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Mine water characterisation and monitoring borehole GGA01, UK Geoenergy Observatory, Glasgow

UK Geoenergy Observatories Programme

Open Report OR/20/021

BRITISH GEOLOGICAL SURVEY

UK GEOENERGY OBSERVATORIES PROGRAMME

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Mine water characterisation and monitoring borehole GGA01, UK Geoenergy Observatory, Glasgow

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Front cover

Borehole GGA01 during construction showing 3 casings and ERT cables

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Summary

This report and accompanying data release describe the 'as-built' borehole GGA01 at the UK Geoenergy Observatory in Glasgow, as well as summarising hydrogeological testing and an initial geological interpretation.

Mine water borehole GGA01 at the UK Geoenergy Observatory in Glasgow is screened across the Glasgow Upper mine working and overlying sandstone roof. The mine working is interpreted to be filled with a loosely packed mine waste. Hydrogeological evidence from test pumping indicates that the borehole is very high yielding. Borehole GGA01 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 borehole GGA01 at Cuningar Loop in Rutherglen, Greater Glasgow, took place between 11th June and 21st August 2019 (start of drilling to casing installation date). The borehole targets the Glasgow Upper mine working, with the slotted screen at -34.82 m to -38.42 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_GGA01.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/10.5285/0d496c68-f79b-4956-8cd2-4970d1e86145 A A Monaghan, H F Barron, V Starcher, K M Shorter, K Walker-Verkuil. 2020. UK Geoenergy Observatories Glasgow Borehole GGA01 Data Release.
and this report cited as:
MONAGHAN A A, BARRON H F, STARCHER V, SHORTER K M, WALKER-VERKUIL K. 2020. Mine water characterisation and monitoring borehole GGA01, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/021.

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

Table 1 GGA01 as-built data

Borehole number	GGA01	
Site	GGERFS01	
Easting (British National Grid)	262318.712	
Northing (British National Grid)	662877.923	
Drilling platform level (metres above Ordnance Datum AOD)	10.88	
Drilling started	11/06/2019	
Final casing installed	21/08/2019	
As-built borehole start height or datum (top Boode casing flange, metres AOD)	9.99	
Installation details		
Borehole detail	**Depths (drill length from drill platform level, metres)**	**Diameter size**
Made ground casing	0.0 – 17.0	24” (610 mm OD x 575 mm ID)
Rockhead casing	0.0 – 29.7	18” (457 mm OD x 425 mm ID)
Boode Well (BW) casing	0.0 – 45.7	280 mm OD x 248 mm ID
BW Slotted pipe with pre-glued gravel pack	45.7 – 49.3	311 mm OD x 248 mm ID
BW casing sump	49.3 – 52	280 mm OD x 248mm ID
Geological details	**Depths (drill length from drill platform level, metres)**	**Depths, relative to Ordnance Datum (m)**
Base of made ground	8.3	+2.58
Base of superficial deposits	26.0	-15.12
Top Glasgow Upper mineworking	47.60	-36.72
Base Glasgow Upper mine working	48.86	-37.98
Final drilled length	52.0	-41.12
BGS SOBI reference number	NS66SW BJ 3755	BGS ID 20693596

