Vattenfall Wind Power Ltd

Thanet Extension Offshore Wind Farm

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Vattenfall Wind Power Ltd

Thanet Extension Offshore Wind Farm

Report 3 of 3: Geophysical Investigation

Report

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Vattenfall Wind Power Ltd

Thanet Extension Offshore Wind Farm Report 3 of 3:

Geophysical Investigation Report

June 2018

Drafted By:	Report 3 of 3: Geophysical Investigation Report
Approved By:	Helen Jameson
Date of Approval	June 2018
Revision	A

Fugro Survey B.V.

Thanet Extension Offshore Wind Farm

United Kingdom Continental Shelf, North Sea

Report 1 of 3:
Geophysical Investigation Report

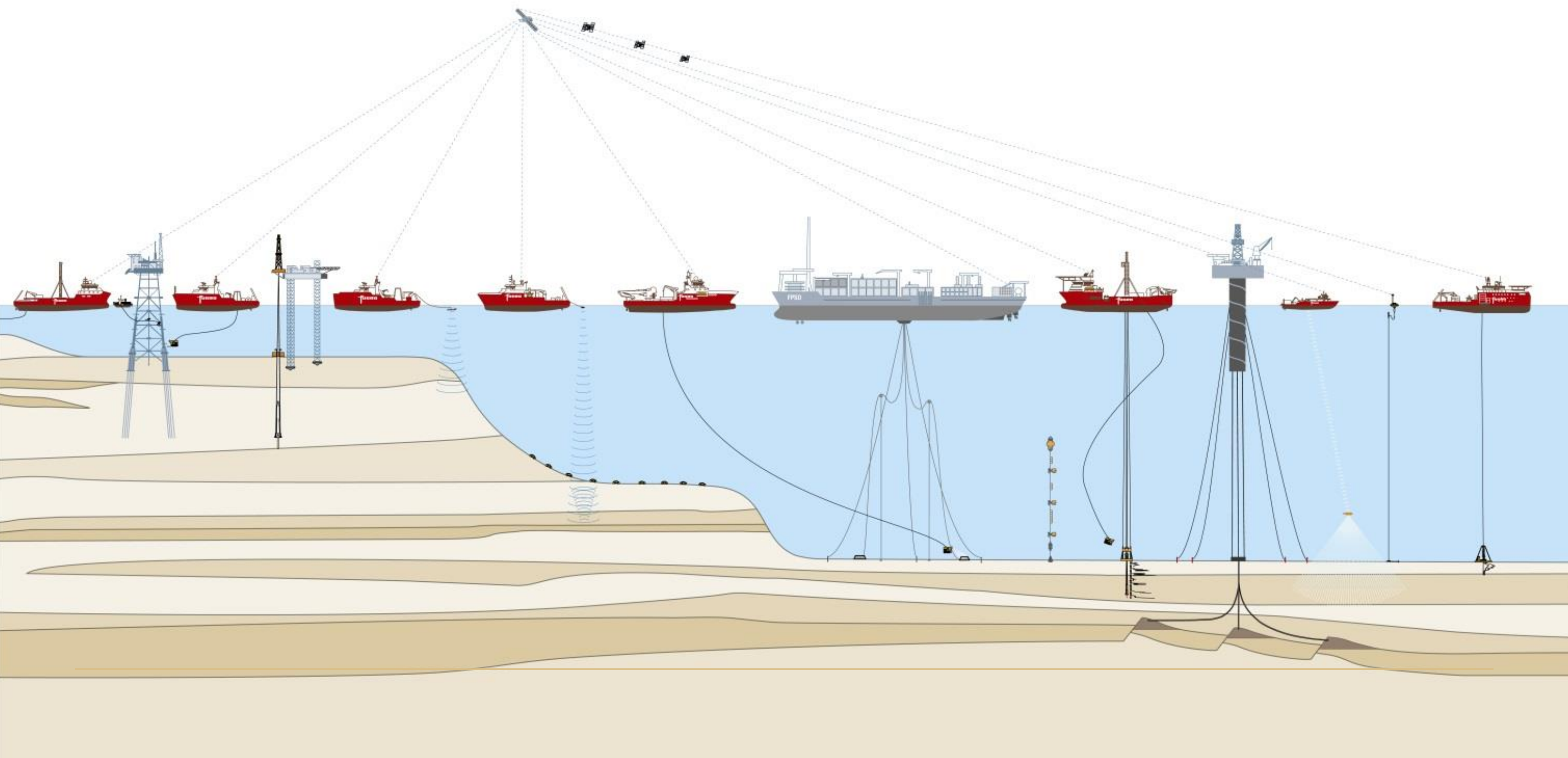
Volume 3 of 3:
Geophysical Site Survey

July to September 2016

Fugro (FSBV) Report No.: GE051-R1

Vattenfall Wind Power Ltd.

Revision 0



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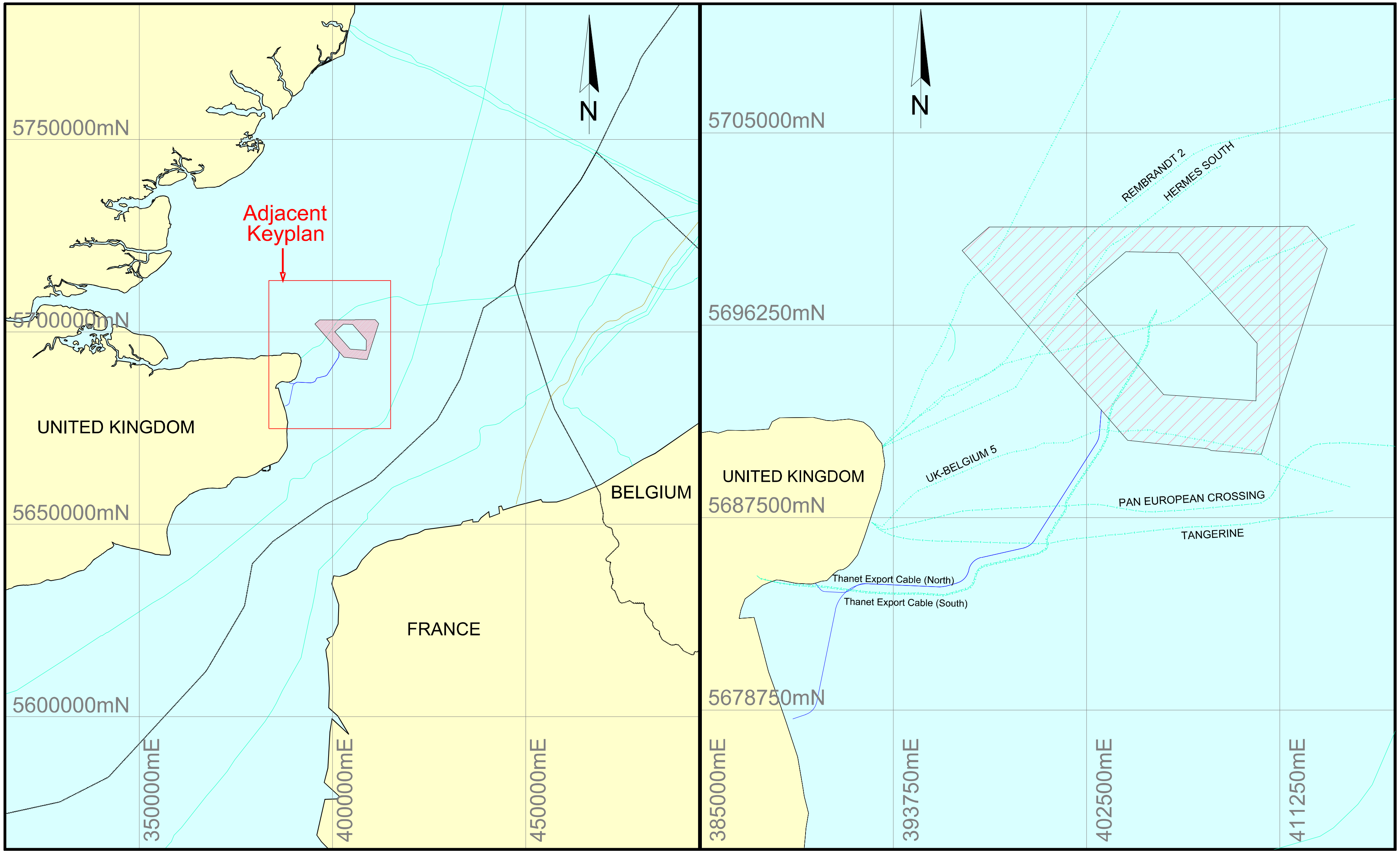
REPORT AMENDMENT SHEET

Issue No.	Report section	Page No.	Table No.	Figure No.	Description
0	1.1	1	-	-	Text amended
0	1.3	3	-	-	"European Terrestrial System 1980" replaced with "…1989"
0	2.2	4	-	-	Updated minimum water depth
0	various	various	-	2.2, 2.4	Added KP markers
0	2.5	11	-	-	Text amended
0	2.6	20	2.8	-	Table amended for MAG target
0	2.8.1	23	-	-	Text amended
0	2.8.1	24	-	2.12	Legend added to figure
0	3.6	31	-	-	Text amended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REMBRANDT 2
HERMES SOUTH
UK-BELGIUM 5
UNITED KINGDOM
PAN EUROPEAN CROSSING
TANGERINE
Thanet Export Cable (North)
Thanet Export Cable (South)

KEYPLAN

EXECUTIVE SUMMARY

Thanet Extension Export Cable Route Corridor (Route A and Route B)	
Introduction	
Survey Dates:	July to September 2016
Equipment (Geophysical):	Sidescan sonar (SSS), single beam echo sounder (SBES), multibeam echo sounder (MBES), pinger (SBP), and magnetometer (MAG).
Coordinate System:	Datum: European Terrestrial Reference System 1989 (ETRS89) Projection: UTM Zone 31N, CM 3°E
Bathymetry	
Water depths throughout the export cable route corridor range between approximately -2.51 m above LAT and 18.0 m below LAT. As a general trend, the seabed along the route deepens towards the north-east, where the route connects to the Thanet Extension OWF site. Seabed gradients are typically less than five degrees except within areas of dunes, outcrops and seabed ridges. Local seabed gradients of up to 35 degrees were observed in these areas.	
Seabed Features	
Subaqueous dunes of varying scales are abundant within the export cable route corridor, indicating a complex tidal and bottom-current regime. Generally, the seabed is characterised by SAND and GRAVEL sediments with localised silty or clayey components and coarse SAND- to GRAVEL-sized shell fragments.	
Geology	
The shallow sub-surface geological conditions within the survey area have been interpreted based on SBP data, together with information from multichannel UHR sparker/air gun data from the Thanet Extension OWF site and BGS standard geological maps (Ref. 8). The limit of interpretation of the SBP data was generally up to 5 m below seabed. Three (3) seismic units were identified along the length of the export cable route corridor including formations from Holocene age to late Cretaceous.	
Seabed and Sub-seabed Hazards	
Wrecks	
Three (3) wrecks were identified during the survey within the export cable route corridor. Three (3) further charted wrecks were not identified during the survey. One rock dump area was identified in close proximity to one of the three charted but not observed wrecks, and is expected to cover the wreck.	
Cables	
A total of five (5) cables (based on the ENC and Admiralty charts) cross the proposed export cable Route A and Route B options. All five cables were detected by geophysical survey equipment Two (2) of these cables (Thanet Export Cable (North) and (South)) also run parallel to the proposed route for an extended distance. A further eight (8) suspected/unknown cables (not shown on the ENC and Admiralty charts) were observed within the export cable route corridor.	
Thanet Export Cable (North)	Up to 3 m offset with respect to the database position
Thanet Export Cable (South)	Up to 5 m offset with respect to the database position
Tangerine	Up to 33 m offset with respect to the database position
Pan European Crossing	Up to 5 m offset with respect to the database position
UK-Belgium 5	Up to 30 m offset with respect to the database position
Unknown Cables	Not charted

Seabed Geohazards	
Seabed gradients	Local seabed gradients within areas of ridge and sand dune crests reach a maximum of 35 degrees.
Outcrops	Areas of outcropping chalk were identified within the export cable route corridor, notably from KP 10.0 to KP 10.6, and KP 19.4 to KP 22.0.
Other contacts	Numerous suspected items of debris and unknown magnetometer contacts were observed within the route TEOW corridor.
Sub-seabed Geohazards	
Coarse Sediments / GRAVEL Layers / Boulders/ Subcrops	Patches of hard / GRAVEL layers associated with subcropping sediments were identified along the majority of the export cable route corridor.

DOCUMENT ARRANGEMENT

REPORT 1: GEOPHYSICAL INVESTIGATION REPORT

VOLUME 1: OPERATIONS & CALIBRATIONS

VOLUME 2: GEOPHYSICAL SITE SURVEY

VOLUME 3: GEOPHYSICAL ROUTE SURVEY

REPORT 2: GEOTECHNICAL INVESTIGATION REPORT

REPORT 3: ENVIRONMENTAL INVESTIGATION REPORT

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APPENDICES

A. ROUTE ALIGNMENT CHARTS

TABLES

FIGURES

LIST OF CHARTS

ABBREVIATIONS

BGS	British Geological Survey
bLAT	below Lowest Astronomical Tide
bsb	below seabed
CM	Central Meridian
COG	Centre of Gravity
CPT	Cone Penetration Test
CRP	Common Reference Point
DGPS	Differential Global Positioning System
DTM	Digital Terrain Model
DTU13	Danish Technical University 2013
ENC	Electronical Nautical Chart
EPSG	European Petroleum Survey Group
ETRS89	European Terrestrial Reference System 1989
FEMU	Fugro EMU Ltd.
Fm	Formation
FSBV	Fugro Survey B.V.
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HIPS	Hydrographic Information Processing System
HVF	HIPS Vessel File
ITRF	International Terrestrial Reference Frame
LAT	Lowest Astronomical Tide
MAG	Magnetometer
MBBS	Multibeam Backscatter Sonar
MBES	Multibeam echo sounder
MV	Motor Vessel
OWF	Offshore Wind Farm
QC	Quality Control
SBES	Single beam echo sounder
SBP	Sub-bottom profiler
SCS	Single channel seismic
SIPS	Sonar Information Processing System
SIS	Seafloor Information System
SSS	Sidescan sonar
TEOW	Thanet Extension Offshore Wind Farm
TPU	Total Propagated Uncertainty
TVG	Time variable gain
TWT	Two way travel (time)
UHR	Ultra High Resolution
UHRS	Ultra High Resolution Seismic
UKOOA	United Kingdom Offshore Operators Association
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator

VORF	Vertical Offshore Reference Frame
WGS84	World Geodetic System 1984

1. INTRODUCTION AND SCOPE OF WORK

1.1 General

Vattenfall Wind Power Ltd. contracted Fugro Survey B.V. (FSBV) to perform a geophysical investigation to improve the bathymetrical, morphological and geological understanding of the Thanet Extension Offshore Wind Farm, located north-east of Kent off the United Kingdom coast. The investigation included the wind farm site and the proposed export cable route corridor. Furthermore the geophysical results were used for UXO/obstructions clearance for the following geotechnical campaign. The results of the geotechnical campaign will be integrated with the geophysical data to create a ground model. The ground model will serve as the base for the design and installation requirements.

Geophysical information for the Thanet Extension Offshore Windfarm site and export cable route are gathered and described in this report (GE051 / R1). This volume of the report (GE051 / R1 / Vol 3) focuses on the geophysical investigation of the export cable route (Option A and Option B).

Details of the geophysical survey operations, including vessels and equipment, and a discussion of data quality and accuracy, are included in the Operations and Calibrations Report, which forms Volume 1 of the report (GE051 / R1 / Vol1).

The geophysical survey was carried out between July and September 2016.

The geophysical survey was carried out using the survey vessels MV Fugro Pioneer for the site and RV Discovery and Valkyrie for the cable route. The port in Great Yarmouth was the closest to the Thanet Extension Offshore Wind Farm area and it was used as main base for the survey operations.

Unless otherwise specified, all geographical and projection coordinates in the report and in the charts are based on local datum ETRS89. Projection coordinates are expressed in Universal Transverse Mercator (UTM) grid, Zone 31, Northern Hemisphere. The vertical datum is Lowest Astronomical Tide (LAT). The time standard is UTC +1.

The investigation provided geophysical bathymetric and shallow seismic data using the following equipment: sidescan sonar (SSS), magnetometer, multibeam and single beam echo sounder (MBES/SBES), sub-bottom profiler (SBP) and ultra-high resolution multichannel sparker (UHR). UHR data was acquired on the Thanet Extension site only.

1.2 Purpose of Work

The general objectives for the site and cable route surveys were to:

- Gather accurate bathymetric data and assess topography for areas with steep gradients, and provide assessment of seabed movements;
- Collect sidescan sonar data and provide interpretation of seabed sediments and identification of any object on the seabed larger than 1 m;
- Collect sub-bottom profiler seismic data to assess variations in thickness of seabed sediments and shallow geology;
- Collect UHR seismic data and build a seismic stratigraphic model of the deeper geology (not for export cable);
- Locate any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas and buried channels;
- Collect magnetometer data and include this data in an assessment of the regional geology, and provide identification of any magnetic anomalies;
- Gather seismic information about geotechnical borehole locations;
- Provide acoustic sediment type data to inform benthic surveys;
- Production of charts and maps suitable for use in GIS systems, including track plots, bathymetry (relative to LAT) and seabed features with contacts.

1.3 Geodetic Parameters

Unless otherwise specified, all geographical and projection coordinates in the report and in the charts are based on local datum European Terrestrial System 1989 (ETRS89). Projection coordinates are expressed in Universal Transverse Mercator (UTM) grid, Zone 31, Northern Hemisphere. The vertical datum is Lowest Astronomical Tide (LAT). The time standard is UTC +1.

Satellite navigation and positioning was operated in differential mode. DGPS geographical coordinates were based on datum World Geodetic System 1984. The UKOOA datum shift parameters were used for the transformation from WGS84 to the local coordinates in the ETRS89 datum. The geodetic parameters are detailed in Table 1.1.

Table 1.1: Project geodetic and projection parameters

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<tr><td colspan="3">UTM Zone</td><td colspan="6">31 Northern Hemisphere</td></tr>
<tr><td colspan="3">Central Meridian:</td><td colspan="6">003º 00’ 00.000” East</td></tr>
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<tr><td colspan="3">False Northing:</td><td colspan="6">0 m</td></tr>
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<tr><td colspan="3">Units:</td><td colspan="6">Metre</td></tr>
<tr><td colspan="3">EPSG Code:</td><td colspan="6">25831</td></tr>
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Notes:

1. Source: Starfix.NG. Starfix.NG determines the transformation parameters according to the Memo of C. Boucher and Z. Altamimi, dated 18 May 2011.
2. This is the right-handed coordinate frame rotation convention used by the Fugro Starfix navigation software.
3. The coordinate transformation parameters are the combined result of the 14 parameter transformation from ITRF2008 to ETRS89 and do take into account the yearly changes on the mentioned epoch.

   The WGS 84 realisation is nearly equal to the ITRF2008 on the above mentioned epoch. WGS 84 is maintained by the US Department of Defence to be nearly identical to ITRF2008.

2. SURVEY RESULTS

2.1 General

Two export cable route options, namely Export Cable Route A and Export Cable Route B, were investigated, including a survey corridor of approximately 500 m to each side of the proposed routes. Both routes commence with KP 0 at the Thanet Extension wind farm site. The route options follow an identical path until they split near KP 15. From there on, Route A continues southwards and reaches the mainland at KP 22.830 while Route B arrives at its landfall location at KP 17.784.

A separate report is dedicated to the results of the Thanet Extension site survey. This report solely focuses on the proposed export cable route.

2.2 Bathymetry

Water depths within the surveyed cable route corridor range between approximately -2.51 m above LAT and 18.0 m below LAT. The deepest section is in the north-east where the route connects to the Thanet Extension wind farm site, from where the seabed progressively becomes shallower towards the mainland in the south-west. An overview of the survey area is provided in Figure 2.1.

The newly acquired bathymetry dataset covers the data extent of two previous surveys from 2007 and 2012.

