Geotechnical Report for
Energinet Eltransmission A/S

Project:
11783 Additional Scope - Preliminary Geotechnical Investigation for Energy Island - Bornholm I and Bornholm II

Description:
Additional Scope: Field Operations, Measured and Derived Geotechnical Parameters and Final Results

Survey Date:
February 2023

Project Number:
11783

Client Reference:
21/07851-01

Report Status:
Final

REPORT AUTHORISATION AND DISTRIBUTION

Report Status	Additional Scope: Field Operations, Measured and Derived Geotechnical Parameters and Final Results	Final
Compilation	Project Engineer	……………………………….. Andrew Scott
QC Approval	Project Engineering Manager	……………………………….. Phil Burgess
Authorisation	Head of Geoconsultancy	……………………………….. Simon McDowell

Revision	Date	Title	Report Ref
0	18/10/2023	Additional Scope: Field Operations, Measured and Derived Geotechnical Parameters and Final Results	Draft
1	27/11/2023	Additional Scope: Field Operations, Measured and Derived Geotechnical Parameters and Final Results	Final

Distribution

1 Copy

Attention:
Thore Sortemos XTVSO@energinet.dk
Steen Petersen XSTPE@energinet.dk

SERVICE WARRANTY

USE OF THIS REPORT

This report has been produced by Gardline Limited in fulfilment of its contractual obligations to the client. The client and the contract are both identified on the front cover of this report.

This report has been prepared with due care and diligence and with the skill reasonably expected of a reputable contractor experienced in the types of work carried out under the contract and as such the findings in this report are based on an interpretation of data which is a matter of opinion on which professionals may differ and unless clearly stated is not a recommendation of any course of action.

Gardline Limited has prepared this report for the client(s) identified on the front cover in fulfilment of its contractual obligations under the referenced contract and the only liabilities Gardline Limited accept are those contained therein.

Please be aware that further distribution of this report, in whole or part, or the use of the data for a purpose not expressly stated within the contractual work scope is at the client's sole risk and Gardline Limited recommends that this disclaimer be included in any such distribution.

GARDLINE LIMITED
Endeavour House, Admiralty Road, Great Yarmouth, Norfolk NR30 3NG England
Telephone +44 1493 845600 Fax +44 1493 852106
www.gardline.com

EXECUTIVE SUMMARY

This report presents the operational details and geotechnical results for the additional scope undertaken within the Bornholm I and Bornholm II Offshore Wind Farm site, Denmark. The scope is an extension of the main geotechnical site investigation for Bornholm I and Bornholm II. Originally, two locations were planned to be re-drilled using Geobor-S coring techniques to acquire high quality core samples; however, this was reduced to one location following operational activities as discussed in Section 1. Operational details and Final Results for the main scope of the Bornholm I and Bornholm II OWF project can be found in the *Volume I: Field Operations Report* and *Volume II: Measured and Derived Geotechnical Parameters and Final Results* reports respectively.

The site investigation was located in the Baltic Sea, partially within Danish Territorial waters and partially on the Danish Continental Shelf. The site is approximately 20km south-west of the Island of Bornholm, covering a total area of around 652km^2. Figure I shows the project location boundaries. Figure II shows the location of the borehole discussed in this report; that is, BH-207_b located towards the south-western side of the Bornholm II site area. Water depth was measured to be around 41m at BH-207_b.

