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HESSELØ EXPORT CABLE ROUTE

BURIAL ASSESSMENT STUDY

RAMBØLL

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BURIAL ASSESSMENT STUDY

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1. EXECUTIVE SUMMARY

An export cable route (ECR) is planned, connecting the Hesselø OWF in Kattegat to the Danish onshore electrical grid. The cable route has an accumulated length of approximately 70 km.

Acquired seabed survey and geotechnical data have been assessed to find the most suitable methods for installation and burial of the cable below the seabed. The subdivision of the ECR is illustrated with KP points in section 7.5.4.

Various installation methods have been evaluated, based on the encountered soil conditions. In general, the soil conditions are very variable along the cable route. Some areas are dominated by unevenly eroded surface of Glacial tills or Late glacial sands, overlaid by Post Glacial deposits. Other areas show thick successions of extremely soft postglacial clays.

With regards to boulders, the most conspicuous features are the dense boulder fields towards land where boulders built up reefs and a less dense field on the western branch of the ECR.

There is a low to moderate risk of encountering Unexploded Ordnance on site. The risk is primarily due to the presence of Allied Mine Fields from World War Two.

Vessel traffic and fishing activities are assessed to have limited or no impact on the installation, however the occurrence of marine mammals (seals) and military areas (restricted/danger) must be considered.

An analysis of available survey data from 2020, and all other relevant data, has been evaluated with the following conclusion for trenching and burial methodology:

ECR section	Soil conditions	Burial depth	Recommend Trenching and Post Lay Burial Solution
A	Eroded glacial till and post glacial deposits	1.1m	Dredging/pre-trenching from barge or vessel
B	Transition zone, from glacial till to late glacial deposits	1.1/>2.5m	Dredging/pre-trenching from barge or vessel changing to flying / heave compensated' jetting machine solution
C	Relatively thick succession of post glacial deposits	>2.5	'Flying / heave compensated' jetting machine solution/dredging
D	Eroded glacial till and post glacial deposits	>2.5	Dredging/pre-trenching from barge or vessel
E	Relatively thick succession of post glacial deposits	>2.5	'Flying / heave compensated' jetting machine solution/dredging
F	Thick succession of post glacial clay	>2.5	'Flying / heave compensated' jetting machine solution.
G	Thick succession of post glacial clay	>2.5	'Flying / heave compensated' jetting machine solution.
SS_E	Thick succession of post glacial clay	>2.5	'Flying / heave compensated' jetting machine solution.
SS_W	Thick succession of post glacial clay	>2.5	'Flying / heave compensated' jetting machine solution.

2. INTRODUCTION

Energinet is planning an export cable between Gilleleje and the upcoming offshore windfarm at Hesselø. The investigations include geophysical survey, onshore airborne lidar survey and geotechnical investigations.

The Burial assessment study (BAS) is based on reporting of geophysical and geotechnical data from 2020 acquired by Rambøll on behalf of Energinet.

The 2020 campaign comprised the following:

- Side Scan Sonar (SSS) and Sub Bottom Profiling (SBP)
- Magnetometry (MAG) and Multibeam Echo Sounder (MBES)
- Airborne Lidar (Light Detection And Ranging) mapping
- Grab sampling
- Vibrocores
- CPT

The aim of the investigations is to provide greater knowledge of the nature of the seabed, sedimentary materials and environmental conditions prior to installation of new export cable. The survey must map the static and dynamic elements of the seabed and upper soil stratification to ca. 10m below seabed.

The current assessment is taking into account the following:

- Bathymetry
- UXO desk top study
- GEUS desktop study
- Seabed surface geology and interpreted geophysical/geological/geotechnical data
- Fugro survey of the site area

Furthermore, the study discusses in general terms vessel traffic, fishing and hazard identification which may have an impact on the routing and burial of the cables.

The presented detailed analysis of the seabed conditions along the cable route, and within the surveyed cable route corridor, has special focus on the trenchability of the seabed within the recommended/required burial depths, the potential impact of vessel traffic and fishing activities, the thermal properties of the sediments, plus other potential man-made or natural obstacles along the route. Based on these parameters the cable route has been divided into distinct sections, and a recommendation of the burial methodology and burial depths has been provided for each cable section.

3. PROJECT DESCRIPTION

In June 2020 the Danish Parliament decided to commence the development of the offshore wind farm (OWF) project, Hesselø aiming for a capacity of ca. 1000 MW. It is planned to build and connect the OWF to the Danish onshore electrical grid from 2023 to 2027.

The OWF site is located in the inner Danish sea, Kattegat, and has been subject to screening studies. The OWF site is planned to be connected with the Danish mainland at the island, Sjælland, located ca. 30km-40km south of the OWF site. The locations of the windfarm site and the export cable route are illustrated in Figure 3-1.

The area of investigation subject to the present assignment is defined by the cable RPL and the cable route corridor. The cable route has a cumulated length of ca. 70 km. The corridor width has a nominal width of 1000m with local extensions up to 1400 m.

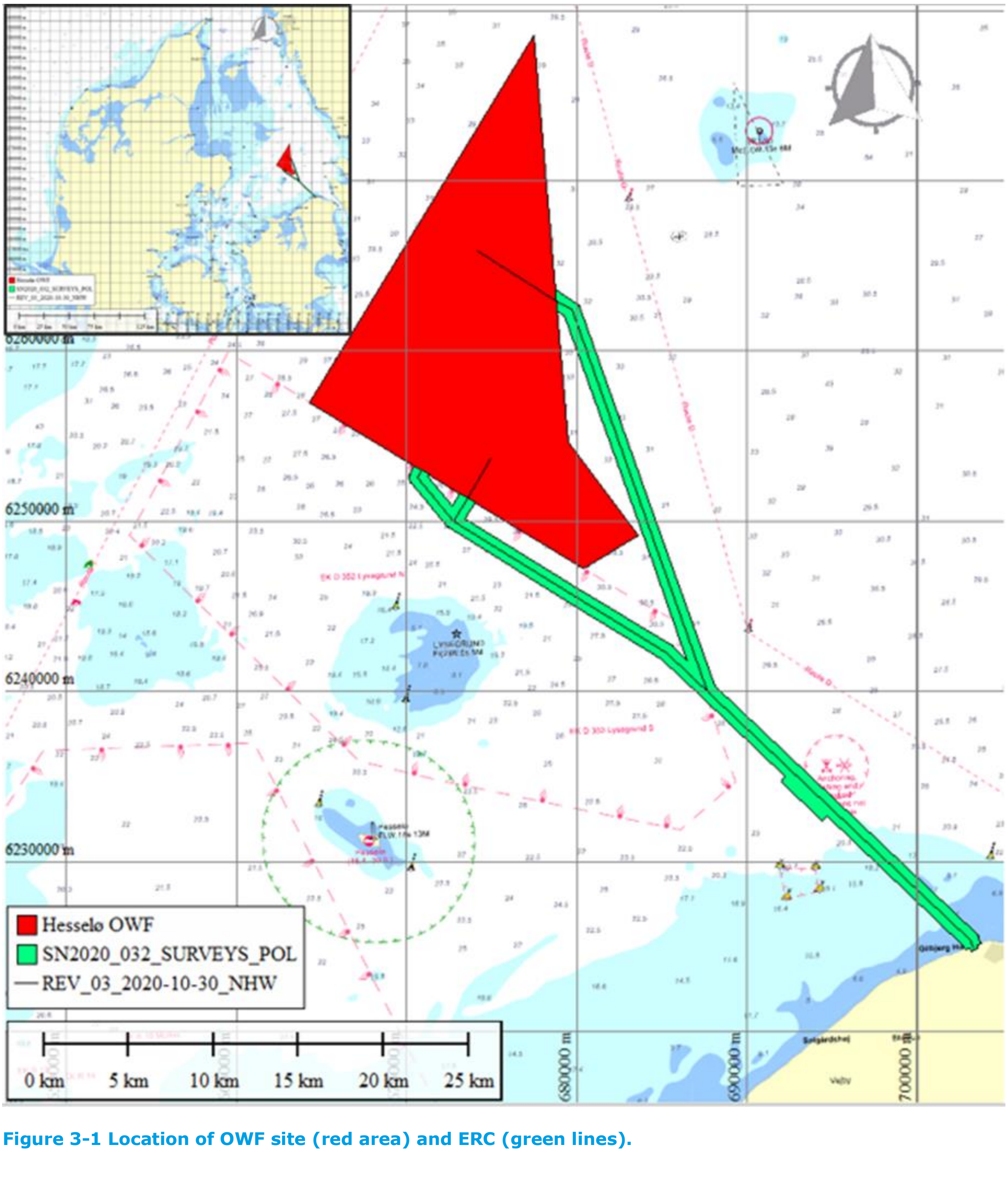

Figure 3-1 Location of OWF site (red area) and ERC (green lines).

The corridor which represents the Hessel Export Cable Route is divided into twelve blocks ranging from GL01 to GL12 where GL01 is the block closest to the landfall at Gilleleje. An overview of the survey blocks is seen in Figure 3-2. Further, the conditions at the two connections from the ECR to the two substations are considered, cf. Figure 3-3.

The RPL (Route Position List) for the Hesselø ECR is found in Appendix 3.

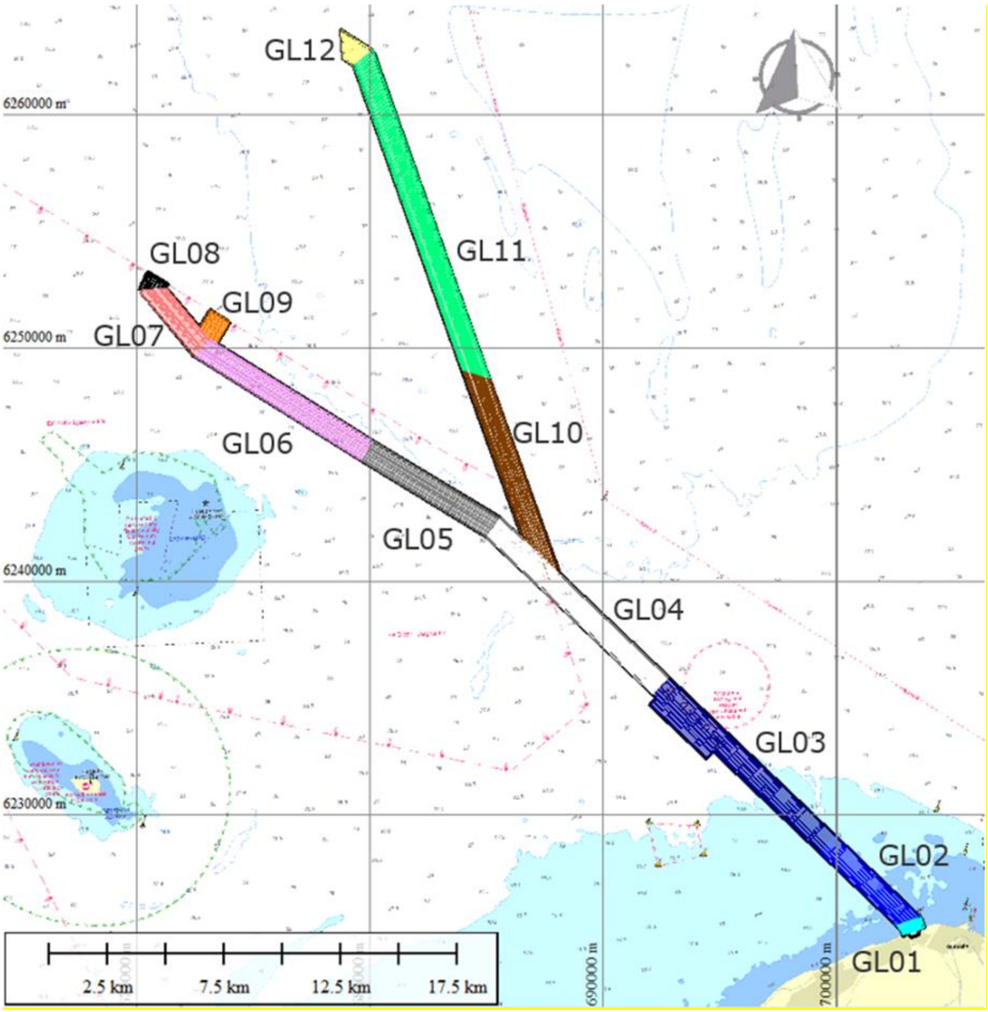

Figure 3-2 ECR, overview of survey blocks

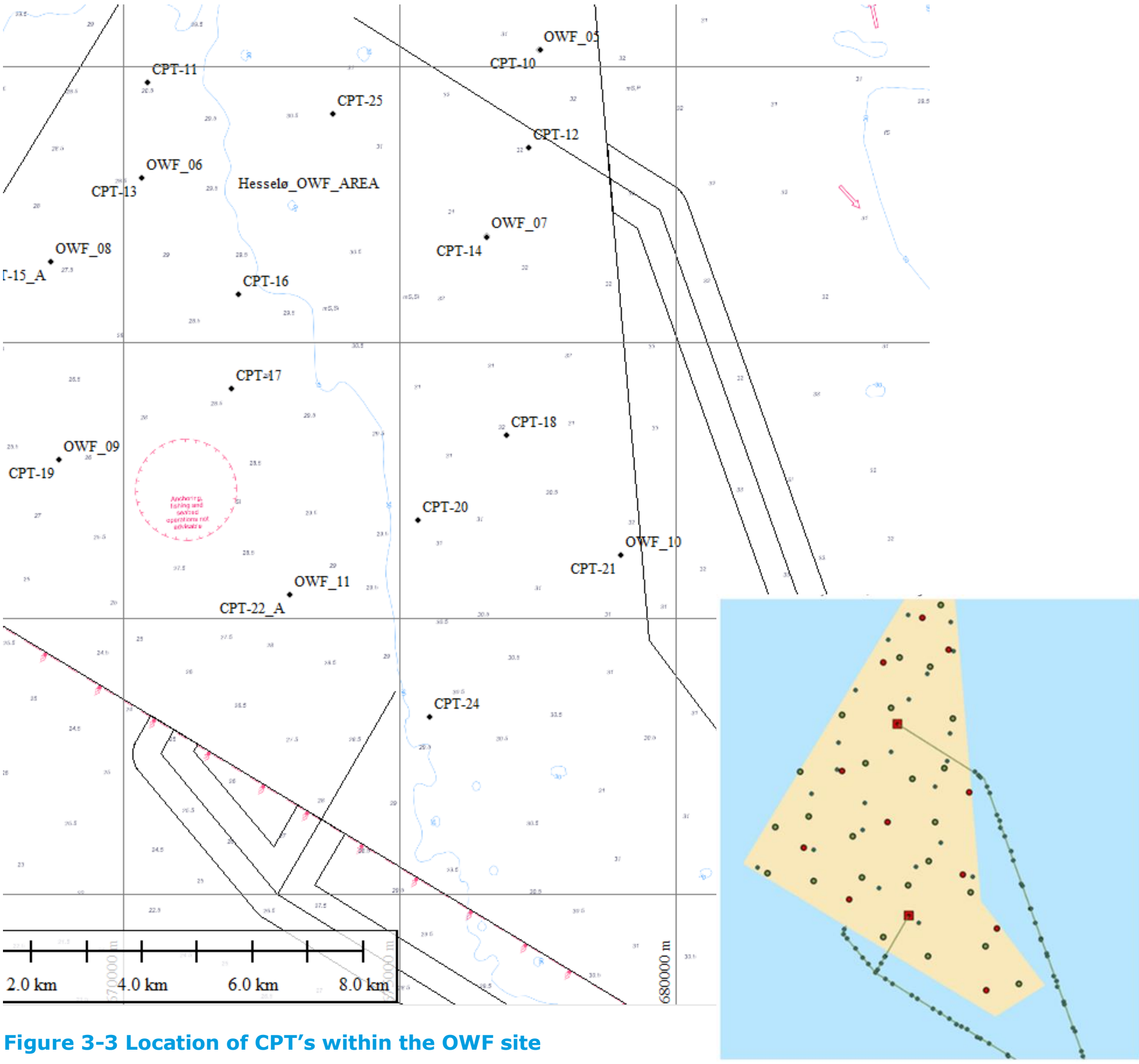

Figure 3-3 Location of CPT's within the OWF site

3.1 Geodetic reference systems

All coordinates in charts and data are referenced to coordinate system UTM 32N and datum ETRS89. All elevations are referenced to DTU18

4. AVAILABLE DATA

4.1 Background data

The following background data and reports have been used for this Burial assessment study:

- Cable trajectory is provided by Energinet

4.2 Survey data, cable route

The Hesselø export cable route has been subject to a seabed survey in 2020 by Rambøll /Ref. 1 /. The Burial assessment study is primarily based on data from this survey.

The functional requirements were:

- Accurate bathymetric data and charts in the surveyed area.
- Morphology and natural features of the seabed surface such e.g. as mega-ripples, sand-waves, boulders, outcropping geology, seaweed and reefs.
- Possible man-made features such as wrecks, debris, fishing gear, trawl marks, anchor scars, objects of potential archaeological interests and UXOs.
- Features of potential conservation interest including but not limited to; sandbanks, gravel reef, cobble reef, rocky reef and biogenic reef structures.

The survey data consisted of:

- Geophysical survey
- GEUS desktop study
- Geotechnical investigations (CPT, Vibrocores, grab sampling)
- Geophysical data: Side Scan Sonar (SSS), Multi-Beam Echo-Sounding (MBES), Sub Bottom Profiling (SBP) and Magnetometer (MAG)
- Lidar data
- Geophysical and geotechnical reporting
- Fugro survey of the site area

Further, Ramboll has conducted an interpretation of the geotechnical data ref. /1/ to assess the strength of the soils. This interpretation forms the base of the assessment of the proposed burial method.

4.3 Survey data, site

For the site, the survey was carried out by Fugro, ref. /8/. This data is used for assessing the ground conditions at the East and West substations.

4.4 Geotechnical investigation, ECR

The soil investigation campaign carried out by Rambøll comprises:

- Vibrocore sampling and CPT at 60 positions (ECR)
- Grab sampling at 55 positions (54 were successful)

The vibrocores and CPT's aim at determining the soil conditions down to a target depth of 3 or 6 m depth. The grab samples aim at determining the soil conditions at the seabed level.

With respect to the vibrocores, it should be noted that for some positions, the penetration is considerably longer than the recovered core length. For other positions, more core length is recovered, compared to the penetration. This is related to two phenomenon's which are very common when retrieving vibrocores from very soft clays or very dense sands. The differences can be explained by:

- Core loss/compaction due to very soft soil, typically soft clay. The penetration is longer than the actual core length and air gaps may be seen in the cores. The locations where this occurs coincides with very low strength seen on the corresponding CPT
- Core gain due to bulking of relatively dense sand layers. When the vibrocore is retrieved, the sand gets looser, leading to additional core length observed, compared to the penetration.

This has been taken into account in combination with e.g. the seismic data during interpretation of the soil model. The vibrocore profiles and the GeoGIS2020 database reflects the data as recorded in the laboratory.

4.5 Geotechnical investigation, OWF

The soil investigation campaign carried out by Gardline. This data is used for assessing the ground conditions at the East and West substations.

5. GEOLOGICAL SETTING

5.1 Background knowledge

The Hesselø OWF cable corridor is situated in the southern Kattegat. The area has been previously investigated in relation to i.a. establishing the adjacent Anholt OWF and exploration for marine materials. Based on the available data, a desk study presenting geological framework for the region has been prepared by GEUS. Further details regarding the desktop study are found in /2/.

Both the Hesselø OWF and the cable corridor are located within the Sorgenfrei-Tornquist zone, where numerous extensional and strike-slip faults run generally in the NW-SE direction. The Sorgenfrei-Tornquist zone is an active tectonic zone and earthquake activity is still being observed. Reactivation along the existing basement fractures has been pointed out as one of geotechnical challenges in the study prepared by GEUS. Figure 5-1 shows the location of major faults within the study area.

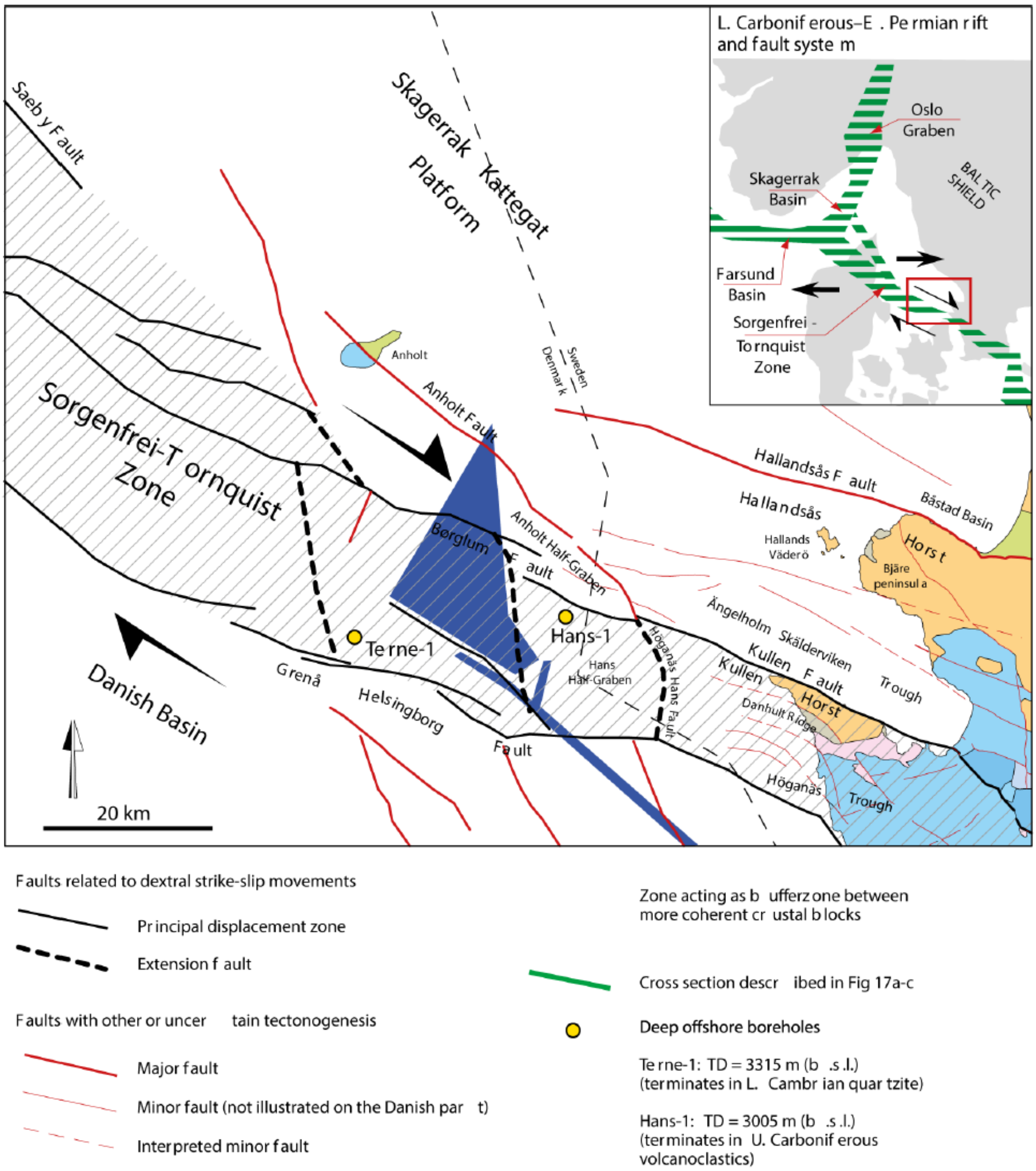

Figure 5-1 Tectonic framework for the southern Kattegat: location of major faults forming part of the Sorgenfrei-Tornquist Zone within the study area

The top pre-Quaternary surface is found at relatively large depths below the seabed and significantly below the survey investigation depth.

The Quaternary sediment cover in the Kattegat region is thick and composed of Eemian and Weichselian glacial and interglacial deposits overlain by successions of Late Weichselian glaciomarine and Holocene marine sediments.

After the gradual retreat of the ice sheet the region was subjected to isostatic depression that led to relatively high sea level despite of eustatic sea level being at low. The area was inundated and became part of a relatively open area towards the northwest marine basin were glaciomarine conditions prevailed. A thick succession of Late Glacial glaciomarine sediments dominated by fine-grained clays can be found on top of glacial tills. The southernmost part of the Hesselø OWF area and the associated cable corridor is located in the marginal part of the southern Kattegat late glacial glaciomarine basin deposition area.

A global eustatic sea level rise followed the period of deglaciation. However, the faster glacio-isostatic rebound of the crust resulted in a fall of the relative sea level in the Kattegat and Baltic Sea. The initial Late Weichselian highstand was therefore followed by a forced regression and significant erosion of the Late Glacial deposits. Within the study area the upper boundary of the Late Glacial glaciomarine succession is marked as a pronounced erosional unconformity.

When the eustatic sea-level surpassed the isostatic rebound, the relative sea level begun to rise – which in Kattegat was dated to about 11.4 ka BP. This regional marine inundation marks the beginning of the Littorina transgression, and the increasing relative sea level resulted in, amongst other changes, alterations to the hydrographical conditions of the Kattegat region and led to deposition of marine muds/gyttja in the deeper parts of the Kattegat.

During the early Holocene, at the beginning of the marine transgression a tidally dominated estuary with fine grained infill and large tidal mouth bars and banks developed just south-west from the Hesselø OWF cable corridor (Figure 5-2).

The Hesselø OWF area has been submerged most of the time after the last deglaciation, but in the lowstand period around 10.5 ka BP only partly, and lowstand sediments can be found. Already in the initial phase of the Holocene transgression the Hesselø OWF area was again fully submerged. The cable corridor area has a longer transgression history with postglacial marine sediments being very thin or absent in its southernmost part.

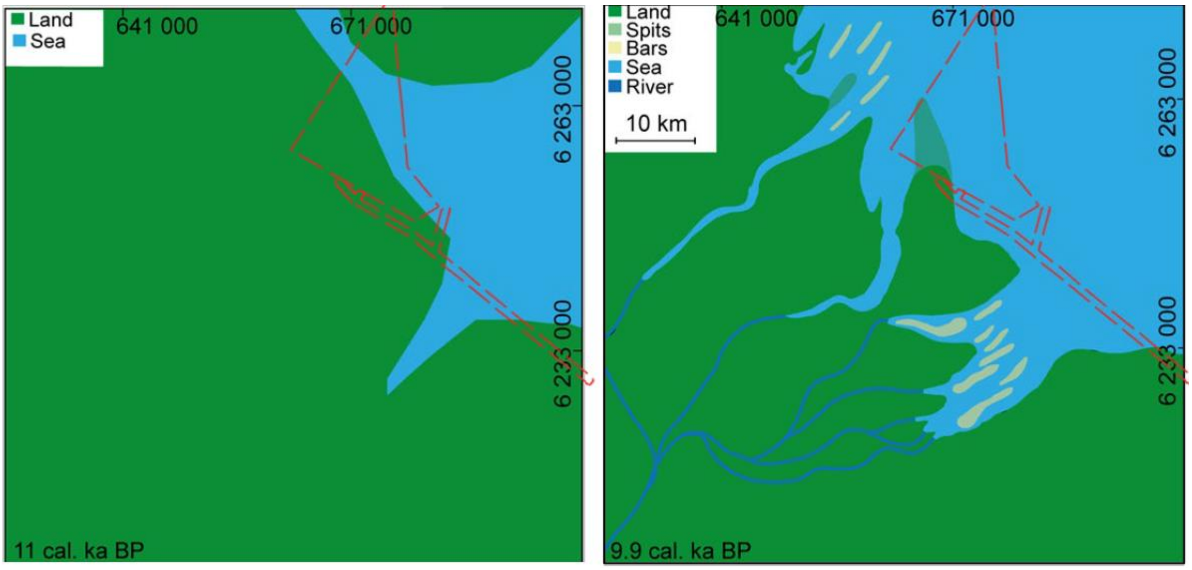

Figure 5-2 Paleogeography of the study area during the Early Holocene lowstand (11 ka BP) and early transgression (9.9 ka BP)

As a result of previous studies, the Quaternary succession has been divided into three main geological units: GL (Glacial), LG (Late Glacial) and PG (Post Glacial). A short summary of the seismic facies units is presented in the Table 5-1.

Table 5-1 Geological unit division of the Quaternary succession based on background knowledge.

Unit	Age	Lithology	Description/ depositional environment
PG Post Glacial	PG III	Holocene (most recent)	Structureless clay to fine sand
	PG II	Holocene	Interlayered medium and coarse-grained sand layers and laminated silt to clay
	PG I	Early Holocene	Medium- to coarse grained sand, may contain cobbles and pebbles. Fining upwards.
LG Late Glacial	Late Weichselian	Clays with dropstones, might include thin layers of coarser sediments, silt to sand. Generally weakly laminated to structureless.	Late Weichselian highstand sediments deposited in glaciomarine environment during the local highstand caused by depression from the Weichselian ice sheet. Found both in the basin areas as well as in the deeply eroded channels and reaching significant thicknesses of up to 75m /3/. As the highstand was followed by a regression and significant erosion of the LG deposits marked as a pronounced erosional unconformity.
GL Glacial	Weichselian	Glacial till	In the southernmost part of the southern Kattegat glacial sediments are represented by tills from the Weichselian glaciation.

5.2 Observed geological conditions along the cable corridor

Interpretation of the recorded Sub-bottom profiler (SBP) data has been performed in the whole survey area. Vibrocores, CPT's as well as grab sampling results have been used to support the interpretation.

A summary of the interpreted horizons is shown in the following Table 5-2.

Table 5-2 Summary of the mapped geological units and interpreted horizons, ECR

<table>
<tr><th colspan="3">Geological unit</th></tr>
<tr><td rowspan="6">Post Glacial (PG)</td><td colspan="2">PG IV SA (Coarse sand and gravel)</td></tr>
<tr><td rowspan="2">PG III</td><td>PG III.1 SA (Sand)</td></tr>
<tr><td>PG III.2 CL (Clay)</td></tr>
<tr><td rowspan="2">PG II</td><td>PG II.1 SA (Sand)</td></tr>
<tr><td>PG II.2 CL (Clay)</td></tr>
<tr><td colspan="2">PG I SA (Sand)</td></tr>
<tr><td rowspan="2">Late Glacial (LG)</td><td colspan="2">LG SA (Sand)</td></tr>
<tr><td colspan="2">LG CL (Clay)</td></tr>
<tr><td>Glacial (GL)</td><td colspan="2">GL (Sand till/Clay till)</td></tr>
</table>

A more detailed division of the cable corridor (ECR only, not array) in segments with similar subsurface geology can be found in /1/, Appendix 3. In general, based on results of the completed investigations, the following can be concluded:

KP = (0.0-9.2)

- Along the initial part of the corridor the subsurface consists generally of glacial tills formed out of the ground moraine material as well as late glacial sands found in the southernmost part of the corridor. The glacial deposits are cut by channels filled with late glacial-fresh water clays and overlain by a thin layer of Holocene deposits.
- Surface sediments consist of mainly till/diamicton with areas of coarse sand and gravels and mainly sand towards landfall. Late glacial clays are present at the seabed at locations where fresh-water channels eroded into the glacial deposits.

KP = (9.2-18.0)

- At this location, a transition from the area where glacial tills are found just below the seabed towards the Late Glacial basin occurs. A thick succession of Late glacial glaciomarine deposits is found north from KP=9.0, below a generally 0.5-2.5m thick layer of Holocene transgressive sediments.
- Surface sediments are interpreted as muddy sands and they occur at areas where most recent Holocene deposits outcrop the seabed. These deposits are composed of fine-grained sediments, typically silty clay grading into sand or clayey sand in more shallow parts of the survey area.

KP = (18.0-27.0) western arm & KP = (21.75-27.0) eastern arm

- This segment of the cable corridor is located east (north-east) from Lysegrund and characterised by presence of a relatively thick succession of Late Glacial and Post Glacial sands underlying Holocene fine-grained sediments.
- Seabed sediments area dominated by muddy sand and sand.

KP = (27.0-35.0) western arm

- This segment is characterised by presence of 0.2-1.7m thick succession Holocene sands deposited on a very unevenly eroded surface representing the top of Glacial tills or Late glacial sands.
- Surface sediments are sand which changes to coarse sand with gravel at locations where glacial tills are found at shallow depths below the seabed.

KP = (35.0-43.5) northern part of the western arm

- A typically 1m to 6m thick succession of post glacial deposits overlies late glacial clays.
- This section is dominated by muddy sand which changes to sand in the northernmost part, near the Hesselø OWF site.

KP = (27.0-35.0) eastern arm

- This part of the cable corridor can be characterised be presence of a very thick succession of generally soft and weakly consolidated postglacial clays
- Surface sediments consist of muddy sand.

In summary, glacial tills are outcropping the seabed or are present at shallow depths below the seabed in the southernmost part of the cable corridor (KP=0.0-9.2) as well as in the central part of the corridor, north-east from Lysegrund (KP=27.0-35.0, western arm).

The central segment, between KP=(18.0-27.0, western arm) and KP=(21.75-27.0, eastern arm) located east from Lysegrund can be characterised by presence of a relatively thick succession of Late Glacial to Post Glacial sands found below approx. 0.5-2.0 m thick cover of Holocene fine-grained sediments.

Along the remaining part of the route, the Post Glacial deposits are underlain by Late Glacial clays.

The Holocene succession is 0-12 m thick (typically between 0.5-6.0m) and present throughout entire cable corridor, except along its southern part where the Holocene deposits are local and found at selected location only.

In the following sections, the geological units are described.

5.2.1 Post Glacial deposits (PG)

The Post Glacial deposits form the youngest sedimentary succession within the southern Kattegat region. Within the cable corridor they reach a total thickness of up to around 12 meters and can be found throughout entire survey area.

5.2.1.1 PG IV (Coarse Sand and Gravel)

The first Post Glacial unit - PG IV, is composed of very coarse sediments found in the southernmost part of the cable corridor. It is interpreted as Holocene coarse sand and gravel as well coastal sediments eroded and redeposited on the margins of the till core and comprises a very thin cover layer at locations where glacial tills are present close to the seabed (see Figure 5-3). As the thickness of this unit does not exceed 1m, mapping of this sediment package is based dominantly on the side scan sonar and grab sampling data.

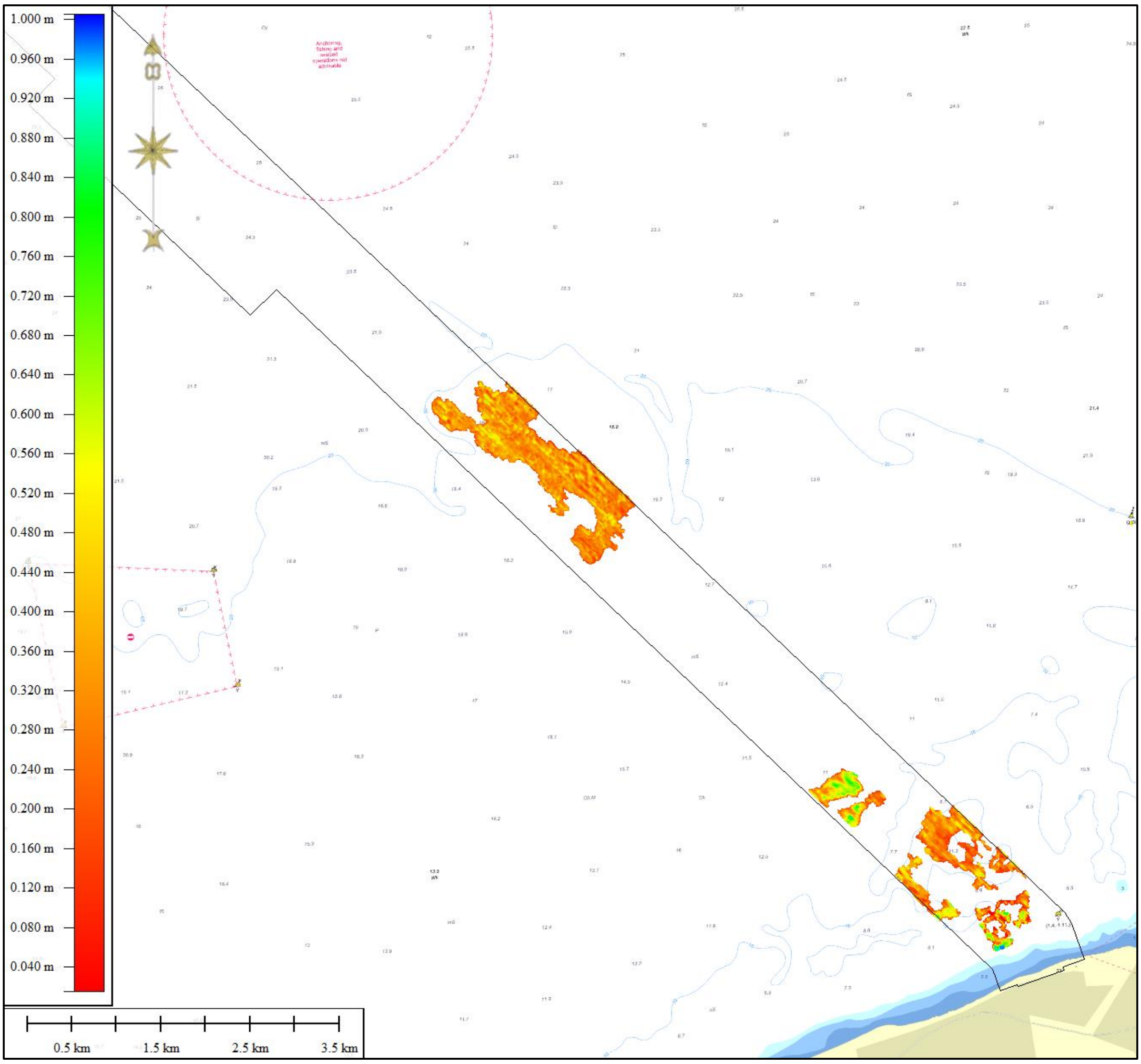

Figure 5-3 Thickness map of the Holocene unit PG IV composed of coarse-grained sediments, sand and gravel. Typical thickness of the unit: 0.2-0.5m.

5.2.1.2 PG III (Sand and Clay)

The unit PG III represents the youngest sediments deposited after the latest marine transgression and it has been identified throughout entire cable corridor. It is composed of fine-grained sediments, typically silty clay grading into sand or clayey sand in more shallow parts of the survey area.

Based on sedimentological composition, PG III has been subdivided into two units, PG III.1 and PG III.2. The first unit PG III.1 is described as clayey, silty sand, while PG III.2 is composed of silty, sandy clays. Both units are of the same age and the lateral boundary between them is gradual.

The total thickness of deposits belonging to unit PG III varies between 0 and 5 meters, lying typically between 0.5-3.0 m throughout most of the cable corridor. Packages thicker than 3 m are interpreted at very few locations (see Figure 5-4). A map showing thickness of the unit PG III.1 is presented on the Figure 5-5 and an isopach map for PG III.2 is shown on Figure 5-6.

