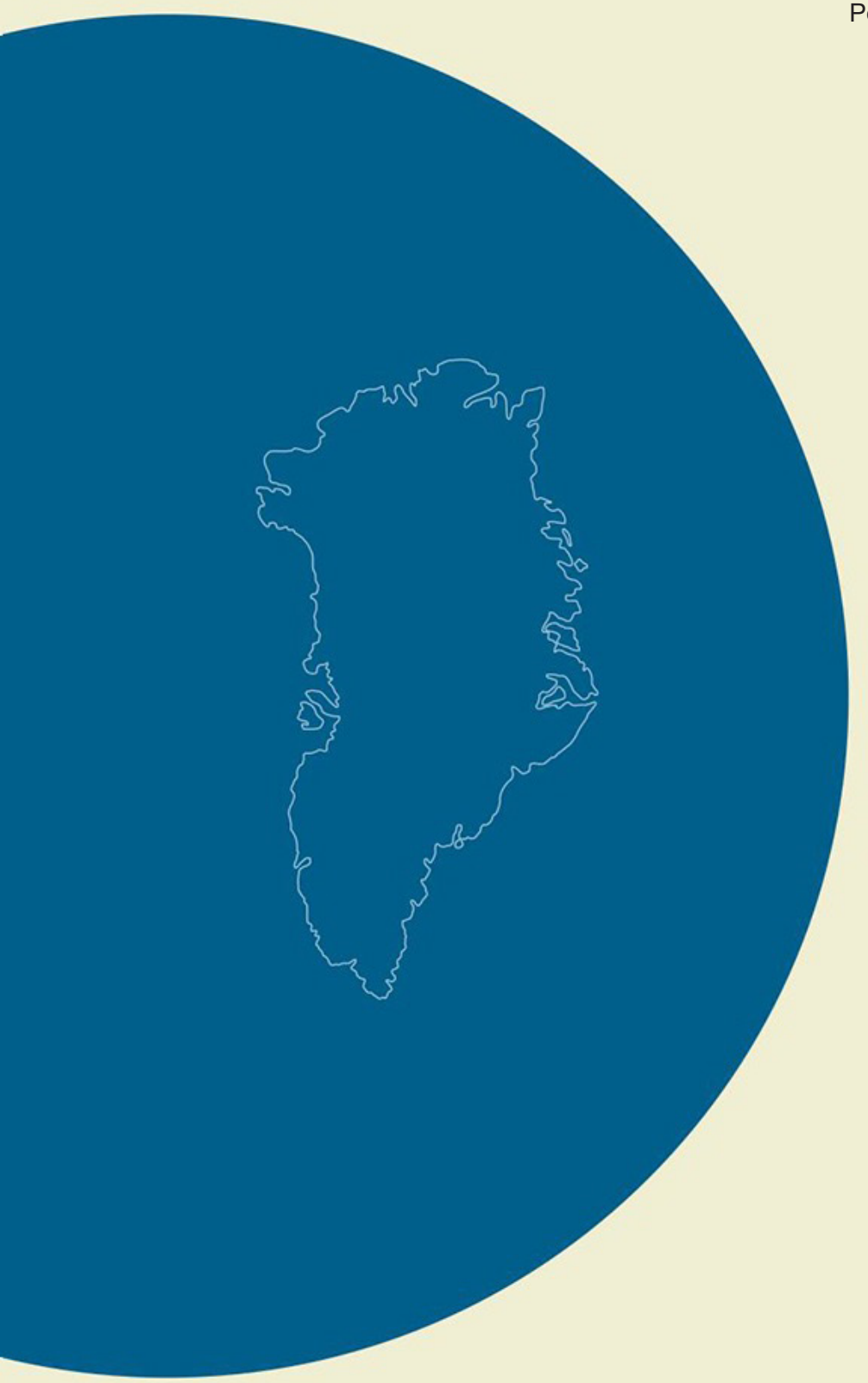
DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/3

# Brorson Halvø-1 core Well, GGU 517003, Wollaston Forland, North-East Greenland: Completion Report

Peter N. Johannessen & John Boserup



GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENVIRONMENT AND ENERGY

GEUS

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Confidential report

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

**CONTENTS**

## 1. General information

### 1.1 Borehole data

| | |
|---|---|
| Country | Greenland / Denmark |
| Borehole number | GGU 517003 |
| Borehole name | Brorson Halvø-1 |
| Area | North-East Greenland, Wollaston Forland |
| Operator | GEUS |
| Drilling operator | GEUS |

| | |
|---|---|
| Borehole Location | |
| Altitude: | 101 m above mean sea level. |
| Coordinates WGS 84: | Latitude: 74°35.227´ N, Longitude: 19°34.327´ W |
| UTM Zone: | 27W 8278 050 N - 542 356 E |

| | |
|---|---|
| Drill rig | Sandvik DE 130 |
| Drilling contractor | GEUS |
| Casing diameter | 64/57 mm |
| Casing depth | 35 m |
| Borehole diameter | 56 mm |
| Core diameter | 42 mm |
| Total depth | 225.6 m |
| Core recovery | 99% |
| Status | Abandoned open hole. The hole collapsed. |

| Logistic history: | |
|---|---|
| Transportation of rig and crew to drill site at Brorson Halvø | July 30th – August 1st 2010 |
| Establishment of field camp and drilling rig | August 2nd–3rd 2010 |
| Spud | August 3rd 2010 |
| Drilling completed | August 12th 2010 |
| Drill rig back at Daneborg | August 14th 2010 |
| Effective drilling | 10 days |
| Total days on drill location | 14 days |

## 1.2 Borehole summary

Brorson Halvø-1, GGU 517003, was drilled during the summer of 2010 in northern Wollaston Forland approximately 37 km northeast of the Daneborg military station (Fig. 1.1). Brorson Halvø-1 is the fourth corehole in an onshore drilling program in East and North-East Greenland that started in 2008 with the drilling of the Blokelv corehole in central Jameson Land. The drilling program is part of collaboration between GEUS and a number of oil companies regarding Petroleum Geological Studies, Services and Data in East and North-East Greenland. Fieldwork and drilling was financed by GEUS. Subsequent analytical work is financed by sponsoring companies. A more detailed description together with all analytical results will be delivered to sponsoring companies during 2011.

The primary objective was to core the marine clay- and siltstones of the Upper Jurassic Bernbjerg Formation of the Hall Bredning Group to obtain fresh unweathered and continuous samples for investigations of source rock potential and detailed stratigraphic extent on this mudstone succession.

The Brorson Halvø-1 borehole was spudded on August 3$^{rd}$ 2010 and completed on August 12$^{th}$ 2010 at a total depth of 225.6 m. The core recovery was 99%. The core diameter is 42 mm and cores are stored in 34 core boxes of c. 25 kg each, with a total weight of c. 850 kg. The borehole was abandoned. The borehole collapsed after pulling the casing.

Logging in the field included a total gamma log from terrain surface and down to 210 m. which was the length of the logger cable.

