Norham West Mains Farm Borehole: operations report

Geology and Regional Geophysics Programme

Internal Report IR/13/033

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND REGIONAL GEOPHYSICS PROGRAMME

INTERNAL REPORT IR/13/033

Norham West Mains Farm Borehole: operations report

D Millward, T Kearsey, M A E Browne

Keywords

Report; Berwick upon Tweed; Ballagan Formation; borehole.

National Grid Reference

391600 648130

Front cover

Drilcorp Ltd Beretta T151S top drive drilling rig at Norham, Berwick upon Tweed.

Bibliographical reference

MILLWARD, D, KEARSEY, T, BROWNE, M A E. 2013. Norham West Mains Farm Borehole: operations report. *British Geological Survey Internal Report*, IR/13/033. 39pp.

Keyworth, Nottingham British Geological Survey 2013

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 the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

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

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

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

Acknowledgements

The authors and the members of the TW:eed Project would like to thank the following people especially:

Mr Alistair Birkett of John Wilson & Sons Farmers Ltd for allowing us to site the borehole on his farm, and for his enthusiasm and interest in our project.

Mr Dave Gowans and his team at Drilcorp Ltd for their skill and professionalism in achieving our objectives, and for their interest in and support for our project.

Contents

FIGURES

TABLES

1 Introduction

A borehole was drilled to a total depth of 501.33 m by Drilcorp Ltd at Norham West Mains Farm, near the village of Norham, Berwick upon Tweed. Work was commenced on the 27th of March 2013 and completed on 7th June 2013. The borehole was fully cored from 10.22 m to its total depth through rocks of the Lower Carboniferous Inverclyde Group.

Obtaining cores from the Norham West Mains Farm Borehole is a major task within the TW:eed Project, which is investigating how limbed vertebrates adapted to walk on land around 360 million years ago (see http://www.tetrapods.org/). This was a key stage in the evolution of life on Earth and shaped the future evolution of vertebrates, including the eventual appearance of humans. The project builds on some unique new fossil finds made recently in the Scottish Borders and adjacent areas. Analysis of the borehole will provide a framework upon which this research is to be pinned. This scientific research programme is being undertaken by a consortium of organisations led by the University of Cambridge, and including the universities of Southampton and Leicester, the National Museums of Scotland and the British Geological Survey, and funded through the Natural Environment Research Council.

1.1 BOREHOLE LOCATION AND REGISTRATION DATA

The borehole is registered in the Single Online Borehole Index (SOBI) at BGS.

Table 1. Borehole location and registration data

Borehole name	**Norham West Mains Farm**
Location:	Norham West Mains Farm, Norham, near Berwick upon Tweed, Northumberland TD15 2JY
100km grid square	NT 94 NW
Grid reference	391589.85 648135.10
Surface level	49.67 m above Ordnance Datum
Total depth	501.33 m
SOBI Registration No.	**NT 94 NW 20**
Date drilling commenced	6th April 2013
Date drilling completed	25th May 2013
Drilling company	Drilcorp Ltd, Kinley Hill Farm, Hawthorn, Seaham SR7 8SW, Co Durham
Wireline geophysical logging company	European Geophysical Services Ltd, 22 The Stables, Sansaw Business Park, Hadnall, Shrewsbury SY4 4AS

1.2 RATIONALE FOR THE BOREHOLE

The rationale for the cored borehole is set out in the grant application to NERC. The borehole is a critical component of the research plan that will provide the key spatial and temporal framework to establish the evolutionary sequence of the animals and the timeframe in which recovery from the mass extinction event at the end of the Devonian occurred. High resolution lithological, sedimentological, lithostratigraphical, biostratigraphical, palynological, petrological and isotope data from the core will enable us to understand how the sedimentary and climate systems changed with time. Our studies of the tetrapod-bearing localities will be integrated with the framework and correlation will be made more widely across the Midland Valley of Scotland providing robust models for understanding the ecosystems.

1.3 BOREHOLE SPECIFICATION

The specification for the borehole and cores was as follows:

- A near vertical borehole is to be drilled to a maximum depth below ground level of approximately 500 m;
- A full sequence of cores is to be acquired through Lower Carboniferous sedimentary rocks from rockhead to total depth (TD);
- The main objective is to core through the Ballagan Formation, into the underlying Kinnesswood Formation;
- The cores are to be nominally 100 mm in diameter;
- The cores should be of high quality with a minimum of surface scoring and drilling induced damage.
- A suite of geophysical logs will be run as far as is possible in open hole.

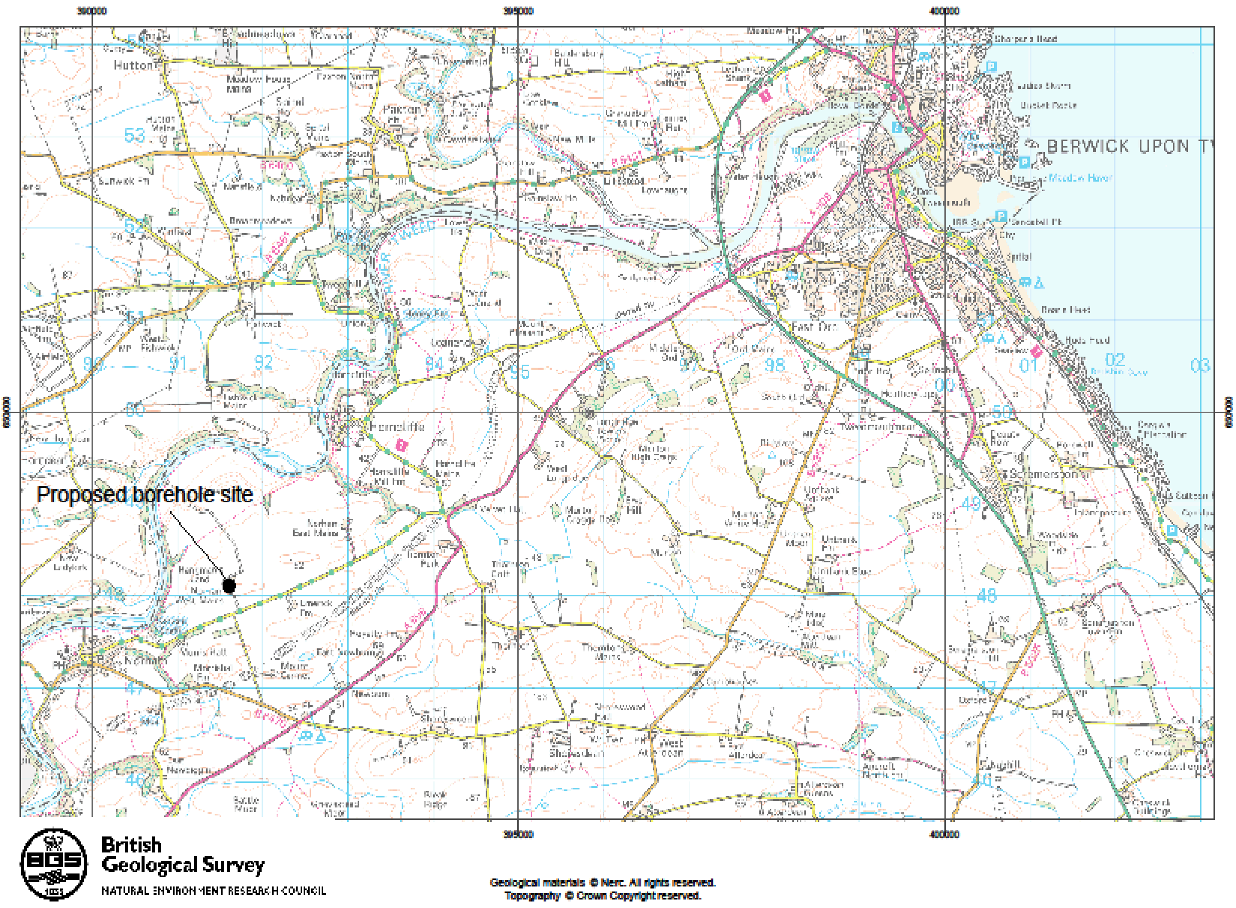


Figure 1. Location map

2 Borehole prognosis and site selection

2.1 EXISTING GEOLOGICAL INFORMATION

Geological mapping at 1:10,560 scale of the Eyemouth district in 1962–1970 provides detailed field data along the course of the Whiteadder River. More recently, the area south of this along the Tweed valley was surveyed at 1:10 000 scale as part of a rapid resurvey of the Coldstream district. These provide the location of exposures of the Ballagan Formation and recorded valuable structural data.

Although a number of BGS stratigraphical boreholes in East Lothian (Spilmersford [NT46NE73], East Linton [NT57NE2], and Burnieknowes [NT77SE9]) have proved the Ballagan Formation previously, none of these had reached the base of the formation and all were sited in the East Lothian "basin", away from the main localities from which tetrapod fossils had been found. The Marshall Meadows Borehole [NT95NE5], located not far from Burnmouth also did not bottom the formation. None of the boreholes in the BGS archive within the Berwick – Chirnside – Coldstream outcrop of the Ballagan Formation south of the Southern Uplands massif prove its full thickness. The only one here deep enough to prove the base of the formation is the Hutton Castle Barns Borehole [NT85SE1]. This was drilled in 1927 and proved the base of the Ballagan Formation at 142 m below ground level. The location of this borehole is about 6 km north of Norham.

No seismic lines cross this area.

2.2 SITE SELECTION

Several field visits were made to the Chirnside – Whiteadder – Coldstream area in order to assess the existing geological data and to get a feel for the geology. The objective was to find, within the 500 m depth limit set by the budget, a site that would allow the greatest thickness of Ballagan Formation to be penetrated and one that would provide a high probability of coring through its base. The base was considered more important than the uppermost part of the formation which is well exposed at Burnmouth. Given the very wide outcrop of the Ballagan Formation in this area and the likely wide error range in predicting the thickness at any point away from the known borehole, a location beneath the base of the Fell Sandstone Formation was preferred, to provide the best chance of reaching the base of the Ballagan Formation. The wide plateau area just south of the River Tweed between Norham and Horncliffe (Figure 1) is underlain by a sandstone unit about 20 m thick that is 20–40 m below the base of the Fell Sandstone. This sandstone is exposed along the south cliff of the Tweed and did not appear to be cut by faults with significant displacement. This area was therefore considered most suitable.

In siting the borehole in this area, the built-up areas were avoided to minimise disturbance, but the rest comprises prime agricultural land. The West Mains Farm site offered an ideal location in terms of access from the main road and the presence within the complex of buildings at the farm, of an old concrete platform that is currently unused. The site measured about 25 by 30 m, sufficient space for our contractors to work. The site also had a water supply, essential for the drilling fluids. Though the farm house itself is unoccupied, 4 cottages are located within about 100 m of the site. This meant that operational hours had to be restricted to the day shift, in consideration of the residents.

2.3 PROGNOSIS

With the information outlined above thickness estimates for the Ballagan in this area are subject to much uncertainty. A cross-section was constructed across the Ballagan Formation outcrop, from the outcrop of its base though the Hutton Castle Barns Borehole and the proposed West Mains Farm site. The folded structure recorded from the Whiteadder was reinterpreted to give an envelope of values for the thickness of the formation. The full estimate of about 470 m at Burnmouth gave a conservative thickness value. The site at Norham West Mains Farm is located 20–40 m beneath the base of the Fell Sandstone Formation, so giving the figure quoted below.

The geological succession was estimated as follows:

Superficial deposits (mostly till)	<10 m
Ballagan Formation	about 450 m
Kinnesswood Formation	up to 30 m to be drilled

2.4 PERMISSIONS AND LICENCES

2.4.1 Planning permission

Northumberland County Council was consulted about any requirement for planning permission through the Council's formal pre-planning advice portal. The drilling of a scientific borehole was not considered to be development under the Town and Country Planning Act and formal permission was not required.

2.4.2 EA licence

The Environment Agency was consulted about any requirement for permits or licences to carrying out the works. As groundwater was not to be explored for, nor to be abstracted, no licence or permit was required.

2.5 HEALTH AND SAFETY

A copy of Drilcorp's HSF09 Construction Design and Management Safety Plan was provided to BGS prior to commencement of the operation. A separate BGS Risk Assessment and Safe System of Working for BGS project members was completed and copy provided to Drilcorp. The HSE Form F10 Notification of construction project was completed prior to commencing operations.

2.6 ENVIRONMENTAL MATTERS

The protection of the natural environment was a critical consideration with regard to the operation and the concern of the partners in the TW:eed project was conveyed to the contractor through the tendering and contracting process and was subsequently monitored throughout. No watercourses were accessible directly from the site and all necessary precautions for the protection of groundwater against contamination were taken, including using double bunded tanks for the storage of fuel oil.

As far as is known, the site is not considered to have any form of pollution associated with it so no special conditions were attached to handling and disposal of wastes. All drilling fluids, spoil and slurry from the borehole were disposed of according to statutory constraints.

No environmental incidents were recorded during the operation.

The need to minimise the disturbance to, and environmental impact on, the site (including approaches to the site) was also considered as important for the occupants of the cottages located within 100 m of the site. Therefore drilling operation was restricted to 12 hour day shifts over the 7 day working week. Noise levels at the cottages were monitored by the contractor and found to be significantly below levels at which action is required.

3 Borehole design and drilling operation

Drilcorp Ltd planned and drilled the borehole using a Beretta T151S track-mounted top drive drilling rig (see cover photograph) using a biodegradable polymer-based mud-flush circulated with a positive displacement mud pump through settling tanks and mud-cleaning facility. The Atlas Copco Geobor-S wireline triple-barrel coring system was used throughout. The original plan included reaming and casing the upper part of the borehole at 250–300 m. During this stage a diverter would be fitted to the top of the borehole to control any gas encountered during drilling of the lower part.

The original plan was to construct the borehole in the following main stages (Figure 2):

1. Construction of a concrete drilling chamber to 2 m depth in order to collect return drilling mud and for later fitting of the gas diverter;
2. Open hole drilling at 12.25 inches to depth of 10 m, with installation of 9.625 inches diameter grouted casing;
3. Geobor-S coring from 10 to 250–300 m;
4. Wireline-logging 0 to 250–300 m;
5. Reaming of the borehole using a 216 mm rock roller with insertion of 168 mm grouted casing; installation of gas diverter;
6. Geobor-S coring 250–300 m to TD;
7. Wireline logging of lower part of borehole;
8. Decommissioning the borehole and reinstating the site.

These stages were based on the following coring rate assumptions made by Drilcorp: 10–100 m at 20 m per shift; 100–200 m at 18 m per shift; 200–300 m at 15 m per shift; 300–400 m at 12 m per shift; and 400–500 m at 9 m per shift.

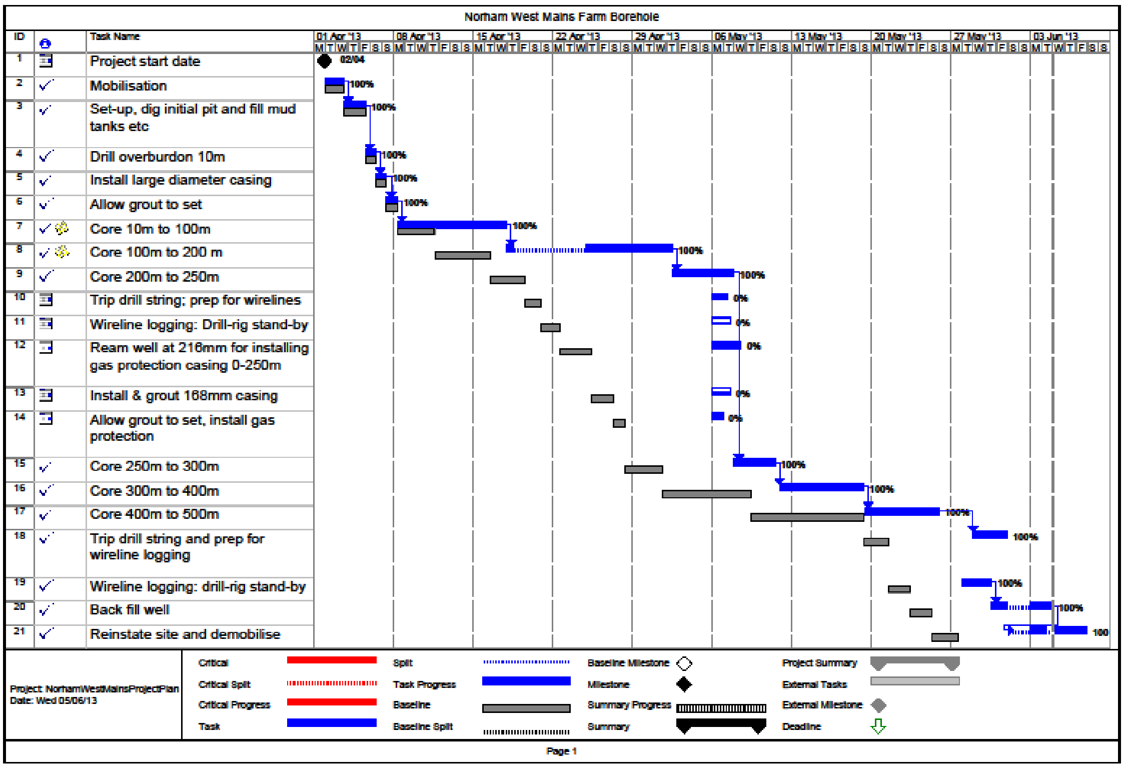


Figure 2. Gantt chart comparing planned and actual progress
The planned (baseline) activities are in grey, actual in blue.