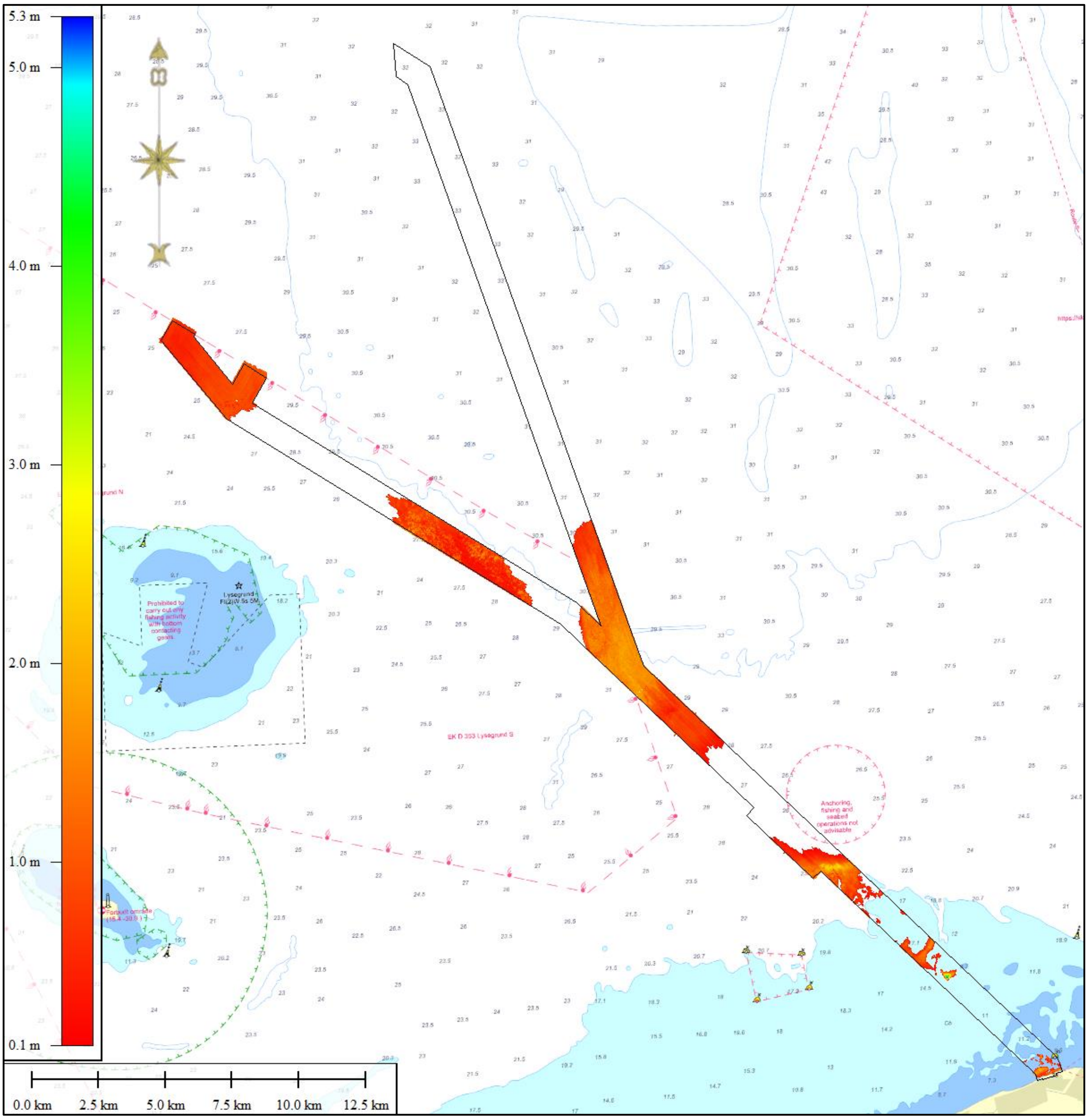

Figure 5-4 Thickness map of the Holocene sand unit PG III.1 SA, typical thickness of the unit: 0.5-2.5m.

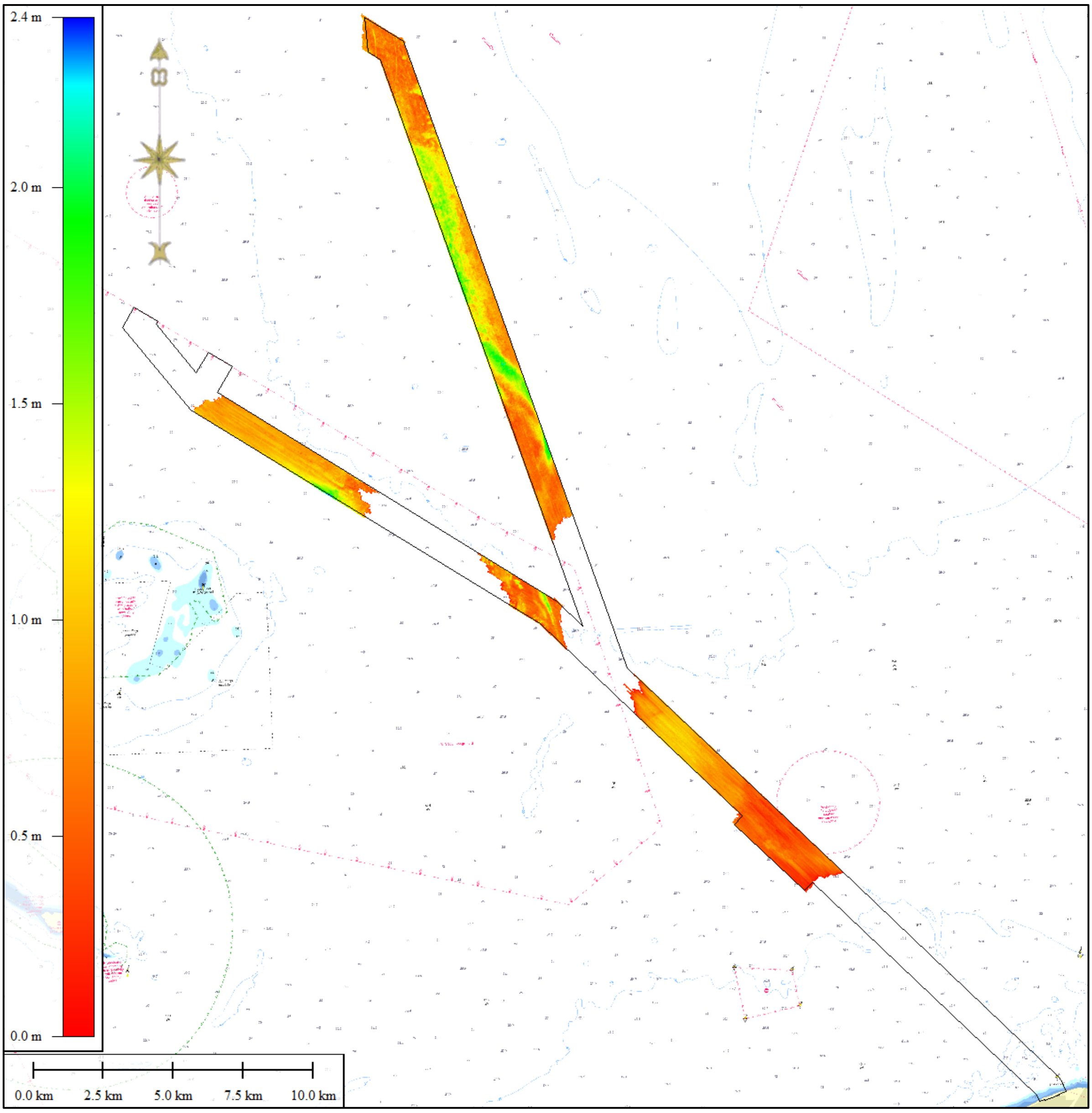

Figure 5-5 Thickness map of the Holocene clay unit PG III.2 CL, typical thickness of the unit: 0.5-2.0m.

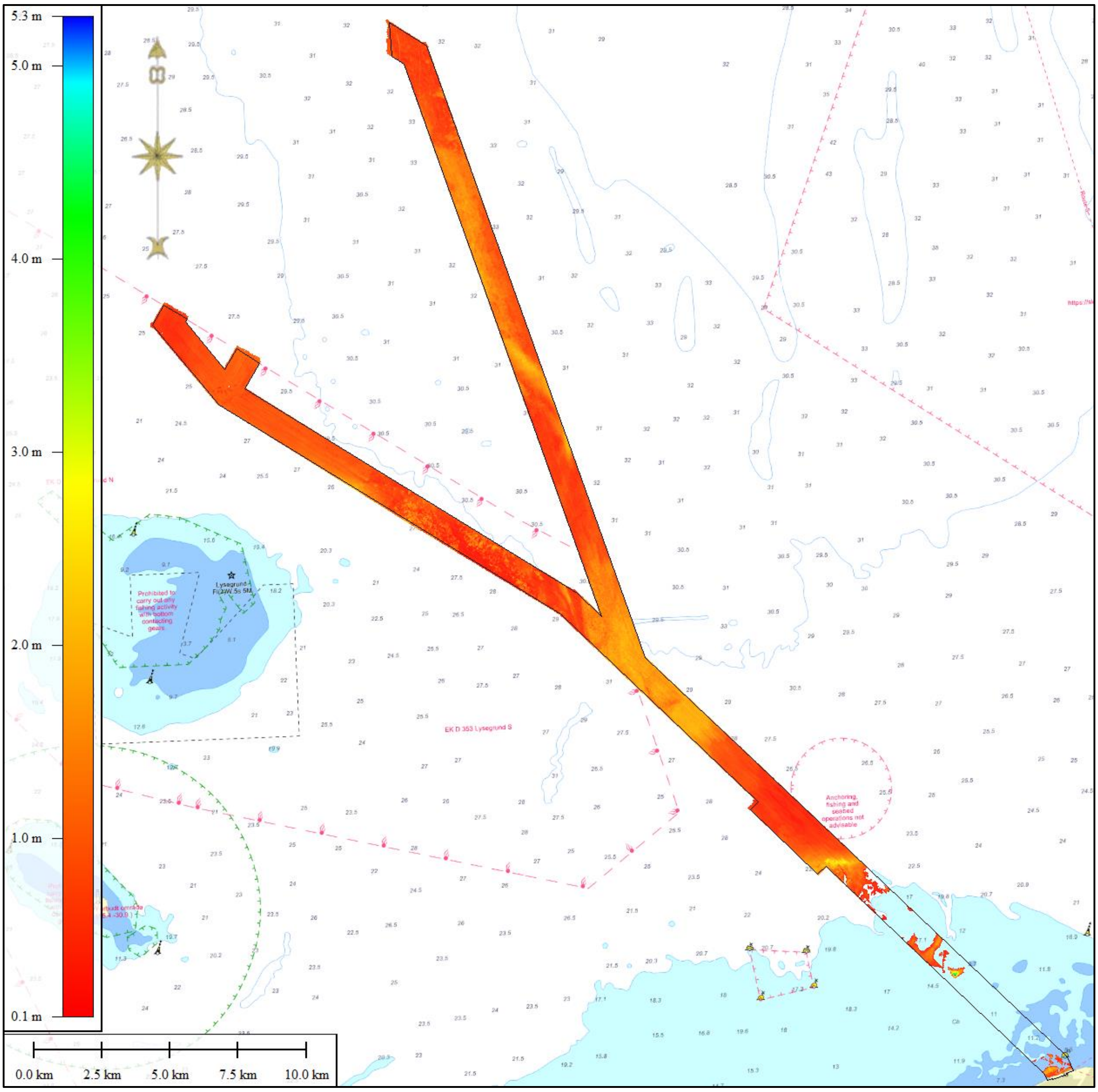

Figure 5-6 Total thickness map of the youngest Holocene deposits- unit PG III.1 SA and PG III.2 CL.

5.2.1.3 PG II (Sand and Clay)

The unit PG II overlies PG I and has been divided into two separate units based on their sedimentological composition. The lower part, PG II.1 is composed of sand and directly overlies PG I, while the upper part PG II.2 is composed of very fine-grained clays.

PG II.1 has been found in the central part of the cable corridor (at locations GL03_11, GL03_12, GL03_13, GL03_12, GL04_01, GL04_02) as well as in the northernmost part of its western arm (at locations GL06_04, GL06_05, GL09_01, GL09_02, GL07_01, GL07_02 and GL08_01). Based on the vibrocore descriptions, it is generally composed of fine- to medium silty, clayey sand with thin clay layers and it might contain plant remains.

The unit PG II.1 has similar lithological composition to PG I, however, it shows a very different seismic reflection pattern.

PG II.1 has a typical thickness of around 0.3-0.5 m. However, along the section GL12 located close the Hesselø OWF site it reaches its maximum thickness of up to 1.5 m. The isopach map showing thickness of the PG II.1 unit is presented on the Figure 5-7.

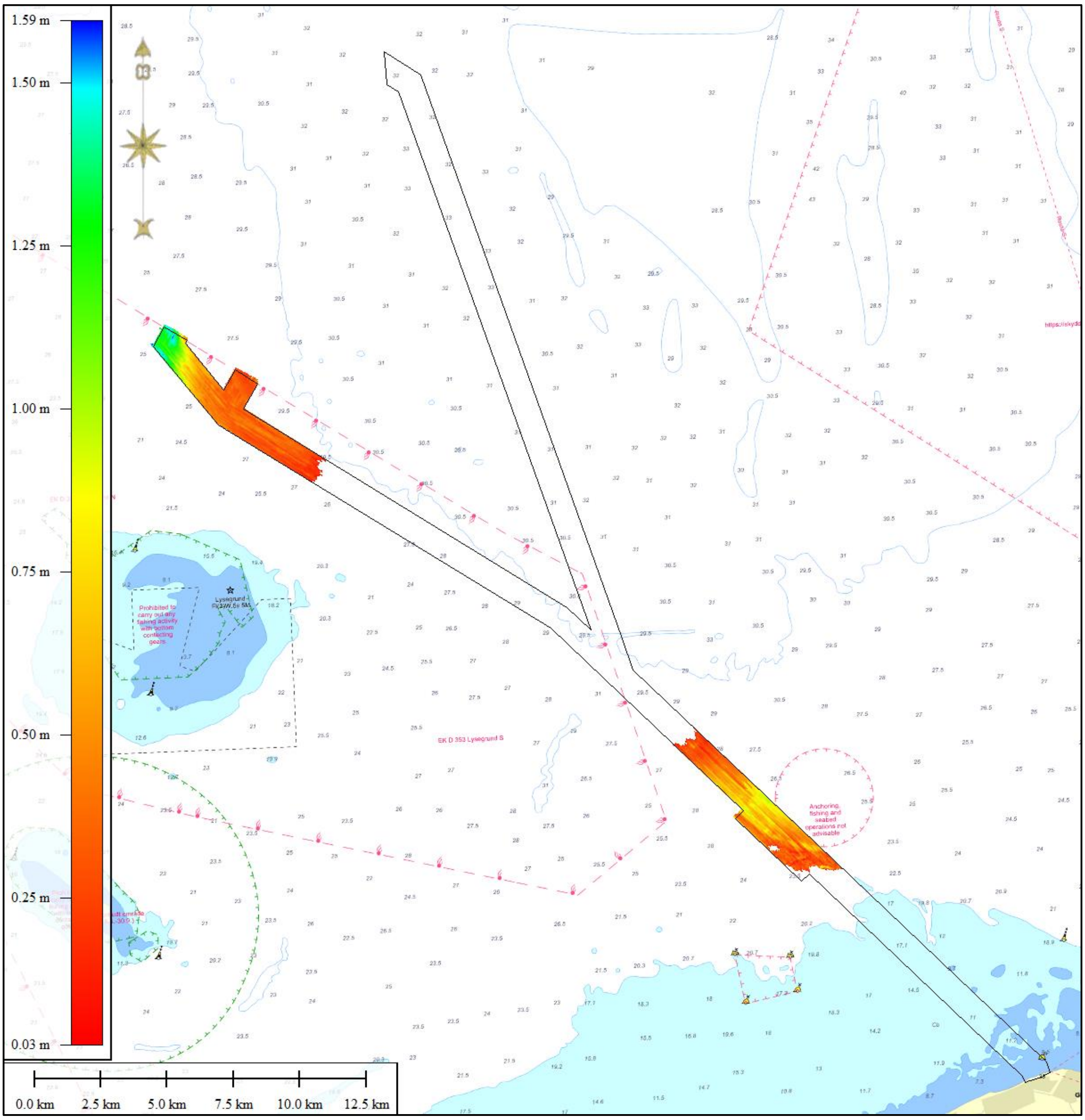

Figure 5-7 Thickness map of the Holocene sand unit PG II.1 SA.

PG II.2 comprises the upper, fine-grained part of the PG II sequence. It is composed of very sandy to slightly sandy clays with its lower part containing thin layers of sand or sand with gravel, as described for example in the vibrocore GL11_02. Like PG II.1, it has been found in the central part of the cable corridor as well as in the northernmost part of its western branch, where it conformably overlies PG II.1. However, PG II.2 has been also penetrated along the eastern branch of the cable corridor, where it reaches significant thickness of up to 12 m within channels, while in the western and central part of the cable corridor the unit PG II.2 has a typical thickness of 1-2m. The thickness map of the PG II.2 unit is shown on the Figure 5-8.

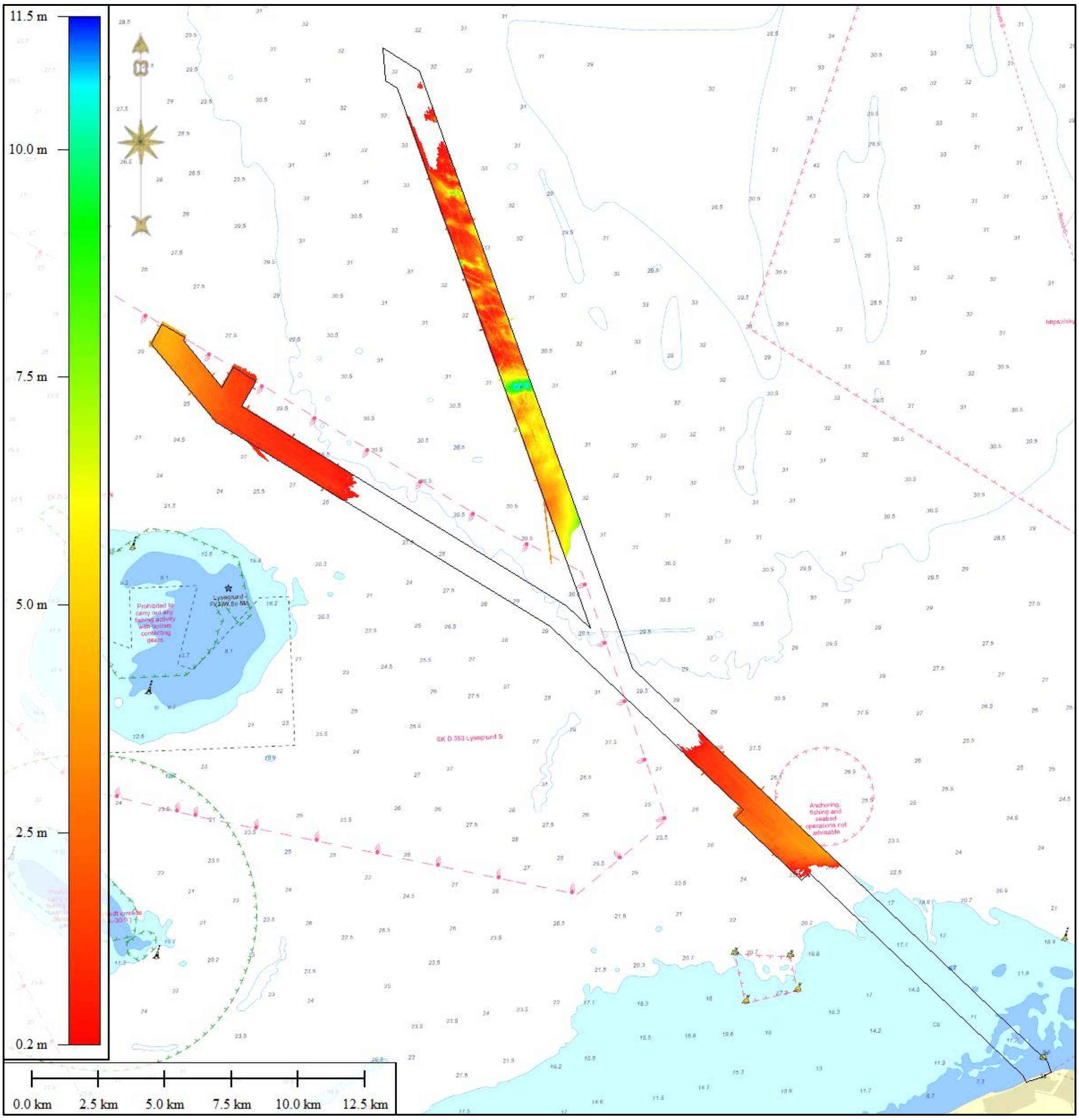

Figure 5-8 Thickness map of the Holocene clay unit PG II.2 CL.

In summary, the sediments of PG II are characterised by upwards fining reflecting deepening of the basin and are interpreted as transgressive systems tract sediments, deposited during the Early Holocene sea level rise. The lower unit PG II.1 forms initial sandy coastal deposits, while the younger unit PG II.2 is composed of primarily clays. PG II.2 forms both coastal deposits as well as channel infill, reaching significant thicknesses of up to 12 m along the eastern branch of the cable corridor, where its upper boundary shows reflection truncation and is therefore interpreted as an erosional unconformity (see Figure 5-9).

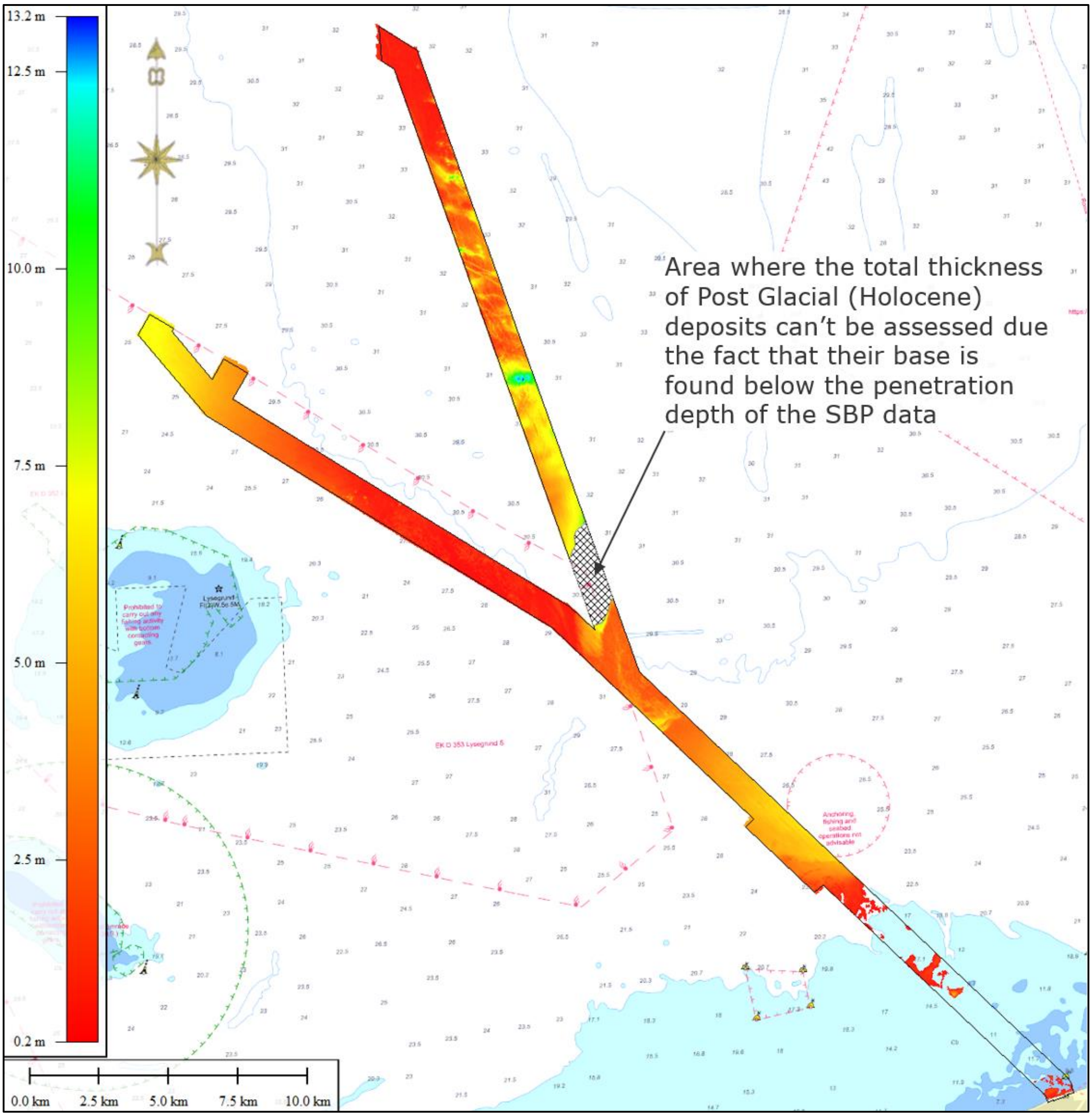

Figure 5-9 Total thickness of the Post Glacial sediments, typically: 0.5-6.0m.

5.2.2 PG I (Sand)

The PG I unit consist primarily of fine- to coarse grained sand deposited during the Early Holocene transgression and interpreted as post glacial sediments. It has been penetrated in, e.g. vibrocores GL04_02, GL04_04 and GL04_05 where it is described as clayey, silty or gravelly sand that might contain plant remains or high plasticity clay layers- as identified in the vibrocore GL04_01.

In the cable corridor the PG I unit is limited to the central and north-western part of the corridor where it is laterally continuous and interpreted as coastal sediments deposited during Early Holocene coastal marine conditions.

At the area adjacent to the vibrocore GL06_02 PG I has been found to fill channel-like depressions in the glacial and late glacial deposits. It should be noted that these channel-like features are characterised by small dimensions (up to 2-3 m deep) and later discontinuity. The origin of the features can't be clearly indicated, but it can be most probably associated with presence of Late Glacial blocks of dead ice, minor fresh-water channels or iceberg scars filled subsequently with younger deposits.

The thickness of PG I varies between 0 and 8 m, with typical values of around 1-2 m within most of the cable corridor. The thickest package is found in the central part of the cable corridor, adjacent to locations GL10_01 and GL04_04 (east from Lysegrund) where up to 8 m of the Early Holocene sands have been identified. The extent and thickness map of PG I are shown on Figure 5-10.

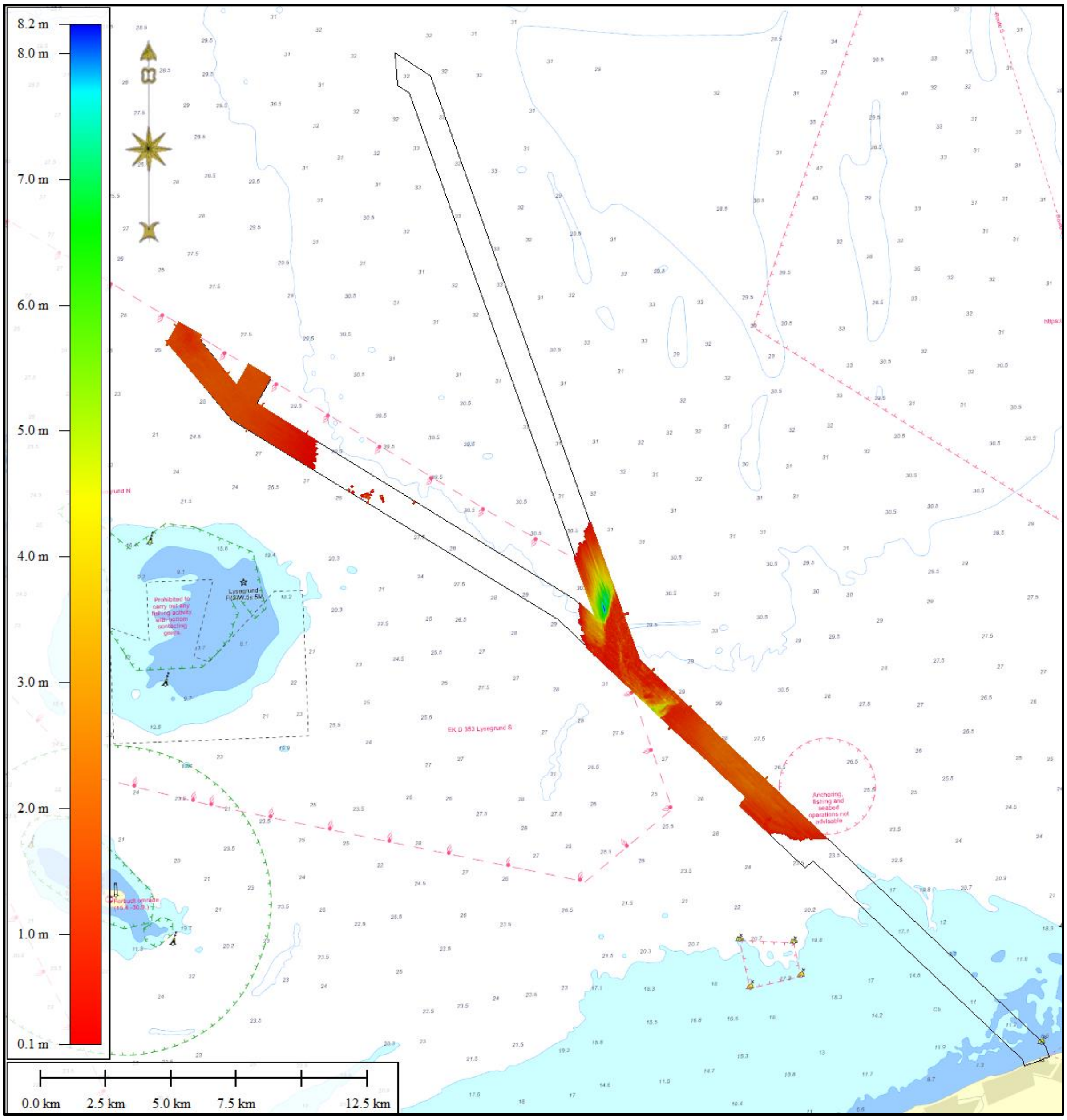

Figure 5-10 Thickness map of the Early Holocene sand unit PG I.

The lower boundary of the Post Glacial deposits is a pronounced erosional unconformity down to approx. 35 m below sea level.

Based on the sedimentological composition and the internal reflection pattern the succession has been divided into a lower low stand systems tract (unit PG I) and an upper transgressive systems tract (units PG II and PG III). Additionally, a fourth unit PG IV composed of very coarse sediments has been mapped in the southernmost part of the cable corridor in order to align subsurface geology with the seabed geology observed on the side scan sonar data.

5.2.4 Late Glacial deposits (LG)

Late Glacial sediments are widespread in the southern Kattegat and are found both in the basin areas as well as in the deeply eroded channels. Accordingly, this unit has been penetrated at many locations throughout entire cable corridor. In the southernmost part (along sections GL02 and GL03) it forms laterally limited channel infills within the glacial succession, while towards the north (north from the location GL03_08) both, thickness and lateral extent of the succession increase significantly.

Within the cable corridor the unit is generally composed of soft, silty, locally sandy (or with sand laminae) clays characterised by high plasticity- as described in vibrocores GL11_04 or GL12_01 located close to the Hesselø OWF site. These soft clays are interpreted as glaciomarine deposits filling the Late Glacial basin. Where the Late Glacial deposits are interpreted as glaciomarine deposits filling the Late Glacial basin, the acquired SBP data did not penetrate to the lower boundary of the unit as it can reach significant thicknesses of up to 75 m. Hence, the base of the LG clays could have been mapped in selected areas only.

The southern and the central parts of the cable corridor are located in the marginal part of the Late Glacial basin and the succession is represented here by coarser-grained deposits characteristic for more proximal environments.

Sand found at locations GL03_11, GL04_03, GL04_05, GL04_06, GL04_07 and GL04_08 forms the upper part of the Late Glacial sequence. Its precise thickness is unknown as the SBP-data did not penetrate the lower boundary of these deposits. Based on the available seismic data, it can be concluded that Late Glacial sands form a relatively thick upper part of the Late Glacial succession and extends along the sections GL04 and GL05, between vibrocores GL04_03 and GL05_01.

Along the cable corridor section GL05 the Late Glacial sands have been described at locations GL05_01, GL05_05, GL05_07 as well as GL06_01, where they are underlying the Holocene units and are found next to glacial tills. It should be mentioned that neither the base or the lateral boundary between the Late Glacial sands and glacial tills can be mapped on the available SBP-data due to the fact that SBP signal penetration is limited in coarse or highly compacted sands as well glacial tills and no corresponding reflectors can be seen on the seismic section.

Late Glacial sands with gravel have also been penetrated by vibrocore GL02_01 located in the southernmost part of the cable route. The lateral boundary between the Late Glacial sands and adjacent glacial tills can’t be mapped here due to limited signal penetration.

An overview map presenting depth in meters below seabed to the top the Late Glacial deposits is shown on the Figure 5-11.

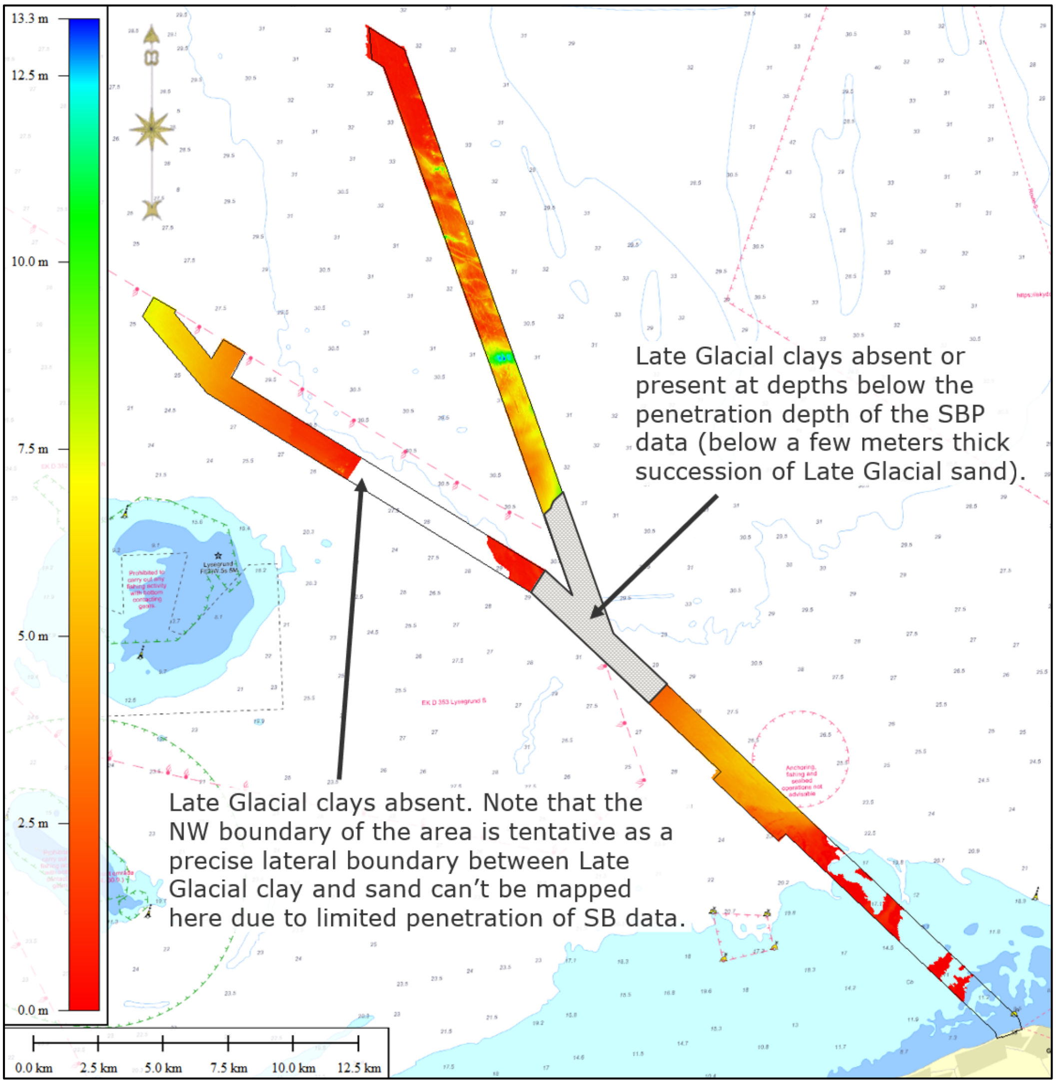

Figure 5-11 Depth in meters below seabed to the top of the Late Glacial succession (LG CL).

5.2.5 Glacial deposits (GL)

Glacial sediments have been penetrated at 7 locations in the southernmost part of the cable route (GL02_02, GL02_03, GL02_05, GL03_01, GL03_04, GL03_06, GL03_07) and at 3 locations along the western arm of the cable route (GL05_04, GL05_06, GL06_02).

Within the OWF Hesselø cable corridor glacial deposits are generally represented by clay tills and sand tills formed out of the ground moraine material of glaciers and ice sheets. In the vibrocore GL_02 glacial tills are interbedded with glacial meltwater deposits (meltwater clays).

The lithological composition as well as geotechnical parameters vary significantly within the till packages. In the vibrocore GL05_04, where glacial tills are found at depths between 0.2 m and 3.3 m below the seabed, the till has been described as very sandy and weak, while at the location GL05_06 the till also contains sand, but has normal strength in the uppermost part and it becomes weaker with depth.

The seismic recordings did not penetrate to the lower boundary of the glacial deposits what makes it impossible to assess the total thickness of this unit.

Two major ice marginal ridges cross the cable corridor area just south from the Hesselø OWF site as well as its southernmost part (see Figure 8-24). As described by GEUS, the interpretation of retreating ice marginal ridges is supported by the seabed surface sediment map where the ridges in general consist of till, often superimposed by a thin layer of Holocene transgressive sand and gravel, coastal sediments eroded and redeposited on the margins of the till core (see Figure 8-24).

The extent of glacial deposits along the cable corridor supports the previous studies and can be correlated to the presence of the ice marginal ridges. Figure 5-12 shows areas of the cable Hesselø OWF cable corridor where the glacial deposits have been found close to the seabed, while Figure 5-13 shows depth to the top of the till deposits in the western arm of the cable route (left) and in the southern part of the corridor (right).