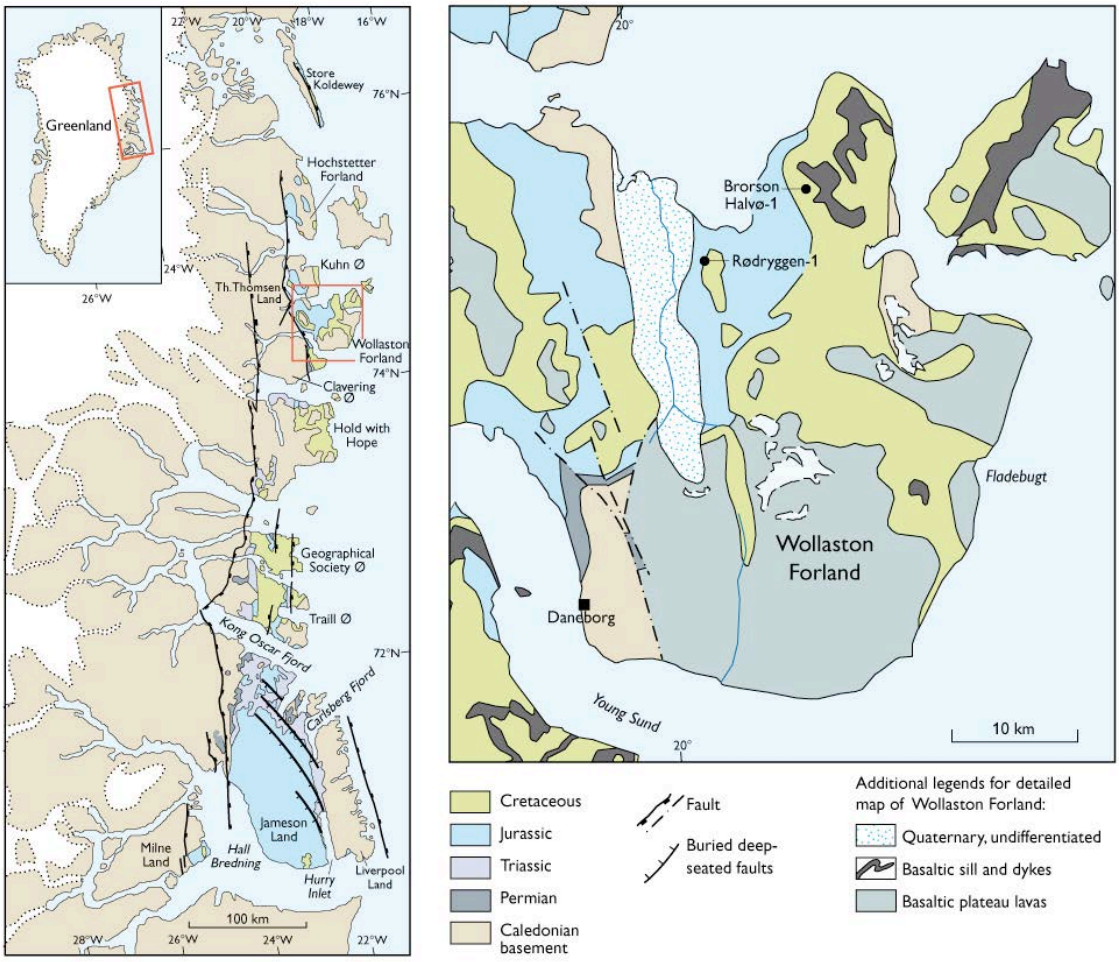


Figure 1.1. Map of East Greenland showing the Permian–Cretaceous outcrops and major faults. The detailed map of Wollaston Forland, with the location of the Brorson Halvø-1 borehole marked, also includes Quaternary deposits and basaltic sills, dykes and plateau lava outcrops. The location of the Rødryggen-1 borehole drilled in 2009 is also marked on the map. Map of East Greenland based on Surlyk (2003).

**2. Drilling operation:**

The drilling camp personal:

Senior Research Geologist Peter N. Johannessen, GEUS
Senior technician John Boserup, GEUS
Catering (Laboratory technician) Annette Ryge, GEUS
Driller Lars Thomsson and Anders Clausen
Drillers assistants Andreas Frandsen, and Anders Pilgaard
Logging Annette Ryge, GEUS

Logistics were handled by POLOG
Helicopter from Air Greenland was chartered for a full field season.

Drilling was carried out by a Sandvik DW 130 wire line rig, with an inner and outer casing diameter of 57 mm and 64 mm, respectively. Core barrels are 1.5 and 3 m long. The bore-hole diameter is 56 mm, whereas the core diameter is 42 mm.
Field Drilling equipment was shipped by boat from Denmark to Iceland. From Iceland it was flown with a Dash 8 to Constable Pynt in Greenland and from there with Twin Otter plane to Danmarkshavn. From Danmarkshavn the rig was initially mobilised by helicopter to a drill-site on Store Koldewey. After completion of the Store Koldewey drillhole, the rig was moved to the Brorson Halvø drillsite – etither directly by helicopter sling or via Danmarkshavn to Daneborg by Tinotter plane. From Daneborg the drill rig parts were brought to the Brorson Halvø drill site by helicopter slings, a distance of c. 37 km. The helicopter was a Eurocopter AS-350 which has a max sling load of 1.3–1.4 tons. (Fig. 2.1).
Mobilisation of the drill rig and camp took 4 days and the effective drilling took 12 days (Fig. 2.2, Appendix A). Casing was drilled to 15.8 m. Demobilisation and down-hole logging took 2 days.
Water for drilling was supplied from the nearest river at about 120 m lateral distance and 13 m vertical distance by a diesel-driven water pump through inflatable hoses into a 5000 l basin. Permafrost was present from a few decimetres below terrain surface and down to about 100 m.

