Netherlands Enterprise Agency

Site Studies Wind Farm Zone Borssele

Geophysical Survey Wind Farm Site III

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DNV·GL

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Date:	**Our reference:**	**Your reference:**
2015-08-28	DNV Doc. No:1KI2TUA-12 Sign: MICWAG Corresp. No.:	

Zone Borssele Site Data - Geophysical Survey Site III and IV

The following geophysical reports produced by Fugro Engineers B.V. have been reviewed by DNV GL:

1. Geophysical Site Investigation Survey / Dutch Continental Shelf, North Sea / Borssele Wind Farm Development Zone / Wind Farm Site III / Report No. GH157-R1, Revision A /2015-08-14
2. Geophysical Site Investigation Survey / Dutch Continental Shelf, North Sea / Borssele Wind Farm Development Zone / Wind Farm Site IV / Report No. GH157-R2, Revision A / 2015-08-14

Comments to the documents have been given in Verification Comment Sheet (Reference /A/).

DNV GL has found that the above referenced reports provide sufficient geophysical detail to establish a preliminary design geological model. Such a model can be relied upon to establish general geologic conditions, including discussions on site variability, in order to establish future geotechnical investigation campaigns.
Please note that detailed geotechnical investigations will need to be performed in order to address potential data gaps in future preliminary investigations, in particular the lack of a specific wind farm layout.

References:

/A/: Verification Comment Sheet "644235-VCS-08-Rev01" dated 25.08.2015
Doc-ID: 644235-VCS-08-rev01-Geophysical_Survey WFSIII WFSIV

Sincerely
for Det Norske Veritas, Danmark A/S

f.

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Fugro Survey B.V.

Geophysical Site Investigation Survey
Dutch Continental Shelf, North Sea

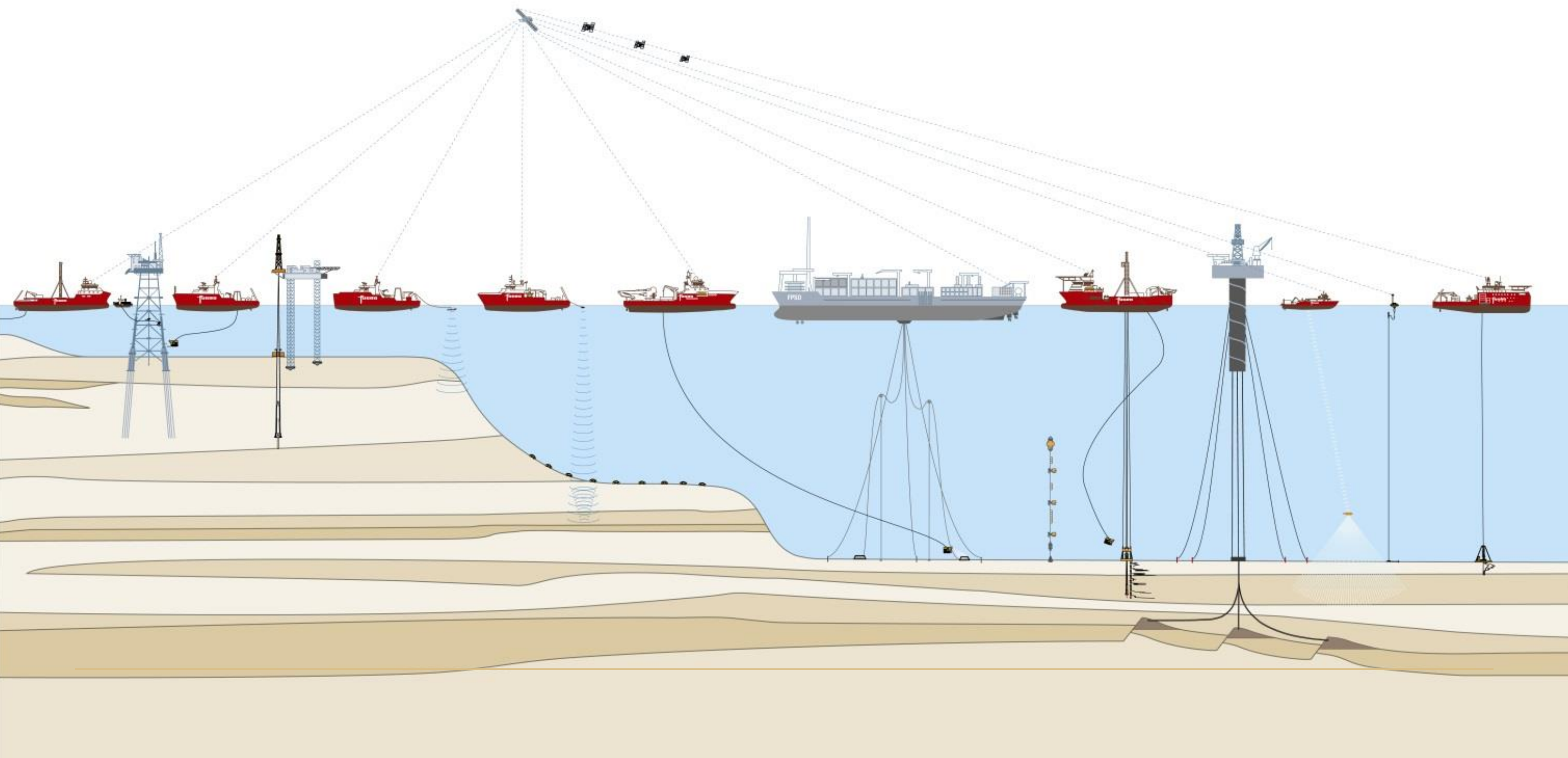
Borssele Wind Farm Development Zone
Wind Farm Site III

25 May to 20 June 2015
Fugro (FSBV) Report No.: GH157-R1
Fugro (FOSPA) Document No.: 687/15-J322

Rijksdienst voor Ondernemend Nederland
Client Reference: WOZ15000012

Netherlands Enterprise Agency

Revision A



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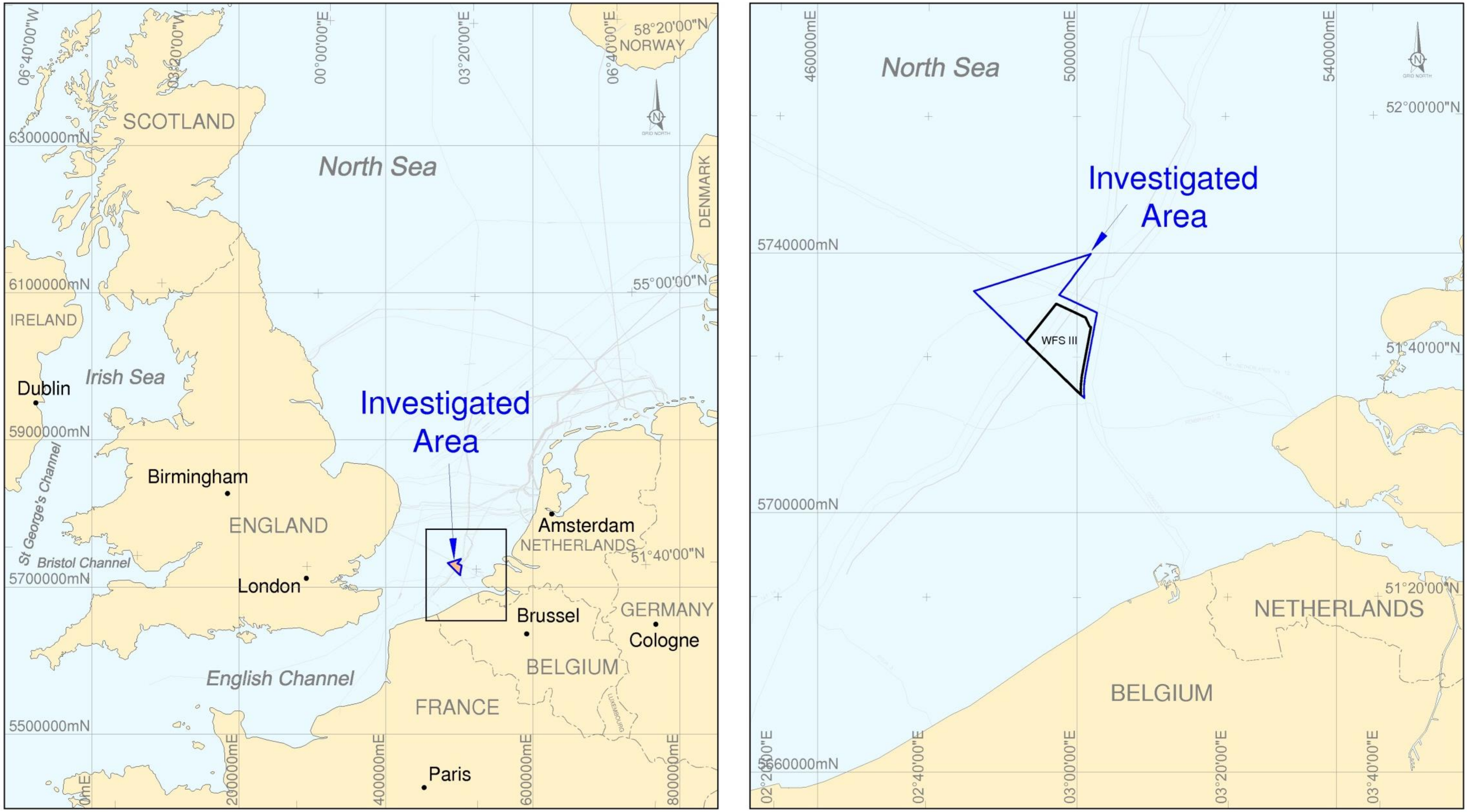
1	Issue for Approval	M. Marchetti D. Taliana	V. Minorenti	P-P Lebbink	06 July 2015
Rev	**Description**	**Prepared**	**Checked**	**Approved**	**Date**

REPORT AMENDMENT SHEET

Issue No.	Report section	Page No.	Table No.	Figure No.	Description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SCOTLAND
IRELAND
Irish Sea
Dublin
St George's Channel
Bristol Channel
Birmingham
ENGLAND
London
English Channel
FRANCE
Paris
BELGIUM
Brussel
NETHERLANDS
Amsterdam
GERMANY
Cologne
DENMARK
NORWAY
Investigated Area
6300000mN
6100000mN
5900000mN
5700000mN
5500000mN
200000mE
400000mE
600000mE
800000mE
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55°00'00"N
51°40'00"N
00°00'00"E
03°20'00"E
06°40'00"E
North Sea
Investigated Area
WFS III
NETHERLANDS
BELGIUM
5740000mN
5700000mN
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460000mE
500000mE
540000mE
52°00'00"N
51°40'00"N
51°20'00"N
02°40'00"E
03°00'00"E
03°20'00"E
03°40'00"E

Keyplan

SAMENVATTING

Borssele Windpark Kavel III			
Introductie			
Onderzoek data:	25 mei – 20 juni 2015		
Apparatuur (geofysisch):	Side scan sonar (SSS), single beam echo sounder (SBES), multibeam echo sounder (MBES), pinger (SBP), 2D ultra high resolution seismic sparker (2DUHR) en magnetometer (MAG)		
Coördinaten systeem:	Datum: ETRS89 European Terrestrial Reference System 1989 Projectie: UTM Zone 31N, CM 3°E		
	Apparatuur	**Hoofd lijnen (WPK IV)**	**Kruisende lijnen (WPK III & WPK IV)**
	MAG	1285.51 km	324.83 km
	MBES	1295.92 km	301.63 km
	SSS	1313.36 km	357.56 km
	SBP	1265.97 km	361.73 km
	2DUHR	269.97 km	280.66 km
Bathymetrie			
De waterdiepte in het onderzoeksgebied varieert tussen -15 m aLAT en -37 m aLAT. De zeebodem wordt gekarakteriseerd door een complex patroon van zandbanken, parallel aan de kust georiënteerd. Op deze zandbanken zijn duinen van verschillende grootte gevormd.			
Zeebodem Kenmerken			
De zeebodem wordt gekenmerkt door een complex patroon van beddingsvormen. Over het algemeen hebben de duinen een NW - ZO en W - O oriëntatie en variëren in grootte van groot tot zeer groot. De golflengte van de duinen ligt tussen de 80 m en 550 m, en de hoogte varieert tussen de 2.5 m en 11 m. Bovenop de grote zandduinen zijn kleinere duinen afgezet met een gemiddelde golflengte van 10 m - 20 m en een hoogte variërend van 0.25 m tot 0.75 m.			
Geologie			
De ondiepe onderliggende geologische condities in het onderzoeksgebied zijn geïnterpreteerd op basis van pinger SBP en UHR sparker data gecombineerd met informatie van standaard geologische kaarten. De maximale diepte die kon worden bereikt met de pinger SBP was 20 m onder de zeebodem. De interpretatie die is gemaakt aan de hand van de UHR sparker data heeft een maximum diepte van 80 m - 100 m, dit voldoet aan de gestelde specificaties. Er zijn vier (4) lithologische units geïdentificeerd:			
UNIT A	Unit A wordt gekarakteriseerd door een transparante tot semi-transparante seismische facies. De interne reflectors zijn discontinue met lage tot medium amplitude en hoge frequentie, en worden vaak gemaskeerd door diffractiehyperbolen. Deze hyperbolen zijn gerelateerd aan de zandduinen die op de zeebodem aanwezig zijn. Met name onder de breed uitgestrekte NO-ZW georiënteerde zandbank (Buitenbank 3) zijn de seismische facies bijna volledig transparant. De basis van deze unit (Reflector A) is een onregelmatig oppervlak sub-parallel aan de zeebodem en komt voor van 1 m tot 13 m onder de zeebodem. Deze eenheid is gecorreleerd aan de Southern Bight Formation en bestaat uit los tot compact ZAND.		
UNIT B	Unit B wordt gekenmerkt door discontinue reflectors met een parallelle tot chaotische samenstelling, lage tot hoge amplitude en variabele frequentie. De basis van deze unit (Reflector B) wordt gevormd door een paleokanaal/erosievlak dat door Kwartaire (Unit C) en Tertiaire formaties (Unit D) snijdt. De diepte waar de basis van Unit B voorkomt varieert tussen de -30 m en -72 m aLAT. Deze unit is gecorreleerd aan de Kreftenheye en Eem Formations. Er wordt verwacht dat deze unit uit compact tot zeer compact ZAND (en soms uit stugge tot zeer stugge KLEI) bestaat en is afgezet in een fluviatiel en ondiep marien milieu (respectievelijk).		
Unit E	Unit E wordt gekarakteriseerd door parallele reflectors met hoge continuïteit, hoge frequentie en een lage tot matige amplitude. De reflectors in de unit worden gedeeltelijk gemaskeerd door multiples van de zeebodem. Een sterke interne reflector, parallel aan de basis van de unit, is geïnterpreteerd als Ruisbroek ZAND. De diepte waar de basis van de unit voorkomt varieert tussen de -45 m en -145 m aLAT. Unit E is gecorelleerd aan de Tongeren Formation en bestaat uit compact tot zeer compact ZAND.		
UNIT F	Unit F wordt gekenmerkt door parallelle reflectors met hoge continuïteit en matige frequenties, de amplitude varieert in deze unit; in het bovenste gedeelte van Unit F komen reflectoren met een hoge amplitude voor maar deze worden lager met een toenemende diepte. De bovengrens van deze unit is door het hele onderzoeksgebied waargenomen, behalve in het zuid-westen. In dit deel van het onderzoeksgebied wordt Unit F afgesneden door het erosievlak; de basis van unit B (Reflector B). Unit F is gecorreleerd aan de Dongen Formation en bestaat uit zeer stugge tot harde KLEI en compact kleiig ZAND.		

Zeebodem en sub-zeebodem Hazards	
Wrak	
1723	Afwijkende positie: 75 m ten noord-oosten van de verstrekte locatie.
Geen van de andere wrakken die voorkomen in de aangeleverde database, zijn gedetecteerd met een van de gebruikte onderzoekstechnieken.	
Kabels	
FARLAND NORTH	De positie komt overeen met de aangeleverde database positie. Er is geen afwijking in de positie gevonden.
UK-NL 8	Er zijn mogelijk een aantal kleine exposures. Afwijkende positie: tot 390 m van de verstrekte locatie.
UK-NL 11	Er is één (1) mogelijke exposure waargenomen in de SSS en MBES data. Er is geen afwijking in de positie gevonden.
RIOJA 3	Gedeeltelijk in exposure. Er is geen afwijking in de positie gevonden.
SEA-ME-WE3	Er zijn twee (2) exposures waargenomen in de SSS data. Er is geen afwijking in de positie gevonden.
Pijpleidingen	
NORFRA	Tussen de zandgolven zijn er exposures. Er is geen afwijking in de positie gevonden.
ZEEPIPE	Er zijn lange delen van de pijpleiding in exposure en een klein gedeelte is in freespan. Er is geen afwijking in de positie gevonden.
Zeebodem Geohazards	
Zandduinen	Er zijn twee hoofd bewegingsrichtingen: 1) In NO-richting met een gemiddelde snelheid van 1.7m/j; 2) In ZW-richting met een gemiddelde snelheid van 3.2 m/j (Ref.14).
Keien	Er zijn geen keien geïdentificeerd.
SSS contacten	Er zijn 234 SSS contacten waargenomen in het Wind Park Kavel III onderzoeksgebied.
Magnetometer contacten	Er zijn 685 MAG contacten gedetecteerd in het Wind Park Kavel III onderzoeksgebied.
Sub-zeebodem Geohazards	
Paleokanaal sedimenten	In het paleokanaal zijn de Unit B sedimenten gekenmerkt door discontinue reflectors met een parallele tot chaotische samenstelling en zijn er laterale variaties in de seismische eigenschappen geobserveerd. Dit is herkend als de typerende laterale variatie in alluviale afzettingen (b.v. zand, klei, grind etc.) (Kreftenheye Formation).
Anomalieëen van SBP	Hoge amplitude reflecties veroorzaakt door de mogelijke aanwezigheid van grindige lagen.
Anomalieën van UHR	In de basis van Unit B, voornamelijk in het paleokanaal, zijn reflecties met een hoge amplitude waargenomen, deze reflecties zijn mogelijk veroorzaakt door de aanwezigheid van compactere sedimenten en/of grindige lagen. Een aantal seismische anomalieën hebben een omgekeerde polariteit, dit kan wijzen op de mogelijke aanwezigheid van veen lagen en / of biogas in de sedimenten.
Breuken	
In Unit F (specifiek in sub-unit F3 en F4) zijn breuksystemen actief geweest. Deze breuksystemem zijn gerelateerd aan ‘tektonische sediment’ deformaties, binnen de Unit. De deformaties zijn waarschijnlijk veroorzaakt door een tijdelijke verandering in de dichtheid gerelateerd aan het verminderen van de compactie in de vroege afzettingsgeschiedenis van deze kleiige-siltige sedimenten.	
Aanbevolen Boringen	
Er zijn zes (6) boringen aanbevolen in het Wind Park Kavel III onderzoeksgebied.	
Aanbevolen CPT	
Er zijn negentien(19) CPT’s aanbevolen in het Wind Park Kavel III onderzoeksgebied.	

EXECUTIVE SUMMARY

Borssele Wind Farm Site III			
Introduction			
Survey Dates:	25 May – 20 June 2015		
Equipment (Geophysical):	Side scan sonar (SSS), single beam echo sounder (SBES), multibeam echo sounder (MBES), pinger (SBP), 2D ultra high resolution seismic (2DUHR) and Magnetometer (MAG).		
Coordinate System:	Datum: ETRS89 European Terrestrial Reference System 1989 Projection: UTM Zone 31N, CM 3°E		
Survey kilometres	**EQUIPMENT**	**MAIN LINES (WFS III)**	**CROSS LINES (WFS III & WFS IV)**
	MAG	1285.51 km	324.83 km
	MBES	1295.92 km	301.63 km
	SSS	1313.36 km	357.56 km
	SBP	1265.97 km	361.73 km
	2DUHR	269.97 km	280.66 km
Bathymetry			
Water depth across the survey site ranges from -15 m to -37 m aLAT. The seabed is characterized by a complex pattern of shore-parallel sandbanks, with superimposed dunes of different orders.			
Seabed Features			
The seabed is characterized by a complex pattern of bedforms with large to very large dunes of various orders. These dunes have a general NW to SE and W to E direction, with an average wavelength between 80 m and 550 m and a height ranging from 2.5 m to 11 m. Superimposed on the major sand dunes, other minor dunes with 10 - 20 m average wavelength and height ranging from 0.25 m to 0.75 m are present.			
Geology			
The shallow sub-surface geological conditions within the survey area have been interpreted based on pinger and UHR sparker data and information from standard geological charts. Penetration of the pinger SBP was restricted to 20 m below seabed. The limit of interpretation of the UHR data to achieve satisfactory results was set at a depth of 80-100 m, as per Client specification. Four (4) lithological units were identified while are the only present in the area			
UNIT A	Unit A is characterized by a transparent to semi-transparent seismic aspect. Internal reflectors are discontinuous with low to medium amplitude and high frequency, but are very often masked by diffraction hyperbola related to the presence of sand dunes on the seabed. In particular, below the wide NE-SW elongated sandbank (Buitenbank 3), the seismic facies is almost completely transparent. The base of this Unit (Reflector A) is an uneven surface sub-parallel to the seabed that ranges from 1 m up to 13 m bsb. This Unit is expected to comprise loose to dense SAND and is correlated to the Southern Bight Formation.		
UNIT B	Unit B is characterized by discontinuous reflectors with parallel to chaotic configuration, low to high amplitude and variable frequency. The base of this Unit (Reflector B) is a palaeochannel/erosional surface that cuts the Quaternary (Unit C) and Tertiary formations (Unit D and E). The depth of the base of Unit B ranges from -30 m to -72 m aLAT. Unit B is expected to comprise dense to very dense SAND (sometimes stiff to very stiff CLAY), correlated to the Kreftenheye and Eem Formations, deposited respectively in fluvial and shallow marine environment.		
UNIT E	Unit E is characterized by parallel reflectors with high continuity and frequency, and low to moderate amplitude. The reflections within this unit are partly hidden by the presence of seabed multiples. A strong intra-formational reflector parallel to the base was interpreted as Ruisbroek SAND. The depth of the base of Unit E ranges from -45 m to -145 m aLAT. Unit E is expected to comprise dense to very dense SAND. It has been correlated to the Tongeren Formation.		
UNIT F	Unit F is characterized by parallel reflectors with high continuity, high amplitude in the upper part decreasing with depth, and moderate frequency. The upper boundary (Reflector E) of this unit is seen throughout the area, except in the south-west part where it is truncated by the erosional surface at the base of Unit B (Reflector B). Unit F is expected to be comprised very stiff to hard CLAY and dense clayey SAND member toward the base. This Unit has been correlated to the Dongen Formation.		
Seabed and Sub-seabed Hazards			
Wreck			
1723	Offset 75 m NE of database location		
None of the other known wreck listed in the database was detected with any of the survey techniques.			
Cables			

FARLAND NORTH	Found in the Client-supplied position. No offset was found.
UK-NL 8	A few small sections of possible exposure. Offset: up to 390 m from the provided position.
UK-NL 11	One section of possible exposure in SSS and MBES. No offset was found.
RIOJA 3	Partly exposed. No offset was found.
SEA-ME-WE3	Two exposed sections visible in SSS data. No offset was found.
Pipelines	
NORFRA	Exposed between sand waves. No offset was found.
ZEEPIPE	Long sections exposed, one small section in freespan. No offset was found.
Seabed Geohazards	
Sand dunes	There are two main directions of movement, one in NE-direction with an average speed of 1.7 m/yr and one in SW direction with an average speed of 3.2 m/yr (Ref.14).
Boulders	No boulders were identified.
SSS targets	234 SSS targets were detected in the WFS III area.
Magnetometer targets	685 MAG targets were detected in the WFS III area.
Sub-seabed Geohazards	
Palaeochannel Infill	Within the palaeochannel, Unit B is characterized by discontinuous reflectors with parallel to chaotic configuration and presents lateral changes in seismic attributes recognized as the typical lateral variation of alluvial deposit (i.e. sand, clay, gravel etc.) (Kreftenheye Formation).
Anomalies from SBP	High amplitude reflections due to possible gravelly layers.
Anomalies from UHR	At the base of Unit B, mainly within the main channelling feature, high amplitude reflections were observed that could be represents denser sediment and / or gravelly layers. Few seismic anomalies exhibits also reverse polarity and could be interpreted as possibly peat and / or biogenic gas charged sediments.
Faulting	
Unit F (in particular Sub-Unit F3 and F4) is affected by faulting systems related to intra-formational ‘sediment tectonic’ deformations. These deformations are probably due to the relaxation of temporary states of density inversion and linked to under-compaction in the early burial history of the clayey-silty sediment.	
Boreholes recommended	
Six (6) BH are recommended in the WFS III site	
CPT Recommended	
Nineteen (19) CPT are recommended in the WFS III site	

DOCUMENT ARRANGEMENT

REPORT 1:	**WIND FARM SITE III**
	VOLUME 1: TEXT REPORT (Survey Results and Operations & Calibrations)
	VOLUME 2: CHARTS
	VOLUME 3: CHARTS
	VOLUME 4: CHARTS
REPORT 2:	WIND FARM SITE IV
	VOLUME 1: TEXT REPORT (Survey Results and Operations & Calibrations)
	VOLUME 2: CHARTS
	VOLUME 3: CHARTS
	VOLUME 4: CHARTS

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F. VESSEL SPECIFICATIONS

G. EQUIPMENT SPECIFICATIONS

H. HSE

I. TABULATED SURVEY RESULTS

J. TRACK CHARTS

K. BATHYMETRY CHARTS

L. SEABED AND SEDIMENT CLASSIFICATION CHARTS

M. CONTACT CHARTS

N. GEOLOGICAL CHARTS

O. GEOLOGICAL PROFILES

P. GEOHAZARD CHARTS

Q. PROPOSED BOREHOLE LOCATIONS

R. TRANSMITTAL REPORT

LIST OF CHARTS

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Encl.	Drawing	Chart Name	Scale
		A34008B, A34008C)	
8	DWG002-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34009, A34010, A34011)	
9	DWG003-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34012, A34013, A3401314, A34014A)	
10	DWG004-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34015, A34016, A34017A)	
11	DWG005-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34018A, A34018BC, A34019A)	
12	DWG006-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34020, A34021, A34022)	
13	DWG007-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34023, A34024, A34025)	
14	DWG008-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34026, A34027, A34028)	
15	DWG009-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34029, A34030, A34030A)	
16	DWG010-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A34031)	
17	DWG011-WFS3_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Lines A34032, A34033)	

Volume 4 of 4:

Encl.	Drawing	Chart Name
	WFS III and WFS IV - Sections	
1	DWG001-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL001)
2	DWG002-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF012)
3	DWG003-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL002)
4	DWG004-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF011)
5	DWG005-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL003)
6	DWG006-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF010)
7	DWG007-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF009)
8	DWG008-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF008)
9	DWG009-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL004)
10	DWG010-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF007)
11	DWG011-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF006)
12	DWG012-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF005A)
13	DWG013-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL005A)
14	DWG014-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line UHRINF004A)
15	DWG015-WFS3-4_UHR_Section_10k	Interpreted UHR Seismic Sections (Based on Line A3A4XL006, A3A4XL007, UHRINF003, UHRINF002, A3A4XL008, UHRINF001)

Abbreviations

2DUHR	2D Ultra High Resolution
APOS	Acoustic Positioning Operator Station
bsb	below seabed
CHIRP	Compressed High Intensity Radar Pulse
COG	Centre of Gravity
CPT	Cone Penetration Test
CRP	Common Reference Point
CTD	Conductivity Temperature Depth (probe)
C-O	Computed minus observed
C/W	Comes With
DGPS	Differential Global Positioning System
DMS	Dynamic Motion Sensor
ETRS89	European Terrestrial Reference System 1989
FOSPA	Fugro Oceansismica S.p.A.
FSBV	Fugro Survey B.V.
GLONASS	Global Navigation Satellite System (Russia)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HiPAP	High Precision Acoustic Positioning system
HSE	Health, Safety and Environment
(a)LAT	(above) Lowest Astronomical Tide
MBES	Multibeam Echo Sounder
MSL	Mean Sea Level
M.V.	Motor Vessel
PDOP	Position Dilution of Precision
QC	Quality Control
Rx	Receiving transducer
RVO	Rijksdienst voor Ondernemend Nederland
SBES	Single Beam Echo Sounder
SBP	Sub-bottom Profiler
SIS	Seafloor Information System
SSS	Side Scan Sonar
STD	Salinity Temperature Depth (probe)
SVP	Sound Velocity Profile
TP	Tow point
Tx	Transmitting transducer
UKOOA	United Kingdom Offshore Operators Association
USBL	Ultra Short Baseline
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
UXO	UneXploded Ordnance
WFS	Wind Farm Site
(B)WFZ	(Borssele) Wind Farm Zone
WGS84	World Geodetic System 1984

1. INTRODUCTION AND SCOPE OF WORK

1.1 General

RVO contracted Fugro Survey B.V. (FSBV) to perform a geophysical soil investigation to improve the geophysical and geotechnical understanding of zones III and IV of the Borssele Wind Farm Zone (BWFZ). Geophysical information for offshore wind farm of Site III has been gathered and described in this report to suitably progress the design and installation requirements.

The geophysical survey was carried out using the survey vessel M.V. Fugro Pioneer. Den Helder was the mobilisation port.

The geophysical survey was carried out between 25 May and 20 June 2015.

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 zone is GMT + 2 hours.

The investigation provided geophysical bathymetric and shallow seismic data focused on the Investigation Area for Wind Farm Zones III & IV, using the following equipment: side scan sonar (SSS), magnetometer (MAG), multi- and single beam echo sounder (MBES/SBES), sub-bottom profiler (SBP) and ultra-high resolution seismic survey (UHR).

One of the main purposes of the survey is to provide information on the presence of all seabed features including any natural objects and any non-natural objects such as wrecks, debris, existing cables and pipelines or UXO’s.

The acquired data will be used to provide input into the specification and scope for a geotechnical sampling and testing programme and to assist design of the offshore foundations/structures and cable burial.

Processing, interpretation and reporting were carried out by Fugro Oceansismica S.p.A. (FOSPA) in Rome (Italy).

The Project was split into two components: the Geophysical Scope (SSS, SBP, MBES and MAG) and the Seismic Scope (UHR).

This report details the results and operational activities of the Borssele WFS III survey.

1.2 Purpose of Work

The general survey objectives for each survey site were:

- To obtain an accurate bathymetric chart of the development areas WFS III & IV;
- To identify/confirm the positions of known wrecks, pipelines, possibly electrical cables and any other natural objects
- To produce isopach charts showing the thickness of the main geological formations including any mobile sediments and any other significant reflector levels which might impact on the engineering design;
- To locate any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, buried channels, etc.;
- To provide detailed geological interpretation showing facies variations and structural feature changes via appropriate maps and sections;
- To list the exact position of existing (active & inactive) cables and pipelines.
- To provide proposed positions for a geotechnical sampling and testing programme following the completion of the geophysical survey;
- To prepare a comprehensive interpretative report on the survey results in order to assist design of the offshore foundations / structures and cable burial.

1.3 Site Description

The proposed Wind Farm Survey (WFS III & IV) areas are located in the Borssele WFZ. The coordinates of the corners of the Investigated Area (WFS III & IV) are presented in the table below.

