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Environmental baseline characterisation and monitoring borehole GGB05, UK Geoenergy Observatory, Glasgow

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UK GEOENERGY OBSERVATORIES PROGRAMME

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Environmental baseline characterisation and monitoring borehole GGB05, UK Geoenergy Observatory, Glasgow

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Rig during the drilling of GGB05

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Summary

This report and accompanying data release describe the 'as-built' borehole GGB05 at the UK Geoenergy Observatory in Glasgow, as well as summarising hydrogeological testing and an initial geological interpretation.

Environmental characterisation and monitoring baseline borehole GGB05 at the UK Geoenergy Observatory in Glasgow is screened across a sandstone beneath rockhead, and thought to be around 5 m above recorded stoop and room mine workings in the Glasgow Upper coal. Initial hydrogeological indications from the test pumping suggest that borehole GGB05 is moderately yielding. There is a hydrogeological data logger installed in the borehole.

1 Introduction

Drilling of the environmental baseline and monitoring borehole GGB05 at Cuningar Loop in Rutherglen, Glasgow City Region, took place between 5th July and 11th October 2019 (start of drilling to casing installation date). The borehole targets a sandstone beneath rockhead and above recorded stoop and room (pillar and stall) mine workings of the Glasgow Upper Coal, with the slotted screen at –30.56 to -32.45 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_GGB05.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/e0ec7462-b731-47c6-93d6-e4613fb44be0 K Walker-Verkuil, V Starcher, H F Barron, K M Shorter, J Elsome, A A Monaghan. 2020. UK Geoenergy Observatories Glasgow Borehole GGB05 Data Release
and this report cited as:
WALKER-VERKUIL K, STARCHER V, BARRON H F, SHORTER K M, ELSOME J, MONAGHAN A A 2020. Environmental baseline characterisation and monitoring borehole GGB05, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/031

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

Table 1 GGB05 as-built data

Borehole number	GGB05	
Site	GGERFS05	
Easting (British National Grid)	262353.098	
Northing (British National Grid)	662510.136	
Drilling platform level (metres above Ordnance Datum AOD)	12.35	
Drilling started	05/07/2019	
Final casing installed	11/10/2019	
As-built borehole start height or datum (top Boode casing flange, metres AOD)	11.74	
Installation details		
Borehole detail	**Depths (drill length from drill platform level, metres)**	**Diameter size**
Made ground casing	0.0 – 17.7	16" (406.4 mm OD x 381.2 mm ID)
Rockhead casing	0.0 – 39.6	323.9 mm OD x 301.9 mm ID
Boode Well (BW) casing	0.0 – 43.0	165 mm OD x 146 mm ID
BW Slotted pipe with pre-glued gravel pack	43.0 – 44.8	191 mm OD x 146 mm ID
BW Casing Sump	44.8 – 46.0	165 mm OD x 146 mm ID
Geological details	**Depths (drill length from drill platform level, metres)**	**Depths, relative to Ordnance Datum (m)**
Base of made ground	7.3	+5.05
Base of superficial deposits	40.0	-27.65
Final drilled length	46.0	-33.65
BGS SOBI reference number	NS66SW BJ 3765	BGS ID 20693606