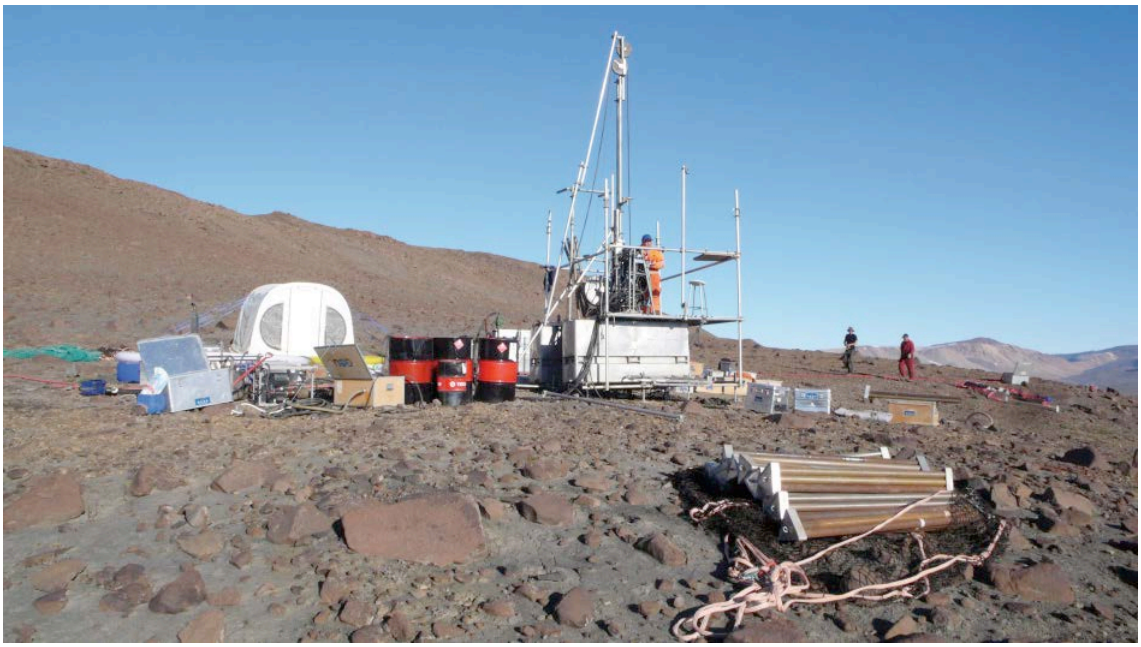

Figure 2.1. Brorson Halvø-1 drill rig and core logging tent.

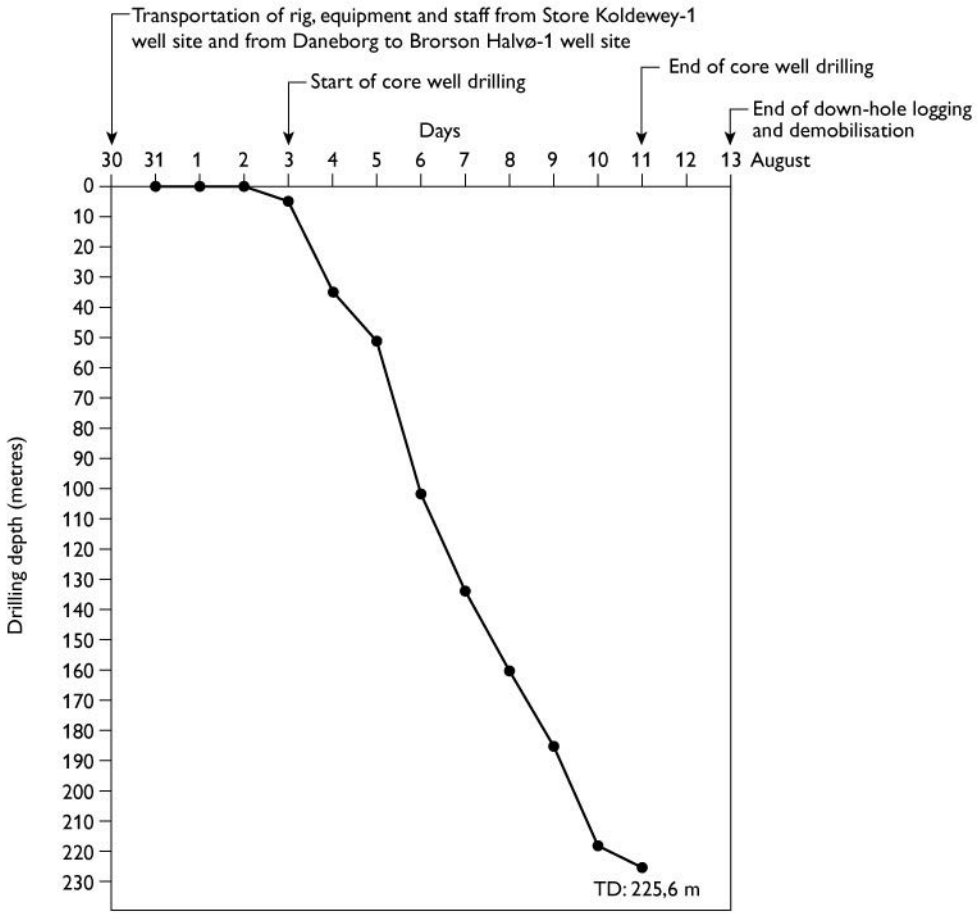


Figure 2.2. Progress chart; achieved drilling depth after the arrival at the Brorson Halvø site (30.07.2010) and until TD (11.08.2010).

## 3. Geological and geophysical data

The Brorson Halvø-1 borehole is located on the western part of Brorson Halvø (Halvø = peninsula), Wollaston Forland (Fig. 1.1). Outcrops near the drill site are characterised by dark mudstones of the Upper Jurassic–Lower Cretaceous Bernbjerg Formation overlain by light grey or yellowish-weathering mudstones of the Lower Cretaceous Albrechts Bugt Member followed by red mudstones of the Lower Cretaceous Rødryggen Member which is overlain by the Barremian shale of the informal "Mid Cretaceous sandy shale sequence" *sensu* Nøhr-Hansen (1993) (Figs 3.1 & 3.2). The drill site was situated on a small plateau formed by the lowermost part of the Barremian shale (Fig. 3.1).

