Danish Offshore Wind 2030 – Kriegers Flak II – Rødvig – Ringsbjerg
Location 5A – Landfall Rødvig
Site Investigations for Horizontal Directional Drilling (HDD)

Geo project no. 208116
Report 72, 2024-12-20

Summary

The electrical infrastructure in Denmark is expanding significantly, which includes connecting underground cables from new wind farms in the North Sea and Inner waters in Denmark to the major transformer stations. Due to cables crossing infrastructure, topographic challenges, protected areas, streams etc. the crossings are planned partly as Horizontal Directional Drilling (HDD).

This particular report concerns cable route at location 5A, from Rødvig to Ringsbjerg at the landfall at Rødvig.

The field works comprises of one geotechnical borehole with in situ strength testing, soil sampling and groundwater level monitoring and a geophysical survey using ERT. Furthermore, geological description and laboratory testing is carried out.

The cable depth for location 5A is planned approximately 5-10 metres below ground level (m b.g.l) and in this depth the HDD will mainly penetrate marine deposits of limestone with no content of mica. A thin layer of cerithium clay (fishclay) is found around 6.4 m b.g.l. Geo recommend that the HDD is kept above or below this layer.

The limestone is general unhardened with hardened parts or hardened with unhardened parts and a large variation in the geotechnical parameters is to be expected.

As the geology and geotechnical parameters is based on only 1 borehole and extrapolated 1.3 km from the borehole, the likelihood of similar ground conditions is very small.

Geo project no. 208116
Report 72, 2024-12-20
Client ref.: Danish Offshore Wind 2030 –Kriegers Flak II – Rødvig -Ringsbjerg

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Content

Enclosures

1 Project

The electrical infrastructure in Denmark is expanding significantly, which includes connecting underground cables from new wind farms in the North Sea and Inner waters in Denmark to the major transformer stations. Due to cables crossing infrastructure, topographic challenges, protected areas, streams etc. the crossings are planned partly as Horizontal Directional Drilling (HDD).

The project contains geotechnical and geophysical investigations for three cable routes from the North Sea (1, 2 and 3), one cable route from Kattegat II (4) and one cable route from Kriegers Flak II (5) as show in Figure 72.1.

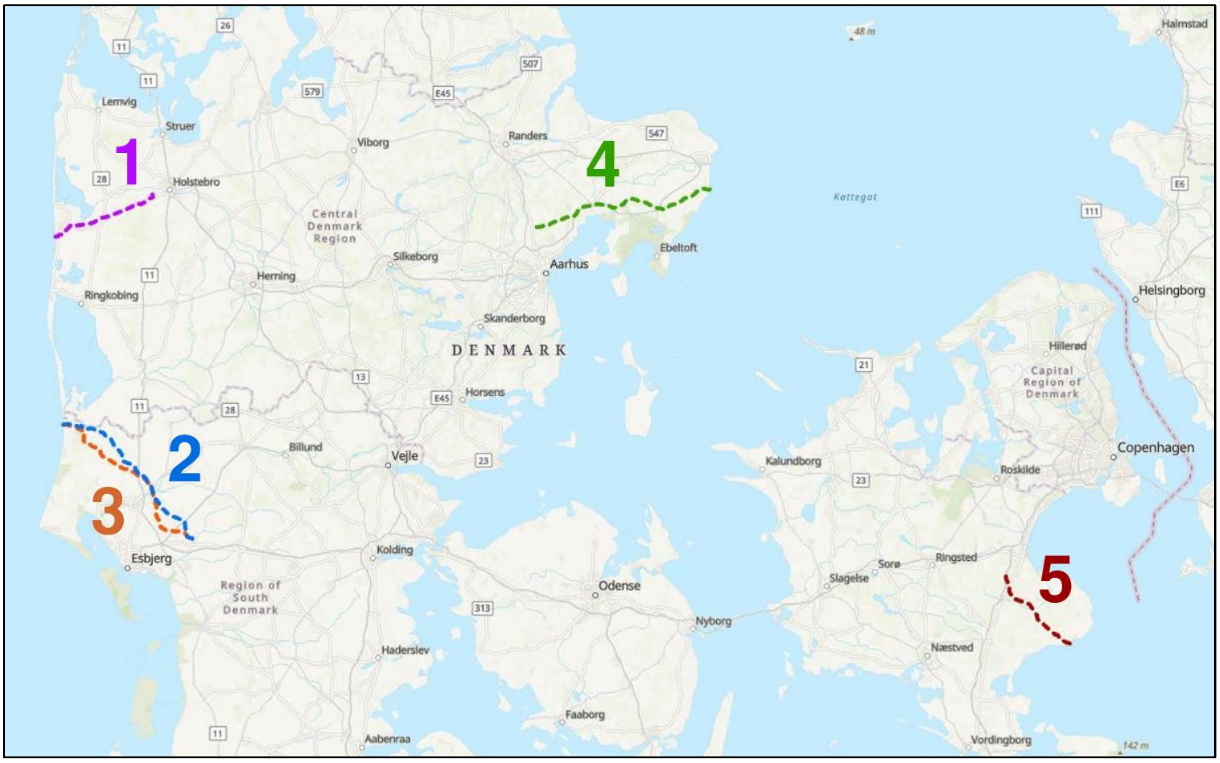


Figure 72.1: Overview map of the five cable routes planned in this project.

This report concerns the cable route from Rødvig to Ringsbjerg (cable route 5) at location 5A as illustrated in Figure 72.2 (and in the overview map cf. enclosure 72.1.1), and at the landfall at Rødvig using HDD. The cable depth for this location 5A is - according to Energinet - approximately 5-10 m b.g.l.

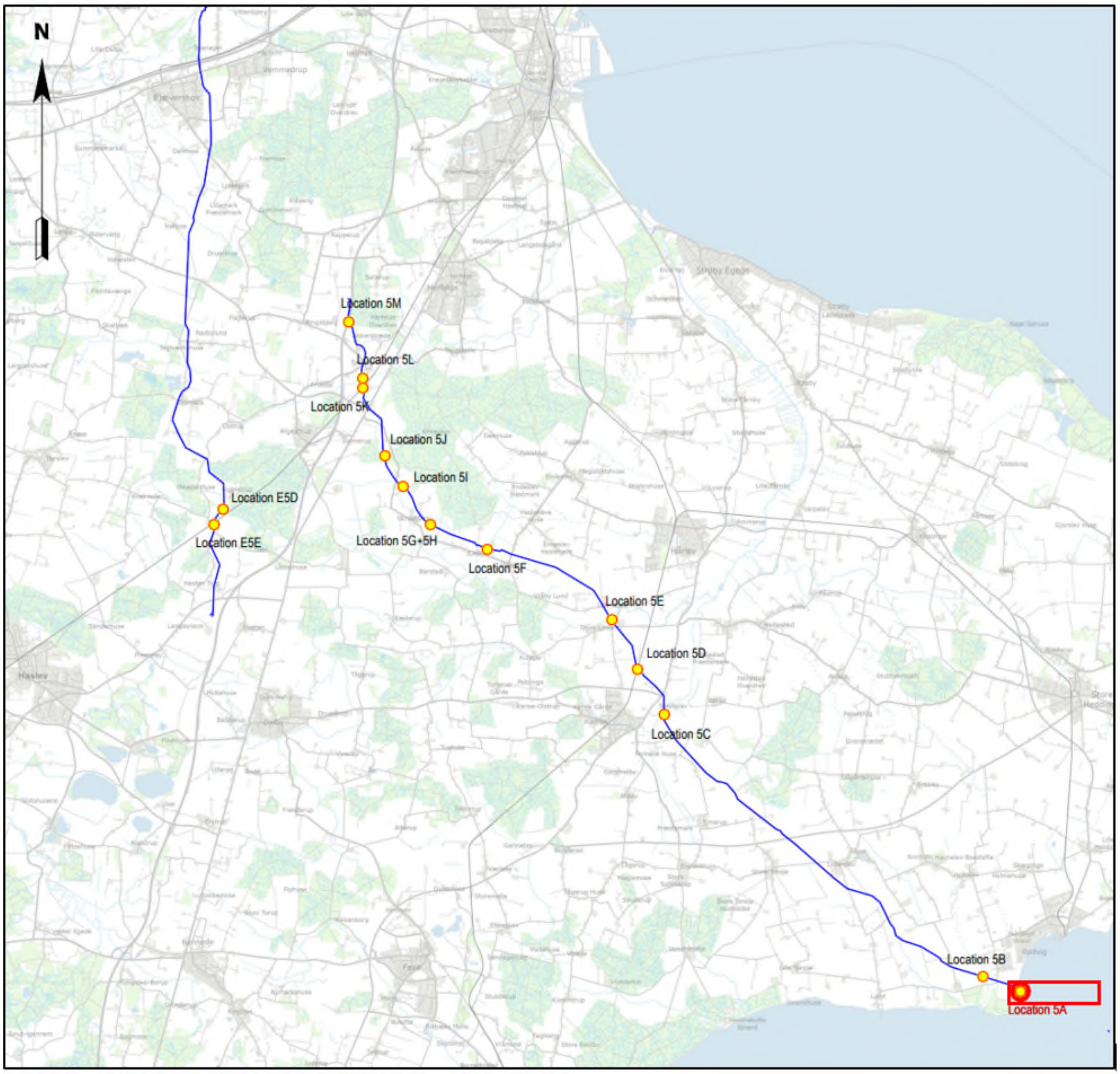


Figure 72.2: Overview map of cable route 5. Location 5A marked with red and the landfall with a red box.