3.1 PROGRESS AND COMPARISON WITH THE DRILLING PLAN

Work started on 27th March 2013 with the ground penetrating radar survey of the site to exclude the presence of services, prior to excavating the drilling chamber The site was handed back to the farmer on 7th June 2013. Drilling operations were from 6th April until TD was reached on 25th May 2013. Daily reports of all operations and consumables used were submitted to BGS on the day following. A daily diary compiled from these reports is included as Appendix A. Depth progress is shown in Figure 3 and a comparison of the planned and actual drilling progress is shown in Figure 2.

Though rockhead was reached at 4.2 m below ground level, the borehole was drilled open hole to a depth of 10.22 m at which point casing was grouted in to competent sandstone, providing protection for continued drilling. Cuttings samples of this section were taken by the drillers from the mud shakers.

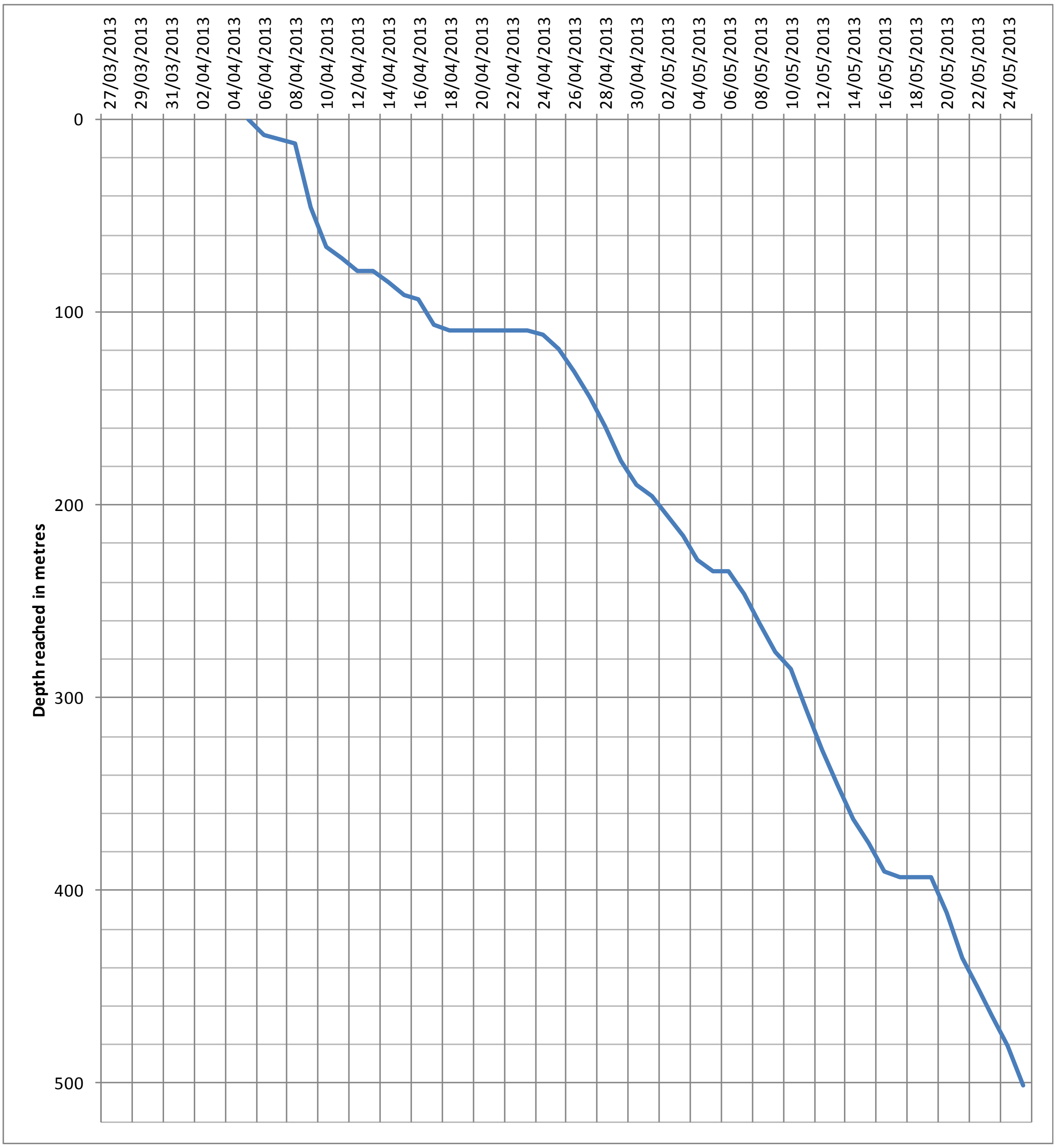


Figure 3. Cumulative drilling progress

Drilling the entire length of the 500 m borehole with a single diameter coring set-up is a difficult task in a sequence containing a significant proportion of mudrock which is likely to swell. Maintaining verticality and the stability of the borehole wall throughout drilling operations were key to a successful outcome. Two methods employed by Drilcorp were crucial to this. The first involved using an oversize drill bit at 151 mm diameter (the usual diameter used with Geobor-S is 147 mm). This seemingly small extra clearance between the diameter of the Geobor casing and the borehole wall meant that few problems were encountered from blockage by accumulating drilling cuttings and from binding of the casing on the borehole wall. Initially a PDC (polycrystalline diamond compact) bit was used but this performed poorly in the hard cementstones. A change to a Carbonardo bit on 16th April 2013 at 91.33 m gave much improved performance throughout the rest of the borehole, contributing significantly to minimal surface damage to the core obtained. The second method involved the careful selection and maintenance of the properties of the drilling fluids used. Drilcorp sought and followed technical advice from Baroid (the "mud doctors"), a division of Haliburton. The acoustic imager logs over the intervals for which these logs are available (see below) show that the borehole was maintained within 1.5° of the vertical.

Interruptions to progress were experienced between 51 and 110 m, at 234.33 m and finally at 393.33 m. The first of these intervals was the most problematic in terms of delays caused by repeated loss of fluid circulation. Circulation was completely lost below 52 m and again at about 63 m. This interval has some core loss, possibly associated with faults. A little deeper, drilling fluid was once again lost in the upper part of the sandstone unit at a depth of 70–74 m. The core recovered from this last interval showed a steep, centimetre-wide open fracture, clearly the cause of the problem. At this stage the interval from 51.20 to 78.33 m was grouted to seal the fractures. Drilling then continued but circulation was once again lost at about 103 m, also in the upper part of a sandstone unit. This zone proved more difficult to seal, eventually requiring a special grout to fix. However, below this depth a small percentage of circulating fluid continued to be lost and episodically total loss was experienced. This is attributed to the zone at about 103 m, but the problem was kept under control by fluid additives.

A shorter delay which proved less problematical was at 234.33 m where the overshot device became detached from the winch cable used to retrieve the inner core barrel to the surface. This meant that the core could only be recovered from the base of the borehole by removal of the whole drill string. Fortunately, the core was recovered fully and undamaged.

At 393.33 m core slipped from the barrel after problems had been encountered unlatching it. At this depth a crane was deployed to remove and reinsert the full string in 12 m lengths in order to save some time. Highly fragmented core was recovered, lodged in the outer barrel and bit.

The only major change to the original borehole plan was the decision by Drilcorp to omit the operational stages leading to casing of the upper part of the borehole to a depth of 250–300 m to protect the drill string from becoming tight in the lower section of the borehole, most likely as a result of swelling of the mudstone (Figure 2). The decision was made on 9th May 2013 at approximately 264 m on the basis that, from a drilling perspective, the strata are very competent, and the borehole was stable and showing no signs of the mudstone swelling. In general, core recovery approached 100% and gave no cause for concern. Also, minimal torque had been experienced on the drill string during drilling operations. This situation was monitored during advance to TD without the need to reassess the casing requirement.

The 490 m of continuous Geobor-S core recovered at Norham is thought to be the longest achieved in the UK at present. The overall high quality of the cores retrieved throughout the entire drilled length is testimony to the design of this coring system and the skill of the drillers.

3.2 CORE RECOVERY

The 3 m long plastic liners with their cores were extracted from the core barrel, split into 1.5 m lengths, plastic end caps fitted and placed in wooden core boxes to provide protection during transport. As soon as possible after recovery the cores were inspected visually by the authors in order to produce a summary log (see section 4), essential to monitoring stratigraphical progress. For this purpose the core liner was split lengthwise.

No formal estimate of percentage core recovery has been made at this stage, though visually it can be seen that for much of the depth core recovery is almost 100%. The intervals where core loss is recorded by the driller are listed in Appendix B and those observed from inspection of the cores by the authors are marked graphically in Appendix C. There is very little evidence of drilling-induced damage to any of the core. Some of the intervals of core loss or poor recovery are known to be associated with faults and their damage zones.

Two other intervals where core has been lost or seriously damaged are associated with cores that slipped out of the core barrel during attempted recovery. The core is held in the core barrel by springs at the base of the inner barrel. Sometimes these fail to hold the core during or after attempts to detach the core from the base of the hole and the core may slip from the barrel when it is withdrawn. In such instances core can be recovered intact, but at times there is complete failure. This occurred at 91.33 m and the 1 m interval above this had to be drilled out. Similarly core slipped at 393.33 m; however, much of this was recovered as small fragments.

3.3 WIRELINE GEOPHYSICAL LOGGING

In variance to the drilling plan, wireline geophysical logging was undertaken only once TD had been reached. The neutron-porosity, bulk density, natural gamma and spectral gamma logs were run within the Geobor-S casing, because of concerns about stability of the borehole once fluid circulation had ceased and the Geobor casing had been removed. This proved to be a wise decision as these are the only logs that extend for the full length of the borehole. Some attenuation of the data is a consequence though we were able to run the natural gamma and spectral gamma in open hole for sections of the sequence; comparison of the latter inside and out will enable recalibration of the full data.

Blockages occurred in the borehole at two levels during removal of the Geobor casing, firstly at 303 m when casing was withdrawn to 238 m, and secondly at 203 m when the casing was fully removed. Therefore the open-hole calliper, natural gamma, resistivity, sonic, magnetic susceptibility and acoustic imager data extend only for the intervals 10–203 m and 238–303 m.

All data will be uploaded into the BGS RECALL system.

3.4 BOREHOLE COMPLETION

Decommissioning of the borehole was carried out after completion of the geophysical logging. The Environment Agency’s guidance document “Good practice for decommissioning redundant boreholes and wells” was followed. The borehole was backfilled with pea gravel to a depth of 117 m and then grouted with cement to the base of the drilling chamber. The drilling chamber was then filled with concrete.

4 Summary of the borehole geology

The geological succession in the borehole is entirely within the Ballagan Formation: the base was not reached. This important objective was not achieved, though we do have a very thick rock succession available for detailed analysis. A full graphic log is included as Appendix C, and the succession is briefly summarised in Figure 4. A full analysis of the geology will follow the detailed logging to take place later this year but here attention is drawn to some of the main features.

Rockhead was encountered at 4.2 m below ground level. The overlying superficial deposits consist of stony sandy clay (diamicton), interpreted as till (boulder clay).

Coring commenced within the upper part of the major fluvial sandstone that forms the river cliff along the south bank of the Tweed at least from the west end of Norham to the Union Bridge, north of Horncliffe, a total distance of about 5 km. The sandstone underlies Norham Castle and we refer to this sandstone informally as the Norham Castle Sandstone. As this unit has been used as dimension stone, the disused quarries along the outcrop provide good 3-dimensional information on the internal structure of the sandbody in conjunction with our new data.

Sandstone units of 4 m or more thick and typically cross-bedded are distributed throughout the succession and some have conglomerate at the base (see Figure 4). In addition, the middle section of the borehole (284–365 m) contains units of very fine- to fine-grained sandstone that is intensely ripple laminated.

Sandstone units are sparse in thick intervals within the succession, for example between 175 and 265 m and in the lowest 80 m. The number of cementstone beds may have been underestimated during the visual examination: the lack of differential erosion seen at outcrop makes it difficult to identify them in smooth and commonly dirty core. Except in the lowest 80 m of the succession, cementstone beds are relatively sparse compared with Burnmouth.

Evaporite beds: 22 beds of evaporite have been identified, the thickest being 93 cm at 322 m. Fifteen of these beds occur in the basal 80 m of the succession where they are typically clustered in short intervals and occur with the greatest number of cementstone beds, many of which are compound in nature. The highest unit of evaporite was identified at c. 183 m and is composed of gypsum, but those from deeper levels (232 m and below) contain both anhydrite and gypsum. The evaporate beds are typically nodular, commonly with thin chicken-wire-like intercalations of grey mudstone. Some of the beds contain massive anhydrite.

Anhydrite is almost never seen near surface, within zones of circulating groundwater and gypsum is very mobile under these conditions, as at Edington Mill near Chirnside on the Whiteadder River. Dissolved evaporite units at such levels may be represented by narrow zones of collapse-breccia and evidence for this in the higher parts of the sequence should be looked for once the cores have been sliced.

Structural dip: visually, bedding partings in the mudstone/siltstone parts of the sequence are consistently less than 5°. In one zone, dip increases downwards to a fault, beneath which the dip returns to very shallow. Higher dips seen in the sandstones refer to cross-bedding. The acoustic image will give more precise dips and dip directions for the intervals for which we have these data.

Faults: a number of faults have been identified in the cores, mostly occurring in the mudstone or siltstone lithologies where the damage zones of fault-rock with slickensides are typically narrow. The thinness of these zones and the continuity of the Norham Castle Sandstone outcrop suggest that the throw on these faults is small.

