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Mine water characterisation and monitoring borehole GGA04, UK Geoenergy Observatory, Glasgow

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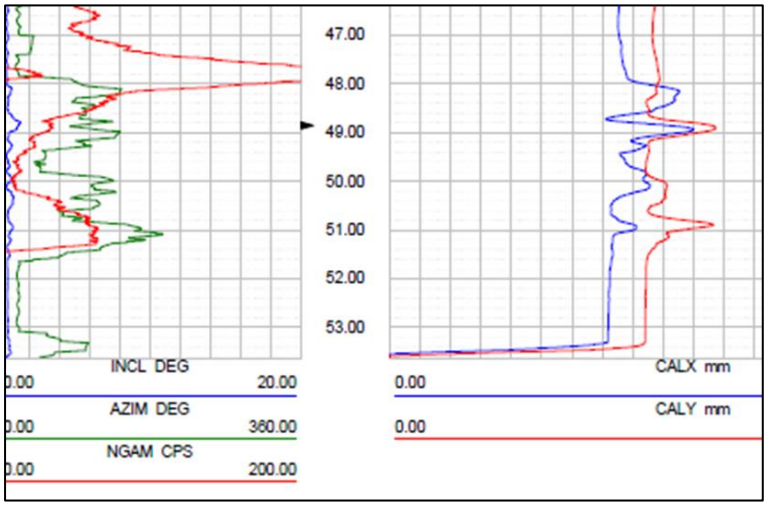
Open Report OR/20/024



BRITISH GEOLOGICAL SURVEY

UK GEOENERGY OBSERVATORIES PROGRAMME

OPEN REPORT OR/20/024

Mine water characterisation and monitoring borehole GGA04, UK Geoenergy Observatory, Glasgow

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Part of the open hole wireline log dataset for GGA04

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Summary

This report and accompanying data release describe the 'as-built' borehole GGA04 at the UK Geoenergy Observatory in Glasgow, as well as summarising hydrogeological testing and an initial geological interpretation.

Mine water borehole GGA04 at the UK Geoenergy Observatory in Glasgow is screened across the Glasgow Upper coal and overlying sandstone roof. The borehole was drilled within an area of stoop (pillar) and room mine workings and is interpreted to have hit a coal pillar or partially collapsed pillar and a possibly fractured sandstone roof. It can be used for characterising and monitoring a fractured rock mass within a mine working area. Initial hydrogeological indications from the test pumping indicate that borehole GGA04 is high yielding. Borehole GGA04 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 GGA04 at Cuningar Loop, in Rutherglen, Glasgow City Region, took place between 28th June and 22nd October 2019 (start of drilling to casing installation date). The borehole targets the Glasgow Upper coal in an area with mine workings, with the slotted screen at -35.29 to -38.89 m relative to Ordnance Datum.

The borehole was drilled as part of a set of six mine water*, 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_GGA04.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/10.5285/83ab3481-45d9-475d-8814-008edc9fb1cb V Starcher, H F Barron, V Starcher, A A Monaghan, K M Shorter, K Walker-Verkuil. 2020. UK Geoenergy Observatories Glasgow Borehole GGA04 Data Release
and this report cited as:
STARCHER V, BARRON H F, MONAGHAN A A, SHORTER K M, WALKER-VERKUIL K. 2020. Mine water characterisation and monitoring borehole GGA04, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/024

* Five boreholes were completed as mine water boreholes and one was completed as a sensor testing borehole

Table 1 GGA04 as-built summary data

Borehole number	GGA04	
Site	GGERFS02	
Easting (British National Grid)	262337.727	
Northing (British National Grid)	662687.960	
Drilling platform level (metres above Ordnance Datum AOD)	12.41	
Drilling started	28/06/2019	
Final casing installed	22/10/2019	
As-built borehole start height or datum (top Boode casing flange, metres AOD)	12.11	
Installation details		
Borehole detail	**Depths (drill length from drill platform level, metres)**	**Diameter size**
Made ground casing	0.0 – 17.6	24" (610 mm OD x 575 mm ID)
Rockhead casing	0.0 – 41.3	18" (457 mm OD x 425 mm ID)
Boode Well (BW) casing	0.0 – 47.7	280 mm OD x 248 mm ID
BW Slotted pipe with pre-glued gravel pack	47.7 – 51.3	311 mm OD x 248 mm ID
BW Casing Sump	51.3 – 53.3	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	+3.91
Base of superficial deposits	37.7	-25.29
Top Glasgow Upper mine working	49.46	-37.05
Base Glasgow Upper mine working	50.60	-38.19
Final drilled length	53.63	-41.22
BGS SOBI reference number	NS66SW BJ 3758	BGS ID 20693599

