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Mine water characterisation and monitoring borehole GGA08, UK Geoenergy Observatory, Glasgow

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Open Report OR/20/028

BRITISH GEOLOGICAL SURVEY

UK GEOENERGY OBSERVATORIES PROGRAMME

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Mine water characterisation and monitoring borehole GGA08, UK Geoenergy Observatory, Glasgow

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Front cover

Installation of uPVC casing for screened section of GGA08 with pre-glued gravel pack and ERT cable being attached

Bibliographical reference

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TABLES

Summary

This report and accompanying data release describe the 'as-built' borehole GGA08 at the UK Geoenergy Observatory in Glasgow. They also describe initial hydrogeological testing completed after borehole construction and provide an initial geological interpretation.

Mine water characterisation and monitoring borehole GGA08 at the UK Geoenergy Observatory in Glasgow is screened across the Glasgow Main mine working and overlying sandstone roof. The mine working is interpreted as a roadway with a void, mine waste and wood encountered. Initial hydrogeological indications from the test pumping suggest borehole GGA08 is very high yielding. Borehole GGA08 has ERT and DTS cables installed between the borehole casing and the surrounding rock, and a hydrogeological data logger installed within the borehole.

1 Introduction

Drilling of the mine water characterisation and monitoring borehole GGA08 at Cuningar Loop in Rutherglen, Glasgow City Region, took place between 25th June and 6th December 2019 (start of drilling to casing installation date). The borehole targets the Glasgow Main mine working, with the slotted screen at -73.71 to -76.41 m relative to Ordnance Datum.

The borehole was drilled as part of a set of six mine water[1], five environmental baseline and a seismic monitoring borehole as part of the UK Geoenergy Observatory in Glasgow. Further details of the purpose and planned infrastructure at the Observatory are described in Monaghan et al. (2019) and a geological characterisation of the area is provided in Monaghan et al. (2017).

This document and accompanying data files provides the definitive information on the 'as-built' borehole infrastructure.

- Table 1 and Figure 1 provide a summary of the borehole. Figure 1 is also included in the information release [*Summary_BGS_Log_Page1_GGA08.pdf* and *Summary_BGS_Log_Page2_GGA08.pdf*].
- Appendix A lists the files making up the information release.

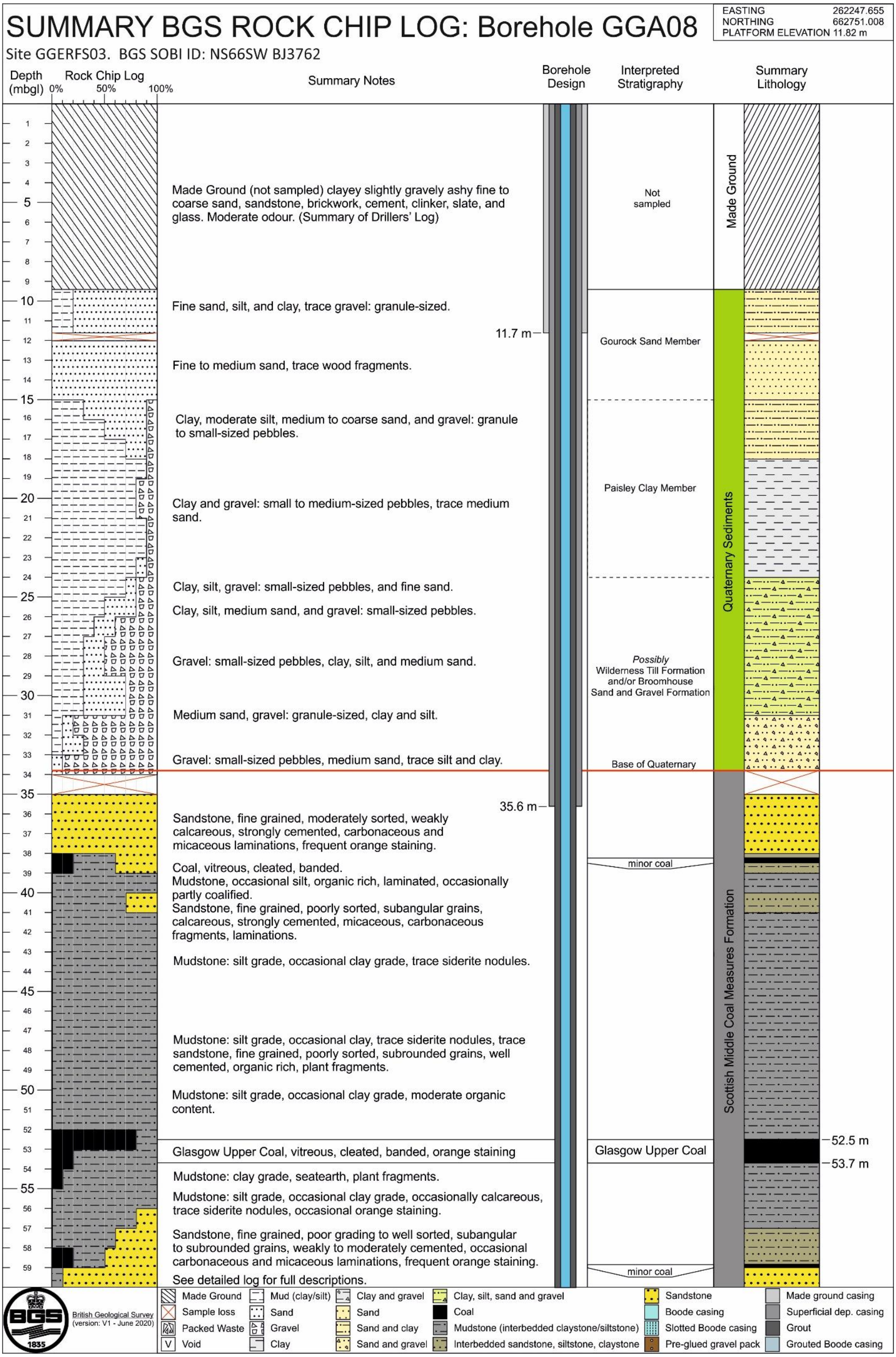
1.1 CITATION GUIDANCE

Any use of the data should be cited to:
DOI: https://dx.doi.org/10.5285/b19497aa-75a5-4f51-8089-299f9229b9ca H F Barron, Starcher V, K Walker Verkuil, K M Shorter, A A Monaghan. 2020. UK Geoenergy Observatories Glasgow Borehole GGA08 Data Release
and this report cited as:
BARRON H F, STARCHER V, WALKER-VERKUIL K, SHORTER K M, MONAGHAN A A 2020. Mine water characterisation and monitoring borehole GGA08, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/028

[1] Five boreholes were completed as mine water boreholes and one was completed as a sensor testing borehole

Table 1 GGA08 as-built summary data

Borehole number	GGA08	
Site	GGERFS03	
Easting (British National Grid)	262247.655	
Northing (British National Grid)	662751.008	
Drilling platform level (metres above Ordnance Datum AOD)	11.82	
Drilling started	25/06/2019	
Final casing installed	06/12/2019	
As-built borehole start height or datum (top Boode casing flange, metres AOD)	11.37	
Installation details		
Borehole detail	**Depths (drill length from drill platform level, metres)**	**Diameter size**
Made ground casing	0.0 – 11.7	24" (610 mm OD x 575 mm ID)
Rockhead casing	0.0 – 35.6	18" (457 mm OD x 425 mm ID)
Boode Well (BW) casing	0.0 – 85.5	280 mm OD x 248 mm ID
BW Slotted pipe with pre-glued gravel pack	85.53 – 88.23	311 mm OD x 248 mm ID
Sump – Open hole with end cap	88.23 – 88.40	280 mm OD x 248 mm ID
Geological details	**Depths (drill length from drill platform level, metres)**	**Depths, relative to Ordnance Datum (m)**
Base of made ground	9.4	+2.42
Base of superficial deposits	33.8	-21.98
Top Glasgow Upper mineworking	52.5	-40.68
Base Glasgow Upper mine working	53.7	-41.88
Top Glasgow Ell Coal	74.7	-62.88
Top Glasgow Ell Coal	76.5	-64.68
Top Glasgow Main mine working	87.7	-75.88
Base Glasgow Main mine working	90.7	-78.88
Final drilled length	91.37	-79.55
BGS SOBI reference number	NS66SW BJ 3762	BGS ID 20693603