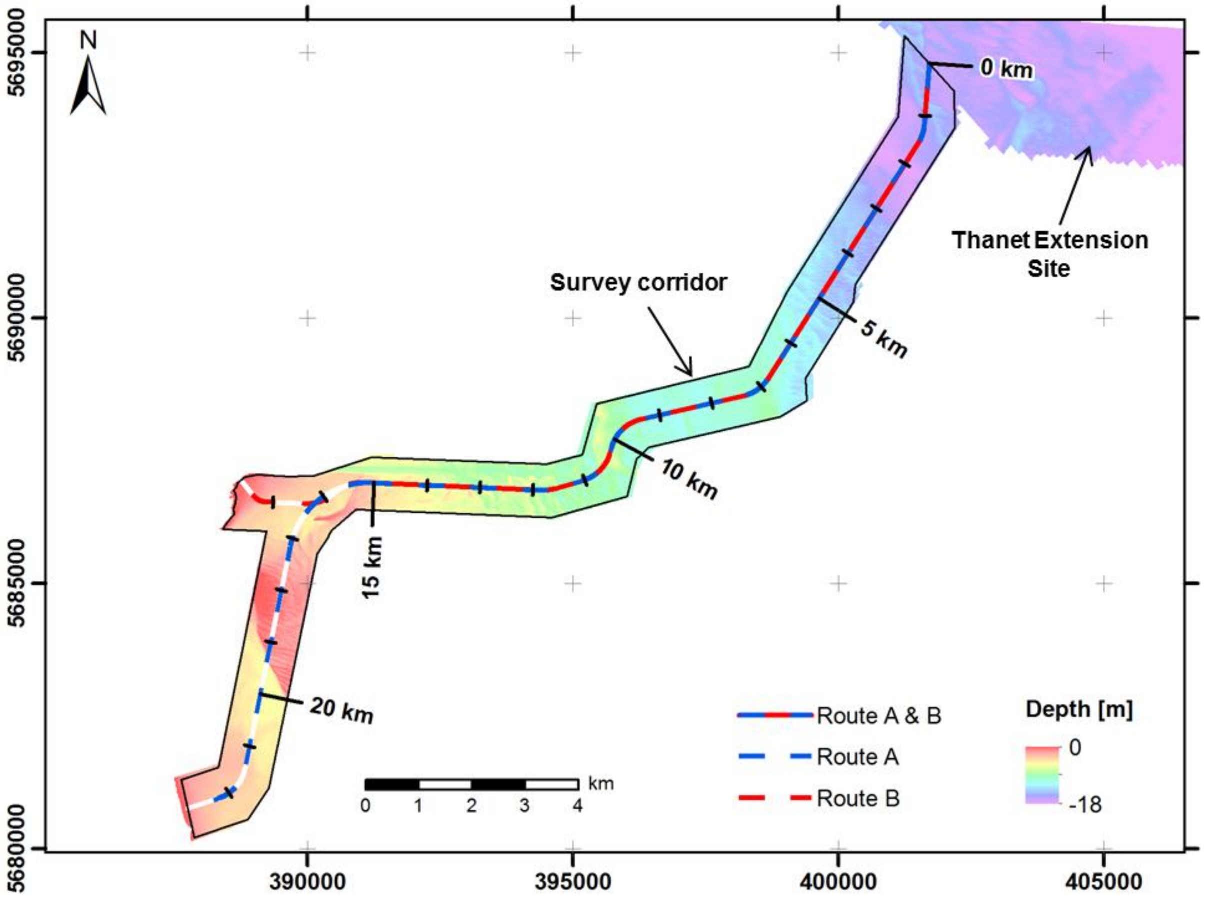


Figure 2.1: Bathymetric overview of the proposed Export Cable Routes A and B

Large parts of the seabed within the survey site are generally flat with gradients of less than five degrees, shown as a green colour in Figure 2.2. However, dunes, outcrops and, especially, seabed ridges are highly abundant throughout the route corridor, many of which exhibit slopes that exceed five degrees. Two areas in particular are characterised by numerous features with steeper seabed gradients: firstly, a section around a plateau-like outcrop between KP 8.5 and KP 10.5 of Route A/Route B; and secondly, between KP 15.0 and KP 20.0 of Route A. These areas are illustrated in Figure 2.2. In the latter area, maximum gradients of up to 35 degrees are reached. The aforementioned bedforms and features are described in detail in Section 2.3.

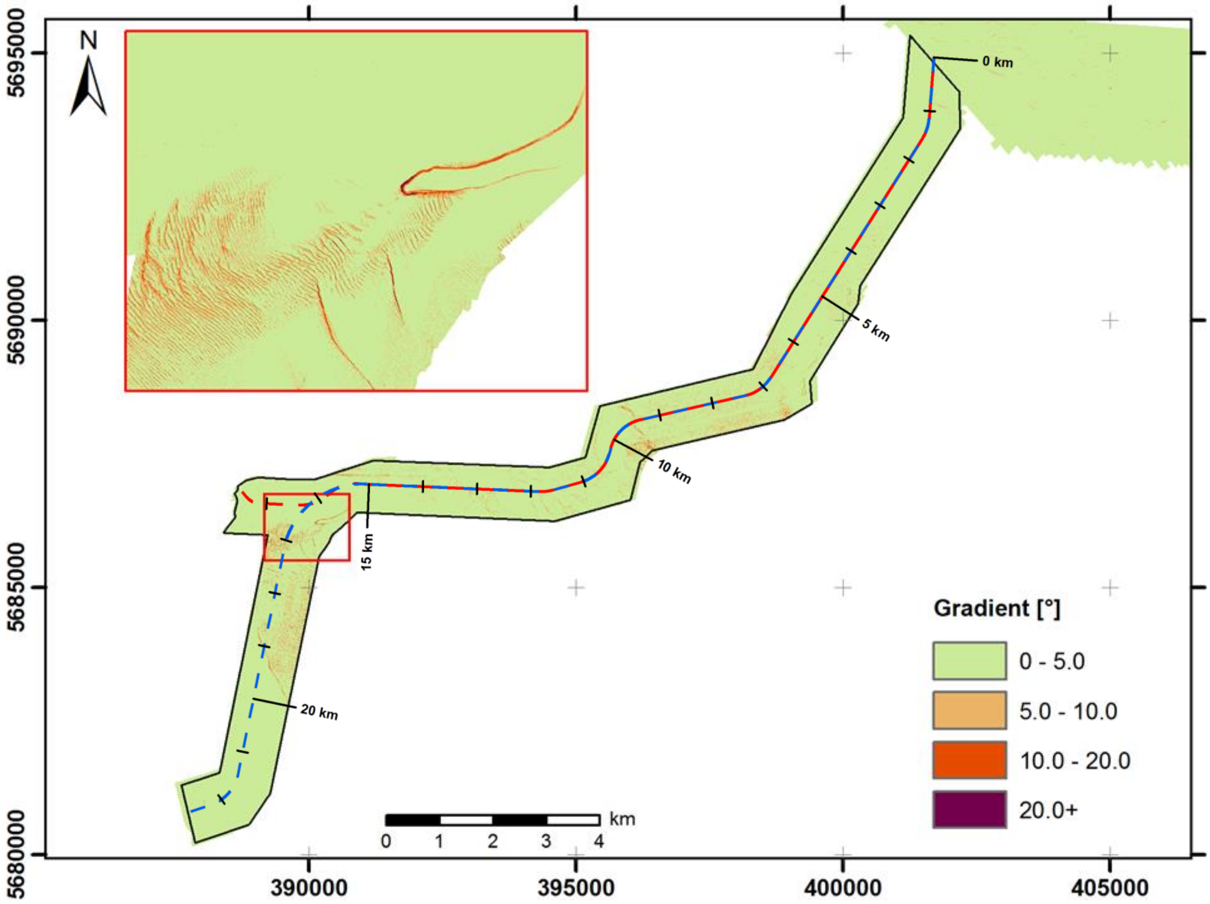


Figure 2.2: Seabed gradients calculated from MBES data (1 m grid)

2.3 Sedimentary Bedforms

Sedimentary bedforms identified within the cable route corridor are presented in the Seabed Features and Sediments panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

Current-induced bedforms of various scales occur in several sections of the cable routes. According to Ashley et al. (2002, Ref. 1), current related seabed features such as ripples, sand waves and dunes can be jointly defined as dunes and classified in terms of height, spacing between features and shape (2D or 3D) as first order descriptors (Table 2.1 and Figure 2.3). This classification is used to describe the morphological features within the Thanet Extension site and export cable route corridor.

Dunes (D-I, D-II, D-III) and ridges (R-I, R-II) described in this report have been categorised based on these descriptors, as detailed in Table 2.2 and Table 2.7.

Table 2.1: Classification scheme for seabed bedforms (Ref. 1)

General Class: Dune				
		First Order Description		
Size				
Spacing	0.6-5 m	5-10 m	10-100 m	>100 m
Height	0.075-0.4 m	0.4-0.75 m	0.75-5 m	>5 m
Term	*small*	*medium*	*large*	*very large*
Shape				
2D	Straight-crested, little or no scour in trough			
3D	Sinuous, catenary or linguoid/lunate crested, deep scour in trough			
		Second Order description		
Superposition				
Simple	No bedforms superimposed			
Compound	Smaller bedforms superimposed			

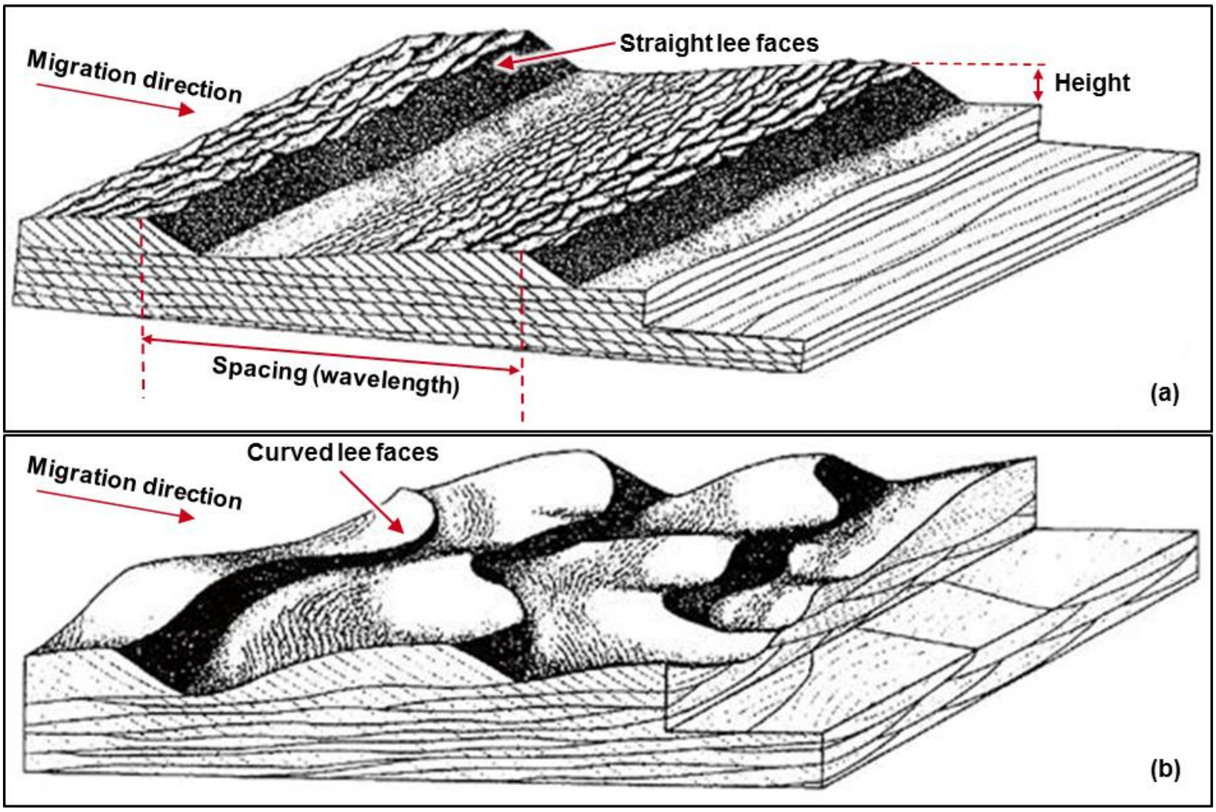


Figure 2.3: First order description parameters of (a) 2D and (b) 3D seabed dunes (Ref. 1 modified)

The morphology, distribution and orientation of these dunes are an indicator for large sediment transport and current direction. Statistical analysis and modelling of sand dune mobility (e.g. Ref. 2 and Ref. 3) shows that they typically migrate in the range of several metres per year. The high seabed gradients on the lee side of the dunes are identified as seabed hazards.

Subaqueous dunes of different scales are abundant, indicating a complex tidal and bottom-current regime. Table 2.2 provides data examples with description and classification of these bedforms.

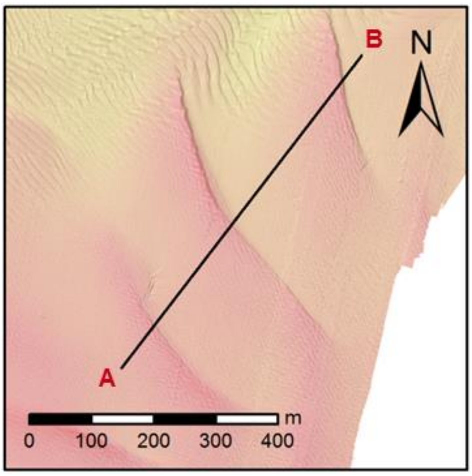
Several very large subaqueous 2D compound dunes with 200 m to 250 m spacing and height of about 1 m to 3 m, categorised as class D-I, are found between KP 16.5 and KP 18.0. Furthermore, a few isolated, large to very large compound dunes with superposed small and medium dunes occur around KP 9.5. No single current direction can be determined in the latter section as both major bedforms as well as superposed and surrounding smaller dunes change in symmetry and orientation. It is assumed that tidal currents play a major role in forming these bedforms but local current patterns, such as eddies driven by seabed morphology, may affect them as well.

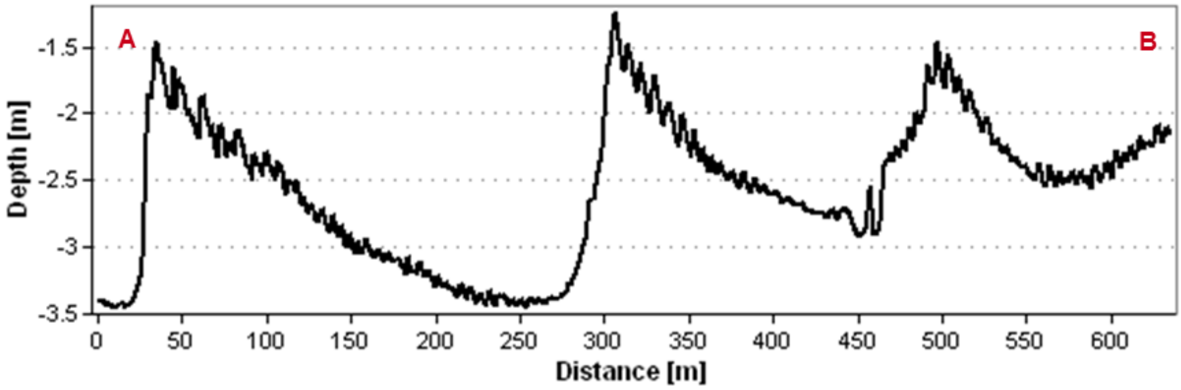
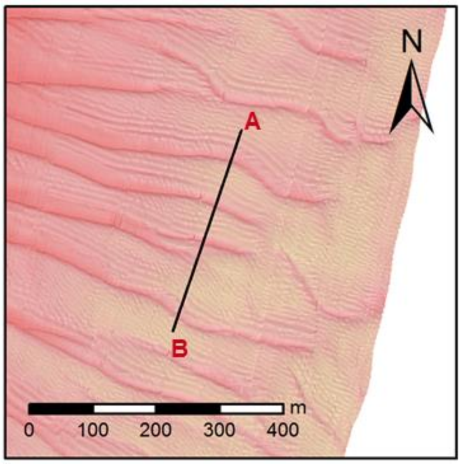
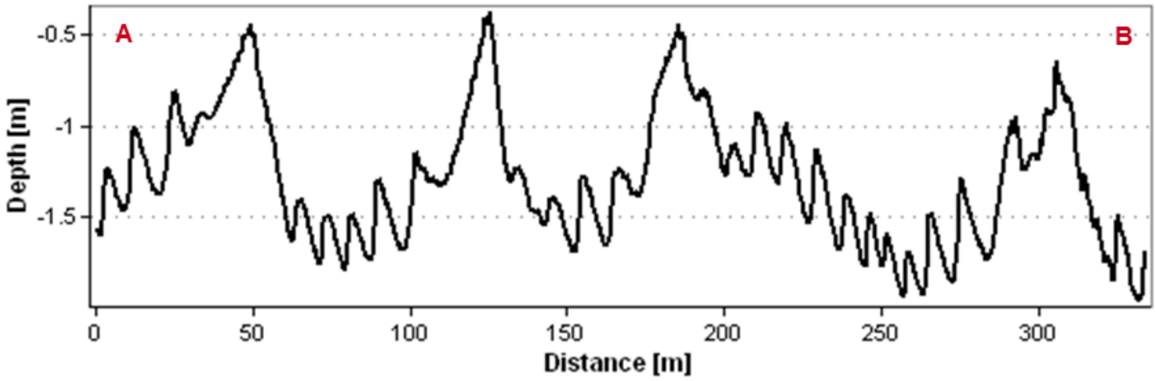
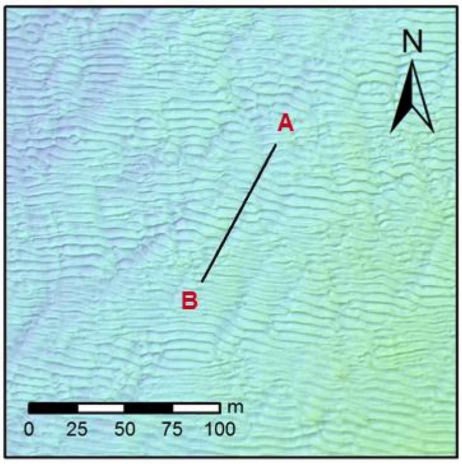
According to Stow et al (2009, Ref. 4) dunes of this size and composition suggest a low to moderate current (0.5 to 1.0 m/s)

The section of Route A between KP 16.5 and KP 19.5 is characterised by a large field with dunes of various shapes and dimensions. Most of them are classified in Table 2.2 as D-II dunes – medium to large 2D and 3D dunes, in some places superposed by small and medium dunes. They run predominantly towards the north-east indicating a net current in the same direction.

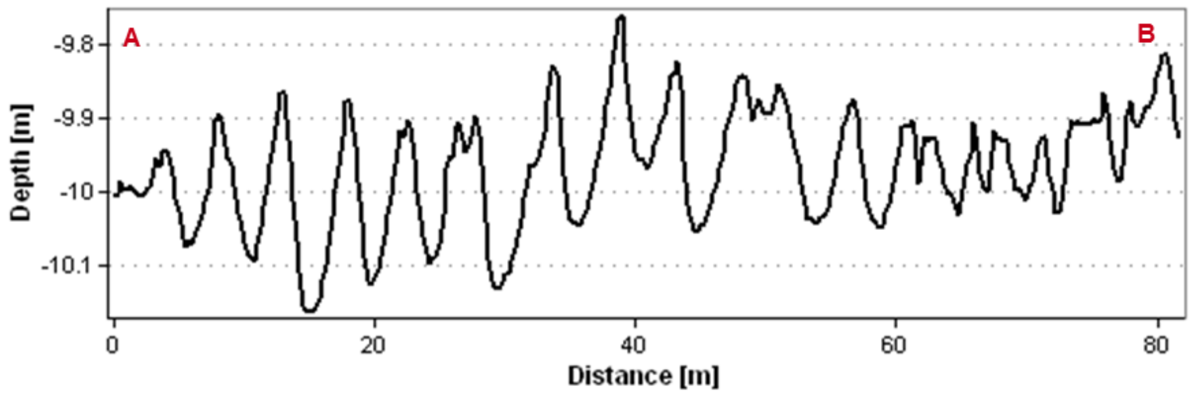
In almost all areas that feature a sediment layer of sufficient thickness, rather than just a veneer of sediment overlying chalk, small and medium 2D and 3D dunes, defined as class D-III in Table 2.2, are abundant. As a result, their absence can be used as an indicator for a hard sub-surface horizon being close to the seabed. The two main areas with sediment coverage of a few decimetres (estimate) to a few metres thickness, namely between KP 6.5 and KP 10.0 and between KP 16.5 and KP 19.4, are almost completely covered by these D-III dunes either as superposing or sole bedforms.

Table 2.2: List and description of bedforms within the survey route corridor

Class	Wavelength	Height	Bedform Description	Data Example
D-I	200 - 250 m 4 - 8 m	1 - 3 m 0.1 - 0.4 m	Very large, mostly south-west to north-east trending, subaqueous 2D dunes superposed by small to medium 3D dunes.	

Class	Wavelength	Height	Bedform Description	Data Example
				
D-II	8 – 25 m 1–10 m	2 - 8 m 0.1 – 0.4 m	Medium to large, mostly south-west to north-east trending 2D and 3D subaqueous dunes with straight and bifurcating crest lines. In some areas superposed by small to medium 3D dunes.	
				
D-III	3–10 m	0.1 – 0.6 m	Small to medium 2D and 3D dunes with straight and bifurcating crest lines. Abundant in areas with sufficient sediment supply. Most common orientation is south-west to north-east. Symmetry as well as orientation varies frequently indicating different current patterns and possibly localised eddies.	

Class	Wavelength	Height	Bedform Description	Data Example



(Refer to Seabed Features and Sediments Panel - Alignment Charts, Appendix A)

2.4 Seabed and Sediment Classification

Seabed features and sediment classification are presented in the Seabed Features and Sediments panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

A general classification of the seabed sediment is conducted primarily based on multibeam backscatter and sidescan sonar data. The backscatter mosaic for the export cable route corridor is shown in Figure 2.4. As a rule of thumb, high backscatter strength (dark grey) corresponds with coarser sediments whereas low backscatter (light grey) indicates finer grain sizes. However, apart from seabed type, backscatter strength is also affected by, among others, incident angle, water depth and near-surface sub-bottom horizons. Hence, variations in intensity within one sediment type can occur across the site.

