British Geological Survey
Expert | Impartial | Innovative

# Environmental baseline characterisation and monitoring borehole GGB04, UK Geoenergy Observatory, Glasgow

UK Geoenergy Observatories Programme

Open Report OR/20/030

BRITISH GEOLOGICAL SURVEY

UK GEOENERGY OBSERVATORIES PROGRAMME

OPEN REPORT OR/20/030

# Environmental baseline characterisation and monitoring borehole GGB04, UK Geoenergy Observatory, Glasgow

J Elsome, K Walker-Verkuil, V Starcher, H F Barron, K M Shorter, A A Monaghan

*Contributors*

J Burkin, B O Dochartaigh, E Callaghan

*Editor*

M Spence



*Keywords*

Borehole drilling, UKGEOS, mine water heat, environmental baseline, superficial deposits

*National Grid Reference*

SW corner 262353, 662500
NE corner 262353, 662500

*Front cover*

Manhole chamber at for access to borehole GGB04

*Bibliographical reference*

ELSOME J, WALKER-VERKUIL K, STARCHER V, BARRON H F, SHORTER K M, MONAGHAN A A 2020. Environmental baseline characterisation and monitoring borehole GGB04, UK Geoenergy Observatory, Glasgow. *British Geological Survey Open Report*, OR/20/030. 22pp.



Keyworth, Nottingham British Geological Survey 2020

## BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

*The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.*

*The British Geological Survey is a component body of UK Research and Innovation.*

*British Geological Survey offices*

**Environmental Science Centre, Keyworth, Nottingham NG12 5GG**

Tel 0115 936 3100

**BGS Central Enquiries Desk**

Tel 0115 936 3143
email enquiries@bgs.ac.uk

**BGS Sales**

Tel 0115 936 3241
email sales@bgs.ac.uk

**The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP**

Tel 0131 667 1000
email scotsales@bgs.ac.uk

**Natural History Museum, Cromwell Road, London SW7 5BD**

Tel 020 7589 4090
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

**Cardiff University, Main Building, Park Place, Cardiff CF10 3AT**

Tel 029 2167 4280

**Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB**

Tel 01491 838800

**Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB**

Tel 01232 666595
www.bgs.ac.uk/gsni/

**Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU**

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

**UK Research and Innovation, Polaris House, Swindon SN2 1FL**

Tel 01793 444000
www.ukri.org

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

# Acknowledgements

This report is the culmination of a huge amount of work delivered by many staff from BGS, the UK Geoenergy Observatories contractors BAM Nuttall/ BAM Ritchies, Ramboll, Drilcorp and others. Special thanks go to the UK Geoenergy Observatories Science Advisory Group (GSAG) for on- call support to maximise science opportunities during the construction phase, and to project partners including landowners, local residents and regulatory bodies (in particular Clyde Gateway, SEPA and The Coal Authority). Within BGS the communications and engagement team of C Chapman, C Buchanan and T Galley have had a significant role in enabling the borehole construction, and many BGS data management and informatics experts have had a large part to play in making datasets openly available. G Baxter, R Dearden, J Midgley, S Burke, C Abesser, S Hannis, T Kearsey and S Henderson are also thanked for their input to planning the borehole and the checking of datasets.

# Contents

**Acknowledgements** ..... **i**

**Contents** ..... **i**

**Summary** ..... **3**

**1 Introduction** ..... **3**

1.1 Citation guidance ..... 3

1.2 As-built borehole location ..... 6

1.3 Drilling and as-built lengths and heights ..... 7

**2 As-built borehole design** ..... **9**

2.1 Basis of design ..... 10

**3 Drilling, casing, annulus grouting and testing methodology** ..... **10**

3.1 Sensors installed ..... 12

**4 Borehole logs** ..... **12**

4.1 Drillers' log ..... 12

4.2 BGS rock chip log ..... 12

**5 Archived rock chip samples** ..... **13**

**6 Initial hydrogeological indications** ..... **14**

6.1 Borehole cleaning ..... 14

6.2 Test pumping ..... 14

**7 Initial geological interpretation** ..... **15**

**8 References** ..... **16**

**Appendix A: Summary of the borehole GGB04 files in this information release** ..... **17**

**Appendix B Pre-drill borehole prognosis** ..... **17**

## FIGURES

Figure 1 GGB04 summary log based on rock chip returns ..... 5

Figure 2 Location map of borehole GG0B04, 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]. ..... 6

Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right) ..... 7

Figure 4 As-built borehole schematic for GGB04 ..... 9

Figure 5 Pre-drill borehole prognosis for site GGERFS05, boreholes GGB04 and GGB05 based on semi-regional geological models and nearby legacy boreholes ..... 18