SUMMARY BGS ROCK CHIP LOG: Borehole GGA08
EASTING 262247.655
NORTHING 662751.008
PLATFORM ELEVATION 11.82 m
Site GGERFS03. BGS SOBI ID: NS66SW BJ3762
Depth (mbgl)
Rock Chip Log 0% 50% 100%
Summary Notes
Borehole Design
Interpreted Stratigraphy
Summary Lithology
Made Ground (not sampled) clayey slightly gravely ashy fine to coarse sand, sandstone, brickwork, cement, clinker, slate, and glass. Moderate odour. (Summary of Drillers' Log)
Not sampled
Made Ground
Fine sand, silt, and clay, trace gravel: granule-sized.
11.7 m
Gourock Sand Member
Fine to medium sand, trace wood fragments.
Clay, moderate silt, medium to coarse sand, and gravel: granule to small-sized pebbles.
Paisley Clay Member
Clay and gravel: small to medium-sized pebbles, trace medium sand.
Quaternary Sediments
Clay, silt, gravel: small-sized pebbles, and fine sand.
Clay, silt, medium sand, and gravel: small-sized pebbles.
Gravel: small-sized pebbles, clay, silt, and medium sand.
Possibly Wilderness Till Formation and/or Broomhouse Sand and Gravel Formation
Medium sand, gravel: granule-sized, clay and silt.
Gravel: small-sized pebbles, medium sand, trace silt and clay.
Base of Quaternary
35.6 m
Sandstone, fine grained, moderately sorted, weakly calcareous, strongly cemented, carbonaceous and micaceous laminations, frequent orange staining.
minor coal
Coal, vitreous, cleated, banded.
Mudstone, occasional silt, organic rich, laminated, occasionally partly coalified.
Sandstone, fine grained, poorly sorted, subangular grains, calcareous, strongly cemented, micaceous, carbonaceous fragments, laminations.
Mudstone: silt grade, occasional clay grade, trace siderite nodules.
Scottish Middle Coal Measures Formation
Mudstone: silt grade, occasional clay, trace siderite nodules, trace sandstone, fine grained, poorly sorted, subrounded grains, well cemented, organic rich, plant fragments.
Mudstone: silt grade, occasional clay grade, moderate organic content.
Glasgow Upper Coal, vitreous, cleated, banded, orange staining
Glasgow Upper Coal
52.5 m
53.7 m
Mudstone: clay grade, seatearth, plant fragments.
Mudstone: silt grade, occasional clay grade, occasionally calcareous, trace siderite nodules, occasional orange staining.
Sandstone, fine grained, poor grading to well sorted, subangular to subrounded grains, weakly to moderately cemented, occasional carbonaceous and micaceous laminations, frequent orange staining.
minor coal
See detailed log for full descriptions.
BGS 1835
British Geological Survey (version: V1 - June 2020)
Made Ground
Sample loss
Packed Waste
Void
Mud (clay/silt)
Sand
Gravel
Clay
Clay and gravel
Sand
Sand and clay
Sand and gravel
Clay, silt, sand and gravel
Coal
Mudstone (interbedded claystone/siltstone)
Interbedded sandstone, siltstone, claystone
Sandstone
Boode casing
Slotted Boode casing
Pre-glued gravel pack
Made ground casing
Superficial dep. casing
Grout
Grouted Boode casing

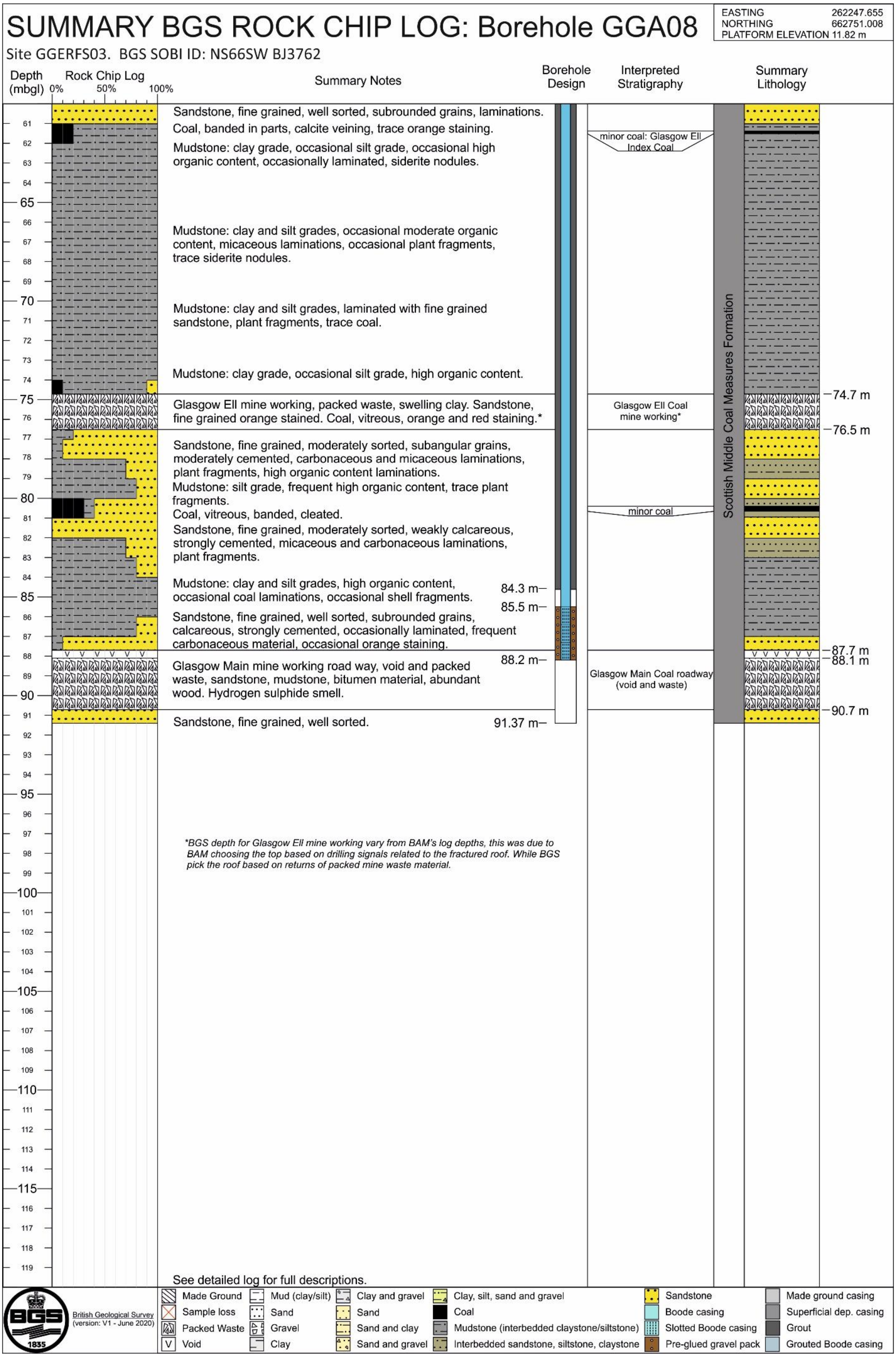


Figure 1 GGA08 summary log based on rock chip returns

1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGA08 is part of the UK Geoenergy Observatory: Glasgow Geothermal Energy Research Field Site (GGERFS) located on the southern side of the River Clyde in Rutherglen, South Lanarkshire, four kilometres south-east of Glasgow city centre (Figure 2).

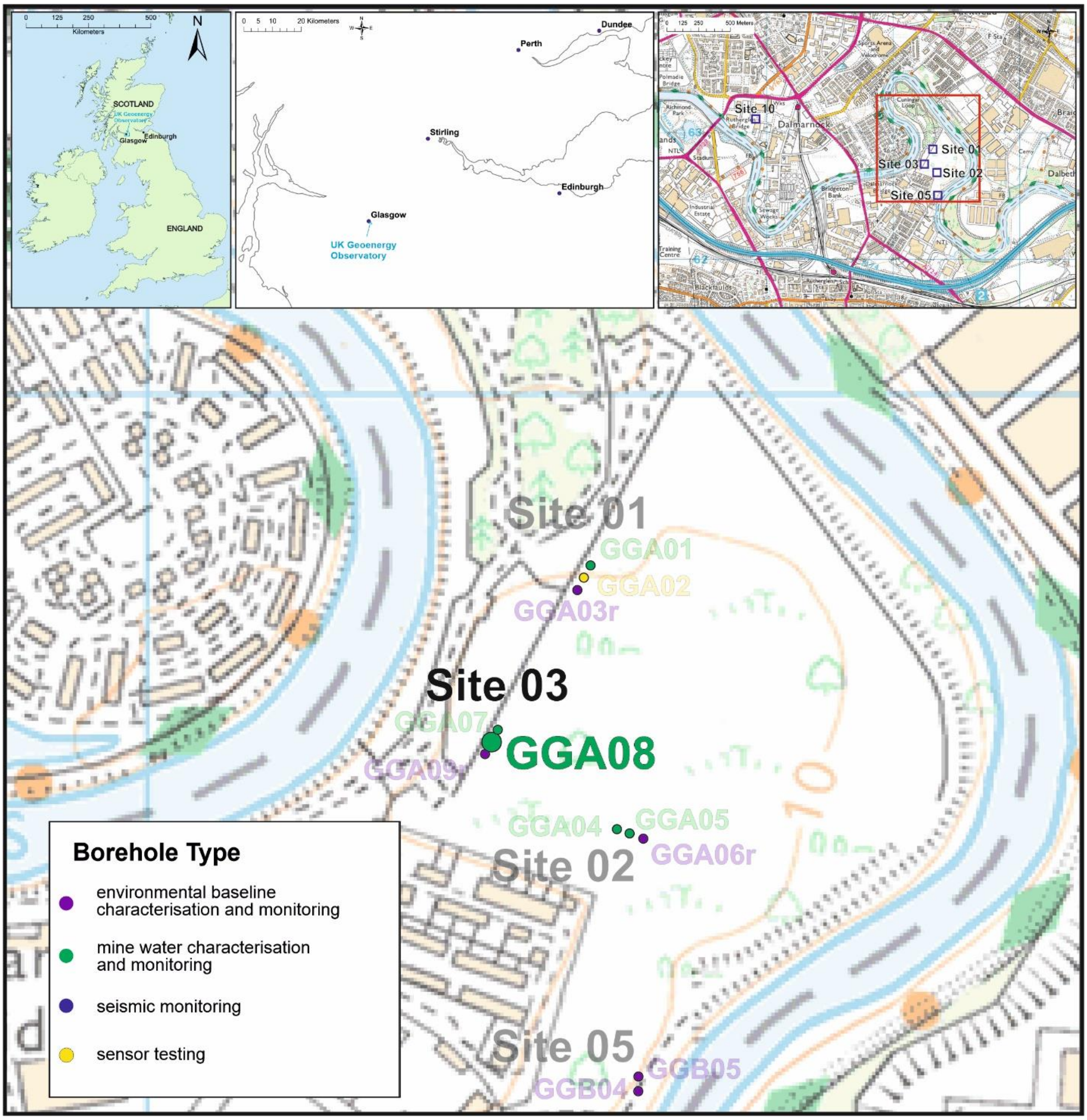


Figure 2 Location map of borehole GGA08, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

1.3 DRILLING AND AS-BUILT LENGTHS AND HEIGHTS

Borehole drilling took place from a built-up gravel platform, with the reference datum for drilled depth (measured in metres below ground level; mbgl) being the drilling platform ground level (measured in metres above Ordnance Datum; m AOD; Figure 3). All drillers' logs, sample depths, BGS rock chip logs and wireline logs, together with the stated installation depths of ERT sensors and fibre-optic cables are referenced to the drilling platform level. After drilling had been completed the borehole casings were cut down and a manhole chamber was installed (Tables 2,3).