Geo has been requested to investigate the soil and hydrological conditions prior to execution of the HDD.

2 Investigations

The investigation contains geotechnical field and laboratory works (carried out by Geo) and geophysic works (carried out by WSP).

As the geology and geotechnical parameters is based on only 1 borehole and extrapolated 1.3 km from the borehole, the likelihood of similar ground conditions is very small. Therefore, the geology and geotechnical parameters has to be used with the greatest precaution.

2.1 Geophysical investigations

The geophysical survey is performed using the ERT (Electrical Resistivity Tomography) method. ERT determines the variation of the electrical resistivity in the subsurface by transmitting electrical current between two steel electrodes (current electrodes) while simultaneously measuring the voltage difference between two other steel electrodes (potential electrodes).

The instrument used for the ERT survey is the ABEM Terrameter LS 2 (by Guideline Geo AB) and electrode cables with 21 electrode take outs per cable. Along the cable, take outs are positioned for each 2.5 m and at each take out, ground contact is established by a stainless-steel electrode pressed into the ground.

During the data collection process, the electrodes are set up along a profile line with equal distances between the electrodes. Measurements are made in a long range of different electrode combinations (configurations), and the data collection is automatically controlled by the instrument. Through this process, data containing information about electrical resistivity at different depths along the entire profile is measured in one integrated process.

Lateral resolution along the profile depends on the smallest distance between electrodes, while the investigation depth depends primarily on the largest distance between two electrodes in one measurement.

The resistivity measurements are carried out by a protocol (software setup) assigning electrodes in a large variety of configurations, which secures a dense data coverage with more than 800 measurements for each 50 m profile.

Note, that the depth of investigation is reduced at the ends of the profile and the largest penetration depth appears in the central part of the profile.

2.2 Geotechnical investigations

At the location, one geotechnical borehole has been executed. The target depths of the investigation point has been reached. The terrain level and coordinates of the investigation point has been measured using GPS in system UTM32N/ETRS89 and with DVR90 as vertical reference. The location of the point is shown on the site plan cf. enclosure 72.1.2.

The borehole has been executed using 6” rotary shell and auger in clay and percussion drilling in sand from a hydraulic drill rig. In the boreholes strata are registered, samples taken and in situ tests carried out as required by Energinet.

The sampling at this location consists of:

- Small disturbed samples for geological description and laboratory testing

The in situ tests at this location consists of:

- Field vane test[1]
- Standard penetration test (SPT)[2]

The borehole has been completed with installation of an Ø25 mm (diameter) standpipe made of PVC. The filter screening is carried out during simultaneous withdrawal of the casing. To ensure a tight seal between water aquifers the annulus above/below the screened pipe is sealed with expanding bentonite pellets in cohesive soils. Level of the screened pipe is chosen in accordance with the soil conditions and proposed depth of the planned HDD. The screened pipe is presented on the borehole profile.

The groundwater level is registered in the standpipes after completing the boreholes and again minimum 5 days hereafter. All results are shown on the borehole profile cf. enclosure 72.2.1.

According to the Danish legislation "Brøndborebekendtgørelse"[3] the boreholes are decommissioned/sealed within a few weeks after the drilling was carried out and the groundwater level is registered. The decommission/sealing is carried out by inserting expanding bentonite bars in the standpipe and thereafter removing the top standpipe approximately 1 m b.g.l.

2.3 Laboratory tests

The geological description of all samples have been carried out in accordance to the Danish dgf-Bulletin 1, 2021 (Danish Geotechnical Society) and standard classification tests required by Energinet have been performed. The standards used for classification tests in Geos laboratory are listed in Table 72.1.

Table 72.1: Standards for classification tests.

Classification test	Standard
Natural water content	DS/EN ISO 17892-1:2014
Atterberg limits	DS/CEN ISO 17892-12:2018

3 Results

3.1 Geophysical results

3.1.1 ERT software and interpretation workflow

Following the data collection process, data is imported and processed in Aarhus Workbench (version 6.9.0.0). Data are inspected and data points, either directly faulty or heavily influenced by noise, are removed. Subsequently, the complete profile is inverted by 2D inversion in two different parameter settings and layer models.

In Aarhus Workbench, the inverted resistivity models are visualised along with geological information from boreholes in the vicinity of the profile. Based on this comparison, a geological interpretation can be performed and visualized along with a geophysical model. Figure 72.3 summarizes this workflow.

[1] Danish Geotechnical Society, dgf-Bulletin 14, 1999, "Referenceblad for Vingeforsøg", version 3
[2] DS/EN ISO 22476-3 Geotechnical investigation and testing – Field testing – Part 3: Standard penetration test
[3] BEK nr. 1260 af 28/10/2013 - Bekendtgørelse om udførelse og sløjfning af boringer og brønde på land.

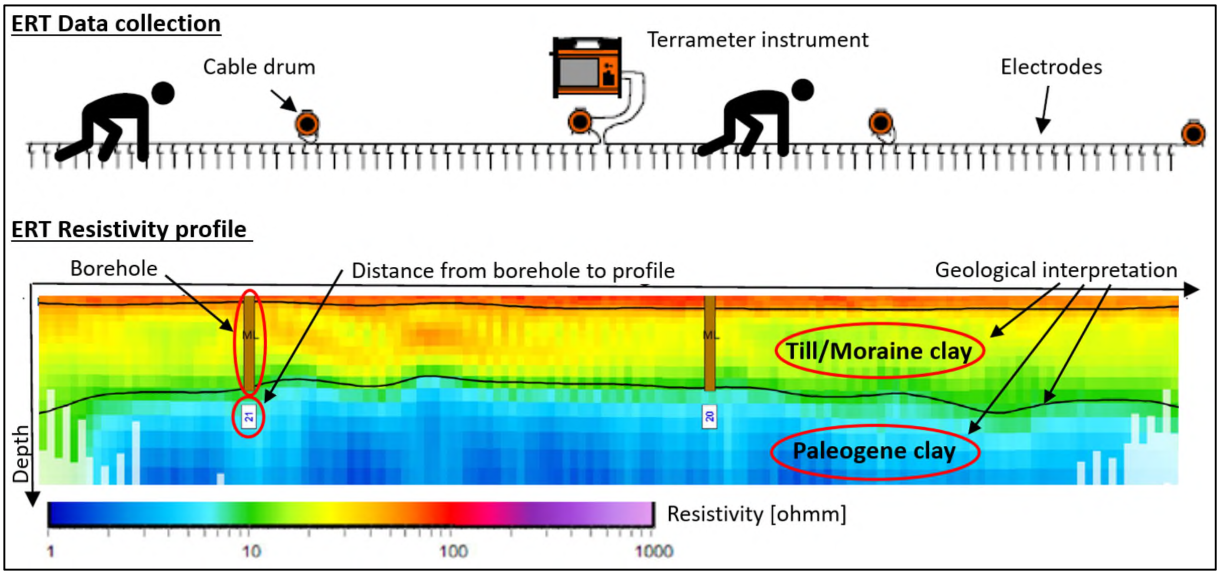


Figure 72.3: An illustration of the ERT workflow from data collection during fieldwork to the resistivity section and finally the geological interpretation.

Enclosure 72.1.3 contains a resistivity section based on inversions of the ERT measurements. The section is based on *smooth inversion*, which is characterized by a smooth variation in the resistivity values. The model is defined by 20-40 layers with fixed layer boundaries and the resistivity values are determined by the inversion process.

Geological layers are illustrated as black and dotted lines on the longitude profile as a cautious interpretation from the ERT, borehole and CPT data. The top soil extent is not marked as the geophysical method is not sufficient to resolve shallow occurrences.

3.1.2 Geological interpretation of resistivity values

Electrical resistivity tomography determines the electrical resistivity properties of the subsoil. The magnitude of the resistivity depends on various geological parameters such as the type of the sediment or rock (clay, sand, limestone, etc.), water saturation and the presence of saline ions.

Generally, the geophysical models can be interpreted to geology according to Figure 72.4.

