Netherlands Enterprise Agency

Geotechnical Report

Geological Ground Model
Borssele Wind Farm Site II

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DNV·GL

Netherlands Enterprise Agency (RVO.nl)
Croeselaan 15 | 3521 BJ | Utrecht
P.O. Box 8242 | 3503 RE| Utrecht
Netherlands

Det Norske Veritas, Danmark A/S
Energy
Technical
Tuborg Parkvej 8, 2nd Floor
DK2900 Hellerup
Denmark
Tel: +45 39 45 48 00
Fax: +45 39 45 48 01

Date:	**Our reference:**	**Your reference:**
2015-08-05	DNV GL Doc. No: 1KI2TUA-11, Rev.02 Sign: MICWAG Corresp. No.:	

Zone Borssele Site Data – Geological Ground Model

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

1. Geological Ground Model / Wind Farm Site I / Borssele Wind Farm Zone / Dutch Sector, North Sea / Report No. N6016/05 Issue 3 /
07-15-2015
2. Geological Ground Model / Wind Farm Site II / Borssele Wind Farm Zone / Dutch Sector, North Sea / Report No. N6016/06 Issue 4 /
08-03-2015

Comments to the documents listed above have been given in the referenced Verification Comment Sheet (Reference /A/). Meanwhile report 2 was updated to issue 4. However, no further comments were necessary.

DNV GL has found that the above referenced reports provide proper geological models of the corresponding wind farm sites which can be relied upon to establish general geologic conditions, including discussions on site variability, in order to establish future geotechnical investigation campaigns. The data in this report can be used for establishing a Design Basis for Offshore Wind Turbine Structures in accordance with DNV-OS-J101.

Please note that detailed geotechnical investigations will need to be performed in order to address potential data gaps in the preliminary investigations, in particular the lack of a specific wind farm layout.

References:

/A/: Verification Comment Sheet "VCS-644235-07"
Revision 02, dated 29.07.2015
Doc-ID: 644235-VCS-07-rev02-Foundation feasibility study
(Geological Ground Model) WFSI and II

Sincerely
for Det Norske Veritas, Danmark A/S

Niels Bo Kristensen
Principal Engineer

Mobile: +45 20 37 57 42
Direct: +45 39 45 48 92
Niels.Bo.Kristensen@dnvgl.com

Michael Wagner
Senior Engineer

Direct: +49 40 36149 7914
Michael.Wagner@dnvgl.com

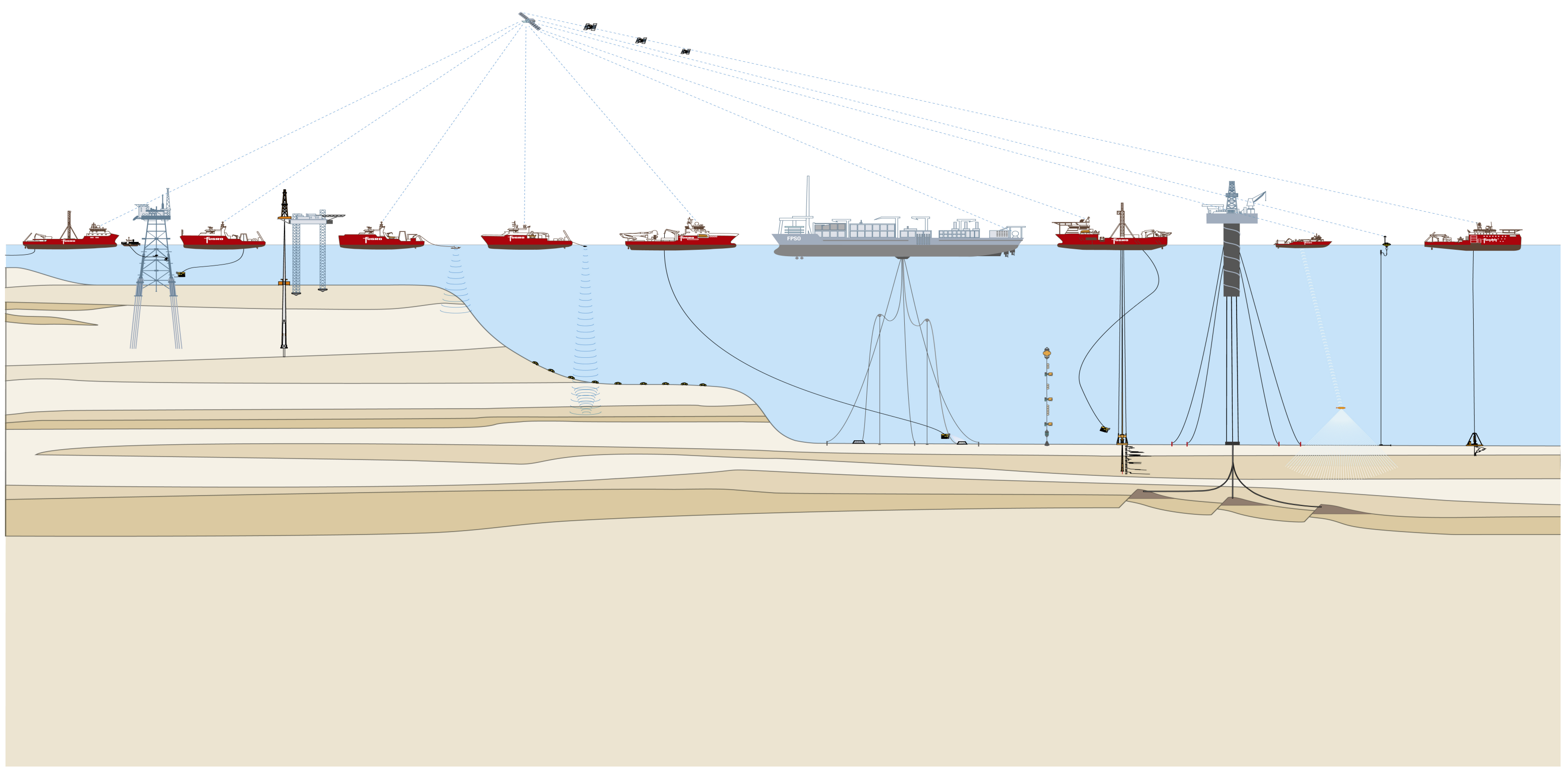
Geological Ground Model
Wind Farm Site II
Borssele Wind Farm Zone
Dutch Sector, North Sea

Client Reference No. TN48112

Fugro Report No. N6016/06

Issue 4

Rijksdienst voor Ondernemend Nederland (RVO)



Geological Ground Model
Wind Farm Site II
Borssele Wind Farm Zone
Dutch Sector, North Sea

Client	Rijksdienst voor Ondernemend Nederland (RVO)
Client Address	Croeselaan 15 3521 BJ Utrecht The Netherlands
Client Reference No.	TN48112
Fugro Report No.	**N6016/06 (4)**

Report Issue No.	Date	Report Status	Approved
4	03-August-2015	Final - Revised	
3	15-July-2015	Final - Revised	LJP
2	02-July-2015	Final	LJP
1	05-June-2015	Fugro approved draft	LJP

Prismastraat 4
P.O. Box 130
2630 AC Nootdorp
The Netherlands
Phone: 31-70-3111444
E-Mail: febvinfo@fugro.nl

Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15
3521 BJ Utrecht
The Netherlands

Attention: Mr R. de Bruijne

Our ref: N6016/06 (4)/WVK/BNR

Nootdorp, 03 Aug 2015

Geological Ground Model - Wind Farm Site II
Borssele Wind Farm Zone - Dutch Sector, North Sea

This report presents a geological ground model. The report was prepared in accordance with Contract WOZ1500008 between Rijksdienst voor Ondernemend Nederland (RVO) and Fugro Engineers B.V., dated 17 March 2015.

The principal team members for report preparation were Mr E. Tervoort, Dr B. Klosowska and Dr B. Meijninger (Geologists). We acknowledge the valuable assistance of Mr R. de Bruijne, who acted as Client contact for this project.

Thank you for the opportunity to be of service. Please do not hesitate to contact us if you require any additional information.

Yours faithfully
FUGRO ENGINEERS B.V.

for **R. Atsma**
Senior Project Engineer

CONTENTS

LIST OF PLATES FOLLOWING MAIN TEXT: Plate

REPORT ISSUE CONTROL

Section	Page No.	Plate No.	Issue No.	Revision
Summary	iii to vi	-	3	Editorial adjustments.
Main Text	All	-	4	Editorial adjustments.
Plates following Main Text		1-1	3	Editorial adjustments.
		3-1, 3-2	3	Editorial adjustments.
		3-18, 3-19	4	Updates following revised interpretation
		3-28, 3-29, 3-30	4	Updates following revised interpretation

Notes:

1) The definitive copy of this report is held in Fugro's information system
2) Report distribution is restricted to project participants approved by the Client
3) The *report* issue number is the same as the highest issue number of any individual page
4) Pages of this report are at Issue 2, except those pages listed above
5) The number at the bottom left-hand corner of each page shows the Fugro report number and page issue number. The number in brackets indicates the issue number of the page

QUALITY MANAGEMENT RECORD

Project Lead: E. Tervoort - Project Geologist

Report Review: W. van Kesteren – Senior Geologist

Report Approval: L.J. Peuchen – Principal Geotechnical Engineer

Report Section	Prepared By	Checked By
Main Text	BBK/EPT/BLM/WVK	WVK/LJP
Plates following Main Text	BBK/EPT/BLM/LHT/RTN/ WVK	WVK/LJP
Section A	TAD/LDH/EGR/HHG/SS	WSO
Section B	TAD/LDH/EGR/HHG/SS	WSO

Person(s):

LJP: J. Peuchen
WVK: W. van Kesteren
EPT: E. Tervoort
BLM: B. Meijninger
BBK: B. Klosowska
LHT: L. van der Horst
RTN: R. Toonen
WSO: W. Sotthewes
TAD: T. Duijster
LDH: L. Both
EGR: E. Grall
HHG: H. Hagen
SS: S. Soekhoe

SUMMARY

The Dutch Ministry of Economic Affairs is responsible for the legislative framework for the development of offshore wind farms in the Netherlands. Within this framework (a) (concession) tender(s) for subsidy for construction and installation of (a) wind farm(s) will be organized under the SDE+ regulation. As part of the tender preparations, the Netherlands Enterprise Agency (RVO), henceforth referred to as 'Client', has requested Fugro to perform a geotechnical investigation of Wind Farm Site (WFS) I & II of the Borssele Wind Farm Zone (BWFZ). The Borssele Wind Farm Zone is located in the Dutch Sector of the North Sea, approximately 36 km from the coastline (refer to Plate 1-1 "Vicinity Map").

The objective of the geotechnical investigation and associated laboratory testing programme for WFS I and WFS II is to:

- improve the geological and geotechnical understanding;
- update an earlier geological and geophysical model;
- provide a detailed geological ground model;
- determine the vertical and lateral variation in seabed conditions;
- provide relevant geotechnical data to progress the design of windfarm foundation elements, including, but not limited to foundations and cables.

The offshore phase of the geotechnical investigation included geotechnical borehole drilling with downhole sampling and in situ testing, seafloor in situ testing and geotechnical laboratory testing. An office programme of geotechnical laboratory testing and reporting of results followed the offshore phase.

This report is one of a set of Fugro reports (refer to Plate 1-2 "List of Fugro Reports"). This particular report provides a concise and coherent geological ground model for WFS II (Plate 1-1), which takes account of geotechnical and geophysical data specifically acquired for WFS I and WFS II. The geological ground model provides an integrated framework that links (1) geophysical data interpretation, (2) geotechnical parameters and (3) site suitability, particularly geological features and processes which can be potential hazards (geohazards) for windfarm development, including but not limited to support structures (foundations) and cables.
Plates following this summary text provide key information, as follows:

- Plate 3-4 shows bathymetry. It highlights major sand banks and associated seabed erosion and sediment deposition processes;
- Plate 3-7 presents an example cross-section of geophysical data with interpreted geotechnical unit boundaries and cone penetration test (CPT) data at the geotechnical locations superimposed;
- Plate 3-13 presents the subcrop of the Tertiary geotechnical units below the Quaternary geotechnical units (i.e. Units A and B). This map illustrates the termination of the dipping Tertiary geotechnical units to the base of the Quaternary sediments and, as a consequence, the absence of younger geotechnical units in the stratigraphic profiles towards the southwest. In this respect, the subcrop map can be regarded as a zonation map (i.e. indicating zones with similar stratigraphy). Note that geotechnical Units A and B are present over the entire WFS II. Unit D is the youngest Tertiary unit at WFS II. Unit F1a is the oldest geotechnical unit that subcrops below the Quaternary units, within the depth coverage of the geological ground model. The depth to the top of these geotechnical units increases to northeast.

The depth coverage of the geological ground model and geotechnical parameter values is to approximately 90 m relative to Lowest Astronomical Tide (LAT). This depth coverage corresponds broadly with the maximum geotechnical investigation depth. The source data from geophysical survey extend below 90 m relative to LAT.

The available geotechnical and geophysical data align well. They provide a robust basis for the geological ground model. The geological ground model fits published regional frameworks. The geotechnical data set further enhances and refines the understanding of the identified soil units.

The geotechnical parameters include CPT data, Atterberg limits, particle size distribution, soil unit weight, relative density, undrained shear strength and shear wave velocity. The parameter values indicate that spatial soil variability is limited for a majority of the fourteen soil units. Notable exceptions are Units E1 to E3.

Geotechnical assessment of suitability of possible foundation elements indicates that the more commonly used types are feasible, particularly multiple pile and monopile foundations.

SAMENVATTING

Het Ministerie van Economische Zaken is verantwoordelijk voor het wettelijke kader van de ontwikkeling van windparken op zee in Nederland. Binnen dit kader vallen inschrijvingen voor de Stimulering Duurzame Energie (SDE+) subsidieregeling voor de bouw en installatie van (een) windpark(en) op zee. T.b.v. de voorbereiding van de inschrijvingen heeft de Rijksdienst Voor Ondernemend Nederland (RVO) Fugro gecontracteerd voor een geotechnisch onderzoek in de kavels WFS I & II van windgebied Borssele (BWFZ). Het windgebied Borssele ligt in het Nederlandse deel van de Noordzee, ongeveer 36 km voor de kust (zie Plate 1-1 "Vicinity Map").

Het doel van het geotechnisch onderzoek en bijbehorend programma van laboratoriumproeven is om:

- inzicht te verkrijgen in de geologische en geotechnische omstandigheden;
- het bestaande geofysische en geologische model te verfijnen;
- een gedetailleerd geologisch grondmodel te genereren;
- de verticale en laterale variabiliteit van de grond te bepalen;
- relevante geotechnische data voor de ontwikkeling van het ontwerp van windpark funderingsconstructies beschikbaar te stellen, inclusief maar niet gelimiteerd tot funderingen en kabels.

Het geotechnisch onderzoek op locatie bestond uit geotechnische boorgaten met monsternames en in situ testen, sonderingen vanaf de zeebodem en geotechnische laboratoriumproeven. Vervolgens zijn op kantoor een geotechnisch laboratorium testprogramma en rapportage van de resultaten uitgevoerd.

Dit rapport is er één uit een reeks Fugro rapporten (zie Plate 1-2 "List of Fugro Reports"). Dit specifieke rapport presenteert een coherent geologisch grondmodel voor WFS II (Plate 1-1), op basis van gegevens van geotechnische en geofysische onderzoeken die specifiek zijn uitgevoerd voor zowel WFS I en WFS II. Het geologisch grondmodel geeft een kader met integrale verbanden tussen (1) interpretatie van geofysische gegevens, (2) geotechnische parameters en (3) geotechnische geschiktheid van het windgebied, met name geologische kenmerken en processen met potentiële risico's voor ontwikkeling van een windpark, inclusief maar niet gelimiteerd tot funderingen en kabels.