## TABLES

Table 1 GGB04 as-built summary data ..... 4

Table 2 Summary of start heights and datums used for GGB04 ..... 8

Table 3 Summary of heights for as-built borehole features for GGB04 ..... 10

Table 4 Summary of drilling, casing, grouting and testing of GGB04. Depths are in metres below drilling platform level (mbgl). ..... 11

Table 5 Overview of GGB04 borehole cleaning parameters ..... 14

Table 6 Overview of GGB04 slug test parameters ..... 15

Table 7 Summary of files in the borehole GGB04 information release ..... 17

# Summary

This report and accompanying data release describe the 'as-built' borehole GGB04 at the UK Geoenergy Observatory in Glasgow, as well as summarising hydrogeological testing and an initial geological interpretation.

Environmental baseline characterisation and monitoring borehole GGB04 at the UK Geoenergy Observatory in Glasgow is screened across a sand and gravel unit in the upper part of the superficial deposits. Hydrogeological evidence from test pumping indicates that the borehole is very low yielding. There is a hydrogeological data logger installed in the borehole.

# 1 Introduction

Drilling of the environmental baseline and monitoring borehole GGB04 at Cuningar Loop in Rutherglen, Glasgow City Region, took place between 4th July and 1st August 2019 (start of drilling to casing installation date). The borehole targets a sand and gravel unit within the superficial deposits (Gourock Sand Member), with the slotted screen at +1.77 to -0.23 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_GGB04.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/d31f33b8-b34a-4843-b2d2-545722bf94ae<br><br>J Elsome, K Walker-Verkuil, V Starcher, H F Barron, K M Shorter, A A Monaghan. 2020. UK Geoenergy Observatories Glasgow Borehole GGB04 Data Release |
| ***and this report cited as:*** |
| ELSOME J, WALKER-VERKUIL K, STARCHER V, BARRON H F, SHORTER K M, MONAGHAN A A 2020. Environmental baseline characterisation and monitoring borehole GGB04, UK Geoenergy Observatory, Glasgow. British Geological Survey Open Report, OR/20/030. |

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

**Table 1 GGB04 as-built summary data**

| | | |
|---|---|---|
| **Borehole number** | GGB04 | |
| **Site** | GGERFS05 | |
| **Easting** (British National Grid) | 262352.976 | |
| **Northing** (British National Grid) | 662500.043 | |
| **Drilling platform level** (metres above Ordnance Datum AOD) | 12.40 | |
| **Drilling started** | 04/07/2019 | |
| **Final casing installed** | 01/08/2019 | |
| **As-built borehole start height or datum** (top Boode casing flange, metres AOD) | 11.86 | |
| **Installation details** | | |
| **Borehole detail** | **Depths (drill length from drill platform level, metres)** | **Diameter size** |
| Made ground casing | 0.0 – 9.5 | 8¾" (219.1 mm OD x 198.7 mm ID) |
| Boode Well (BW) plain casing | 0.0 – 10.63 | 113.8 mm OD x 103.8 mm ID |
| BW Slotted pipe with pre-glued gravel pack | 10.63 – 12.53 | 144 mm OD x 103.8 mm ID |
| BW Casing Sump | 12.53 – 13.53 | 113.8 mm OD x 103.8 mm ID |
| **Geological details** | **Depths (drill length from drill platform level, metres)** | **Depths, relative to Ordnance Datum (m)** |
| Base of made ground | 9.0 | +3.4 |
| Final drilled length | 16.00 | -3.6 |
| BGS SOBI reference number | NS66SW BJ 3764 | BGS ID 20693605 |