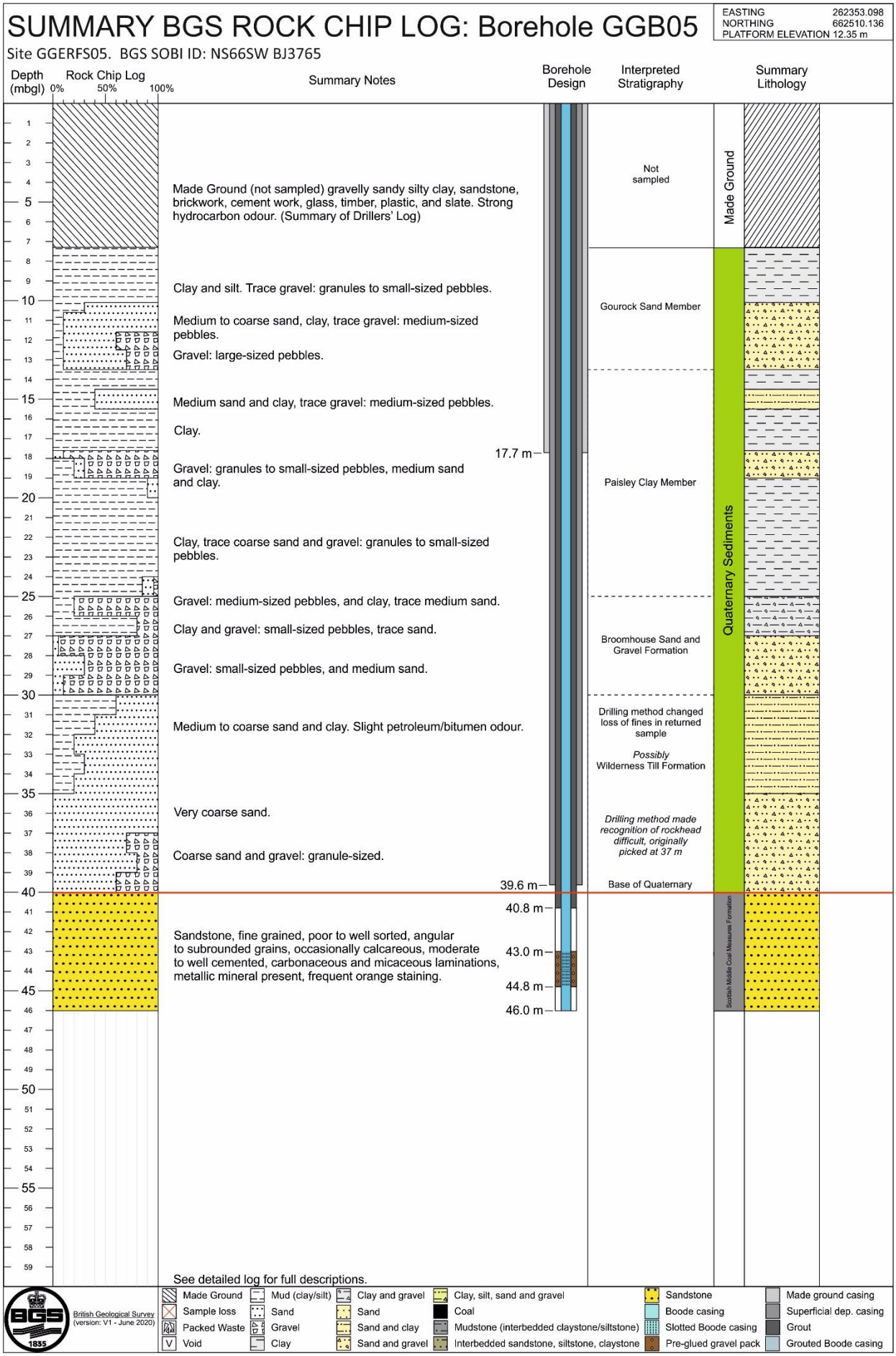

Figure 1 GGB05 summary log based on rock chip returns

1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGB05 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).