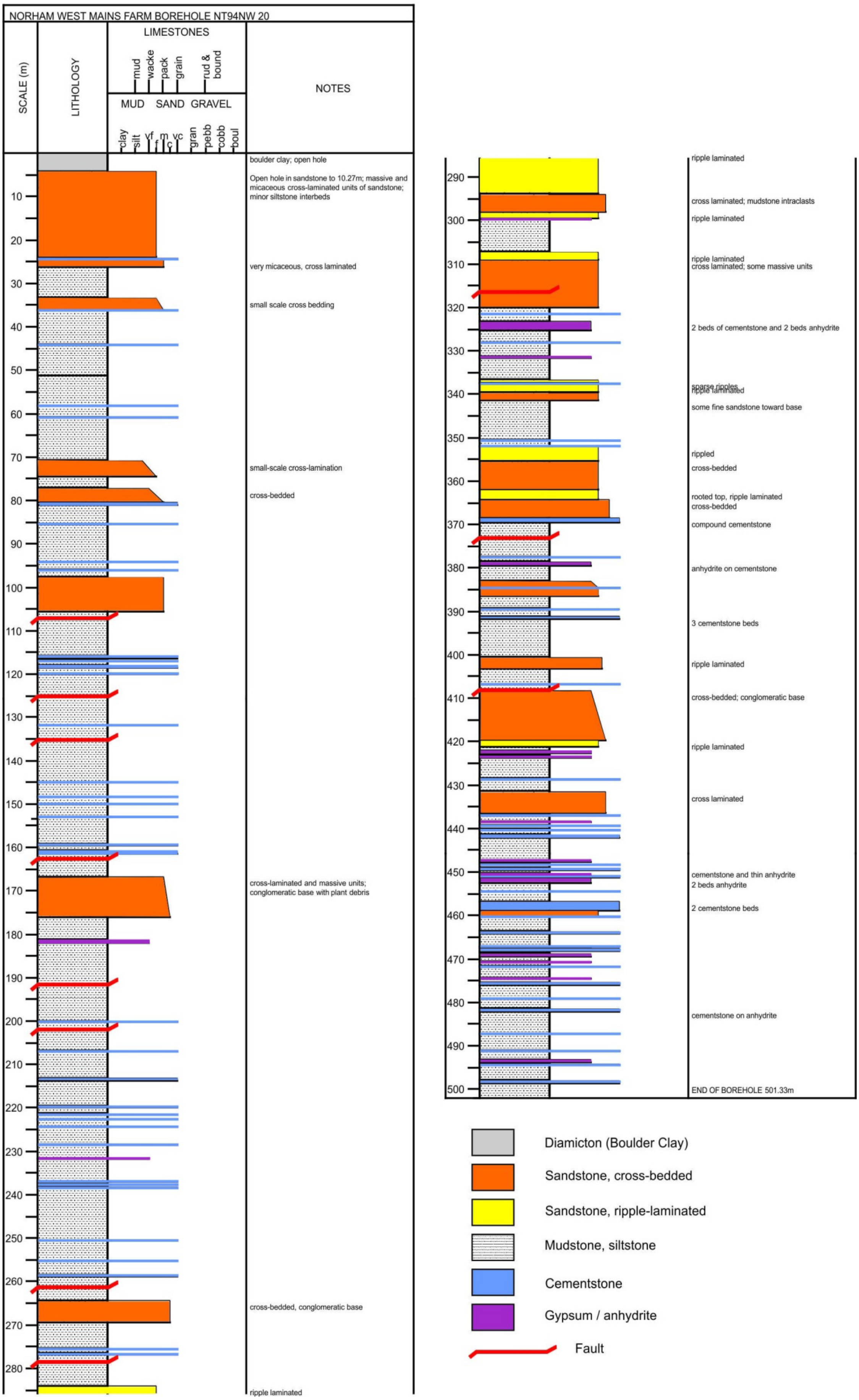


Figure 4. Summary lithological log for the Norham West Mains Farm Borehole

5 Core Plan

The core has been transferred to the National Geological Repository at BGS, Keyworth, where it will be accessioned as part of the National Boreholes Core Collection. The project plan for our cores is as follows:

- The cores will be sliced lengthways, with one half to be kept as a reference and the other to be logged and sampled for analysis.
- The sliced cores will be photographed and access to these images will be arranged for all consortium researchers.
- A core panel will be held to allow members an overview of the cores and to decide the sampling strategy.
- Lithological and sedimentological logging will be carried out by a consortium team from BGS and Leicester and Southampton universities. Sampling for all subsequent detailed palynological, petrological, micropalaeontological and isotope investigations during logging.
- All materials from the borehole will be archived in the BGS collections.

Appendix 1 Norham West Mains Farm Borehole, operations diary

Date	Operations	Cored length	Depth reached	Water level	Flush returns	Planned core length
27/03/2013	Survey company on site to survey borehole location; nothing found beneath borehole location so ok to dig with JCB. Concrete cut at 2.4mx2.4m, broke out with JCB, then hole dug to 2m depth. Concrete rings and road plate did not arrive, so hole covered by the site cabin for safety.					
03/04/2013	Take delivery of Drilcorp plant and equipment, and hire equipment. Lay out water supply line. Note: Telehandler engine kept stopping, requiring use of jump leads; at 12:00 would not start, fitter called. Fitter arrived and noted alternator broken. Arrived back on site at 18.30 to replace. Hence ¾ of the shift wasted.					
04/04/2013	Start to set up site. Place chamber rings and concrete in place. Exchange welfare units. Install water supply.					
05/04/2013	Continue setting up site and taking deliveries of the above. Filling circulation tanks with water. Note water supply very slow. Left running overnight; security guard to turn off when full.		0			
06/04/2013	Start to mix and hydrate drilling fluid. Drilling open hole to 8.3.		8.3			
07/04/2013	Open hole drilling at 12 ¼"; flush borehole clean; install casing (9 5/8") and grout annulus to surface; clean down all grouting equipment; Stand by waiting for grout to set	OH	10.22		100%	
08/04/2013	Cut down 13$^{3/8"}$ & 9$^{5/8"}$ casings. Set all equipment up ready to core; Waiting for grout to set; Start Geobor-S coring PDC bit	2.11	12.33		100%	20
09/04/2013	Continued coring	33.00	45.33		100%	20
10/04/2013	Mix mud (polymers) in mixing tank and transfer to circulation tank and prepare to core; Coring from 45.33-53.83; Lost some core on run 15 – measure borehole and core scrubbed; Coring from 53.83-63.33; **Lost flush, borehole torqueing up**. Possible fault, stopped coring and mixed up fresh mud; Coring from 63.33-66.33	21.00	66.33		100-20%	20
11/04/2013	Pull Geobor and check bit. Slight bit blockage, cleaned and ran back in; coring from 66.33-69.33; Mix mud and refill circulation tanks- Circulation loss 1.833hrs; Core from 69.33-72.33. **flush completely lost, probably from open fracture** (see core); Fill tanks and mix quick gel and N-seal, all pumped down borehole with no effect. Tanks to be filled overnight by security ready for morning. Circulation loss 5.5hrs	6.00	72.33		70-0%	20
12/04/2013	Re-fill tanks and mix muds 1hr standing; coring from 72.33-75.33; fill tanks back up 2.83hrs standing; mix more mud in both tanks 0.83 standing; clean up and pull all Geobor ready for grouting of the borehole (1500-1730); set up all grout plant (1730-1800); grout borehole (2 mixes); wash down all grout plant; 5hrs standing.	6.00	78.33		0%	20
13/04/2013	Borehole dipped and grout back to 62.50m; another 1 ½ mixes pumped down borehole and all grouting equipment cleaned down; waiting for grout to set	0.00	78.33			
14/04/2013	Borehole dipped and level of grout checked; grout back to 51.20m; this is good and should have blocked all loss zones in the borehole. Start coring out the grout back down to rock @ 78.33m; flush holding perfect in well; dump of some mud and remix to proper mix. 6hrs standing; Coring from 78.33-84.33. **Grouted from 51.20-78.33m.**	6.00	84.33		100%	20

15/04/2013	Coring from 84.33-85.83; pull geobor from well to inspect bit. Bit blocked so removed and cleaned; mix mud to top up circulation tanks. Coring from 85.83-91.33; Pull geobor as suspect bit blocked. Bit blocked so cleaned and removed. **Suspect mudstones swelling in well and causing abnormal bit pressures.**	7.00	91.33		100%	20
16/04/2013	Set up and ream borehole with 6" full-face bit to clear any obstructions (swelling mudstones) down to base 91.33. (**1m of dropped core which was dropped at end of last run was drilled out. This was ok'd by client** . **Set up Geobor with carbonado bit** and run to base of well (flushed on way in); coring from 91.33-93.33. (rock turned hard and slow to drill).	2.00	93.33		100%	20
17/04/2013	Run rods back to 93.33m; coring from 93.33-106.82. **Flush totally lost at 103m** Fill tanks ready to core 6m tomorrow morning before borehole grouted again to seal of fractures. Rods pulled back safe and site made safe.	13.50	106.83		100 to 0%	18
18/04/2013	Coring from 106.83-109.53 with no circulation returns up well. Pull Geobor from well and grout up base of well to seal off flush loss. 3 mixes pumped. Site cleaned down and made safe. Waiting for grout to set. Level to be checked in morning and topped up if necessary.	3.00	109.83		0%	18
19/04/2013	Grout level dipped in well. Level @ 108m - borehole needs grouting again. Waiting for more grout products to arrive on site; Nuffins grout arrived on site and 7 mixes pumped down well. All equipment cleaned down and site made safe. Stand grout setting	0.00	109.83			
20/04/2013	Dip grout level in borehole and grout @ 105m; 1 mix of nuffins grout mixed and 7 mixes of normal cement and silica sand mixed and pumped down well and left all weekend to set. Grout setting	0.00	109.83			
21/04/2013	Closed down	0.00	109.83			
22/04/2013	Grout level checked, noted at 103m. 45 bags of Nuffins super flow grout collected from Washington and brought to site. Mix grout but unable to pump down alkathene pipe. All equipment cleaned down. Metal grout pipes brought from Drilcorp yard. Grout pipes ran into well ready to grout in morning	0.00	109.83			
23/04/2013	6 x mixes of Nufin supaflow mixed and pumped down well. All equipment cleaned down and grout pipes pulled from well. Water level at start of shift was 27.13m and after grout was 17.84m so hopefully borehole is sealed now. Waiting for grout to set. Good site tidy up. Clean all plant and equipment set up pumps to mix mud refill circulation tanks. Mix mud ready for drilling ops. Fuel all plant.	0.00	109.83	27.13		
24/04/2013	Run rods and clean out grout with 6" PDC bit ready for Geobor coring. Small problems with flush loss but brought under control with the use of sc plug. Run Geobor casing back to base. Carry out 1.5m core run.	1.50	111.33	14.2	100%	18
25/04/2013	Coring from 111.33-118.33	7.50	118.83	12.83	70-80	18
26/04/2013	Mix mud circulate into tanks prepare to start coring ops. Coring ops from 118.83m to 120.33m. Mix mud and circulate into tanks. Coring ops from 120.33m to 126.33m. Mix mud along with lost circulation fluid and circulate around BH to regain flush. Coring ops from 126.33m to 130.83m.	12.00	130.83	9.65	30-60%	18
27/04/2013	Top up mud tanks with new mud and circulate, flush BH clean, prepare to start coring ops. Coring ops from 130.83m to 135.33m. Mix mud circulate tanks; still losing some flush due to poor ground conditions. Coring ops from 135.33m to 141.33m. Mix muds circulate round BH and tanks. Coring ops from 141.33m to 144.33m flush BH clean for night	13.50	144.33	16.27	50-70%	18
28/04/2013	Mix up mud. Circulate tanks flush BH prepare to start coring ops. Coring ops from 144.33m to 153.33m. Mix up mud transfer to circulation tanks and circulate. Coring ops from 153.33m to 156.33m. Mix mud. Circulate tanks. Coring ops from 156.33m to 159.33m.	15.00	159.33	18.43	70-80%	18

29/04/2013	Coring from 159.33-177.33m	18.00	177.33	18.43	80%	18
30/04/2013	Coring from 177.33-189.33 m	12.00	189.33	18.43	80%	18
01/05/2013	Mix fresh mud, circulate tanks, prepare to start coring ops; Coring from 189.33-192.33m. Total loss of flush, water supply for tanks unable to keep up with core runs; pull 30m of Geobor casing out of BH, mix up lost circulation fluid (Diamond Seal) and circulate around BH until return of flush to surface; 70% flush return to surface; prepare to start coring ops. 6.66hrs standing; Coring ops from 192.33m to 195.33m pull safe secure BH for night.	6.00	195.33	12.18	0-80%	18
02/05/2013	Coring from 195.33 to 198.33m; lost all water during core run standing waiting for poor water supply to refill tanks. 2.25hrs; Mix tanks with fresh mud and lost circulation fluid and pump around BH; 100% flush gained by lost circulation fluid. 1hr; Coring ops from 198.33m to 205.83m flush BH clean	10.50	205.83	12.18	0-100%	15
03/05/2013	Coring ops from 205.83m to 216.33; Mud in tanks full of sand overshot getting tight in BH; pull Geobor safe and mix fresh mud in separate tank and flush	10.50	216.33	9.43	100%	15
04/05/2013	Coring from 216.33 – 228.33	12.00	228.33	9.43	100%	15
05/05/2013	Coring from 228.33-234.33; Pull geobor from well due to overshot becoming stuck in barrel.	6.00	234.33	9.43	100%	15
06/05/2013	Continue to pull geobor from well; Once Geobor pulled from well inner barrel retrieved and core removed. All re-set back up and Geobor ran back into well; Geobor ran slowly to base of well to retrieve lost core of last run	0.00	234.33			
07/05/2013	Circulate mud in tanks set up prepare to start coring ops; Coring ops from 234.33m to 246.33m	12.00	246.33	10.72	90%	15
08/05/2013	Circulate mud in tanks set up prepare to start coring ops; Coring ops from 246.33m to 261.33m	15.00	261.33	10.72	90%	15
09/05/2013	Circulate mud in tanks set up prepare to start coring ops; Coring ops from 261.33m to 276.33m	15.00	276.33	11.47	90%	15
10/05/2013	Circulate mud in tanks set up prepare to start coring ops; coring ops from 276.33m to 279.33m. Finish setting up de-sander; fill and mix mud ready to use; Coring ops from 279.33m to 285.33m	9.00	285.33	11.13	90%	15
11/05/2013	Circulate mud in tanks flush BH set up prepare to start coring ops; Coring ops from 285.33m to 306.33m	21.00	306.33	11	90%	15
12/05/2013	Circulate mud in tanks flush BH set up prepare to start coring ops; Coring ops from 306.33m to 327.33m	21.00	327.33	11	90%	12
13/05/2013	Circulate mud in tanks flush BH set up prepare to start coring ops; Coring ops from 327.33m to 345.33m	18.00	345.33	14.22	90%	12
14/05/2013	Circulate mud in tanks, flush BH, set up prepare to start coring ops; Coring ops from 345.33m to 363.33m. Empty 3 large tanks with gully sucker. Mix up good thick mud and flush BH	18.00	363.33	14.22	90%	12
15/05/2013	Circulate mud in tanks. Flush BH set up prepare to start coring ops; Coring ops from 363.33m to 375.33m. Rig running sluggish then cut out; fuel problem - change fuel filters, carry out light service on engine; rig running well again; mix mud, flush BH well	12.00	375.33	17.33	90%	12
16/05/2013	Circulate mud in tanks. Flush BH set up prepare to start coring ops; Coring ops from 375.33m to390.33m	15.00	390.33	17.33	90%	12
17/05/2013	Circulate mud in tanks. Flush BH, set up prepare to start coring ops; Coring ops from 390.33m to 394.83m. Unable to de-latch barrel. Try to de-latch barrel; Scott and Dave Gowans arrive with equipment to de-latch barrel; de-latch barrel and retrieve from BH. Slipped core when de-latching barrel try to retrieve core from BH; unable to retrieve core, carry out 1.50m core run to collect slipped core, still no recovery. Core lodged in outer barrel /core bit	3.00	393.33	17.33	90%	12

18/05/2013	Empty tanks and mix fresh new mud to condition BH; pump BH clean with fresh mud to help stabilize BH before pulling drill string. Prepare site for crane arriving to pull casing	0.00	393.33	17.33		
19/05/2013	Set up crane and pull all rods from well in 12m sections at a time and clear core from bit. Once bit cleared rods ran back into well. Couple of bridged sections encountered @ 234m and 387m. Rods had to be flushed back down to base and upon unlatching barrel found broken mudstone inside the barrel. Borehole flushed for an hour before leaving site	0.00	393.33	17.33		
20/05/2013	Coring from 393.33-411.33 borehole flushed at end of shift	18.00	411.33		100%	9
21/05/2013	Coring from 411.33-435.33 borehole flushed at end of shift	24.00	435.33		100%	9
22/05/2013	Coring from 435.33-450.33 borehole flushed at end of shift	15.00	450.33		100%	9
23/05/2013	Coring from 450.33 – 465.33 borehole flushed at end of shift	15.00	465.33		100%	9
24/05/2013	Coring from 465.33 – 480.33 borehole flushed at end of shift	15.00	480.33		100%	9
25/05/2013	Coring from 480.33 – 501.33 borehole flushed at end of shift; TD reached at 501.33 m at c 20:00 hrs	21.00	501.33		100%	9
26/05/2013	Flush borehole and occasionally turn to avoid casing becoming stuck in borehole					
27/05/2013	Flush borehole and occasionally turn to avoid casing becoming stuck in borehole					
28/05/2013	EGS on site; wireline logging in casing (neutron porosity, bulk density, spectral gamma, natural gamma); Waggon in at 20.00 to be loaded up with equipment to go back to yard					
29/05/2013	Pull rods from 501.33 back to 240.33 and make ready to log; EGS logging borehole and will be most of the night. Borehole not open beyond 303m. Standing on client to make a decision on running back into borehole or pulling out					
30/05/2013	David Millward decided to pull all remaining rods from well and not run back in; Pull rods from 240.33 till all rods are out of borehole; EGS logging borehole; J.C.Environmental on site taking slurry away and waiting for EGS to finish etc					
31/05/2013	Gravel and cement collected from jewsons in Berwick with trailer as required. Back filling borehole with gravel to 117m; Load lorry (W.Marley) with a complete load of equipment from site and making all equipment ready for collection					
	No working 01, 02 June					
03/06/2013	Borehole dipped at 117m. Collect 2" Honda pump up from Jewsons at Berwick; Prepare grouting equipment ready to grout; Grout up borehole back to ground level (98 bags - 14 mixes – 7 bags per mix). Load lorry with Russian doll tanks and various small tools, also roll on roll off tank. Empty tanks using gully sucker. Continue to tidy site whilst waiting for security					
04/06/2013	Borehole dipped, grout back to 3.35m. Reinstate site and de-mob gear. Delivery of 2000ltrs of fuel. Delivery of 4.5m3 of concrete to backfill top of borehole and chamber					
05/06/2013	De-mob plant and equipment tidy site prepare for handover Friday					
06/06/2013	Off hire plant and equipment tidy site prepare for handover Friday					
07/06/2013	Water meter read and disconnected. Site handed over.					

