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Mine water characterisation and monitoring borehole GGA05, UK Geoenergy Observatory, Glasgow

UK Geoenergy Observatories Programme

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BRITISH GEOLOGICAL SURVEY

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NE corner 262347, 662685

Front cover

Installation of screened section of borehole GGA05 with ERT cable and sensor on outside of uPVC casing

Bibliographical reference

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BRITISH GEOLOGICAL SURVEY

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TABLES

Summary

This report and accompanying data release describe the 'as-built' borehole GGA05 at the UK Geoenergy Observatory in Glasgow, as well as summarising hydrogeological testing and an initial geological interpretation.

Mine water borehole GGA05 at the UK Geoenergy Observatory in Glasgow is screened across the Glasgow Main mine working void and overlying sandstone roof. The mine working is a water-filled void and initial hydrogeological indications from the test pumping are of a very high yielding borehole. Borehole GGA05 has ERT and DTS cables installed between the borehole casing and the rock wall and has a hydrogeological data logger installed within the borehole.

1 Introduction

Drilling of the mine water characterisation and monitoring borehole GGA05 at Cuningar Loop, in Rutherglen, Glasgow City Region took place between 1st July and 11th October 2019 (start of drilling to casing installation date). The borehole targets the Glasgow Main mine working, with the slotted screen at -71.48 to -74.18 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 provide 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_GGA05.pdf* and *Summary_BGS_Log_Page2_GGA05.pdf*].
- Appendix A lists the files making up the information release.

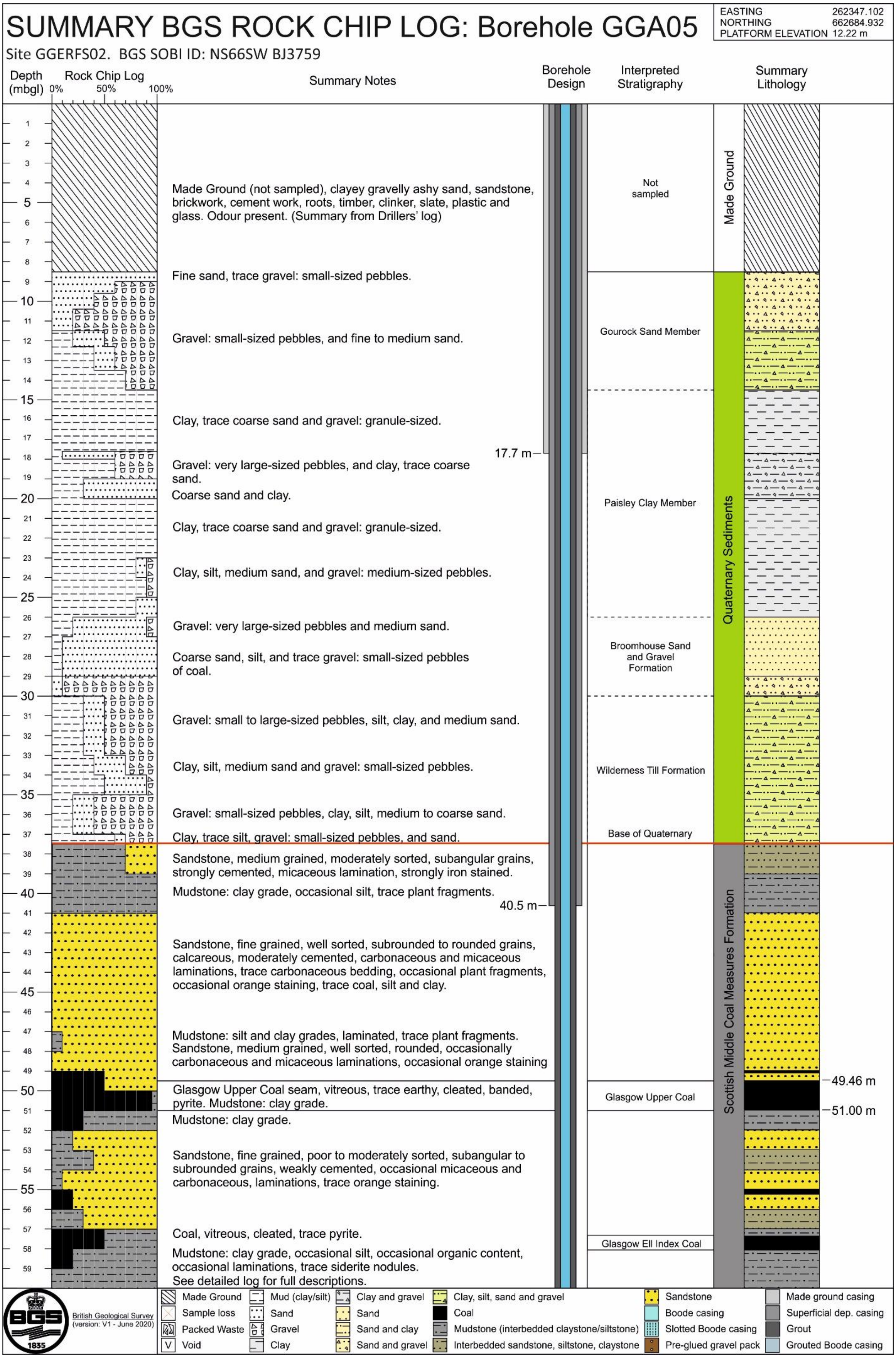
1.1 CITATION GUIDANCE

Any use of the data should be cited to:
DOI: https://dx.doi.org/10.5285/714fe9fc-ce77-4479-8053-1c5fd4e86f06 H F Barron, V Starcher, A A Monaghan, K Shorter, K Walker-Verkuil. 2020. UK Geoenergy Observatories Glasgow Borehole GGA05 Data Release
and this report cited as:
BARRON H F, STARCHER V, MONAGHAN A A, SHORTER K, WALKER-VERKUIL K. 2020. Mine water characterisation and monitoring borehole GGA05, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/025.