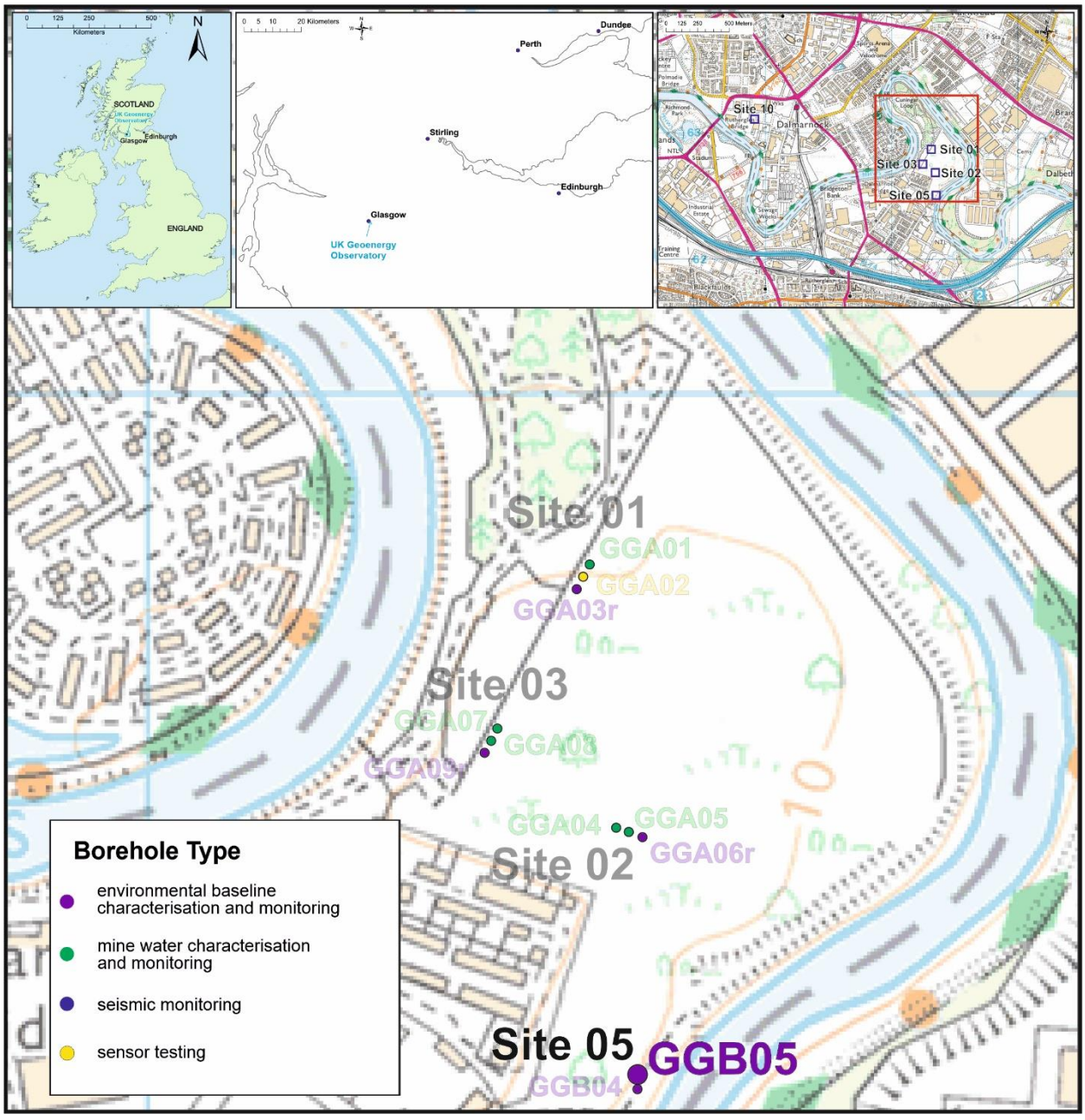

Figure 2 Location map of borehole GGB05, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

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, and BGS rock chip logs 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).