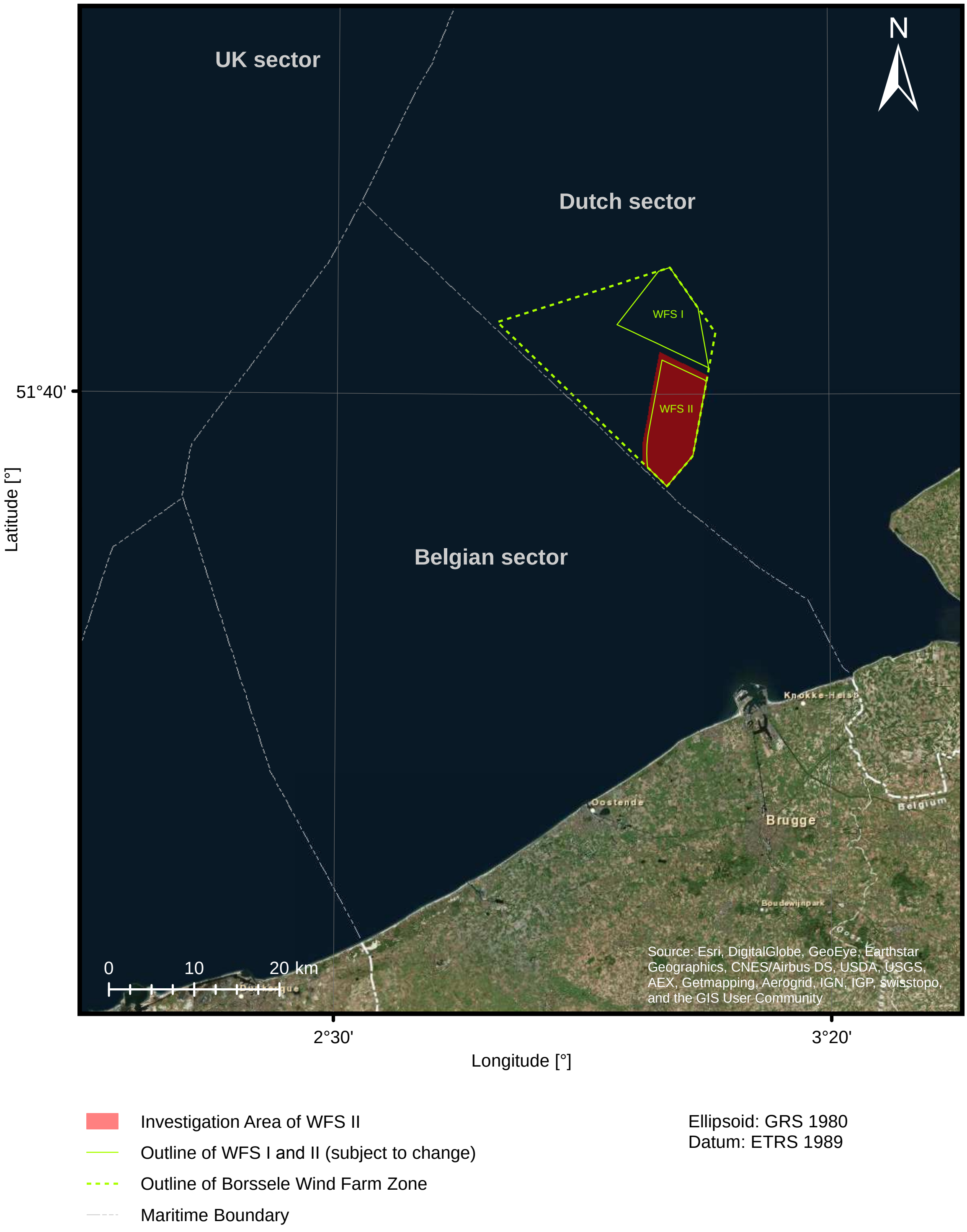
Kerninformatie is weergegeven door middel van afbeeldingen (plates) volgend op de tekst van deze samenvatting:

- Plate 3-4 laat de waterdiepte zien. Significante zandbanken zijn zichtbaar en de daarmee samenhangende processen van erosie en afzetting van sedimenten;
- Plate 3-7 laat een voorbeeld zien van een doorsnede van het grondmodel, met onder andere, geofysische interpretatie, overgangen van geotechnische lagen en sondeergegevens (CPT) van de geselecteerde geotechnische meetlocaties;
- Plate 3-13 presenteert geotechnische lagen van het Tertiair, waar ze grenzen met de bovenliggende geotechnische lagen (Units A en B) van het Kwartair. Deze kaart illustreert de dip van Tertiaire grond lagen t.o.v. de ondergrens van de Kwartaire sedimenten. Daarnaast laat het de afwezigheid zien van de jongere geotechnische lagen in het zuidwestelijke deel van het grondmodel. Deze informatie kan worden beschouwd als een zonekaart, die zones aangeeft met overeenkomstige laagopbouw. Hierbij kan worden opgemerkt dat Units A en B aanwezig zijn in het gehele windgebied WFS II. Unit D is de jongste geotechnische laag van het Tertiair van WFS II. Unit F1a is de oudste geotechnische laag die grenst aan de Kwartaire lagen, binnen het verticale bereik van het geologisch grondmodel. De diepte tot de top van deze geotechnische lagen neemt toe in noordoostelijke richting.

Het verticale bereik van het geologisch grondmodel en de geotechnische parameters is tot ongeveer 90 m beneden LAT (Lowest Astronomical Tide). Dit niveau komt globaal overeen met de maximale diepte van het geotechnisch onderzoek. Data van geofysisch onderzoek zijn beschikbaar vanaf de zeebodem tot dieper dan 90 m beneden LAT. De beschikbare geotechnische en geofysische data laten een goede correlatie zien. De data zijn een geschikte basis voor het geologische grondmodel. Dit model past binnen het kader van de gepubliceerde regionale geologie. De geotechnische gegevens verhogen en verfijnen de kennis van de geïdentificeerde grondlagen.

De presentatie van geotechnische parameters omvat gegevens van sonderingen (CPT), Atterbergse grenzen, korrelverdeling, volumiek gewicht, relatieve dichtheid, ongedraineerde schuifsterkte en schuifgolfsnelheid. De geotechnische parameters van de meeste grondlagen laten een beperkte laterale variabiliteit zien. Van de veertien grondlagen zijn E1 tot E3 de uitzonderingen.

De geotechnische evaluatie van de geschiktheid van mogelijke funderingsoplossingen geeft aan dat de veel voorkomende typen kunnen worden toegepast, met name (mono) paalfunderingen.



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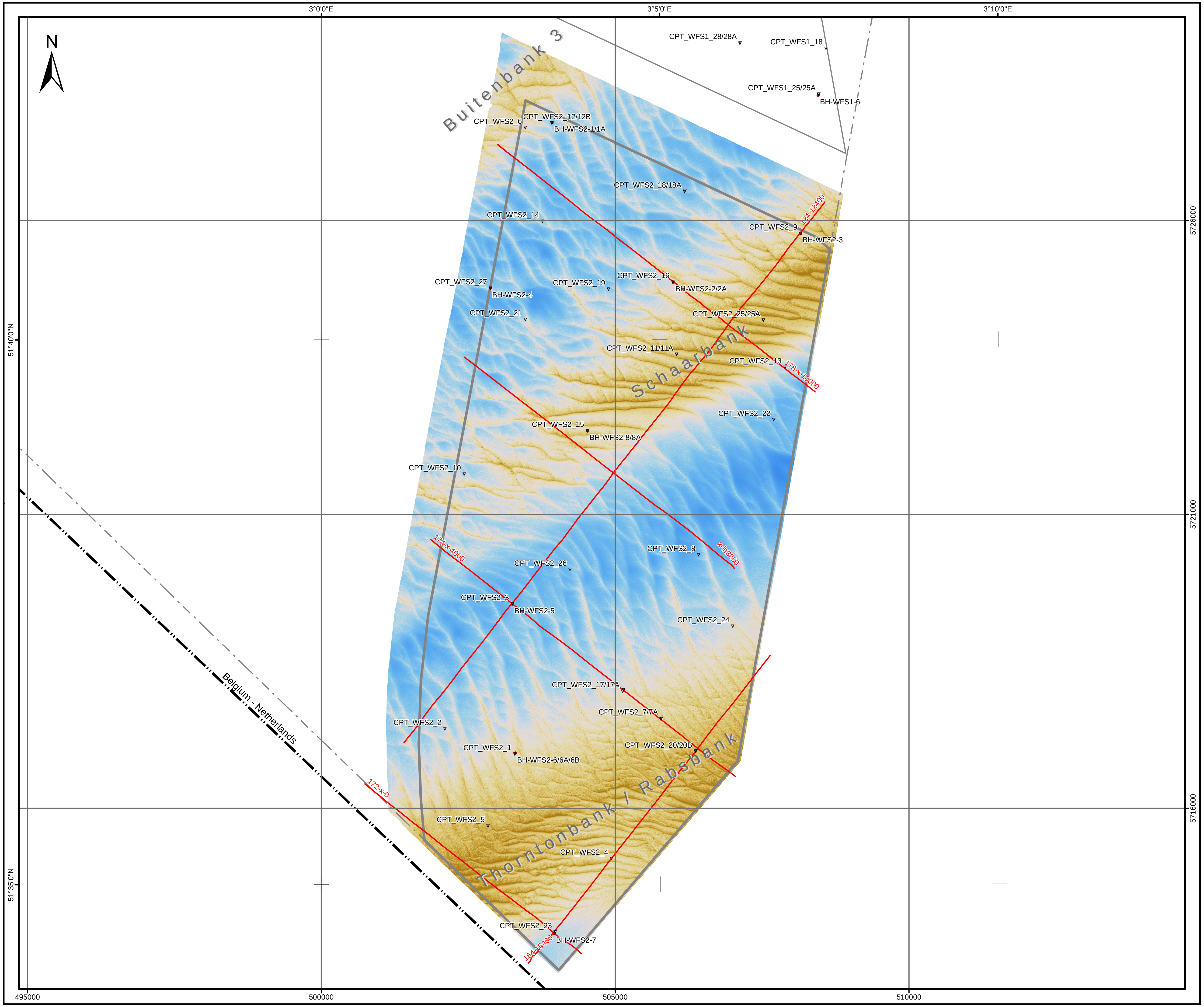
VICINITY MAP

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

Report Number	Title	Contents
N6016/01	Geotechnical Report - Investigation Data - Geotechnical Borehole Locations Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including geotechnical logs, results from downhole (seismic) cone penetration tests and results from geotechnical laboratory tests.
N6016/02	Geotechnical Report - Investigation Data - Seafloor In Situ Test Locations Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including interpreted geotechnical logs and results from seafloor cone penetration tests.
N6016/03	Geotechnical Report - Investigation Data - Geotechnical Borehole Locations Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including geotechnical logs, results from downhole (seismic) cone penetration tests and results from geotechnical laboratory tests.
N6016/04	Geotechnical Report - Investigation Data - Seafloor In Situ Test Locations Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including interpreted geotechnical logs and results from seafloor cone penetration tests.
N6016/05	Geological Ground Model Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geological ground model including, stratigraphy, lateral soil variability, geohazards, basic geotechnical parameter values and assessment of geotechnical suitability of selected types of structures.
N6016/06	Geological Ground Model Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geological ground model including, stratigraphy, lateral soil variability, geohazards, basic geotechnical parameter values and assessment of geotechnical suitability of selected types of structures.
N6016/07	Geotechnical Report - Laboratory Test Data Wind Farm Sites I & II Borssele Wind Farm Zone - Dutch Sector, North Sea	Results of advanced static and cyclic laboratory tests.

LIST OF FUGRO REPORTS

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report

Bathymetry [m below LAT]

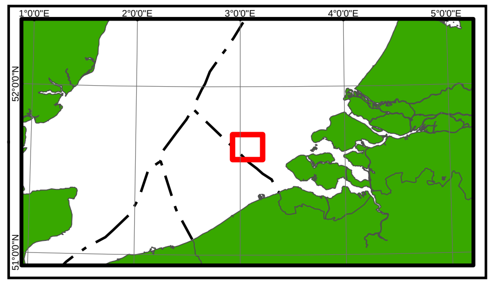
-13, -17, -21, -25, -29, -33, -37, -39

NOTES:

- Reproduced from Deep (2015)
- Resolution cells 1m x 1m
- Data acquired by Multi-Beam Echo Sounder (MBES)

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

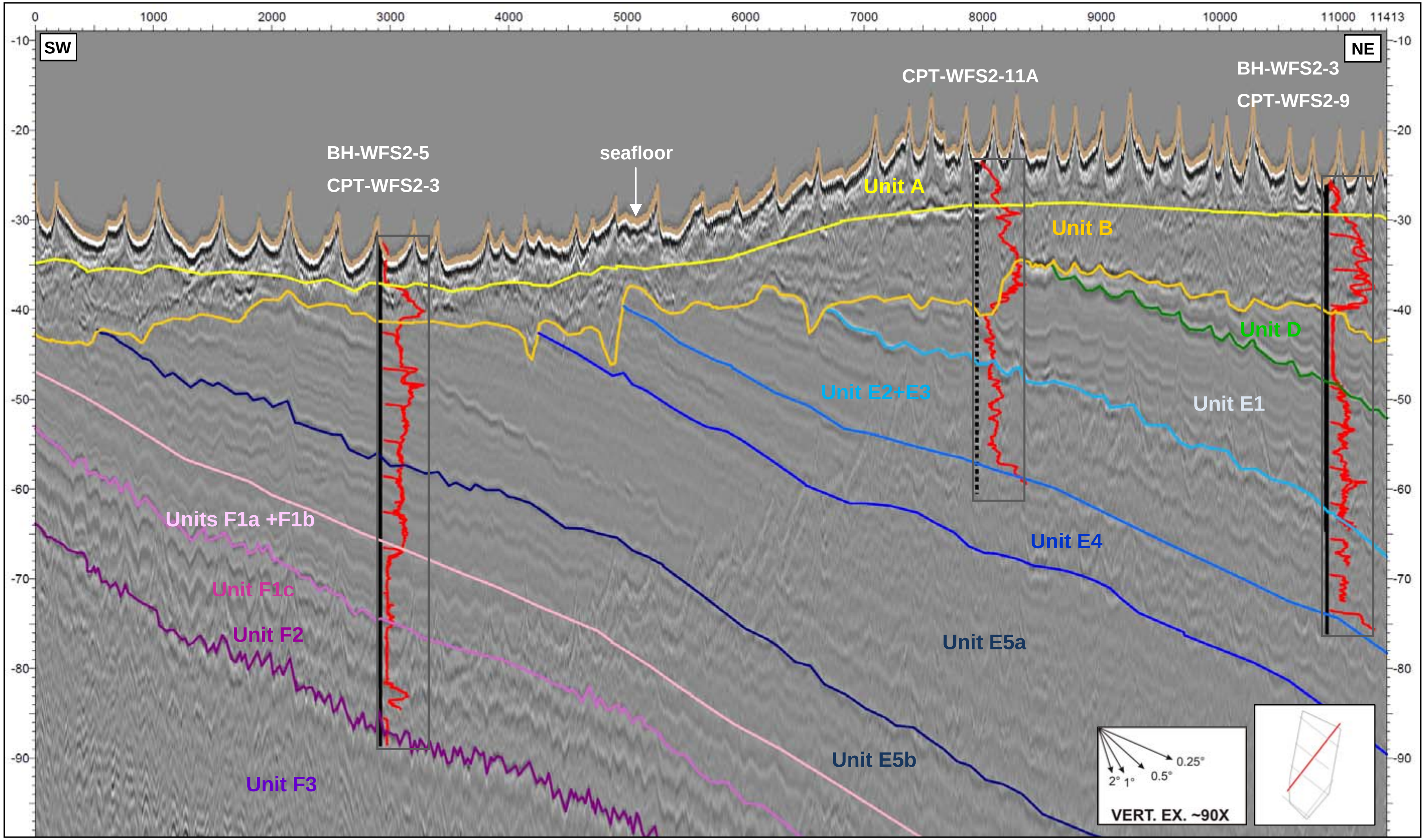
Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