Appendix 2 Core record

DATE	RUN	Box nos	FROM	TO	CORED	RECOVERY	FLUSH %	RUN TIME mins
08/04/2013	1	1, 2	9.33	12.33	3.00	3.00	100	50
09/04/2013	2	3, 4	12.33	15.33	3.00	3.00	100	40
09/04/2013	3	5, 6	15.33	18.33	3.00	3.00	100	25
09/04/2013	4	7, 8	18.33	21.33	3.00	3.00	100	15
09/04/2013	5	9, 10	21.33	24.33	3.00	3.00	100	16
09/04/2013	6	11, 12	24.33	27.33	3.00	3.00	100	10
09/04/2013	7	13, 14	27.33	30.33	3.00	3.00	100	30
09/04/2013	8	15, 16	30.33	33.33	3.00	3.00	100	30
09/04/2013	9	17, 18	33.33	36.33	3.00	3.00	100	40
09/04/2013	10	19, 20	36.33	39.33	3.00	3.00	100	30
09/04/2013	11	21, 22	39.33	42.33	3.00	3.00	100	35
09/04/2013	12	23, 24	42.33	45.33	3.00	3.00	100	40
10/04/2013	13	25, 26	45.33	48.33	3.00	3.00	100	30
10/04/2013	14	27, 28	48.33	51.33	3.00	3.00	100	34
10/04/2013	15	29	51.33	54.33	3.00	1.28	70	32
10/04/2013	16	30, 31	54.33	57.33	3.00	3.00	70	40
10/04/2013	17	32, 33	57.33	60.33	3.00	3.00	90	40
10/04/2013	18	34, 35	60.33	63.33	3.00	2.70	20	35
10/04/2013	19	36, 37	63.33	66.33	3.00	2.70	90	50
11/04/2013	20	38, 39	66.33	69.33	3.00	3.00	90	80
11/04/2013	21	40, 41	69.33	72.33	3.00	3.00	0	40
12/04/2013	22	42, 43	72.33	75.33	3.00	3.00	0	40
12/04/2013	23	44, 45	75.33	78.33	3.00	3.00	0	70
13/04/2013	24	46, 47	78.33	81.33	3.00	3.00	100	120
13/04/2013	25	48, 49	81.33	84.33	3.00	3.00	100	100
14/04/2013	26	50	84.33	85.83	1.50	1.50	100	60
15/04/2013	27	51	85.83	87.33	1.50	1.50	100	75
15/04/2013	28	52, 53	87.33	90.33	3.00	2.83	100	135
15/04/2013	29	–	90.33	91.33	1.00	0.00	100	30
16/04/2013	30	54, 55	91.33	93.33	2.00	2.00	100	60
17/04/2013	31	56, 57	93.33	96.33	3.00	3.00	100	150
17/04/2013	32	58, 59	96.33	99.33	3.00	3.00	100	120
17/04/2013	33	60, 61	99.33	102.33	3.00	3.00	0	50
17/04/2013	34	62, 63	102.33	105.33	3.00	3.00	0	45
17/04/2013	35	64	105.33	106.83	1.50	1.50	0	65
18/04/2013	36	65	106.83	108.33	1.50	1.50	0	20
18/04/2013	37	66	108.33	109.83	1.50	1.20	0	40
24/04/2013	38	67	109.83	111.33	1.50	1.50	100	30
25/04/2013	39	68, 69	111.33	114.33	3.00	3.00	80	140
25/04/2013	40	70, 71	114.33	117.33	3.00	3.00	80	147
25/04/2013	41	72	117.33	118.83	1.50	1.50	70	80
26/04/2013	42	73	118.83	120.33	1.50	1.50	70	60
26/04/2013	43	74, 75	120.33	123.33	3.00	3.00	80	152

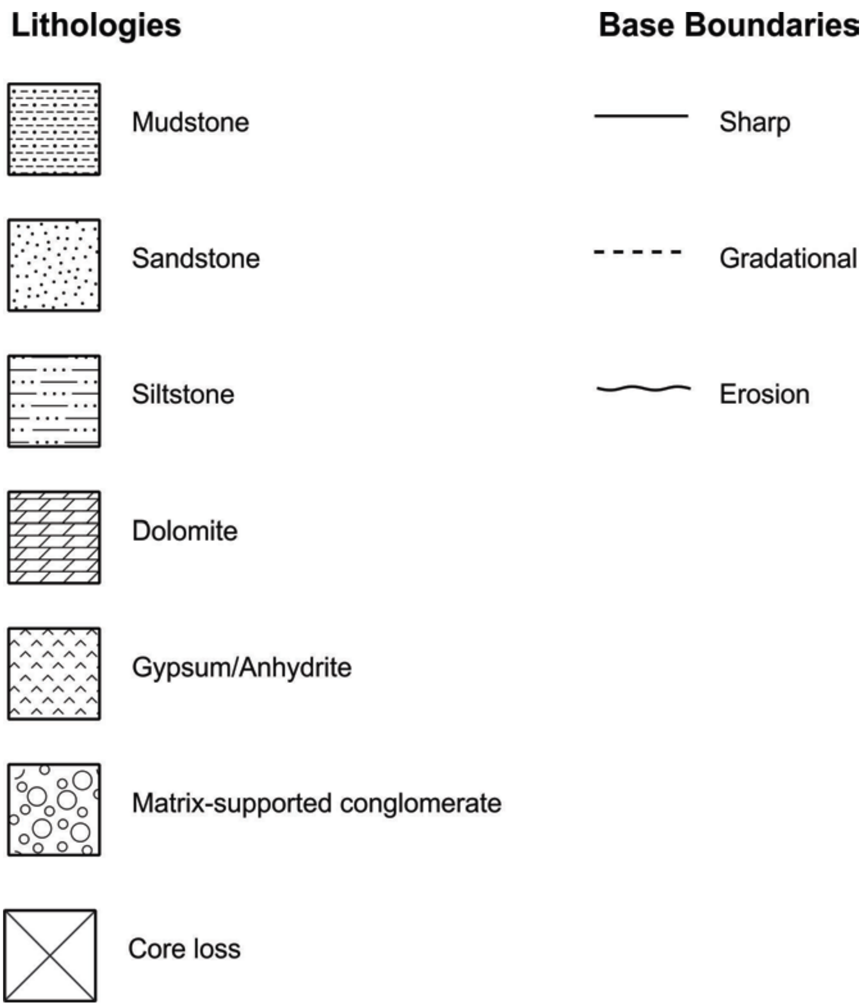
26/04/2013	44	76, 77	123.33	126.33	3.00	2.75	70	140
26/04/2013	45	78, 79	126.33	129.33	3.00	3.00	70	130
26/04/2013	46	80	129.33	130.83	1.50	1.50	60	80
27/04/2013	47	81	130.83	132.33	1.50	1.50	70	83
27/04/2013	48	82, 83	132.33	135.33	3.00	3.00	80	159
27/04/2013	49	84, 85	135.33	138.33	3.00	3.00	80	142
27/04/2013	50	86, 87	138.33	141.33	3.00	3.00	70	162
27/04/2013	51	88, 89	141.33	144.33	3.00	3.00	80	154
28/04/2013	52	90, 91	144.33	147.33	3.00	3.00	80	96
28/04/2013	53	92, 93	147.33	150.33	3.00	3.00	80	100
28/04/2013	54	94, 95	150.33	153.33	3.00	3.00	80	136
28/04/2013	55	96, 97	153.33	156.33	3.00	3.00	80	142
28/04/2013	56	98	156.33	157.83	1.50	1.50	80	30
28/04/2013	57	99	157.83	159.33	1.50	1.50	70	90
29/04/2013	58	100, 101	159.33	162.33	3.00	3.00	80	184
29/04/2013	59	102, 103	162.33	165.33	3.00	3.00	80	152
29/04/2013	60	104, 105	165.33	168.33	3.00	3.00	80	128
29/04/2013	61	106, 107	168.33	171.33	3.00	3.00	80	97
29/04/2013	62	108. 109	171.33	174.33	3.00	3.00	80	40
29/04/2013	63	110, 111	174.33	177.33	3.00	3.00	80	90
30/04/2013	64	112, 113	177.33	180.33	3.00	3.00	80	136
30/04/2013	65	114, 115	180.33	183.33	3.00	3.00	80	118
30/04/2013	66	116, 117	183.33	186.33	3.00	3.00	80	129
30/04/2013	67	118, 119	186.33	189.33	3.00	3.00	80	158
01/05/2013	68	120, 121	189.33	192.33	3.00	3.00	NIL	180
01/05/2013	69	122, 123	192.33	195.33	3.00	3.00	80	153
02/05/2013	70	124, 125	195.33	198.33	3.00	3.00	80	110
02/05/2013	71	126, 127	198.33	201.33	3.00	3.00	NIL	123
02/05/2013	72	128, 129	201.33	204.33	3.00	3.00	100	148
02/05/2013	73	130	204.33	205.83	1.50	1.50	100	92
03/05/2013	74	131	205.83	207.33	1.50	1.50	100	103
03/05/2013	75	132, 133	207.33	210.33	3.00	3.00	100	180
03/05/2013	76	134, 135	210.33	213.33	3.00	3.00	100	110
03/05/2013	77	136, 137	213.33	216.33	3.00	3.00	100	120
04/05/2013	78	138, 139	216.33	219.33	3.00	3.00	90	180
04/05/2013	79	140, 141	219.33	222.33	3.00	3.00	90	60
04/05/2013	80	142, 143	222.33	225.33	3.00	3.00	90	80
04/05/2013	81	144, 145	225.33	228.33	3.00	3.00	90	80
05/05/2013	82	146, 147	228.33	231.33	3.00	3.00	90	90
05/05/2013	83	148, 149	231.33	234.33	3.00	3.00	90	90
07/05/2013	84	150, 151	234.33	237.33	3.00	3.00	90	148
07/05/2013	85	152, 153	237.33	240.33	3.00	3.00	90	121
07/05/2013	86	154, 155	240.33	243.33	3.00	3.00	90	133
07/05/2013	87	156, 157	243.33	246.33	3.00	3.00	90	127
08/05/2013	88	158, 159	246.33	249.33	3.00	3.00	90	120
08/05/2013	89	160, 161	249.33	252.33	3.00	3.00	90	120
08/05/2013	90	162, 163	252.33	255.33	3.00	3.00	90	143

08/05/2013	91	164, 165	255.33	258.33	3.00	3.00	90	102
08/05/2013	92	166, 167	258.33	261.33	3.00	3.00	90	129
09/05/2013	93	168, 169	261.33	264.33	3.00	3.00	90	143
09/05/2013	94	170, 171	264.33	267.33	3.00	3.00	90	80
09/05/2013	95	172, 173	267.33	270.33	3.00	3.00	90	42
09/05/2013	96	174, 175	270.33	273.33	3.00	3.00	90	91
09/05/2013	97	176, 177	273.33	276.33	3.00	3.00	90	139
10/05/2013	98	178, 179	276.33	279.33	3.00	3.00	90	150
10/05/2013	99	180, 181	279.33	282.33	3.00	3.00	90	192
10/05/2013	100	182, 183	282.33	285.33	3.00	3.00	90	151
11/05/2013	101	184, 185	285.33	288.33	3.00	3.00	90	104
11/05/2013	102	186, 187	288.33	291.33	3.00	3.00	90	92
11/05/2013	103	188, 189	291.33	294.33	3.00	3.00	90	82
11/05/2013	104	190, 191	294.33	297.33	3.00	3.00	90	74
11/05/2013	105	192, 193	297.33	300.33	3.00	3.00	90	43
11/05/2013	106	194, 195	300.33	303.33	3.00	3.00	90	96
11/05/2013	107	196, 197	303.33	306.33	3.00	3.00	90	107
12/05/2013	108	198, 199	306.33	309.33	3.00	3.00	90	128
12/05/2013	109	200, 201	309.33	312.33	3.00	3.00	90	90
12/05/2013	110	202, 203	312.33	315.33	3.00	3.00	90	96
12/05/2013	111	204, 205	315.33	318.33	3.00	3.00	90	84
12/05/2013	112	206, 207	318.33	321.33	3.00	3.00	90	98
12/05/2013	113	208, 209	321.33	324.33	3.00	3.00	90	102
12/05/2013	114	210, 211	324.33	327.33	3.00	3.00	90	114
13/05/2013	115	212, 213	327.33	330.33	3.00	3.00	90	98
13/05/2013	116	214, 215	330.33	333.33	3.00	3.00	90	102
13/05/2013	117	216, 217	333.33	336.33	3.00	3.00	90	92
13/05/2013	118	218, 219	336.33	339.33	3.00	3.00	90	112
13/05/2013	119	220, 221	339.33	342.33	3.00	3.00	90	100
13/05/2013	120	222, 223	342.33	345.33	3.00	3.00	90	98
14/05/2013	121	224, 225	345.33	348.33	3.00	3.00	90	106
14/05/2013	122	226, 227	348.33	351.33	3.00	3.00	90	113
14/05/2013	123	228, 229	351.33	354.33	3.00	3.00	90	97
14/05/2013	124	230, 231	354.33	357.33	3.00	3.00	90	62
14/05/2013	125	232, 233	357.33	360.33	3.00	3.00	90	74
14/05/2013	126	234, 235	360.33	363.33	3.00	3.00	90	78
15/05/2013	127	236, 237	363.33	366.33	3.00	3.00	90	62
15/05/2013	128	238, 239	366.33	369.33	3.00	3.00	90	94
15/05/2013	129	240, 241	369.33	372.33	3.00	3.00	90	138
15/05/2013	130	242, 243	372.33	375.33	3.00	3.00	90	152
16/05/2013	131	244, 245	375.33	378.33	3.00	3.00	90	139
16/05/2013	132	246, 247	378.33	381.33	3.00	3.00	90	69
16/05/2013	133	248, 249	381.33	384.33	3.00	3.00	90	92
16/05/2013	134	250, 251	384.33	387.33	3.00	3.00	90	102
16/05/2013	135	252, 253	387.33	390.33	3.00	3.00	90	94
17/05/2013	136	254, 255	390.33	393.33	3.00	3.00	100	98
20/05/2013	137	256, 257	393.33	396.33	3.00	3.00	100	92