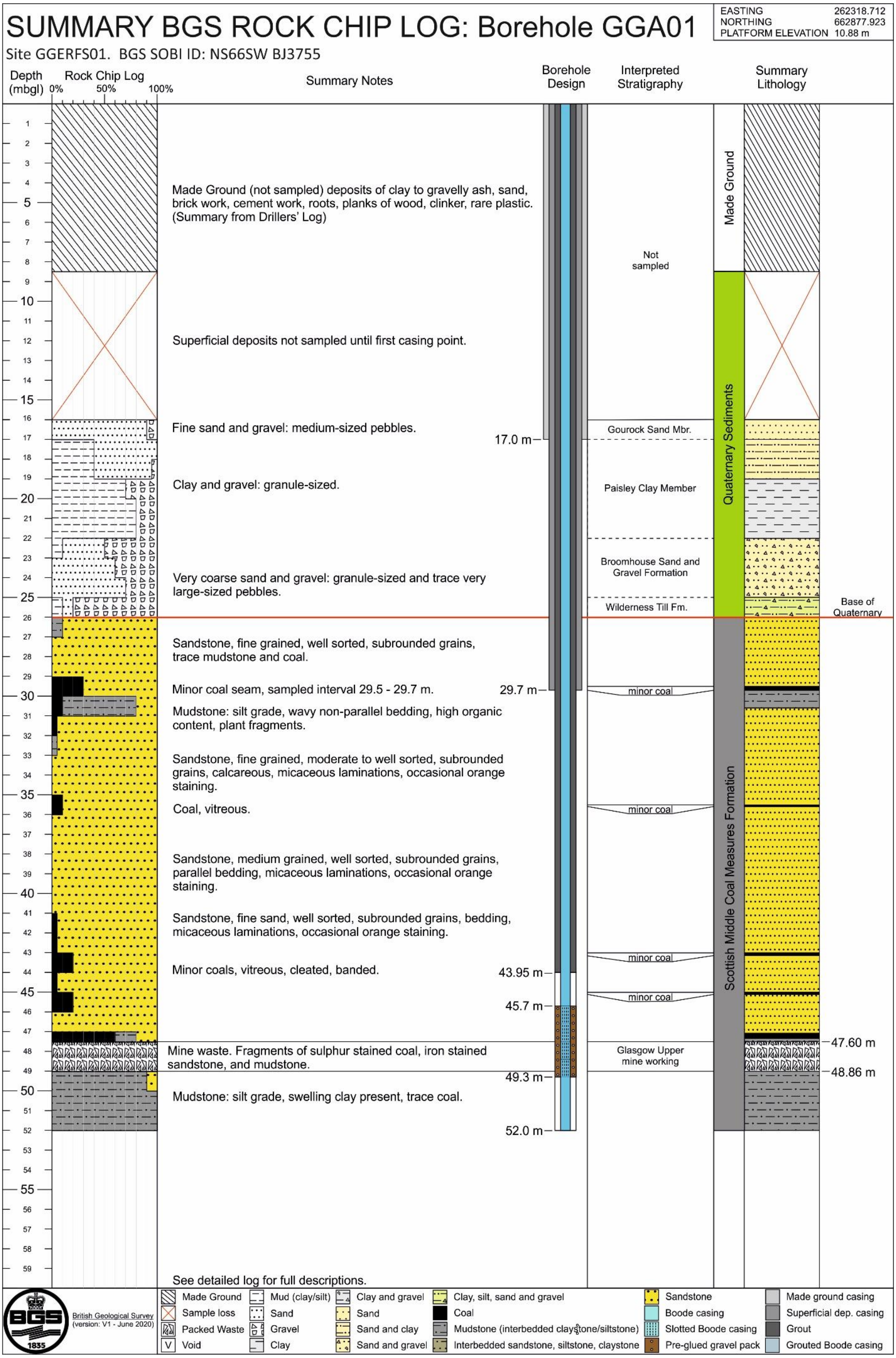

Figure 1 GGA01 summary log based on rock chip returns

1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGA01 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).

