficial deposits in the Clyde valley consist of a complex succession of glacial till, marine, lacustrine and fluvio-glacial deposits, overlain by fluvial deposits, recent alluvium and anthropogenic deposits, which locally reach around 50 m in thickness. There is widespread made, filled and landscaped ground mantling the natural superficial deposits.

The geological information in this report and accompanying 3D model characterise the various superficial deposits, and give an indication of their thickness and lateral extent. This has created a better understanding of the Quaternary (superficial) geology of the Glasgow Observatory area. The model allows users to visualise the subsurface sequences to be found beneath the Glasgow Observatory site and the surrounding area.

The model presented in this report builds on previous superficial deposit models of the Glasgow area, developed by BGS since 2005. A number of reports have been published describing previous models of the area, including Merritt et al. (2009), Monaghan et al. (2012, 2014) and Arkley et al. (2013). The pre-drill Glasgow Observatory model (Arkley, 2019) incorporated additional borehole data to increase the model resolution in the vicinity of the Glasgow Observatory borehole sites and incorporated post-2005 to pre-2018 borehole data received by BGS. This version of the model has been updated in the vicinity of the Glasgow Observatory boreholes and represents a UKGEOS ‘post-drill’ understanding of the superficial deposits in and around the Glasgow Observatory.

The models are an interpretation of digital datasets held by the British Geological Survey. A summary of the construction method, limitations of the models and a brief description of the modelled units are given.

1 Modelled Volume, Purpose and Scale

This report provides an overview of the post-drill superficial deposits 3D geological model for the UK Geoenergy Observatory (UKGEOS) in Glasgow.

The model updates previous BGS superficial models of central-eastern Glasgow and the pre-drill Glasgow Observatory model (Arkley, 2019).

The model was constructed to define the three-dimensional spatial distribution of the superficial deposit succession from Devensian glacial till to recent made ground present in the vicinity of the Glasgow Observatory, to help users with an understanding of the (Quaternary) superficial deposits of the area. The post-drill model incorporates the 12 boreholes drilled at the Glasgow Observatory in Dalmarnock borehole (Site 10) and the Cuningar Loop (Sites 1, 2, 3 and 5).

The UKGEOS Glasgow area is located in the East End of Glasgow (Dalmarnock) and Rutherglen, straddling the boundary between Glasgow City and South Lanarkshire councils on the north and south sides of the River Clyde (Figure 1).

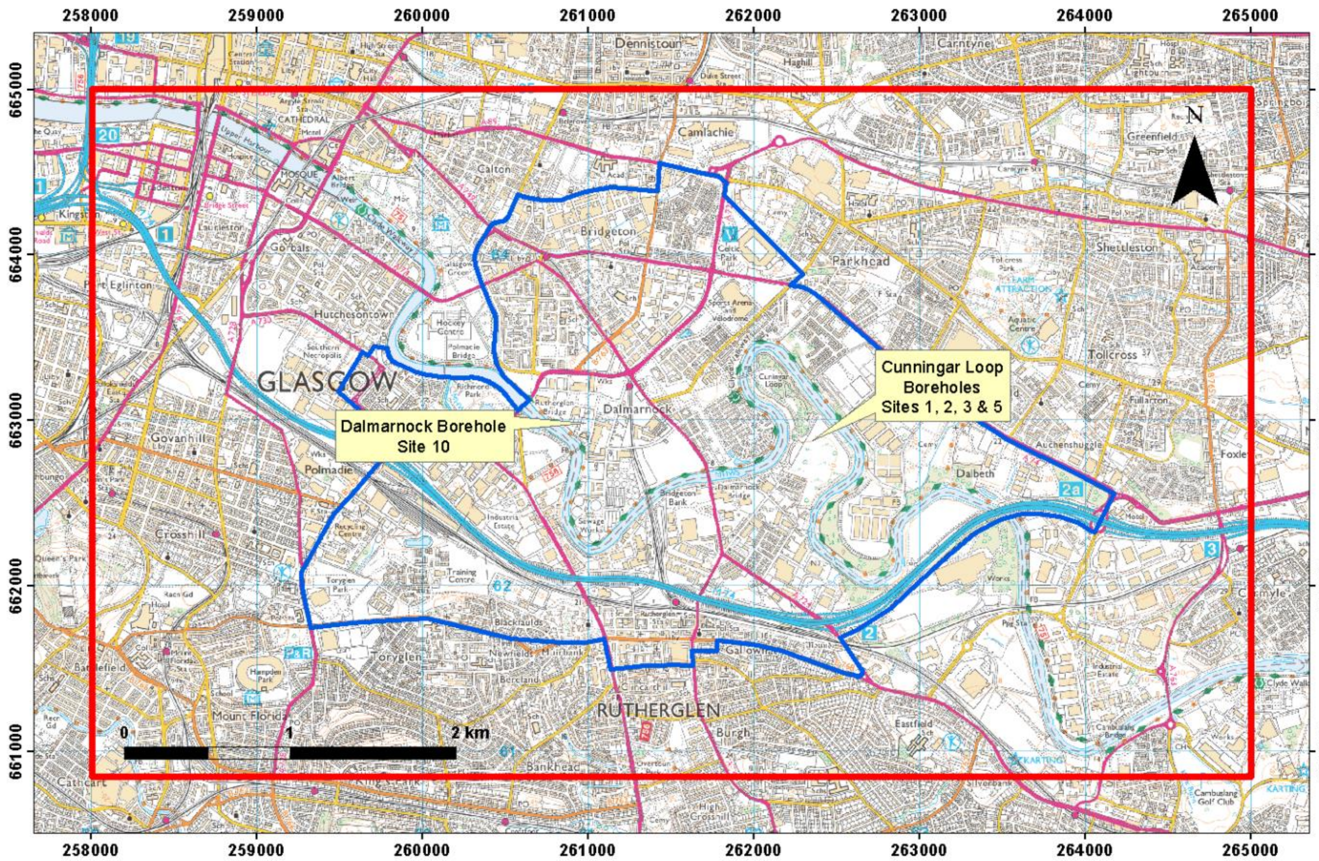

Figure 1 Location map of the superficial deposits model area (red outline) and Glasgow Observatory borehole locations. The blue line is the 2018 extent of the Clyde Gateway urban regeneration area. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

The model area encompasses the Clyde Gateway urban regeneration area, c.840 hectares, comprising sports facilities and housing for the 2014 Commonwealth Games, some pre-existing 19th and 20th century legacy housing, and vacant and derelict land with a history of multiple former industrial use and housing (Figure 1).

The aim of the 3D geological model is to describe the distribution of the Quaternary-aged deposits based on a review and the interpretation of the available data held by BGS, largely comprising Site Investigation and exploration borehole data. This has been achieved by entering compositional and lithostratigraphic information into BGS databases and generating surfaces of geological units within the bespoke models using GSI3D software. The results of the Glasgow Observatory boreholes have been incorporated into the interpretation of the complex Quaternary geology in this area.

The ground surface across the study area is between 2 m and 60 m above Ordnance Datum (OD; Figure 2).

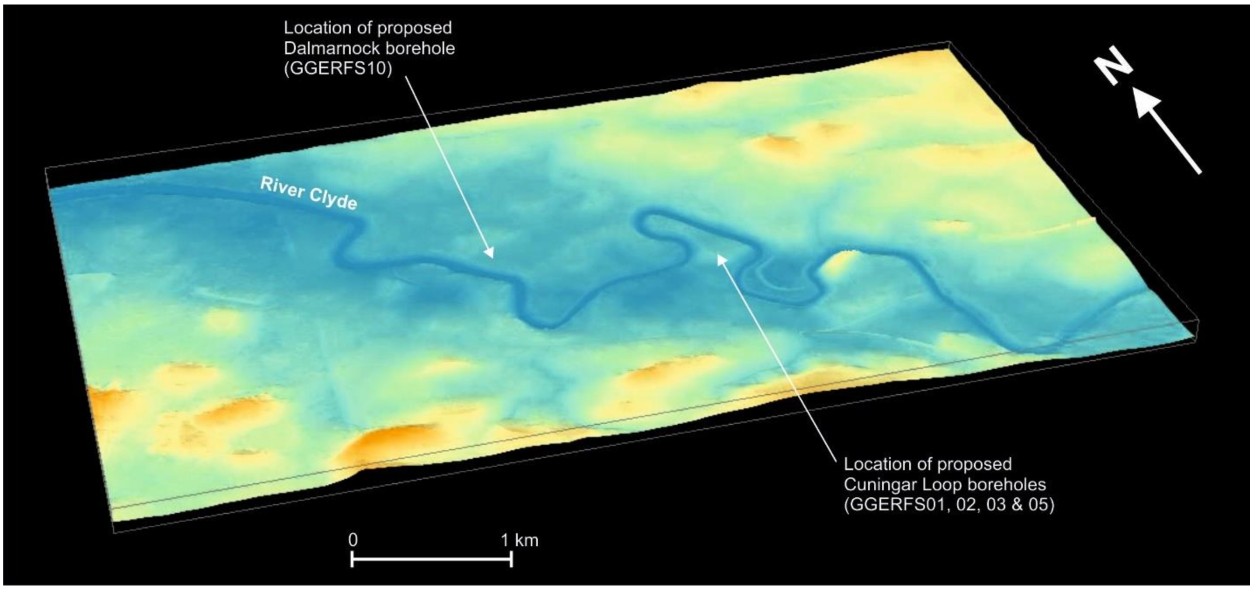

Figure 2 3D view of the Digital Terrain Model (5 m cell size) in the vicinity of the Glasgow Observatory. The ground surface across the study area is between 2 m and 60 m above Ordnance Datum (OD). The course of the River Clyde can be clearly seen snaking its way north-westwards along the low ground of the Clyde valley (blue colours) with higher ground (orange colours) to the northeast and southwest. NEXTMap Britain elevation data from Intermap Technologies.

The area surrounding the Glasgow Observatory zone falls within the previously published 'Central Glasgow' model (Merritt et al., 2009; Monaghan et al., 2014). The Glasgow Observatory model has been updated between the coordinates SW corner 258000, 660850, NE corner 265000, 665000 to include boreholes drilled between 2005 - 2018 and increase the model resolution in the vicinity of Glasgow Observatory borehole sites (pre-drill model, Arkley, 2019). It comprises an area of approximately 7 km x 4 km. The post-drill version of the model described here has been updated with the results of the Glasgow Observatory boreholes.

The model extends to rockhead which lies between 36 m above OD and 40 m below OD. The Glasgow Observatory post-drill superficial deposits model is most suitable for use at scales between 1:10 000 to 1:50 000 scale, but is also useful for providing guidance at other scales. Users are advised against basing interpretations on extreme exaggeration of the vertical or horizontal scales of the model.

1.1 CITATION GUIDANCE

Any use of the model should be cited to:
DOI: Arkley, S and Callaghan E. (2021) UKGEOS Glasgow post-drill superficial deposits model. NERC EDS National Geoscience Data Centre. (Dataset). https://doi.org/10.5285/915f690f-32cf-41b7-984e-c32344d3a543
and this report cited as:
Arkley, S and Callaghan E. 2021. Model metadata report for the post-drill superficial deposits model, UK Geoenergy Observatory in Glasgow. British Geological Survey Open Report, OR/21/034. 52pp

2 Modelled Surfaces/Volumes

2.1 GEOLOGICAL SETTING

The model area is located within the lower reaches of the Clyde valley, which is thought to have been glaciated multiple times over the last 0.5 Ma, most recently during the Main Late Devensian glaciation when ice advanced into the Clyde basin. Glacial ice retreated from the Glasgow area by around 15,000 years BP, at a time when the relative sea level had risen locally to almost 40 m above current sea level and inundated low-lying coastal areas. The relative sea level then fell during the Holocene and resulted in a series of raised estuarine flats around the Glasgow area at progressively lower elevations (approximately 12 m to 3 m above current sea level).

In the vicinity of the Glasgow Observatory, the underlying Carboniferous rocks have been scoured by glacial, river and coastal erosion processes leaving an irregular undulating surface buried beneath the Quaternary sediments. Deposited on top of this is a complex succession of Quaternary superficial deposits, varying laterally and vertically across short distances, including widespread glacial till and marine, lacustrine and fluvio-glacial deposits, overlain by fluvial deposits, recent alluvium and anthropogenic (man-made) deposits (Figure 3).

The Quaternary deposits are of variable thicknesses, up to 50 m thick, with thicker accumulations of superficial deposits infilling a broadly NW–SE trending channel following the modern-day River Clyde. There is also widespread made, filled and landscaped ground relating to a variety of prior industrial land use, which in some places reaches 10–15 m thick. Table 1 summarises the sequence. The Quaternary geology of the Clyde valley is described in detail in Browne and McMillan (1989), Forsyth et al. (1996), Finlayson et al. (2010) and Finlayson (2012).

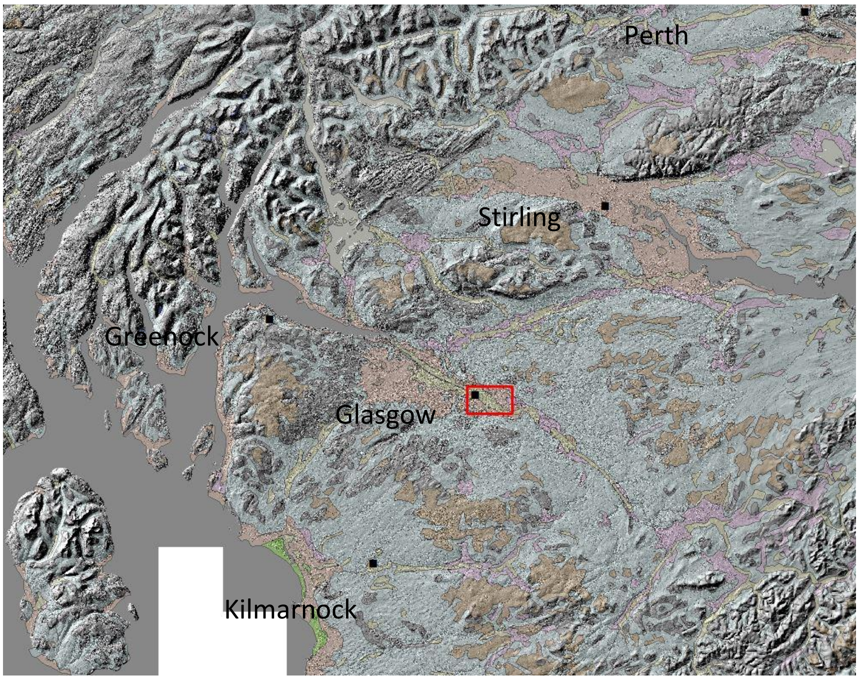

Figure 3 Location of the model area (red rectangle) and the surrounding topography, depicted by the NEXTMap Surface model hillshade. Superficial deposits (BGS Geology 625K are overlain as coloured tints: blue – glacial till, pink – glacial sand and gravel, orange – raised marine deposits, brown – peat, yellow – alluvium and green – blown sand).

CLAY AND SILT		SAND AND GRAVEL		DIAMICTON	PEAT	LITHOLOGY
Marine	Lac/Fluv	Marine	Lac/Fluv	Glacial	Organic	ORIGIN
		Gourock	Law		Clippens	FLANDRIAN
		Killearn				DEVENSIAN
Paisley						
		Bridgeton				
	Bellshill					
			Ross			
			Broomhouse			
				Wilderness		
			Cadder			

Table 1 Summary of origin of superficial deposits stratigraphic units in the model area: lithology, origin and age (Lac – lacustrine, Fluv – fluvial).

Code	**Geological Unit**	**Equivalent description on 1: 10, 000 scale published map**
Water	Water	Unattributed polygons or underlying sediments described
MGR-ARTDP	Made Ground (made and worked ground undifferentiated)	Made Ground (MGR), Made Ground and Worked Ground (WMGR), Infilled Ground (WMGR)
PEAT-P	Peat	Peat – blanket or basin peat, Flandrian (PEAT)
LAWSG-XCZSVP	Law Sand and Gravel Member	Alluvium – modern river floodplains – located along the upper reaches and tributaries to the River Clyde, Flandrian (ALV). Also includes some Alluvial Fan Deposits, Flandrian (ALF) and some River Terrace Deposits, Flandrian (RTD1 and RTD2)
GOSA-XCZSV	Gourock Sand Member	Marine Deposits – located along the lower reaches of the River Clyde, Flandrian (MDU) and Alluvium – modern river floodplains – along the upper reaches of the River Clyde, Flandrian (ALV)
KARN-XSV	Killearn Sand and Gravel Member	Generally Raised Marine Deposits, Devensian (RMDV), Raised Marine Deltaic Deposits, Devensian (RMDDD) or Raised Marine Intertidal and Subtidal Deposits, Devensian (RMIS)
PAIS-XCZS	Paisley Clay Member	Generally Raised Marine Deposits, Devensian (RMDV) or Raised Marine Intertidal and Subtidal Deposits, Devensian (RMIS)

BRON-XSVZ	Bridgeton Sand Member	Largely concealed beneath younger deposits, where present, exposures usually represented as Raised Marine Deposits, Devensian (RMDV)
RSSA-XSV	Ross Sand Member	Glaciolacustrine Deposits, Devensian (GLLDD), Glaciolacustrine Deltaic Deposits, Devensian (GLDDD) or Glaciofluvial Deposits, Devensian (GFDUD)
RSSA-XSZ	Ross Sand Member (silt, sand)	Largely concealed beneath younger deposits, identified at depth from borehole data, rare exposures represented as Glaciolacustrine Deposits, Devensian (GLLDD) or Glaciolacustrine Deltaic Deposits, Devensian (GLDDD)
BHSE-XSV	Broomhouse Sand and Gravel Formation (sand and gravel)	Largely concealed beneath younger deposits, where present, exposures usually represented as Glaciofluvial Deposits, Devensian (GFDUD), but also as Glaciofluvial Ice-Contact Deposits, Devensian (GFICD)
BHSE-S	Broomhouse Sand and Gravel Formation (sand)	Not recorded on the maps in the UKGEOS Glasgow area (concealed beneath younger deposits), identified at depth from borehole data
WITI-DMTN	Wilderness Till Formation	Till - Devensian (TILLD)
CADR-XSV	Cadder Sand and Gravel Formation	Generally concealed beneath younger deposits, identified at depth from borehole data, rare exposures represented as Glaciofluvial Deposits, Devensian (GFDUD)
SUPD-XSV	Sand and gravel	Not recorded on the maps in the UKGEOS Glasgow area (concealed beneath younger deposits), identified at depth from borehole data

Table 2 The 15 lithostratigraphic units differentiated in the 3D superficial deposits model of the model area, in stratigraphic order.

Table 2 summarises the 15 lithostratigraphic units included in the superficial deposits model of the UKGEOS Glasgow area in stratigraphic order. Geological units are based on borehole and 1:10 000 scale geological map data., X indicates that each lithology is represented (e.g. XSV is a unit containing sand and gravel as opposed to SV which would be gravelly sand), where C=clay, Z=silt, S=sand, V=gravel, DMTN=diamicton, ARDP=artificial deposits, P=peat

A description of each of the modelled units is given below in approximately ascending (oldest/deepest first) order.

2.2 SAND AND GRAVEL UNIT (SUPD_XSV)

This small, un-named sand and gravel unit is thought to pre-date the Cadder Sand and Gravel Formation. The unit is generally thin (less than a few metres thick) and of limited lateral extent. It has been identified in a small number of boreholes in the northern part of the model area.