One sediment sample obtained by a vibrocorer was located within the cable route corridor and was used as reference point in the northern section. The findings at the date of issue of this report are illustrated in Figure 2.4.

Where applicable, seabed features and relief, such as the onset of small to medium subaqueous dunes, are taken into account and used to help define sedimentary boundaries.

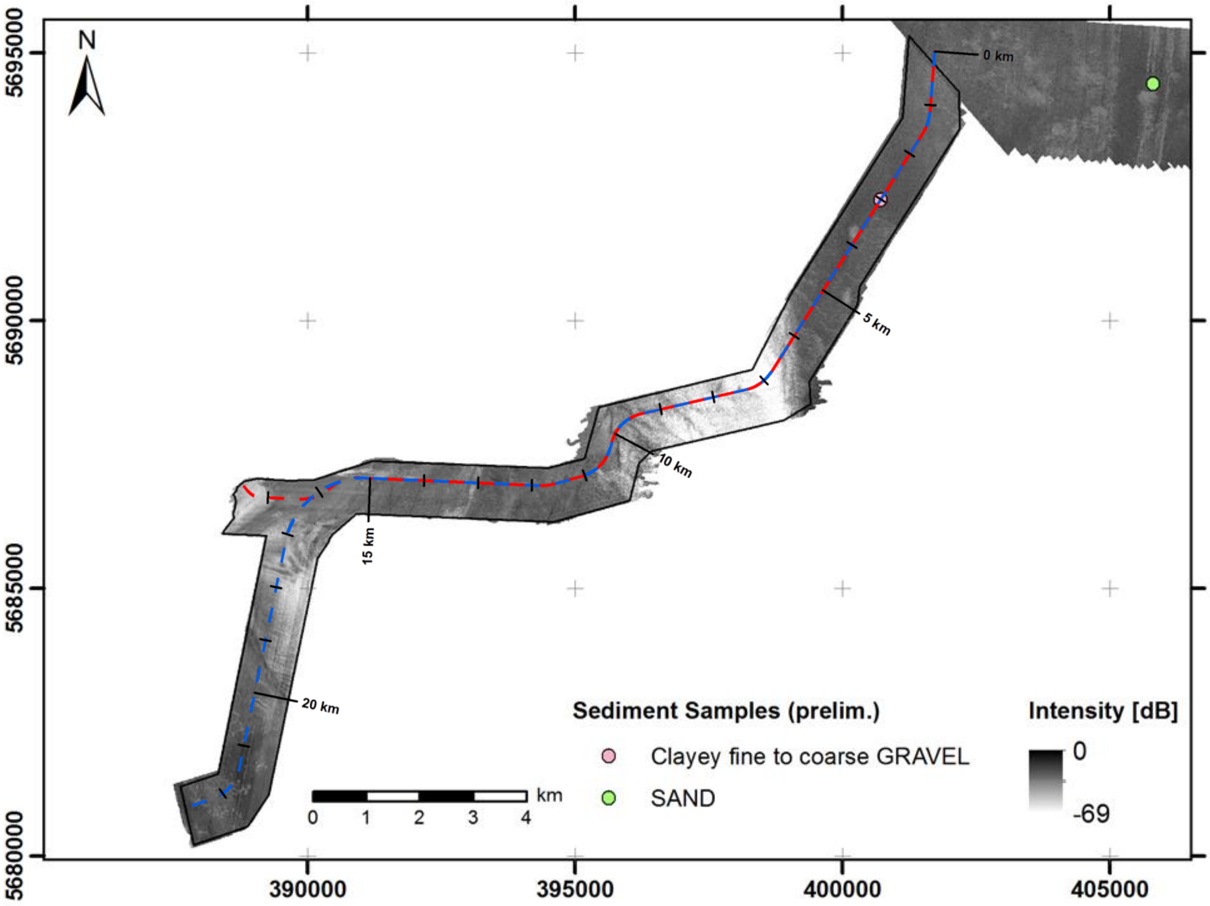


Figure 2.4: Multibeam backscatter data for the Thanet Extension export cable routes

Generally, the seabed is characterised by a thin layer of SAND and GRAVEL sediments with silty or clayey components in certain areas. For charting purposes, sediment types are summarised into four categories, namely: clayey or silty SAND; (fine to coarse) SAND; gravelly SAND; and sandy GRAVEL. These sediment types are supplemented by an additional category for outcrops.

From KP 0 to KP 5.8 the seabed is composed of loose sandy GRAVEL and gravelly SAND with occasional patches of fine to coarse SAND. The sediment layer is assumed to be limited to a veneer over structureless chalk, based on the vibrocore sample within this area which shows the chalk unit at 12 cm below seabed. Numerous seabed ridges exist in this section of the route, which are thought to be a result of erosion and are further discussed in section 2.5. On a small scale, backscatter data suggests that finer sediments deposit on the lee slope of these ridges.

From KP 5.8 to approximately KP 10.0 a pocket of thicker sediments is seen in the SBP data and is further supported by a cover of small to medium dunes as well as the formation of a few large to very large dunes. The sediment type changes to mostly clayey SAND with fine to coarse sandy patches. The limit of this section is marked by a plateau-like outcrop that stretches over about 600 m along the proposed route corridor between KP 10.0 and KP 10.6 (Route A and Route B).

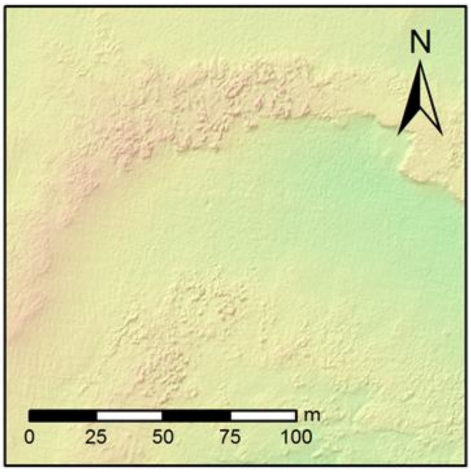
Following the outcrop the seabed is predominantly characterised by a veneer of fine to coarse SAND overlying chalk with similar morphology to the section between KP 0 and KP 5.8. Smaller areas of gravelly and clayey SAND are identified. These most likely represent areas of a thickened sediment layer as they are covered by small and medium dunes.

From about the point where the two routes split (KP 15.0) to KP 16.4 of Route A, and approximately KP 17.0 of Route B, a large area of outcropping chalk is observed, which is locally covered by a veneer of fine to coarse SAND. The remaining 750 m of Route B as far as its landfall position show a thickening sediment layer mostly composed of clayey SAND.

Sediments of up to a few metres thickness are deposited between KP 16.4 and KP 19.4 along Route A. They are of clayey and fine to coarse sandy composition and are fully covered by sand dunes of various types (D-I, D-II and D-III) and dimensions.

The final section of Route A, from KP 19.4 to the landfall location at KP 22.830, crosses scattered and patchy outcrops of chalk. A MBES example of these outcrops is provided in Table 2.3. The areas between the outcrops are covered by fine to coarse SAND with some small to medium dunes formed locally.

Table 2.3: Data Example of Outcrops and the Reef

Seabed Feature	Dimension & Description	Data Example
Outcrop	Highly irregular seabed, with outcropping and sub-cropping of the underlying geological unit. Numerous scattered boulders and boulder clusters resulting in chaotic undulations with negligible or no sediment cover. The outcrops can appear as seabed elevation of up to several metres in some places.	

(Refer to Seabed Features and Sediments panel of the Alignment Charts, Appendix A)

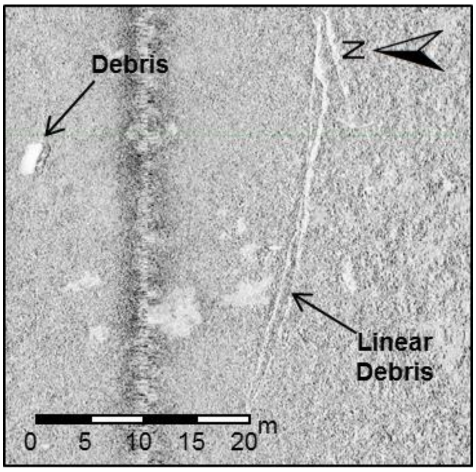
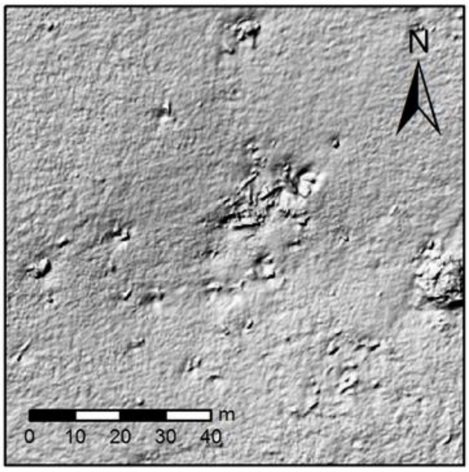
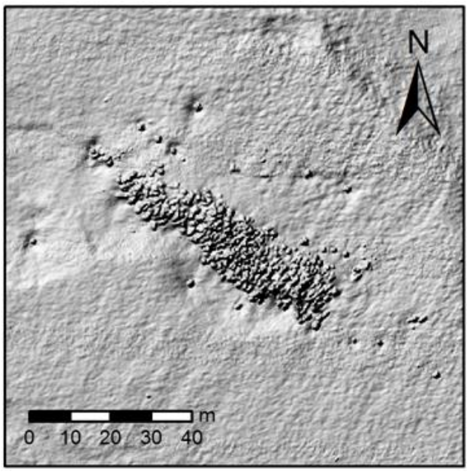
2.5 Seabed Contacts

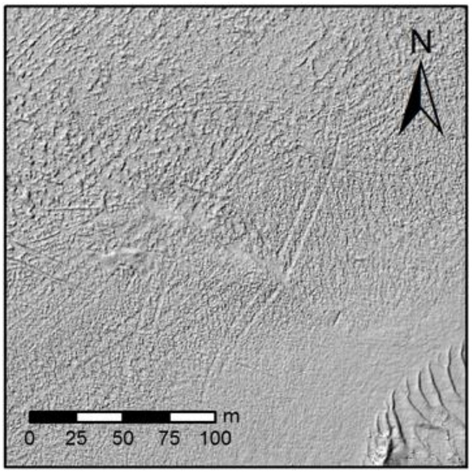
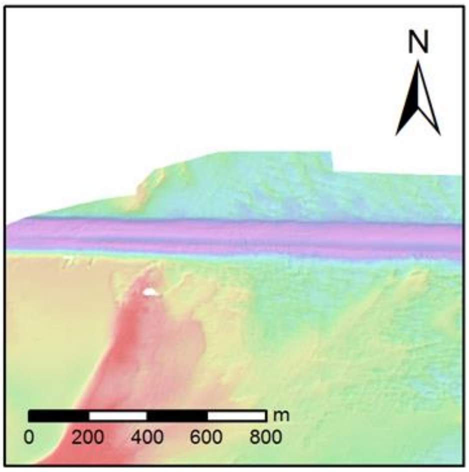
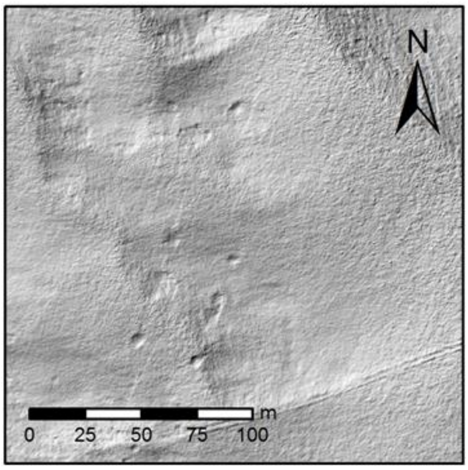
All anthropogenic seabed features described below are shown in the Seabed Features and Sediments panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

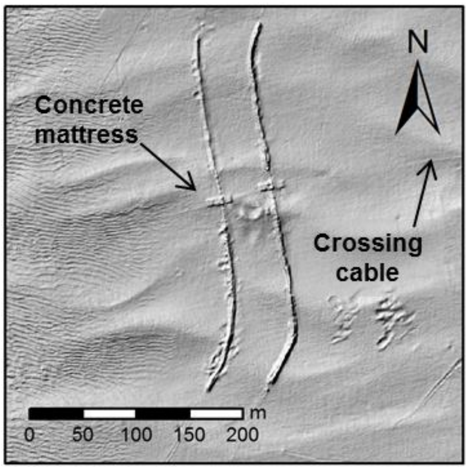
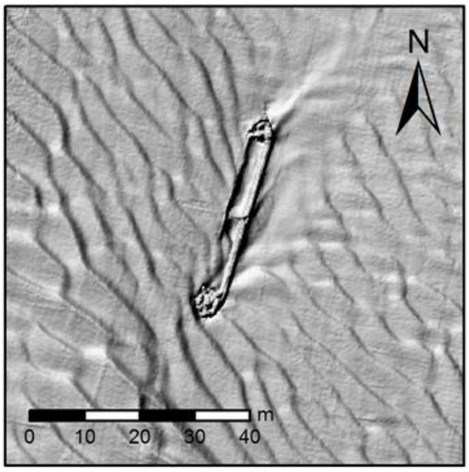
This section describes identified seabed features of both natural and anthropogenic origin. While dunes and dune crests are illustrated on the alignment charts provided in Appendix A, they are discussed in the previous section and, hence not described here. Most examples provided in Table 2.4 are taken from the hill-shaded bathymetry dataset as it is found to better pronounce features with low relief.

A number of man-made features were identified in the MBES and MBBS data including linear debris, debris fields, rock dumps, trawl scars, anchors and anchor pull-out scars, spudcan depressions and cables. Additional debris items or features that could not be resolved in the MBES data were picked from the SSS records. A complete list of all sidescan sonar targets is included in the GIS deliverables accompanying this report.

Table 2.4: Overview and data examples of anthropogenic seabed features

Seabed Feature	Dimension & Description	Data Example
(Linear) Debris	Linear debris items include but are not limited to (anchor) chains, ropes, fishing gear, small cable or pipe sections. A total of 122 linear debris items were found in the MBES, MBBS and SSS data. A further 360 debris or suspected debris items were identified from the SSS data. Lengths of objects vary between approximately 1 m and 180 m. The example to the right shows a debris item and a linear debris item taken from the SSS records.	
Debris field	Four debris fields were identified within the cable route corridor. The example to the right shows a shipwreck that has fallen apart with its parts scattered across the surrounding seabed.	
Rock dump	Two areas with rock dumps were found. One along the coastline next to (assumed) jetties, to the north of the final section of Route B. The other area is shown in the data example to the right. This rock dump occurs in close proximity to one of three charted but not observed wrecks, and is expected to cover the wreck.	

Anchor (pull-out) and trawl scars	Seabed scars from anthropogenic activity are mostly related to anchoring and fishing/trawling. Typical characteristics include anchor pull-out scars at one end of the feature or a set of two parallel scars indicative of trawling tracks (see example on the right). Man-made seabed scars were found along the whole route corridor, though a higher density of trawling scars was observed about 500 m south of KP 17.2 of Route B.	
Trench	An approximately 2.9 km long and 125 m wide trench was identified about 250 m north of KP 12.9 (Route A and Route B). It is assumed to be the result of dredging activities and extends as a straight feature from the western edge of the survey corridor towards the east, where the trench gradually merges with the surrounding seabed. The trench does not cross the proposed export cable routes (Route A or Route B).	
Spudcan depressions	Spudcan depressions usually appear in sets of three (triangle), four (square) or six (rectangle) depending on the type of rig/barge that was used. Due to the occurrence of mobile sediments in the survey area, a complete set was not always visible. A total of 16 depressions were identified in the MBES data. These are limited to a small area about 150 m south of KP 11.6 (Route A and Route B). Dimensions range between 4.7 m and 14.1 m in length, 3.1 m and 8.9 m in width, and 0.1 m and 0.4 m in depth.	

Cables	The survey area is crossed by several cables in the database. The presence of some of these cables is confirmed by MBES, SSS and, partially, SBP and MAG data. A further eight uncharted cables or cable segments were identified which are assumed to represent disused or newly laid cables. As most cables are trenched and buried, only the remaining seabed elevation is visible in the sonar data rather than the actual cable. Further details are provided in Table 2.5.	
Shipwrecks	A total of three shipwrecks (including one debris field related to a shipwreck) were identified from MBES, MBBS, SSS and MAG data along the cable route. A list of their position is provided in Table 2.6.	

All anthropogenic seabed features described above are shown on the alignment charts in Appendix A. Table 2.5 below lists the as-found cables and their offsets from the positions on admiralty charts.

Table 2.5: Cables crossing the export cable route corridor

Cable	Magneto-meter	SSS	MBES	Remarks
Thanet Export Cable (North)	YES	YES	YES	Up to 3 m offset with respect to the database position
Thanet Export Cable (South)	YES	YES	YES	Up to 5 m offset with respect to the database position
Tangerine	YES	YES	YES	Up to 33 m offset with respect to the database position
Pan European Crossing	YES	YES	YES	Up to 5 m offset with respect to the database position
UK Belgium 5	NO	NO	YES	Up to 30 m offset with respect to the database position
8x Unknown	YES	YES	YES	Potential unknown cable

A total of three (3) wrecks were observed within the export cable route corridor. Their as-found coordinates are provided in Table 2.6.

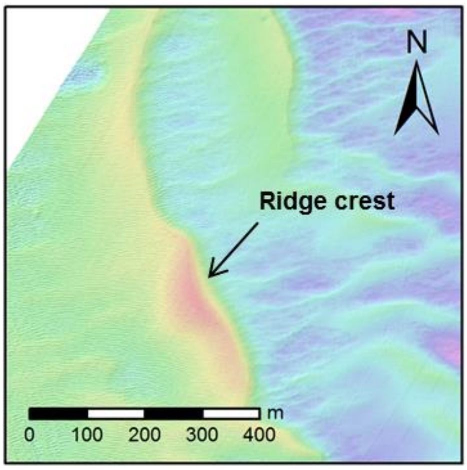
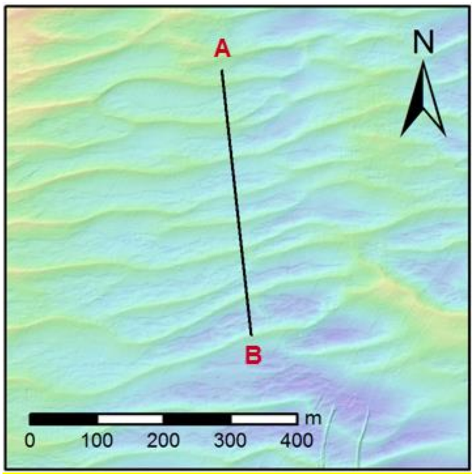
Three (3) further charted wrecks were not identified during the survey. A rock dump area was identified in close proximity to one of these wreck locations, and is expected to cover the wreck.

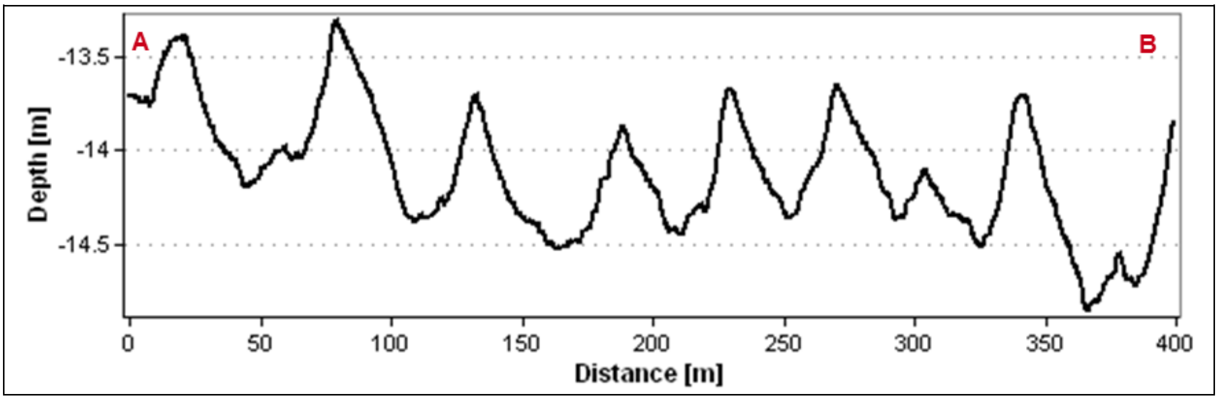
Table 2.6: As-found wreck locations within the export cable route corridor

Wreck	Easting [m]	Northing [m]	Detected on:			Remarks
			Magneto-meter	SSS	MBES	
ThanetExt_D_S0016	400236	5691670	YES	YES	YES	
ThanetExt_V_S0156	389783	5685530	YES	YES	YES	
Debris field	395535	5687287	YES	YES	YES	Numerous scattered debris

Apart from man-made features, different seabed patterns and features of natural origin are identified. These are described below in Table 2.7.

Table 2.7: Description and data examples of natural seabed features

Class	Wavelength	Height	Bedform Description	Data Example
R-I	N/A	Several metres	In contrast to sediment waves these features are not related to currents but present a surface expression of an underlying geological unit, e.g. chalk.	
R-II	30- 200 m	0.5 – 5.0 m	While their morphological appearance resembles large and very large dunes, these ridges are part of the underlying chalk unit with only a veneer of sediment cover. It is assumed that current induced erosion of the chalk forms these ridges.	