Figure I – Bornholm I and Bornholm II OWF Survey Area

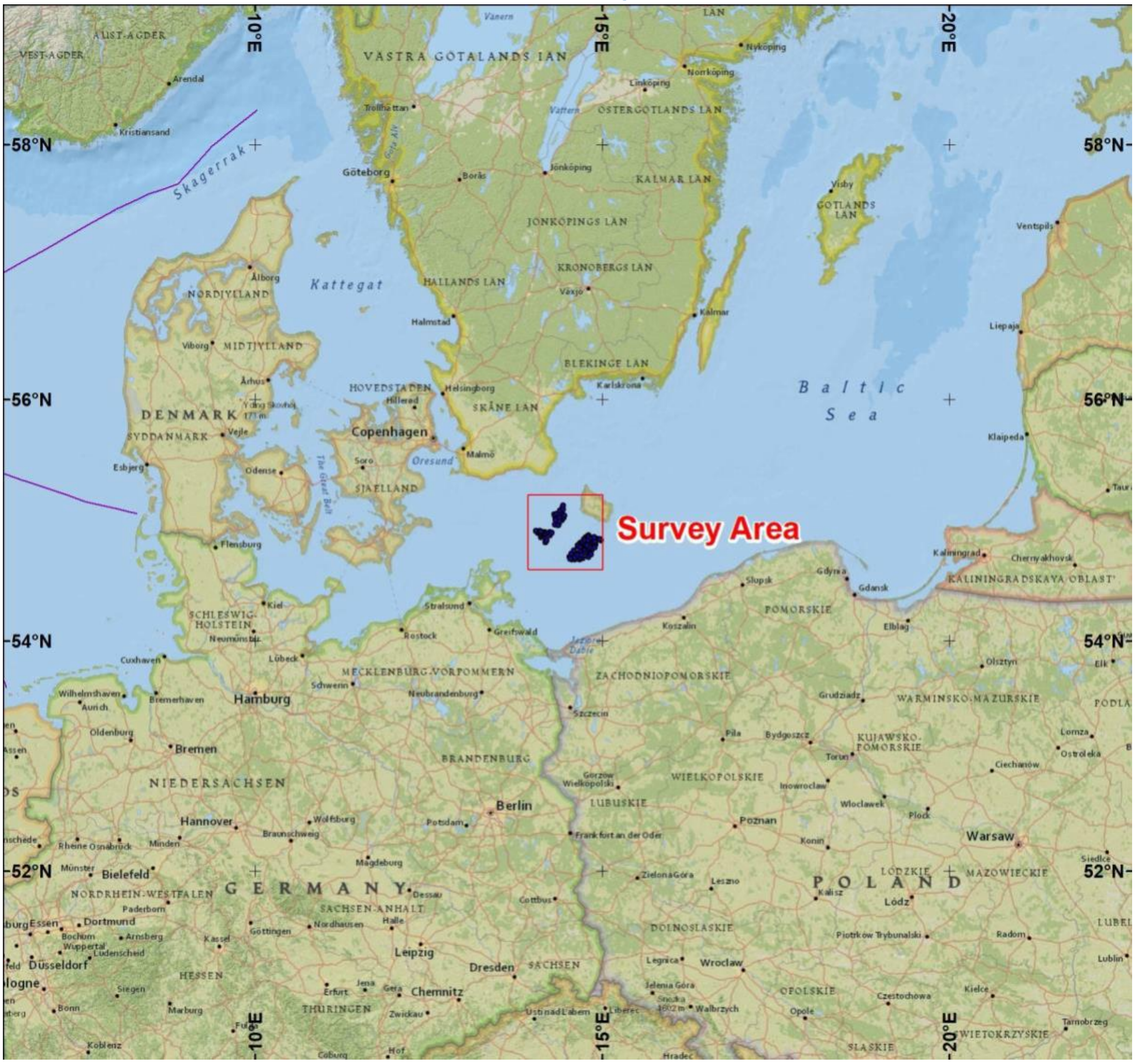
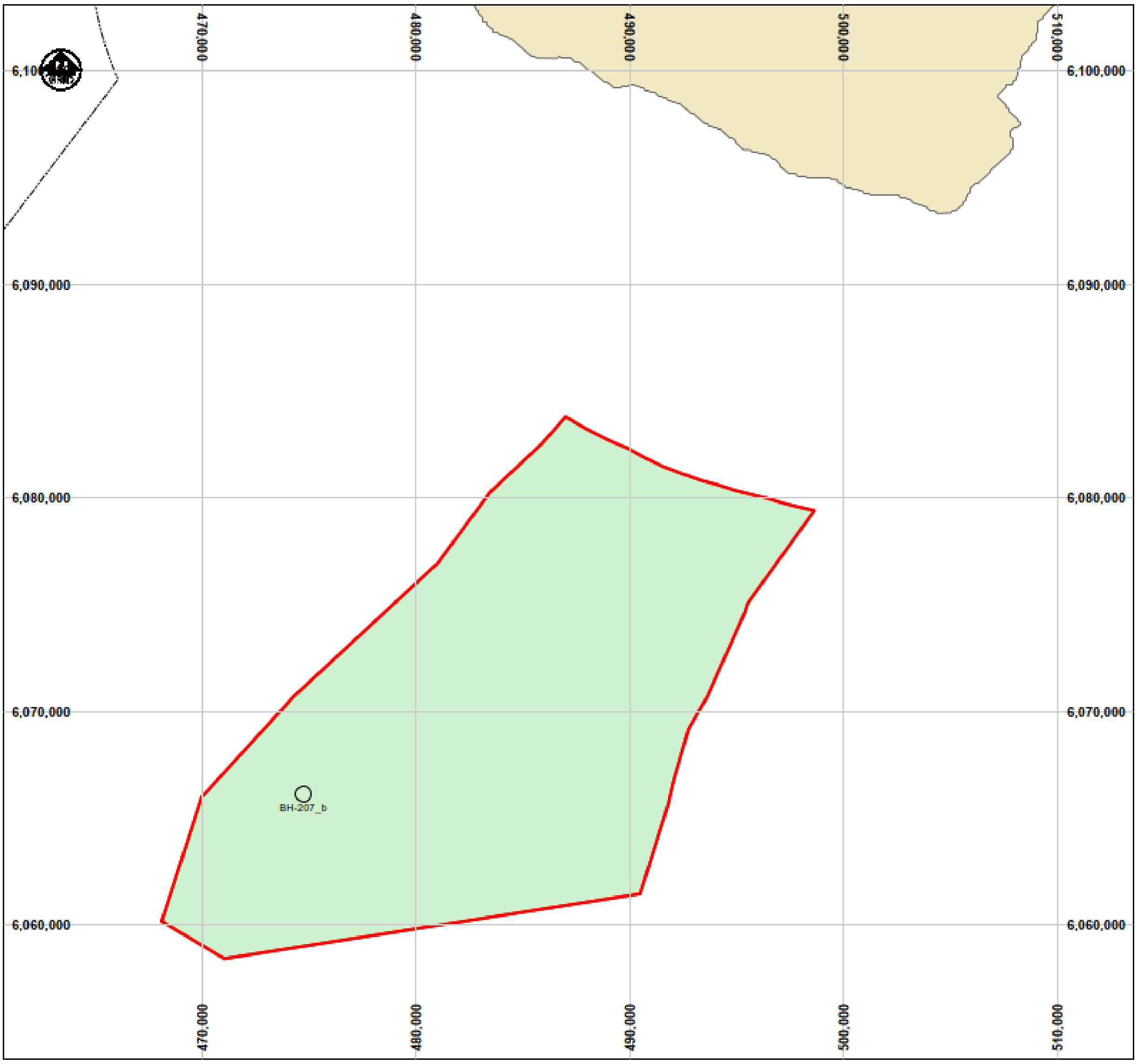


Figure II – BH-207_b Location Overview



Survey operations were conducted with respect to ETRS89 Datum, UTM Grid Zone 33N. The grid system is presented in Eastings and Northings (m).

Water depths are reduced to Mean Sea Level (MSL) in metres and can be found in APPENDIX 1 together with location coordinates.

The objective of this additional scope was to acquire high quality geotechnical cores through the use of Geobor-S coring techniques. Location BH-207_b was selected due to the issues with core recovery and quality encountered at BH-207 during the main site investigation; this is further detailed in Section 3. Acquired cores were subject to an onshore rock-focused laboratory testing programme to facilitate the results of the main geotechnical scope and support the preliminary design requirements of wind turbine foundation design and installation. Onshore laboratory testing comprised of Saturated Moisture Content, Density by Immersion, Point Load and Unconfined Compressive Strength testing. Additional details on the laboratory testing programme are discussed in Section 4.

The geotechnical drilling vessel mobilised to conduct the scope was the M.V. Kommandor Susan. Table I provides a summary of the fieldwork, including fieldwork dates and vessel details.

Table I – Fieldwork Summary

Fieldwork Summary	
Survey Vessel	M.V. Kommandor Susan
Mobilisation Port	Grenaa, Denmark
Mobilisation Date	16/02/2023
Fieldwork Dates	21/02/2023 – 28/02/2023
Geobor-S Coring Boreholes	1 (BH-207_b)
Demobilisation Port	Grenaa, Denmark
Demobilisation Date	01/03/2023

On completion of the laboratory testing programme, offshore field descriptions were reviewed and updated as per the onshore test results. This solely involved reviewing the strength descriptions as per the Point Load and UCS test results. Downhole drilling was previously conducted at BH-207 by the M.V Kommandor Susan in May 2022, where rock coring was performed using PQ3 techniques. As part of this report, an analysis was performed comparing the recovery and quality of the acquired rock cores between these two methods where possible.