After the hydrogeological test pumping had been completed the borehole head works were installed in the manhole chamber. The as-built borehole therefore has a different start height or reference datum level, which is the top of the blue Boode casing flange (Figure 3). Depths down the borehole can be expressed as lengths from the top Boode casing, or relative to Ordnance Datum (Tables 2,3).

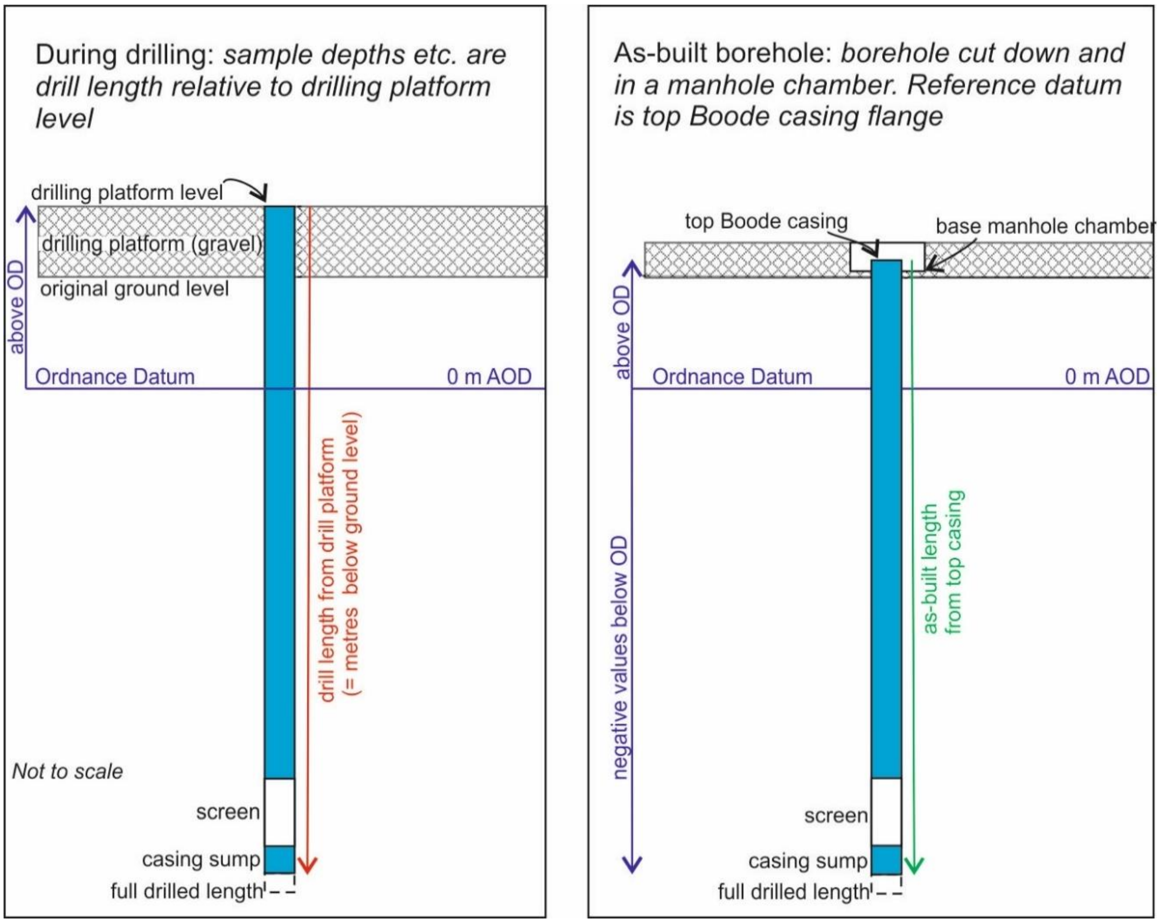


Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)

Table 2 Summary of start heights and datums used for GGA08

<table>
<tr><th>Stage</th><th>Borehole start height/
reference datum used
(m AOD)</th><th>Used in</th></tr>
<tr><td>Drilling platform level – built up gravel platform</td><td>11.82</td><td>Drillers and BGS logs, sample depths, wireline and optical dataset. ERT and DTS cable installation.</td></tr>
<tr><td>As-built borehole start height (top Boode casing flange)</td><td>11.37 (recorded as 11.370)</td><td>Reference datum for future Observatory users</td></tr>
<tr><td colspan="2">Conversion Rock chip sample depths, logs, wireline and optical depths – to convert from drill length to beneath as-built borehole start height</td><td>As-built depth below start height = drill length – (11.82 – 11.37) m
i.e
As-built depth below start height = drill length – (0.45) m</td></tr>
</table>

2 As-built borehole design

The Glasgow Geoenergy Observatory boreholes have been designed for a range of scientific research purposes over a 15-year lifetime, with 2 sets of sensor cables installed on the outside of the bedrock casing (mine water boreholes). As such, their construction is not typical of mine water or environmental monitoring boreholes that would be installed for commercial schemes.

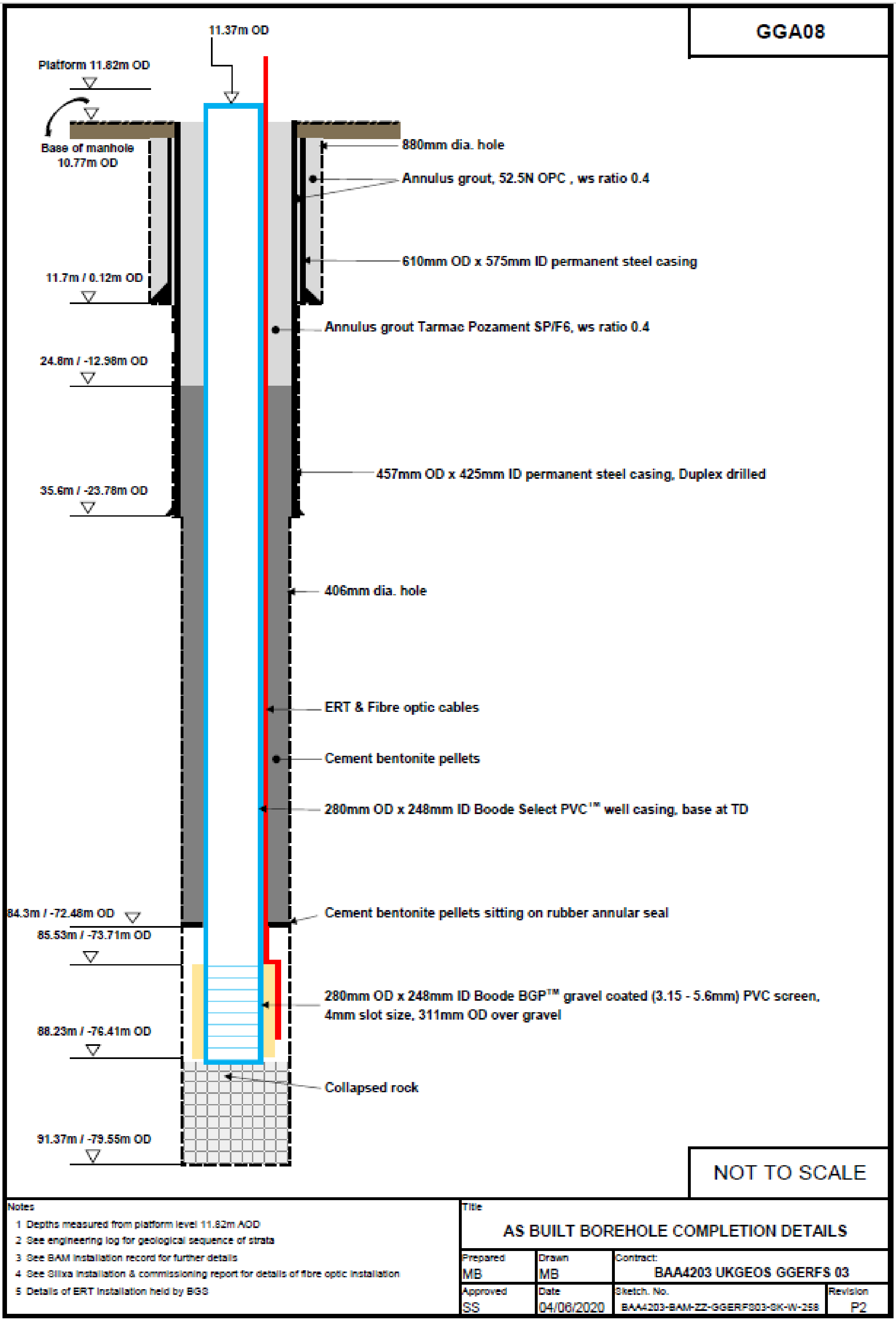


Figure 4 As-built borehole schematic for GGA08

The rationale for the borehole design was as follows;

i. Separate borehole casings were installed through the made ground, superficial deposits and bedrock sections of all the UK Geoenergy Observatory boreholes at Cuningar Loop, with the annulus of the different casing sections grouted before the next section was drilled. This was done to prevent the mixing of groundwaters of different quality, which could occur if vertical flow paths were created during drilling (important to avoid from both an environmental quality and scientific research perspective).

ii. Additional measures were planned to be taken during drilling to prevent the mixing of waters from different mine workings, as a precaution in case the Glasgow Upper, Ell and Main workings were later found to be hydraulically isolated. This was necessary to preserve the in-situ conditions for scientific research, and to minimise any environmental impact should one mine working contain water of much poorer quality. In order to achieve this, it was planned to seal the Glasgow Upper and Glasgow Ell mine workings with a plug of grout as they were encountered, and then drill though the centre of the plug as the borehole progressed downwards to the target Glasgow Main mine working. Due to having mine water quality data from the Glasgow Upper mine working (GGA02) and Glasgow Main mine working (GGA05) that showed good and similar water quality in advance of drilling and in agreement with SEPA, GGA08 progressed to the Glasgow Main target interval without sealing of the Glasgow Upper or Ell mine workings.