2.3 CADDER SAND AND GRAVEL FORMATION (CADR)

The Cadder Sand and Gravel Formation is found mainly to the north of the River Clyde (Figure 4), with deposits tens of metres thick associated with the deep bedrock depressions of the Kelvin buried valley-system. In the model area, the unit has largely been truncated by the emplacement of overlying tills and by modern river erosion, resulting in modification of the original depositional morphology of the unit. However, a few boreholes in the north-eastern corner of the modelled area show sand and gravel deposits lying beneath glacial till up to 20 m thick.

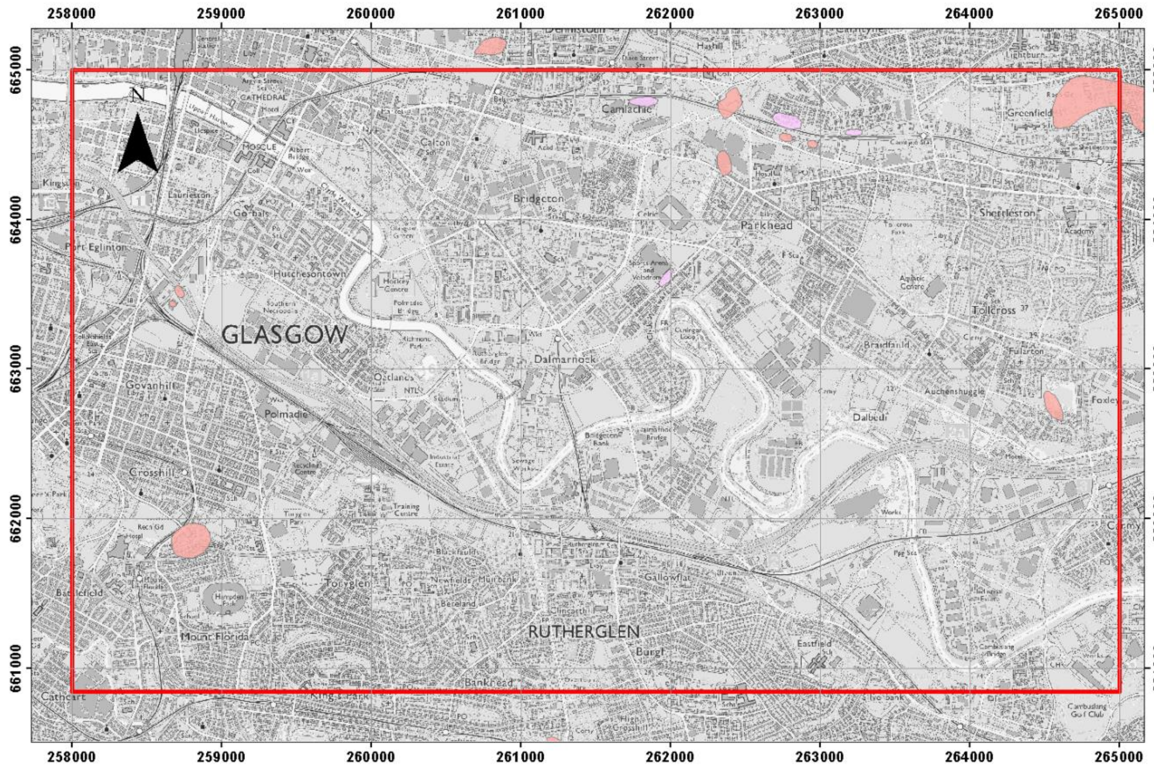

Figure 4 Modelled distribution of Cadder Sand and Gravel Formation (orangey pink) and the Sand and Gravel unit (pink) across the model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

2.4 WILDERNESS TILL FORMATION (WITI)

The Late Devensian Wilderness Till Formation is the most extensive unit in the Clyde area (Figure 5) and is named after temporary sections seen in the Wilderness Plantation area north of Bishopbriggs. It is characterised by a diamicton comprising isolated boulders, gravel and cobbles in a firm to stiff sandy, silty to clayey matrix (Browne and McMillan, 1989). Generally, it rests directly on bedrock in the model area, but is underlain in places by older sand and gravel deposits (probably belonging to the Cadder Sand and Gravel Formation). Drumlins, which are large mounds formed during emplacement of the till below moving glacier ice, are a characteristic landform associated with the Wilderness Till Formation. Drumlins constrain the hilly terrain of Central Glasgow and the surrounding areas where the Wilderness Till is exposed at the surface. Along the Clyde valley, buried drumlins cause considerable spatial variation in the thickness of overlying sediment deposits. The thickness of these glacial till deposits is highly variable across the model area, reaching almost 50 m thick in some places whilst being absent in other areas.

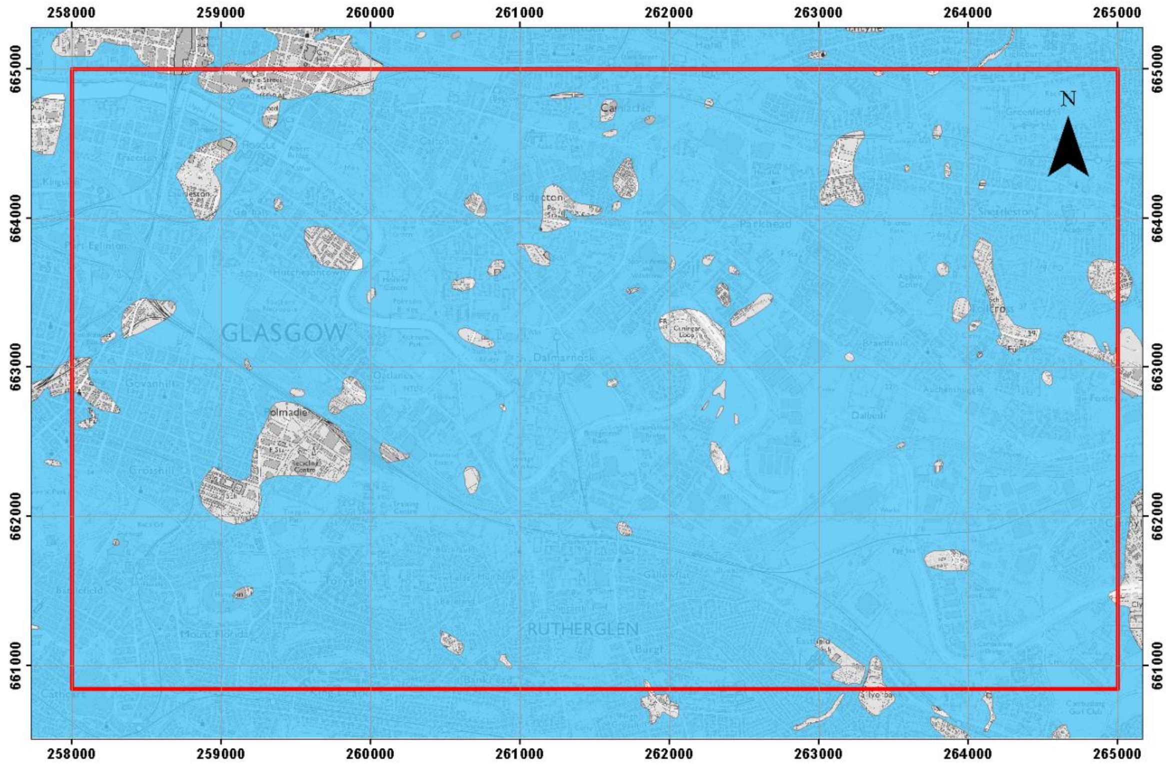

Figure 5 Modelled distribution of Wilderness Till Formation (pale blue) across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

Four boreholes drilled as part of the UK Geoenergy Observatory encountered clay, silt, sand and pebbles interpreted as the Wilderness Till Formation (GGC01, GGA01, GGA02, GGA05), with a fifth borehole (GGB05) tentatively interpreted (Barron et al. 2020a; Kearsey et al. 2019; Monaghan et al. 2020a,b; Walker-Verkuil et al. 2020b). Interestingly, two boreholes that reached rockhead did not return diamicton as had been expected (GGA04, GGA08) but up to 12 m of dominantly sand and gravel, interpreted as channelised deposits of the Broomhouse Sand and Gravel Formation (section 2.5 below; Barron et al. 2020b; Starcher et al. 2020a). The post-drill geological model updated in the Cuningar Loop area therefore contains small areas where the Wilderness Till Formation is absent (Figure 5). The remaining boreholes had poor returns of the superficial deposits or terminated in the shallower superficial deposits.

2.5 BROOMHOUSE SAND AND GRAVEL FORMATION (BHSE)

The Broomhouse Sand and Gravel is named after the Broomhouse area of eastern Glasgow where this unit generally overlies the Wilderness Till Formation. It comprises glaciofluvial ice-contact deposits, which produce features such as esker ridges, mounds, isolated flat-topped kames and kettleholes. Overall, the most abundant deposit is sand, except in esker ridges where gravel dominates. In some places this unit may also contain cobbles, clay and silt. The sands are planar and trough cross-bedded, ripple laminated and horizontally laminated; the gravels are typically massive or crudely bedded. Deposits are up to 25 m thick and flow directions were towards the east (Browne and MacMillan, 1989). The noted occurrences of Broomhouse Sand and Gravel Formation are coincident with areas of dense borehole data. This implies that there may be more extensive deposits in the area than have been modelled (Figure 6), but a lack of data means that further deposits remain undetected. Two components of the Broomhouse Sand and Gravel Formation have been modelled in this area: Broomhouse Sand and Gravel Member and the Ross Sand Member.

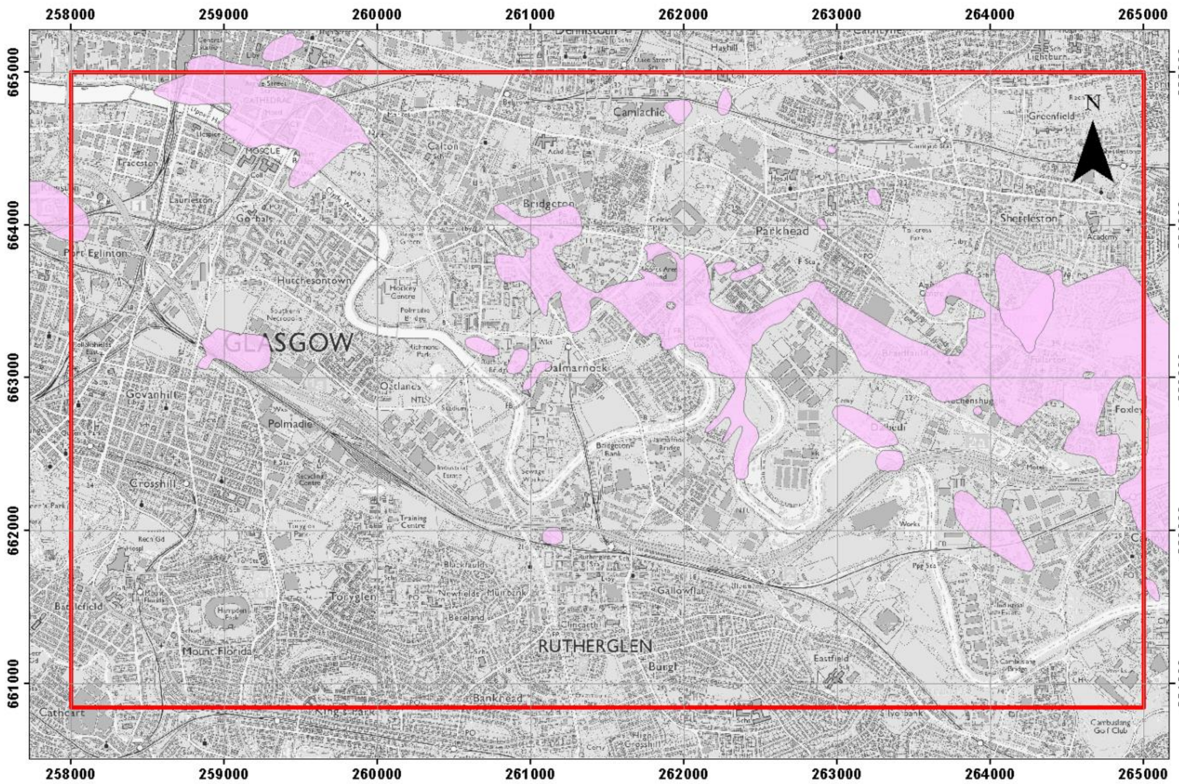

Figure 6 Modelled distribution of Broomhouse Sand and Gravel Formation (pink) across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

Seven boreholes drilled as part of the UK Geoenergy Observatory encountered sand and gravel interpreted as the Broomhouse Sand and Gravel Formation (GGC01, GGA01, GGA02, GGA04, GGA05, GGA08, GGB05; Barron et al. 2020a,b; Kearsey et al. 2019; Monaghan et al. 2020a,b; Starcher et al. 2020a, Walker Verkuil et al. 2020b). In the post-drill model, up to 12 m of dominantly sand and gravel has been interpreted as channelised deposits (Figure 6; Figure 21). The geometry is constrained by adjacent Observatory and legacy boreholes containing diamicton/glacial till deposits.

2.5.1 Ross Sand Member (RSSA)

The main lithologies of the Ross Sand Member, a member of the Broomhouse Sand and Gravel Formation, are sand or sand and silt, with clays at the base and thin local gravel layers. As noted above, the deposits are glacio-lacustrine in origin with deposits found in the south-east of Glasgow (Figure 7) interpreted to have formed in deltaic systems at the margins of glacial 'Lake Clydesdale' (Browne and MacMillan, 1989). For modelling purposes, the lithologies have been separated into two units, a main unit of sand with minor gravel (RSSA-XSV), and an underlying finer-grained sand with silt (RSSA-XSZ).

The Ross Sand Member is found draping the Wilderness Till Formation and is overlain by deposits of the Bridgeton Sand Member and Paisley Clay Member. Where it outcrops at the surface, the Ross Sand Member corresponds to glaciofluvial deltaic (and/or subaqueous fan) deposits (GFDD) on BGS Geology 10K.

The Ross Sand Member has been mainly recognised at the eastern end of the model area, where it reaches up to 18 m thick in places.

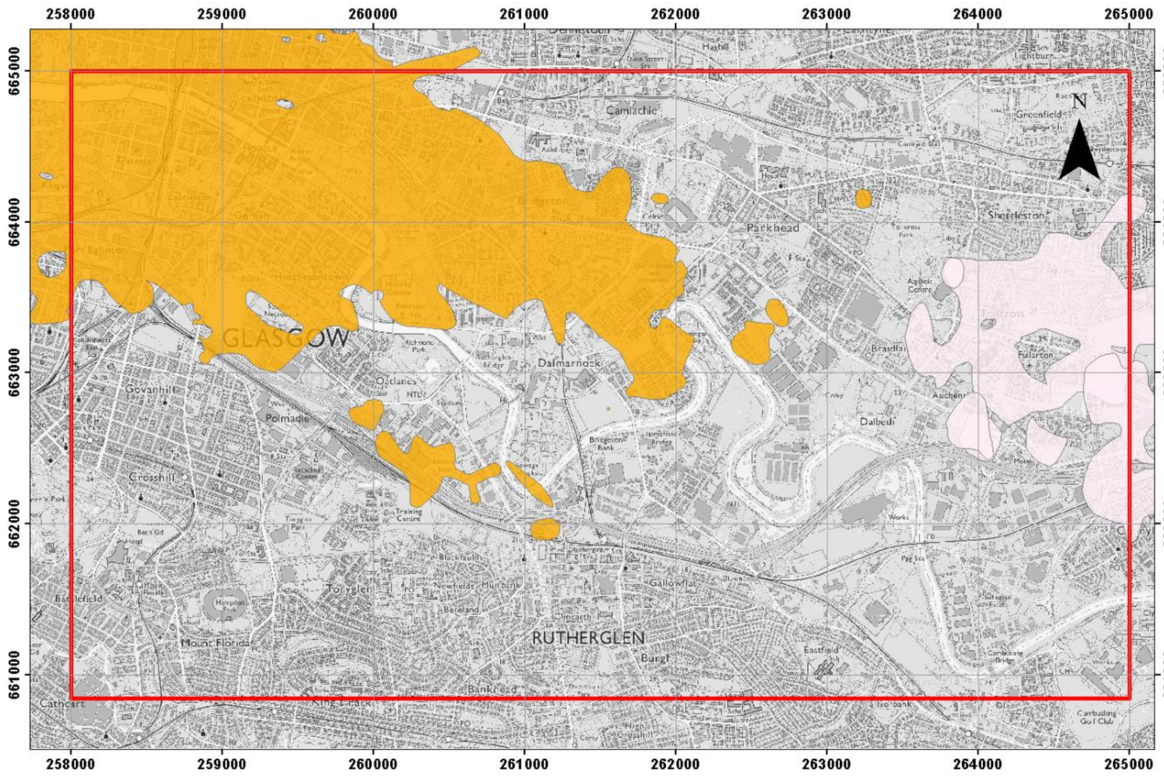

Figure 7: Modelled distribution of Bridgeton Sand Member (orange) and Ross Sand Member (pale pink), across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

2.6 CLYDE CLAY FORMATION

The Clyde Clay Formation is part of the British Coastal Deposits Group and includes mainly Late Devensian deposits from marine isotope stages 2, 2a-b $\delta^{18}O$. Within the UKGEOS Glasgow area, the formation is modelled as three component members: the Bridgeton Sand Member, the Paisley Clay Member and the Killearn Sand and Gravel Member.

2.6.1 Bridgeton Sand Member (BRON)

The Bridgeton Sand Member is characterised by fine to medium, massive dense sand or silty sand. Locally, fine to coarse gravel and boulders occur in a sandy matrix. There is some flat bedding but generally the deposits are massive. The unit is largely confined to the Clyde valley (Figure 7), where it overlies the Wilderness Till and Broomhouse Sand and Gravel formations. The Bridgeton Sand Member is thought to be up to 32 m thick in some north-western parts of the model area.

Browne and MacMillan (1989) suggested that the sands were deposited as submarine outwash fans formed during catastrophic draining of pro-glacial Lake Clydesdale to the north-west, along the line of the Clyde valley, following breaching of the glacier dam.

2.6.2 Paisley Clay Member (PAIS)

The Paisley Clay Member typically comprises finely layered clay and silt-clay deposited in a glaciomarine setting. In borehole records it is often described as a grey and grey-brown, occasionally laminated, clayey silt and silty clay, often with a mottled appearance. The retreating glaciers are believed to have been to the north-west, in the sea lochs of the Southern Highlands.

Relative sea level was high when deposition of the Paisley Clay Member commenced and some clays were deposited at elevations up to 40 m above OD (Browne and McMillan, 1989). The Paisley Clay Member drapes the underlying topography, and appears to thin out over the tops of drumlins (Wilderness Till Formation) and bedrock 'highs'. To the south-east of Glasgow, all clay units at the ground surface within lowland areas (max. 40 m to 45 m above OD) are assumed to be deposits of the Paisley Clay Member (Figure 8). All BGS Geology 10K polygons coded as raised marine deposits-Devensian (RMDV) have been interpreted as outcrops of the Paisley Clay Member. The Paisley Clay deposits within the model area are thought to exceed 35 m thick in places.