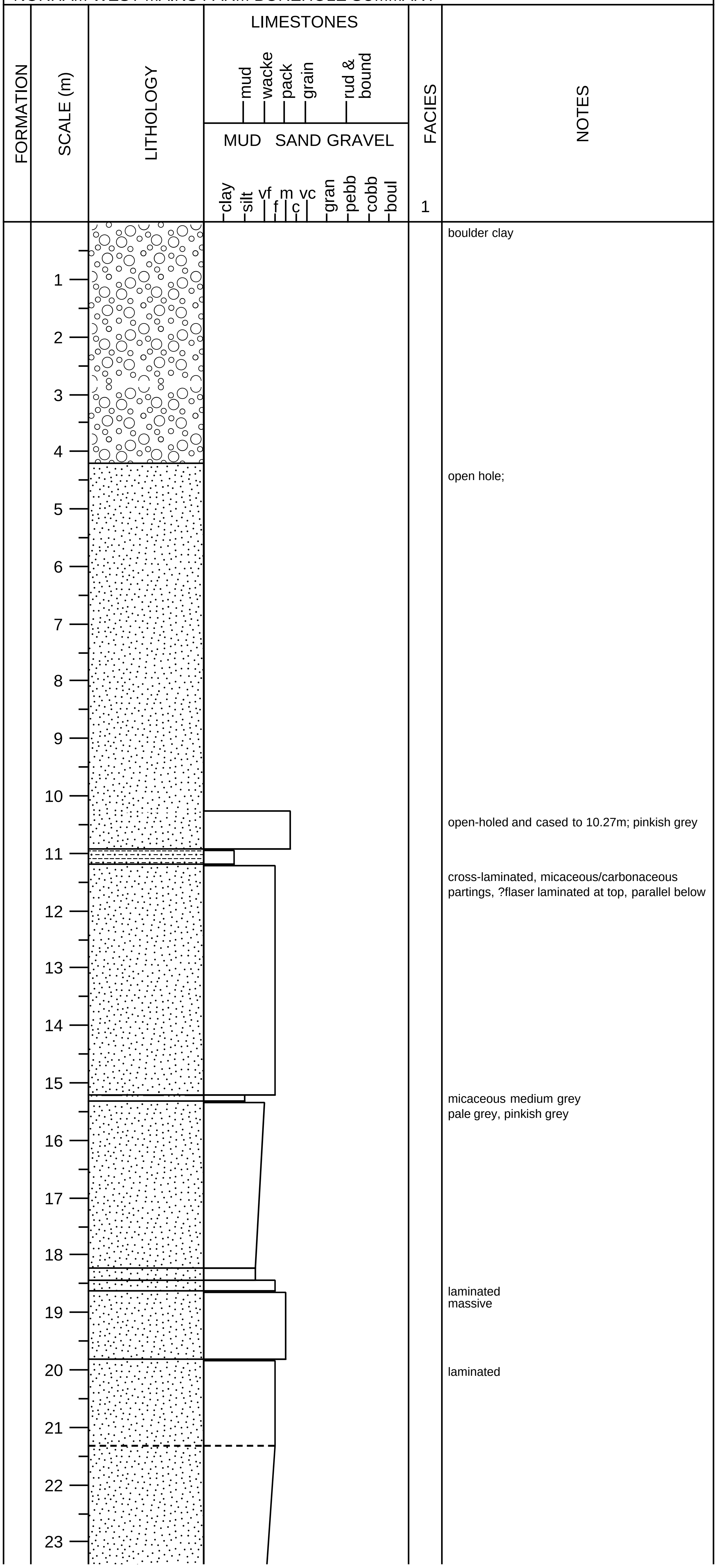
20/05/2013	138	258, 259	396.33	399.33	3.00	3.00	100	68
20/05/2013	139	260, 261	399.33	402.33	3.00	3.00	100	64
20/05/2013	140	263, 263	402.33	405.33	3.00	3.00	100	51
20/05/2013	141	264, 265	405.33	408.33	3.00	3.00	100	94
20/05/2013	142	266, 267	408.33	411.33	3.00	3.00	100	78
21/05/2013	143	268, 269	411.33	414.33	3.00	3.00	100	40
21/05/2013	144	270, 271	414.33	417.33	3.00	3.00	100	36
21/05/2013	145	272, 273	417.33	420.33	3.00	3.00	100	60
21/05/2013	146	274, 275	420.33	423.33	3.00	3.00	100	72
21/05/2013	147	276, 277	423.33	426.33	3.00	3.00	100	70
21/05/2013	148	278, 279	426.33	429.33	3.00	3.00	100	64
21/05/2013	149	280, 281	429.33	432.33	3.00	3.00	100	61
21/05/2013	150	282, 283	432.33	435.33	3.00	3.00	100	60
22/05/2013	151	284, 285	435.33	438.33	3.00	3.00	100	90
22/05/2013	152	286, 287	438.33	441.33	3.00	3.00	100	98
22/05/2013	153	288, 289	441.33	444.33	3.00	3.00	100	104
22/05/2013	154	290, 291	444.33	447.33	3.00	3.00	100	92
22/05/2013	155	292, 293	447.33	450.33	3.00	3.00	100	109
22/05/2013	156	294, 295	450.33	453.33	3.00	3.00	100	138
23/05/2013	157	296, 297	453.33	456.33	3.00	3.00	100	128
23/05/2013	158	298, 299	456.33	459.33	3.00	3.00	100	112
23/05/2013	159	300, 301	459.33	462.33	3.00	3.00	100	123
23/05/2013	160	302, 303	462.33	465.33	3.00	3.00	100	120
24/05/2013	161	304, 305	465.33	468.33	3.00	3.00	100	120
24/05/2013	162	306, 307	468.33	471.33	3.00	3.00	100	123
24/05/2013	163	308, 309	471.33	474.33	3.00	3.00	100	121
24/05/2013	164	310, 311	474.33	477.33	3.00	3.00	100	116
24/05/2013	165	312, 313	477.33	480.33	3.00	3.00	100	60
25/05/2013	166	314, 315	480.33	483.33	3.00	3.00	100	120
25/05/2013	167	316, 317	483.33	486.33	3.00	3.00	100	94
25/05/2013	168	318, 319A	486.33	489.33	3.00	3.00	100	63
25/05/2013	169	319B, 320	489.33	492.33	3.00	3.00	100	68
25/05/2013	170	321, 322	492.33	495.33	3.00	3.00	100	62
25/05/2013	171	323, 324	495.33	498.33	3.00	3.00	100	74
25/05/2013	172	325, 326	498.33	501.33	3.00	3.00	100	63

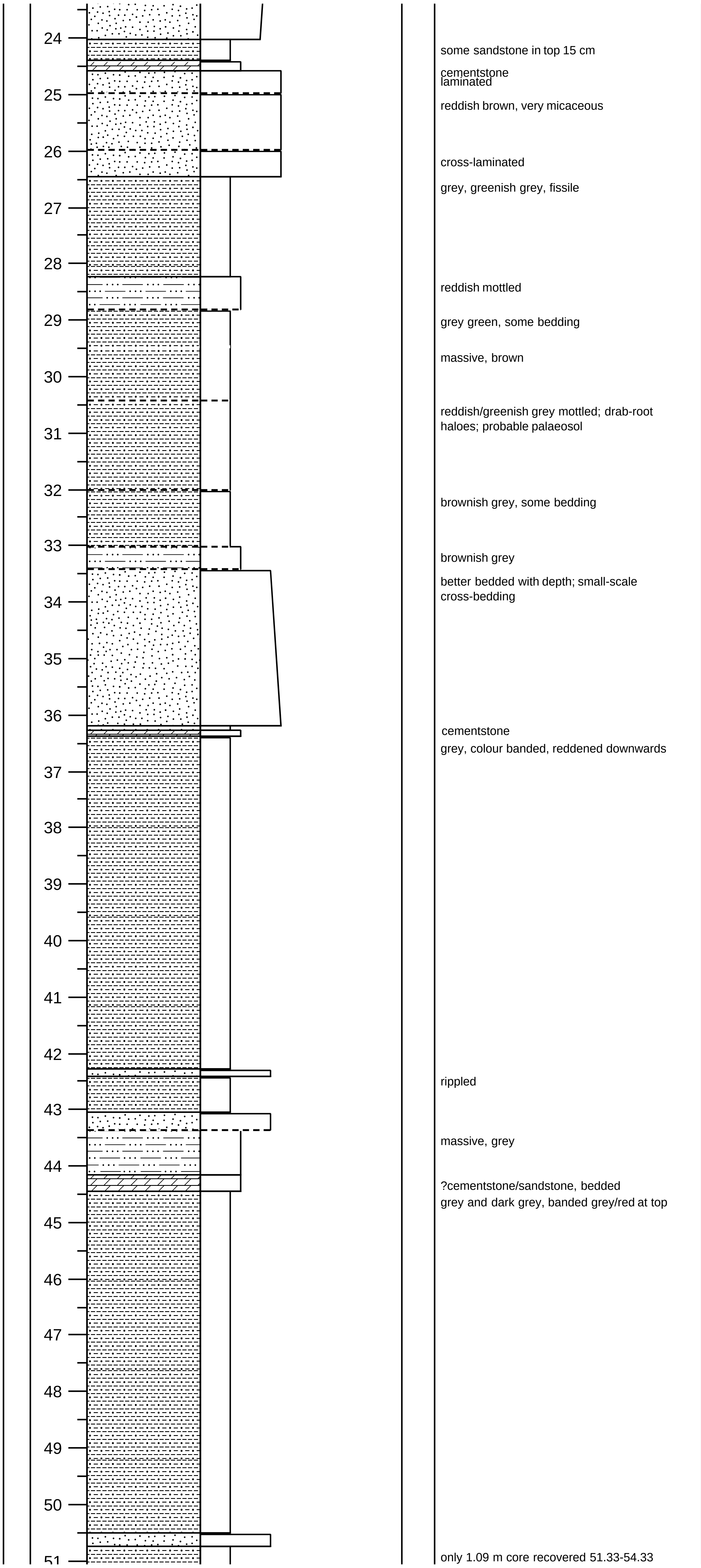
Appendix 3 On-site lithology log

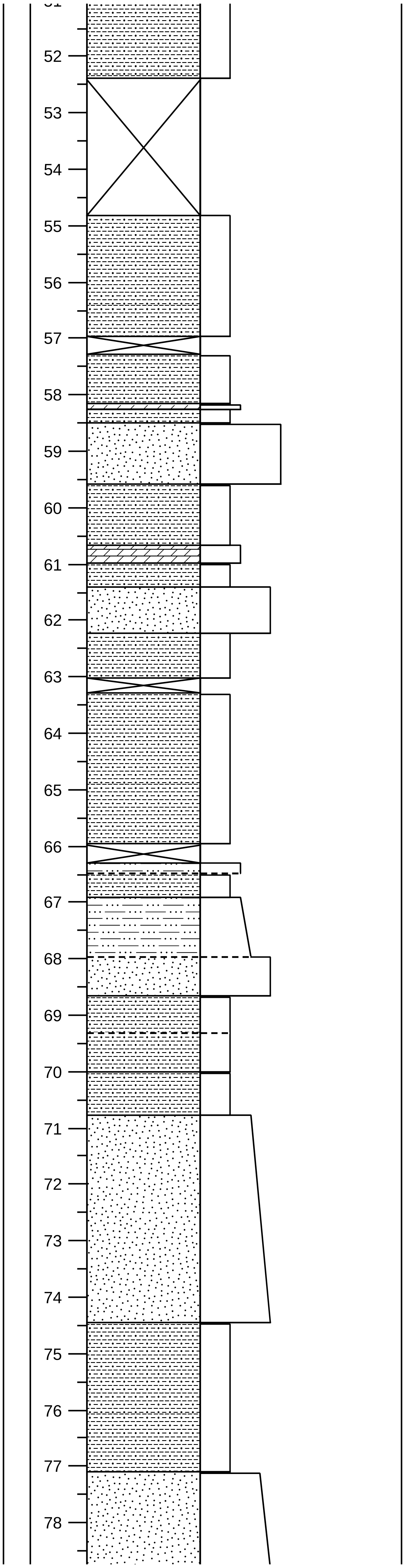
Key



NORHAM WEST MAINS FARM BOREHOLE SUMMARY




24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
some sandstone in top 15 cm
cementstone
laminated
reddish brown, very micaceous
cross-laminated
grey, greenish grey, fissile
reddish mottled
grey green, some bedding
massive, brown
reddish/greenish grey mottled; drab-root haloes; probable palaeosol
brownish grey, some bedding
brownish grey
better bedded with depth; small-scale cross-bedding
cementstone
grey, colour banded, reddened downwards
rippled
massive, grey
?cementstone/sandstone, bedded
grey and dark grey, banded grey/red at top
only 1.09 m core recovered 51.33-54.33



CIRCULATION LOST; uncertain which depths core lost from

dark grey; broken core

?cementstone

cross-bedded

grey

2 thin cementstone beds, mudstone interbed

grey

grey, gypsum nodules at 63.85; some broken core and loss: CIRCULATION LOST

grey, hard

grey, jointed

grey/pale grey, laminae, gypsum layers

cross-bedded at base

grey, some gypsum beds

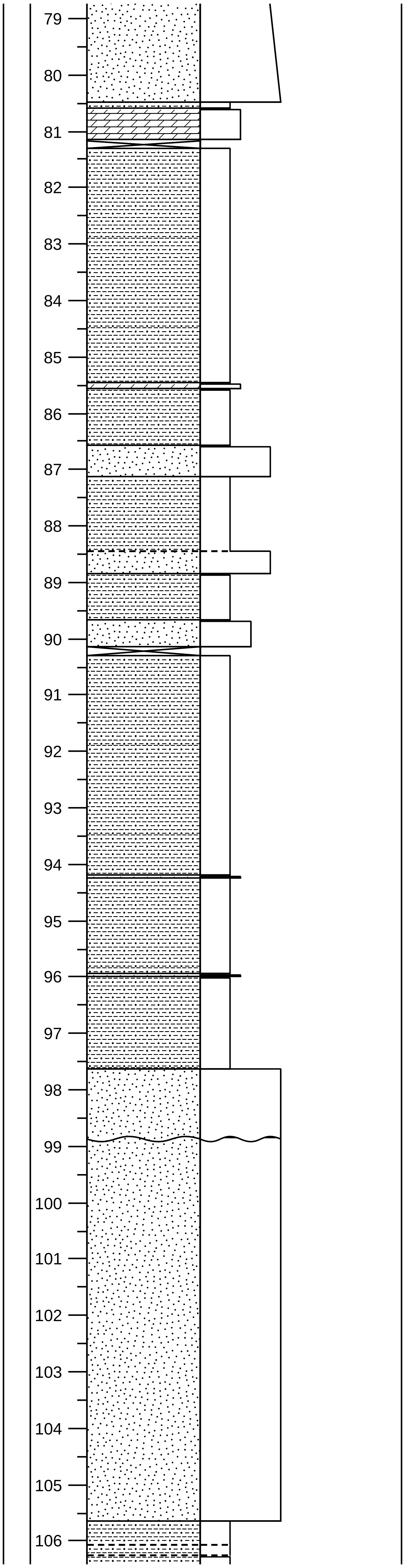
grey, 'maroonish' colour, laminated

grey mottled; ?conglomeratic

reddish grey irony cement; finely micaceous in upper part; well jointed 71.65-72.50; lower part grey with small-scale cross-lamination

massive grey and wet at top; reddish staining downwards; becoming laminated around 76.03m; intensely fractured below 76.60m

reddish brown; reddish brown mudstone 10cm thick base at 78.80m; below 78.33 becoming strongly cross-bedded and micaceous



laminated; grey

cementstone; pale grey, becoming grey; laminated; clasts in layer

laminated; grey mottled in part; fractured below 81.90

cementstone

grey, bedded

pale grey, laminated

red and grey, laminated

reddish grey, laminated

grey, laminated; broken at base

grey, becoming laminated at base; 90.33-91.33m slipped from core barrel and drilled out on instruction

pale grey, microfractured

grey, bedded; some paler layers

siltstone/sandstone; massive siltstone 12cm thick base at 95.33m; irregular base

cementstone

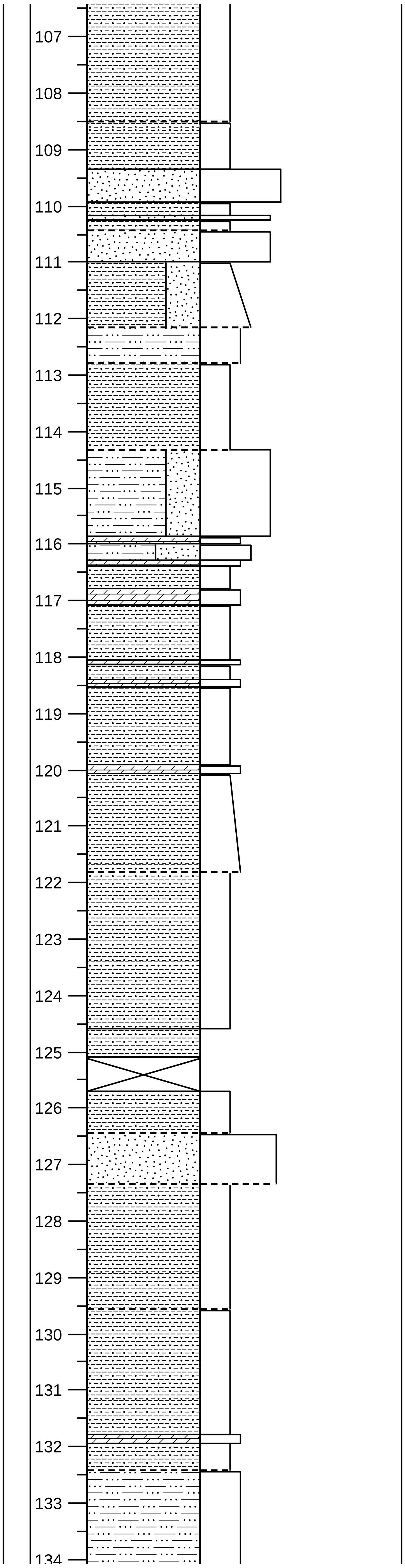
grey laminated

pale grey; small scale cross-lamination

cross-bedded; micaceous/carbonaceous partings; steep open fractures 100.68-101.36m; CIRCULATION LOST AT 103m

grey

FAULT in mudstone



grey; reddish grey

FAULT in mudstone
grey

pale grey; cross-laminated,
micaceous/carbonaceous partings

grey
pale grey
grey, fractured

fine-scale cross-lamination; thin sandstone interbeds

grey

grey; wet around 113.33m; sandstone 10cm thick base at 114.18m

parallel laminated; thickest sandstone 10 cm base at 114.68m

pale grey
striped; burrowed

grey, laminated

grey; well laminated

grey; broken

grey becoming shades of brown downwards

cementstone, brown

grey; laminated; some sandy beds to 1cm thick; 15cm thick ?burrowed sandstone bed base at 120.56m; possible mudstone breccia 5cm thick base at 121.52m