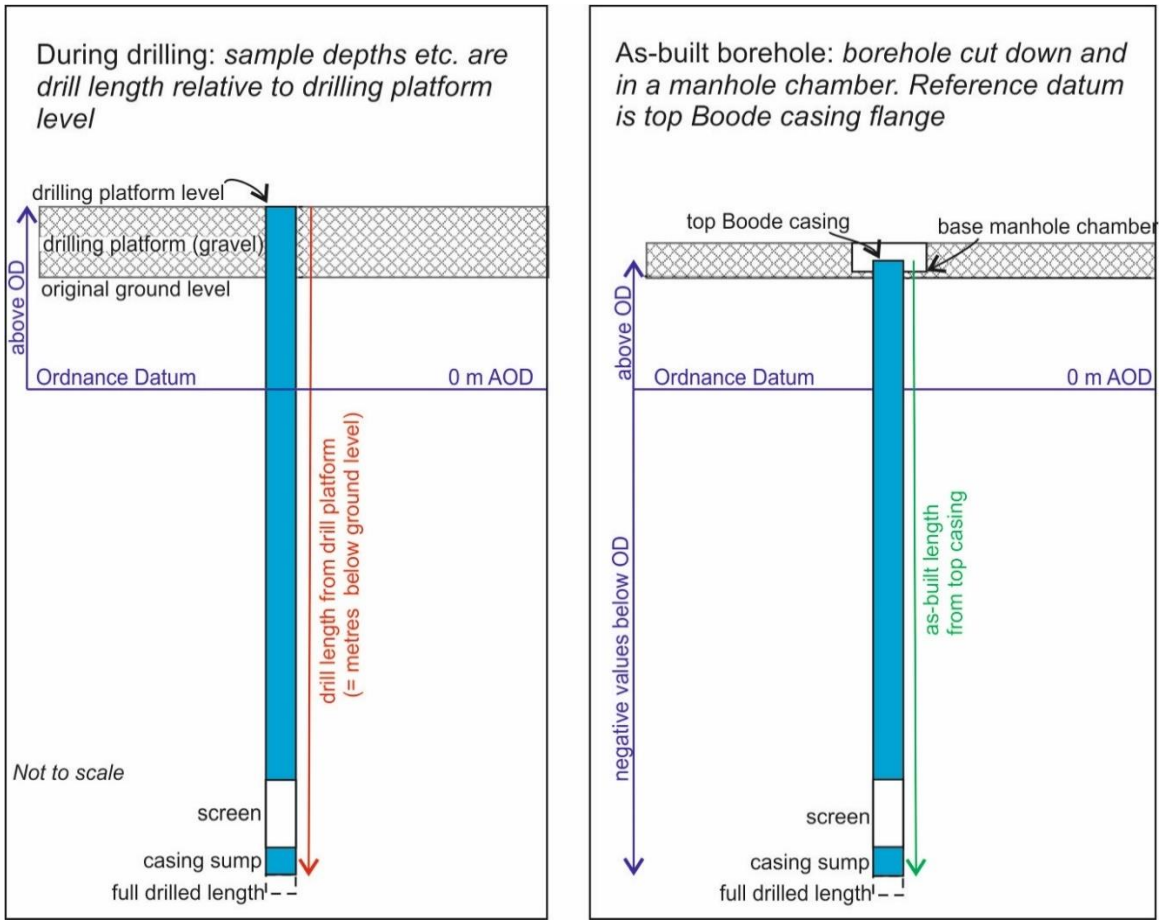

Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)

Table 2 Summary of start heights and datums used for GGB05

Stage	**Borehole start height/ reference datum used (metres above Ordnance Datum AOD)**	**Used in**
Drilling platform level – built up gravel platform	12.35	Drillers and BGS logs, sample depths
As-built borehole start height (top Boode casing flange)	11.74 (recorded as 11.738)	Reference datum for future Observatory users
Conversion Rock chip sample depths, logs – to convert from drill length to beneath as-built borehole start height		As-built depth below start height = drill length – (12.35-11.74) m *i.e* As-built depth below start height = drill length – (0.61) m

2 As-built borehole design

The UK Geoenergy Observatory boreholes have been designed for a range of scientific research purposes over a 15-year. Their construction is not typical of mine water or environmental monitoring boreholes that would be installed for commercial schemes.