TABLE OF CONTENTS

APPENDICES

APPENDIX 1 - LOCATIONS

1.1 Location Map

1.2 Enhanced Location Map

1.3 Borehole Location Summary

APPENDIX 2 – LOGS

2.1 Legend

2.2 BH-207_b Borehole Log

APPENDIX 3 – EQUIPMENT SPECIFICATION

3.1 Kommandor Susan Vessel Specification

3.2 Kommandor Susan Drilling Specification

3.3 Geobor-S Coring System

APPENDIX 4 – DRILLING LOGS

4.1 BH-207_b Drillers Log

APPENDIX 5 – CALIBRATION DATA

5.1 Kommandor Susan Laboratory Calibration Data

APPENDIX 6 – POSITIONING

6.1 BH-207_b Survey Positioning Report

APPENDIX 7 – DAILY PROGRESS REPORTS

7.1 Kommandor Susan Daily Progress Reports

APPENDIX 8 – SAMPLING

8.1 Sample List

8.2 Sample Photographs

APPENDIX 9 – ROCK TEST RESULTS

9.1 Determination of Rock Strength, Density and Moisture Content

9.2 UCS with Young's Modulus Test Enclosures

9.3 Determination of the Point Load Strength Index

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbols

%	Percent
°	Degrees
µm	Micrometres
cm	Centimetres
C_u	Degree of Sorting
d	Depth of borehole below sea level
g	grams
kN	Kilo Newton
kN/m^2	Kilonewton per square meter
kPa	Kilo Pascal
m	Metre
ml	Millilitres
mm	Millimetre
MPa	Mega Pascal
^oC	Degrees Celsius
w	Water content
γw	Unit weight of water
σ_1-σ_3	Deviatory stress
σ_m’	Estimated mean effective stress at test depth
σ_{v0}	Total overburden stress

LIST OF ABBREVIATIONS

Abbreviations

A	Axial
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
B	Bag
BS	British Standard
BSB	Below Seabed
CH	Clay of high plasticity
CL	Clay
CM	Clay of intermediate plasticity
CV	Clay of very high plasticity
D	Diametrical
DGNSS	Differential Global Navigation Satellite System
Dth	Down the hole
ETRS	European Terrestrial Reference
Ex	Example
HCl	Hydrochloric acid
I	Irregular Block/Lump
ISO	International Standards Organisation
ISRM	International Society for Rock Mechanics
MH	Silt of high plasticity
ML	Silt of low plasticity
OH	Gyttja of high plasticity
OL	Gyttja of low plasticity
OWF	Offshore Wind Farm
P	Push Number
Q	Quart
SBES	Single Beam Echo Sounder
Stbd	Starboard
T	Tube
UCS	Unconfined Compressive Strength
USC	Unified Soil Classification
UTM	Universal Transverse Mercator
WISON	Wireline Sounding

ADDITIONAL SCOPE: FIELD OPERATIONS, MEASURED AND DERIVED GEOTECHNICAL PARAMETERS AND FINAL RESULTS

1 Scope of Project

1.1 General

Energinet Eltransmisson A/S (Energinet) commissioned Gardline Limited (Gardline) to support the development of a new offshore wind farm (OWF) through the acquisition of geotechnical data which will inform the basis for evaluation of methods for wind turbine foundation design and installation. This scope is an extension to the main geotechnical site investigation near Bornholm, involving the application of Geobor-S coring techniques to acquire high quality core samples at select locations within the site investigation area.

Cores were subjected to a rock-focused onshore laboratory testing programme to obtain high quality test results that facilitate the main site investigation. Tests included Saturated Moisture Content, Bulk and Dry Density by Immersion, Point Load and Unconfined Compressive Strength Testing. Further details on the laboratory testing programme can be found in Section 4.

Two locations were targeted for this scope, which were BH-102_a and BH-207_b. These locations were selected due to showing lower rock quality and recoveries when sampled using PQ3 coring techniques. During fieldwork operations for BH-102_a, deteriorating weather conditions resulted in this borehole being terminated after reaching a depth 13.40m, the last 4.07m of which was rock material. Due to the limited amount of rock acquired at this location, BH-102_a was deemed not representative for the purposes of this scope and therefore is not discussed further in this report.

Geobor-S coring techniques are limited to a total depth of 100m which includes water depth. The target depth and termination criteria for BH-207_b was therefore determined in regards to this limitation.

The water depths were obtained by SBES (Single Beam Echo Sounder). Depths are to the vertical datum MSL (Mean Sea Level) in metres. Additional information on the Geodetics can be found in Section 5. The water depth at BH-207_b is presented on the log in APPENDIX 2.

Digital data was provided for this project in the form AGS4.1 data. One AGS data file is provided with this project that includes all relevant information on fieldwork operations and laboratory testing.

2 Offshore Activities

2.1 General

Offshore activities were conducted on the M.V. Kommandor Susan. The vessel is a DP2 drilling vessel with a twin tower drill frame used to deploy a Geobor-S piggyback system through the moon-pool. Full vessel and equipment specifications can be found in APPENDIX 3.

Detailed descriptions of the methods used can be found in the method statements in Section 3. A full breakdown of the production summary can be found on the final daily progress reports presented in APPENDIX 7.

The horizontal reference system for this project obtained from ultra-short baseline (USBL) was set to ETRS89. The vertical reference system obtained by seabed echo sounder is provided as elevations relative to MSL based on DTU21MSL. A full positioning report can be found in APPENDIX 6.

Location maps are presented in APPENDIX 1. An enhanced location map is provided that includes all locations tested at position 207 for the main geotechnical site investigation for comparison. The legend on the maps indicate the type of operations conducted for each location.

The list of contractors involved in the offshore activities of the project and their roles are given in Table 2.1.

Table 2.1 - List of Contractors

Contractor	Responsibilities
Gardline Limited	Lead Contractor Project Management Sample Logging and Field Testing Geotechnical Reporting Positioning

2.2 Summary of Activities

Table 2.2 summarises fieldwork undertaken during the Geobor-S Scope. Please see APPENDIX 7 for a full breakdown of daily operations.

Table 2.2 - Fieldwork Summary

Fieldwork Summary	
Survey Vessel	M.V. Kommandor Susan
Mobilisation Port	Grenaa, Denmark
Mobilisation Date	16/02/2023
Fieldwork Dates	21/02/2023 – 28/02/2023
Geobor-S Coring Boreholes	1 (BH-207_b)
Demobilisation Port	Grenaa, Denmark
Demobilisation Date	01/03/2023

2.3 Time Breakdown

Table 2.3 details the time breakdown of operations that were conducted on the M.V. Kommandor Susan. This includes the time spent on location BH-102_a.