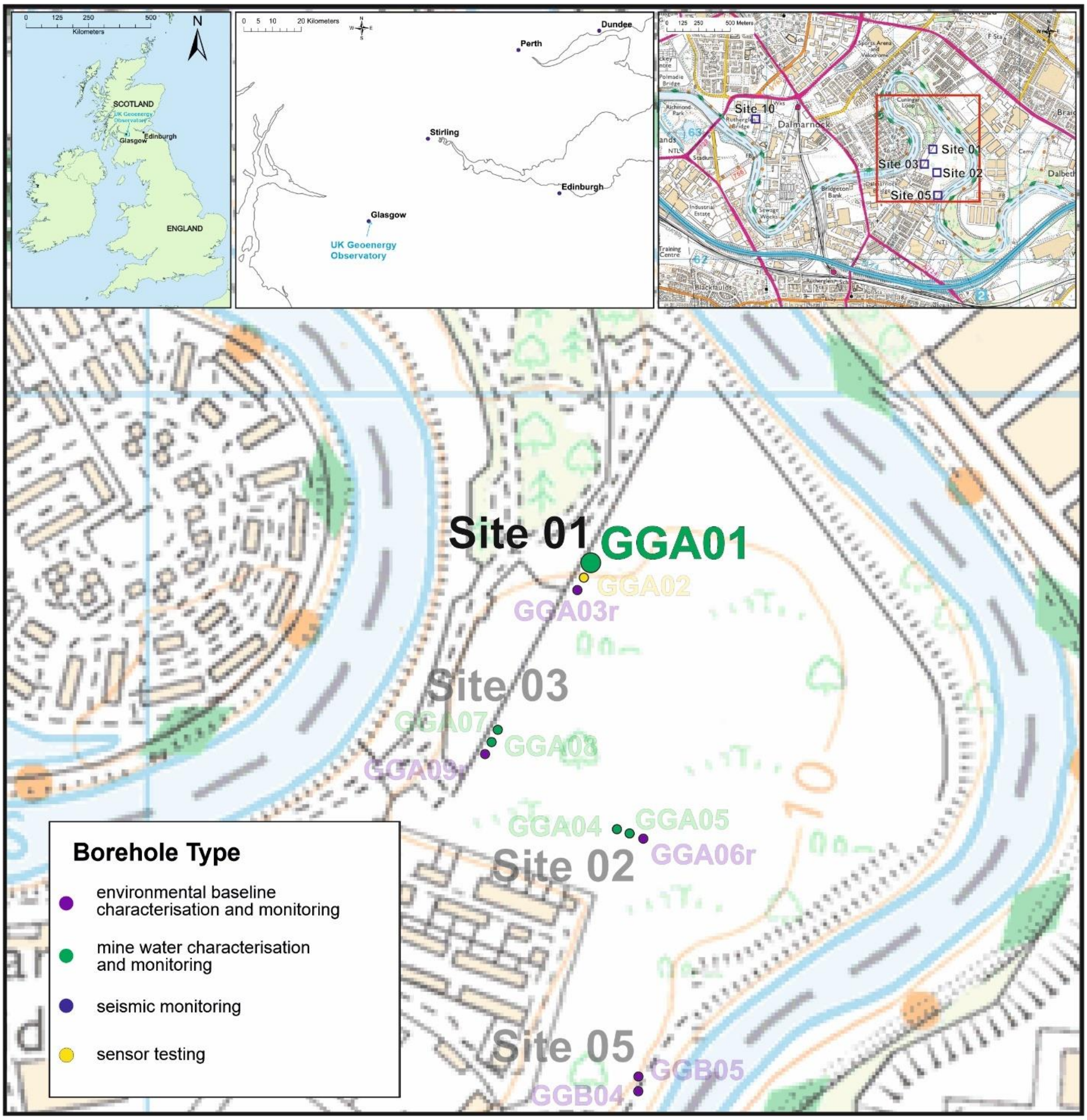

Figure 2 Location map of borehole GGA01, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

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).

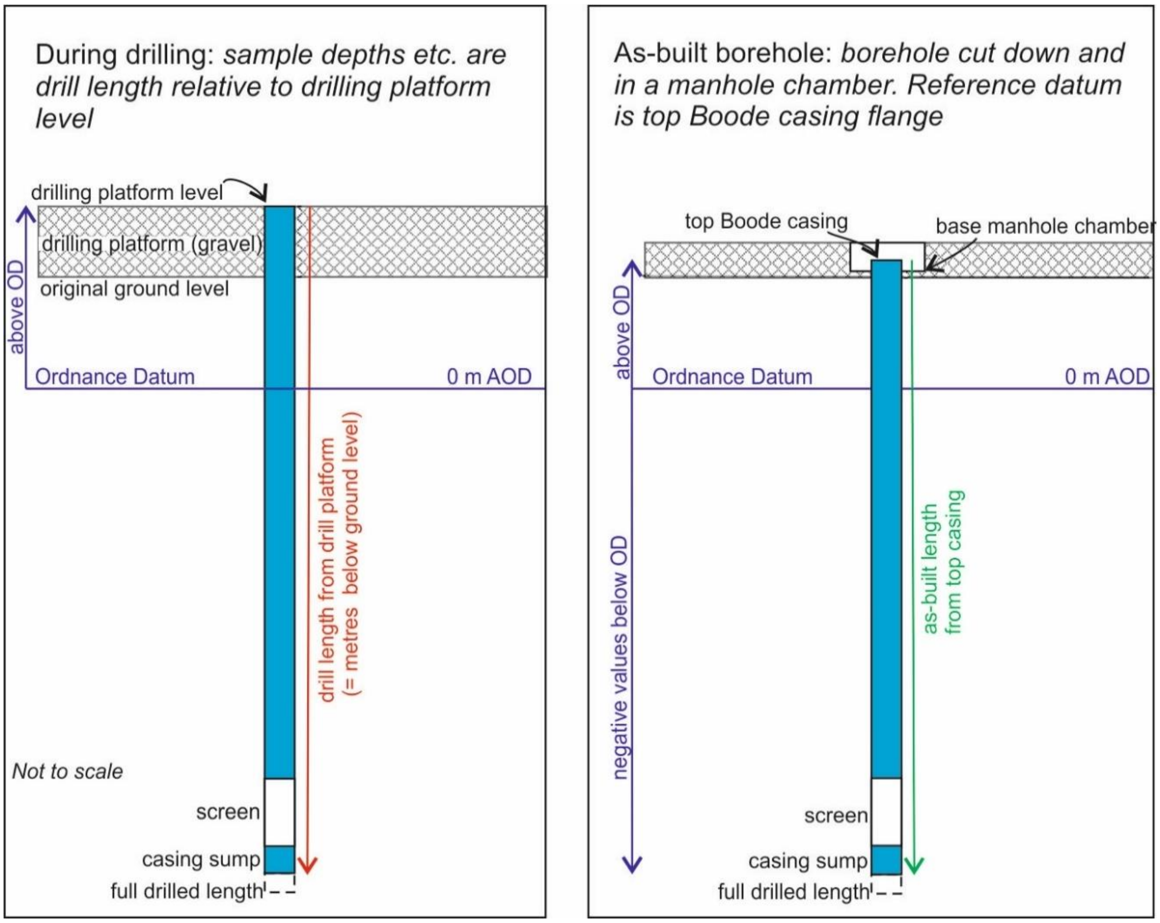

Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)