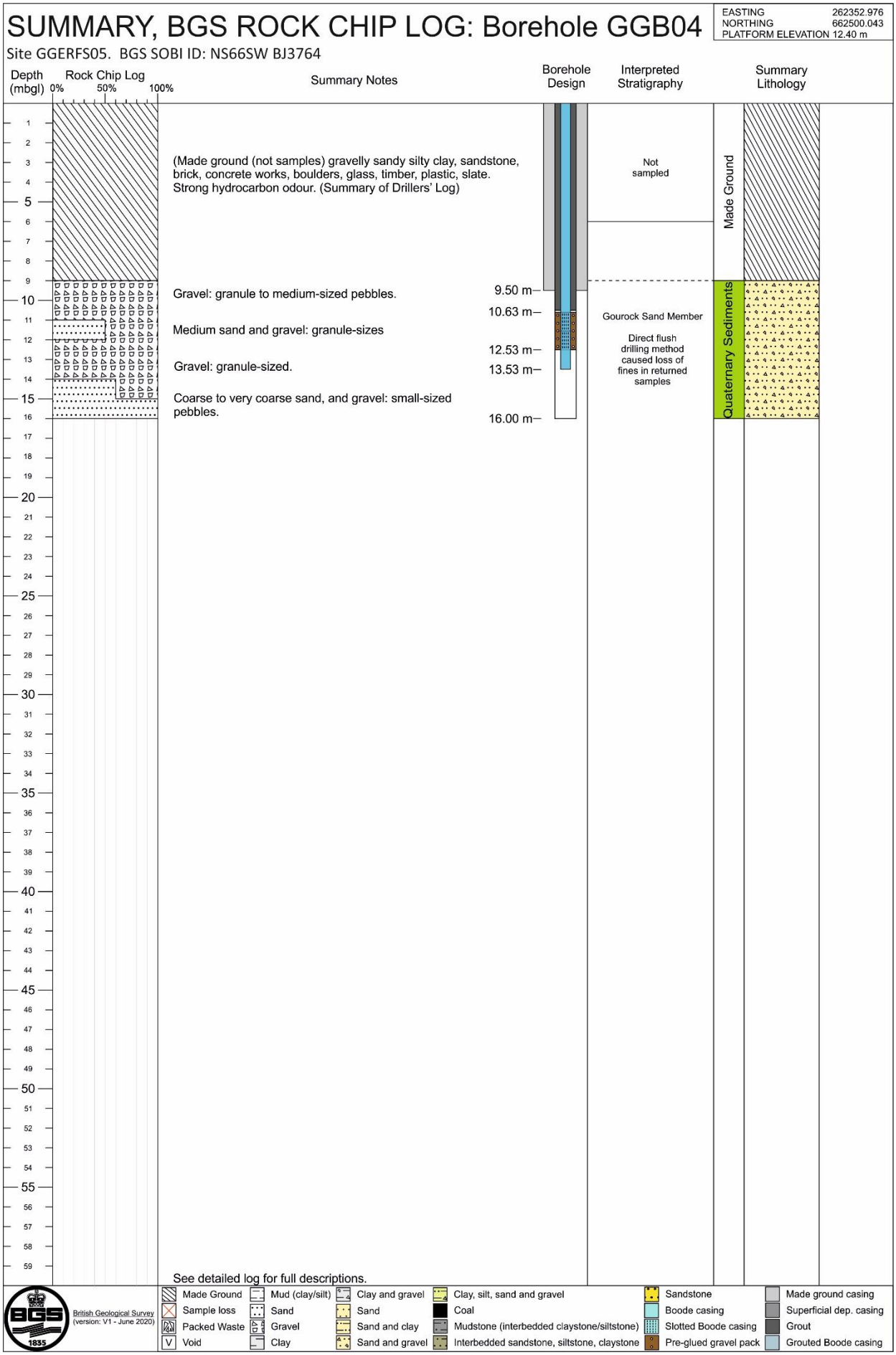


**Figure 1 GGB04 summary log based on rock chip returns**

## 1.2 AS-BUILT BOREHOLE LOCATION

Borehole GGB04 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).