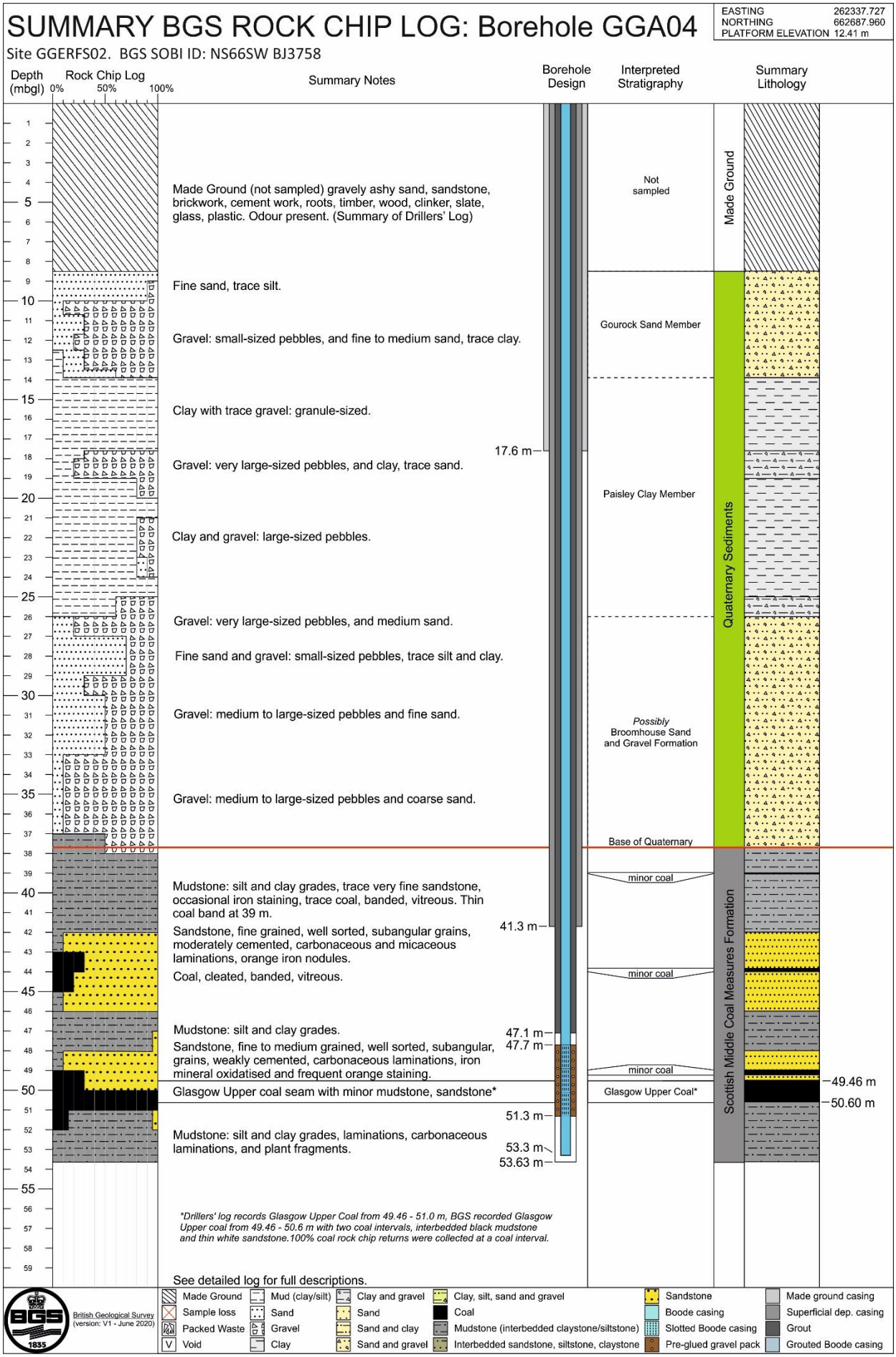

Figure 1 GGA04 summary log based on rock chip returns

1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGA04 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).