Table 1.1: The Investigated Area (WFS III & IV) Coordinates

Corner	UTM Coordinates (ETRS89 Zone 31)		Geographical Coordinates (ETRS89 Zone 31)	
	Easting [m]	Easting [m]	Latitude [° North]	Longitude [° East]
1	501 206.55	5 715 990.05	51°35'41.85069"	3°01'02.70652"
2	498 105.40	5 718 993.72	51°37'19.07151"	2°58'21.47587"
3	484 178.55	5 732 482.80	51°44'34.90964"	2°46'15.04580"
4	502 204.67	5 738 191.47	51°47'40.48057"	3°01'55.08576"
5	501 596.03	5 737 419.55	51°47'15.50204"	3°01'23.30142"
6	501 295.71	5 737 029.57	51°47'02.88171"	3°01'07.62161"
7	499 896.90	5 735 250.44	51°46'05.29898"	2°59'54.62123"
8	499 606.10	5 734 853.41	51°45'52.44715"	2°59'39.45170"
9	499 162.03	5 734 202.55	51°45'31.37785"	2°59'16.29187"
10	498 921.93	5 733 890.54	51°45'21.27699"	2°59'03.77185"
11	497 317.09	5 731 880.72	51°44'16.20204"	2°57'40.12517"
12	497 318.10	5 731 880.24	51°44'16.18652"	2°57'40.17784"
13	498 917.64	5 731 156.71	51°43'52.78598"	2°59'03.57873"
14	503 163.37	5 729 155.30	51°42'47.97401"	3°02'44.83470"
15	503 145.62	5 729 063.79	51°42'45.01228"	3°02'43.90682"
16	503 087.60	5 728 749.79	51°42'34.84956"	3°02'40.87359"
17	503 060.61	5 728 616.79	51°42'30.54501"	3°02'39.46313"
18	503 040.61	5 728 532.79	51°42'27.82640"	3°02'38.41845"
19	503 016.60	5 728 399.79	51°42'23.52178"	3°02'37.16337"
20	502 997.61	5 728 265.80	51°42'19.18502"	3°02'36.16985"
21	502 947.62	5 727 984.80	51°42'10.09026"	3°02'33.55691"
22	502 911.61	5 727 804.80	51°42'04.26450"	3°02'31.67555"
23	502 873.61	5 727 636.79	51°41'58.82687"	3°02'29.69102"
24	502 843.61	5 727 465.80	51°41'53.29263"	3°02'28.12325"
25	502 816.61	5 727 333.80	51°41'49.02039"	3°02'26.71299"
26	502 773.62	5 727 102.80	51°41'41.54390"	3°02'24.46709"

27	502 746.62	5 726 981.79	51°41'37.62739"	3°02'23.05734"
28	502 720.61	5 726 824.80	51°41'32.54621"	3°02'21.69820"
29	502 687.63	5 726 630.80	51°41'26.26717"	3°02'19.97512"
30	502 651.62	5 726 449.82	51°41'20.40961"	3°02'18.09472"
31	502 627.63	5 726 304.80	51°41'15.71584"	3°02'16.84140"
32	502 599.62	5 726 160.82	51°41'11.05580"	3°02'15.37884"
33	502 566.62	5 725 966.82	51°41'04.77672"	3°02'13.65518"
34	502 548.63	5 725 881.80	51°41'02.02499"	3°02'12.71613"
35	502 535.62	5 725 796.80	51°40'59.27382"	3°02'12.03643"
36	502 468.61	5 725 460.82	51°40'48.39949"	3°02'08.53849"
37	502 430.62	5 725 256.80	51°40'41.79612"	3°02'06.55527"
38	502 413.62	5 725 195.80	51°40'39.82186"	3°02'05.66861"
39	502 401.61	5 725 111.82	51°40'37.10367"	3°02'05.04121"
40	502 356.63	5 724 880.80	51°40'29.62642"	3°02'02.69369"
41	502 328.63	5 724 709.82	51°40'24.09235"	3°02'01.23182"
42	502 313.63	5 724 637.80	51°40'21.76133"	3°02'00.44918"
43	502 297.62	5 724 540.82	51°40'18.62240"	3°01'59.61339"
44	502 285.62	5 724 479.83	51°40'16.64838"	3°01'58.98724"
45	502 279.62	5 724 418.82	51°40'14.67361"	3°01'58.67345"
46	502 251.63	5 724 273.83	51°40'09.98080"	3°01'57.21297"
47	502 230.62	5 724 152.83	51°40'06.06442"	3°01'56.11647"
48	502 173.62	5 723 911.83	51°39'58.26423"	3°01'53.14390"
49	502 136.62	5 723 717.82	51°39'51.98477"	3°01'51.21366"
50	502 106.83	5 723 546.63	51°39'46.44387"	3°01'49.65934"
51	502 102.62	5 723 513.82	51°39'45.38189"	3°01'49.43950"
52	502 089.61	5 723 466.83	51°39'43.86103"	3°01'48.76133"
53	502 070.62	5 723 369.83	51°39'40.72146"	3°01'47.77086"
54	502 042.63	5 723 197.82	51°39'35.15398"	3°01'46.31043"
55	502 018.63	5 723 064.82	51°39'30.84917"	3°01'45.05856"
56	502 004.62	5 723 002.83	51°39'28.84278"	3°01'44.32814"
57	501 979.63	5 722 846.83	51°39'23.79348"	3°01'43.02438"
58	501 951.61	5 722 701.83	51°39'19.10028"	3°01'41.56324"
59	501 903.62	5 722 447.83	51°39'10.87905"	3°01'39.06083"
60	501 880.63	5 722 338.83	51°39'07.35107"	3°01'37.86236"
61	501 821.62	5 722 000.85	51°38'56.41156"	3°01'34.78532"
62	501 749.62	5 721 674.85	51°38'45.85996"	3°01'31.03304"
63	501 729.62	5 721 563.83	51°38'42.26653"	3°01'29.99046"
64	501 714.63	5 721 504.83	51°38'40.35690"	3°01'29.20950"
65	501 681.63	5 721 311.83	51°38'34.10997"	3°01'27.48922"
66	501 661.63	5 721 214.83	51°38'30.97034"	3°01'26.44703"
67	501 615.62	5 720 936.83	51°38'21.97212"	3°01'24.04872"
68	501 573.62	5 720 730.85	51°38'15.30509"	3°01'21.86044"
69	501 561.62	5 720 658.83	51°38'12.97397"	3°01'21.23504"
70	501 545.62	5 720 550.83	51°38'09.47822"	3°01'20.40101"
71	501 518.62	5 720 430.83	51°38'05.59415"	3°01'18.99463"
72	501 491.62	5 720 296.83	51°38'01.25690"	3°01'17.58810"
73	501 420.63	5 719 933.83	51°37'49.50744"	3°01'13.89018"
74	501 366.62	5 719 629.83	51°37'39.66759"	3°01'11.07673"
75	501 335.61	5 719 447.86	51°37'33.77758"	3°01'09.46143"
76	501 297.61	5 719 143.85	51°37'23.93724"	3°01'07.48110"
77	501 250.62	5 718 728.86	51°37'10.50459"	3°01'05.03209"
78	501 245.62	5 718 666.85	51°37'08.49739"	3°01'04.77130"
79	501 209.62	5 718 397.85	51°36'59.79026"	3°01'02.89598"
80	501 179.62	5 718 028.86	51°36'47.84644"	3°01'01.33161"
81	501 171.63	5 717 919.86	51°36'44.31821"	3°01'00.91488"
82	501 172.63	5 717 779.86	51°36'39.78646"	3°01'00.96519"
83	501 162.61	5 717 509.85	51°36'31.04642"	3°01'00.44102"
84	501 155.62	5 717 383.86	51°36'26.96822"	3°01'00.07613"
85	501 160.62	5 717 188.86	51°36'20.65611"	3°01'00.33374"
86	501 157.63	5 717 005.86	51°36'14.73249"	3°01'00.17613"
87	501 160.62	5 716 726.86	51°36'05.70133"	3°01'00.32823"
88	501 162.62	5 716 688.86	51°36'04.47127"	3°01'00.43174"
89	501 167.63	5 716 493.86	51°35'58.15915"	3°01'00.68982"
90	501 184.62	5 716 245.86	51°35'50.13134"	3°01'01.56989"

The WFS III and IV, included in the Investigated Area are shown in Figure 1.1.

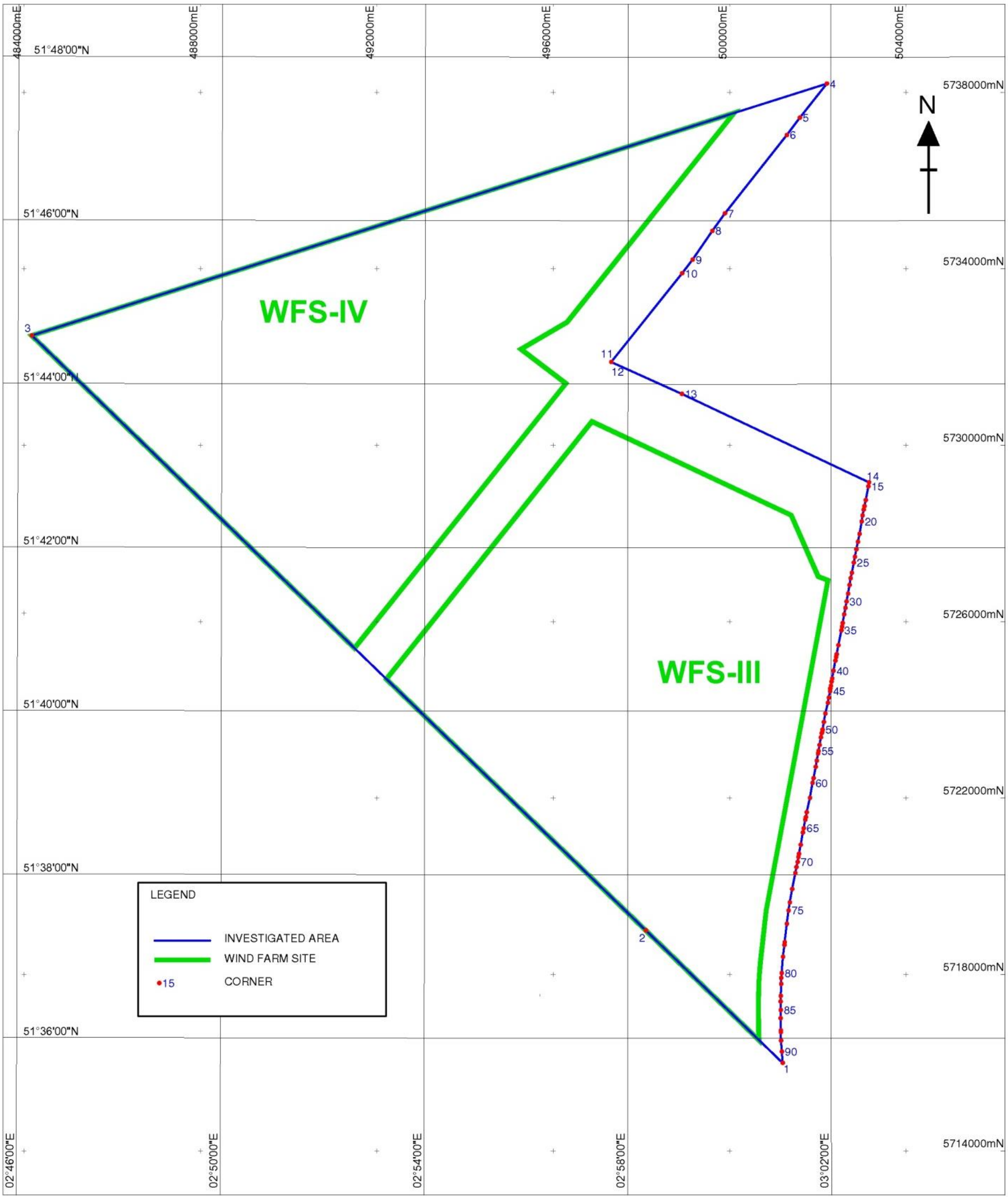


Figure 1.1: The Investigated Area (WFS III & IV)

Figure 1.3 to Figure 1.8 show all known cables and pipelines (including out of use).

1.4 Survey Program

For all lines the single beam and multibeam echo sounders were used simultaneously with the side scan sonar, sub bottom profiler and magnetometer, with a main line spacing of 100 m. The multichannel seismic survey UHR data were acquired with a line spacing of 400 m. The cross lines were planned with 2000 m line spacing, but during the survey, in accordance with the Client it was decided to add 151 km of extra cross lines, in order to better understand the geology of the survey area.

In total 2054 survey kilometres were acquired within WFS III and WFS IV areas with the geophysical equipment (MB, SSS, Magnetometer and SBP) and 776 km survey kilometres with UHR system. The figures are presented below (Figure 1.3 to Figure 1.8).

In particular, within WFS III area, were acquired:

EQUIPMENT	MAIN LINES (WFS III)	CROSS LINES (WFS III & WFS IV)
MAG	1285.51 km	324.83 km
MBES	1295.92 km	301.63 km
SSS	1313.36 km	357.56 km
SBP	1265.97 km	361.73 km
2DUHR	269.97 km	280.66 km

The line name convention is presented below.

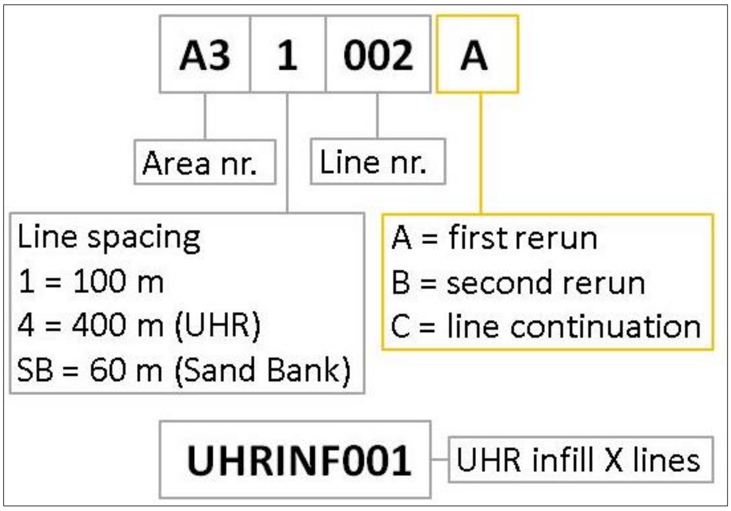


Figure 1.2: Line name convention

Please note that lines run with different equipment have different suffix:

- *SSS: _SL_NavMerged for Low Frequency, _SH_NavMerged for High Frequency*
- *SBP: _HMP_101 to _HMP_105 depending on the number of files acquired with the same line name*
- *UHR: .MIG.EQUAL, .MIG.TRUE Migrated Equalized and Migrated True Amplitude in seconds*
  .MIG.EQUAL.DEPTH, MIG.TRUE.DEPTH Migrated Equalized and Migrated True Amplitude in m
  .UNMIG.EQUAL, .UNMIG.TRUE Unmigrated Equalized and Unmigrated True Amplitude in s
  .NT3 Near Trace

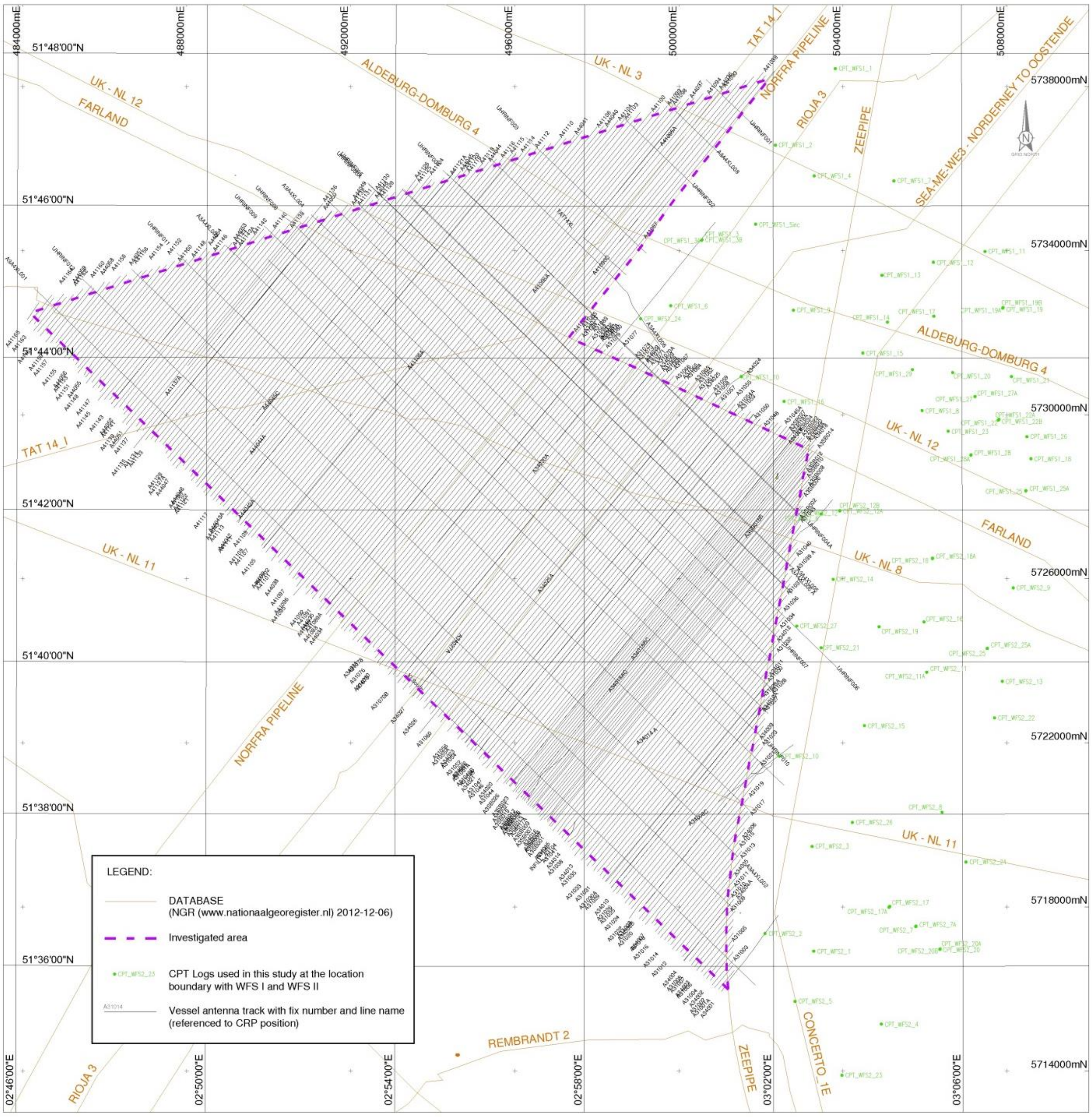


Figure 1.3: CRP track plot.

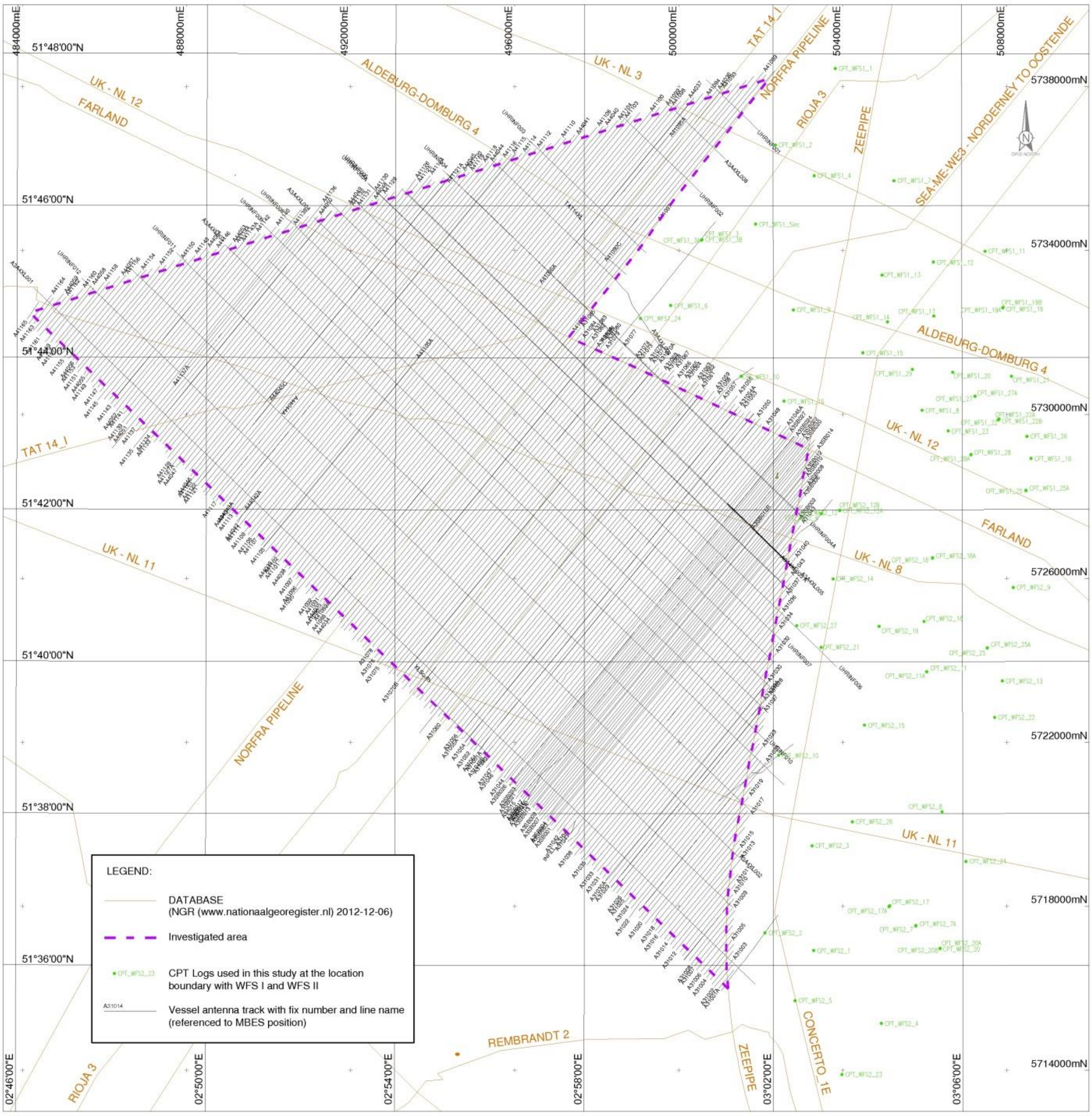


Figure 1.4: MBES track plot.

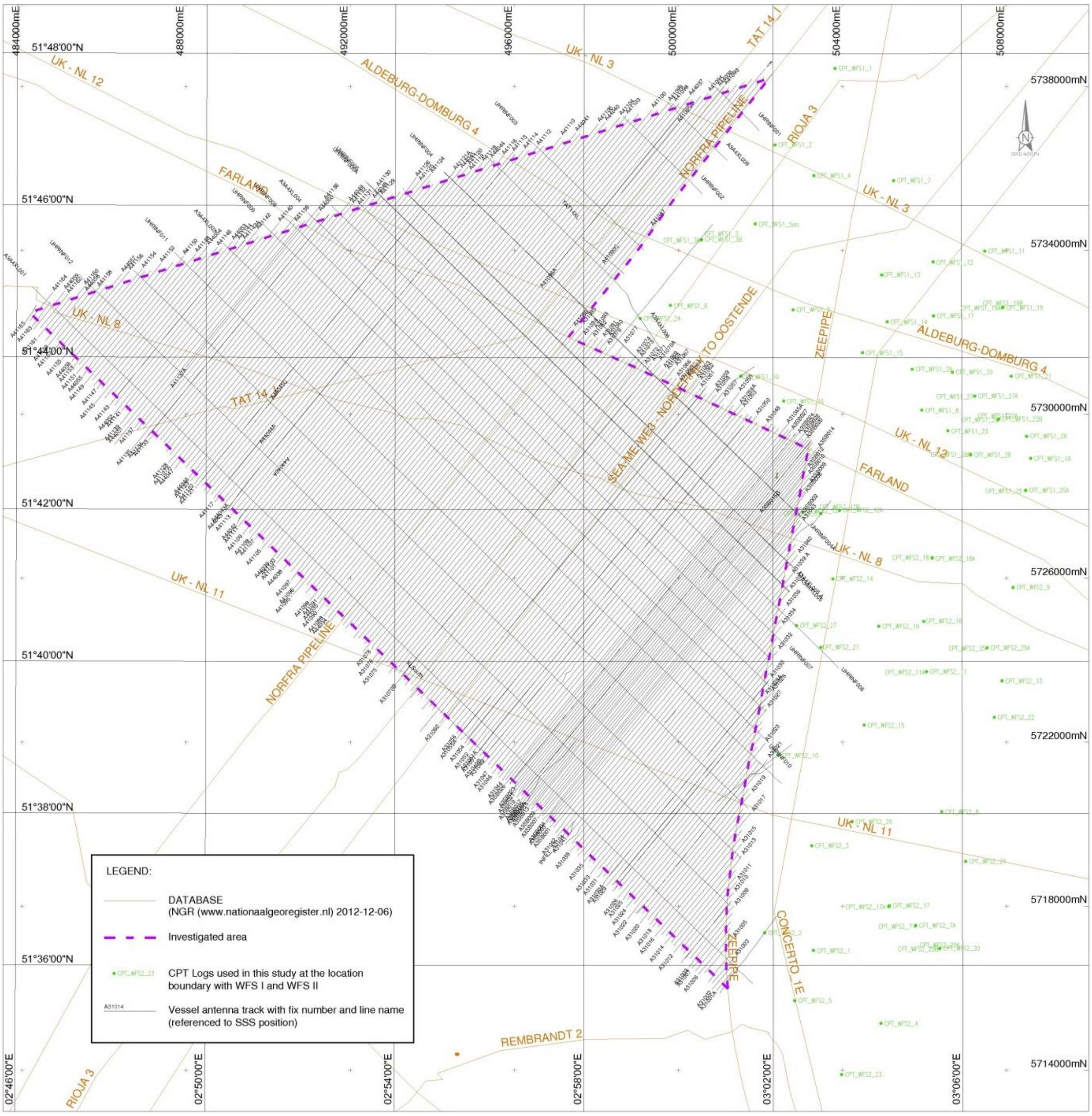


Figure 1.5: SSS track plot

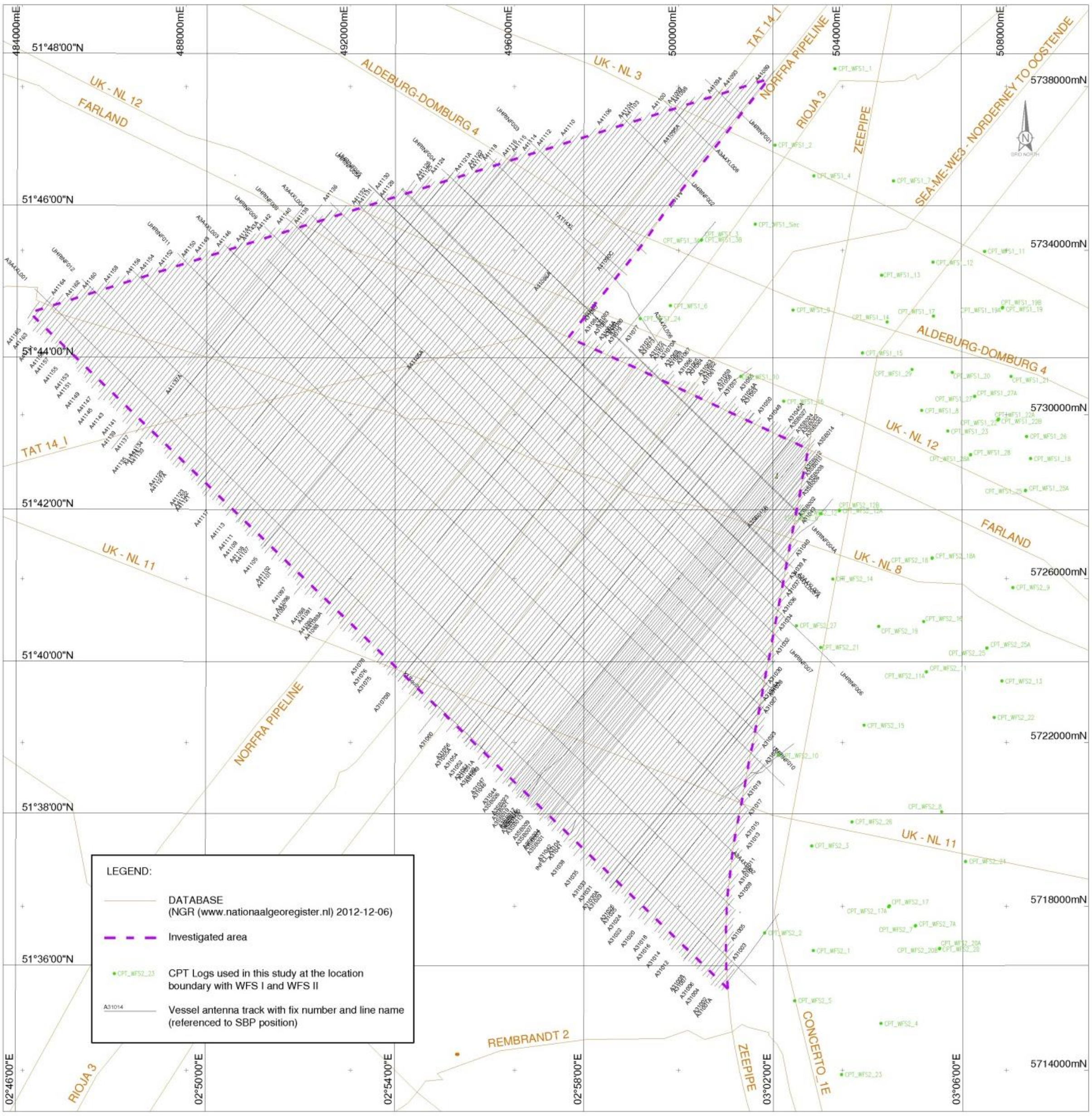


Figure 1.6:SBP track plot

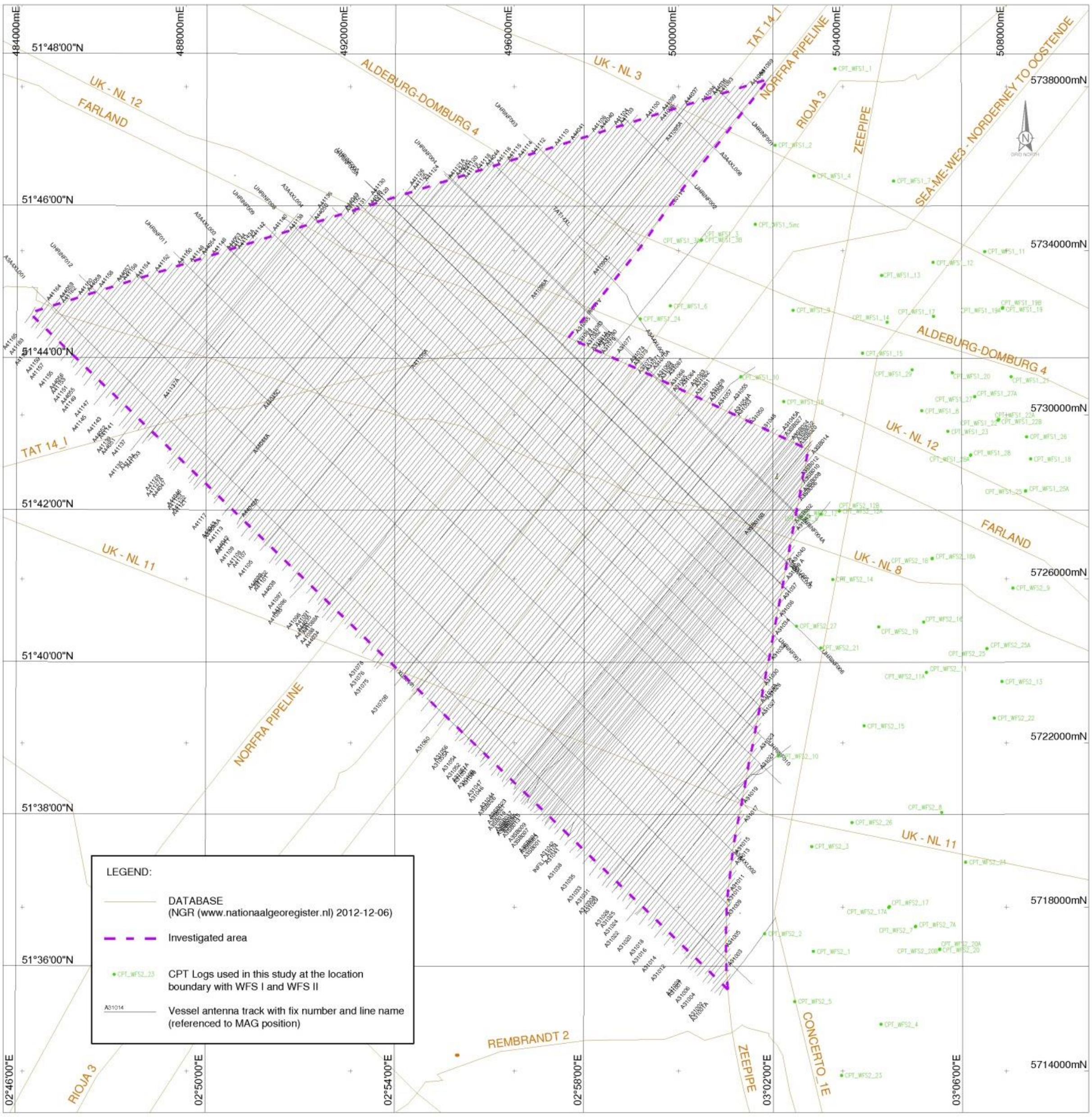


Figure 1.7: Magnetometer track plot

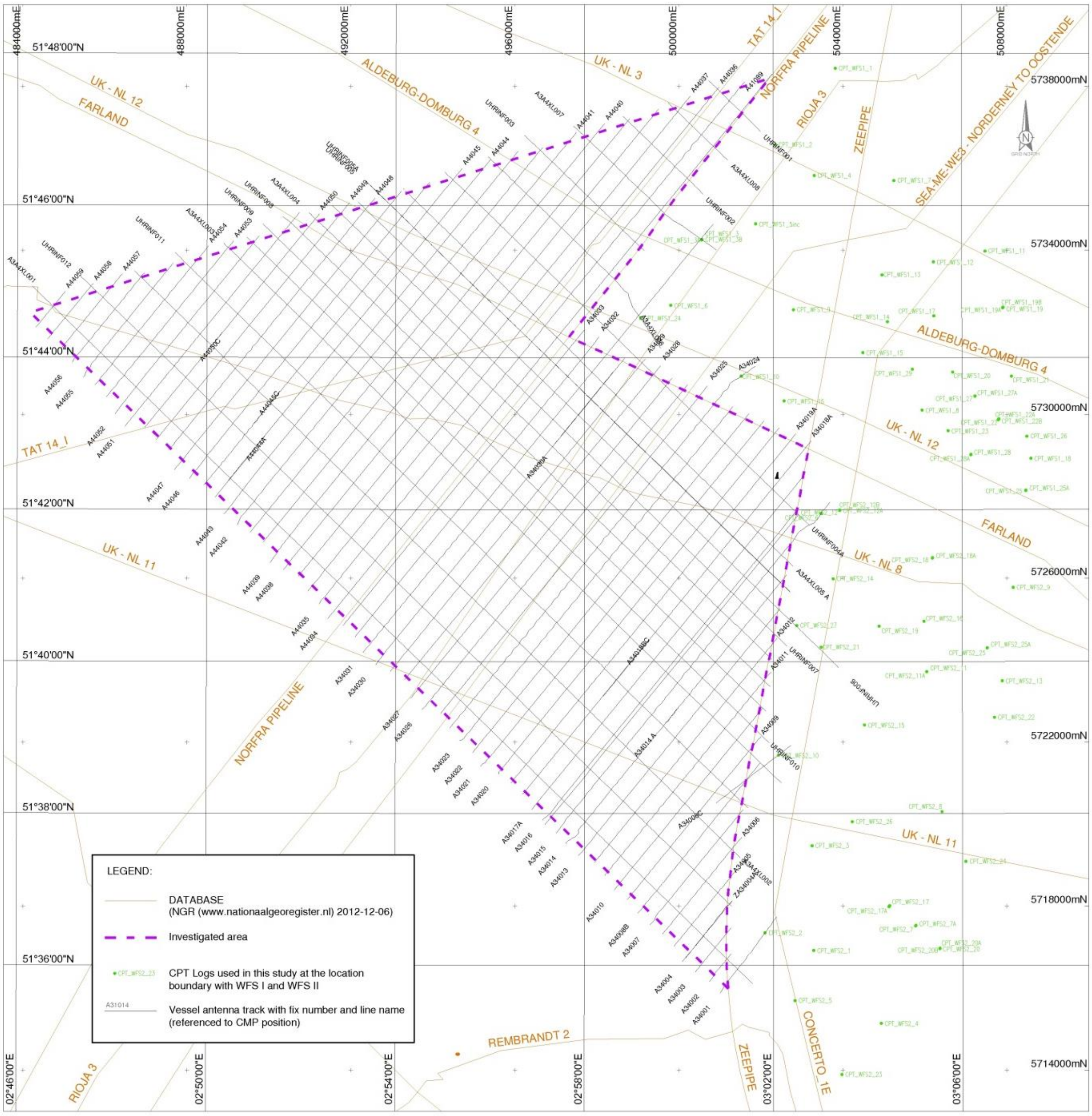


Figure 1.8: UHR track plot.

1.5 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 1980 (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 zone is UTC + 2 hours.

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 1.2.

Table 1.2: Project geodetic and projection parameters

Global Positioning System Geodetic Parameters[1]								
Datum:	WGS84							
Spheroid:	WGS84							
Semi major axis:	a = 6 378 137.000 m							
Inverse Flattening:	$^{1}/_{f}$ = 298.257223563							
Local Datum Geodetic Parameters [2]								
Datum:	ETRS89							
Spheroid:	GRS80							
Semi major axis:	A = 6 378 137.000 m							
Inverse Flattening:	1/f = 298.257222101							
Datum Transformation Parameters [3] from WGS84 to ED50								
Shift dX:	+0.0471	m	Rotation rX:	-0.00211	arcsec	Scale Factor:	+0.0016	ppm
Shift dY:	+0.0562	m	Rotation rY:	-0.01274	arcsec			
Shift dZ:	-0.0038	m	Rotation rZ:	+0.02095	arcsec			
Project Projection Parameters								
Grid:	UTM							
Projection Type:	Transverse Mercator							
UTM Zone	31 Northern Hemisphere							
Central Meridian:	003º 00’ 00.000” East							
Latitude of Origin:	00º 00’ 00.000” North							
False Easting:	500 000 m							
False Northing:	0 m							
Scale factor on Central Meridian:	0.9996							
Units:	Metre							

Notes:
1.Fugro Starfix navigation software always uses WGS84 datum as a primary datum for any geodetic calculations;
2. Source: FUGRO
3. This is the Bursa-Wolfe rotation convention as opposed to the coordinate frame rotation used in Starfix software.