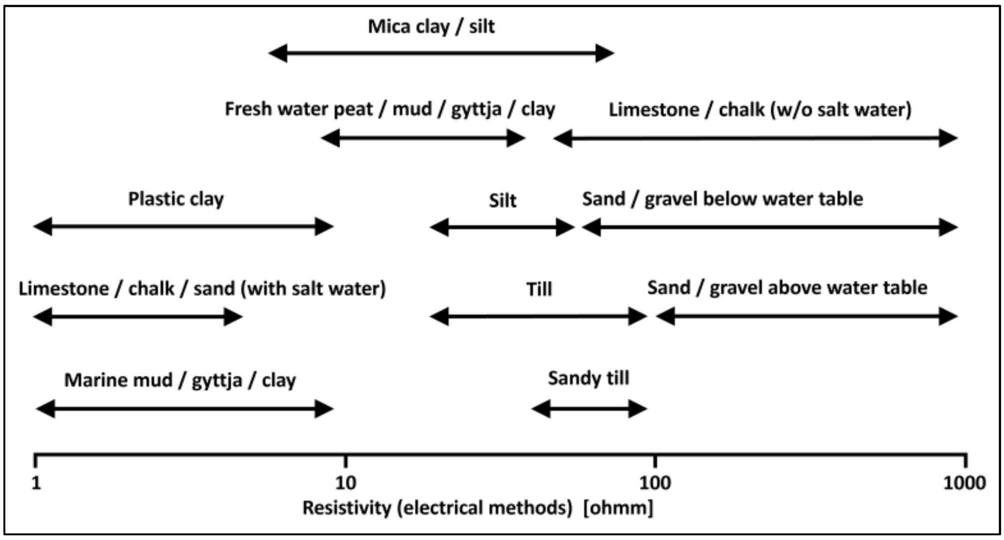


Figure 72.4: Geological interpretations according to resistivity values.

3.1.3 ERT profile 5A-1

ERT profile 5A-1 (see figure 72.5 below) has a length of 155 m. Data were collected with an electrode spacing of 2.5 m. The inverted profile has a data residual of 0.81. A residual under 1 indicates that the measured data are in good accordance with the determined 2D model and subsurface structures are expected to be well resolved.

During data collection of cable route 5 there was a fair amount of precipitation resulting in generally good electrode contact while measuring.

In Profile 5A-1, low resistivities (10-20 ohmm) dominate in the most shallow 2-3 m for most of the profile, however for distances of 110-145 m high resistivities of 100-500 ohmm are seen on top of the low resistivity layer. Underneath, resistivities of 100-200 ohmm are seen throughout the profile in the interval between elevations of -2 down to -8 meters. From an elevation of -8 and downwards, low resistivities of 7-25 ohmm are then seen down to the bottom of the profile. The upper boundary of these resistivities gently dips towards the northwest.

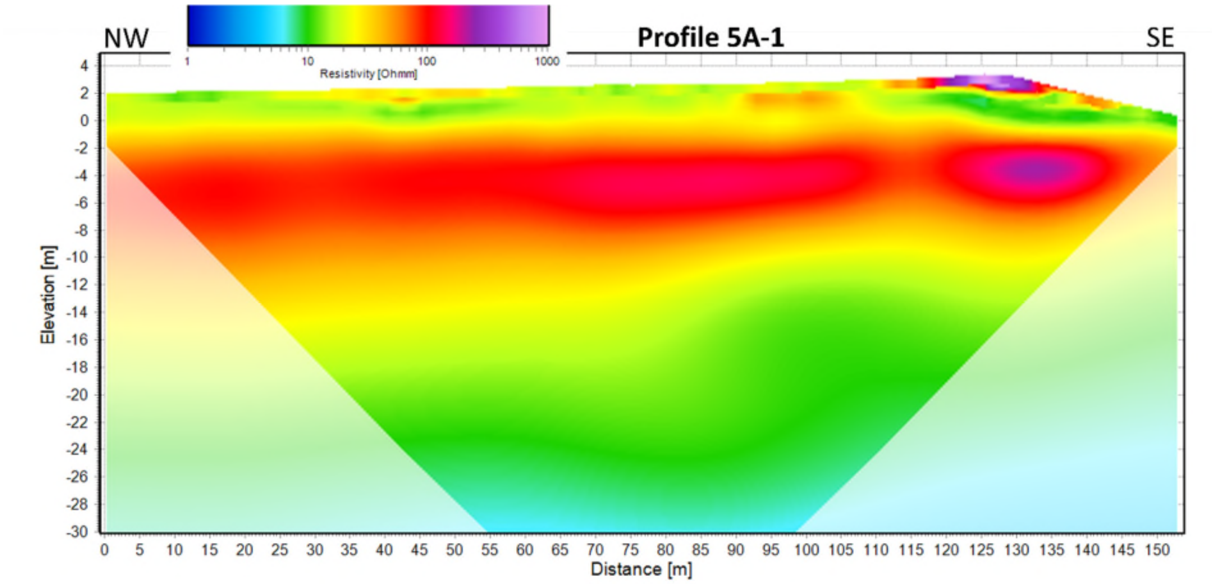


Figure 72.5: ERT Profile 5A-1.

3.2 Geological description of the location

Location 5A is described and interpreted based on the project borehole 5A.01. Further knowledge is added from the online soil type map and geomorphological maps from GEUS, ref /4/, /5/ and /6/, and literature covering the geological history of the area, ref /7/ and /8/. Knowledge of the deeper geological layers is added from nearby boreholes and the FOHM model (2024), ref /9/.

The interpretation of the geological conditions is shown in the conceptual geological section along HDD 5A in Figure 72.6.

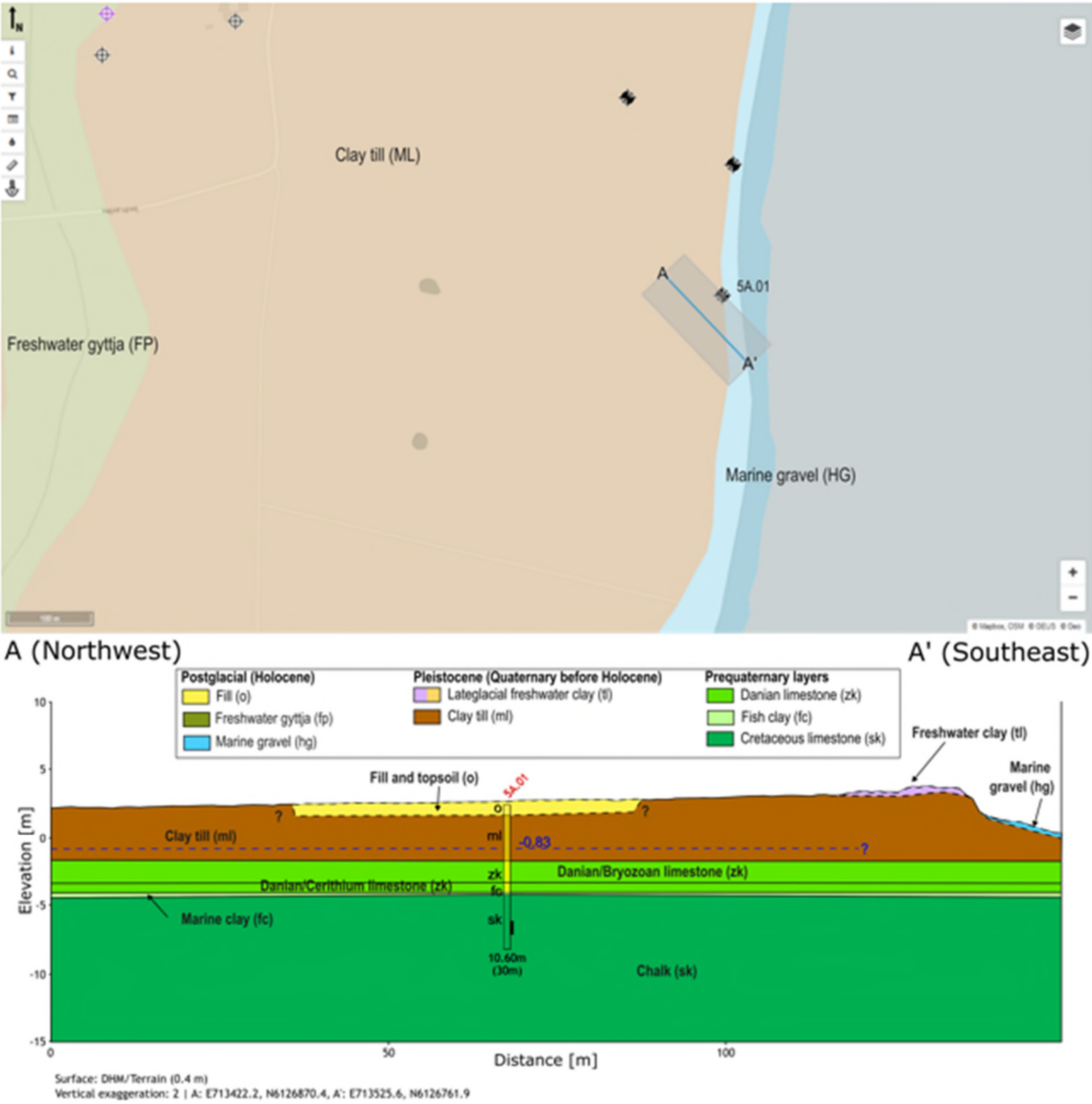


Figure 72.6: The upper panel holds a map view with the location of borehole 5A.01. The map view shows the expected soil type one m below terrain, ref /4/, around the planned HDD location. The lower panel shows the conceptual geological section along HDD 5A including borehole logs and interpreted geological units indicated by GEUS symbols. The filter level is marked by a black box attached to the borehole log and the groundwater level measurement is marked in blue.