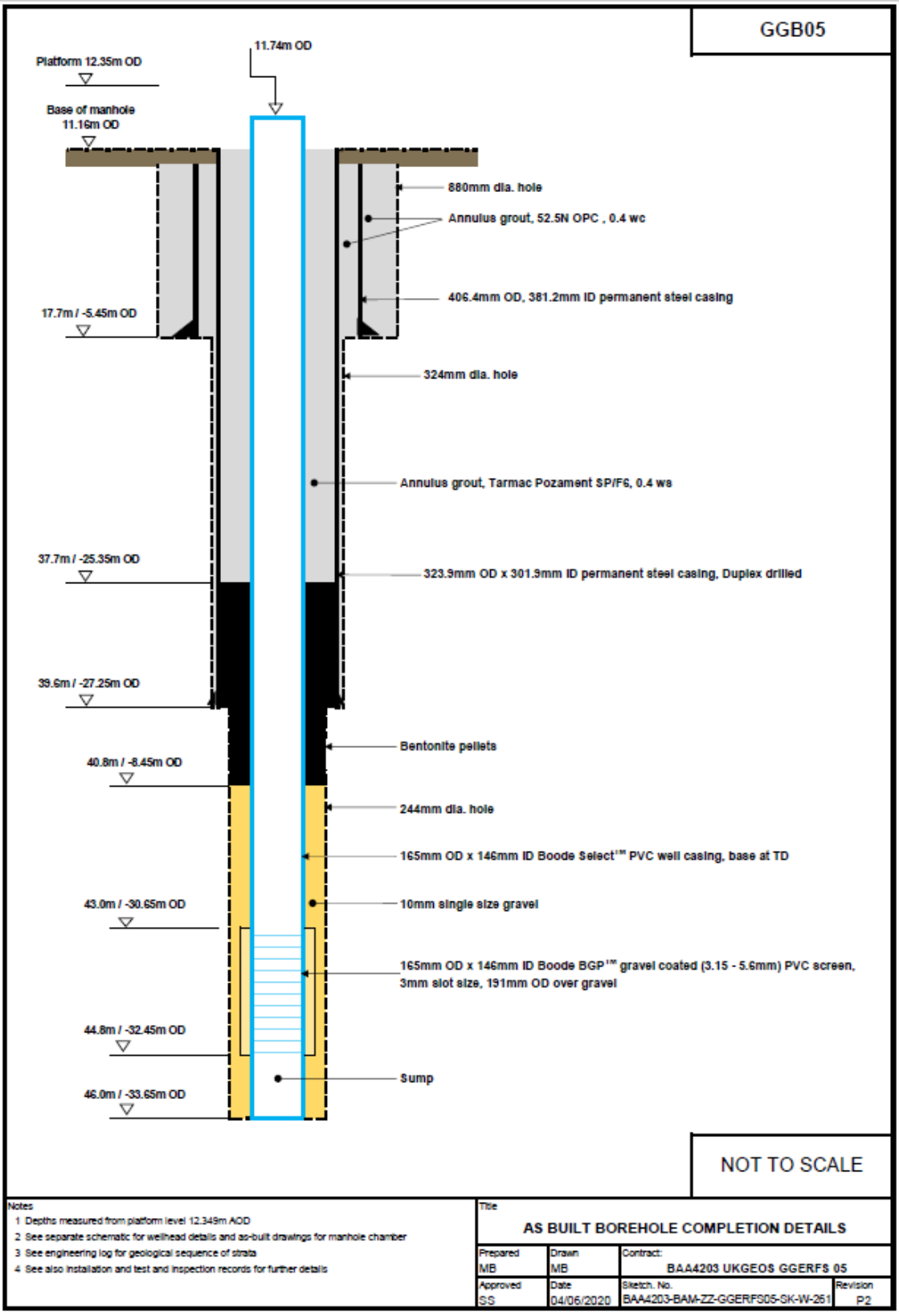

Figure 4 As-built borehole schematic for GGB05

2.1 BASIS OF DESIGN

The basis of the GGB05 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 (sandstone) and is fully sealed above the screen, so that all hydrogeological observations from this borehole relate only to this interval.

iii. A screen slot size of 3 mm was used in the sandstone, with a 3.15 to 5.6 mm sized bonded gravel pack attached.

iv. The borehole sump was included to catch any fines that enter through the slotted screen.

v. Gravel filled the remaining annular space around the gravel pack and was overlain by a bentonite layer (37.7 – 40.8 mbgl) to ensure a good top seal. Once the bentonite had set sufficiently (24 hours) then the annulus was grouted with a SP/F6 mix.

Table 3 **Summary of heights for as-built borehole features for GGB05**

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	43.0	-30.65	42.39
Base slotted screen	44.8	-32.45	44.19
Base installed casing sump	46.0	-33.65	45.39