2. SURVEY RESULTS

2.1 Geomorphological Background

The BWFZ is plotted on the nautical chart of the North Sea, compiled by the UK Hydrographic Office (see Figure 2.1). As can be observed from this plot, four parallel sandbanks are crossing the survey area. From shore to sea these are the Rabsbank, Schaar, Buitenbank 3 and Buitenbank 2. A morphodynamic desk study was carried out by Deltares (Ref.14). From historical bathymetric surveys in the BWFZ area Deltares has found that the water depth in the area ranges from -15 to -40 aLAT. The seabed morphology in this area is characterized by high sedimentary dynamics, with static shore-parallel sandbanks overlaid with dynamic shore-perpendicular sand dunes. The sandbanks and sand dunes observed in Belgian sector of the North Sea, directly adjacent to the BWFZ area, are up to 30 meters high and can be several kilometres wide and several tens of kilometres long (Ref.15). Statistical analysis of sand dunes mobility (Ref.14) shows that there are two main directions of sand dune movement, one in NE-direction with an average speed of 1.7 m/yr and one in SW direction with an average speed of 3.2 m/yr. According to Ref.11, the seabed features (ripples, sand waves and dunes) can be classified in terms of dune height, spacing between features and dune shape (2D or 3D) as first order descriptors (Table 2.1). This classification is used to describe the morphological features in the BWFZ.

Table 2.1: Classification scheme for subaqueous bedforms (Ref. 11)

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			

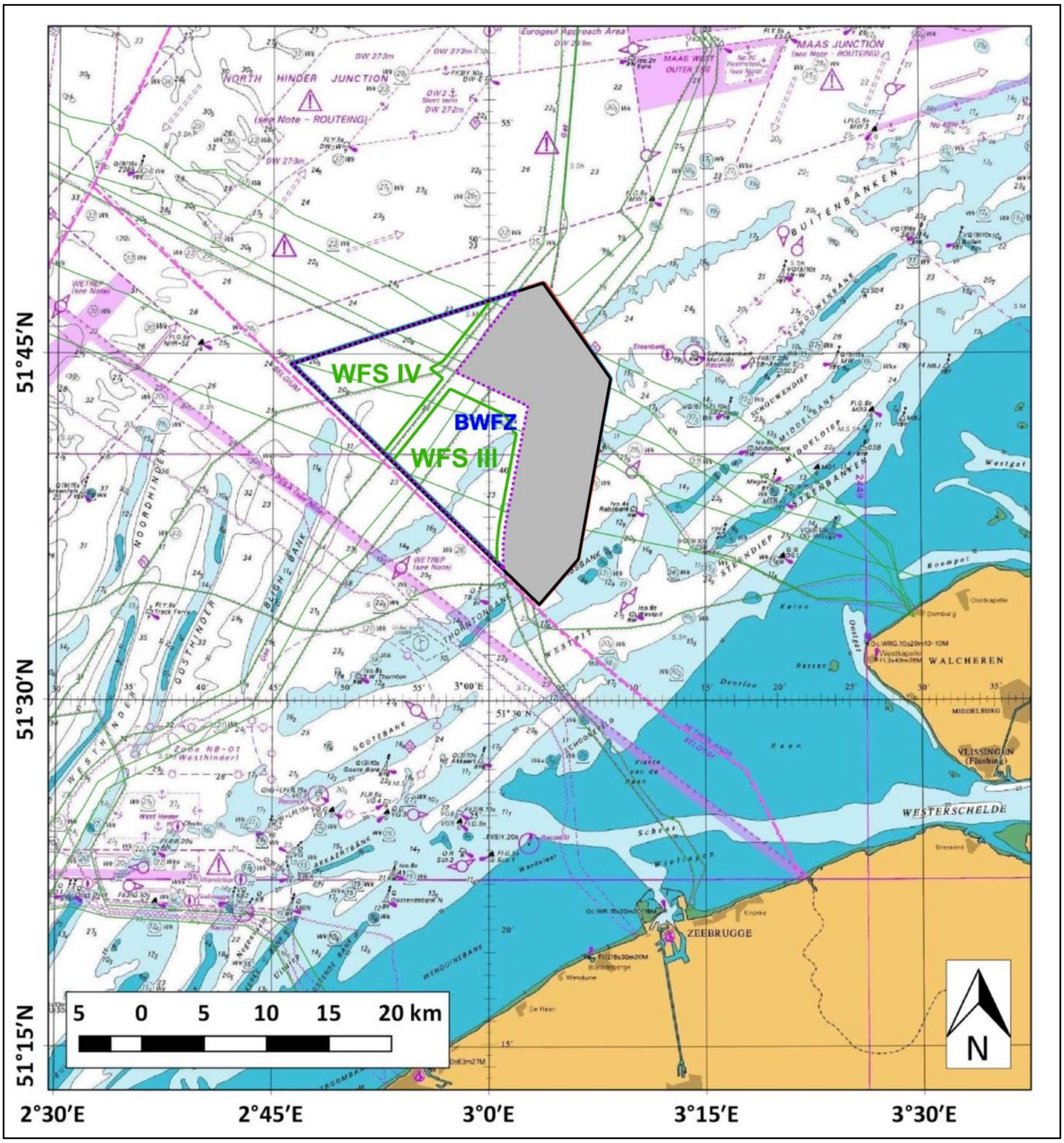


Figure 2.1: Location of the BWFZ, WFS III and IV on a nautical chart.

2.2 Bathymetry

The bathymetry of the entire BWFZ shows a dynamic morphology characterized by a complex pattern of shore-parallel like sandbanks, with superimposed dunes of different orders. In WFS III area, Buitenbank 3 is present. MBES data are presented in Figure 2.2.

In particular, within WFS III area, the bathymetry ranges between -15 m on the major dune crests in the westernmost part of the survey, and approximately -37 m in the south-eastern part of the survey area, in the depressed zones between the dunes.

The dunes have a general NW to SE and W to E crests direction, with an average wavelength between 80 m and 550 m and a height ranging from 2.5 m to 11 m. Superimposed on the major ones, other minor dunes with 10 - 20 m average wavelength and height ranging from 0.25 m to 0.75 m are also present (see also **Geo-Hazard Chart**, Appendix P).

The bathymetry for WFS III is presented in Bathymetry Charts, Appendix K.

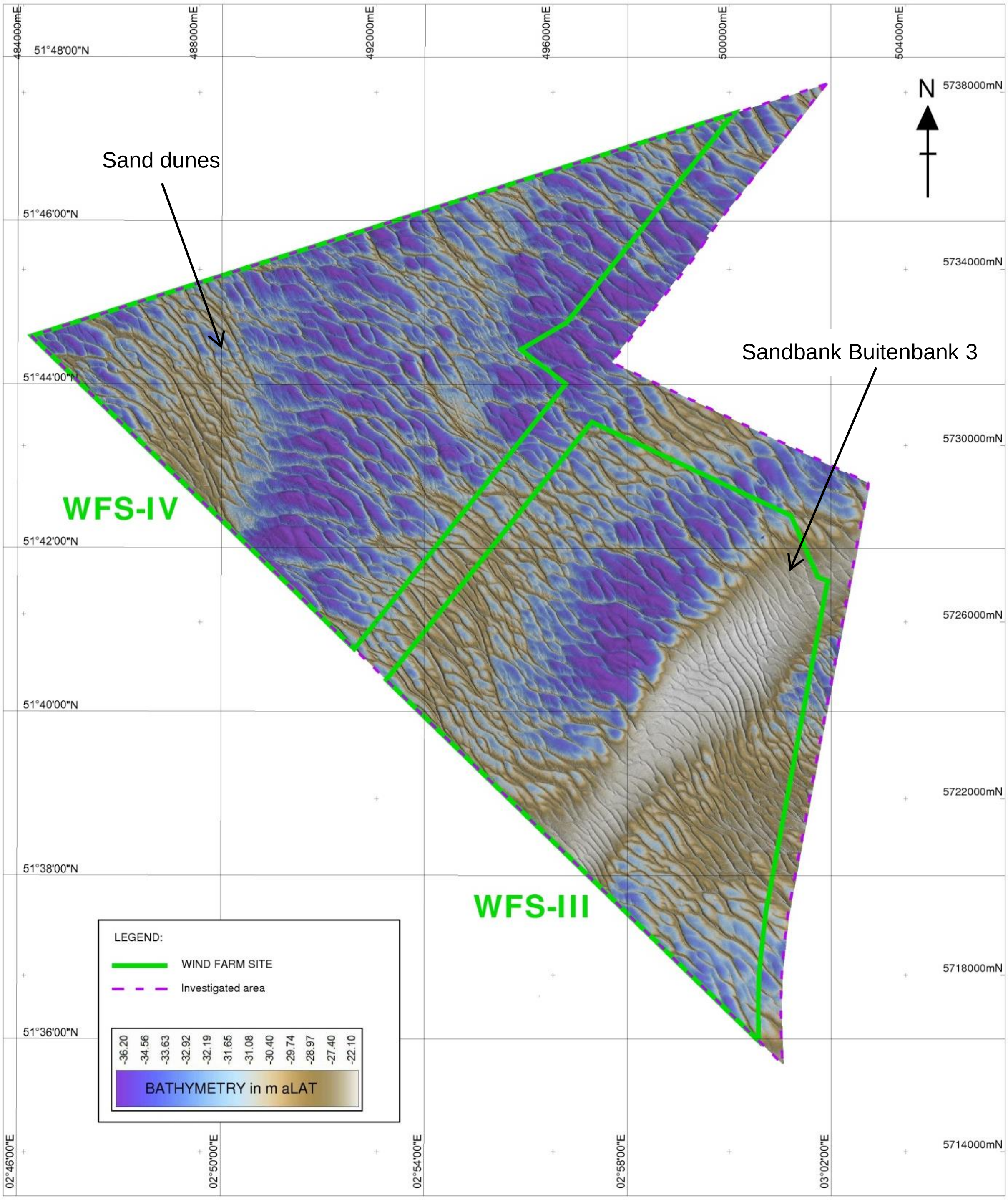


Figure 2.2: MBES data in m aLAT

2.3 Seabed features

The analysis of Side Scan Sonar data was based on the acoustic facies characteristics, including overall pattern, shape, dimensions, backscattering strength, orientation, depth etc.

The seabed is characterized by a medium backscatter, typical of sandy sediments, with local ridges and small higher backscatter patches, possibly related to coarser sediments.

The sand dunes were interpreted accordingly to the classification (Ref.11). Following this classification, only the wavelengths were measured, and the relative height are calculated from the following formula (Ref.12):

$$H = 0{,}0677\,\lambda^{0{,}80998}$$

A bedform map was derived from the MBES data, characterizing areas with different sand dune shape, spacing and crest line orientation. The results are presented in this report as a .tiff file with seabed classification with the shaded relief from MBES in transparency.

The WFS III area is characterized by three classes, sub-divided according to the different wavelengths. The results are shown in Table 2.2 and presented into the **Geohazard Charts**, Appendix P.

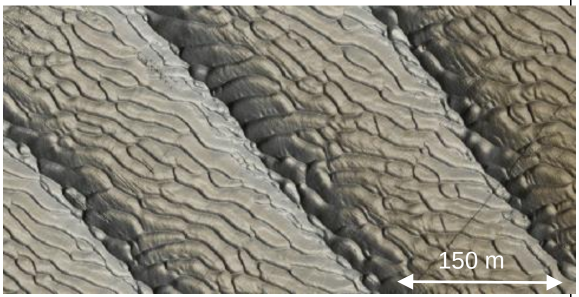
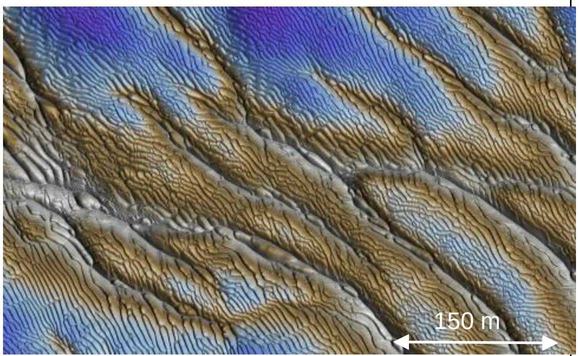
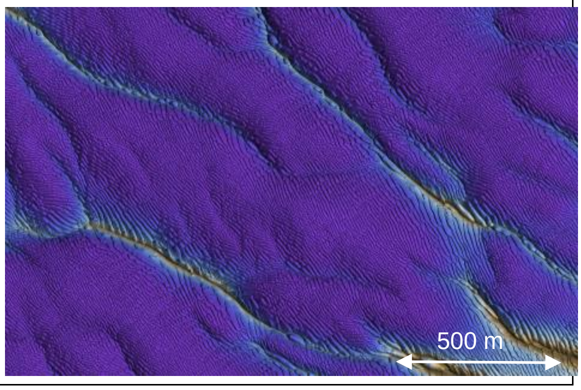
The first class is characterized by large to very large 2D and 3D sand dunes, with wavelength ranging from 80 m to 200 m and heights ranging from 2.35 m to 4.95 m. Smaller dunes, superimposed on the major ones are present with wavelengths ranging from 10 m to 20 m and heights ranging from 0.50 m and 0.77 m.

The second class is characterized by very large 3D sand dunes, with wavelength ranging from 200 m to 300 m and heights ranging from 4.95 m to 9.20 m. Smaller dunes, superimposed on the major ones are present with wavelengths ranging from 5 m to 10 m and heights ranging from 0.25 m and 0.43 m.

The third class is characterized by very large 3D sand dunes, with wavelength ranging from 300 m to 550 m and heights ranging from 6.90 m to 11.23 m. Smaller dunes superimposed on the major ones are present with wavelengths ranging from 5 m to 15 m and heights ranging from 0.28 m and 0.60 m.

Results of this classification are shown in Appendix L and in Figure 2.3.

Table 2.2: Classification scheme for subaqueous bedforms within the Survey Area

Class	Spacing / Wavelenght	Height	Bedform description	Data examples
1	80-200 m	2.35-4.95 m	Large to very large 2D and 3D sand dunes.	
	10-20 m	0.50-0.77 m	Medium to large 3D sand dunes	
2	200-300 m	4.95-9.20 m	Very large 3D sand dunes	
	5-10 m	0.25-0.43 m	Medium 3D sand dunes	
3	300-550 m	6.90-11.23 m	Very large 3D sand dunes	
	5-15 m	0.28-0.60 m	Medium to large 3D sand dunes	

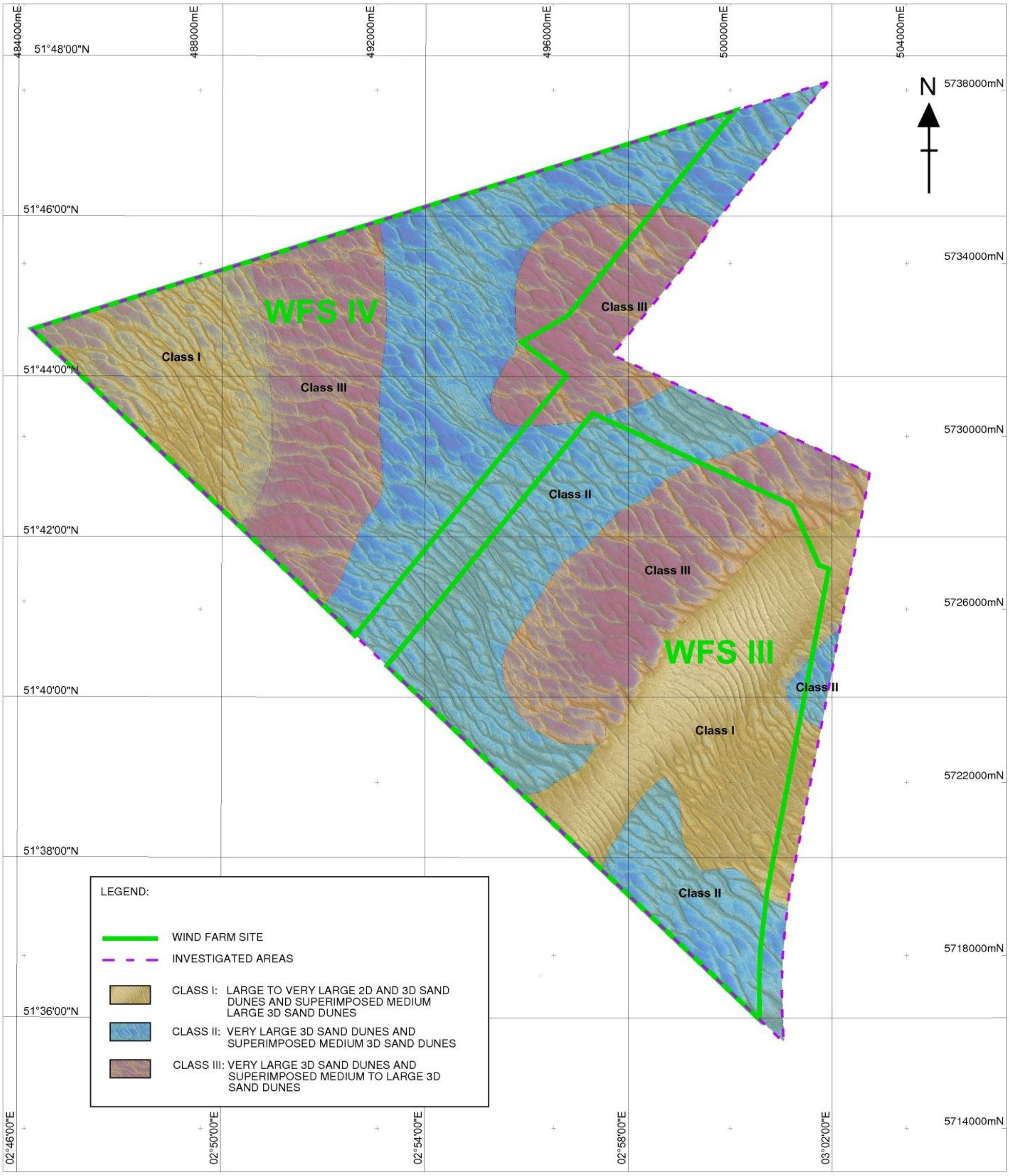


Figure 2.3: Seabed Classification map.

2.4 Seabed Sediment Classification

A general classification of the seabed sediment was calculated from the backscatter analysis of the MBES data. The general principles behind this analysis are explained by Ref.13. The resulting seabed analysis is correlated with the SSS seabed mosaic in order to provide additional information for the seabed sediment classification. Sediments that can be found within the WFS III area mostly consist of dense to very dense sands and loose sands. In particular, for the study area two classes were chosen based not only on the correlation with the SSS mosaic data but also with the results of the CPTs and BHs performed by FEBV in WFS-I and WFS-II areas.

The backscatter analysis of the WFS III area shows a general trend of denser material on the top of the sand dunes, while finer material is found between the sand dunes troughs. This is most likely caused by the top of the sand dunes being mechanically eroded by strong currents, exposing the denser and older sediments and meanwhile providing shelter for the finer sediments in the troughs.

Results of this classification are shown in Appendix L and in Figure 2.4.

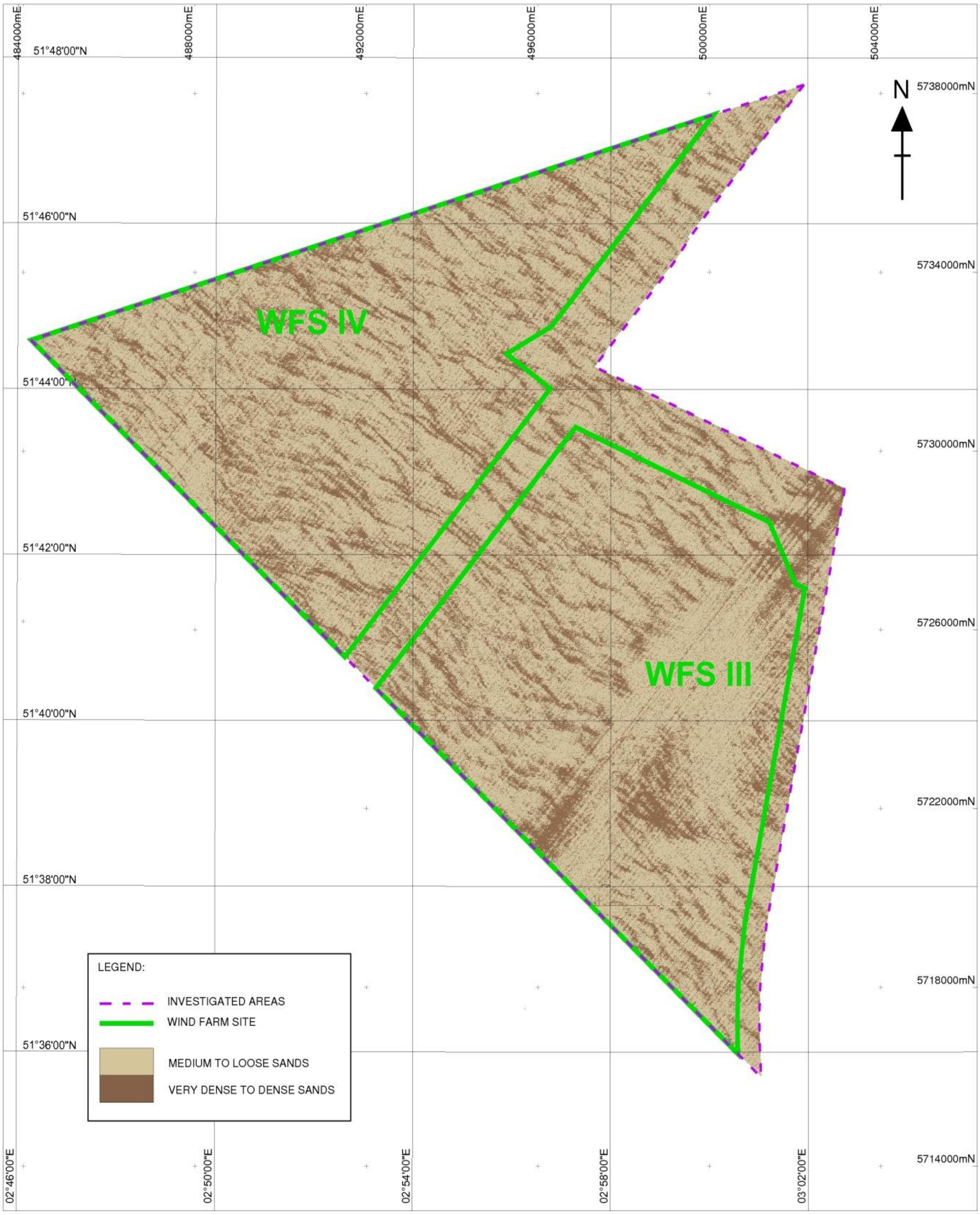


Figure 2.4: Sediment Classification map

2.5 Archaeological background

An archaeological desk study prepared by Vestigia (Ref.17) focuses on two (2) types of archaeological remains. Of both types the archaeological sensitivity is expressed (i.e. how likely it is in a given area to encounter archaeological remains). The first relates to early prehistoric sites and finds, either directly on the seabed, or covered by later sediments, buried under the seabed. Presently early prehistoric sites have not been identified within the wind farm zone itself. Overall, the chance to encounter prehistoric archaeology within the wind farm zone is small (=low sensitivity). The second relates to historic wrecks and other objects, such as lost equipment or cargo and crashed airplanes. Thus far, three objects have been identified as a shipwreck within the boundaries of the whole wind farm zone. Only one has been further identified and is considered to be of no archaeological value. There are a number of obstructions reported within the wind farm zone, at the time of writing of the desk study, these were unidentified and could be wrecks, part of wrecks, but also lost objects, e.g. anchors, chains, cargo, garbage, etc. They may also be the remains of aircrafts, lost in the World War II. For the entire wind farm zone the chance to encounter historic archaeology (shipwrecks, airplanes, etc.) is average (=medium sensitivity).

The results for this survey might include potential archaeological features although none of the contacts encountered could be positively identified as such. Therefore, all contacts labelled as ‘unknown’ or ‘debris’ could potentially be archaeological features.

2.6 Wrecks

The known wreck locations that Vestigia identified in the area of the BWFZ from Ref.22 are displayed in Figure 2.5.

Table 2.3 shows the coordinates of the known wreck locations within the WFS III survey area.

Table 2.3: Known wreck locations in WFS III

	Easting	Northing	MAG	SSS	MBES	Remarks
Wrecks						
3666	497 810.85	5 726 560.52	NO	NO	NO	
1703 (Alca Torda)	496 425.62	5 722 668.73	NO	NO	NO	
1723	500 691.06	5 727 857.99	Possibly	YES	YES	75 m NE of database location
42 (*)	497 508.20	5 722 112.61	Possibly	NO	NO	
1693	498 499.50	5 717 848.70	NO	NO	NO	Outside of survey area

(*) Ref 6

MBES and SSS data acquired 100% coverage of the seabed and magnetometer lines were run every 100 m in order to verify any possible magnetic anomaly related with wrecks. However, this line spacing is not adequate to ensure a good assessment. Moreover, the survey area is characterized by strong currents and relative sediment movements (see Ref.14) that can bury eventual objects on the seabed. This interpretation cannot be confirmed by SBP data, as multiple diffractions caused by the irregular seabed masked the genuine returns from the sub-seabed objects.

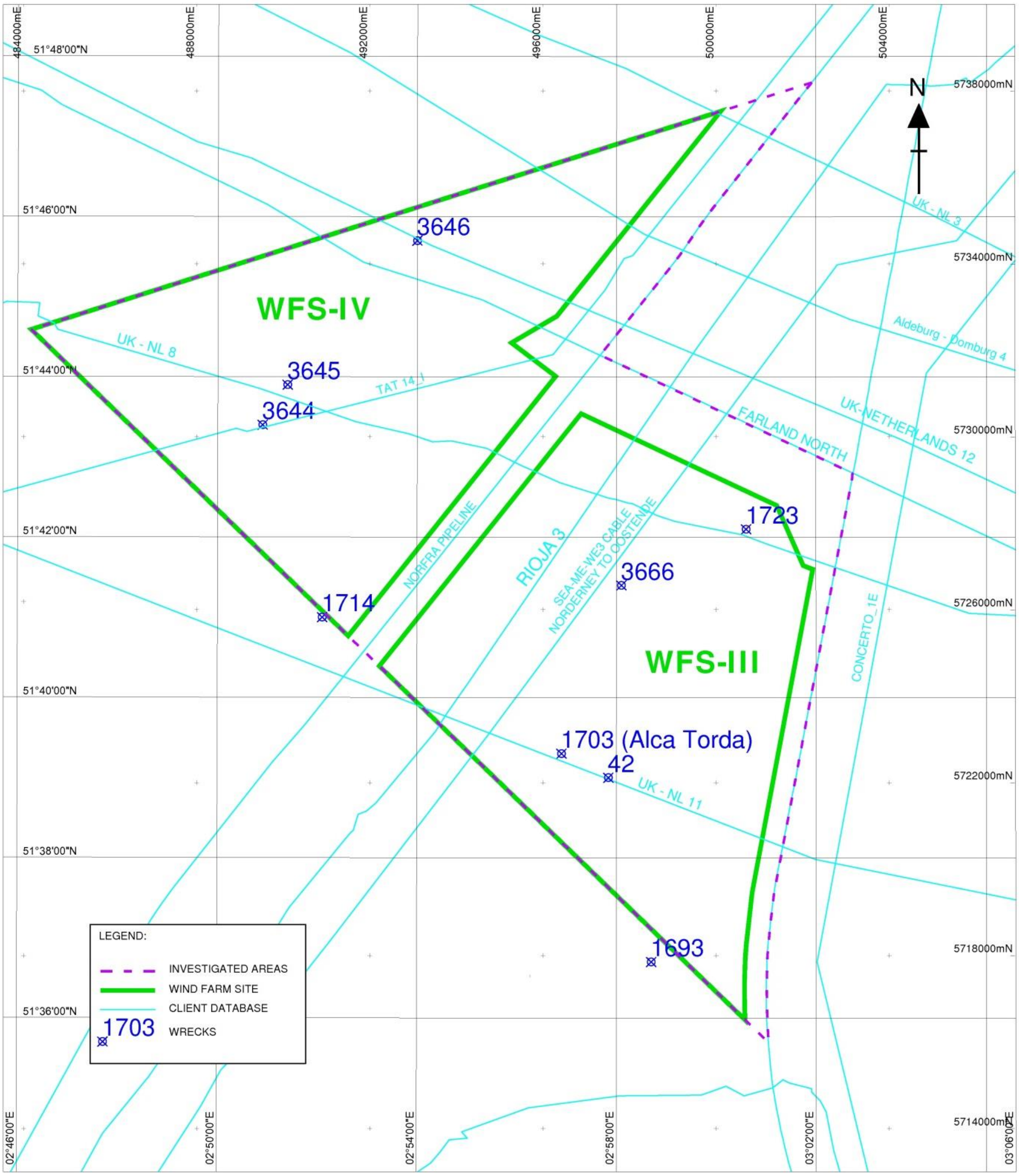


Figure 2.5: Known wrecks locations in the Investigated area

Wreck locations are seldom reliable as often their final positions are last known or mayday positions instead of the actual sinking locations. These positions are also often derived from old imprecise positioning systems.

In the WFS III area wreck location 1723 was confirmed with MBE, SSS and MAG (see Figure 2.6).

None of the other known wreck listed in the database was detected with any of the survey techniques.

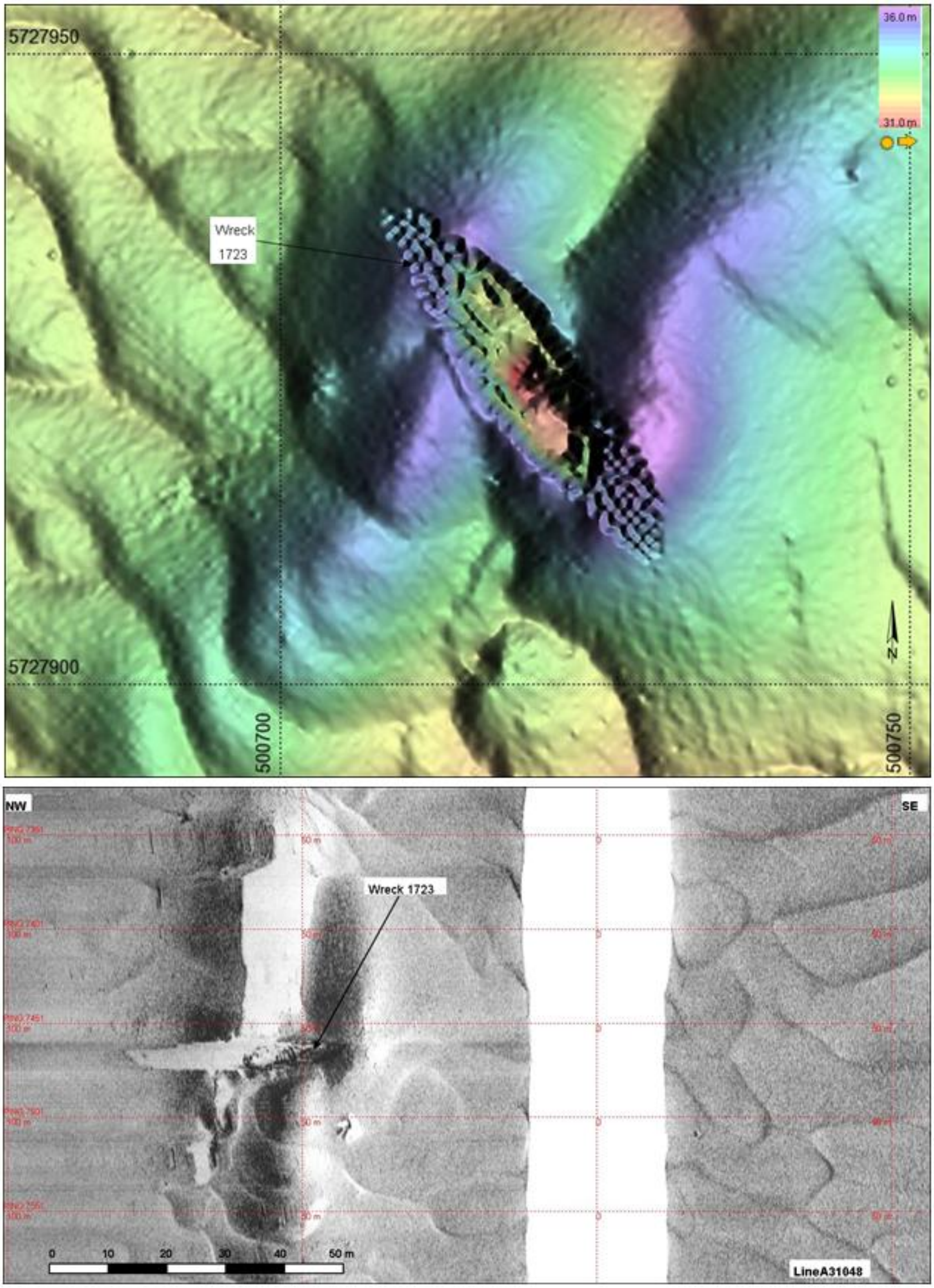


Figure 2.6: SSS and MBES data showing Wreck 1723

2.7 Pipelines and cables

The WFS III area is crossed by two (2) pipelines and five (5) cables. All cables and pipelines were recognized and followed by Magnetometer. MBES and SSS data were used to confirm, where possible, the cables and pipeline positions. Results are shown in the **Contact Charts** – Appendix M.

In WFS III area the NORFRA pipeline was detected to be often exposed on the seabed between the sand dunes. A variable offset in the detection of the NORFRA pipeline was observed between the MAG data and the SSS/MBES data due to limitation in positioning of the magnetometer towed fish. However the interpreted position of the NORFRA pipeline was always found within the accuracy level of the magnetic sensor.

The Zeepipe pipeline (see Figure 2.7) within WFS III was detected to be exposed on the seabed in long sections (one small section in freespan). The exposed segments were cross-referenced between Magnetometer, MBES and SSS surveys, and then mapped.

In WFS III five (5) cables crossing from NE to SW and from NW to SE the survey area were detected, and mapped on **Geohazard Charts**, Appendix P. Some sections of these cables were not recognized in the dataset; this can be related to different burial depths. This interpretation is not confirmed by SBP data, as multiple diffractions caused by the irregular seabed masked the genuine returns from the cables.

Within WFS III survey area three (3) unknown linear targets, two of them assumed to be related, were also identified only by Magnetometer data, not corresponding to any cable from the database provided by Client. They could be interpreted as buried abandoned cables.

Figure 2.8 shows an overview of the detected cables and pipeline. Table 2.4 lists the as-found cables and pipelines and their offsets from the Client supplied database.