The seabed features described above are shown on the alignment charts in Appendix A.

2.5.1 Comparison between Dunes and R-II Ridges

The ridges that occur in the south-western sector of the survey corridor, here classified as R-II, were described as sand waves in previous third party survey reports. This section discusses the characteristics of these ridges and the main differences between the ridges and sand waves or dunes.

As mentioned in Section 2.3, in the literature dunes are generally understood as mobile systems that usually migrate in the direction of the residual current. Based on the orientation of identified dunes of various scales, there are two dominant current directions within the investigated area, approximately flowing from (1) north to south and (2) south-east to north-west.

Comparing bathymetry datasets from 2007, 2012 and 2016, presented in Figure 2.5, a shift of the class D-II dunes at KP 9.5 of the survey corridor can be measured, confirming the mobility of the dunes. Furthermore, SBP data clearly shows a layer of loose sediment between the base and the crest of the dune. Due to the lack of overlapping data, the migration speed of south-east to north-west trending D-I dunes cannot be investigated at this stage.

In contrast, Figure 2.5 shows that the R-II ridges have remained stagnant over the last four years. Sub-bottom data reveals that a layer of loose sediment between the peak and base of the ridges is missing. Occasionally small amounts of sediment are deposited on the ridge crests, but, these are unrelated to the ridge formation. The underlying chalk layer follows a dune-like shape suggesting that the ridges are part of this unit. Essentially, this area is interpreted to be starved of sediment with too little supply to allow formation of dunes. The shape of the ridges is thought to be related to a combination of current-induced erosion and the dipping underlying chalk.

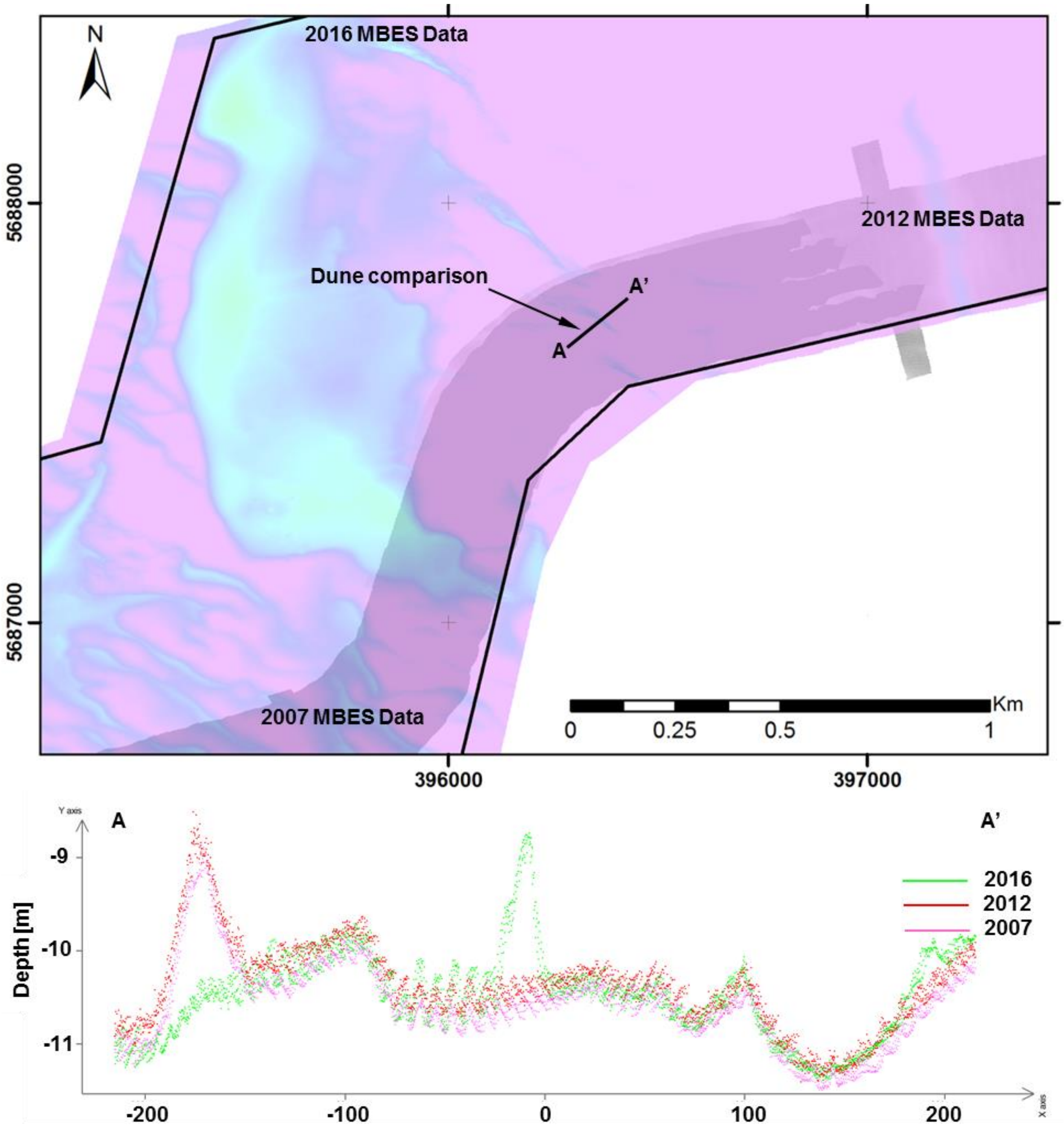


Figure 2.5: Comparison of bathymetry data from 2007, 2012 and 2016 over very large dunes (mobile) and chalk ridges (non-mobile)

The seabed morphology along the export cable route corridor is presented in Figure 2.6 to Figure 2.9 below.

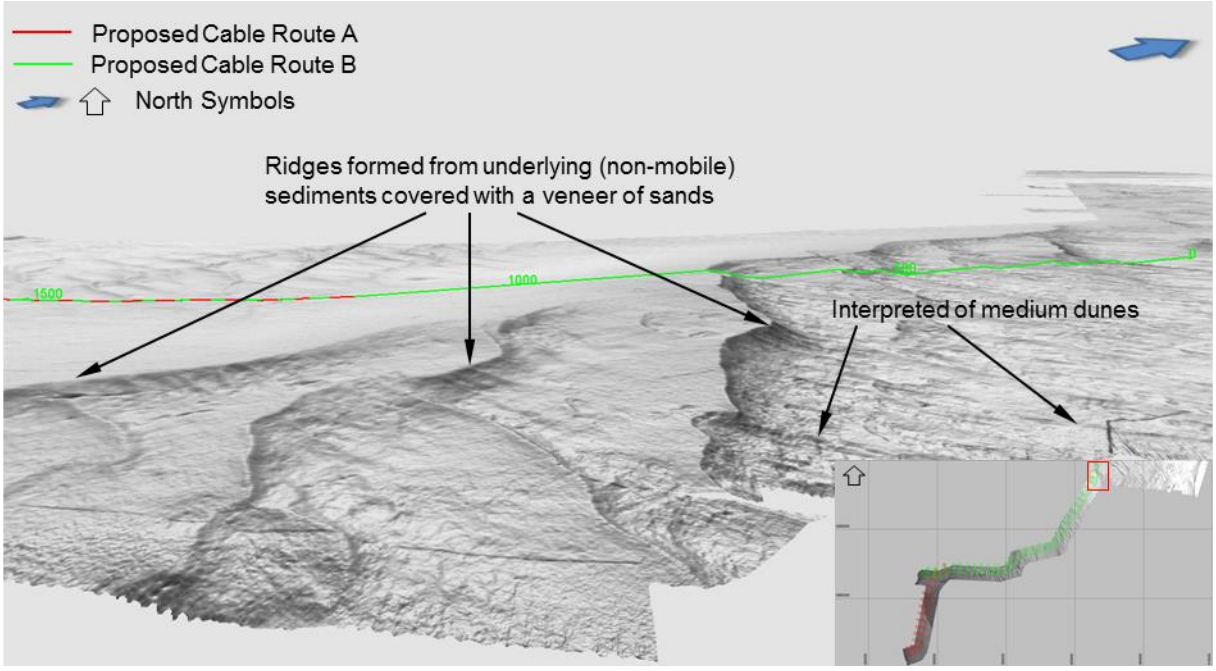


Figure 2.6: 3D view of an area of ridges associated with underlying dipping sediments between KP 0.0 and KP 1.5 (Route A and Route B)

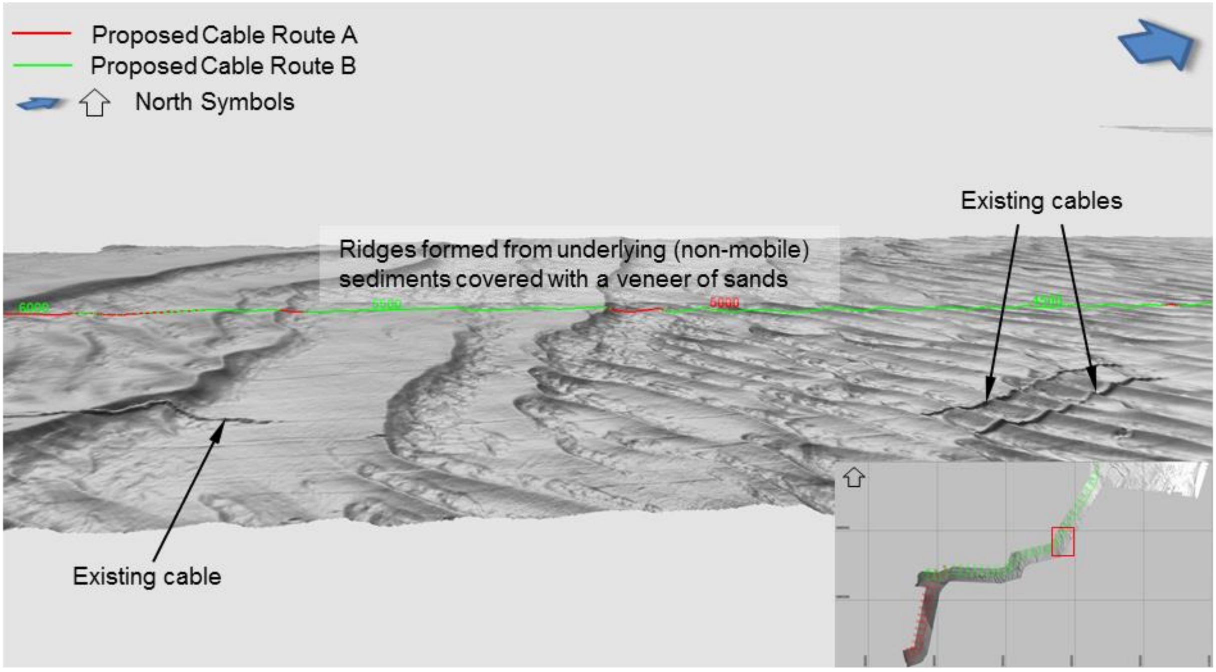


Figure 2.7: 3D view of existing cables identified within an area of ridges between KP 4.0 and KP 6.0 (Route A and Route B)

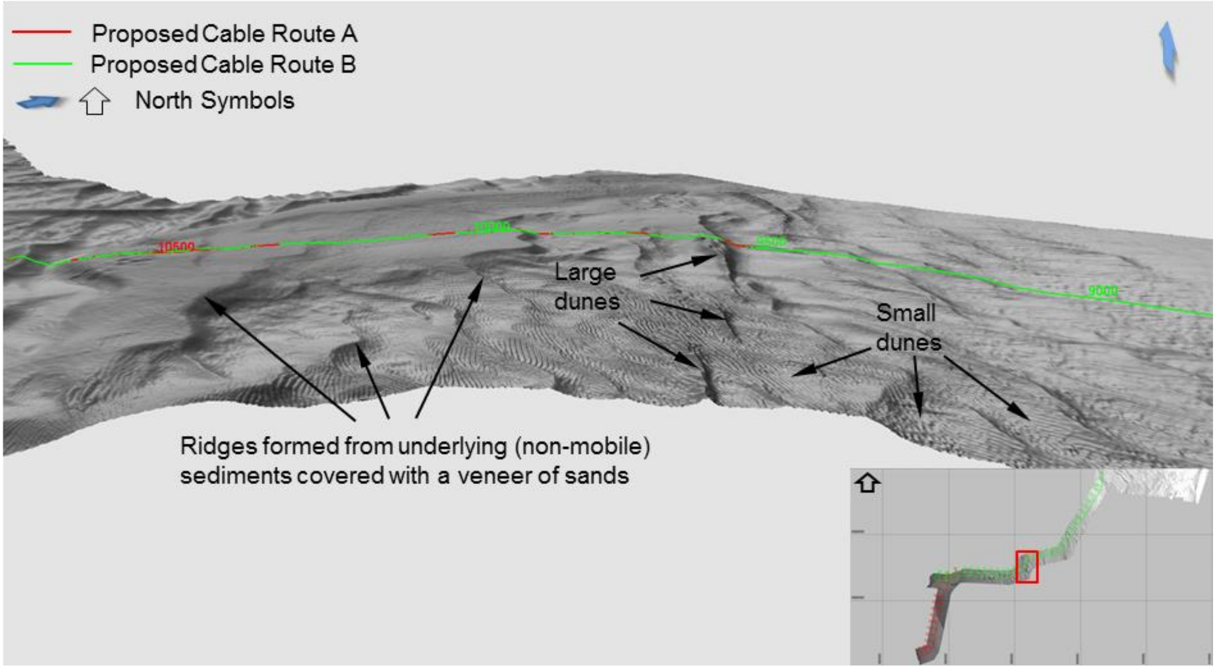


Figure 2.8: 3D view indicating sand dunes superposed on sediment ridges between KP 9.5 and KP 10.5 (Route A and Route B)

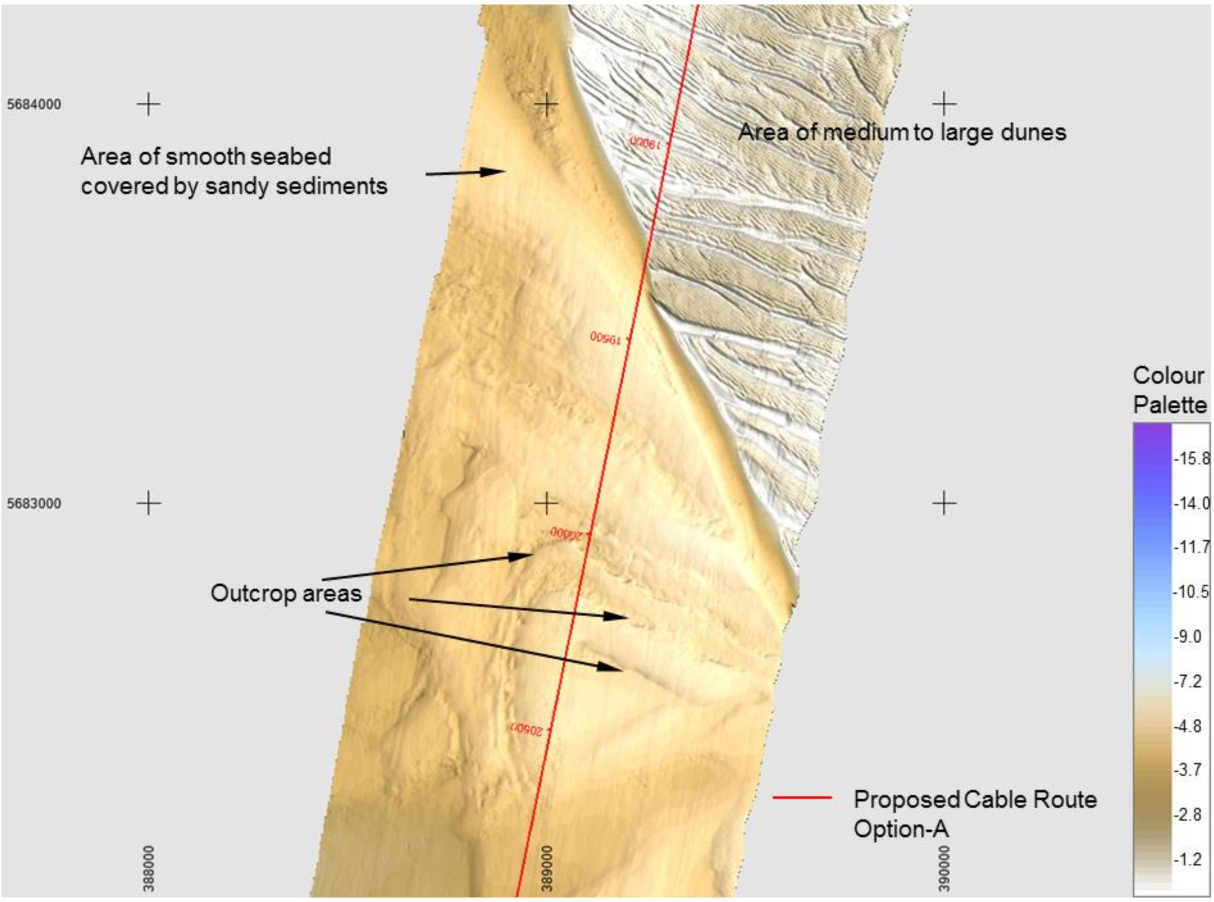


Figure 2.9: Seabed morphology between KP 19.0 and KP 20.0 (Route A)

2.6 Other Contacts

Within the export cable route corridor 395 SSS contacts were digitised, with heights ranging from 0.0 m (no measurable height) up to 4.2 m (shipwreck). (The highest non-wreck contact was 1.6 m). These targets were categorised according to feature class and certainty. The majority of the targets (32) were identified as boulders (minimum height of 1.0 m). The complete list of contacts can be found in the GIS deliverables. The contacts are plotted on the **alignment charts** in Appendix A.

A total of 5144 magnetometer contacts were detected within the export cable route corridor. These magnetic anomalies range in magnitude between 5.0 nT/m and 18,000 nT/m.

The magnetic data were also assessed to see if any geological information could be extracted from the dataset.

Where interpretation of the contacts was possible this information was correlated within the GIS database. The locations are plotted on the **Seabed Features and Sediments panel** of the alignment charts in Appendix A. A summary of the observed contacts is presented in Table 2.8.

Table 2.8: Summary table of SSS and magnetometer contacts

<table>
<tr><th>Sensor</th><th>Target Classification</th><th>No. Targets</th></tr>
<tr><td rowspan="6">SSS</td><td>Suspected debris</td><td>353</td></tr>
<tr><td>Wrecks</td><td>3</td></tr>
<tr><td>Boulder</td><td>32</td></tr>
<tr><td>Depression</td><td>16</td></tr>
<tr><td>Fish traps</td><td>3</td></tr>
<tr><td>Possible boulder/outcrop</td><td>42</td></tr>
</table>

<table>
<tr><th>Sensor</th><th colspan="2">Target Classification</th><th>No. Targets</th></tr>
<tr><td rowspan="7">MAG</td><td colspan="2">Unknown</td><td>3379</td></tr>
<tr><td rowspan="4">Cables</td><td>Thanet Export Cable North</td><td>1224</td></tr>
<tr><td>Thanet Export Cable South</td><td>531</td></tr>
<tr><td>Tangerine</td><td>8</td></tr>
<tr><td>Pan European Crossing</td><td>2</td></tr>
<tr><td colspan="2">Wrecks</td><td>42</td></tr>
<tr><td colspan="2">Unknown linear contact</td><td>3</td></tr>
</table>

2.7 Regional Geology

The survey area is located in the southern North Sea, offshore United Kingdom. The area is situated on the London-Brabant massif that formed a structural high in Palaeozoic times.

During the Triassic the southern North Sea was dominated by rifting processes, forming a sedimentary basin as a set of narrow rifts and grabens formed, causing subsidence of the Variscan topography. The rifting process can also be related to the opening of the Atlantic Ocean.

In the late Jurassic, widespread subsidence allowed a shallow marine sediment depositional environment across the southern North Sea, this process continued in the Early Cretaceous. Around the Early Cretaceous, lithospheric extension and localised rifting ceased, however, it was replaced by thermal subsidence and gentle regional crustal downwarping. Towards the end of the Early Cretaceous the area where the survey area is located is characterised by deltaic, coastal and shallow marine clastics. During the Late Cretaceous a major eustatic sea-level rise caused a maximum sea level rise of 100 m – 200 m above the current level and flooded the whole of the European area. This caused a decrease in the supply of terrigenous material but allowed extensive deposition of pure calcareous chalk on the continental shelves. A post-rift sag phase from Late Cretaceous to Present was mainly characterised by subsidence and a quiet tectonic environment in the North Sea basin. However, during the Late Cretaceous and Tertiary a few compressional tectonic pulses occurred in the southern North Sea basin. A last significant pulse during the Mid-Miocene caused a major unconformity within the basin (Figure 2.10).