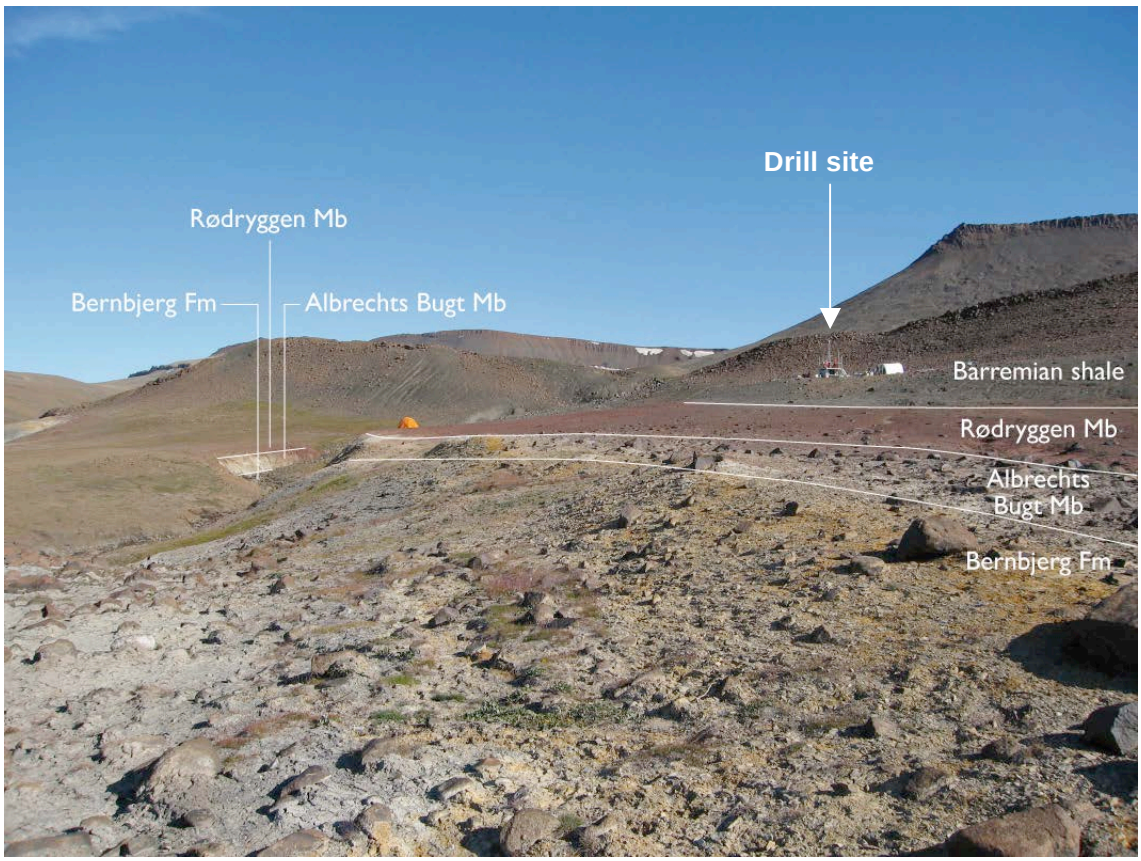


Figure 3.1. Lithostratigraphy at the drill site. The target for the drilling was the Upper Jurassic, dark mudstones of the Bernbjerg Formation. The drill site is situated on a small plateau formed by the lowermost part of the Barremian shale of the informal "Mid Cretaceous sandy shale sequence" *sensu* Nøhr-Hansen (1993). The Lower Cretaceous Rødryggen Member with its distinct red color in the field is overlain by the Barremian shale and is underlain by the Lower Cretaceous Albrechts Bugt Member with its distinct yellowish color due to weathering processes. The lowermost part is grey mudstones of the Bernbjerg Formation.

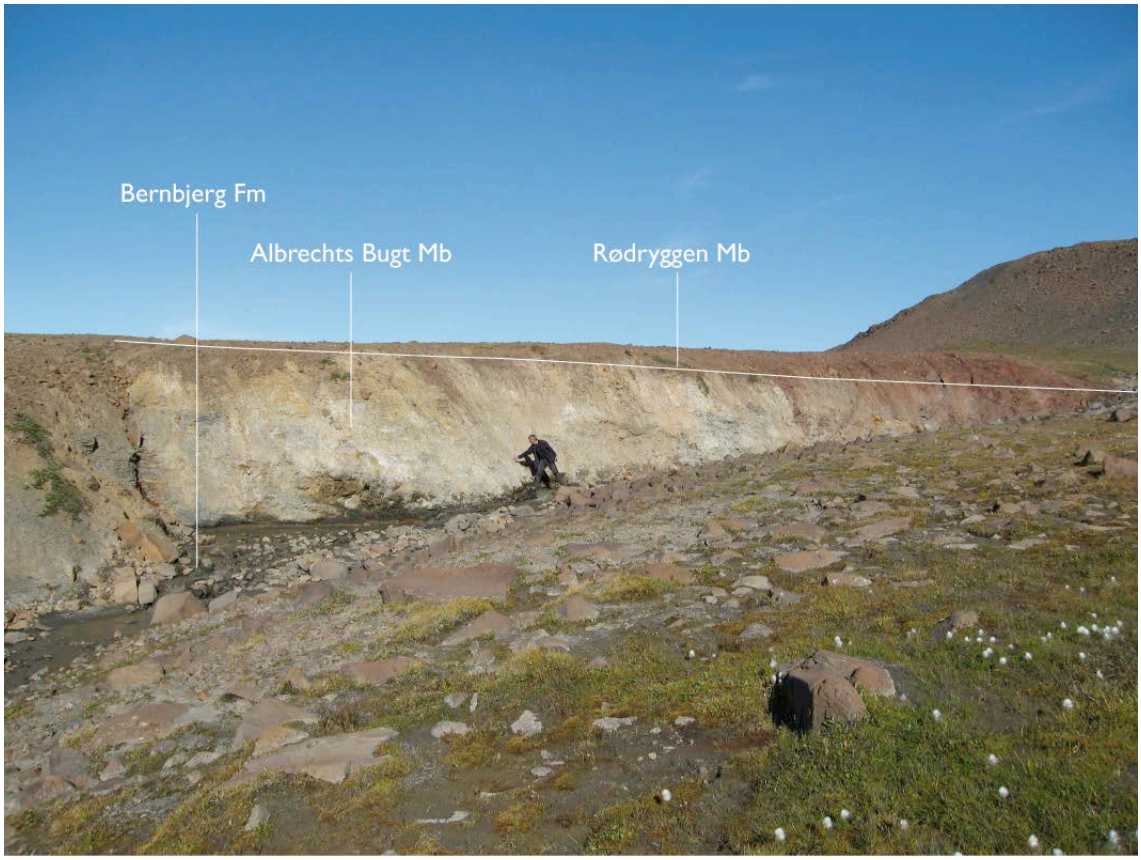


Figure 3.2. The stratigraphy from an outcrop near the well site.

### 3.1 Objectives

The target of the drilling was the Upper Jurassic Bernbjerg Formation. The thickness of the formation is unknown at the drill site and nowhere is the formation exposed in its full original thickness, but is estimated to have been approximately 600 m (Maync 1947, Surlyk 1977). The purpose of the drilling was to acquire fresh unweathered and continuous samples for investigations of the source rock potential of the mudstones by applying modern source rock analysis and to obtain samples for detailed stratigraphic information on the mudstones.

### 3.2 Results

The Brorson Halvø-1 core recovered the following 225.7 m thick succession:

| Strata | Lithology | Depth (m) | Thickness (m) |
|---|---|---|---|
| **Barremian shale** | Grey silty claystones | 0-9.65 m | 9.65 m |
| **Rødryggen Mb** | Red silty claystones and siltstones | 9.65-30.68 m | 21.03 m |
| **Albrechts Bugt Mb** | Grey siltstones | 30.68-37.70 m | 7.02 m |
| **Bernbjerg Fm** | Dark grey clayey org.-rich siltstones | 37.70-225.7 m | 188,00 m (TD) |

The base of the Bernbjerg Formation was not reached.

### 3.3 Coring

Conventional coring was performed from terrain surface to TD at 225.7 m. A sedimentological log was carried out on the un-slapped core (Fig. 3.3). The core recovery was 99% with a very high quality of core material.