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

Table 1 GGA05 as-built summary data

Borehole number	GGA05	
Site	GGERFS02	
Easting (British National Grid)	262347.102	
Northing (British National Grid)	662684.932	
Drilling platform level (metres above Ordnance Datum AOD)	12.22	
Drilling started	01/07/2019	
Final casing installed	11/10/2019	
As-built borehole start height or datum (top Boode casing flange, metres AOD)	12.12	
Installation details		
Borehole detail	**Depths (drill length from drill platform level, metres)**	**Diameter size**
Made ground casing	0.0 – 17.7	24" (610 mm OD x 575 mm ID)
Rockhead casing	0.0 – 40.5	18" (457 mm OD x 425 mm ID)
Boode Well (BW) plain casing	0.0 – 83.7	280 mm OD x 248 mm ID
BW Slotted pipe	83.7 – 86.4	280 mm OD x 248 mm ID
BW Casing Sump	86.4 – 88.1	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	8.5	3.72
Base of superficial deposits	37.5	-25.28
Top Glasgow Upper coal	49.46	-37.24
Base Glasgow Upper coal	51.00	-38.78
Top Glasgow Ell Coal (from optical camera)	71.9	-59.68
Base Glasgow Ell Coal (from optical camera)	72.6	-60.38
Top Glasgow Main mine working	84.66	-72.44
Base Glasgow Main mine working	85.36	-73.14
Final drilled length	88.5	-76.28
BGS SOBI reference number	NS66SW BJ 3759	BGS ID 20693600


SUMMARY BGS ROCK CHIP LOG: Borehole GGA05
EASTING 262347.102
NORTHING 662684.932
PLATFORM ELEVATION 12.22 m
Site GGERFS02. BGS SOBI ID: NS66SW BJ3759
Depth (mbgl)
Rock Chip Log 0% 50% 100%
Summary Notes
Borehole Design
Interpreted Stratigraphy
Summary Lithology
Made Ground (not sampled), clayey gravelly ashy sand, sandstone, brickwork, cement work, roots, timber, clinker, slate, plastic and glass. Odour present. (Summary from Drillers' log)
Fine sand, trace gravel: small-sized pebbles.
Gravel: small-sized pebbles, and fine to medium sand.
Clay, trace coarse sand and gravel: granule-sized.
Gravel: very large-sized pebbles, and clay, trace coarse sand.
Coarse sand and clay.
Clay, trace coarse sand and gravel: granule-sized.
Clay, silt, medium sand, and gravel: medium-sized pebbles.
Gravel: very large-sized pebbles and medium sand.
Coarse sand, silt, and trace gravel: small-sized pebbles of coal.
Gravel: small to large-sized pebbles, silt, clay, and medium sand.
Clay, silt, medium sand and gravel: small-sized pebbles.
Gravel: small-sized pebbles, clay, silt, medium to coarse sand.
Clay, trace silt, gravel: small-sized pebbles, and sand.
Sandstone, medium grained, moderately sorted, subangular grains, strongly cemented, micaceous lamination, strongly iron stained.
Mudstone: clay grade, occasional silt, trace plant fragments.
Sandstone, fine grained, well sorted, subrounded to rounded grains, calcareous, moderately cemented, carbonaceous and micaceous laminations, trace carbonaceous bedding, occasional plant fragments, occasional orange staining, trace coal, silt and clay.
Mudstone: silt and clay grades, laminated, trace plant fragments.
Sandstone, medium grained, well sorted, rounded, occasionally carbonaceous and micaceous laminations, occasional orange staining
Glasgow Upper Coal seam, vitreous, trace earthy, cleated, banded, pyrite. Mudstone: clay grade.
Mudstone: clay grade.
Sandstone, fine grained, poor to moderately sorted, subangular to subrounded grains, weakly cemented, occasional micaceous and carbonaceous, laminations, trace orange staining.
Coal, vitreous, cleated, trace pyrite.
Mudstone: clay grade, occasional silt, occasional organic content, occasional laminations, trace siderite nodules.
See detailed log for full descriptions.
17.7 m
40.5 m
Not sampled
Gourock Sand Member
Paisley Clay Member
Broomhouse Sand and Gravel Formation
Wilderness Till Formation
Base of Quaternary
Glasgow Upper Coal
Glasgow Ell Index Coal
Made Ground
Quaternary Sediments
Scottish Middle Coal Measures Formation
49.46 m
51.00 m
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

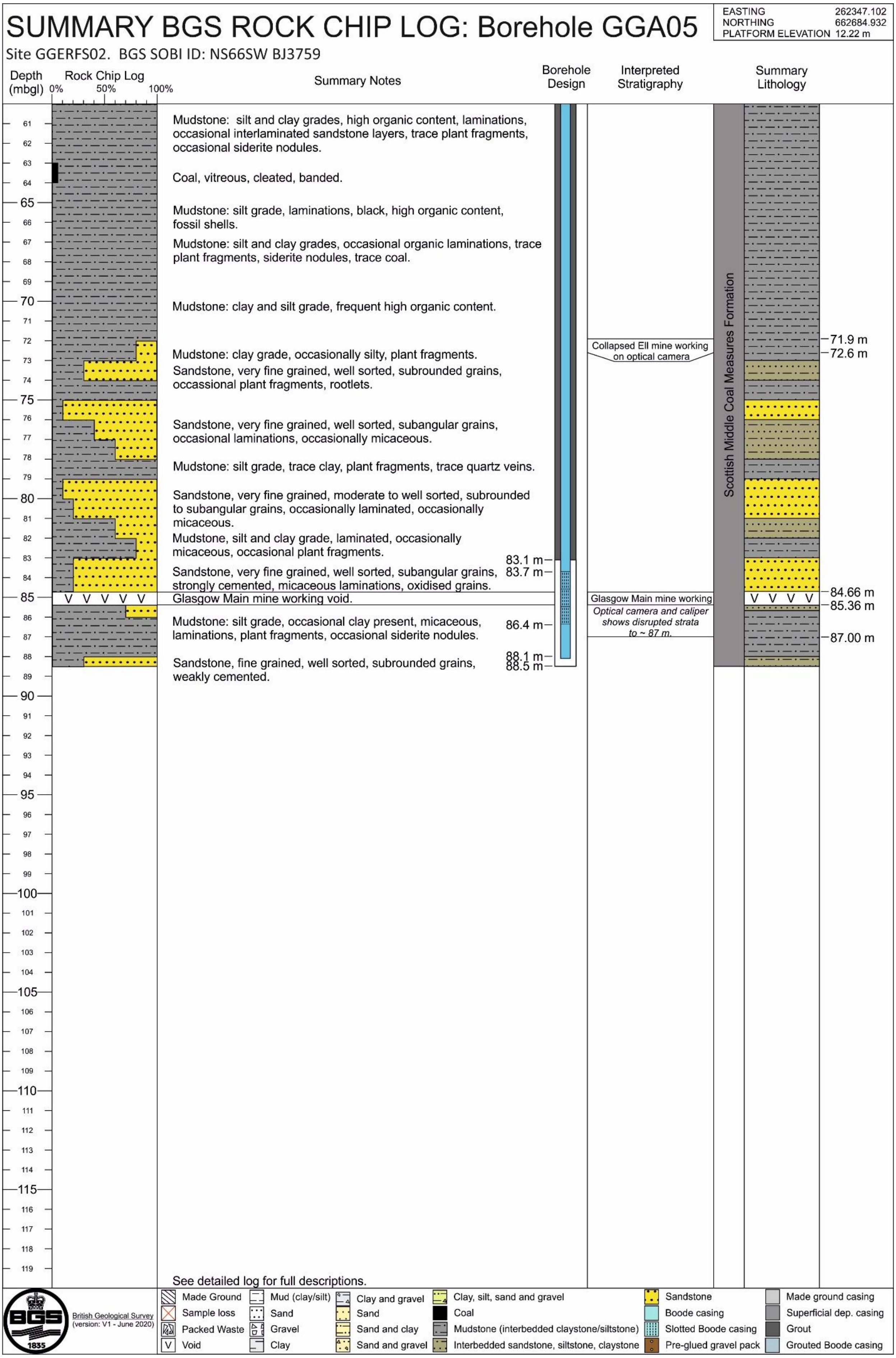


Figure 1 GGA05 summary log based on rock chip returns

1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGA05 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).