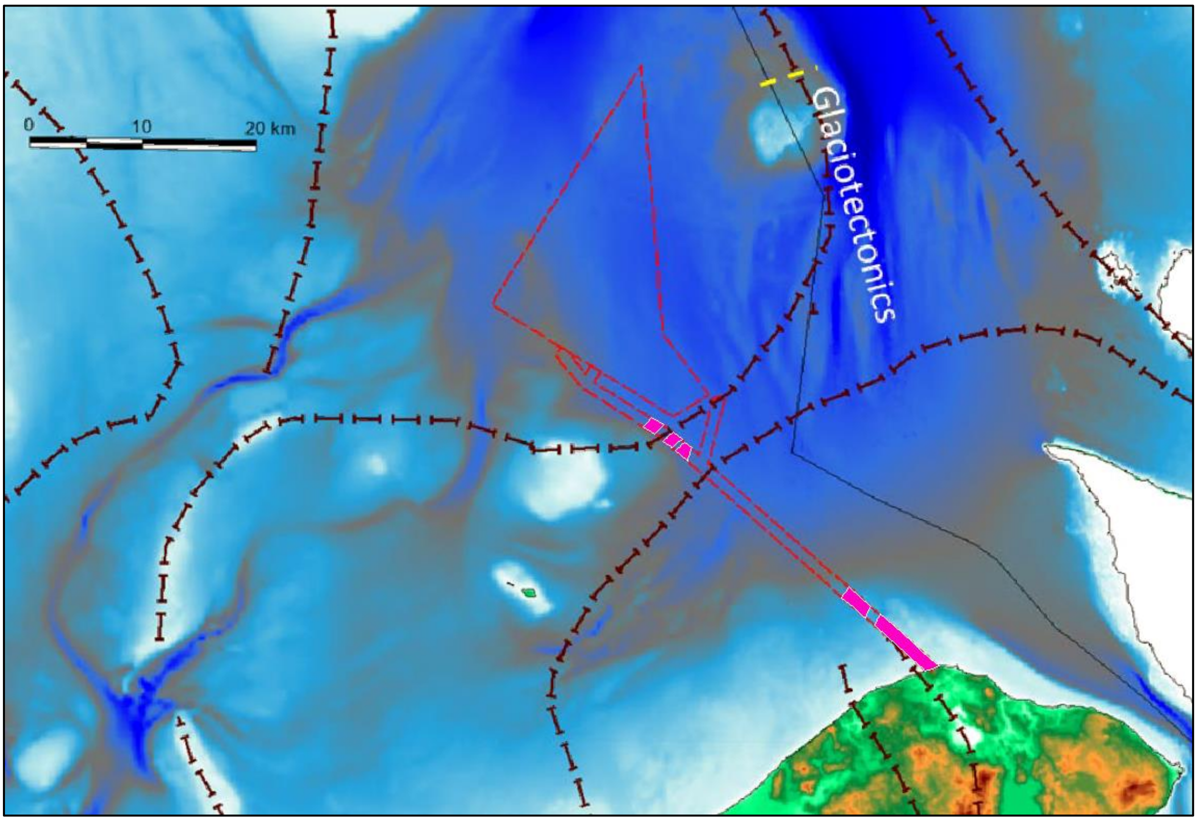

Figure 5-12 Distribution of the glacial deposits (GL) along the cable corridor. The areas where glacial sediments have been identified close to the seabed are marked with pink. Ice marginal ridges interpreted in the previous studies in the southern Kattegat region are marked with black

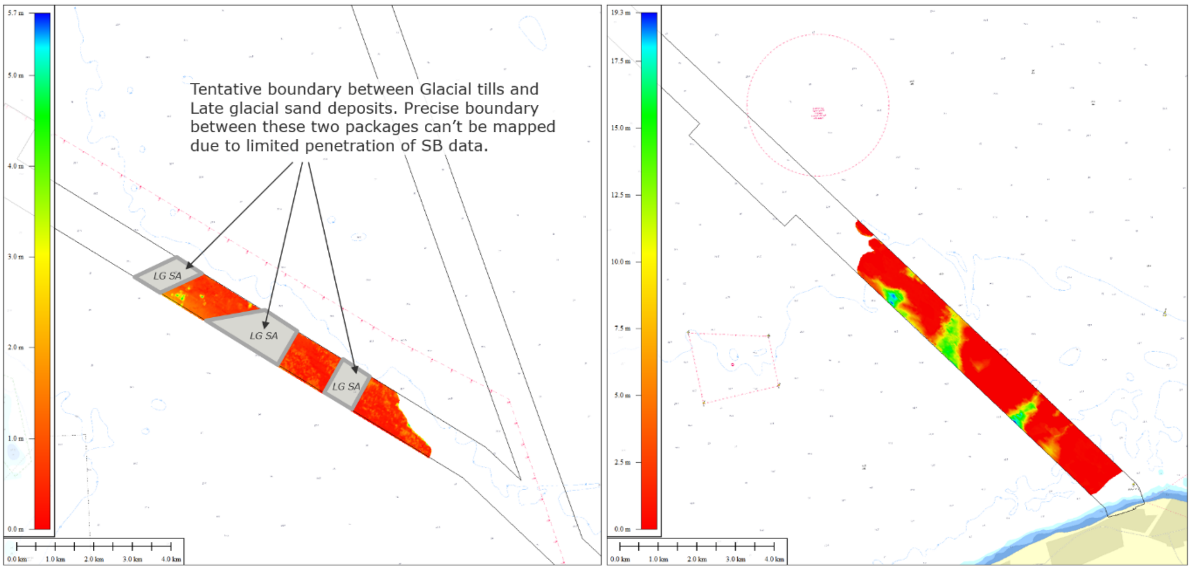

Figure 5-13 Depth in meters below seabed to the top of the Glacial succession (GL).

5.2.6 Seabed surface geology and boulder fields

An integrated seabed surface geology interpretation for the Hesselø ECR corridor is derived from a palette of all acquired and related geophysical datasets. The interpreted results are an outcome from raw or processed bathymetry, backscatter, side-scan sonar, grab samples, vibrocores and finally cross correlated with sub bottom profiler.

The seabed is divided into the following seabed substrate types, cf. the Danish Råstof-bekendtgørelsen (BEK no. 1680 of 17/12/2018, Phase IB):

- Substrate type 1 - Sand, silt and mud
- Substrate type 2 - Sand, gravel and pebbles
- Substrate type 3 - Sand, gravel and pebbles, and larger stones
- Substrate type 4 - Stony areas and stone reefs with 25-100% of larger stones

Stones with diameter >10 cm are considered as larger stones

Figure 5-14 shows an overview of the interpreted seabed substrate types for the ERC corridor. The predominant seabed substrate along the corridor is of type 1 – sand, silt and mud. The area located in the southern part of the corridor (nearshore), is characterised by coarse sand, gravel and large amount of pebbles/stone at the seabed. Here the seabed substrate is varying between type 1 to 4.

With regards to boulders, the most conspicuous features are the dense boulder fields towards land in block GL01 to GL03 where boulders built up reefs and a less dense field in GL05 and GL06.

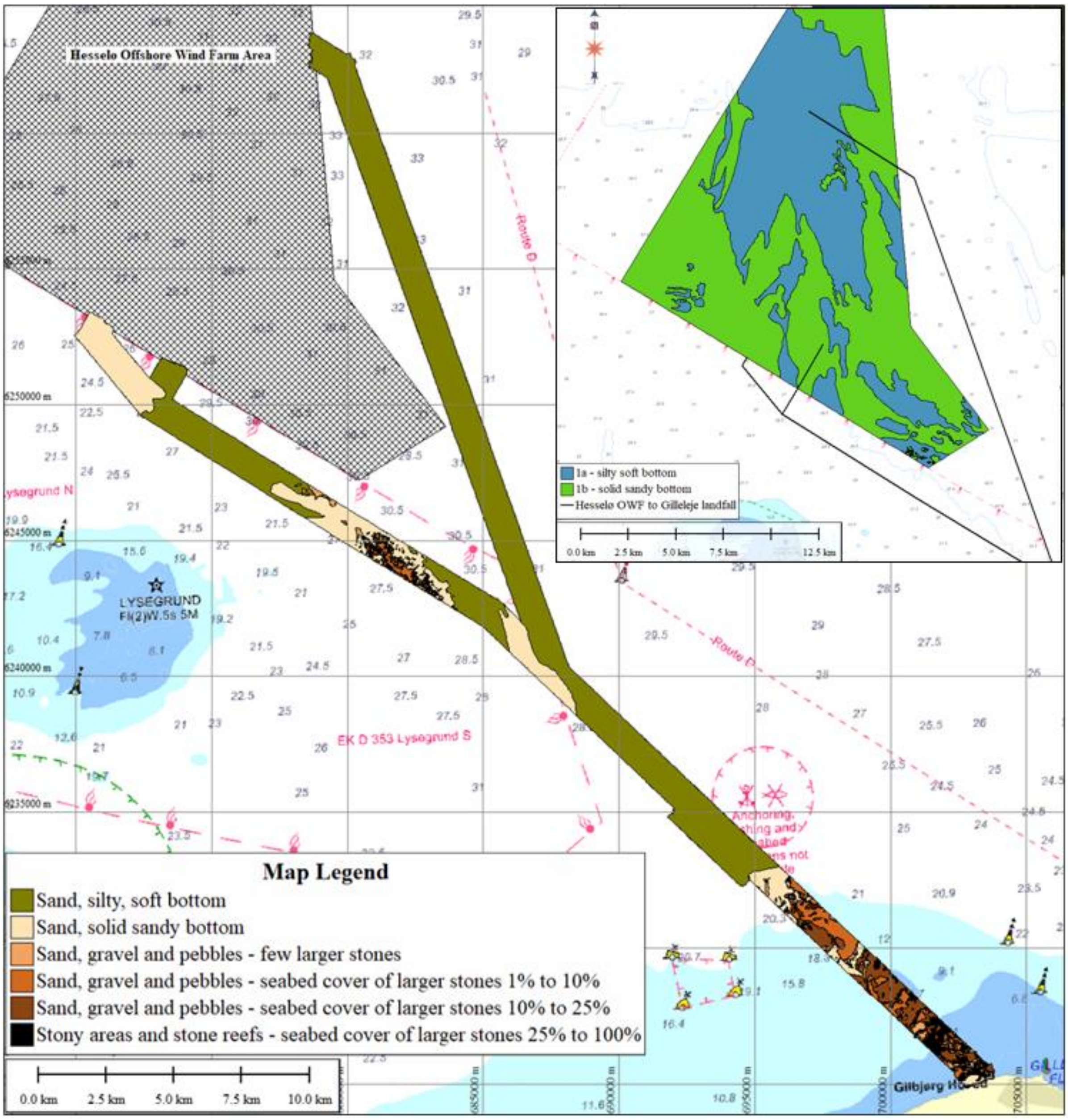

Figure 5-14 Overview of the interpreted seabed substrate types alongside the ECR corridor from Gilbjerg Hoved in the south to the OWF area in the north.

5.3 Observed geological conditions in the OWF area

From the geophysical survey carried out in the OWF area, ref. /8/, we have received the following from Fugro:

- Interpreted and gridded seismic horizons
- the Kingdom project (without seismic data)

Comparing these data with the geological model established for the ECR area, it has proven possible to combine the two data sets in order to provide maps showing the pars of the ECR (Eastern and Western arm) going into the OWF area, cf. Figure 5-15.

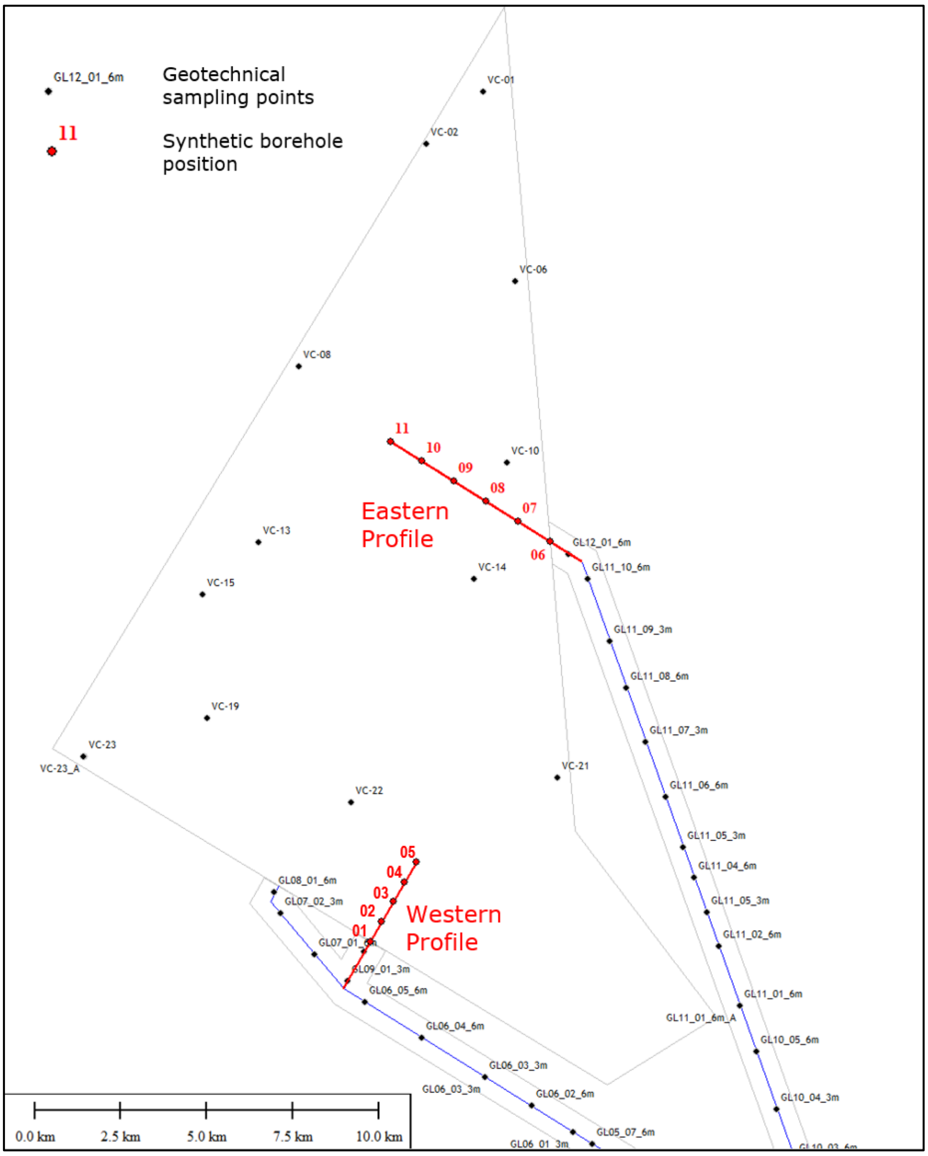

Figure 5-15 OWF area with ECR Eastern and Western are going into the OWF area. Geological sections along the Western and Easter profiles are illustrated on the Figure 5-22 and 5-23.

The correlation between the three surfaces within the uppermost layers identified by Fugro and the ECR model is illustrated in the
Table 5-3. It should be noted that:

- Fugro’s interpretation is based on seismic data only – this implies that Vibrocore or CPT data is not taken into account

- Fugro has picked 3 horizons within the uppermost succession – these are the three most pronounced reflectors observed on the SBP sections separating Fugro's units A, B and C. Rambøll has interpreted 6 geological boundaries based on the intergrated G&G results;

It seems that Fugro has interpreted unit tops, while we have interpreted unit bases – it is therefore not easy to directly compare the interpretation results for the larger area – it can only be done locally.

Table 5-3 Extending the ECR model into the OWF, Western and Eastern arms of the ECR

Geological unit	Fugro horizon	ECR model layer (Western arm)	ECR model layer (Eastern arm)
	SBP_H01	Base PG III.1 (Sand)	-
	SBP_H05	Base PG II (Clay/Sand)	-
	SBP_H10	Base PG I (Sand)	-
	SBP_H10	-	PG III.2 (Clay)

The cross sections showing correlation with seismic horizons interpreted by Fugro are illustrated in Figure 5-16 and Figure 5-17.

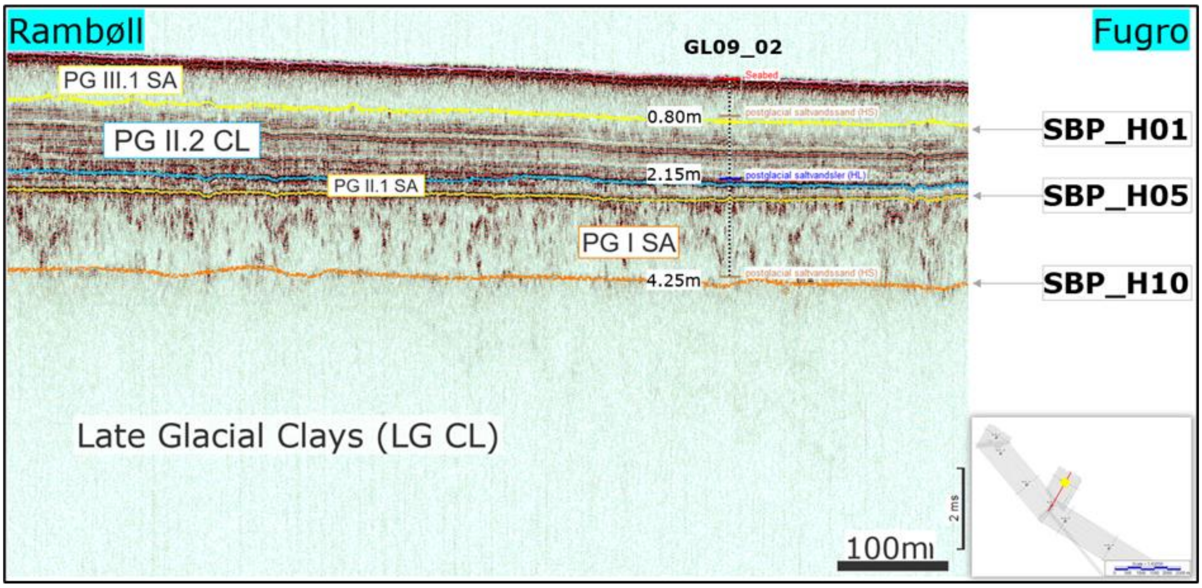

Figure 5-16 Western arm, cross section showing correlation between seismic horizons interpreted for Hesselø ECR and OWF site areas

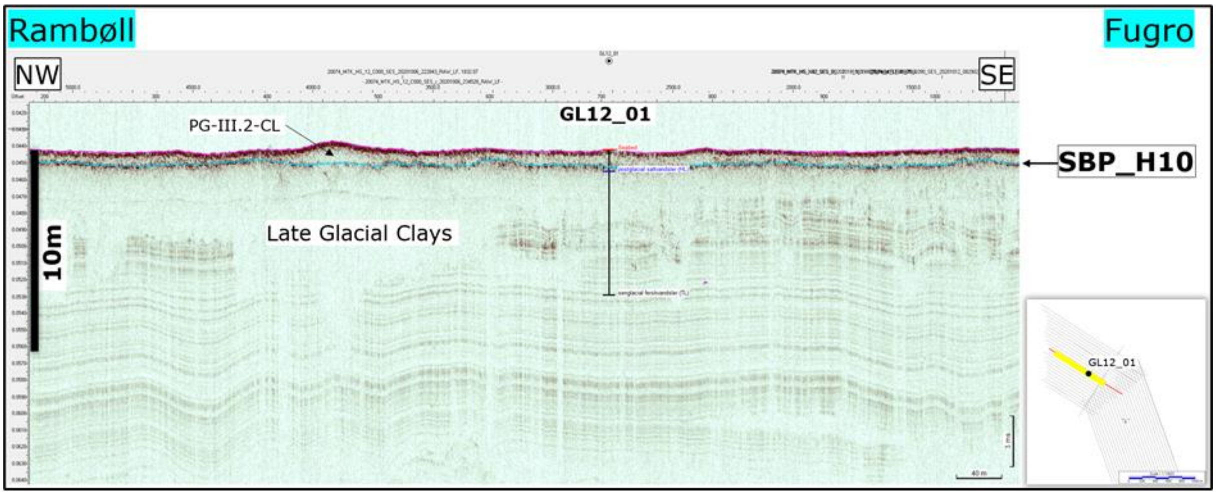

Figure 5-17 Eastern arm, cross section showing correlation between seismic horizons interpreted for Hesselø ECR and OWF site area

The interpreted surfaces are illustrated in Figure 5-18, Figure 5-19 and Figure 5-20 for the Western arm Figure 5-21 for the Eastern arm.

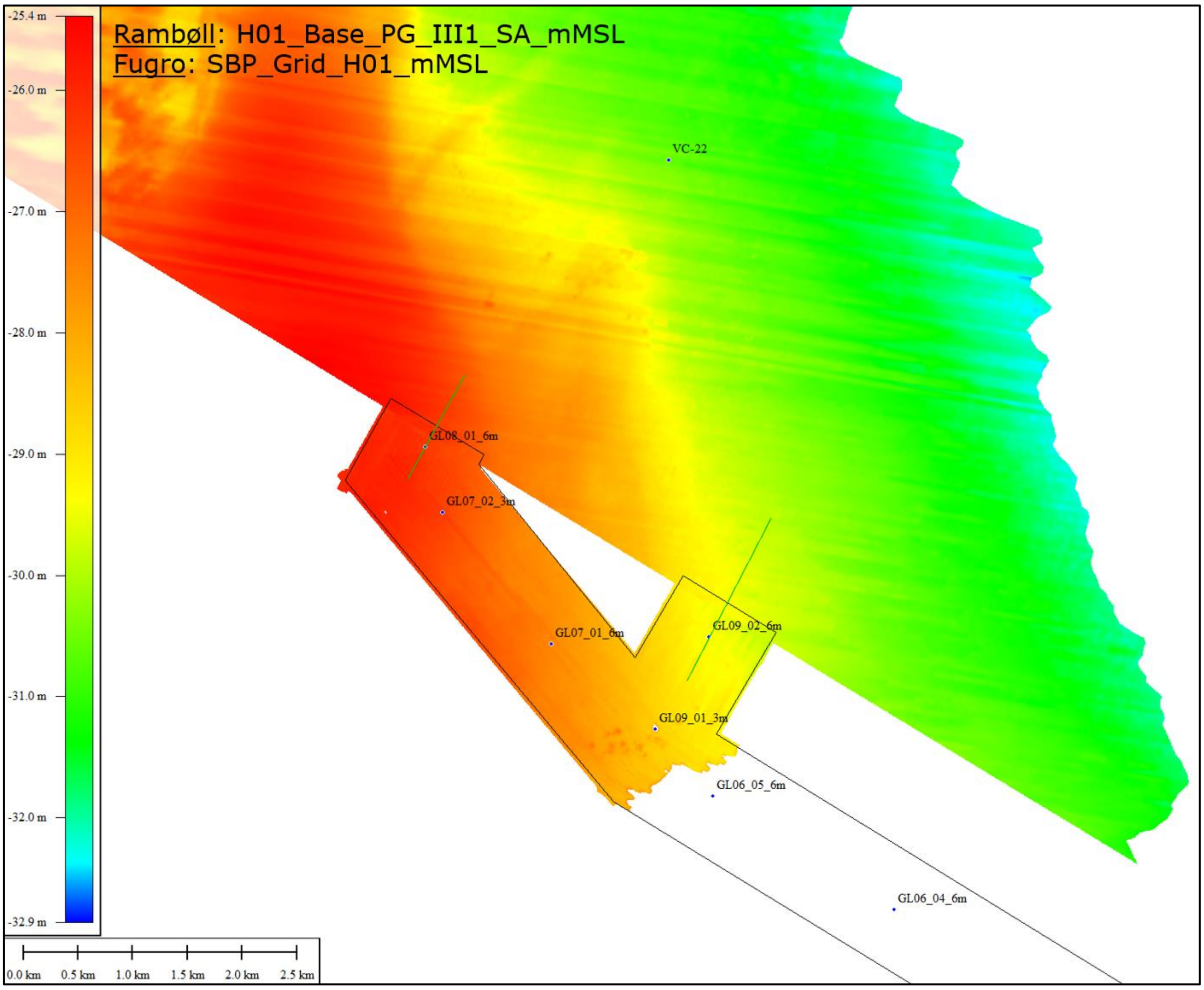

Figure 5-18 Western arm, Base PG III (Sand). Difference between models approx. 5 cm

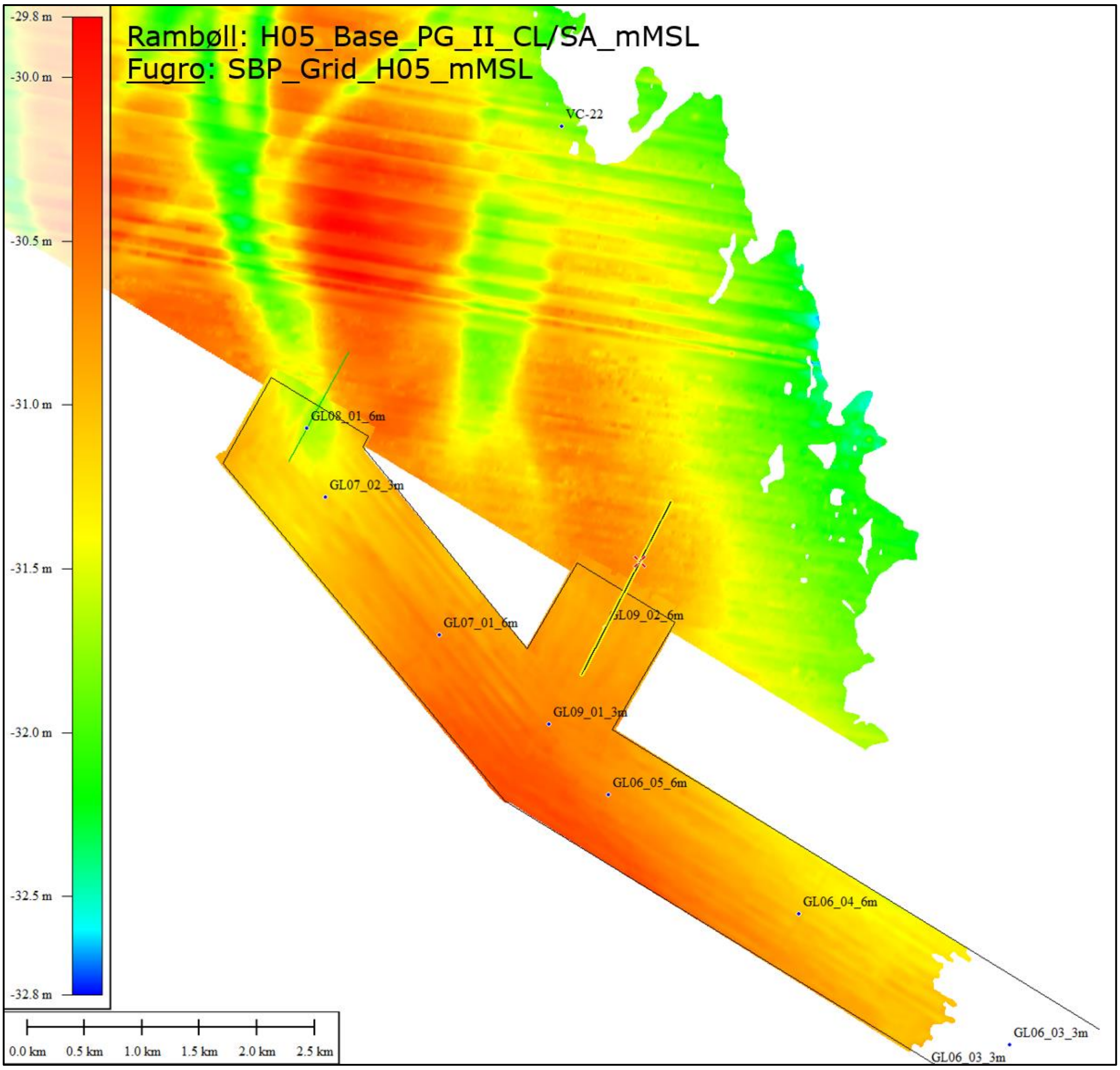

Figure 5-19 Western arm, Base PG II (Sand). Difference between models approx. 15-20 cm

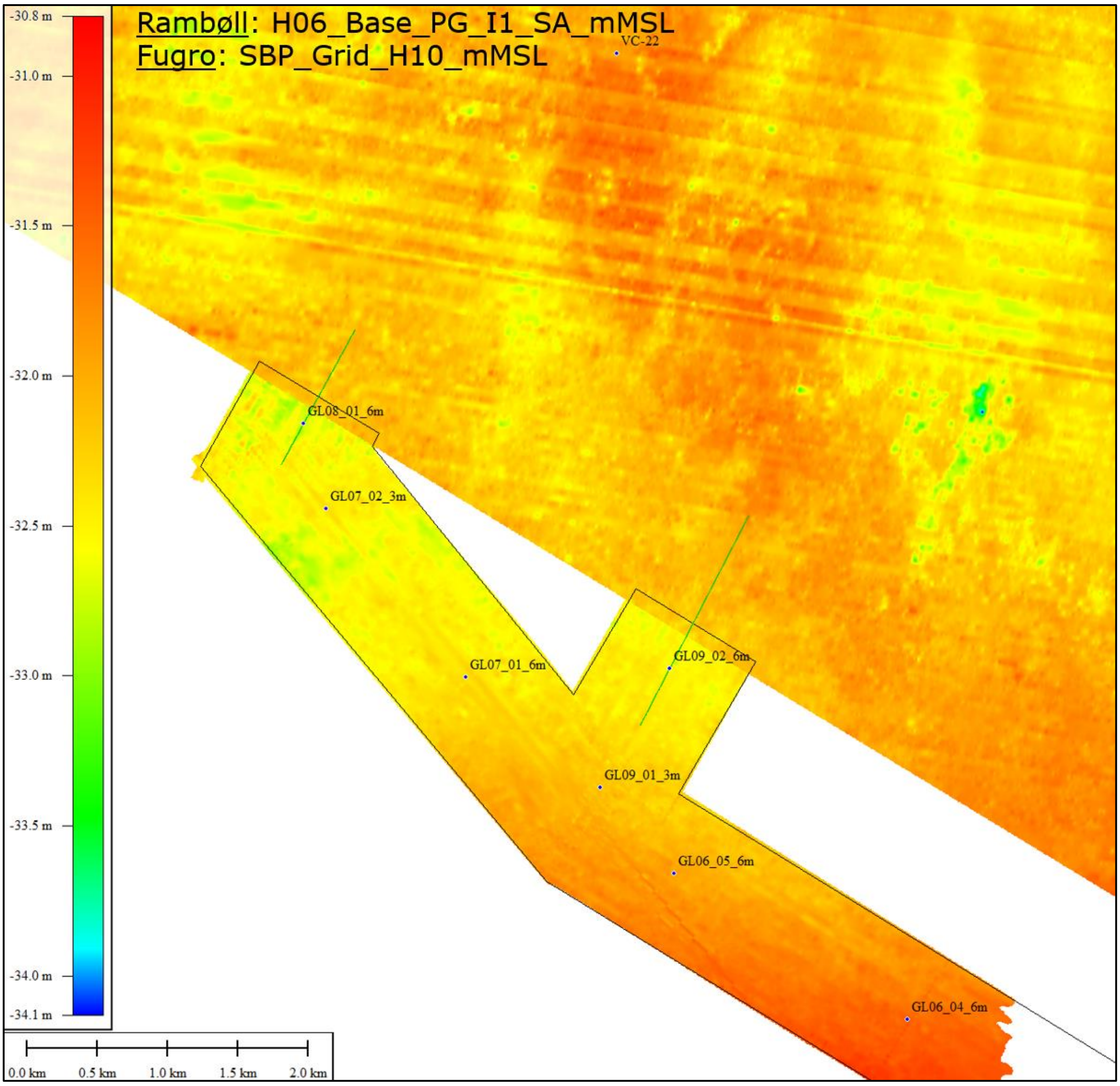

Figure 5-20 Western arm, Base PG I (Sand). Difference between models approx. 30-45 cm

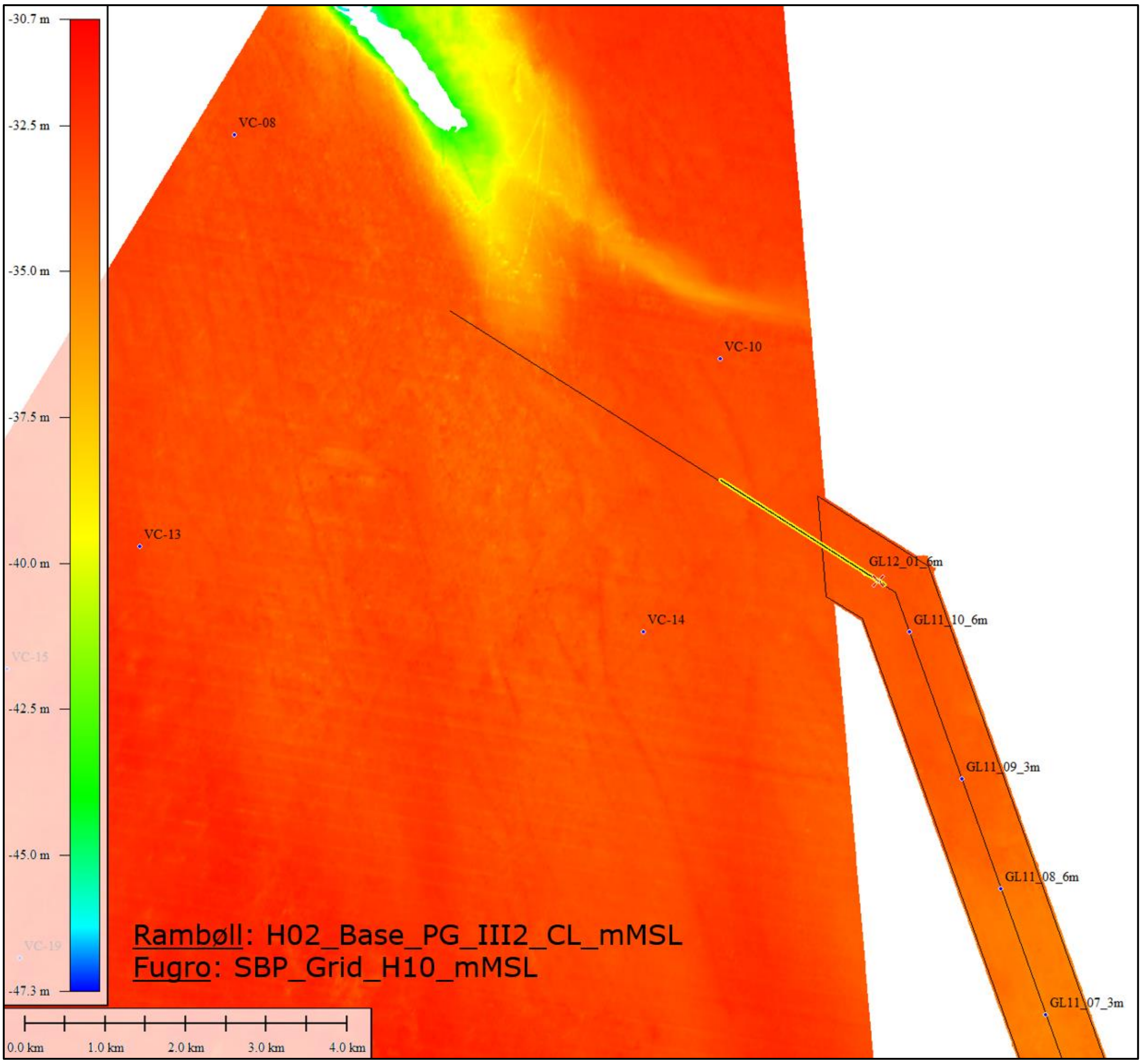

Figure 5-21 Eastern arm, Base PG III (Clay). Difference between models approx. 0-5 cm

The following figures illustrate geological sections along the Western and Easter profiles (location of these profiles is shown on the Figure 5-15).

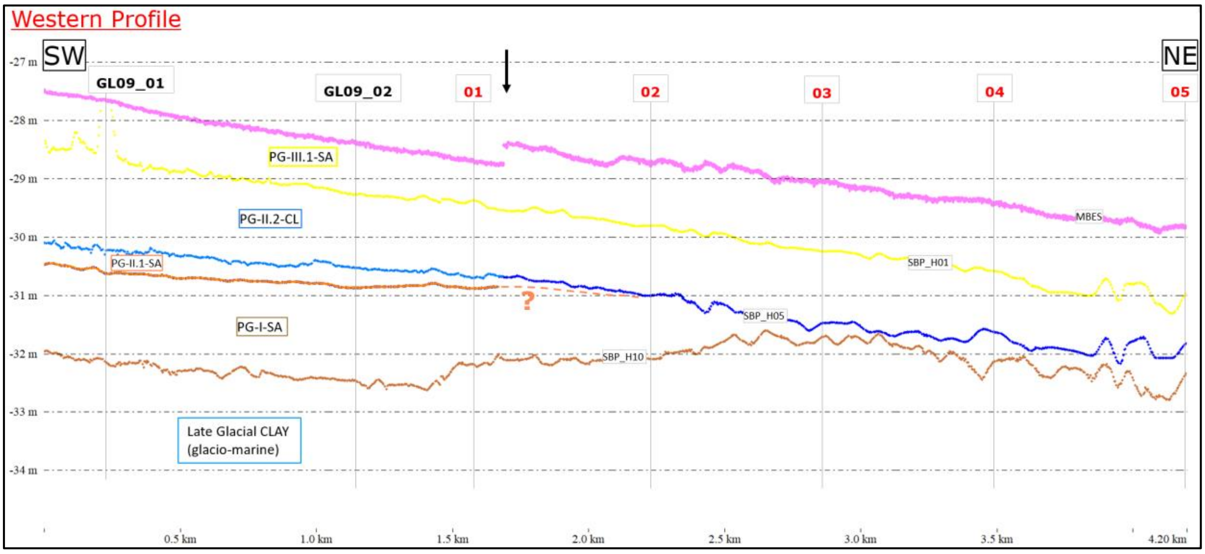

Figure 5-22 Geological sections along the Western profile. The black arrow marks merging point between Hesselø ECR and OWF site areas. Geotechnical sampling points (CPTs and VCs carried out by Mewo) as well as synthetic borehole positions are included.