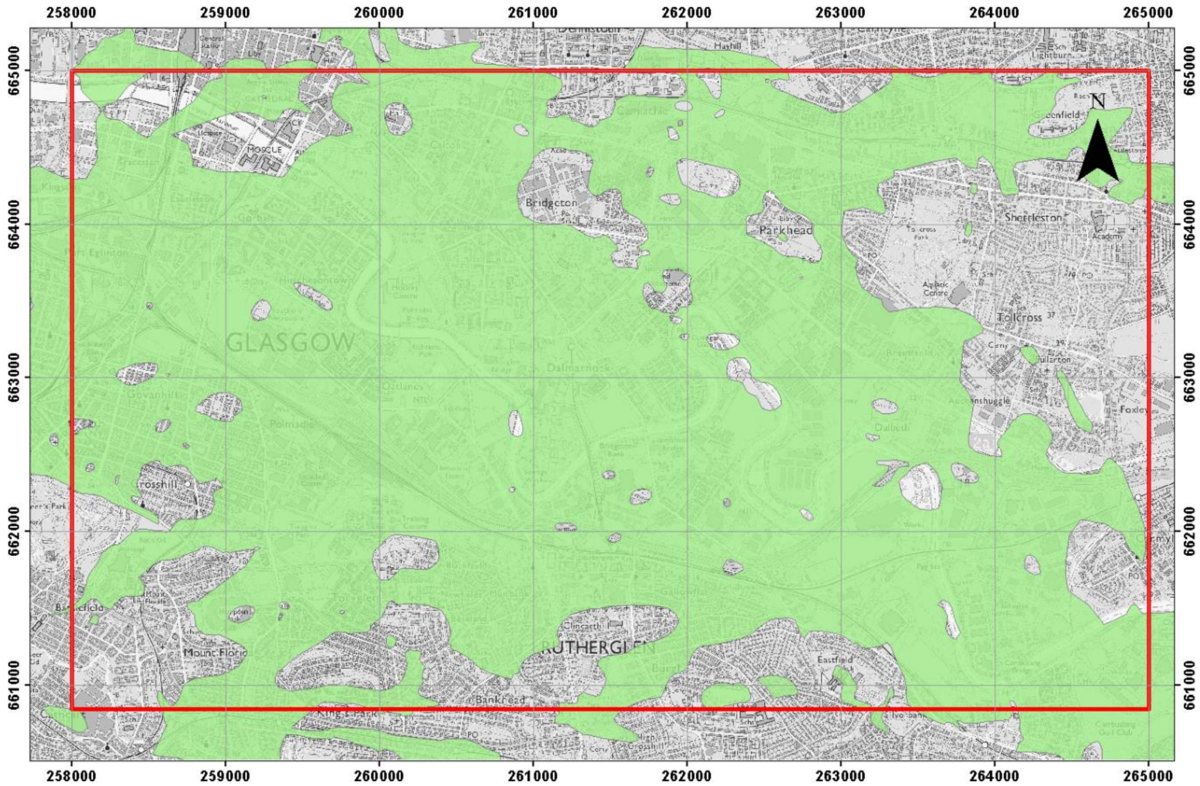

Figure 8: Modelled distribution of Paisley Clay Member (green) across the UKGEOS Glasgow superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

Seven boreholes drilled as part of the UK Geoenergy Observatory encountered clay, silt and minor gravel interpreted as the Paisley Clay Member (GGC01, GGA01, GGA02, GGA04, GGA05, GGA08, GGB05; Barron et al. 2020a,b; Kearsey et al. 2019; Monaghan et al. 2020 a,b; Starcher et al. 2020 a, Walker Verkuil et al. 2020 b), up to around 11 m thick. The returns were poor in two other boreholes that reached this depth and no interpretation has been made of those boreholes. The extent of the Paisley Clay Member has not changed from the pre-drill model.

2.6.3 Killearn Sand and Gravel Member (KARN)

The Killearn Sand and Gravel Member is a patchy deposit comprising of varying proportions of sand and some clay layers. The deposits are commonly found in inter-drumlin areas along the Clyde Valley (Figure 9), and the distribution suggests that it formed as a result of marginal marine processes associated with the Late Devensian marine incursion responsible for the deposition of the Paisley and Linwood clays. The maximum level of the marine incursion thought to be responsible for the Killearn Member is approximately 34–36 m above OD (Rose, 1975; Browne and McMillan, 1989; Hall et al., 1998). Deposits are thought to reach almost 15 m thick in some eastern parts of the model area.

The Killearn Sand and Gravel Member is thought to have been deposited in a range of environments, including beaches, and fluvial and deltaic systems. Rose (1975) describes temporary sections north of Erskine Bridge where Killearn Member sands and gravels overlie Broomhouse Sand and Gravel Formation. Here the Killearn Sand and Gravel Member is well bedded, with beds displaying shallow dip to the south-west. It is suggested that the sedimentary structures are consistent with shoreline processes, hence that the unit in this area is a beach gravel. Rose (1975) also describes ice wedge casts suggesting that a periglacial environment persisted in the period following the deposition of the Killearn Sand and Gravel Member. It is suggested that these features may have formed during the cold period associated with the cooling event of the Younger Dryas. During this time, there is evidence glaciers re-advanced in the Loch Lomond area, but the Clyde remained ice free.

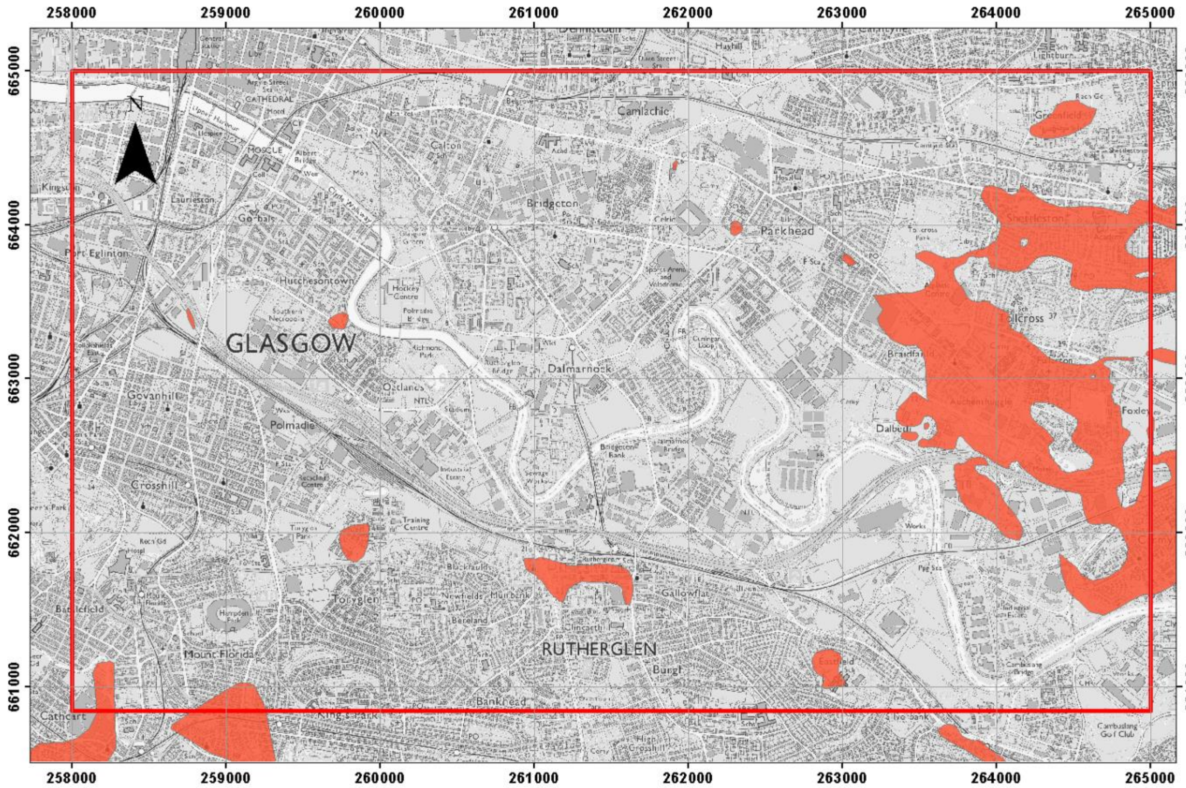

Figure 9: Modelled distribution of Killearn Sand and Gravel Member (red) across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

2.7 CLYDEBANK CLAY FORMATION

2.7.1 Gourock Sand Member (GOSA)

The Gourock Sand Member forms extensive deposits in the Clyde valley, extending across the low ground either side of the River Clyde (Figure 10). The unit typically consists of fine to coarse sand with some gravel, silt and clay and organic detritus. The deposits are likely to have formed in estuarine environments, with a fluvial dominance in the east, becoming progressively more marine westwards with shallow channels linked by tidal flats (Browne and McMillan, 1989). The deposits have been modelled to be over 15 m thick in some central and north-western areas.

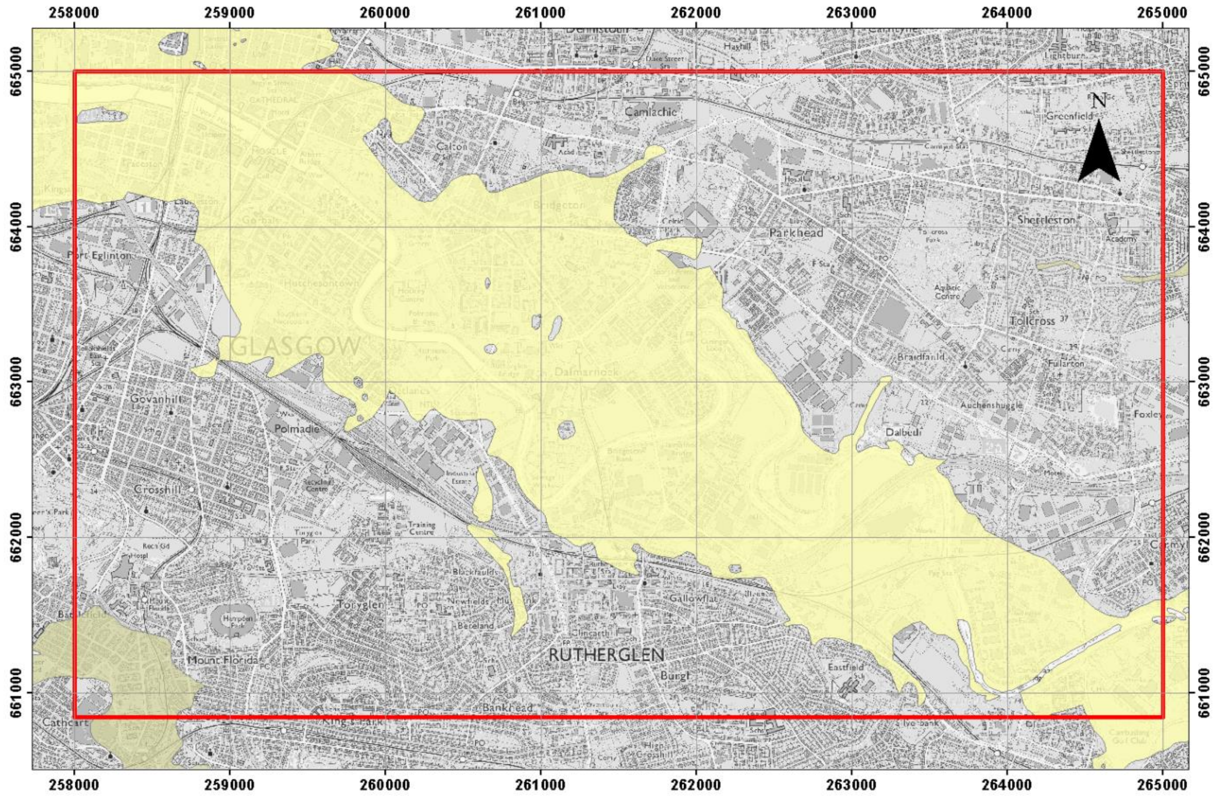

Figure 10: Modelled distribution of Gourock Sand Member (pale yellow), Law Sand and Gravel Member (greeny yellow) and peat (brown), across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

All twelve boreholes drilled as part of the UK Geoenergy Observatory encountered sand, sand and gravel and/or clay, sand and silt interpreted as the Gourock Sand Member beneath made ground. The extent of the Gourock Sand Member has not changed from the pre-drill model.

2.8 CLYDE VALLEY FORMATION

2.8.1 Law Sand and Gravel Member (LAWSG)

The Law Sand and Gravel Member comprises fine to coarse sand with some silt, fine gravel and organic matter deposited in river channels and associated floodplains. The Law Sand and Gravel Member includes recent (currently accumulating) river deposits; in the model area these deposits are mainly found associated with the White Cart Water in the south-western corner of the modelled area. Small alluvial fans and deposits associated with minor streams are also included in this unit.

2.9 PEAT

Small discrete deposits of peat, consisting of dark, organic rich, humic material formed by the accumulation of partially decomposed vegetation, are found in places in the model area. Peat accumulations are generally associated with lacustrine and alluvial sediments, where they may form surface deposits, or form bands or lenses within the strata (discussed below).

2.10 MADE GROUND (MGR)

Made ground in the 3D model represents a combination of made and worked ground including filled and partially back-filled pits and quarries - hence it comprises all anthropogenic deposits.

Glasgow has a long and varied industrial past and these deposits are what remains of the former land uses and developments in the area (Figure 11).

Areas of made and worked ground were primarily identified using BGS Geology 10K (1:10 000 scale) polygons. These were subsequently altered to encompass areas where boreholes reported additional areas of artificial ground (Figure 11). Alterations were made using the Ordnance Survey maps to identify the extent of industrial areas, housing developments and other information. It is likely that more extensive but thinner deposits of made ground occur within the model that are not currently represented. Artificial (made) ground has not been subdivided. Made ground is thought to be up to 27 m in places in the model area and have a variable composition. Its distribution in the model is patchy (Figure 11) and is likely to be much more extensive than modelled.

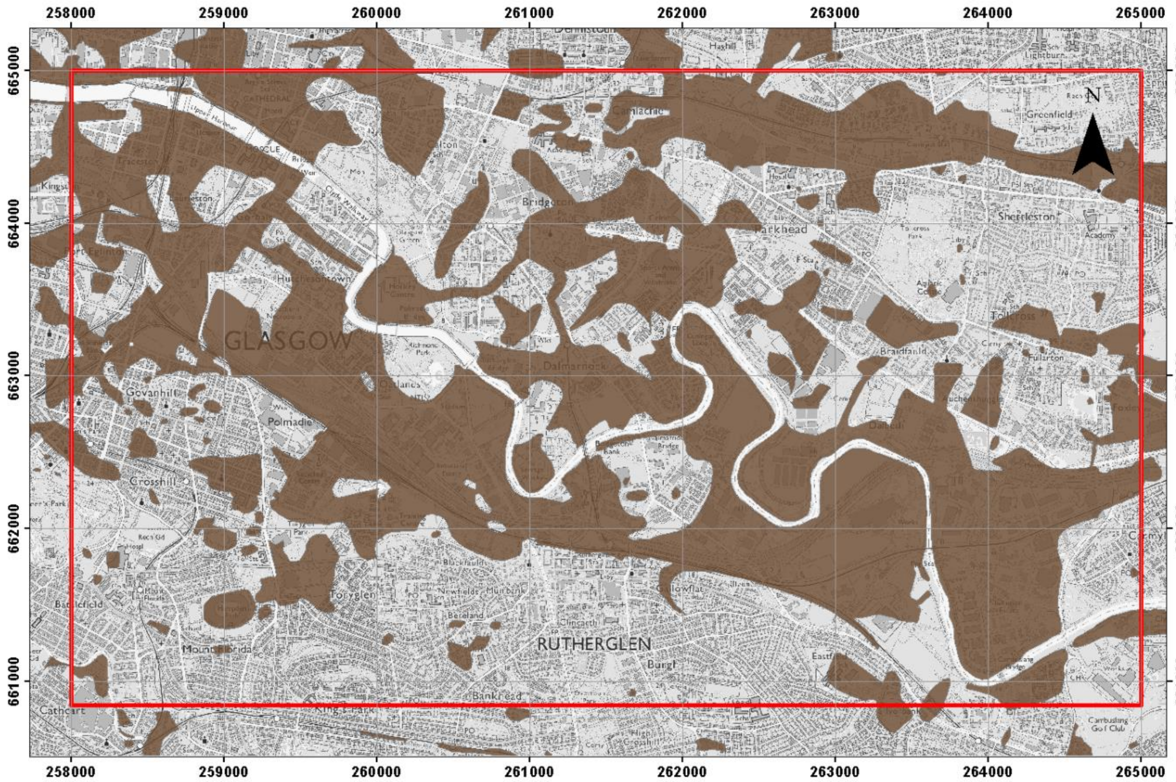

Figure 11: Modelled distribution of made ground (MGR), across the superficial geology model area (red outline). 1 km grid squares shown. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL).

All twelve boreholes drilled as part of the UK Geoenergy Observatory encountered made ground and the extent has not changed from the pre-drill model. The made ground was less than a metre thick in borehole GGC01 at Dalmarnock. It was between 7.5 - 9.5 m thick in 11 boreholes at Cuningar Loop including rubble, bricks, ashy sand, timber, clinker, glass etc. consistent with the building demolition rubble known to have been disposed at this site.

2.11 LENSES

Many of the units described above contain considerable variation in lithologies within their strata. Where thin deposits of a contrasting lithology to the main unit are recorded within borehole descriptions, these have been depicted by the modelling of a lens contained within the ‘parent’ unit. In general, only lithological sub-units with thicknesses greater than approximately 2 m have been identified as separate lenses.

The only lens modelled in the model area is a small, thin peat lense; located in the south-western corner of the model.

3 Model Workflow

The superficial deposits model was constructed using GSI3D© software and the standard modelling workflow was followed (Kessler et al. 2009). The software utilises a range of data such as boreholes, digital terrain models (DTM) and geological linework to enable the geologist to construct a 3D model.

The workflow initially involves correlating the various geological units through strings of borehole logs in 2D cross-sections, the cross-sections intersect to form an interlocking network across the model area (Figures 12-17). Construction of the cross-sections is intuitive and flexible; combining borehole and outcrop data with the geologist's experience to refine the interpretation. The correlated sections and geological map data provide information on the lateral extent of each geological unit which is saved as an 'envelope' for of the geological units.

Using both the information from the cross-sections and the geographical extent of each unit (envelope) a calculation algorithm creates the triangulated surfaces for the top and base of each unit. In order to control the relative vertical ordering of the calculation, a generalised vertical section file (.gvs) is established. A proprietary legend file (.gleg) is created to control symbolisation of the cross-section and model. The modeller can view all the units in 3D and iteratively return to the cross-section to make amendments or add further cross-sections to refine the model. This process is a standard methodology for modelling Quaternary and simple bedrock horizons and is fully documented in Kessler et al. (2009).