Table 2 Summary of start heights and datums used for GGA01

Stage	Borehole start height/ reference datum used (m AOD)	Used in
Drilling platform level – built up gravel platform	10.88	Drillers and BGS logs, sample depths, wireline log. ERT and DTS cable installation.
As-built borehole start height (top Boode casing flange)	9.99 (recorded as 9.986)	Reference datum for future Observatory users
Conversion Rock chip sample depths, wireline log – to convert from drill length to beneath as-built borehole start height		As-built depth below start height = drill length – (10.88- 9.99) *i.e* As-built depth below start height = drill length – (0.89)

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.

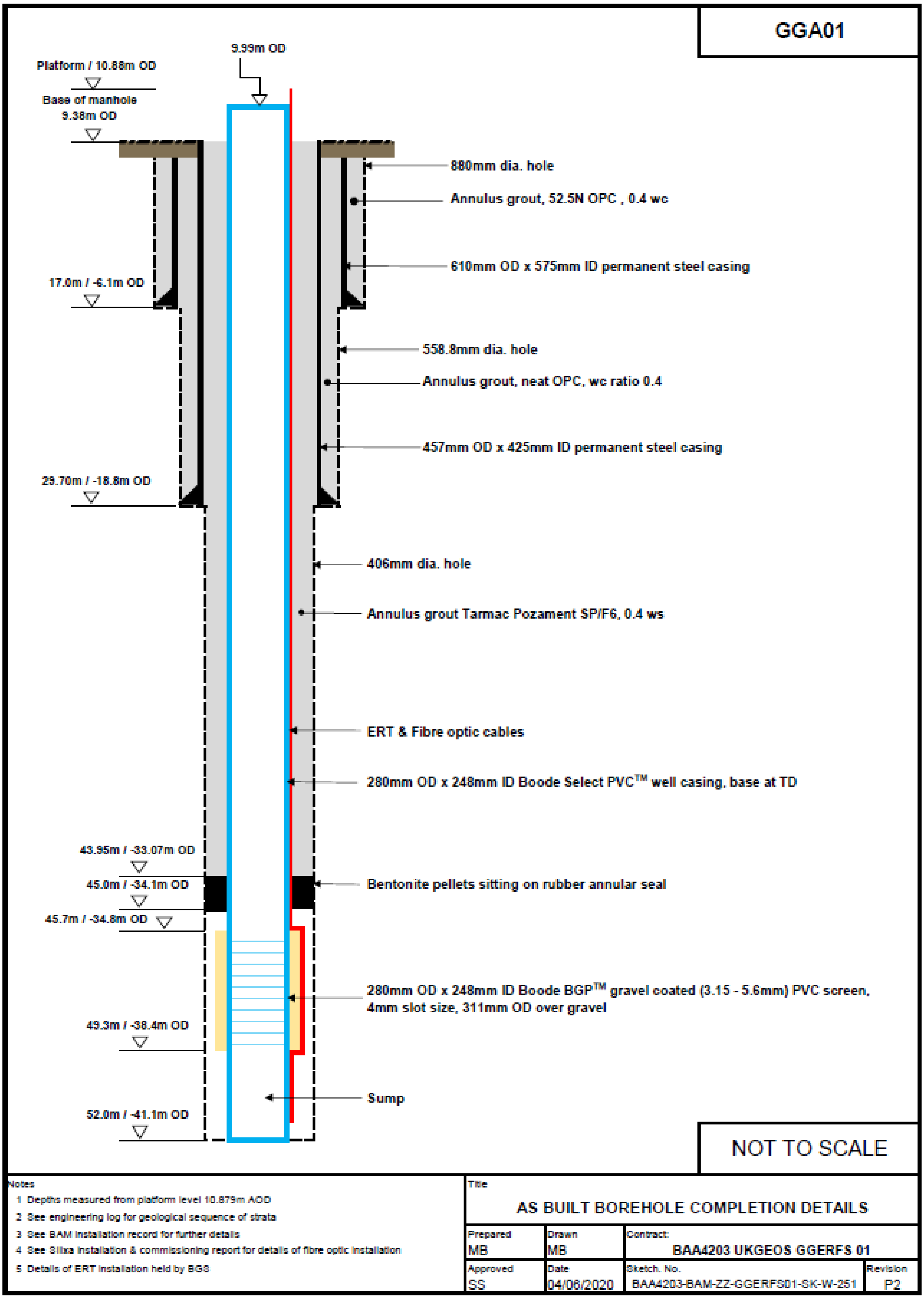

Figure 4 As-built borehole schematic for GGA01

2.1 BASIS OF DESIGN

The basis of the GGA01 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 mine working) 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 GGA01 (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 with a 3.15 to 5.6 mm sized bonded gravel pack attached. As the mine working is filled with mine waste, the gravel pack is intended to stop ingress of larger pieces of waste 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 45.0 mbgl above the Glasgow Upper mine working to support the emplacement of a permanent grout seal. A layer of bentonite pellets was emplaced (43.95 – 45.00 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). This grout mix was chosen as a compromise between strength and favourable high conductivity for the use of the ERT cables.

Table 3 Summary of heights for as-built borehole features for GGA01

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	45.7	-34.82	44.81
Base slotted screen	49.3	-38.42	48.41
Base installed casing sump	52	-41.12	51.11
ERT sensor positions	See Table 5 below	Not shown	See Table 5 below
Position of DTS termination unit	Base Termination unit depth: 51.1	Base Termination unit depth: -40.22	Base Termination unit depth 50.21

3 Drilling, casing, annulus grouting and testing methodology

Borehole GGA01 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 (Tables 1, 4).

Table 4 summarises the steps involved in the drilling of GGA01, further details are given in the borehole information summary at the end of the Drillers' log file (see section 4.1). Other points of note include