iii. The borehole is screened only across the target interval (the Glasgow Main mine working) and is fully sealed above the screen, so that all hydrogeological observations from this borehole relate only to this interval.

iv. The large internal diameter of the bedrock casing and slotted screen section of borehole GGA08 (248 mm ID) was chosen to accommodate a large borehole pump capable of delivering a high flow rate.

v. A screen slot size of 4 mm was used in the Glasgow Main mine working, with a 3.15 to 5.6 mm sized bonded gravel pack attached. The gravel pack is intended to stop ingress of larger pieces of mine waste that could clog the slotted screen.

vi. The borehole sump was planned to be included both for the termination unit of the sensor cables (see below) and to catch material that may enter through the slotted screen. However, due to a block obstructing the borehole in the final stages of construction (see Table 4), only a 20 cm sump was possible for this borehole. The termination unit of the fibre-optic cable had to be placed above the screened interval so it did not interfere with the ERT cable over the screened section.

vii. A finned rubber annular seal was placed above the screened section at 84.3 mbgl above the Glasgow Main mine working to support emplacement of a permanent grout seal. A bentonite cement pellet layer was first emplaced to seal and reduce pressure on the finned seal. Once the it had set sufficiently the annulus was grouted in stages with bentonite cement pellets and a SP/F6 mix (Figure 4).

Table 3 Summary of heights for as-built borehole features for GGA08

Feature	Depths (drill length from drill platform level, metres)	Height (m) relative to Ordnance Datum	As-built length (m) down hole from top casing datum (top Boode flange)
Top slotted screen	85.53	-73.71	85.08
Base slotted screen	88.23	-76.41	87.78
Base open sump	88.40	-76.58	87.95
ERT sensor positions	See Table 5 below	See Table 5 below	See Table 5 below
Position of DTS termination unit	Base of Termination unit depth: 83.7	Base of Termination unit depth: -71.88	Base of Termination unit depth: 83.25

3 Drilling, casing, annulus grouting and testing methodology

Borehole GGA08 was drilled and cased in separate sections for made ground, superficial deposits and bedrock. In between the sections the drill rig moved off to complete sections of other boreholes on site, thus the overall timescale for the borehole appears much longer than would be expected (Table 4).

Table 4 summarises the steps involved in the drilling of GGA08, further details are given in the borehole information summary at the end of the Drillers' log file (see section 4.1). Other points of note include

- Both water and bentonite mud were used as drilling fluids in the superficial section. Water flush was used throughout the drilling of the bedrock section.
- The drilling technique in the made ground section was piling rig with auger. In the superficial deposits, open hole drilling with both reverse and direct circulation, and also duplex drilling (drilling while casing) were used. The drilling method in the bedrock section was rotary open hole with reverse circulation.
- Fluid and rock chip samples were taken from the superficial deposits and bedrock sections for academic researchers and rock chip samples were taken for archiving in the BGS National Geological Repository.

Table 4 Summary of drilling, casing, grouting and testing. All depths are in metres below drilling platform level (mbgl).

<table>
<tr><th colspan="2">Drilling and installation summary:</th></tr>
<tr><td>25/06/2019</td><td>Drilled and installed made ground and superficial casing with BAM piling rig to 11.6 mbgl, with a 34 ¾” (880 mm) auger – made ground level was recorded at 9.4 mbgl</td></tr>
<tr><td>26/06/2019</td><td>Made ground and superficial casing grouted – casing installed to 11.7 mbgl</td></tr>
<tr><td>Various times and suspensions during 29/08/2019 – 12/09/2019</td><td>Drilled superficials to rockhead with Fraste rig from 11.6 mbgl to 34.5 mbgl, with a 22” (558.8 mm) tri-cone bit
• Rockhead was 33.8 mbgl
• Problems with hole collapse were encountered in mobile sections of sand and gravel and various techniques were tried:
(i) change from reverse circulation to direct flush
(ii) an increasing concentration of bentonite flush
(iii) following hole collapse after rockhead had been reached, grouting up the hole to base made ground section and re-drilling
(iv) change to casing while drilling ‘duplex drilling’</td></tr>
<tr><td>Various times during 21/10/2019 – 30/10/2019</td><td>Resume drilling to rockhead with Conrad rig, using duplex drilling method. Advancing 18” casing to 35.60 mbgl</td></tr>
<tr><td>31/10/2019</td><td>Grouting the annulus of superficial to rockhead 18” casing – rig moved off to drill a different borehole</td></tr>
<tr><td>18/11/2019 – 22/11/2019</td><td>Drilling to Glasgow Main mine working with a 16” tri-cone drill bit. Glasgow Main void/waste encountered at 87.7 – 90.7 mbgl.
18/11/2019 Glasgow Upper Coal and possible mine workings encountered from 52.5 to 53.7 mbgl, drilling indications including faster drilling, large volumes of coal and mudstone shakers, smell of H_2S. No indication of void, but above coal drilling was faster at excess water at shakers suggesting water production from fractures. Soft grey clay from approximately 53.5 to 54.5 mbgl
20/11/2019 Coal returns at shakers 61.45 to 62.37 mbgl – Glasgow Ell Index Coal
21/11/2019 Glasgow Ell workings encountered from 74.7 to 76.5 mbgl, drilling indications including faster drilling, abundant grey clay balls, coal fragments and mudstone at shakers – no indication of void, likely to be packed waste
22/11/2019 Glasgow Main workings/roadway encountered at 87.7 mbgl with void to 88.1m and mine waste and wood beneath. Drilling indications included fragment of tarpaulin (roof covering?) then cuttings almost entirely wood fragments with accompanying H_2S smell. See Figure 5 below. Base of waste at 90.7 m into underlying sandstone.
22/11/2019 End Depth: 91.37 mbgl</td></tr>
<tr><td>Various times during 25/11/2019 – 03/12/2019</td><td>Aimed to drill 3m sump, however hole collapsed at base. After several attempts and changes of bit type, an obstruction was identified at around 88.3 mbgl.</td></tr>
<tr><td>04/12/2019</td><td>CCTV camera run down hole to view obstruction. A large block, most likely sandstone is laying across the hole. Causing bit to kick off when trying to drill though it. Decision was made to install casing above the obstruction.</td></tr>
<tr><td>06/12/2019</td><td>Silixa installed fibre optics and BGS installed ERT cables on to casing during installation.</td></tr>
</table>

Drilling and installation summary:	
	Bentonite: 83.7 – 84.3 mbgl Seal: 84.3 mbgl Screens: 85.5 – 88.2 mbgl Sump: No sump, only a cap: 88.2 – 88.4 mbgl • No sump only end cap. • Fibre optics terminated above seal due to lack of sump
Various times, in stages 09/12/2019 – 10/01/2019	Grouting annulus to surface
08/01/2020	Borehole cleaning
10/01/2020	Cased hole logs run by Robertsons Geo Services.
03/02/2020	Hydrogeological testing: step test • Conducted at 5, 10, 15, 20, 25 l/s
04/02/2020	Hydrogeological testing: Constant rate pump test: • Conducted at 20 l/s

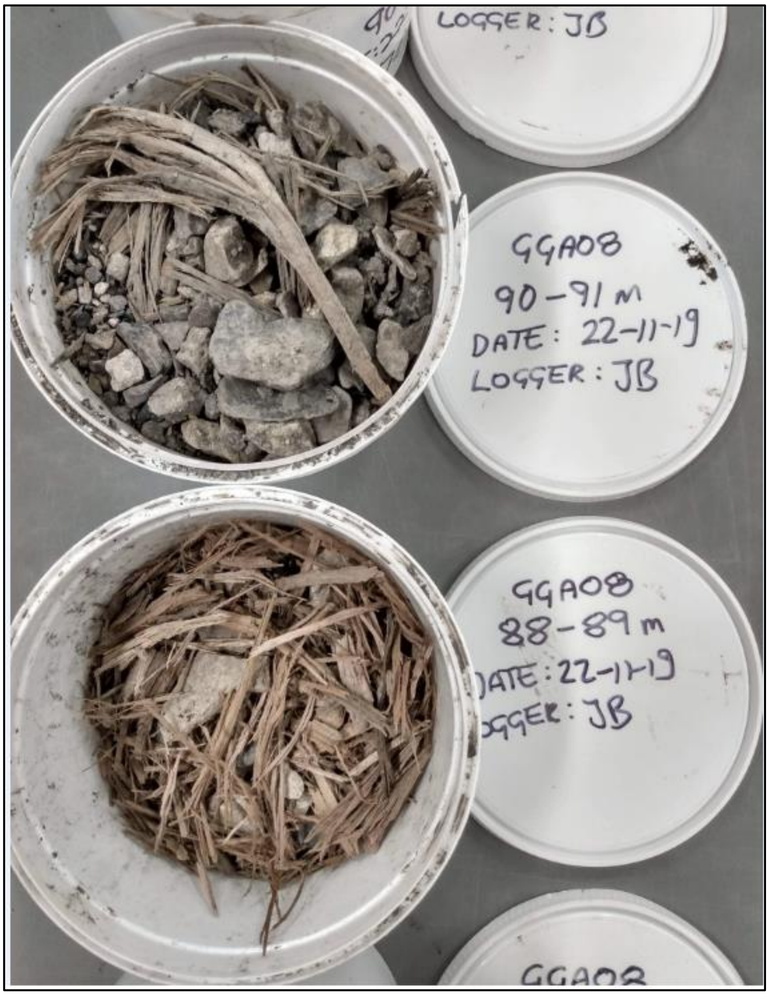


Figure 5 Returned mine waste and wood fragments from the Glasgow Main mine working on borehole GGA08 tubs from 88 – 89 m and 90 – 91 m

3.1 SENSORS INSTALLED

3.1.1 Electrical resistivity tomography (ERT) downhole sensors

Electrical resistivity tomography (ERT) is a geophysical technique that uses electrode arrays to profile the electrical resistivity of the subsurface. At UKGEOS Glasgow electrode cables were deployed in the six mine water characterisation boreholes to facilitate cross-borehole imaging of geoelectrical properties and the automated remote 4D monitoring of natural and induced changes in subsurface conditions.