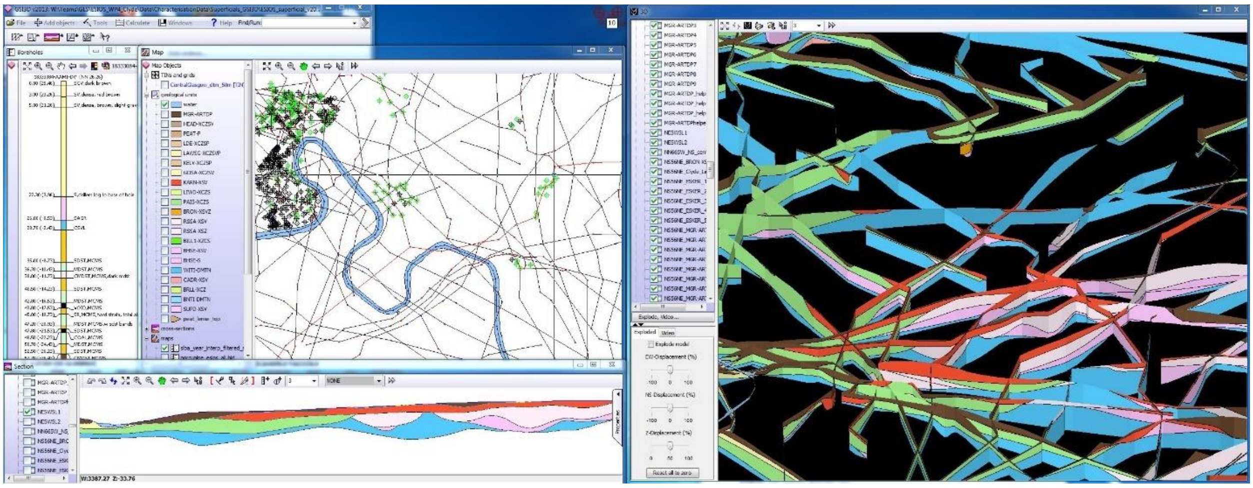

Figure 12 Screengrab of the GSI3D software showing the borehole, map and section window on the left-hand side and a view of the interlocking sections in the 3D window on the right-hand side.

3.1 PRE-DRILL MODEL WORKFLOW

The pre-drill superficial deposits model was updated in two parts:

Part 1: Incorporated boreholes drilled between 2005 - 2018 into the superficial model, in areas where it was felt the new data would significantly improve the resolution and accuracy to the model to better fit with available geological data (Figure 13).

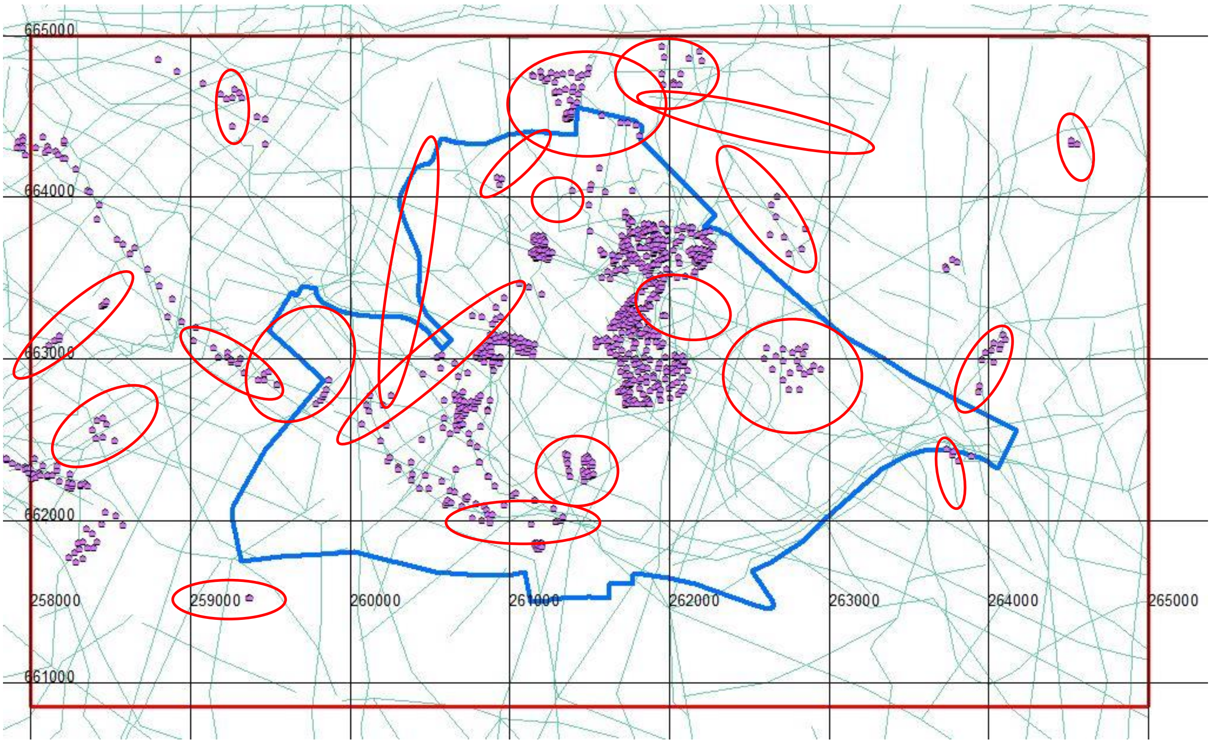

Figure 13 Areas circled in red show where the pre-drill model was updated/improved during, green lines indicate existing GSI3D section lines from the published Central Glasgow model, purple dots represent the location of boreholes entered into the BGS borehole database post-2005. The blue line is the 2018 extent of the Clyde Gateway urban regeneration area.

In detail, in pre-drill model updating part 1:

The approach taken was to focus on updating existing section line interpretations and adding new section lines in the areas with new borehole data (Figure 13). This improved the detail and certainty in parts of the model.

The post-2005 boreholes were used to update the model in the following ways:

- **Added into existing sections –** existing sections were re-routed to include additional boreholes where possible, this was the neatest approach if a section was already present nearby (Figures 14, 15).
- **Used to create a new section** – new sections were created or existing sections extended if there wasn't an existing section close to the additional boreholes. New sections were always extended to cross existing sections so the geological units could be tied-in with the existing network of sections.
- **Projected into existing sections** – where an existing section passed through a large number of additional boreholes spread along its length, the most appropriate approach was to project close boreholes into the existing section and adjust the geological linework as necessary. This approach quickly improved existing sections without the need to re-draw the section.
- **Informed the presence or absence of a unit across the model** – away from the lines of section the additional boreholes provide a constraint when drawing the geological unit 'envelopes' which show the lateral extent of a unit

Changes were also made to any crossing sections where necessary and edits were made to the associated geological envelopes, where required.

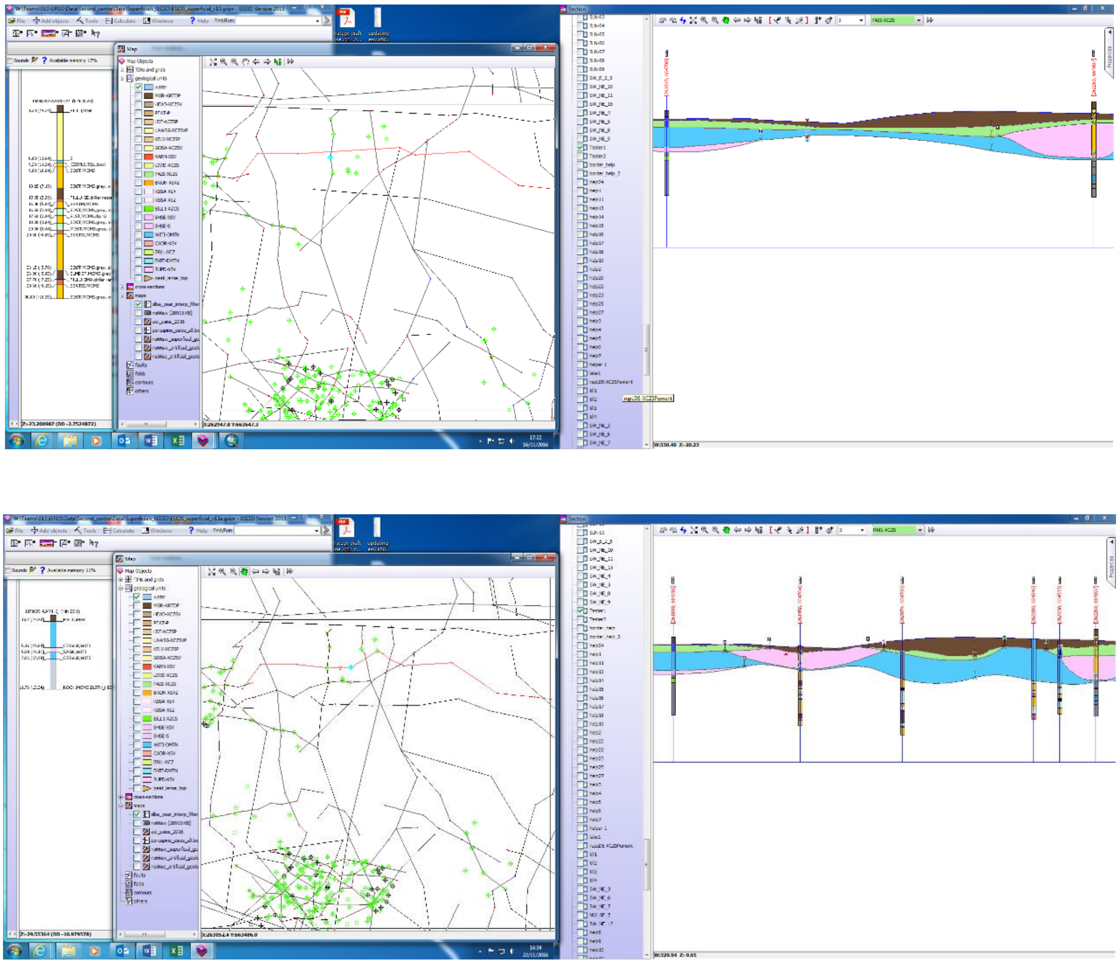

Figure 14 Example of a GSI3D section (Tester 1) which was significantly altered by including an additional 4 boreholes drilled since 2005. The upper image (original section) contained little borehole information to constrain the geology in this part of the section which has resulted in the construction of fairly simple geology. The lower image (updated section) indicates how additional borehole data suggests the presence of a further sand-body (pink), confirms the presence of till (blue) above rockhead across this part of the section, indicates that the Paisley Clay (green) has a patchy extent and provides improved constraint on the thickness and lateral extent of all the superficial deposits.

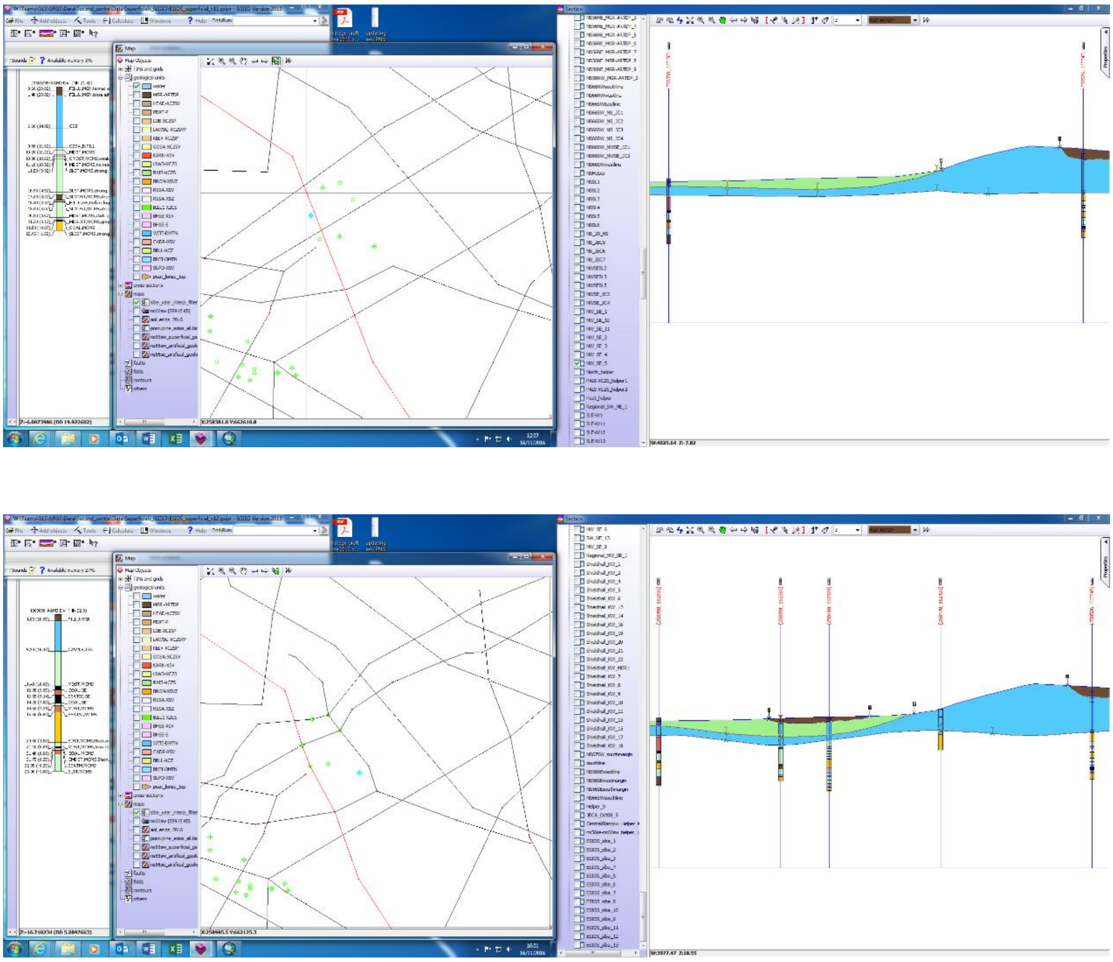

Figure 15 Example of a GSI3D section (NW_SE_5) which required little alteration when an additional 3 boreholes, drilled since 2005, were added: Upper image (original section) - little constraint in this part of the section – geology extrapolated from nearest borehole data and geological map at the surface. Lower image (updated section) – three additional boreholes confirm the superficial deposits present as predicted and provide improved constraint on the thickness of the deposits.

Part 2 pre-drill model updating:

Once provisional borehole sites for the UKGEOS Glasgow boreholes had been chosen (Sites 1, 2, 3, 5 and 10), an additional 16 sections were completed passing through these points (Fig. 16) to illustrate what sequence of superficial deposits were expected at the sites.

Section lines were chosen to include as many additional boreholes in the vicinity of the proposed borehole sites to provide the highest resolution as possible in the site area. Sections were also placed to cross existing lines of section so the geology could be tied in with the existing network of sections.

The sections were created and geological linework drawn to increase the resolution of the model in the vicinity of the proposed sites to give our best indication of what lies beneath the site for boreholes prognoses.

Following the editing of sections and envelopes across the model area, the model was calculated, grids for each geological unit were exported (25m cell size) into an ArcGIS project along with information such as boreholes used, and lines of section (Arkley, 2019). A rockhead grid was also calculated and exported for use in the bedrock model.

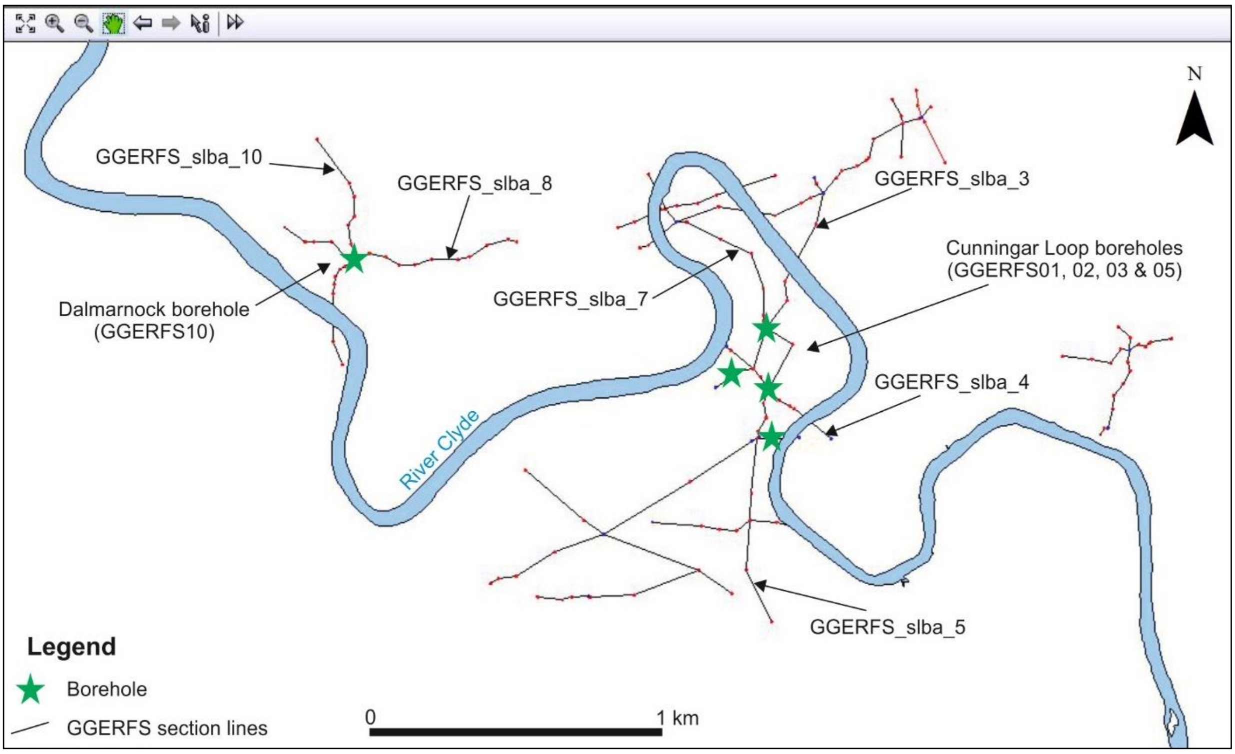

Figure 16 Summary map of Glasgow Observatory borehole locations and new sections constructed in GSI3D through the sites in the pre-drill model (Arkley, 2019).

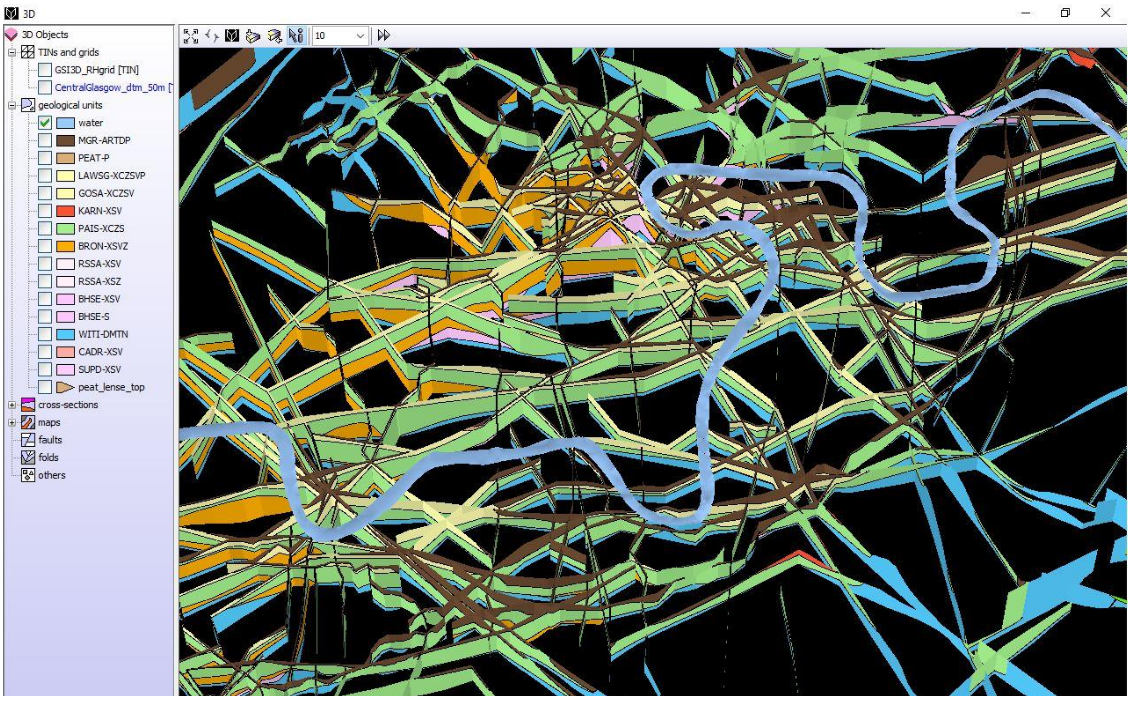

Figure 17 Network of sections constructed in the model area viewed in 3D, in the pre-drill model.