3 Drilling, casing, annulus grouting and testing methodology

Borehole GGB05 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 GGB05, 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 the drilling technique varied from open hole with reverse circulation, open hole with direct flush to casing while drilling (duplex drilling) in response to problems with mobile sand and gravel (see Table 4 below). The bedrock section was open hole drilling 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:	
05/07/2019 – 08/07/2019	Drilled made ground with BAM piling rig to 17.6 mbgl, with a 34 ¾" (880 mm) auger • Base made ground was recorded at 7.3 mbgl • Made ground and superficial casing installed to a depth of 17.7 mbgl, deeper than the expected 11.0 mbgl, due to a sand interval at the shallower casing depth
09/08/2019	Drilled superficial deposits to rockhead with Conrad rig from 17.6 mbgl to rockhead with a 14 ¾" (374 mm) tri-cone bit **Problems encountered:** Sand had risen in borehole to 7.5 mbgl, the rig switched to direct flush
12/08/2019	Continue drilling to rockhead using direct flush
13/08/2019	Continue drilling to rockhead, added bentonite to flush during the day due to hole instability
14/08/2019 – 15/08/2019	Continue drilling towards rockhead from 26-29.5 mbgl Slow rate of drilling and large volumes of sand returning. Drilling stopped to discuss alternative approaches and drilling halted due to safety concerns on undermining rig
16/08/2019	Conrad rig moved from site
23/09/2019	Conrad rig returned to site and set up
Various times during	Drilling to rockhead using casing while drilling method used (duplex drilling) with direct flush –bentonite flush used for drilling

Drilling and installation summary:	
24/09/2019 – 01/10/2019	
02/10/2019	Continue drilling to rockhead with duplex method. Rockhead was initially thought to be encountered between 36.0 and 37.0 mbgl.
03/10/2019	Target depth reached at 40.0 mbgl. Preparing for casing and grout
04/10/2019	Reaming casing down, reached a depth of 39.6 mbgl Could not advance casing to 40.0 m – had advanced far enough for grouting
07/10/2019	Grouting bottom of borehole casing
08/10/2019	Drilling through grout
09/10/2019	Continue drilling out grout and drill ahead to TD Sand and gravel returned at around 39.0 – 40.5 mbgl – likely rockhead mis-identified due to the small nature of the cuttings returned when using direct flush
10/10/2019	Drilled to TD of 46.0 mbgl.
11/10/2019	Installation of Boode casing to 45.8 mbgl Casing design: Bentonite seal: 40.8 – 37.7 mbgl Screened interval: 43.0 – 44.8, 3 mm slotted Boode casing with 3.15 to 5.6 bonded gravel pack Gravel within annulus: 46.0 – 40.8 mbgl
14/10/2019 – 18/10/2019	Staged grouting of borehole annulus above bentonite seal
23/10/2019	Borehole cleaning – pumped approximately 3 borehole volumes over 50 minutes
13/02/2019	Hydrogeological testing: step test at 1/2/3/4/5 l/s
14/02/2019	Hydrogeological testing: constant rate test at 4.4 l/s for 5 hours

3.1 SENSORS INSTALLED

3.1.1 Hydrogeological data logger

A CT2X data logger was installed in GGB05 on 09/01/2020 to a depth of approximately 30 m below the top of the casing, and was raised on 13/01/2020 to approximately 25 m below the top of the casing. The data logger was removed during the test pumping on GGB05 (Drilcorp installed their own data logger during the tests). The data logger was re-installed upon completion of the constant rate test and 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 GGB05 on 16/03/2020 for 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, a sandstone beneath rockhead.

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_GGB05.pdf*]. This is a record of the lithologies encountered, as recorded on-site by the drillers. Apart from the upper part of the made ground section which is based on trial pits, this log was not recorded by a geotechnical engineer. Due to the nature of the driller's log, there are differences between it and BGS rock chip log (Section 4.2).

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

4.2 BGS ROCK CHIP LOG

BGS geologists were on site during borehole drilling to collect samples, record a field lithological log and to make decisions based on this log, such as the positioning of 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 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_GGB05.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. 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 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 [*GGB05_archived_rock_chips.xlsx*]. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGB05.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.

6 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.

6.1 BOREHOLE CLEANING

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

Borehole cleaning was done using an airlift and carried out for 45 minutes, by which time the field parameters being monitored (Table 5) had stabilised. A summary of the borehole cleaning carried out is in Table 5.