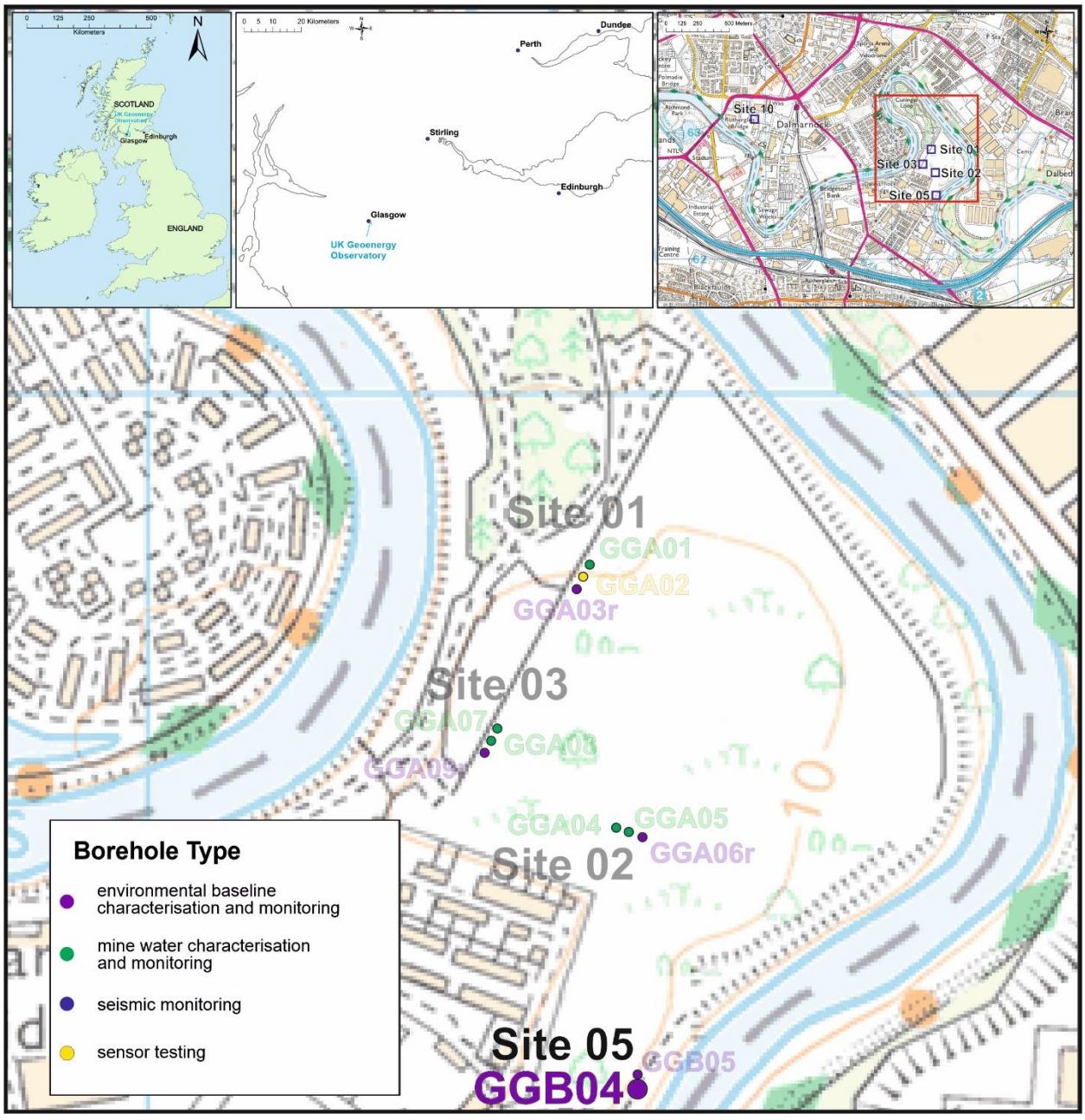


**Figure 2 Location map of borehole GG0B04, UK Geoenergy Observatory in Glasgow. The other mine water and environmental baseline boreholes are shown for reference. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].**