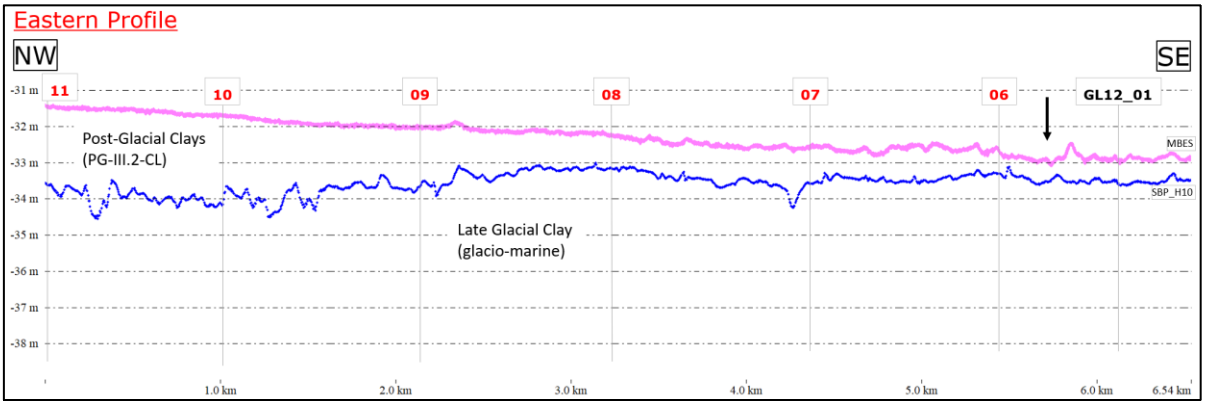

Figure 5-23 Geological sections along the Eastern profile. The black arrow marks merging point between Hesselø ECR and OWF site areas. Geotechnical sampling points (CPTs and VCs carried out by Mewo) as well as synthetic borehole positions are included.

Western Arm

At the area adjacent to the Hesselø OWF site and the Western arm of the ECR corridor the Holocene marine clayey, silty sand is underlain by Holocene estuarine and coastal deposits-primarily clays (PG-II.2-CL), with the lowermost part composed of a thin (≈30-50 cm) layer of sand, typically with clay laminae (unit PG-II.1-SA). Below the PG II, Holocene sand characterised by a very distinct, chaotic seismic reflection pattern, typically medium and poorly graded (can contain clayey laminae, as described in GL09_02) has been interpreted. The Holocene sediments are underlain by Late Glacial glacio-marine clays. The depth to the base of these clays can not be indicated based on the available data as it found below the penetration depth of the SBP.

Eastern Arm

At the area adjacent to the Hesselø OWF site and the Eastern arm of the ECR corridor the Holocene marine silty clays, characterised by high plasticity as described in the GL12_01 are underlain by Late Glacial clays, also characterised by high plasticity. The base of the clays is found below the penetration depth of the SBP data.

6. MAN-MADE HAZARDS

6.1 Fishing activities

Fishing gears are conveniently divided into two categories based on their mechanism of capture. Thus, fishing gears are considered to be either active gears, i.e. when they are propelled or towed in pursuit of the target species, or passive gears, i.e. when the target species move into or towards the gear. In this study we are only concerned of active gear types. Most active commercial fishing gears involve a vessel towing a net or dredge through the water column or across the seabed. There are a multitude of different designs of nets and dredges, each developed to meet the demands of catching a particular species or fishing in a certain environment. The majority of towed fishing gears can be described as either trawls or dredges. Trawls are fished either in mid-water, just off or in direct contact with the seabed. In contrast dredges are exclusively used to capture species that live or feed in the benthic habitats, and thus they have been designed to maximize their contact with the seabed. In this study we are only concerned with gear types that are in contact with the bottom i.e. bottom trawling (e.g. beam and otter trawlers) and dredges, ref. /9/.

The International Council for the Exploration of the Sea (ICES), has Kattegat as a part of the ecoregion the Greater North Sea, which includes the North Sea, English Channel, Skagerrak, and Kattegat. The description of the fishing activity by gear types are based on the ecoregion, but with a specific focus on Kattegat.

Nephrops or Norwegian lobster, now the primary target species in the Kattegat, is caught almost exclusively by Danish and Swedish vessels using demersal otter trawls, which is a bottom trawling gear type. In the Swedish EEZ of the Kattegat *Nephrops* fisheries by Swedish fishers are conducted using stationary gears. As *Nephrops* reside in shallow burrows, the fishery is characterised by relatively low catchability and high trawling intensity. As a result, the Kattegat is an area of relatively high trawling intensity at European and global scale. Based on trawling effort in 2017, it was estimated that ~53% of all sublittoral mud habitat in the Kattegat was impacted by mobile bottom-contacting fishing gear, Ref./10/. The passage of a *Nephrops* trawl has been found to have a generally minor physical and visual impact on the soft sedimentary seabed, represented by a flattening of the normally mounded sediment surface and disturbance of the sessile epifauna. Fewer openings of *Nephrops* burrows has been observed in trawled areas, which suggests that the delicate and complex structure of the burrow system may be severely damaged by the action of the gear. *Nephrops* habitats generally occur below 20m depth where muddy sediments dominate. The highest trawling intensities for *Nephrops* typically occur in the northern areas, around the Kattegat trench system in the east, and sporadic areas in the south, Ref. /10/ and Figure 6-1. The spatial distribution of the Danish *Nephrops* fishery is stable between years with the highest landings occurring in the northern Kattegat and on the Danish shelf and slope of the Skagerrak, Ref. /10/.

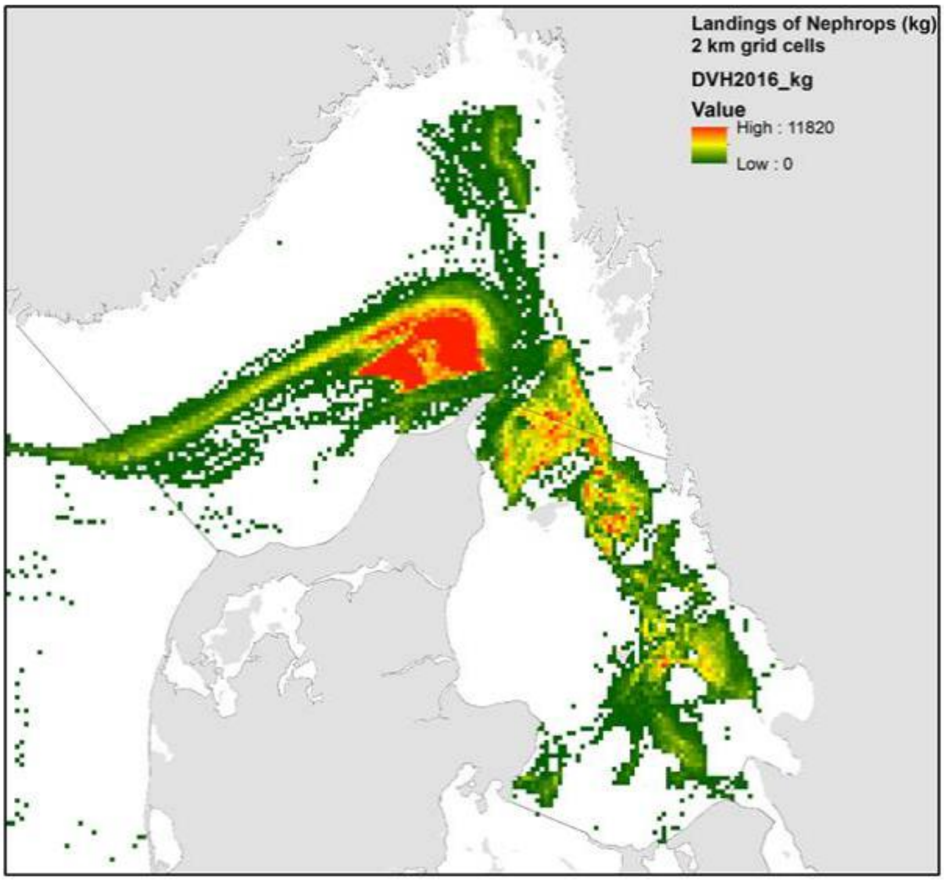

Figure 6-1 Distribution and density in landings (kg) of the Danish *Nephrops* fishery in the Danish Economic Exclusive Zone (EEZ) in the Kattegat and Skagerrak. The landings are based on data from the Vessel Monitoring System (VMS) and logbook information from vessels of and exceeding 12 meters of length, ref. /11/.

From the geophysical survey ref. /1/ a significant amount of trawl marks etc. has been identified. Based on the bathymetric average grid along the cable route corridor statistics for trawls marks were calculated using a pseudo-surface derived from the 25 cm average grid, Table 6-1. The values are only derived from areas with trawl marks in order to avoid potential depressions and boulders – this means that combined areas with boulder and trawl marks are not included.

Table 6-1 Trawl mark stats. Note that the stats are based on the average grid rather than the minimum, therefore the uncertainty of +/- 0.05 m.

Minimum depth	0.016 m	+/- 0.05
Maximum depth	0.142 m	+/- 0.05
Average depth	0.068 m	+/- 0.05

Figure 6-2 is an overview of trawling activity within the investigation area in 2019. The data presented is based on AIS data with a speed filter as trawling from otter trawlers mainly is done at speeds from 2 to 4 knots. As can be seen on the figure, little to none fishing intensity was observed in the nearshore areas, whereas the intensity is larger in the eastern cable corridor than the western section.

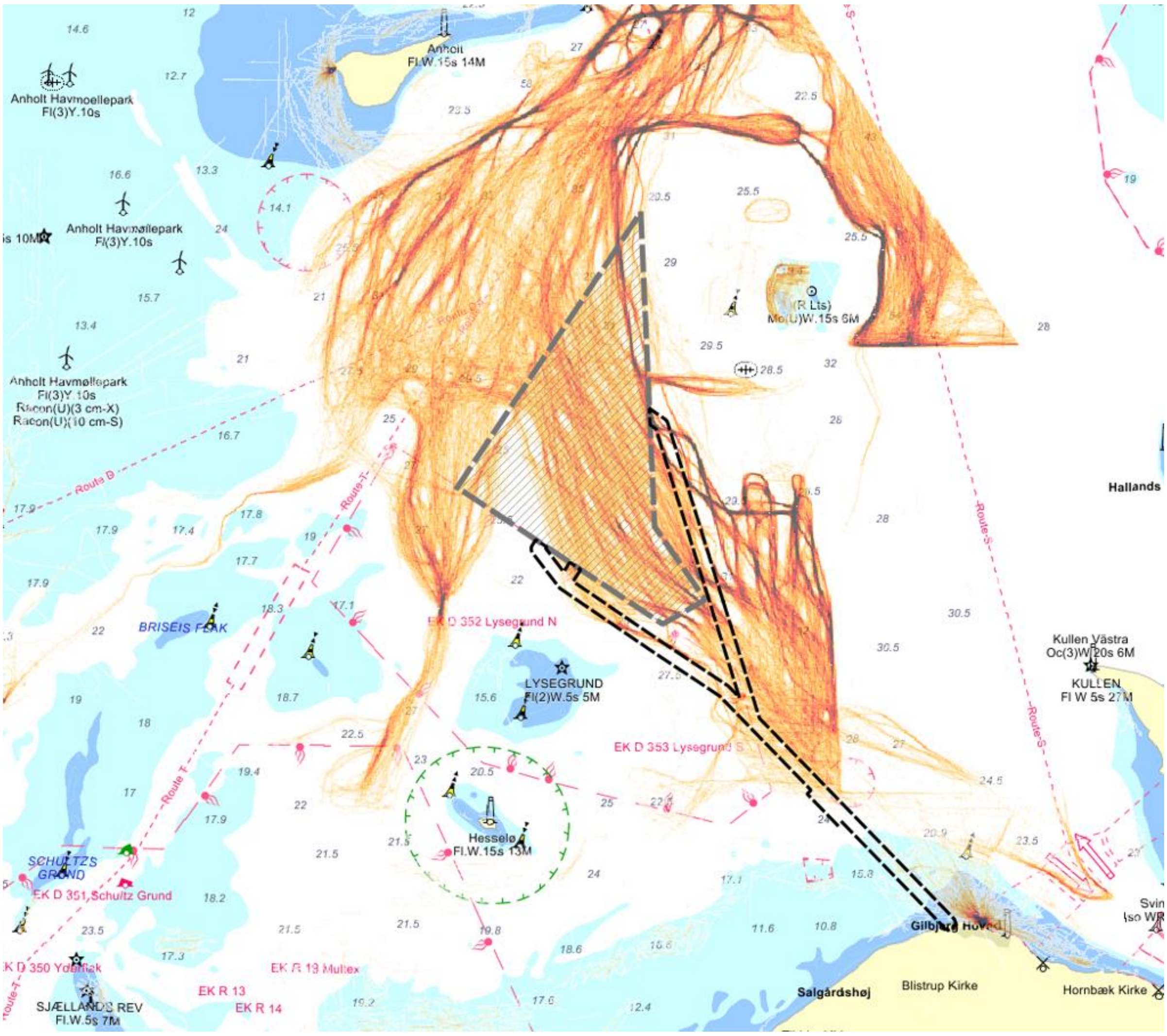

Figure 6-2 Ship traffic intensity covering only fishing ships sailing 2-4 knots corresponding to trawling speeds, from 1st of January 2019 until 31st of December 2019 in the area around the OWF and its cables corridors. The data does not cover the north-eastern corner, which is why a straight line is seen.

6.2 Bottom trawl

The impact of bottom trawling is highly dependent on the design of the gear type. In this section a short description of the different gear types is made. This is done to give a basic understanding of how the gear type works and what part of the gear type that has an impact to the bottom. Lastly, it is assessed how the different trawlers potentially may impact the buried cable.

6.2.1 Beam trawls

Beam trawls derive their name from the rigid beam supported by the two shoes at either end, Figure 6-3. The net is attached to the beam, shoes and ground rope that runs between the base of the shoes. Thus, the mouth of the net is held open regardless of the speed at which the net is towed through the water. The shoes act as skis that glide across the surface of the seabed and spread the load of the gear and prevent it from sinking into soft substrata. Beam trawls are designed to catch shrimps, prawns and flatfish that live on or buried in the top few centimetres of the sediment. Various configuration of chains are attached between the beam shoes. Theses chains are called tickler chains, and they are designed to disrupt the surface of the seabed and disturb or dig out the target species.

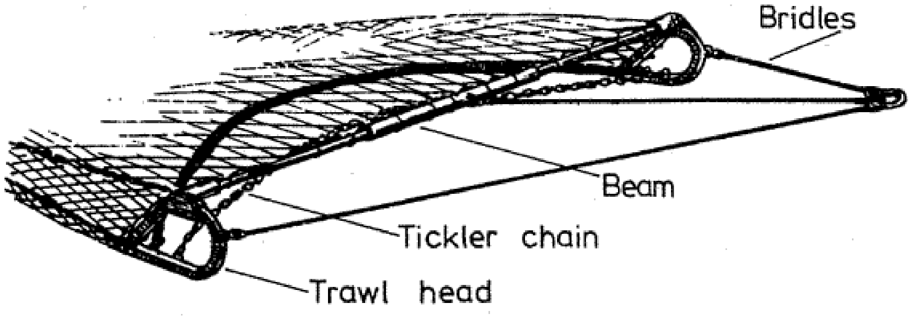

Figure 6-3 Principal features of a beam trawl, source FAO.

Flattening of the bottom topography is the main physical impact of beam trawling. The chains of a beam trawl are designed to penetrate the upper few centimetres of the sediment, and these parts cover the whole width of the gear /12/. The most conspicuous physical impact from beam trawling is flattening of bottom features such as ripples and irregular topography. The longevity of physical impact is determined by sediment type and natural disturbances, and has been shown to last from a few hours to more than a year. In practice, fishermen will tune the intensity of seafloor contact to the type of sediment. On soft grounds, where the risk of fastening is high, seafloor contact will be less intense compared to harder grounds.

The effect of an array of chains running consecutively over the seabed is that the increase in penetration depth becomes less and the additional effect smaller with an increasing number of chains. The passage of the first chain compacts the sediment, diminishing the effect of elements passing later. After about seven passages the increase in penetration is hardly noticeable. Fluctuations in the pressure exerted on the seabed indicate that beam trawls are not in steady contact with the seabed. Both variations in seabed morphology and vessel movements may cause a variable bottom contact of the gear. As a consequence, the penetration depth is not constant along the track.

Measurements of penetration depths between 1 and 8 cm are expected from beam trawls. The penetration depth depends on the sediment type ref. /12/. The largest values were noticed on very fine to fine muddy sand. Beam trawls have a penetration depth of ≤10 cm on both, muddy and sandy sediments ref. /13/, cf. Table 6-2.

Table 6-2 Average penetration depth of the flatfish beam trawl, taking into account the penetration depth of the individual components and their relative width in relation to the total width of the gear ref. /12/.

	Penetration depth (cm)		Width (m)		Penetration depth of the gear (cm)
	Trawl head	Ticklers and groundgear	4 trawl shoes	Groundgear for 2 trawls	
4 m beam trawl (chain mat)	6	2	1.08	7	2.6
4 m beam trawl (tickler chains)	6	2.2	1.24	7	2.7
12 m beam trawl (chain mat)	6	2	1.58	21	2.3
12 m beam trawl (tickler chains)	6	2.2	2.52	22	2.6

As mentioned in 6.1, Kattegat belongs to the ecoregion the Greater North Sea, and here it is assessed by ICES that beam-trawl fisheries operate in the shallow parts of the southern and central North Sea, with particularly intense activity off the southeast coast of England.

It is assessed that there are none too little activity from beam-trawlers that operate within the investigated area. Furthermore, the penetration depth of the gear, independent of sediment type, does not have any potential to reach the buried cable. The worst-case scenario in terms of penetration depth from beam-trawlers are ≤10 cm on both, muddy and sandy sediments. The smallest recommended burial depth is 1.1 m, which is based on the presence of medium dense sand in Section A, see 8.3.2. Also, there are little to none bottom trawling activity expected in Section A which primarily is a nearshore area.

6.2.2 Otter (bottom) trawls

Otter trawls derive their name from the two otter boards or doors that are fixed between the warps and bridles, Figure 6-4. Otter board or trawl doors are designed so that they are pulled through the water they plane in opposite directions. This action holds the wings of the net open. The otter boards must be towed at a certain speed for this effect to be achieved. Otter trawls fished on the bottom for demersal species target species such as cod, whiting and *Nephrops*. The gear can be rigged with tickler chains to change the selectivity towards flatfishes such as plaice.

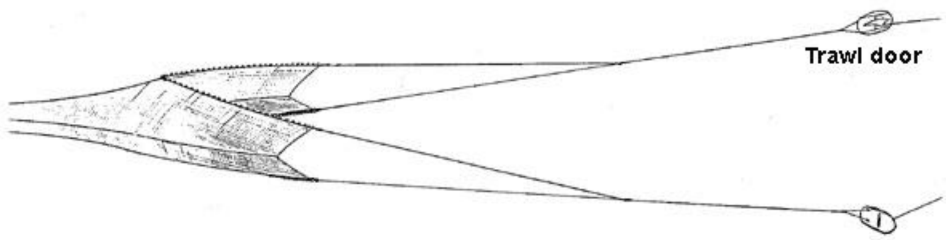

Figure 6-4 Principal features of an otter (bottom) trawl, source FAO

Furrows are created by the doors of the otter trawls. The trawl doors are the main part of an otter trawl that is rigged to penetrate the sediment. Furrows and berms created by the trawl doors are the most conspicuous physical impacts from otter trawls. Trawl doors penetrate deeper into the sediments than dredges and beam trawls and create an irregular bottom topography rather than flattening natural features. The passage of an otter trawl was found to have a generally minor physical and visual impact on the seabed compared to beam trawling in terms of impacted area, as beam trawl marks were observed to have widths of up to 22 m whereas otter board marks showed widths up to 6 m, Table 6-3. A study, ref. /13/, has shown that the penetration depth of the otter doors can be up to 35 cm in muddy sediments (≤ 10 cm in sandy sediments).

Table 6-3 Average penetration depth of demersal trawling, taking the penetration depth of the individual components and their relative width in relation to the total width of the gear into account ref. /12/.

	Penetration depth (cm)				Width (m)				Penetration depth of the gear (cm)
	Otter boards	Sweeps	Groundgear	Clump	Otter boards*	Sweeps	Groundgear	Clump	
2 outrigger trawls, operated from a large beam trawler (> 24 m)	8.4	0.1	1.8	9.7	2.3	6.4	25.6	/	1.89
Twin trawl, operated from a large beam trawler (> 24 m)	8.4	0.1	1.8	9.7	1.2	127	58	0.6	0.69
Twin trawl, operated from a stern trawler (> 24 m)	8.4	0.1	1.8	9.7	1.2	62.2	47.8	0.6	0.94
Otter trawl, operated from a stern trawler (> 24 m)	8.4	0.1	1.8	9.7	1.2	42.4	40.6	/	1.01

In two-boat or pair trawling, each vessel tows only one warp. Keeping station at a set distance apart provides the horizontal forces required to spread the gear, rendering the need for otter boards unnecessary. This means that two vessels of relatively modest engine power can between them tow a comparatively large trawl, increasing the volume of water swept per vessel by between 50 and 100%. Shackled between warps and bridles, a heavy wire sweep ensures good bottom contact. In all other respects the net is similar to that used in a single boat trawl, with floats and heavy rockhopper ground rope providing the vertical forces around the net mouth.

Because of the similarities between the nets of pair trawls and otter trawls, other characteristics are the same as those described earlier for the single bottom otter trawl ref. /12/, cf. Table 6-3.

The worst-case scenario in terms of penetration depth from otter-trawlers are 35 cm on muddy sediments, whereas it is ≤ 10 cm in sandy sediments. This corresponds well with the trawl mark stats reported in table Table 6-1. Surface sediments are interpreted as muddy sand from section B to section G, including SS_W and SS_E where the burial depth of the cable is > 2.5 m, except for section B that has a transition zone from 1.1 to > 2.5 m depth. It is assessed that the main bottom trawling activity in the investigated area comes from otter-trawlers. The penetration depth of the gear, independent of sediment type, does not have any potential to reach the buried cable. Also, there are little to none bottom trawling activity expected in Section A which primarily is a nearshore area.

6.2.3 Twin trawls

Some trawlers fish two bottom trawl nets side by side from the same vessel, Figure 6-5. Twin trawls are composed of two single otter trawls and are thus comparable in design to single otter trawls. The main difference is the clump between the two nets, which ensures seafloor contact by the centre part of the trawl and often has an intense seafloor contact and sediment penetration. In twin trawls, sweeps and bridles are standard and function as a herding device. Multi-rig trawls are composed of more than two single otter trawls and appear in a wide variety of riggings. Because of the similarities between the nets of twin (or multi-rig) trawls and otter trawls, other characteristics are the same as those described earlier for the single bottom otter trawl ref. /12/, cf. Table 6-3.

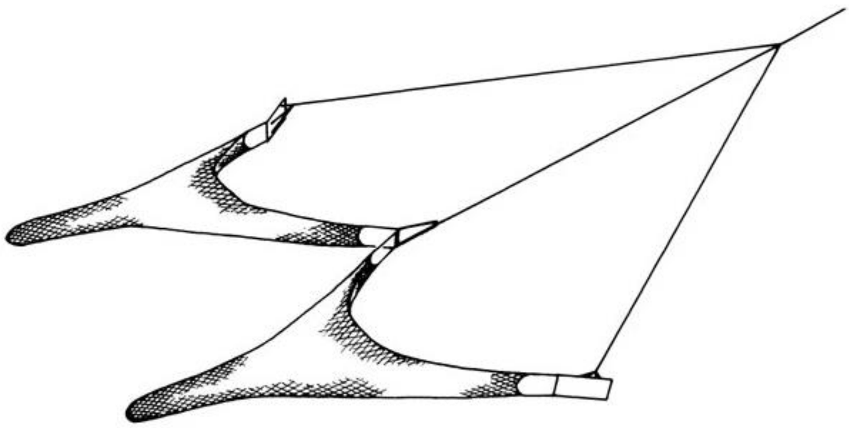

Figure 6-5 Principal features of a twin trawl, source FAO.

The worst-case scenario in terms of penetration depth from twin-trawlers are 35 cm on muddy sediments, whereas it is ≤ 10 cm in sandy sediments. This corresponds well with the trawl mark stats reported in Table 6-1. Surface sediments are interpreted as muddy sand from section B to section G, including SS_W and SS_E where the burial depth of the cable is > 2.5 m, except for section B that has a transition zone from 1.1 to > 2.5 m depth. The penetration depth of the gear, independent of sediment type, does not have any potential to reach the buried cable. Also, there are little to none bottom trawling activity expected in Section A which primarily is a nearshore area.

6.2.4 Dredges

Dredges are of two varieties: dredges (or drags) that harvest animals living at the surface of the substrate (for example, scallops and sea urchins) by scraping the surface of the sea bottom, and dredges that penetrate the sea bottom to a depth of 30 cm or more to harvest macro-infauna (for example, clams and cockles), ref. /12/ and Figure 6-6. Some surface dredges include rakes or teeth to penetrate the top layer of substrate and capture animals recessed into the seabed. Infaunal dredges can be further separated into those that penetrate the substrate by mechanical force (i.e., long teeth) and those that use water jets to fluidise the sediment (hydraulic dredges).

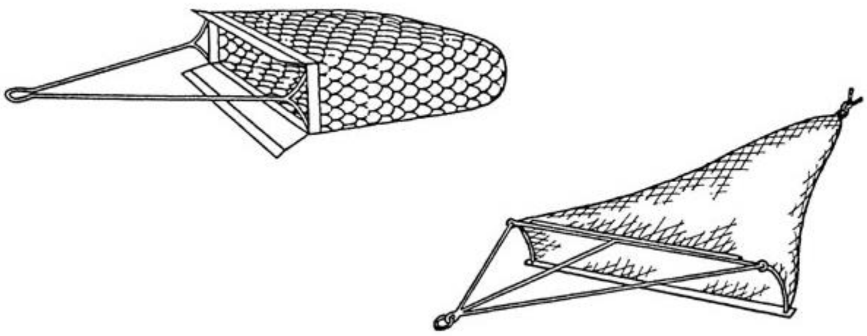

Figure 6-6 Principal features of a dredger, source FAO.

Fishing for mussels in Denmark is under strict regulation. It is so, to protect common eelgrass and areas with reef formations. Furthermore, there are restrictions to the maximum capacity of vessels allowed in nearshore areas. The closest activity with dredges to the project are two vessels allowed to fish for mussels in the Isefjord, ref. /14/.

As there are no fishing activity from dredges in the area, there are no impact on the cable on the cable burial depth.

6.3 Conclusion

The trawl mark stats that were observed in the area, and the reported penetration depth from literature indicates that bottom trawling has no impact to the buried cable despite of sediment and gear type.

6.4 Ship traffic assessment

We have briefly assessed the ship traffic in the water area surrounding the anticipated alignment of the soon-to-be buried cable between Gilleleje and Hesselø offshore wind farm. A navigational chart of the area is shown in Figure 6-7Figure 6-8 which also shows the cable alignment.

The assessment looks at the historical ship traffic. As basis for the assessment are ship registrations AIS (Automatic Identification System) data covering 1st of July 2020 until 1st of May 2021 and navigational charts of the area. Data are only used from 1st of July 2020 as the main shipping routes in Kattegat were changed from this date. However, they are scaled to represent a full year. Moreover, the traffic volumes have been compared with similar data covering all of 2019 before the COVID-19 pandemic to ensure adequate annual ship traffic numbers.

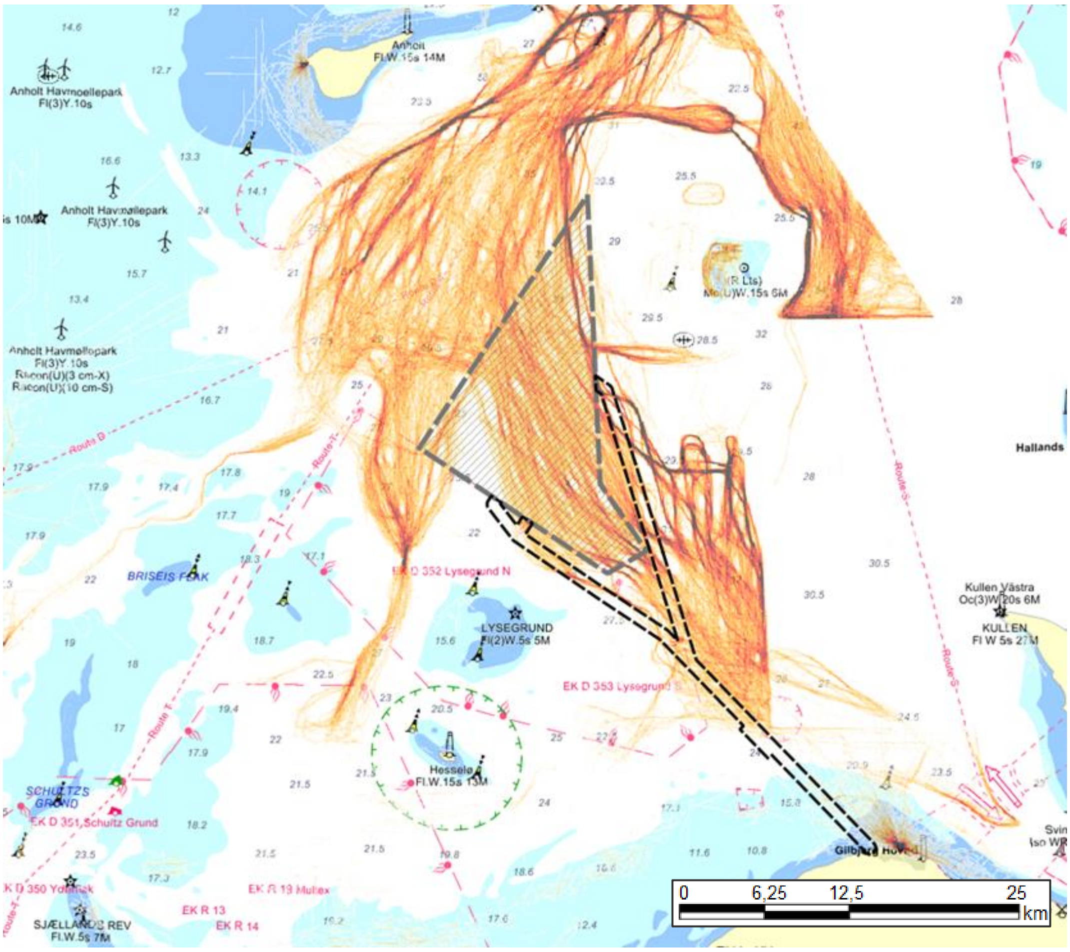

Figure 6-7 Navigational chart

6.4.1 Current area specific traffic

This section presents the current area and the ship traffic that sails near and across the alignments of the cable corridors between Hesselø offshore wind farm and Gilleleje at the north coast of Sealand. Figure 6-8 shows a nautical chart marking Hesselø OWF and the cable corridors between Gilleleje and the OWF. At the nautical chart are the navigational ship routes in Kattegat shown together with the sea markings, bathymetry, etc. The water depth at the OWF is 25 m-30 m, whereas the water depth decreases closer to Gilleleje. The light blue area at the nautical chart has depths between 10 m-20 m, and closer to land the darker blue area has depth between 0 m-10 m.

The OWF is located north of the shooting areas in the territorial sea, which is described further in ref. 0. The cables corridors enter the shooting areas “EK D 353 Lysegrund S” area in the split of the cable corridors. Thereafter the southwestern cable stays within the border of shooting areas "EK D 352 Lysegrund N". The cable corridor also crosses the border of the red circle northwest of Gilleleje. The red circle marks the restricted area with a historic wreck as stated in ref. 0.

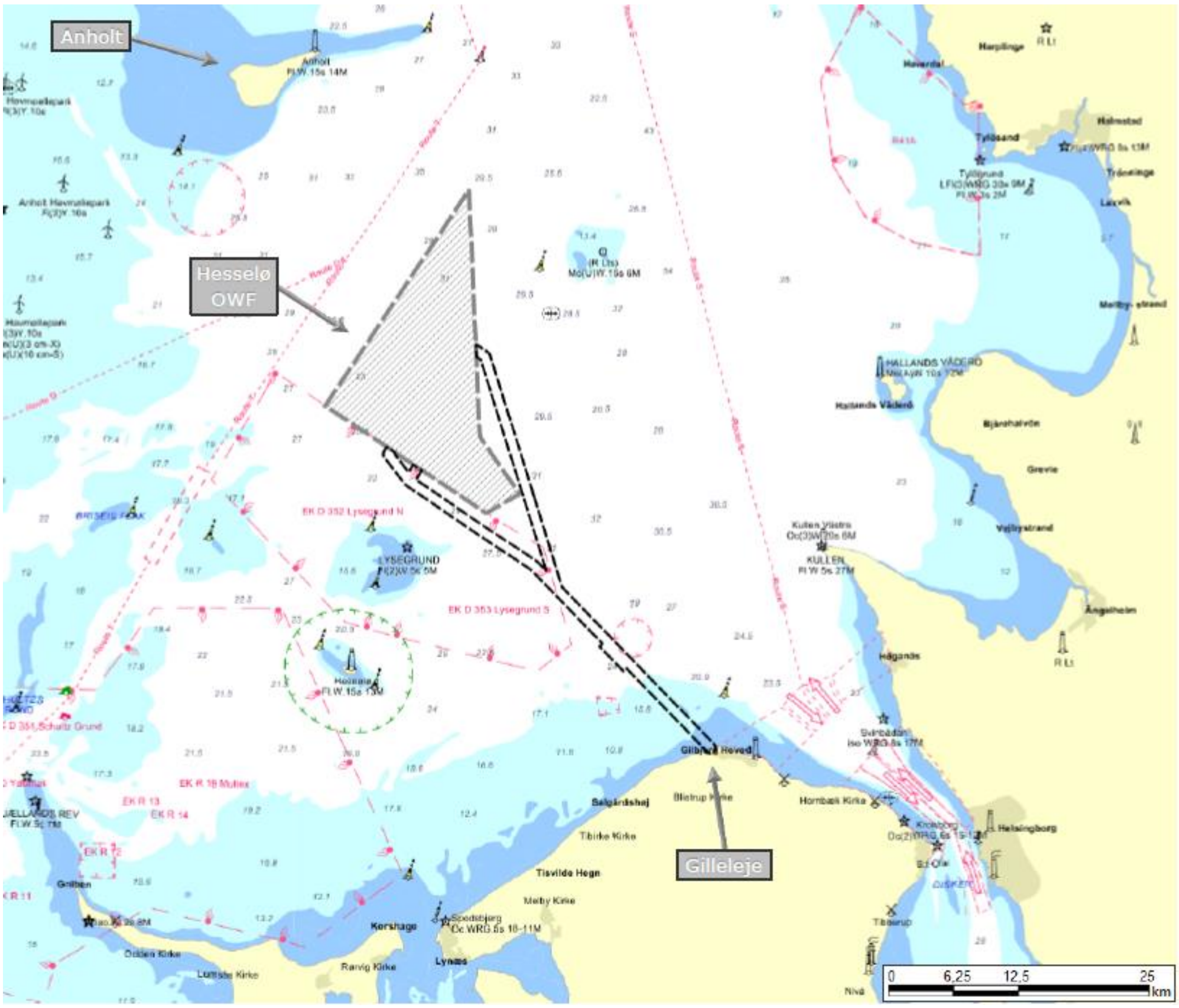

Figure 6-8 Navigational chart for the southern part of Kattegat showing main ship routes, sea markings and bathymetry. The area of Hesselø OWF (the grey shaded area) is overlayed on the chart together with the position for the cable corridors and cable alignment (the dashed black lines). Source of the navigational chart: https://kartor.eniro.se/?l=nautical

The ship traffic intensity is shown in Figure 6-9 where both commercial ship traffic and yachting are illustrated. A black colour indicates a high intensity followed by a red colour. The transition from red to orange to yellow indicates medium and white is a low intensity. In this context, commercial traffic is anything but yachtsmen and includes, for example, cruise ships, ferries, cargo ships, fishing boats and military vessels.

The intensity map is illustrated using ship registrations (AIS data) covering 1st of July 2020 until 1st of May 2021 together with the nautical chart and location of the OWF and cable corridors. The period of data is chosen because "*on 1st July 2020, new shipping routes in the Kattegat and Skagerrak entered into force*" ref. 0. For this area, the changes are that the shipping "Route D" between east of Anholt and The Sound is removed. This route had a kink next to the eastern border of the OWF. The shipping routes since the 1st of July 2020 is without "Route D". The routes in Kattegat go either east of the OWF along the Swedish coast on "Route S" or west of the OWF on "Route T" which can be seen in Figure 6-9.

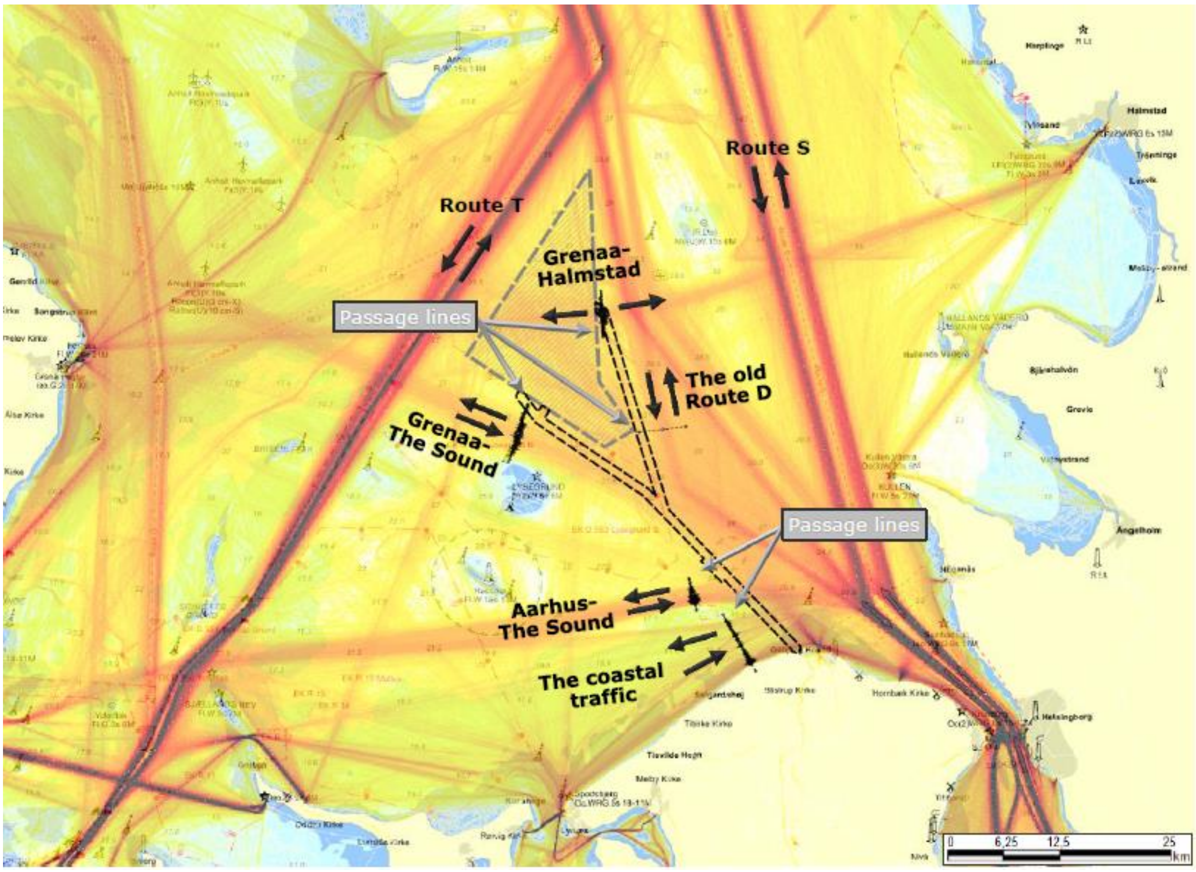

Figure 6-9 Ship traffic intensity covering from 1st of July 2020 until 1st of May 2021 in the area around the OWF and its cables corridors. The identified routes crossing the cable corridor and location of the passage lines are marked.