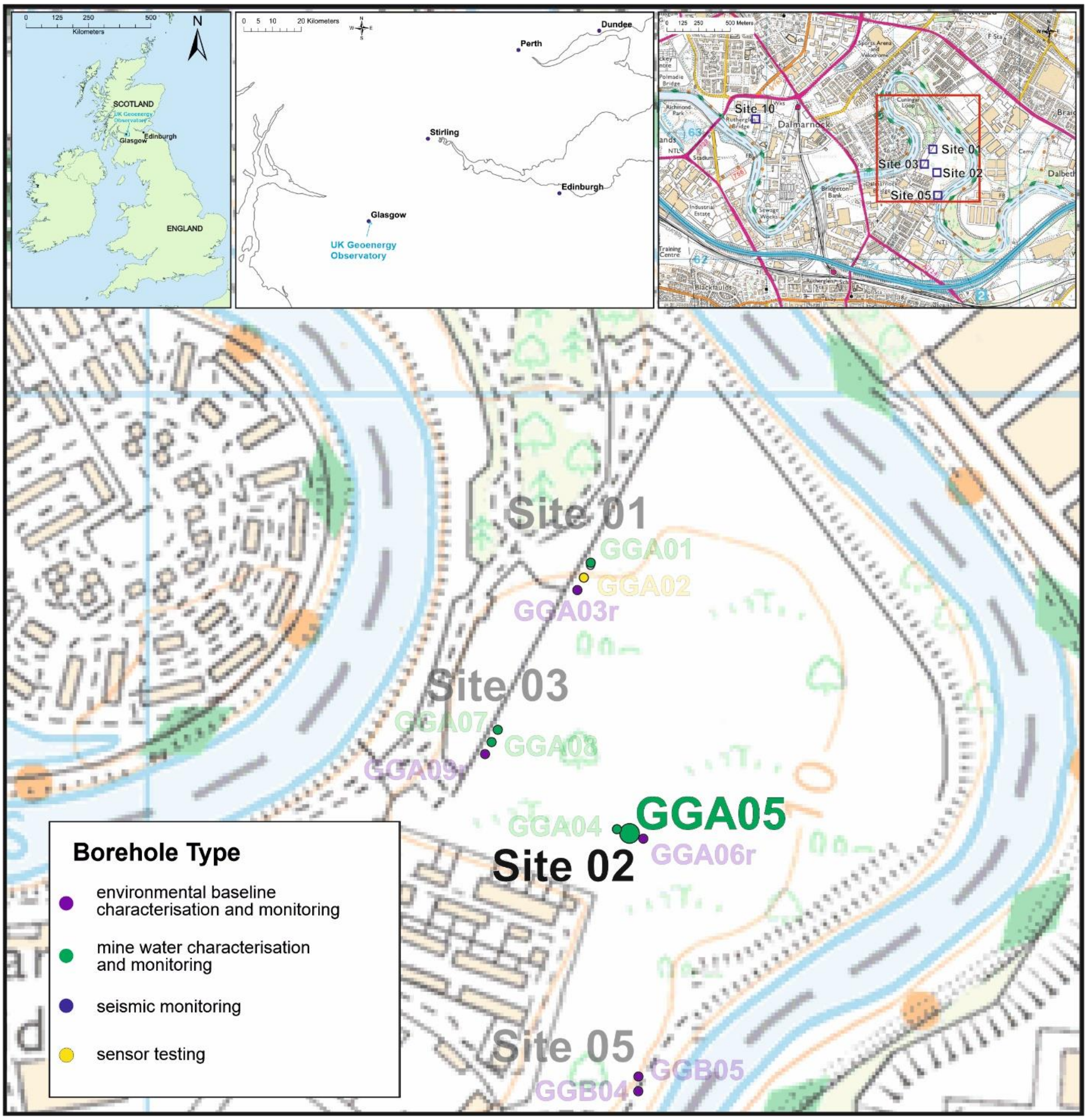


Figure 2 Location map of borehole GGA05, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

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).