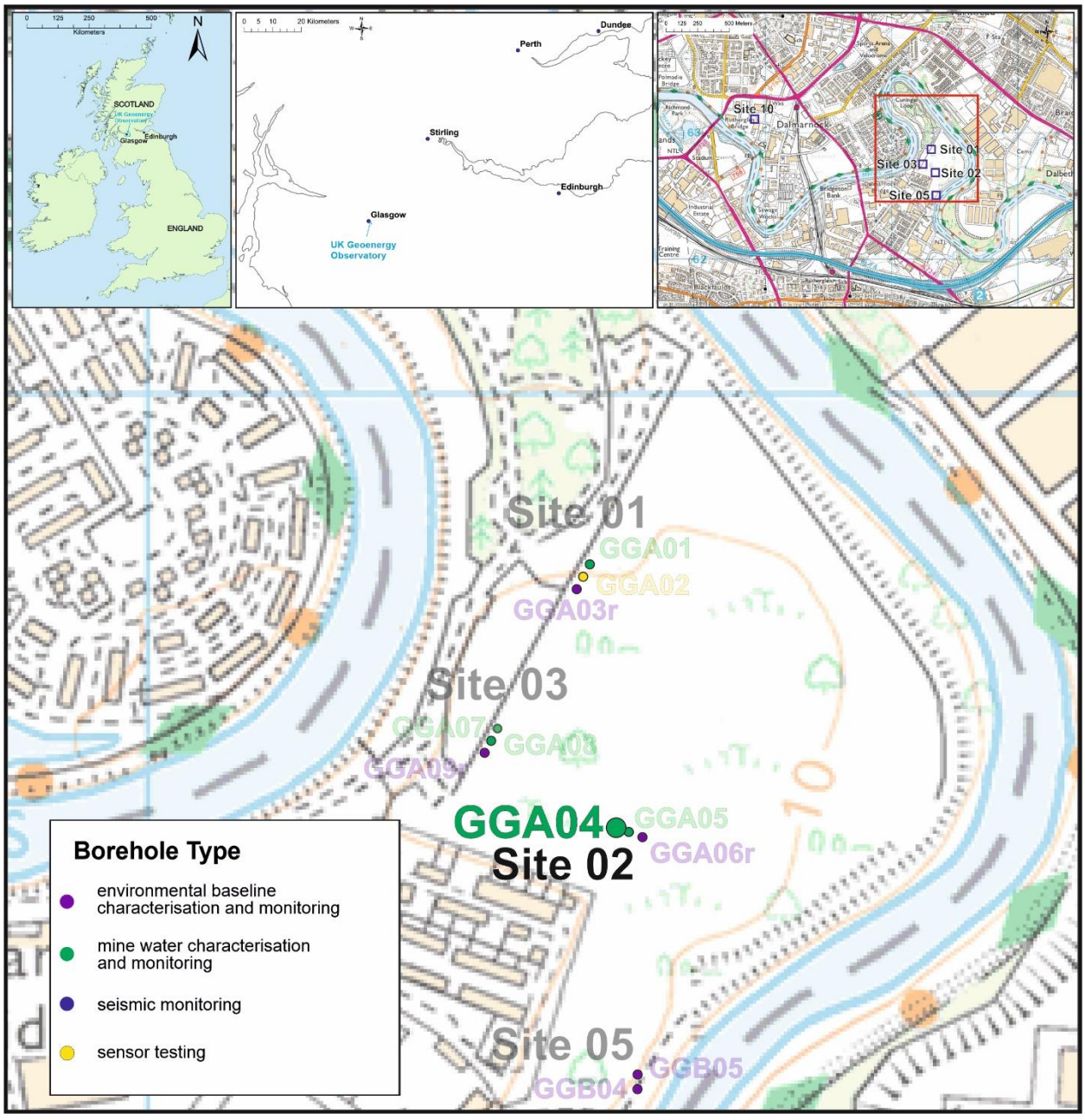

Figure 2 Location map of borehole GGA04, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

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).

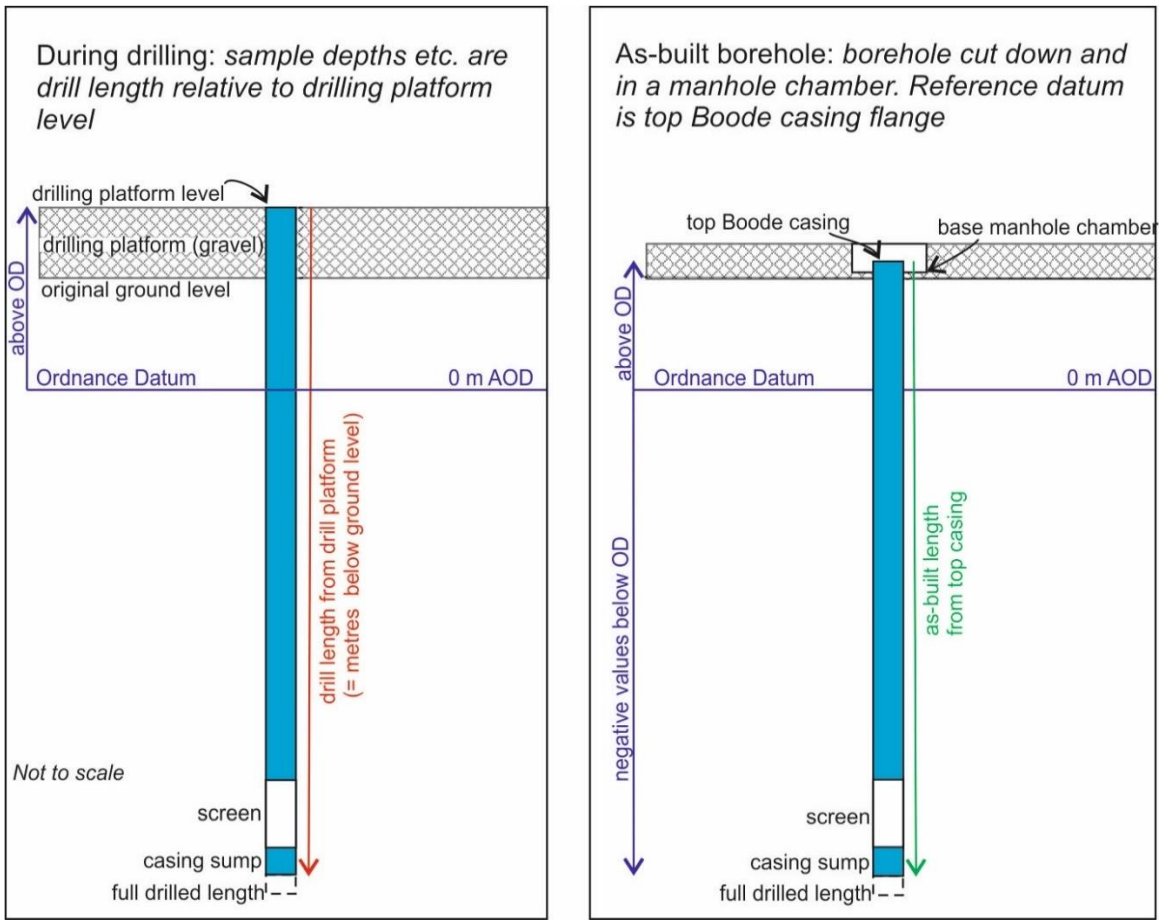

Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)

Table 2 Summary of start heights and datums used for GGA04

Stage	Borehole start height/ reference datum used (m AOD)	Used in
Drilling platform level – built up gravel platform	12.41	Drillers and BGS logs, sample depths, wireline datasets. ERT and DTS cable installation.
As-built borehole start height (top Boode casing flange)	12.11	Reference datum for future Observatory users
Conversion Rock chip sample depths, wireline logs – to convert from drill length to beneath as-built borehole start height		As-built depth below start height = drill length – (12.41-12.11) m *i.e* As-built depth below start height = drill length – (0.3) 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.