Geological description

In borehole 5A.01, the upper approx. 0.7 m consist of recent fill consisting of clay and mull. The fill deposits superpose clay till that extends to a depth of approx. 4.1 m b.g.l.

Below the clay till, Danian limestone is found to around 6.4 m b.g.l. The upper app. 2 meters of the Danien Limestone consists of Bryozoan Limestone and the lower app. 0.5 meter consists of Cerithium Limestone.

Below the Danien Limestone, a thin layer of marine clay is found. The marine clay superposes Cretaceous/Maastrichtien chalk to the bottom of the borehole at 10.6 m b.g.l.

Detailed borehole information, sample descriptions and other borehole specific data is shown on the borehole log, Enclosure 72.2.1.

Geological interpretation

The HDD 5A is located at Stevns, just south of Rødvig and Stevns Klint with the southeastern part of the HDD reaching into the coastline. The terrain level starts at sea level, 0 m DVR90, rising to around +3 m DVR90. The terrain level slightly decrease in northwestern direction and stabilizes around level +2 m DVR90.

Postglacial, marine deposits of gravel and sand are to be expected along the coastline. These sediments represent sand and gravel sediments deposited during the Littorina Transgression and recent beach sedimentation.

Clay till is expected along the majority of the profile. The glacial till was deposited primarily during a glacial advance (Young Baltic advance) from a southeastern direction but the lower part of the till may have been deposited during the main glacial advance from the NE. The glacial advances during the Weichselian have eroded the top of the Danien limestone.

The glacial deposits are underlain by limestone deposits of Danien age, the upper part of the danien deposits consists of Bryozoan Limestone, that were deposited in the relatively warm sea that formed in The Danish Basin. The sea currents formed the limestone into mounds separated by flint-bands.

The Bryozoan Limestone is underlain by a thin bed of Cerithium Limestone, that represents deposition in a relatively shallow ocean during a warm period.

The Cerithum Limestone grades into a marine clay (The Fish Clay layer) that marks the transition from Cretaceous to Tertiary. This marine clay was deposited in a deeper ocean, representing dramatic climatic changes – probably due to an asteroid impact.

The marine clay is underlain by chalk of Cretaceous/Maastrichtian age. This limestone was deposited during a warmer period, when a relative deep ocean covered the area forming comparatively horizontal layers of chalk separated by bands of flint.

3.3 Geotechnical results

The geotechnical investigation carried out for this location is described in section 2.2 and the geological results are described in section 3.2.

3.3.1 Hydrogeology

The groundwater levels have been measured in the standpipes immediately after completing the boreholes and again minimum 5 days hereafter. The groundwater level readings are illustrated on the borehole profiles and furthermore listed in Table 72.2.

Table 72.2: Ground water readings/measurements.

Borehole no.	Ground level (m DVR90)	Date	Depth (m b.g.l.)	Level (m DVR90)	Bottom of filter (m b.g.l.)
5A.01	+2.4	2024-11-14 2024-12-09	3.2 2.3	-0.8 +0.1	9.4

3.3.2 Laboratory tests

Results of the laboratory classification tests are presented either on the borehole profile and/or in enclosure 72.4 (plasticity index.).

No thermal conductivity tests are carried out at this location.

4 Derivation of geotechnical parameters

4.1 Strength parameters

4.1.1 Cone penetration test (CPT)

No CPT is carried out at this location

4.1.2 Standard penetration test (SPT)

The frictional angle φ', from SPT are determined by transforming the data obtained to a relative density as described in DS/EN ISO 22476-3, cf. ref. /2/

Derivation of N_{60} values has been carried out using appendix A in DS/EN ISO 22476-3 using an energy ratio, E_r, of 0.6.

$$N_{60} = \frac{E_r}{60} \cdot \lambda \cdot C_N \cdot N$$

The frictional angle φ' has been derived using Teixeira and Hatanaka and Uchida, cf. ref. /3/.

$$\varphi'_p = 15° + \sqrt{24 \cdot (N_1)_{60}}$$ *(Teixeira, 1996)*

$$\varphi'_p = 20° + \sqrt{15.4 \cdot (N_1)_{60}}$$ *(Hatanaka and Uchida, 1996)*

4.1.3 Field vane test

In cohesive soils the undrained shear strength, c_u is derived from the equation $c_u = \mu \cdot c_{fv}$ where c_{fv} is the shear strength from field vane test and μ is a correction factor based on local experience. Based on experience Geo suggest μ = 1.0 in late glacial or glacial clay deposits.

4.2 Stiffness

4.2.1 Cone penetration test

Not relevant

4.2.2 Undrained shear strength

For late glacial and glacial clay deposits the oedometer stiffness, E_{oed}, is estimated from experience as

$$E_{oed} = \frac{4000 \cdot c_u}{w}$$

where: c_u = undrained shear strength derived from the CPT or the field vane test in kPa
w = natural water content in %

For recent or postglacial, organic soil the oedometer stiffness, E_{oed}, is estimated from experience as

$$E_{oed} = \frac{1000 \cdot c_u}{w}$$

where: c_u = undrained shear strength derived from the CPT or the field vane test in kPa
w = natural water content in %

4.3 Permeability

For uniform graded sand the permeability, k, is suggested estimated by:

$$k = 0.01 \cdot d_{10}^2$$

where d_{10} is the grain size at 10 % by weight.

(Not relevant at this location)

5 Evaluation of geotechnical parameters

Recommendations for geotechnical parameters are given in the following paragraphs based on the specific soil type, field tests (SPT and/or field vane test), laboratory tests and Geos general experience with similar soil types.

The values in Table 72.3 are representative values, and both lower and higher values (peak values) must be expected to appear in the actual investigation points as well as in the deposits between the investigation points. Ranges of soil parameters are given and relevant parameters must be selected depending on the situation considered.

The listed geotechnical parameters are:

q_c Tip resistance (from CPT)

γ: Weight density above water level
γ': Effective weight density below water level
φ': Effective friction angle
c': Effective cohesion
c_u: Undrained shear strength
k: Permeability
E_{oed}: Oedometer stiffness

Table 72.3: Soil parameters, Location 5A.

Soil description	q_c (MPa)	γ/γ' (kN/m³)	φ' (°)	c' (kPa)	c_u (kPa)	k (m/s)	E_{oed} (MPa)
Fill: Clay mull	-	18/10	25-30	0	50-100	$1 \cdot 10^{-6} - 1 \cdot 10^{-8}$	4-8
Fill: Clay	-	20/10	25-30	0	100-200	$1 \cdot 10^{-6} - 1 \cdot 10^{-7}$	6-12
Clay Till, (Gc)	-	21/11	30-34	4-20	40-250	$1 \cdot 10^{-7} - 1 \cdot 10^{-9}$	10-70
Limestone (Da)	-	19-22/9-12	38-45	0-50	100-200	$1 \cdot 10^{-3} - 1 \cdot 10^{-5}$	100->300
Limestone (Ct)	-	19-21/9-11	33-45	30-200	300-> 1000	$1 \cdot 10^{-3} - 1 \cdot 10^{-5}$	300->1000

Geo has no geotechnical experience with the thin layer of cerithium clay found between level -4.0 and -4.2 thus no parameters are given.

6 Recommendations

According to Energinet the plan is to carry out HDD from the vicinity of the borehole and towards the sea at 5-10 m b.g.l., untill the end of the offshore part of the cable is reached at sea.

In this depth, the HDD will mainly penetrate marine deposits of limestone with no content of mica. A thin layer of cerithium clay (fishclay) is found around 6.4 m b.g.l. Geo recommend that the HDD is kept above or below this layer.

The limestone is general unhardened with hardened parts or hardened with unhardened parts and a large variation in the geotechnical parameters is to be expected.