BATHYMETRY

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

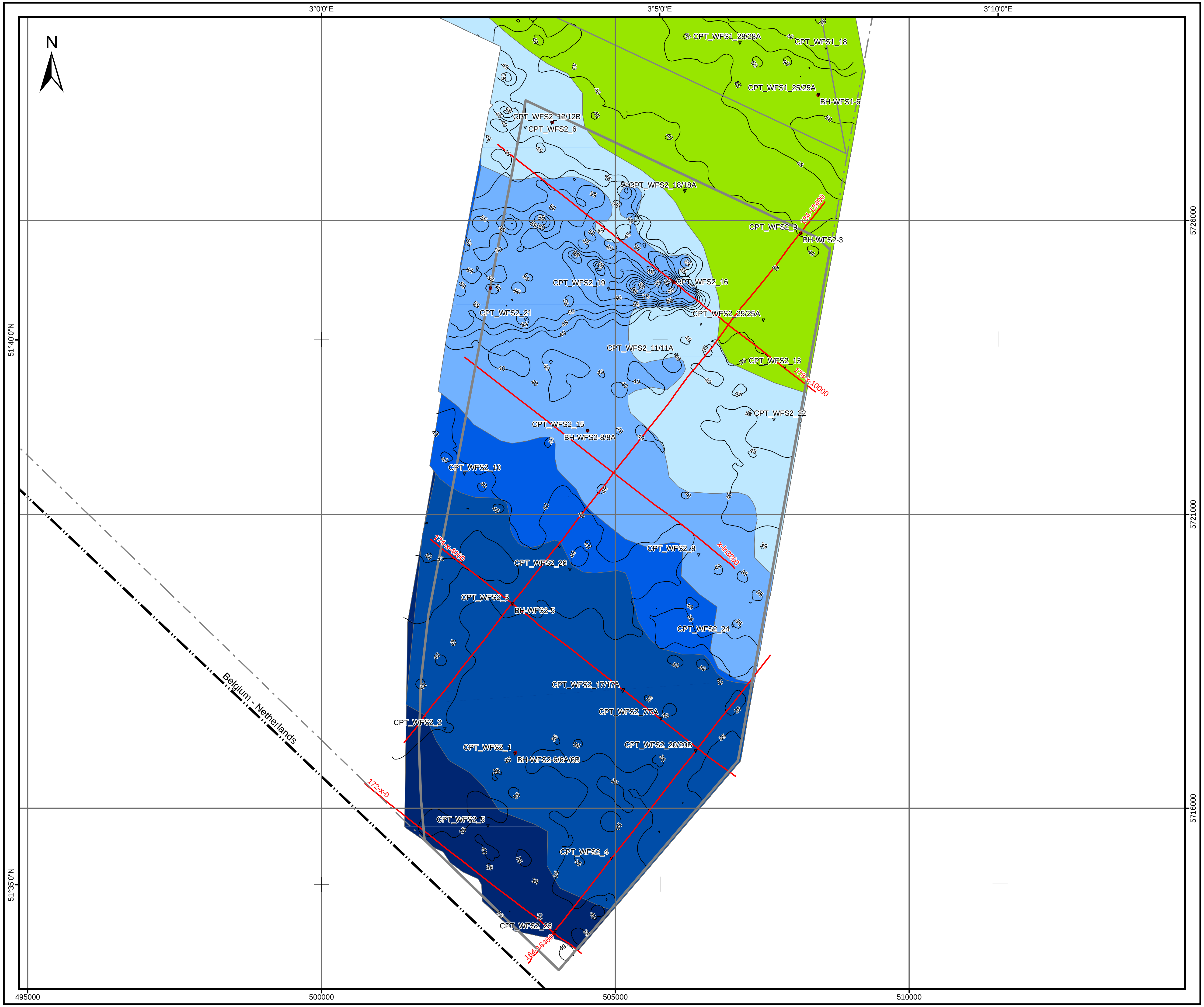
Fugro Report No. N6016/06	Issue 2	Plate 3-4
Printed: 02/07/2015 18:50:15		Author: BLM



NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE 124-12400

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of depth to base of Unit B [m below LAT]

Subcrop of Tertiary Units

- Unit D (Rupel Clay Mb.)
- Unit E1 (Ruisbroek Sand Mb.)
- Unit E3 (Bassevelde 3 Sand Mb.)
- Unit E4 (Bassevelde 2 Sand Mb.)
- Unit E5a (Bassevelde 1 Sand Mb.)
- Unit E5b (Bassevelde 1 Sand Mb.)

NOTES:

- Base of Unit B (Pleistocene) represents an erosional surface truncating underlying dipping Tertiary strata
- Tertiary units subcropping at base of Unit B are represented, i.e. intersection of unit boundaries with base of Unit B
- Outline of units based on interpretation from Multi-Channel Seismic data

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
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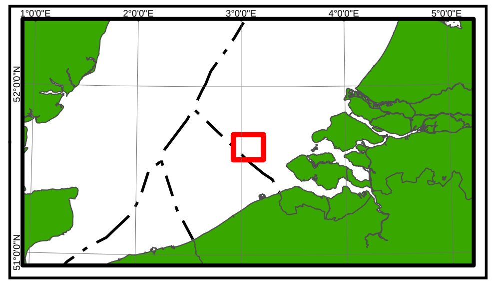

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Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

TERTIARY UNITS BELOW UNIT B (KREFTENHEYE FM. / EEM FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 2	Plate 3-13
Printed: 02/07/2015 22:23:30		Author: BLM

1. INTRODUCTION

1.1 Purpose of Report

The Dutch Ministry of Economic Affairs is responsible for the legislative framework for the development of offshore wind farms in the Netherlands. Within this framework (a) (concession) tender(s) for subsidy for construction and installation of (a) wind farm(s) will be organized under the SDE+ regulation. As part of the tender preparations, the Netherlands Enterprise Agency (RVO), henceforth referred to as ‘Client’, has requested Fugro to perform a geotechnical investigation of Wind Farm Site (WFS) I & II of the Borssele Wind Farm Zone (BWFZ). The Borssele Wind Farm Zone is located in the Dutch Sector of the North Sea, approximately 36 km from the coastline (refer to Plate 1-1 “Vicinity Map”).

The objective of the geotechnical investigation and associated laboratory testing programme for WFS I and WFS II is to:

- improve the geological and geotechnical understanding;
- update an earlier geological and geophysical model;
- provide a detailed geological ground model;
- determine the vertical and lateral variation in seabed conditions;
- provide relevant geotechnical data to progress the design of windfarm foundation elements, including, but not limited to foundations and cables.

The offshore phase of the geotechnical investigation included geotechnical borehole drilling with downhole sampling and in situ testing, seafloor in situ testing and geotechnical laboratory testing. An office programme of geotechnical laboratory testing and reporting of results followed the offshore phase.

This particular report provides a concise and coherent geological ground model for WFS II (Plate 1-1), which takes account of geotechnical and geophysical data specifically acquired for WFS I and WFS II. The geological ground model provides an integrated framework that links (1) geophysical data interpretation, (2) geotechnical parameters and (3) site suitability, particularly geological features and processes which can be potential hazards (geohazards) for windfarm development, including but not limited to support structures (foundations) and cables.

1.2 Scope of Report

This report comprises the following:

- Geological ground model;
- Geotechnical parameters versus depth per investigated geotechnical location;
- Geotechnical parameters versus depth per geotechnical unit;
- Assessment of geotechnical suitability of selected types of structures, including an inventory of (geo)hazards and constraints that may affect design and installation of the planned structures, including cables and temporary structures such as jack-up platforms.

The geological ground model applies to an area demarcated as Investigation Area on the vicinity map (Plate 1-1). Note that the text sections of the report and the plates (i.e. Plates 1-1, 3-1 to 3-32 and 5-1) refer to WFS II as defined at the start of the Fugro investigation. The outline of WFS II is subject to change.

The depth coverage of the geological ground model and geotechnical parameter values is to approximately 90 m relative to Lowest Astronomical Tide (LAT). This depth coverage corresponds broadly with the maximum geotechnical investigation depth. The source data from geophysical survey extend below 90 m relative to LAT.

1.3 Project Responsibilities and Use of Report

This report presents information according to a project specification determined and monitored by the Client.

This report must be read in conjunction with “Guide for use of Report”, Section C.

Fugro understands that this report will be used for the purpose described in this “Introduction” section. That purpose was a significant factor in determining the scope and level of the services. Results must not be used if the purpose for which the report was prepared or the Client’s proposed development or activity changes. Results may possibly suit alternative use. Suitability must be verified.

1.4 Report Format

This report is one of a set of Fugro reports for WFS I and WFS II (Plate 1-2).

This report uses and summarises information from sources listed in Section 2. The reader should consult the source information for details, particularly for topics with an indirect link to the geological ground model, e.g. morphodynamic and metocean desk studies. Understanding of site conditions improves upon further data acquisition and interpretation. This means that some of the source interpretations may be superseded by information presented in this report. Also, source information may be updated after publication of this report.

The principal sections of this report are the Summary, Main Text, Plates following the Main Text, and Sections A and B. Comments are as follows:

- The Summary section allows a quick-scan management overview. It includes a selection of plates. The selected plates are duplicates from a larger set of Plates following the Main Text;
- Section 2 of the Main Text focuses on methodology;
- Sections 3 to 5 provide the principal information as described in Section 1.2 Scope of Report. These text sections should be read in conjunction with the Plates following the Main Text, where applicable;
- Each of the Sections 3 to 5 starts with primary information, which may consist of links to Plates following the Main Text. Plate numbering starts with a Section number, e.g. Plate 3-2 belongs to Section 3;
- Sections A and B summarise geotechnical parameter values presented and explained in Fugro reports N6016/03 and N6016/04 titled “Geotechnical Report – Investigation Data – Wind Farm Site II“ (Plate 1-2);
- Section C and Appendix 1 provide general practice statements and terminology. This background information supports the Main Text. It will be familiar to expert users of the type of information presented in this report.

2. STUDY OVERVIEW

2.1 Sources of Information

Client-supplied information included the following:

- Coordinates of WFS II (RVO, 2014);
- Information available on the RVO-website for Borssele: (http://offshorewind.rvo.nl).

  This information includes (but not exclusively) the following studies (i.e. reports and accompanying data in GIS-format):
  - Geological Desk Study (CRUX Engineering BV, 2014)
  - UXO Desk Study (REASeuro, 2014)
  - Morphodynamical Desk Study (Deltares, 2014)
  - Archaeological Desk Study (Vestigia, 2014)
  - Metocean Desk Study (Deltares, 2015)
  - Geophysical Site Survey (Deep, 2015a and b).

  Data from Geophysical Site Survey in digital file format (e.g. *.SEGY, *.XYZ-format):
  - Multi-Beam Echo Sounder (MBES) data
  - Side Scan Sonar (SSS) data
  - Magnetometer (MAG) data
  - Sparker data, Multi-Channel Seismic (MCS)
  - Pinger data, Sub-Bottom Profiler (SBP).

Section 3 includes details about the geophysical site survey data, i.e. data resolution and data coverage, particularly Plates 3-1 and 3-2 titled: ‘Design Basis for Site Characterisation’.

Geotechnical investigation data for WFS II (Plate 1-2), which include:
- Geotechnical logs, results from downhole (seismic) cone penetration tests (CPT) and results from geotechnical laboratory tests for eight locations to depths ranging between approximately 50 m and 82 m below seafloor (bsf) (and approximately 50 m and 60 m bsf for seismic CPT);
- Interpreted geotechnical logs and results from seafloor cone penetration tests (CPT) for twenty seven locations to depths ranging between approximately 13 m and 50 m bsf.

Fugro’s database provided additional information, including:

- Information about the regional geology;
- General geotechnical data;
- Previous geotechnical investigation data applicable to nearby sites;
- Electronic Navigation Chart (ENC).

2.2 Data Interpretation and Geotechnical Analysis

The following data analysis steps were taken:

- Compilation of geotechnical, geophysical and geological data in a Geographic Information System (i.e. ArcGIS) and seismic and geological interpretation software (i.e. Kingdom Suite), including information from the Fugro database;
- Independent verification of data interpretations (e.g. site use, seafloor conditions and seismostratigraphy) given in previous studies (i.e. geological desk study, UXO desk study, morphodynamic desk study, archaeological desk study, metocean desk study and geophysical site survey), where possible;
- Identification of geotechnical units using geological and geotechnical engineering criteria, including composition, geotechnical properties and behaviour as determined by laboratory tests and interpretation of CPT results;
- Assessment of a lithostratigraphic framework based on interpreted geotechnical unit boundaries and geotechnical unit descriptions, and correlation of the geotechnical units with the lithostratigraphy for the Quaternary and Tertiary of both the Netherlands and Belgium;
- Assessment of a seismostratigraphic framework based on the geophysical character of the available MCS data and reference to previous investigations (i.e. Fugro database and literature);
- Ground truthing of seismostratigraphic units based on geotechnical logs, results from (seismic) cone penetration tests (CPT) and results from geotechnical laboratory tests (Plate 1-2);
- Correlation of the lithostratigraphic unit boundaries with the seismostratigraphic unit boundaries and (re)interpretation of seismic horizons (i.e. tracing seismic reflections or unconformable surfaces on MCS data) to extrapolate the geotechnical unit boundaries at the geotechnical locations to the entire site, where possible;
- Gridding of geotechnical unit boundaries and assessing the depth and the thickness variation of the geotechnical units;
- Characterisation of the interpreted geotechnical units in view of their geotechnical parameters (i.e. parameters relevant to the geological ground model) and the lateral variation;
- Assessment of suitability of a selection of permanent and temporary foundation types and of cables in view of the geological ground model;
- Iteration of analysis steps, where required to improve interpretation.

The presented geological ground model is for WFS II and takes account of geotechnical and geophysical data specifically acquired for both WFS I and WFS II.

Subdivision into geotechnical units and sub-units considers:

- Geological formations and formation members' boundaries interpreted from seismic reflection data;
- Thicknesses of soil layers (i.e. main soil types) and their lateral continuity across the site.

The Quaternary lithostratigraphy according to Rijsdijk et al. (2005) applies, with adjustments as explained in Section 3.

The presented lithostratigraphy of the Tertiary is based on Dutch onshore nomenclature (TNO, 2013a to c). This report further differentiates the Dutch nomenclature according to the Belgium lithostratigraphy (Vandenberghe et al., 2004), where appropriate. Section 3 provides details.

The interpretation of the seismic reflection data is based on the data as processed and provided by Deep (2015a and b). Comments are as follows:

- Depths of the seismic reflections do not match (i.e. vertical mis-tie) at some of the intersections of the seismic reflection lines (i.e. MCS track lines). This results in discrepancies in the depth of the interpreted seismic horizons.
- The MCS data are affected by seafloor multiples at approximately twice the water depth below sea level. As a consequence, the continuation of the seismic reflections is obscured at the depth interval where the seafloor multiples appear. The interpretations of the seismic horizons are inferred from the relation with the trend of the seismic reflections within the same seismostratigraphic unit.
- The MCS data are locally affected by zones with acoustic noise disturbing the seismic reflection signal. The interpretation of the continuation of the horizons in these zones has been inferred from the trend of the horizon from adjacent seismic lines.