Table 2.4: Offsets of cables found in WFS III

	MAG	SSS	MBES	Remarks
Cables				
FARLAND NORTH	YES	NO	NO	Found in the same position provided by the Client
UK-NL 8	YES	YES	NO	A few small sections of possible exposure. Offset: up to 390 m from the provided position.
UK-NL 11	YES	YES	NO	One section of possible exposure in SSS and MBES
RIOJA 3	YES	YES	YES	Partly exposed
SEA-ME-WE3	YES	YES	NO	Two exposed sections visible in SSS
Pipelines				
NORFRA	YES	YES	YES	Exposed between sand waves
ZEEPIPE	YES	YES	YES	Long sections exposed, one small section in freespan

Please note that the Magnetometer data have a horizontal accuracy of approximately 1-3 m.

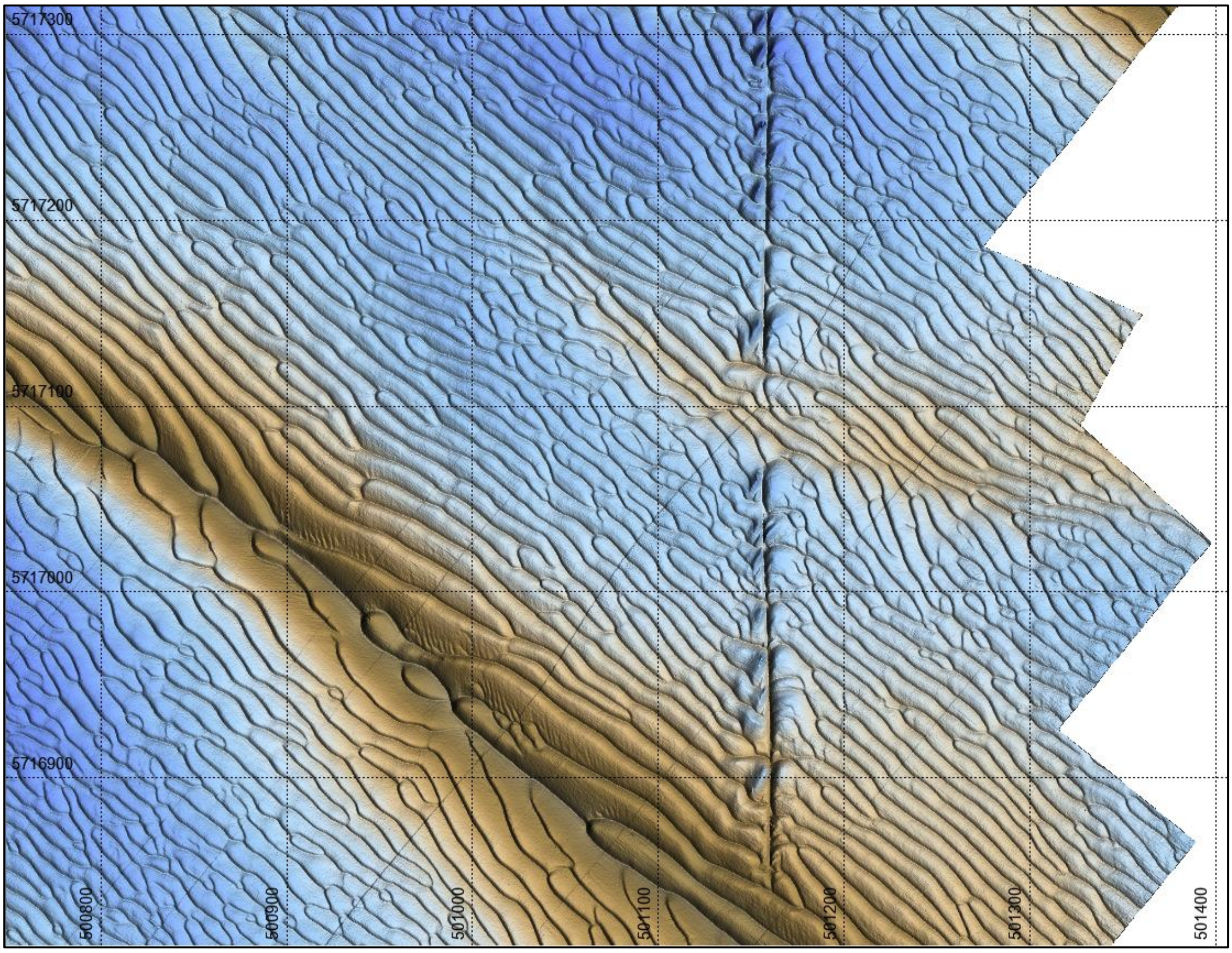


Figure 2.7: MBES data example of Zeepipe exposure pipeline in WFS III.

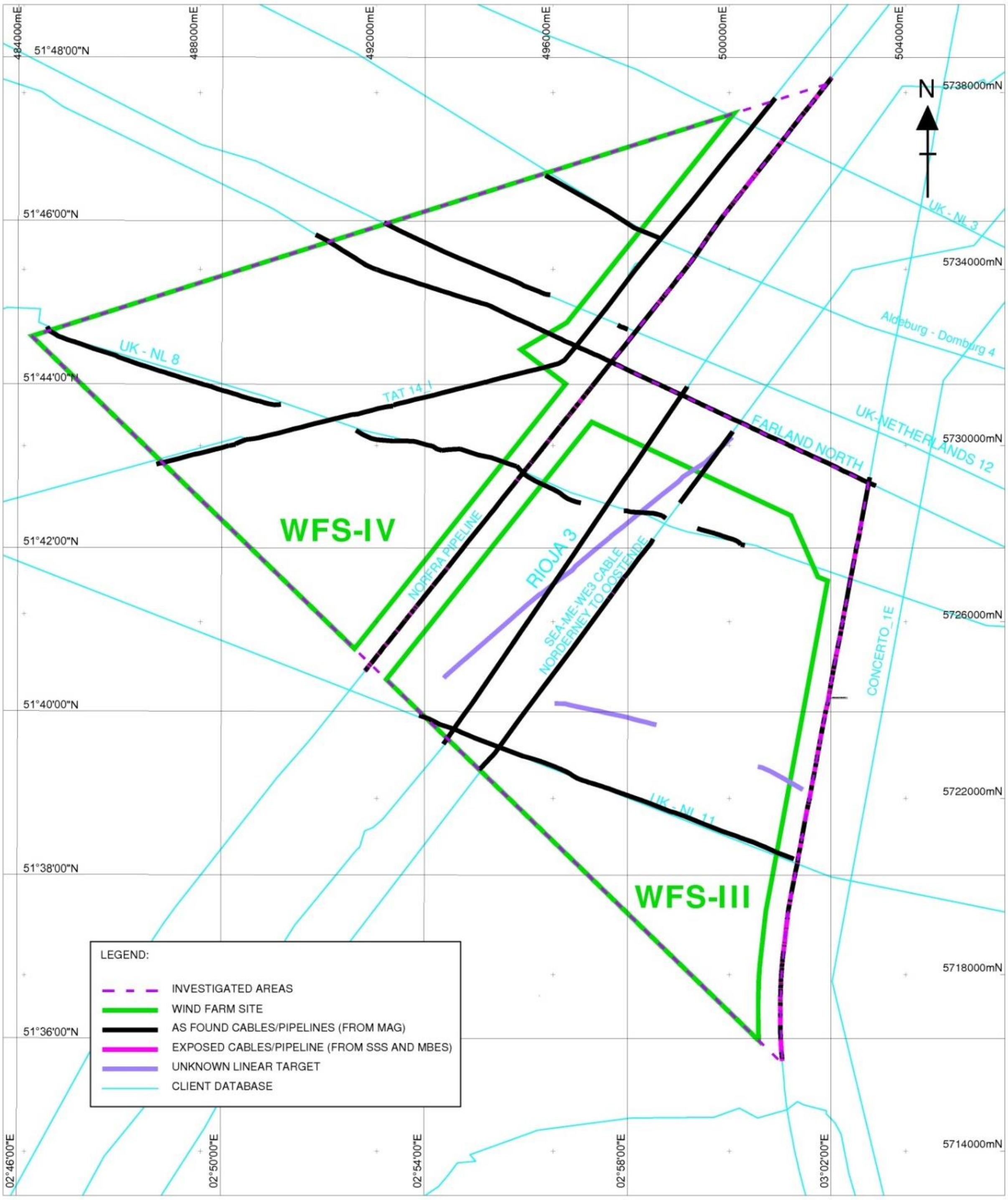


Figure 2.8: Overview map of cables and pipelines in the Investigated area

In black: from Magnetometer data; in cyan as provided by the client; in magenta: identified in MBES and SSS data; in violet: unknown linear targets.

2.8 Other contacts

An UXO desk study was prepared by REASeuro (Ref.8). It comprised a historical inventory, a risk assessment and recommendations. The historical research indicated that the entire survey areas are to be considered as an UXO risk area due to World War I and II related activities. Based on the report from the following hazards are likely to be encountered:

- Naval mines;
- Bombs
- Depth charges
- Naval mine destruction charges
- Torpedoes
- Grenades

Due to seabed dynamics and intensive post war seabed disturbance (i.e fishing/trawling activities) UXO might have moved. It is however stated that: "Until 2005 most of the UXO that were encountered in fishing nets were simply put overboard, often in the direct vicinity of known shipwrecks. These locations were normally avoided because of the risk of damaging the fishing nets, thus offering a gathering place of remnants of war". During the surveys in the BWFZ no UXO detection survey was carried out. The 100 meter line spacing between the magnetometer survey lines was not suitable to perform an UXO survey. The acquisition of high resolution magnetometer data does facilitate identification or confirmation of positions of known wrecks (potential gathering places) and other possible unknown ferruginous debris. The high resolution MBES and SSS survey allow better understanding of the morphology and movement of the sand dunes and forms a base that can be used to identify objects, debris fields and wrecks. As is stated in the desk study it is recommended to reassess the UXO related risks based on the first draft of the design for the wind farm.

Within the survey area, 234 SSS targets were recognized, with dimensions and heights ranging from 0.2 to 9.7 m and generally less than 1 m respectively (except for the Wreck 1723, dimensions 17.58 m x 3.9 m x 2.75 m). These targets were observed spread throughout the entire survey area and were interpreted as to be only debris patches. No boulders were expected considering the palaeo-environmental context and none were identified. A noisy magnetic area was found at the Sandbank Buitenbank 3 location. Multiple causes of such an anomalous magnetic distribution are possible, such as geological surficial anomalies and/or scattered buried objects.

Moreover, 685 MAG targets were recognized, with anomaly amplitudes ranging from 1 nT to 12982 nT. The major targets were observed in correspondence of the cables and pipelines crossing the WFS III area, but there are also a number of smaller targets spread throughout the survey area. The interpretation of these targets permitted to follow three (3) unknown linear targets, two of them assumed to be related, that were not listed in any previous database.

SSS and MAG contact were correlated, where possible. For full details see Appendix I – Tabulated Survey Results and **Contact Charts** – Appendix M.

2.9 Geological Background

A geological desk study has been carried out by CRUX Engineering BV (Ref.3). Most information in this report was derived from the geological maps compiled by British Geological Survey (Ref.1), and more recent lithological descriptions are suggested by Reference 7. In this report, however, the terms used in the geological maps (Ref.1) will be maintained. The survey area is located in the southern North Sea, offshore Netherlands, near the border with Belgium. The southern North Sea resulted from the tectonic spreading that started in the Triassic and ceased in the Early Cretaceous time. To the south-west of the area, a major feature is present: the London-Brabant High, having constituted a major structural high since Triassic time (Figure 2.9).

In Cretaceous times, the area of the southern North Sea was set in a shallow water environment and sediments from this period consist mainly of evaporites and limestones. In the Late Cretaceous the Alpine orogeny started in Central Europe, which led to large volumes of erosional material rocks being exposed to sub-areal erosion and contributed to the deposition of sediments in the North Sea throughout the Tertiary period. During this period the area experienced different rates of thermal subsidence, in response to the gradual lithospheric cooling of an underlying Mesozoic rift dome, dominated by broad syncline downwrapping towards a depositional axis to the north-east (Ref.2), where the Pliocene to Holocene geological units thicken in section view. The approximate location of BWFZ is located in the south-west part of this broad syncline (Figure 2.10).

In correspondence of the Borssele WFZ, Tertiary deposits form a monocline dipping towards NE (Figure 2.10). These deposits are truncated on top by an erosional unconformity, resulting from regional uplift related to Savian tectonic phase (Ref.10), and overlaid by Quaternary deposits.

During the Quaternary, the North Sea basin has been subject to numerous sea level changes related to glacial and inter-glacial periods. This has resulted in shallow marine to fluvial deposits in inter-glacial periods alternated with erosional/channelling processes during low-stands in the glacial periods (Figure 2.11). During the Holocene, a rapid sea level rise was experienced due to melting of glacial ice caps. The North Sea basin was drowned and therefore deposits from this period, which in the area are found on and directly under the seabed, are related to a shallow marine environment and to the subaqueous mobile sands (sand dunes) that make up the most recent geological formations.

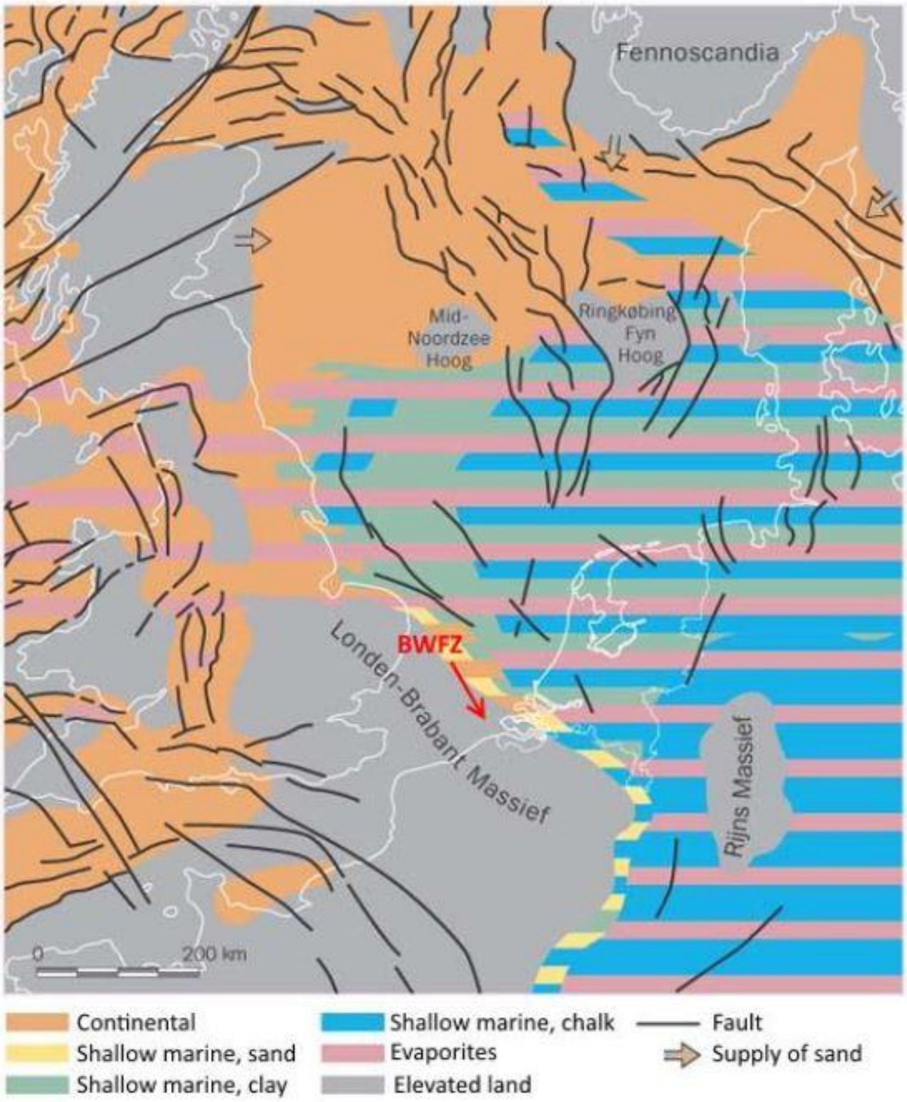


Figure 2.9: Paleo-geographic map of Northwestern Europe in the Triassic period.

In Figure 2.8 the location of the BWFZ is indicated in red. Modified from Reference 7.

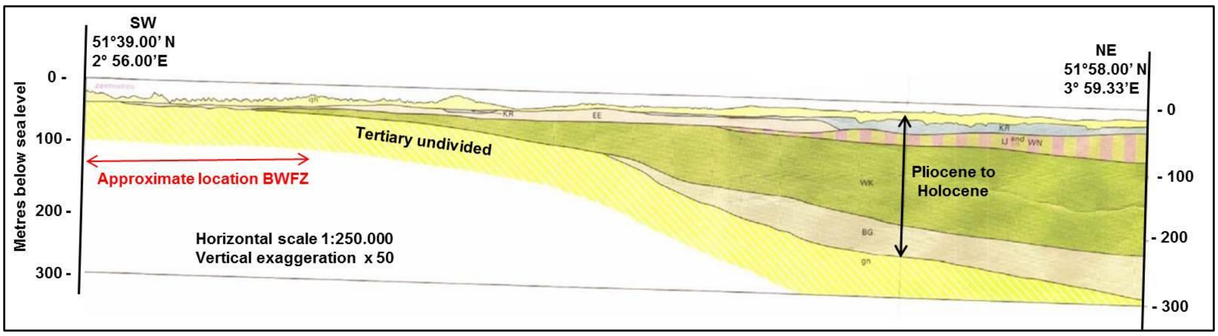


Figure 2.10: Schematic cross-section.

The figure shows the general relations of the sedimentary formations between Tertiary undivided (Paleocene to Miocene) and Pliocene to Holocene. Modified from Reference 1.

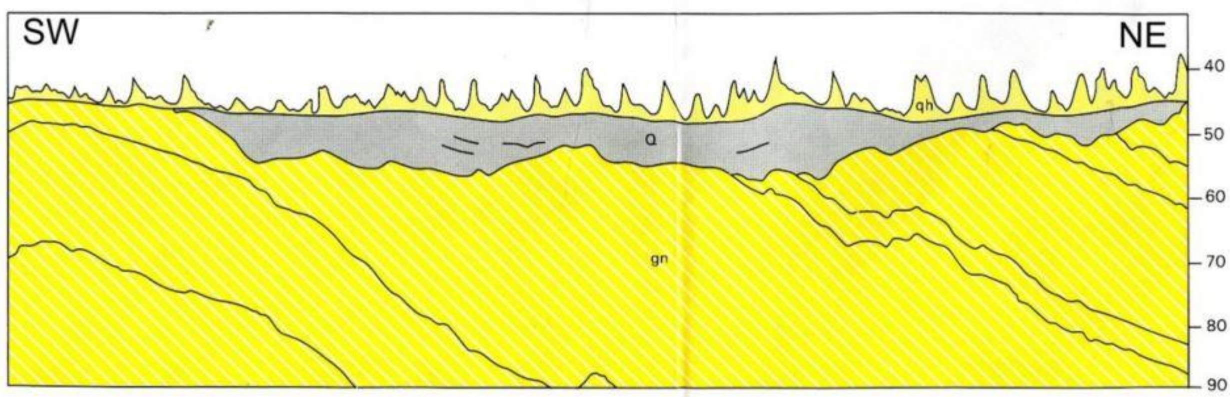


Figure 2.11: Schematic cross-section.

The figure shows Quaternary channel deposits over Tertiary undivided deposits (Palaeocene to Miocene). Quaternary deposits depicted in grey, Tertiary undivided deposits are the tilted yellow layers underneath. Vertical exaggeration 50x. Colors and nomenclature in accordance with Reference 1.

2.9.1 Geology of the Survey Area

Limited geophysical and geotechnical research has been carried out in the BWFZ so far. From the DINOloket repository, managed by the Dutch Geological Survey (Ref.8) only a limited number of borehole locations are found in the survey area, none of them reaching more than 6 meters. Therefore, lithological and thickness information provided in the present report refer to values that can be found in CPT logs supplied by FEBV at the adjacent WFS I and II (Ref.4), available publications (Ref.7,8,9) and onshore geological information as well.

The presented lithostratigraphy of the Quaternary formations is according to Ref.7 that better reflect the lithological characteristics in the investigated area. It is assessed to be more applicable than the onshore lithostratigraphy for the Quaternary proposed by TNO (Ref 8).

The presented lithostratigraphy of the Tertiary is according to Dutch onshore nomenclature (Ref.8) that was differentiated according to the more detailed Belgian lithostratigraphy (Ref.9, 21), where appropriate. Furthermore the Tertiary lithostratigraphy was defined separately for onshore and offshore The Netherlands; the onshore nomenclature is more detailed and it is assessed to be more applicable respect to the offshore nomenclature for the Tertiary (Ref.8, 21), as shown in Table 2.5.

Table 2.5: Tertiary Lithostratigraphic Correlation

<table>
<tr><th>Belgian Lithostratigraphy</th><th colspan="3">Netherlands Lithostratigraphy Onshore</th><th colspan="2">Netherlands Lithostratigraphy Offshore</th><th colspan="3">Chronostratigraphy</th></tr>
<tr><th>Member</th><th>Formation</th><th colspan="2">Member</th><th>Formation</th><th>Member</th><th>Age</th><th>Epoch</th><th>Period</th></tr>
<tr><td>Rupel Clay</td><td>Rupel</td><td colspan="2">Rupel Clay</td><td rowspan="3">Rupel</td><td>Rupel Clay</td><td rowspan="3">Rupelian</td><td rowspan="3">Oligocene</td><td rowspan="13">Tertiary</td></tr>
<tr><td>Ruisbroek Sand</td><td rowspan="5">Tongeren</td><td rowspan="5">Zelzate</td><td>Ruisbroek</td><td rowspan="3">Vessem</td></tr>
<tr><td>Watervliet Clay</td><td>Watervliet</td></tr>
<tr><td>Bassevelde 3 Sand</td><td rowspan="3">Bassevelde</td><td rowspan="3">*Undifferentiated*</td><td rowspan="3">Priabonian</td><td rowspan="10">Eocene</td></tr>
<tr><td>Bassevelde 2 Sand</td><td rowspan="2"></td></tr>
<tr><td>Bassevelde 1 Sand</td></tr>
<tr><td>Onderdijke</td><td rowspan="7">Dongen</td><td colspan="2" rowspan="3">Asse</td><td rowspan="7">Dongen</td><td rowspan="3">Asse</td><td rowspan="2">Bartonian</td></tr>
<tr><td>Buisputten</td></tr>
<tr><td>Zomergem</td><td rowspan="5">Lutetian</td></tr>
<tr><td>Onderdale</td><td colspan="2" rowspan="4">Brussels Sand / Brussels Marl</td><td rowspan="4">Brussels Sand / Brussels Marl</td></tr>
<tr><td>Ursel</td></tr>
<tr><td>Asse</td></tr>
<tr><td>Wemmel</td></tr>
</table>

Table modified after Reference 20

In detail:

- The main difference between the Netherlands onshore and offshore Tertiary lithostratigraphy is that the onshore Tongeren Formation is part of the offshore Vessem Member and named thereafter, i.e. the Tongeren Formation is omitted from the offshore Tertiary lithostratigraphic nomenclature. Note that the offshore Vessem Member represents the lower part of the offshore Rupel Formation (below the Rupel Clay Member), and that the offshore Rupel Formation therefore correlates with both the onshore Rupel Formation and the onshore Tongeren Formation (Ref.20), as shown in Table 2.5.

- The Watervliet (or Goudsberg) Clay member of the Tongeren formation (see Table 2.5) is limited only to the onshore area (southern Limburg area) according to Reference 8, and not present in the Southwest Netherlands, where BWFZ is located (Figure 2.12). While, the Steensel Sand member above the Rupel Clay member is present and restricted only to the Roer valley Graben (Figure 2.12) and then not displayed in Table 2.5.

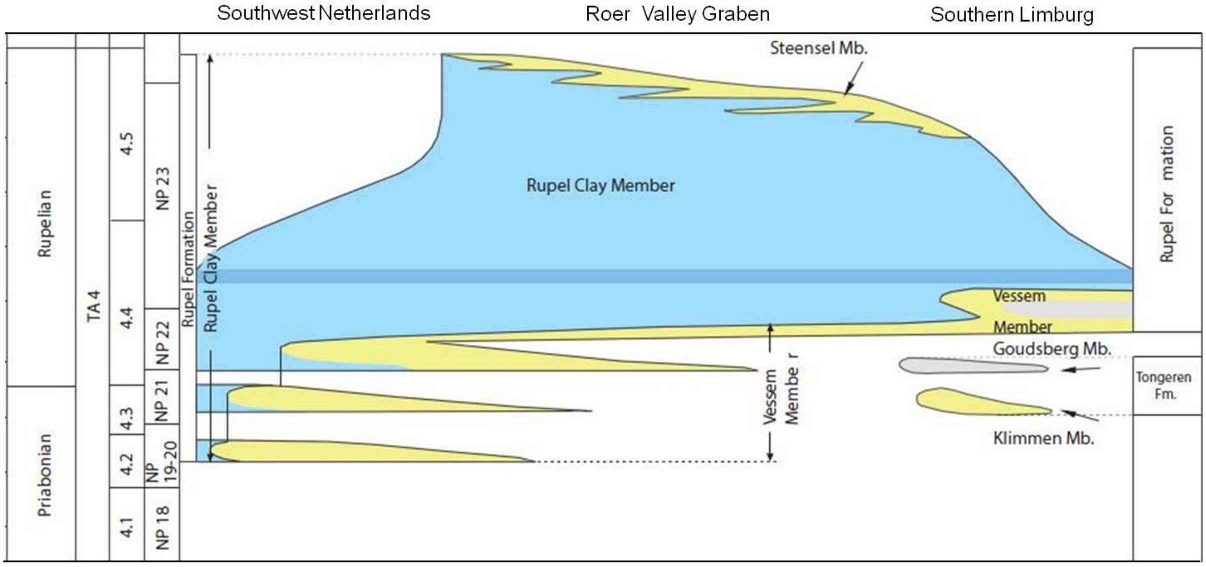


Figure 2.12: Upper Eocene-Early Oligocene stratigraphy across The Netherlands area.

Figure modified after Reference 8

- The Bassevelde Sand Member (Tongeren Formation) and the Asse Member (i.e. Dongen Formation) have been further subdivided based on Belgian lithostratigraphy (Ref.21). The lithostratigraphy according to Reference 21 differentiates the Bassevelde Sands in three separate units (based on micro-fauna) (see Table 2.5).

- The lithostratigraphic unit names defined by the Dutch onshore nomenclature for the Tertiary are almost the same as the corresponding Belgian lithostratigraphic member names. The Belgian Sector of the North Sea is adjacent to the Borssele WFZ, and then a correlation with the Netherlands lithostratigraphy onshore was done (see Table 2.5). The middle-upper part of the Dongen Formation (Bartonian and Lutetian in age) corresponds with the Maldegem Formation (in Belgian nomenclature), as shown in Figure 2.13, and was further differentiated in the Onderdijke Member (clay), Buisputten Member (sand), Zomergem Member (clay), Onderdale Member (sand), Ursel Member (clay), Asse Member (clay) and Wemmel Member (sand with intercalation of calcarenite horizons) (see Table 2.5) (Ref.20).

- In this area, based on the correlation between CPT logs (Ref.4) and the seismic UHR data the Dongen Formation was interpreted up to the Onderdale clayey Sand member corresponding to the upper part of the Brussels Sandstone member in Dutch nomenclature (see Table 2.5).
According to Ref.8 the member of the Brussels Sand (Dongen Formation) over large areas has been eroded. In particular it is missing as a result of erosion on the Southern Early tertiary High, which corresponds to the WFS III and IV survey areas. The lithological description of Unit F as very stiff to hard Clay was confirmed by CPT log data and seismic character of UHR.

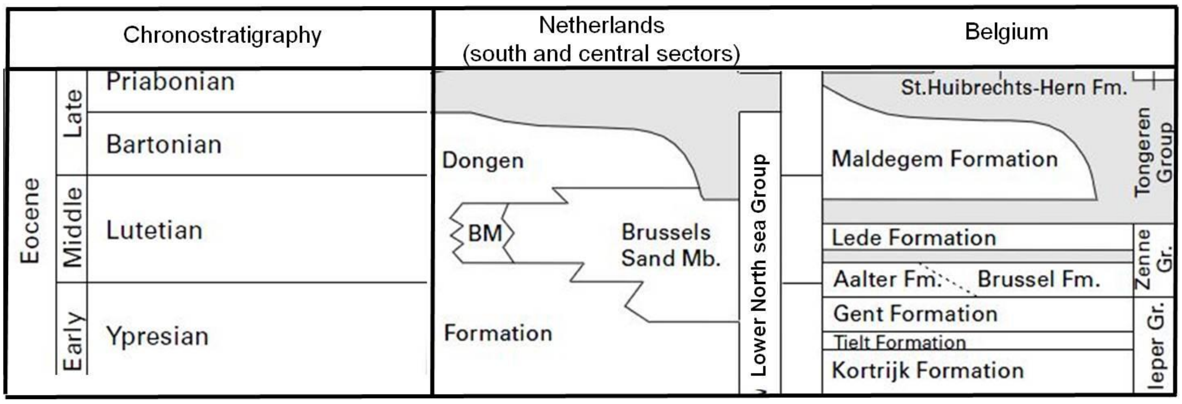


Figure 2.13: Eocene stratigraphic correlation between The Netherlands and Belgium area.

Table modified after Reference 8

The Table 2.6 shows an overview of the relevant geological formations of the area and a correlation between Fugro (this report) and Deep (Ref.17), Seismic Stratigraphic Units.

Table 2.6: Overview of the relevant geological formations and correlation between Fugro and Deep results

Chronostratigraphy		Formation/Member		Seismostratigraphic Unit/Sub-Unit (Fugro, 2015)		Seismostratigraphic Unit (Deep, 2015)
Quaternary	Holocene	Southern Bight		A		U7
	Pleistocene	Kreftenheye /Eem		B		U6
Tertiary	Early Oligocene To Upper Eocene	Tongeren	Ruisbroek Sand	E	E1	U5
			Bassevelde (Ba3)			
			Bassevelde (Ba2)		E2	U4
			Bassevelde (Ba1)			U3
	Early to Middle Eocene	Dongen	Onderdijke	F	F1+F2	
			Buisputten			U2
			Zomergem		F3	
			Onderdale		F4	U1

In WFSIII Unit C and Unit D (present in WFSIV area) are eroded.

The Kreftenheye, Brown Bank and Eem Formations were undifferentiated within Unit B, to adhere to the geological model developed by FEBV (Ref.4) and approved by Client.

In the WFS III, Unit C (Westkapelle Ground Fm. - Pleistocene) and Unit D (Rupel Fm as Rupel Clay member - Oligocene) are not present (see Table 2.6).

A mismatch between the stratigraphic log of the two surveys, is that the top of the Dongen Formation was set by Deep at the top of the intensely faulted interval, while in this report the top of Unit F was set at the transition from Bassevelde Sand member (Tongeren Formation) to underlying Onderdijke Clay member (Dongen Formation), based on CPT logs (Table 2.7), which is a bit higher (Table 2.6).

Tertiary units, mainly sand and clay in different proportions with local variable amounts of gravel and calcareous contents, become older to the south-west (Figure 2.14) and therefore the depositional hiatus between these units and the upper Quaternary deposits, mainly made up of sand with local occurrences of gravel and clay, increase towards the south-west.

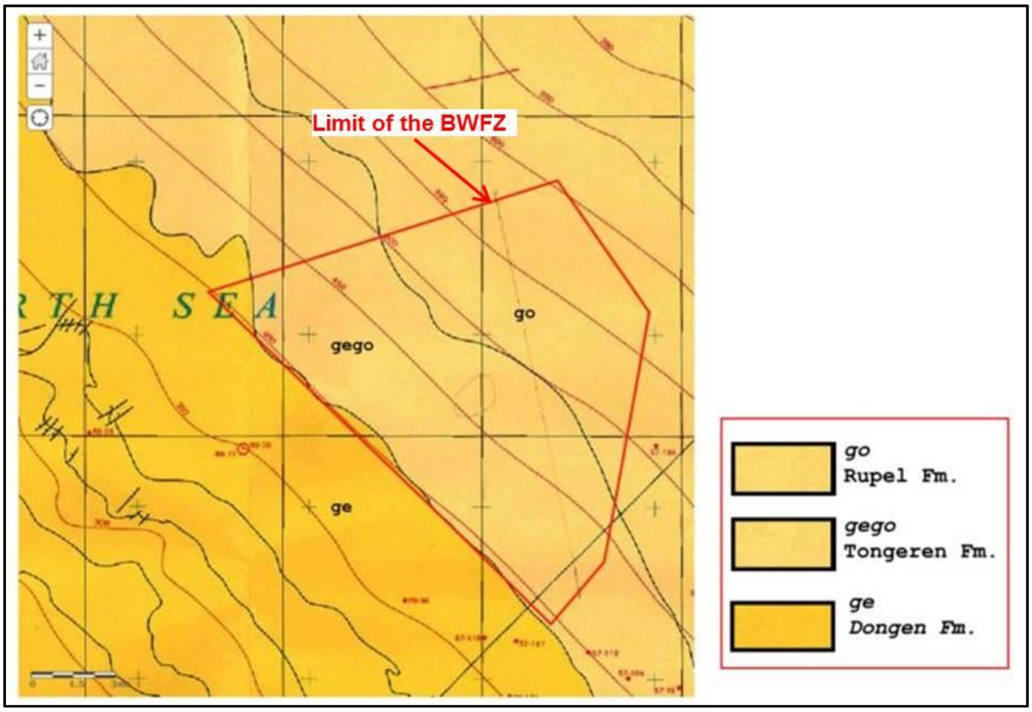


Figure 2.14: Sub-outcrop of the Rupel, Tongeren and Dongen Formations at the top of the Tertiary.

Figure modified after Reference 3.

2.9.2 Shallow geology

The interpretation was carried out for the full length of Sub Bottom Profiler data; furthermore the Near Trace dataset was used to check the interpretation (see Section 6.2.5 for further details).

UNIT A (Seabed to Reflector A - Holocene)

Unit A (Holocene in age) is characterized by transparent to semi-transparent seismic aspect and is observed throughout the entire survey area. The internal structure is characterized by discontinuous reflectors with low to medium amplitude and high frequency, but is very often masked by diffraction hyperbola related to the presence of sand dunes on the seabed. In the southernmost part of the survey area, in particular in the Parcel IIIa, internal reflectors are not present or very thin, while in the northern part, where present, they are thicker (see Figure 2.15 to Figure 2.21). Below the wide NE-SW elongated sandbank (Buitenbank 3), the seismic facies is almost completely transparent.

This Unit is expected to comprise loose to dense SAND, as confirmed by CPTs and BHs acquired by FEBV in adjacent WFS I and WFS II (see Table 2.7).

The base of this Unit (Reflector A) is an uneven surface sub-parallel to the seabed, interpreted to be due to mechanic erosion (seabed friction) processes similar to the actual ones, due to the strong currents present in the area in the Holocene period (Ref.16). The depth of this reflector ranges from less than 1 m in the troughs between the sand dunes of the southernmost part of the survey area, up to 13 m bsb below the major dunes crests in the northern part of the sandbank. It may be possible that the depth of this reflector increases below the sand bank, but the denser/coarser sediments present in this area often reduce penetration of the seismic signal, masking the base of Unit A (Appendix N, Chart No.1). The depth of the base of Unit A ranges from a minimum of -44 m aLAT on the north-western flank of the sand bank to maximum -28 m aLAT m in the sand bank area (Appendix N, Chart No.2).