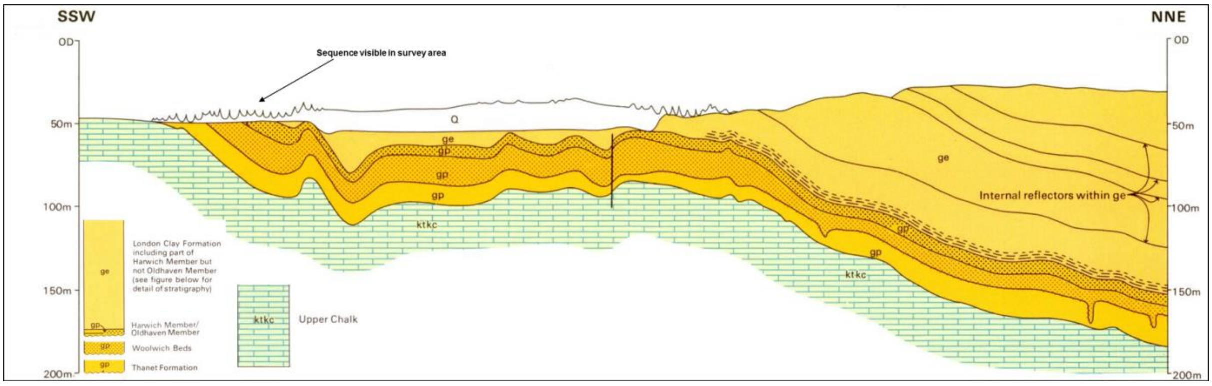


Figure 2.10: Cross section showing the Late Cretaceous to Quaternary sediments, 5 km from the survey area (modified from ref. 8)

Within the Tertiary, sedimentation is dominated by marine-shelf and marginal marine depositions as a result of a succession of transgressive cycles mainly due to eustatic sea level changes. Therefore Tertiary sediments contain regional unconformities. During the Paleocene, a shallow marine environment was present in the area where the proposed wind farm location is planned, resulting in the deposition of mudstones, fine grained (decalcified glauconitic) sands or muddy sands. Neogene sediments are in general absent due to a non-depositional environment and erosional processes. However, in some areas in the North Sea basin a period of regression preceded a renewed transgression period in the latter stages of the Miocene and the earliest period in the Pliocene. During the Quaternary, deltaic systems developed in a north-west direction from continental Europe, resulting in the deposition of shallow-water and deltaic sediments. During this period, the North Sea basin has been subject to several sea level fluctuations and associated glacial and inter-glacial periods (Figure 2.11). During the interglacial periods the deposited sediments eroded and channels formed.

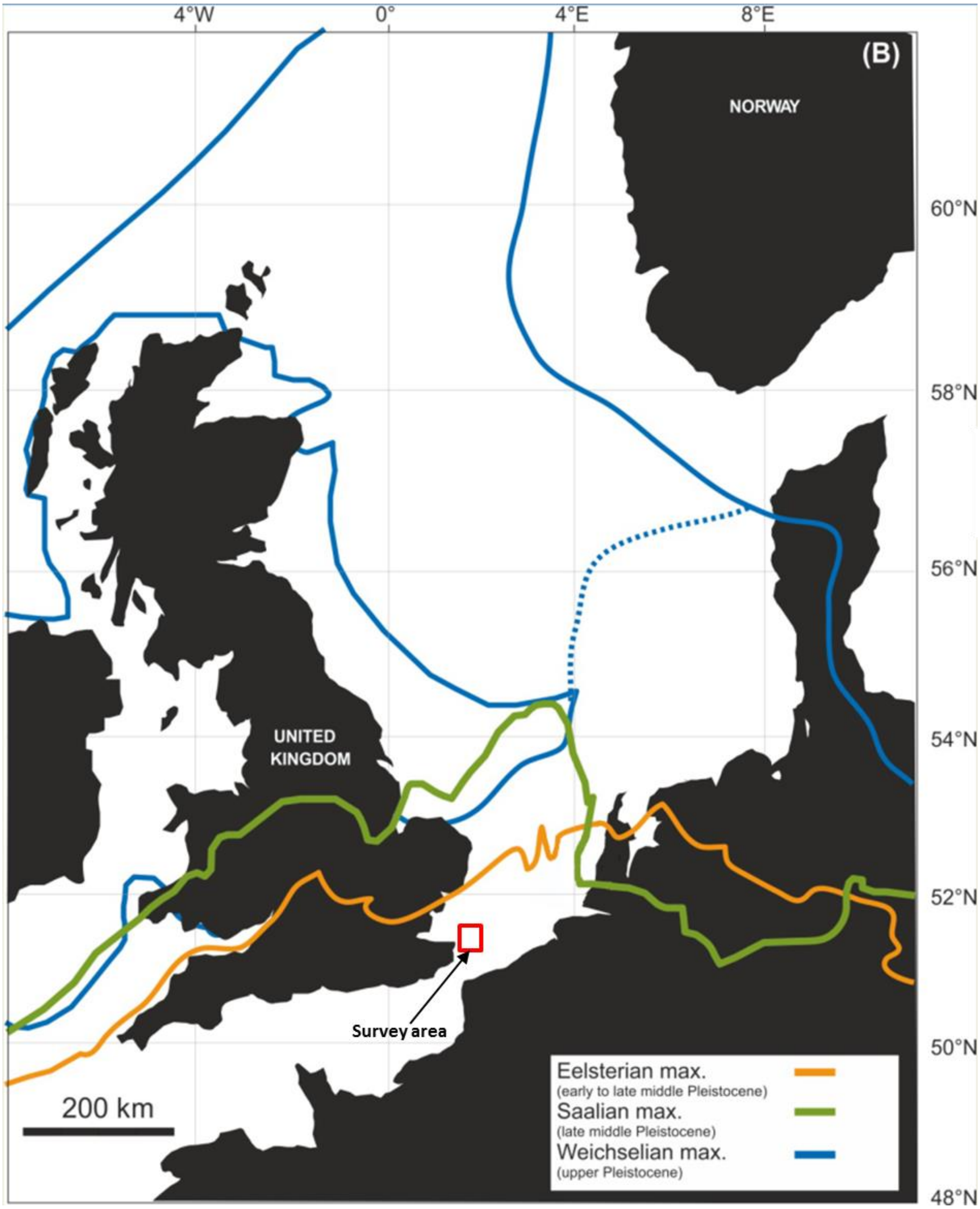


Figure 2.11: Overview of the glacial extents in the North Sea Basin during the Holocene (modified from ref. 9)

2.8 Local Geology

2.8.1 Overview

The geological interpretation was based on sub-bottom profiler data. Geotechnical data were available at the time of issue of this report (ref. 10), and included seabed cone penetration test (CPT) and vibrocore sampling performed from MV Bucentaur from 12 September to 16 September 2016.

This section should be read in conjunction with **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

Sub-bottom profiler data quality was considered moderate. The limit of penetration reached with the sub-bottom profiler (or limit of useful acoustic penetration) was typically only up to 5 m within the export cable route corridor, with the exception of an area where sand banks and dipping sediments were observed.

Prior the start of the analyses of the acquired data, data interpretations (e.g. seafloor conditions, site use and seismostratigraphy) given in previous available studies was considered. Soil strata identified during the geotechnical data interpretation were correlated with the seismo stratigraphic unit boundaries guiding definition of soil units. Where possible, the picked seismic surfaces were extended and updated.

Subsequently geological formations (and members) were identified using a combination of geological, geotechnical and geophysical data and published lithostratigraphy for the Quaternary of the Dutch Sector of the North Sea Basin;

Soil units were lastly characterised in view of their geotechnical parameter values (i.e. parameters relevant to the geological ground model) and spatial variation.

A seismo-stratigraphic model was derived to interpret the seismic data across the Thanet Extension wind farm site and the export cable route. This stratigraphy is based on published geological studies (Ref. 11 and Ref. 12).

Seismic descriptions and characteristics of the units along the export cable routes were interpreted in association with the Thanet Extension site survey area. The Quaternary geology within the cable corridor down to the limit of interpretation of 10 m bsb has been sub-divided into three (3) seismic Units (Units A, D and E). A detailed description of the interpreted seismic units is presented in Section 2.8.2 and Table 2.9.

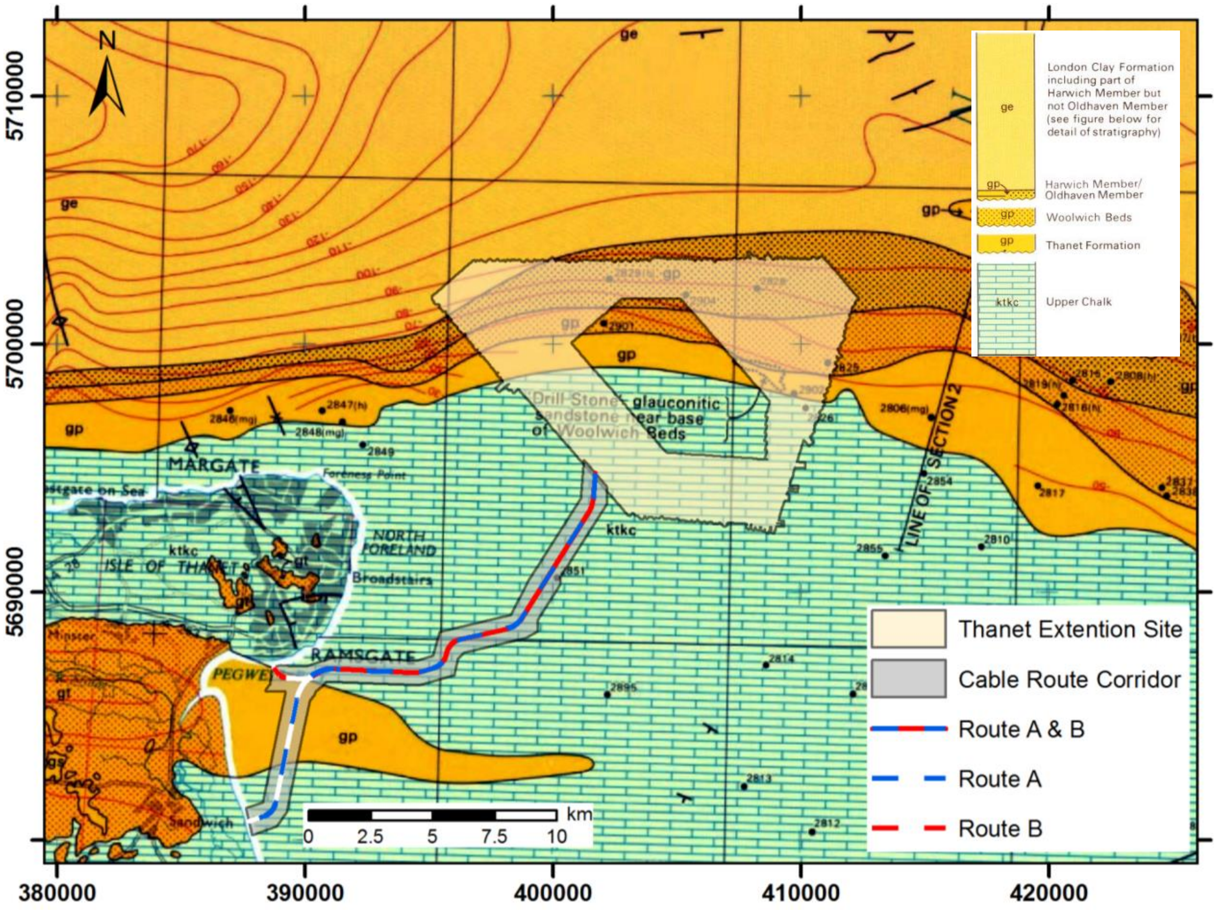


Figure 2.12: Survey area superimposed on geological chart (modified from ref. 8)

Table 2.9: Overview of the interpreted seismic units

Seismic Units	Reflectors		Base of Unit min/max depth in m bLAT (1)	Base of Unit min/max depth in m below seabed (1)	Geometry of the base of the Unit	Unit seismic signature	Amplitude distribution within the Unit	Continuity of internal reflectors	Geometry of Unit	Indicative lithology (2)	Depositional environment	Formation	Age
	Top	Base											
A	Seabed	H01	22.9 / 30.4	1.4 / 7.8	Erosional surface	Discontinuous internal reflectors	Variable from low to medium	Low	Controlled at the upper boundary by sand dune morphology	Coarse SAND, with shells and shell fragments, rare SILT and CLAY laminae and rare GRAVEL	Marine	Southern Bight	Holocene
D	H09	H10	19 / 91	1 / 74	Smooth to slight undulated	Parallel to sub-parallel internal reflectors	Medium to high	Medium to high	Sheet-like	Glauconitic sands, silts and silty clay with basal flint conglomerate	Shallow-marine	Thanet Formation	Palaeocene
E	H10	H20	84 / 185	67 / 164	Erosional Surface	Parallel to sub-parallel internal reflectors	Low to medium	Low to high	Sheet-like	White Chalk with flint and gravels/ cobbles	Marine	Upper Chalk	Late Cretaceous

Notes:
The seismo stratigraphy presented has been derived from Ref. 8.

2.8.2 Local Stratigraphy

UNIT A (Seabed to Horizon H01 - Southern Bight Fm - Holocene)

The geological profile of the base of Unit A is presented in the Longitudinal Profile Panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

Unit A (Holocene in age) is observed occasionally along the export cable route corridor. By correlation with the seabed sampling, the uppermost unit is interpreted to comprise very loose clayey fine to coarse GRAVEL of various lithologies. The internal structure of Unit A is characterised by discontinuous reflectors with low to medium amplitude. Very often this unit forms a veneer of sediments that cannot be resolved within the SBP data.

The base of Unit A(Horizon H01) is predominantly an uneven sub-horizontal surface, and is interpreted to be currently mobile, accumulating to form the different bedforms at the seafloor.

The depth to the base of Unit A ranges between 0.0 m bLAT and 12.7 m bLAT (0.0 m to 3.4 m bsb).

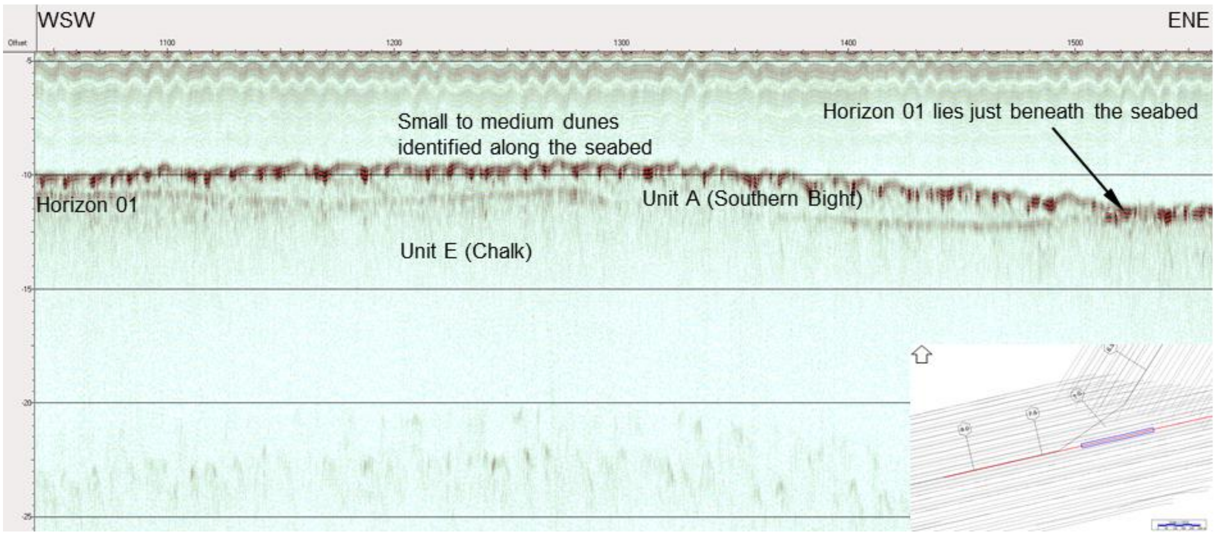


Figure 2.13: SBP data example illustrating sub-seabed geology near KP 7.0 (Route A and Route B) (Depth in meters below LAT)

UNIT D (H01 to H10 – Thanet Formation – Palaeocene)

The geological profile of the base of Unit D is presented in the Longitudinal Profile Panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

Based on UHR seismic data acquired within the Thanet Extension site, Unit D is generally characterised by moderate to good continuity, parallel to sub-parallel internal reflectors with moderate to strong amplitude reflections. However, within the export cable corridor, internal reflectors of this unit were not clearly defined. This unit was interpreted as belonging to the Thanet Formation, deposited in a shallow marine environment, and was identified between KP 16.5 and KP 20.0 (Route A). Between KP 16.8 and KP 17.5 (Route B) this unit gradually increases in thickness, from a pinch-out point at

KP 16.8 to more extensive deposits towards the south-west and KP 17.5. Within these areas, the Thanet Formation is interpreted to be part of a Palaeocene sediment-filled syncline that extends broadly across to the west (Ref. 8). Based on the stratigraphic description in Ref. 2, Unit D could contain glauconitic sands, silts and silty clay with basal flint conglomerate.

The base of Unit D (Horizon H10) is characterised by a strong amplitude good continuity reflector, which has been interpreted as a bedding plane possibly representing an angular unconformity. In some areas, the horizon could not be mapped due to pinching out at the seabed (not resolvable) or being beyond the limit of acoustic penetration. The depth to the base of Unit D ranges from0.0 m bLAT (0.0 m bsb) to beyond the limit of useful acoustic penetration.

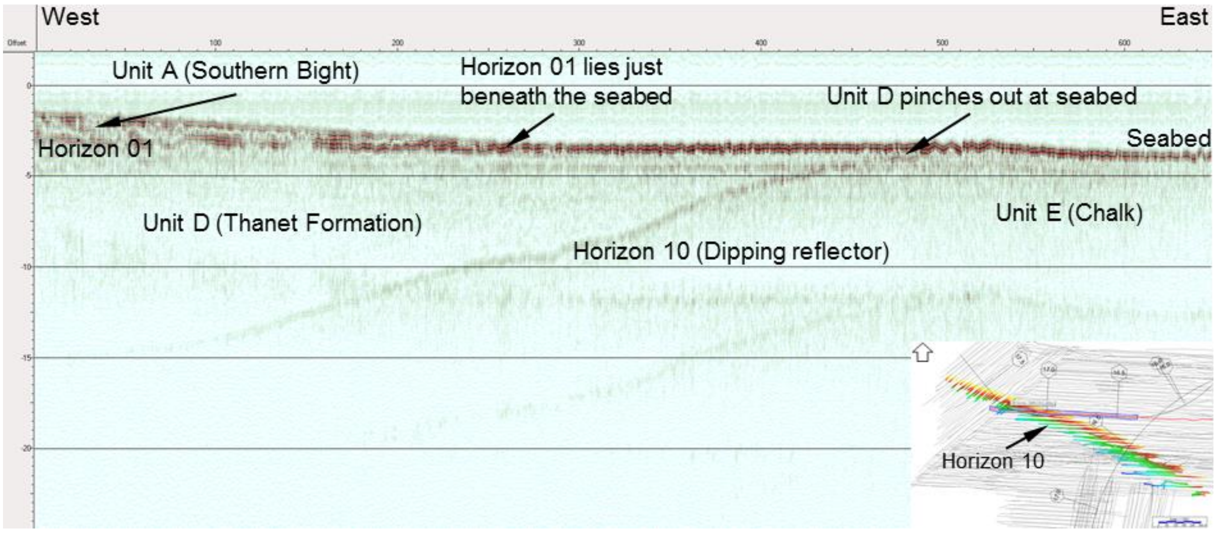


Figure 2.14: SBP data example illustrating Unit D pinching out at the seabed near KP 16.8 (Depth in meters below LAT)

UNIT E (H10 to H20 – Upper CHALK Formation - Upper Cretaceous)

The geological profile of the base of Unit E is presented in the Longitudinal Profile Panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

Unit E is generally characterised by poor to good continuity, parallel to sub-parallel internal reflectors with low to moderate amplitude reflections. The reflectors within this unit are mostly masked by the presence of seabed and peg leg multiples. This unit was interpreted as belonging to the Upper CHALK Formation, deposited in a marine environment. Based on the acquired geotechnical soil samples and the stratigraphic description in Ref. 8, this unit should contain white CHALK with flint and gravels / cobbles.

The base of Unit E is beyond of the limit of sub-bottom profiler penetration.

2.9 Installation Constraints

This section summarises the potential seabed hazards and subsurface geohazards to engineering work identified in the geophysical data across the Thanet Extension export cable route corridor. The results are presented in the Seabed Features and Sediments panel of **Alignment Charts GE051_Route-Opt-A and GE051_Route-Opt-B** in Appendix A.

The following main geohazards were identified:

- **Existing infrastructure, cables, pipelines and wrecks:**
  - **Cables:** Five (5) cables were observed in the export cable route corridor.
  - **Wrecks:** Three (3) wrecks were observed in the export cable route corridor.

- **Seabed hazards:**
  - **Sand dunes**: Very large sand dunes (mobile sands) migrating at a rate of approximately 2-4 m/year in a NE direction, with lee side gradients up to 35 degrees.
  - **Other contacts:** numerous suspected debris and unknown magnetometer contacts were observed throughout the export cable corridor.

- **Sub-seabed geohazards**
  - **Coarse sediments / GRAVEL layers / Boulders / Outcrops:** Patches of hard / GRAVEL layers were identified throughout the majority of the export cable route corridor.

3. DATA REDUCTION AND PROCESSING

3.1 Positioning and Navigation

Navigation, motion and GNSS tide data processing was undertaken at the Fugro office in Portchester, UK, using POSPac MMS software; version 6.2.