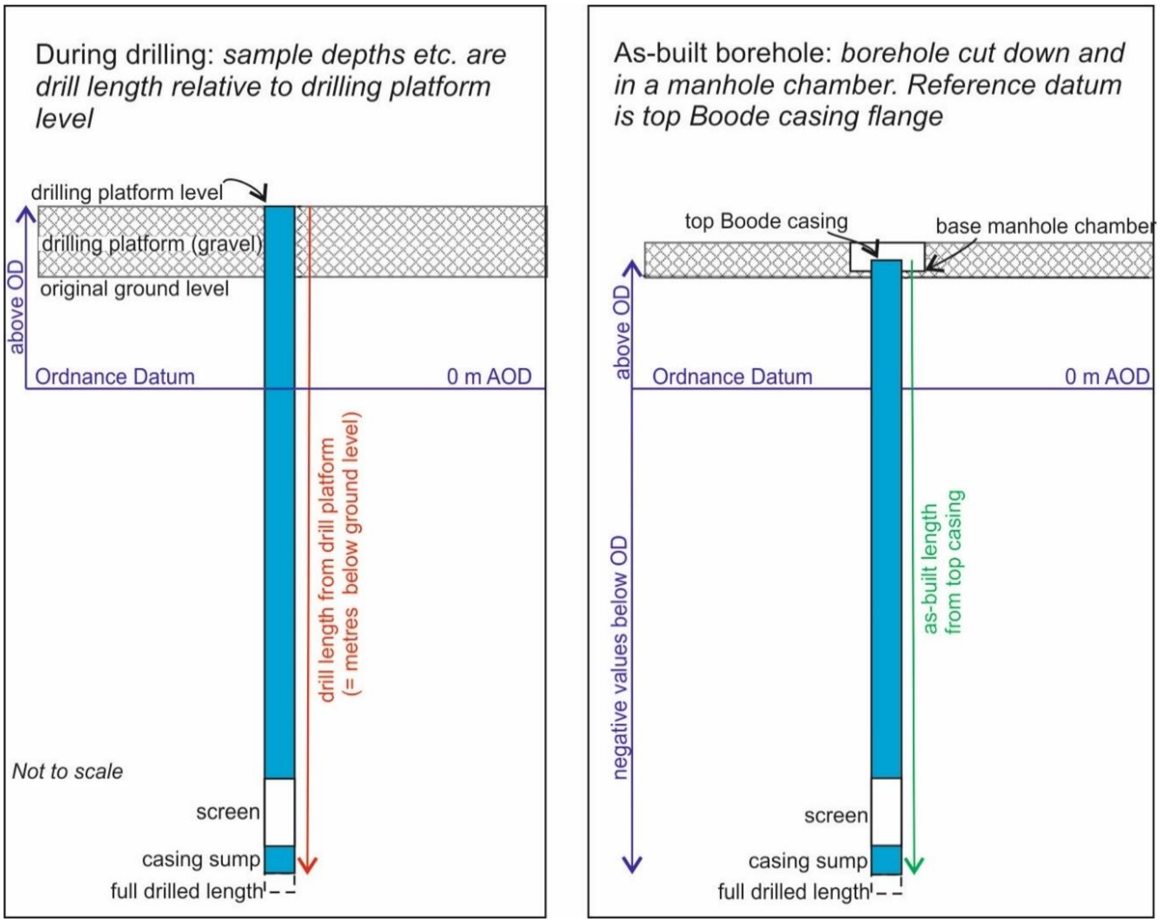


Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)

Table 2 Summary of start heights and datums used for GGA05

Stage	**Borehole start height/ reference datum used (m AOD)**	**Used in**
Drilling platform level – built up gravel platform	12.22	Drillers and BGS logs, sample depths, wireline and optical datasets. ERT and DTS cable installation.
As-built borehole start height (top Boode casing flange)	12.12 (recorded as 12.116)	Reference datum for future Observatory users
Conversion Rock chip sample depths, wireline and optical depths – to convert from drill length to beneath as-built borehole start height		As-built depth below start height = drill length – (12.22 – 12.12) m *i.e* As-built depth below start height = drill length – (0.1) m

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.

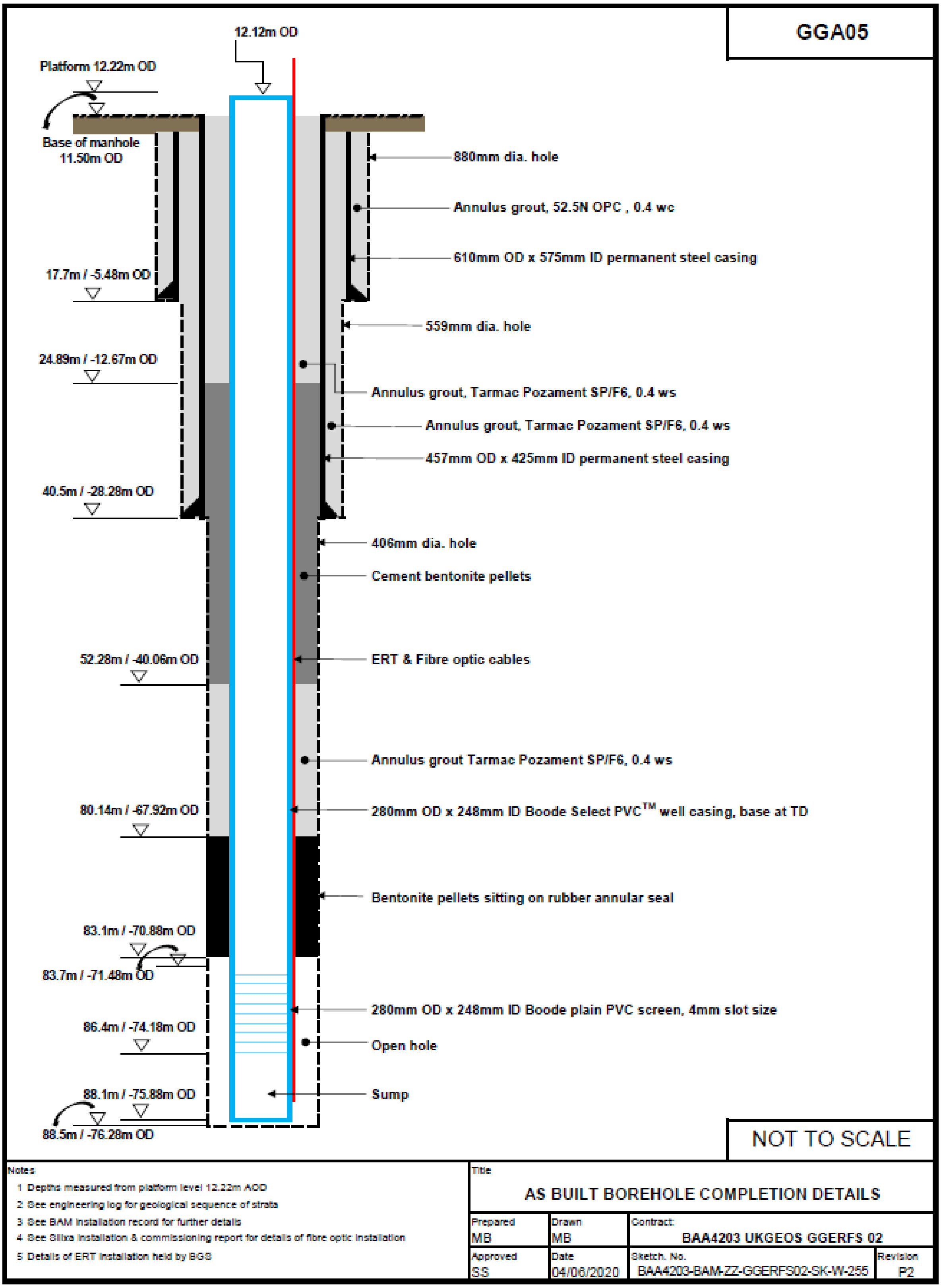


Figure 4 As-built borehole schematic for GGA05

2.1 BASIS OF DESIGN

The basis of the GGA05 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. In practice it was found that the Glasgow Upper coal was intact at this location, and that the Glasgow Ell mine working was not identifiable during drilling (see sections 3 and 9 below for further details). Consequently, GGA05 progressed to the Glasgow Main target interval without the need for 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 GGA05 (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 no pre-formed or surrounding filter pack.

vi. A sump section was included in the borehole design to accommodate the termination unit of the fibre optic sensor cables (see below) and to catch any fines that enter through the slotted screen.

vii. A finned annular rubber seal was placed at 83.1 mbgl above the Glasgow Main mine working to support the emplacement of a permanent grout seal. A layer of bentonite pellets was first emplaced (80.14 – 83.1 mbgl) to seal and reduce pressure on the finned seal. Once the bentonite had set sufficiently (24 hours) the annulus was grouted in stages with SP/F6 mix and bentonite cement pellets (Figure 4).