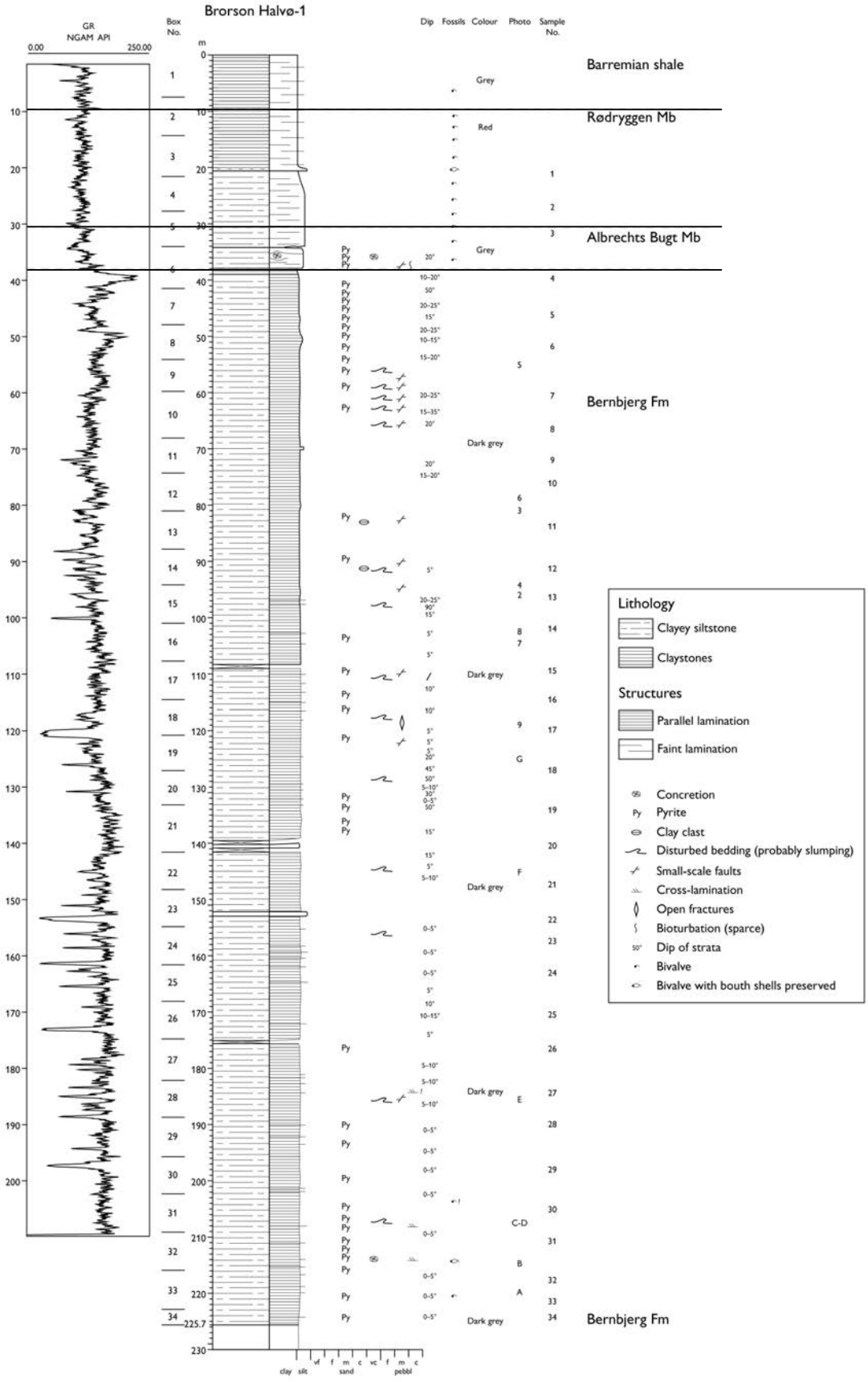


Figure 3.3. Sedimentological log of the Brorson Halvø-1 core. GR log was measured in the drill hole.

### 3.4 Sampling programme on drill site

A total of 34 whole core samples for gas analyses were collected immediately from the base of the recovered core for every 3 m in average. Samples have lengths up to about 10 cm and they were stored in sealed metal cans.

A total of 232 samples from the core was collected for preliminary Rock-Eval/TOC screening and biostratigraphic age identification based on dinoflagellates at GEUS.

### 3.5 Logging

Logging of the Brorson Halvø-1 borehole was initiated immediately after the drilling was completed. A total gamma ray log and conductivity log was planned. However, due to lack of logging cable only a total gamma ray log down to 210 m was obtained.

Generally claystones of the Bernbjerg Formation are characterised by higher GR readings than all the overlying strata in the well (Fig. 3.3). The uppermost 3 m claystones of the Bernbjerg Formation is characterised by higher GR readings than seen elsewhere in the well. This high GR section corresponds to the uppermost claystones overlying the clayey siltstones that constitute the rest of the Bernbjerg Formation (Fig. 3.3). Overall the gamma ray signal decreases upwards in the cored Bernbjerg Formation. Numerous peaks of low GR signals, 0.2-1.5 m thick, characterise the lower ¾ of the Bernbjerg Formation. Some of these peaks may correspond to thin, 0.1-0.8 m thick, siltstones observed in the cores. But other peaks may correspond to concretions as seen in outcrops near the well site, but not recognised in the core (Fig. 3.4).


Figure 3.4. Photo of concretion in outcrop in the clayey siltstones of the Bernbjerg Formation, near the drill site.

The boundary between the Bernbjerg Formation and the Albrechts Bugt Member is clearly seen on geochemical logs as a major decrease in TOC going from the Bernbjerg Formation to the overlying Albrechts Bugt Member Fig. 3.5.