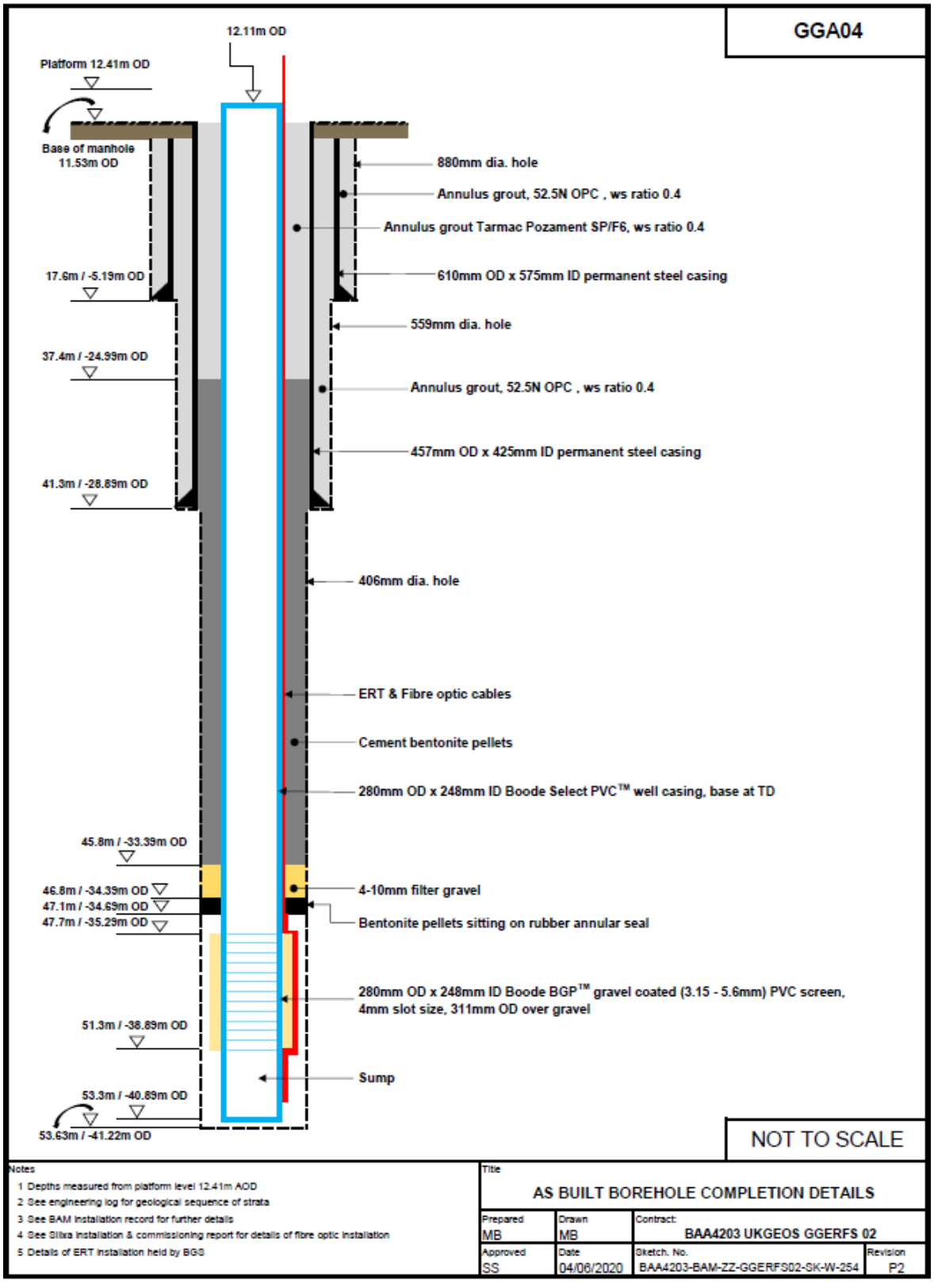

Figure 4 As-built borehole schematic for GGA04

2.1 BASIS OF DESIGN

The basis of the GGA04 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. The borehole is screened only across the target interval (the Glasgow Upper coal and overlying sandstone) and is fully sealed above the screen, so that all hydrogeological observations from this borehole relate only to this interval.

iii. The large internal diameter of the bedrock casing and slotted screen section of borehole GGA04 (248 mm ID) was chosen to accommodate a large borehole pump capable of delivering a high flow rate.

iv. A screen slot size of 4 mm was used in the Glasgow Upper coal target interval, 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 coal that could clog the slotted screen.

v. 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.

vi. A finned annular rubber seal was placed at 47.1 mbgl above the screened section to support the emplacement of a permanent grout seal. A layer of bentonite pellets was overlain to seal and reduce pressure on the finned seal. After airlift and pumping due to a grout ingress event (Table 4), the finned seal may have reversed and the bentonite seal was reduced to 0.6 m thickness (Figure 4), bentonite cement pellets were then used to form the annulus seal.

vii. The annulus was grouted in stages with bentonite cement pellets and a SP/F6 mix. The bentonite cement pellets were used to increase the viscosity and decrease the time required for the grout to set.