ERT INSTALLATION

An ERT cable was fastened to the outside of the Boode well casing, including across the screened section, and the casing and cables were then lowered into the borehole (Figure 4, Table 5). Two ERT cables were installed on the casing to provide full depth coverage. The cables are designed to be connected to the same measurement instrument so that all of the deployed sensors can be used as part of the same measurement scheme. When the casing and cables had been installed, the annulus between the casing and rock wall was grouted above the screened section to seal in the casing and provide a good electrical connection between the ERT electrodes and the surrounding formation. Appendix B provides a more detailed description of the installation method for the ERT and fibre-optic cables.

OUTPUT DATA

The data will be measured by a BGS-designed system known as PRIME, which connects multiple ERT electrodes to a common control unit so that the resistivity between various electrode pairs can be continuously scanned. The PRIME system is operated remotely and designed for minimum on-site intervention. All acquisition strategy design, measurement scheduling and data download will be undertaken remotely via a secure 3G/4G Wireless internet link.

Table 5 Position of the ERT sensors in GGA08 relative to drilling platform and as built datums

Drill platform datum level (m AOD)		11.82	
As-built datum level at top casing flange (m AOD)		11.37	
Electrode Number Cable 1	**Electrode Number Cable 2**	**Depth below drill platform datum [m]**	**Depth below as-built final datum (m)**
32		34.92	34.47
31		35.67	35.22
30		36.42	35.97
29		37.17	36.72
28		37.91	37.46
27		38.66	38.21
26		39.41	38.96
25		40.16	39.71
24		40.91	40.46
23		41.65	41.20
22		42.40	41.95
21		43.15	42.70
20		43.90	43.45
19		44.65	44.20
18		45.39	44.94
17		46.14	45.69
16		46.89	46.44
15		47.64	47.19
14		48.39	47.94
13		49.14	48.69
12		49.88	49.43
11		50.63	50.18
10		51.38	50.93
9		52.13	51.68
8		52.88	52.43
7		53.62	53.17
6		54.37	53.92
5		55.12	54.67
4		55.87	55.42
3		56.62	56.17
2		57.36	56.91
1		58.11	57.66
	40	58.86	58.41
	39	59.61	59.16
	38	60.36	59.91
	37	61.10	60.65
	36	61.85	61.40
	35	62.60	62.15
	34	63.34	62.89
	33	64.09	63.64
	32	64.84	64.39
	31	65.59	65.14

	30	66.33	65.88
	29	67.08	66.63
	28	67.83	67.38
	27	68.57	68.12
	26	69.32	68.87
	25	70.07	69.62
	24	70.81	70.36
	23	71.56	71.11
	22	72.31	71.86
	21	73.06	72.61
	20	73.80	73.35
	19	74.55	74.10
	18	75.30	74.85
	17	76.04	75.59
	16	76.79	76.34
	15	77.54	77.09
	14	78.28	77.83
	13	79.03	78.58
	12	79.78	79.33
	11	80.53	80.08
	10	81.27	80.82
	9	82.02	81.57
	8	82.77	82.32
	7	83.51	83.06
	6	84.26	83.81
	5	85.01	84.56
	4	85.75	85.30
	3	86.50	86.05
	2	87.25	86.80
	1	88.00	87.55

3.1.2 Fibre-optic cables (FO)

The fibre-optic cables installed within the borehole are optoelectronic devices that can act as series of "distributed temperature sensors" (DTS). These measure a continuous profile of the temperature along the cable. When an interrogator box is connected to the top of the cable, a pulsed laser signal propagates through the fibre optic cable and measurements of the temperature-dependent backscatter is recorded. In a passive mode the DTS monitors temperature variability and can be used to infer flow pattern from naturally occurring thermal anomalies. The fibre optic cables also have the ability to measure distributed acoustics should an iDAS interrogator box be connected.

The cables installed into the Glasgow mine water boreholes are all active DTS which are characterised by a copper core. Electric currents can be applied to this core to generate a heat pulse. The associated temperature profiles generated by this known pulse can be observed and will provide further insight into the flow system and rock mass, for example characterisation of fractures.

FIBRE-OPTIC CABLE INSTALLATION

The DTS fibre-optic cable was fastened on to the outside of the Boode well casing and installed into the borehole (Figure 4). Subsequently the annulus of the borehole above the screened section was grouted between the casing and rock wall and around the cable. The termination unit of the FO cable was installed above the first ERT sensor and was wrapped in insulation material to ensure that the metal of the unit did not interfere with the ERT signal. Appendix B provides a more detailed description of the installation method for the ERT and the fibre optic cables, along with the contractors report included in the information release [*FibreOpticCable Installation Report BGS V1.2 GGA08 18052020.pdf*]

Installation depths of cables and the termination unit are shown in Table 3 above.

OUTPUT DATA

The passive DTS cables are used in conjunction with a DTS interrogator box, which generates the light signal and interprets the signal return. For use of the active DTS system a separate heat pulse control unit is also needed.

3.1.3 Hydrogeological data logger

A CT2X data logger was installed in GGA08 on 10/01/2020 to a depth of approximately 30 m below the top of the casing, and was raised on 22/01/2020 to approximately 20 m below the top of the casing. The data logger was removed during the test pumping on GGA08 (Drilcorp installed their own data logger during the tests). The data logger was re-installed upon completion of the constant rate test on borehole GGA08, approximately 20 m below the top of the casing, and remained in place for the duration of the remaining test pumping of the surrounding UKGEOS boreholes. It was removed from the borehole after the completion of the test pumping programme to allow the borehole casing to be cut down. The data logger will be replaced at a future date, when BGS staff are allowed to return to site following the COVID-19 pandemic, for continuous downhole groundwater monitoring. As with all groundwater observations in this borehole, the data logger is monitoring groundwater conditions only in the screened target interval, the Glasgow Main mine working.

This data logger measures the following parameters:

- Pressure (mbars) (which is converted to borehole water level by compensating for air pressure, measured separately onsite by a barometer)
- Groundwater temperature (°C)
- Groundwater conductivity (specific electrical conductivity or SEC) (µS/cm) (also expressed as Salinity (PSU) and Total dissolved solids (mg/L))

Data from the logger will be downloaded monthly and become available on the UKGEOS website.

4 Borehole logs

4.1 DRILLERS' LOG

The drilling contractors log is included in the data pack [*Drillers_Log_GGA08.pdf*]. This is a record of the lithologies encountered, as recorded on-site by the drillers. Apart from the upper part of the made ground section which is based on trial pits, this log was not recorded by a geotechnical engineer. Due to the nature of the driller's log, there are differences between it and BGS rock chip log (Section 4.2).

The borehole information summary sheets at the end of the drillers' log records the drilling progress each day, casing sizes, flush type used etc. All eleven drillers' logs for UKGEOS boreholes at Cuningar Loop have been exported by the drilling contractor to the file

UKGEOSCuningar_BAA4203_FinalAGS.AGS in the Association of Geotechnical Specialists standard text file format.

4.2 BGS ROCK CHIP LOG

BGS geologists were on site during borehole drilling to collect samples, record a field lithological log and to make decisions based on this log, such as the positioning of borehole screens and seals. A one litre tub of rock chips from the open hole drilling was generally taken every metre, to be representative of the lithologies encountered in that metre. Other notable features such as the top and base depths of key intervals such as coals and mine workings were recorded in discussion with the drillers.

Subsequently, the rock chip tubs were transported to BGS Edinburgh. Tubs containing unconsolidated superficial deposits were placed in a cold store. Rock chip tubs were dried and logged by BGS geologists working in a laboratory with the aid of a microscope.

The resulting lithological log record [*Detailed_BGS_Rockchiplog_GGA08.pdf and .xlsx*] gives the percentage of lithologies returned as rock chips within the 'metre' tub, with some sedimentological characteristics. The dictionaries controlling the majority of the fields are provided via the tab on the spreadsheet. A sedimentological scheme was used to describe the lithologies to facilitate comparison with core logging of UKGEOS borehole GGC01:

- The Udden-Wentworth grain size scale was used
- With initial logging taking place at drill site, a classification level of mud/mudstone, sand/sandstone was used. Following the hierarchy of the BGS Rock Classification Scheme (Hallsworth and Knox, 1999), subsequent logging in the laboratory subdivided mud/mudstone to clay and silt, and to the sandstone grain sizes (fine, medium etc) and the gravel to granule and pebble grades. Percentages on the graphic logs are given at the mud/mudstone and sand/sandstone classification level. Detail on clay/silt etc is given in the descriptive field in the BGS rock chip log.
- Grain sizes, angularity, sorting and percentages etc were referred from a standard grain size card based on Tucker (2011).
- Logging was <u>not</u> based on ISO 14688-1:2002 (geotechnical engineering standard).

5 Wireline (geophysical) downhole data

Wireline logging or geophysical logging is the process of measuring the properties of geological units using sensors attached to a winch cable (wireline) suspended in the borehole. Measurements are made continuously down the borehole by raising or lowering the sensor tools. The property measurements are then converted to a standard series of geophysical logs.

5.1 ACQUISITION

5.1.1 Cased hole logs

The wireline logs were acquired by Robertson Geo Services. They were acquired as cased hole logs which refers to the fact that the tools were run after the Boode casing had been installed and grouting of the annulus had been completed. Information about the tools and their associated certification is located within the report '*Wireline Logging Report for UKGEOS Glasgow Conducted by Robertson Geo Ltd On behalf of BGS 9/1/20 -----10/1/20'* included in the information release [*BAM Nuttall Glasgow Report Final.pdf*].