Table 5 Overview of GGB05 borehole cleaning parameters

Technique used	*Airlift*
Date	*23/10/2019*
Length of time borehole cleaning continued (minutes)	*45*
Approximate volume of water removed (m^3)	*2.66*
Borehole water level drawdown (m)	*0.42*
Borehole volume (m^3)	*0.75*
Number of borehole volumes removed	*Approx. 3.5*
Field parameters measured for borehole cleaning monitoring	*Dissolved oxygen/ SEC (conductivity)/ Temperature/ Oxidation-reduction potential/ pH/ turbidity*
Average temperature of removed water (°C)	*11.8*
Summary of outcome	*At the end of cleaning the water quality field parameters were stable and the turbidity readings were consistently zero*

6.2 TEST PUMPING

Test pumping was carried out to establish the hydraulic characteristics of the mine workings, shallow bedrock and superficial deposits, and the extent to which these units are connected at

individual sites and across different sites. The first consistent set of groundwater samples for chemistry analysis was also collected during test pumping.

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

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

Initial hydrogeological indications from the test pumping suggest that borehole GGB05 is moderately yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

Table 6 Overview of GGB05 test pumping

Step test	
Date of step test	*13/02/2020*
Number of steps	*5*
Length of steps (hours)	*1*
Length of pumping during step test (hours)	*5*
Length of manually monitored recovery during step test (hours)	*1*
Pumping rates for each step (l/s)	*1/2/3/4/5*
Maximum drawdown at end of final step (m)	*4.84*
Constant rate test	
Date of constant rate test	*14/02/2020*
Length of pumping during step test (hours)	*5*
Length of manually monitored recovery during step test (hours)	*1*
Pumping rate for constant rate test (l/s)	*4.4*
Maximum drawdown at end of constant rate test (m)	*5.0*
Average groundwater temperature during constant rate test (°C)	*11.14*
Groundwater geochemical samples collected during constant rate test	*Two samples: one after 2 hours and one after 4 hours*

7 Initial geological interpretation

Integration of drillers' information, rock chip logs, preliminary hydrogeological indications from borehole cleaning and test pumping, together with correlation to legacy borehole data has allowed an initial geological interpretation of borehole GGB05 (Figure 1).

The made ground composition including brickwork, cementwork, glass and timber 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 7.3 m was similar to the pre-drill borehole prognosis (Appendix B). From 6.5 – 7.3 m drilled depth samples of green-stained clay and silt were collected, this interval is included as part of the made ground as it appears to have been significantly altered by man-made processes. A similar deposit is seen in borehole GGB04 adjacent.

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, clay and silt of the alluvial Gourock Sand Member to around 13.5 m, and clay with gravel and sand of the raised marine Paisley Clay Member to around 25 m drilled depth (Figure 1). Underlying gravel, sand and clay could represent glaciofluvial deposits of the Broomhouse Sand and Gravel Formation to around 30 m drilled depth. Beneath 30 m the drilling method changed to casing while drilling with direct flush, with very poor returns, small cuttings and loss of fines. Sand and clay were returned to around 35 m drilled depth and the tentative interpretation of the Wilderness Till Formation (Figure 1) is influenced by borehole records nearby (NS66SW BJ630 and BJ583). Initially, rockhead was thought to have been encountered at between 36 – 37 m drilled depth, deeper than the pre-drill borehole prognosis (Appendix B), though identification was difficult due to the small size of the cuttings returns using casing while drilling. However, on continued drilling, further sand and gravel was returned between 39 – 40 m with rockhead at 40 m. Possibly the 'sand and gravel' returns between 37 – 40 m drilled depth represent large glacially-transported bedrock blocks, or very deeply weathered bedrock.

The fine-grained sandstone beneath rockhead appears typical of those in the Scottish Middle Coal Measures Formation above the Glasgow Upper coal. At this location the mine abandonment plans show a stoop and room workings in the Glasgow Upper coal, prognosed at approximately 5 m beneath the base of the screened interval in GGB05.

8 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.

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Appendix A: Summary of borehole GGB05 files in this information release

Table 7 Summary of files in the borehole GGB05 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_GGB05.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_GGB05.pdf Detailed_BGS_Rockchiplog_GGB05.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_GGB05.pdf	PDF
Spreadsheet of archived rock chip samples. *NOTE: depths are given relative to drill platform level*	GGB05_archived_rock_chips.xlsx	XLSX

Appendix B Pre-drill borehole prognosis

The pre-drill borehole prognosis (Figure 5) 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 5 were updated on paper at site during the drilling phase, Figure 5 does not represent the learnings or local, site specific considerations used during the drilling phase.