Table 3 Summary of heights for as-built borehole features for GGA04

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	47.7	-35.29	47.4
Base slotted screen	51.3	-38.89	51.0
Base installed casing sump	53.3	-40.89	53.0
ERT sensor positions	See Table 5 below	See Table 5 below	See Table 5 below
Position of DTS termination unit	Base Termination unit depth: 52.8	Base Termination unit depth: -40.39	Base Termination unit depth: 52.5

3 Drilling, casing, annulus grouting and testing methodology

Borehole GGA04 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 GGA04, 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:

- Bentonite mud was used as a drilling fluid in the natural superficial deposits to below rockhead section of the borehole, to improve hole stability through sections of sand and gravel. Water flush was used for drilling of the bedrock section.
- The drilling technique in the made ground section was piling rig with auger. In the superficial deposits and bedrock sections rotary open hole with reverse circulation was used.
- 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:	
28/06/2019	Drilled and installed made ground and superficial casing with BAM piling rig to 17.6 mbgl, with a 34 ¾" (880 mm) auger – base made ground level was recorded at 8.5 mbgl
01/07/2019	Made ground and superficial casing grouted
11/09/2019 – 17/09/2019	Drilled superficial deposits to rockhead with Conrad rig from 17.6 to 41.6 mbgl with 22" (558.8 mm) tri-cone bit –changed to bentonite mud flush after difficulty drilling through sand and gravel sections – rockhead encountered at 37.7 mbgl
17/09/2019 – 19/09/2019	Superficial to rockhead casing set-up, installed and grouted – installed to 41.3 mbgl
16/10/2019 – 17/10/2019	Drilled out grout and continued to Glasgow Upper coal with 16" tri-cone drill bit – total depth reached at 53.6 mbgl Glasgow Upper coal encountered at 49.46 – 50.6 mbgl with drilling returns at shaker indicating at least two thin coals plus interbedded black laminated mudstone and thin white sandstones, with no evidence of a void – grey clay observed below coal **Problems Encountered:** • 16/10/2019 – Minor wood fragments in cuttings, came from stabilising wood block used to centre casing (not returned from borehole)
18/10/2019	Robertsons Geo ran open-hole optical televiewer, gamma and caliper on open borehole to allow further investigation of the Glasgow Upper coal seam **Problems Encountered:** • Televiewer did not receive a clear picture due to suspended solids in the borehole • Borehole diameter is too wide for acoustic televiewer

Drilling and installation summary:	
22/10/2019	Casing installation: Silixa installed fibre-optic and BGS installed ERT cables on to the casing during installation Design: • Bentonite seal in borehole annulus • Finned seal on Boode casing: 47.10 mbgl • Screened interval: 47.7 – 51.30 mbgl, 4 mm slotted Boode casing with 3.15 to 5.6 mm bonded gravel pack • Cased Sump: 51.30 – 53.30 mbgl
23/10/2019	A 3.0 m SP/F6 grout plug was placed above bentonite plug. **Problems Encountered:** • Drillers checked inside the borehole casing and detected grout 40 minutes after placing the grout in the borehole annulus on top of the bentonite plug. (A discrete water sampler was used and the grey sample had a pH of 11.2) • Remedial action was taken quickly to ensure that the grout would not set in the casing – airlift was used to purge the borehole (approx. 30m^3 water was removed) • Then the borehole was pumped from 12.15 until the end of the shift at a rate of 2l/s, water quality parameters returned to their expected baseline and discrete interval samples were taken, the pH returned to 7.2 and the borehole was deemed to be flushed of grout
24/10/2019	Concern that the seal may have failed and/or inverted on airlift – only 0.3 m of bentonite was remaining – 1.0 m of gravel was added to the annulus on top of the remaining bentonite plug to test, it was dipped and concluded it had remained on top of the plug
25/10/2019	1.0 m of bentonite cement pellets added to annulus, to ensure seal above the bentonite and gravel plug – rig then moved to completion of grouting on adjacent borehole GGA05
28/10/2019 – 07/11/2019	Grouting annulus to completion using bentonite cement pellets and SP/F6 grout
13/11/2019	Borehole cleaning completed for 2 hours, parameters stabilised
27/01/2020	Hydrogeological testing: step test
10/01/2020	Cased hole wireline completed by Robertson Geo Services
28/01/2020	Hydrogeological testing: constant rate test

Annulus grout entered the inside of the borehole casing on 23/10/19 via the screened section but the mechanism by which the grout reached the screened section is uncertain. Hypotheses include a non-intact finned seal and bentonite plug and grout flow down the borehole annulus, or grout flow through linked vertical and horizontal fractures in the rock mass from above the bentonite seal to the screened section. Unfortunately, the suspended sediment in the water prevented a successful optical camera image of the coal/mine working interval prior to casing and seal installation. The caliper log shows the borehole wall to be uneven in the sandstone above the Glasgow Upper coal (Figure 5). This interval was included in the screened section (Figures 1, 5) as the caliper response may have been due to fracturing. The seal was placed at the level of the overlying mudstone which had returned a caliper response indicative of a smooth borehole wall and not indicative of major open fractures.