Jacobs and De Batist (1996) correlated seismostratigraphy to Palaeogene lithostratigraphy. They compared the seismic facies with the lithofacies for the Maldegem Formation and showed that seismic facies not always correlate with lithological facies.

Gridding of the horizon interpretations considers the MCS track lines in the main sailing direction (i.e. NE-SW oriented track lines). This approach avoids artefacts due to vertical mis-ties at the intersections with other MCS track lines. However, this does not compensate for the vertical mis-ties of the MCS track lines. As a consequence, interpreted surfaces (i.e. horizons) will vertically shift along the track lines, resulting in an alignment of kinks in the contour lines along the track lines. This becomes more apparent for the deeper horizons where the shifts are larger (e.g. Plates 3-20 to 3-23).

The interpolation between the track lines is based on a flex grid routine (2D/3D PAK, Kingdom Suite), which combines minimum curvature and minimum tension algorithms in a single routine. The grids have a 50 m cell size. For these grids, interpolation considers a minimum curvature value of 0.5 (from 1 – minimum tension, to 0 – minimum curvature) to fit the data and a value of 10 (out of 11) for smoothing.

The understanding of the soil conditions for the deeper geotechnical units is based on extrapolation of the soil conditions from the same geotechnical units penetrated elsewhere. This approach is necessary because the penetration depth of the geotechnical data does not cover the full vertical extent of the geological model at all locations. More uncertainty applies to interpretation of the soil conditions for the deeper geotechnical units.

The identification of geohazards from the MCS data is limited by the spacing (i.e. minimum 400 m) between the track lines of MCS data. Geological features between track lines will remain undetected.

2.3 Geodetic Parameters

The geodetic parameters for horizontal positioning are presented on Plate 2-1.

Lowest Astronomical Tide (LAT) and seafloor were used as vertical reference levels for water depth measurement and geotechnical sampling and testing depth, respectively. The depth references of the unit boundaries of the geological model (i.e. cross-sections and depth maps) refer to LAT.

The use of the geodetic information presented must consider the accuracy of measurements, particularly where use may differ from original intentions.

3. GEOLOGICAL GROUND MODEL

3.1 Overview

The geological ground model is mainly presented by plates providing the following principal information:

- Plates 3-1 and 3-2 present design basis information for site characterisation;
- Plate 3-3 presents the lithostratigraphic framework, reproduced after De Lugt (2007). The correlation between the onshore and offshore lithostratigraphy is presented in Table 3.3, not on this plate;
- Plates 3-4 and 3-5 show bathymetry and the derived seafloor gradient;
- Plate 3-6 presents track lines of Multi-Channel Seismic (MCS) survey and section lines of selected cross-sections;
- Plates 3-7 to 3-12 present cross-sections of seismic reflection (MCS) data with the interpreted geotechnical unit boundaries and cone resistance (CPT) data at the geotechnical locations superimposed;
- Plate 3-13 presents the subcrop of the Tertiary geotechnical units below the Quaternary geotechnical units (i.e. Units A and B). This map illustrates the termination of the dipping Tertiary geotechnical units to the base of the Quaternary sediments and, as a consequence, the absence of younger geotechnical units in the stratigraphic profiles towards the southwest. In this respect, the subcrop map can be regarded as a zonation map (i.e. indicating zones with similar stratigraphic profile). Note that geotechnical Units A and B are present over the entire WFS II. Unit D is the youngest geotechnical unit and Unit F1a the oldest geotechnical unit that subcrops below the Quaternary units. The depth to the base of the Tertiary geotechnical units increases to northeast;
- Plates 3-14 to 3-23 present the depths (relative to LAT) of the geotechnical units (Units A to F3). Note that geotechnical Units E2 and F2 are too thin to be reliably picked from MCS data. These units have been combined with geotechnical Unit E3 and Unit F1c, respectively. Geotechnical units are absent where no data are presented within the boundary of WFS II;
- Plates 3-24 to 3-32 present the thickness of geotechnical Units A to F2. Note that geotechnical Units E2 and F2 are too thin to be reliably picked from MCS data. These units have been combined with geotechnical Unit E3 and Unit F1c, respectively. The base of geotechnical Unit F3 is below the depth considered for the geological ground model.

Table 3.1 summarises stratigraphy interpreted for WFS II (i.e. to 90 m below LAT) in terms of geotechnical units.

The following naming convention applies:

- An uppercase letter indicates a geological formation (Fm.);
- A number indicates a geological formation member (Mb.);
- A lowercase letter indicates a soil layer of considerable thickness (i.e. thicker than 2 m) that is laterally continuous across the site and which shows distinct geotechnical characteristics.

Table 3.1: Stratigraphy - WFS II

Unit	Sub-Unit	Depth to Base of Unit[1)] [m LAT]	Vertical Thickness Range[2)] [m]	Soil Description	Comments
A	-	25 to 41	1 to 15	Loose to very dense medium SAND	▪ At top locally a thin to medium thin bed of loose sand ▪ At base locally a thin to medium thin bed of clayey sand or clay ▪ Base follows trend of sandbanks ▪ Variable thickness due to bedforms (i.e. sand waves) at seafloor
B	-	32 to 91	0 to 59	Medium dense to very dense medium SAND, locally gravelly, locally bed(s) of clay	▪ Irregular surface at base - erosional ▪ Scour hollow present in NW part of WFS II ▪ Thickness largest at scour hollows and at sandbanks
D	-	35 to 48	0 to 11	Very stiff to hard fat CLAY	▪ Present in NE part of WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit appears as wedge thickening to NE, due to truncation by Unit B
E1	-	37 to 63	0 to 15	Medium dense to dense silty (or clayey) fine to medium SAND, locally with (many) glauconite	▪ Present in NE part of WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit truncated by Unit B within WFS II ▪ Scour hollow removed locally part of unit
E2	-	36 to 74	0 to 19	Medium dense very clayey fine to medium SAND, with thick to thin beds of CLAY, with (many) glauconite	▪ Present in NE part of WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit is relatively thin and varies in soil conditions across WFS II ▪ Soil conditions of Unit E2 are comparable with Units E1 and E3 ▪ Unit truncated by Unit B within WFS II ▪ Scour hollow removed locally part of unit
E3	-			Medium dense to very dense silty fine to medium SAND, locally with thin to thick beds with (many) glauconite	▪ Present in N half of WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit truncated by Unit B within WFS II ▪ Scour hollow removed locally part of unit
E4	-	36 to 85	0 to 14	Very dense fine to medium SAND	▪ Present in N half of WFS II ▪ Unit characterised by relatively high CPT q_c values ▪ Dipping gently (0.5°) to NE ▪ Unit truncated by Unit B within WFS II ▪ Scour hollow removed locally part of unit

Unit	Sub-Unit	Depth to Base of Unit[1)] [m LAT]	Vertical Thickness Range[2)] [m]	Soil Description	Comments
E5	E5a	36 to 107	0 to 28	Dense to very dense silty fine SAND	▪ Present over almost entire WFS II ▪ Unit is characterised by very high friction ratio, indicating glauconite content ▪ Dipping gently (0.5°) to NE ▪ Thickness increases to NNE ▪ Unit truncated by Unit B within WFS II ▪ Appearance of irregular surface (artifacts) due to mis-ties of MCS data
	E5b	38 to 121	0 to 14	Medium dense to dense silty fine SAND, locally with thin to medium beds with (many) glauconite	▪ Present over almost entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit truncated by Unit B within WFS II ▪ Appearance of irregular surface (artifacts) due to mis-ties of MCS data
F1	F1a	44 to 129	5 to 10	Stiff CLAY with thin to medium beds of sandy clay	▪ Present over entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Unit truncated by Unit B within WFS II ▪ Appearance of irregular surface (artifacts) due to mis-ties of MCS data
	F1b			Hard very sandy CLAY	▪ Present over entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Appearance of irregular surface (artifacts) due to mis-ties of MCS data
	F1c	55 to 145	7 to 17	Very stiff CLAY, fissured	▪ Present over entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Fissures coincide with faulted interval on MCS data
F2	-			Medium dense to dense clayey SAND	▪ Present over entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Generally 3 m to 4 m thick
F3	-	-	-	Very stiff CLAY, fissured	▪ Present over entire WFS II ▪ Dipping gently (0.5°) to NE ▪ Fissures coincide with faulted interval on MCS data

Notes:
- LAT = relative to LAT
- 1) Depths and thicknesses based on geophysical and geotechnical data
- 2) Thickness range can be influenced by dipping strata, where unit is truncated by base of Unit B

Sections 3.2 to 3.5 provide supplementary information.

3.2 Geological Setting

The Borssele WFZ is part of the Southern Bight, i.e. the area of the southern North Sea between the Netherlands, Belgium and the United Kingdom. The Southern Bight is situated on the London-Brabant Massif, which has been a major structural high since Palaeozoic time.

The North Sea Basin is an extensional basin that developed at the beginning of the Cenozoic as the result of post-rift thermal relaxation of the lithosphere, isostatic adjustment and sediment loading (Ziegler, 1990). Thermal subsidence was interrupted by occasional compressional tectonic events.

Crustal movements resulted in thermal uplift of the British Isles (Ziegler, 1990) at the start of the Tertiary (i.e. Early Palaeocene). These movements are attributed to the Alpine orogeny (i.e. mountain building) and resulted in a sudden increase in supply of siliciclastic material. Throughout the Palaeogene (i.e. Palaeocene, Eocene, and Oligocene), a shallow shelf sea environment persisted in the Borssele WFZ. Water depth during high stand periods probably never exceeded 100 m (Cameron et al., 1992). During Eocene times, the shallow sea extended westwards, well into the English Channel. During the Pyrenean tectonic phase at the end of the Eocene and beginning of Oligocene, large areas of the North Sea basin became sub-aerially exposed due to uplift (Ziegler, 1990), including the Borssele WFZ. The area was prone to erosion.

At the end of the Oligocene, the Alpine mountain building resulted in the associated Savian tectonic phase (De Jager, 2007). This tectonic phase, in conjunction with sea level fall, resulted in erosion.

The Neogene (i.e. Miocene and Pliocene) was a period of sediment starvation. The depocentre shifted northwards into the main North Sea Basin (Balson, 1989; Cameron et al., 1989). From the end of the Miocene onwards, a complex fan delta system developed. This gradually evolved into an alluvial plain prograding from the east, from a large Baltic River System (Overeem, 2002).

In Quaternary times, the area of the Borssele WFZ was subject to global sea level fluctuations due to Pleistocene glaciations (Laban, 1995) and partially by glacio-isostacy. This resulted in deep erosion features referred to as scour hollows (Liu et al., 1993). The Holocene led to flooding of the continental shelf. It has remained essentially sediment starved (Jacobs and De Batist, 1996). Holocene deposits occur mainly in the form of sand banks (Liu et al., 1993).

3.3 Lithostratigraphic Framework

Table 3.2 presents the lithostratigraphic framework selected for the Borssele WFZ.

The Quaternary lithostratigraphy according to Rijsdijk et al. (2005) applies. It is assessed to be more applicable than the onshore lithostratigraphy for the Quaternary proposed by TNO (2013a to c).

Table 3.2 Lithostratigraphic Framework for Borssele WFZ

Geotechnical		Lithostratigraphy		Seismostratigraphy Deep (2015a and b)	Time Scale		
Unit	Sub-Unit	Member	Formation	Unit	Age	Epoch	Period
A			Southern Bight	U7		Holocene	Quaternary
B			Kreftenheye/Eem	U6	Weichselian/ Eemian	Pleistocene	
C1			Westkapelle Ground	U5		Pliocene	Tertiary
C2							
D		Rupel Clay	Rupel	U4	Rupelian	Oligocene	
E1		Ruisbroek Sand	Tongeren				
E2		Watervliet Clay					
E3		Bassevelde 3 Sand		U3			
E4		Bassevelde 2 Sand			Priabonian	Eocene	
E5	E5a	Bassevelde 1 Sand					
	E5b						
F1	F1a	Onderdijke	Dongen		Bartonian		
	F1b						
	F1c			U2			
F2		Buisputten					
F3		Zomergem			Lutonian		

The presented lithostratigraphy of the Tertiary is according to Dutch onshore nomenclature (TNO, 2013a to c). This report further differentiates the Dutch onshore nomenclature according to the Belgian lithostratigraphy (Vandenberghe et al., 2004; Maréchal, 1993), where appropriate. Comments are as follows:

- The Tertiary lithostratigraphy has been defined separately for onshore and offshore The Netherlands. The Dutch onshore nomenclature is more detailed and assessed to be more applicable than the Dutch offshore nomenclature for the Tertiary (TNO, 2013d; Van Adrichem Boogaert and Kouwe, 1997). Note that the onshore and offshore lithostratigraphic unit names show differences, as shown in Table 3.3;
- The main difference between the Dutch 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;
- The lithostratigraphic unit names defined by the Dutch onshore nomenclature for the Tertiary are almost the same as the corresponding Belgian lithostratigraphic unit names. The Belgian Sector of the North Sea is adjacent to the Borssele WFZ;
- The Bassevelde Sand Member (Tongeren Formation) and the Asse Member (i.e. Dongen Formation) have been further subdivided based on Belgian lithostratigraphy (Vandenberghe et al., 2004). The lithostratigraphy according to Vandenberghe et al. (2004) differentiates the Bassevelde Sands in three separate units (based on micro-fauna);

- The Dutch Asse Member correlates with the Belgium Maldegem Formation. The Maldegem Formation has been further differentiated in the Onderdijke Member (clay), Buisputten Member (sand), Zomergem Member (clay), Onderdale Member (sand), Ursel Member (clay) and Asse Member (clay). The clay of the Zomergem Member is the deepest lithostratigraphic unit encountered above 90 m LAT;
- Plate 3-3 presents a comparison between the Belgian and the Dutch offshore lithostratigraphic nomenclature (modified after De Lugt, 2007). Differences are significant. Particularly, the Dutch offshore Rupel Formation correlates with both the Belgian Rupel Group and the Tongeren Group.

Table 3.3 Lithostratigraphic Correlation for The Netherlands – Units D to F

<table>
<tr><th colspan="3">Lithostratigraphy</th><th colspan="3">Lithostratigraphy Onshore</th><th colspan="2">Lithostratigraphy Offshore</th><th colspan="3">Time Scale</th></tr>
<tr><th>Unit</th><th>Sub-Unit</th><th>Stratigraphy</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>D</td><td></td><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="12">Tertiary</td></tr>
<tr><td>E1</td><td></td><td>Ruisbroek Sand</td><td rowspan="6">Tongeren</td><td rowspan="6">Zelzate</td><td>Ruisbroek</td><td rowspan="3">Vessem</td></tr>
<tr><td>E2</td><td></td><td>Watervliet Clay</td><td>Watervliet</td></tr>
<tr><td>E3</td><td></td><td>Bassevelde 3 Sand</td><td rowspan="4">Bassevelde</td><td rowspan="4">Undifferentiated</td><td rowspan="4">Priabonian</td><td rowspan="9">Eocene</td></tr>
<tr><td>E4</td><td></td><td>Bassevelde 2 Sand</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">E5</td><td>E5a</td><td rowspan="2">Bassevelde 1 Sand</td></tr>
<tr><td>E5b</td></tr>
<tr><td rowspan="3">F1</td><td>F1a</td><td rowspan="3">Onderdijke</td><td rowspan="5">Dongen</td><td colspan="2" rowspan="5">Asse</td><td rowspan="5">Dongen</td><td rowspan="5">Asse</td><td rowspan="4">Bartonian</td></tr>
<tr><td>F1b</td></tr>
<tr><td>F1c</td></tr>
<tr><td>F2</td><td></td><td>Buisputten</td></tr>
<tr><td>F3</td><td></td><td>Zomergem</td><td>Lutonian</td></tr>
</table>

The Tertiary strata below Unit B are gently dipping (< 0.5^{o}) to NNE and form an angular relationship with the base of Unit B, i.e. the tertiary strata are truncated. As a consequence, the Tertiary strata subcropping below the base of Unit B become progressively older to the southwest (see Plate 3-13). The angular relationship is probably due to tilting during the Savian (Alpine) tectonic phase at the transition from Rupelian to Chattian (middle to late Oligocene).