Raw POS data was imported into POSPac MMS and a post-processed kinematic method was used which utilised multiple Ordnance Survey RINEX base station data and IGS precise ephemeris and clock corrections. On the completion of processing an inertially aided GNSS position track, named a Smoothed Best Estimate Trajectory (SBET), was created.

The data were processed using offsets from the vessel datum for all sensors. Equipment offsets from the CRP position are presented in the **Operation and Calibrations Report** (Report GE051-R1 Volume 1).

3.2 Multibeam Echo Sounder

3.2.1 Bathymetry Processing Workflow

Multibeam processing was undertaken at the Fugro office in Portchester, UK, using QPS QINSy software (version 8.14.1) and QPS Fledermaus (version 7.7.0).

Multibeam data were recorded in QINSy DTM files online and were imported into QPS Processing Manager. The data was then reduced to LAT by applying the processed SBET track exported from POSPac MMS software.

Vertical misalignment between adjacent lines and sound velocity refraction errors were identified from a bathymetry standard deviation surface and corrected in QPS Qloud. Data point cleaning was then conducted in Fledermaus processing suite using the CUBE algorithm, which uses site specific parameters to ensure no valid data are removed. (noise is flagged only and remains within the raw data set). The bathymetry was gridded at the specified 0.25 m bin size and a further quality control was carried out against the specification before finally being signed off using the Fugro validation form.

3.3 Backscatter Data

Multibeam backscatter data collected by the MBES onboard the R.V. Fugro Discovery and Valkyrie was processed using QPS Fledermaus Geocoder. Backscatter processing was divided based on the data collected from each vessel.

A correction of -3 dB has been applied along the export cable route corridor to compensate for the decibel offset introduced by enabling the Dual Swath functionality of the Kongsberg EM2040 (see Figure 3.1).

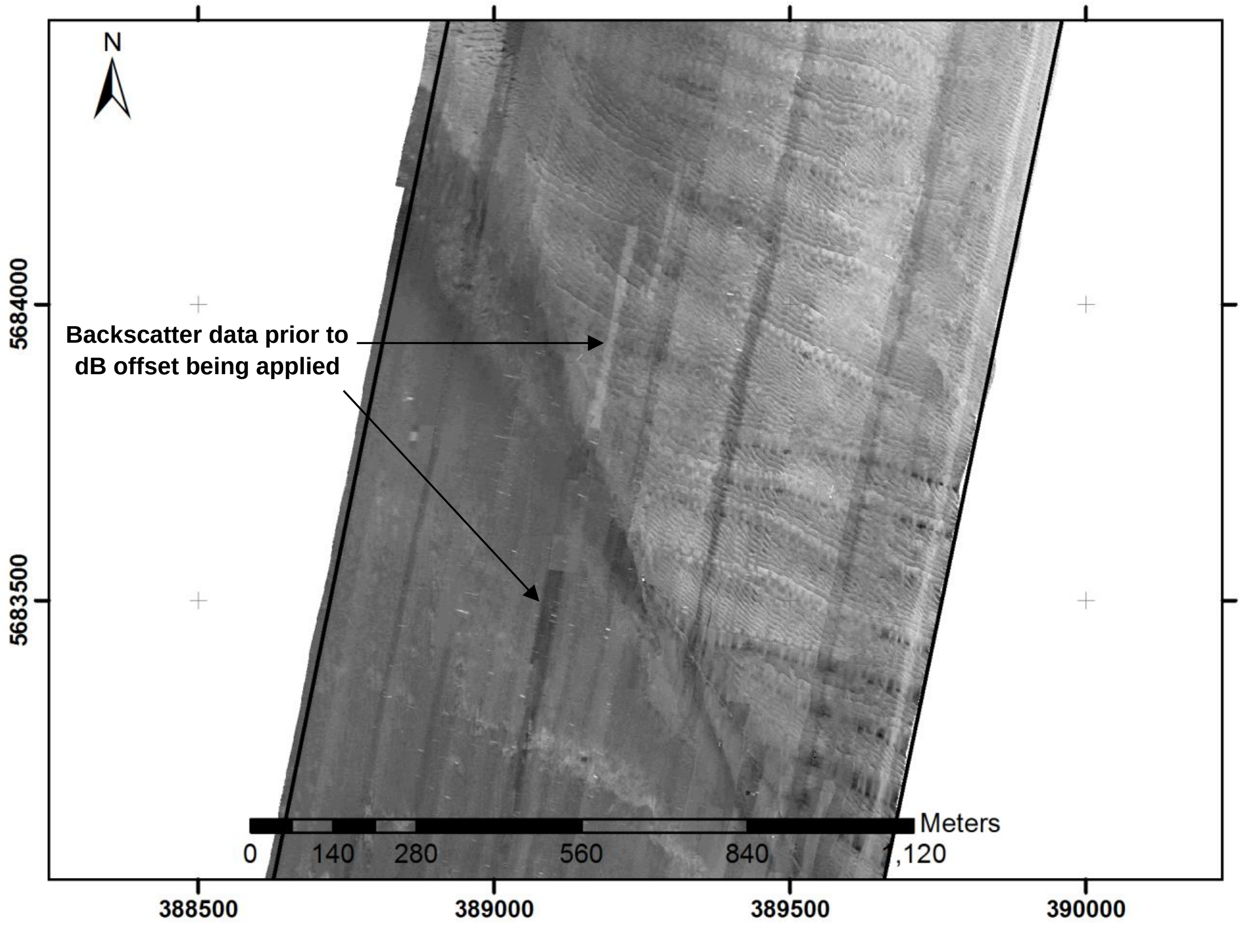


Figure 3.1: Backscatter data showing requirement for dB offsets

3.4 Sidescan Sonar

Data were recorded in digital format (.xtf) using the Geosuite and CODA software. The records were corrected for slant-range distortion before interpretation.

The *.xtf files were imported into Chesapeake SonarWiz software, where a full quality control of each line was carried out. At the same time, data were analysed and checked for discrete sonar contacts, and the positions were compared with MBES data.

The SSS mosaic (GeoTiff file) was created within SonarWiz using high and low frequency data with a cell size of 0.5 m x 0.5 m.

Each SSS contact was checked for positioning against MBES data.

3.5 Magnetometer

Data processing was undertaken at the Fugro offices in Portchester, UK, using the software Oasis Montaj; version 9.0 enabled with UXO Marine.

The magnetometer data were imported from raw text files (interpolator .INT format) into an Oasis Montaj database. Following import, the data were checked for noise spikes, quality and positioning.

Any rejected lines were removed from the project and marked down to be rerun or infilled where appropriate.

The data were filtered to reduce the data to a residual value. During the filtering process, Fugro EMU utilised a ß-Spline filter to remove small amplitude high frequency noise from the data. This noise is usually related to momentary loss of signal or small changes in the tow fish orientation as it is pulled behind the vessel.

A series of non-linear filters of reducing width and tolerance were then applied to fit a curve to the longer wavelength (diurnal, heading and geological) anomalies. The non-linear filters locate and remove data that falls outside user defined limits of the filter width (in number of samples) and filter tolerance (or amplitude, in nanoTesla). The filtered curve was subtracted from the magnetic total field data to calculate the residual value.

The navigation data was despiked and smoothing using a 300 mean rolling window filter. Altitude data were despiked and cleaned where required.

The data were gridded using the minimum curvature gridding method to generate a smooth surface while attempting to honour source data as closely as possible. The residual data were gridded and subsequently X, Y and Z derivative grids were calculated in order to create the analytic signal grid. The analytic signal grid is the square root of the sum of the squares of the individual derivative grids and provides the magnetic gradient in nanoTesla per metre (nT/m). Fugro EMU used a grid cell size of 0.5 m and a blanking distance of 4.0 m.

Targets were selected from the analytic signal grid using the Blakely Test; a grid peak finding algorithm. For high resolution UXO surveys, Fugro EMU use a Level 4 peak detection which requires grid values in all of the nearest grid cells to be lower for a target to be selected.

A smoothing (Hanning) filter was applied to the grid before target selection to minimise the number of multiple targets picked on single anomalies. A grid value cut-off of 5 nT/m was used for target selection to ensure all anomalies above this limit were selected.

3.6 Sub-bottom Profiler

Data processing was undertaken at the Fugro office in Portchester, UK, using the software GeoSuite Allworks; version 2.6.

The quality of the sub-bottom profiler data was considered moderate due to poor weather conditions during the survey operation which limited the effectiveness of the post-processing algorithms applied to the seismic data.

Data were imported from raw SEGY format files. Following import, the data were checked for quality, penetration and resolution against the requirements of the project scope of work. A trackplot was produced for immediate navigation QC and to ensure coverage was achieved.

A bandpass filter was applied to remove noise from the data and improve the appearance of the data. Different bandpass filters were tested to ensure that the correct one is ultimately used. A Time-Varying Gain (TVG) and/or AGC was applied to improve the appearance and interpretability of reflectors.

Heave and tidal corrections were applied to the data to reduce the data to LAT. In intertidal areas, a ten second shift was applied to the SEGY trace to ensure that areas above LAT were not cut-off. The tidal data was logged in real-time onboard the vessel and applied in GeoSuite Allworks using a date/time synchronised text file

3.7 Data Interpretation

3.7.1 Bathymetry Data Interpretation

Bedform zonation was performed in ArcGIS (v10.3.1) software and the DTM file (cell size 0.25 m x 0.25 m) was used as basis for the interpretation. A bedform zonation map was derived from a manual demarcation of homogeneous areas in terms of sand dune shape, wavelength and crest line orientation. The bedform zonation was exported in GeoTiff,.dwg format and .shp file.

3.7.2 Sidescan Sonar Data Interpretation

SSS records were examined both for significant targets and for the general level of backscatter from the seabed. The contacts detection on the SSS data files was done using the SonarWiz software with the SSS waterfall visualisation for optimal resolution. Targets with dimensions above 1.0 m were picked. Smaller target size where also picked where the resolution of the data was sufficient. Where objects were detected their geographic location was logged, together with the length, width, height and identification.

The level of confidence achieved for target picking is generally good for the high frequency SSS data. Due to adverse sea state conditions in combination with shallow water depths, noise was observed towards the limit of the SSS range on the high frequency data. The confidence level of the target picking was good up to a range of 40 to 60 m. Beyond this range, a lower confidence level was achieved. However, considering the significant overlap and coverage achieved, and the additional use of the low frequency SSS data, the confidence level for the central 10 m corridor between the main survey lines is moderate. Each SSS contact was checked for positioning against MBES data.

3.7.3 Magnetometer Data Interpretation

All the magnetic targets were picked using Oasis Montaj (v8.5).

Magnetometer targets were automatically picked on the analytic signal gridded data using a threshold of 5 nT/m for the magnetic anomalies. Resulting targets were individually reviewed to assess the veracity of the Oasis Montaj algorithm. During this review artefacts were manually deleted from the target database.

Besides individual magnetic objects, the majority of the cables and pipelines from the database present in the survey area were identified by the magnetometer data.

All as-found magnetic anomalies were cross-referenced with the SSS and MBES data.

4. REFERENCES

Reference 1: Ashley et al. (1990). Classification of large-scale subacqueous bedforms: A new look at an old problem. Journal of Sedimentary Petrology, vol. 60, No. 1, January, 1990, pp. 160-172

Reference 2: Németh et al. (2002). Modelling sand wave migration in shallow shelf seas. Continental Shef Research, vol. 22, pp. 2795 - 2806

Reference 3: Tonnon et al. (2006). The morphodynamic modelling oftidal sand waves on the shoreface. Coastal Engineering, vol. 54, pp. 279 – 296

Reference 4: Stow et al. (2009). Bedform-velocity matrix: The estimation of bottom current velocity from bedform observations. Geology, vol. 37, pp. 327 – 330

Reference 5: Pearce et al (2014). Repeated mapping of reefs contructed by *Sabellaria spinulosa* Leuckart 1849 at an offshore wind farm site. Continental Shelf Research, vol. 83, pp. 3 - 13

Reference 6: Presentation by Muffy Seiderer (2013): Balancing the provision of infrastructure enhancements against their enfironmental cost

Reference 7: http://mapgateway.findmaps.co.uk/wms/

Reference 8: Thames Estuary (Sheet 51N – 00) – British Geological Survey. 1:250 000

Reference 9: Alastair G.C. Graham, Martyn S. Stoker, Lidia Lonergan, Tom Bradwell, Margaret A.Stewart (2010) The Pleistocene Glaciations of the North Sea basin.

Reference 10: Geotechnical Report Field Operations and Results report. Thanet Extension Offshore Windfarm Geotechnical Site investigation 2016. Fugro Document No.: GE051/WPE-01(02)

Reference 11: Thanet Offshore Wind LTD. Post Construction Geophysical Surveys – Spring 2012. Gardline Project Ref. 9078. 2012

Reference 12: Thanet Offshore Wind LTD – Geophysical Survey – Final Report. Ref 4306r1. 2005

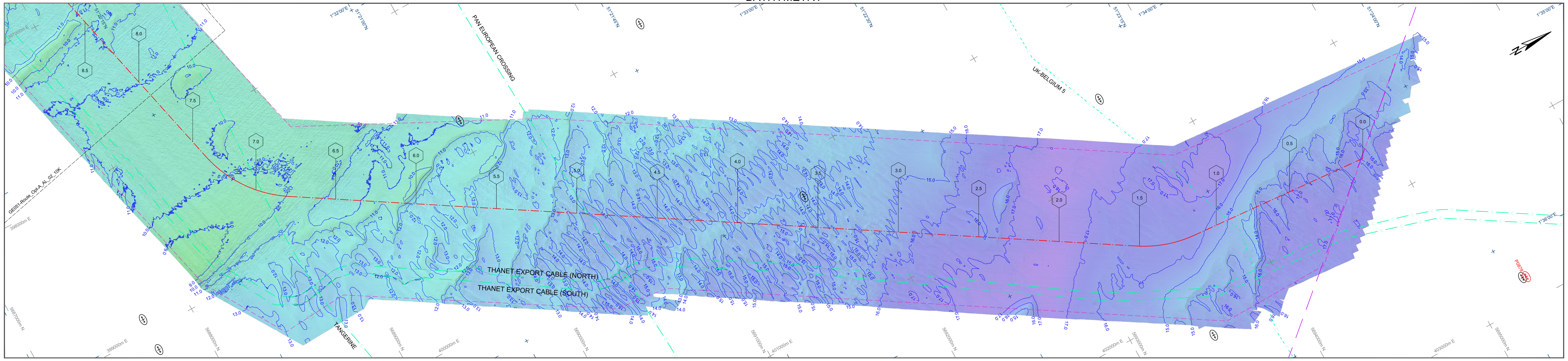
APPENDICES

A. ROUTE ALIGNMENT CHARTS

A. ROUTE ALIGNMENT CHARTS

Drawing	Chart Name	Scale	Enclosure
ALIGNMENT CHART			
Export Cable Route Option-A	GE051-Route_Opt-A_AL_01_10K	1 : 10,000	01
Export Cable Route Option-A	GE051-Route_Opt-A_AL_02_10K	1 : 10,000	02
Export Cable Route Option-A	GE051-Route_Opt-A_AL_03_10K	1 : 10,000	03
Export Cable Route Option-B	GE051-Route_Opt-B_AL_01_10K	1 : 10,000	04
Export Cable Route Option-B	GE051-Route_Opt-B_AL_02_10K	1 : 10,000	05

BATHYMETRY



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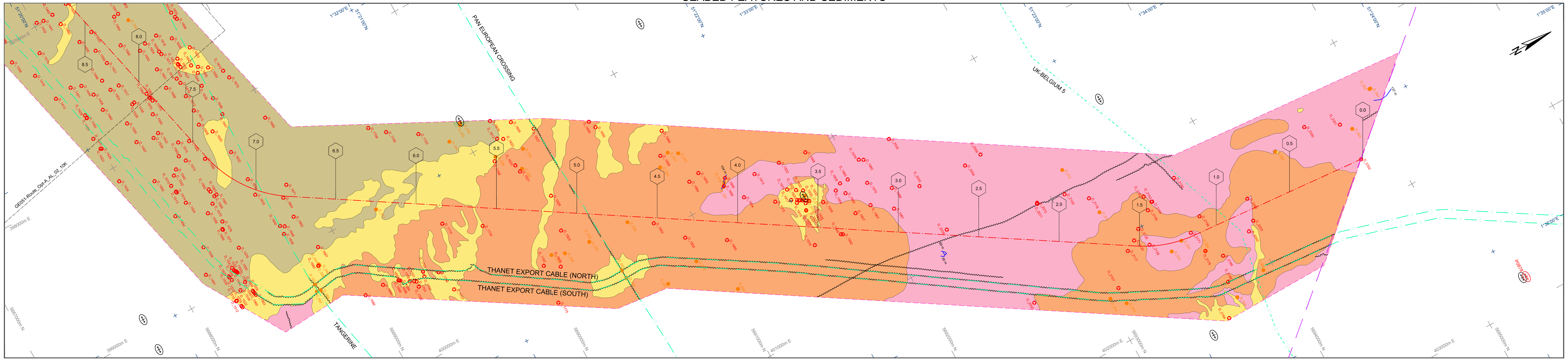
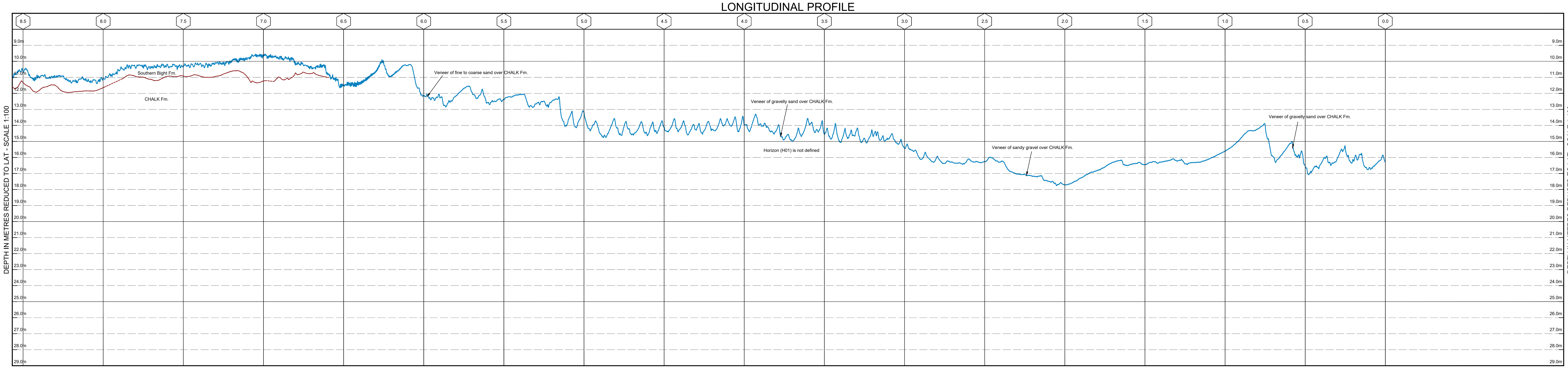


LONGITUDINAL PROFILE



ENGINEERING NOTES

LEGEND:

GENERAL

- U.T.M. GRID
- GEOGRAPHICAL GRID
- KILOMETRE POST
- PROPOSED CABLE ROUTE
- OTHER CABLE ROUTES
- PROPOSED ROUTE CORRIDOR
- CHART MATCHLINE
- WRECK (FROM ENC AND ADMIRALTY CHARTS)

DEPTH RANGE PALETTE:
(DEPTH IN METRES)
0, 5, 10, 15, 20

BATHYMETRY

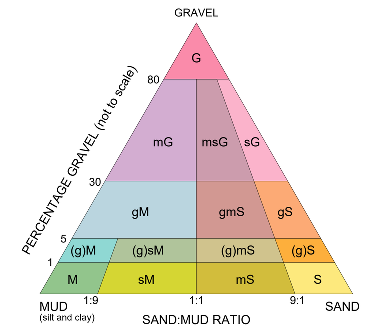
- DEPTH CONTOUR AT 1.0 METRE INTERVALS

SEABED FEATURES AND SEDIMENTS

- FINE TO COARSE SAND
- CLAYEY TO SILTY SAND
- GRAVELLY SAND
- SANDY GRAVEL
- OUTCROP
- D_123 MAGNETOMETER CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- V_567 SIDESCAN SONAR CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- AS-FOUND CABLE / UNKNOWN LINEAR DEBRIS
- l x w x d DEPRESSION WITH DIMENSIONS IN METRES (nmd = NON MEASURABLE DEPTH)
- P123 AS-FOUND WRECK WITH SSS ID NUMBER (PREFIX OMITTED)
- 10 m LINEAR DEBRIS WITH LENGTH
- AREA OF MAGNETIC ANOMALY

LONGITUDINAL PROFILE

- SEABED PROFILE
- HORIZON H01
- INFERRED HORIZON H01
- HORIZON H10
- INFERRED HORIZON H10
- INTERNAL REFLECTOR



NOTES:

1) BATHYMETRY FROM KONGSBERG EM2040 AND RESON 7125 DUAL HEAD MULTIBEAM ECHO SOUNDER, PROCESSED WITH 0.25 m BIN SIZE.
2. WATER DEPTH REDUCED TO LAT USING ELLIPSOIDAL HEIGHT FROM STARPACK BEST SOLUTION AND THE VORF MODEL.
3) SEABED FEATURES INTERPRETATION BASED ON EDGETECH 4200FS (100 / 500 kHz DEEP SECTION, 300 / 600 kHz SHALLOW SECTION) SIDESCAN SONAR DATA, RECORDED AT 50 m AND 100 m SWATH.
4) SHALLOW GEOLOGY INTERPRETATION BASED ON POLE-MOUNTED MASSA TR-1075 PINGER ARRAY AND SOACSY SEACHIRP.
5) LONGITUDINAL PROFILE VERTICAL SCALE 1:100. DEPTH IN METRES.
6) SHALLOW GEOLOGICAL INTERPRETATION BASED ON ASSUMED ACOUSTIC VELOCITY IN SEDIMENTS OF 1600 m/s.
7) MAGNETIC ANOMALIES DERIVED FROM FUGRO EMU GEOWING FIXED WING GRADIOMETER SYSTEM AND GEOMETRIC MAGNETOMETER G-882 TOWED FROM TWO SEPARATE EIVA SCAN FISHES.
8) BACKGROUND INFORMATION IS EXTRACTED FROM ENC AND ADMIRALTY CHARTS.