2.9.3 Deeper geology

The interpretation of the deeper geology was carried out through UHR; where possible the Sub-bottom Profiler results were integrated to confirm the UHR Interpretation (see Section 6.2.6 and Section 6.2.5 for further details). Furthermore the Near Trace dataset was used to check the interpretation. A correlation with the info provided in the geotechnical CPT logs (WFS2_2, WFS2_10, WFS2_27; WFS2_6; WFS2_12b; WFS2_21; WFS1_10; WFS1_24; WFS1_3b) crossed by seismic data and supplied by Fugro FEBV at the locations boundary with the previous WFS I and WFS II survey areas (Ref.4).

Table 2.7: CPT logs used in this study at the locations boundary with WFS I and WFS II

CPT ID	Easting (m)	Northing (m)	Water depth aLAT (m)	CPT Depth (m)
WFS2_2	502 099	5 717 347	-29.1	35,50
WFS2_10	502 430	5 721 682	-27.3	13,43
WFS2_27	502 874	5 724 485	-30.4	22,90
WFS2_6	503 467	5 727 576	-23.7	36,53
WFS2_12b	503 923	5 727 656	-30.5	34,00
WFS2_21	503 469	5 724 314	-29.0	26,43
WFS1_10	501 516	5 730 926	-30.0	37,16
WFS1_24	499 068	5 732 335	-28.2	25,78
WFS1_3b	500 562	5 734 259	-34.4	25,42

An example of the correlation between UHR seismic data and CPT data log is presented below (Figure 2.17).

The limit of the interpretation to achieve satisfactory results was set at deep penetration up to 80 m depth as Client request (Ref.5).

The vertical resolution of the UHR data was estimated as 2.0 m, and true thickness of sediment layers thinner than 2.0 m, would not be resolved. The (along-line) horizontal resolution of the dataset was estimated as 4 m.

A proposed geological or stratigraphic correspondence with the reflectors interpreted, was based on lithological descriptions of the geotechnical CPT logs (Ref.4) and published geological information (Ref.7, 8, 9) in combination with observed seismic facies.

The geology across the survey area comprises of three (3) units: Unit B (Quaternary), Units E and F (Tertiary) (see Table 2.5). A detailed description of the interpreted seismic units is presented below. (see Figure 2.15 to Figure 2.17).

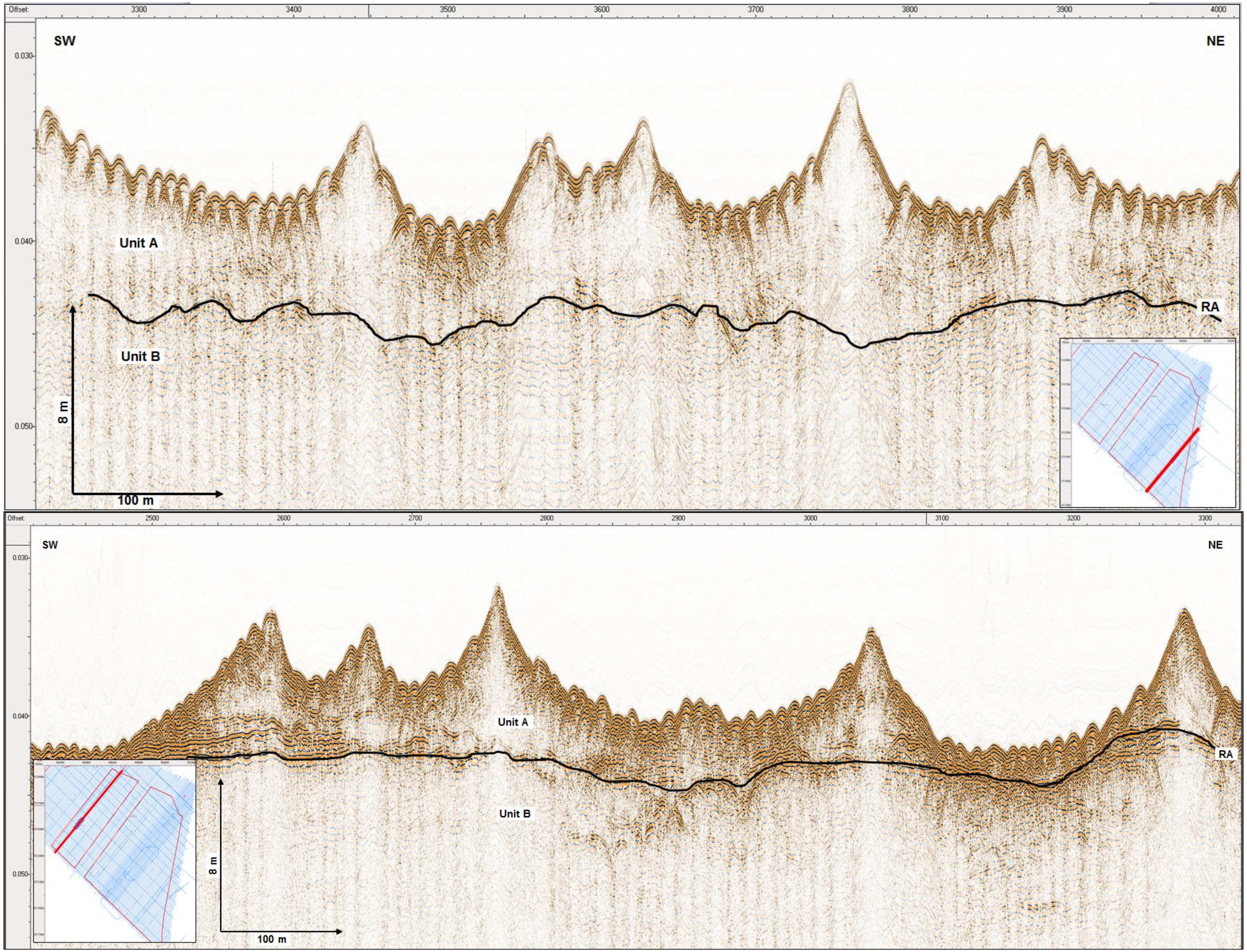


Figure 2.15: SBP data examples on Line A34012 (above) and Line A31077 (below)

The Figure shows Reflector A (RA) the base of Holocene deposits

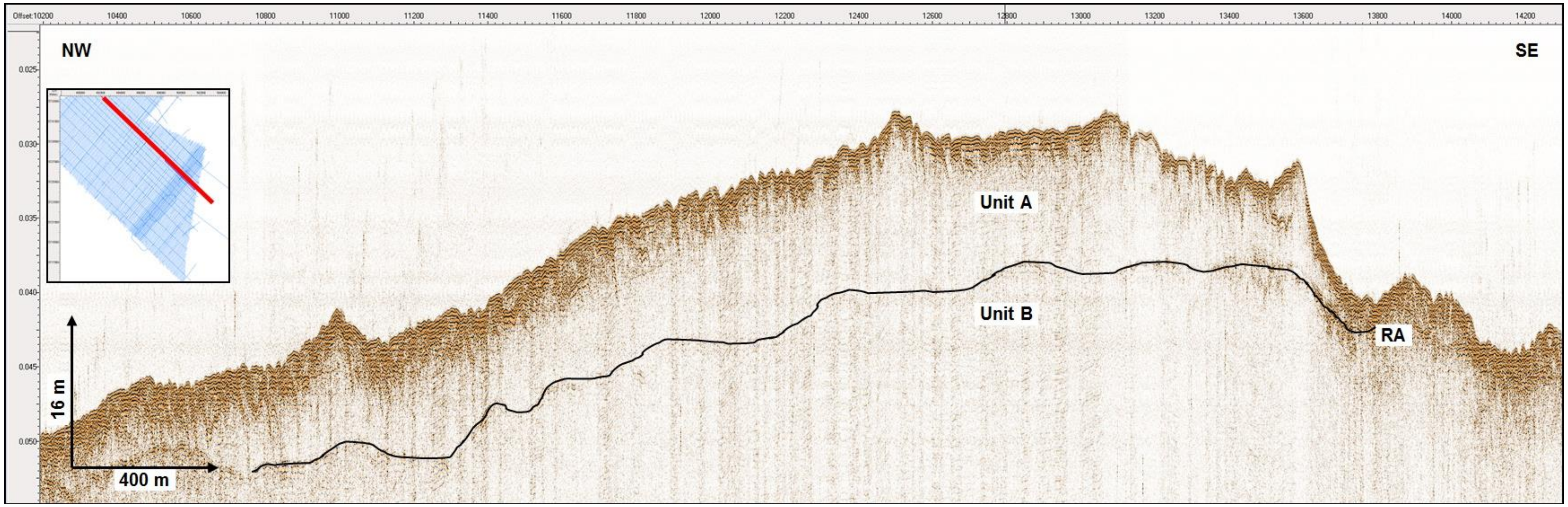


Figure 2.16: SBP data examples on Line UHRINF006 showing the sand bank Buitenbank3.

The Figure shows Reflector A (RA) the base of Holocene deposits

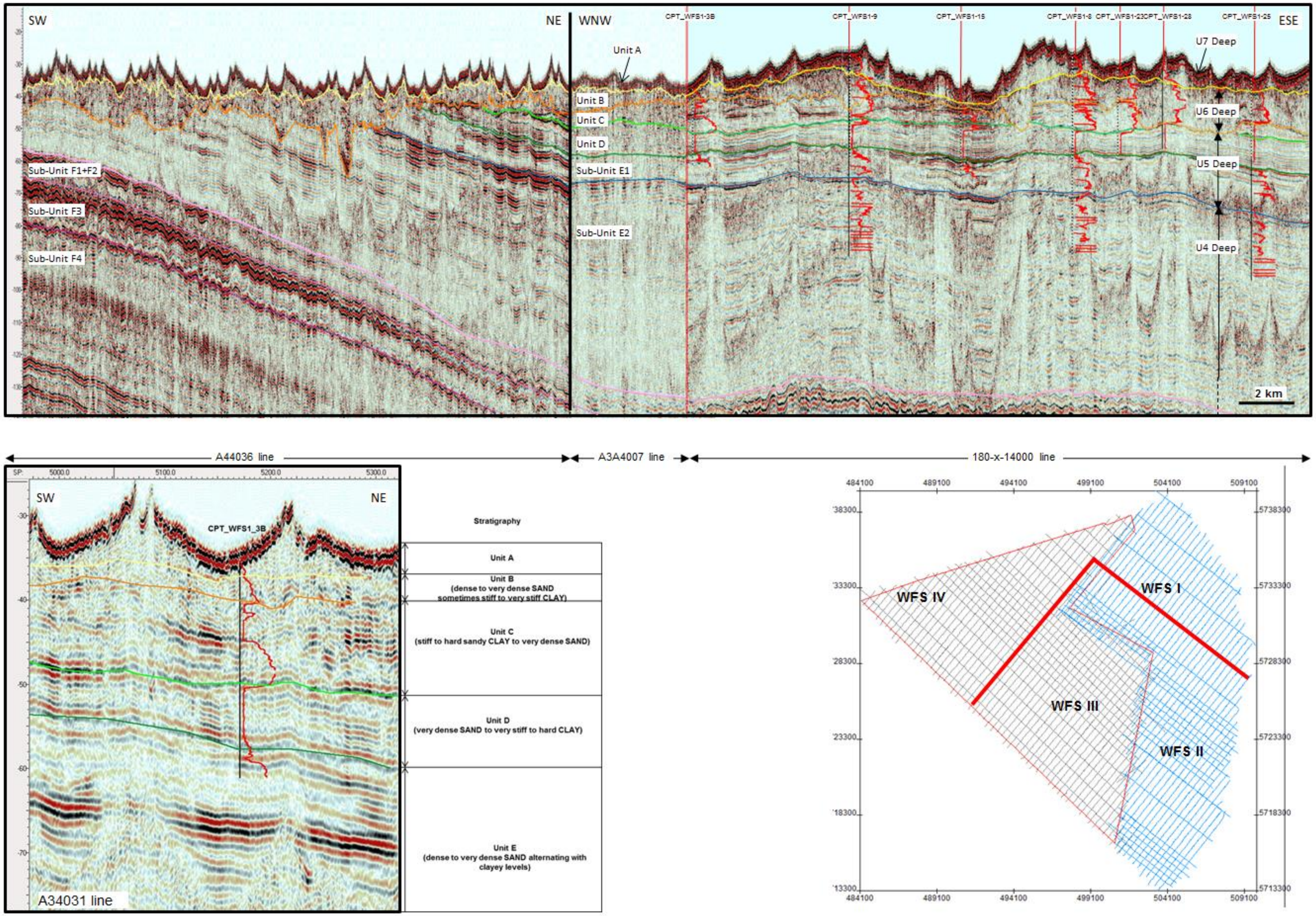


Figure 2.17: Correlation between UHR seismic data and CPT data

2DUHR seismic data: (A44036+A3A4x007+180-x-14000); CPT data (box marks maximum values of 50 MPa), below a detailed stratigraphic correlation with CPT_WFS1-3B log..

UNIT B (Reflector A to Reflector B - Pleistocene)

Unit B (Pleistocene in age) is characterized by discontinuous reflectors with parallel to chaotic configuration, low to high amplitude and variable frequency. This Unit can be seen throughout the area from UHR and SBP, where the base (Reflector B) is shallow (< 20 m below Seabed). The geometry of this Unit is sheet–like shaped. See Figure 2.15 to Figure 2.21.

The base of this Unit (Reflector B) is a palaeochannel/erosional surface overlying the Tertiary Formations (Unit E and F) (Figure 2.18). Where fluvial deposits are present the base of Unit B is a palaeochannel surface and the underlying Tertiary deposits are deeply eroded (Figure 2.18).

Some high amplitude seismic anomalies are present within this Unit. They and could be interpreted as denser sediment and/ or gravelly deposits carried out into the southern North Sea Basin by large rivers during interglacial periods (Figure 2.19). Few seismic anomalies exhibit also reverse polarity and could be interpreted as possibly peat layers and/or biogenic gas charged sediments. The diagnostic criteria for peat (typically high-amplitude and exhibiting pulse-broadening) and gas (typically reverse polarity and with acoustic turbidity obscuring reflections beneath) were not clearly identified. Therefore, these anomalies were interpreted as possible peat layers and/or biogenic gas charged sediments, and not split out into peat occurrences and gas occurrences. In addition, these peat and/or gas anomalies had a different character to those observed in WFS I and II (Ref.18), implying that the character of the peat and/or gas in WFS III and IV is different to that in WFS I and II. Intrusive testing has been recommended to ground truth some of these features (see also Geo Hazard Chart, Appendix P). See also paragraph 2.10.3.

The depth of the base of Unit B ranges from a minimum of -30 m aLAT to maximum -62 m aLAT in the middle of the survey area, and the contour interval for charting was set to 2 m (see Appendix N, Chart No.4). Its interval thickness reaches a maximum value of 22 m (see Appendix N, Chart No.3).

Unit B, based on CPT logs (see Table 2.7), is expected to comprise dense to very dense SAND (sometimes stiff to very stiff CLAY), and it was correlated to the, Eem, and Kreftenheye Formations deposited respectively in shallow marine and fluvial environment (Table 2.5). The vertical resolution and the lateral discontinuities of the seismic data do not permit to separate the two units.

According with the interpretation in this report, the Kreftenheye Formation could be present only in the area where palaeochannel surfaces are present.

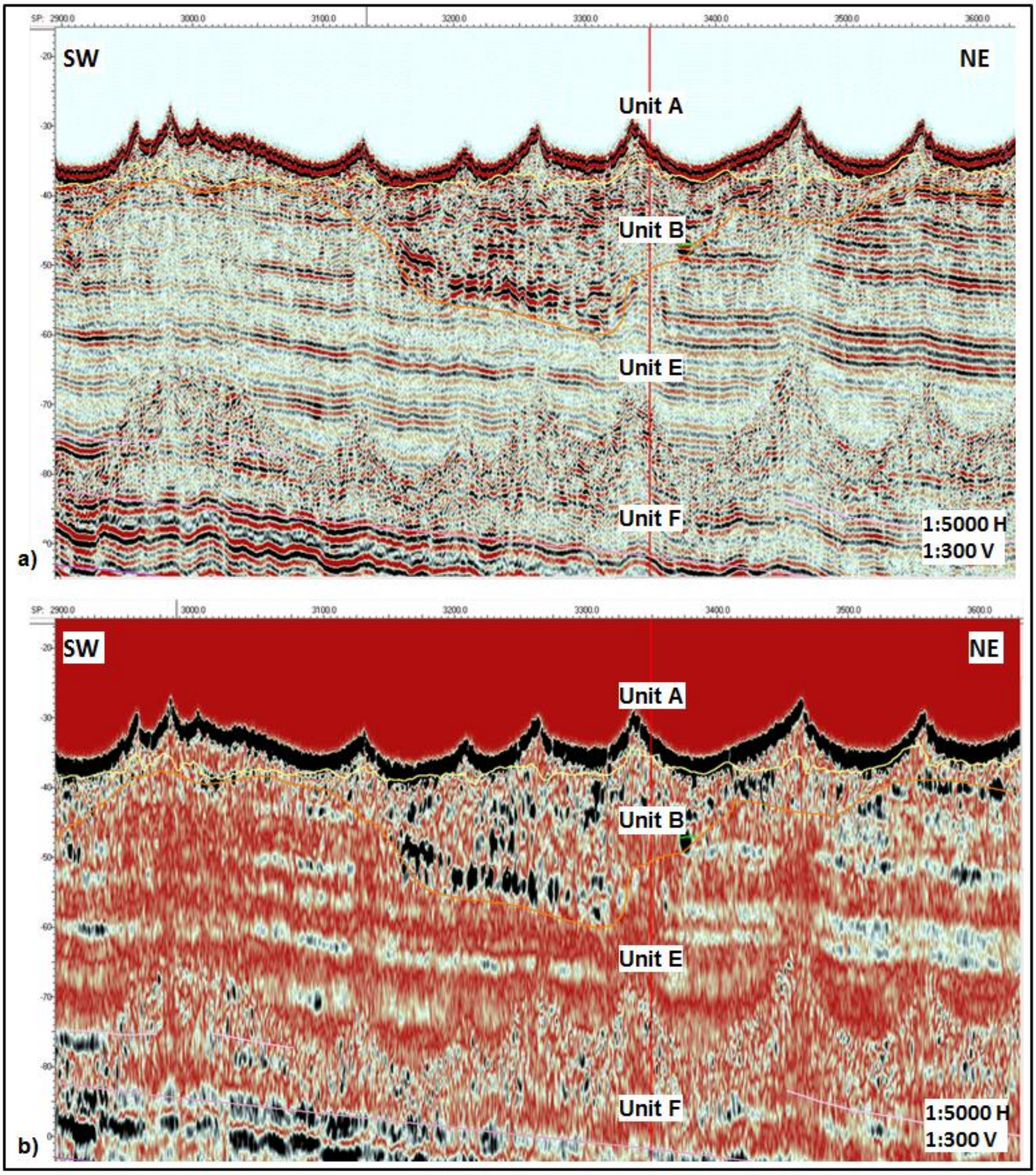


Figure 2.18: Examples of UHR data.

a) Evidence of Palaeochannel surface (RB) – Equalised Migrated (line A44037);

b) Evidence of Palaeochannel surface (RB) – Envelope seismic attribute (line A44037).

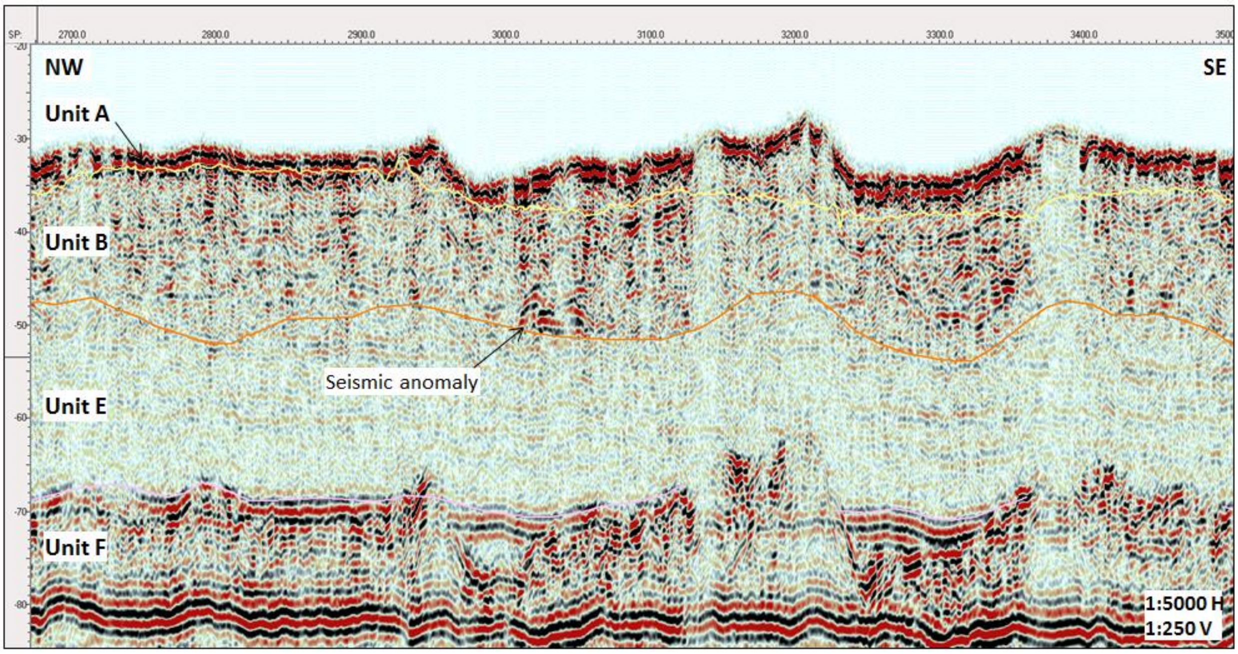


Figure 2.19: Example of UHR seismic data (INF009)

Seismic Anomaly could be interpreted as possible denser sediment and / or gravelly layers.

UNIT E (Reflector D to Reflector E - Tertiary)

Unit E (Upper Eocene to Early Oligocene in age) is characterized by parallel reflectors with high continuity and frequency (2 m), and low to moderate amplitude. The reflections within this unit are partly hidden by the presence of seabed multiples (Figure 2.20).

The geometry of this Unit is sheet-like and its lower boundary forms an unconformity with the underlying older Tertiary Formation (Dongen Fm.). This Unit, based on observed strong intraformational Reflector, was divided in two Sub-Units respectively E1 and E2.

The depth of the base of Sub-Units E1 ranges from a minimum of -45 m aLAT to maximum -51m aLAT towards the NE corner of the survey area, and the contour interval for charting was set to 2m (Appendix N, Chart No.8). Its interval thickness reaches a maximum value of 5 m (Appendix N, Chart No.7).

The depth of the base of Unit E ranges from a minimum of -45 m aLAT to maximum -51 m aLAT towards NE, and the contour interval for charting was set to 5 m (see Appendix N, Chart No.6). Its interval thickness reaches a maximum value of 65 m (see Appendix N, Chart No.5). See Figure 2.17 to Figure 2.21.

Unit E, based on CPT logs (Table 2.6), is expected to comprise dense to very dense SAND, deposited in a shallow marine environment.

Unit E was correlated to the Tongeren Formation, and the Sub-Unit E1 was correlated to the Ruisbroek SAND member (Table 2.5).

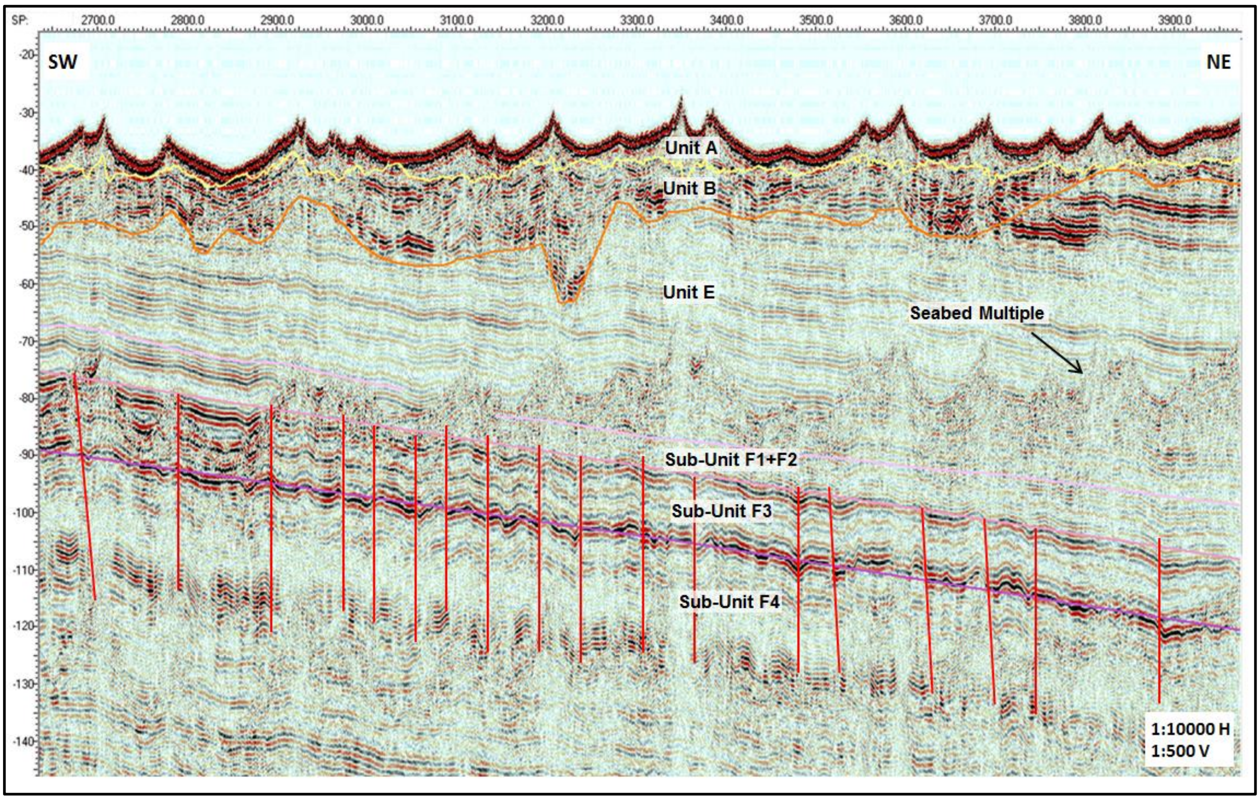


Figure 2.20: Example of Stratigraphy in UHR seismic data (A34023)

Unit F (Reflector E to Limit of Interpretation)

Unit F (Early to Middle Eocene in age) is characterized by parallel reflectors with high continuity, high amplitude in the upper part decreasing with depth and moderate frequency. See Figure 2.17 to Figure 2.21.

The Upper boundary (Reflector E) of this Unit can be observed throughout the area, except in the south-west part where it is truncated by the erosional surface at the base of Unit B (Reflector B). This Unit, based on CPT logs (Table 2.7) and observed seismic character, was divided in three Sub-Units F1+F2, F3 and F4 (Figure 2.21), considering the vertical resolution of the data (Figure 2.21).

A wide range of intraformational ‘sediment tectonic’ deformations is found mainly within Sub-Units F3 and F4. These deformations are due probably to the relaxation of temporary states of density inversion linked to undercompaction in the early burial history of the clayey-silty sediment of the argillaceous upper member (Sub-Unit F3) (Ref.18).

The density of faults is high within the Sub-Unit F3 and F4, approximately one every 50 m and the decimetre fault planes are sub-vertical. The interval affected by faulting is located between -50 m aLAT and -120 m aLAT toward the deeper parts of the area. See also Paragraph 2.10.2.

Based on the correlation of the seismic data with CPT logs (Table 2.7), the lower boundary is characterized by a clear transition to the transgressive Sandstone member of the underlying Sub-Unit F4 (Figure 2.21) deposited in a shallow marine environment (Ref.8, 19, 20).

Unit F, based on CPT logs at the boundaries with WFS I and II (Table 2.7), is expected to comprise very stiff to hard CLAY and sandy CLAY member (Sub-Unit F1+F2), very stiff CLAY (Sub-Unit F3) and dense clayey SAND member at the base (Sub-Unit F4) deposited in marine and shallow marine environment, and has been correlated with the Dongen Formation (Table 2.5).

The depth of the base of Sub-Units F1+F2 ranges from a minimum of -45 m aLAT to maximum -115 m aLAT towards NE, and the contour interval for charting was set to 5 m (Appendix N, Chart No.10). Its interval thickness reaches a maximum value of 10 m (Appendix N, Chart No.9).

The depth of the base of Sub-Units F3 ranges from a minimum of -60 m aLAT to maximum -130 m aLAT towards NE, and the contour interval for charting was set to 5m (Appendix N, Chart No.12). Its interval thickness reaches a maximum value of 15 m (Appendix N, Chart No.11).

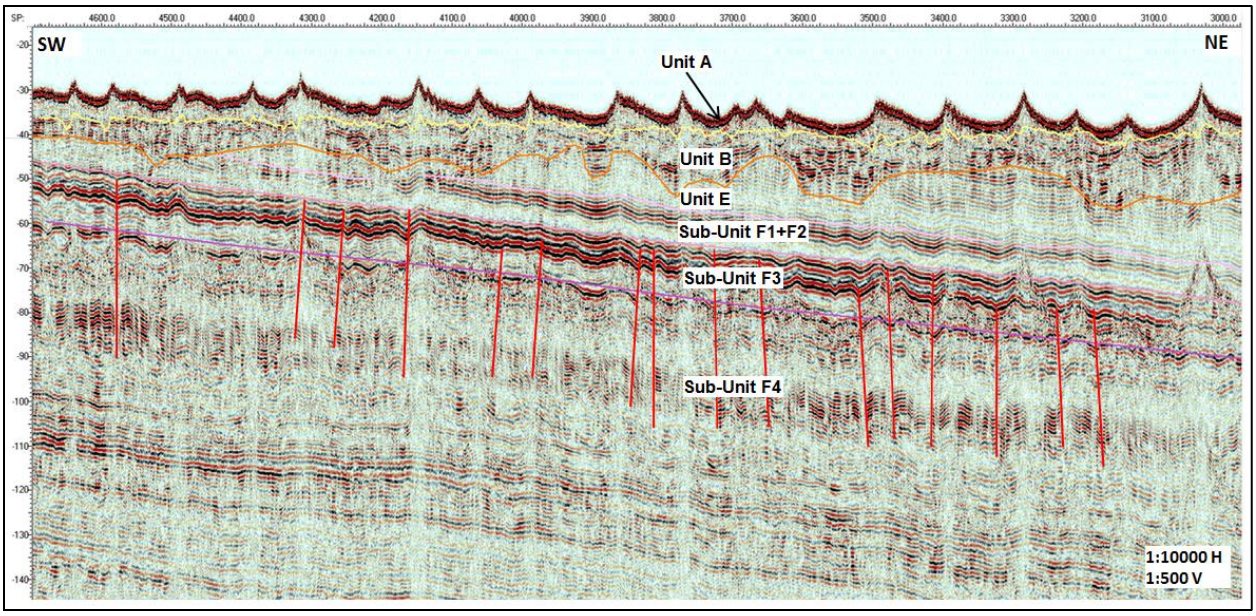


Figure 2.21: Intraformational "sediment tectonic" deformations.

The deformations shown in the figure are due to clay tectonics in the Dongen Fm. (Sub-Unit F3 and Sub-Unit F4) (line A34024).

An overview of the seismostratigraphic units interpreted is presented in Table 2.8.

Table 2.8: Overview of the interpreted seismic Units

Seismic Units	Reflectors		Depth of the base of Seismic Unit a LAT (m)	Lower Boundary configuration	Reflection Configuration	Amplitude	Continuity	Frequency	Geometry of Unit	Lithology CPT (FEBV)	Depositional environment	Formation	Age	Maximum thickness (m)
	Upper	Lower												
A	Seabed	RA	-32 / -42	Uneven surface	Masked by transparent to semi-transparent seismic aspect	Low to moderate	Discontinuous	High	Undefined	Loose to dense SAND	Marine	Southern Bight	Holocene	13
B	RA	RB	-30 / -72	Erosional surface	From parallel to chaotic	Variable from low to high	Discontinuous	Variable	Sheet -like shaped	Dense to very dense SAND (sometimes stiff to very stiff CLAY)	Shallow marine and fluvial environment	Kreftenheye/ Eem	Pleistocene	26
E	RD	RE	-45 / -145	Erosional surface	Parallel	High to moderate	High	High (2 m)	Sheet like	Dense to very dense SAND	Shallow marine	Tongeren	Early Oligocene To Upper Eocene	70
F	RE	Limit of interpretation	-	-	Parallel	High in the upper part decreasing with depth	High	Moderate	Sheet like	Very stiff to hard CLAY and dense clayey SAND toward the base	Marine and shallow marine environment	Dongen	Early To Middle Eocene	-

2.10 Installation Constraints

This section contains an assessment of the potential geologic conditions hazardous to engineering works at the seabed and sub-seabed. The MBES, SSS, MAG, SBP and UHR digital seismic data were analysed for the following constraints:

- **Seabed hazards:** sand dunes, that there are two main directions, one in NE-direction with an average speed of 1.7 m/yr and one in SW direction with an average speed of 3.2 m/yr (Ref.14). No boulder were identified;
- **Wrecks:** one wreck was identified by MBES, SSS and MAG data, with dimensions of 17.58x3.9x2.75 m with approximate coordinates of 500727.97 mE, 5727923.74 mN;
- **Palaeochannel Infill**, that could be comprised by denser sediment and / or gravelly layers associated with Unit B;
- **Peat layers and/or biogenic gas charged sediments** through strong amplitude reverse polarity reflections;

The seabed and sub-seabed hazards were shown in Appendix P **- Geohazard Charts**.

2.10.1 Palaeochannel infill (within Unit B)

Unit B, characterized by discontinuous reflectors with parallel to chaotic configuration, presents lateral changes in seismic attributes recognized as the typical lateral variation of alluvial deposit (i.e. sand, clay, gravel etc.). These features could represent a punch-through risk for jack up rigs, due to lateral changes in mechanic resistance.

From the interpretation of SBP and 2DUHR, several diffractions and high amplitude levels, considered as seismic anomalies, were detected throughout the survey area in the palaeochannel infill of Unit B (Figure 2.23 to Figure 2.25) The seismic anomalies detected and shown in the charts (see **Hazard Chart** – Appendix) can be interpreted as denser sediment and / or gravelly layers. Few seismic anomalies exhibits also reverse polarity and could be interpreted as possibly peat and / or biogenic gas charged sediments.