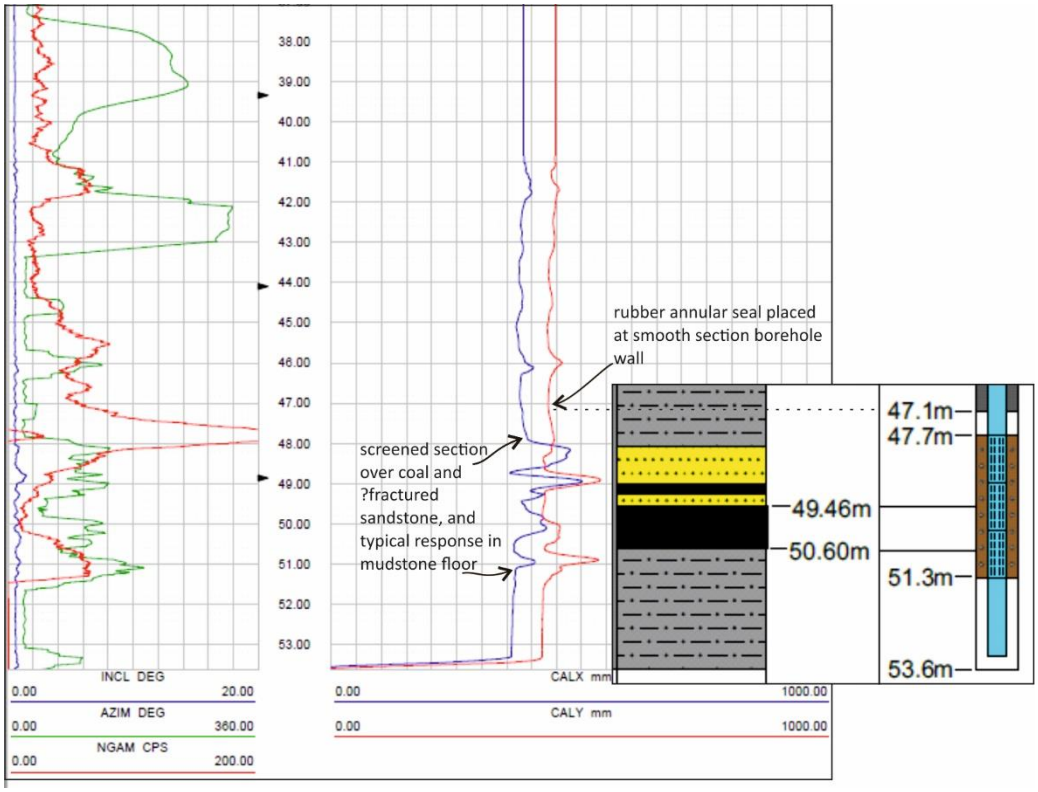

Figure 5 Annotated image of the open hole caliper log (and gamma log on left hand side) over the screened interval, with the summary lithology and screened interval shown (key on Figure 1).

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). When the casing and cable 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)		12.41
As-built datum level at top casing flange (m AOD)		12.11
Electrode number	**Depth below datum [m]**	**Depth below final as-built datum (m)**
24	34.48	34.18
23	35.22	34.92
22	35.96	35.66
21	36.71	36.41
20	37.45	37.15
19	38.19	37.89
18	38.93	38.63
17	39.68	39.38
16	40.42	40.12
15	41.16	40.86
14	41.90	41.60
13	42.65	42.35
12	43.39	43.09
11	44.13	43.83
10	44.87	44.57
9	45.62	45.32
8	46.36	46.06
7	47.10	46.80
6	47.84	47.54
5	48.59	48.29
4	49.33	49.03
3	50.07	49.77
2	50.81	50.51
1	51.56	51.26

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 GGA04 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 GGA04 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 GGA04 (Drilcorp installed their own data logger during the tests). The data logger was re-installed upon completion of the constant rate test on borehole GGA04, 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 GGA04 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 only in the screened target interval, the Glasgow Upper coal/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_GGA04.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 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/sedimentological log and to make decisions based on this log, such as the positioning of the slotted screens and seal. 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 deposit were placed in a cold store. Rock chip tubs were dried and logged by BGS geologists in a laboratory with the aid of a microscope.

The resulting lithological log record [*Detailed_BGS_Rockchiplog_GGA04.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 not 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 GGA04, 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 PDF data with these caveats.

5.2 SUMMARY AND OUTPUTS

The following wireline logs were run within Borehole GGA04 (Table 6)

Table 6 Wireline logs run for GGA04. All downhole depths in the released datasets were measured from the drill platform depth 12.41 m. Open hole log depths are approximate.

Wireline Log	Depth below drill platform level (12.41 m AOD)	Depth below final datum (top casing) (12.11 m AOD)
Gamma cased hole	2.8 – 52.4	2.5 – 52.1
Caliper cased hole	2.8 – 52.4	2.5 – 52.1
Inclination cased hole	2.8 – 52.4	2.5 – 52.1
Azimuth cased hole	2.8 – 52.4	2.5 – 52.1
Gamma open hole	3 – 53 (approx.)	3 – 53 (approx.)
Caliper open hole	3 – 53 (approx.)	3 – 53 (approx.)