This report considers Unit C as Tertiary, based on an erosional surface and an angular relationship between the base of Unit B and the top of Unit C. Comments are as follows:

- Unit C is the youngest stratigraphic unit below the base of Unit B and is present in the north-eastern part of Borssele WFZ (i.e. WFS I);
- Unit C is interpreted as the Westkapelle Ground Formation, based on geological information (Laban et al., 1992). The Westkapelle Ground Formation is of Pleistocene age, according to Rijsdijk et al. (2005) and Laban et al. (1992);
- Unit C may possibly be of Pliocene age, i.e. may correspond with the Brielle Ground Formation. The Brielle Ground Formation should include glauconite. The available data for Unit C1 show no significant glauconite content. Unit C2 includes some glauconite;
- Resolution on Westkapelle Ground Formation versus Brielle Ground Formation would require age dating.

General deviations apply between the measured unit boundary depths at the geotechnical locations and the derived horizon depths from the geophysical data. This mainly relates to inevitable uncertainties for processing of geophysical data, e.g. time/depth conversion. The difference in depths between the interpreted geotechnical unit boundaries and the interpreted seismic horizons can be up to 2 m over the investigated depth range.

3.4 Seismostratigraphic Framework

Table 3.2 includes a comparison of the selected lithostratigraphic framework for Borssele WFZ and seismostratigraphy interpreted by Deep (2015a and b). Comments are as follows.

For Borssele WFZ, the description and thickness of most geotechnical units correlate well with the seismostratigraphic units.

The seismostratigraphic unit boundaries (i.e. base of Units U7, U6 and U5) correlate well with the lithostratigraphic unit boundaries (i.e. base of Units A, B and C), which are erosional surfaces.

The base of Unit U4 and the base of Unit U3 appear as strong amplitude reflections on seismic data and are concordant. The base of seismostratigraphic Unit 4 is an internal reflection of the lithostratigraphic Tongeren Formation. This might coincide with the Pyrenean tectonic phase. The base of seismostratigraphic Unit 3 relates to the top of an intensely faulted interval within the lithostratigraphic Dongen Formation. These faults have small displacement and are intra-formational. This fault pattern has been described for polygonal fault systems in the Rupel Clay Member (Rupel Formation) and the Ieper Clay Member (Dongen Formation), (Dehandschutter et al., 2002; Horseman et al., 1987). The faulted interval shows fissures in the geotechnical clay samples. The fissures provide some indication for deformation within this interval.

3.5 Geotechnical Units at WFS II

Geotechnical Unit A is interpreted as the Southern Bight Formation (Holocene). The Southern Bight Formation consists of the Bligh Bank Member and the Buitenbanken Member (Balson et al., 1991). The older Buitenbanken Member has been reworked and incorporated in the Bligh Bank Member. The geotechnical data do not allow distinguishing the Southern Bight Formation. The Holocene sediments are interpreted to be deposited over a relatively flat base (possibly a tidal flat of Pleistocene age). This flat base appears as a planar seismic reflection on MCS data.

Geotechnical Unit B is interpreted as Pleistocene sediments. The expected Pleistocene formations at Borssele WFZ are the Eem Formation (possibly including the Brown Bank Member) and probably locally the Kreftenheye Formation on top. The Kreftenheye Formation is generally coarser grained than the Eem Formation, while the Eem Formation is more clayey and contains marine shells and shell fragments (Rijsdijk, 2013). The fluvial deposits of the Kreftenheye Formation have been interpreted to reach the Borssele WFZ just in the north (i.e. WFS I) and an isolated patch inside the Borssele WFZ, south of WFS I and west of WFS II (Rijsdijk, 2013). The sediments of the marine Eem Formation can be partially reworked and incorporated in the Kreftenheye Formation. The geotechnical data do not allow for distinguishing these Pleistocene formations.

Unit B in the Borssele WFZ is thin in comparison to the Pleistocene strata further north on the Dutch Shelf of the North Sea. This is due to the relative position of the Borssele WFZ at the margin of the North Sea Basin. Therefore, eustatic sea level fluctuation during the Pleistocene glaciations resulted in erosion and non-deposition. The base of Unit B (Pleistocene) is an erosional surface, which locally incises deeply in the underlying strata. These local incisions are referred to as scour hollows (Le Bot et al., 2005; Liu et al., 1993). The scour hollows are probably associated with marine currents, rather than fluvial processes. The infill of these scour hollows results in much thicker (up to tens of metres) Pleistocene strata. The Pleistocene infill of the scour hollows and paleo-channels contains (marine) shells and shell fragments.

Unit B appears as chaotic or transparent reflections with low lateral continuity on the MCS data. The limited lateral continuity might be due to small channels that have been observed locally on the MCS and SBP data.

Geotechnical Unit B shows diffraction hyperbola in the MCS data. This might be indicative for boulders. However, boulders are not expected. This is because ice sheets did not reach the Borssele WFZ during the Pleistocene glaciations and there are no nearby sources for the boulders. The hyperbola might reflect patches of gravel that act as a larger body.

Units C1 and C2 (Westkapelle Ground Formation) are absent at WFS II.

Geotechnical Unit D is present at WFS I and locally present at the north-eastern part of WFS II. This unit relates to the Rupel Clay Member of the Rupel Formation. The Rupel Formation can generally be subdivided in three members (Plate 3-3): Steensel Member (sand) on the top, Rupel Clay Member and Vessem Member (sand) at the base. Only the clay member (i.e. Rupel Clay Member) is interpreted to be present at the Borssele WFZ. The sand unit below the Rupel Clay Member is interpreted to be part of the Tongeren Formation.

Unit D appears as high amplitude, continuous, parallel reflections. The underlying Unit E (Tongeren Formation) appears as low amplitude, continuous, parallel reflections. The change in amplitude marks the transition from clay (Rupel Formation) to sand (Tongeren Formation).

Unit D consists of heavy, dark brown-grey clays, which have been deposited in a marine environment, based on TNO (2014). The Rupel Clay Member is pyrite-rich, contains hardly any glauconite and calcium carbonate is concentrated in septarian concretions. No septarian concretions have been sampled at the Borssele WFZ. The Rupel Clay Member has been described to be fissured (TNO, 2014; Dehandschutter et al., 2002; Horseman et al., 1987).

The sampled clays of geotechnical Unit D are over-consolidated and show platy texture, i.e. fissured. Laboratory results of triaxial compression tests on clay samples of Unit D show that the remoulded shear strength ($c_{u;r}$) is generally higher than the measured undrained shear strength (c_u) for undisturbed (intact) soil samples. This difference in soil strength may be explained by the platy texture in the clay. The platy texture probably introduces weak zones that may act as preferential failure planes. When the clay is remoulded, these weak zones are dispersed.

Clay samples from geotechnical Unit D showed some swelling during the re-compression or consolidation phase of laboratory tests. This might be due to the clay mineralogy, as the Rupel Clay Member is known to contain swelling minerals such as smectite (Jacobs and De Coninck, 1992).

Geophysical data for WFS I show localised deformation features in Unit D, i.e. folded reflections forming diapiric structures. These features were not found at WFS II. Mud diapirism might be present at WFS II, as the lateral extent of these features (< 150 m) is smaller than the MCS line spacing (400 m). Cone penetration tests were performed within diapiric structures, as part of the geotechnical investigation. The tests showed similar soil conditions to the undisturbed clays. Mud diapirs have been described and tested elsewhere in the Rupel Clay Member, e.g. in the Scheldt estuary (Schittekat et al., 1983).

Geotechnical Unit E (Tongeren Formation) shows medium amplitude reflections towards the base of the seismostratigraphic unit. Some seismic reflection at the base shows onlap on the underlying Dongen Formation. The transition from the Dongen Formation to the Tongeren Formation coincided with the Pyrenean orogeny at the transition from Bartonian to Priabonian (late Eocene).

Geotechnical Unit E1 (Ruisbroek Sand Member) has a significant glauconite content. Glauconitic grains are sand-size clay aggregates, which can easily deform under mechanical stress (Van Alboom et al., 2012). The glauconite content was examined and confirmed by visual inspection of the soil samples. Glauconite may also be inferred from high sleeve friction values in the CPT data.

Geotechnical Unit E2 (Watervliet Clay Member) is known (TNO, 2013b) to include locally lignite, or brown coal. The lignite probably marks the onset of a transgressive phase. Seismic amplitude anomalies on MCS data can be interpreted as lignite or shallow gas within the Tongeren Formation. The seismic amplitude anomalies were targeted to be confirmed by geotechnical data, but the necessary depth was not achieved.

Units E3, E4 and E5 can be identified from CPT cone resistance. These units correlate with the Bassevelde Sand Units (Ba3, Ba2 and Ba1 respectively). These units show significant mica content.

Internal seismic reflections can be observed within Unit E5a. These seismic reflections are not continuous over WFS II. Peaks in CPT cone resistance correlate locally with these reflections (Plate 3-7, 3-8 and 3-10). Similar seismic reflections can be observed elsewhere within Unit E5a, without associated CPT peaks. This situation precludes further differentiation of Unit E5a.

Geotechnical Units F1 to F3 are related to the Asse Member of the Dongen Formation. Units F1 to F3 show higher amplitude reflections than the overlying Tongeren Formation, characterising a clay-dominated unit.

Unit F1c (Onderdijke Member) shows platy structures. The top of Unit F1c corresponds with the top of a zone of small scale faulting inferred from the MCS data (Plates 3-7 to 3-11).

Geotechnical Unit F2 (Buisputten Member) consists of sands.

Geotechnical Unit F3 (Zomergem Member) consists of clays, showing platy structures as identified for geotechnical Unit F1c.

3.6 Seafloor Conditions and Site Use

Water depth will change over time as a result of seabed mobility. The reader should consult Deltares (2014) for detailed information. Comments are as follows:

- Sand banks form prominent seabed features in the Borssele WFZ. Three scales of bedforms can be distinguished for the Borssele WFZ: (tidal) sand banks, sand waves and mega ripples. Refer to Appendix 1, document titled Site Characterisation, for general descriptions of these bedforms;
- The migration of sand waves varies within the Borssele WFZ. This leads to bed load partings, e.g. scour zones due to divergent patterns in sediment transport;
- Existing and future windfarms can act as hydraulic obstructions, which can contribute to changing conditions and hence changes in the general scheme of scour and deposition;
- The Borssele WFZ can be subject to multi-year fluvial sediment starvation or surplus.

The reader should consult Deep (2015a and b), REASeuro (2014), Vestigia (2014) for detailed information about site use. Site use refers to past and/or present activities that can put constraints on the development of the wind farm site. Examples of site use are seafloor objects and activities having led to disturbance of soil. Comments are as follows:

- Seafloor objects within the Borssele WFZ include cables and pipelines, wrecks and other debris. Not all cables and pipelines are in service;
- The cables and pipelines may be partially or completely buried by the mobile bedforms. Fugro has no information on trenching and whether mattresses or rock dumps have been used locally for stabilisation of the cables and pipelines. Trenching and post-lay stabilising activities cause disturbance of the seabed;
- Trawl fishing and UXO clearance activities have been documented for the Borssele WFZ. This will have caused local disturbance of the seabed;
- There is evidence of prehistoric human activities in the southern North Sea. This relates to the last ice age (Weichselian glacial). Sea level was much lower than today and a land bridge existed between England and mainland Europe. The archaeological desk study showed a low probability of encountering well-preserved early prehistoric sites with in situ remains within WFS II. The probability of soil disturbance due to prehistoric human activities is assessed negligible for WFS II;
- The geotechnical site investigation (Plate 1-2) used intrusive geotechnical investigation techniques (i.e. borehole drilling and in situ testing). These activities cause local soil disturbance.

4. GEOTECHNICAL PARAMETER VALUES

Sections A and B summarise geotechnical parameter values reported and explained in Fugro Report Nos. N6016/03 and N6016/04 (refer to Plate 1-2). Note that the presented information represents measured values and derived values, as defined in Appendix 1, document titled Geotechnical Analysis.

Section A presents location-specific parameter values versus depth:

- Normalized CPT parameters;
- CPT net cone resistance;
- Water content and Atterberg limits;
- Soil unit weights;
- Particle size distribution;
- Relative density;
- Undrained shear strength;
- Shear wave velocity and shear modulus at small strain.

Section B presents the same parameter values but grouped versus depth per geotechnical unit. A single plate presents data for a maximum of 12 geotechnical locations. Locations have been divided over four plates (a to d) on a geographical basis in the NNE direction of the dipping Tertiary units, starting from the North.

5. COMMENTS ON SITE SUITABILITY

5.1 Potential Site-specific Hazards

Table 5.1 and Plate 5-1 present identified geological features and processes, which can be potential hazards (geohazards) for structures, i.e. windfarm support structures (foundations) and cables. Sections 5.2 to 5.6 provide supplementary information for consideration. The information is high level (indicative) and not intended to be complete or comprehensive.

Table 5.1 includes approximate and subjective probability indicators for hazards: Negligible (N), Low (L) and High (H) probability. Appendix 1, document titled “Geotechnical Analysis”, explains these expressions. An indicator between brackets, e.g. [L], refers to a situation considering appropriate measures for countering the hazard, such as source elimination, avoidance, implementation of a barrier, minimising consequences and design for the hazard (ISO, 1998).

The following example illustrates how to read Table 5.1 and Sections 5.2 to 5.6. Adverse metocean conditions can change an initially flat seafloor to an uneven seafloor. This situation is assessed to have High probability H (no brackets) for affecting placement of a gravity base foundation (GBS), if no appropriate measures for countering the hazard are implemented. The example situation is assigned Negligible probability [N] (with brackets) when appropriate measures for countering the hazard are implemented, such as scour-resistant seabed preparation and availability of equipment for removal of loose sediments immediately before GBS placement.