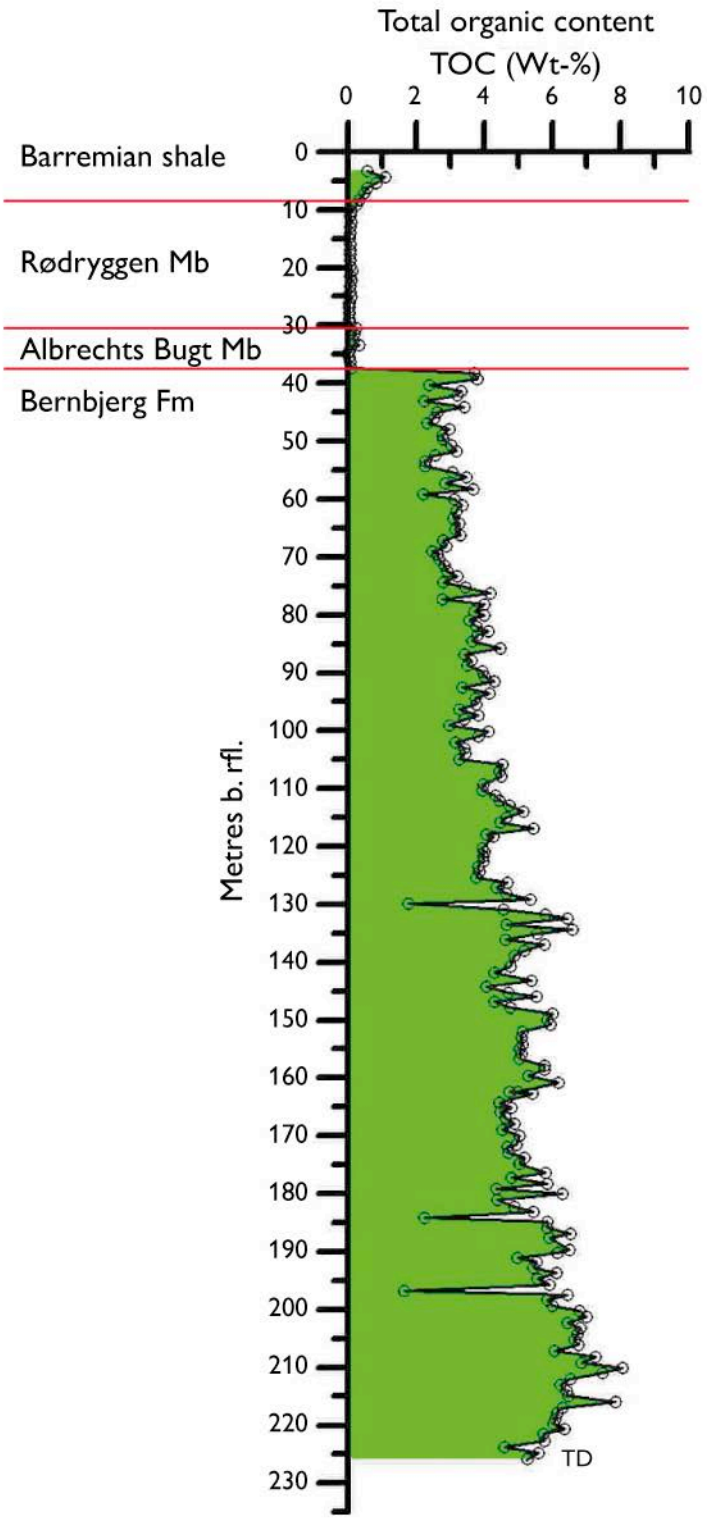


Figure 3.5. Total organic content (TOC) log from the Brorson Halvø-1 well based on core samples. The general TOC decreases up through the clayey siltstones of the Bernbjerg Formation. An abrupt fall in TOC characterises the boundary between the Bernbjerg Formation and the overlying Albrechts Bugt Member.

### 3.6 Biostratigraphy of the cored succession

No studies of the biostratigraphy of core samples have yet been carried out for the Brorson Halvø-1 core. Biostratigraphic investigations have however been done on outcrops nearby the Brorson Halvø-1 well (Surlyk 1977, Alsen 2006).

The Barremian shale belongs to the “Mid Cretaceous sandy shale sequence” *sensu* Nøhr-Hansen (1993).

The Rødryggen Member is Early Cretaceous (Late Valanginian) in age based on ammonites (Alsen 2006).

The Albrechts Bugt Member is Early Cretaceous (Early Valanginian) in age based on ammonites (Alsen 2006).

The Bernbjerg Formation is Late Jurassic in age (ranges from the Late Oxfordian to the Early Volgian) on Wollaston Forland. The upper portions of the formation have everywhere been removed by pre-Valanginian erosion (Surlyk 1977).

Core samples have been taken for dinoflagellates analysis carried out by GEUS, and will form the basis for a biostratigraphic dating of the core in the near future.

### 3.7 Lithology

The Brorson Halvø-1 core covers four lithostratigraphic units (Figs 3.3 & 3.6). The cores were un-slapped when they were described at the well-site.

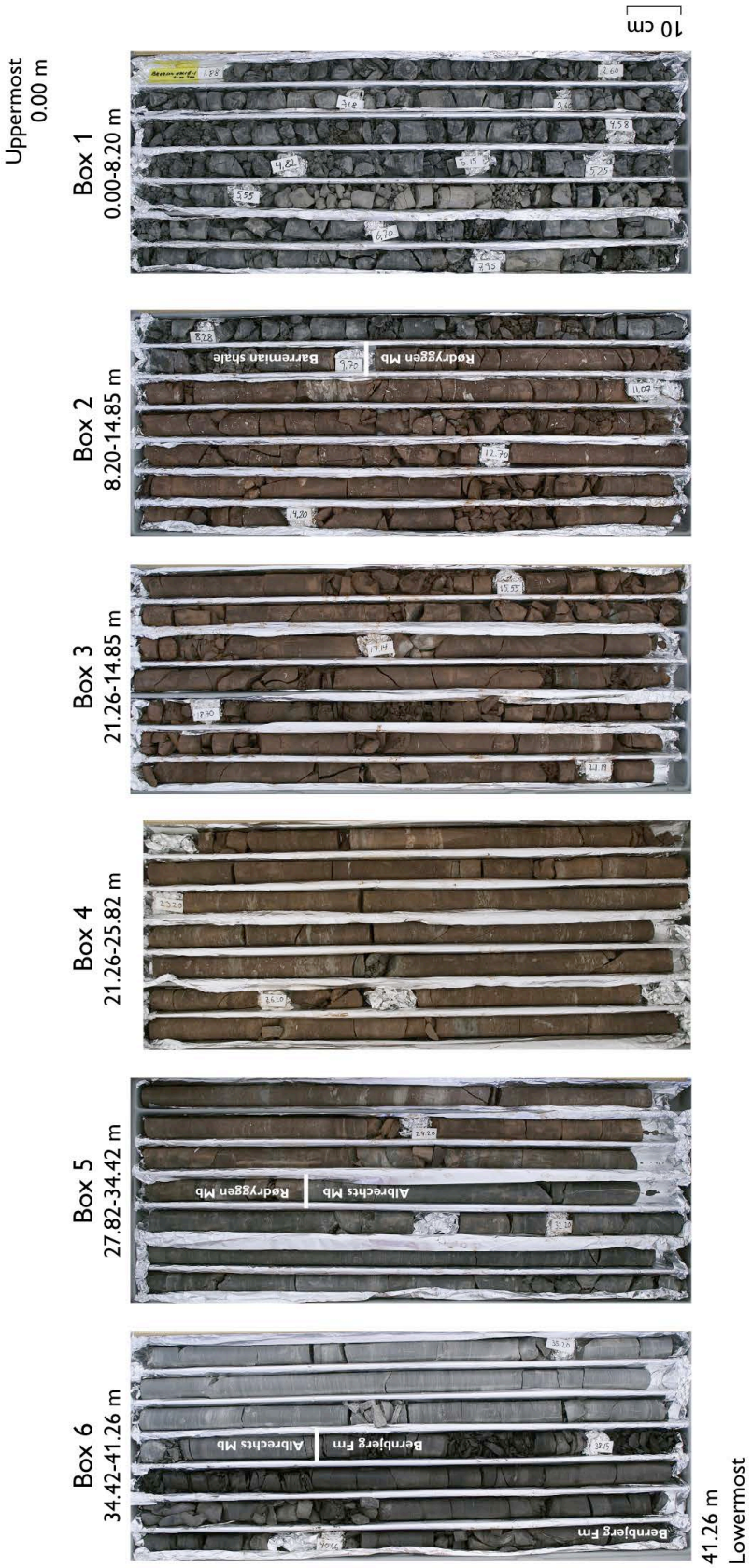


Figure 3.6. Core photos of the six uppermost boxes: 1-6 showing the Barremian shale, Rødryggen Mb., Albrechts Bugt Mb., and Bernbjerg Fm.

**Barremian shale (informal name) 0–9.65 m.**

**Lower Cretaceous**

*Description*: The uppermost part of the cored interval consists of 9.65 m thick grey laminated, silty claystones with intercalated thin clean siltstone laminae. The silty claystones are similar to the upper part of the Rødryggen Member, except for the grey colour.

*Interpretation*: The silty claystones were deposited during low energy conditions, probably in deep water. The thin clean siltstone laminae suggest occasionally input of more coarse-grained sediment during higher energy levels, probably gravity flow or storm processes.