- Water was used as drilling fluid throughout the drilling of the superficial deposits and bedrock sections
- 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 metres below drilling platform level (mbgl).

Drilling and installation summary:	
11/06/2019	Drilled with BAM piling rig to 16.0 mbgl, with a 34 ¾" (880 mm) auger and installed made ground and superficial casing to 17 mbgl – the casing sank through its own weight into the superficials by 1m – the base of the made ground was encountered at 8.3 mbgl
12/06/2019	Made ground and superficial casing grouted.
10/07/2019 – 12/07/2019	Drilled superficials to rockhead with Fraste rig from 16.0 mbgl to 30.3 mbgl, with a 22" (558.8 mm) tri-cone bit. Installed casing to 29.7 mbgl Rockhead was encountered at ~26.0 mbgl
15/07/2019	Grouting of superficial to rockhead casing
19/08/2019 – 20/08/2019	Drilled to Glasgow Upper with Fraste rig from 30.0 mbgl to 52.0 mbgl, with a 16" (406 mm) tri-cone bit The Glasgow Upper encountered as waste from 47.6 – 48.86 mbgl – drilling indications included faster drilling, increased volume of cuttings return at the shakers and smell of H_2S gas – cuttings returns mainly sticky light grey clay, coal and rock fragments of sandstone, siltstone and mudstone
21/08/2019	Fibre optic and ERT cables attached on to exterior of casing during casing installation. Silixa and BGS ERT staff • Bentonite seal: 43.95 – 45.00 mbgl • Seal: 45.0 mbgl • Screened interval: 45.7 – 49.3 mbgl with gravel pack • Cased Sump: 49.3 – 52.0 mbgl
Various times between 22/08/2019-06/09/2019	Grouting the annulus of the Boode well casing to 14.0 mbgl, in stages
14/10/2019	Borehole cleaning began at a rate of 1.5 l/s with an aim to pump 3 borehole volumes, pump became blocked
15/10/2019	Conrad rig use to air lift the borehole, clearing the debris casing cuttings and silt – approximately 46.0 m^3 of water abstracted
16/10/2019	Borehole cleaning carried out using submersible pump –cleaning run from 13:15-15:30. See Table below
25/10/2019 - 28/10/2019	Grouting the annulus of the Boode Well casing completed from approx. 14 mbgl to 2.68 mbgl
09/01/2020	Cased hole logs run by Robertsons Geo Services
14/01/2020	Hydrogeological testing: step test. Conducted at 5, 10, 15, 20, 25 l/s
15/01/2020	Hydrogeological testing: constant rate pump test at 20 l/s for 5 hours