Table 5.1: Potential Site-specific Hazards and Constraints for Structures

Geological Feature / Hazard Type	Occurrence Area	Constraints on Structure	Constraint/ Hazard Probability				
			Pile Foundations (PL)	Jack-up Platforms (JU)	Gravity Base Foundations (GB)	Suction Caisson Foundations (SC)	Cables (CB)
Bedforms (sand waves and mega ripples) / uneven seafloor	Entire WFS II	▪ JU: uneven seafloor causing high and non-uniform VHM loading on legs ▪ GB: seabed preparation required for foundation stability/ stiffness ▪ SC: installation requires initial embedment before applying suction (hydraulic leaks) ▪ CB: trenching on locally steep slope	N [N]	L [N]	H [N]	L [N]	L [N]
Migrating bedforms / mobile seabed sediments	Entire WFS II	▪ All: exposure or burial of structure due to local, general and regional scour or sedimentation affecting structure stability, structure stiffness ▪ CB: exposure or burial of cable affecting thermal characteristics; spanning of cable leading to snagging from trawling or anchoring	H [L]	L [N]	H [N]	H [L]	L [N]

Geological Feature / Hazard Type	Occurrence Area	Constraints on Structure	Constraint/ Hazard Probability				
			Pile Foundations (PL)	Jack-up Platforms (JU)	Gravity Base Foundations (GB)	Suction Caisson Foundations (SC)	Cables (CB)
Loose to medium dense sand	Locally in Unit A	▪ All: cyclic loading of seabed and structure can affect structure stability and structure stiffness ▪ CB: liquefaction of sand can affect cable flotation and thermal characteristics	H [N]	L [N]	H [N]	L [N]	L [N]
Alternation of sand and clay (inferred from depositional environment)	Infill of paleo-channels and scour hollows (Unit B)	▪ JU: possibility of leg punch through followed by jack-up instability ▪ SC: installation may not be feasible	N [N]	L [N]	N [N]	H [L]	N [N]
Very dense sand/ hard clay	▪ Unit D, F1a, F1c, F3 – stiff to very stiff clay ▪ Unit E4 – very dense sands	▪ PL: early refusal of pile installed by impact driving ▪ SC: limited penetration ▪ CB: trenching difficulties	L [N]	N [N]	N [N]	L [L]	L [N]
Gravels and cobbles, septarian and pyrite concretions	▪ Unit B – locally with gravels and cobbles ▪ Unit D – possibly septarian and pyrite concretions	▪ PL: possibly early refusal or damage and pile verticality issues during pile driving ▪ SC: limited penetration ▪ CB: trenching difficulties	L [N]	N [N]	N [N]	L [L]	L [N]
Glauconitic sands	Unit E1 (possibly Unit E5)	GB: differential settlement of foundation due to compressibility of glauconitic grains in sand	N [N]	N [N]	L [N]	N [N]	N [N]
Mud diapir	Unit D	None	N [N]	N [N]	N [N]	N [N]	N [N]
Fissured clay structure	Unit D and Unit F1c/F3	GB: low foundation bearing/sliding resistance compared to soil with no fissures	N [N]	N [N]	L [N]	N [N]	N [N]
Swelling clays	Unit D and Unit F	None	N [N]	N [N]	N [N]	N [N]	N [N]
Lignite (brown coal)	Unit E2 (not proven)	None	N [N]	N [N]	N [N]	N [N]	N [N]
Shallow gas	Unit E2 (not proven)	▪ GB: possible migration of shallow gas into skirted compartment, affecting foundation performance ▪ SC: possible migration of shallow gas into caisson, affecting foundation performance	N [N]	N [N]	L [N]	L [N]	N [N]
Polygonal faulting	Unit F1b and F3	GB: low foundation bearing/sliding resistance compared to soil with no faulting	N [N]	N [N]	L [N]	N [N]	N [N]

Geological Feature / Hazard Type	Occurrence Area	Constraints on Structure	Constraint/ Hazard Probability				
			Pile Foundations (PL)	Jack-up Platforms (JU)	Gravity Base Foundations (GB)	Suction Caisson Foundations (SC)	Cables (CB)
Existing structures, e.g. pipeline and cable	Refer to Section 3.6	▪ All: avoid immediate area around object for structures ▪ All: potentially disturbed ground compared to areas away from object ▪ All: potential interruption in hydraulic flow regime affecting scour and soil deposition processes ▪ CB: avoidance may not be practicable; windfarm power/communication cables will require crossings	H [N]	H [N]	H [N]	H [N]	H [L]
Future structures, e.g. wind farm itself (wind turbines, transformer station, cables) and structures in region	Entire WFS II	All: potential interruption in hydraulic flow regime affecting scour and soil deposition processes	L [N]	N [N]	L [N]	L [N]	L [N]

N : Negligible probability
L : Low probability
H : High probability

- Descriptor (without brackets): approximate and subjective probability for a situation with no specific measures countering the hazard
- Descriptor between brackets [...]: approximate and subjective probability for a situation considering appropriate measures for countering the hazard

5.2 Pile Foundations

Pile foundations are assessed feasible at WFS II.

Design and installation should take account of the constraints given in Table 5.1.

The assessment considers monopiles, jacket piles and piles for tripod support structure installed by impact driving.

Where applicable, driven pile installation should be sufficiently robust for penetration of very dense sand layers and/or concentrations of gravels, cobbles and septarian concretions in the subsurface.

5.3 Jack-up Platforms

Use of jack-up platforms for temporary works is assessed feasible at WFS II.

Jack-up placement and operation should take account of the constraints given in Table 5.1. Particularly, scour and soil deposition around spudcans should be allowed for:

- Scour can make periodic re-levelling of the jack-up necessary, can increase required leg length and can reduce spudcan soil resistance after jack-up placement;
- Risk assessments for jack-up siting should consider structural integrity for a scenario of strongly non-uniform soil support of a spudcan, i.e. moment loading;
- Soil deposition around and on a spudcan will affect required extraction forces.

5.4 Gravity Base Foundations

Gravity base foundations are assessed feasible at WFS II.

Design and installation should take account of the constraints given in Table 5.1.

Design should consider seabed preparation to allow for potentially uneven and sloping seafloor and to allow for loose to medium dense sands that can show significant loss of strength upon cyclic loading.

Any seabed preparation (levelling, ground improvement) prior to foundation installation should consider potential disruption by rapid scour and sedimentation processes.

It is assessed that scour protection will be required, except if the foundation base or skirt tip can be positioned below long-term scour levels.

High mechanical stresses applied to glauconitic sands can cause significant deformation and compression of the glauconitic grains, compared to quartz-type particles. Increased differential settlement of a gravity base foundation may result.

5.5 Suction Caisson Foundations

Suction caisson foundations are assessed marginally feasible.

Design considerations should include:

- Constraints given in Table 5.1;
- Sloping and uneven seafloor conditions that can affect caisson penetration and required sealing for initial suction application;
- Relatively shallow water depths that will limit allowable suction pressures, in particular on the sand banks Schaarbank and Thorntonbank / Rabsbank;
- Scour protection, except if the caisson skirt tip can be positioned well below long-term scour levels;
- Measures for caisson penetration taking account of interbedded sand/clay layers, concentrations of gravels and cobbles and septarian concretions.

It may be possible to design for difficult conditions for caisson penetration. Tjelta (2015) provides guidance.

5.6 Cables

Installation and operation of cables are assessed feasible at WFS II.

Design and installation should take account of the constraints given in Table 5.1.

Design should consider long-term scour and soil deposition processes for thermal response and any minimum cable burial requirements.

Activities for cable burial should consider potential disruption by rapid scour and sedimentation processes.

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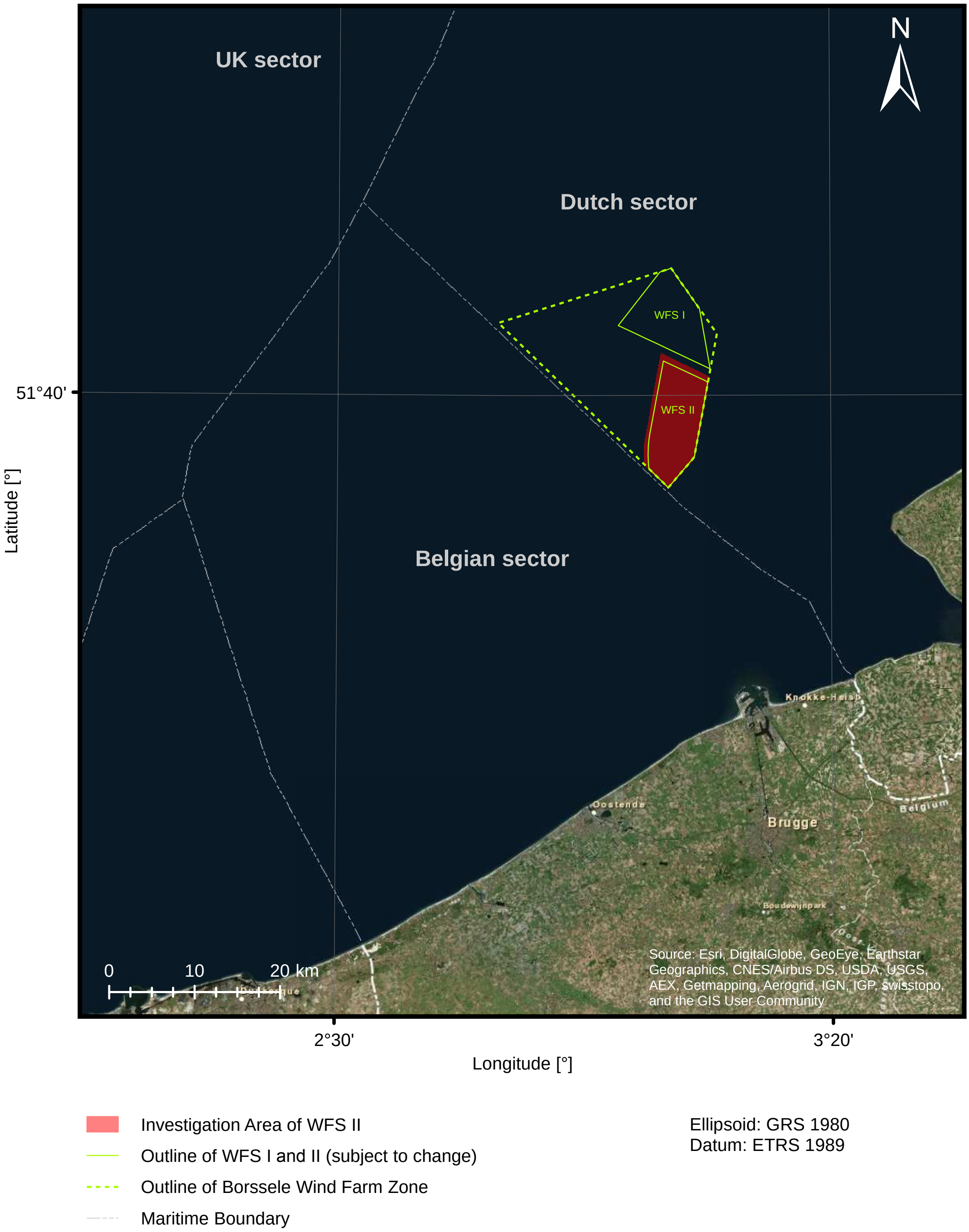

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VICINITY MAP

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

Report Number	Title	Contents
N6016/01	Geotechnical Report - Investigation Data - Geotechnical Borehole Locations Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including geotechnical logs, results from downhole (seismic) cone penetration tests and results from geotechnical laboratory tests.
N6016/02	Geotechnical Report - Investigation Data - Seafloor In Situ Test Locations Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including interpreted geotechnical logs and results from seafloor cone penetration tests.
N6016/03	Geotechnical Report - Investigation Data - Geotechnical Borehole Locations Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including geotechnical logs, results from downhole (seismic) cone penetration tests and results from geotechnical laboratory tests.
N6016/04	Geotechnical Report - Investigation Data - Seafloor In Situ Test Locations Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geotechnical data including interpreted geotechnical logs and results from seafloor cone penetration tests.
N6016/05	Geological Ground Model Wind Farm Site I Borssele Wind Farm Zone - Dutch Sector, North Sea	Geological ground model including, stratigraphy, lateral soil variability, geohazards, basic geotechnical parameter values and assessment of geotechnical suitability of selected types of structures.
N6016/06	Geological Ground Model Wind Farm Site II Borssele Wind Farm Zone - Dutch Sector, North Sea	Geological ground model including, stratigraphy, lateral soil variability, geohazards, basic geotechnical parameter values and assessment of geotechnical suitability of selected types of structures.
N6016/07	Geotechnical Report - Laboratory Test Data Wind Farm Sites I & II Borssele Wind Farm Zone - Dutch Sector, North Sea	Results of advanced static and cyclic laboratory tests.

LIST OF FUGRO REPORTS

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

DGPS Geodetic Parameters	
Datum	WGS84 (World Geodetic System 1984)
Ellipsoid	WGS84 (World Geodetic System 1984)
Semi-Major Axis, a	6378137.000 m
Inverse Flattening, 1/f	298.257223563
Transformation Parameters (from WGS84 to Local Grid)	
Source Shift	
dX	+0.05363 m
dY	+0.05083 m
dZ	- 0.08598 m
Rotation and Scale	
rX	- 0.002128"
rY	- 0.012872"
rZ	+0.020805"
dS (Scale Factor)	- 0.002561 ppm
Local Grid Geodetic Parameters	
Datum	ETRS89 (European Terrestrial Reference System 1989)
Ellipsoid	GRS80 (Geodetic Reference System 1980)
Semi-Major Axis, a	6378137.000 m
Inverse Flattening, 1/f	298.257222101
Local Projection Parameters	
Projection	Universal Transverse Mercator
UTM Zone	31 North
Central Meridian (CM)	03° 00' 00" E
Latitude of Origin	00° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale Factor on CM	0.9996
Units	metres

Example Coordinates		
Local grid coordinates	Easting	503819.64 m E
	Northing	5738442.18 m N
Local geographical coordinates	Latitude	51° 47' 48.5644" N
	Longitude	03° 03' 19.3986" E
WGS84 geographical coordinates	Latitude	51° 47' 48.5803" N
	Longitude	03° 03' 19.4204" E

GEODETIC PARAMETERS

BORSSELE WIND ZONE, WFS I – DUTCH SECTOR, NORTH SEA

DESIGN APPROACH

General Procedure:	– Refer to documents titled "Site Characterisation" and "Geotechnical Analysis" presented in Appendix 1 – According to ISO 19900 (2013) Section 5
Premise(s):	– Design basis verification required; site characterisation is for conceptual phase and suitable for use in FEED, subject to a separate verification of the design basis
Type of Structure(s) and Purpose:	Multiple foundation concepts are considered (e.g. pile(s), caisson, gravity base), jack-up and cable; final foundation design to be selected at later stage
Location:	– Dutch Sector of the North Sea – Refer to Plate 1-1 for site location

DATA COVERAGE

Met-ocean Data:	Not considered: outside scope of Project Specification
Environmental Baseline:	Not considered: outside scope of Project Specification
UXO Information:	Refer to Section 3.6 of Main Text, titled Seafloor Conditions and Site Use
Archaeological Information:	Not considered: outside scope of Project Specification
Geological Data:	Refer to Section 3 of Main Text, titled Geological Ground Model and to Plate 3-4
Geophysical Survey Data:	– Multi-Beam Echo Sounder (MBES), Side Scan Sonar (SSS), Magnetometer (MAG); line spacing: approximately 100 m – Multi-Channel Seismic (MCS), Sparker; penetration: approximately 200 m bsf; line spacing: approximately 400 m – Sub-Bottom Profiler (SBP), Pinger; penetration: approximately 10 m bsf; line spacing: approximately 100 m
Geotechnical Data:	Refer to Section 3 of Main Text titled Geological Ground Model, Section 4 of Main Text titled Geotechnical Parameter Values and to Plate 3-4
Monitoring Data:	None available for study
Physical Modelling Data:	None available to the authors of this document

SITE USE

Historic and Current Site Use:	– Refer to Section 3.6 of Main Text, titled Seafloor Conditions and Site Use
Changes in Site Conditions since Data Acquisition:	Not known at time of issue of this report

SEAFLOOR CONDITIONS AND (SITE) HAZARDS

Seafloor:	– Variable elevations, including potential for mobile seabed sediments, disturbance by geotechnical site investigation – Structure(s) to be designed and positioned to suit as-found seafloor conditions – Refer to Main Text for details
Local Scour:	Refer to Sections 3 and 5 of Main Text, titled Geological Ground Model and Comments on Site Suitability, respectively
General Scour:	Refer to Sections 3 and 5 of Main Text, titled Geological Ground Model and Comments on Site Suitability, respectively
Regional Scour:	To be considered
Low-Strength Seabed Soils:	Very loose SAND can be present at seafloor
Other (Site)Hazards:	Refer to Section 5 of Main Text, titled Comments on Site Suitability
Interpretive Limit(s):	– Assessment of seafloor conditions and (site) hazards results from interpretation of data available at the time of study – Hazard identification can be based on reasonably-inferred understanding – A hazard may remain undetected because of partial data coverage or detection limits of deployed tools