## 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 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).

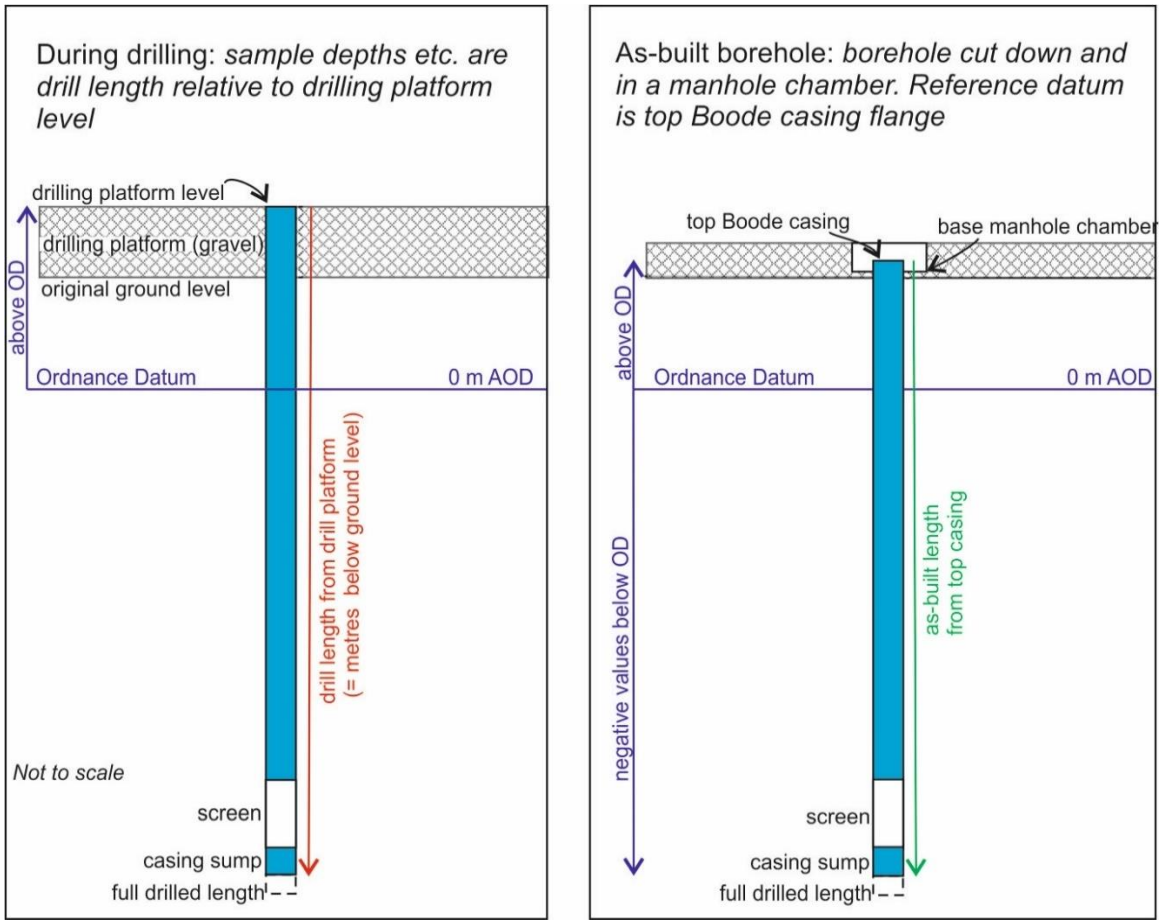


**Figure 3 Images summarising the datums and depths/lengths/heights during drilling (left) and as-built (right)**

**Table 2 Summary of start heights and datums used for GGB04**

| Stage | Borehole start height/ reference datum used (m AOD) | Used in |
|---|---|---|
| Drilling platform level – built up gravel platform | 12.40 | Drillers and BGS logs, sample depths |
| As-built borehole start height (top Boode casing flange) | 11.86 (recorded as 11.861) | Reference datum for future Observatory users |
| **Conversion** Rock chip sample depths – to convert from drill length to beneath as-built borehole start height | | As-built depth below start height = drill length – (12.40 – 11.86) m<br>*i.e*<br>As-built depth below start height = drill length – (0.54) 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 lifetime. Their construction is not typical of mine water or environmental monitoring boreholes that would be installed for commercial schemes.