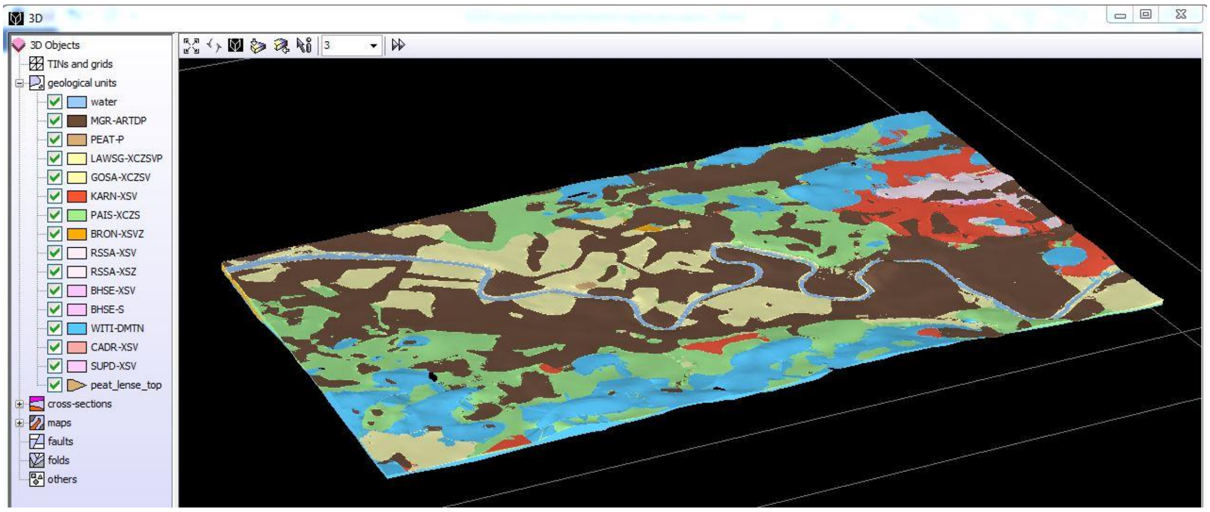

Figure 18 Overview of the calculated superficial deposits model across the model area, looking north-east, 3x vertical exaggeration. NEXTMap Britain elevation data from Intermap Technologies.

3.2 POST-DRILL MODEL UPDATES

The post-drill model incorporates the lithology and stratigraphical interpretations of the 12 UKGEOS boreholes. The depths and stratigraphical units were exported from the BGS *Borehole Geology* database and new .bid and .blg file were created. For this model, the bedrock was combined into a single unit and labelled it SR-CARB (Sedimentary Rock-Carboniferous Undifferentiated).The start height used was the drilling platform height.

Four key sections within the Cuningar Loop were redrawn through the new boreholes

- *GGERFS_slba_3* (Figure 20)
- *GGERFS_slba_4* (Figure 21)
- *GGERFS_slba_5* (Figure 22)
- *GGERFS_slba_7* (Figure 23)

Two sections were redrawn through borehole GGC01 at Dalmarnock

- *GGERFS_slba_8* (Figure 24)
- *GGERFS_slba_10* (Figure 25)

In addition, two new sections were created GGERFS_slba_15 and GGERFS_slba_16. GGERFS_slba_7 was extended southwards to cross other sections. Small parts of 4 other sections were deleted.

3.3 OUTPUTS

The 3D superficial deposits model contains 15 superficial units (Figure 18) and is of use in borehole prognosis, site planning and can be used in hydrogeological conceptual models. The calculated rockhead surface has also been exported and shows significant variability across the area from -40 m to +36 m relative to OD (Figure 19).

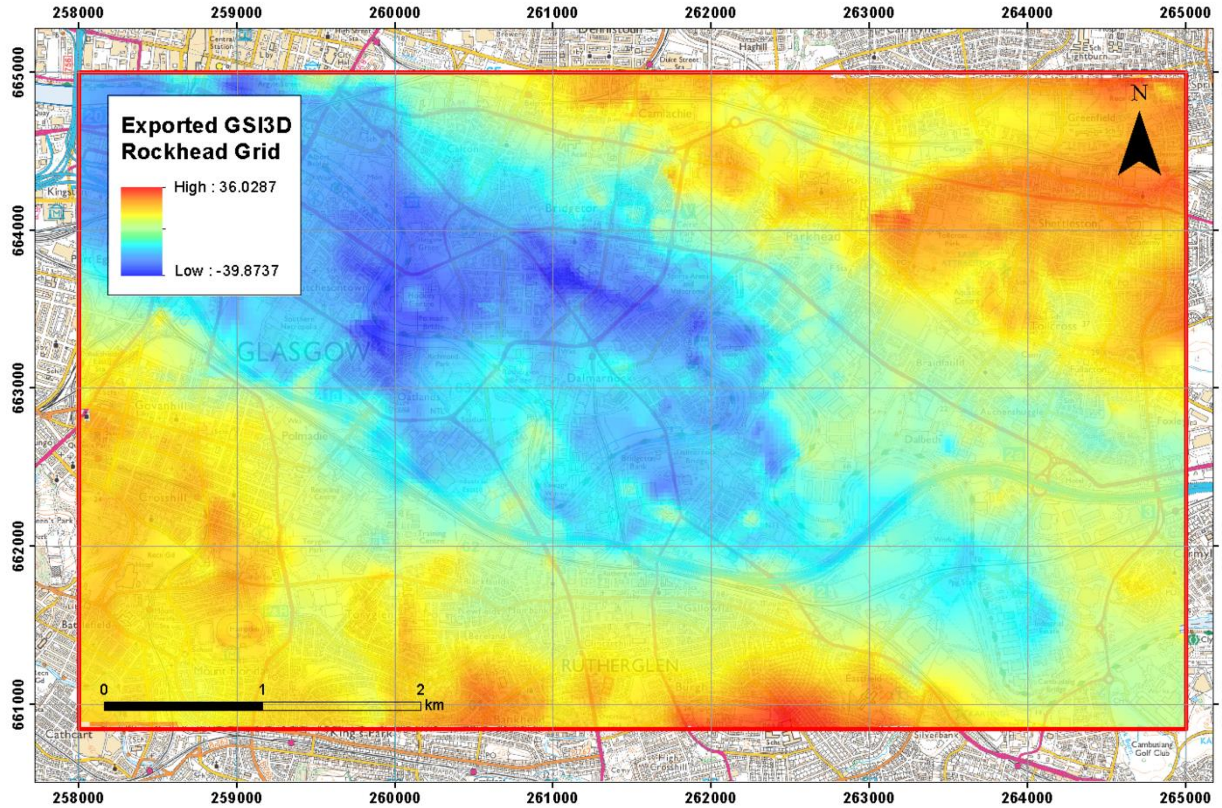

Figure 19 Rockhead surface for the model area, generated in GSI3D by combining the bases of all the modelled superficial units. Low values are in blue and high values are in red. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

4 Model Datasets

The model was constructed using a variety of datasets including NEXTMap® Digital Elevation Model ©Intermap Technologies, the BGS digital borehole database, BGS 1:10 000 scale digital maps (BGS Geology 10K, 2009), BGS 1:50 000 maps (BGS Geology 50K, 2008), field slip scans, historic maps and scanned geological cross-sections. Other literature such as BGS regional geological guides and scientific papers influenced the correlation of geological units.

Published BGS superficial model of Glasgow (2013) and pre-drill UKGEOS Glasgow model	CentralGlasgow_v3_7.gsipr and UKGEOS_Glasgow_superficial_checked.gsipr
GVS	Glasgow_master_LEX_RCS_GVS_Jan2013v3.gvs
Legend	Glasgow_master_LEX_RCS_GLEG_Jan2013v3.gleg
BOREHOLE_INDEX	Porcupine_ESIOS_all.bid and GGERFS_Boreholes.bid
BOREHOLE_LOGS	Porcupine_ESIOS_all.blg and GGERFS_Boreholes.blg
DEM, NextMap	CentralGlasgow_dtm_50m
1:10 000 scale map sheets	NS56SE and NS66SW

Table 3 Summary of the key datasets and associated files used in the construction of the superficial deposits model.

4.1 MAP DATA

BGS published maps of the superficial deposits over the model area includes map sheets NS66SW (2007) and NS56SE (2007) at 1:10 000 scale, and map sheets 30E Glasgow (1994) and 31W Airdrie (1992) at 1:50 000 scale (Figure 20). The associated BGS Memoirs form a definitive reference source for the geology of this area (Hall et al., 1998, Forsyth et al., 1996). Map data is available as GIS shapefiles (BGS Geology 10K) or as scans (Mapviewer).

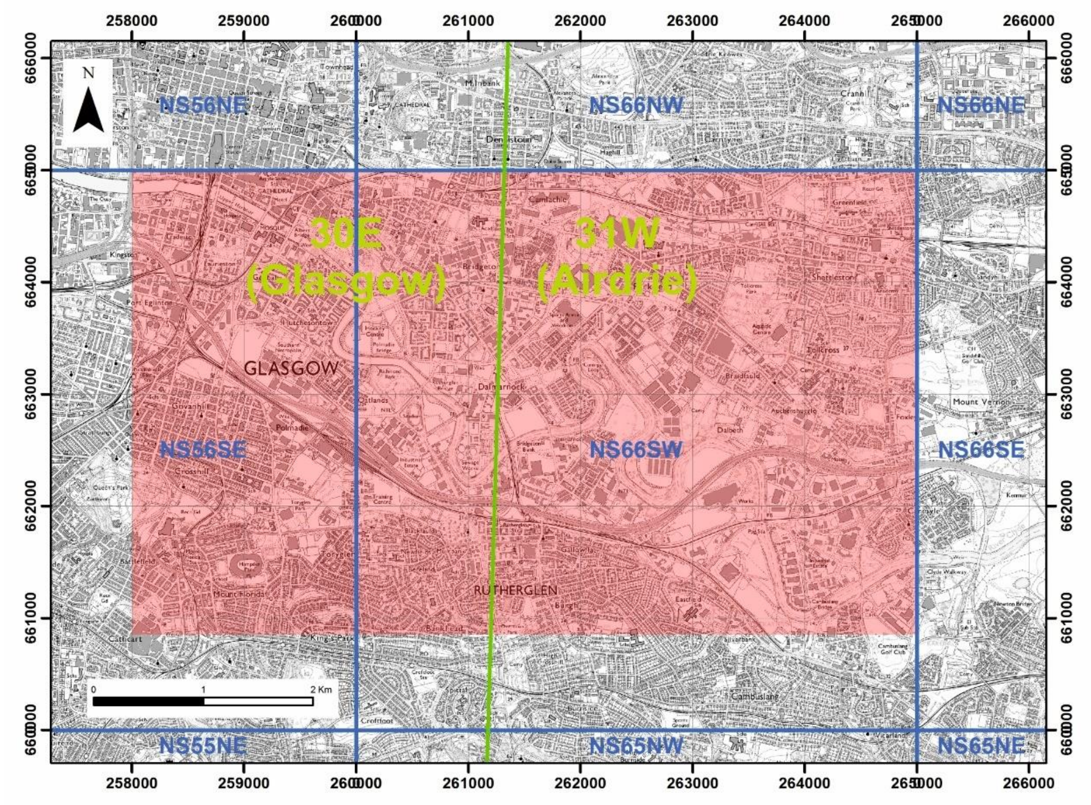

Figure 20 1:50 000 scale (green) and 1:10 000 scale (blue) geological map sheets covering the UKGEOS Glasgow model area (pink). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

The model broadly matches the corresponding 1:10 000 scale digital geological map data of the area (Figure 21), some differences are present as a result of incorporating new (post-2005) borehole data which post-date the map construction. The map shows an extensive area of alluvium (river deposits) through the centre, representing the floodplain of the River Clyde. A variety of raised marine, lacustrine and glaciofluvial deposits have been mapped between areas of alluvium and the glacial till that is only seen at the surface over higher ground. Bedrock is mapped 'at or close' to the surface in a few areas where superficial deposits are absent. Bedrock units and faults are represented in separate maps and models (see Kearsey and Burkin, 2021).

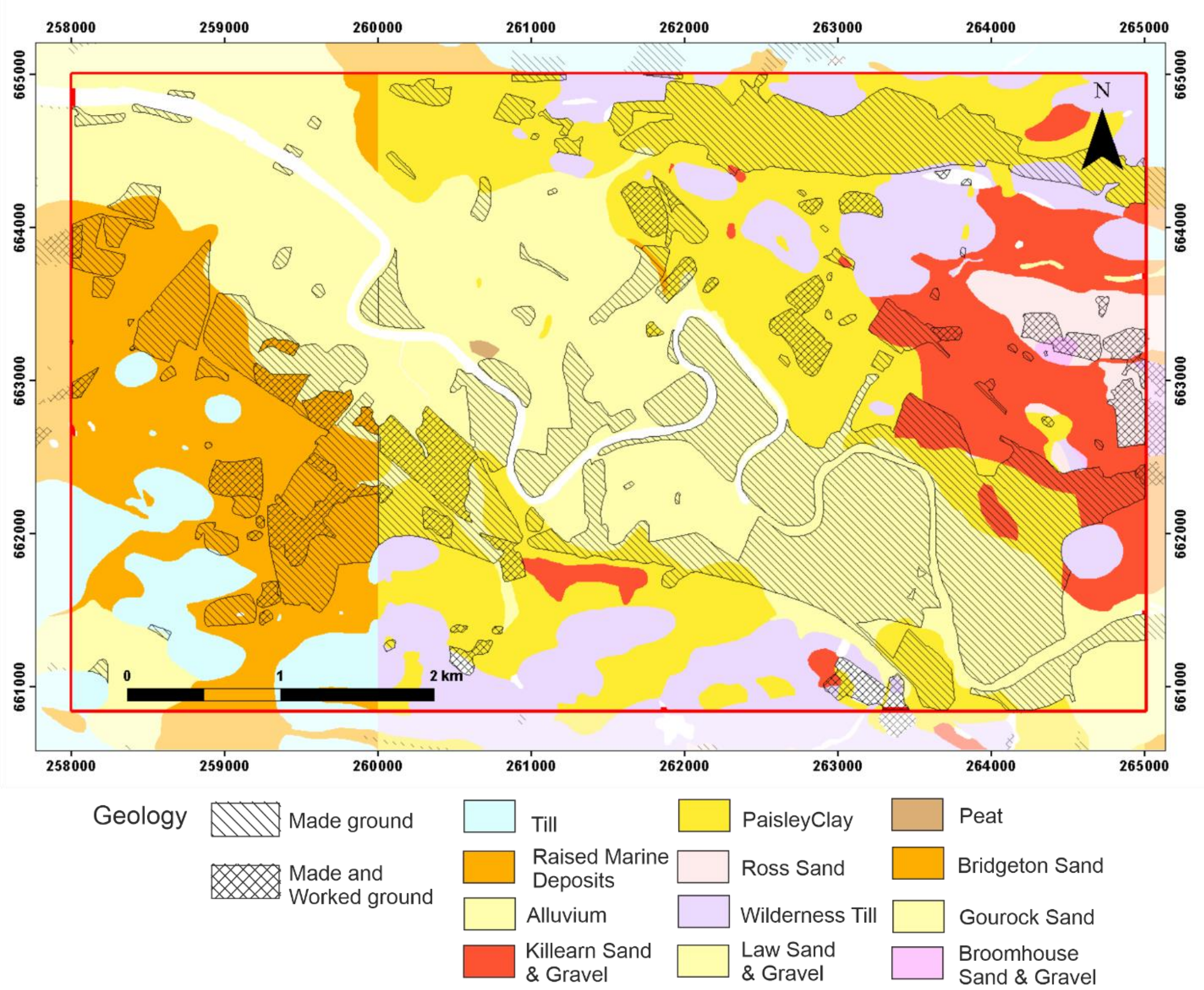

Figure 21 Summary of superficial geology from BGS©UKRI 2016 BGS Geology 10K data.

4.2 GVS AND GLEG FILES

The GSI3D geological vertical sequence (.gvs) file contains all the geological units in their correct and unique super-positional (stratigraphical) order. The geological legend (.gleg) file assigns colours and textures to the different geological units. The files were assembled in a combination of Notepad, Wordpad and Excel and iterated as the model expanded and new units were encountered. The GVS was created using BGS Geology 50K data. The .gleg file was created by using data from the BGS 1:10 000 and 1:50 000 BGS Geology datasets.

4.3 DIGITAL ELEVATION MODEL

The superficial deposits model is capped by an extract of the NEXTMap® Digital Elevation Model from ©Intermap Technologies. The maximum horizontal NEXTMap® resolution of 5 m was subsampled to 50 m for the previous 'Central Glasgow' model to reduce the file size and allow model calculation. The same extract was used for the Glasgow Observatory pre- and post-drill models to avoid any 're-snapping' of the existing geological linework to a new surface in the cross-sections. The elevation range of the ground surface in the model area is +2 m to +59 m above Ordnance Datum (OD). Figure 22 clearly shows the sinuous course of the River Clyde along the low ground of the Clyde valley (blue colours) with higher ground (yellow-red colours) to the northeast and southwest.