Table 3 Summary of heights for as-built borehole features for GGA05

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	83.7	-71.48	83.6
Base slotted screen	86.4	-74.18	86.3
Base installed casing sump	88.1	-75.88	88.0
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: 87.6	Base of Termination unit depth: -75.38	Base of Termination unit depth: 87.5

3 Drilling, casing, annulus grouting and testing methodology

Borehole GGA05 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 GGA05, further details are given in the borehole information summary at the end of the Driller's 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 with both reverse circulation and direct flush was used. The bedrock section was drilled using 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).

Drilling and installation summary:	
01/07/2019	Drilled and installed made ground and superficial casing with BAM piling rig to 17.7 mbgl with a 34 ¾" (880 mm) auger
02/07/2019	Made ground and superficial casing grouted
19/08/2019 – 27/08/2019	Drilled superficial deposits with Conrad rig from 17.7 mbgl to 30.5 mbgl with a 22" (558.8 mm) tri-cone bit **Problems Encountered:** 20/08/2019 – Issues with clogging of bit while drilling out sand in casing using reverse circulation drilling 21/08/2019 – Switched to direct flush drilling 23/08/2019 – Changed to reverse circulation drilling 27/08/2019 - Hole had collapsed from 30.5 to 26.0 mbgl – Drill bit sticking due to gravel clogging – switched back to direct flush drilling
02/09/2019 – 05/09/2019	Continue drilling to rockhead with direct flush from 23.0 (hole had collapsed) – 41.0 mbgl – bentonite mud added to drill flush to increase hole stability Rockhead encountered at 37.5 mbgl
06/09/2019 – 10/09/2019	Superficial to rockhead casing installed and grouted. Casing installed at 40.5m bgl
03/10/2019 – 08/10/2019	Drilled out grout and continued to Glasgow Upper mine working with a 16" tri-cone drill bit 04/10/2019 – Glasgow Upper coal seam encountered 49.46 – 51.00 mbgl – coal seam was intact (bright, clean coal chippings retrieved) suggesting a pillar encountered, as prognosed from mine plan – as no workings encountered, the hole was considered stable and drilling continued without grouting the coal seam

Drilling and installation summary:	
	07/10/2019 – Drilling ahead towards Glasgow Ell mine working – no drilling indications of Ell workings, but very faint H_2S smell noticed at around 72.5 mbgl 08/10/2019 – Hit Glasgow Main mine working void at 84.66 – 85.36 mbgl, no signs of packed waste – H_2S smell from returns – drill string had occasionally 'torqued-up' from around 82.0 mbgl, a possible indication of fractured rock above the mine working
09/10/2019	38.0 m^3 of mine water purged from Glasgow Main mine working void over ~ 20 minutes – a 9-bottle water-quality sampling suite was taken by BGS to characterise the Glasgow Main mine water – BAM also took their own samples to characterise the mine water BGS also used a discrete interval sampler to obtain another discrete 9-bottle water-quality sampling suite from the Glasgow Main mine working void – BAM also took their own suite via discrete sampling A strong smell of H_2S noted during borehole purging
10/10/2019	RobertsonGeo conducted wireline logging with optical camera, open-hole caliper and gamma ray logs indicating that the Glasgow Ell was present at 72.0 mbgl and was a collapsed void with a tightly packed waste – also a small void (<10cm) indicated at 51.0 mbgl, beneath the Glasgow Upper Coal
11/10/2019	Installation of uPVC Boode casing with fibre optics and ERT Casing design: • Bentonite plug on top of finned seal ~3.00 m thick. • Finned seal placed at 83.1 mbgl • Screened section 83.7 to 86.4 mbgl, 4 mm slotted Boode casing. • Cased Sump 86.4 – 88.1 m with open hole to 88.5 m
14/10/2019 – 08/11/2019	Grouting annulus in stages using SP/F6 grout – some grout losses in interval below Glasgow Upper Coal, bentonite cement pellets used from around 52 m to around 25 m
12/11/2019	Borehole cleaning for 72 minutes
10/01/2020	Cased hole logs run by Robertsons Geo Services
22/01/2020	Hydrogeological testing: step test at 5, 10, 15, 20, 25 l/s
23/01/2020	Hydrogeological testing: Constant rate pump test at 20 l/s

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 relative to drilling platform and as-built datums

Drill platform datum level (m AOD)		12.22	
As-built datum level at top casing flange (m AOD)		12.12	
Electrode number Cable 1	**Electrode number Cable 2**	**Depth below drill platform datum [m]**	**Depth below as-built casing flange datum (m)**
32		33.77	33.67
31		34.52	34.42
30		35.26	35.16
29		36.00	35.90
28		36.75	36.65
27		37.49	37.39
26		38.23	38.13
25		38.97	38.87
24		39.72	39.62
23		40.46	40.36
22		41.20	41.10
21		41.94	41.84
20		42.69	42.59
19		43.43	43.33
18		44.17	44.07
17		44.91	44.81
16		45.66	45.56
15		46.40	46.30
14		47.14	47.04
13		47.88	47.78
12		48.63	48.53
11		49.37	49.27
10		50.11	50.01
9		50.85	50.75
8		51.60	51.50
7		52.34	52.24
6		53.08	52.98
5		53.83	53.73
4		54.57	54.47

3		55.31	55.21
2		56.05	55.95
1		56.80	56.70
40		57.54	57.44
39		58.28	58.18
38		59.02	58.92
37		59.77	59.67
36		60.51	60.41
35		61.25	61.15
34		61.99	61.89
33		62.74	62.64
32		63.48	63.38
31		64.22	64.12
30		64.96	64.86
29		65.71	65.61
28		66.45	66.35
27		67.19	67.09
26		67.93	67.83
25		68.68	68.58
24		69.42	69.32
23		70.16	70.06
22		70.91	70.81
21		71.65	71.55
20		72.39	72.29
19		73.13	73.03
18		73.88	73.78
17		74.62	74.52
16		75.36	75.26
15		76.10	76.00
14		76.85	76.75
13		77.59	77.49
12		78.33	78.23
11		79.07	78.97
10		79.82	79.72
9		80.56	80.46
8		81.30	81.20
7		82.04	81.94
6		82.79	82.69
5		83.53	83.43
4		84.27	84.17
3		85.01	84.91
2		85.76	85.66
1		86.50	86.4

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) to produce a continuous profile of in-situ 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 are recorded. In passive mode DTS monitors in-situ temperature variation and can be used, for example, 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 and so include a copper element, which can be used to generate a heat pulse. The decay of this heat pulse can be monitored using the DTS fibre and used to infer the presence of flow zones, or regions of increased thermal conductivity.