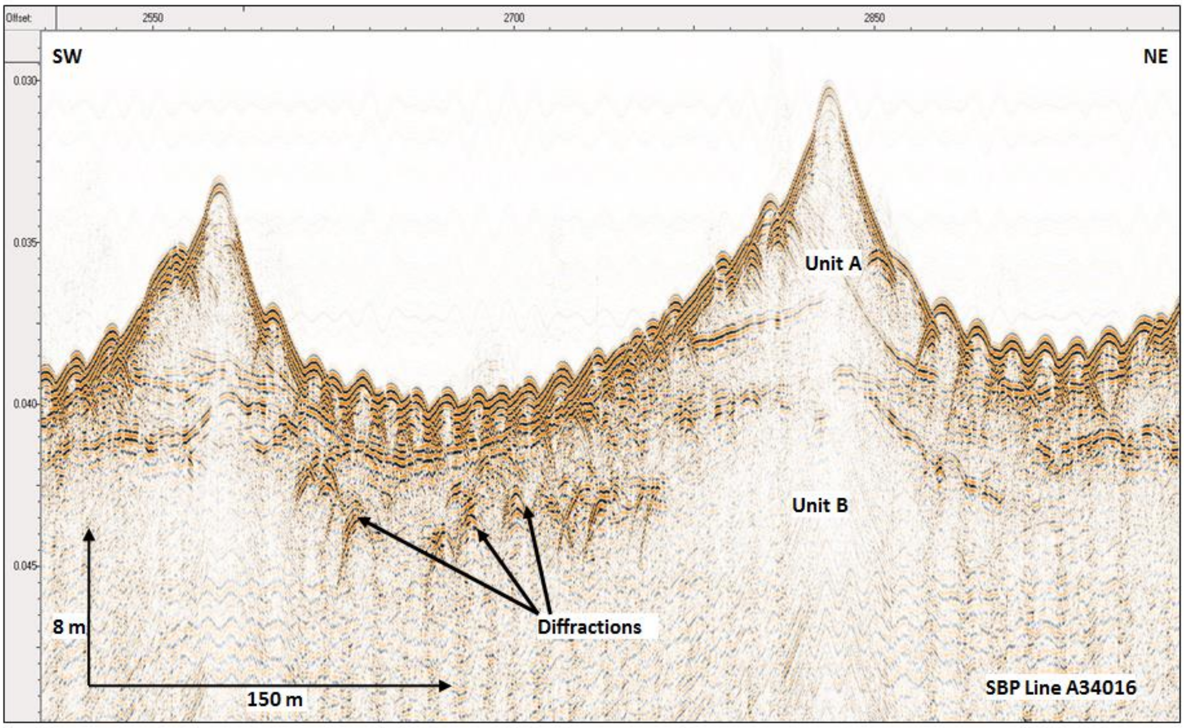


Figure 2.22: SBP Example showing Seismic Anomaly (A34016)

The diffractions could be interpreted as possible gravelly layers.

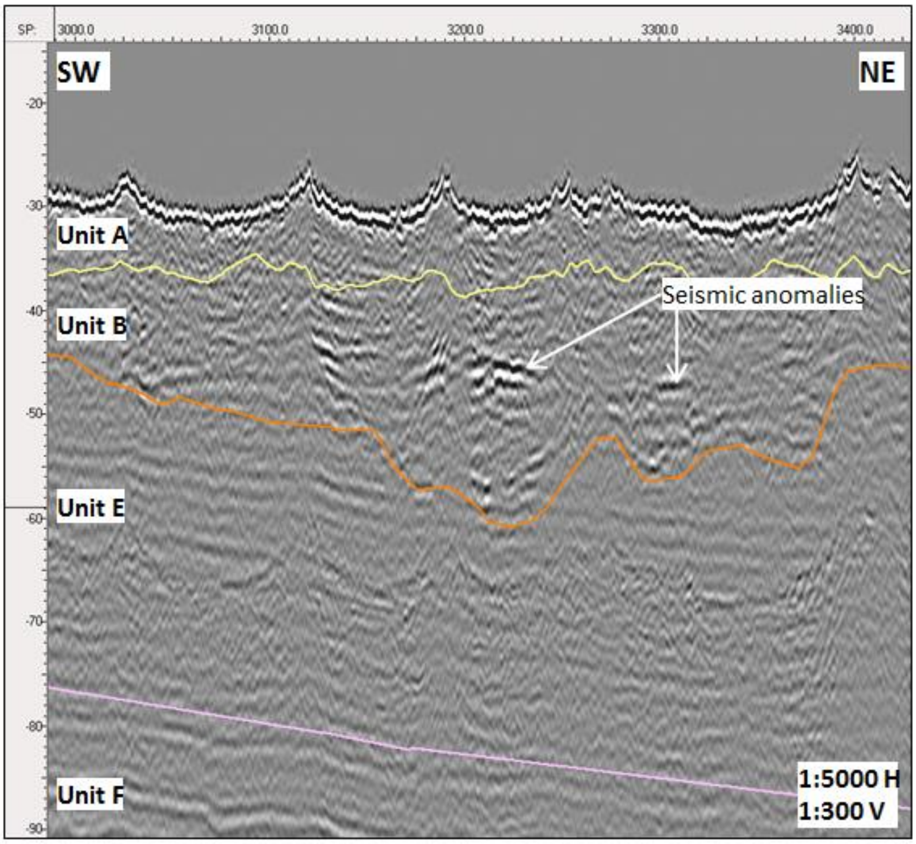


Figure 2.23: Example of Seismic Anomaly in UHR seismic data (A34020)

Seismic Anomaly could be interpreted as possible denser sediment and / or gravelly layers.

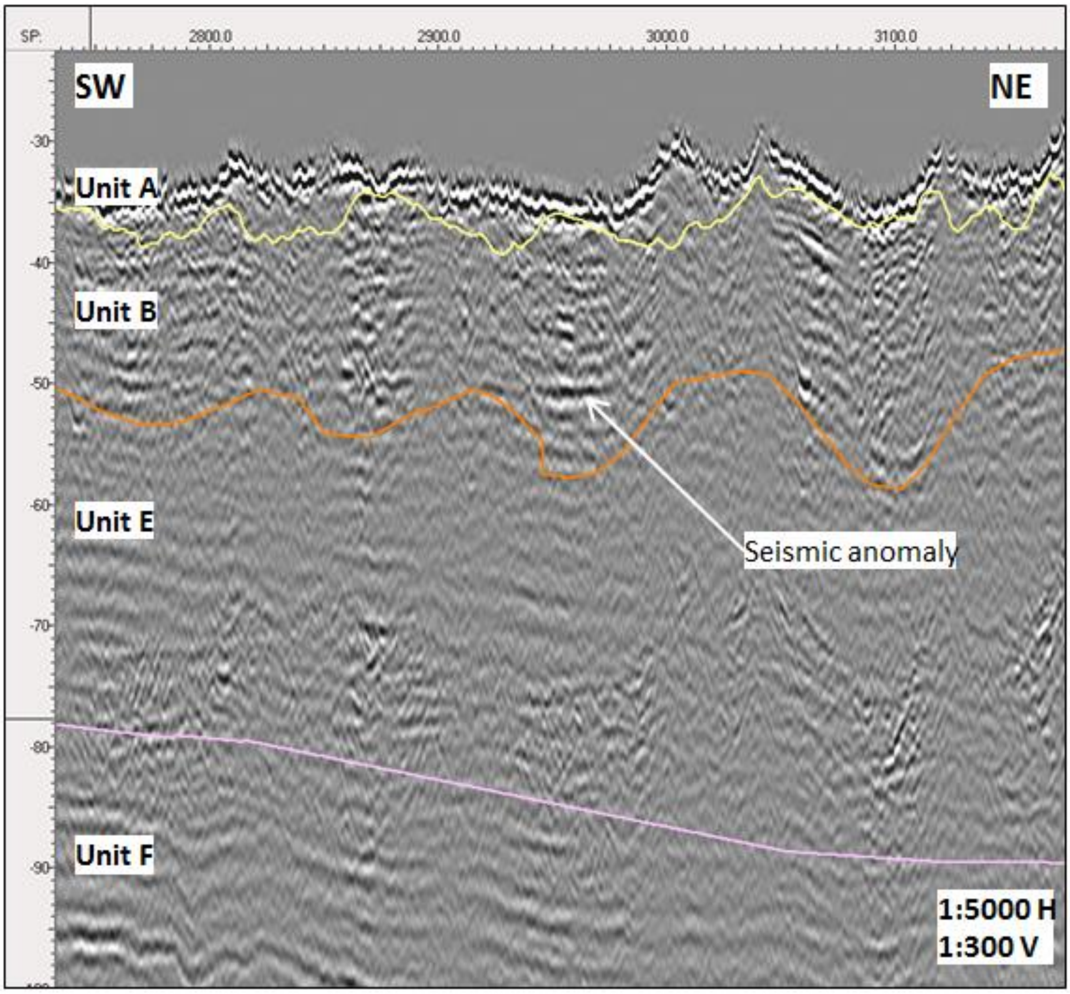


Figure 2.24: Example of Seismic Anomaly in UHR seismic data (A34014A)

Seismic Anomaly could be interpreted as possible denser sediment and / or gravelly layers.

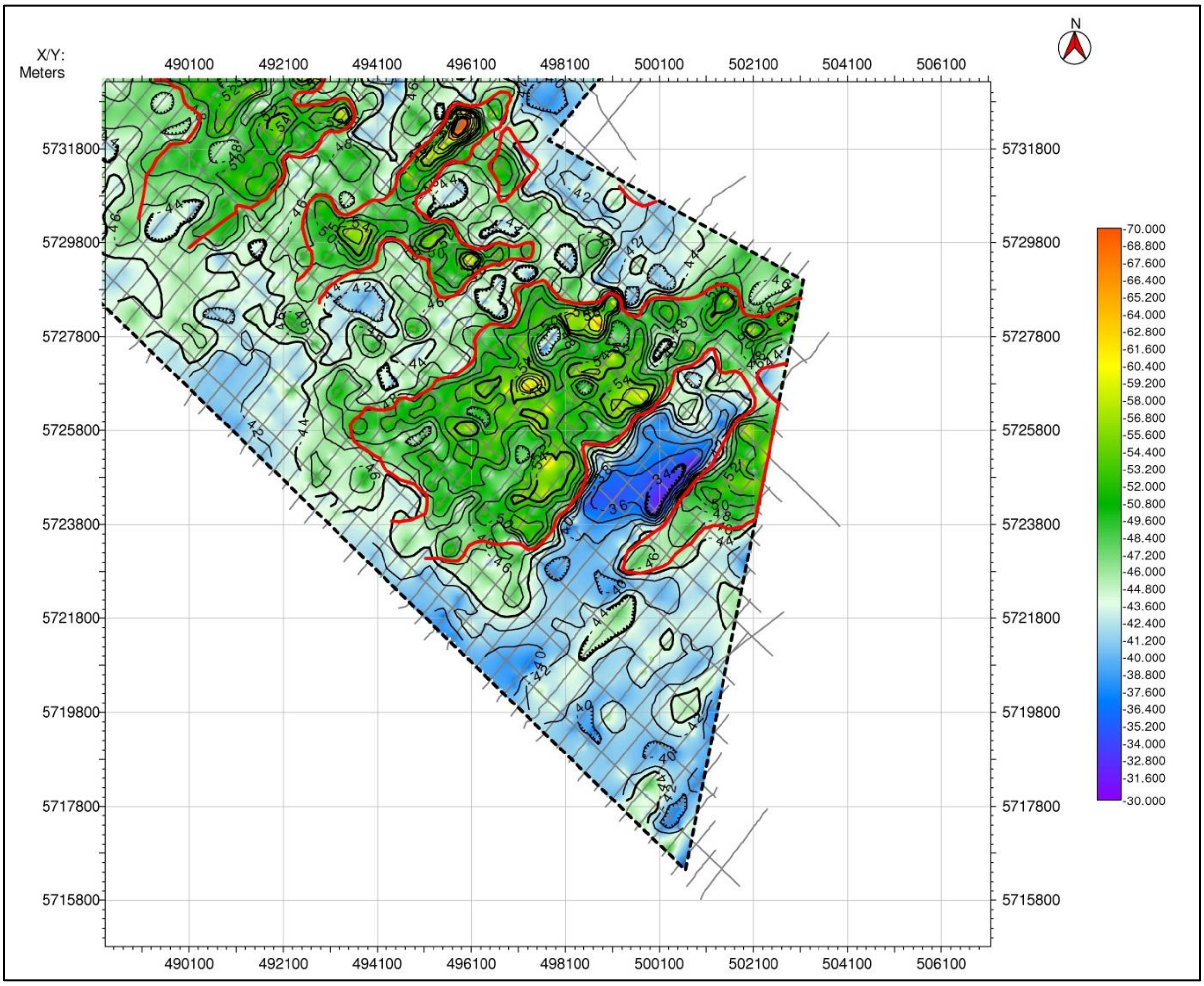


Figure 2.25: Base map of Unit B highlights the palaeochannel areas.

2.10.2 Faulting

Unit F (in particular Sub-Unit F3 and F4) is affected by a fault system related to intraformational ‘sediment tectonic’ deformations. These deformations are probably due to the relaxation of temporary states of density inversion linked to undercompaction in the early burial history of the clayey-silty sediment (Ref.23).

The density of faults is high within Unit F, approximately one every 50 m and the fault planes are sub-vertical. Within the WFSIII area these faults have depths that range between -50 m aLAT and -120 m aLAT, so were not interpreted to pose engineering challenges.

2.10.3 Peat layers and/or shallow biogenic gas accumulations

The UHR digital seismic data were analysed for seismic indicators of shallow biogenic gas charged sediments and / or peat and examined at deep penetration up to 80 m depth.

These anomalies show high amplitude, reverse polarity (consistent with gas) and acoustic blanking of the deeper layers (Figure 2.26, Figure 2.27).

They are present mainly within the main channelling feature at the base of Unit B.

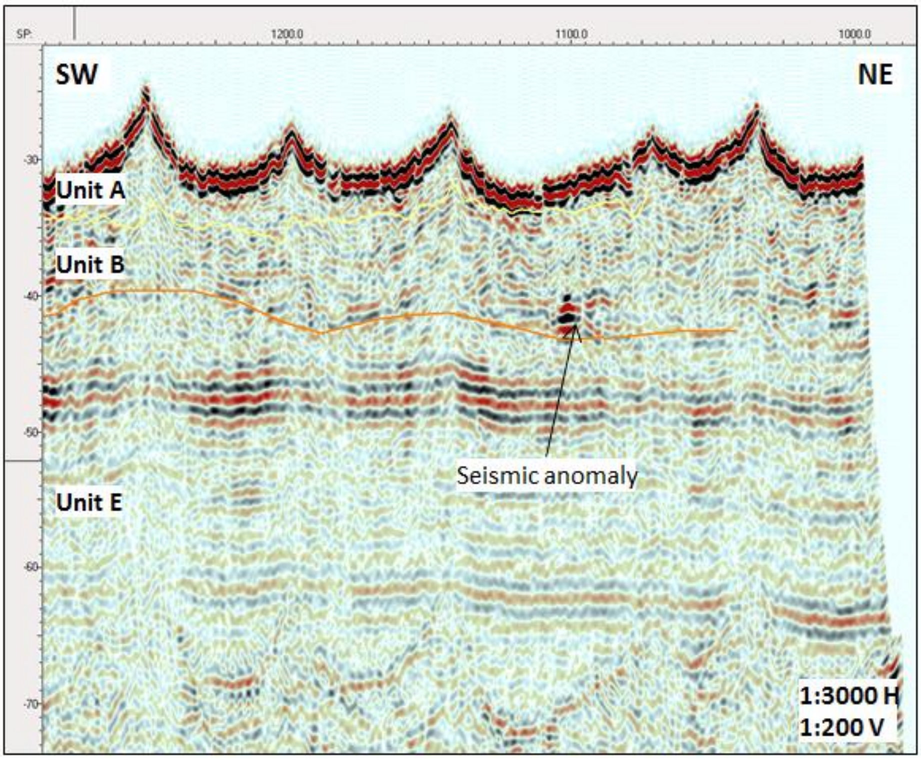


Figure 2.26: Example of Seismic Anomaly in UHR seismic data (A34025)

Seismic Anomaly could be interpreted as possible shallow biogenic gas charged sediments and / or peat.

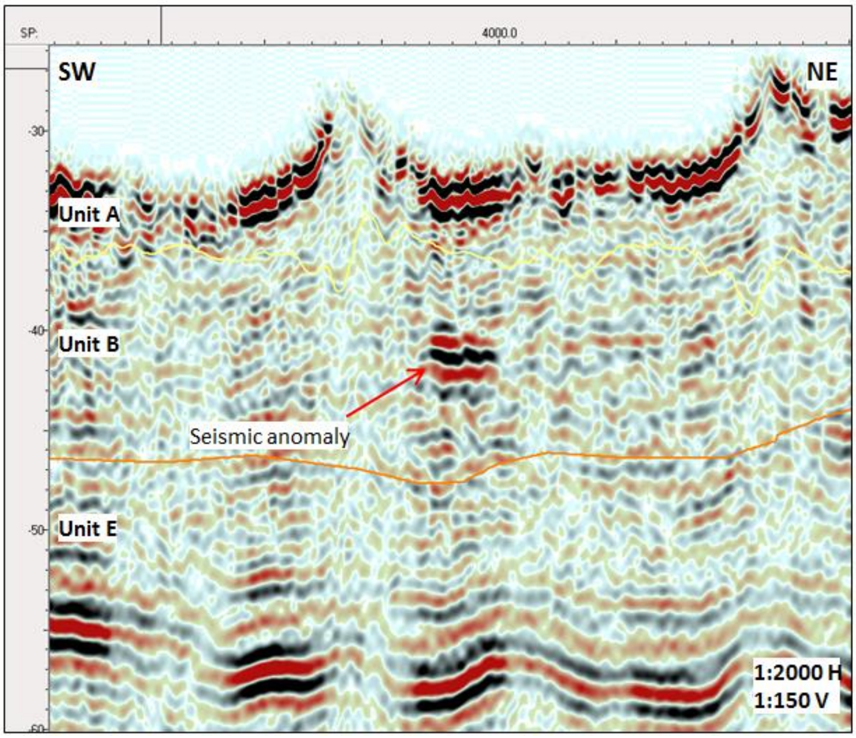


Figure 2.27: Example of Seismic Anomaly in UHR seismic data (A34025)

Seismic Anomaly could be interpreted as possible shallow biogenic gas charged sediments and / or peat.

2.11 Recommendations for borehole locations

To collect geological and geotechnical information and better evaluate the foundation and installation conditions or the Offshore Wind Farm, Fugro presents below a seabed Piezo-cone penetration testing (CPT) Plan and a geotechnical borehole Plan.

The recommended borehole and CPT tests are meant to serve as verification to the geophysical survey and to assess the final borehole plan, which will be drafted by the Client at each wind turbine locations.

The present preliminary geotechnical investigation includes Down the hole CPTs (DTH-CPT) at all boreholes.

Six (6) borehole and nineteen (19) CPT locations are proposed in this report for WFS III survey area (Parcel A and B) based on the final seismic interpretation of the survey area (see Figure 2.28 and Figure 2.29).

The six (6) proposed BH locations were chosen in order to verify the interpretation, attest the lithostratigraphy and the nature of seismic anomalies highlighted from the seismic interpretation. One of the goals of the boreholes campaign is to define the potential presence of some geohazards that were not detected by the seismic survey as: Peat levels within Unit B (Kreftenheye Fm.), Lignite at the top of unit E (Tongeren Fm.).

Most of the locations were positioned on the buried palaeochannel infill (Pleistocene), to verify the mechanical resistance of these alluvial deposits in order to avoid hazard as punch-through.

The proposed borehole and CPT locations listed on Table 2.8 and 2.9 in Appendix Q are referring only to the Geological Model of the survey area and not to each wind turbine locations.

Due to assumed operational constraints no BHs and CPTs locations were positioned in water depth < -20 m aLAT and at a distance of at least 50 m from MB, SSS and MAG Contacts. Most of them were also chosen on the two UHR seismic crossed sections.

Another assumed operational constrains could be the gradient of the seabed that should be less than 5 degrees. At this purpose a **Seabed Gradient Map** was calculated to better define the area with <5 and >5 degrees (see Appendix Q). All the BH and CPT were located on a seabed less than 5 degrees.

Table 2.9: Proposed Borehole locations within WFS III

BH Name	Line Name (shot point)	Cross Line	Water Depth (m aLAT)	Easting	Northing	Latitude [N]	Longitude [E]	GOAL
BH1	A34019A (5133)	-	-28.00	496669.30	5721939.68	51°38'54.41"	02°57'06.69"	Check for the presence of gravel beds mainly within Unit B, but not only. (CPT 3)
BH2	A34021 (2547)	A3A4XL003	-38.00	498235.52	5725130.44	51°40'37.72"	02°58'28.13"	Assessment of the composition of the high amplitude anomaly present inside the palaeochannel infill deposit (probable inclusion of gravel). (CPT 4)
BH3	A34012 (2116)	UHRINF011	-30.00	500196.86	5721832.41	51°38'50.97"	03°00'10.24"	Assess the geotechnical properties of a seismic anomaly present within Unit B. (CPT 8)
BH4	A3A4XL001 (8095)	-	-29.00	500029.09	5717838.56	51°36'41.69"	03°00'01.51"	Stratigraphy of the southern side of the survey area and determine the presence of the polygonal fault system subunit within unit F. (CPT 9)
BH5	A34030 (1865)	-	-31.00	494299.10	5725991.50	51°41'05.49"	02°55'03.13"	Assessment of properties of complex Quaternary and prominent top Tertiary reflectors
BH6	A34031 (3191)	A3A4XL004	-34.00	496621.57	5729488.39	51°42'58.75"	02°57'03.95"	Determine the complex nature and properties of the Quaternary scour hollow infill and youngest Tertiary – possibly extend BH to 80m to correlate down sequence

Table 2.10: Proposed CPT locations within WFS III

CPT Name	Line Name (shot point)	Cross Line	Water Depth (m aLAT)	Easting	Northing	Latitude [N]	Longitude [E]	GOAL
CPT1	A34016 (1875)		-33.00	498420.10	5722190.65	51°39'02.56"	02°58'37.79"	Determination of Tertiary Stratigraphy
CPT2	A34016 (2900)	-	-21.00	500445.40	5724675.8	51°40'23.01"	03°00'23.19"	Assess Thickness and apparently complex properties of Upper Tertiary soils and possible very thin Quaternary
CPT3 (*)	A34019A (5131)	-	-28.00	496672.87	5721943.19	51°38'54.52"	02°57'06.88"	Assess the geotechnical properties (gravel beds) (BH1)
CPT4 (*)	A34021 (2547)	A3A4XL003	-38.00	498241.23	5725137.54	51°40'37.95"	02°58'28.43"	Assess the geotechnical properties of the palaeochannel infill (Unit D) and the eventual presence of Lignite at the Top of Unit E (Kreftenheye Fm, and Tongeren Fm.) and evaluation of pronounced reflectors within upper part of Tertiary soils. (BH 2)
CPT5	A34019A (3243)	UHRINF007	-27.00	500396.76	5726519.76	51°41'22.69"	03°00'20.66"	Assess the geotechnical properties of a high amplitude body present within Unit D (Kreftenheye Fm)
CPT6	A34023 (3000)	UHRINF008	-36.00	498613.05	5726860.59	51°41'33.72"	02°58'47.76"	Assess younger Tertiary deposits

CPT Name	Line Name (shot point)	Cross Line	Water Depth (m aLAT)	Easting	Northing	Latitude [N]	Longitude [E]	GOAL
CPT7	A34016 (3632)	UHRINF005 /5A	-26.00	501898.66	5726443.17	51°41'20.21"	03°01'38.88"	Assess the geotechnical properties mainly of the palaeochannel infill (Unit B)
CPT8 (*)	A34012 (2118)	UHRINF011	-30.00	500192.57	5721827.72	51°38'50.82"	03°00'10.02"	Assessment of Tertiary stratigraphic sequence along eastern part of site III for correlation of soils data. (BH3)
CPT9 (*)	A34006 (1735)	A3A4XL001	-29.00	500083.74	5717908.89	51°36'43.97"	03°00'04.35"	Assess the geotechnical properties of the palaeochannel infill (Unit D) and the eventual presence of Lignite at the Top of Unit E (Kreftenheye Fm, and Tongeren Fm.). (BH4)
CPT 10	A3A4XL001 (7149)	-	-34.00	497916.48	5719868.28	51°37'47.38"	02°58'11.63"	Determination of very thin Holocene and upper part of Tertiary Deposits
CPT 11	UHRINF010 (1600)	A34013	-32.00	500865.10	5723288.99	51°39'38.12"	03°00'45.03"	Determination of very thin Holocene and upper part of Tertiary Deposits
CPT 12	A34030 (1865)	-	-31.00	494299.77	5725992.24	51°41'05.52"	02°55'03.16"	Assessment of properties of complex Quaternary and prominent top Tertiary reflectors.
CPT 13	A34029 (3156)	-	-31.00	494928.27	5726141.73	51°41'10.38"	02°55'35.88"	Assess the geotechnical properties of Unit A, B, E, and F for lateral continuity
CPT 14	UHRINF010 (3534)	A34028	-34.00	496539.59	5727485.68	51°41'53.92"	02°56'59.75"	Assess the geotechnical properties of Unit A, B, E, and F for lateral continuity
CPT 15	A34031 (2499)	-	-32.00	495279.51	5727833.38	51°42'05.14"	02°55'54.09"	Assess the geotechnical properties of Unit A, B, E, and F for lateral continuity
CPT 16	A3A4XL004 (3891)	A34028	-35.00	497478.85	5728650.63	51°42'31.65"	02°57'48.64"	Assess the geotechnical properties of Unit A, B, E, and F for lateral continuity
CPT 17	A34031 (3190)	A3A4XL004	-34.00	496618.79	5729484.23	51°42'58.62"	02°57'03.80"	Assess the geotechnical properties, in particular the palaeochannel infill deposit (probable presence of gravelly layers)
CPT 18	UHRINF012 (5127)	A34027	-30.00	494599.55	5724470.59	51°40'16.27"	02°55'18.86"	Assess the geotechnical properties mainly of the palaeochannel infill
CPT 19	A34023 (3800)	A3A4XL005 A	-34.00	500199.25	5728791.94	51°42'36.24"	03°00'10.38"	Determination of very thin Holocene and upper part of Tertiary Deposits

(*) CPT associated to BH

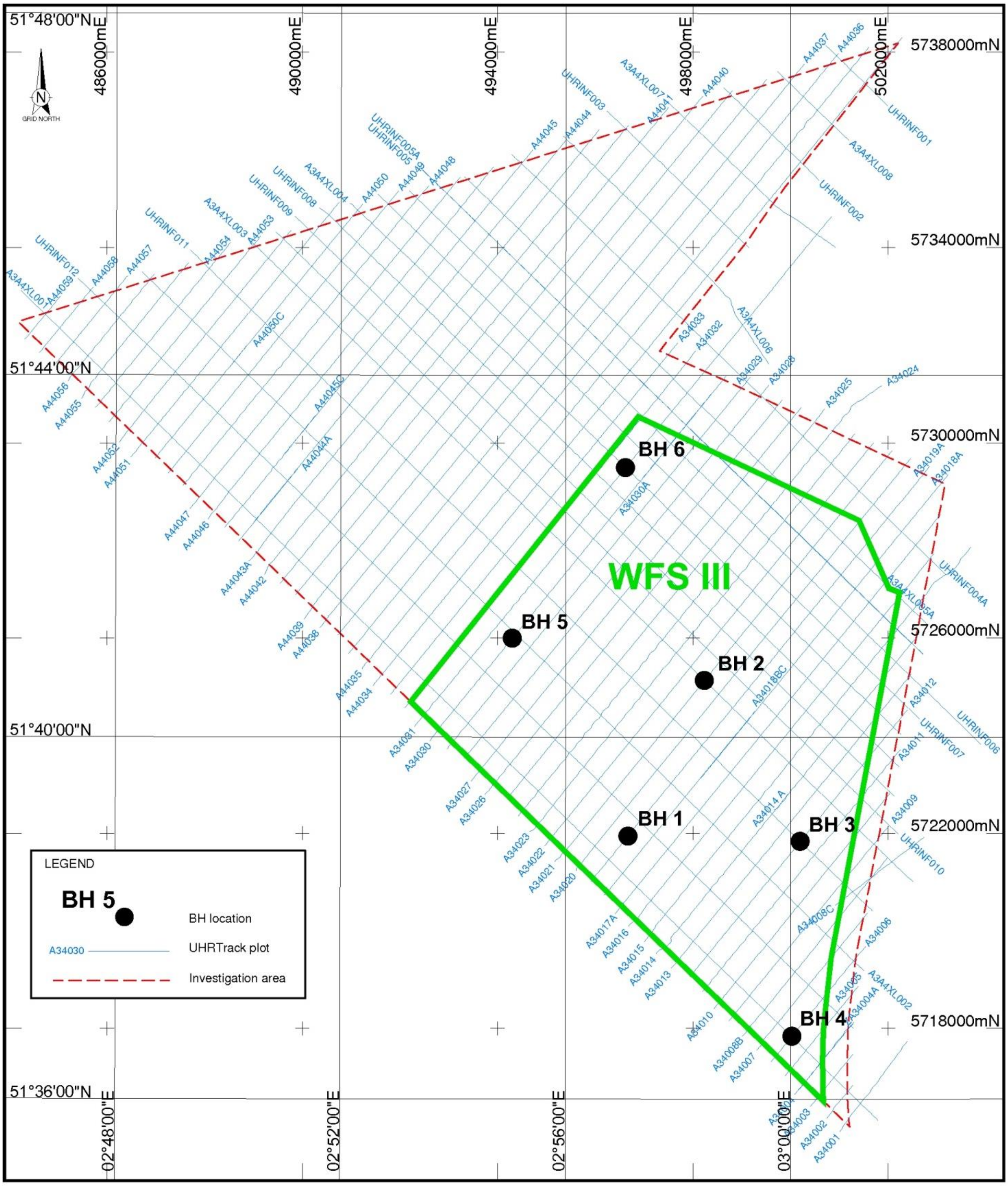


Figure 2.28: Proposed Borehole locations within WFS III

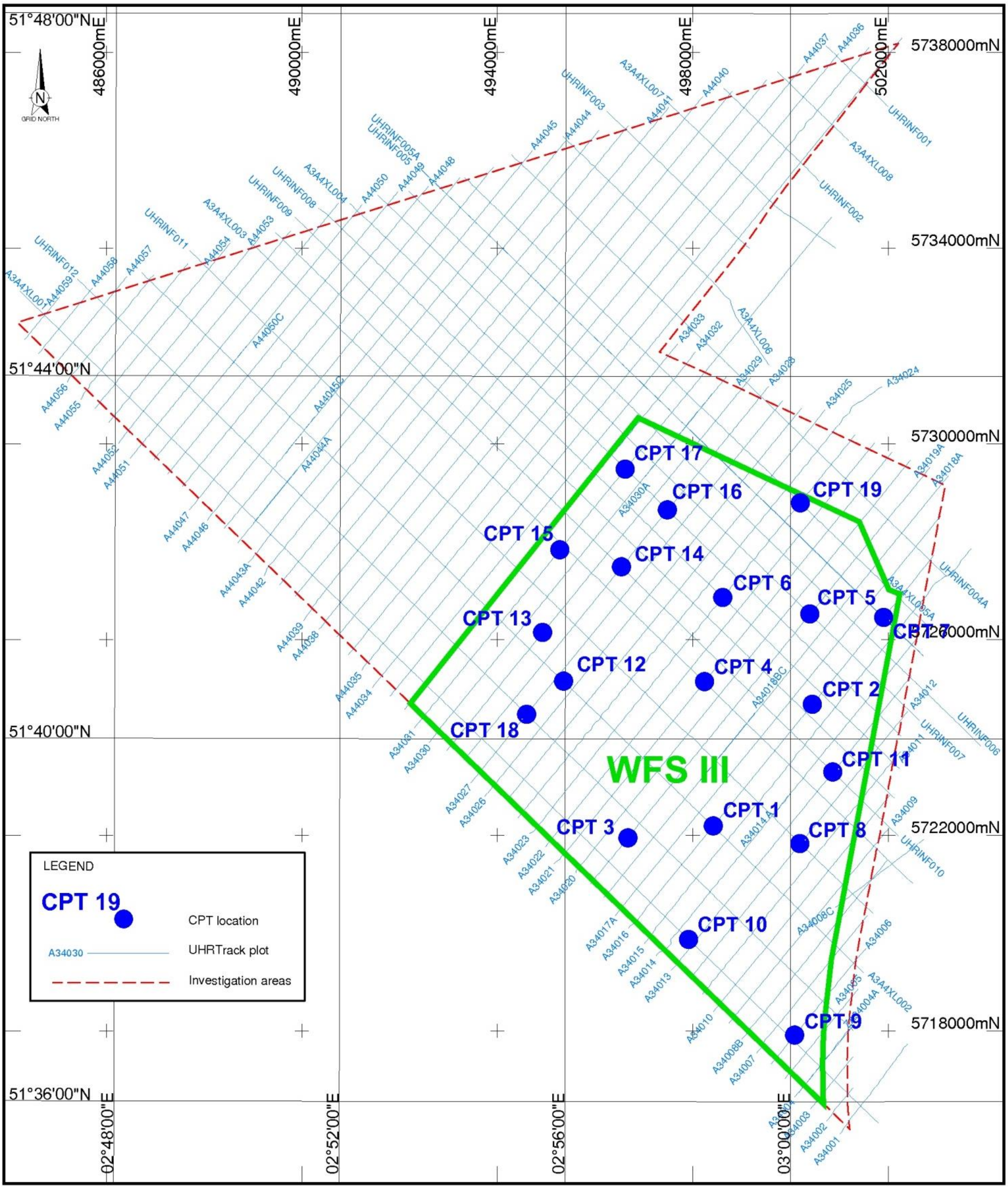


Figure 2.29: Proposed CPT locations within WFS III

3. OPERATIONS

3.1 Operation Summary

The geophysical survey for the Borssele Windfarm Area III and IV was performed by the vessel M.V. Fugro Pioneer between 25 May and 20 June 2015.

The mobilisation of the M.V. Fugro Pioneer took place on 25 May 2015 in the port of Den Helder (The Netherlands). During mobilisation all instruments were also tested to ensure proper functioning. The mobilisation was completed on 26 May and at the same day the vessel started sailing to the survey site. On 27 May the equipment was deployed and calibrated and the acquisition started.

On 2 June the vessel sailed to Zeebrugge (Belgium) for crew change and vessel replenishment. Geophysical operations resumed on 3 June.

Survey operations were completed on 19 June and the vessel started sailing to Den Helder for demobilisation that began on 20 June in Den Helder.

Sea state conditions were occasionally marginal thought the survey across the two (2) wind farm sites. Prior the commencing of the survey, workable weather limits were agreed with the Client. In particular such limits were set as H_S > 1.5 m, W_{S_10} > 15 m/s for over a minimum of 2 hours (W_W). In total four (4) days (9.1%) of weather standby were observed (29 and 31 of May and 3 and 13 of June), all of them above the mentioned threshold limit. Full details of weather conditions are detailed in Appendix E.

From 8 to 11 June the survey operations continued in only one line direction due to poor weather conditions.