Table 2.3 - Time Breakdown of Operations – Kommandor Susan

Activity	Time (hh:mm)	Percentage (%)
Contractors Time	00:00	0.0
Mob/Demob	00:00	0.0
Operational Transit	00:00	0.0
Operational Geobor-S Drilling	42:15	12.6
Setup (All activities)	51:45	15.4
Standby Port	109:00	32.4
Standby Weather	84:25	25.1
Transit	48:35	14.5
Unallocated / Disputed Time	00:00	0.0
Total	**336:00**	100.0

2.4 Field Personnel

Key personnel on board the M.V. Kommandor Susan during the Geobor-S Scope are listed below in Table 2.4.

Table 2.4 – Field Personnel

Gardline	Name	From	To
Master	Tomasz Balicki	13/02/2023	01/03/2023
Offshore Project Manager	Francis Leigh	13/02/2023	01/03/2023
Drill supervisor	Mark Laws	13/02/2023	01/03/2023
Drill supervisor	David Savory	13/02/2023	01/03/2023
Driller	Dmytro Filipchuk	13/02/2023	01/03/2023
Driller	Paul Gogan	13/02/2023	01/03/2023
Driller	Ollie Ethridge	26/02/2023	01/03/2023
Roughneck	Cosmin Chira	13/02/2023	01/03/2023
Roughneck	Michael Rogers	13/02/2023	01/03/2023
Roughneck	Jefferz Colby-Bradley	13/02/2023	01/03/2023
Roughneck	Abdul bin Samigin	13/02/2023	01/03/2023
Rig Mechanic	Rogelio Magabo	13/02/2023	26/02/2023
Rig Mechanic	Adi Abdullah	13/02/2023	01/03/2023
Geotechnical Operator	Mark Beloncio	13/02/2023	01/03/2023
Geotechnical Operator	Ador Lutao	13/02/2023	01/03/2023
Geotechnical Operator	Felix Bengay	26/02/2023	01/03/2023
Geotechnical Engineer (GIC)	Elinor Morgan	13/02/2023	01/03/2023
Geotechnical Engineer	Augustas Buozius	13/02/2023	01/03/2023
Geotechnical Engineer	Filip Benic	13/02/2023	01/03/2023
Lab Technician	Julyan Jollivet	13/02/2023	01/03/2023
Lab Technician	Sarah Lindsay	13/02/2023	01/03/2023

Gardline	Name	From	To
Surveyor (SIC)	Miguel Molina Ferrie	13/02/2023	01/03/2023
Surveyor	Stefanie Gaide	13/02/2023	01/03/2023
Energinet	**Name**		
Client Rep.	Stephen Mumford	13/02/2023	01/03/2023

3 Drilling Operations

3.1 General

The Geotechnical survey was conducted through a piggyback Geobor-S drilling system utilising the downhole WISON system on the. M.V. Kommandor Susan.

The M.V. Kommandor Susan is fitted with a dedicated mud mixing tank with mixing hopper and agitator. Mud mixing is via a venturi hopper system circulated using Magnum Mission centrifugal pumps which are installed with 100% redundancy.

Guar gum drilling mud was used to both flush and stabilise the borehole. The drilling mud was mixed to a manufacturer's weight specification to best suit the ground conditions encountered during the drilling process.

3.2 Geobor-S Drilling System

The Geobor-S drilling system utilises a triple tube wireline coring system that cuts a 146mm hole and produces high quality core samples of 102mm nominal diameter. Geobor-S drill bits have a narrow cutting surface and produces a small kerf around the core sample to reduce disturbance. Rig specifications are detailed in Table 3.1.

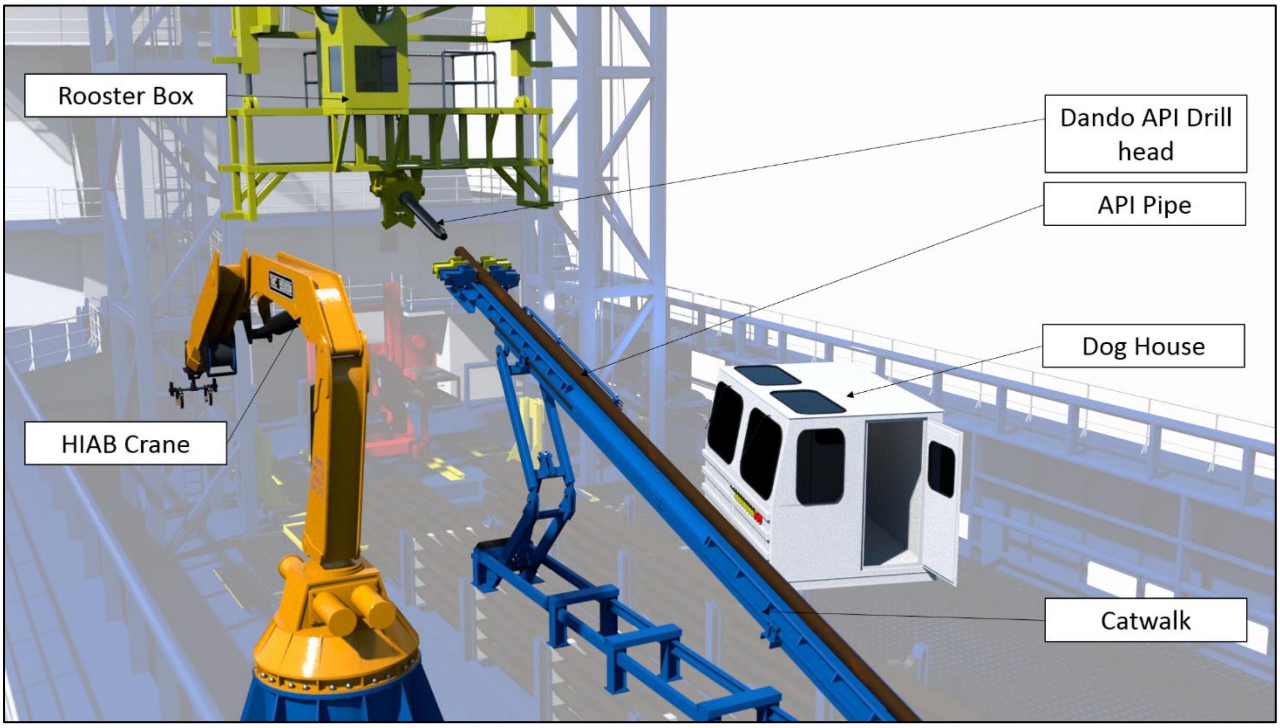
Table 3.1 - Rig Specification

Rig No / Name	K3-50 Twin Derrick
Weight of Seabed Frame	13 Tonnes
Base Area	4.00m^2
Maximum Thrust force	100kN
Maximum Pull Up Force	500kN
Mud System	GD Pumps with Guar gum and Tunnel Gel
Drill Bits	PDC coring bit with 3 wing PDC non coring tool.