5.1.2 Open hole logs

During the drilling, Robertsons Geo services were contracted to run logs to assist in drilling decisions. For GGA08, caliper and gamma open hole logs were acquired prior to the installation of the Boode casing. The data was output as a PDF and other file types but as these logs were designed to be used purely for assisting in drilling decisions, there is no associated report and the headers are not complete. Since the open hole data may be useful for future users, it was decided to release the data with these caveats.

5.1.3 Optical and CCTV camera data

An optical camera was deployed into borehole GGA08 prior to casing installation. The aim of the camera was to assist in the placement of the screened section and to identify any potential problem areas with regard to grouting of the annulus. The data has not been processed and does not have complete headers as it was acquired to assist in the drilling and not as a final output. In particular users should note that the depth reference was incorrect and there is a *c.*0.8 m offset from the optical camera depths and the drilled depths noted at key horizons. However, given the excellent quality of the image and the variety of lithologies visible it was decided to release the data with these caveats.

A CCTV camera was run into borehole GGA08 to gain further information about the obstruction within the Glasgow Main mineworking (04/12/19 in Table 4 above). The images from this camera are available but it must be noted that this data was acquired specifically to address a drilling issue and has not been edited. The open hole section below the superficial deposits casing appears after *c.*8 minutes, the Glasgow Main mine working at around 22 minutes 48 seconds, and the obstruction in the Glasgow Main mine working from 23 minutes.

5.2 SUMMARY AND OUTPUTS

The following wireline logs were run within borehole GGA08 (Table 6)

Table 6 Wireline logs run for GGA08. All downhole depths in the released datasets were measured from the drill platform depth 11.82 m. *Open hole logs and CCTV depths are approximate.*

Wireline Log	Depth below drill platform depth (11.82 m AOD)	Depth below final datum (top casing) (11.37 m AOD)
Gamma cased hole	2.7-87.9	2.25 – 87.45
Caliper cased hole	2.7-87.9	2.25 – 87.45
Inclination cased hole	2.7-87.9	2.25 – 87.45
Azimuth cased hole	2.7-87.9	2.25 – 87.45
Cement Bond Log	1.67- 87.8	1.22 – 87.41
Gamma open hole	0 – 88.3	-0.45 – 87.85
Caliper open hole	0 – 88.3	-0.45 – 87.85
Optical camera	31 - 88	30.5 – 87.5
CCTV camera	0 - 88	-0.45 – 87. 55

The logs were output in the following formats:

1. PDF

Separate PDF files showing the cased logs and the open hole logs are included [*Cased_hole_GGA08_BoreholeGeometry.pdf, Cased_hole_GGA08_CementBondLog.pdf* and *Open_hole_GGA08_Composite_051219.pdf*]. The header data provides information about the borehole location, the drilling datum and the casing and drill depths of each section for the cased hole logs only. Note that all depths on the logs are based on the drill platform datum.

2. LAS

Conventional geophysical logs are provided in LAS format [*Cased_hole_GGA08_BoreholeGeometry.las, Cased_hole_GGA08_CementBondLog.las and Open_hole_GGA08_Composite_051219.las]*. This is a column separated ASCII format. Almost all specialist logging software is capable of loading and interpreting geophysical log data in LAS format. In addition to this LAS files can also be viewed in any software capable of manipulating an ASCII text file, including Notepad (Windows), VI (Unix) or spreadsheets (e.g. Microsoft Excel).

Open hole logs have also been provided as .csv and .WCL files as supplied by the contractor. A file of dip data is also included as provided by the contractor [*Open_hole_GGA08_DipsData_051219.csv and .txt*] corresponding to the interpretations on *Open_hole_GGA08_Composite_051219.pdf*, this data has not been checked and as is received.

3. HTML/BMP

The optical camera is output as an HTML file with associated .bmp and other files. There is no header information. '*index.html'* will open in Google Chrome or equivalent, though may take a few minutes depending on computing power.

4. MP4

The CCTV file is output as a MP4 file [*GGA08_CCTV_041219.mp4*] and can be read by most video players.

5.2.1 Problems and caveats with the wireline logs

No editing has been done on the cased hole logs. BGS reviewed the data and made minor comments primarily relating to the header information and the scale used in the .pdf files.

The borehole is roughly vertical (inclination less than 2 degrees) and undeviated. The borehole azimuth log shows a lot of variation between 0 and 360 degrees because of very slight changes in direction from the vertical.

The cement bond log [*Cased_hole_GGA08_CementBondLog.pdf*] only records useful data when the sensor is below water level. For borehole GGA08, the water level was 2.2 m, so the valid data is between 2.2 – 87.8 m. The amplitude in GGA08 is lower than in the other two cement bond logs is in wells GGA02 & GGA05 because it was reprocessed by the logging operator to measure the amplitude at the time given by the transit time (TX1 – RX1) values of the cement bond log, whereas in the other two wells, the amplitude was picked as the absolute value of maximum amplitude found within a user defined time window.

The open hole logs [e.g. *Open_hole_GGA08_Composite_051219.pdf]* and the optical camera were acquired for the purposes of providing real time data during the drilling. They have not been edited or processed. There is missing header information and any detailed review of these logs must be done with the understanding of their original purpose. Users should note that the depth reference was incorrect and there is a *c*.0.8 m offset from the drilled depths noted at key horizons (see Figure 6 below).

The CCTV camera was run to obtain information about the Glasgow Main mine working obstruction (see Table 4 and section 8). There are no depths added to the MP4 file so it should be used purely as a visualisation tool and not for interpretative purposes.

6 Archived rock chip samples

Section 4.2 describes how representative one litre tubs of rock chips were taken every metre during open hole drilling. These samples have been archived in the National Geological Repository at BGS Keyworth for future research. The data pack includes a spreadsheet summarising the rock chip tubs available [*GGA08_archived_rock_chips.xlsx*]. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGA08.pdf and .xlsx*].

During drilling of GGA08, a set of 'preserved' unwashed rock chip samples representative of every 3 m was collected in a sample bag, placed in an airtight jar (Areojar) with a de-oxygenating sachet and kept in a fridge (on site) and cold store (at BGS). These samples are available for future research.

During-drilling fluid and rock chip samples were also supplied to a number of University groups for their ongoing research. Data from that research will be returned to NERC/BGS data centre and made publically available on a 2 year timescale.

7 Initial hydrogeological indications

A brief summary is provided here of various hydrogeological measurements recorded during borehole construction, cleaning and test pumping. Further detail will be provided in future hydrogeological information releases.

7.1 BOREHOLE CLEANING

Borehole cleaning was undertaken after the installation of casing and slotted screen with the aim of removing any drilling-related material and fluid from inside the casing.

Borehole cleaning was done using an airlift and carried out for two hours, by which time the field parameters being monitored (Table 7) had stabilised. A summary of the borehole cleaning carried out is in Table 7.

Table 7 Overview of GGA08 borehole cleaning parameters

Technique used	*Airlift*
Date	*09/01/2020*
Length of time borehole cleaning continued (minutes)	*120*
Approximate volume of water removed (m^3)	*25.94*
Borehole water level drawdown (m)	*Not recorded*
Borehole volume (m^3)	*4.27*
Number of borehole volumes removed	*Approx. 6*
Field parameters measured for borehole cleaning monitoring	*Dissolved oxygen/ SEC (conductivity)/ Temperature/ Oxidation-reduction potential/ pH/ turbidity*
Average temperature of removed water (°C)	*10.2*
Summary of outcome	*At the end of cleaning the water quality field parameters were stable and the turbidity readings were consistently zero*

7.2 TEST PUMPING

Test pumping was carried out to establish the hydraulic characteristics of the mine workings, shallow bedrock and superficial deposits, and the extent to which these units are connected at individual sites and across different sites. The first consistent set of groundwater samples for chemistry analysis was also collected during test pumping.

Two tests were carried out. A step test was carried out first to establish yield-drawdown relationships in the borehole, allow selection of an appropriate pumping rate for a constant rate test, and allow estimations of borehole efficiency. After groundwater level recovery, a constant rate test at a suitable rate to allow estimation of aquifer transmissivity and other hydraulic parameters was completed.

Each test was carried out using a submersible pump of suitable capacity to provide the desired pumping rate(s). During each test, groundwater levels in the tested borehole were monitored using a downhole pressure transducer, and also by manual dips. Groundwater levels in all other boreholes on site were monitored throughout the test using a downhole pressure transducer, and by occasional manual dips.

Initial hydrogeological indications from the test pumping suggest that borehole GGA08 is very high yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

Table 8 Overview of GGA08 test pumping parameters

Step test	
Date of step test	*03/02/2020*
Number of steps	*5*
Length of steps (hours)	*1*
Length of pumping during step test (hours)	*5*
Length of manually monitored recovery during step test (hours)	*1*
Pumping rates for each step (l/s)	*5/10/15/20/25*
Maximum drawdown at end of final step (m)	*1.44*
Constant rate test	
Date of constant rate test	*04/02/2020*
Length of pumping during step test (hours)	*5*
Length of manually monitored recovery during step test (hours)	*1*
Pumping rate for constant rate test (l/s)	*20*
Maximum drawdown at end of constant rate test (m)	*1.49*
Average groundwater temperature during constant rate test (°C)	*12.4*
Groundwater geochemical samples collected during constant rate test	*Two samples: one after 2 hours and one after 4 hours*

8 Initial geological interpretation

Integration of drillers' information, rock chip logs, preliminary hydrogeological indications from borehole cleaning and test pumping, downhole optical camera and wireline log data together with correlation to legacy borehole and mine plan data has allowed an initial geological interpretation of borehole GGA08 (Figure 1).

The made ground composition including sandstone, slate and cement is as expected from legacy data nearby and the prior land use history as a site where housing demolition rubble was disposed of. The thickness of the made ground at 9.4 m drilled depth was greater than pre-drill prognosis (Appendix C), though compatible with a complex and variable anthropogenic deposit.