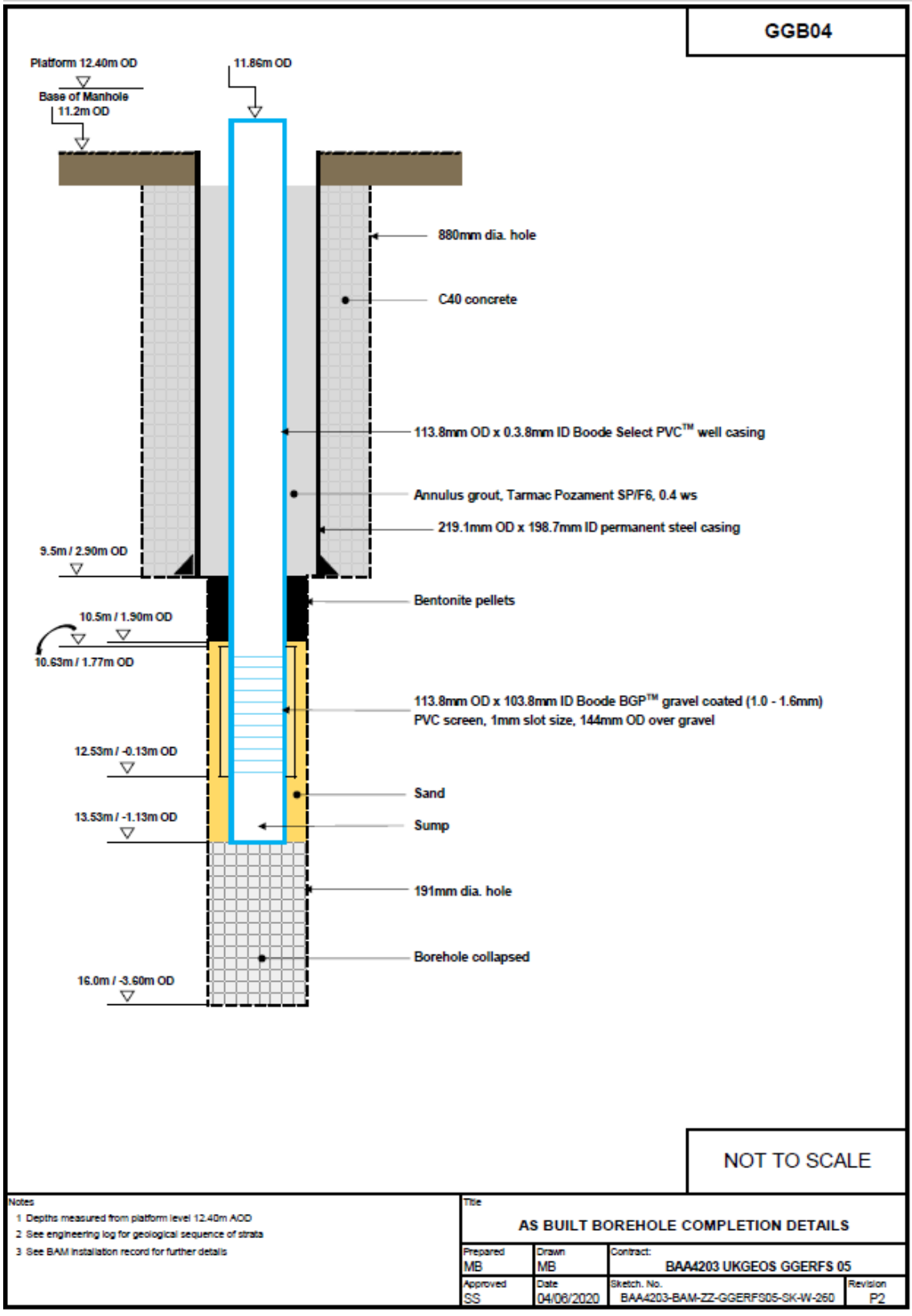


**Figure 4 As-built borehole schematic for GGB04**

## 2.1 BASIS OF DESIGN

The basis of the GGB04 borehole design was as follows;

i. Separate borehole casings were installed through the made ground and 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 (a sand in the shallow superficial deposits) and is fully sealed above the screen, so that all hydrogeological observations from this borehole relate to this target interval. A screen slot size of 1 mm was used with a 1.0 to 1.6 mm sized bonded gravel pack attached.

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

Sand filled the remaining annular space around the gravel pack and was overlain by a bentonite layer (9.5 – 10.5 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 GGB04**

| 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 | 10.63 | 1.77 | 10.09 |
| Base slotted screen | 12.53 | -0.13 | 11.99 |
| Base installed casing sump | 13.53 | -1.13 | 12.99 |

# 3 Drilling, casing, annulus grouting and testing methodology

Borehole GGB04 was drilled and cased in separate sections for made ground and superficial deposits. 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 GGB04, 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 flush, and water with bentonite mud were using through the drilling of the superficial deposits.
- The drilling technique in the made ground to superficial deposits section was piling rig with auger. In the superficial deposits section rotary open hole with direct flush was used.

- Fluid and rock chip samples were taken from the superficial deposits 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 of GGB04. Depths are in metres below drilling platform level (mbgl).**

| **Drilling and installation summary:** | |
|---|---|
| 04/07/2019 | Drilled and installed made ground and superficial deposits casing with BAM piling rig to 9.5 mbgl, with a 34 ¾" (880 mm) auger – made ground level was recorded at 9.0 mbgl |
| 05/07/2019 | Made ground and superficial casing grouted |
| 31/07/2019 | Drilled superficials to target screened interval depth with Beretta rig from 9.0 to 16.0 mbgl using a 7 ½" (191 mm) tri-cone bit<br>**Problems encountered:**<br>• At 15 mbgl mobile sand and gravel were encountered – when the drill string was removed in order to installed the casing pipe the hole collapsed back to 10.4 mbgl<br>• The direct flush drilling method caused loss of fines in the samples returned |
| 01/08/2019 | Re-drill borehole with bentonite flush and install casing.<br>Casing design:<br>• Bentonite seal: 9.5 – 10.5 mbgl<br>• Screen interval: 10.63 – 12.53 mbgl, 1 mm slotted Boode casing with 1.0 to 1.6 mm bonded gravel pack.<br>• Sump: 12.53 – 13.53 mbgl<br>**Problems encountered:**<br>• The re-drilled the hole collapsed back to 13.53 mbgl – due to the collapse it was decided to install a 1 m sump and 2 m of slotted screen slighter shallower than planned |
| 02/08/2019 | Boode casing grouted and completed |
| 11/08/2019 | Borehole cleaning began<br>**Problems encounters:**<br>• Borehole pumped dry within 1 min at 2-3 l/s – wait to recharge |
| 14/08/2019 | Continue borehole cleaning, 3 borehole volumes pumped – waited for recharge after each volume |
| 15/08/2019 | Further borehole cleaning |
| 17/02/2020 | Falling head slug test |

### 3.1 SENSORS INSTALLED

#### 3.1.1 Hydrogeological data logger

A CT2X data logger was installed in GGB04 on 09/01/2020 to a depth of approximately 11 m below the top of the casing. The data logger was removed during the slug test on GGB04 (Drilcorp installed their own data logger during the test), but was in place for the remainder of the test pumping programme. It was removed from the borehole again after the completion of test pumping programme, to allow the casing to be cut down. The data logger was reinstalled in GGB04 on 16 March 2020 for continuous groundwater monitoring. As with all groundwater observations in this borehole, the data logger is monitoring groundwater conditions only in the screened target interval, the sand and gravel unit near the top of the superficial deposits.