The Geobor drilling system is mounted on the rooster box above the main API drill head, referred to as a piggyback system. In order to protect the Geobor drill string from subsea conditions, a riser casing is installed from the rooster box to the Seabed Frame at mudline; this is clamped in place thus providing the system with constant heave compensation.

Geobor utilises a HIAB crane and pipe "rod shoot" handling system to deploy the Geobor casing, limiting the amount of manual handling by the crew on deck. The Geobor drill string is then lowered down through the casing; this is lifted into the rooster box by the piggyback systems' headline winch in 2m sections. A lifting sub is screwed on to the top of each pipe section in order to facilitate the use of the headline winch. The pipe is clamped into place by the piggyback, then the light lifting sub is removed and the wire sent back down to the first drill pipe which is lifted to the rooster box and screwed together using the drill drive. The piggyback clamps are opened, and pipe lowered down through the riser casing. This process is repeated until mudline is reached. **Figure III** illustrates the drilling system on the deck of the Kommandor Susan.

Figure III – Kommandor Susan Drilling System



3.3 Geobor-S Coring Operations

The Geobor-S coring system utilised a triple barrel rotary core system, compromising an outer and inner barrel with a plastic core retaining liner. To achieve a core run the inner barrel assembly is latched into the outer core barrel with a plastic liner inside.

Recovery of core samples was achieved by rotation of the drill bit which cuts away the material around the core leaving a “stick” of material that is retained within the core liner triple barrel system. The sample was held within the plastic liner with the help of a core catcher housed within the cutting shoe. Once the target sample depth was reached the string was clamped, the power swivel removed and the mud valve opened, allowing the inner barrel to be removed utilising the over shot. The over shot was lowered down to the bottom of the string to retrieve the inner barrel back to deck using the sample winch mounted on the drill floor.

Once the inner barrel was on deck, the liner was removed from the barrel and transferred to the onboard testing laboratory. Core samples were photographed and non-intrusively field logged by experienced Gardline Geotechnical Engineers. Samples were retained within their core liner, wrapped and sealed for storage.

3.4 BH-207_b Fieldwork Operations

BH-207_b was destructively drilled from mudline to 9.40m to prioritise the acquisition of high quality geotechnical cores in competent bedrock. Continuous Geobor-S core runs were then conducted to a final depth of 42.40m. Rock material was first encountered at 9.95m, found as CHALK, with the first 0.55m of material representing a CLAY TILL.

Due to a malfunctioning segment of the drill rig, the rate of penetration could not be controlled, causing aggressive drilling through the weak rock material. However, core recovery was still very competent throughout the borehole with minimal core loss. The borehole was terminated to avoid equipment damage due to reducing borehole stability.

On completion of core run 21, an issue was encountered where some joint bolts sheared and operations were suspended for over five hours while the problem was resolved. On core run 22, the first 40cm of material was milled due to the sheared bolt and returned a core sample of smaller diameter. No testing was scheduled on this core run as a result of this issue.

Overall quality of the acquired cores was excellent, giving plentiful quantities of competent rock for reliable onshore laboratory testing. Chalk units could be fully defined and were identified with fine gravel to stone size clasts and inclusions of chert.

3.5 Geobor-S Coring Analysis

Geobor-S coring operations were carried out in accordance with the requirements of ISO 19901-8:2014. In total, 24 cores were acquired from location BH-207_b.

All data acquired in the field was entered into Gardline's proprietary software TerraFusion to create the preliminary borehole log, showing the unitisation of the soil and rock material encountered along with all offshore laboratory test results. In terms of offshore laboratory testing, only five moisture contents were conducted for BH-207_b. The borehole log is presented 10m per page and includes detailed soil and rock descriptions, moisture contents, densities and UCS test results. TCR, SCR and RQD data is also present on the log. Coordinates and water depths along with dates of each location are stated on each log. The push sample column as presented on the log uses different shades to illustrate sample recoveries; white is no recovery, light grey is penetration and dark grey is recovery. Geotechnical logs can be found in APPENDIX 2.

Layer descriptions were based on visual sample descriptions carried out offshore. All unit descriptions were reviewed and updated where required following the completion of the onshore laboratory testing programme. Only compressive strength descriptions were updated with the Point Load and UCS test results as no other description defining tests were conducted. The borehole log was also re-unitised from the original fieldwork log following a review of all location data.

For all 24 core runs, rock quality designation was very high, averaging at a value of 85% with a minimum value of 65% on C01 and a maximum of 100% on C19. This was predominately influenced by chert inclusions. Core recoveries were even higher, with over 97% of cored material successfully brought back up to the deck of the Kommandor Susan. Eighteen core runs achieved 100% core recovery and the minimum core recovery experienced was 65% on C01.

The original borehole at location 207 was drilled during the scope of the main geotechnical site investigation using API drilling and PQ3 coring techniques. Over the same depth interval that was cored at BH-207_b, recoveries at location BH-207 were considerably lower, acquiring just under 60% of material between 13.00m and 42.70m; no core runs achieved 100% recovery. Due to client representative concerns, the core liners for samples acquired at BH-207 were not split with an exact saw in the field while a safety concern was investigated. The quality of these core runs was therefore not fully defined. The drilling fluid retained within the liners saturated the cores and made them unsuitable for onshore laboratory testing. As a result, no comparison can be made between test results from BH-207 and BH-207_b.

4 Laboratory Testing Programme

4.1 General

The objective of the laboratory testing programme was to evaluate the pertinent physical and mechanical characteristics of the rock materials encountered at the site. This section of the report discusses the laboratory testing programme performed. Tests were performed in accordance with standards outlined by Energinet Eltransmission A/S and are summarised in Table 4.1.

Onshore laboratory test results are considered to be of high quality and representative of the rock materials encountered at BH-207_b. No testing issues were experienced for this project.