The superficial deposits are interpreted as a Quaternary age succession of glacial and post-glacial deposits, following existing legacy interpretations and geological models (e.g. Arkley, 2019). A preliminary interpretation comprises sand, silt and clay and clay of the alluvial Gourock Sand Member to around 15 m. Clay with gravel and sand to *c.*24 m drilled depth is interpreted as the raised marine Paisley Clay Member (Figure 1), though the position of the base is unclear. From 24 m to rockhead at 33.8 m drilled depth, drilling returns of clay, silt, sand and gravel were observed, with a dominant gravel and sand between 31 m to rockhead. However, as seen in other boreholes (e.g. GGA03r) the use of direct flush during drilling used may have affected the sample returns. An additional consideration is that borehole stability was a challenge in the lower part of the superficial deposits and that sand and gravel may have moved into the borehole, influencing the drill returns. This section likely represents one or both of the glaciofluvial Broomhouse Sand and Gravel Formation and a sandy glacial diamicton of the Wilderness Till Formation (Figure 1). Rockhead at 33.8 m drilled depth is within error limits of pre-drill prognosis (Appendix C).

The bedrock succession appears typical of the Scottish Middle Coal Measures Formation. The *c.*17 m section above the Glasgow Upper coal is more claystone- and siltstone-dominated compared to other UKGEOS and legacy boreholes nearby and the cored reference section in GGC01 (Kearsey et al. 2019; Figure 1). The *c.*20 m claystone- and siltstone-dominated Glasgow Upper to Glasgow Ell section and interbedded sandstone, siltstone and claystone Glasgow Ell to Glasgow Main section are typical. The Cambuslang Marble (musselband) was recognised as shell fragments in the rock chips, and is visible on the optical camera image at around 85.3 m drilled depth (Figure 6). *Note that the optical image and caliper open hole data have an incorrect depth reference and around 0.8m needs to be added to the depths to match the Drillers' and BGS logs.*

8.1 MINE WORKINGS

The ***Glasgow Upper coal and mine working*** was recognised from 52.5 to 53.7m drilled depth from drilling indications including faster drill rate, large quantities of coal and mudstone in the drill cuttings and a smell of hydrogen sulphide (this depth interval being within the error limits of the pre-drill prognosis.) Above the coal drilling was faster, with excess water in the drilling fluid returns suggesting water production from fractures. A soft grey clay was returned beneath the coal to around 54.5 mbgl.

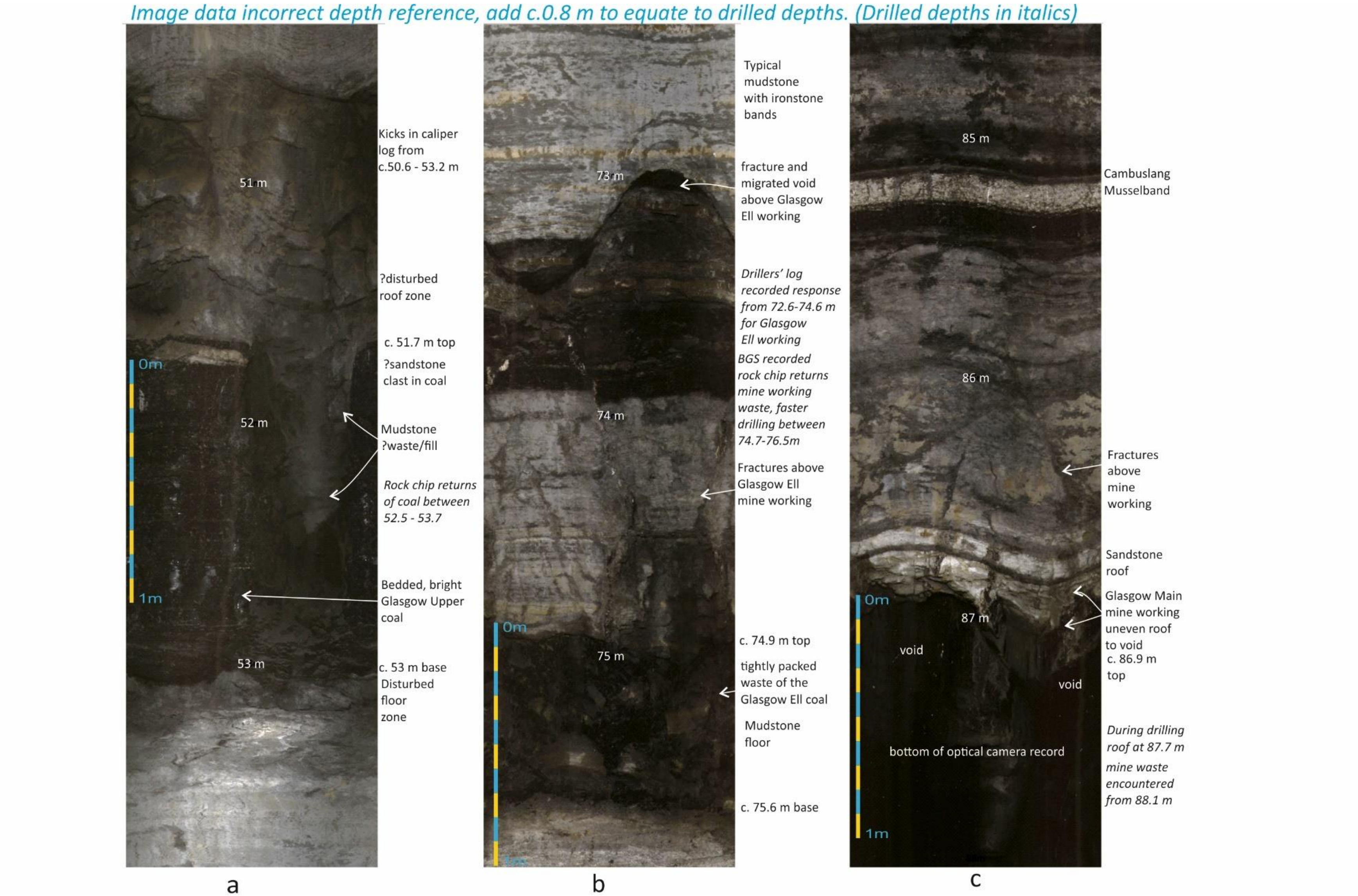


Figure 6 Optical camera image of the three mineworkings encountered in GGA08 (a) Glasgow Upper coal and mine working (b) Glasgow Ell packed waste and fractures associated with the mine working (c) Glasgow Main mine working

The optical camera image shows coal from around 51.7 – 53 m as well as an area of broken grey mudstone, suggesting that the borehole penetrated the edge of a coal pillar (Figure 6). A disrupted zone is also imaged in the mudstone above the Glasgow Upper coal, and below the coal. The open hole caliper data has kicks from c.50.6 – 53.2 m drilled depth.

The 1.2 m thickness of the Glasgow Upper coal is typical of that observed in the UKGEOS boreholes and legacy data, but thinner than the 1.7 m recorded in borehole GGA08 adjacent.

Mine abandonment plans* show stoop and room (pillar and stall) workings of the Glasgow Upper coal in the vicinity of GGA08 on the 1884 plan, removed to total extraction by the time of the 1933 plan. A fault (3.5ft throw down to the east) is shown around 20 m to the south-west of GGA08 and a 'want' or washout of the coal is present around 30 m to the east.

The ***Glasgow Ell mine working*** was recognised from 74.7 to 76.5 m drilled depth from drilling indications including faster drilling, abundant grey clay balls, coal fragments and mudstone at shaker screens with an interpretation of mine waste.

The optical camera data shows a packed mine waste from 74.9 – 75.6 m and overlying fractured strata with migrated voids between 73.0 – 74.9 m and the open hole caliper data also shows a number of kicks in this interval (Figure 6). The drillers' log recorded the Glasgow Ell mineworking from 72.6 – 74.6 m with broken strata to 76.1 m drilled depth.

The Glasgow Ell mine working waste and fractured zone is compatible with a mine abandonment plan (1933) which records total extraction in this area, with an extraction date of January 1881. A NW-SE trending fault of throw 9 ft (2.7 m) down to the east is shown on the mine abandonment plan 15 m to the north-west of GGA08. The pre-drill prognosis had been adjusted from that shown in Appendix C based on results of drilling GGA02 and GGA05, such that the depth of the Ell mineworking in GGA08 was as expected and compatible with mine spot height information some distance away. The 0.7 m thickness of the tightly packed waste on the optical camera and the fracturing and migrated voids above, suggest collapse of the mine working from the expected mined thickness of *c*.1.2+ m coal thickness on the mine abandonment plan (1933) and *c*1.4 m Glasgow Ell coal thickness in GGC01 (Kearsey et al., 2019).

The mine abandonment plans for the ***Glasgow Main mine working*** record total extraction of the area around GGA08 with a number of former access roads dated 1924 – 1926 marked within a few metres of the borehole location (and within error of the georeferencing of the mine plan). A NW-SE trending fault with throw to the east is shown around 10 m to the south-west of GGA08, a spot height of -78 m rel OD (741 ft rel colliery datum/equates to 89 m drill length) is around 44 m away, and a worked coal thicknesses of 36 inches is noted (0.91 m) nearby.

During drilling the Glasgow Main mine working, rock chip returns included fragments of tarpaulin or rubber material interpreted as a roof covering and then a void from 87.7 – 88.1 m drilled depth. Underneath the void, wood fragments and mine waste were returned (Figure 6) with an accompanying hydrogen sulphide smell. The base of working was at 90.7 m drilled depth into underlying sandstone. Given the 3 m thickness of the mine working, the borehole is interpreted to have penetrated a roadway of the Glasgow Main, in agreement with those observed on the mine abandonment plan.

Open hole optical camera and CCTV data show an uneven sandstone roof to a water filled void of the mine working (Figure 6). The caliper data shows a kick at the void, right at the end of the caliper run. Fractures can be observed on the optical camera image for around a metre above the roof of the mine working (Figure 6).