The ship traffic in Figure 6-9 generally follows the main shipping routes shown in the navigational chart in Figure 6-8. In addition, there are also other routes of moderate intensity, which sail across the waters of Kattegat in Figure 6-9 or sail nearby the coast crossing the alignments of the cable corridor to the OWF.

The identified routes with high or moderate intensity crossing the alignments of the cable corridor to the OWF are marked in Figure 6-9 and listed below:

1. Route 1: Grenaa – Halmstad
2. Route 2: Grenaa – The Sound
3. Route 3: Aarhus – The Sound
4. Route 4: The old Route D
5. Route 5: The coastal traffic

The identified routes where ships sail and induce a possible risk for the cable are further detailed. Route 1 crosses the cable corridor at the location where it connects to the OWF on the eastern border. Route 2 goes nearly parallel with the western cable corridor between the OWF and the cable corridor split. The ship traffic on Route 3 and 5 crosses nearly perpendicular to the cable alignment. And finally, the possible risk from Route 4 related to ships still using the old main navigational "Route D" sailing south parallel to the cable corridor followed by a kink next to the eastern border of the OWF where ships go towards the sound.

To assess the risk from ship traffic anchoring and damaging the buried export cables, some passage lines have been used to identify the ship traffic. The passage lines are located perpendicular to the busy shipping routes next to the cable corridors based on the intensity map in the area. Across each of them, the ship traffic has been counted and calculated for the distribution by ship type and lengths based on AIS data. These passage lines are also shown on the map in Figure 6-9.

In the following is a description of the traffic over the passage lines, where the number of ships by ship type is counted for the proportion of boats that have an AIS transmitter for each passage line as well as the total. Table 6-4 to Table 6-8 summarize the ship traffic measured at each of the passage lines from Figure 6-9. The ships traffic counted across the passage lines is scaled from the 10 months of data to a whole year. The ship traffic is compared to similar ship counts in year 2019 to compare if the COVID-19 pandemic had any effect on the ship traffic activities. With the used data since 1st of July 2020 there are no significant change seen compared to previous ship traffic in general. The removal of the main navigational "Route D" have had a huge effect, since only 25 % of ships are crossing this passage line. Furthermore, the ferry company Stena Line has opened a new route 2nd of February 2020, ref. 0. They write on their website that, "Our new Grenaa to Halmstad route (formerly Grenaa - Varberg) opens on 2nd February 2020." This has increased the ship traffic across the passage line "Grenaa - Halmstad" with nearly 375 % from 2019 to the used data since 1st of July 2020. It is noted that the "Grenaa – Halmstad" ferry route passes through the proposed Hesselø windfarm area, and across the connection to the export cables. The impact from the ferry route on the layout of the Hesselø windfarm has not been addressed in the present memo.

In the following, tables corresponding to each passage line are presented with the absolute ship counts across these lines for ships type and length. In average, five to nine ships per day sail across any of these passage lines.

Since not all ships define their characteristics, they will then be in the "Unknown" column if they haven't specified theirs ship length in the AIS data. Ships smaller than 100 m are split into 25 m intervals, whereafter 50 m and 100 m are used for the intervals to handle the amount of large commercial ships with greater length crossing any of the passage lines.

Table 6-4 The different ship types with their ship length that crosses the passage line "Grenaa/Halmstad" in the used AIS data (scaled to a full year).

	Unknown	0m-25m	25m-50m	50m-75m	75m-100m	100m-150m	150m-200m	200m-300m	Total
Fast ferry	0	0	0	0	0	0	0	0	**0**
Fishing ship	97	320	6	0	0	0	0	0	**424**
General cargo ship	0	6	0	4	17	8	40	2	**77**
Oil products tanker	0	0	0	0	20	49	1	0	**71**
Other ship	2	0	2	212	0	0	0	0	**217**
Passenger ship	0	0	0	0	0	1036	0	0	**1036**
Pleasure boat	7	58	0	2	0	0	0	0	**67**
Support ship	0	0	79	14	0	0	0	0	**94**
Total	**107**	**384**	**88**	**233**	**37**	**1093**	**41**	**2**	**1985**

The route between Grenaa and Halmstad has in average six ships per day crossing the passage line. Further, the passenger ship being the most frequent ship type across the passage line with all ships within the length interval of 100 m-150 m. The Stena Line passenger ship "STENA NAUTICA" with a length of 136 m has passed 1009 times across the passage line. Some smaller fishing ships are also crossing there. Only a few large ships in addition to the Stena Line ferry have crossed from July to May in the used historical AIS data.

For the route between Grenaa and The Sound presented in Table 6-5, there have in average been five ships per day crossing the passage line. On this route, a large part of the ship traffic is related to general cargo ship with a ship length between 75 m-100 m. The three most frequent cargo ships cross 89 to 114 times per year. The following most frequent ships are also cargo vessels and a support ship with respectively 66, 37 and 30 crossings. Most of the cargo ships across this passage line are seen fewer than five times per year.

Table 6-5 The different ship types with their ship length that crosses the passage line "Grenaa/The Sound" in the used AIS data (scaled to a full year).

	Unknown	0m-25m	25m-50m	50m-75m	75m-100m	100m-150m	150m-200m	200m-300m	Total
Fast ferry	0	0	0	0	0	0	0	0	**0**
Fishing ship	8	71	38	30	0	0	0	0	**148**
General cargo ship	100	1	1	85	1024	131	30	4	**1375**
Oil products tanker	0	0	0	5	19	28	2	0	**54**
Other ship	6	5	20	24	22	8	2	0	**88**
Passenger ship	0	0	0	0	0	1	0	0	**1**
Pleasure boat	1	23	1	8	0	0	0	0	**34**
Support ship	8	13	76	20	8	2	0	0	**128**
Total	**124**	**113**	**137**	**173**	**1073**	**170**	**35**	**4**	**1828**

For the route between Aarhus and The Sound, there have in average been seven ships per day crossing the passage line. On this route, a large part of the ship traffic is related to cargo ship between 50 m and 200 m in length and some oil tankers. The four most frequent ships are cargo ship with length between 158 m and 185 m which count for 391 of the crossings. The three most frequently seen cargo ships are Ro-Ro carriers.

Table 6-6 The different ship types with their ship length that crosses the passage line "Aarhus/The Sound" in the used AIS data (scaled to a full year).

	Unknown	0m-25m	25m-50m	50m-75m	75m-100m	100m-150m	150m-200m	200m-300m	Total
Fast ferry	0	0	0	0	2	2	0	0	**5**
Fishing ship	12	29	10	0	0	0	0	0	**50**
General cargo ship	10	0	1	65	748	424	635	4	**1885**
Oil products tanker	0	0	0	0	90	94	10	1	**194**
Other ship	8	4	18	8	23	13	1	0	**76**
Passenger ship	0	0	0	0	0	1	0	1	**2**
Pleasure boat	6	61	1	7	0	0	0	0	**76**
Support ship	0	23	44	4	0	31	0	0	**102**
Total	**36**	**116**	**74**	**84**	**863**	**565**	**646**	**6**	**2390**

In Table 6-7 are the ship counts across the passage line "The old Route D" presented where there in average have been nine ships per day. The ship traffic that has the most crossing is both smaller fishing vessels and larger cargo and oil tankers. The most frequent crossings are represented by four fishing vessels with length of 15 m-18 m each and with 72-78 crossings. In 2019, the same passage line was passed by 995 fishing vessels, 6,824 cargo ships and 3,462 oil tankers. The removal of the "Route D" reducing the traffic clearly shows an effect since only 25 % of ship traffic are counted compared to year 2019 with the main decrease seen for cargo ships and tankers. In fact, the number of fishing vessels has remained at the same level or increased slightly. Overall, fewer ships are therefore sailing on the old Route D, which the intensity map in Figure 6-9 also shows with less intense colour.

Table 6-7 The different ship types with their ship length that crosses the passage line "The old Route D" in the used AIS data (scaled to a full year).

	Unknown	0m-25m	25m-50m	50m-75m	75m-100m	100m-150m	150m-200m	200m-300m	Total
Fast ferry	0	1	0	0	0	2	0	0	**4**
Fishing ship	241	766	58	23	0	11	0	0	**1098**
General cargo ship	1	4	1	46	286	203	373	169	**1082**
Oil products tanker	0	0	0	5	109	131	192	65	**502**
Other ship	5	12	41	14	8	38	2	1	**122**
Passenger ship	0	1	0	0	2	0	11	0	**14**
Pleasure boat	26	126	6	5	0	0	0	0	**163**
Support ship	0	8	107	11	10	7	1	0	**144**
Total	**274**	**918**	**212**	**103**	**415**	**392**	**580**	**235**	**3130**

In average, the coastal traffic has eight ships per day crossing the passage line. As Table 6-8 shows, the ship type crossing here are mostly smaller pleasure boats and larger cargo ships. The ship traffic crossing most frequent is a pilot the supporting ships through The Sound but also cargo ships. The cargo ships have length between 85 m and 128 m each and with 25-107 crossings over the passage line next to the coast.

Table 6-8 The different ship types with their ship length that crosses the passage line "The coastal traffic" in the used AIS data (scaled to a full year).

	Unknown	0m-25m	25m-50m	50m-75m	75m-100m	100m-150m	Total
Fast ferry	0	0	0	0	0	0	**0**
Fishing ship	14	110	0	0	0	0	**125**
General cargo ship	2	11	0	107	511	251	**882**
Oil products tanker	0	0	0	0	1	2	**4**
Other ship	48	85	90	34	20	2	**280**
Passenger ship	0	2	2	0	0	0	**5**
Pleasure boat	132	1068	12	14	0	0	**1226**
Support ship	4	74	72	8	1	11	**170**
Total	**200**	**1351**	**176**	**163**	**534**	**266**	**2692**

6.4.2 Future traffic

The future traffic relates to the ships that still not sail or haven't been active due to the COVID-19 pandemic. With the removal of the main navigational "Route D", the ship traffic across the passage line has decreased since year 2019. The expected ship traffic in the future on "Route D" will decrease further for cargo ships and oil tankers since these are expected to use the nearby main navigational routes instead.

For the new ferry route between Halmstad and Grenaa, the ship traffic may change. The traffic will depend on the interest in the ferry route and the COVID-19 pandemic might also have affected its possibilities to increase the operations. There might therefore in the future be an increasing activity for the ferry which isn't show on the intensity map in Figure 6-9.

6.4.3 The risk of anchor drops

The cable alignment is in open water where ships are not expected to make additional manoeuvres or change in direction. The cable will primarily be crossed by vessels sailing in an east/west direction entering and exiting The Sound, except from the ferry route. The ferry sails between Grenaa and Halmstad.

To assess the risk from ship traffic anchoring and damaging the burial cables, the frequency for ships uncontrolled anchor drops is qualitatively assessed. The frequency for uncontrolled anchor drops is extracted from the DNV ref. 0 appendix E about "Unintentional Anchor Drops from Ships Under Way". The frequency is 2.7 x 10^{-8} for an accidental anchor drops per km.

For each of the identified routes crossing the cable corridor, the distance across has been measured in km. For route 1, 3 and 5 sailing perpendicular to the cable alignment, the distance is about 2 km across. For route 2, the distance is about 5 km, and for the remaining route 4, it is about 6 km. Ships on route 4 do not sail across the cable alignment, but sail parallel to it, where the ships nearest (33 % of the route) are assumed to induce a possible risk. This risk at route 4 is reduced but still assumed conservative since anchors are dropped and dragged parallel to the cable alignment. Therefore, the damage to the cables is less expected.

With the earlier presented ship counts across each passage line for each ship type it is assumed, that no pleasure boat will lead to an uncontrolled anchor drop. It is assumed that pleasure boats keep their anchors under a hatch or attached to the boat. Larger ships have their anchors outboards which may cause uncontrolled anchor drops.

The formula used for estimating the occurrence for an anchor drops pr year is presented below:

$$\begin{aligned}&\mathit{Anchor\ drops\ pr\ year}\\&\qquad = \mathit{Frequency\ of\ anchor\ drops\ per\ km}\\&\qquad \times \mathit{Distance\ sailed\ across\ cable\ corridor\ in\ km}\\&\qquad \times \mathit{Number\ of\ vessels\ in\ the\ area\ of\ the\ cable\ corridor}\\&\qquad \times \mathit{Fraction\ of\ non\ pleasure\ boats}\end{aligned}$$

For Route 1, the formula is used with the following values, which gives the annual frequency for an anchor drop.

$$\mathit{Anchor\ drops\ pr\ year} = 2.7 \times 10^{-8} \times 2 \times 1{,}985 \times 97\% \times 100\% = 1.04 \times 10^{-4}$$

This gives the yearly return period of an accidental anchor drop every 9,657 years for Route 1. The frequencies and return periods for the other routes are listed up in Table 6-9. Here also the total frequency and return period are presented representing the overall risk.

Table 6-9 Estimation of return period for ships accidental anchor drop.

Routes	Anchor drops pr year	Return period pr year
Grenaa – Halmstad	$1.04{\cdot}10^{-4}$	9,657
Grenaa – The Sound	$2.42{\cdot}10^{-4}$	4,129
Aarhus – The Sound	$1.25{\cdot}10^{-4}$	8,000
The old Route D	$1.60{\cdot}10^{-4}$	6,243
The coastal traffic	$1.41{\cdot}10^{-4}$	7,105
Total	$\mathbf{7.72{\cdot}10^{-4}}$	**1,296**

The risk of uncontrolled anchor drops for each route is found to occur approximately once every 4,100-9,600 year. In total, it is estimated that an anchor drop may be observed approximately once every 1,300 year anywhere on the cable alignment.

The potential consequence of an anchor drop is that the cable is caught by the fluke of the anchor and damaged. To assess the consequences of an accidental anchor drop, the largest ship for each route has been identified. The ship traffic for the identified routes show that cargo ships were the largest ships on the routes. These vary between 150 m and 300 m in length for the largest ships. For Route 1 the most common ship is the 136 m passenger ferry between Grenaa and Halmstad.

Indicative anchor sizes specified for ships with various displacement are found in ref. 0. These are shown in Table 6-10.

Table 6-10 Relationship between ship size, anchor mass and fluke length for stockless anchors, ref. 0.

Displacement [tonnes]	Anchor mass [kg]	C, fluke length [m]	C⊥ , Projected fluke length [inches]	C⊥ , Projected fluke length [m]
1,500	900	0.84	23.4	0.6
3,600	1,440	0.91	25.3	0.6
10,000	3,060	1.26	35.1	0.9
45,000	8,700	1.83	50.9	1.3
175,000	17,800	2.31	64.3	1.6
350,000	26,000	2.64	73.5	1.9

The largest ships crossing the cables to Hesselø OWF are assessed to have a displacement of 10,000 tonnes for the passenger ferry and approximately 45,000 tonnes for the cargo ships. The anchors' projected fluke length, the length the anchors dig into the seabed, are in general up to about 1.5 m.

6.4.4 Conclusion

The ship traffic in the water area surrounding the anticipated alignment of the proposed buried cable between Gilleleje and Hesselø offshore wind farm have been assessed. To assess the risk, historical ship traffic data covering from 1st of July 2020 until 1st of May 2021 and a navigational chart of the area have been used. The data is used to identify ships types, sizes and the number of crossings that could induce risk to the cable corridor and alignment.

Together with the report from Det Norske Veritas AS, a semi-quantitative approach has been used to estimate the frequency of uncontrolled anchor drops. The frequency of ships anchor drops is in general a rare event. The moderate ship traffic across the cable corridor and alignment for each of the identified routes does not significantly increase the occurrence of damaging the burial cables.

The largest ship crossing the cable alignments given the AIS-data are assessed to have anchors which can dig about 1.5 m into the seabed. Accidental anchor drops from ships dragged along the seabed can catch and damage the cables if they are buried less than 1.5 m into the seabed, even though the frequency for this is assessed to be low with a return period higher than 1,300 years. The risk for cables buried below this level is assessed to be insignificant in relation to accidental anchor drops.

6.5 Burial Protection Index (BPI)

The concept of a burial protection index (BPI) was first proposed by Mole et al, 1997 /Ref/ and further defined by Allen, 1998 /Ref /. The concept is that stronger seabed soils provide greater protection for a cable upon burial than weaker soils, a relationship which can be seen on Figure 6-10.

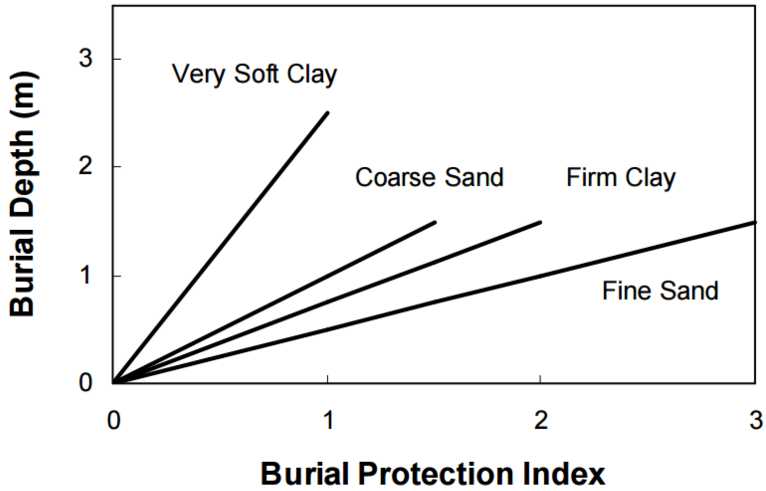

Figure 6-10 Relationship between BPI and burial depth in different soils /Ref 4/

Further indexing was given in /Ref 4/:

BPI = 1 Depth of burial consistent with protecting a cable from normal fishing gear only. Would be appropriate to water depths greater than say 50 to 100m, where anchoring of ships is unlikely, or in areas where anchoring and shipping is prohibited.

BPI = 2 Depth of burial will give protection from vessels with anchors up to approximately 2 tonnes. This may be adequate for normal fishing activity, but would not be adequate for larger ships (eg tankers, large container ships)

BPI = 3 Depth of burial sufficient to protect from anchors of all but the largest ships. Suitable for anchorages with adjustments made to suit known ship/anchor sizes.

Based on the assessment of the vessel traffic (moderate traffic and low risk of anchor drops) and the limited fishing activities, the burial assessment index BPI is set to BPI=1, even though the maximum water depth is ~34 m.

6.6 Off limit areas

In the following sections, the information and maps shown stems from publicly available databases.

6.6.1 Cultural heritage

Figure 6-11 shows the location of cultural heritage objects according to the National Museum of Denmark. An aircraft (red dot) seems to be located at the landfall. Further, a wreck is located close to the northern substation (blue dot). Further, wrecks are seen close to the alignment in areas GL03, GL04 and GL10. Supplementing this, an archaeological study has been carried out based on the latest geophysical data from the ECR/OWF surveys.

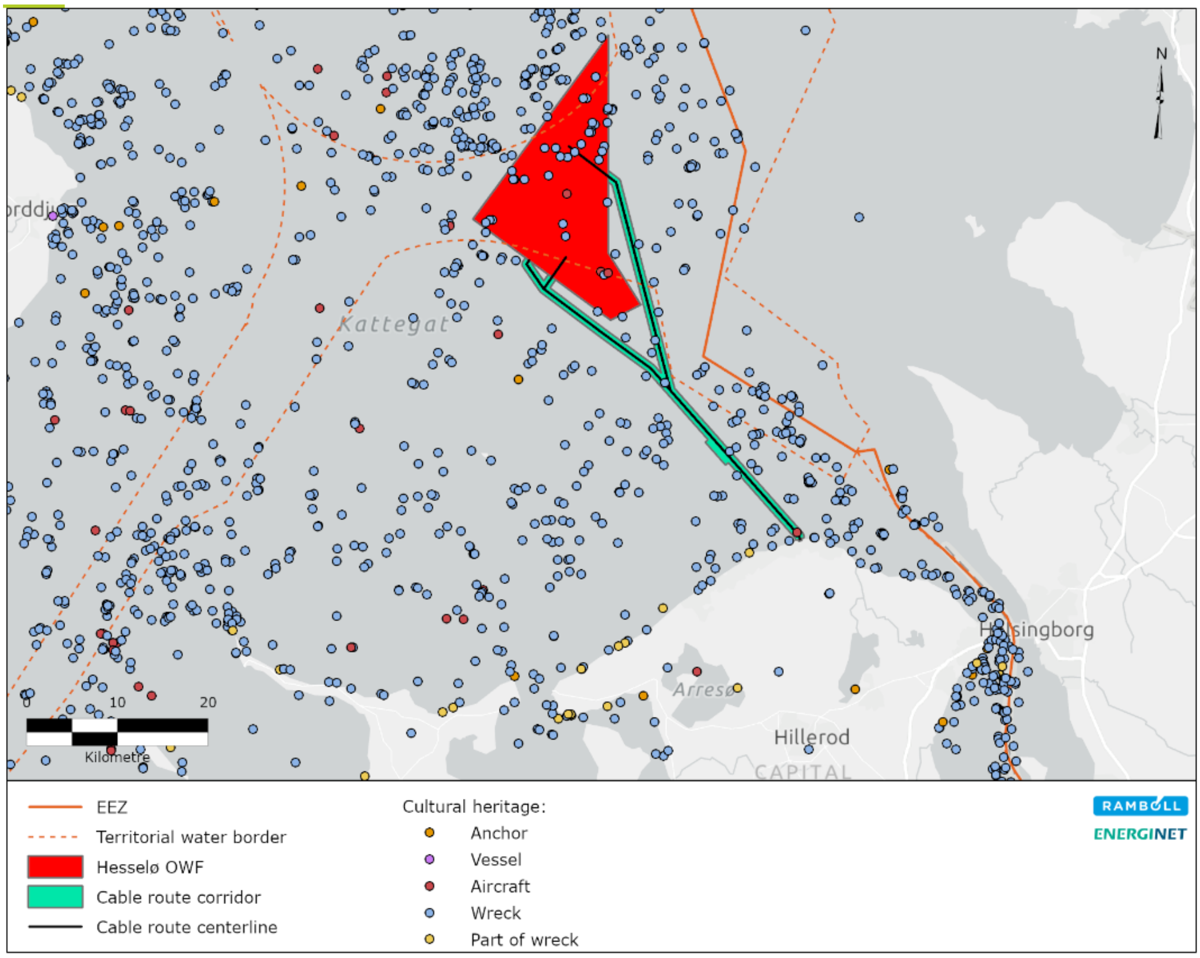

Figure 6-11 Cultural heritage locations

6.6.2 Forest reserve and constructions related to coastal protection

At the landfall, the area is a forest reserve (Hesselø Fredskov) and thus protected by the Nature protection act, cf. Figure 6-12. Further, constructions related to costal protection (Hesselø Kystbeskyttelsesanlæg) are located close to the ECR alignment, cf. Figure 6-13.

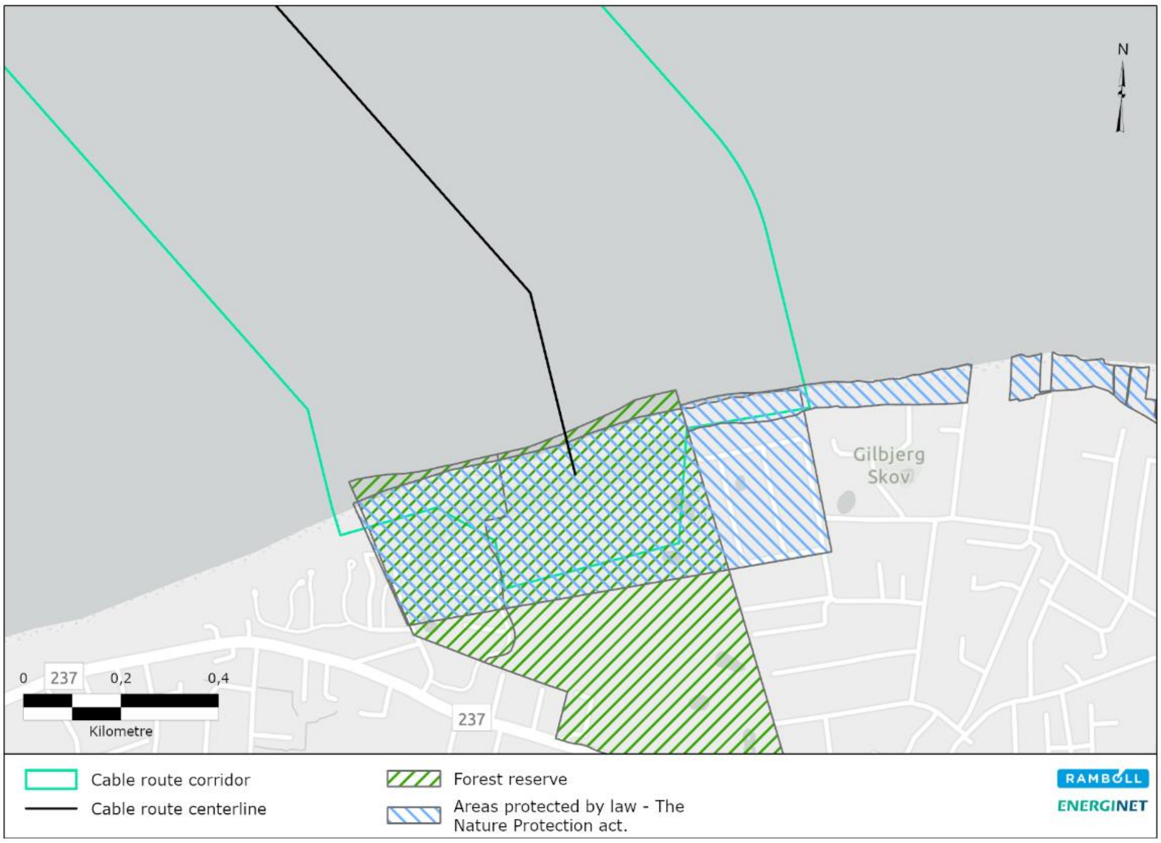

Figure 6-12 Forest reserve Hesselø fredskov

Figure 6-13 Costal protection area (Hesselø Kystbeskyttelsesanlæg)

6.6.3 Marine mammals

The distribution and abundance of grey seals across the Baltic Sea is illustrated in Figure 6-14. There is a regular occurrence and no regular reproduction in the ECR/OWF area.

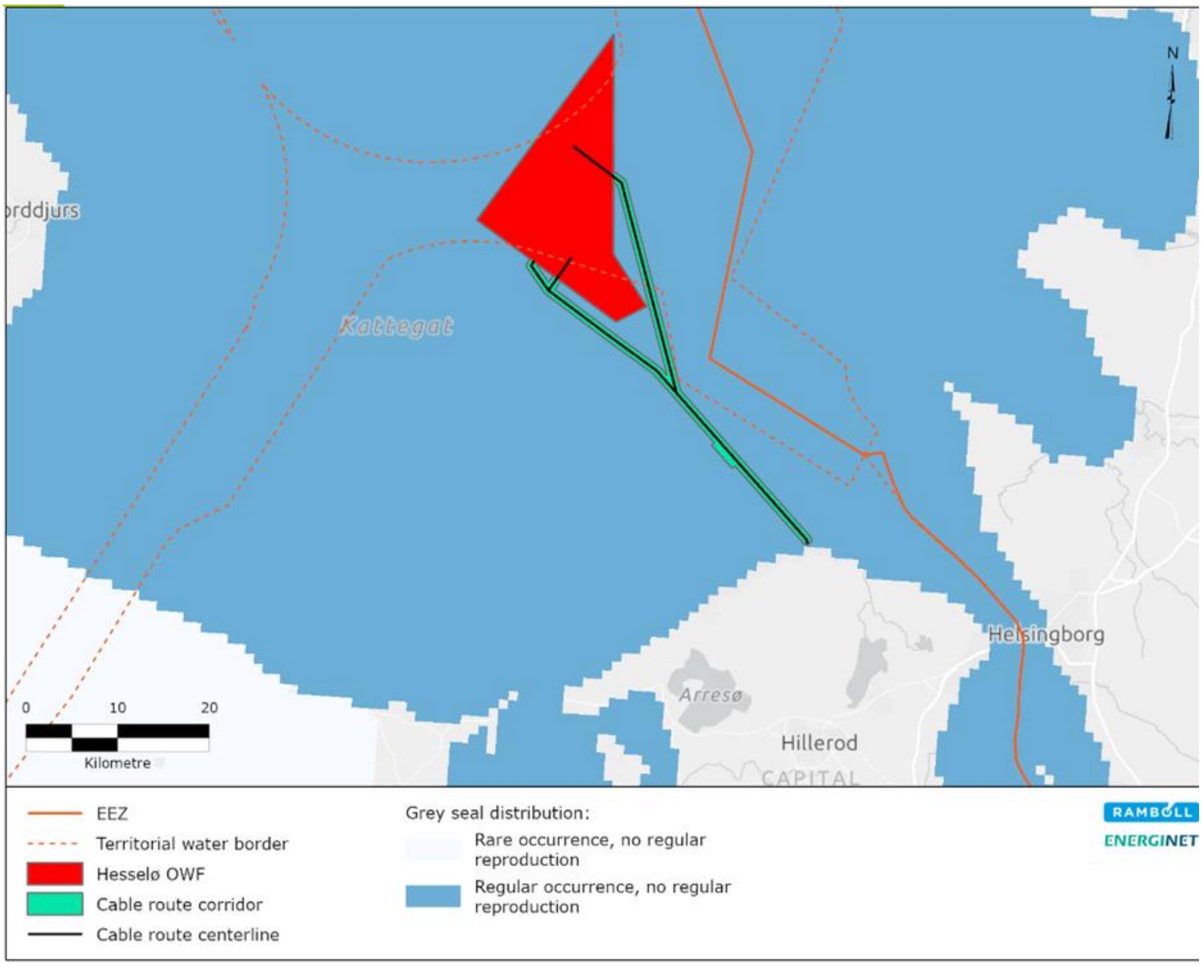

Figure 6-14 Grey seals, abundance in the area

The distribution and abundance of Harbour porpoise across the Baltic Sea is illustrated in Figure 6-15. There is a common occurrence and reproduction in the ECR/OWF area. The presence of sea mammals needs to be considered when selecting the installation method and in relation to permits (noise, seabed disturbance).

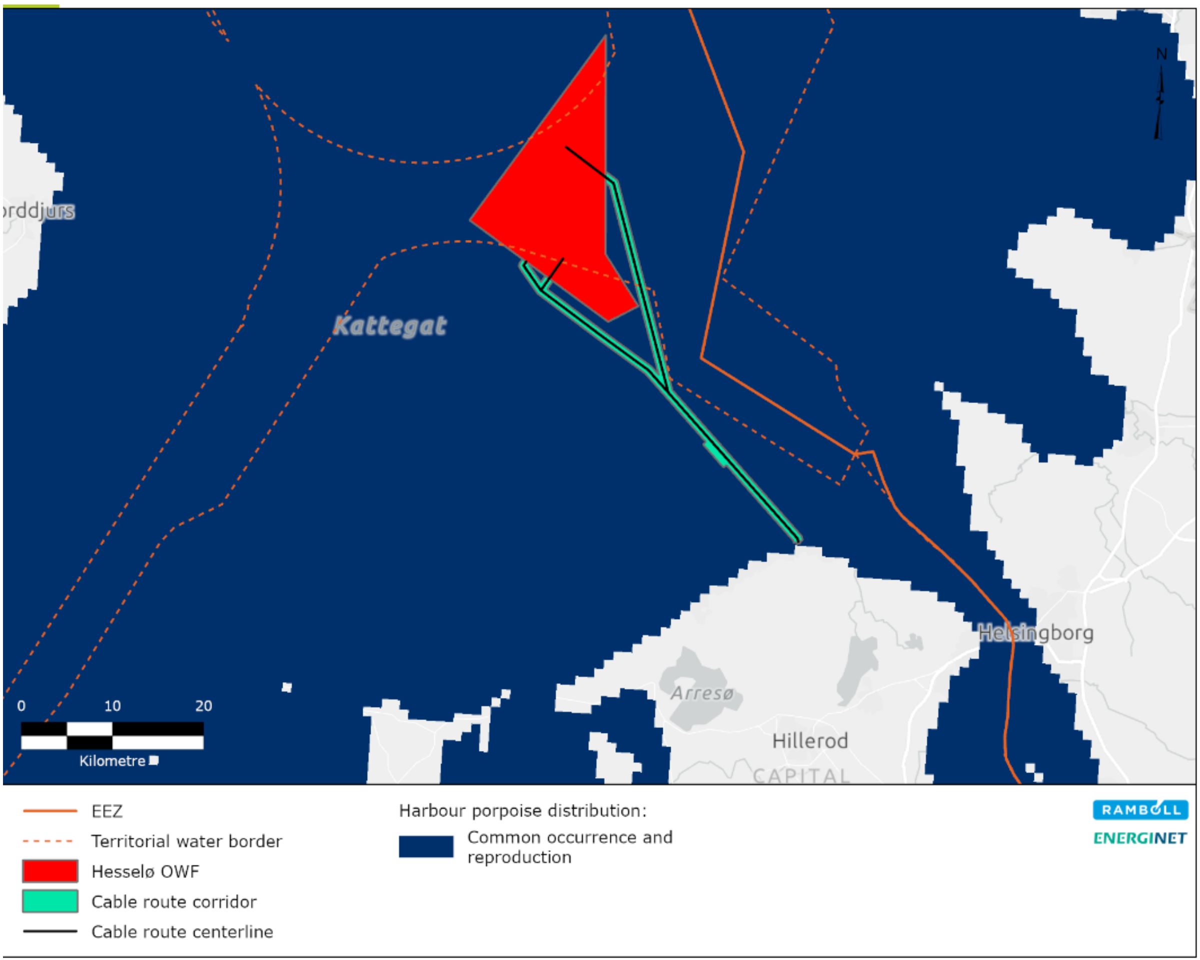

Figure 6-15 Harbour porpoise, abundance in the area

The distribution and abundance of Harbour seal across the Baltic Sea is illustrated in Figure 6-16. There is a common occurrence and reproduction in the ECR/OWF area.

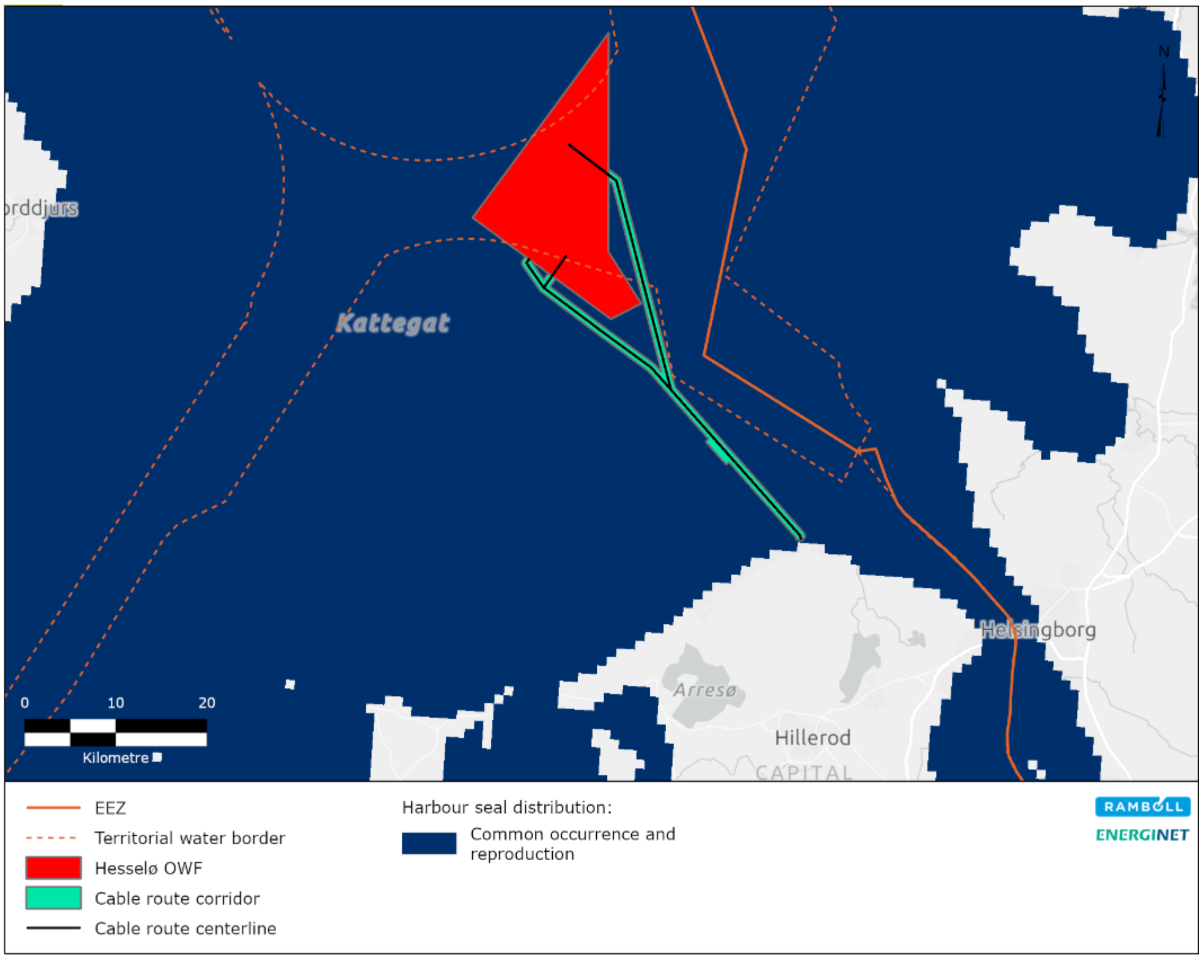

Figure 6-16 Harbour seal, abundance in the area

6.6.4 Military areas

The military areas are illustrated in Figure 6-17. It is seen that parts of areas GL04, GL05 and GL10 are placed in a restricted area, while areas GL06 through GL09 and part of area GL05 are placed in a danger area.