Table 4.1 – Laboratory Testing Standards

Laboratory Test Type	Standard
Geological Description	Danish Geotechnical Society Bulletin 1, ISO 14688, ISO 14689
Water Content	ISO 17892-1
Saturated Water Content	BS 1377-2
Bulk and Dry Density (Immersion Method)	ISO 17892-2
Unconfined Compressive Strength (UCS)	ISO 17892-7
Point Load	ISRM Point Load Method

A summary of completed onshore laboratory tests and the laboratory they were completed in are presented in Table 4.2. Numbers presented in this table represent the tests that were scheduled for the project along with how many of these were completed and how many were cancelled. No tests were cancelled for this project.

Table 4.2 – Onshore Laboratory Testing Schedule

Classification Test Type	Lab	Scheduled	Completed	Cancelled
Saturated Water Content	Geolabs	8	8	0
Bulk and Dry Density (Immersion)	Geolabs	8	8	0
UCS (Stress-Strain)	Geolabs	8	8	0
Point Load	Gardline	8	8	0

A summary of completed offshore laboratory tests conducted on the Kommandor Susan are presented in Table 4.3.

Table 4.3 – Offshore Laboratory Testing Schedule

Classification Test Type	Completed
Sample Photographs*	43
Water Content	5
Point Load	5
*Two photographs were taken for most core runs as the vessel photo board was only 1m in length	

4.2 Soil and Rock Description

Descriptive terms are based on "A guide to engineering geological soil description" - Danish Geological Society, Bulletin 1 and both ISO 14688 and ISO 14689 and are described in the following order:

- MAIN SOIL/ROCK TYPE
- Degree of induration
- Grain size and degree of sorting (SAND) / plasticity (CLAY)
- Minor components
- Structures
- Colours
- Mineralogy
- Carbonate content
- Colloquial names (if known)
- (Relative density) / (Shear strength) / (Compressive strength)
- Depositional Environment
- Age

4.2.1 Main Soil/Rock Type

The classification of soils is usually based on grain size, induration, sorting and plasticity. The classification of rocks is based on engineering experience, physical and structural properties, compressive strength, induration and basic field tests such as the rock acid test. Quality of the rock cores is defined by the total core recovery, solid core recovery and rock quality designation; these are not included in the rock descriptions but are presented on the borehole log. For clarity, the main soil or rock type is always written in capital letters.

4.2.2 Degree of Induration

The degree of induration for soils and rocks is based on the descriptive terms in the Danish Geotechnical Bulletin and is presented in Table 4.4. Soils are defined by degrees of induration H1 and H2, where higher degrees of induration are used to indicate that the material is rock.

Table 4.4 – Degree of Induration

Symbol	Term	Description
H1	Unlithified	The material can easily be formed by hand. Grainy material will fall apart when dry.
H2	Slightly Indurated	The material can easily be cut with a knife and can be scratched with a fingernail. Individual grains can be picked out with the fingers when the material is grainy.
H3	Indurated	The material can be cut with a knife but cannot be scratched with a fingernail. Individual grains can be picked out with a knife when the material is grainy.
H4	Strongly Indurated	The material can be scratched with a knife. Individual grains do not come out with a knife. Fractures will follow grain surfaces.
H5	Very Strongly Indurated	The material cannot be scratched with a knife. Cracks and fracture surfaces will go through individual grains in grainy material.

4.2.3 Particle Size, Degree of Sorting and Plasticity of Soils

The basic soil types as defined by particle size analysis are as follows:

GRAVEL	Coarse	20.0mm to 60.0mm
	Medium	6.0mm to 20.0mm
	Fine	2.0mm to 6.0mm
SAND	Coarse	0.60mm to 2.0mm
	Medium	0.2mm to 0.60mm
	Fine	0.060mm to 0.2mm
SILT	Coarse	0.02mm to 0.060mm
	Medium	0.0060mm to 0.02mm
	Fine	0.002mm to 0.0060mm
CLAY		Less than 0.002mm

The soil descriptions presented were derived from visual description only as no PSD or Hydrometer tests were conducted.

A glacial TILL deposit must always be expected to contain all grainsize fractions and to be unsorted. Therefore, both grainsize and sorting are omitted when describing glacial TILL. Classification of glacial TILL deposits are based on the Danish Geotechnical Bulletin summarised in Table 4.5.

Table 4.5 – Classification of glacial TILL deposits

Grain Fraction	CLAY (%)	SILT (%)	SAND (%)	$I_p = W_l - W_p$ (%)
GRAVEL TILL	<12		>25	<4
SAND TILL	<12		>45-50	<4
SILT TILL	<12	>45-50		<4
CLAY TILL, (Very silty) (Very sandy) (Sandy ("normal")) (Medium plasticity) (High plasticity)	 12-15 12-15 12-15 >20 >30			 4-7 4-7 7-10 >10 >25

The identification and description of fine-grained soils during offshore operations is based on a set of hand tests including plasticity and dilatancy. Table 4.6 below outlines the criteria used to determine the degree of plasticity as described in the Danish Geotechnical Bulletin. As no Atterberg testing was performed, Table 4.6 is presented below for reference only.

Table 4.6 – Degree of Plasticity

Term	w_L %	I_P %	Clay Percentage (%)	USC-System
Clay, very fat	>80	>50		CV
Clay, fat	50-80	25-50		CH
Clay, lean	30-50	10-25		CM
Clay, silty / sandy	<30	7-10	15-20	CL
Clay, very silty / sandy	<30	4-7	10-15	CL
Silt, very clayey		4-7	<10	ML
Silt, clayey / sandy		<4	<10	ML

OL: Gyttja of Low plasticity
OH: Gyttja of High plasticity
ML: Silt of low plasticity
MH: Silt of high plasticity
CV: Clay of very high plasticity
CH: Clay of high plasticity
CM: Clay of intermediate plasticity
CL: Clay of low plasticity

4.2.4 Secondary Components

The description of secondary constituents was performed offshore by visual observation. Secondary soil constituents within a fine soil are classified based on the descriptive terms used in the Danish Geotechnical Bulletin and are summarised in Table 4.7.

Table 4.7 – Secondary Constituent Classification (Fine Soils)

Term	Principal Soil Type	Secondary Constituent
Slightly sandy / slightly gravelly	SILT or CLAY	<10%
Sandy / gravelly	SILT or CLAY	10 - 25%
Very sandy / very gravelly	SILT or CLAY	>25%

Secondary soil constituents within a coarse soil are classified as summarised in Table 4.8.