**Rødryggen Member (Palnatokes Bjerg Formation) 9.65–30.68 m.**

**Lower Cretaceous**

*Description*: The Rødryggen Member is 21.03 m thick and is subdivided in a lower unit, 10.43 m thick, of red laminated medium-grained clayey siltstone and an upper unit, 10.60 m thick, of red silty claystone. Both units contain numerous bivalve shells.

*Interpretation*: The thin siltstone laminae within the upper silty claystone unit suggest occasionally input of more coarse-grained sediment during higher energy levels – probably gravity flow or storm processes. As the lower part of this member is more coarse-grained than the upper part it was probably deposited during slightly higher energy regimes. The red colour is probably due to an oxidised iron content.

**Albrechts Bugt Member (Palnatokes Bjerg Formation) 30.68–37.70 m.**

**Lower Cretaceous**

*Description*: Medium-grained parallel laminated, grey clayey siltstones containing numerous bivalve shells, 7.02 m thick, characterise the Albrechts Bugt Member. The lowermost part contains abundant pyrite concretions, low degree of bioturbation and small-scale faults.

*Interpretation*: It is assumed that the bivalves lived on the sea floor and therefore are *in situ*. Thus the abundant bivalve shells suggest that the marine sea floor was well oxygenated. The fine grain-size suggests deposition in a calm environment in a deep marine setting.

**Bernbjerg Formation 37.70–225.7 m (Total Depth).**

**Upper Jurassic**

*Description*: Parallel laminated, dark grey clayey organic-rich siltstones, 188 m thick, characterise the Bernbjerg Formation (Fig. 3.7, box 20). Some cleaner siltstone laminae and occasionally very fine-grained sandstone laminae, 0.5-2 cm thick, are intercalating the clayey siltstones and may show low-angled cross-lamination and small-scale folded and ortherwise disturbed laminae (Fig. 3.8).


Figure 3.7. Core photos of the clayey siltstones of the Bernbjerg Formation. Box 20: Inclined, c. 30°, parallel lamination. Box 33: Parallel lamination. A bivalve fossil with both shells is preserved. Box 13: Inclined parallel lamination with disseminated pyrite.

Siltstone laminae and very fine-grained sandstone laminae are most common in the lower 2/3 of the core (Fig. 3.3). The contacts to under- and overlying clayey siltstones are commonly sharp. In a few places the lower boundary is strongly undulating with the underlying mudstone intruding the sandstone (Fig. 3.8, box 16 & 19). Folded and otherwise disturbed laninae also occur in the clayey siltstones. The laminae of the lowermost part of the cored Bernbjerg Formation are generally dipping 0-5° (Fig. 3.3, 143-225.7 m). The remaining overlying part of the formation is characterised by much more varied dips, most often 5-25°. Maximum dip is 90° (vertical laminae) in a 1 m thick section just above the middle part of the formation (Fig. 3.3, 98 m and Fig. 3.9, box 15).

Some sections contain numerous pyrite concretions and disseminated pyrite (Fig. 3.3, 225-175 m, 140-80 m & 65-40 m, and Fig. 3.7. box 13). No fossils are seen, except for very few bivalve shells observed in the lowermost 20 m of the core (Fig. 3.10, box 33). No bioturbation is observed.

A single concretion occurs in the lowermost part of the cored Bernbjerg Formation (Fig. 3.3, 214 m). Concretions are probably much more abundant than has been observed in the core, because numerous concretions up to 1 m long and 0.5 m thick characterise the upper part of the Bernbjerg Formation in outcrops nearby the core well site (Fig. 3.4). In these

outcrops also ammonites and belemnites are often seen, but they have not been recognised in the cored section.
A few normal faults with a vertical throw of 0.5 - 2 cm are seen (Fig. 3.10). High-angle fractures are common, in places calcite cemented. An open fracture within the clayey siltstones has a distinct white crystal growth into the fracture cavity (Fig. 3.3, 119,25 m, and Fig 3.9, box 18).
The total organic carbon (TOC) content increases with depth in the core (Fig. 3.5). The highest GR log peak correlates to the most fine-grained part (claystone) of the Bernbjerg Formation situated immediately below the siltstones of the Albrechts Bugt Member (Fig. 3.3, c. 40 m). Many distinct spikes on the GR log are not reflected on the sedimentological core log or on geo-chemical logs (Fig. 3.3 and Fig. 3.5).

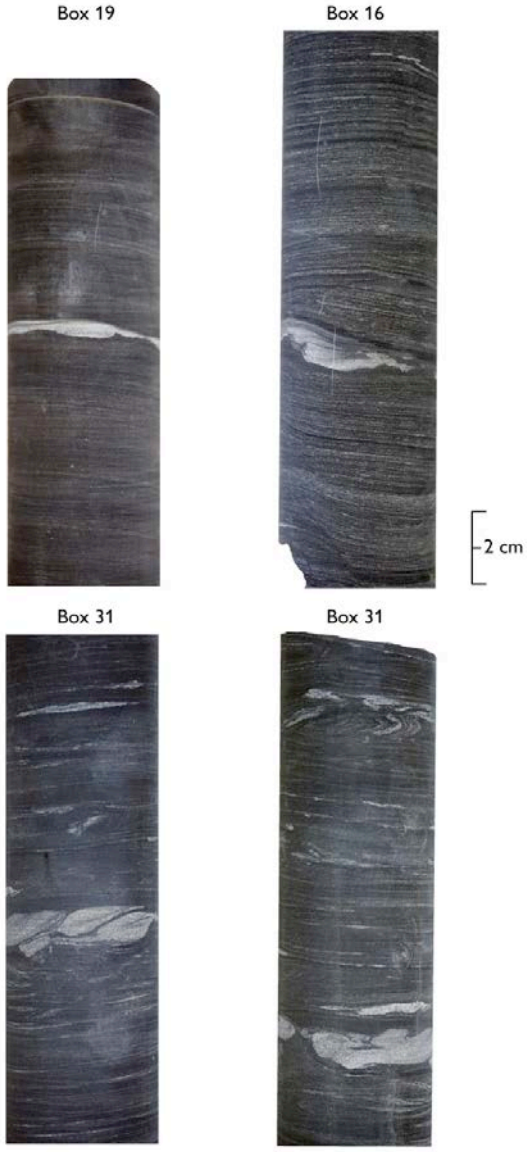


Figure 3.8. Core photos of the clayey siltstones of the Bernbjerg Formation. Some cleaner siltstone laminae and occasionally very fine-grained sandstone laminae, 0.5-2 cm thick are interbedded in the clayey siltstones.


Figure 3.9. Core photos of the clayey siltstones of the Bernbjerg Formation. Box 15: Vertical inclined laminae. Box 18: Open fractures with white crystal growth into the cavity.


Figure 3.10. Core photos of the clayey siltstones of the Bernbjerg Formation. Small-scale normal faults. A vertical throw of 1 cm is seen in box 33.