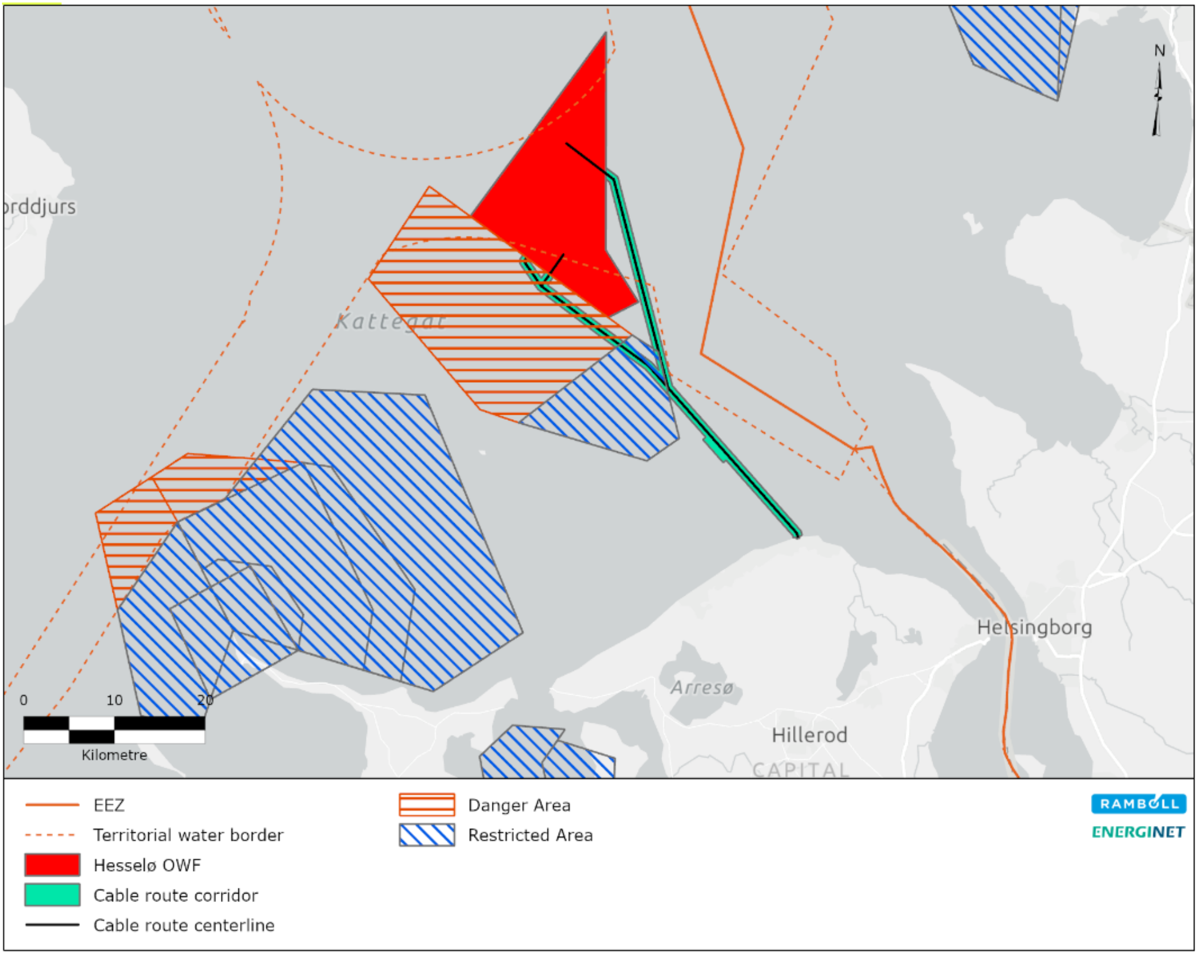

Figure 6-17 Military areas

6.6.5 Natura 2000 protected areas

The location of nearby Natura 2000 protected areas is illustrated in Figure 6-18. A Natura 2000 protected area is located at the landfall. A close-up of this area is seen in Figure 6-19. The concerned habitat types are sandbanks and reefs. It should be noted that the boulder field in this area is covered by the geophysical survey presented in this report.

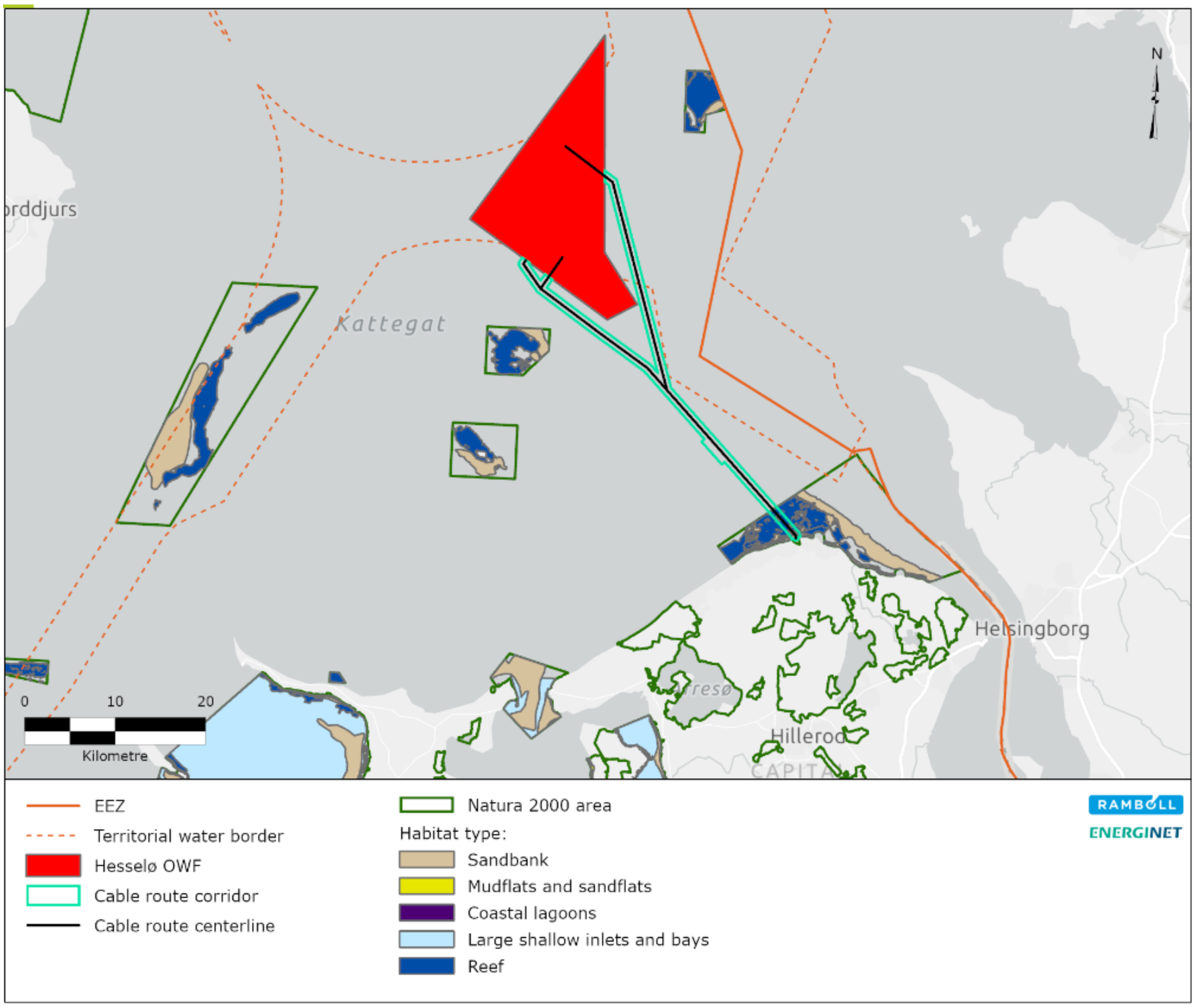

Figure 6-18 Natura 2000 protected areas

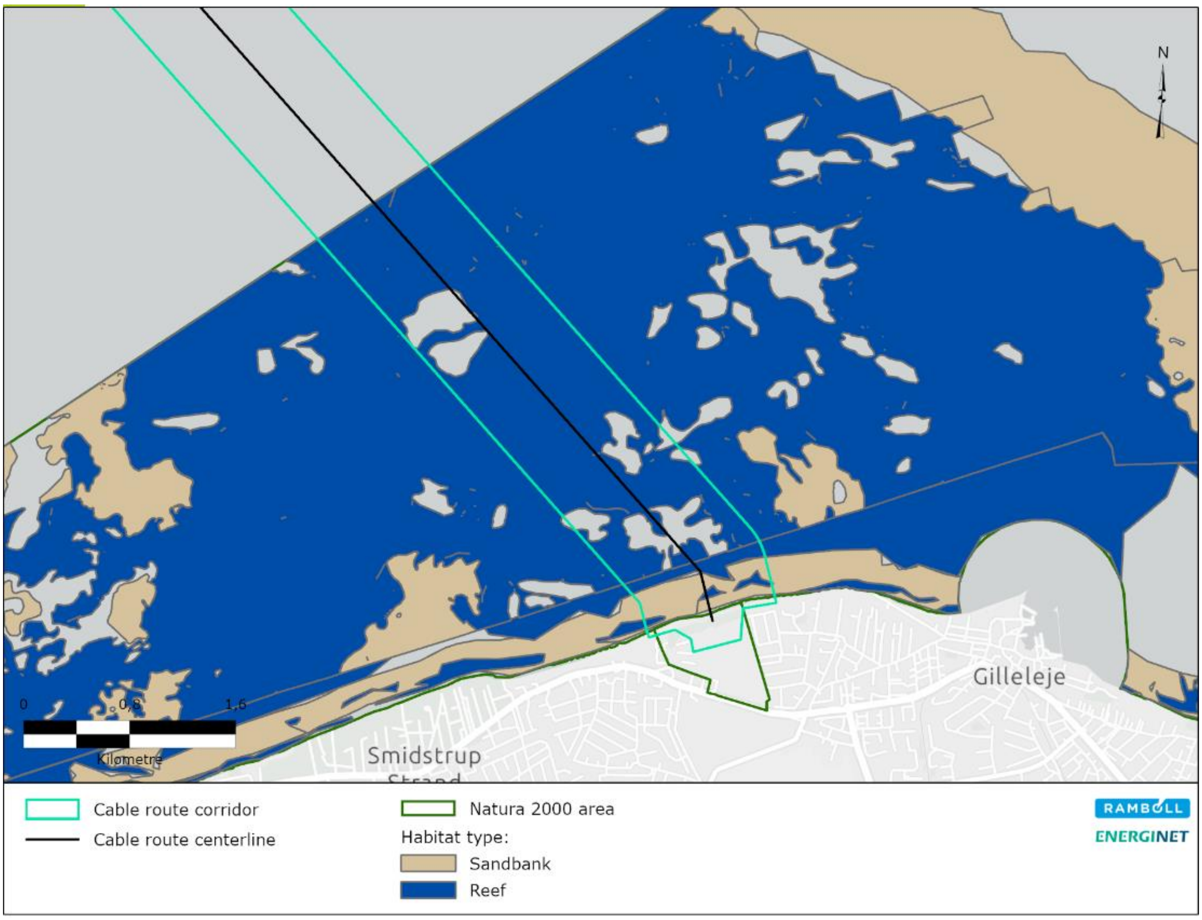

Figure 6-19 Natura 2000 protected area at the landfall

6.7 Potential UXO and other man-made anomalies

The potential UXO contamination of the Hesselø windfarm has been assessed by RPS in ref. /3/. Based on the conclusions of the research and the risk assessment undertaken, RPS has found there to be a varying Low and Moderate risk from encountering Unexploded Ordnance on site. The risk is primarily due to the presence of Allied Mine Fields from World War Two, cf. Figure 6-20

RPS also notes that the seabed sediment noted throughout the site appears to consist mainly of sands and muddy sands, with isolated areas of glacial till. In the softer sediments it is possible for munitions to be scoured by currents and subsequently become buried. An additional potential cause of burial on the Hesselø wind farm site is the liquefaction phenomenon, a consequence of the earthquakes that have affected the area. Thus, RPS would require further geotechnical information such as CPT data to analyse the seabed sediment and subsurface geology to determine the likelihood of liquefaction causing burial of Unexploded Ordnance.

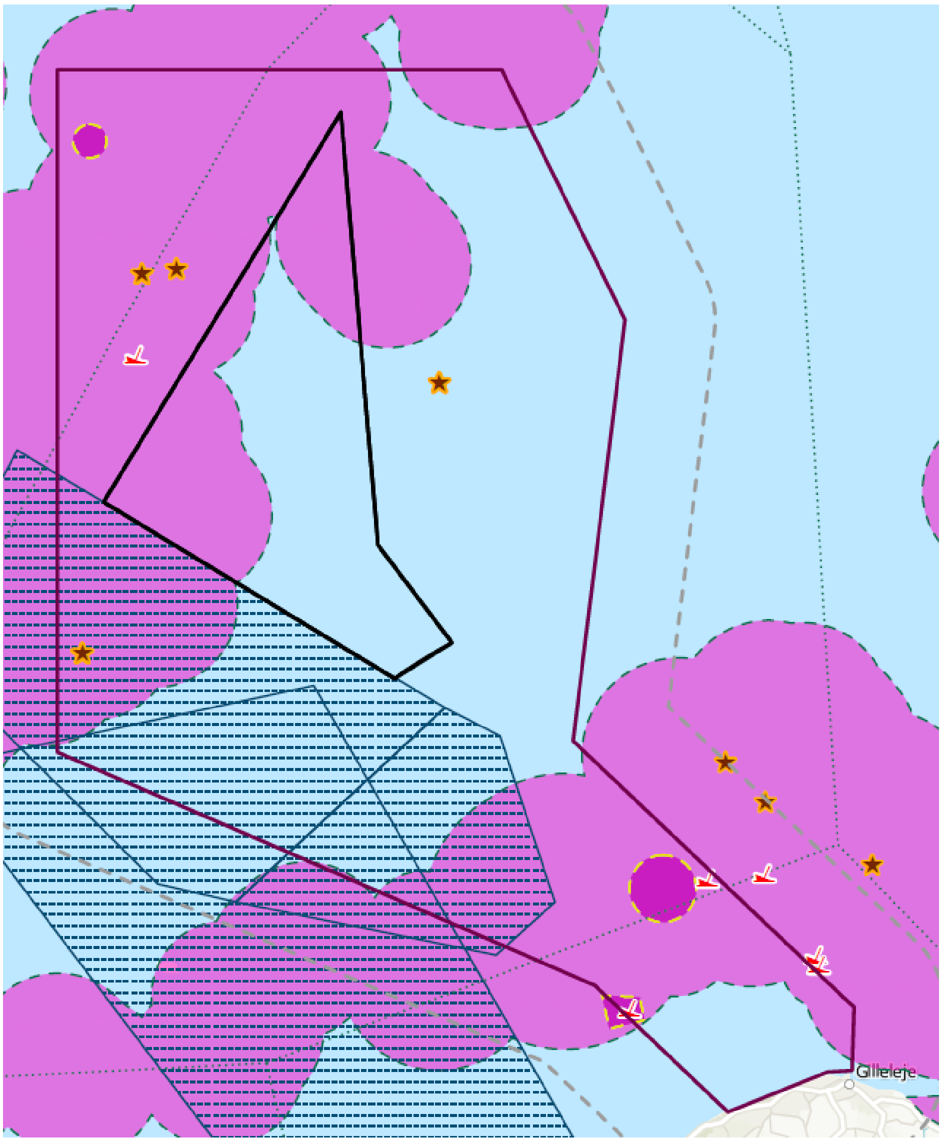

Figure 6-20 UXO related features. Light pink=British WWII minefield, dark pink=historic minefield, unspecified origin. Dashed areas = Firing exercise area

From the magnetic anomaly survey carried out by Rambøll in 2020, it is seen that some concentrated zones of high magnetic intensity are found and that the main part is located around the dense boulder zones, cf. Figure 6-21. In these boulder fields it can be difficult to correlate the magnetic anomalies with targets from the SSS and MBES data, therefore, the correlation in these areas must be evaluated with a significantly low confidence. Outside the boulder fields, many of the magnetic anomalies are not visible on the MBES and SSS data. These anomalies should however still be considered as objects that may be encountered during any activities on the seabed. The anomalies are most likely anthropogenic debris either below the mudline or they are too small to be detected on the MBES or SSS data.

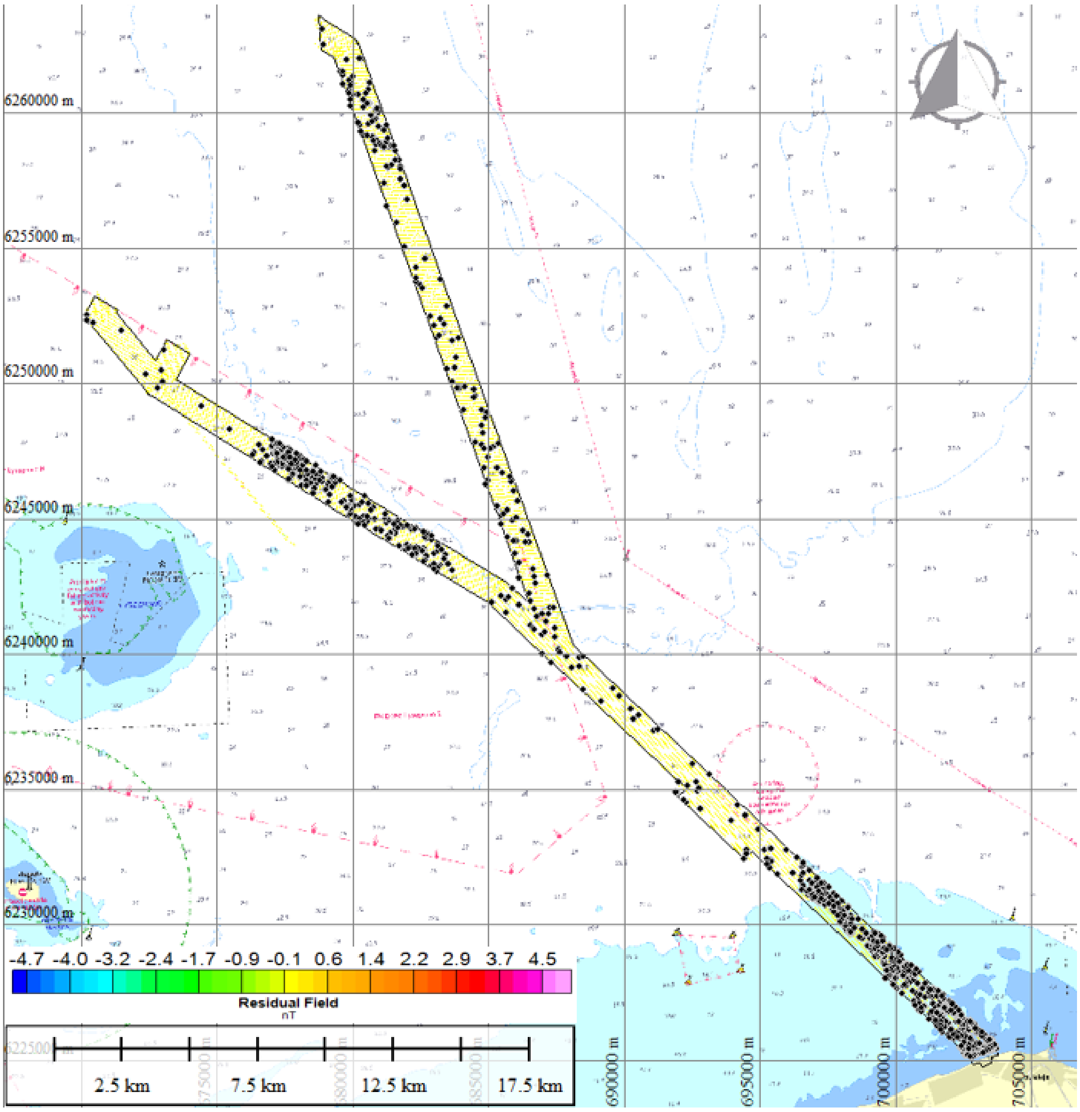

Figure 6-21 Location of magnetic anomalies

6.8 Ship wrecks

The 2020 survey has found no ship wrecks in the vicinity of the planned cable route

7. GEO HAZARDS

Geo hazards are seabed features, and natural environments that pose, or might pose a risk to the cable installations. The risk can occur either during the installation or after burial.

The hazards can be divided into primary and secondary hazards. The primary hazards include conditions that will directly damage the cables in an area. This can be natural conditions that will move and thereby subject the cable to wear and fatigue.

The secondary hazards do not directly damage the cables but may expose them to the primary hazards.

Also is considered the soils ability to conduct heat away from the cable once it is operating. This is done by evaluating the thermal properties of the different soil layers, including organic layers.

7.1 Neotectonics and earthquake activity

As mentioned by GEUS in /2/, the geotechnical challenges for the Hesselø and cable corridor areas include neotectonics and earthquake activity within the Sorgenfrei-Tornquist zone, presence of gas in sediments and great thickness of weakly consolidated glaciomarine clay.

Based on the available SBP data, no recent faulting activity or sediment dislocation within the Holocene sequence has been observed along the cable corridor. However, given the fact that the Sorgenfrei-Tornquist zone is an active tectonic zone, risk for reactivation along the existing deeper fractures can't be fully excluded.

7.2 Shallow gas

Presence of gas influences acoustic properties of sediments, typically leading to strong signal attenuation, masking of underlying reflectors and possibly the presence of phase-reversed reflection events. Accumulations of shallow gas within the cable corridor are manifested dominantly as acoustic blanking and occur primarily within the fine-grained units LG GL, PG II.1 SA and PG II.2 CL. One of the most pronounced shallow gas accumulations has been found in the southern part of the cable corridor, along the section GL03, and it is shown on the Figure 7-1.

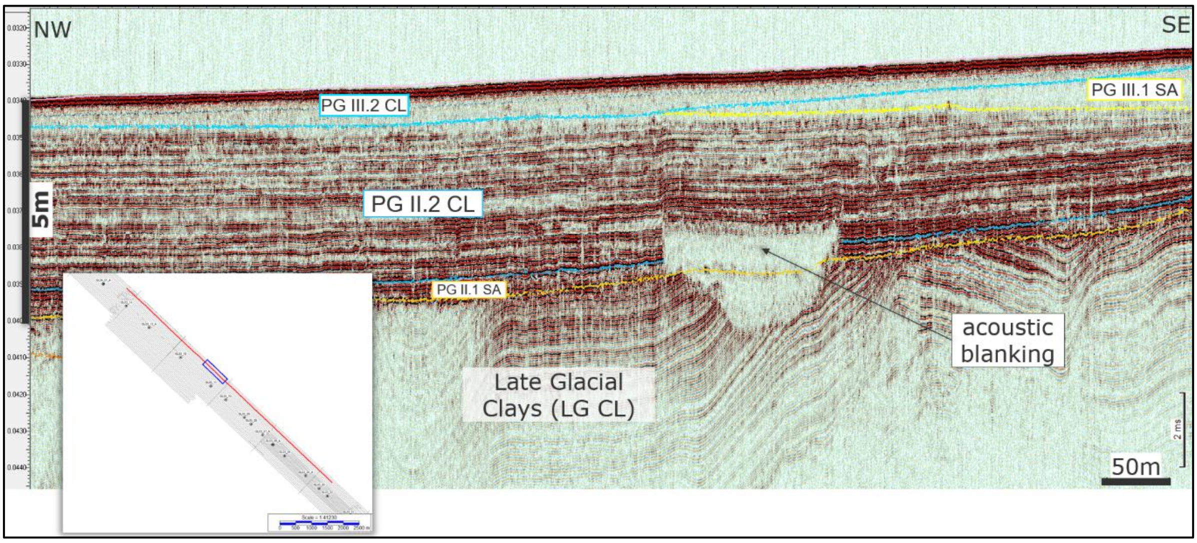

Figure 7-1 Example of a shallow gas accumulation

Pockmarks at the seabed have been only identified at one location, in the western arm of the cable corridor, as illustrated on Figure 7-2.

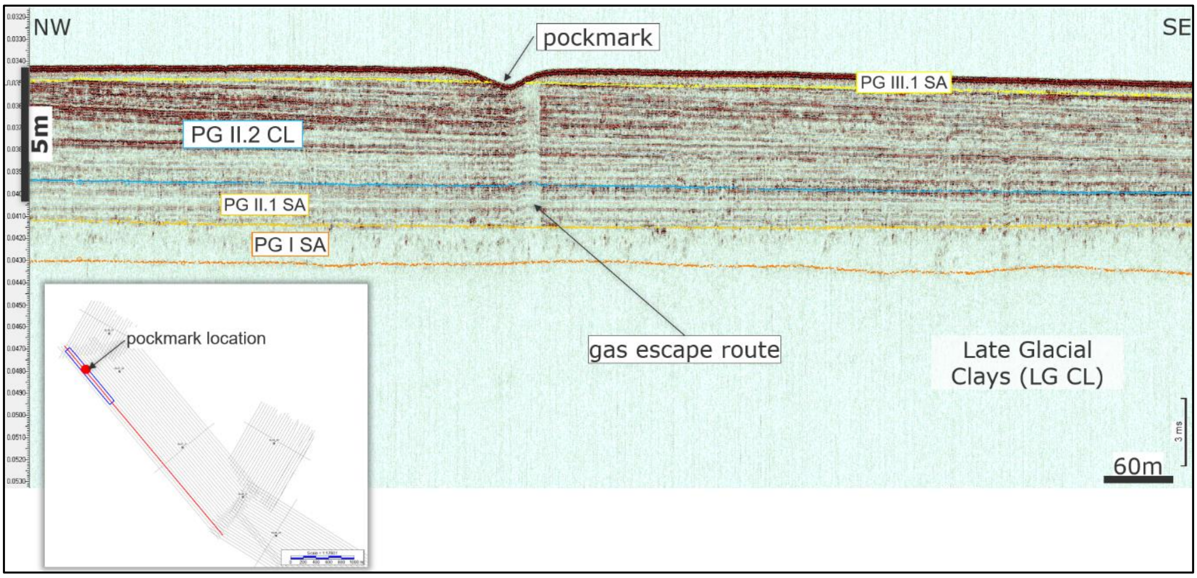

Figure 7-2 Location of the pockmark identified on the acquired SBP data, line 20085_MTK_GL_07_L405_SES_20201107_200440_RAW_LF

Results of geophysical mapping indicate that minor shallow gas accumulations occur within the fine-grained units LG GL, PG II.1 SA and PG II.2 CL throughout the entire cable corridor and are manifested primarily as acoustic blanking observed on the SBP data. The occurrences can be characterised as minor and no evidence for large scale gas-filled structures have been found based on the available data. Most evident manifestations of gas-filled sediments have been mapped on the SBP data and presented on Figure 7-3.

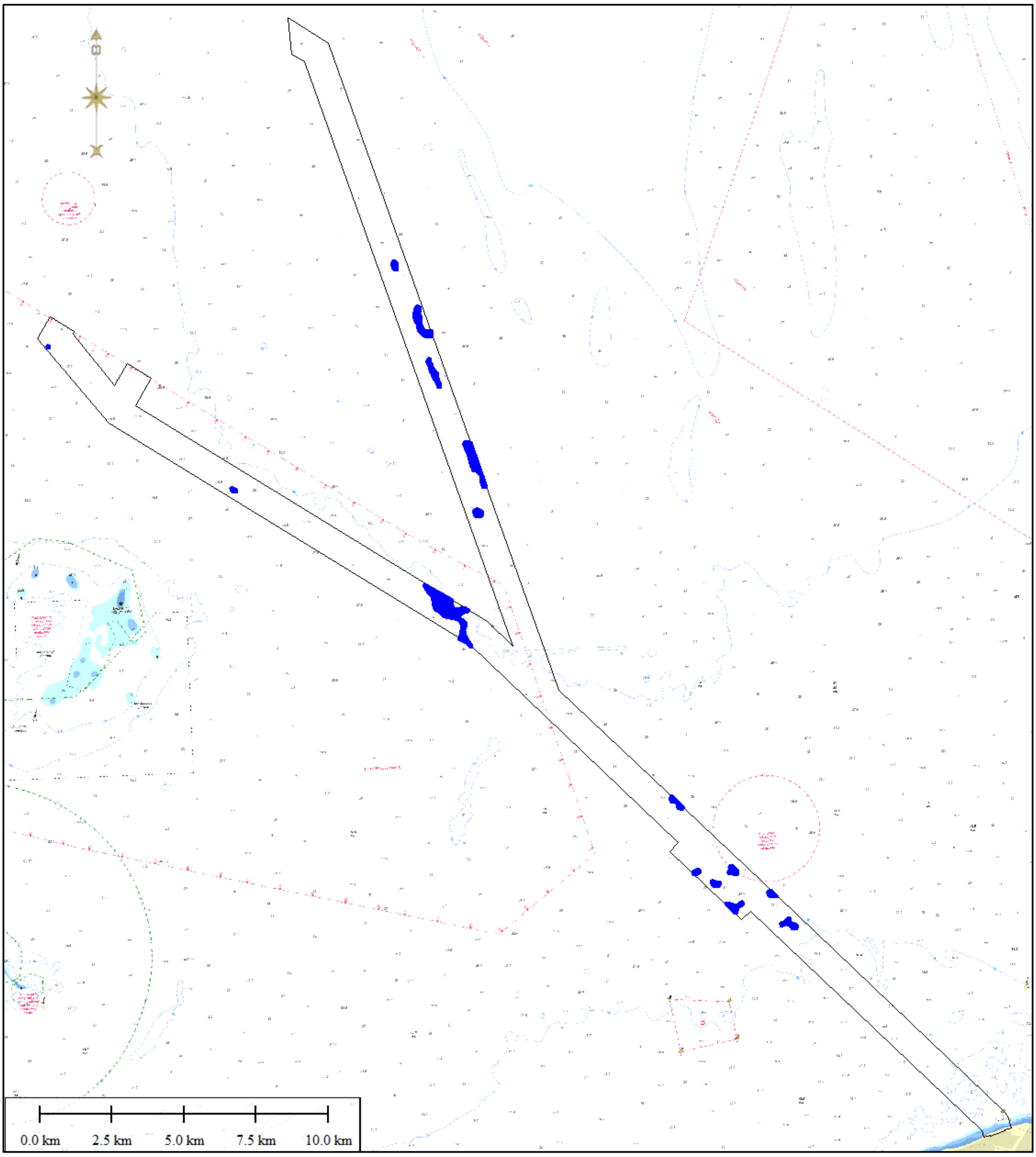

Figure 7-3 Overview of locations showing the most pronounced presence of gas-filled sediments (marked with blue) within the Hesselø cable corridor.

7.3 Seabed mobility

A mobile seabed is usually represented by moving sand dunes and erosion. These features can prove to be a secondary hazard to the cables in the area by exposing the cables after installation. The cables are thereby exposed to primary hazards like the man-made hazards or current and wave-based hazards.

The mobility of the seabed is highly influenced by the current and wave action in an area. The current and wave activity can be considered a primary hazard at exposed sections of the cables or before the cable has been buried.

Wave and current action can move the cables in an undulating motion. This motion can cause rocks and other hard object to grind on the cables and pose a risk of damaging them. In areas where the cables are in a free span, the movement can cause fatigue and ultimately failure of joints.

No direct study of the currents and wave action has been performed along the cable route, however the area is near shore. However, based on the geophysical survey, we consider the general risk of seabed mobility to be low.

Due to the low mobility of the seabed, any depression or trench left behind from the cable installation will only slowly be filled by natural sedimentation. This must be considered in the installation process.

7.4 Bathymetry of the route

The bathymetry data from Hesselø cable route survey shows that the cable route water depths are ranging between 0.9 m to 34 m according to DTU18. The bathymetric data can be seen in Figure 7-4 and on the cross-sections in A-A’, B-B’ and C-C’, cf. Figure 7-5.

From the bathymetry data, the slope along the cable route reveals that the seabed surface is quite flat, and slopes do not exceed 1 degree for most of the area. Close to the landfall (KP 0-9), the slope ranges from 0 to 4 deg. The slope in degrees can be seen in Figure 7-6. The most conspicuous slopes (12-15 deg.) are related to the dense boulder field at the landfall and local occurrences where in some cases the boulders are forming stone reefs.

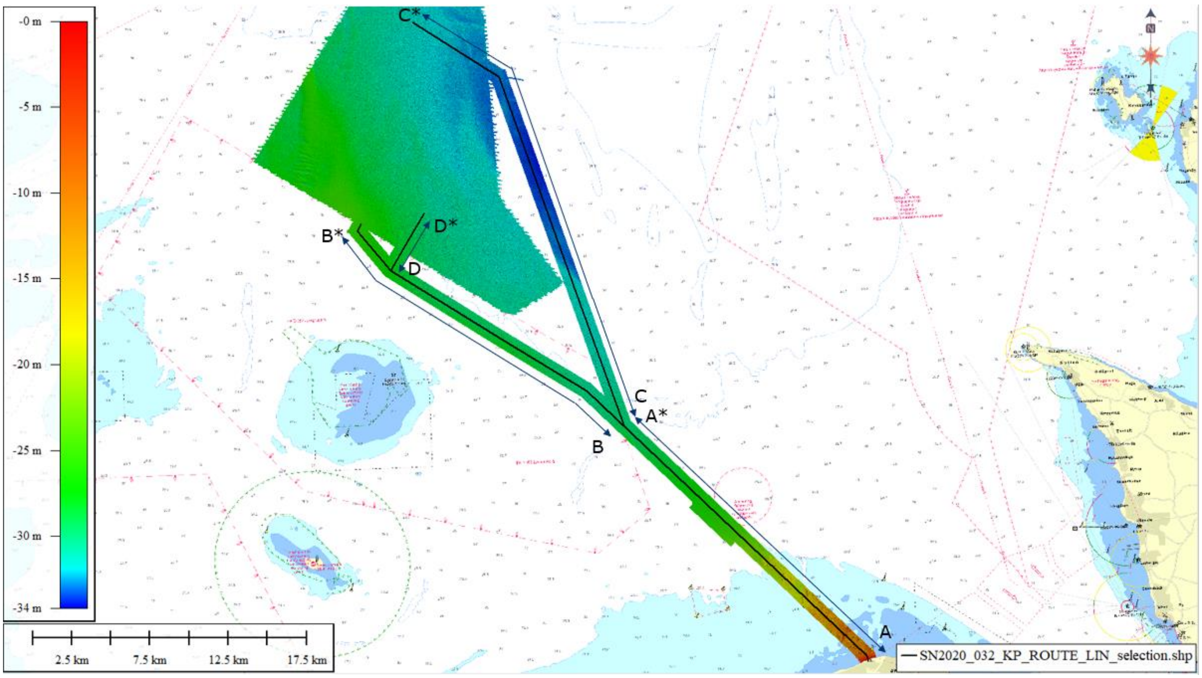

Figure 7-4: Water depth for the cable route

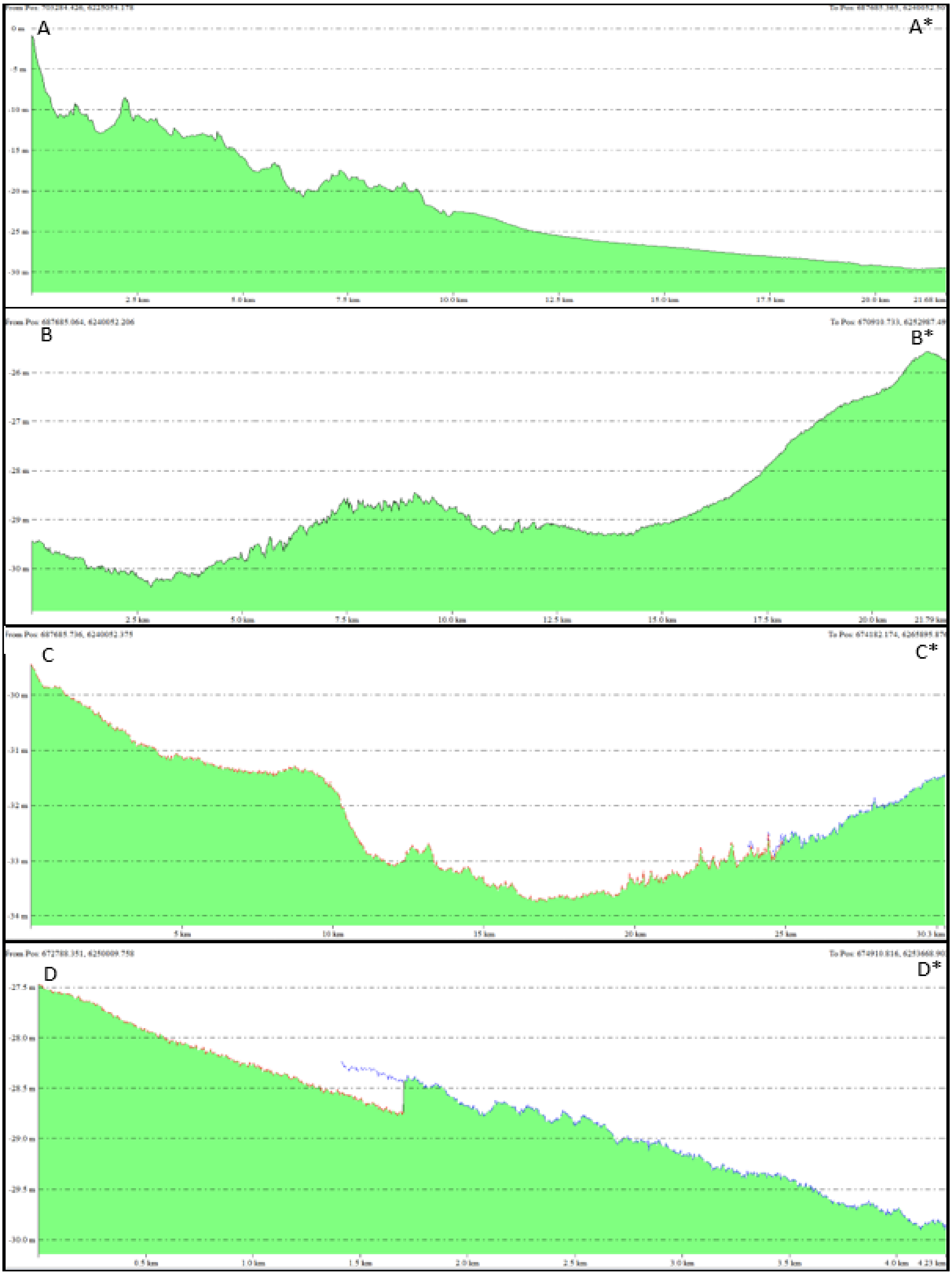

Figure 7-5: Cross-sections of the bathymetry along the cable route

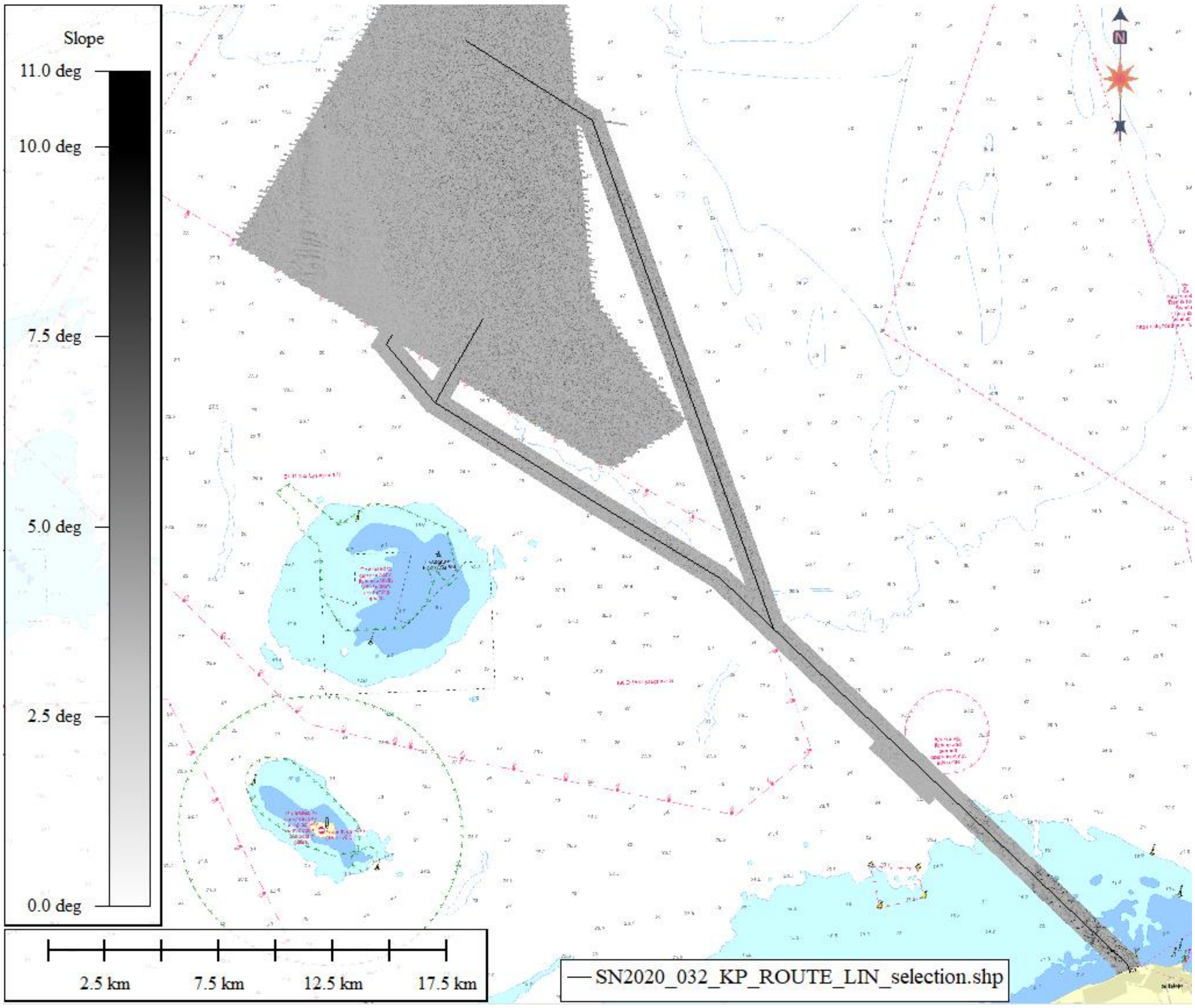

Figure 7-6: Slope in degrees along the cable route

7.5 Hard soils and very soft soils

7.5.1 Definition of hard soils or very soft soils

Areas with observed and/or interpreted 'very soft soil' (i.e. very soft clay or mud) are selected on basis of the following criteria:

- All layers of Gyttja or Peat Clay respectively.
- "Very soft" or "Very soft to soft", or "Extremely low strength", or "Very low strength" or "Very low strength to low strength" cohesive sediments (clay, mud, gyttja etc.), evaluated as such in /Ref 1/, e.g. having undrained shear strength < 20 kPa.