FIBRE-OPTIC CABLE INSTALLATION

The DTS fibre-optic cable was fastened on to the outside of the Boode well casing, including across the screened section 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 below the first ERT sensor 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 GGA05 18052020.pdf*]

Installation depths of 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 GGA05 on 13/01/2020 to a depth of approximately 25 m below the top of the casing. The data logger was removed during the test pumping on GGA05 (Drilcorp installed their own data logger during the tests). The data logger was reinstalled upon completion of the constant rate test on borehole GGA05, approximately 25 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 was reinstalled in GGA05 on 16/03/2020 for the purpose of continuous downhole groundwater monitoring. As with all groundwater observations in this borehole, the data logger is monitoring groundwater conditions in only 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_GGA05.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 driller's log record 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_GGA05.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 & 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 GGA05, caliper and gamma open hole logs were acquired prior to the installation of the Boode casing. The data was output as a PDF file 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 camera image

An optical camera was deployed into borehole GGA05 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 originally acquired purely to assist in the drilling and not as a final output. However, given the good quality of the image it was decided to release the data with these caveats.

5.2 SUMMARY AND OUTPUTS

The following wireline logs were run within Borehole GGA05 (Table 6)

Table 6 Cased hole wireline logs run for GGA05. All downhole depths in the released datasets were measured from the drill platform level 12.22m. *Open hole logs and camera depths are approximate.*

Wireline Log	Depth below drill platform level (12.22 m AOD)	Depth below final datum (top casing) (12.11 m AOD)
Gamma cased hole	2.67 – 87.36	2.57 – 87.26
Caliper cased hole	2.67 – 87.36	2.57 – 87.26
Inclination cased hole	2.67 – 87.36	2.57 – 87.26
Azimuth cased hole	2.67 – 87.36	2.57– 87.26
Cement bond log	1.9 – 87.4	1.8 – 87.3
Caliper open hole	4 – 88 (approx.)	4 – 88 (approx.)
Gamma open hole	4 – 88 (approx.)	4 – 88 (approx.)
Optical camera	40 – 88 (approx.)	40 – 88 (approx.)

Wireline 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_GGA05_BoreholeGeometry.pdf, Cased_hole_GGA05_CementBondLog.pdf* and *Open_hole_GGA05_Borehole_Geometry.pdf*]. The header data provides information about the borehole location, the drilling datum and the casing and drill depths of each section. This is only available in the final cased hole logs. 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_GGA05_BoreholeGeometry.las*, *Cased_hole_GGA05_CementBondLog.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). Only the cased hole logs are available in the LAS format.

3. HTML/BMP

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

5.2.1 Problems and caveats with the wireline logs and camera

No editing has been done on the cased hole logs, although 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_GGA05_CementBondLog.pdf*] only records useful data when the sensor is below water level. For borehole GGA05, the water level was 2.8 m, so the valid data is between 2.8 m – 87.4 m.

The open hole logs [*Open_hole_GGA05_Borehole_Geometry.pdf]* and the optical camera were acquired for the purposes of providing real time data during the drilling of the bedrock section. They have not been edited or processed and there is no accompanying .las file. There is missing header information and any review of these logs must be done with the understanding of their original purpose.

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 [*GGA05_archived_rock_chips.xlsx*]. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGA05.pdf and .xlsx*].

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 pump 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 GGA05 borehole cleaning parameters

Technique used	*Airlift pump*
Date	*12/11/2019*
Length of time borehole cleaning continued (minutes)	*72*
Approximate volume of water removed (m^3)	*24.59*
Borehole water level drawdown (m)	*Not recorded*
Borehole volume (m^3)	*4.26*
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)	*10.9*
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 indicate that borehole GGA05 is very high yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

Table 8 Overview of GGA05 test pumping parameters

Step test	
Date of step test	*22/01/2020*
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)	*2.44*
Constant rate test	
Date of constant rate test	*23/01/2020*
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)	*2.26*
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 GGA05 (Figure 1).

The made ground composition, including brickwork, timber and slate 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 8.5 m drilled depth was less 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, gravel and clay of the alluvial Gourock Sand Member to around 14 m, and clay and gravel of the raised marine Paisley Clay Member to around 26 m drilled depth (Figures 1, 5). Underlying sand and gravel to around 30 m drilled depth could represent glaciofluvial deposits of the Broomhouse Sand and Gravel Formation. A gravel, sand, silt and clay unit logged between 30 – 37.5 m drilled depth is interpreted as a sandy glacial diamicton (till) of the Wilderness Till Formation (Figures 1, 5). Rockhead was recognised at 37.5 m drilled depth, within error limits of pre-drill prognosis (Appendix C).

Figure 5 Image of the superficial deposits returned for GGA05 from 25 – 37 m drilled depth

The bedrock succession appears typical of the Scottish Middle Coal Measures Formation. The *c.*12 m section of sandstone with claystone and siltstone interbeds above the Glasgow Upper coal and the *c.*22 m clay- and siltstone-dominated Glasgow Upper to Glasgow Ell section are typical compared to other UKGEOS and legacy boreholes nearby and the cored reference section in

GGC01 (Kearsey et al. 2019; Figure 1). The Glasgow Ell to below the Glasgow Main section comprises interbedded sandstone, siltstone and claystone. The Cambuslang Marble (musselband) was not recognised in the rock chips, though is tentatively interpreted on the optical camera data as a bed at around 82.8 m drilled depth.

8.1 MINE WORKINGS

The ***Glasgow Upper coal*** was recognised by returns of clean, bright coal chippings from 49.46 – 51.00 m drilled depth indicating an intact coal seam of 1.54 m thickness, at a depth within the error limits of the pre-drill prognosis. Based on georeferenced mine abandonment plans (1884 and 1933)[*] the borehole is interpreted to have penetrated the centre of a stoop (pillar) in an area of stoop and room workings. This was intentional as the target for this borehole was the underlying Glasgow Main mine working and an intact Glasgow Upper meant that sealing of this mine working was not required (see section 2). The known error in the georeferencing of the mine plan based on limited surface features meant it was uncertain that the objective of drilling an intact pillar would be achieved. The optical camera data clearly shows the coal seam from around 49.43m – c.50.8 m and appears to show that the lower part of the coal seam is dull, whereas the upper part is bright and vitreous (Figure 6).

The open hole caliper log recorded a marked kick underneath the Glasgow Upper coal at 51 m and the optical camera image shows a disrupted zone at 50.9 m – 51 m. The floor of the Glasgow Upper coal returned rock chips of claystone and possible seatearth (paleosol). On grouting the annulus between the borehole casing and rock wall, there were some losses at the level beneath the Glasgow Upper coal, together with the open hole caliper and optical data suggesting some disturbance of the claystone floor of the coal pillar. This could be a result of floor lift and heave and/or pillar punching that are common phenomenon in mine workings (Wuest, 1992; Chen et al., 2017; Mo et al. 2020).