As the geology and geotechnical parameters is based on only 1 borehole and extrapolated 1.3 km from the borehole, the likelihood of similar ground conditions is very small.

As the location is close to the sea Geo recommend that the risk of high water level is taken into account when establishing drilling pits.

Depending on the drilling method used, minor ground settlements may develop in the vicinity of the HDD centreline as well as close to the drilling pits.

Risks and procedures for execution must be evaluated in detail when a contractor has been assigned and depths, diameter etc. of HDD decided.

Preliminary Risk assessment based on the interpreted geology and the soil conditions met in the boreholes and CPT's is attached in enclosure 72.5.

7 References

/1/ *NGI Publication #156 - Interpretation of Cone Penetrometer Data for Offshore Sands*, T. Lunne and H. P. Christoffersen , NGI, 1985

/2/ *DS/EN ISO 22476-3 Geotechnical investigation and testing – Field testing – Part 3: Standard penetration test.*

/3/ *In situ testing in Geomechanics*, Fernando Schnaid, 2009

/4/ *Danmarks digitale jordartskort 1:25.000*, version 7, GEUS, 2024

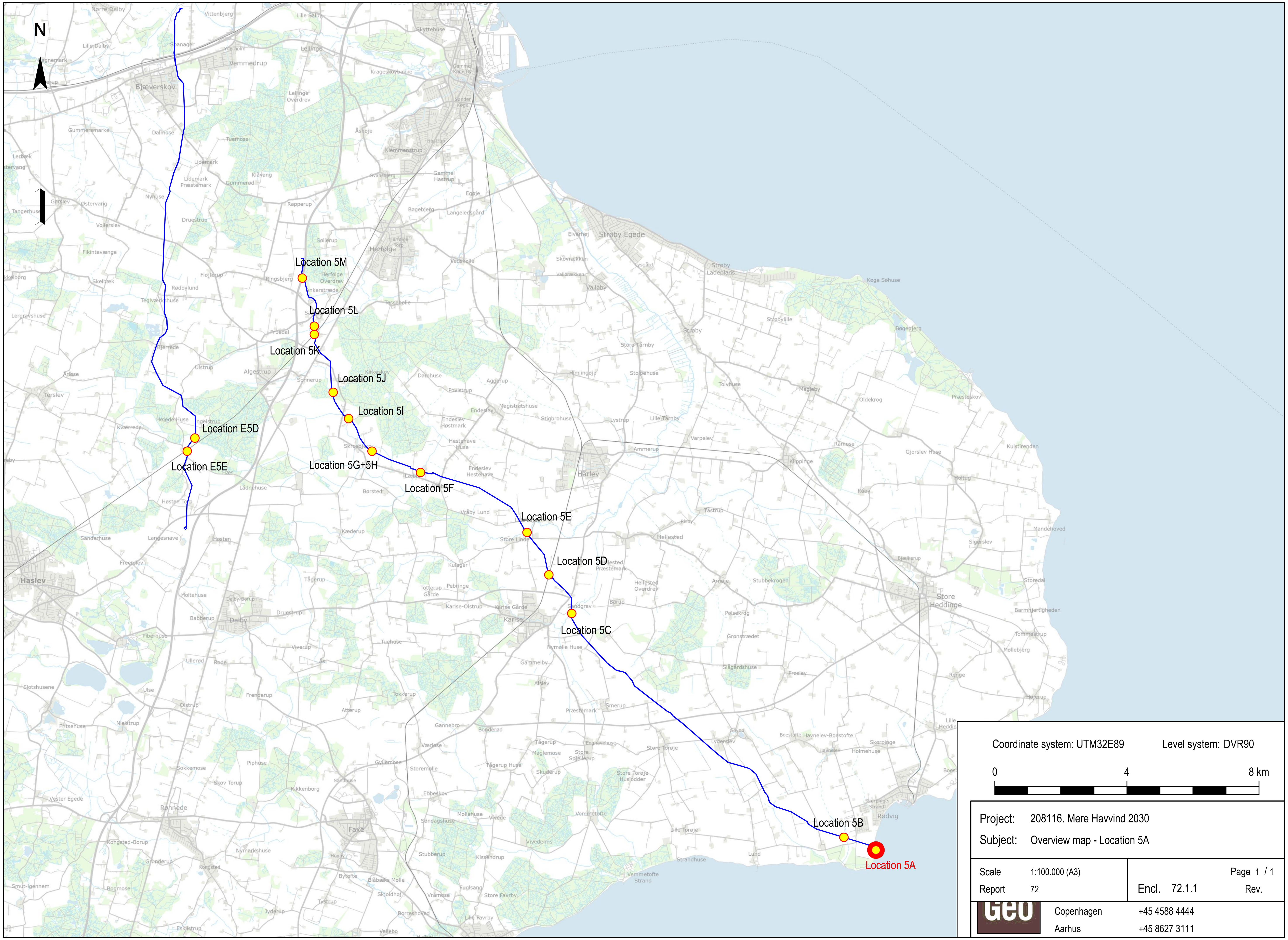
/5/ *Geomorphological map of Denmark 1:200.000*, version 3, GEUS, 2022

/6/ *Pre-Quaternary surface topography of Denmark 1:250.000*, GEUS, 1994

/7/ *Istiden i det danske landskab, Houmark-Nielsen M., Lindhard og Ringhof, 1. udgave, 1. oplag, 2021*

/8/ *Geologisk Set – Sjælland og øerne,* GEUS, GO Forlag og Geocenter Danmark, 1. udgave, 2017

/9/ *Samling af geologiske modeller for Sjælland og Lolland-Falster, FOHM – Fælles offentlig hydrologisk model,* Miljøstyrelsen 2025 (in prep.)



Coordinate system: UTM32E89   Level system: DVR90

0   4   8 km

Project: 208116. Mere Havvind 2030

Subject: Overview map - Location 5A

Scale	1:100.000 (A3)		Page 1 / 1
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GEO   Copenhagen +45 4588 4444
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Legend:

Borehole with CPT
a: Point no.
b: Terrain level

Planned cable route

Planned HDD

Location of longitudinal profile (Encl. 72.1.3)

Seabed level 0,5 m

Coordinate system: UTM32E89 Level: DVR90

0 80 160 m

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Subject: Landfall. Rødvig 5A	Report 72	Encl. 72.1.2 Rev.

Geo
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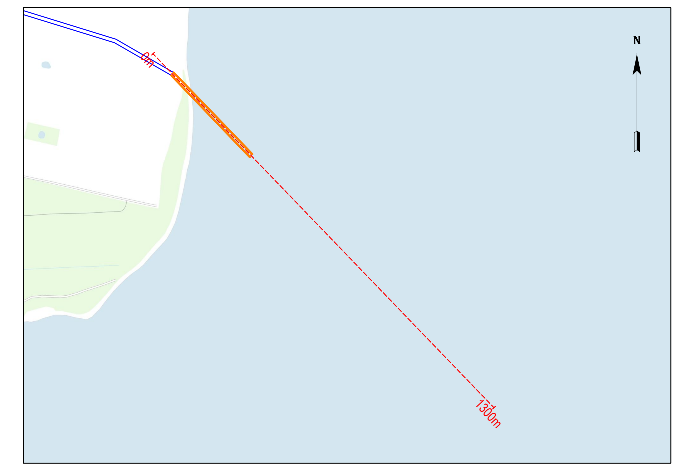

Legend:

- Top soil / Fill
- Sand / Gravel
- Clay till
- Silt
- Clay
- Clay/peat (postglacial)
- Limestone
- Terrain (Dansk Højde Model)
- Seabed level
- Borehole
- Cone penetration test, Tip resistance, q_c
- d:XXm Distance between ERT-line and borehole
- Planned HDD
- Interpretation of geological boundaries
- Highest measured groundwater level

Colorbar: Resistivity (Ohmm) 1 – 10 – 100 – 1000

x 1:500 — 0, 20, 40 m
y 1:200 — 0, 8, 16 m

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Subject: Longitudinal profile - Landfall. Rødvig 5A	Report 72	Encl. 72.1.3 Rev.