grey, fractured, with brown overtones 122.50-123.10m

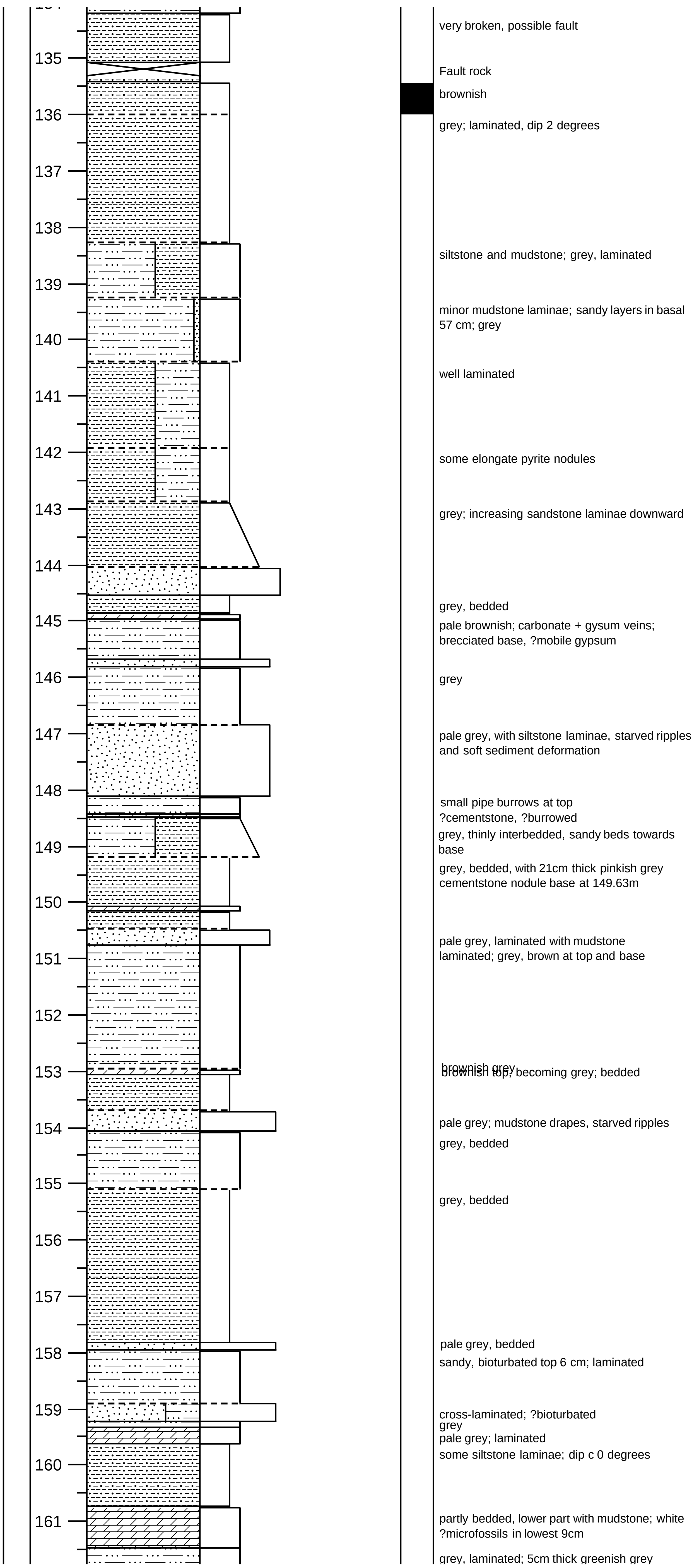
Fault rock

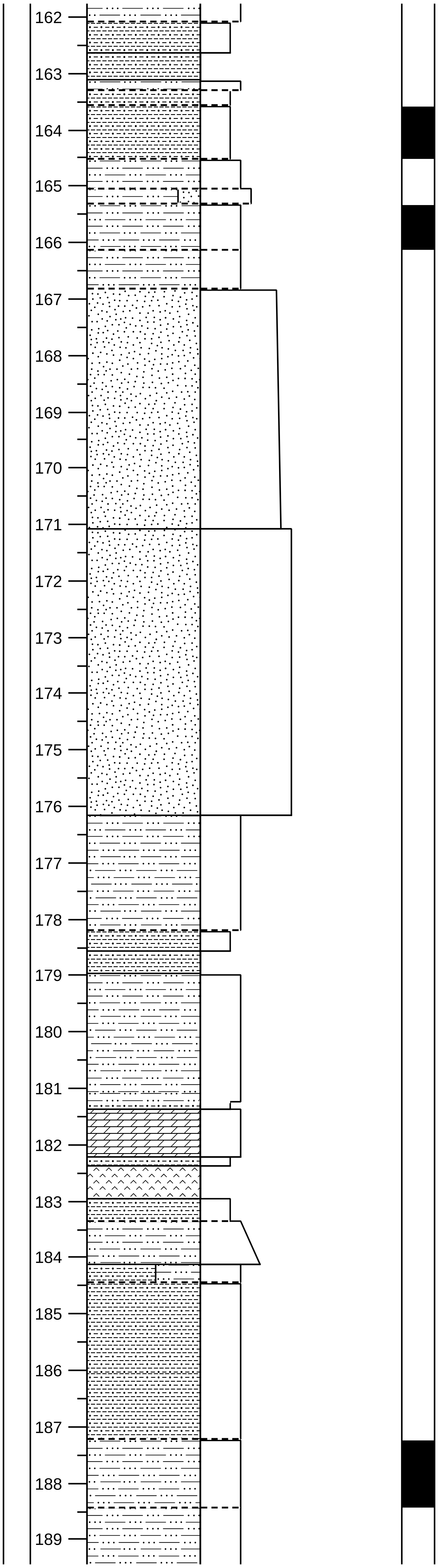
carbonaceous-micaceous laminae increase to base

grey, bedded with silty laminae; 5cm hard band base at 127.70m

grey and brown, becoming mottle banded in lowest metre

brown and grey cementstone
mudstone and siltstone, laminated; brown and grey
some mudstone and sandy laminae; sandstone basal 12cm; dip c 5 degrees


135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
very broken, possible fault
Fault rock
brownish
grey; laminated, dip 2 degrees
siltstone and mudstone; grey, laminated
minor mudstone laminae; sandy layers in basal 57 cm; grey
well laminated
some elongate pyrite nodules
grey; increasing sandstone laminae downward
grey, bedded
pale brownish; carbonate + gysum veins; brecciated base, ?mobile gypsum
grey
pale grey, with siltstone laminae, starved ripples and soft sediment deformation
small pipe burrows at top
?cementstone, ?burrowed
grey, thinly interbedded, sandy beds towards base
grey, bedded, with 21cm thick pinkish grey cementstone nodule base at 149.63m
pale grey, laminated with mudstone
laminated; grey, brown at top and base
brownish grey
brownish top; becoming grey; bedded
pale grey; mudstone drapes, starved ripples
grey, bedded
grey, bedded
pale grey, bedded
sandy, bioturbated top 6 cm; laminated
cross-laminated; ?bioturbated
grey
pale grey; laminated
some siltstone laminae; dip c 0 degrees
partly bedded, lower part with mudstone; white ?microfossils in lowest 9cm
grey, laminated; 5cm thick greenish grey



laminated mudstone base at 161.66m

grey, bedded

FAULT

brown and grey

brown and some grey; bedded

grey with red and some green mottling

grey and some brown

brown

grey

grey; carbonaceous-micaceous cross-laminae; more massive below 167.90m

massive becoming cross-bedded with carbonaceous-micaceous laminae; off white; isolated pyrite-rich mudstone rip-up clasts below 173.5; possibly coaly streaked in basal parts of co-sets; black pyritous coaly mudstone rip ups below 173.84; 21 cm thick unit base at 175.26 containing many coalified plant? fragments to 3 cm; base flattish

grey, bedded with sandy laminae in basal 70cm

grey, bedded

FAULT rock

grey to brown, grey below 180,1; bedded; mudstone laminae 179.65-179.83;

grey

laminated; ?cementstone

grey

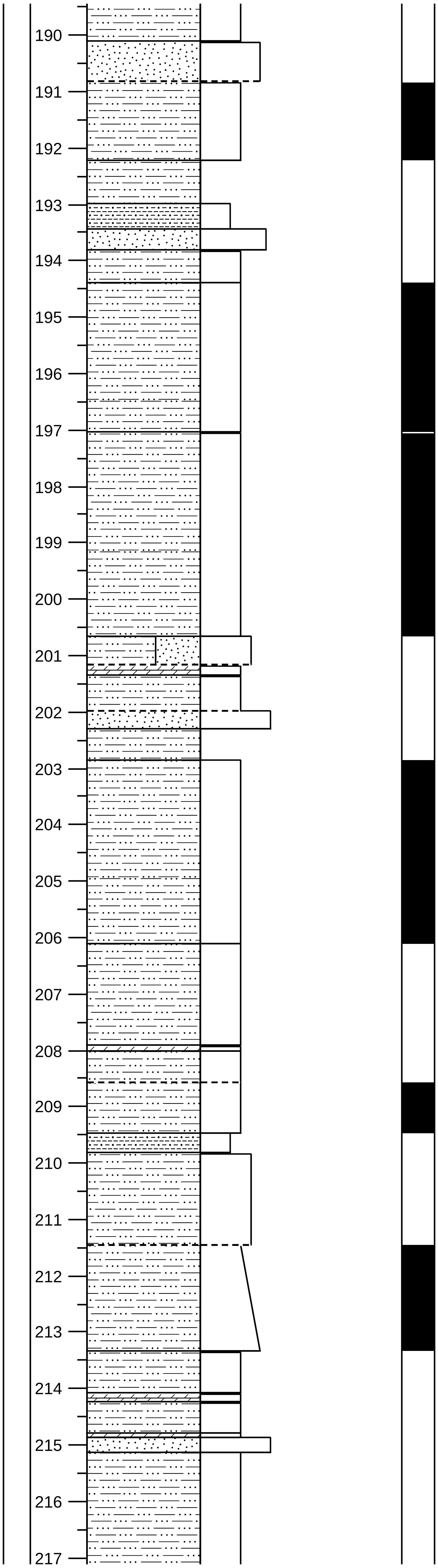
GYPSUM; bedded; irregular layers with 'cottage cheese' texture and chicken-wire mudstone; laminated dark grey mudstone laminae/beds

2 subhorizontal gypsum veins

silty, bedded, brown band 10cm base at 185.63

bedded

gypsum "eyes"



laminated; dark grey mudstone laminae 21cm thick base at 190.54m

bedded

FAULT rock, grey; slickensided, sandy at base

bedded

bedded

sandy base

brown, grey 12cm band base at 196.15m and from 196.62 to 196.82m; bedded, with muddy layers; sandy base

mainly brown below 198.53m, grey below 200.2m; 10cm thick sandstone base at 199.19; 7cm thick sandstone base at 199.60m

grey; pink gypsum band

cementstone, brownish grey

bedded

cross-laminated, rippled; ?small burrows

FAULT

pale grey top 20cm; bedded; 15cm sandstone at 205.37

grey, bedded; sandstone bed 15cm base at 206.58m, 5cm base at 206.83m; fine sandstone beds in 30cm interval with base at 207.78m

cementstone

grey; bedded, reverse graded units 2-4cm siltstone to fine sandstone

brown, grey near base

grey, bedded

siltstone and very fine sandstone; top 13cm red green and grey mottled; 25cm thick sandstone base at 210.75m, 20cm thick sandstone base at 211.27

bedded, grey; dip less than 5 degrees

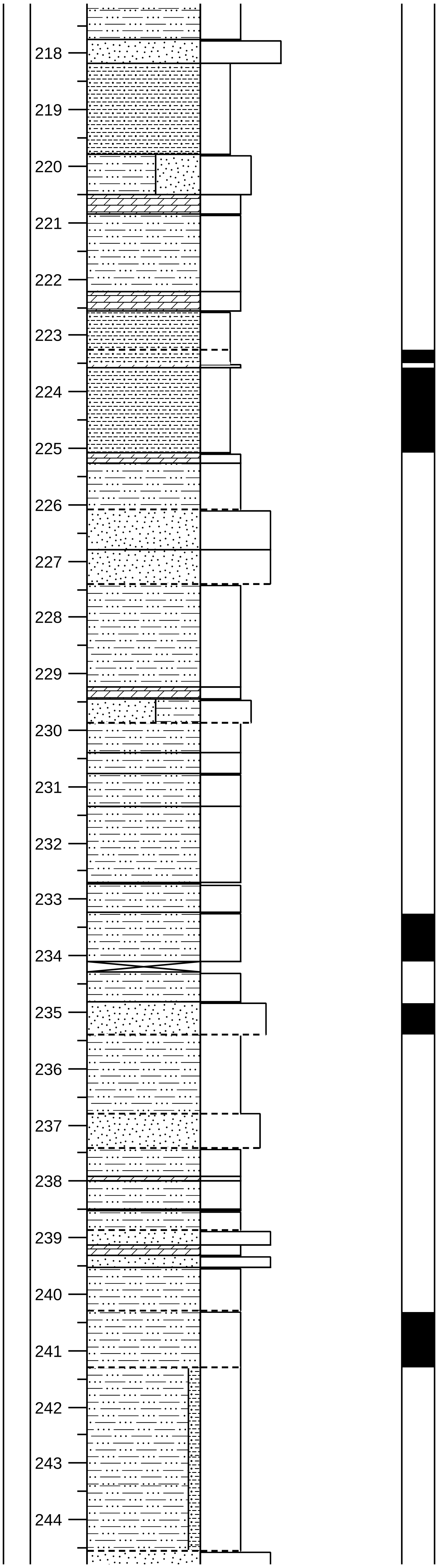
grey, bedded

cementstone, pale grey

small pellets gypsum at 214.32

cementstone

grey, bedded; very fine sandy laminae; 8cm thick sandstone bed base at 216.91m; 23cm thjick base at 217.48m



off-white

grey/dark grey; bedded; thin subhorizontal gypsum veins at 218.25m

grey, bedded

cementstone?, grey

grey, sandy layers, bedded

cementstone

grey, silty, burrowed (?chondrites-like)

brown, bedded

cementstone

brown, grey at top and base; 7cm sandy bed base at 224.87

cementstone

grey, bedded, 11cm thick fine sandstone base at 225.51m

pale grey; cross-bedded; muddy beds in lower part

bedded, grey

grey, well laminated; narrow gypsum vein 227.04m; sandy 228.45-228.70m

cementstone; brown grey, compound

3 narrow subhorizontal gypsum veins

disturbed 18cm to 230.36m with small nodules pyrite (?plant bed)

plant impressions in lower 2-3cm

top 17cm rooty and massive, bedded below

grey, bedded; gypsum veins near base

anhydrite/gypsum, irregular top

brown, bedded

red, green, brown mottling to 234.53m

brown; gypsum veins

grey, bedded

grey, bedded

grey, laminated with sandy laminae

cementstone, grey

cementstone; nodules gypsum above and below

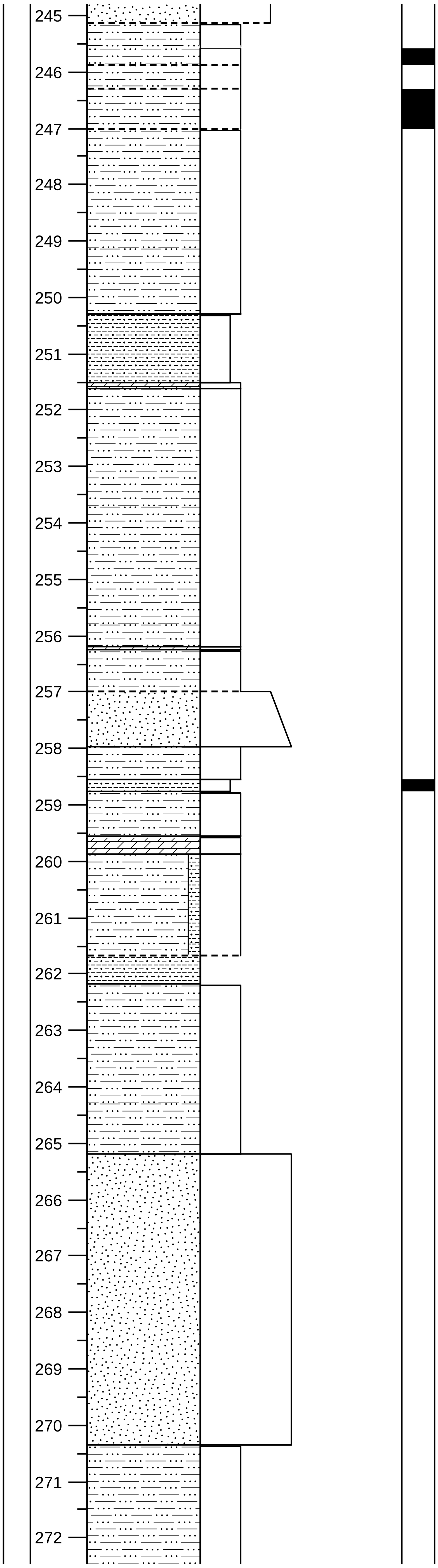
cementstone

grey, bedded

brownish, bedded

grey, bedded; subordinate mudstone; c 15cm mudstone base at 244.33

off-white, bedded



off-white, bedded

grey, bedded

grey

brownish

sandy in basal 14cm; grey

silty, grey, bedded; sandy laminae near base

cementstone, rooty like fabric at top, pale grey

grey, bedded; some mudstone beds; dip c3 degrees

cemenstone, grey

grey, bedded

pale grey,; cross bedded; conglomeratic basal 16cm; clasts max 4 x 1 cm, mudstone, cementstone