The optical camera data above the Glasgow Upper coal pillar appears to show extensional fracturing along horizontal bedding planes (Figure 6), an interesting observation given the complex stress/strain and fracturing patterns understood around mine workings and in flooded legacy workings (e.g. NCB, 1975; Younger and Adams, 1999 page 26; Todd et al., 2019).

The ***Glasgow Ell mine working*** was not recognised during drilling. A very faint hydrogen sulphide smell noticed at around 72.5 m drilled depth was later correlated to a tightly packed mine waste observed on the optical camera data from 71.9 m – 72.6 m (Figure 6). A significant kick was also observed on the open hole caliper data from 72.0 m – 72.7 m. The optical camera and caliper data is compatible with a mine abandonment plan (1933) which records total extraction in this area, extraction dates of January 1881 and November 1923 are some distance away. The pre-drill borehole prognosis was adjusted from that shown in Appendix C based on results of drilling GGA02 such that the depth of the Ell mineworking in GGA05 optical camera data was as expected and compatible with mine spot height value of -59.8 m relative to OD 46 m away (equates to 72 m drill length). The 0.7 m thickness of the packed waste is smaller than the *c*.1.2+ m coal thickness summarised on the mine abandonment plan (1933) and *c*1.4 m Glasgow Ell coal thickness in GGC01 (Kearsey et al., 2019), suggesting collapse of the mine working. Near-vertical and inclined fractures can be seen on the optical camera for around 1 – 2 m above and below the Glasgow Ell mine working waste (Figure 6).

The mine abandonment plans for the ***Glasgow Main mine working*** record total extraction of the area around GGA05 at January 1928. GGA05 is around 20 m from a number of former access routes and 50 m from a spot height of -75 m rel OD (753.84 ft rel colliery datum/equates to 87.2

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[*] Mine abandonment plan scans available from The Coal Authority

m drill length) and worked coal thicknesses of 36 – 38 inches noted (0.91 m – 0.96 m). The presence and depth of the mine working is well constrained.

During drilling the Glasgow Main mine working was encountered as a water-filled void at 84.66 m – 85.36 m drilled depth, within the error limits of the pre-drill prognosis. There was a smell of hydrogen sulphide and the drill string had occasionally 'torqued-up' from around 82.0 m drilled depth, a possible indication of fractured rock above the mine working.

The optical camera data shows a void from c. 84.4 m – 85.1 m (with a block at around 84.95 m), with underlying broken rock to around 86.1 m and a caved (black) zone to c.86.6 m (Figure 6). Caliper data shows significant kicks from c.84.4 m – 85.3 m and 86.3 m – 86.8 m drilled depth with an intervening uneven zone. The lower parts of this disrupted zone and lower caved zone were not reported as easier drilling and the rock chip returns of siltstone and very fine sandstone were not noted as stained or possible waste. This disrupted section is tentatively interpreted to be have been affected by floor lift (floor heave; see examples of this phenomenon in Wuest, 1992; Chen et al., 2017; Mo et al. 2020).

The thickness of the Glasgow Main mine working open void recorded as 0.7 m during drilling is thinner than the worked coal thicknesses on the mine abandonment plan, whereas the voids and disrupted zone from c 84.4 m – 86.8 m on the caliper and optical data at 2.4 m is thicker than the mine abandonment plan worked thickness.

There do not appear to be fractures on the optical camera data in the immediate sandstone roof of the Glasgow Main mine working (Figure 6) or up to 82 m drilled depth, and the open hole caliper data is smooth within that interval.

8.2 FAULTS

The mine abandonment plans for the 3 worked seams encountered show two NW-SE trending faults of throws 0.6 m – 2.7 m (2-9ft) down to the east, to the south-west and north-east of borehole GGA05.

The mine abandonment plan also shows a NNE trending 'want' or washout of the Glasgow Upper Coal seam around 30m to the east of GGA05.