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)		10.88
As-built datum level at top casing flange (m AOD)		9.99
Electrode Number	**Depth below drill platform (m)**	**Depth below as-built datum (m)**
24	32.82	31.93
23	33.56	32.67
22	34.31	33.42
21	35.05	34.16
20	35.79	34.90
19	36.53	35.64
18	37.28	36.39
17	38.02	37.13
16	38.76	37.87
15	39.50	38.61
14	40.25	39.36
13	40.99	40.10
12	41.73	40.84
11	42.47	41.58
10	43.22	42.33
9	43.96	43.07
8	44.70	43.81
7	45.44	44.55
6	46.19	45.30
5	46.93	46.04
4	47.67	46.78
3	48.41	47.52
2	49.16	48.27
1	49.90	49.01

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 GGA01 11 26052020.pdf*]

Installation depths of the termination unit is 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 GGA01 on 17/01/2020, upon completion of the constant rate test on borehole GGA01, to a depth of approximately 10 m below the top of the casing. It remained in the borehole for the duration of test pumping of the remaining UKGEOS boreholes. It was removed from the borehole after the completion of the test pumping programme to allow the borehole casing to be cut down. The data logger will be replaced at a future date, when BGS staff are allowed to return to site following the COVID-19 pandemic restrictions, for continuous downhole groundwater monitoring. As with all groundwater observations in this borehole, the data logger is monitoring groundwater conditions only in the screened target interval, the Glasgow Upper 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_GGA01.pdf*]. This is a site 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. In particular, interpretations of till and boulder clay should be treated with caution. Due to the nature of the drillers' log, there are differences between it and BGS rock chip log (Section 4.2).

The borehole information summary sheets at the end of the drillers' log records the drilling progress each day, casing sizes, flush type used etc. All eleven Drillers' logs for UKGEOS boreholes at Cuningar Loop have been exported by the drilling contractor to the file *UKGEOSCuningar_BAA4203_FinalAGS.AGS* in the Association of Geotechnical Specialists standard text file format.

4.2 BGS ROCK CHIP LOG

BGS geologists were on site during borehole drilling to collect samples, record a field lithological/sedimentological log and to make decisions based on this log, such as the positioning of the borehole 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 working in a laboratory with the aid of a microscope.

The resulting lithological log record [*Detailed_BGS_Rockchiplog_GGA01.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**

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*].

5.2 **SUMMARY AND OUTPUTS**

The following wireline logs were run within Borehole GGA01 (Table 6)

Table 6 Cased hole wireline logs run for GGA01. All downhole depths in the released datasets were measured from the drill platform level 10.88 m

Wireline Log	Depth below drill platform Platform depth (10.88 m AOD)	Depth below final datum (top casing) (9.99 m AOD)
Gamma cased hole	3.2 -50.9	2.31 – 50.01
Caliper cased hole	3.2–50.9	2.31 – 50.01
Inclination cased hole	3.2–50.9	2.31 – 50.01
Azimuth cased hole	3.2 –50.9	2.31 – 50.01

Wireline logs were output in the following formats:

1. PDF

A PDF file showing all of the logs is included [*Cased_hole_borehole_geometry_GGA01.pdf*] . The header data 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 [*Cased_hole_borehole_geometry_GGA01.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 these logs and no editing has been done on them. 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 caliper log indicates a constant separation between the X and Y readings. This is related to the probe leaning to one side of the borehole. The probe is quite heavy and even with centralisers, it can tilt/lean to one direction. This means the calipers may not read identical even in a perfectly round casing. It does not indicate an oval casing shape.

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 [*GGA01_archived_rock_chips.xlsx*]. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGA01.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 a submersible 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 GGA01 borehole cleaning parameters

Technique used	***Submersible pump***
Date	*16/10/2019*
Length of time borehole cleaning continued (minutes)	*120*
Approximate volume of water removed (m^3)	*47*
Borehole water level drawdown (m)	*0.19*
Borehole volume (m^3)	*2.51*
Number of borehole volumes removed	*Approx. 18.5*
Field parameters measured for borehole cleaning monitoring	*Dissolved oxygen/ SEC (conductivity)/ Temperature/ Oxidation-reduction potential/ pH/ turbidity*
Average temperature of removed water (°C)	*12.6*
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 GGA01 is very high yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

Table 8 Overview of GGA01 test pumping

Step test	
Date of step test	*14/01/2020*
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)	*2.12*
Constant rate test	
Date of constant rate test	*15/01/2020*
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)	*1.805*
Average groundwater temperature during constant rate test (degrees C)	*12.0*
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 GGA01 (Figure 1).

The made ground composition including brickwork, ash, 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 8.3 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 17 m drilled depth, with clay with sand and gravel of the raised marine Paisley Clay Member to around 22 m drilled depth (Figure 1). Underlying sand and gravel could represent glaciofluvial deposits of the Broomhouse Sand and Gravel Formation, with a gravel, sand and silt unit logged between 25 – 26 m drilled depth interpreted as a sandy glacial diamicton (till) of the Wilderness Till Formation (Figure 1). Rockhead was recognised at 26 m drilled depth, within error limits of pre-drill prognosis (Appendix C).