grey, bedded

brown; ?ped structure

brown and grey

?cementstone; brownish grey

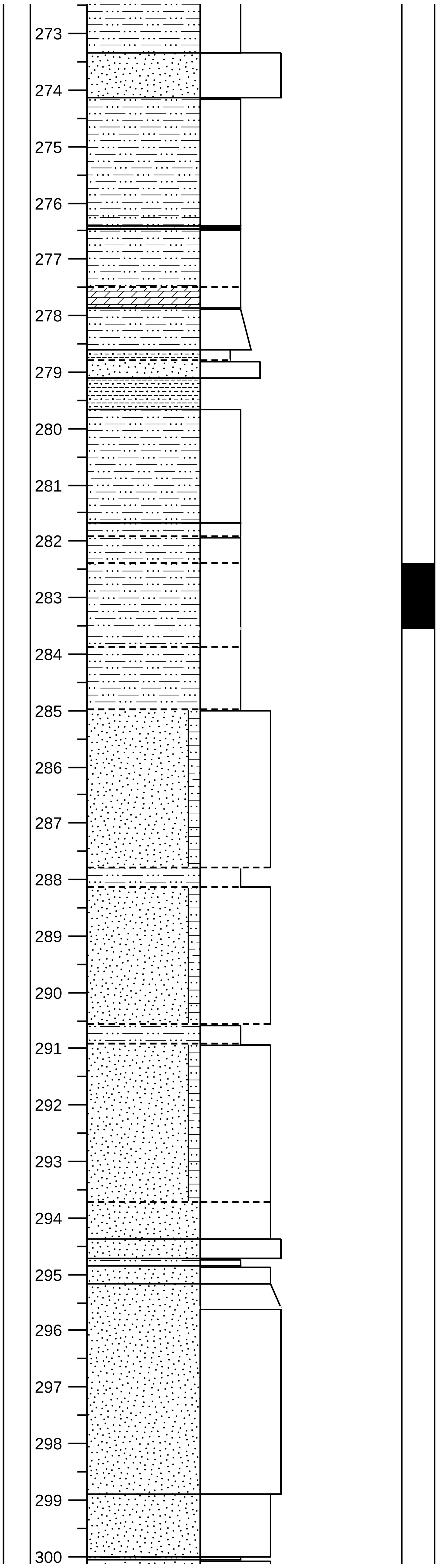
grey, bedded, some mudstone interbeds

FAULT in mudstone, grey

grey, some brown

pale grey; cross bedded, with carbonaceous and micaceous partings abundant; conglomeratic basal 14 cm with cementstone clasts up to 3cm

grey, locally brown in part; bedded, some mudstone beds



pale grey; ripple laminated; carbonaceous partings

grey bedded; very fine sandstone 5cm base at 275.44; 7cm thick sandstone at 275.63

cementstone, grey, bedded
grey, bedded

cementstone, brown

grey, bedded; very fine sandy laminae in basal 32cm

grey, bedded
pale grey

FAULT rock in mudstone, dark grey with many polished, slickensided surfaces
grey, bedded; 12cm thick very fine grained sandstone base at 280.66

brown and grey mottled; rooty
grey and brown, bedded

brown, bedded

grey; 8cm sandstone bed base at 283.65
grey, bedded

pale grey; ripple laminated

grey bedded

pale grey; ripple laminated; carbonaceous and micaceous partings; "striped beds"

grey, bedded

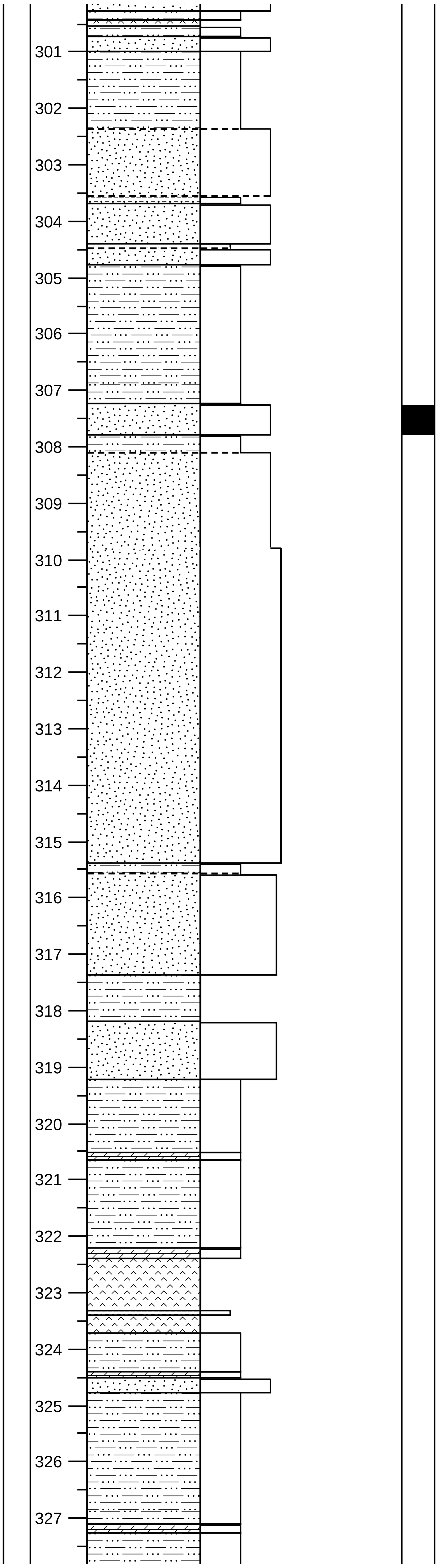
pale grey; ripple laminated; carbonaceous and micaceous partings; "striped beds"

pale grey; parallel laminated; common carbonaceous-micaceous partings

massive
grey, bedded
rippled; carbonaceous-micaceous partings
parallel bedded

sporadic mudstone intraclasts 2 x 7 cm; basal zone 17cm thick with large dark grey intraclasts 2 x 7 cm; highly carbonaceous-micaceous below 298.71

parallel laminated except for basal 30cm ripple laminated



Gypsum and anhydrite

bioturbated

grey, bedded

grey and brown; parallel bedded

brownish grey; cross-laminated

grey, sometimes brown, bedded; sandy laminae and beds below 306.43; 5cm thick sandstone base at 306.99, with roots or suncracks; 4cm thick sandstone base at 306.95

brown

grey, bedded

pale grey; ripple laminated and parallel laminated; carbonaceous and micaceous partings

pale grey; cross-bedded with many carbonaceous and micaceous partings; some massive subunits between 312.33 and 313.83; mudstone intraclasts at c 314.1

grey

cross-laminated; irregular channel base

?FAULT

cross-bedded

grey, bedded; rippled sandy beds 27 cm interval base at 320.49m

cementstone, grey, massive

grey, bedded; gypsum vein near base

cementstone, pale brown; gypsum enclaves

Anhydrite, minor gypum; bedded; thin grey mudstone laminae

Anhydrite/gypsum, irregular base

grey, bedded; gypsum nodules and veins; 3cm anhydrite base at 324.24

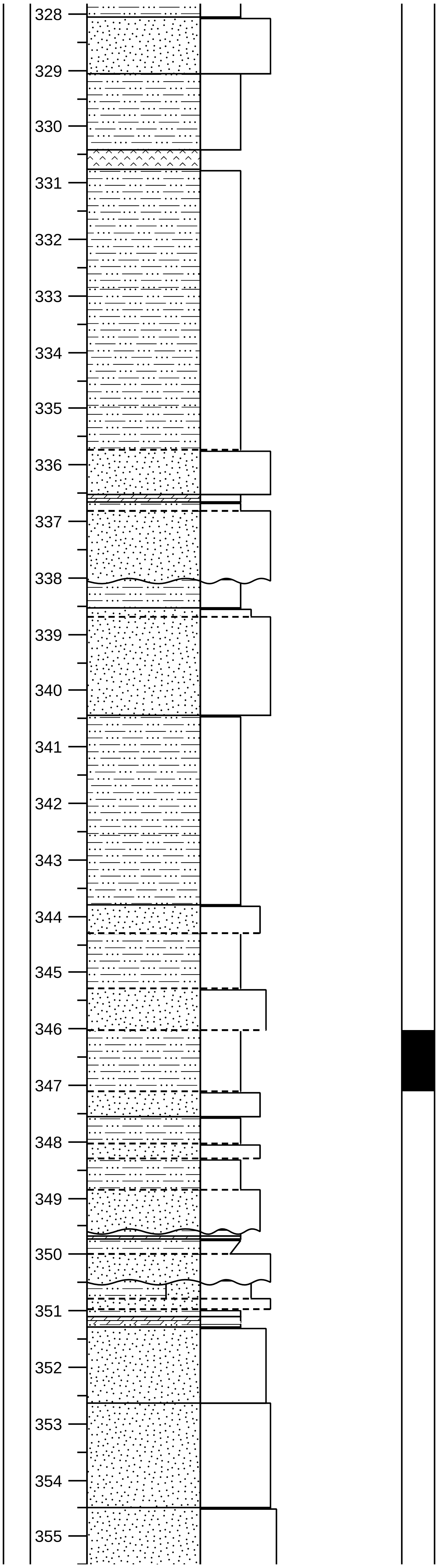
cementstone; brownish grey

grey, rippled

grey bedded; 16cm thick fine sandstone bas at 325.83 with /roots or suncracks

cementstone, grey

grey; fine grained sandy laminae; 10cm mudstone at base



pale grey; grey interbeds siltstone; ripple laminated

grey; bedded; low dip

Gypsum and some anhydrite; nodular, chicken-wire siltstone; irregular top and base

grey, bedded; thin mudstone partings in upper part; thin rippled sandy mainae in lower part

pale grey; interbedded with grey siltstone; sparse ripples

sandy ?cementstone; ?rooted/burrowed

ripple laminated; mudstone tops to units 15-25cm thick

grey, bedded; sandy laminae; bioturbated, ?roots

?PALAEOSOL

grey with brownish overtones; cross-bedded; gysum vein along base

grey with brownish overtones; thin sandy laminae at top; a few thin mudstone beds up to 18cm thick; a few pink gypsum nodules in 20cm interval with lowest at 343.13m

grey/pale grey; laminated; burrowed

grey and brown; bedded

grey with brown tinge;laminated

grey; contains 5cm mudstone

grey

grey, brown near top; bedded

grey; cross-bedded in lower part

cementstone, grey

grey; silty laminae

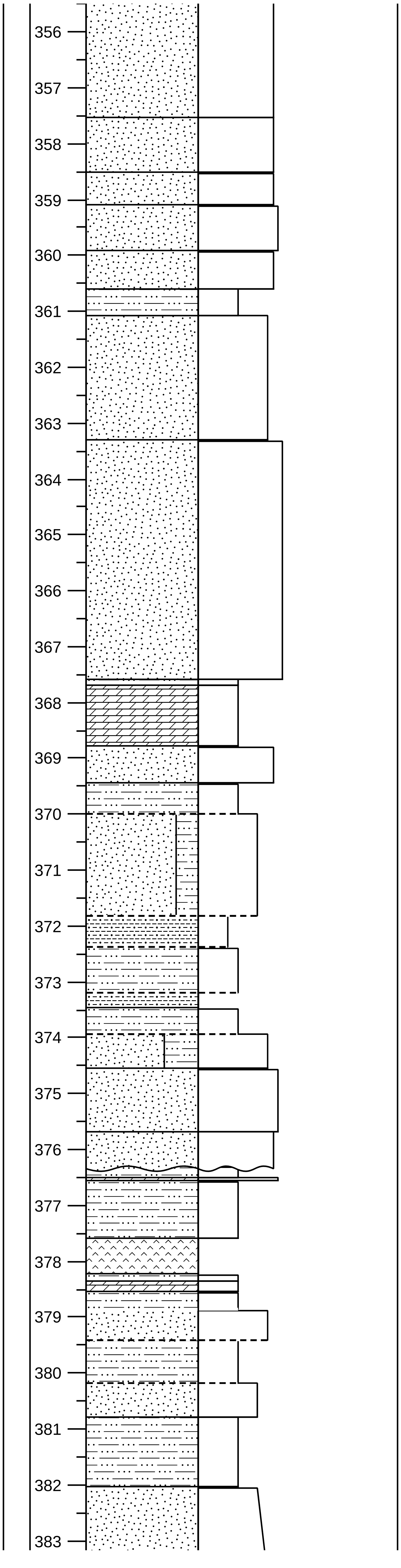
rippled

cementstone, grey

laminated with siltstone interbeds

grey; rippled with some parallel laminae; very irregular bedding in basal 20cm

pale grey; small scale cross lamination; 5cm unit with mudstone intraclasts 3x1cm base at 355.10m; carbonaceous - micaceous partings; sub unit bases at 356.16, 356.76; 1cm



sub unit bases at 356.18, 356.78, 1cm
mudstone intraclasts at base

massive

cross-bedded, carbonaceous - micaceous

massive

cross-bedded

grey, bedded, sandy laminae at base

pale grey; rooted top 10cm; rippled; carbonaceous and micaceous partings

off-white; cross-bedded, carbonaceous micaceous partings abundant; sideritic?