Two (2) variations from the scope of work (Rev0 issued on 25 May) were performed during the project: 1) acquisition of nine (9) additional seismic lines to tie in with geotechnical locations in Borssele Wind Farm areas I and II and 2) acquisition of twelve (12) seismic infill lines to better resolute the subsurface in the most complex areas.

Full details of geophysical operations can be found in the daily operations reports (DOR), Appendix E.

The summary of operational statistics is shown in Table 3.1 and in Figure 3.1

Table 3.1: Operational Statistics

Activity	Hours	Percentage
Mobilisation / demobilisation	27.08	4.38
Calibrations	4.87	0.79
Transit	32.92	5.33
Operational Geophysical	261.67	42.36
Operational Multichannel Seismic	183.11	29.64
Equipment Downtime	12.18	1.97
Deploying or retrieval equipment	22.83	3.7
Standby other	1.88	0.3
Weather standby	56.2	9.1
Port call	15	2.43
TOTAL	617.74	100

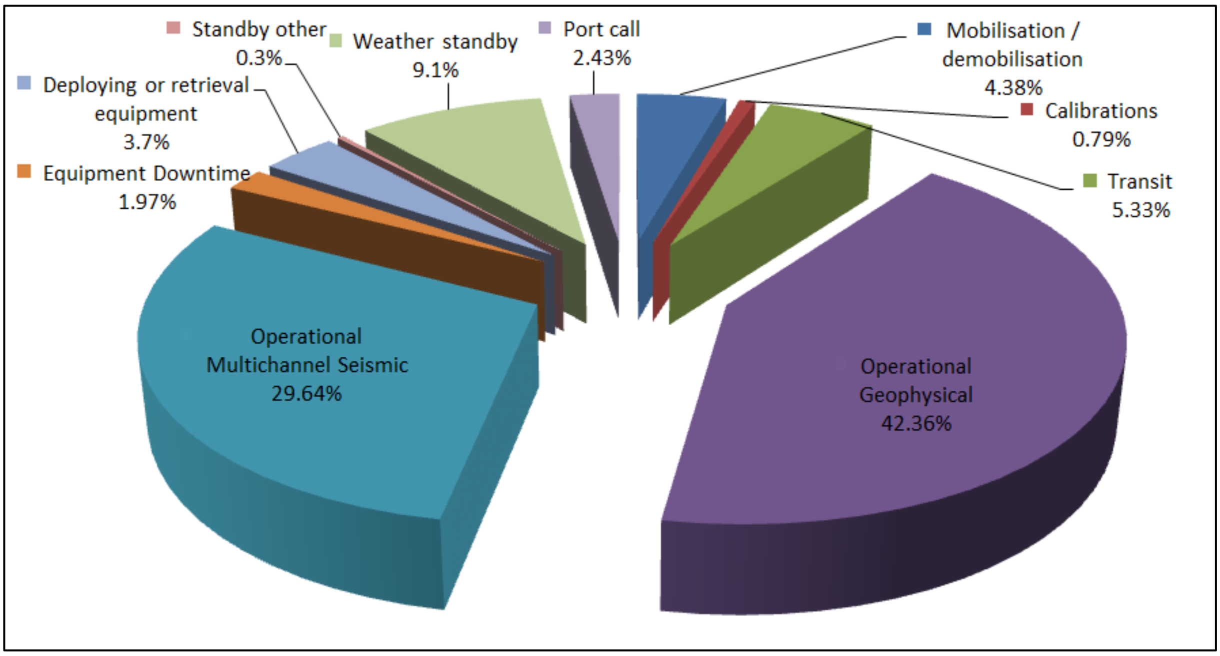


Figure 3.1: Operational statistics graph. Values expressed in percentage

4. SURVEY CONTROL

4.1 Horizontal Control

4.1.1 M.V. Fugro Pioneer

The vessel's Centre of Gravity (COG) was defined as the origin of the vessel's survey coordinate system, or Common Reference Point (CRP). Refer to Figure 4.1 for a photograph, to Figure 4.2 for an offset diagram, and to Table 4.2 for offsets table of M.V. Fugro Pioneer.

Figure 4.1: Photograph of M.V. Fugro Pioneer

Table 4.1: Vessel Specifications

Class	DNVGL
Type	Scientific Research Vessel
Flag	Bahamas Maritime Authority/ Nassau
L.O.A.	53.7 m
Beam	12.5 m
Draught (summer) max	3.1 m + 0.26m blister
tonnage	1322 T
Deck area aft	250 m^2
Deck strenght	5 T/m^2
Deck load	81.6 T

Further details are given in Appendix F.

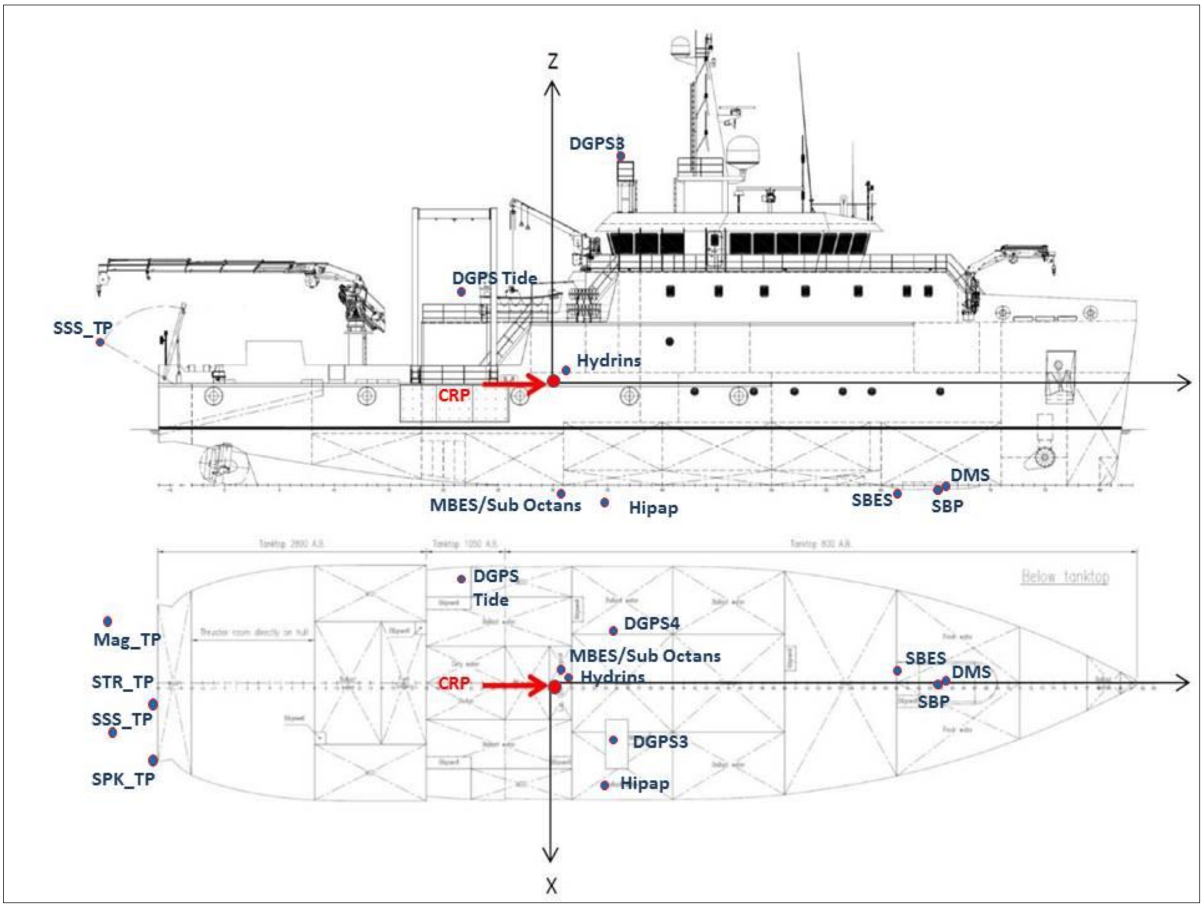


Figure 4.2: Offset diagram M.V. Fugro Pioneer

Table 4.2: Offsets M.V. Fugro Pioneer

Offsets (from CRP)	X [m]	Y [m]	Z [m]
CRP	0.00	0.00	0.00
USBL (deployed position)	3.91	3.56	-6.96
DS1 Draught transducer (for SBES)	-2.22	18.24	-5.54
DS2 Draught transducer (for MBES)	-0.83	1.37	-5.53
SBES transducer	-0.66	20.19	-5.79
SBP 4x4 (centre of array)	0.01	22.24	-5.73
MBES	-0.70	0.49	-6.03
HydrINS (Primary MRU/Heading)	0.39	0.77	0.46
DMS 25 (MRU)	-0.35	21.90	-4.59
Subsea Octans (MRU/Heading)	-0.74	0.96	-5.33
DGPS1	-3.55	16.88	9.42
DGPS2	3.52	16.91	9.40
DGPS3_1 (Starboard)	3.18	4.26	12.06
DGPS3_2 (Port)	-3.17	4.26	12.06
DGPS4	-3.16	5.09	12.06
SSS_TP (Sonar tow-point)	3.75	-23.74	5.30
CTD Crane	5.75	0.0	0.00
DGPS_Tide	-6.23	-7.22	5.30
Mag_TP (Magnetometer tow-point)	-3.66	-23.74	5.30
Streamer_TP (Streamer tow-point)	1.60	-20.82	0.00
Sparker_TP (Sparker tow-point)	6.03	-20.82	1.00
CMP	3.82	-53.18	-3.06

4.2 Vertical Control

The vertical datum was Lowest Astronomical Tide (LAT). All water depths are referenced to LAT and reduced using post processed GNSS height data. . The WGS84 ellipsoid height derived from a GNSS solution will typically have an accuracy of 0.15 m.

All GNSS heights are referenced to LAT by using the Danish Technical University 2013 Mean Sea Surface (DTU13MSS) model. This model makes use of a refined EGM96 geoidal model.

The DTU13MSS is a state of the art worldwide MSS model. The main advantages of the DTU13MSS over other MSS models are:

- based on extended satellite observations between 13 (arctic zones) and 17 years;
- based on more ENVISAT data for climate change corrections;
- extended ICES at coverage (4-7 cycles/month);
- introduced coastal MSS corrections.

This methodology provides accurate and consistent tide values regardless of location, with several advantages over the method of using observed tides from available tide station gauges. The use of GNSS height data eliminates the reliance on remote or very distant tidal observation points, and the requirement to interpolate tide effects between these measurement points. It also allows a fast turnover in the generation of tide corrected data, making them available in real time during the offshore operations. Sporadically, e.g. during sharp line turnings, tide values might show some minor oscillation in the recorded data.

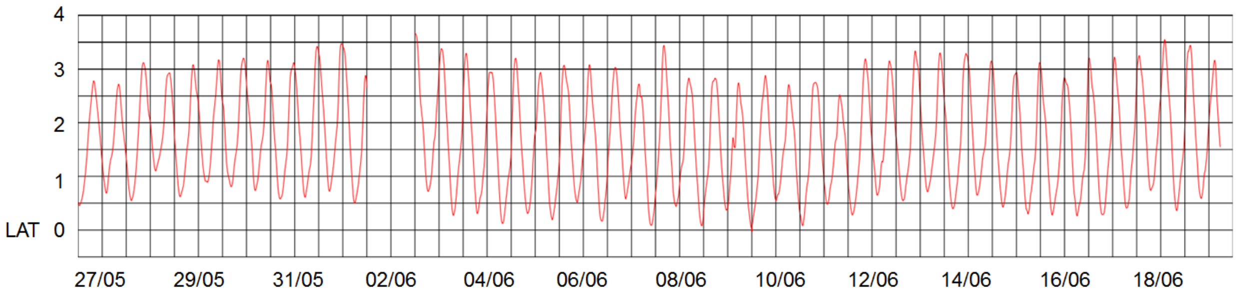


Figure 4.3: Tide Graph during the survey period

Antenna height differences are observed on 09-06-2015 between 13:40 and 15:30 hours (GMT) on DGPS3 and DGPS4. The main tide antenna for 09-06-2015 is DGPS3 which starts to deviate for around 45 minutes from DGPS4, starting at 13:40. This could be caused by loss of satellites (from 12 to 8) during the line turn made after completion of line A31077. The next survey line started at 15:48, which falls outside the tidal bump. Therefore, it can be concluded that no data has been affected by this anomaly.

4.3 Time Reference

All logged data and associated record annotations were referenced to UTC. The Daily Operations Reports and the survey log book were recorded in local time (UTC+2 hrs).

4.4 Survey equipment

The equipment utilized to carry out the survey is shown in table 4.2.

Table 4.3: Equipment on board M.V. Fugro Pioneer

Equipment on board M.V. Fugro Pioneer	
Positioning and Navigation	5 x StarPack unit (c/w cables and antenna)
	1 x Access to Starfix L1, L2, Dif, HP, G2 corrections
	4 x Online survey computer (Starfix.Seis)
	4 x StarPort (network hub)
	1 x iXBlue Hydrins Fibre Optic Gyro compass
	1 x Meridian Gyrocompass
	1 x iXBlue Octans 3000 Motion sensor
	1 x Teledyne TSS DMS-25 Motion sensor
	3 x Additional monitors as helmsman display
	1 x Adams draught reader
	1 x Leica TS15 total station with tripod and prisms
Geophysical Equipment	1 x Kongsberg EA400 SBES (dual frequency transducer, 33 kHz and 210 kHz, hull-mounted)
	2 x SD204 probe with wireless controller
	2 x EdgeTech 4200-FS Digital SSS
	2 x EdgeTech 701-DL Topside unit
	2 x SSS Tow winch (c/w cable and cable counter)
	2 x STR Digital Transceiver
	1 x Massa TR-1075 Pinger 4 x 4 array (hull mounted)
	1 x Kongsberg EM 2040 Dual Head MBES
	2 x Valeport MiniSVP velocity probe
	1 x Kongsberg HiPAP 501 cymbal USBL system
	7 x Beacon
	4 x Kongsberg Mini 34 Transponder
	2 x Kongsberg Maxi Transponder
	1 x Kongsberg APOS system
	2 x Kemo Benchmaster
	1 x Applied Acoustics Duraspark 1000j 200 tip Sparker
	1 x 48 channel solid Geometrics streamer
Digital Data Acquisition	Starfix.GLog/GPlot data acquisition and processing system
	GLogIV system
	Geometrics GeoEel
Data Processing	Starfix.VBA Proc software
	Starfix.Workbench software
	Starfix Geocoder software
	Starfix.Interp software

Equipment on board M.V. Fugro Pioneer	
	Chesapeake SonarWiz 5 software
	Triton Perspective software
	Global Mapper 14 software
	IHS Kingdom 8.8 software
	DECO Geophysical RadExPro and Uniseis software
	MagPick software
	Geosoft Oasis Montaj software
	Bentley MicroStation software
	AutoDesk AutoCAD software

5. EQUIPMENT AND CALIBRATIONS

5.1 Survey Computer

The positioning systems were interfaced to a desktop computer system using Fugro's Starfix Suite for data logging, positioning and processing.

The geodetic and projection parameters listed in Table 1.1 were utilised for the transformation from WGS84 to local datum. The quality parameters of the DGPS position fixes were used to validate the data and to control the processing. A motion sensor was interfaced to enable real-time calculation of the positions of survey sensors from ship's heading, layback and transverse offset to ship's origin.

The following data was logged for processing and plotting purposes:

- line number, fix number, date and time;
- positioning data;
- heading;
- pitch, roll and heave;
- cross-track and chainage relating to the sail line;
- positions of survey sensors;
- computed positions of all vessel offset point;
- motion-compensated bathymetric data.

5.2 Positioning and Navigation System

The positioning system used on M.V. Fugro Pioneer uses a Starfix.G2 solution. The Starfix.G2 solution is Fugro's positioning solution based on GLONASS and GPS with clock and orbit corrections received by the Starpack DGNSS receiver from Fugro's independent network of reference stations. The iXSea Hydrins INS sensor was interfaced to the navigation system to compensate for antenna movement induced by the heave, pitch and roll of the vessel and to provide vessel heading data.

The positioning systems were operated under the following conditions:

- minimum elevation mask of 5 degrees;
- PDOP less than 5;
- minimum number of satellites 5.

The primary positioning system (GPS Antenna StarPack 3) was verified on-board M.V. Fugro Pioneer during vessel mobilisation for a previous survey. The verification took place in the port of Den Helder, the Netherlands, on 22 April 2015 using land survey techniques with total station and known points on the quayside. The results of this verification are shown in Table 5.1. Details of the verification are presented in Appendix A (A.3).

Table 5.1: Positioning system verification M.V. Fugro Pioneer 22 April 2015

Date	Description	∆Easting	S.D.	∆Northing	S.D.
		[m]	[m]	[m]	[m]
22 April 2015	GNSS Antenna StarPack 3	0.02	0.11	0.02	0.12

The comparison of positioning systems GPS Antenna StarPack 3 and GPS Antenna StarPack 4 took place on 22 April 2015 in Den Helder, The Netherlands. The results of this comparison are shown in Table 5.2. Details of the comparison are presented in Appendix A (A.3).

Table 5.2: Positioning system comparison M.V. Fugro Pioneer 22 April 2015

Date	Description	∆Easting	S.D.	∆Northing	S.D.
		[m]	[m]	[m]	[m]
22 April 2015	GNSS Antenna StarPack 3 and 4 comparison	0.02	0.03	-0.02	0.03

5.3 Heading System and Motion Sensor

The survey gyrocompass alignments were checked in Den Helder, The Netherlands, on 22 April 2015 using a total station measurement method (Table 5.3). Detailed reports of the alignment checks are presented in Appendix A (A.4).

Table 5.3: Gyrocompass alignment check M.V. Fugro Pioneer 22 April 2015

Date	Gyro	Method	C-O [°]
22 April 2015	Hydrins	Sunshot	-0.09
22 April 2015	Subsea Octans	Sunshot	-0.09
22 April 2015	Meridian	Sunshot	-0.46
22 April 2015	GNSS Heading	Sunshot	-0.13

5.4 Single Beam Echo Sounder

A Kongsberg EA400 SBES with 33/210 kHz hull-mounted transducer was used for bathymetry. In addition a Hydrins INS was interfaced to the SBES in order to reduce the influence of the vessel's vertical movement on depth readings. Refer to Table 5.4 for the installation details.

Table 5.4: SBES operational installation M.V. Fugro Pioneer

SBES	Kongsberg EA400
Frequency	33 kHz
Range	Dependent on water depth
Heave compensation	iXBlue Hydrins INS / DMS25
Transducer Draft	3.3 m - 3.4 m

5.5 Multibeam Echo Sounder

A Kongsberg EM2040 MBES, in a single transmitting transducer (Tx) / dual receiving transducer (Rx) configuration, was used to accurately map seabed bathymetry across the survey site. An iXBlue Hydrins INS (inertial gyrocompass and motion sensor) mounted close to the CRP was interfaced with the MBES in order to reduce the influence of the ship's movement on depth readings. The vessel draft was measured during mobilisation in Den Helder, The Netherlands, and periodically during the project. Refer to Table 5.5 for the installation details.

Table 5.5: MBES operational installation M.V. Fugro Pioneer

MBES	Kongsberg EM 2040
Frequency	400 kHz
Swath coverage	Variable; modal value 150m
Number of beams	800
Motion & Heave compensation	iXBlue Hydrins INS
Transducer draft	3.4 m to 3.5 m

A MBES calibration was carried out onboard M.V. Fugro Pioneer at 13 April 2015 on the WGT rock dump in K-Block (Dutch Sector, North Sea), at the following coordinates:

Table 5.6: MBES calibration coordinates (WGS84)

Water depth	Latitude [N]	Longitude [E]
25 m	03° 54' 58''	046°29' 11''

The results of these calibrations are summarised in Table 5.7. Details of the calibration are presented in Appendix A (A.5) of this report.

Table 5.7: MBES calibration M.V. Fugro Pioneer 13 April 2015

Date	Derived Corrections	Latency	Pitch	Roll	Yaw
		[sec]	[º]	[º]	[º]
13 April 2015	Tx	0.0	-0.550	+0.050	359.900
	Rx Port	0.0	0.550	39.820	179.900
	Rx Stbd	0.0	0.550	-39.920	179.900

5.6 Side Scan Sonar System

The EdgeTech 4200-FS is a dual simultaneous frequency SSS system, which utilises Full Spectrum CHIRP technology. The frequency utilised for recording the High Frequency data on the project ranged between 530 and 580 kHz approximately, while for the Low Frequency varies between 100 kHZ and 125 KHz.

The data was digitally recorded on Starfix.GLog/GPlot software for digital processing.

A Kongsberg HiPAP USBL positioning system was used for towfish positioning. The EdgeTech 4200-FS system incorporates an internal fluxgate compass which can be used for post-processing of towfish heading values. Refer to Table 5.8 for the installation details.

In order to check if the SSS was working effectively, a verification was carried out on 27 May 2015. The verification consisted of running two (2) vertical sets of two SSS survey lines in opposite directions over the existing Wreck 1723 in the Borssele Wind Farm Zone. The result of this verification can be found in Appendix A (A.7).

Table 5.8: SSS operational installation M.V. Fugro Pioneer

SSS	EdgeTech 4200-FS
Range	100 m / 125 m
Frequency	Linear sweep: 530 - 580 kHz for HF and 100 kHz -125 KHz for LF
Cable out	Variable (depending on water depth and ship's speed)

5.7 Magnetometer

The G-882 Marine magnetometer used for this project has a very high resolution Caesium Vapour performance. They are capable of achieving high sensitivity and sampling rates and are applicable both in shallow and deep water. They have a minimum sensitivity of smaller than 0.004 nT/Hz and maximum sampling rate of 40 samples per second.

The G-882 magnetometer was towed using a separate winch to allow closer proximity to seabed and greater distance from vessel with the aim to improve object detection and minimize general noise level. In order to check if the magnetometer was working effectively, verification was carried out on 27 May 2015. The verification consisted of running two (2) survey lines, with magnetometer, in opposite direction over the existing ZEEPIPE pipeline in the Borssele Wind Farm Zone. The result of this verification can be found in Appendix A (A.8).

5.8 Ultra Short Baseline System

A USBL system allows the measurement of range and bearing from a vessel-based transceiver to a single, subsea transponder. It generally operates through the phase discrimination of an acoustic signal recorded by three orthogonal transducers. A Kongsberg HiPAP USBL positioning system was used on board the M.V. Fugro Pioneer for tow fish positioning.

The M.V. Fugro Pioneer carried out a USBL calibration on 28 August 2014. The calibration was carried out by a Kongsberg technician after the installation of the system during sea trials in the Black Sea and aimed to determine the accuracy and possible corrections for the Kongsberg HiPAP USBL positioning system. The beacon was moored on the sea bottom and the vessel stationed on 4 cardinal points to determine orientation, pitch and roll corrections. These values were the APOS software that controls the HiPAP system.

In addition to the calibration a USBL verification was conducted. The USBL verification was conducted on 27 May 2015 before starting survey operations for the Borssele wind farm site study. The verification was carried out over the Wreck-1723 in the Borssele Wind Farm Zone. The verification was conducted in order to determine the accuracy of the HiPAP USBL system in conjunction with the SSS system. A detailed report of the USBL calibration, verification are presented in Appendix A (A.6 and A.7).

5.9 Sub-bottom Profiler System

The hull-mounted Pinger (HMP), Massa TR-1075 Pinger array installed on-board M.V. Fugro Pioneer was used as the primary tool, for detecting shallow sub-surface layers. The system comprises an array of sixteen (16) transducers, with two (2) additional transducers added to the front row. The array was operated using a 4 x 4 configuration, where all transducers were set in combined mode (Tx/Rx). The transducers were operated at 3.5 kHz.In order to determine the functionality of the sub-bottom profiler system (SBP); a verification was carried out 27 May 2015. The verification consisted of running two sub-bottom profiler lines in opposite directions over existing ZEEPIPE pipeline in the Borssele Wind Farm Zone. The results can be found in Appendix A (A.9).

A TSS DMS-25 motion reference unit was installed close to the transducer array, to compensate for the influence of the vertical movement on the recordings. Refer to Table 5.9 for the SBP (pinger) operational installation details.

Table 5.9: SBP (pinger) operational installation M.V. Fugro Pioneer

HMP (4 x 2 configuration)	Massa TR-1075
Record length	0 ms -95 ms
Frequency	3.5 kHz
Power	4.15 kW (10% of 41.5 kW)
Firing interval	100 ms

5.10 Sparker – UHR system

Seismic data were collected using an Applied Acoustic DuraSpark 400 tips source, in conjunction with a CSP-N 2400 Negative Applied Acoustic power supply and a 48 channel solid Geometrics streamer GeoEel as a receiver.

The Geode digital acquisition system was used throughout the survey. Sparker data was recorded in digital SEG- 8058D format.

The system was operated using the parameters listed in Table 5.9:

Table 5.10: UHR operational installation M.V. Fugro Pioneer

Sparker	Applied Acoustic DuraSpark 400 tips
Power	800 J
Range	250 ms
Source Tow Depth	0.3 m
Shot interval	3.125 m

The 150 m solid Geometrics streamer GeoEel comprised 48 channels, each containing16 hydrophone sensors. The streamer was maintained at the required tow depth of 1.0 m (+/- 0.5m) during acquisition, using streamer balance and level monitoring and correction of the Digicourse active leveller system communicating with Digicourse depth sensors. The streamer was decoupled from the vessel heave using a tow leader and 20 m stretch section. A tail-buoy with beacon was towed from the end of the streamer. Full details are in Appendix D.

The digital streamer specifications are listed in Table 5.11:

Table 5.11: Streamer specification

Streamer model	Geometrics streamer GeoEel
Active Length	150 m
No of Groups	48
Hydrophones	3.125
Streamer Sensitivity	16 per group
Streamer Tow Depth	20µV/µb
Streamer Tow Depth	1.0 ± 0.5 m

Prior the commencing of the survey, the system was repeatedly tested. A full list of tests carried out is reported in Table 5.12.

Table 5.12: Tests results

Mobilisation Quayside Tests			
Test / Cal	**Description**	**Test / Calibration Deliverable**	**Test Result**
Sparker source test	Deploy and Fire the source alongside up to maximum energy	Source fires without malfunction.	Test performed alongside maximum energy fired without malfunction.
Integrated seismic spread test	The following tests will occur with the full system assembled and source firing for 0.5h period as a minimum	Power supply fires without overheating or interruptions. Simulated distance triggering fires the PS without miss-fires	Completed successfully during Test Line at start of the survey
Hydrophone test	Connect streamer to recording unit, uncoil streamer. Record a file whilst tapping each individual hydrophone.	Record tap test, describing spikes recorded on relevant channels.	Completed in workshop prior to vessel mobilisation
Navigation recording test	Log position data including shot number, FFID, centre of source, centre of each receiver group and feather angle.	Log files record valid values for every shot.	Completed during Test Line at start of the survey
Mobilisation tests performed at sea			
Test / Cal	**Description**	**Test / Calibration Deliverable**	**Test Result**
Streamer working noise limit	Record noise file of entire towed spread without source firing	Background noise to ascertain signal to noise ratio to be accepted by client.	Background noise of acceptable level. Noise files are recorded at start and end of every survey line
Seismic source tow depth	Deploy seismic source at various depths to monitor ghost noise levels	Determine optimal tow depth for seismic source	Specification of AAE DuraSpark is 0.3 m source depth.
Streamer tow depth and balancing	Balance streamer to survey specifications	Ensure ghost/wave noise minimised and sound recorded equally across all channels	Streamer balanced and checked on first deployment. Tow depth configured to 1.0 m +/- 0.5 m
Feathering	Monitor feather angle at in line and cross line directions	Feather angle within specification under normal survey conditions	Feather angle is monitored via GPS tail buoy, and logged during each survey line.

Positioning	Log position data, Acquire the same line in opposite directions and compare notable features as observed in the brute stacks. Compare seabed reflections of the brute stacks with processed MBES data.	Difference between positions of notable features in the brute stacks to be within +/- 2 m. The Brute stack seabed reflections (LAT) to be within 0.4 ms of the MBES model converted to time.	P190 merged on the test line in post processing and checked against MBES data
Geological signal assessment	Compare brute stack with prior data from the site	Data quality meets requirements and of comparable quality with reference data.	Brute stack compared with previous data. Data quality meets requirements.

Moreover, Analogue Performance Test and Geometric Leakage Test were performed during a test line, in order to check the streamer. Refer to Appendix A (A10) for full details.

5.11 Sound Velocity Profiler

Two SD204 SVP/CTD profilers (SD1165 and SD1166) were mobilised to acquire a Sound Velocity Profile (SVP) through the water. The profile data was utilised for SBES and MBES data (Table 5.13).

The profilers can be programmed to measure and calculate salinity, conductivity, temperature, depth (density) and sound velocity at varying intervals. The recorded data can be recorded in real-time via a cable connected to a computer or it can be saved as a file of data within the unit to be downloaded at a later date.

Both SVP/CTD profilers were calibrated on 05 June 2014. Also, on 16 April 2015, both profilers were tested simultaneously in order to confirm similarities in data reading and acquisition. The calibration and sound velocity reports can be found in Appendix A (A11).

SVP locations are shown in Figure 5.1

Table 5.13: Sound velocity measurements Coordinates (ETRS89 31N)

Item	Date	Easting	Northing	Latitude	Longitude	Water depth	Average speed of sound
		[mE]	[mN]	N	E	[m]	[m/s]
1	27/05/2015	499692.59	5730226.70	51° 43' 22.69"	2° 59' 43.98"	34.00	1498.84
2	28/05/2015	507903.28	5720071.99	51° 37' 53.79"	3° 06' 51.08"	32.14	1499.83
3	30/05/2015	502871.57	5727413.09	51° 41' 51.59"	3° 02' 29.58"	25.63	1499.77
4	31/05/2015	498335.17	5721672.54	51° 38' 45.79"	2° 58' 33.38"	24.29	1500.30
5	01/06/2015	500039.98	5717059.90	51° 36' 16.49"	3° 00' 02.08"	31.57	1500.77
6	03/06/2015	496824.08	5727110.52	51° 41' 41.79"	2° 57' 14.58"	35.02	1500.35
7	03/06/2015	502739.25	5730688.06	51° 43' 37.59"	3° 02' 22.78"	23.62	1501.01
8	04/06/2015	497134.52	5719306.65	51° 37' 29.19"	2° 57' 30.98"	26.78	1500.90
9	04/06/2015	501552.11	5735513.50	51° 46' 13.81"	3° 01' 20.98"	34.39	1501.33
10	05/06/2015	502617.67	5739424.52	51° 48' 20.39"	3° 02' 16.68"	27.39	1500.99
11	05/06/2015	496357.78	5738047.27	51° 47' 35.79"	2° 56' 49.88"	28.24	1501.18
12	06/06/2015	495711.04	5736706.98	51° 46' 52.39"	2° 56' 16.18"	35.02	1501.24

Item	Date	Easting	Northing	Latitude	Longitude	Water depth	Average speed of sound
		[mE]	[mN]	N	E	[m]	[m/s]
13	07/06/2015	493342.76	5736860.94	51° 46' 57.29"	2° 54' 12.58"	31.72	1501.35
14	07/06/2015	485895.47	5728982.86	51° 42' 41.79"	2° 47' 45.08"	20.06	1501.53
15	07/06/2015	483296.64	5734123.55	51° 45' 27.93"	2° 45' 28.78"	25.59	1501.63
16	08/06/2015	502571.86	5716538.46	51° 35' 59.59"	3° 02' 13.68"	25.41	1504.49
17	08/06/2015	487643.801	5734434.15	51° 45' 38.39"	2° 49' 15.48"	35.70	1501.69
18	08/06/2015	502130.75	5731453.63	51° 44' 02.39"	3° 01' 51.08"	28.18	1502.71
19	09/06/2015	492326.78	5722722.29	51° 39' 19.59"	2° 53' 20.68"	20.01	1502.73
20	09/06/2015	496669.40	5730978.20	51° 43' 46.98"	2° 57' 06.39"	36.15	1502.38
21	10/06/2015	491721.61	5723619.77	51° 39' 48.61"	2° 52' 49.11"	35.67	1502.59
22	10/06/2015	497661.12	5729939.31	51° 43' 13.37"	2° 57' 58.11"	33.47	1502.72
23	11/06/2015	492609.44	5723118.85	51° 39' 32.44"	2° 53' 35.36"	32.30	1502.97
24	11/06/2015	498872.42	5733988.77	51° 45' 24.46"	2° 59' 01.19"	28.67	1503.11
25	12/06/2015	500933.15	5729596.86	51° 43' 02.30"	3° 00' 48.63"	33.86	1503.17
26	12/06/2015	491419.71	5735191.86	51° 46' 03.17"	2° 52' 32.37"	34.82	1503.15
27	12/06/2015	491419.71	5735191.86	51° 46' 03.17"	2° 52' 32.37"	32.99	1504.03
28	13/06/2015	502261.43	5717186.14	51° 36' 20.56"	3° 01' 57.56"	23.15	1505.59
29	13/06/2015	494345.71	5724044.65	51° 40' 02.48"	2° 55' 05.67"	33.56	1504.24
30	14/06/2015	492744.43	5737188.31	51° 47' 07.86"	2° 53' 41.33"	33.67	1503.45
31	14/06/2015	491127.62	5723870.09	51° 39' 56.68"	2° 52' 18.17"	22.91	1504.44
32	15/06/2015	494240.52	5736881.76	51° 46' 57.99"	2° 54' 59.43"	35.07	1503.70
33	15/06/2015	483497.61	5731968.94	51° 44' 18.21"	2° 45' 39.63"	32.62	1504.15
34	16/06/2015	499294.98	5738072.57	51° 47' 36.65"	2° 59' 23.20"	31.23	1504.16
35	16/06/2015	489671.03	5721528.04	51° 38' 40.78"	2° 51' 02.59"	30.47	1505.25
36	17/06/2015	498450.00	5737599.16	51° 47' 21.32"	2° 58' 39.10"	33.40	1504.45
37	17/06/2015	485602.39	5729243.82	51° 42' 50.21"	2° 47' 29.77"	31.90	1505.02
38	18/06/2015	491282.28	5735200.44	51° 46' 03.44"	2° 52' 25.20"	30.99	1504.81
39	18/06/2015	491170.36	5723373.25	51° 39' 40.59"	2° 52' 20.44"	32.04	1505.53
40	19/06/2015	488993.81	5728623.27	51° 42' 30.40"	2° 50' 26.56"	34.06	1505.61

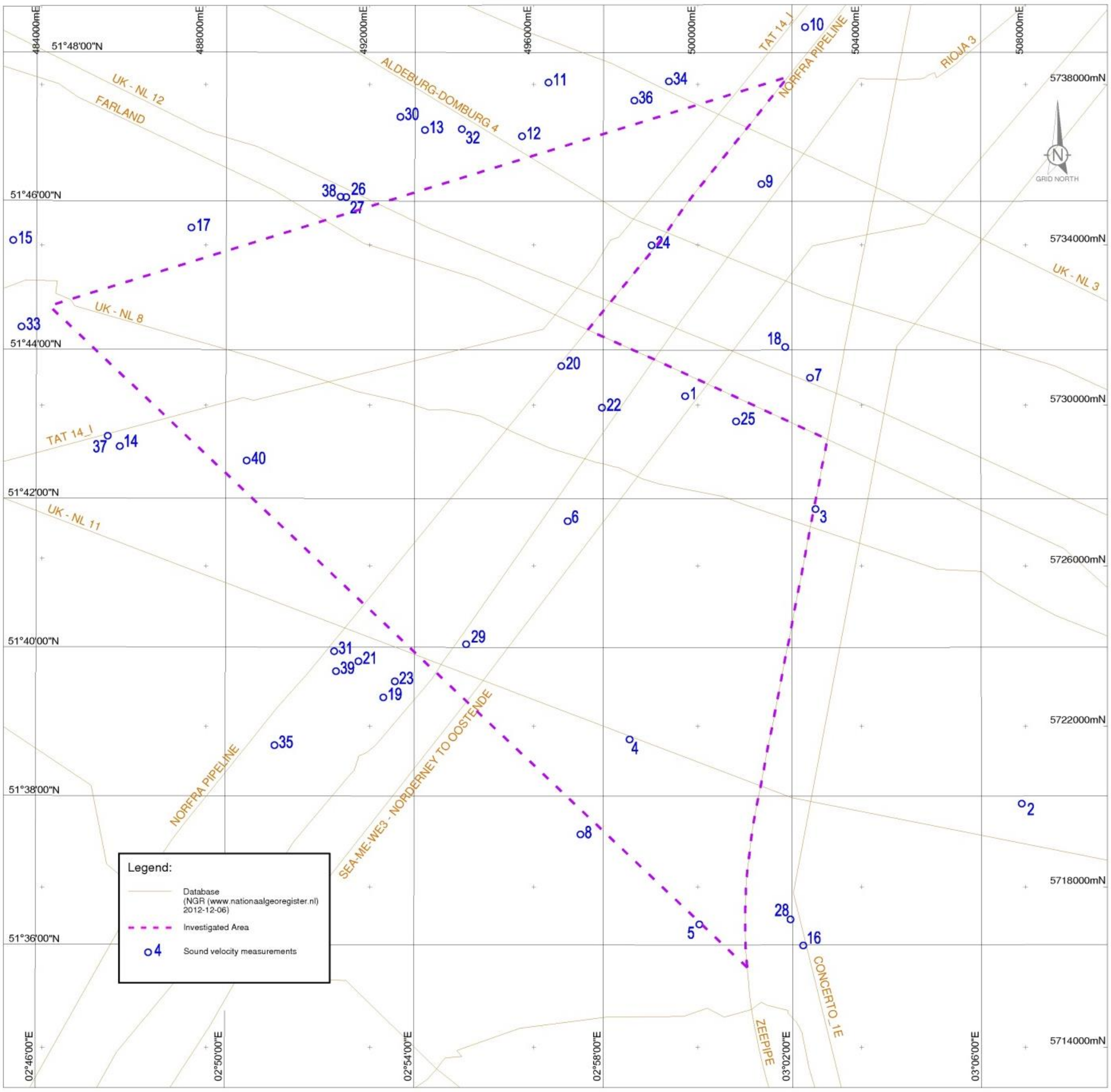


Figure 5.1: Overview of SVP locations.