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_GGB04.pdf*]. This is a record of deposits 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 log and to make decisions based on this log, such as the positioning of borehole screens and seals. A one litre tub of rock chips from the open hole drilling was generally taken every metre, to be representative of the lithologies encountered in that metre. Other notable features such as the top and base depths of key intervals such as coals and mine workings were recorded in discussion with the drillers.

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

The resulting lithological log record [*Detailed_BGS_Rockchiplog_GGB04.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, 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 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 [*GGB04_archived_rock_chips.xlsx*]. For the composition of the samples refer to the BGS rock chip log [*Detailed_BGS_Rockchiplog_GGB04.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 completed using a submersible pump. The borehole was pumped dry, allowed to re-fill and then pumped dry again. This process was carried out several times over the course of three days as the borehole could not sustain the lowest pumping rate. By the end of the final day 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 GGB04 borehole cleaning parameters**

| **Technique used** | ***Submersible pump*** |
|---|---|
| Date | *13/08/2019 - 15/08/2019* |
| Length of time borehole cleaning continued (minutes) | *Approx. 480* |
| Approximate volume of water removed ($m^3$) | *0.14* |
| Borehole water level drawdown (m) | *Borehole ran dry and was allowed to refill before being pumped again and running dry again. This process was repeated several times* |
| Borehole volume ($m^3$) | *0.11* |
| Number of borehole volumes removed | *Approx. 1.3* |
| Field parameters measured for borehole cleaning monitoring | *Dissolved oxygen/ SEC (conductivity)/ Temperature/ Oxidation-reduction potential/ pH/ turbidity* |
| Average temperature of removed water (°C) | *19.0* |
| Summary of outcome | *At the end of cleaning the water quality field parameters were stable* |

## 6.2 TEST PUMPING

Test pumping was carried out to establish the 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. Hydrogeological observations made during borehole cleaning indicated that borehole GGB04 was too low yielding to carry out the step drawdown and constant rate tests conducted on the other UKGEOS boreholes. Instead, a slug test was conducted, which is a standard technique to establish hydraulic parameters in low yielding boreholes.

The slug test was done in two parts between 17/02/2020 and 19/02/2020, using a 4-litre slug. The first part consisted of a falling head test, in which a slug was installed quasi-instantly 2 m below the rest water level. After 20.5 hours, the second part of the test consisted of a rising head test, by removing the installed slug quasi-instantly. During the whole slug test, groundwater levels in GGB04 were monitored using a downhole pressure transducer, and the first five hours of the falling head test were also manually monitored. 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 slug test suggests that borehole GGB04 is very low yielding. Detailed test pumping data and interpretations will be given in a future hydrogeological data release.

**Table 6 Overview of GGB04 slug test parameters**

| **Slug test** | |
|---|---|
| Date of slug test | *17/02/2020* |
| Size of slug used | *4 litres* |
| Length of falling head test from slug insertion to slug removal | *20 hours 35 minutes* |
| Length of rising head test starting from slug removal | *26 hours 47 minutes* |
| Maximum displacement of water when slug initially inserted (m) | *0.48 m* |
| Average groundwater temperature during slug test (°C) | *Water quality parameters not constantly monitored by BGS.*<br>*11.14 °C is average temperature measured by Drilcorp data logger during slug test* |
| Groundwater geochemical samples collected during slug test | *None were collected during the slug test* |

# 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 GGB04 (Figure 1).

The made ground composition including brickwork, concrete and plastic is as expected from legacy data nearby and the prior land use history as a site where housing demolition rubble was disposed of. The thickness of the made ground at 9 m was slightly greater than pre-drill prognosis (Appendix B), though compatible with a complex and variable anthropogenic deposit. From 6 – 9 m drilled depth samples of green-stained sand, clay and silt were collected, this interval is included as part of the made ground as it appears to have been significantly altered by anthropogenic processes. A similar deposit is seen in borehole GGB05 adjacent.

The superficial deposits of the target screened interval are interpreted as Quaternary age, post-glacial deposits of the Gourock Sand Member (Figure 1), following existing legacy interpretations and geological models (e.g. Arkley, 2019). Though the drill returns were thought to be affected by the direct flush drilling method, the sand and gravel are correlated to deeper boreholes nearby.