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Geo-Standard: Legend and Abbreviations

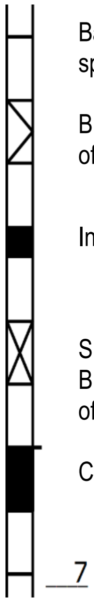
Borehole Profiles. Geotechnical, core and environmental

Description according to dgf-Bulletin 1, rev. 2, December 2021

Soil types

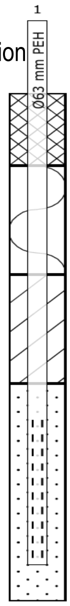
- Fill
- Flags / Concrete / Bedrock
- Mull / Top soil
- Humic
- Peat
- Peaty Gyttja
- Gyttja / Organic clay
- Plant remains
- Shells
- Slags
- Stone/Cobble
- Gravel
- Sand
- Silt
- Clay
- Limestone / Chalk
- Flint / Asphalt
- Sand till / Silt till (clayey, gravelly)
- Clay till (sandy, gravelly)

Samples



- Bag sample (disturbed), specific level
- Bulk sample (disturbed) of an interval, small bag
- Intact tube sample
- SPT sample or Bulk sample (disturbed) of an interval, large bag
- Core sample
- Additional laboratory tests ex. Sample 7

Pipe dimension and -type



Pipe dimension and type

Blind pipe

Screened pipe

Concrete

Backfill material

Sealing

Filter sand

Deposit

Ae	Aeolian (wind)
Br	Brackish
Fi	Fill
Fw	Freshwater
Gl	Glacier
Gr	Igneous/Bedrock
Ls	Landslide
Ma	Marine
Me	Metamorphic
Mw	Meltwater
Ss	Solifluction
Ts	Top soil
Vo	Volcanic
Wd	Wash down

Geological age

Re	Recent
Pg	Postglacial
Lg	Late glacial
Gc	Glacial
Ig	Interglacial
Is	Interstadial
Ng	Neogene
Pn	Paleogene
Mi	Miocene
Ol	Oligocene
Eo	Eocene
Pl	Paleocene
Sl	Selandian
Da	Danian
Ct	Cretaceous
Ju	Jurassic
Tr	Triassic
Si	Silurian
Ca	Cambrian
Pc	Precambrian

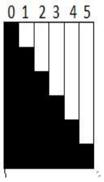
General abbreviations

sl.	slightly
v.	very
w.	with
lam.	lamina(e)
fragm.	fragments
biot.	bioturbation
bryo.	bryozoans
calc.	calcareous
noncalc.	non-calcareous
glauc.	glauconite
T	top of sample
B	bottom of sample

Core samples

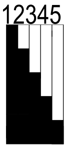
Recovery:	Ratio in percentage between sample length and length of core run (Total Core Recovery, TCR). Value appears at top of core run.
RQD:	Rock Quality Designation. Ratio in percentage between total length of core pieces with length more than 100 mm, and length of core run. Value appears at top of core run.

Fractures



0 = S0	Unfractured	No fractures
1 = S1	Very slightly fractured	20 - 60
2 = S2	Slightly fractured	10 - 20
3 = S3	Fractured	6 - 10
4 = S4	Very fractured	2 - 6
5 = S5	Crushed, blocky	< 2 cm

Induration



1 = H1	Unlithified	Can easily be shaped with fingers
2 = H2	Slightly indurated	Can easily be worked with knife
3 = H3	Indurated	Can be worked with knife
4 = H4	Strongly indurated	Can be scratched with knife
5 = H5	Very strongly indurated	Cannot be scratched with knife

Tests

c_{fv}	Field vane shear strength	(kN/m²)	Measured by vane test in undisturbed soil
c_{rv}	Field vane shear strength	(kN/m²)	Measured by vane test in remoulded soil
N	Standard penetrations test (SPT)		Number of blows per 0.3 m penetration of Ø51 mm SPT probe by use of the energy h · G = 0,76 m · 0,635 kN
w	Water content	(%)	Ratio between weight of water and weight of grains
w_p	Plastic limit	(%)	Water content at the boundary between semisolid and plastic state (NP: Non plastic)
w_L	Liquid limit	(%)	Water content at the boundary between plastic and liquid state
I_P	Plasticity index	(%)	$w_L - w_P$
γ	Unit weight	(kN/m³)	Ratio between total weight and total volume
e	Void ratio		Ratio between pore volume and grain volume
e_{max}	Void ratio, loosest state		Void ratio of very loose standard state
e_{min}	Void ratio, densest state		Void ratio of very dense standard state
I_D	Relative density		$(e_{max} - e)/(e_{max} - e_{min})$
ka	Carbonate content	(%)	Ratio between weight of carbonate and total grain weight
gl	Loss on ignition	(%)	Weight loss by prolonged and high heating, % of total grain weight

Additional tests

In situ tests:

PR	Pressuremeter
FH	Falling Head
PP	Pumping
EL	Elastometer
GA	Gammalog

Laboratory tests:

B	Brazil	S	Simple shear
C	Consolidation	T	Triaxial
D	Specific gravity	U	Unconfined compression
E	e_{max} and e_{min}	V	Shear box
F	Photo	W	Vibration compaction
G	Grain size analysis	SP	Standard proctor test
P	Point load	MP	Modified proctor test

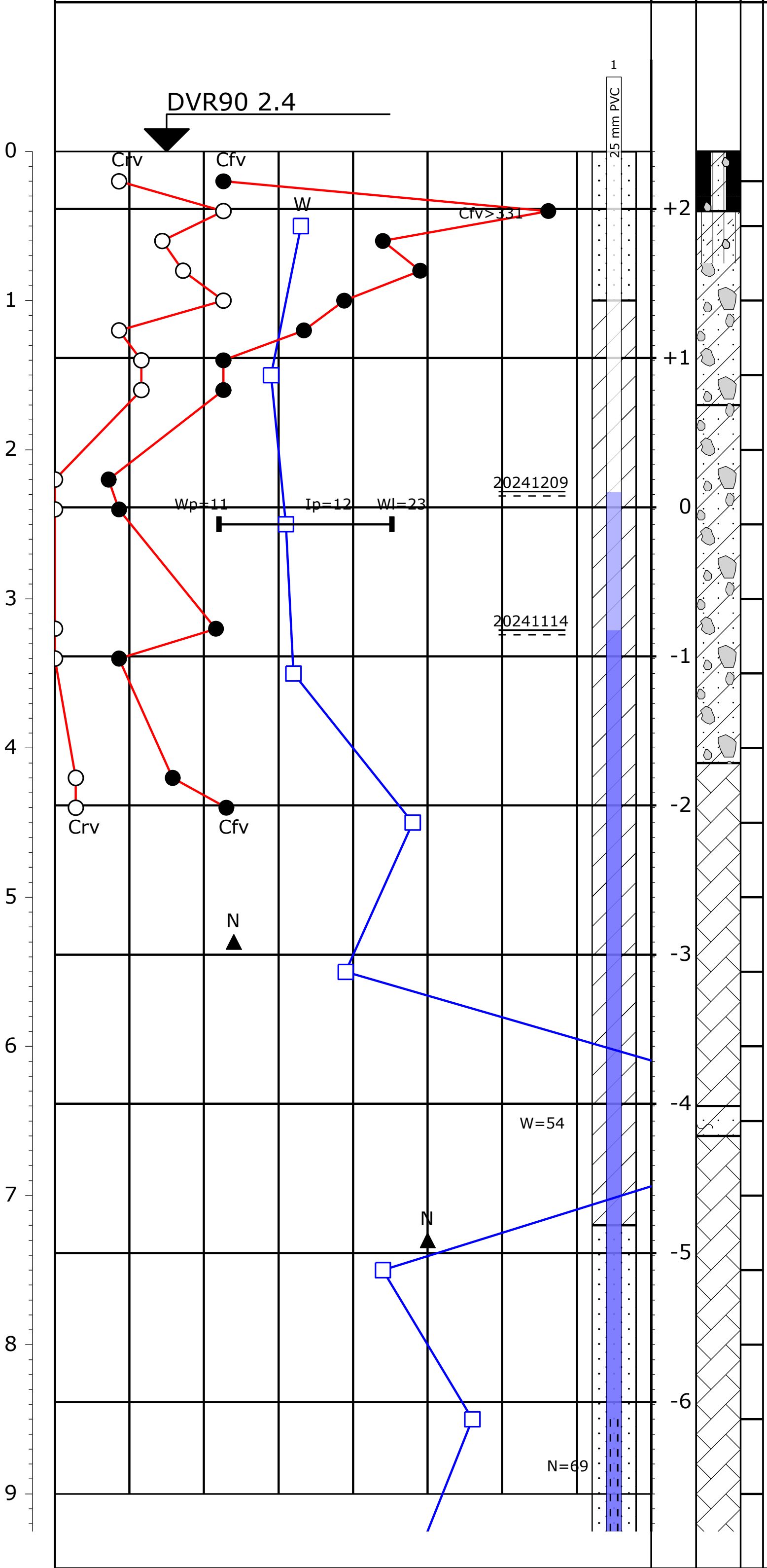
References

Danish Standard:
DS/EN 1997-1:2007 – Geoteknik-Del 1

Danish Geotechnical Society:
- ”A guide to engineering geological soil description” (dgf-Bulletin 1, rev. 2, December 2021)
- ”Felthåndbogen” (dgf-Bulletin 14)