A CCTV camera was run to characterise the obstruction fallen into to the borehole in the final stages of construction – this can be seen at the end of the journey down the borehole

* Mine abandonment plan scans available from The Coal Authority

[*GGA08_CCTV_041219.mp4*] and is interpreted to be a sandstone block lying at a steep angle, possibly a fallen block of roof material as it appears that a pit prop can be seen to the left-hand side of the block. The borehole casing was installed to sit above this obstruction, in the water-filled mine working void, after several attempts to drill though the block failed (Table 4).

9 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.

Datasets are available at https://www.ukgeos.ac.uk/data-downloads

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Appendix A: Summary of borehole GGA08 files in this data release

Table 9 Summary of files in the borehole GGA08 information release

Description	File name	File type
BAM Drillers log – an engineering format log with lithological information as recorded on drill site by the drilling contractor (not a geotechnical engineer). *NOTE: depths are given relative to drill platform level*	Drillers_Log_GGA08.pdf UKGEOSCuningar_BAA4203_FinalAGS.AGS *(this covers all 11 UKGEOS boreholes at Cuningar Loop)*	PDF AGS format
BGS log- detailed. A log recording the percentage of different lithologies returned as rock chips during the open hole drilling on a metre by metre basis. Included as a spreadsheet and a visualisation plot. *NOTE: depths are given relative to drill platform level*	Detailed_BGS_Rockchiplog_GGA08.pdf Detailed_BGS_Rockchiplog_GGA08.xlsx	XLS, PDF
BGS summary log – a 1 or 2 page visualisation of the BGS log and summary interpretation. *NOTE: depths are given relative to drill platform level*	Summary_BGS_Log_Page1_GGA08.pdf Summary_BGS_Log_Page2_GGA08.pdf	PDF
Wireline (geophysical) downhole data for cased hole logs *NOTE: depths are given relative to drill platform level*	Cased_hole_GGA08_BoreholeGeometry.pdf and .las Cased_hole_GGA08_CementBondLog.pdf and .las BAM Nuttall Glasgow Report Final.pdf 'Wireline Logging Report for UKGEOS Glasgow Conducted by Robertson Geo Ltd On behalf of BGS 9/1/20 – 10/1/20.pdf'	LAS, PDF
Wireline (geophysical) downhole data for open hole logs: working data *NOTE: depths are given relative to drill platform level*	Open_hole_GGA08_Composite_051219.pdf *Note: open hole wireline and optical image data incorrect datum used - please add around 0.8 m to equate to drilled depths in Drillers'and BGS logs.* Open_hole_GGA08_DipsData_051219.txt and .csv Files received from Contractor corresponding to dips interpreted in the opne hole composite log, not checked	PDF, LAS, CSV, WCL TXT, CSV
Fibre optic cable installation report *NOTE: depths are given relative to drill platform level*	FibreOpticCable Installation Report BGS V1.2 GGA08 180520.pdf	PDF
Optical camera data *NOTE: depths are given relative to drill platform level*	In 'Optical_camera' folder, use 'index.html' to open. *Note: open hole wireline and optical image data incorrect datum used - please add around 0.8 m to equate to drilled depths in Drillers'and BGS logs.*	HTML, BMP
CCTV *No depths are given*	GGA08_CCTV_041219.mp4	MP4

Spreadsheet of archived rock chip samples *NOTE: depths are given relative to drill platform level*	GGA08_archived_rock_chips.xlsx	XLSX

Appendix B: Detailed installation method for ERT and DTS cables

The ERT cable was loaded onto a cable reel and passed over a sheave wheel which was mounted at an elevation of approximately 3 m. The fibre optic cable was loaded onto a separate cable reel and also passed over the sheave wheel. It was ensured that neither cable dragged on the floor or caught on any other equipment. The Boode well casing was measured from bottom to top edge of the exposed outer surface without the inclusion of the threaded joining sections. The casing length was in the order of 0.9 m per section. Based on borehole installation information including length of screen, desired annulus seal location and length of sump, the nominal positions of the ERT electrodes and fibre-optic cable centralisers was marked onto the casing.

The casing section to be installed was winched into a vertical position at a working height above the borehole. The dead end of the first ERT cable was attached to the base of the screened section and the first sensor was fastened onto the casing in the marked location. The fibre-optic bottom hole assembly (BHA) was placed onto the casing above the screen and fastened into position. It was wrapped in an insulation material to ensure that the metal did not affect the ERT and wrapped in duct tape to protect the equipment as it moved down the borehole. The ERT electrode and fibre-optic cable was secured in place with cable ties and duct tape. The casing was lowered into the borehole and the cables were guided through the centralisers. The next casing string was hoisted into the vertical position and the attachment of sensors resumed.

The screened section had sensors attached directly to it and the cables had to pass through the fins of the rubber seal. The two cables were fastened to the seal with cable ties and jubilee clips and then taped tightly to ensure that there were no loose ends.

Once all of the sensors were in place, the remaining cable was spooled off and the cables within the borehole were tested. Both the ERT cable ends and the fibre-optic cable end were protected from moisture, water ingress and dirt by placing them into a sealed bag and placing into a dry and secure box.

Subsequently the annulus of the borehole was grouted between the casing and rock wall and around the cables. The cabinets with the data recording equipment (PRIME for the ERT and DTS interrogation box for the fibre optics) were installed at a later date.

Appendix C Pre-drill borehole prognosis

The pre-drill borehole prognosis (Figure 7) was produced from semi-regional superficial deposits, bedrock and mine 3D geological models (Arkley, 2019, Burkin and Kearsey, 2019) and legacy boreholes nearby. The prognoses were used in planning the depth, spacing and design of the boreholes and were indicative of the likely unit depths to be encountered. As the prognoses were not based on detailed site specific interpretations, the uncertainty and error values were understood to be quite large.

The pre-drill borehole prognoses as shown in Figure 7 were updated on paper at site during the drilling phase, for example the confirmed depth of the Glasgow Main mine working in GGA05 informed the expected depth of GGA08 Glasgow Main mine working. Being the pre-drill information, Figure 7 does not represent the learnings or local, site specific considerations used during the drilling phase.

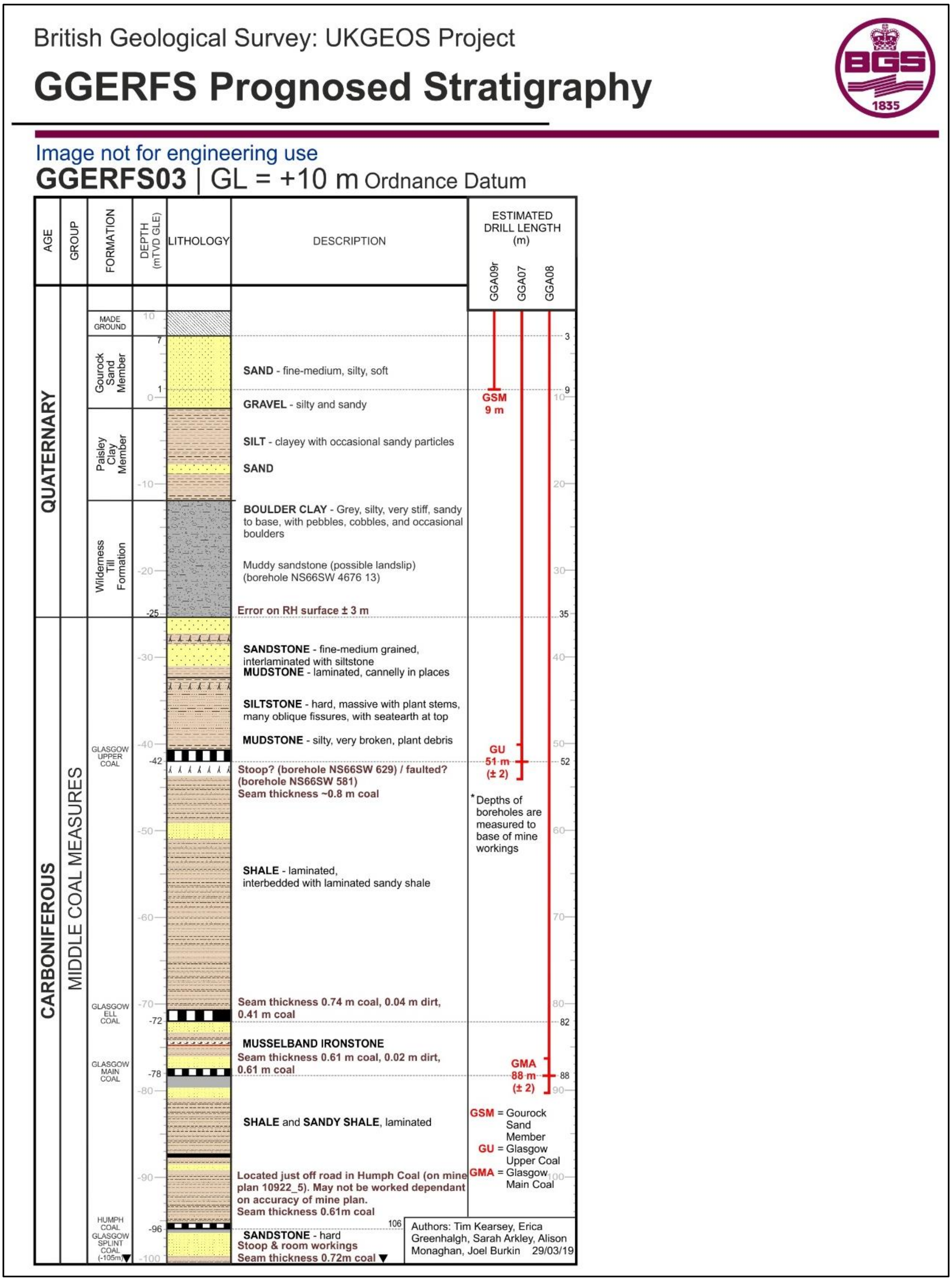

Figure 7 Pre-drill borehole prognosis for site GGERFS03, boreholes GGA07, GGA08, GGA09r based on semi-regional geological models and nearby legacy boreholes.