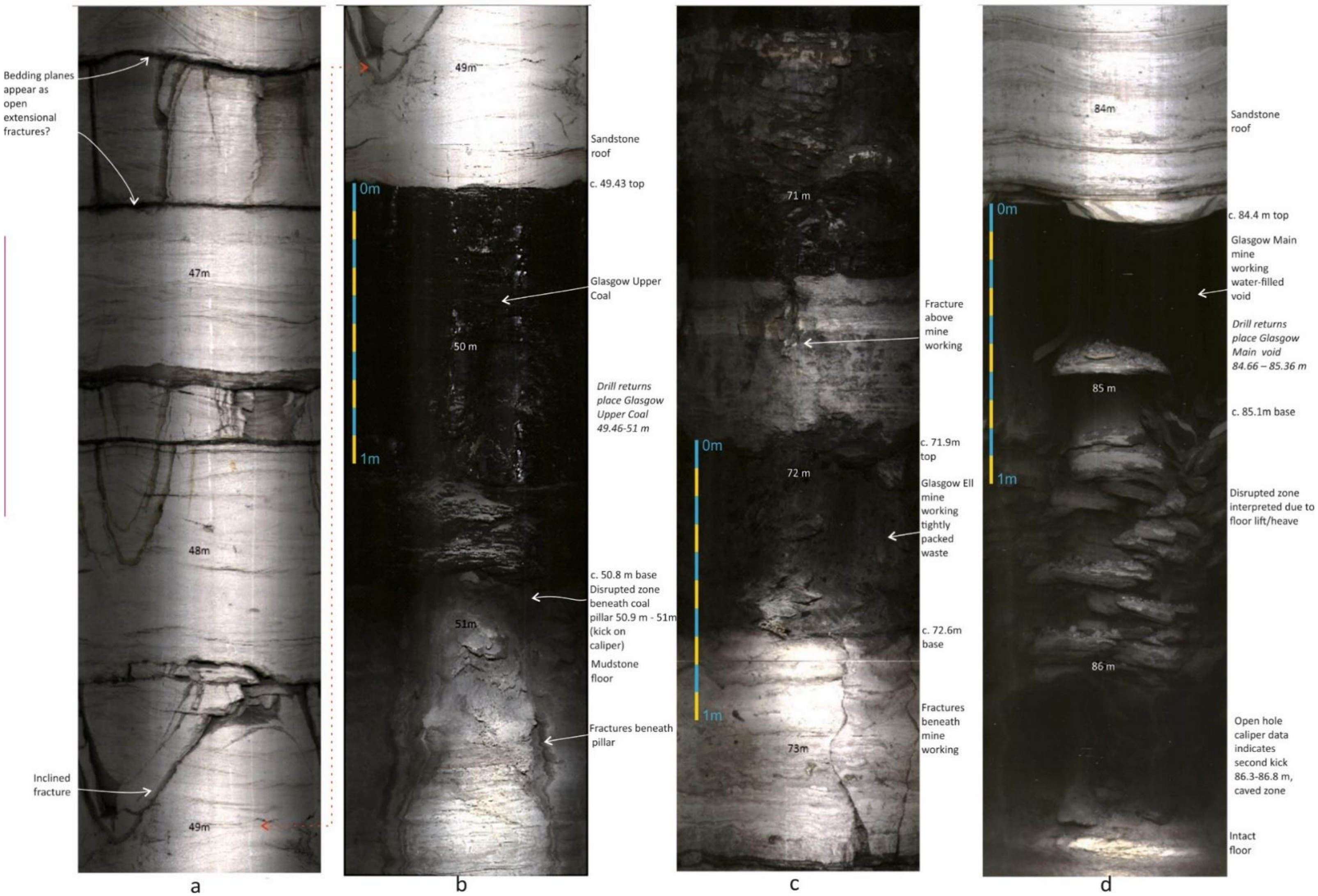

Figure 6 Optical camera images from GGA05 open hole (a) Sandstone above the Glasgow Upper Coal showing sub-horizontal extensional fracturing (b) Glasgow Upper Coal pillar, disrupted floor and fracturing (c) tightly packed waste in the collapsed Glasgow Ell mine working and fracturing above and below the working (d) voids and disruption of the Glasgow Main mine working

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 GGA05 files in this information release

Table 9 Summary of files in the borehole GGA05 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_GGA05.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_GGA05.pdf Detailed_BGS_Rockchiplog_GGA05.xlsx	XLSX, 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_GGA05.pdf Summary_BGS_Log_Page2_GGA05.pdf	PDF
Wireline (geophysical) downhole data for cased hole logs and accompanying report *NOTE: depths are given relative to drill platform level*	Cased_hole_GGA05_BoreholeGeometry.pdf and .las Cased_hole_GGA05_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_GGA05_Borehole_Geometry.pdf	PDF
Fibre optic cable installation report *NOTE: depths are given relative to drill platform level*	FibreOpticCable Installation Report BGS V1.2 GGA05 18052020.pdf	PDF
Optical camera data *NOTE: depths are given relative to drill platform level*	In 'Optical_camera' folder, use 'index.html' to open	HTML, BMP etc.
Spreadsheet of archived rock chip samples *NOTE: depths are given relative to drill platform level*	GGA05_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 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 fibre-optic bottom hole assembly (BHA) was placed onto the casing and fastened into position. This was wrapped in duct tape to protect the equipment as it moved down the borehole. The dead end seal of the first ERT cable was attached above the BHA of the fibre-optics and the first sensor was fastened onto the casing in the marked location. 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 Upper and Ell mine workings in GGA02 informed the expected depths in GGA05. Being the pre-drill information, Figure 7 does not represent the learnings or local, site specific considerations used during the drilling phase.

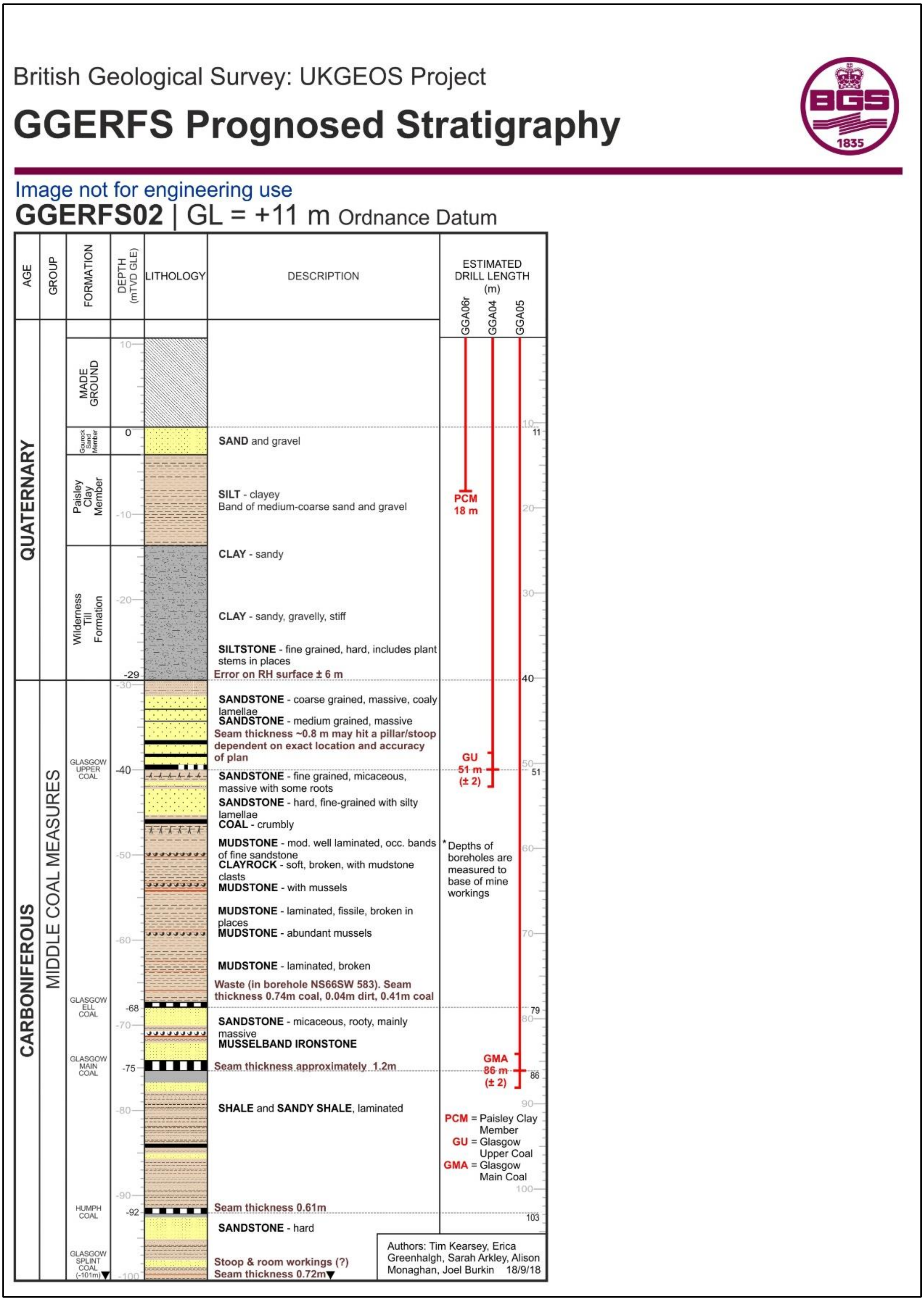

Figure 7 Pre-drill borehole prognosis for site GGERFS02, boreholes GGA04, GGA05, GGA06r based on semi-regional geological models and nearby legacy boreholes