*Interpretation*: As most of the Bernbjerg Formation in the core consists of clayey siltstones, they were probably deposited during calm conditions. The few intercalated silt- and very fine-grained sandstones, some with cross-laminations, may suggest rare situations with higher energy levels, probably storm currents or gravity-flows. The underlying intruding mudstones into the overlying sandstone laminae suggest loading of sand into the soft clayey silt, probably due to rapid deposition of sand. The folded individual silt laminae where probably caused by small-scale slump processes. The 90° dipping (vertical) laminae may suggest larger scale slumping. The high quantity of pyrite concretions, organic matter and very little bioturbation may suggest that the sea bottom was anoxic. Thus, the clayey siltstones of the Bernbjerg Formation were probably deposited in a restricted marine environment with occasional storms or gravity-flow situations delivering more coarse-grained sediments into the deeper parts of the basin. The high amount of total organic carbon (TOC) also suggests anoxic conditions due to the preservation of the large quantities of organic content.

**Depositional evolution of the cored succession of the Brorson Halvø-1 well**

The clayey siltstones of the Bernbjerg Formation are tentatively interpreted to have been deposited in a relative deep, anoxic, low energy marine environment, with numerous small-scale slumping events. The overlying clayey, more coarse-grained, shell-bearing siltstones of the Albrecht Bugt Member and lower part of the Rødryggen Member were probably deposited in a deeper and more oxygenated marine environment. The upper part of the silty

claystones of the Rødryggen Member and the overlying Barremian shale may be interpreted as a return to lower energy regimes again.

### Comparison between the Brorson Halvø-1 well and nearby outcrop data

A sedimentological log was made at an outcrop 750 m West of the well-site (Bjerager, pers. comm. 2010). Here the Albrechts Bugt Member is c. 10 m thick and the Bernbjerg Formation is more than 190 m thick. The Bernbjerg Formation contains numerous thin, up to 2 cm thick very fine-grained sandstone beds. Several 3–10 m thick medium to coarse-grained sandstone beds, are also recorded. The c. 10 m thick sandstone seems to have been deposited in an erosive channel. Thus the sandstone beds are more numerous and more coarse-grained in the nearby outcrops than in the Brorson Halvø-1 core well.

After reaching TD in the Brorson Halvø-1 well, artesic water came up through the well and up to ground level. This may suggest that there could be situated a rather large porous high-pressured sandstone body just below TD. The well may have perforated the top of the sandstone, causing a flow of water through the well and up to the ground surface.

## 4. Future investigations

- A total GR- and density log will be measured in the core-lab at GEUS in order to obtain a complete coverage of the entire drilled succession. This will be reported.
- A Rock-Eval/TOC of core samples will be carried out at GEUS and reported.
- A biostratigraphic age identification based on dinoflagellates will be carried out at GEUS and reported.
- A much more detailed core description/interpretation will be carried out and reported.

## 5. Acknowledgements

Several geologists at GEUS have introduced me to the sediments and stratigraphy of the Brorson Halvø area: Lars Henrik Nielsen, Morten Bjerager, Jussi Hovikoski, Henrik Vosgerau, Stefan Piasecki and Jørgen Bojesen-Koefoed. They have all contributed to this report.

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## 7. APPENDIX

Appendix A: Daily drilling log/report

Appendix B: Rødryggen-1, GGU 517101, Core Box Depths.

Appendix A: Daily drilling report for Brorson Halvø-1 core well

| Date | Cored | Remarks |
|---|---|---|
| 30/7-2/8 2010 | | Flying out crew and equipment from Store Koldewey-1 drill site and Daneborg to Brorson Halvø-1 drill site. Establishment of drill rig and camp. |
| 3/8-2010 | 5 m | Drilling 0–13 m with 85 % core recovery. |
| 4/8-2010 | 30.2 m | Drilling 5–35.2 m with 100% core recovery. |
| 5/8-2010 | 16.5 m | Drilling 35.2–51.68 m with 97% core recovery. |
| 6/8-2010 | 49.1 m | Drilling 51.68–100.8 m with 100% core recovery. |
| 7/8-2010 | 33.4 m | Drilling 100.8–134.2 m with 100% core recovery. |
| 8/8-2010 | 25.9 m | Drilling 134.2–160.05 m with 100% core recovery. |
| 9/8-2010 | 24.5 m | Drilling 160.05–184.58 m with 92% core recovery. |
| 10/8-2010 | 35.1 m | Drilling 184.58–219.7 m with 100% core recovery. |
| 11/8-2010 | 5.9 m | Drilling 225.6 m to TD with 100% core recovery. Gamma logging, and camp, flying equipment back to Daneborg. |
| 12/8-2010 | | Dismantling drill rig and flying equipment back to Daneborg. |
| 13/8-2010 | | Flying drill rig, camp and crew back to Daneborg. |
| 14/8-2010 | | Flying crew back to Daneborg. |

Appendix B: Brorson Halvø-1, GGU 517003, Core box depths.

| BOX | Box TOP (m) | Box BASE (m) | Box core Length (m) |
|---|---|---|---|
| Box 1 | 0,00 | 8,29 | 8,29 |
| Box 2 | 8,18 | 14,89 | 6,71 |
| Box 3 | 14,88 | 21,26 | 6,38 |
| Box 4 | 21,29 | 27,81 | 6,52 |
| Box 5 | 27,76 | 34,39 | 6,63 |
| Box 6 | 34,44 | 41,24 | 6,80 |
| Box 7 | 41,17 | 47,93 | 6,76 |
| Box 8 | 47,71 | 54,35 | 6,64 |
| Box 9 | 54,19 | 61,04 | 6,85 |
| Box 10 | 61,11 | 68,04 | 6,93 |
| Box 11 | 67,64 | 74,31 | 6,67 |
| Box 12 | 74,33 | 80,92 | 6,59 |
| Box 13 | 80,76 | 87,75 | 6,99 |
| Box 14 | 87,75 | 94,37 | 6,62 |
| Box 15 | 94,37 | 100,98 | 6,61 |
| Box 16 | 100,87 | 107,81 | 6,94 |
| Box 17 | 108,32 | 114,88 | 6,56 |
| Box 18 | 114,53 | 120,70 | 6,17 |
| Box 19 | 120,70 | 127,08 | 6,38 |
| Box 20 | 126,95 | 133,41 | 6,46 |
| Box 21 | 133,28 | 140,61 | 7,33 |
| Box 22 | 141,25 | 147,85 | 6,60 |
| Box 23 | 147,85 | 154,71 | 6,86 |
| Box 24 | 154,77 | 161,40 | 6,63 |
| Box 25 | 161,53 | 167,91 | 6,38 |
| Box 26 | 168,01 | 174,76 | 6,75 |
| Box 27 | 175,37 | 182,13 | 6,76 |
| Box 28 | 182,04 | 188,53 | 6,49 |
| Box 29 | 188,69 | 195,72 | 7,03 |
| Box 30 | 195,37 | 202,18 | 6,81 |
| Box 31 | 202,19 | 209,08 | 6,89 |
| Box 32 | 209,04 | 215,95 | 6,91 |
| Box 33 | 215,73 | 222,70 | 6,97 |
| Box 34 | 222,70 | 225,70 | 3,00 |