Table 4.8 – Secondary Constituent Classification (Coarse Soils)

Term	Principal Soil Type	Secondary Constituent
Slightly clayey / slightly silty	SAND or GRAVEL	<5%
Clayey / silty	SAND or GRAVEL	5 - 10%
Very clayey / very silty	SAND or GRAVEL	>10%

In addition to describing secondary soil constituents, shells are described. The terms used are outlined in Table 4.9 below and are based on the descriptive terms used in the Danish Geotechnical Bulletin.

Table 4.9 – Shell Classification

Shell Classification	Description
Shells	Indicating intact or almost intact shells
Shell Pieces	Indicating pieces which can easily be identified by an expert
Shell Fragments	Indicating that the shell fragments are of a size rendering a determination impossible without use of a microscope

4.2.5 Structures

Structures are divided into sedimentary and tectonic. Sedimentary structures include layering, laminations, schliering, crossbedding and anything formed by biological activity. Definition of beds and laminations were based on ISO 14688 as presented in Table 4.10.

Table 4.10 – Bedding Classification

Mean Thickness/Spacing (mm)	Bedding Thickness Term	Bedding Spacing Term
<6	Thin Lamination	Extremely Closely Spaced
6 – 20	Thick Lamination	
20 – 60	Very Thin Bed	Very Closely Spaced
60 – 200	Thin Bed	Closely Spaced
200 – 600	Medium Bed	Medium Spaced
600 – 2000	Thick Bed	Widely Spaced
>2000	Very Thick Bed	Very Widely Spaced

Tectonic structures include folds, fractures, slickensides and faults. Natural rock fractures were classified using the descriptive terms in the Danish Geotechnical Bulletin as presented in Table 4.11.

Table 4.11 – Fracture Classification

Symbol	Term	Description
S1	Unfractured	No fractures observed
S2	Slightly Fractured	Distance between fractures is greater than 10 cm. No vertical fractures.
S3	Fractured	Distance between fractures between 6 and 10 cm.
S4	Very Fractured	Distance between fractures between 2 and 6 cm.
S5	Crushed, Blocky	Distance between fractures less than 2 cm.

4.2.6 Colour

A Munsell colour chart was used for reference when describing the colour of the sample.

4.2.7 Mineralogy

Where contrasting mineralogy was observed in the sample it was noted, such as pockets of glauconite or pyritised burrows.

4.2.8 Carbonate Content

Carbonate content was tested offshore by placing a drop of dilute Hydrochloric Acid (HCl) on the sample and noting the strength of the reaction that occurred.

4.2.9 Colloquial Soil Type Names

Colloquial names were not included in soil descriptions.

4.2.10 Strength Classification

According to ISO 14688 and ISO 14689, fine grained soils are described using shear strength and rocks by unconfined compressive strength, as shown in Table 4.12 and Table 4.13 respectively. No shear strength testing was performed and Table 4.12 is presented for reference only. Compressive strengths of rocks were initially obtained in the field from geological hammer blows and offshore Point Load results, then revised upon the completion of the onshore laboratory testing programme.

Table 4.12 – Soil Strength Classification

Undrained Shear Strength of Clays	Undrained Shear Strength (kPa)
Extremely low	0 – 10
Very low	10 - 20
Low	20 – 40
Medium	40 – 75
High	75 – 150
Very high	150 – 300
Extremely high	>300

Table 4.13 – Rock Strength Classification

Unconfined Compressive Strength of Rocks	Unconfined Compressive Strength (MPa)	Qualitative Interpretation of UCS (Geological Hammer)
Extremely Weak	0.6 – 1.0	Gravel size lumps crush between finger and thumb. Indented by thumbnail.
Very Weak	1 – 5	Crumbles under firm hammer blows. Can be peeled by knife.
Weak	5 – 25	Can be peeled with difficulty. Point of hammer makes shallow indents.
Medium Strong	25 – 50	Cannot be peeled with knife, fractures with single blow of hammer.
Strong	50 – 100	Rock broken by more than one hammer blow.
Very Strong	100 – 250	Requires many hammer blows to break specimen.
Extremely Strong	>250	Rings on hammer blows. Only chipped with geological hammer.

4.2.11 Depositional Environment

The grain size, degree of sorting, strength, sedimentary structures, shells, fossils and presence of organic material were used to determine the depositional environment of the layers.

4.2.12 Age

The geological age of sediments and rock material was determined by cross referencing identified depositional environments with geophysical data from GEOxyz and results from the Network Stratigraphic palynology and micropalaeontology testing conducted on samples for the main geotechnical scope. Geological environment and age are further discussed in Section 6.

4.3 Classification Laboratory Test Results

Basic index laboratory tests were performed offshore during operations in the vessel soil laboratory. Testing included soil and rock descriptions, colour identification and natural moisture contents. Further classification testing was performed onshore based on the laboratory testing schedule agreed between Energinet and Gardline. This comprised of saturated moisture content and density by immersion testing. All onshore classification testing was carried out by Geolabs.

Offshore and onshore test results are presented in the borehole log in APPENDIX 2. Summary tables are presented in APPENDIX 9.

4.3.1 Water Content

Water content testing without density was performed offshore on select material. This involved weighing a small amount of core material immediately following sample extrusion. Samples were then placed in an oven for a set time before being allowed to cool and their dry weight taken.

The samples are dried until they achieve constant mass. Constant mass is defined as the point in which there is less than 0.1% change in mass of the dry material, when dried for at least one more hour. If the change in mass of the sample exceeds 0.1% then the sample is dried in the oven for a further hour, and the weighing process repeated until constant mass is achieved.

Densities were not calculated here as the volume of core material was not known. Water content values presented in this report are measured values and no corrections have been applied. Moisture content testing was carried out in accordance with ISO 17892-1.

4.3.2 Saturated Moisture Content and Density by Immersion

Saturated moisture content and density by immersion testing was carried out onshore on representative rock samples. These were determined by coating the samples in paraffin wax and suspending the sample in water to record the apparent mass. The mass of the samples before and after coating in wax are also recorded. Moistures were then determined by oven-drying the samples after the water suspension stage.

Density by immersion testing was carried out in accordance with ISO 17892-2. Saturated moisture content testing was carried out in accordance with BS1377-2.

4.4 Rock Test Results

Unconfined compressive strength and point load testing of rock samples was conducted as part of the onshore testing programme. All UCS testing was carried out by Geolabs and all Point Load testing was carried out by Gardline. All rock test results are considered to be of very high quality and representative of the tested material.