# 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.

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 Repor*t 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 the borehole GGB04 files in this information release

**Table 7 Summary of files in the borehole GGB04 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_GGB04.pdf<br>UKGEOSCuningar_BAA4203_FinalAGS.AGS *(this covers all 11 UKGEOS boreholes at Cuningar Loop)* | PDF<br>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_GGB04.pdf<br>Detailed_BGS_Rockchiplog_GGB04.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_GGB04.pdf | PDF |
| Spreadsheet of archived rock chip samples. *NOTE: depths are given relative to drill platform level* | GGB04_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, 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 5 were updated on paper at site during the drilling phase. Being the pre-drill information, Figure 5 does not represent the learnings or local, site specific considerations used during the drilling phase.

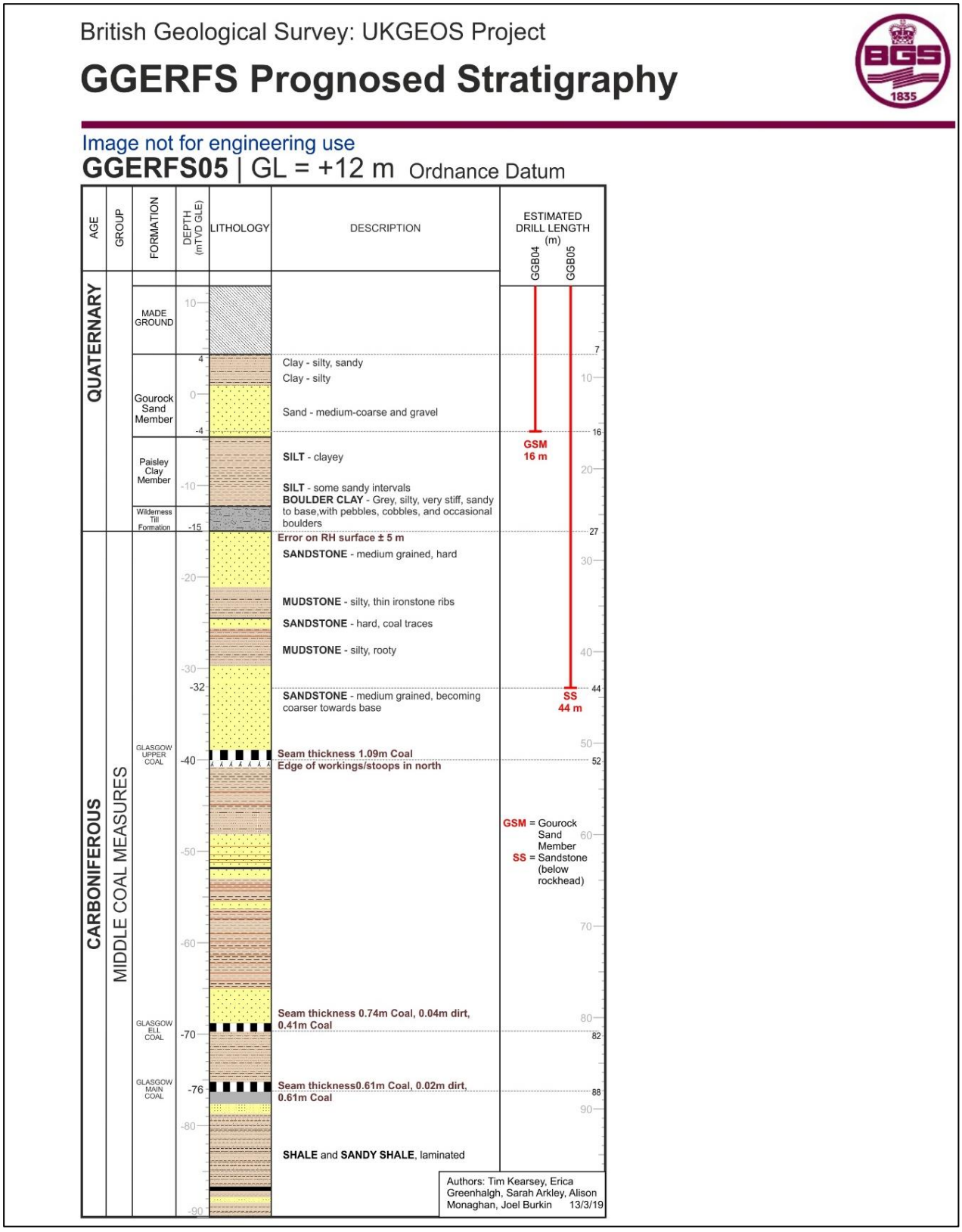


**Figure 5 Pre-drill borehole prognosis for site GGERFS05, boreholes GGB04 and GGB05 based on semi-regional geological models and nearby legacy boreholes**