The bedrock succession appears typical of the Scottish Middle Coal Measures Formation. The *c.*20 m section of sandstone with thin coal and siltstone interbeds above the Glasgow Upper mine working is more sandstone dominant compared to nearby legacy and UKGEOS boreholes (e.g. GGC01 cored borehole, Kearsey et al. 2019).

Figure 5 Glasgow Upper mine working waste returned during drilling borehole GGA01 (stained sandstone, coal pieces, clay)

The Glasgow Upper mine working was recognised during drilling by faster drilling rate, hydrogen sulphide smell, and drill cutting returns of stained coal, sandstone etc. indicating a loosely packed mining waste (Figure 5). This interpretation is compatible with mine abandonment plans* which record total extraction of this area at 1928 (on 1933 plan) following earlier irregular-shaped worked areas and access roads (elongate stoop and room; 1884 plan). The depth of the mineworking at 47.6 – 48.86 m drilled depth is as expected from mine plan spot heights and legacy boreholes nearby and within the ±4 m error limits of the pre-drill prognosis (Appendix C), and in close agreement with the mine working depth in adjacent borehole GGA02 that was drilled first. The 1.26 m thickness of the Glasgow Upper mine working recorded in borehole GGA01 is less than some legacy boreholes nearby and similar to others, and proved to be typical of the Glasgow Upper Coal and mine working or coal seam thickness recorded in the UKGEOS boreholes.

The floor of the Glasgow Upper mine working was comprised of clay and siltstone and could represent a seatearth (rootleted paleosol).

* Mine abandonment plan scans available from The Coal Authority

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

ARKLEY, S. 2018. Model metadata report for the Glasgow Geothermal Energy Research Field Site superficial deposits model. *British Geological Survey Open Report*, Nottingham, UK, OR/18/064, 50pp. http://nora.nerc.ac.uk/id/eprint/524556/

BURKIN, J, and KEARSEY, T. 2019. Model metadata report for Glasgow Geothermal Energy Research Field Site bedrock model. *British Geological Survey Open Report* Nottingham, UK, OR/18/053, 18pp. http://nora.nerc.ac.uk/id/eprint/522737/

HALLSWORTH, C R, and KNOX, R W O'B. 1999. BGS Rock Classification Scheme Volume 3. Classification of sediments and sedimentary rocks. *British Geological Survey Research Report*, RR 99-03.

KEARSEY, T, GILLESPIE, M, ENTWISLE, D, DAMASCHKE, M, WYLDE, S, FELLGETT, M, KINGDON, A, BURKIN, J, STARCHER, V, SHORTER, K, BARRON, H, ELSOME, J, BARNETT, M, and MONAGHAN, A. 2019. UK Geoenergy Observatories Glasgow: GGC01 cored, seismic monitoring borehole – intermediate data release. *British Geological Survey Open Report*, OR/19/049, Nottingham, UK, 36pp. http://nora.nerc.ac.uk/id/eprint/525009/

MONAGHAN, A A, Ó DOCHARTAIGH, B E, FORDYCE, F M, LOVELESS, S, ENTWISLE, D, QUINN, M, SMITH, K, ELLEN, R, ARKLEY, S, KEARSEY, T, CAMPBELL, S D G, FELLGETT, M, and MOSCA, I. 2017. UKGEOS: Glasgow Geothermal Energy Research Field Site (GGERFS): initial summary of the geological platform. Nottingham, UK, *British Geological Survey Open Report*, OR/17/006. http://nora.nerc.ac.uk/id/eprint/518636/

MONAGHAN, A A, STARCHER, V, Ó DOCHARTAIGH, B E, SHORTER, K M, and BURKIN, J. 2019. UK Geoenergy Observatories: Glasgow Geothermal Energy Research Field Site: Science Infrastructure Version 2. Nottingham, UK, *British Geological Survey Open Report*, OR/19/032 http://nora.nerc.ac.uk/id/eprint/522814/

TUCKER, M. E. 2011, Sedimentary Rocks in the Field: A Practical Guide (Geological Field Guide) 4th edition, Wiley-Blackwell 288pp ISBN: 978-0-470-68916-5

Appendix A: Summary of borehole GGA01 files in this information release

Table 9 Summary of files in the borehole GGA01 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_GGA01.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_GGA01.pdf Detailed_BGS_Rockchiplog_GGA01.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_GGA01.pdf	PDF
Wireline (geophysical) downhole data for cased hole logs and accompanying report *NOTE: depths are given relative to drill platform level*	Cased_hole_borehole_geometry_GGA01.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
Fibre optic cable installation report *NOTE: depths are given relative to drill platform level*	FibreOpticCable Installation Report BGS V1.2 GGA01 11 26052020.pdf	PDF
Spreadsheet of archived rock chip samples *NOTE: depths are given relative to drill platform level*	GGA01_archived_rock_chips.xlsx	XLSX

Appendix B: Detailed installation method for ERT and DTS cables

The ERT cable with sensors at an interval shown in Table 5 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; 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 6 were updated on paper at site during the drilling phase, for example the confirmed depth of the Glasgow Upper mine working in GGA02 informed the expected depth of GGA01 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.