A summary of all rock tests and relevant test enclosures are presented in APPENDIX 9.

4.4.1 Unconfined Compressive Strength (UCS)

UCS testing was scheduled to determine the unconfined compressive strength of selected intact rock core specimens.

The specimen is loaded axially in a load frame at atmospheric pressure and at a constant rate of strain; typically, in the order of 0.5-1% per minute until the specimen fails, in order to determine the stress-strain behaviour. All tests were also scheduled to present the stress-strain curves on the enclosures to evaluate the Young's Modulus of the rock samples.

Testing was carried out in accordance with ISO 17892-7.

4.4.2 Point Load

Rock point load tests provide a fast method for index strength tests which can be used to classify and characterise the rock.

A section of rock is taken for testing at its natural moisture content; the shape/dimensions of the rock determine whether the test performed will be Diametral (D), Axial (A), or Block/Irregular Lump (I). The distance between platens before testing is measured by determining the height of the rock specimen in the orientation it is tested in. The test specimen is then placed between the platens of the apparatus, and after ensuring that the gauge is set to 0, a load is applied to the specimen steadily by manually pumping the apparatus until failure occurs. The peak load reading is then recorded, along with the distance between platens at failure. Failure is considered to be invalid if it occurs outside of the stated 10-60 seconds or if the generated fracture surface only passes through one of the two loading points in the testing apparatus.

Testing was carried out in accordance with the ISRM Point Load Method.

5 Geodetic Information and Water Depths

5.1 Equipment

Primary navigation for this project was the C&C Technologies C-Nav DGNSS system using their network of reference stations. Dual independent receivers were used in order to give full redundancy on the systems. The vessel operates with three DGNSS receivers as summarised in Table 5.1 below:

Table 5.1 - GNSS System Overview

DGNSS Receivers		
1	C-Nav Stbd	Oceaneering CNav corrections
2	C-Nav Port	Oceaneering CNav corrections
3	Hemisphere VS110	SBAS EGNOS Europe corrections

5.2 Geodetic Information

A summary of the geodetic information can be found in the Survey Positioning Reports presented in APPENDIX 6.

5.3 Water Depth Measurements and Locations

The water depths were obtained by SBES (Single Beam Echo Sounder). Depths are to the vertical datum DTU21MSL (Mean Sea Level) in metres and is presented on the log in APPENDIX 2.

6 Field Unitisation

6.1 General

Geotechnical unitisation was first performed by dividing the soils and rocks by depositional environment, determined through material and mechanical properties, and supported by geophysical survey information. Once the soils and rocks had been grouped by depositional environment, they were further sub-divided by assessing the material constituents. As BH-207_b was destructively drilled to the approximate rock-head depth, only two geotechnical units were identified within this borehole. These were units 3a and 4c which represent CLAY TILL and CHALK respectively. Table 6.1 provides a summary of all geotechnical units within the site area for completion.

Table 6.1 – Geotechnical Units Summary

Formation	Geotechnical Unit	Description
1	1a	Clay, Gyttja, Organic Clays
	1b	Sands, Silts and Silty Sands
2	2a	Silty Clays
	2b	Sands and Silts
3	3a	Clay Tills and Clays
	3b	Sand Tills, Silt Tills and Massive Sands
4	4a	Limestones and Sandstones
	4b	Mudstones, Marlstones and Siltstones
	4c	Chalks

The derivation of geological age was supported using the information from the geophysical survey and the results of the palynology and micropalaeontology testing conducted on the main geotechnical scope. The age and environment of deposition for each formation are summarised in Table 6.2.

Table 6.2 – Depositional Environment Summary

Formation	Environment of Deposition	Age
1	Marine (Ma)	Postglacial (Pg) – Present day to 11500 years B. P.
2	Glacier / Meltwater (Gl/Mw)	Postglacial / Late Glacial (Pg/Lg) – 11500 to 15000 years B. P.
3	Glacier (Gl)	Glacial (Gc) – 15000 to >22000 years B. P.
4	Marine (Ma)	Cretaceous / Jurassic (Ct/Jr)

6.2 BH-207_b Geotechnical Unit Descriptions

Unit 3a consisted of clay till and represents glacier deposits of characteristically high shear strengths and increased gravel content. Unit 3a was encountered between 9.40m and 9.95m in BH-207_b. This depth range is not representative of this unit as coring was conducted from 9.40m following destructive drilling techniques.

Unit 4c represents bedrock, consisting of chalk material. This unit represents part of the marine deposits of the Cretaceous/Jurassic, supported by the palynological evidence obtained from the samples tested on the main geotechnical scope. This unit for chalk was found to be 32.45m thick, with the borehole terminated before encountering another unit. This contained occasional clasts and stones of chert throughout, with two beds of limestone identified with a greater degree of induration than the surrounding chalk.

A detailed description of all geotechnical units found within the site area can be found in the *Volume II: Measured and Derived Geotechnical Parameters and Final Results* report.

7 References

BS 1377-2. Methods of test for soils for civil engineering purposes – Part 2: Classification tests and determination of geotechnical properties

BS 5930: 2015. Code of practice for ground investigations. British Standards Institute, London.

BS EN ISO 14688-1: 2018. Geotechnical investigation and testing – Identification and classification of soil – Part 1 Identification and description. British Standards Institute, London, England.

BS EN ISO 17892-1: 2014. Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content.

BS EN ISO 17892-2: 2014. Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density.

BS EN ISO 17892-7: 2017. Geotechnical investigation and testing – Laboratory testing of soil – Part 6: Unconfined compressive strength test.

BS EN ISO 19901-8: 2014. Petroleum and Natural Gas Industries – Specific requirements for offshore structures, Part 8: Marine Soil Investigations. British Standards Institute, London, England.

BS EN ISO 22475–1:2006. Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution

Danish Geotechnical Society – Bulletin 1: 1995. A guide to engineering geological soil description. Danish Geotechnical Society. Revision 1.

Gardline. 2023. 11783 – Volume I: Field Operations Report

Gardline. 2023. 11783 – Volume II: Measured and Derived Geotechnical Parameters and Final Results.

GEOxyz. 2023. Geophysical Survey for Offshore Wind Farms And Energy Island BORNHOLM I.

GEOxyz. 2023. Geophysical Survey for Offshore Wind Farms And Energy Island BORNHOLM II.

ISRM: Point Load Test, 1989. Suggested Method for Determining Point Load Strength.

Jensen J.B., Prins L.T. et Bennike O. 2021. Geology desk study offshore Bornholm, Baltic Sea.