Danish Geotechnical Society:
- ”Laboratoriehåndbogen” (dgf-Bulletin 15)
- ”Referenceblad for vingeforsøg”
- ”Referenceblad for SPT-forsøg”

Depth (m)	Test results	Level (m)	Geology	Sample



No.	Geological Description	Env.	Age
1	FILL: MULL: CLAY, low plasticity, sandy, sl. gravelly, noncalcareous, w. few root fragments, dark brown	Fi	Re
2	FILL: CLAY, low plasticity, silty, sandy, gravelly, noncalcareous, w. mull streaks, w. ochre stains, inhomogeneous, olive brown	Fi	Re
3	CLAY TILL, medium plasticity, sandy, sl. gravelly, noncalcareous, w. ochre stains, olive brown	Gl	Gc
4	CLAY TILL, medium plasticity, sandy, sl. gravelly, calcareous, greyish brown	Gl	Gc
5	CLAY TILL - -	Gl	Gc
6	CLAY TILL, medium plasticity, silty, sandy, sl. gravelly, calcareous, w. weathered stone, greyish brown	Gl	Gc
7	CLAY TILL, medium plasticity, silty, sandy, sl. gravelly, calcareous, greyish brown	Gl	Gc
8	CLAY TILL - -	Gl	Gc
9	CLAY TILL - -	Gl	Gc
10	LIMESTONE, unhardened w. hardened parts, sandy, muddy, with black flint, w. ochre stains, light olive brown (Bryozoan limestone)	Ma	Da
11	LIMESTONE - -	Ma	Da
12	LIMESTONE, unhardened w. hardened parts, sandy, muddy, very pale brown (Bryozoan limestone)	Ma	Da
13	LIMESTONE, hardened w. unhardened parts, sandy, muddy, with black flint, very pale brown (Cerithium limestone)	Ma	Da
14	CLAY, high plasticity, sandy, calcareous, organic, w. ochre stains, dark brown - reddish brown (fish clay)	Ma	Da/ Ct
15	LIMESTONE, unhardened w. hardened parts, sandy, muddy, white (chalk)	Ma	Ct
16	LIMESTONE, unhardened w. hardened parts, very sandy - sandy, very muddy, white (chalk)	Ma	Ct
17	LIMESTONE, unhardened, sandy, very muddy, white (chalk)	Ma	Ct
18	LIMESTONE, unhardened w. hardened parts, sandy, very muddy, with black flint, white (chalk)	Ma	Ct
19	LIMESTONE - -	Ma	Ct

Continues

□	10	20	30	W (%)
○ ●	100	200	300	Crv, Cfv (kN/m²)
▲	10	20	30	N (Blow/30 cm)

Soil description acc. to dgf-Bulletin 1, Revision 2, December 2021.

Coordinate system: UTM32E89
X : 713491 (m) Y : 6126842 (m)

Job: 208116 Energinet. Mere Havvind 2030

Drilled by: Geo KEJ/MJA Date: 2024-11-13 Geology by: LCH Borehole: 5A.01

Method: Cased Shell & Auger 6'' DGU no: Encl. No.: 72.2.1 Rev.: 0 P. 1/2

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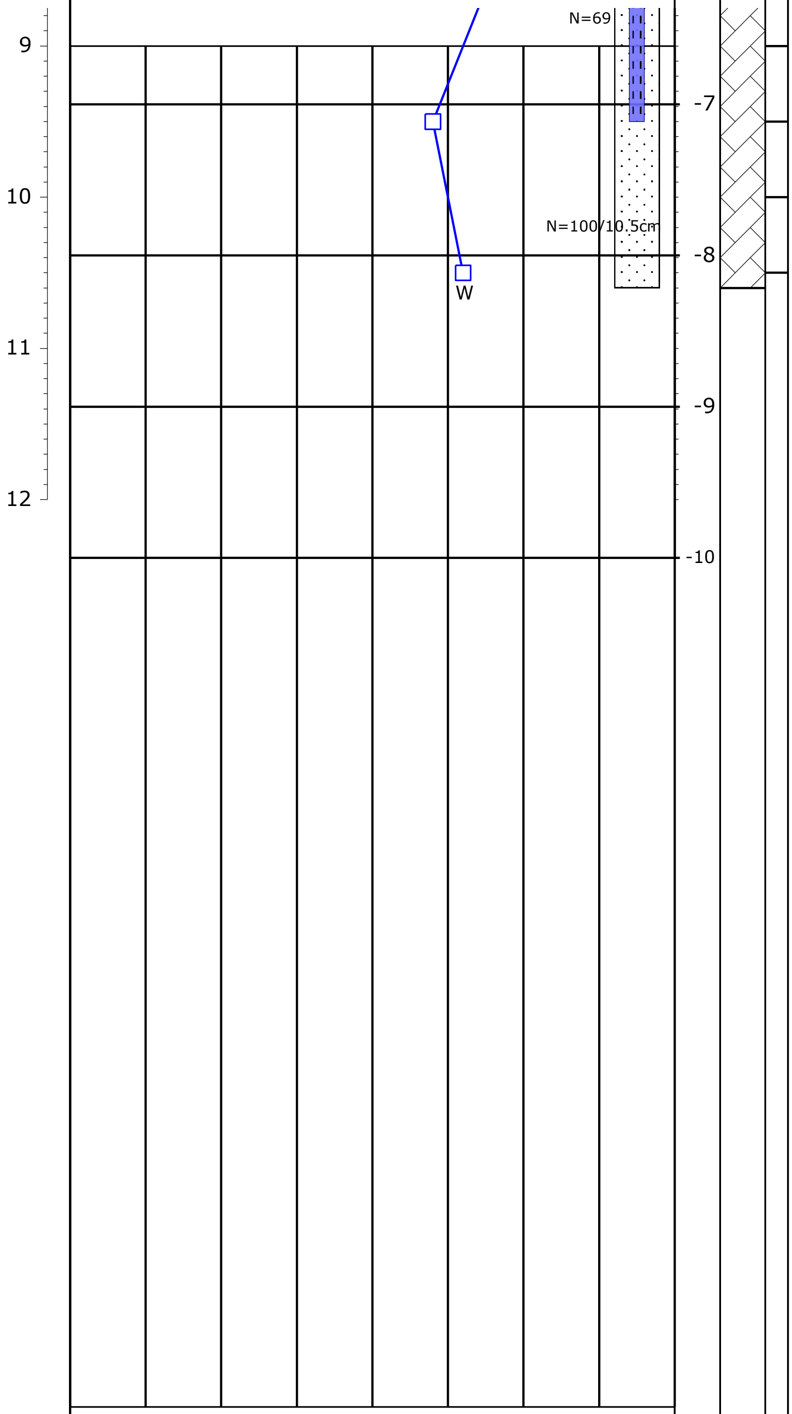
Profile

Depth (m)	Test results	Level (m)	Geology	Sample	No.	Geological Description	Env.	Age
						Continued		
					19	LIMESTONE - -	Ma	Ct
					20	LIMESTONE - -	Ma	Ct
					21	LIMESTONE - -	Ma	Ct
					22	LIMESTONE - -	Ma	Ct



Till deposits may contain cobbles and boulders

□	10	20	30	W (%)
○ ●	100	200	300	Crv, Cfv (kN/m²)
▲	10	20	30	N (Blow/30 cm)

Soil description acc. to dgf-Bulletin 1, Revision 2, December 2021.

Coordinate system: UTM32E89
X : 713491 (m) Y : 6126842 (m)