STRATIGRAPHIC SCHEMATISATION

Ground Type(s):	Interbedded medium dense to very dense SAND and stiff to hard CLAY
Lateral Correlation of Ground Strata:	Refer to Section 3 of Main Text, titled Geological Ground Model
Vertical Correlation of Ground Strata:	Implicitly incorporated in stratigraphic schematisation and selection of other parameter values
Interpretive Limit(s):	– Stratigraphic schematisation results from interpretation of data available at the time of study – Schematisation can be approximate because of partial data coverage or detection limits of deployed tools and an interface between strata may be more gradual than indicated

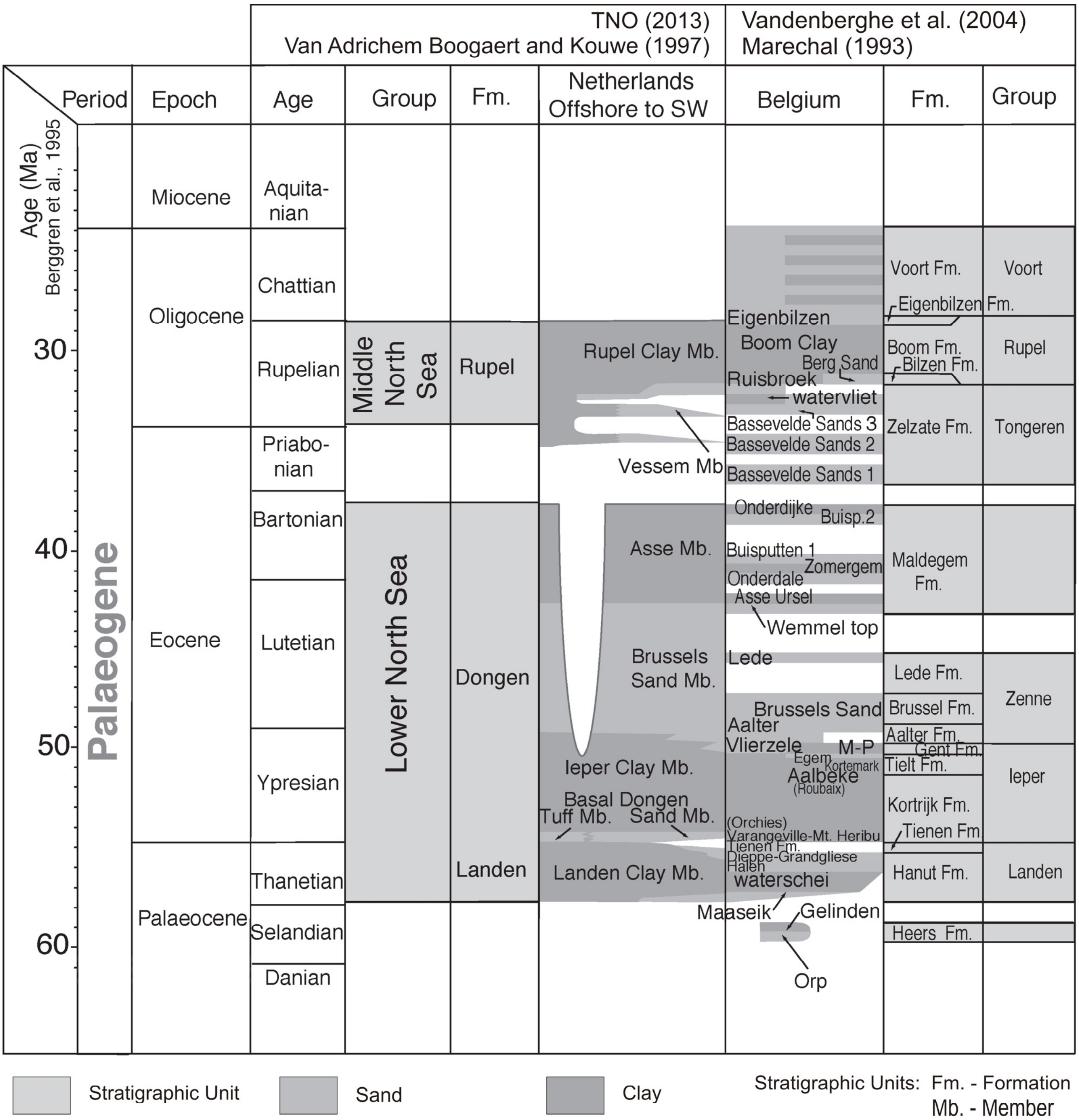
GEOTECHNICAL PARAMETERS

Ground Description:	– According to document titled “Soil Description” presented in Appendix 1 – Based on BSI (1999)
Groundwater Pressure:	Assumed hydrostatic
Basic Physical Properties:	Refer to Sections A and B, titled Geotechnical Parameters
Stress/Strain Parameters:	Refer to Sections A and B, titled Geotechnical Parameters
Geo-thermal Parameters:	Not considered, geo-thermal setting assumed according to seasonal equilibrium
Interpretive Limit(s):	Level of detail and accuracy in interpretation of geotechnical parameter values depend on factors such as test data, sample size, quality, coverage, and availability of supplementary information such as geological understanding

REFERENCES

– BSI British Standards Institution (1999), "Code of Practice for Site Investigations", British Standard BS 5930:1999.

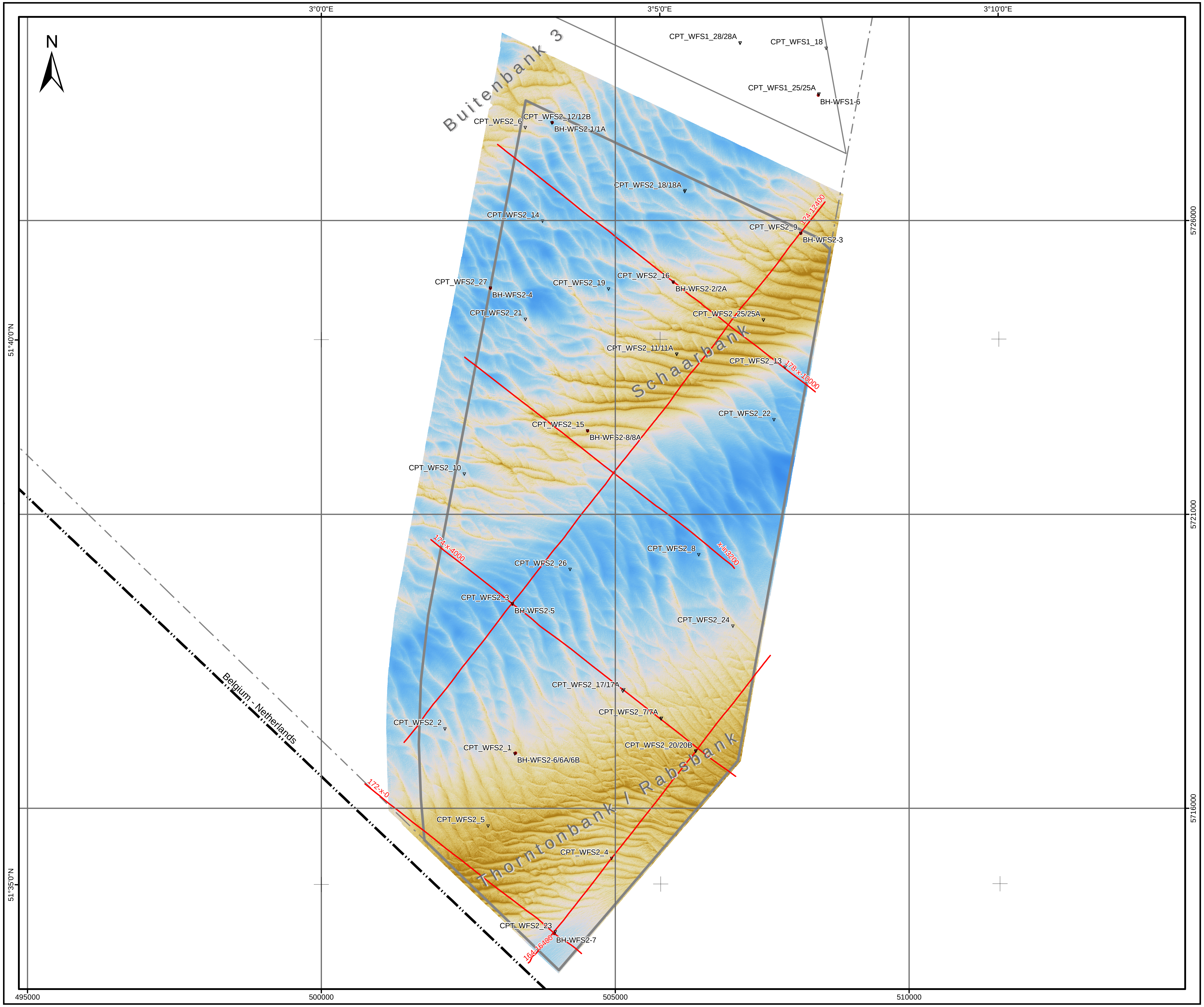
– ISO International Organization for Standardization (2013), “Petroleum and Natural Gas Industries - General Requirements for Offshore Structures”, International Standard ISO 19900:2013.



Simplified lithological correlation between the Netherlands offshore and Belgium.
Modified after DeLugt (2007).

LITHOSTRATIGRAPHIC FRAMEWORK

BORSSELE WIND ZONE, WFS I – DUTCH SECTOR, NORTH SEA



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report

Bathymetry [m below LAT]

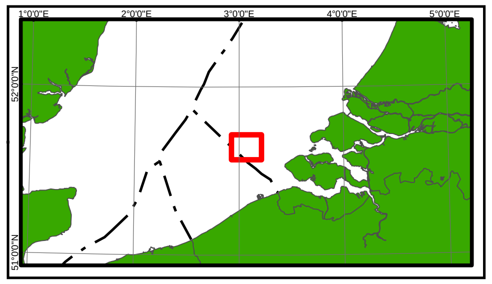
-13, -17, -21, -25, -29, -33, -37, -39

NOTES:

- Reproduced from Deep (2015)
- Resolution cells 1m x 1m
- Data acquired by Multi-Beam Echo Sounder (MBES)

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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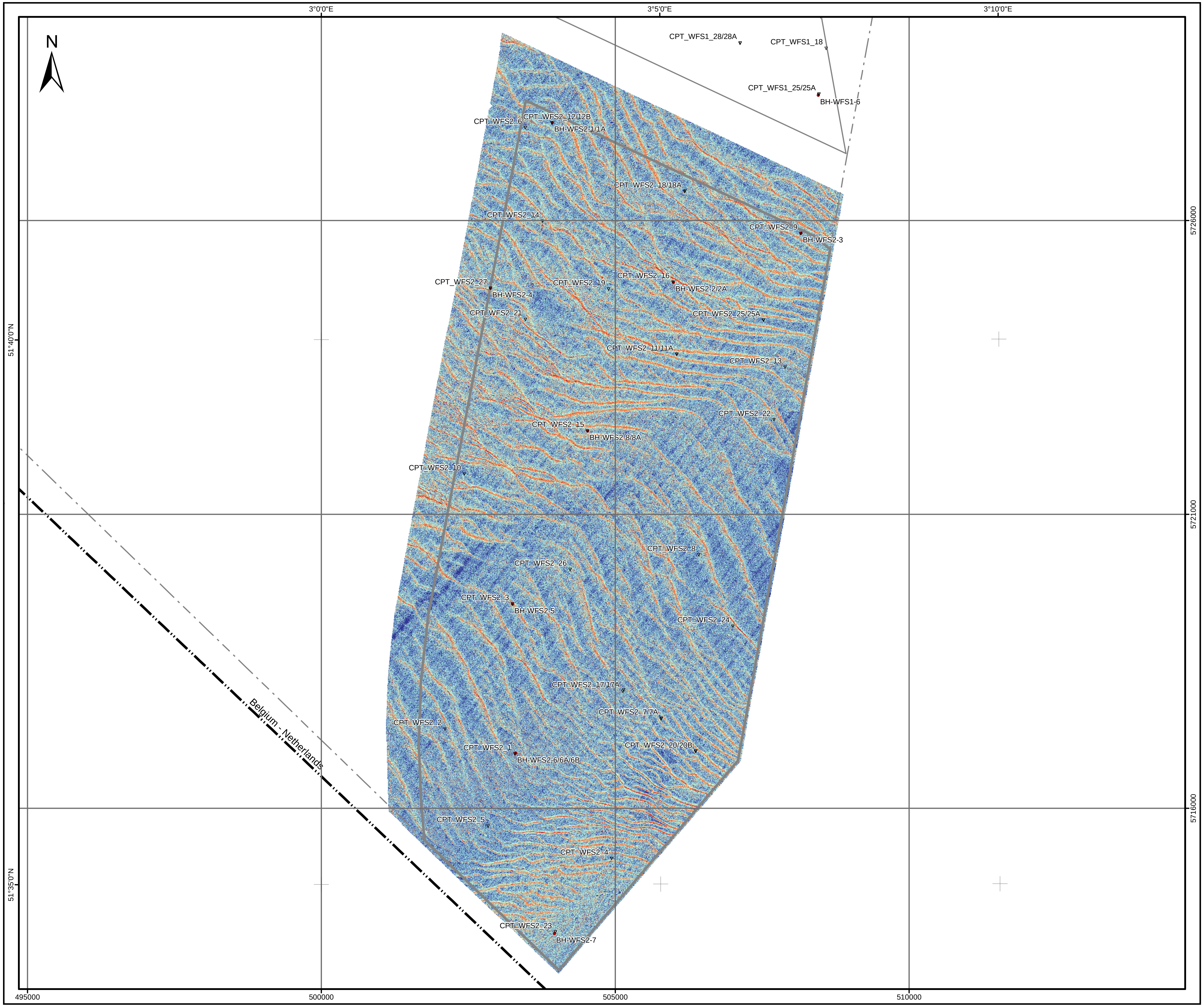
BATHYMETRY

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-4
Printed: 02/07/2015 18:50:15		Author: BLM



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary

Seafloor gradient [deg]

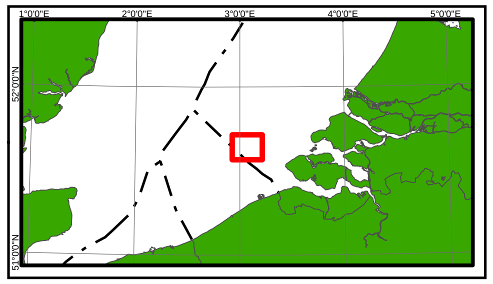
- 0 - 2
- 2 - 5
- 5 - 8
- 8 - 15
- 15 - 50

NOTES:

- Seafloor gradient derived from bathymetry data (2015)
- Gradient determined from 3 x 3 cell neighbourhood around centre cell
- Resolution cell 1m x 1m