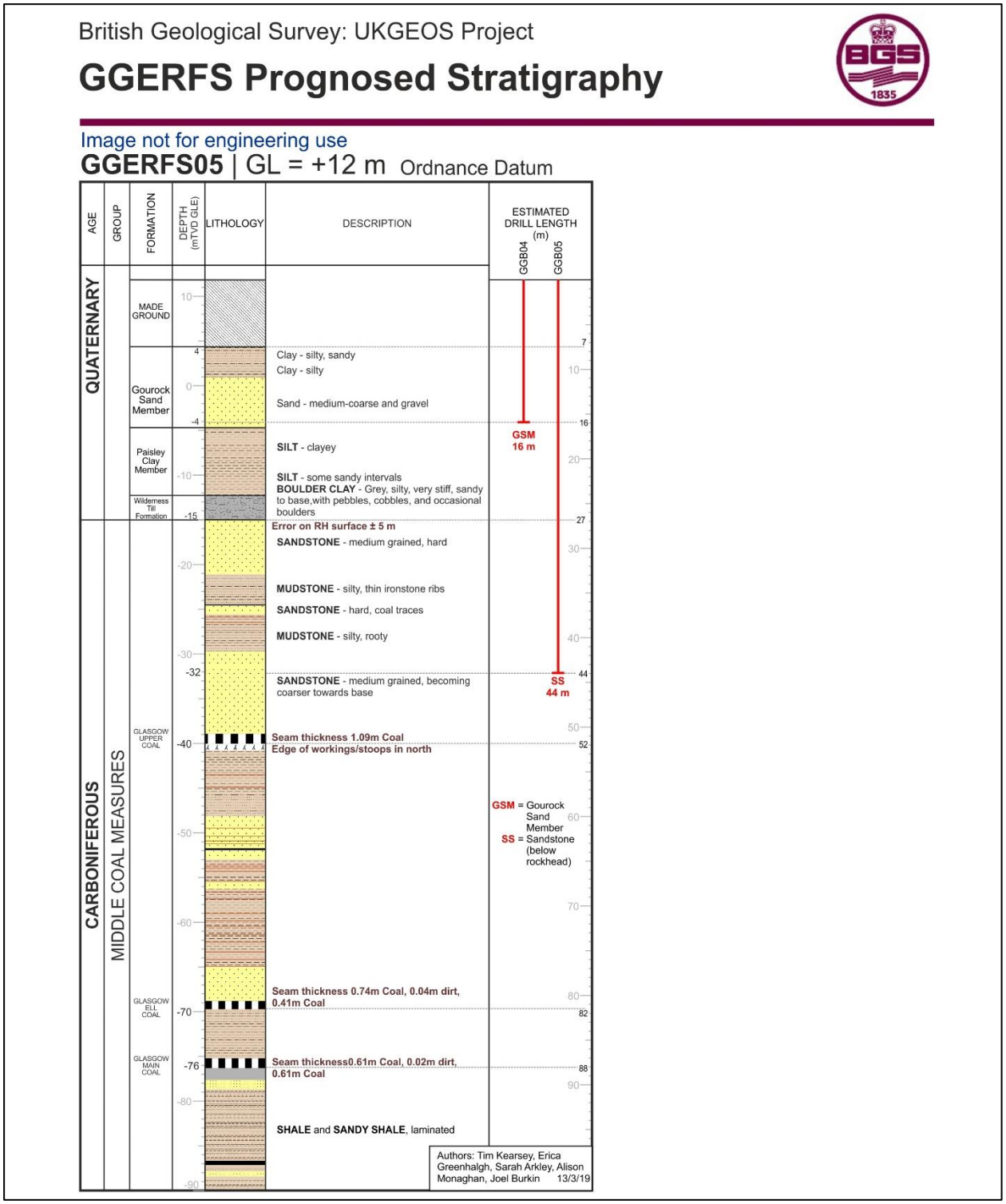

Figure 5 Pre-drill borehole prognosis for site GGERFS05, boreholes GGB04 and GGB05 based on semi-regional geological models and nearby legacy boreholes