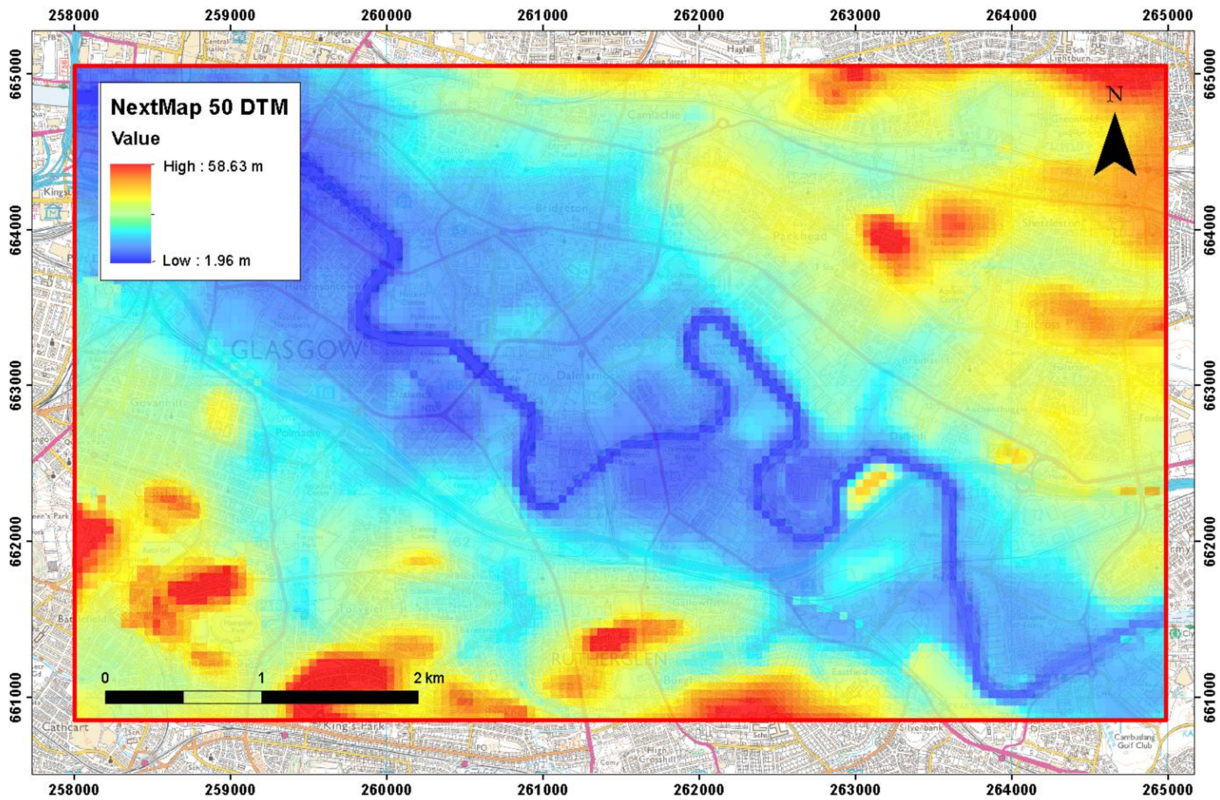

Figure 22 Digital Terrain Model (50 m cell size) across the superficial deposits model area (red outline), as used in the model. NEXTMap Britain elevation data from Intermap Technologies. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

4.4 BOREHOLE DATA

Boreholes, along with geological map data were the primary data sources for the construction of cross-sections across the model area. BGS holds approximately 10 000 borehole records (including site investigations and trial pits) across the area (Figure 23). Although the majority of these (approximately three-quarters) penetrate to depths of less than 30 metres, they define the complex artificial and superficial deposits succession.

Borehole records are held in the BGS *Single Onshore Borehole Index* (SOBI) database and downhole geological information is held in the BGS *Borehole Geology* (BoGe) database. All borehole records are entered into the SOBI database at acquisition, however geological information is entered into BoGe as required. The bulk of geological information was entered for the construction of the Central Glasgow and earlier models, however additional geological information for new borehole data received post-2005 was entered for the UKGEOS Glasgow work. Boreholes were coded with bedrock units from the BGS Lexicon http://www.bgs.ac.uk/lexicon/ and the Rock Classification Scheme (RCS) http://www.bgs.ac.uk/bgsrcs/ as appropriate to log lithology

For the model updates described as 'part 1' in section 3 (above), all borehole data was recalled from the database for the model area, this was then filtered to only include boreholes entered/drilled in 2005 or later. Where multiple interpretations existed for a single borehole, priority was given to interpreter codes AAMI, then ECAL, then SJSE.

Generally, the boreholes selected for use in the GSI3D cross-sections were those which intersected geological rockhead and therefore recorded the full sequence of superficial deposits and/or those which gave detailed descriptions of the geological units. The spread of borehole data was variable (Figure 23) from extremely closely-spaced at site investigation locations to more widely spaced and isolated boreholes. Therefore, the borehole location was also of consideration during selection for inclusion in cross-sections, to ensure an even spatial distribution of borehole data as far as possible. As the model is based on the earlier Central Glasgow model which covers a much larger area, cross-sections extend beyond the boundaries of the model area. This reduces any edge effects.

Recorded borehole start heights are often different to the ground level shown by the digital elevation model (DEM). As the boreholes range in age to over 100 years old, it was generally assumed that the differences were either due to ground level changes as a result of landscaping and development, or due to the relatively coarse 50 m resolution of the DEM. Recorded borehole start heights were used in preference, as opposed to 'hanging' the boreholes on the DEM.

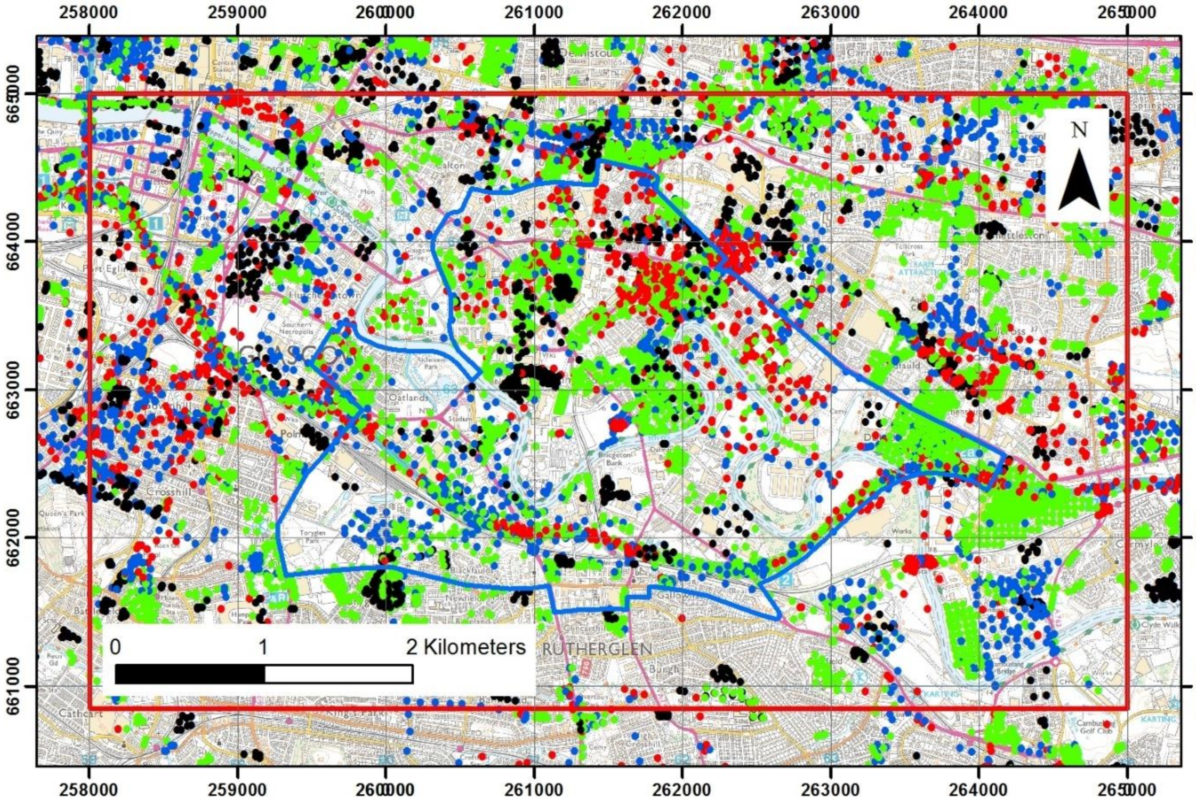

Figure 23 Location of borehole records held in the BGS Single Onshore Borehole Index database as used in the model. Red dots (more than 30 m deep), blue dots (between 10 m and 30 m), green dots (less than 10 m) and black dots (depth unknown/confidential). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL. The blue line is the 2018 extent of the Clyde Gateway urban regeneration area.

As described in section 3.2, the lithology and interpreted stratigraphy of the twelve UK Geoenergy Observatory boreholes drilled in 2018 and 2019 has been incorporated into the post-drill model. Further detail on the boreholes can be found in Barron et al. (2020a, b), Elsome et al. (2020), Kearsey et al., 2019, Monaghan et al. (2020a, b), Monaghan et al. (2021), Shorter et al. (2020a, b), Starcher et al. (2020a, b) and Walker-Verkuil et al. (2020a, b). Borehole information packs are available at https://ukgeos.ac.uk/data-downloads.

5 Model Assumptions and Limitations

Some key assumptions and rules used in the modelling process include:

- Where no boreholes were present, basal units were modelled to the BGS rockhead model (see http://www.bgs.ac.uk/products/onshore/superficialThickness.html). Where the depth of rockhead in boreholes differed from the rockhead model, the borehole depth was taken in preference.
- The depth of water within the tidal limit of the River Clyde was based approximately on a UK Hydrographic Office Admiralty Chart (International Chart Series c.2000). Where no information is available a sub-rectangular river channel cross-section has been assumed.
- Water body extents were extracted from the OS 1:10 000 scale Open data digital map. The River Clyde and lakes/reservoirs exceeding approximately 150 m in width/length are included in the 3D model. During modelling, the water bodies were generally fitted to the mapped water extent and not to the simplified DEM. In places this leads to artefacts where the water surface does not appear to be horizontal.

5.1 GENERAL MODELLING LIMITATIONS

- 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. The 3D geological model represents an individual interpretation of the data available; other interpretations may be valid.
- This model builds upon the earlier models described in Merritt et al. (2009), Monaghan et al. (2012, 2014), Arkley et al. (2013) and Arkley (2019). Over this period of time, a number of different geologists have constructed and updated models. Although efforts have been made to retain consistency of methodologies, some geologists may have interpreted the borehole data in different ways.
- 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.
- The model does not reflect the full complexity of the superficial deposits geology. In reality, surfaces have been subjected to more glacitectonic deformation than is represented in the model. It is also known that made, worked and artificial ground is more widespread than is shown by the model, and could be subdivided into more detail than the ‘made ground’ currently used.
- Smaller rivers, streams and water bodies have not been included in the model.
- The cross-section density and therefore model certainty is variable across the model, and is based on complexity and type of geology, borehole density etc.

5.2 DEM

- The Digital Elevation Model (DEM) was subsampled from a 5 m resolution to 50 m resolution which means the surface distribution and geometry of a geological unit does not reflect the highest resolution possible. This resolution was chosen based on the size of the area, the resolution of the original modelling and the software capability. Some minor mismatches between geomorphological features and modelled units (including water) and the DEM occur due to the coarse resolution of the DEM.

- The DEM may contain artefacts such as trees or artificial structures such as pylons. The majority of these have been stripped out before modelling. If any of these artefacts were found during the modelling then the effects of these were minimised in the model as much as possible.

5.3 BOREHOLE DATA

- The spatial distribution of available borehole data is highly variable with concentrations and gaps. For example, there are concentrations along infrastructure routes such as the M74 and the site of the Commonwealth Games, and scattered areas of very sparse data, particularly in the southern part of the model around Rutherglen.
- The precise relationships between the Quaternary deposits are complex, varying laterally and vertically across short distances, and in areas where borehole data are sparse or absent extrapolation is difficult.
- A subset of the most reliable borehole data has been included to constrain the cross-sections within the model. However, there is also a large subset of borehole data that has not been included within the model. Some of the boreholes are more than 100 years old and although often deep, rockhead and location details are often vague, start heights are not recorded and descriptions of the superficial deposits are brief.
  Factors affecting the usefulness of the borehole include drill depth, the amount of detail described in the log and whether they have been logged to industry standards. The drilled depth is a limitation because not all of the boreholes used in the model reach rockhead. Where clusters of boreholes occur only the deepest boreholes with the most geological information were selected for use in the model. Out of the 10,000 boreholes in the study area, approximately 4500 boreholes have been included in the network of sections with additional boreholes being projected into the sections to inform the geological linework.
- 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.

5.4 MAP DATA

- The geological map linework in the model has been modified during the modelling process to modify the interpretation where new data is available. The most common mapped areas requiring revision relate to worked/made ground activity post-mapping. This model supersedes the published BGS 1: 10 000 scale maps of the Glasgow area (BGS 2007). Updates in line with advances made in geological understanding of the area during 3D modelling are yet to be made to the maps.

5.5 MODELLED SURFACES AND VOLUMES

- The thin nature of made ground, and the thin draped form of some areas e.g. deposits of the Killearn Sand and Gravel Member, means that these units are poorly shown in visualisations of the 3D model.
- A known limitation is that for some thin units close to DEM surface and over topographically variable ground the superficial deposits output grids contain small patches of no modelled surface within the unit extent.
- The modelled volumes representing some elongate units such as water, made ground along road or rail embankments and alluvium are in places spiky/angular due to a combination of steep edges, DEM resolution and limited constraining cross-sections. The size of the angularity is in proportion to the unit and is accepted as a known limitation.

6 Model Quality Assurance

In order for a geological model to be approved for publication or delivery to a client a series of quality assurance checks is 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.

7 Model Uncertainty

Quantitative model uncertainty studies have not been undertaken. However, the cross-sections and borehole data points constraining the superficial deposits model shown in Figures 24 and 25 give an indication of the most certain areas of the model, those with the most cross-sections and data points (e.g. around Cuningar Loop), and the least certain areas (e.g. around Rutherglen). These maps do not qualify increasing uncertainty with depth below the surface, noting that more than half of the boreholes in the model area reached less than 10 m below the surface.

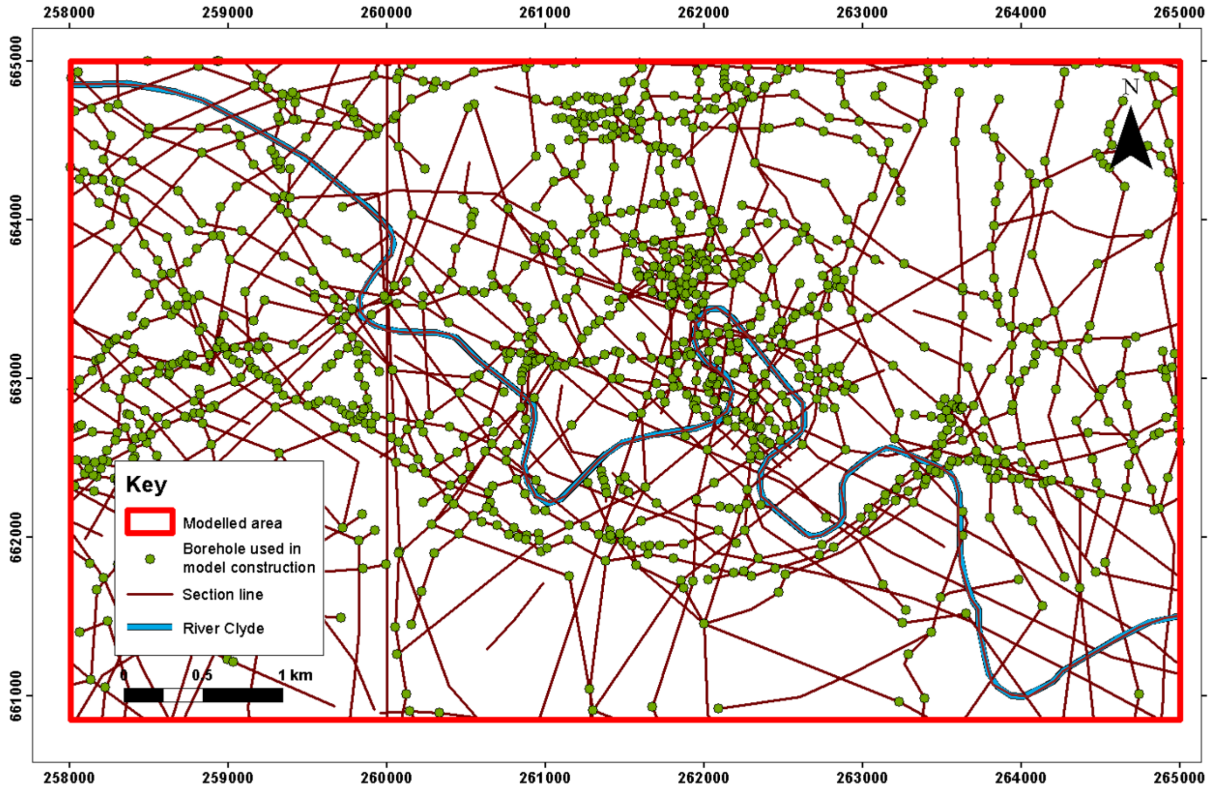

Figure 24 Distribution of boreholes used to construct the correlated cross-sections which constrain the superficial deposits model.

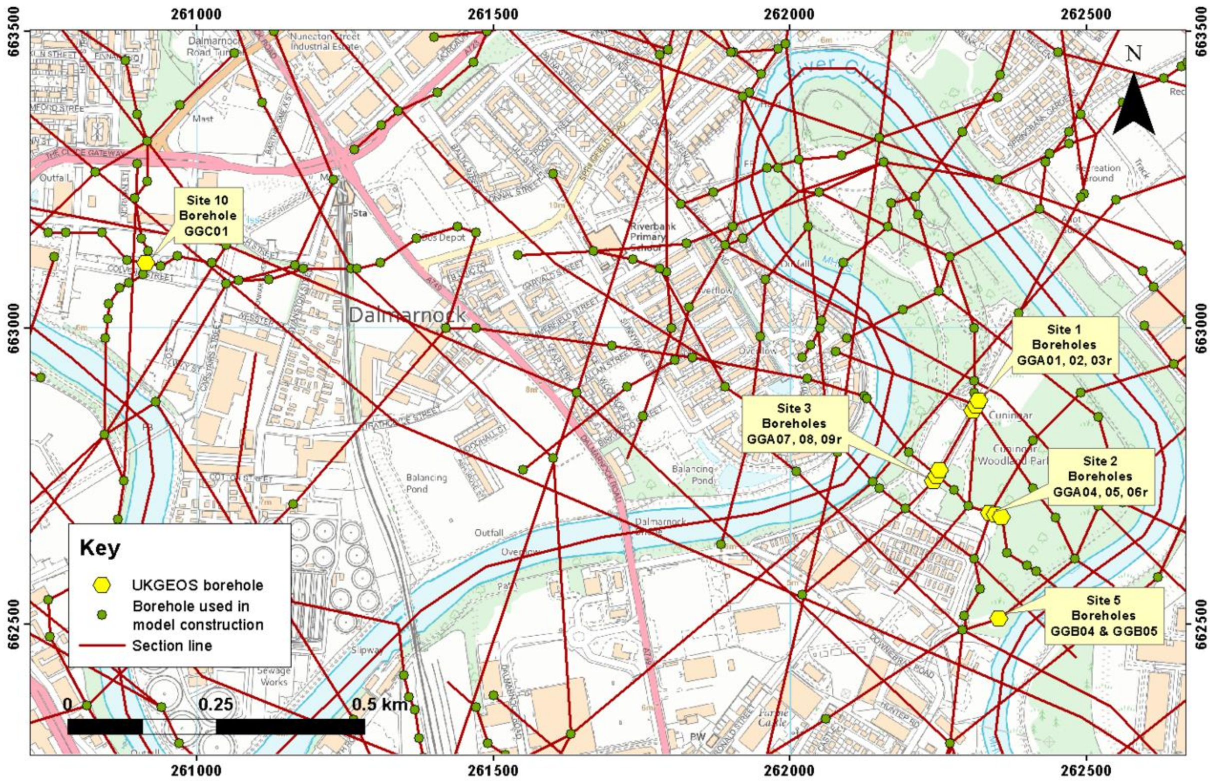

Figure 25 Distribution of boreholes used to construct the correlated cross-sections which constrain the superficial deposits model around the Glasgow Observatory borehole sites. Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

8 Model Exports

Modelled tops, bases, thicknesses and extents have been exported and included in the data release (Table 4). Files are named with the Lexicon and lithological description from the GVS file (e.g. WITI_DMTN_BASE). Z values are in metres relative to Ordnance Datum (positive upwards).