Areas with observed and/or interpreted 'hard soil' (i.e. clay till) are selected on basis of the following criteria:

- All layers described or interpreted as 'clay till' or 'gravel' within the recommended burial depths
- 'Firm' clay, either described as such in the above mentioned survey reports or is evaluated as such in /Ref /, e.g. having undrained shear strength > 40-75 kPa
- 'Stiff' clay, either described as such in the above mentioned survey reports or is evaluated as such in /Ref 1/, e.g. having undrained shear strength >75 kPa

- Very dense granular soils (sand or gravel), described as such in the above mentioned survey reports or is evaluated as such in /Ref 1/, e.g. having Density D >85%.

7.5.2 Evaluation of undrained shear strength and relative density

As described in Section 4.4, for some positions, the penetration of the vibrocores is considerably longer than the recovered core length. For other positions, more core length is recovered, compared to the penetration. This is related to two phenomenon's which are very common when retrieving vibrocores from very soft clays or very dense sands. The differences can be explained by:

- Core loss/compaction due to very soft soil, typically soft clay. The penetration is longer than the actual core length and air gaps may be seen in the cores. The locations where this occurs coincides with very low strength seen on the corresponding CPT
- Core gain due to bulking of relatively dense sand layers. When the vibrocore is retrieved, the sand gets looser, leading to additional core length observed, compared to the penetration.

When comparing vibrocores and CPT, these two effects may cause a mismatch, either because of missing the soft layer at the top of the vibrocores, or because the length of the sand layers seen in the vibrocore is longer than seen on the CPT. Further, some layers which are described as e.g. "Sand, very silty, very clayey" may appear as clay layers on the CPT. In the assessment of the soft and hard soils, emphasis has been put on the CPT data, as these are believed to give the most correct impression of the thickness of the soft layers. Further, in some cases very silty and clayey (and soft) sand layers are treated as soft cohesive soil. For the calculation of the undrained shear strength, an N_{kt} factor of 17 has been used, based on the vane shear tests.

7.5.3 Effect on the burial depth

Hard soil represents risk for the cable to be exposed to currents or man-made activities. The risks associated to the presence of hard soil are related to difficulties which may be encountered in order to reach an adequate burial depth. The hard soil areas shall be considered as a topic of discussion for the selection of the most appropriate burial tool. Hard soil, such as stiff clay (till), which occasionally is present at shallow depths, forms an obstacle to reach the required protection depth of the cable using the most common types of jetting ROVs.

Therefore, the presence of shallow hard soil will require the selection of alternative burial tools / techniques than the ones selected for i.e. loose sandy seabed.

Furthermore, the presence of mud, gyttja and other very soft soils, i.e. very soft clay, represent a risk to damage the cable using certain burial techniques. Heavy underwater machines such as jetting ROVs and ploughs may get stuck when being deployed or when operating on the seabed. In case the burial machine is in direct contact with the cable at that moment, this may lead to damage. Therefore, when encountering these types of soil, alternative burial technique as pre-trenching might be preferred.

Also, the presence of either very soft soils, or hard soils, has a large influence on the recommended burial depths using the BPI approach. As described in Section 6.5, our burial depth recommendations are based on BPI = 1. Recommended burial depths as a function of BPI's and soil types are given in Table 7-1below.

Table 7-1 shows the expected burial depth as a function of BPI level and soil strength

	Cohesive Soils						
	Undrained Shear Strength [kPa]						
	extremely low	very low	low	medium	high	very high	extremly high
	< 10	10 - 20	20 - 40	40 - 75	75 - 150	150 -300	> 300
Burial depth (m) BPI 1	**> 2.5**	**2.5**	**1.5**	**0.8**	**0.6**	**0.5**	**0.5**
Burial depth (m) BPI 2	> 5.0	5	2.2	1.5	1.3	1	0.5
Burial depth (m) BPI 3	> 7.5	7.5	3	1.9	1.5	1.2	1

	Granular Soils				
	Density D [%]				
	very loose	loose	medium dense	dense	very dense
	0 - 15	15 - 35	35 - 65	65 - 85	85 - 100
Burial depth (m) BPI 1	**> 1.3**	**1.3**	**1.1**	**0.8**	**0.6**
Burial depth (m) BPI 2	> 2	2	1.8	1.5	1.3
Burial depth (m) BPI 3	> 2.7	2.7	2.3	1.9	1.5

7.5.4 Subdivision of the ECR

The ECR has been subdivided into 9 sections following the types of soil profiles identified in the ground model. The subdivision is illustrated in Figure 7-7.

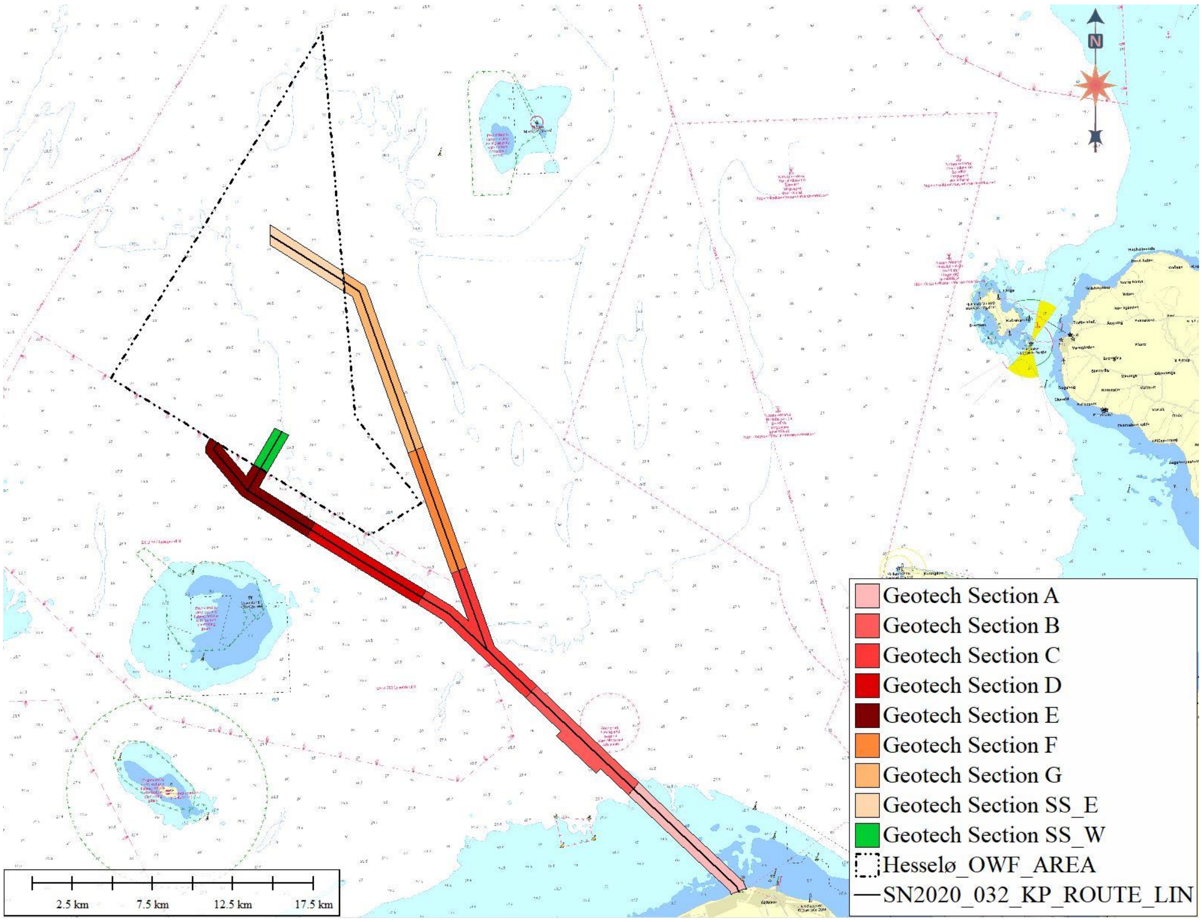

Figure 7-7 Subdivision of the ECR into geotechnical sections

The characteristics of each section according to the ground model is described briefly in Table 7-2:

Table 7-2 Overview of sections and their characteristics according to the ground model

Section	KP	Ground model summary
A	0.0 – 9.2	To the South Glacial till and Late Glacial sands. Channels cut into the Till, filled with Late Glacial clays
B	9.2 – 18.0	Transition zone, soil conditions change from Till towards a thick succession of Late Glacial deposits
C	18.0 – 27.0 (West) and 21.75-27.0 (East)	Relatively thick succession of Late Glacial and Post Glacial deposits
D	27.0 – 35.0 (West)	Unevenly eroded surface of Glacial tills or Late glacial sands, overlaid by Post Glacial deposits
E	35.0 – 43.5 (West)	Relatively thick succession of Late Glacial and Post Glacial deposits
F	27.0 – 35.0 (East)	Thick succession of Post Glacial Clay
G	35.0 – 46.4 (East)	Thick succession of Post Glacial Clay
SS_W	Connection to SS W	Thick succession of Post Glacial Clay
SS_E	Connection to SS E	Thick succession of Post Glacial Clay

In the following sections, an overview of the occurrence of very soft soils (in the upper 5 m) and hard soils (in the upper c. 3 m) at or in the vicinity of the cable route is given for each section of the ECR, using the colour coding illustrated in Figure 7-8

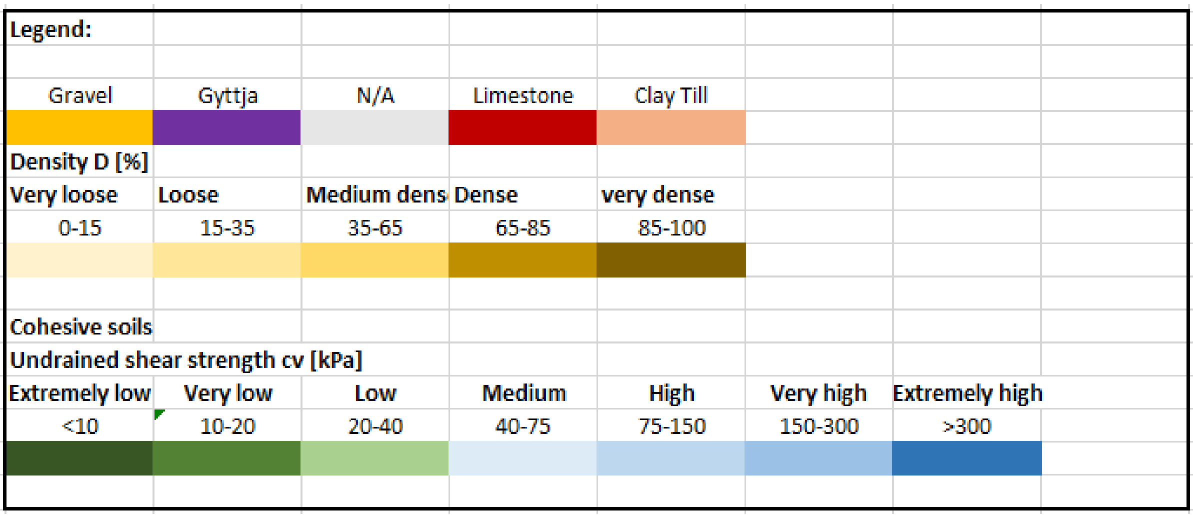

Figure 7-8 Colour coding for soil condition charts

7.5.5 Hard and soft soils, Section A

Section A is characterized by channels cut into the Glacial Till, as illustrated in Figure 7-8. No soft soils are encountered in this section. Hard soils in the form of clay till, sand till, dense sand and gravel is found.

Depth		GL02_01	GL02_02	GL02_03	GL02_04	GL02_05A	GL03_01	GL03_02	GL03_03	GL03_04A	GL03_05	GL03_06	GL03_07
KP	0.00	0.67	1.76	2.74	3.73	4.84	5.36	6.24	6.58	7.26	8.09	8.64	9.05
0-0.5			Clay till			Clay till				Sand till			Clay till
0.5-1.0													
1.0-1.5												Clay till	
1.5-2.0													
2.0-2.5													
2.5-3.0				Sand till			Sand till						
3.0-3.5													
3.5-4.0													
4.0-4.5													
4.5-5.0													
5.0-5.5		Gravel											
5.5-6.0													

Figure 7-9 Section A soil properties

Table 7-3 Section A: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
Landfall		0.0	
GL02_01	Sand from 0.5 to 4.9m Gravel from 4.9-5.9m	0.67	Dense sand from seabed to ~0.5m Very dense sand from 0.5 to 4.9m Gravel CPT refusal at 2.8m
GL02_02	Clay Till at seabed to 0.35m Clay from 0.35 to 3m	1.76	Clay Till High strength clay
GL02_03	Sand and clay layers to 2.6m Sand Till from 2.6 to 4m	2.74	Sand is medium dense and gravelly Clay is medium to high strength Sand till
GL02_04	Clay from seabed to 4.7m	3.73	Medium strength clay
GL02_05	Clay till from seabed to 0.7 m. CPT indicates very firm sand (Clay Till ?) to 3.8m	4.84	Clay till Vibrocore refusal at 0.7m
GL03_01	Sand from seabed to 2.6m Sand till from 2.6 to 4.3m	5.36	Sand is medium dense and dense Sand till
GL03_02	Sand from seabed to 0.3m Clay from 0.3 to 3m (to 6 m from CPT)	6.24	Sand is loose Medium strength clay
GL03_03	Sand from seabed to 0.9m Clay from 0.9 to 3.7m	6.58	Medium strength clay
GL03_04	Clay from seabed to 0.2m Sand till from 0.2 to 4m	7.26	Sand till
GL03_05	Clay from seabed to 3.7m (to 6m from CPT)	8.09	Medium strength clay
GL03_06	Sand from seabed to 0.8m Clay till from 0.8 to 1.3m (to 3m from CPT)	8.64	Loose sand Clay till
GL03_07	Clay till from seabed to 1m (to 2.8m from CPT)	9.05	Clay till

7.5.6 Hard and soft soils, Section B

Section B represents a transition zone where the soil conditions change from Till towards a thick succession of Late Glacial deposits.

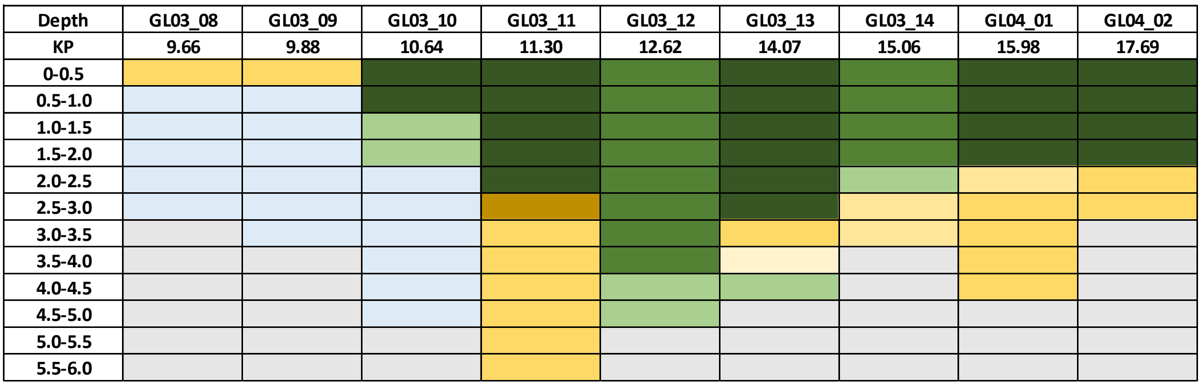

Figure 7-10 Section B soil properties

Table 7-4 Section B: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL03_08	Sand from 0 to 0.3m Clay from 0.3 to 2.6m (to 3m from CPT)	9.66	Loose sand Medium strength clay
GL03_09	Sand from 0 to 0.3m Clay from 0.3 to 3.6m (to 6m from CPT)	9.88	Loose sand Medium strength clay
GL03_10	Sand from seabed to 1m Clay from 1 to 5.2m	10.64	Loose sand Extremely low strength clay from 1 to 2 m Medium strength clay from 2 to 5.2m
GL03_11	Clay (From CPT, vibrocore says sand, clayey) from seabed to 2.3m Sand from 2.3 to 6 m	11.30	Extremely low strength clay Dense sand from 2.3 to 3.3m Medium dense sand from 2.3 to 6m
GL03_12	Clay from seabed to 6m	12.62	Very low strength clay from seabed to 4.2m Low strength clay from 4.2 to 6m
GL03_13	Clay from seabed to 2.7m Sand from 2.7 to 4.7m Clay from 4.7 to 6m	14.07	Very low strength clay Medium dense/loose sand Low strength clay
GL03_14	Clay from seabed to 2.5 m Sand from 2.5 to 4m	15.06	Very low strength clay from seabed to 2m Low strength clay from 2 to 2.5m Loose sand
GL04_01	Clay from seabed to 1.8m Sand from 1.8 to 4.6m	15.98	Very low strength clay Loose sand from 1.8 to 2.3m Medium dense sand from 2.3 to 4.6m
GL04_02	Clay from seabed to 1.7m Sand from 1.7 to 4m	17.69	Very low strength clay Medium dense sand

7.5.7 Hard and soft soils, Section C

Section C is dominated by relatively thick succession of soft Late Glacial and Post Glacial deposits, partly underlain by dense sand.

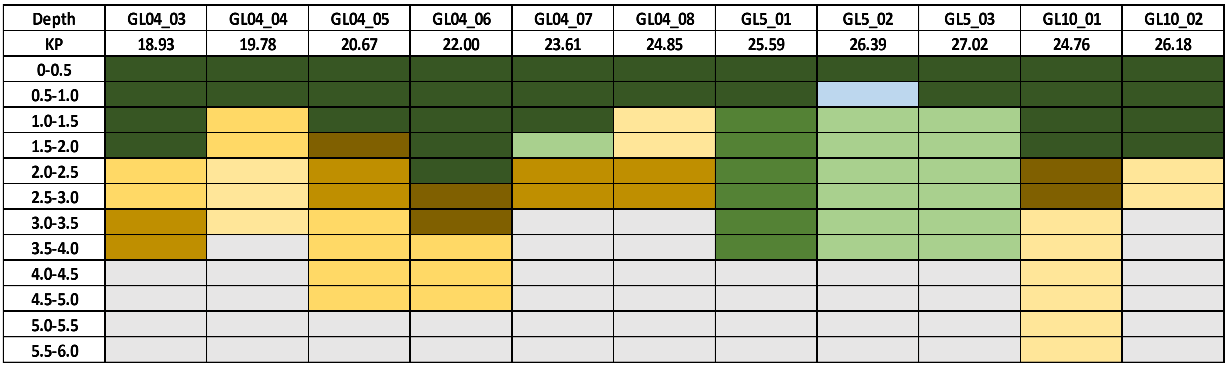

Figure 7-11 Section C soil properties

Table 7-5 Section C: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL04_03	Clay from seabed to ~2m (from CPT) Sand from ~2m to 3.7m	18.93	Extremely low strength clay Medium dense sand from 2 to 3m Very dense sand from 3 to 3.7m
GL04_04	Clay from seabed to ~1m (from CPT) Sand from 1 to 3.6m	19.78	Extremely low strength clay Medium dense sand from 1 to 2m. Loose sand from 2 to 3.6m
GL04_05	Clay from seabed to 1.5m (from CPT) Sand from 1.5 to 6m	20.67	Extremely low strength clay Very dense/dense sand from 1.5 to 3m Medium dense sand from 3 to 6m
GL04_06	Clay from seabed to 2.5m (from CPT) Sand from 2.5 to 6m	22.00	Extremely low strength clay Very dense sand from 2.5 to 2.5m Dense sand from 3.5 to 6m
GL04_07	Clay from seabed to 2m (from CPT) Sand from 2 to 3.6m	23.61	Extremely low strength clay from seabed to 1.5m Low strength clay from 1.5 to 2m Dense sand from 2 to 3.6m
GL04_08	Clay from seabed to 1.2m Sand from 1.2 to 3m	24.85	Extremely low strength clay Medium dense sand from 1.2 to 2m Dense sand from 2 to 3m
GL05_01	Clay from seabed to 6m (from CPT)	25.59	Extremely low strength clay from seabed to ~1m Very low strength clay from 1 to 6m
GL05_02	Clay from seabed to 4m	26.39	Extremely low strength clay from seabed to ~0.5m Medium strength clay from 0.5 to 1m Low strength clay from 1 to 4m
GL05_03	Clay from seabed to 4.7m	27.02	Extremely low strength clay from seabed to ~1m Low strength clay from 1 to 4.7m
GL10_01	Clay from seabed to ~2m (from CPT) Sand from 2 to 6m	24.76	Extremely low strength clay Very dense sand from 2 to 3m Loose sand from 3 to 6m
GL10_02	Clay from seabed to ~2m (from CPT) Sand from 2 to 3m	26.18	Extremely low strength clay Loose sand

7.5.8 Hard and soft soils, Section D

Section D shows unevenly eroded surface of Glacial tills with channels of soft Post Glacial deposits.

Depth	GL05_04	GL05_05	GL05_06	GL05_07	GL06_01	GL06_02	GL06_03
KP	27.91	28.94	29.73	31.17	31.77	33.30	34.81
0-0.5	Clay till		Clay till				
0.5-1.0							
1.0-1.5							
1.5-2.0							
2.0-2.5							
2.5-3.0							
3.0-3.5							
3.5-4.0							
4.0-4.5							
4.5-5.0							
5.0-5.5							
5.5-6.0							

Figure 7-12 Section D soil properties

Table 7-6 Section D: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL05_04	Sand from seabed to 0.2m Clay till from 0.2 to 3.3m	27.91	Clay till
GL05_05	Clay from seabed to 2 m (from CPT) Sand from 2 to 6m (from CPT)	28.94	Extremely low strength clay Very dense sand from 2 to 3.5m Dense sand from 3.5 to 6m
GL05_06	Sand from seabed to 0.2m Clay till from 0.2 to 1.2m	29.73	Clay till Vibrocore refused at 1.2m
GL05_07	Clay from seabed to 2m (from CPT) Sand from 2 to 6m	31.17	Extremely low strength clay Dense sand
GL06_01	Clay from seabed to 1.5m (from CPT) Sand from 1.5 to 3.2m	31.77	Extremely low strength clay Dense sand from 1.5 to 2.5m Medium dense sand from 2.5 to 3.2m
GL06_02	Clay from seabed to 2m (from CPT) Sand from 2 to 4m	33.30	Extremely low strength clay Loose sand/medium dense sand from 2 to 3m Very dense sand from 3 to 4m (CPT refused at 4m)
GL06_03	Clay from seabed to 4m	34.81	Extremely low strength clay from seabed to 1.5m High/very high strength clay from 1.5 to 4m

7.5.9 Hard and soft soils, Section E

Section E is dominated by thick succession of soft Late Glacial and Post Glacial deposits, partly underlain by dense sand.

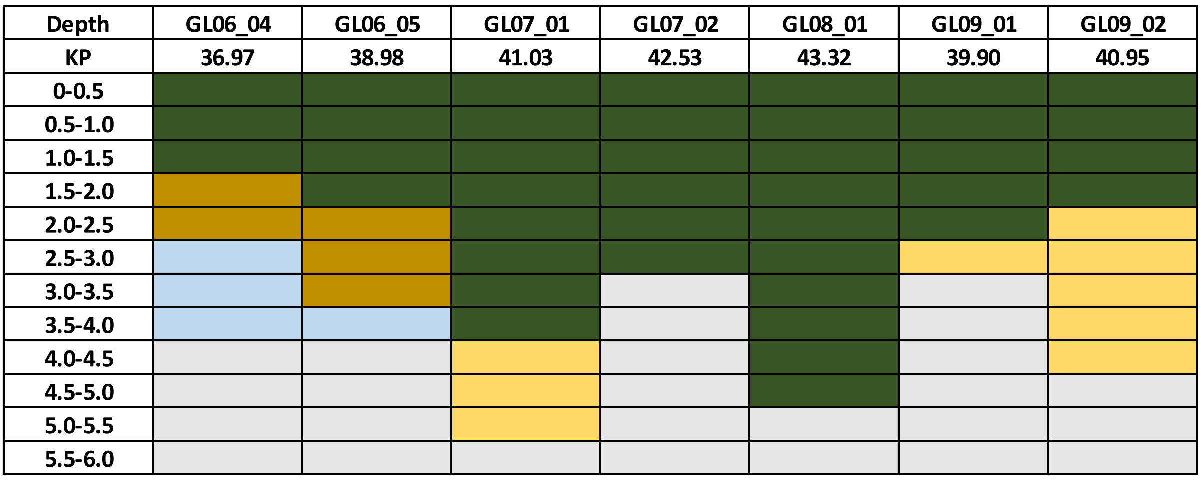

Figure 7-13 Section E soil properties

Table 7-7 Section E: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL06_04	Clay from seabed to 1.5m (from CPT) Sand from 1.5 to 2.5m Clay from 2.5 to 4m	36.97	Extremely low strength clay Dense sand High strength clay
GL06_05	Clay from seabed to 2m Sand from 2 to 3.5m Clay from 3.5 to 3.7m	38.98	Extremely low strength clay Dense sand High strength clay
GL07_01	Clay from seabed to 3.5m (from CPT) Sand from 3.5 to 5.3m	41.03	Extremely low strength clay Medium dense sand
GL07_02	Clay from seabed to 3.2m	42.53	Extremely low strength clay
GL08_01	Clay from seabed to 6m	43.32	Extremely low strength clay
GL09_01	Clay from seabed to 2.5m Sand from 2.5 to 3m (from CPT)	39.90	Extremely low strength clay Medium dense sand
GL09_02	Clay from seabed to 2m Medium dense sand from 2 to 4.3m	40.95	Extremely low strength clay Medium dense sand

7.5.10 Hard and soft soils, Section F

Section F comprises a thick succession of soft Post Glacial Clay

Depth	GL10_03	GL10_04	GL10_05	GL11_01	GL11_02	GL11_03
KP	27.65	29.24	30.90	32.35	34.24	35.26
0-0.5						
0.5-1.0						
1.0-1.5						
1.5-2.0						
2.0-2.5						
2.5-3.0						
3.0-3.5						
3.5-4.0						
4.0-4.5						
4.5-5.0						
5.0-5.5						
5.5-6.0						

Figure 7-14 Section F soil properties

Table 7-8 Section F: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL10_03	Sand from seabed to 0.4m Clay from 0.4 to 6m	27.65	Loose sand Low strength clay
GL10_04	Clay from seabed to 3.7m	29.24	Very low strength clay
GL10_05	Clay from seabed to 6m	30.90	Very low strength clay
GL11_01	Clay from seabed to 6m	32.35	Very low strength clay
GL11_02	Clay from seabed to 6m	34.24	Very low strength clay
GL11_03	Clay from seabed to 3m	35.26	Very low strength clay from seabed to 2m Extremely high strength clay (gravelly?) from 2 to 2.5m Low strength clay from 2.5 to 3m

7.5.11 Hard and soft soils, Section G

Section G comprises a thick succession of soft Post Glacial Clay

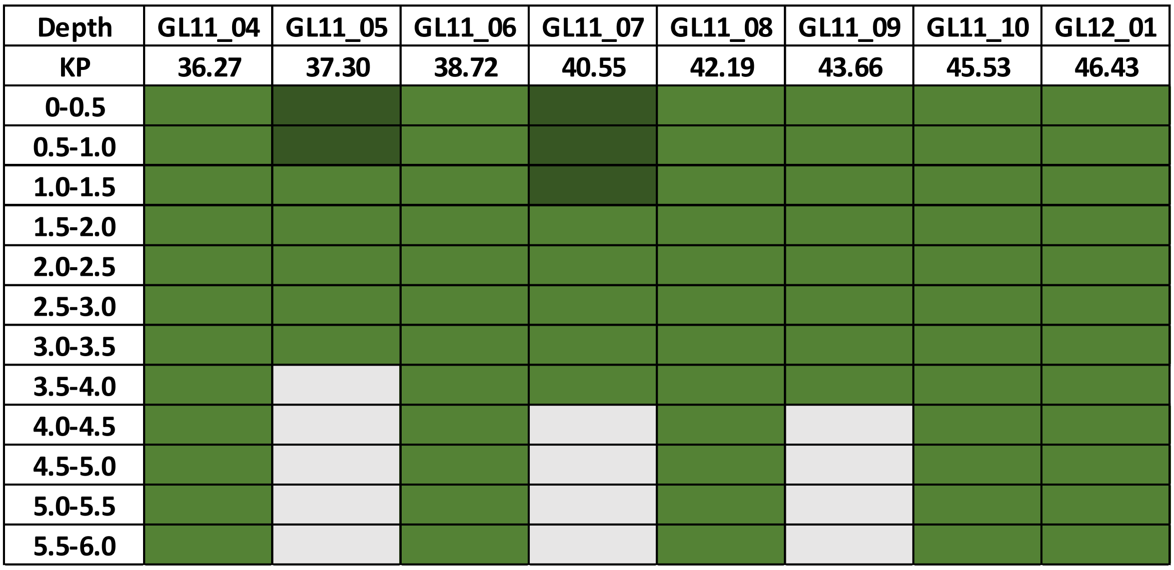

Figure 7-15 Section G soil properties

Table 7-9 Section G: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL11_04	Clay from seabed to 6m	36.27	Very low strength clay from seabed to 6m
GL11_05	Clay from seabed to 3.6m	37.30	Extremely low strength clay from seabed to ~1 m Very low strength clay from ~1 to 3.6m
GL11_06	Clay from seabed to 6m	38.72	Very low strength clay from seabed to 6m
GL11_07	Clay from seabed to 3.8m	40.55	Extremely low strength clay from seabed to ~1.5 m Very low strength clay from ~1.5 to 3.8m
GL11_08	Clay from seabed to 6m (from CPT)	42.19	Very low strength clay from seabed to 6m
GL11_09	Clay from seabed to 4m (from CPT)	43.66	Very low strength clay from seabed to 4m
GL11_10	Clay from seabed to 6m (from CPT)	45.53	Very low strength clay from seabed to 6m
GL12_01	Clay from seabed to 6m (from CPT)	46.43	Very low strength clay from seabed to 6m

7.5.12 Hard and soft soils, connections to Substations East and West

The evaluation of hard and soft soil conditions at the connections to the substations is partly based on data provided by Fugro for the OWF (cf. Section 5.3), in combination with the relevant ECR data provided by Rambøll. In order to access the burial depth along the two connection lines, two cross section have been made and correlated with available CPT and borehole data, resulting in 11 synthetic boreholes, five on the Western arm and 6 on the Eastern arm.

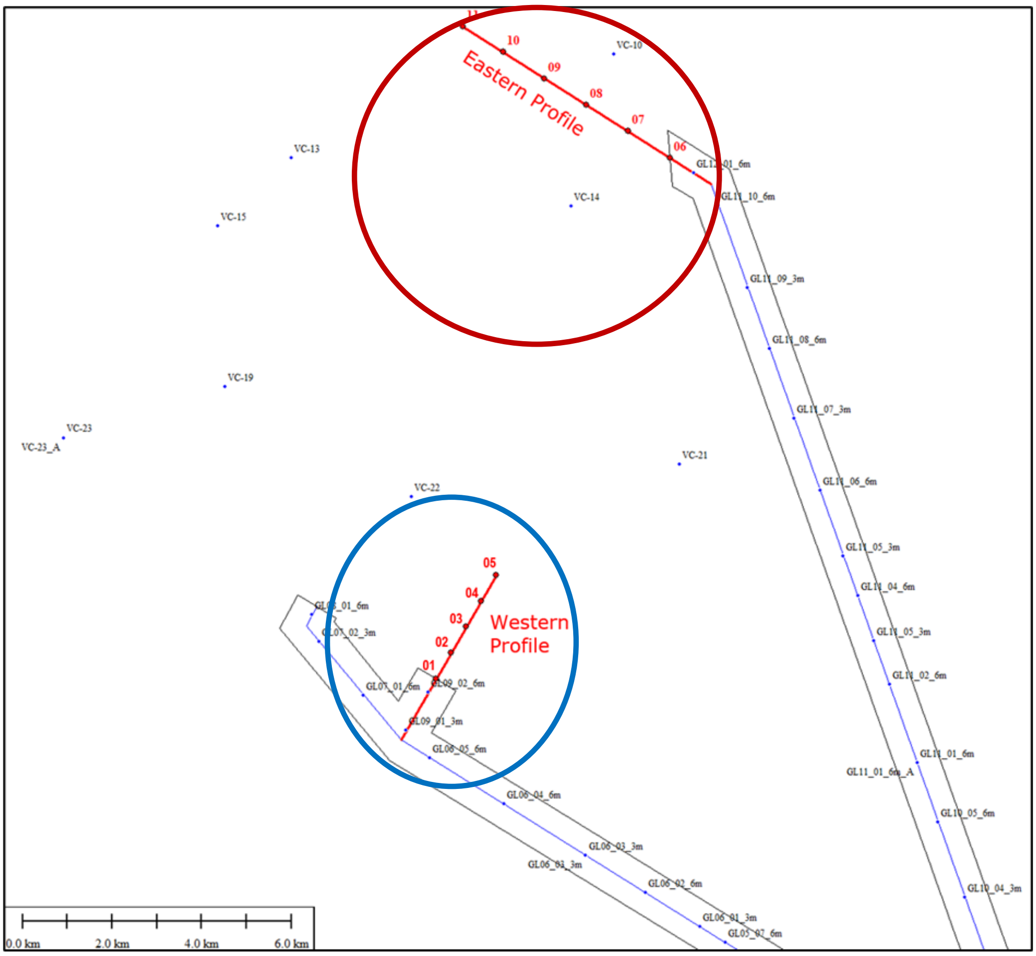

Figure 7-16 Location of substation connections and nearby datapoints (Red circle=SS_E, blue circle=SS_W)

Substation SS_W (Western arm):

The soil profile at the Western arm indicates layers of Post Glacial Sand, Clay and Sand, followed by Later Glacial Clay, cf. Figure 5-22. For assessing the geotechnical properties of these layers, the synthetic boreholes 01 through 05 is correlated with the Vibrocores GL09-01 and GL09-02 located in the ECR

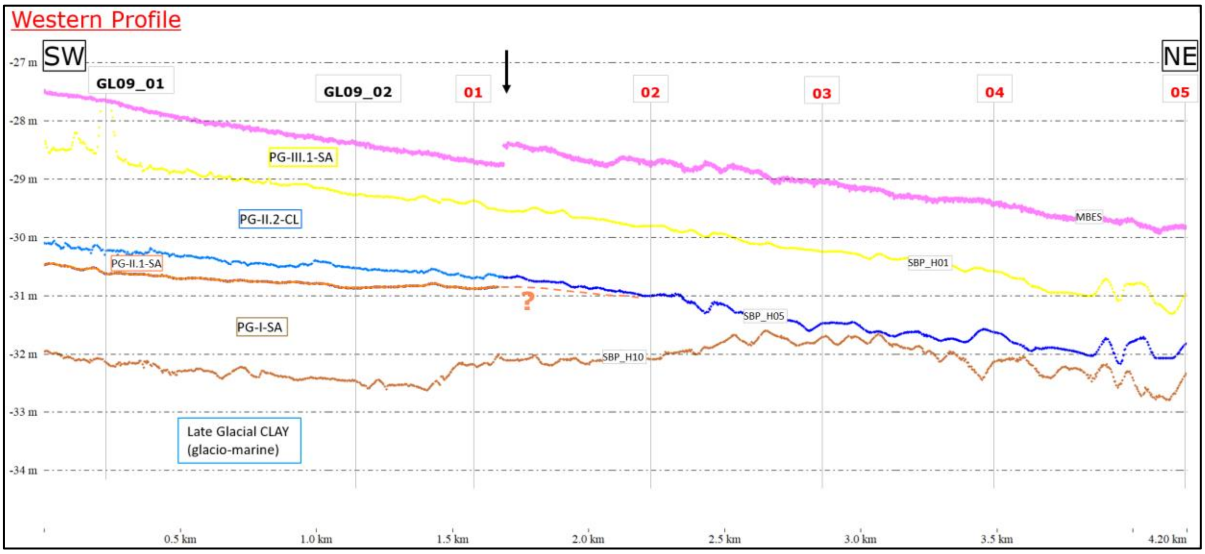

Figure 7-17 Geological section and synthetic boreholes along the Western arm.