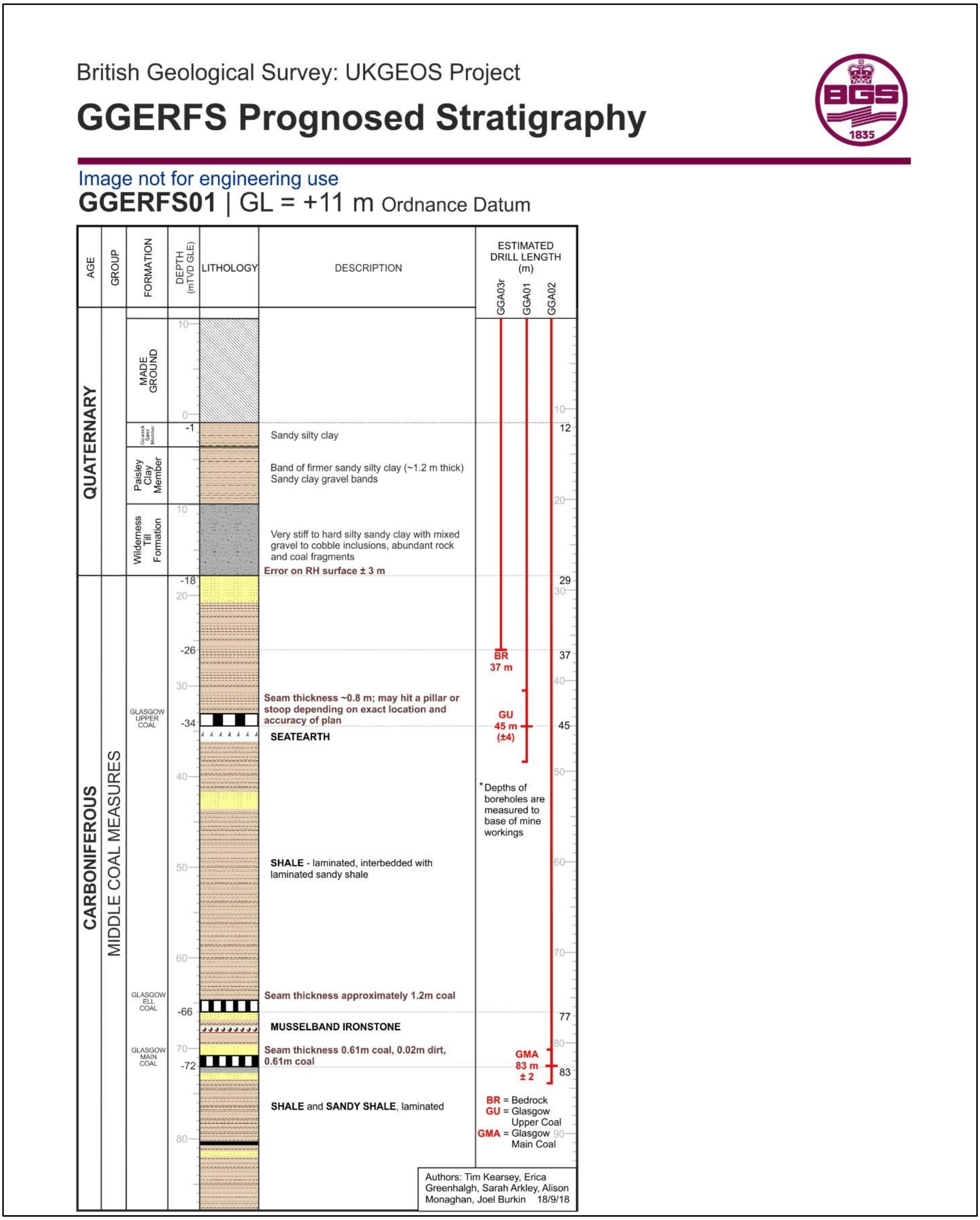

Figure 6 Pre-drill prognosis for site GGERFS01, boreholes GGA01, GGA02, GGA03r based on semi-regional geological models and nearby legacy boreholes.