Folder name in data release	File format	Description
Geological_Unit_Grids_checked_clipped/ GeolUnits_AsciiGrids_checked_clipped	ASCII grids .asc	Top, base and thickness (shell) of each modelled unit
Geological_Unit_Grids_checked_clipped/ GeolUnits_EsriGrids_checked_clipped	ESRI grids	Top, base and thickness (shell) of each modelled unit
Rockhead_Grid_checked_clip	ASCII.asc and ERSI grid format	Rockhead grid calculated in GSI3D
Shapefiles_of_geological_units_sections_and_ bhs_exported_from_GSI3D_checked_clipped Sections_shapefile	ESRI .shp	Extent of geological units and cross-section locations, clipped to the model area
AOI	ESRI .shp	Extent of modelled area of interest

Table 4 Summary table of model exports included in the data release

9 Model Images

9.1 CROSS-SECTION IMAGES

The following figures are updated versions of the sections as shown in Arkley (2019). The sections and superficial deposits interpretations were redrawn to incorporate the UKGEOS boreholes in the post-drill model version.

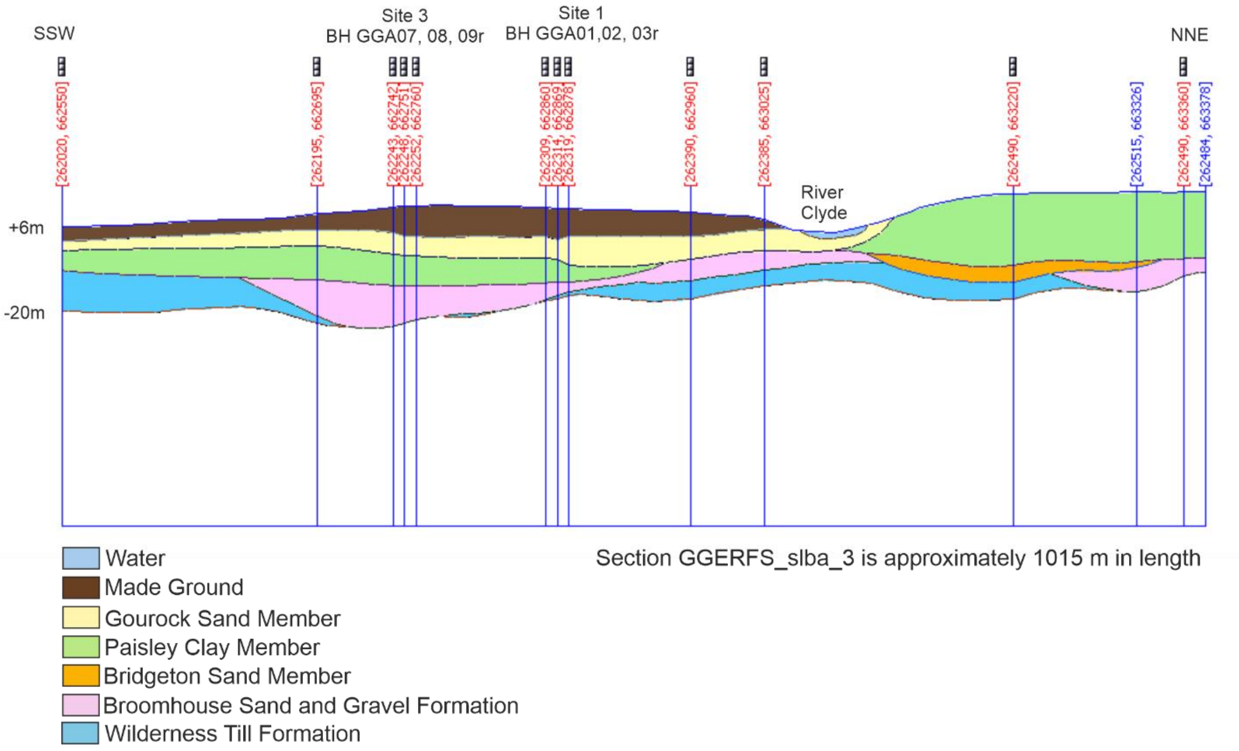

Figure 20 Cross-section *GGERFS_slba_3*, orientated SSW-NNE through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

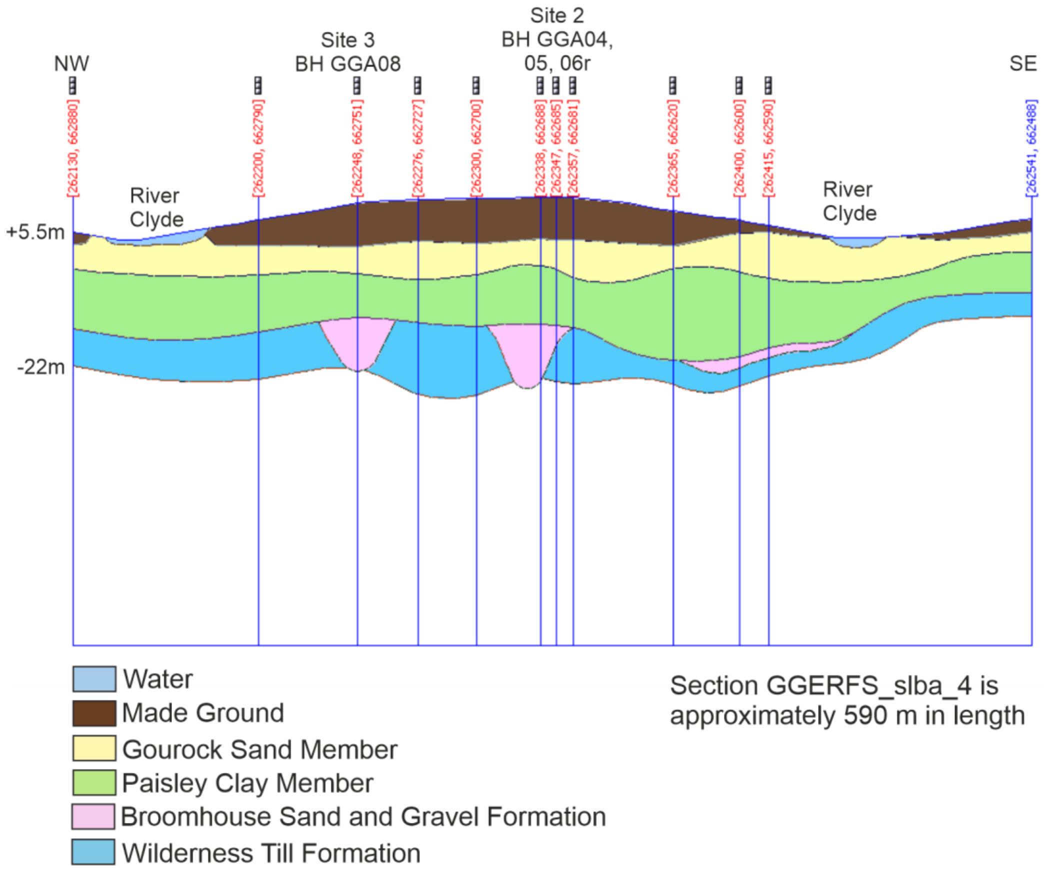

Figure 21 Cross-section *GGERFS_slba_4*, orientated NW-SE through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

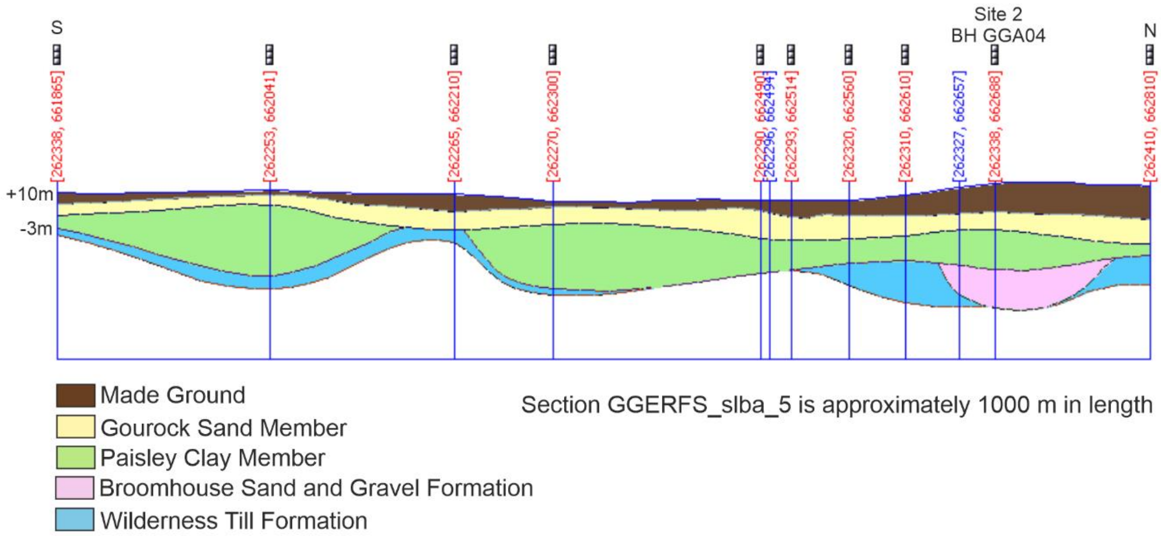

Figure 22 Cross-section *GGERFS_slba_5*, orientated South-North through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

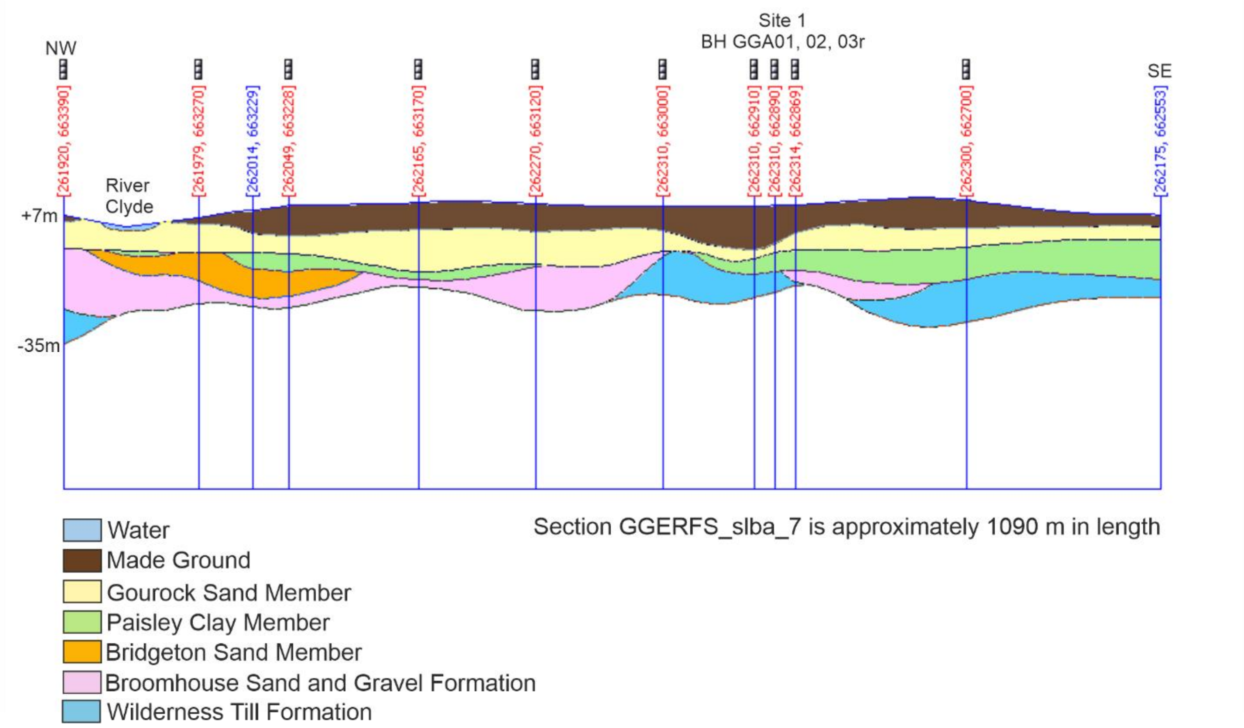

Figure 23 Cross-section *GGERFS_slba_7*, orientated NW-SE through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

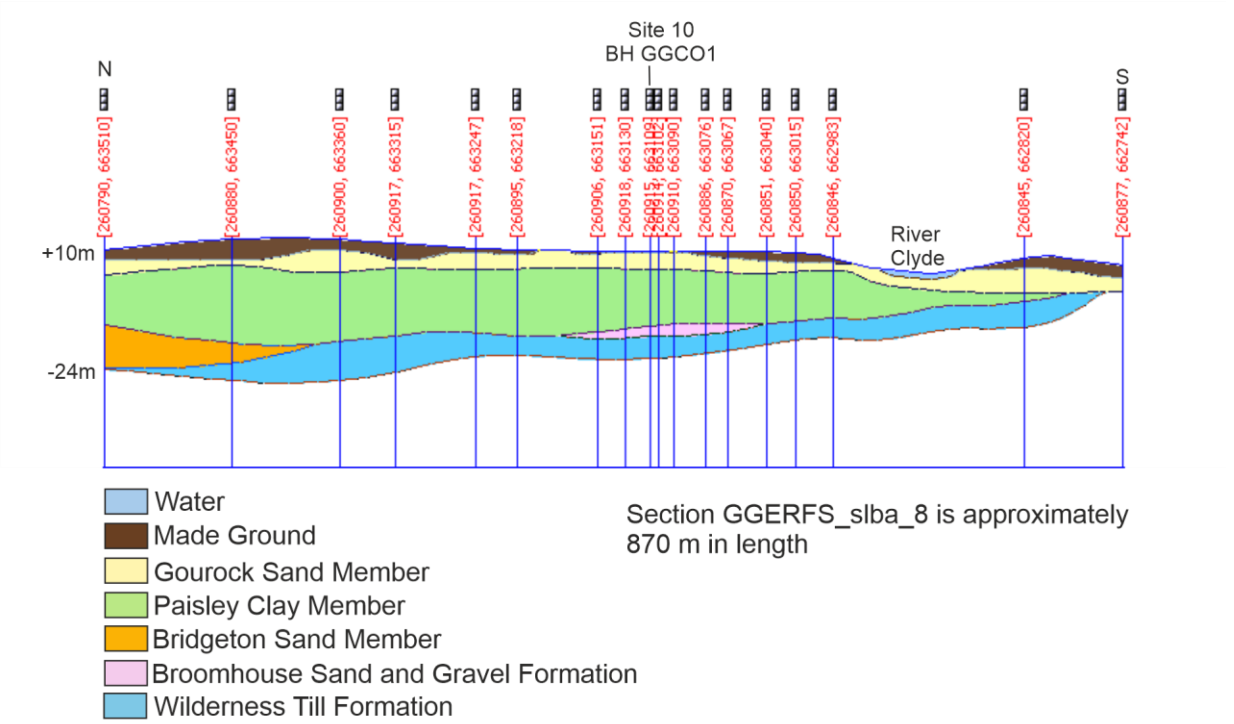

Figure 24 Cross-section *GGERFS_slba_8*, orientated North-South through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

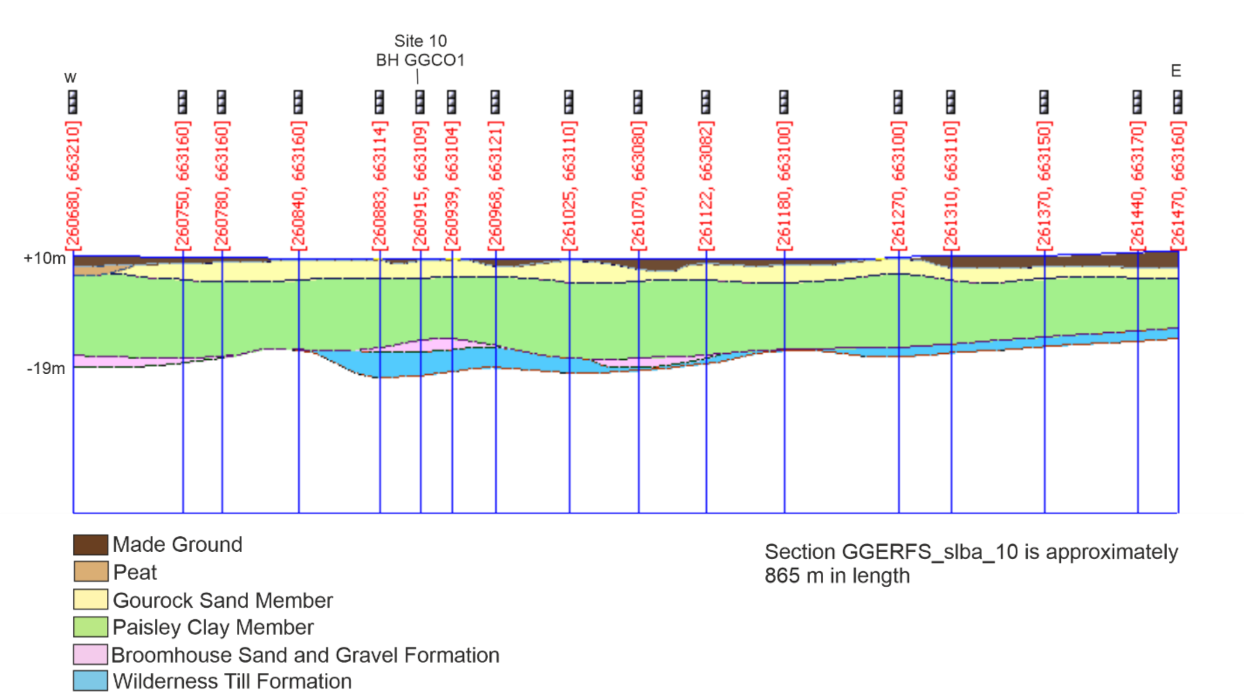

Figure 25 Cross-section *GGERFS_slba_10*, orientated West-East through the superficial deposits model (see Figure 16 for location). Vertical exaggeration x 3. Borehole constraint points shown in red. Ground surface derived from NEXTMap Britain elevation data from Intermap Technologies. Height is in metres relative to Ordnance Datum.