Job: 208116 Energinet. Mere Havvind 2030

Drilled by: Geo KEJ/MJA Date: 2024-11-13 Geology by: LCH Borehole: 5A.01

Method: Cased Shell & Auger 6'' DGU no: Encl. No.: 72.2.1 Rev.: 0 P. 2/2

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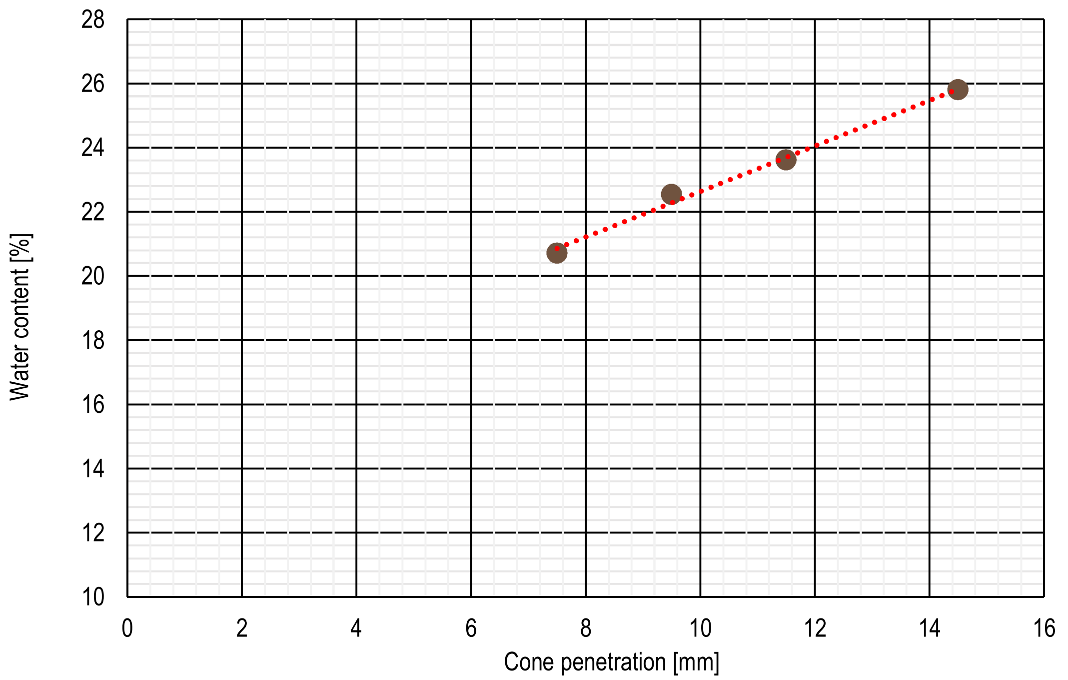
Profile

Liquid Limit, Plastic Limit and Plasticity Index of Soils - Fall-Cone Method

Identification		**Geological description**
Borehole	5A.01	CLAY TILL, medium plasticity
Specimen no.	6	
Depth [m]	2,50	



Results

Initial water content	$w_{initial}$	[%]	14,7
Liquid limit	w_L	[%]	22,6
Plastic limit	w_P	[%]	11,0
Plasticity Index	I_P	[%]	11,6
Particles >0.425 mm	-	[%]	13,4

Notes

Standard

Testing is carried out in accordance with DS/CEN ISO 17892-12:2018 - Fall-Cone Method.

Risk Assessment - Horizontal Directional Drilling

Risk	Consequence (s)	Category	Degree of Risk		Countermeasure (s)	Residual Risk	
			C	L		C	L
Horizontal Directional Drilling							
Difficult/challenging access to the drilling pits due to soft terrain / slippery surface. Especially in depressions, near streams combined with high precipitation periods.	Drilling supplier / equipment getting stuck in the field	I/T/F	1	D	Steel plates can be used to secure access.	1	A
Drilling equipment hitting large boulders, bigger than 20 cm in diameter in till or flint layers in limestone.	Drilling stops	T/F	3	B	Drilling supplier must have a procedure of action in place if this occurs.	3	B
Unstable borehole Especially in areas with broken/fractured limestone	Drilling borehole collapse and causes minor settle-ments of surface Drilling speed decreases / stops	F/T	3	D	Drilling supplier must use a suitable drilling mud to pre-vent collapse of the borehole. The drilling mud can have additive suitable to the soil conditions.	3	A
Very permeable soils (with and without groundwater pressure) causing loss of drill mud / dilution of drilling mud	Reduce lubricating effect (additives) Drilling mud leaks out in the formation and can cause unstable borehole	T/E	2	C	Drilling supplier has to be prepared for an increased con-sumption of drilling mud and handling of excess mud/wa-ter. Use a thick drilling mud if necessary.	2	A
Use of additive in the drilling mud	Additive (chemicals) and can cause pollution of the surrounding soil and water environment.	E	3	B	Drilling supplier must only use additive suitable for the specific soil formation and has to make sure that the ad-ditive are approved/documented for the project.	3	A

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Risk	Consequence (s)	Category	Degree of Risk		Countermeasure (s)	Residual Risk	
			C	L		C	L
Blowout	Unintended loss of drilling mud to terrain or water environment.	T/F/E	4	C	Drilling supplier has to monitor/observe/detect if there is a sudden pressure drop during the drilling works and have a procedure of in action if blowout happens (ex. small decompression holes). Reduce the length of the cable route, because long cable routes have higher risk of blowout due to the higher pressure in the drilling mud. Investigation points (boreholes/CPT) are placed in a secure distance from the planned HDD line. Ensure sufficient depth of HDD, especially when crossing beneath a stream.	3	B
HDD is too close to the surface	Settlements of surrounding terrain, constructions/roads/railway etc. Blowout	F/E	4	C	Carefully planning location of the drilling pits, length and depth of the HDD below terrain, existing constructions, roads, streams, railway etc.	4	B
Very permeable limestone with groundwater pressure makes the drilling mud thinner	Reduce lubrication effect	T/E	1	C	Carefully planning of HDD and ensure sufficient depth.	1	B
Flooding of drilling pit due to heavy precipitation, insufficient lowering/draining of the groundwater table etc.	Drilling stops until pit is drained Loss/damaged of equipment	I/T/F	4	C	Establishing a water lowering/draining system prior to start of drilling. Execution of drilling from terrain if possible.	4	B

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Severity of Consequence (C)					Increasing Likelihood (L)→				
Rating	**Injury /illness** abbreviation (I)	**Property/ Financial** abbreviation (F)	**Time/Quality** abbreviation (T)	**Environment** abbreviation (E)	**Rare** May occur but only in exceptional circumstances (ie. Never heard of in the Industry)	**Unlikely** Could occur in some circumstances (ie. Heard of in the Industry)	**Possible** Might occur in some circumstances (ie. Has happened in the Organisation or more than once per year in the Industry	**Likely** Will probably occur in most circumstances (happened at a Location or more than once per year in the Organisation)	**Almost Certain** Is expected to happen in most circumstances (ie. Has happened more than once per year in the Location)
					A	**B**	**C**	**D**	**E**
5	Multiple fatalities	Extensive damage Incurred significant financial loss	Serious Breach	Massive effect	Medium	High	High	High	High
4	Permanent total disability or 1 fatality	Major damage Substantial financial loss incurred	Major Breach	Major effect	Low	Medium	High	High	High
3	Major health effect / injury	Localised damage. Moderate financial loss incurred	Considerable impact	Localised effect	Low	Medium	Medium	Medium	High
2	Minor health effect / injury	Minor damage. Minor financial loss incurred	Limited impact	Minor effect	Low	Low	Medium	Medium	High
1	Slight health effect / injury	Slight damage Low financial loss incurred	Slight impact	Slight effect	Low	Low	Low	Low	Medium

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Rating	Injury/illness	Property – Premises, and 3rd party	Time/Quality	Environment
5	**Multiple fatalities** - From an accident or occupational illness	**Extensive damage** - Substantial or total loss of operation. Incurred significant financial loss		**Massive effect** - Persistent severe environmental damage or severe nuisance over a large area. Loss of commercial, recreational use or nature conservancy, resulting in major financial consequences for the company. Ongoing breaches well above statutory or prescribed limits.
4	**One to three fatalities or permanent total disability** - From an accident or occupational illness. Irreversible health damage with serious disability or death	**Major damage** - Partial operation loss, 2 weeks shutdown, Substantial financial loss incurred	**Major impact –** Partial operation loss, 2 weeks shutdown, Extensive adverse effect on quality. Potentially restrictive measures and/or impact on grant of licences. Mobilisation of action groups	**Major effect** - Severe environmental damage. The company is required to take extensive measures to restore the contaminated environment. Extended breaches of statutory or prescribed limits, or widespread nuisance.
3	**Major injury or health effects** (including Permanent Partial Disability) - Affecting work performance in the longer term, such as a prolonged absence from work. Irreversible health damage without loss of life, e.g. noise induced hearing loss, chronic back injuries	**Moderate damage** - Partial shutdown Moderate financial loss incurred	**Considerable impact –** Partial shutdown Extensive adverse effect on quality. Mobilisation of action groups	**Localised effect** - Limited discharges affecting the neighbourhood and damaging the environment. Repeated breaches of statutory or prescribed limit, or many complaints.
2	**Minor injury or health effects** - Affecting work performance, such as restriction to activities (Restricted Work Case) or a Lost Time Injury. Limited health effects which are reversible, e.g. skin irritation, food poisoning	**Minor damage** - Brief disruption, Minor financial loss incurred	**Limited impact –** Brief disruption Multiple Stakeholder upset	**Minor effect** - Sufficiently large contamination or discharge to damage the environment, but no lasting effect. Single breach of statutory or prescribed criterion, or single complaint.
1	**Slight injury or health effects** (including first aid case and medical treatment case and occupational illness) - Not affecting work performance or causing disability	**Slight damage** - No disruption to operations, Low financial loss incurred	**Slight impact** – No disruption to operations Individual Stakeholder upset	**Slight effect** – Slight environmental damage, within the fence and within systems. Negligible financial consequences