GEODETIC PARAMETERS:

HORIZONTAL COORDINATE SYSTEM	
GEODETIC DATUM	European Terrestrial Reference System 1989
ELLIPSOID	GRS 1980
Semi-Major Axis	6,378,137.000
Inverse Flattening	298.257 222 101
PROJECTION	ETRS89 / UTM zone 31N
Central Meridian (CM)	03°00'00" E
Latitude of Origin	00°00'00" N
False Easting	500,000mE
False Northing	0mN
Scale Factor at CM	0.9996
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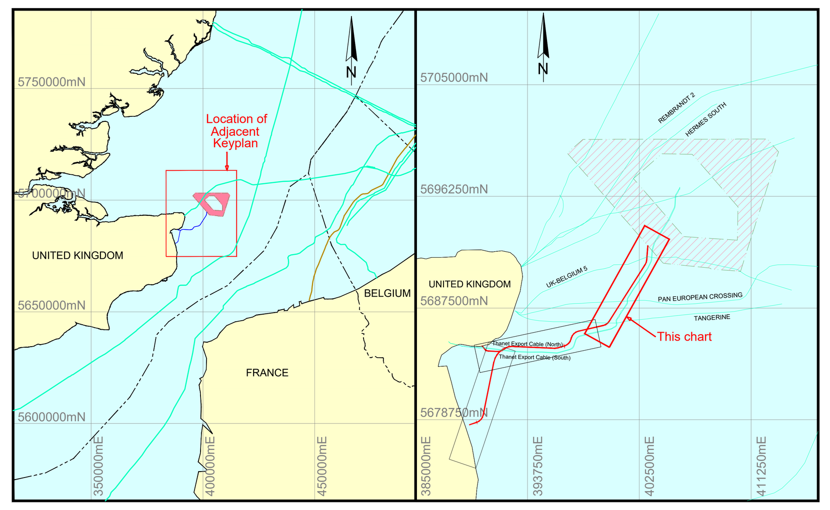
VERTICAL DATUM	LOWEST ASTRONOMICAL TIDE (LAT)



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GEOPHYSICAL ROUTE SURVEY
UK CONTINENTAL SHELF, NORTH SEA
EXPORT CABLE ROUTE OPTION - A
ALIGNMENT CHART
KP 0.000 - KP 8.567

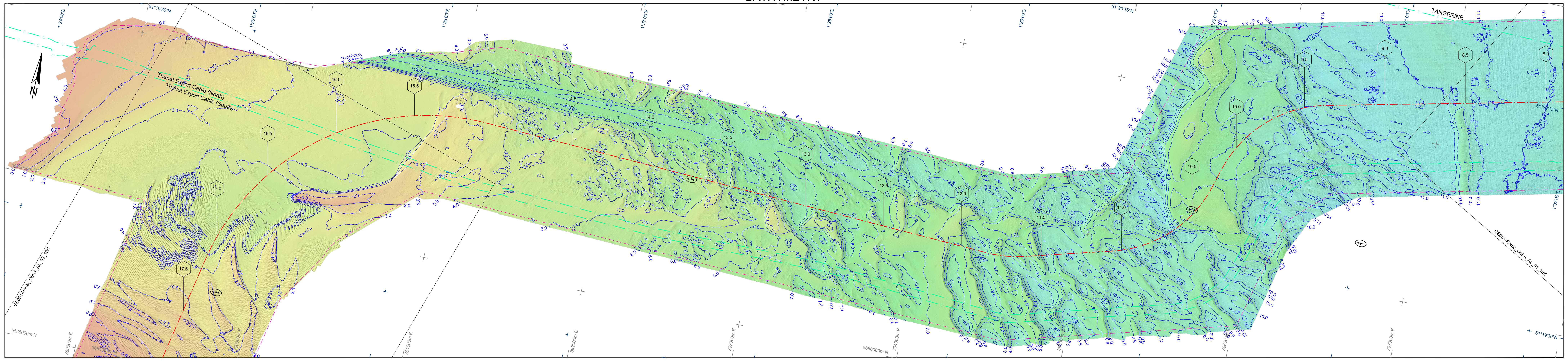
SCALE 1 : 10000 at A0

0 100 200 400 600 800 1000 metres
0 1000 2000 3000 feet

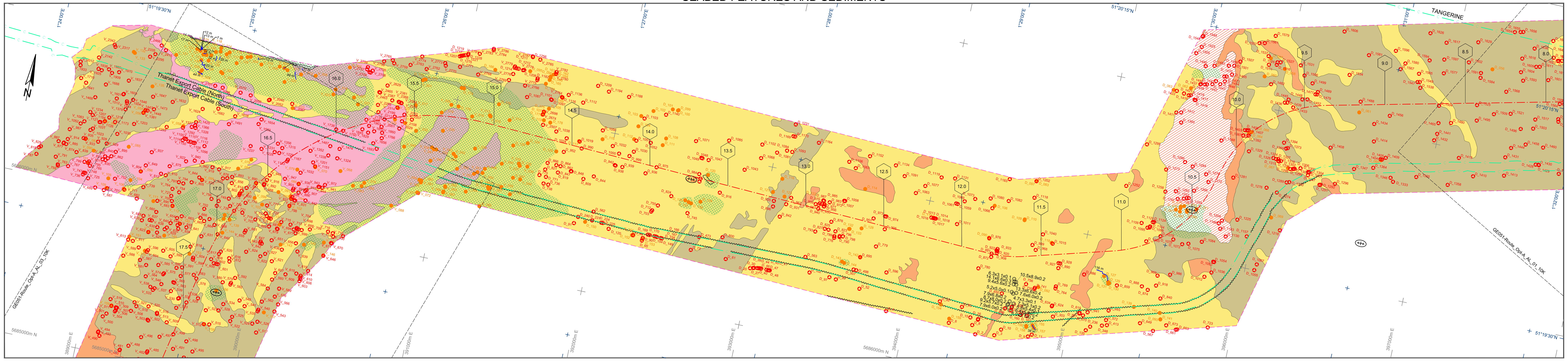
Vessel: RV DISCOVERY & VALKYRIE			Survey Date: JUL - SEPT 2016	Project Ref: GE051		
Issue No:	Date:	Description:	Interpr:	Drawn:	Chkd:	Appr:
1	28/11/2016	Issued for Approval	CM / MS	RB / AS	VMN	PPL
0	03/04/2017	Final Issue	CM / MS	RB / AS	VMN	PPL

Client Ref:	Drawing No:	Chart:	Encl:
-	GE051-Route_Opt-A_AL_01_10K	1 of 3	01

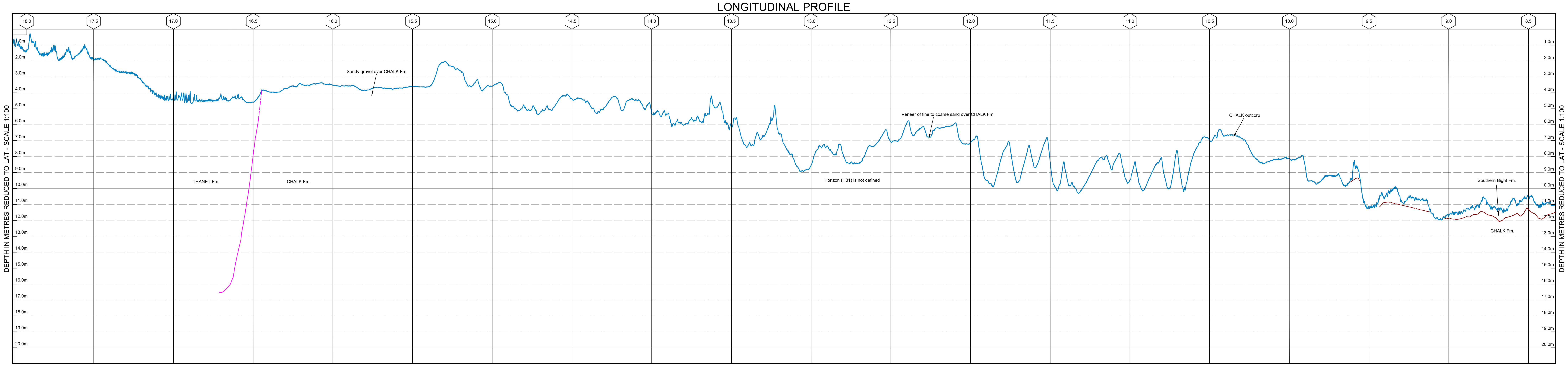
BATHYMETRY



SEABED FEATURES AND SEDIMENTS



LONGITUDINAL PROFILE



ENGINEERING NOTES

LEGEND:

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- PROPOSED CABLE ROUTE
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DEPTH RANGE PALETTE:
(DEPTH IN METRES)
0, 5, 10, 15, 20

BATHYMETRY

- DEPTH CONTOUR AT 1.0 METRE INTERVALS

SEABED FEATURES AND SEDIMENTS

- FINE TO COARSE SAND
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- GRAVELLY SAND
- SANDY GRAVEL
- OUTCROP
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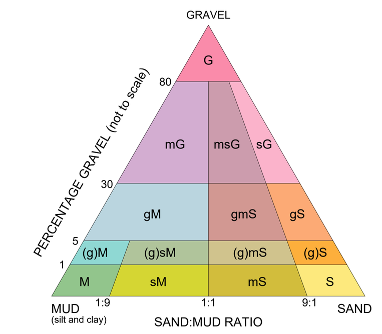

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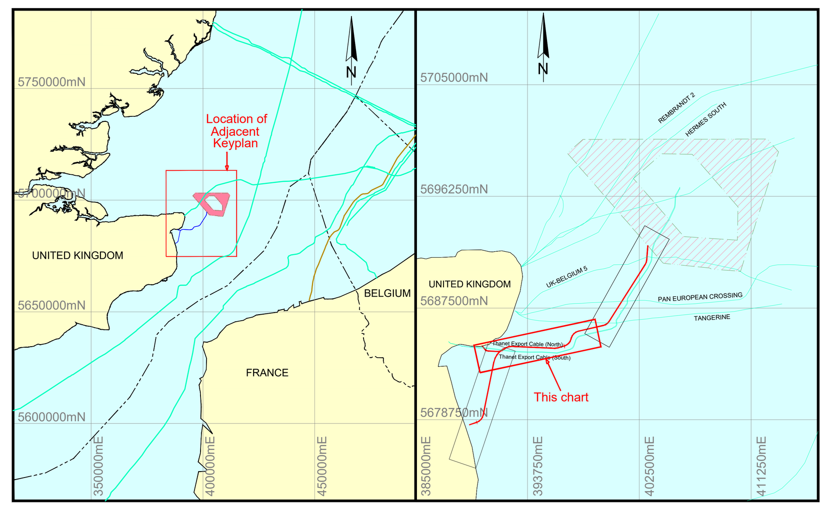
VERTICAL DATUM	LOWEST ASTRONOMICAL TIDE (LAT)



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GEOPHYSICAL ROUTE SURVEY
UK CONTINENTAL SHELF, NORTH SEA
EXPORT CABLE ROUTE OPTION - A
ALIGNMENT CHART
KP 8.330 - KP 18.010

SCALE 1 : 10000 at A0

0 100 200 400 600 800 1000 metres
0 1000 2000 3000 feet

Vessel: RV DISCOVERY & VALKYRIE | Survey Date: JUL - SEPT 2016 | Project Ref: GE051

Issue No:	Date:	Description:	Interpr:	Drawn:	Chkd:	Appr:
1	28/11/2016	Issued for Approval	CM / MS	RB / AS	VMN	PPL
0	03/04/2017	Final Issue	CM / MS	RB / AS	VMN	PPL

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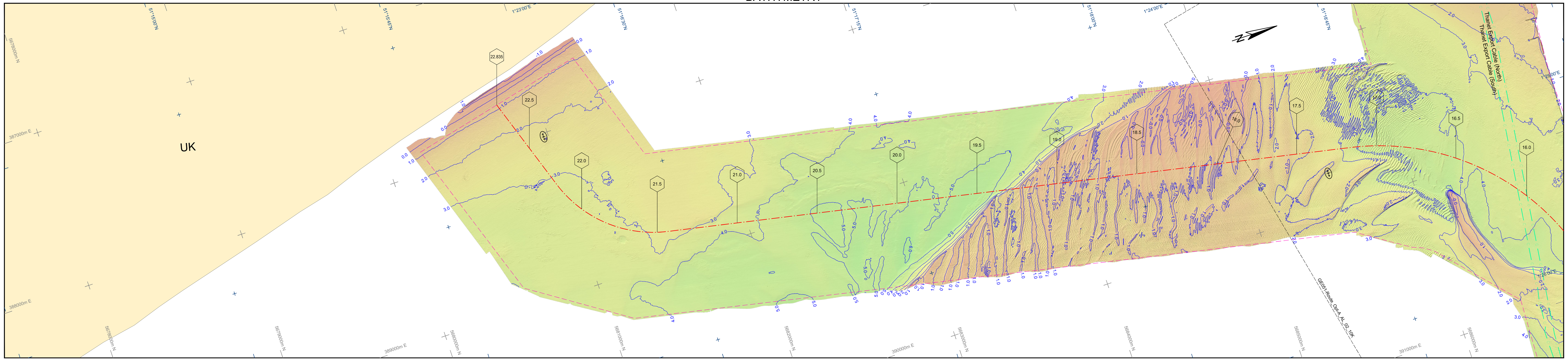
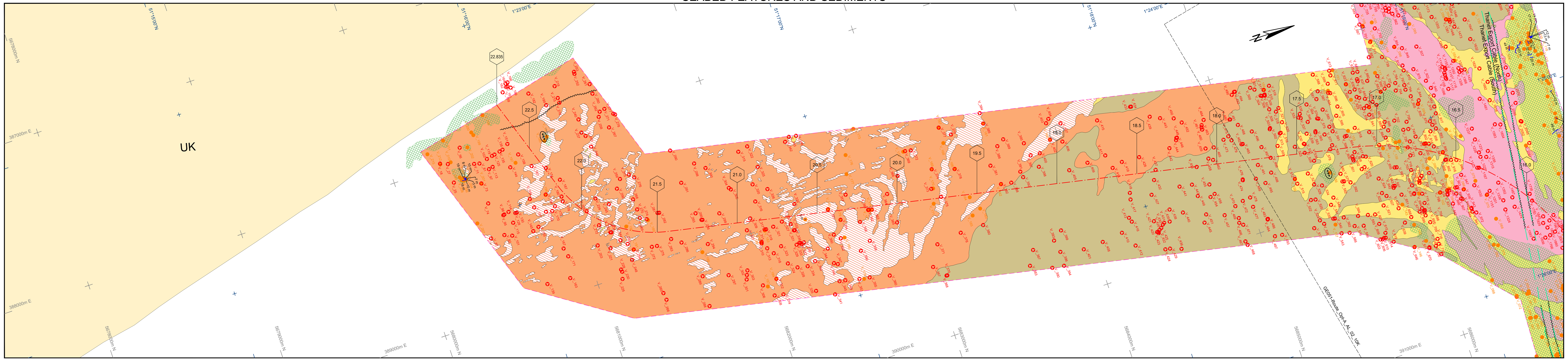
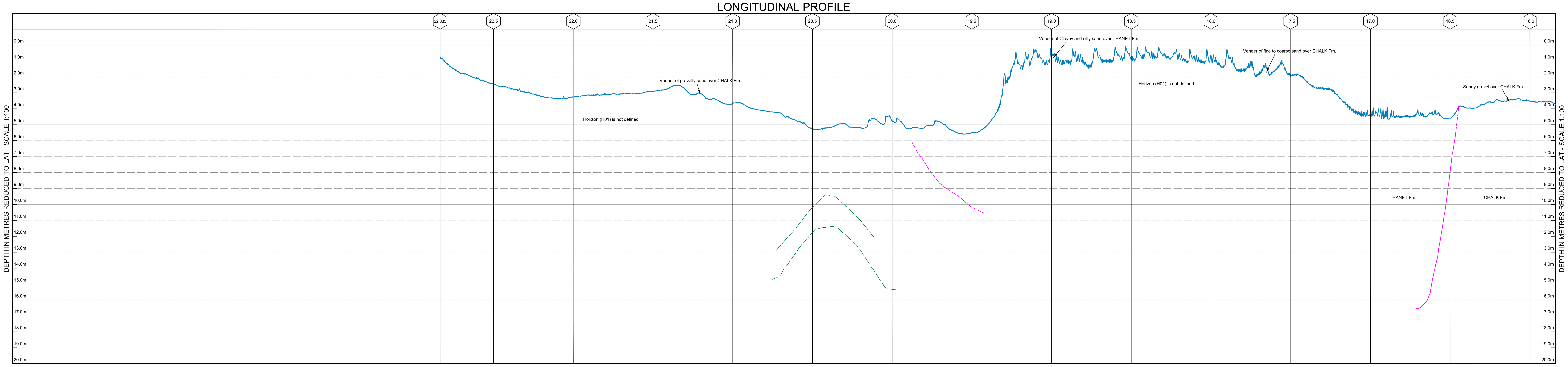
BATHYMETRY



SEABED FEATURES AND SEDIMENTS



LONGITUDINAL PROFILE



ENGINEERING NOTES

LEGEND:

GENERAL

- U.T.M. GRID
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- PROPOSED ROUTE CORRIDOR
- CHART MATCHLINE
- WRECK (FROM ENC AND ADMIRALTY CHARTS)

DEPTH RANGE PALETTE: (DEPTH IN METRES) 0, 5, 10, 15, 20

BATHYMETRY

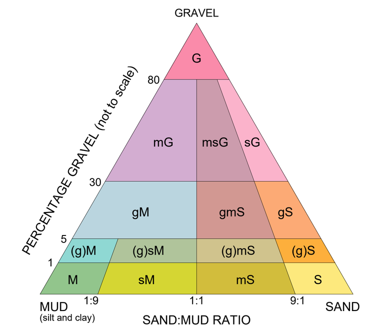
- DEPTH CONTOUR AT 1.0 METRE INTERVALS

SEABED FEATURES AND SEDIMENTS

- FINE TO COARSE SAND
- CLAYEY TO SILTY SAND
- GRAVELLY SAND
- SANDY GRAVEL
- OUTCROP
- MAGNETOMETER CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- SIDESCAN SONAR CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- AS-FOUND CABLE / UNKNOWN LINEAR DEBRIS
- DEPRESSION WITH DIMENSIONS IN METRES (nmd = NON MEASURABLE DEPTH)
- AS-FOUND WRECK WITH SSS ID NUMBER (PREFIX OMITTED)
- LINEAR DEBRIS WITH LENGTH
- AREA OF MAGNETIC ANOMALY

LONGITUDINAL PROFILE

- SEABED PROFILE
- HORIZON H01
- INFERRED HORIZON H01
- HORIZON H10
- INFERRED HORIZON H10
- INTERNAL REFLECTOR



NOTES:

1) BATHYMETRY FROM KONGSBERG EM2040 AND RESON 7125 DUAL HEAD MULTIBEAM ECHO SOUNDER, PROCESSED WITH 0.25 m BIN SIZE.
2. WATER DEPTH REDUCED TO LAT USING ELLIPSOIDAL HEIGHT FROM STARPACK BEST SOLUTION AND THE VORF MODEL.
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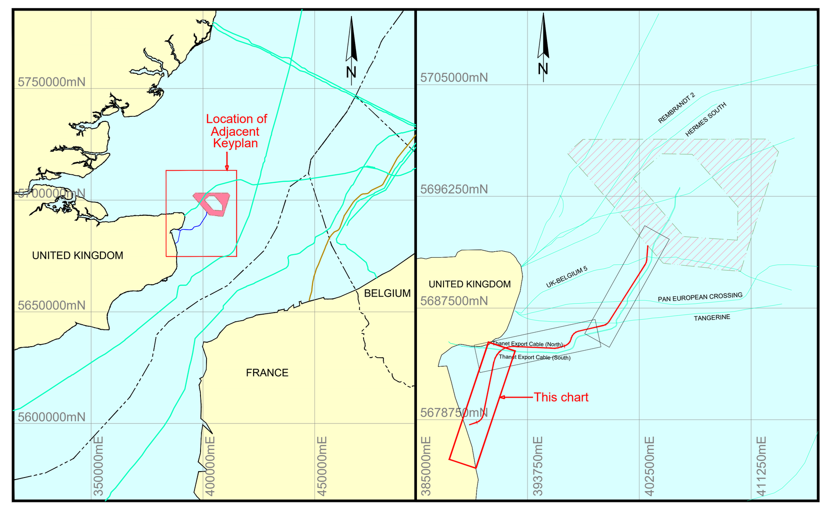
4) SHALLOW GEOLOGY INTERPRETATION BASED ON POLE-MOUNTED MASSA TR-1075 PINGER ARRAY AND SOACSY SEACHIRP.
5) LONGITUDINAL PROFILE VERTICAL SCALE 1:100. DEPTH IN METRES.
6) SHALLOW GEOLOGICAL INTERPRETATION BASED ON ASSUMED ACOUSTIC VELOCITY IN SEDIMENTS OF 1600 m/s.
7) MAGNETIC ANOMALIES DERIVED FROM FUGRO EMU GEOWING FIXED WING GRADIOMETER SYSTEM AND GEOMETRIC MAGNETOMETER G-882 TOWED FROM TWO SEPARATE EIVA SCAN FISHES.
8) BACKGROUND INFORMATION IS EXTRACTED FROM ENC AND ADMIRALTY CHARTS.