Wireline logs were output in the following formats:

1. PDF

PDF files showing the open hole logs and the cased hole logs are included [*Cased_hole_GGA04_BoreholeGeometry.pdf* and *Open_hole_GGA04_Caliper.pdf*]. The header data, which is only available for the cased hole logs provides information about the borehole location, the drilling datum and the casing and drill depths of each section. Note that all depths on the logs are based on the drill platform datum.

2. LAS

Conventional geophysical logs are provided in LAS format for the cased hole logs only [*Cased_hole_GGA04_BoreholeGeometry.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).

5.2.1 Problems and caveats with the wireline logs

There are no problems with 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. No editing has been done on any of the logs.

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 open hole logs [*Open_hole_GGA04_Caliper.pdf*] 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 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 [*GGA04_archived_rock_chips.xlsx]*. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGA04.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 GGA04 borehole cleaning parameters

Technique used	***Airlift pump***
Date	*13/11/2019*
Length of time borehole cleaning continued (minutes)	*120*
Approximate volume of water removed (m^3)	*19.05*
Borehole water level drawdown (m)	*Not recorded*
Borehole volume (m^3)	*2.59*
Number of borehole volumes removed	*Approx. 7*
Field parameters measured for borehole cleaning monitoring	*Dissolved oxygen/ SEC (conductivity)/ Temperature/ Oxidation-reduction potential/ pH/ turbidity*
Average temperature of removed water (°C)	*11.7*
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 GGA04 is high yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

Table 8 Overview of GGA04 test pumping

Step test	
Date of step test	*27/01/2020*
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)	*4/8/12/15.5/20*
Maximum drawdown at end of final step (m)	*31.43*
Constant rate test	
Date of constant rate test	*28/01/2020*
Length of pumping during constant rate test (hours)	*5*
Length of manually monitored recovery during constant rate test (hours)	*1*
Pumping rate for constant rate test (l/s)	*15*
Maximum drawdown at end of constant rate test (m)	*20.97*
Average groundwater temperature during constant rate test (°C)	*12.1*
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 and downhole caliper data together with correlation to legacy borehole and mine plan data has allowed an initial geological interpretation of borehole GGA04 (Figure 1).

The made ground composition including brickwork, cementwork, wood etc. 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 and gravel of the alluvial Gourock Sand Member to around 14 m, and clay and gravel of the Paisley Clay Member to around 26 m drilled depth (Figure 1). Underlying sand and gravel could represent relatively thick (>10 m) glaciofluvial deposits of the Broomhouse Sand and Gravel Formation (Figure 1), with the glacial till (diamicton) interpreted in borehole GGA05 not recognised. Rockhead was recognised at 37.7 m drilled depth, within error of the pre-drill prognosis (Appendix C).

The bedrock succession appears typical of the Scottish Middle Coal Measures Formation comprising around 15 m of interbedded sandstone, siltstone, claystone and coal.

8.1 MINE WORKINGS

Mine abandonment plans[*] (1884 and 1933) show extensive stoop and room (pillar and stall) workings of the Glasgow Upper coal in the vicinity of GGA04. A fault (3ft throw) is shown to the south-east of the GGA04 location and a 'want' or washout of the coal is present around 20 m to the east. The georeferencing of the mine abandonment plans is recognised to have an uncertainty of around 5 – 10 m due to difficulty in matching historical with current day topographic features and joins/wrinkles in the plans, so whilst the location of GGA04 appears to intersect a room it was fully understood pre-drill that the borehole could hit a stoop (pillar) or room.

On drilling GGA04, the Glasgow Upper coal was encountered at 49.46 – 50.6 drilled depth, with the drilling returns at the shaker indicating at least two thin coals plus interbedded black laminated mudstone and thin white sandstones, with no evidence of a void. Grey claystone was observed below the coal. The depth of the coal was as expected from mine plan spot heights, legacy boreholes nearby and boreholes GGA01, GGA02, GGA05, and was within the error limits of the pre-drill prognosis (Appendix C). The 1.14 m thickness of the Glasgow Upper coal recorded in borehole GGA04 is slightly less than is present in legacy and UKGEOS boreholes nearby (with 1.54 m recorded in adjacent borehole GGA05), though borehole NS66SW BJ583 recorded five thin leaves of the Glasgow Upper close to the washout.

Fine to medium-grained sandstone was returned above the coal and kicks on the caliper log in this unit may be due to fracturing (Figure 5). It is interpreted that GGA04 penetrated a coal pillar (perhaps with coal quality/thickness decreasing towards the washout) overlain by a fractured sandstone, or perhaps a partially collapsed pillar or edge of pillar, given that the drill returns across the coal seam were not clean coal throughout.

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

The screened interval, which comprises the Glasgow Upper coal pillar and overlying fractured sandstone, provides opportunities for researchers to characterise and monitor fractured rock within a mine working area. The initial hydrogeological indications are for good yields, but lower than mine water boreholes screened in mine voids and wastes (GGA01, GGA05, GGA07, GGA08).