3 cementstone beds separated by mudstone/siltstone; 8cm siltstone at base

off-white; rippled

grey, bedded

grey

grey, mottled red around 392.08

bedded; sandy in places

FAULT rock

grey, bedded

modestly bioturbated

off-white; rooted top 10cm; clay clasts; carbonaceous-micaceous partings; gypsum veins

siltstone interbeds; some rippled units

?sandy cementstone

grey, some flattish pink gypsum nodules 1x3cm

Anhydrite with some gypsum; nodular to 377.90m; below compacted "massive" with narrow gypsum veins

cementstone, grey

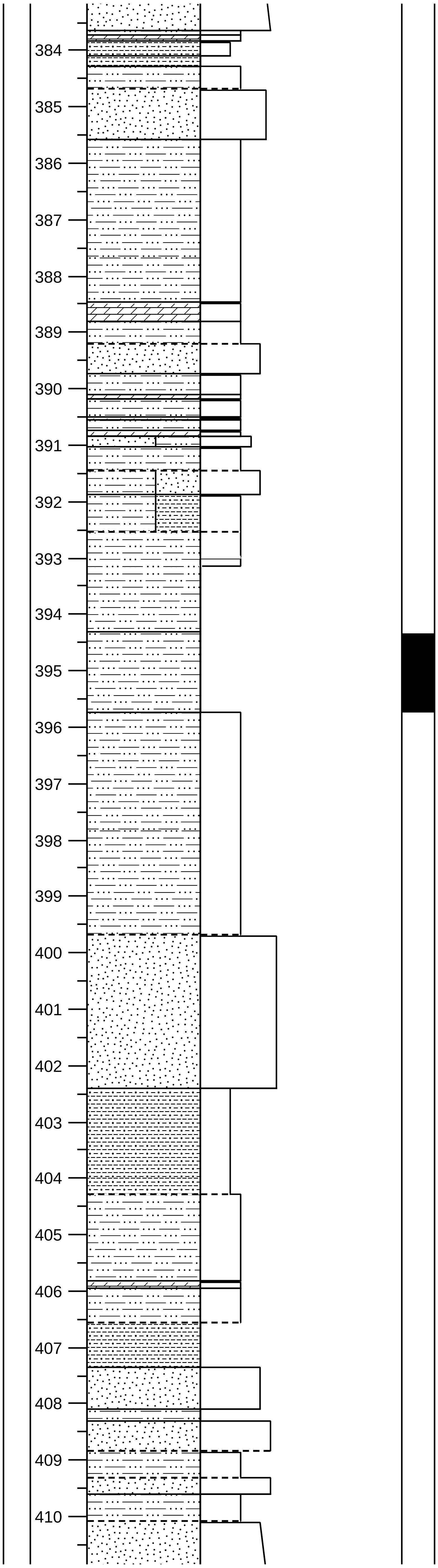
grey, rippled; siltstone and carbonaceous-micaceous partings

grey and brown; bedded

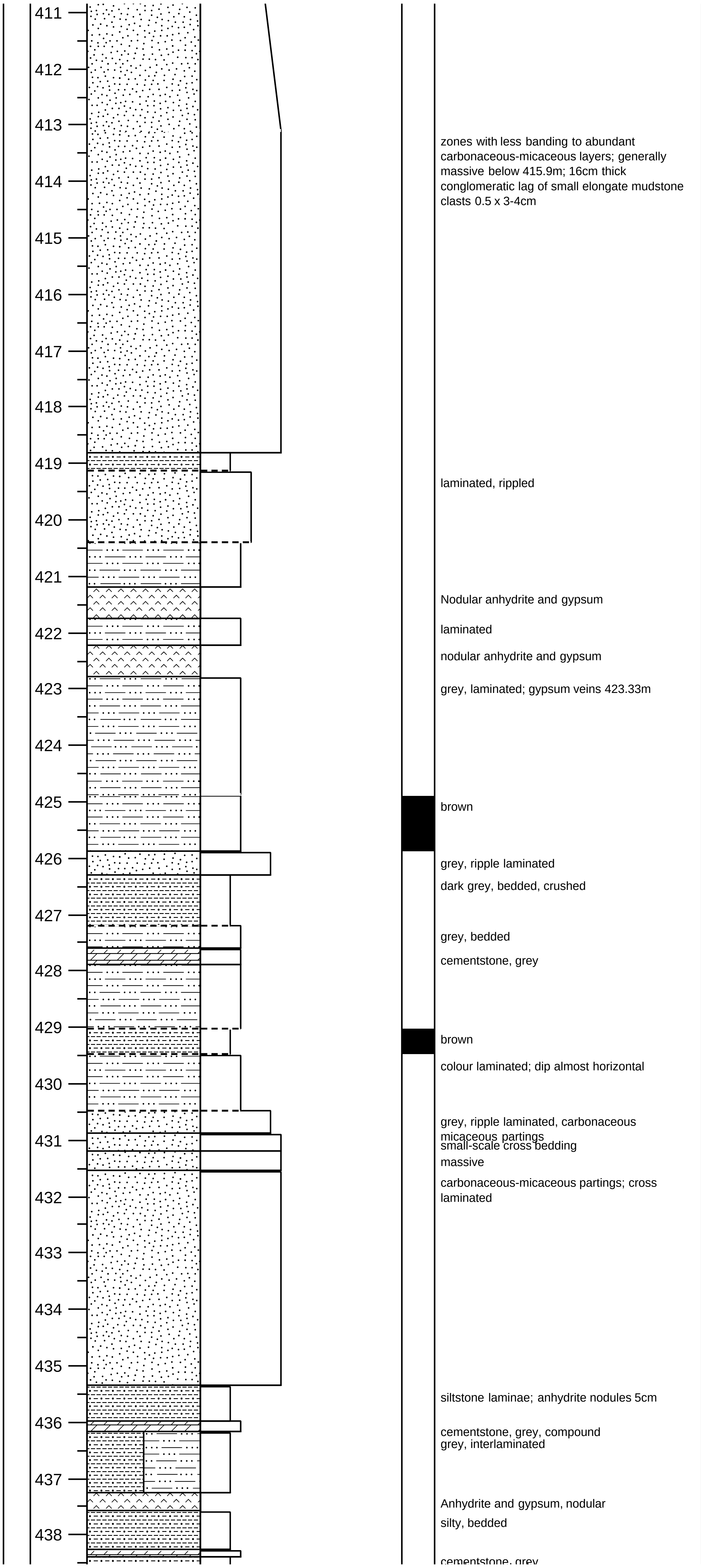
brownish, bedded

bedded; red mottled near base

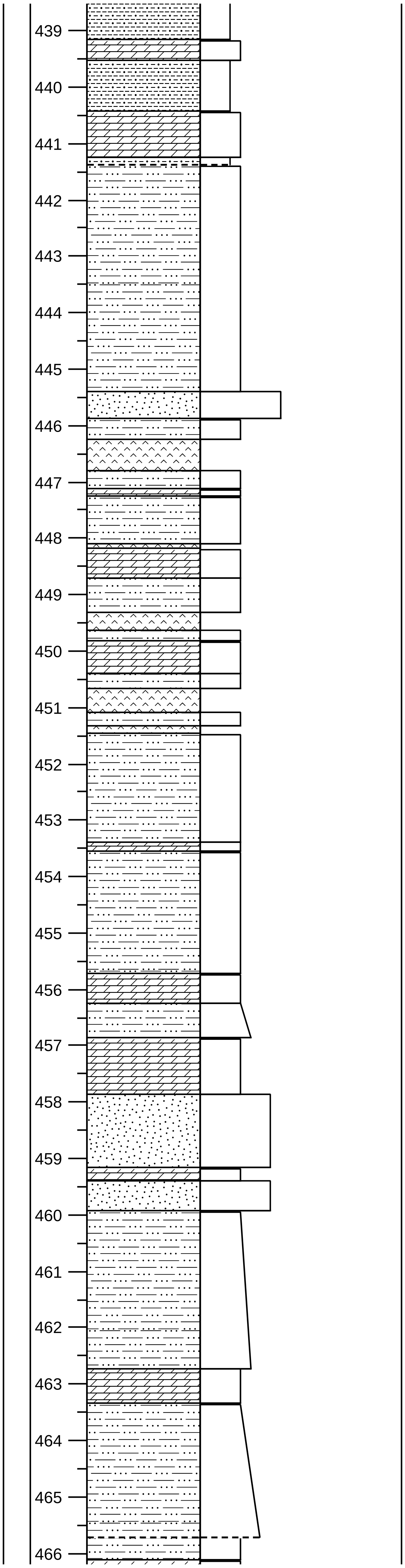
grey; thinly bedded/laminated, more silty in places



cementstone, grey
FAULT rock
grey, bedded
grey, thinly bedded; some small scale cross-beds; bioturbated in part
grey, bedded; locally sandy, brownish
cementstone, grey, siltstone intercalations
grey and brown, bedded
grey, rippled, with siltstone
brown, becomes grey
cementstone, grey
cementstone, nodular
cementstone, grey
darker, clayey at top
broken during core slippage; interlaminated
grey, bedded
grey, brownish tinge
grey
all reduced to gravel from slipped core barrel
?FAULT rock, crushed, grey clay base
grey, bedded
pale grey, rippled; carbonaceous-micaceous partings; small scale cross-beds below 401.03
silty, grey, bedded
grey, bedded
cementstone, grey
grey, crushed, FAULT at base
grey, siltstone laminae; small-scale cross lamination; 5cm dark mudstone crush zone at 407.60m
FAULT in siltstone
cross-bedded, siltstone laminae
cross-bedded, siltstone laminae
some siltstone bands; small scale cross bedding



411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
zones with less banding to abundant carbonaceous-micaceous layers; generally massive below 415.9m; 16cm thick conglomeratic lag of small elongate mudstone clasts 0.5 x 3-4cm
laminated, rippled
Nodular anhydrite and gypsum
laminated
nodular anhydrite and gypsum
grey, laminated; gypsum veins 423.33m
brown
grey, ripple laminated
dark grey, bedded, crushed
grey, bedded
cementstone, grey
brown
colour laminated; dip almost horizontal
grey, ripple laminated, carbonaceous micaceous partings
small-scale cross bedding
massive
carbonaceous-micaceous partings; cross laminated
siltstone laminae; anhydrite nodules 5cm
cementstone, grey, compound
grey, interlaminated
Anhydrite and gypsum, nodular
silty, bedded
cementstone, grey



bedded; crushed base

cementstone, grey

silty, bedded, crushed

cementstone, grey, compound

grey, bedded; some thin mudstone beds; sandy laminae below 444.33m; 7cm sandstone base at 444.73m

wispy carbonaceous micaceous layers; hard, ?dolomitic cement; siltstone interbeds 8cm base at 445.55m and 2cm base at 445.60m

Anhydrite with gypsum; lenticles of siltstone; upper 6cm gypsum

cementstone, grey

nodular anhydrite

cementstone, bedded, mudstone interbeds

anhydrite and gypsum; 3 nodular beds within siltstone

cementstone, brownish grey; with siltstone interbeds

anhydrite, laminated and folded, mudstone laminae

anhydrite with gypsum nodules

cementstone, grey

grey, bedded; thin interbeds of wispy sandstone to 454.03m

cementstone, brownish grey; grey siltstone interbeds

sandstone interbeds near base

cementstone, grey, bedded with siltstone; in part replacement of nodular evaporite??

siltstone partings; carbonaceous-micaceous partings; small-scale cross bedding

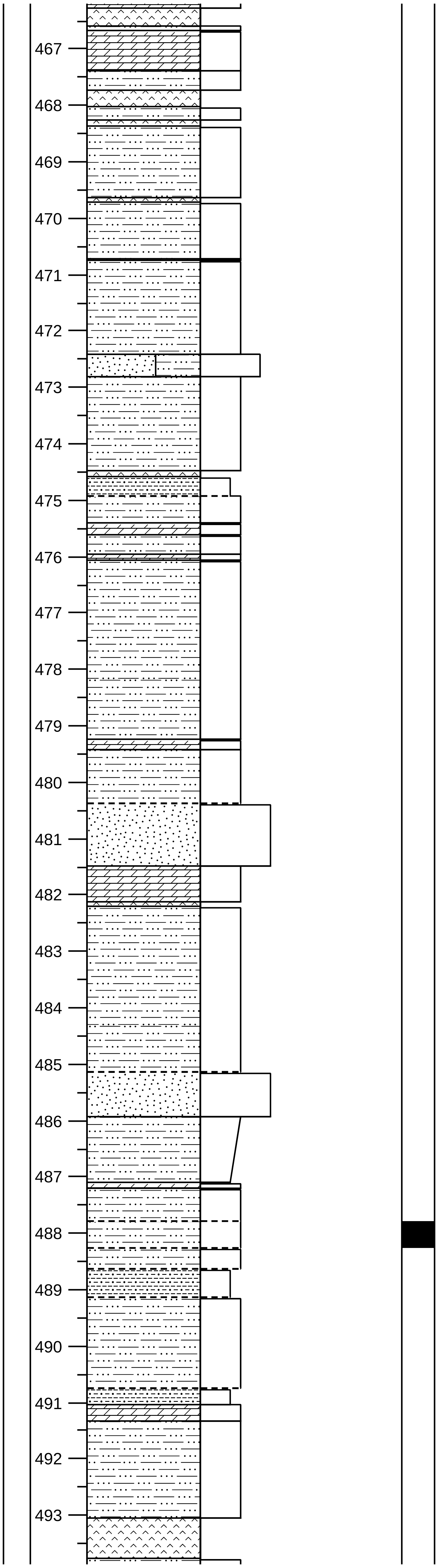
cementstone?; siltstone interbeds

siltstone laminae; small-scale cross bedding

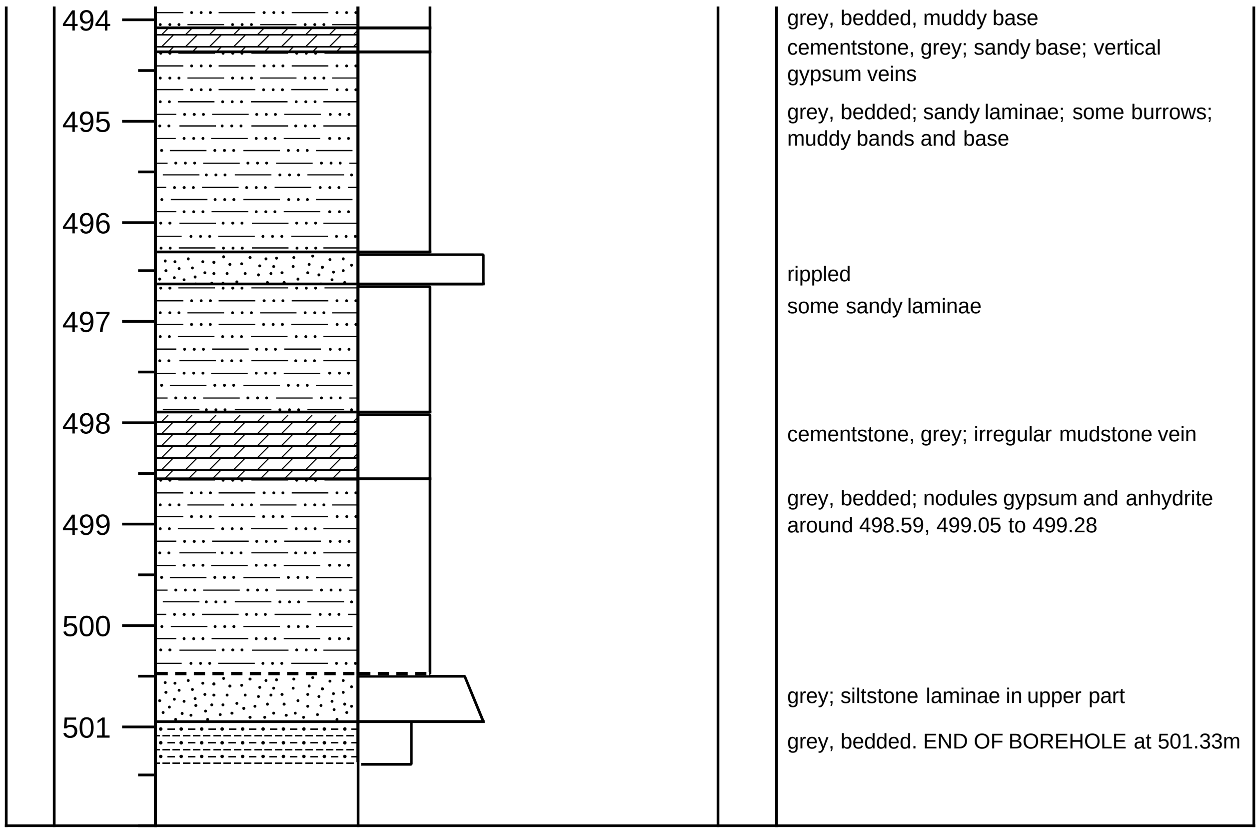
beds up to 3cm very fine sandstone; sandstone predominates 460.83-461.58m

cementstone sandy, 3 beds, nodular, clast rich

grey, bedded; thin sandstone interbeds



cementstone, grey, bedded
anhydrite and gypsum nodules
cementstone, grey, massive; a few mudstone interbeds
grey, bedded
anhydrite; laminar top, nodular base
anhydrite, nodular
very fine sandy laminae 469.09-469.34m
anhydrite, massive
grey, bedded
cementstone
a few sandy beds
laminated and rippled
grey, bedded; 3 cm cementstone base at 473.38m
anhydrite, nodular
dark grey, laminated
cementstone; small gypsum nodules
cementstone, gypsum nodules
grey, bedded; cross-laminated and bioturbated fine-grained sandstone 476.11-476.35m; 12 cm thick bed cross-laminated base at 478.82m; 33cm sandstone bed base at 478.63m; bioturbation around 478.00 to 478.30m
cementstone, grey
smoe mudstone bands
siltstone laminae increasing to base; rippled
cementstone; interbedded siltstone
anhydrite, nodular
grey, bedded with fine sandy laminae; anhydrite nodules around 482.43, 482.60, 482.95, 484.28m
pale grey; carbonaceous-micaceous laminae; mudstone interbeds; mudstone with sharp cross-cutting base at 485.56; bioturbated dolomitic sandstone 20cm thick base at 481.41m
cementstone, grey
brown, bedded
grey
grey, bedded
brownish 489.37-489.90m
grey, bedded; silty base
cementstone, grey, sandy
grey, bedded; sandy laminae in places
andhydrite, nodular, bedded with siltstone; pinky base


494
495
496
497
498
499
500
501
grey, bedded, muddy base
cementstone, grey; sandy base; vertical gypsum veins
grey, bedded; sandy laminae; some burrows; muddy bands and base
rippled
some sandy laminae
cementstone, grey; irregular mudstone vein
grey, bedded; nodules gypsum and anhydrite around 498.59, 499.05 to 499.28
grey; siltstone laminae in upper part
grey, bedded. END OF BOREHOLE at 501.33m