GEODETIC PARAMETERS:

HORIZONTAL COORDINATE SYSTEM	
GEODETIC DATUM	European Terrestrial Reference System 1989
ELLIPSOID Semi-Major Axis Inverse Flattening	GRS 1980 6,378,137.000 298.257 222 101
PROJECTION Central Meridian (CM) Latitude of Origin False Easting False Northing Scale Factor at CM	ETRS89 / UTM zone 31N 03°00'00" E 00°00'00" N 500,000mE 0mN 0.9996
DATUM TRANSFORMATION Source	ITRF2008 to ETRS89 for Epoch 2016. 647540984 (25 August 2016) EPSG dX=+0.05376 dY=+0.05096 dZ=-0.08847 rX=-0.002239" rY=-0.013547" rZ=+0.021897" Scale=+0.0026718ppm
VERTICAL DATUM	LOWEST ASTRONOMICAL TIDE (LAT)



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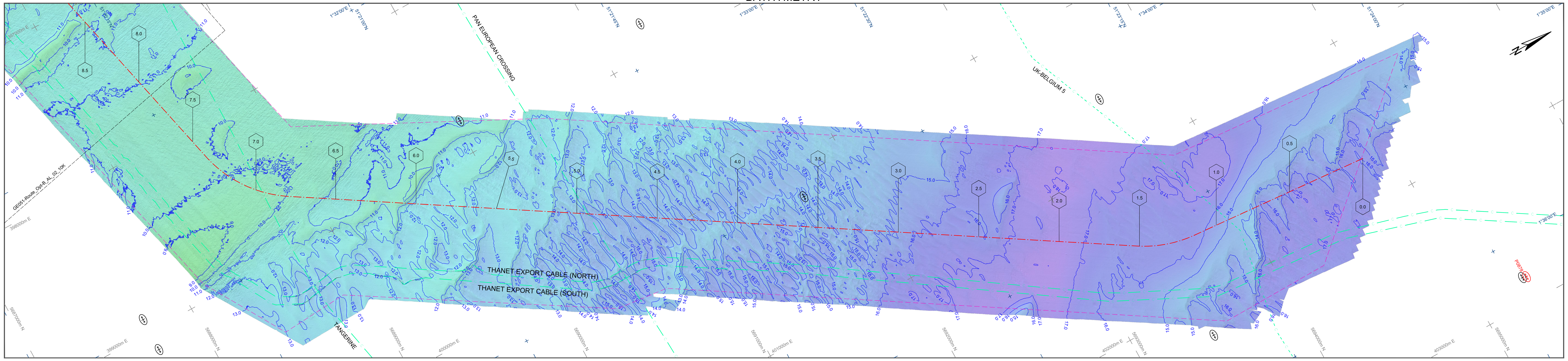
GEOPHYSICAL ROUTE SURVEY
UK CONTINENTAL SHELF, NORTH SEA
EXPORT CABLE ROUTE OPTION - A
ALIGNMENT CHART
KP 15.839 - KP 22.835

SCALE 1 : 10000 at A0

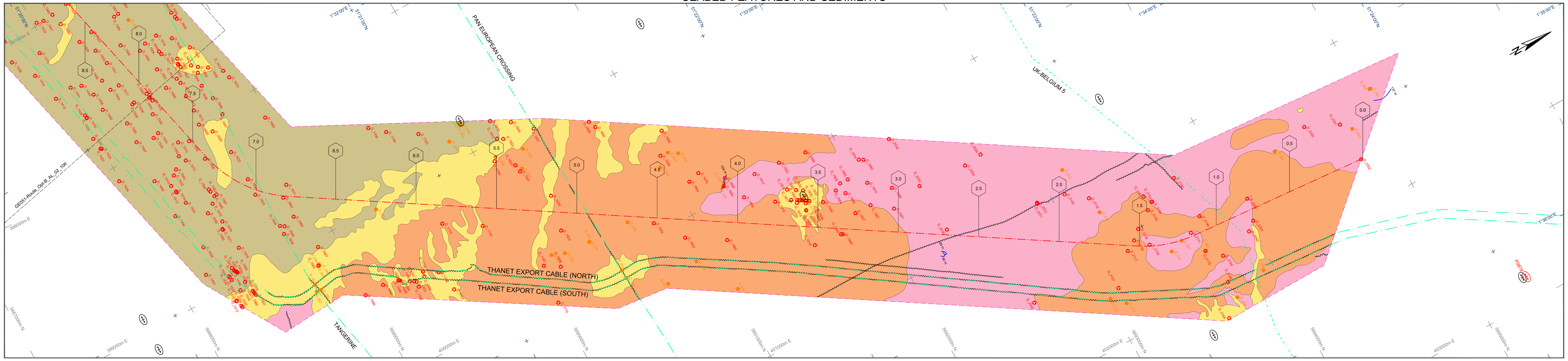
0 100 200 400 600 800 1000 metres
0 1000 2000 3000 feet

Vessel: RV DISCOVERY & VALKYRIE		Survey Date: JUL - SEPT 2016	Project Ref: GE051			
Issue No:	Date:	Description:	Interpr:	Drawn:	Chkd:	Appr:
1	28/11/2016	Issued for Approval	CM / MS	RB / AS	VMN	PPL
0	03/04/2017	Final Issue	CM / MS	RB / AS	VMN	PPL
Client Ref: -		Drawing No: GE051-Route_Opt-A_AL_03_10K	Chart: 3 of 3		Encl: 03	

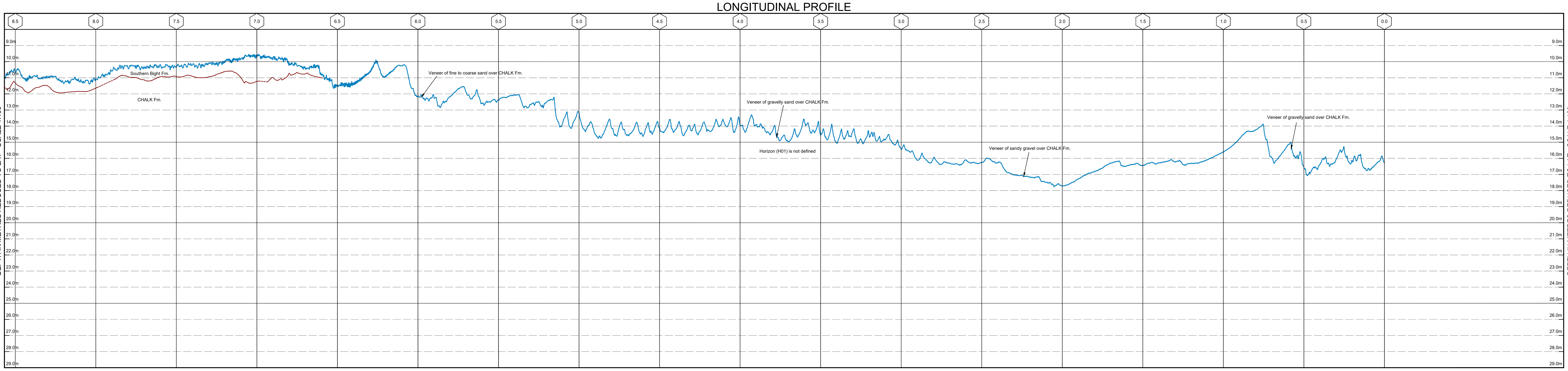
BATHYMETRY



SEABED FEATURES AND SEDIMENTS



LONGITUDINAL PROFILE



ENGINEERING NOTES

LEGEND:

GENERAL

- U.T.M. GRID
- GEOGRAPHICAL GRID
- KILOMETRE POST
- PROPOSED CABLE ROUTE
- OTHER CABLE ROUTES
- PROPOSED ROUTE CORRIDOR
- CHART MATCHLINE
- WRECK (FROM ENC AND ADMIRALTY CHARTS)

DEPTH RANGE PALETTE:
(DEPTH IN METRES)
0, 5, 10, 15, 20

BATHYMETRY

- DEPTH CONTOUR AT 1.0 METRE INTERVALS

SEABED FEATURES AND SEDIMENTS

- FINE TO COARSE SAND
- CLAYEY TO SILTY SAND
- GRAVELLY SAND
- SANDY GRAVEL
- OUTCROP
- D_123 MAGNETOMETER CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- V_567 SIDESCAN SONAR CONTACT WITH REFERENCE NUMBER (PREFIX OMITTED)
- AS-FOUND CABLE / UNKNOWN LINEAR DEBRIS
- l x w x d DEPRESSION WITH DIMENSIONS IN METRES (nmd = NON MEASURABLE DEPTH)
- P123 AS-FOUND WRECK WITH SSS ID NUMBER (PREFIX OMITTED)
- 10 m LINEAR DEBRIS WITH LENGTH
- AREA OF MAGNETIC ANOMALY

LONGITUDINAL PROFILE

- SEABED PROFILE
- HORIZON H01
- INFERRED HORIZON H01
- HORIZON H10
- INFERRED HORIZON H10
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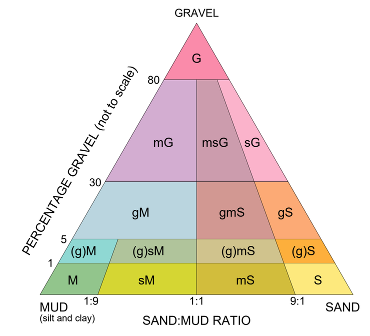

NOTES:

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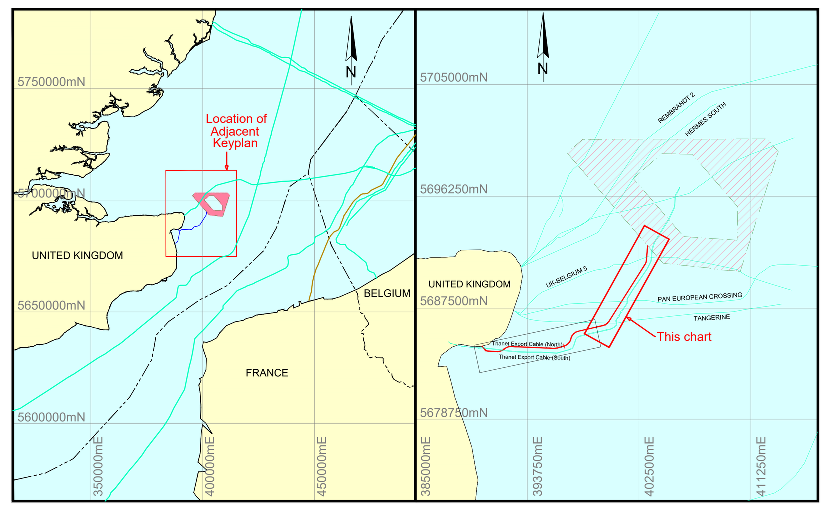
VERTICAL DATUM	LOWEST ASTRONOMICAL TIDE (LAT)



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GEOPHYSICAL ROUTE SURVEY
UK CONTINENTAL SHELF, NORTH SEA
EXPORT CABLE ROUTE OPTION - B
ALIGNMENT CHART
KP 0.000 - KP 8.567

SCALE 1 : 10000 at A0

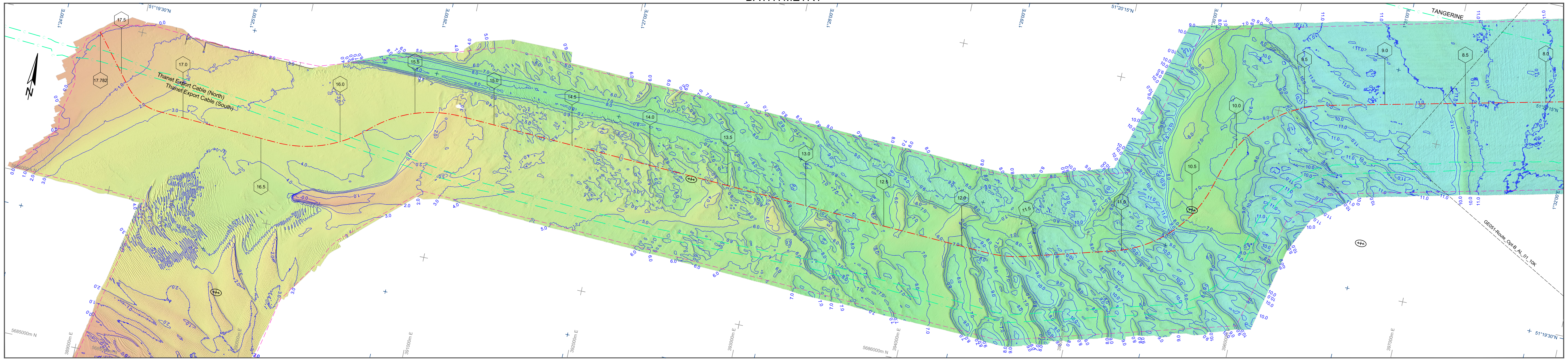
0 100 200 400 600 800 1000 metres
0 1000 2000 3000 feet

Issue No:	Date:	Description:	Interpr:	Drawn:	Chkd:	Appr:
1	28/11/2016	Issued for Approval	CM / MS	RB / AS	VMN	PPL
0	03/04/2017	Final Issue	CM / MS	RB / AS	VMN	PPL

Vessel: RV DISCOVERY & VALKYRIE | Survey Date: JUL - SEPT 2016 | Project Ref: GE051

Client Ref:	Drawing No:	Chart:	Encl:
-	GE051-Route_Opt-B_AL_01_10K	1 of 2	04

BATHYMETRY



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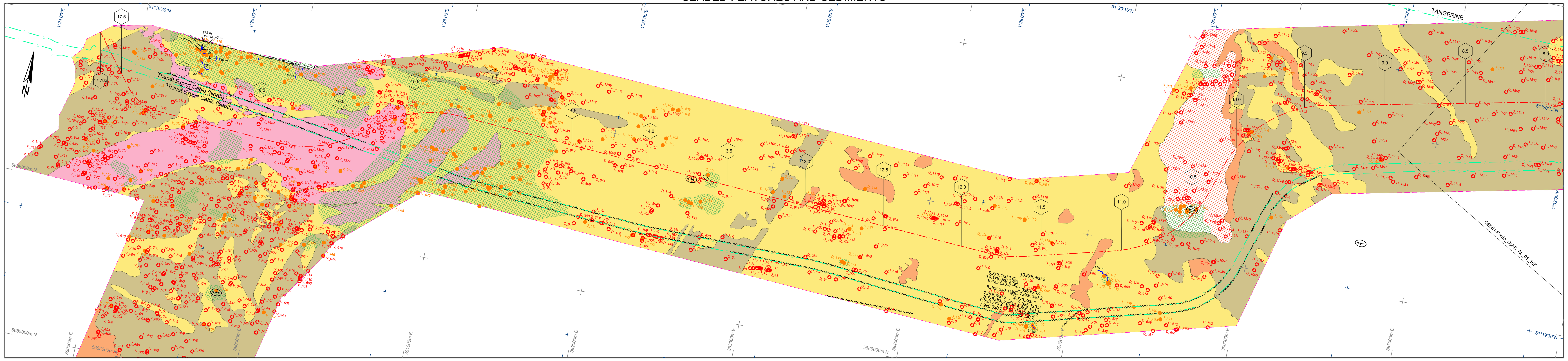
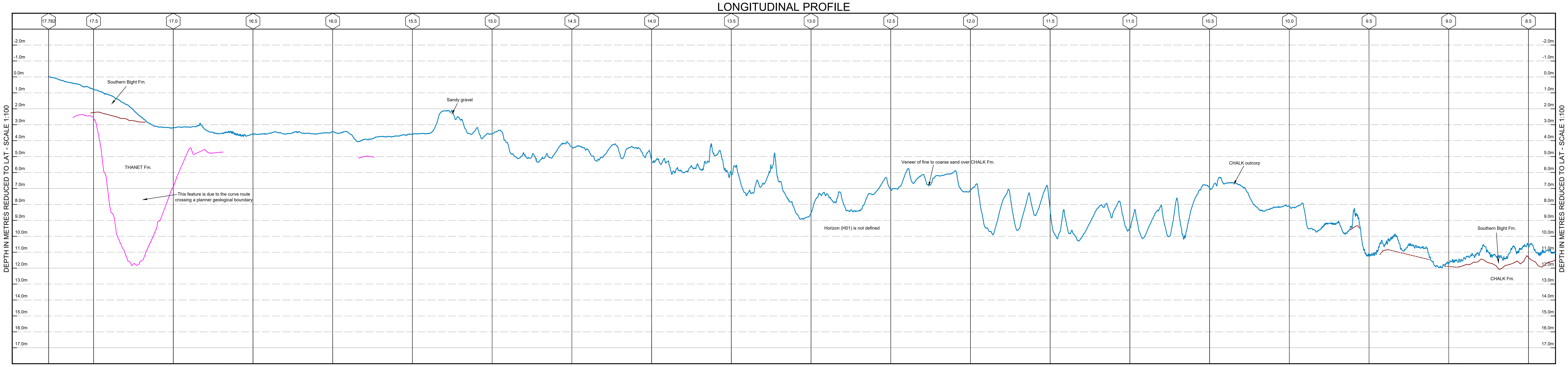


LONGITUDINAL PROFILE



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0, 5, 10, 15, 20

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- INFERRED HORIZON H01
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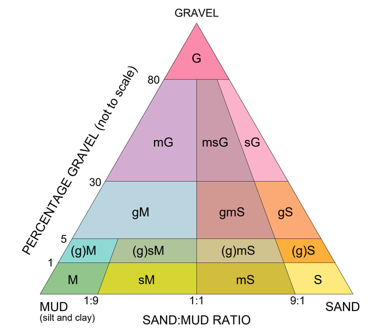

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ELLIPSOID	GRS 1980
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Inverse Flattening	298.257 222 101
PROJECTION	ETRS89 / UTM zone 31N
Central Meridian (CM)	03°00’00” E
Latitude of Origin	00°00’00” N
False Easting	500,000mE
False Northing	0mN
Scale Factor at CM	0.9996
DATUM TRANSFORMATION	ITRF2008 to ETRS89 for Epoch 2016. 647540984 (25 August 2016)
Source	EPSG
	dX=+0.05376 dY=+0.05096 dZ=-0.08847
	rX=-0.002239" rY=-0.013547" rZ=+0.021897" Scale=+0.0026718ppm
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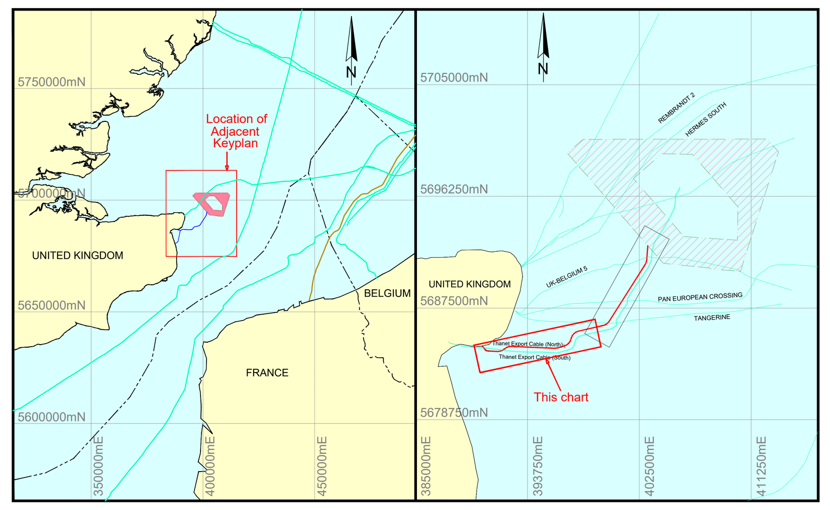

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GEOPHYSICAL ROUTE SURVEY
UK CONTINENTAL SHELF, NORTH SEA
EXPORT CABLE ROUTE OPTION - B
ALIGNMENT CHART
KP 8.330 - KP 17.782

SCALE 1 : 10000 at A0

0 100 200 400 600 800 1000 metres
0 1000 2000 3000 feet

Vessel: RV DISCOVERY & VALKYRIE		Survey Date: JUL - SEPT 2016	Project Ref: GE051			
Issue No:	Date:	Description:	Interpr:	Drawn:	Chkd:	Appr:
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Client Ref:	Drawing No:	Chart:	Encl:
-	GE051-Route_Opt-B_AL_02_10K	2 of 2	05