The geotechnical interpretation of the two available CPT/VC is given in Table 7-10. A good correlation is seen between the CPT/VC data and the artificial boreholes made from the seismics profiles (event though the vibrocore sampling is not able to capture the upper sand layer). Based on this, the geotechnical conditions are assessed and presented in Figure 7-17.

Table 7-10 Section SS_W: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL09_01	Clay from seabed to 2.5m Sand from 2.5 to 3m (from CPT)	39.90	Extremely low strength clay Medium dense sand
GL09_02	Clay from seabed to 2m Medium dense sand from 2 to 4.3m	40.95	Extremely low strength clay Medium dense sand

Depth	GL09_01	GL09_02	01	02	03	04	05
KP	39.90	40.95					
0-0.5			PG.III SA				
0.5-1.0	PG CL						
1.0-1.5			PG II CL/SA				
1.5-2.0							
2.0-2.5			PG I SA				
2.5-3.0	PG SA						
3.0-3.5							
3.5-4.0							
4.0-4.5			LG CL				
4.5-5.0							
5.0-5.5							
5.5-6.0							

Figure 7-18 Section SS_W from CPT/Vibrocores and synthetic boreholes

Substation SS_E (Eastern arm):

The soil profile at the Eastern arm shows a layer of Post Glacial Clay, underlain by Late Glacial Clay, cf. Figure 7-19. For assessing the geotechnical properties of these layers, the synthetic boreholes 11 through 06 is correlated with the Vibrocore GL12_01 at the ECR.

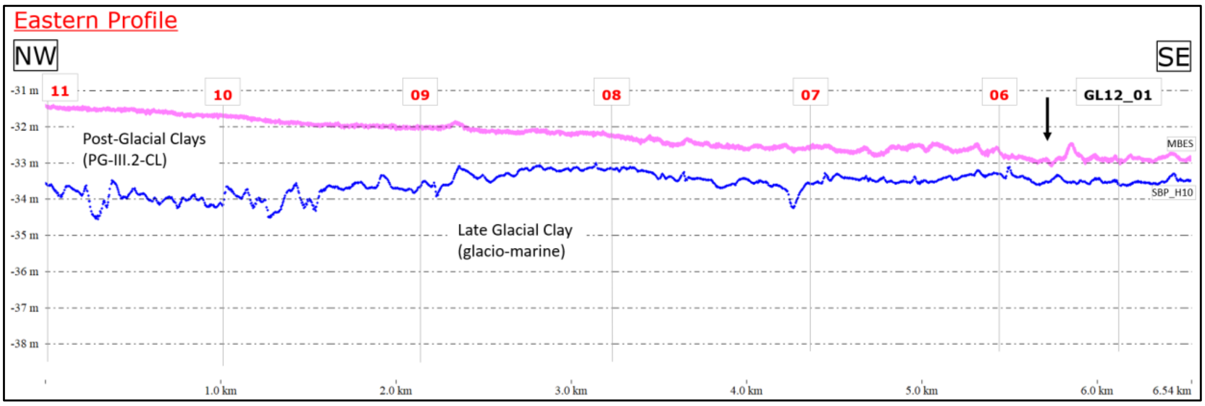

Figure 7-19 Geological section and synthetic boreholes along the Eastern arm.

The geotechnical assessment of the single CPT/VC is given in Table 7-11.

Table 7-11 Section SS_E: General occurrence and distribution of hard soils within the upper c. 3-6m

VC / CPT	Description/evaluation	KP	Properties
GL12_01	Clay from seabed to 6m (from CPT)	46.43	Very low strength clay from seabed to 6m

Section SS_E (Eastern arm) comprises a thick succession of soft Post Glacial/Late Glacial Clay. Seismic data fits very nicely with the CPT/VC data, showing also Post Glacial clay on top of Late Glacial Clay. However, the geotechnical properties are the same for the two clay layers, describing it as a very low strength clay, cf. Figure 7-20.

Depth	GL12_01	06	07	08	09	10	11
KP	46.43						
0-0.5	PG CL				PG CL		
0.5-1.0	LG CL	LG CL					
1.0-1.5			LG CL	LG CL			
1.5-2.0					LG CL		
2.0-2.5						LG CL	LG CL
2.5-3.0							
3.0-3.5							
3.5-4.0							
4.0-4.5							
4.5-5.0							
5.0-5.5							
5.5-6.0							

Figure 7-20 Section SS_E from CPT/Vibrocore and synthetic boreholes

7.6 Thermal conductivity and Organic Content

The heat generated by a buried power cable must be dissipated through the soil. This parameter is quantified by the thermal conductivity (or the opposite; thermal resistivity) of the soil.
The parameters that influence the thermal conductivity of a soil can be summarized as followed:

- Air/gas: Presence of air/gas leads to high values of thermal resistivity. Water is a better conductor than air.
- Organic matter: The presence of organic matter will generally give a very high thermal resistivity.
- Mineralogy: The highest thermal conductivity will be given by the presence of quartz.
- Soil density and compaction: Compacted granular backfills can have good thermal properties. Since most of the heat conduction is through the soil mineral particles and their contacts, one must ensure a high-density soil mixture to maximize these contacts. For this reason, well-graded sand to fine gravel can be a good thermal backfill for offshore conditions.

Generally, native soils (in case that ROV jetting or cable plough is used as burial techniques) do not make good thermal backfills (due to the destruction of the natural compaction) especially if good conductive soils are contaminated with organic material that can be commonly found on the top soil.

During the soil investigation executed in 2020, the measurements of thermal conductivity have been performed and available data can be found in the Geotechnical data report /Ref 1/. The thermal conductivity of the selected soil samples has been provided using the thermal needle probe as specified by ASTM5334-08. The measured parameters given are the thermal conductivity λ in W/(m°C), see Table 7-13.

Thermal conductivity was measured on 52 vibrocores giving a good coverage of the planned alignment. The depths vary between 1.3 and 1.6 meters.

The thermal conductivity / resistivity values have been identified according to the following classification which is depending on the cable design and dissipation:

Table 7-12 Typical classification of soil according to the thermal conductivity / thermal resistivity values.

To avoid	Normal	Favourable
	Thermal conductivity W/(m K)	
<1	1.0-1.4	>1.4
	Thermal resistivity (m K)/W	
>1	1.0-0.7	<0.7

The thermal conductivity values in Table 7-13 colour coded where red is values below 1 W/(m K) (to be avoided) and green is favourable conditions with values > 1.4 W/(m K).

Six (6) positions show very low values, where 26 positions show favourable conditions. The remaining 20 positions show normal conditions.

Table 7-13 Summary of the Thermal Conductivity Tests/Ref 1/

Vibrocore	Spec. No.	Geology	Depth [m]	λ [W/(m°C)]
GL02_02	2	CLAY, Gc	1.5	1.7
GL02_03	2	SAND, Lg	1.6	1.68
GL02_04	2	CLAY, Lg	1.5	1.4
GL03_01	3	SAND, Lg	1.45	2.09
GL03_02	2	CLAY, Lg	1.5	1.19
GL03_03	2	SAND, Pg	1.5	1.62

GL03_04A	2	SAND TILL	1.5	2.54
GL03_05	2	CLAY, Lg	1.5	1.55
GL03_08	2	CLAY, Lg	1.55	1.45
GL03_09	2	CLAY, Lg	1.4	1.15
GL03_10	3	CLAY, Lg	1.5	1.2
GL03_11	2	SAND, Lg	1.5	2.69
GL03_12	3	CLAY, Pg	1.5	1.32
GL03_13A	2	CLAY, Pg	1.5	1.08
GL03_14	2	CLAY, Pg	1.5	0.86
GL04_01A	2	CLAY, Pg	1.5	1.64
GL04_02	2	CLAY, Pg	1.5	0.98
GL04_03A	2	CLAY, Pg	1.5	1.98
GL04_04	2	SAND, Pg	1.5	1.6
GL04_07	2	SAND, Pg	1.6	1.87
GL04_08	2	CLAY, Pg	1.5	2.11
GL05_01	2	CLAY, Lg	1.5	1.31
GL05_02	2	CLAY, Pg	1.5	2.36
GL05_03	2	CLAY, Pg	1.5	1.43
GL05_04	3	CLAY TILL	1.5	2.17
GL05_05	2	SAND, Pg	1.5	2.51
GL05_06A	2	CLAY TILL	1.3	2.04
GL06_01	3	CLAY, Pg	1.5	1.88
GL06_02	2	CLAY, Pg	1.5	2.36
GL06_03	2	CLAY, Pg	1.5	3.21
GL06_04	2	CLAY, Pg	1.5	1.67
GL06_05	2	CLAY, Pg	1.5	1.12
GL07_01	3	CLAY, Pg	1.5	1.09
GL07_02	3	CLAY, Pg	1.6	1.2
GL08_01	2	CLAY, Pg	1.5	0.99
GL09_01	2	CLAY, Pg	1.5	0.96
GL09_02	3	CLAY, Pg	1.5	1
GL10_02	2	SAND, Pg	1.4	1.87
GL10_03A	2	CLAY, Pg	1.5	1.3
GL10_04	2	CLAY, Pg	1.5	1.19
GL10_05	2	CLAY, Pg	1.5	1.37
GL11_01A	2	CLAY, Pg	1.5	1.1
GL11_02	2	CLAY, Pg	1.5	1.19
GL11_03	2	CLAY, Pg	1.5	2.18
GL11_04	2	CLAY, Pg	1.5	1.89
GL11_05	2	CLAY, Lg	1.6	1.11
GL11_06	2	CLAY, Pg	1.5	1.25
GL11_07	2	CLAY, Pg	1.6	1
GL11_08	3	CLAY, Lg	1.5	0.92
GL11_09	2	CLAY, Lg	1.5	1
GL11_10	2	CLAY, Lg	1.5	0.94
GL12_01	2	CLAY, Lg	1.5	1.08

Furthermore, as explained above, organic content present in the soil shall be considered as a critical issue to be considered when choosing certain burial techniques.

The organic content was measured for all samples where visual inspection indicated organic matter to be present. The results are indicated in Table 7-14.

For the Late glacial Clay, the organic content is measured to 13.3 % in a single sample. In the Postglacial clay it ranges from 0.9 to 8.6 %, whereas the Postglacial Sand shows a range of 1.0 – 8.3 %. No occurrences of Gyttja or Peat have been found, and the organic content seems to stem from plant remains in the Post glacial deposits.

In areas where non-favourable thermal conductivity or organic content is present within soils above the buried cable the recommended burial method should secure that trench backfill has less severe thermal properties. This may require sand backfill of an open trench.

Table 7-14 Summary of the Organic content /Ref 1/

Vibrocore no.	Spec. No.	Depth [mbs]	Organic content [%]	Soil layer
GL03_03	1	0	1	SAND, Pg
GL03_03	2	0.8	1	SAND, Pg
GL03_09	1	0.2	1.7	SAND, Pg
GL03_10	2	0.5	2.4	SAND, Pg
GL03_12	1	0.1	2.8	CLAY, Pg
GL03_12	2	0.85	8	CLAY, Pg
GL03_13A	1	0.3	8.6	CLAY, Pg
GL03_13A	3	2.35	4.2	CLAY, Pg
GL03_14	1	0.5	2.5	CLAY, Pg
GL03_14	4	3.2	1.4	SAND, Pg
GL04_01A	1	0.5	5.2	CLAY, Pg
GL04_01A	3	2.5	1.4	CLAY, Pg
GL04_02	1	0.5	1.5	CLAY, Pg
GL04_03A	1	0.5	5.6	CLAY, Pg
GL04_04	1	0.3	1.6	CLAY, Pg
GL04_05B	1	0.4	4	CLAY, Pg
GL04_07	2	0.9	1.7	SAND, Pg
GL05_03	1	0.5	2.4	SAND, Pg
GL05_04	1	0.1	1.3	CLAY, Pg
GL05_05	1	0.15	3.1	SAND, Pg
GL05_07	1	0.1	1.5	SAND, Pg
GL06_01	1	0.5	1.5	SAND, Pg
GL06_02	1	0.3	3	CLAY, Pg
GL06_03	1	0.1	3.4	CLAY, Pg
GL06_03	1	0.5	2.4	CLAY, Pg
GL06_03	4	4	2.9	CLAY, Pg
GL06_04	1	0.8	6.5	CLAY, Pg
GL06_05	1	0.5	2.8	CLAY, Pg
GL06_05	3	2.1	0.9	CLAY, Pg
GL07_01	2	0.5	3.5	SAND, Pg
GL07_01	2	1	8.3	SAND, Pg
GL07_02	1	0.1	1.3	SAND, Pg
GL07_02	4	2.5	7	CLAY, Pg
GL08_01	1	0.1	1.4	SAND, Pg
GL08_01	3	2	6.8	CLAY, Pg
GL09_01	2	1	5.1	CLAY, Pg
GL09_02	2-1	0.55	2.6	SAND, Pg
GL09_02	2-2	0.65	5.6	SAND, Pg
GL10_01A	1	0.5	2.7	SAND, Pg
GL10_03A	1	0.2	1.6	SAND, Pg
GL10_04	1	0.15	1.6	CLAY, Pg
GL10_05	1	0.2	1.7	CLAY, Pg
GL11_02	1	0.15	3.4	CLAY, Pg
GL11_03	1-1	0.2	1.6	CLAY, Pg
GL11_04	1	0.3	3.9	CLAY, Pg
GL11_07	1	0.5	3.2	CLAY, Pg
GL11_08	2	0.8	3.5	CLAY, Pg
GL11_09	1	0.1	2	CLAY, Pg
GL12_01	2	1.45	13.3	CLAY, Lg

8. CABLE BURIAL AND PROTECTION RECOMMENDATIONS

8.1 General overview of burial methods

There exist two principle cable installation approaches:

1. Simultaneous lay and burial of the cable using for instance a plough dragged across the seabed by a vessel. The approach is generally robust with a high degree of precision in placement; however, this technique implies a direct mechanical contact between the cable and the machine, which increases the damage risks due to negligence, human error, and high cable tension.
2. The post lay burial of the cable (PLB). Here the cable is laid in one fast operation, either a) on the seabed or b) in a previously trenched trench. Which, a) or b), is primarily dependent of the nature of the seabed's hardness and trenchability, however environmental and other concerns (see section 8.1.3) may also have an impact. In both cases the burial will be carried out in a second operation. The post lay burial approach is generally found to be more flexible regarding cable lay and trenching options and does generally not imply large tensions to the cable itself.

As mentioned, two principles for installation and burial exist for the post lay burial approach:

- Jetting or mechanical chain cutting, where the cable is buried in one operation after cable lay
- Pre-trenching, where a trench has been created prior to the cable lay, in which the cable is laid. After the cable lay, a second operation of covering the cable has to be performed.

Rock protection may be chosen in instances where cable burial cannot be achieved (extremely hard ground/boulder fields). Where the cable has had no or very limited burial a rock berm may be installed. These rock berms are typically around 1m high of the seabed and 7m wide to create a 3:1 profile, the length of the berms will vary depending on the ground conditions Where burial has created a trench but still protected the cable to acceptable levels, the use of concrete mattresses for additional protection may be feasible.

In the following both jetting/cutting and pre-trenching methods will be discussed in more detail.

8.1.1 Jetting or mechanical chain cutting

Water jetting tools carry a "sword" of water nozzles and use pressurized sea water from water pump systems on board the cable vessel to briefly fluidize or liquefy sediments long enough to deposit the cable which sinks down through a slot. The water nozzles are directed to maximize the trench depth. The cable settles into the trench behind the machine, under its own weight, to the planned burial depth. The jetting tool embeds the cable system in such a way as to also maximize the gravitational replacement of the suspended sediments within the trench. The suspended sediments solidify over the cable; hence no post-install work is usually needed.

A jetting tool is usually installed on a remotely operated vehicle (ROV) fitted with trenching and burial tools as well as video and navigational aids, but it may also be controlled by a diver in more shallow waters.

Many different jetting tools and ROVs are on the market, specialized for the different water depths and seabed conditions. Some jetting tools may have a cutting device installed or a small mechanical plough, whereas ROV's may be designed in such a way, that they can be 'free flying', or at least have very little weight on the seabed (useful in areas with very soft sediments), or be very heavy and crawl/drive on the seabed (useful in areas with for example high currents, and/or much force is needed for the trenching work).

The width of the corridor affected the most by the jetting method is usually 1-2m centred along the cable itself, however, dependent of the nature of the seabed impact may be seen in widths up to 3-5m.

Depending on the seabed and the ROV used the water jetting can progress at speeds of 200-600 m/h with an average of probably 300 m/h.

In cohesionless soil (e.g. sand) the water jetting fluidizes the seabed allowing the cable to sink through it. In cohesive materials such as clay water jetting is used for cutting out lumps of soil.

Jetting is widely used for post lay burial of cables near crossing of existing pipelines and cables, as well as relatively soft clays, and (not too dense) sandy soils, whereas the method usually is unfit in areas where the seabed consists of hard strength till, boulders and other hard/dense seabed conditions.

Some jetting systems, such as the SeaREX, have been designed to offer burial in up to 100 kPa (undrained shear strength) soils and trench depths of up to 3 meters in non-cohesive seabed conditions.

The water jetting method may also be used as a supplement when burying the cable in previously trenched sections.

If the soils are varying and stiff clay is encountered an ROV based mechanical chain cutting tool can be mobilised. The mechanical chain cutting tool, which weighs 10-20 tonnes and up, relies on a seabed that can support it and this method has the advantage that soils with stiffness up to 250 kPa can be excavated. Mechanical chain cutting has a slower progress speed than jetting. Due to mobilisation expenses a change between tools is not normally economically favourable.

Another post-lay burial method by jetting is the Mass Flow Excavation (MFE) method, which can be used to disperse loose coverings and soft clays. An MFE jet-frame has very powerful water jets which penetrate the seabed and bring the soil in suspension. The water flow removes the suspended sediment and a trench is created into which the cable is sunk. The water for the MFE is supplied from high pressure jets and dredge pumps. Amongst other tasks, MFEs are used for trenching and route preparation for subsea cables as well as for seabed levelling and sand wave clearance when conventional equipment may not be applicable.

8.1.2 Pre-trenching

Pre-trenching, the formation of a trench in the seabed prior to the cable lay and subsequent cable burial, encompasses many different methods, such as:

- Pre-trenching by ploughing
- Pre-trenching by wheel trencher or chain cutter
- Pre-trenching by excavation (mechanical dredges)
- Pre-trenching by suction dredger (hydraulic dredges)

The above pre-trenching methods usually require an extra operation of burying the cable by backfilling the established trench. Sometimes an operation of boulder clearance prior to either pre-trenching or cable lay may be found feasible, because any boulders left in the trench may cause damage to the cable once installed and/or result in a lower DOB than planned. The latter is also true if much debris has accumulated in the trench prior to cable lay; sometimes removal of debris prior to cable lay is performed and/or the water jetting will be used as an aid during the cable burial process (see above) to secure the planned burial depth.

Pre-trenching by ploughing, such as the Ecosse subsea trenching system Scar plough, is a method that involves the creation of a narrow trench (much like a ploughshare known from agriculture) by dragging/pulling a mechanical plough after a relatively large vessel. The ploughing procedure, which may involve more than one pass in order to reach the acquired depth, leaves an impact width of the seabed typically between 5 and 10m, including the 'shoulders' of soil left by the plough on each side of the trench. Ploughing is usually used in water depths too deep for dredging by excavation, and is the fastest pre-trenching method, with a speed of up to 5.000 m/h. However, ploughs are usually designed for a narrow range of soil properties, and if the soil characteristics change appreciably problems may result. Also, in areas with very soft seabed, the plough is too heavy to be utilized, since it will sink into the seabed. These concerns need to be addressed since ploughing followed by cable lay and with subsequent jetting to final depth may be economically favourable.

Pre-trenching by using wheel trencher or chain cutter is often used in areas with particular hard and rocky seabed and relatively large water depth where mechanical excavation is impossible. The methods are also relatively slowly in operation, but leave a rather controlled impact on the seabed with trench widths of only 0.6-1.0 meters.

Dredging/pre-trenching by excavation is often used on stretches where water jetting or for instance ploughs cannot be used and is typically performed in areas with relatively low water depths, for instance close to shore. Broadly speaking it is the arm length of the excavator, as known from land construction work, being the limitation of the operating depth; hence normally this method is not used in areas with water depths larger than 18-20m. The excavator is placed on a barge or a vessel. The excavator digs a trench in the seabed c. 1 m wide and 1-1,5m deep, and leaves the excavated soil on one side along the trench. While the method excavates a trench in a very controlled and detailed manner, it is relatively time-consuming having a speed of the trenching work itself of only c. 50m/h.

Dredging/pre-trenching by usage of suction dredgers can either be performed by using a combination of suction pipes and mechanical cutters or alike, or plain suction. A plain suction dredge utilizes an open pipe to suck material from the bottom surface without the use of an agitating or mixing device. Plain suction dredges are generally used where the material is loose/soft and an agitating device is not necessary to suck material from the bottom surface. Also the trailing hopper suction dredger (TSHD), which when working trails its suction pipe(s) fitted with a dredge drag head, are often used in loose sand and soft clay/mud. The common suction cutter dredge typically uses a rotating cutter device to agitate and stir up material on the bottom surface where it sucks up the mixture of sediment and water, is also often used where firm or till clay is present. The dredging of trenches and covering cables are performed by usage of equipment and vessels equipped with precise positioning instruments as well as dynamic positioning and tracking facilities.

8.1.3 Environmental concerns

An overview of the possible environmental disturbance related to the installation and operational phased is seen in Table 8-1

Table 8-1 Overview of environmental concerns

Installation, Maintenance and repair work, Removal	**Operational phase**
Seabed disturbance Damage/disturbance of organisms Re-suspension of contaminants Visual disturbance Noice/vibrations (vessels, laying maschinery) Emissions and waste from vessels	Introduction of artificial hard substrate Electromagnetic fields Thermal radiation

Visual disturbance is mainly related to sea birds, mitigation may be avoiding wintering, resting and fourageing areas of sensitive species.

Electromagnetic fields may impair the orientation of fish and marine mammals and affect migratory behaviour.

Thermal radiation may increase bacterial activity and alter the sediment. Alteration of sediment chemistry might possibly exert secondary impacts on benthic fauna and flora. It should be noted that the content of organic matter in the sediments determines these processes.

8.2 Client specified/Authority required minimum burial depth

In the Danish sector the standard burial depth specified by Energinet is 1.0 meters below seabed. There is no official minimum burial depth specified by the Danish authorities.

8.3 Recommended Burial Depth for the Hesselø cable

8.3.1 Burial assessment maps

The workflow to establish the recommended burial depth will shortly be described in this section, together with a description of the burial assessment and alignment charts

- The water depth along the alignment is found in Appendix 2
- The seabed classification, the seismic interpretation and borehole profiles for each of the surveyed sections are found Appendix 4: Cable Route Charts
- A list of KP points is found in Appendix 3
- An overview of the soil conditions along the alignment and a summary of the various factor affecting the burial depth is found in Appendix 1.
- Slope of seabed, Figure 7.1. The maximum slope of 12-15 deg. is assumed for all sections as it is not considered a concern in relation to cable burial

8.3.2 Recommended burial depths

The recommended burial depth for each section is seen in Appendix 1 together with the summarized soil conditions. The following has been considered:

Section A:

- Hard soils are encountered in the form of clay till
- The entire section is placed in a boulder field
- MAG anomalies and UXO risk is present in the area
- The recommended burial depth is 1.1 m based on the presence of medium dense sand

Location	Report section		GL02_01	GL02_02	GL02_03	GL02_04	GL02_05A	GL03_01	GL03_02	GL03_03	GL03_04A	GL03_05	GL03_06	GL03_07
KP		0.0	0.67	1.76	2.74	3.73	4.84	5.36	6.24	6.58	7.26	8.09	8.64	9.05
Fishing	6.1	No Impact												
Vessel traffic	6.2	Limited impact, rare anchor drops												
Cultural heritage	6.4.1	Aircraft	None											
Natura 2000/Forrest reserve	6.4.2/6.4.5		None											
Natura 2000/Reef			Reef											
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)												
Military areas (restricted/danger)	6.4.4	None												
UXO risk areas	6.5								UXO - WWIII					
MAG anomalies	6.5	MAG												
Shallow gas	7.2	Minor occurences												
Sloping seabed	7.5	up to 12 - 15 deg. at boulder field reefs, otherwise up to 4 deg.												
Boulders	5.2.6	Boulderfield												
Thermal conductivity	7.7		ND	1.7	1.68	1.4	ND	2.09	1.19	1.62	2.54	1.55	ND	ND
Hard Soil														
Soft soil		None												
Recommended burial depth		1.1												

Figure 8-1 Overview chart, section A

Section B:

- Soft soils are encountered from approx. KP 10.
- MAG anomalies and UXO risk is present in the area
- Two locations show unfavourable thermal properties
- The recommended burial depth up till KP 10 is 1.1 m based on the presence of medium dense sand. For the remaining part of this section the recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL03_08	GL03_09	GL03_10	GL03_11	GL03_12	GL03_13	GL03_14	GL04_01	GL04_02
KP		9.66	9.88	10.64	11.30	12.62	14.07	15.06	15.98	17.69
Fishing	6.1	No impact								
Vessel traffic	6.2	Limited impact, rare anchor drops								
Cultural heritage	6.4.1						Wreck			
Natura 2000/Forest reserve	6.4.2/6.4.5	None								
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)								
Military areas (restricted/danger)	6.4.4	None								
UXO risk areas	6.5	WWII UXO								
MAG anomalies	6.5	MAG								
Shallow gas	7.2	Minor occurences								
Sloping seabed	7.5	< 1 deg.								
Boulders	5.2.6									
Thermal conductivity	7.7	1.45	1.15	1.2	2.69	1.32	1.08	0.86	1.64	0.98
Hard Soil										
Soft soil										
Recommended burial depth		1.1		>2.5 m						

Figure 8-2 Overview chart, section B

Section C:

- Soft soils are encountered in the entire section
- MAG anomalies, UXO risk and military restricted zone is present in the area
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL04_03	GL04_04	GL04_05	GL04_06	GL04_07	GL04_08	GL5_01	GL5_02	GL5_03	GL10_01	GL10_02
KP		18.93	19.78	20.67	22.00	23.61	24.85	25.59	26.39	27.02	24.76	26.18
Fishing	6.1	No impact										
Vessel traffic	6.2	Limited impact, rare anchor drops										
Cultural heritage	6.4.1				Wreck					Wreck		
Natura 2000/Forest reserve	6.4.2/6.4.5	None										
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)										
Military areas (restricted/danger)	6.4.4											
UXO risk areas	6.5	UXO										
MAG anomalies	6.5							MAG				
Shallow gas	7.2	Minor occurences										
Sloping seabed	7.5	< 1 deg.										
Boulders	5.2.6	None										
Thermal conductivity	7.7	1.98	1.6	ND	ND	1.87	2.11	1.31	2.36	1.43	ND	1.87
Hard Soil				at 1.5m	at 2.5m						at 2m	
Soft soil												
Recommended burial depth		> 2.5 m										

Figure 8-3 Overview chart, section C

Section D:

- Soft soils are encountered in the major part of the section, with 2 positions with hard soil (Clay till at seabed level).
- MAG anomalies and military restricted zone is present in the area
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL05_04	GL05_05	GL05_06	GL05_07	GL06_01	GL06_02	GL06_03
KP		27.91	28.94	29.73	31.17	31.77	33.30	34.81
Fishing	6.1	No impact						
Vessel traffic	6.2	Limited impact, rare anchor drops						
Cultural heritage	6.4.1	None						
Natura 2000/Forest reserve	6.4.2/6.4.5	None						
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)						
Military areas (restricted/danger)	6.4.4							
UXO risk areas	6.5	None						
MAG anomalies	6.5	MAG						
Shallow gas	7.2	Minor occurences						
Sloping seabed	7.5	< 1 deg., 12-15 deg. at boulder field reefs						
Boulders	5.2.6	Local occurences						
Thermal conductivity	7.7	2.17	2.51	2.04	ND	1.88	2.36	3.21
Hard Soil			At 2m				At 3m	
Soft soil								
Recommended burial depth		> 2.5 m						

Figure 8-4 Overview chart, section D

Section E:

- Soft soils are encountered in the major section entire section
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL06_04	GL06_05	GL07_01	GL07_02	GL08_01	GL09_01	GL09_02
KP		36.97	38.98	41.03	42.53	43.32	39.90	40.95
Fishing	6.1	No impact						
Vessel traffic	6.2	Limited impact, rare anchor drops						
Cultural heritage	6.4.1	None						
Natura 2000/Forest reserve	6.4.2/6.4.5	None						
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)						
Military areas (restricted/danger)	6.4.4							
UXO risk areas	6.5	None						
MAG anomalies	6.5	None						
Shallow gas	7.2	Minor occurences						
Sloping seabed	7.5	< 1 deg.						
Boulders	5.2.6							
Thermal conductivity	7.7	1.67	1.12	1.09	1.2	0.99	0.96	1.0
Hard Soil		None						
Soft soil								
Recommended burial depth		> 2.5 m						

Figure 8-5 Overview chart, section E

Section F:

- Soft soils are encountered in the major section entire section
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL10_03	GL10_04	GL10_05	GL11_01	GL11_02	GL11_03
KP		27.65	29.24	30.90	32.35	34.24	35.26
Fishing	6.1	No impact					
Vessel traffic	6.2	Limited impact, rare anchor drops					
Cultural heritage	6.4.1	None					
Natura 2000/Forest reserve	6.4.2/6.4.5	None					
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)					
Military areas (restricted/danger)	6.4.4	None					
UXO risk areas	6.5	None					
MAG anomalies	6.5	None			MAG, few		
Shallow gas	7.2	Minor occurences					
Sloping seabed	7.5	< 1 deg.					
Boulders	5.2.6						
Thermal conductivity	7.7	1.3	1.19	1.37	1.1	1.19	2.18
Hard Soil							At 2m
Soft soil							
Recommended burial depth		>2.5 m					

Figure 8-6 Overview chart, section F

Section G:

- Soft soils are encountered in the entire section
- MAG anomalies are present in the area
- Two locations show unfavourable thermal properties
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL11_04	GL11_05	GL11_06	GL11_07	GL11_08	GL11_09	GL11_10	GL12_01
KP		36.27	37.30	38.72	40.55	42.19	43.66	45.53	46.43
Fishing	6.1	No impact							
Vessel traffic	6.2	Limited impact, no anchor drops							
Cultural heritage	6.4.1	None							
Natura 2000/Forest reserve	6.4.2/6.4.5	None							
Marine mammals	6.4.3	Grey seal (regular occurence), Harbour porpoise and Harbour seal (common occurence and reproduction)							
Military areas (restricted/danger)	6.4.4	None							
UXO risk areas	6.5	None							
MAG anomalies	6.5	MAG, few			MAG				
Shallow gas	7.2	Minor occurences							
Sloping seabed	7.5	< 1 deg., 12-15 deg. at boulder field reefs							
Boulders	5.2.6	Local occurence							
Thermal conductivity	7.7	1.89	1.11	1.25	1.0	0.92	1.0	0.94	1.08
Hard Soil		None							
Soft soil									
Recommended burial depth		> 2.5 m							

Figure 8-7 Overview chart, section G

Section SS_W:

- Soft soils are encountered in the entire section
- MAG anomalies are present in the area
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL09_01	GL09_02	
KP		39.90	40.95	
Fishing	6.1	No impact		
Vessel traffic	6.2	Limited impact		
Cultural heritage	6.4.1	None		
Natura 2000/Forest reserve	6.4.2/6.4.5	None		
Marine mammals	6.4.3	Grey seal, Harbour porpoise and Harbour seal		
Military areas (restricted/danger)	6.4.4			
UXO risk areas	6.5	None		
MAG anomalies	6.5	None		
Shallow gas	7.2	Minor occurences		
Sloping seabed	7.5	< 1 deg.		
Boulders	5.2.6	None		
Thermal conductivity	7.7	0.96	1.0	
Hard Soil		None		
Soft soil				
Recommended burial depth		> 2.5 m		

Figure 8-8 Overview chart, section SS_W

Section SS_E:

- Soft soils are encountered in the entire section
- A single location shows unfavourable thermal properties
- The recommended burial depth is > 2.5 m due to the presence of extremely low strength clay

Location	Report section	GL12_01			
KP		46.43			
Fishing	6.1	No impact			
Vessel traffic	6.2	Limited impact, no anchor drops			
Cultural heritage	6.4.1	None			
Natura 2000/Forest reserve	6.4.2/6.4.5	None			
Marine mammals	6.4.3	Grey seal, Harbour porpoise and Harbour seal			
Military areas (restricted/danger)	6.4.4	None			
UXO risk areas	6.5	None			
MAG anomalies	6.5	MAG			
Shallow gas	7.2	Minor occurences			
Sloping seabed	7.5	< 1 deg.			
Boulders	5.2.6				
Thermal conductivity	7.7	1.08			
Hard Soil		None			
Soft soil					
Recommended burial depth		> 2.5 m			

Figure 8-9 Overview chart, section SS_E

8.4 General recommendations

- Areas with hard soils (tills and very dense sands) and areas with very low strength soils (very low strength clays) have been identified along the route. A special emphasis should be made regarding these areas, as they have consequences for which type of burial equipment should be used and may also cause safety issues during the cable during installation.
- Very low strength soil (such as the extremely low strength clays seen) can cause a jetting ROV to sink down in the soil during operations thus maybe damaging the cables. Therefore, it is recommended in these sections to use ROVs that are free flying, or at least ROVs that can adjust their weight to a minimum on the seabed.
- When jetting for post lay burial it is generally recommended to conduct several passes until depth of lowering is achieved.
- Generally, it is recommended to carry out clearance of boulders prior to cable lay. Boulder clearance may even be feasible prior to pre-trenching activities.

8.5 Recommended burial techniques

Based on the above assessment of burial depth and soil properties, the following recommendations of burial method are given.

It is basically recommended that an eventual tender on cable protection be based on functional requirements to achieve recommended trenching/burial depths, and possibly thermal properties of backfill. Hence the methodology stated herein is only guidance.

Due to the uneven seabed conditions any one type of trenching equipment cannot deliver the full profiles. It is therefore foreseen that two methods must be employed.

It is important to focus on the number of mobilisations. It may be that one type of equipment has a higher production rate, however the mobilisation costs are a substantial part of total expenses.

In the hard soils area (Section A with Clay Till), dredging/pre-trenching by excavation from a barge or vessel may be a feasible option. This option is made possible by the modest water depth in the area. This method may also be considered where the extremely low strength clay is underlain by hard soils.

In the soft soil areas (representing the main part of the cable route, e.g section F and G) a flying or heave compensated jetting machine solution should be considered. Depending on the equipment, this solution may also be feasible in some areas where both soft and hard soils are encountered.

In the areas dominated by soft soil (e.g Section F and G) a flying or heave compensated jetting machine solution is suggested.

In case trenching is not possible (e.g. in the boulder fields), rock protection may be required. In sections where the cable has had no or very limited burial a rock berm may be installed. These rock berms are typically around 1m high of the seabed and 7m wide to create a 3:1 profile, the length of the berms will vary depending on the ground conditions. Where burial has created a trench but still protected the cable to an acceptable level, the use of concrete mattresses for additional protection may be feasible for additional protection.

9. FUTURE WORK AND MAINTENANCE

The following section includes general recommendations in regards to future inspection work on the cable routes after installation of the cables.

To assess if the correct burial depths have been achieved on each cable, a post-lay Depth Of Burial (DOB) survey is recommended. If the cable will be buried using jetting methods and the trenched areas must be covered with back-fill, the DOB survey must be performed with a cable tracking system.

As the post-lay DOB surveys are most likely performed while the cables are still inactive, a passive cable tracking system are recommended for the survey. The passive systems require a tone to be applied to the cables, and to be able to do this a requirement is that the cables are be inactive at the time of survey.

Several systems are available on the market and utilized by various contractors. Examples of passive trackers are the Orion system from Optimal Ranging, the TSS 350 from Teledyne and the Smartrak from Innovatum.

The Orion system is also able to use the active 50Hz frequency of an active cable, which is very useful if the cables are activated before the DOB survey is performed.

Combined with a higher possible tracking speed than competing systems, the Orion system is probably the most cost efficient system when combined with a high speed ROV or ROTV.

Active cables trackers like the TSS 440 are also on the market for tracking the cables. The range, however, is most likely insufficient for tracking the cables at the required 2.5m burial depth.

Due to the weak water currents in the region, most underwater survey platforms (ROV and ROTV) can be used for DOB surveys.

The DOB survey must be able to provide a detailed baseline position of the buried cable. This baseline can then be used in future maintenance surveys to assess the burial depth at the given time.

The mobility of the seabed only poses a limited risk to the cable after installation. The recommendation is to perform an annual survey along the cable route in the initial years after installation. The surveys should be performed early in the year to detect influences from winter storms.

The geophysical surveys should include MBES surveys to monitor the mobility of the seabed and a SSS survey to check for potential hazards in close proximity of the cables.

Due to the apparent stable nature of the seabed, the annual surveys could be limited to the first two years if the data confirms the immobility of the seabed and that the cable do not move after installation. After the initial annual surveys, a re-evaluation of the frequency of the surveys should be conducted to it might be best to reduce the frequency during the lifetime of the project.

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APPENDIX 1
SOIL OVERVIEW AND BURIAL ASSESMENT CHARTS

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APPENDIX 2
WATER DEPTH

APPENDIX 3
KP ROUTE LIST

[Text]

APPENDIX 4
CABLE ROUTE SURVEY CHARTS

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APPENDIX 5
LIST OF APPREVIATIONS