9.2 THICKNESS MAPS

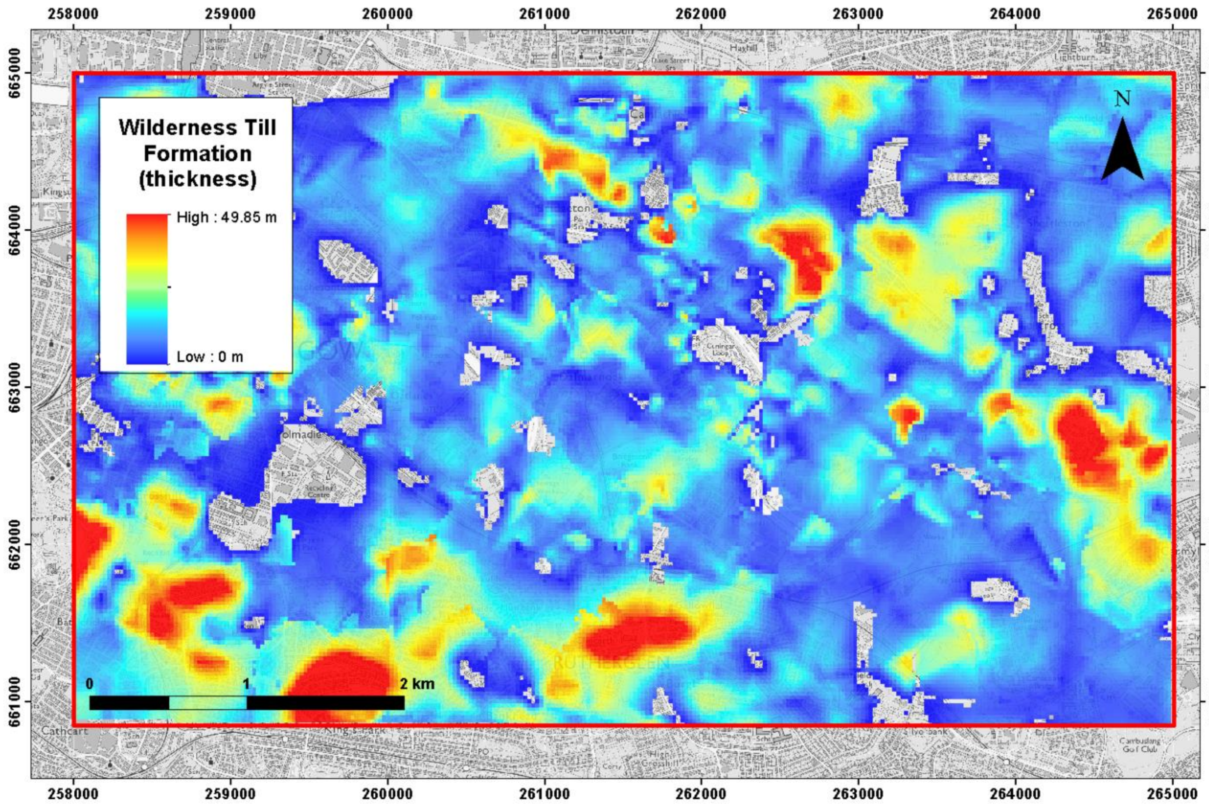

Figure 26 Modelled distribution and thickness of Wilderness Till Formation (WITI) across the model area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

This deposit of glacial till is widespread across the modelled area and beyond. It is thought to be almost 50 m thick in till-cored drumlins shaped by the over-riding Late Devensian glaciers.

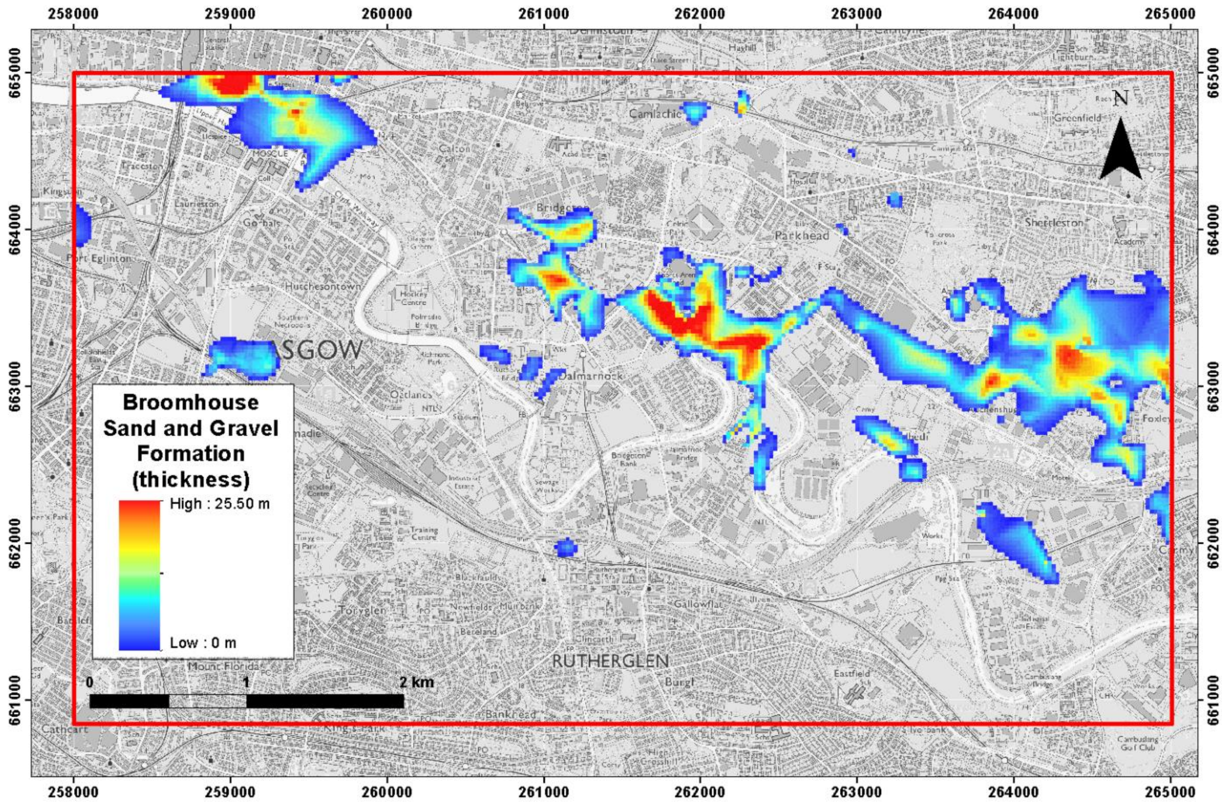

Figure 27 Modelled distribution and thickness of the Broomhouse Sand and Gravel Formation (BHSE) across the model area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

This deposit of fluvio-glacial sand and gravels generally occurs at a significant depth beneath the surface, as its known occurrence (shown above) is dependent on the presence of deep borehole records, more extensive deposits may lie undetected in areas where there are a lack of data points. The unit is over 20 m thick in places.

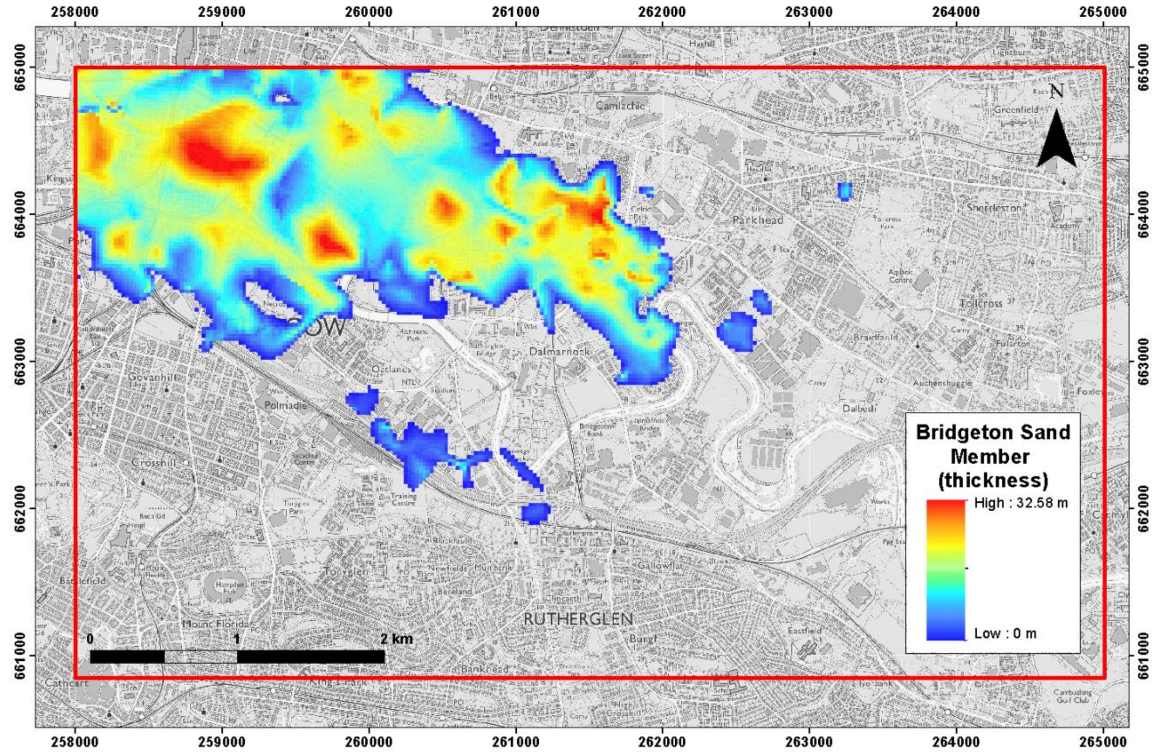

Figure 28 Modelled distribution and thickness of the Bridgeton Sand Member (BRON) across the area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

This deposit of marine sands is significant in the north-western corner of the modelled area where it is over 30 m thick in places.

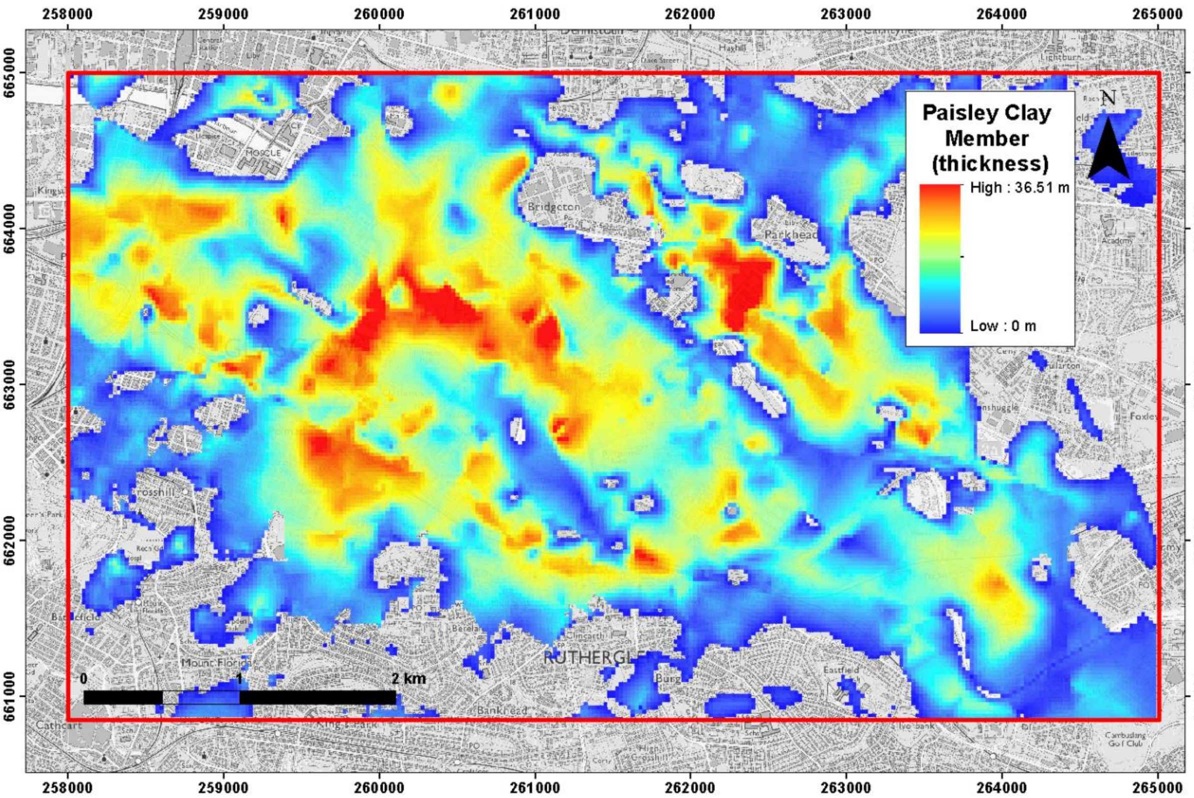

Figure 29 Modelled distribution and thickness of the Paisley Clay Member (PAIS) across the model area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

These laminated marine clays and silts are extensive within the Clyde Valley and are over 30 m thick in places.

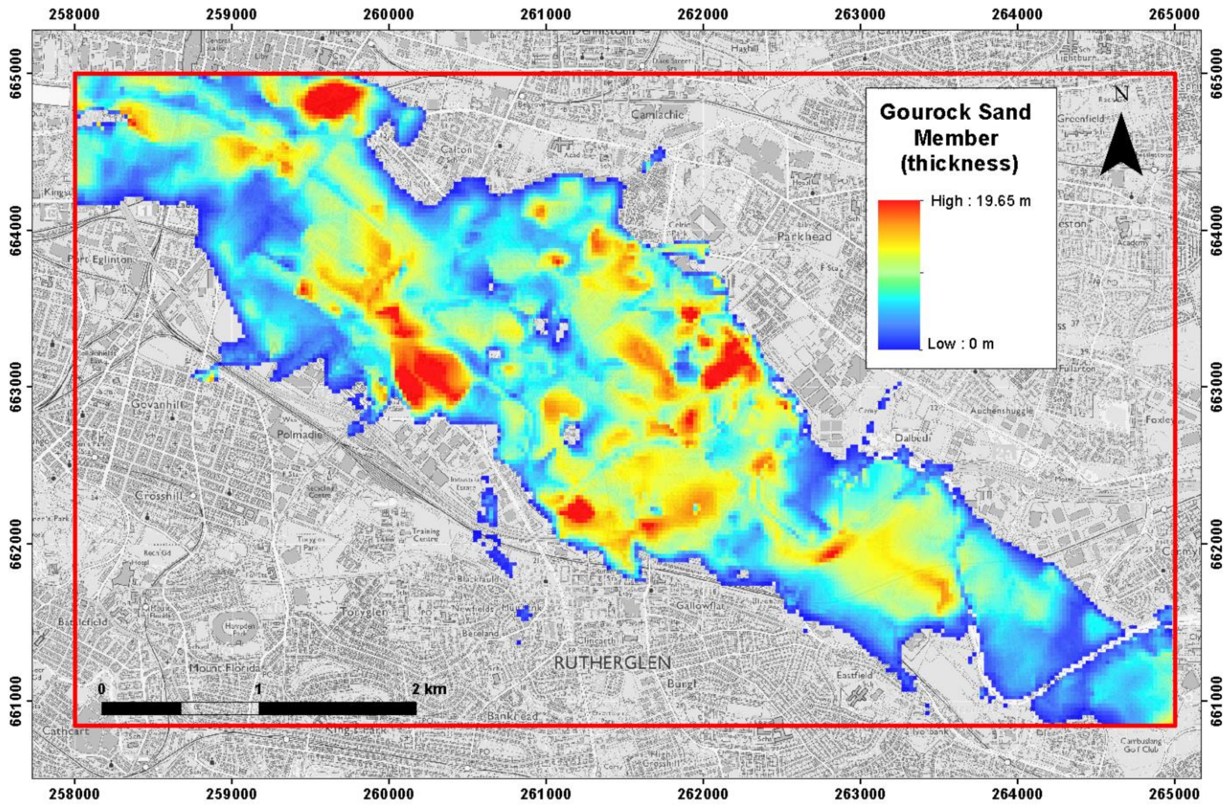

Figure 30 Modelled distribution and thickness of the Gourock Sand Member (GOSA) across the model area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

These marine sands are extensive within the Clyde Valley and are over 15 m thick in places.

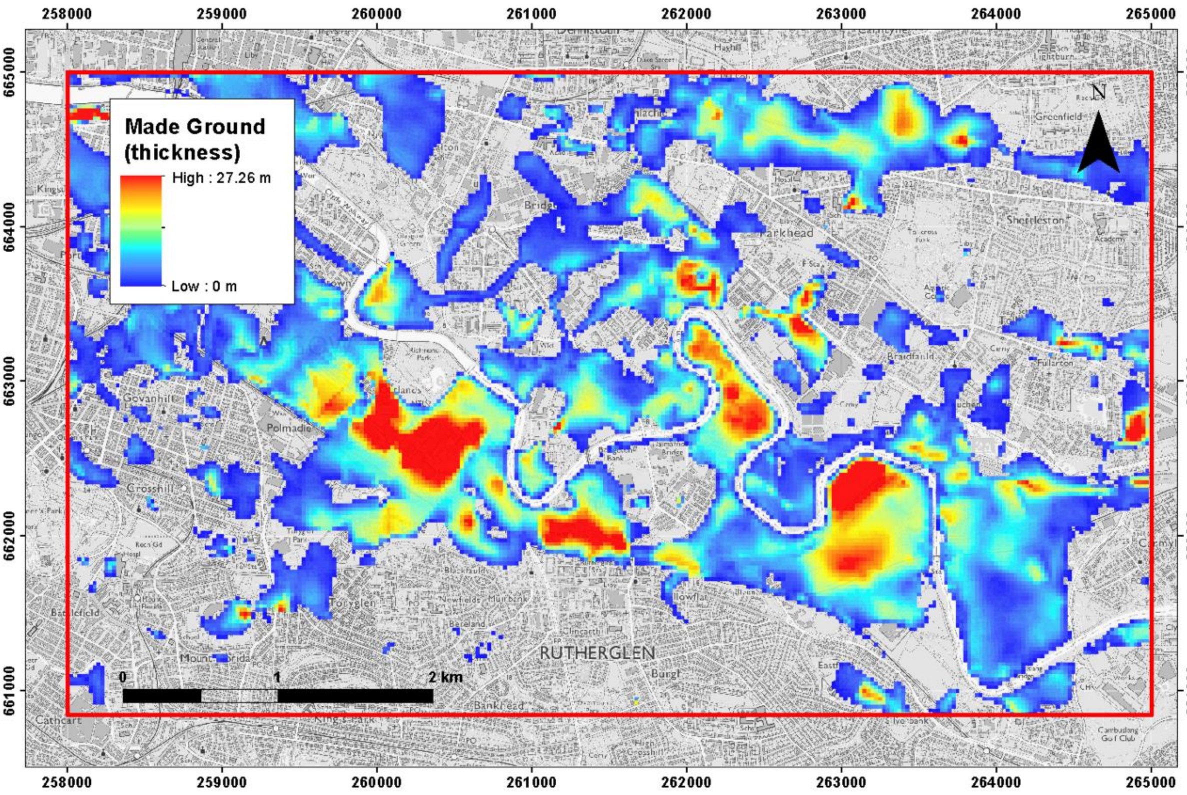

Figure 31 Modelled distribution and thickness of the Made Ground (MGR) across the model area (red outline). Includes mapping data licensed from Ordnance Survey. © Crown Copyright and/or database right 2021. Licence number 100021290 EUL.

Figure 31 highlights the variable made ground thickness. The thickest deposits are shown in red and reach over 20 m thick in places. These are a relic of the area's industrial past and they often represent formerly worked areas such as the infilled sand and gravel pits at Cuningar Loop, areas of former heavy industry such as the Clydebridge Steel Works at the east side of the study area or sites of significant infrastructure such as that at the former Polmadie Mineral Depot at the west end of the study area. Additional made ground, associated with former land use and development is likely to be present across most of the modelled area, mantling the natural superficial deposits.

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