6. DATA REDUCTION AND PROCESSING

6.1 Data processing

6.1.1 Positioning and Navigation

All raw DGPS data were edited to remove erroneous fixes. No smoothing filters were applied to the position data during acquisition.

The antenna position was corrected to the vessel common reference point position (CRP) using measured offsets, during the acquisition of data. Each tow point/sensors position across the vessel was calculated in StarfixVBAProc by applying vessel offset measurements. Equipment offsets from CRP position are shown in Figure 4.2.Real-time logging of navigation was acquired using Fugro's Starfix.Seis navigation system. Bathymetric sounding (water depth) data was logged in Kongsberg SIS software.

The processing of the acquired navigation data was carried out using the Starfix.Proc software.

6.1.2 Multibeam echo sounder

All water depths were referenced to Lowest Astronomical Tide (LAT) and reduced using post processed GPS height data collected in real time on board the M.V. Fugro Pioneer.

MBES data were processed using Starfix.VBAProc and Starfix.Workbench systems (Starfix.Suite 10.1 SP3).

The processing sequences were as follows:

Kongsberg EM2040

- Bottom detection.
- Sound velocity input at depth of instrument head (-6.029).

Starfix.Proc system

- Kongsberg EM2040 raw data (*.fbf) imported and datum set to WGS 84 UTM 31 N.
- Sound velocity compensation. SVPs were collected during the survey every 12 hours. SVPs have been stored in a cast library created through cast software (Starfix Tool), which returns a virtual computed SVP depending on position and time of multibeam data.
- Heave, pitch, roll and head offset applied (after data tracing for spikes and visually checked in graphic editor).
- Trace Filter applied to MBES data with following parameters:
  - Trace2D Across: 1 (cut off interpolate points)
  - Trace2D Along: 1 (cut off interpolate points)
  - Threshold: 0.3
- Position, heading, draft applied (after data traced for spikes and visually checked in graphic editor).
- Tide applied. Tide data from predicted tide used in VBAProc.
- Spurious data were removed by visual inspection swath by swath (Starfix.SwathEdit).

Starfix.Workbench system

- Data manually cleaned with the aim of reducing random noise and correct overlapping.
- Data gridded with Reduced Stats algorithm to 0.5 x 0.5 m bin size
- DTM files creation (*.B2N).
- Bathymetric contour lines (interval 5 m) extrapolated from DTM.
- XYZ ascii file and a georeferenced Tiff image were outputted from the DTM.
- Maps contoured and presented to a scale of 1:20 000.

MBES data were acquired to compel to the IHO S-44 Order 1a standard according to specifications issued by the Maritime and Coastguard Agency (MCA).The graphs below, show that such requirements were met with the survey settings used throughout the survey. Please note that the total horizontal (THU) and vertical (TVU) uncertainty were based on a water depth of 30 m and an opening angle of 130º.

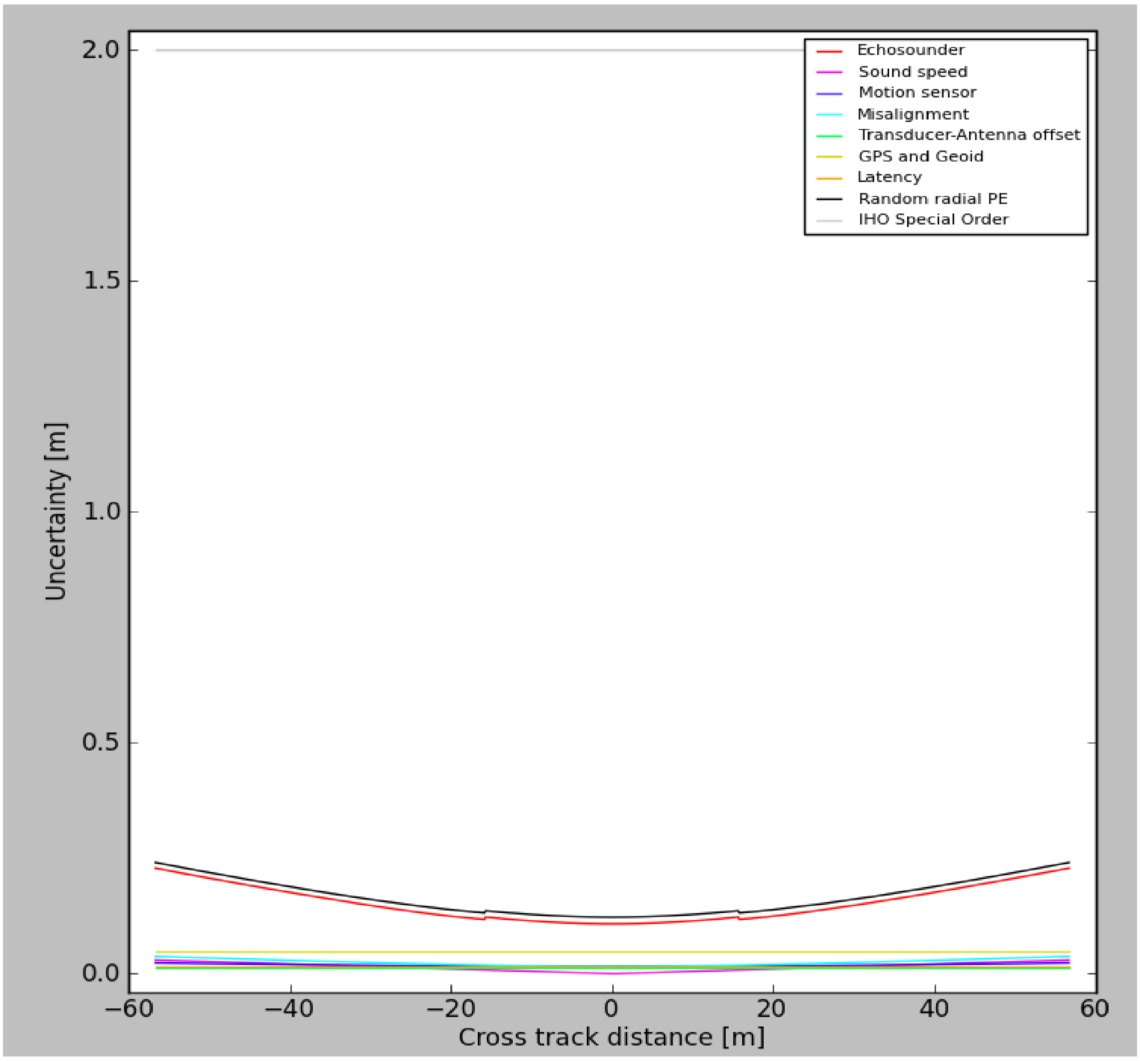


Figure 6.1: Total horizontal uncertainty (THU)

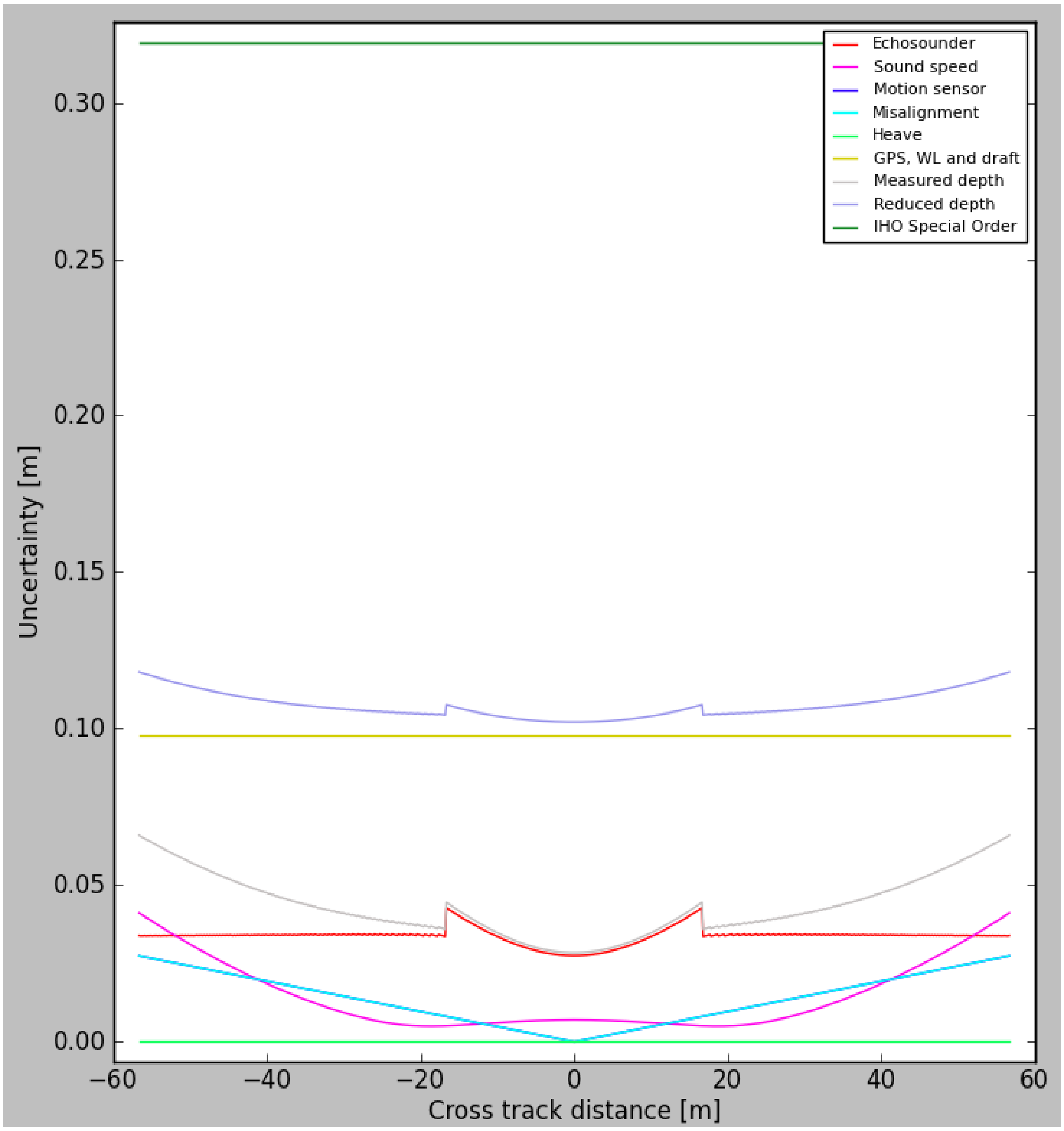


Figure 6.2: Total vertical uncertainty (TVU)

6.1.3 Backscatter data

The Backscatter data were processed using the Starfix Geocoder software.

The processing sequences are as follows:

- Each line was imported in .pos format;
- Input file setting:
  - MBES Position file: Raw Port-MBES .pos and Raw Stbd-MBES .pos;
  - Backscatter source: MBES Intensity.
- Corrections setting: Apply Lambert, Apply Gain Power, ApplyArea Correction.
- Angle varying gain:
  - AVG trend;
  - Filter size: 100
- Mosaic bin size: 0.5 m

- Output file setting: write XY and corrected backscatter.

Each line was exported in .XYB and .geotiff format with a cell size of 0.5 m x 0.5 m and then imported in Global Mapper 14 software to create the mosaic with a cell size of 0.5 m x 0.5 m.

6.1.4 Side San Sonar

Data were recorded in digital format (.xtf) using the Starfix Glog/Gplot software.

Onboard the *.xtf files were imported into SonarWiz software, where a full QC of each line was carried out. The records were corrected for slant-range distortion and gain. At the same time, data were analysed and checked for discrete sonar contacts. Then the positions were compared with MBES data.

The filters applied were as follows:

- AGC: (resolution 50 - intensity 20);
- EGN: (port intensity 0 - stbd intensity 0);
- TVG Curve: (logR: 4.0 – R: 0.00-0.50).

The SSS mosaic was created using high frequency data. At times, low frequency data were used to cover the nadir zones, wherever possible.

After the SSS data processing, each line was exported in .geotiff format with a cell size of 0.5 m x 0.5 m. Then, geotiffs were imported in Global Mapper 14 software to create the final mosaic with a cell size of 0.5 m x 0.5 m.

Each SSS contact was checked for positioning against MBES data. Final contacts are presented in listings in Appendix I.

6.1.5 Magnetometer

Magnetometer data were recorded in digital format (*.pos) using the Starfix software.

All magnetometer data were processed for position using Starfix VBAProc and exported as *.csv file.

Each file was therefore imported into Oasis Montaj software for data QC, sensor altitude and position checks. A β-spline filter was run where necessary, to remove lower amplitude, high frequency noise. A series of non-linear filter was applied to fit a smoothed curve to the data. The results of the non-linear filters were than subtracted from the result of the β-spline filter to calculate a residual magnetometer data channel.

A final comparison was made between the magnetic residuals data against raw data to ensure that no noise was present in the filtered data.

Residual and the analytic signal were calculated and exported as Oasis Montaj database.

6.1.6 Sub-bottom Profiler

The SBP data files were recorded using the Starfix Glog/Gplot software. Two types of data file were recorded, .glog files (as raw data) and .segy files. Heave corrections were recorded during acquisition in the raw pinger data. If required for future additional processing, heave values can be extracted from the acquired data and provided as text file.

QC consisted of checking the data for positioning errors, cross-checking them with MBES and SSS data.

Several tests were carried out in order to achieve best results on SBP data. The best processing parameters of consisted of:

- Low cut filter: 2000 Hz;
- High cut filter: 5500 Hz;
- Trace average: 2;
- TVG Curve: gain from 5 to 50 starting at time 0

6.1.7 UHR System

The Sparker - UHR data were acquired to investigate the shallow geology in the survey area. In order to achieve this, the seismic profiles were interpreted to identify significant seismic reflectors and geological hazards, up to a depth of 80 meters below seabed.

All the data were QCed and processed onboard M.V. Fugro Pioneer.

On board quality control of the UHR data was performed in RadExPro software package. Parameter tests and preliminary processing were completed in order to produce a preliminary brute stack for each survey line. The quality of the UHR data was generally good.

Streamer depth was monitored by 3 remote-controlled depth controllers (birds), and was annotated on the observers logs every 200 shots. Streamer feather angles were monitored using the GPS tail buoy and annotated on the observers logs. Synchronisation between shot points and files was constantly monitored.

Data were converted from the time to the depth domain using the smoothed velocity field derived from pickings, and were cross checked with information resulting from the geotechnical campaign in WFSI and WFSII (via tie-in lines, see also Ref.20). For each line two outputs were created: True Amplitude migrated and Equalized migrated. SEG-Y outputs were performed with a standard 3200 byte EBCDIC textual header reporting recording data and processing flow.

All details of final processing are shown in Appendix D.

6.1.8 Near Trace Seismic Sections from UHR data

A further processing flow on the UHR data was performed to obtain the Near Trace sparker section with the aim to fill potential imaging gaps between the Pinger and UHR data. These sections, where necessary, were analysed to support the interpretation of the complex shallow Pleistocene formations.

Near trace dataset was created by extraction of channel 3 from UHR dataset. Channel 3 was found to have a better signal to noise ratio than channel 1 or 2 because less affected by stern noise and better balanced. For improving overall data quality from the near trace the following processing steps were applied with the purpose to enhance signal to noise ratio and signal coherence (this processing is different from the UHR processing flow):

- Band pass filter 100 - 2000 Hertz
- T ^ 1.2 gain recovery function (tests were performed)
- F - X deconvolution
- FK filtering with a slop of 1 ms/ tr (tests were performed)
- Final AGC with a 50 ms window

Other processing routine like Time Frequency Denoise and Predictive Decon was tested but found ineffective or detrimental for signal improvement.

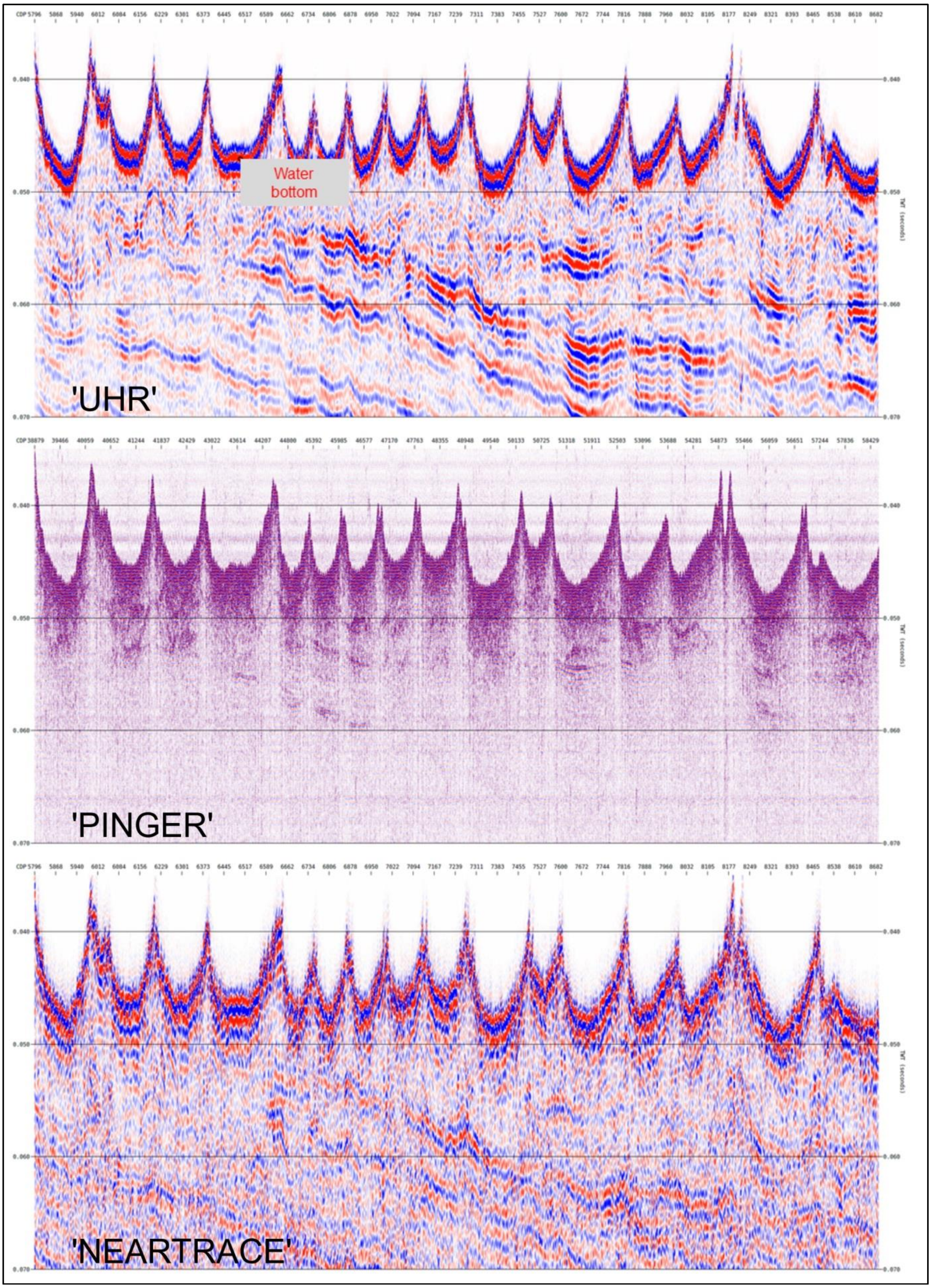


Figure 6.3: Comparition between UHR, Pinger, Near Trace data.

6.2 Data Interpretation

6.2.1 Bathymetry data interpretation

Bedform zonation was performed in Global Mapper 14 software and the DTM file (cell size 0.5 m x 0.5 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. For each detected class the wavelength was measured and the height calculated according to Ref 11.

The bedform zonation was exported in geotiff and .dwg format.

6.2.2 Backscatter data interpretation

The backscatter analysis was performed using Triton Perspective processing software. This software runs an automated soil classification module (*SeaClass*) based on Backscatter intensity. In particular, for the study area two classes were chosen based not only on the correlation with the SSS mosaic data but also with the results of the CPTs and BHs performed by FEBV in WFS-I and WFS-II areas.

The processing sequences were as follows:

- Create Training Set: it was enter ground truth information in order to generate a set of data points to be used in the neural net training process.
  - Sampling grid size: 5 m x 5 m;
  - Number of classes: 2;
  - Type of classes: dense sands and loose sands.
- Neural Net Training: it was used the training set already created to train the neural net.
- Classify: it was used the neural net to automatically classify the backscatter mosaic.

A grid cell size of 10 m x 10 m was chosen to create a smoother generalization of the sediment types and smoother polygon boundaries. Resulting seabed classification was cross-referenced with available surficial soil samples to ensure overall consistency between datasets.

After completion of the seabed classification map the grid was exported as a geotiff format.

6.2.3 Side Scan Sonar data interpretation

Side scan sonar records were examined both for significant targets and for the general level of backscatter from the seabed. The nature of the seabed sediments was interpreted from the acoustic facies, i.e. the textural appearance combined with the acoustic reflectivity of the sonar records.

The contacts detection on the SSS data files was done using the SonarWiz software with the SSS waterfall visualization for optimal resolution. Targets with dimensions above 0.2 m were 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.

Each SSS contact was checked for positioning against MBES data. Final contacts are presented in listings in Appendix I and on charts in Appendix M.

6.2.4 Magnetometer data interpretation

All the magnetic targets were picked using MagPick software in concert with the analytic signal raster data.

Magnetometer targets were picked on residual data. The analytic signal raster image was used just as a background to enhance the map results, and is not a grid, but a linear image of the nT/m data. Initially it was decided to use a threshold of 5 nT for the magnetic anomalies, but while some cables were detected with values less than 5 nT, it was decided to keep all the picked anomalies.

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

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

The magnetic contacts are presented in listings in Appendix I and on charts in Appendix M.

6.2.5 Sub-bottom Profiler data interpretation

The interpretation of SBP data was performed using Kingdom Suite software vers 8.8.

Each SBP line was imported into a Kingdom project (in seconds) and then vertically bulk shifted, with values ranging from 0.001 s to 0.005 s, in order to minimize the difference with seabed depth converted in seconds from MBES data.

The seabed and the first reflector (RA) were detected by their acoustic properties and manually picked throughout the entire survey area, checking at the intersection between main and cross lines.

To import SBP interpretation into UHR Kingdom Project (in metres), the following procedure was applied:

- Thickness of Unit A (depth below seabed) in metres was calculated using a velocity of 1600 m/s to convert time to depth;
- From this horizon a grid in metres was created and then exported from SBP Kingdom Project;
- The grid was then imported into UHR Kingdom Project (in metres);
- Finally, a base to Reflector A (metres below LAT) was calculated adding the Unit thickness to the UHR seabed surface.

The horizons were exported (in meters with position in easting and northing and their thickness below seabed) and were used to produce an isopach map.

6.2.6 UHR data interpretation

The interpretation of the processed seismic data was performed using Kingdom software vers. 8.6 and 8.8. The interpretation of the seismic data is based on recognition of the sedimentary facies, layer continuity and seismic texture of layers identified in the seismic profiles. Eight (8) seismic units were identified across the survey area. Subsequently, these units were fitted into the geological framework derived from FEBV CPTs logs, previous reports desk studies and references about the geology of the area. The final geological model of the area is carried out with the depth migrated stacked profile to facilitate the creation of a geological model depth.

After interpretation the following features were mapped:

- Depth to base on the main reflections;
- Locations of any structural complexities or geo-hazards within the shallow geological succession such as faulting, accumulations of shallow gas or buried channels;

Gridding was performed using Kingdom software vers 8.6. The cell size was chosen taking into account the seismic profiles resolution, the line spacing and the geological surfaces spatial variability. Gridding algorithms used were *Inverse distance to a power* and *Minimum Curvature,* parameters are presented in Table 6.1.

Table 6.1: Gridding parameters and methodology

Grids	Gridding method	Cell size (m)	Smoothness	Distance weight power
RA	Inverse Distance to a Power	25 x 25	4	2
RB	Inverse Distance to a Power	100 x 100	8	2
RE	Inverse Distance to a Power	100 x 100	8	2
RE1	Inverse Distance to a Power	100 x 100	8	2
RF1+F2	Minimum Curvature	100 x 100	9	--
RF3	Minimum Curvature	100 x 100	9	--

The results of the interpretation are:

- Geological cross-sections identifying all significant features and horizons;
- Contour maps showing thickness of each formations/units;
- Contour maps (isolines) of the five significant geological formations as depth to top of formation below (LAT).

The results were drawn in AutoCAD 2015.

7. DATA QUALITY AND ACCURACY

7.1 Positioning and Navigation

The Starfix G2 system performed well throughout the survey. The number of minimum satellites was set to five (5) satellites to ensure good data accuracy. The accuracy for the StarPack (Primary and Secondary system) is 0.1 m.

7.2 Bathymetry

Accuracy of bathymetric data depends on seabed depth. Depth of investigated area moves from 15 m to 40 m. Considering a 0.7° beam angle aperture, the theoretical footprint moves from 0.1 m to 0.5 m. A bin cell size of 0.5 m was chosen for the creation of the final DTM. Targets smaller than 0.5 m can not be recognized in the final DTM.

This Danish Technical University (DTU13) model normally fits very well for all depth data, measured on different days. The accuracy is normally observed to be within 0.15 m.

The software package used to process the bathymetry data did not permit a full analysis of the horizontal and vertical uncertainties of the data. As a result, an analysis of these uncertainties has not been provided.

7.3 Side Scan Sonar

The quality of the side scan sonar data was good. The lateral resolution of the 100-125/530-580 kHz dual frequency data is approximately 0.2 m. Obstructions smaller than the resolution of the sonar may not have been detected. Some of the data were acquired in marginal weather. Marginal lines were all QCed and overlaid against other existing acquired lines to ensure that the imaging of the seabed was of sufficient quality to meet the survey requirements.

Heights of seabed obstructions estimated from the side scan sonar data are considered to have an accuracy of ± 0.1 m. The positional accuracy of features, interpreted from the side scan sonar data, depends on a combination of the vessel positioning, acoustic positioning of the towfish relative to the vessel and interpretation of position relative to the towfish. For this dataset the overall positional accuracy is estimated as 1-3 m.

7.4 Magnetometer

The positional accuracy of features interpreted from the magnetic data depends on a combination of the quality of the differential GPS positions received, the measurement of cable out and the USBL accuracy. Moreover, the detectability decreases with distance from the survey line. Therefore, where targets are not mapped between lines this does not mean that no targets are present. Typical flying heights were in the range of 2 m to 5 m. Due to the uneven seabed some areas were surveyed with the magnetometer flying at more than 7 m from the seabed.

The quality of the magnetic data was good. In some lines some noise (up to 5 nT) was observed. This was probably caused by towing the sparker too close to the magnetometer. Processing sequences were set to minimise such noise in the data.

The positional accuracy of the magnetic data is estimated considering a radius of approximately 1-3 m.

7.5 Accuracy of Sub-Seabed Data

7.5.1 Vertical Accuracy - Sub Bottom Profiler

The quality of the sub-bottom profiler data was good.
A useful acoustic penetration of about 25 ms or approximately 20 m below seabed was generally achieved over the survey area. The vertical resolution of the data is estimated as 0.5 m for sub-bottom profiler; soil layers thinner than this may not have been detected.

The line spacing is approximately 100 m; sub-seabed features smaller than 100 m and present between the lines may not have been detected. Depths and positions of soil layers between survey lines are based on interpolation, the reliability of which depends on the complexity of the geology. The sub-seabed depths were estimated using an assumed acoustic velocity of 1600 m/s, which is considered reasonable for the interpreted sediment types, and was cross checked against geotechnical information via tie-in lines. The accuracy of depth estimates depends on the vertical resolution of the data (0.5 m) and the acoustic velocity (1600 m/s) used to convert two-way reflection times to depth and is calculated to be approximately ±1% of sub-seabed depth.

7.5.2 UHR profile

Vertical resolution analysis was carried out on line A34031. Amplitude spectrum was calculated on a 100 ms window and on a 20 ms window below seabed. Peak and -6 dB level frequency and velocity values of 1600 and 1800 m/s (averaged minimum and maximum values founded during velocity picking), were used for calculating averaged wavelength (“lambda”). Vertical resolution was then derived from the relationship “λ/4”. The vertical resolution estimated is about 0.46 m in the shallower part (where an averaged Vp of 1600 m/s is reasonable) and about 0.72 m in the deeper part (Vp of 1800 m/s).

8. PERSONNEL

Table 8.1: Personnel M.V. Fugro Pioneer

Personnel M.V. Fugro Pioneer from 25-05-2015 to 02-06-2015		
Location	Function	Name
Offshore	Party Chief	C. Sakowski
	Surveyor	A. Jones
		K. Bos
	Maintenance Engineer	J. Claudius
	Engineer	B. Luckhoo
		M. Kolapte
		M. Caponi
		M. Provvisionato
	Geophysicist	A. Darbo
		R. Roepnarain
		M. Marchetti
		V. Vitale
	Data Processor	Y.C. Tan
		B. De Tommaso
Personnel M.V. Fugro Pioneer from 02-06-2015 to 20-06-2015		
Location	**Function**	**Name**
Offshore	Party Chief	T. Harrison
	Surveyor	F. Lucenti
		R. Garcia Quinones
	Maintenance Engineer	J. De Wolf
	Engineer	G. Reynolds
		M. Needham
		M. Caponi
		M. Provvisionato
	Geophysicist	M. Marchetti
		V. Anagnostopoulis
		A. Kattenberg
		V. Vitale
		M. Civalleri
	Data Processor	L. Vitiello
		J. Vujevic

9. HEALTH, SAFETY & ENVIRONMENT

Safety standards and procedures onboard the M.V. Fugro Pioneer adhere to company policy supported by the International Association of Geophysical Contractors terms of reference and take due account of Britannia Operators Limited safety procedures. All new staff joining the survey vessel underwent a safety induction tour.

Upon arrival to the vessel, Fugro personnel attended a safety induction. During this induction they were introduced to the chief officer who introduced M.V. Fugro Pioneer safety policies, systems and responsibilities of all individuals to embrace their safety culture. All ongoing and forthcoming operations were discussed and the relevant safety issues were addressed. Personnel were also informed of the lifesaving equipment to be found within their cabins. All personnel were encouraged to approach anyone on board the M.V. Fugro Pioneer if it was thought they were not conducting operations in a safe and responsible manner and stop the job.

Prior to the installation of the survey equipment Fugro personnel discussed and conducted a Risk Assessment and Toolbox Talk. All hazards and risks were identified and control measures discussed and put in place to enable the mobilisation to be conducted in a safe manner.

During any outdoor operations the correct PPE was worn, manual handling techniques were observed and one hand was kept free at all times when ascending or descending stairways.

A daily Vessel Coordination Meeting was held on board between the vessel Master, the survey Party Chief and the Offshore Client Representative. The meeting was used to discuss the previous 24 hours’ operations, planned operations, the current and expected weather and sea state conditions and other safety related matters, including toolbox talks and Permits to Work.

Toolbox talks were performed ahead of all back deck operations.

One (1) HSE incident and one (1) near miss were reported during the survey.

On 13 June 2015 a malfunctioning winch began to pay in cable with the controls set in neutral position. The emergency stop was operated; however the winch continued to rotate. The surveyor released the equipment but sustained a minor injury to his lower left arm.

On 11 June 2015 the vessel suddenly changed heading and both engines stopped automatically. An alarm indicating “load limit” was flashing. While retrieving the survey equipment, the surveyors noted a mooring rope floating in the water. After recovering the mooring rope the survey operations were resumed.

Refer to Appendix H for more details.

Table 9.1: Health, Safety and Environmental summary

Type	Total
Safety induction	3
Toolbox Talks	92
Reportable Incident	1
Vessel Coordination Meeting	24
Safety Meeting	3
HOC / Stop card	7
Vessel Drill	2
Near Miss Incidents	1
Management visit	1

Prior to demobilisation of positioning equipment the relevant Fugro Risk Assessment was reviewed and another toolbox talk was conducted.

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APPENDICES

A. CALIBRATION AND VERIFICATIONS

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This investigation was carried out by Fugro Survey B.V., commissioned by RVO.nl, an agency of the Ministry of Economic Affairs. Whilst a great deal of care has been taken in compiling the contents of this investigation, RVO.nl can not be held liable for any damages resulting from any inaccuracies and/or outdated information.

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