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 GGA04 files in this information release

Table 9 Summary of files in the borehole GGA04 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_GGA04.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_GGA04.pdf Detailed_BGS_Rockchiplog_GGA04.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_GGA04.pdf	PDF
Wireline (geophysical) downhole data for cased hole logs and accompanying report *NOTE: depths are given relative to drill platform level*	Cased_hole_GGA04_BoreholeGeometry.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 log: working data *NOTE: depths are given relative to drill platform level*	Open_hole_GGA04_Caliper.pdf	PDF
Fibre optic cable installation report *NOTE: depths are given relative to drill platform level*	FibreOpticCable Installation Report BGS V1.2 GGA04 18052020.pdf	PDF
Spreadsheet of archived rock chip samples *NOTE: depths are given relative to drill platform level*	GGA04_archived_rock_chips.xlsx	XLSX

Appendix B: Detailed installation method for ERT and DTS cables

The ERT cable with regularly spaced sensors 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 6) was produced from semi-regional superficial deposits, bedrock and mine 3D geological models (Arkley, 2019; Kearsey and Burkin, 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 6 were updated on paper at site during the drilling phase, for example the confirmed depth of the Glasgow Upper mine working in boreholes GGA01, GGA02 and GGA05 informed the expected depth of GGA04 Glasgow Upper mine working. Being the pre-drill information, Figure 6 does not represent the learnings or local, site specific considerations used during the drilling phase.

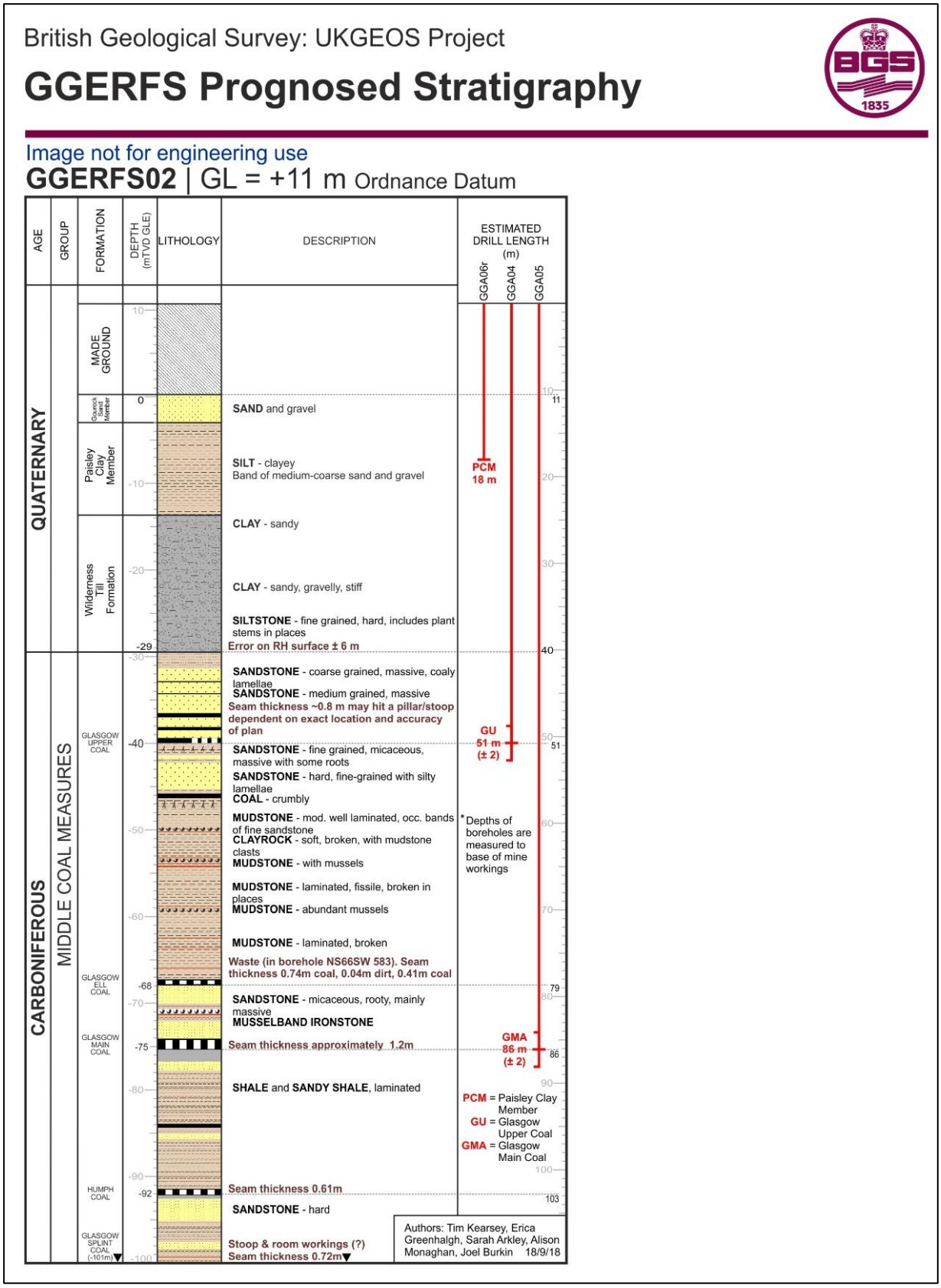

Figure 6 Pre-drill borehole stratigraphic prognosis for site GGERFS02, boreholes GGA04, GGA05, GGA06r based on semi-regional geological models and nearby legacy boreholes.