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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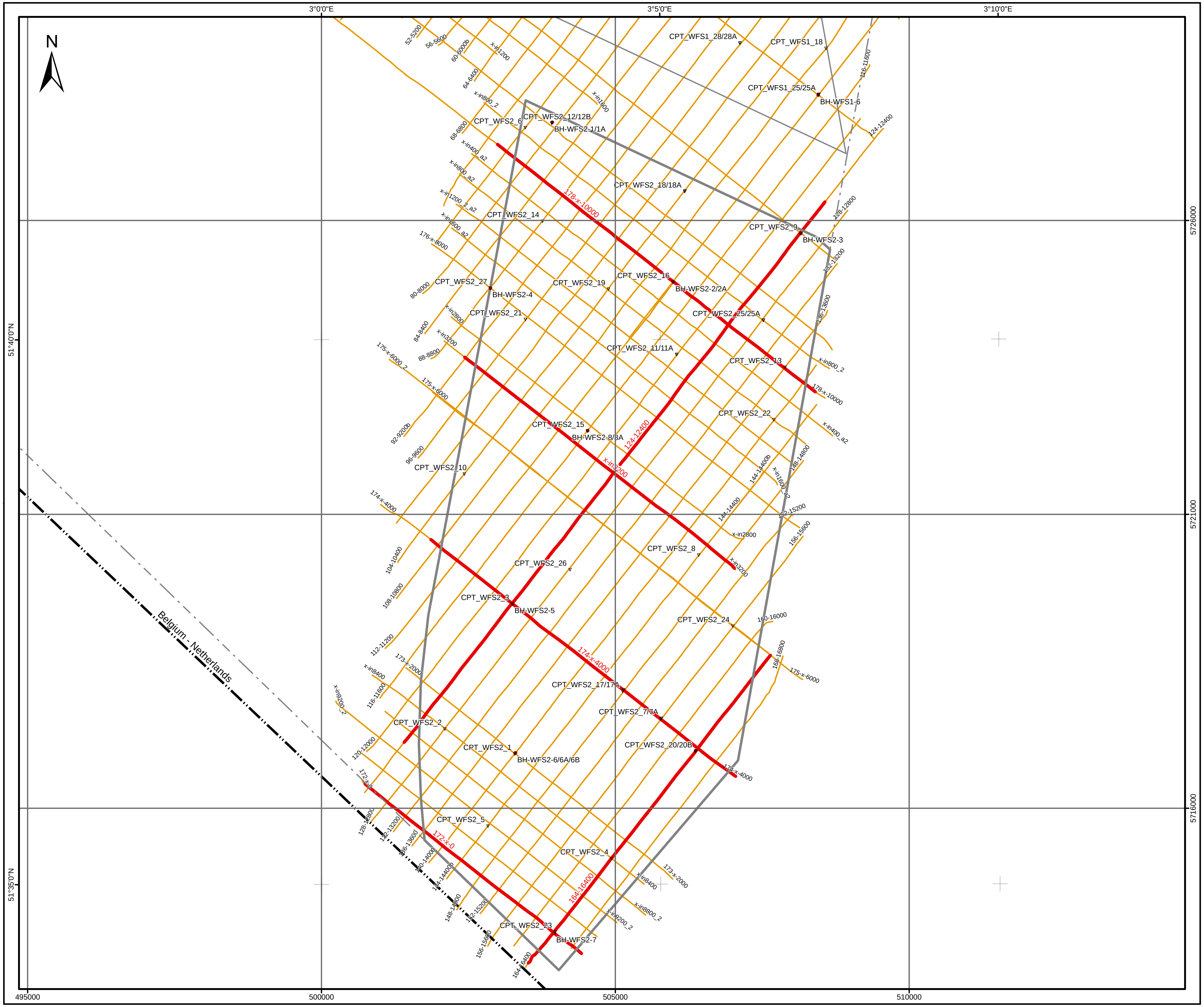
SEAFLOOR GRADIENT

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-5
Printed: 02/07/2015 19:48:11		Author: BLM



LEGEND:

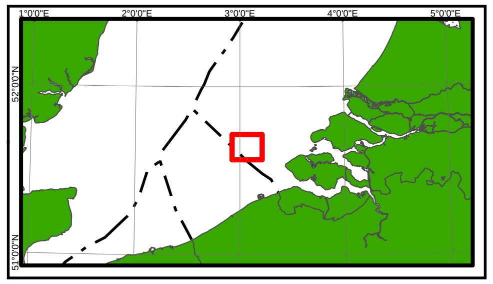
- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Multi-Channel Seismic (MCS) track lines

NOTES:

- Multi-Channel Seismic (MCS) data from Sparker source
- Data acquired by Deep (2015)
- Section lines present part of track lines presented as cross-sections

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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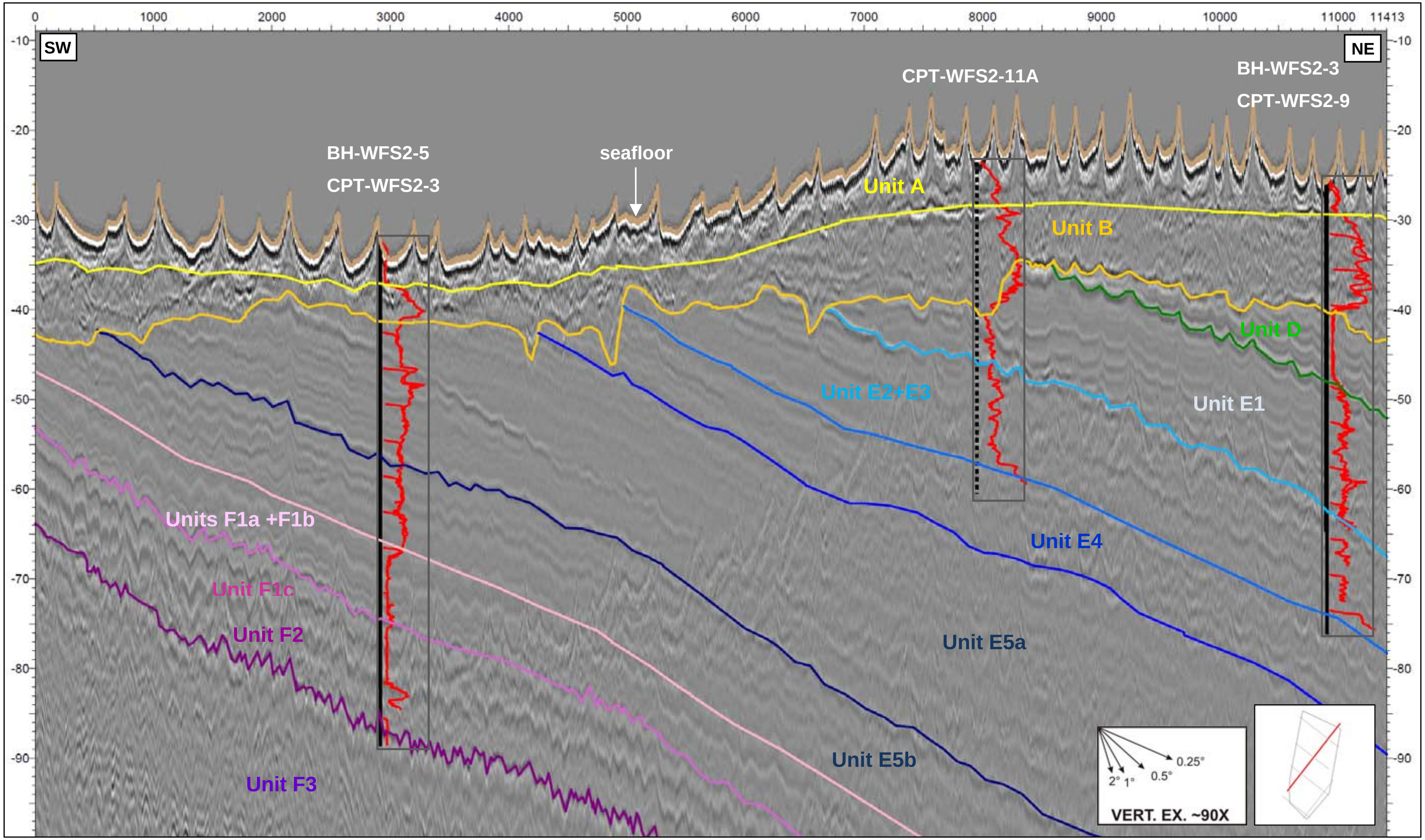
MULTI-CHANNEL SEISMIC (MCS) TRACK LINES AND SECTION LINES

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-6
Printed: 02/07/2015 18:28:18		Author: BLM

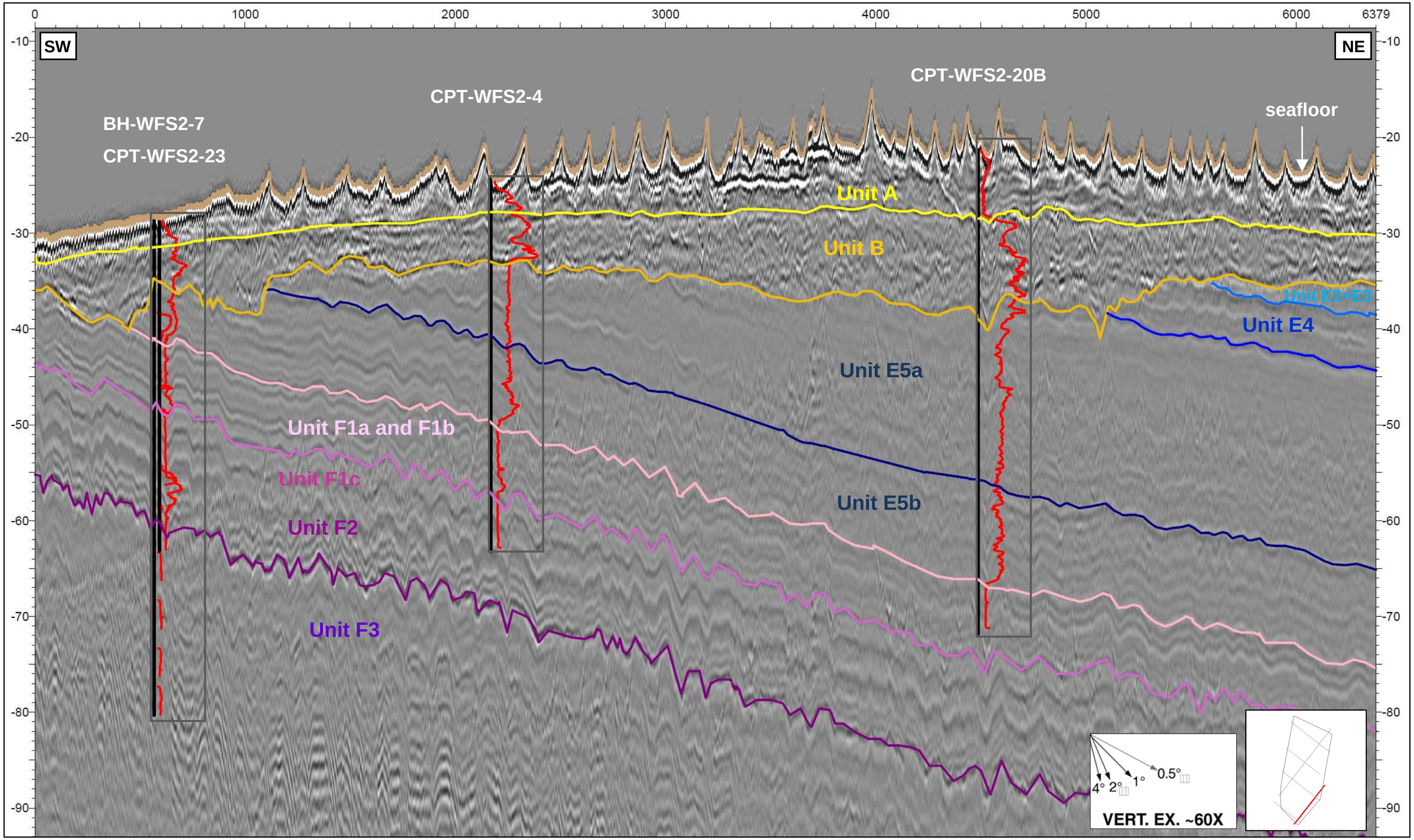


NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE 124-12400

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

ISSUE 01

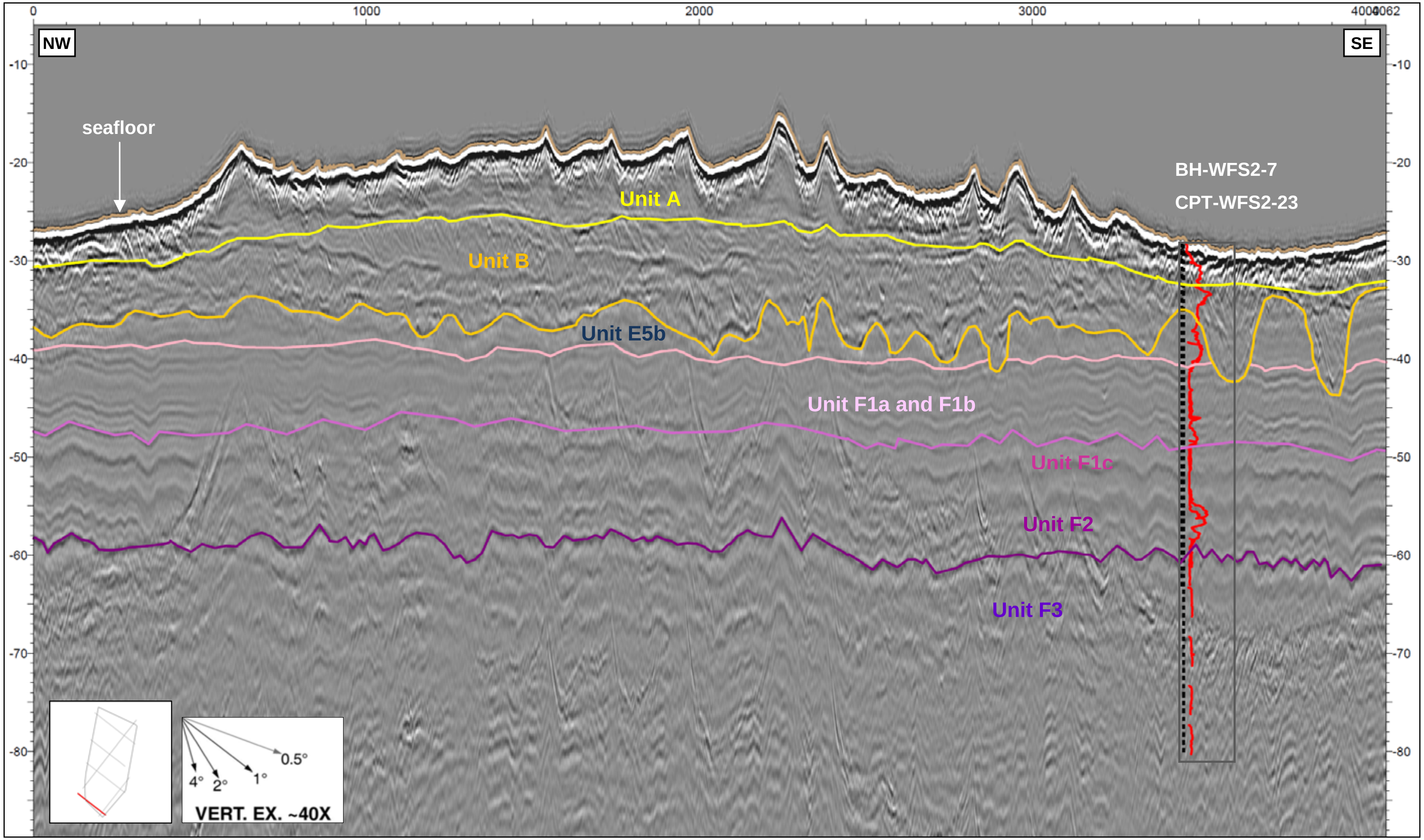


NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE 164-16400

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

ISSUE 01

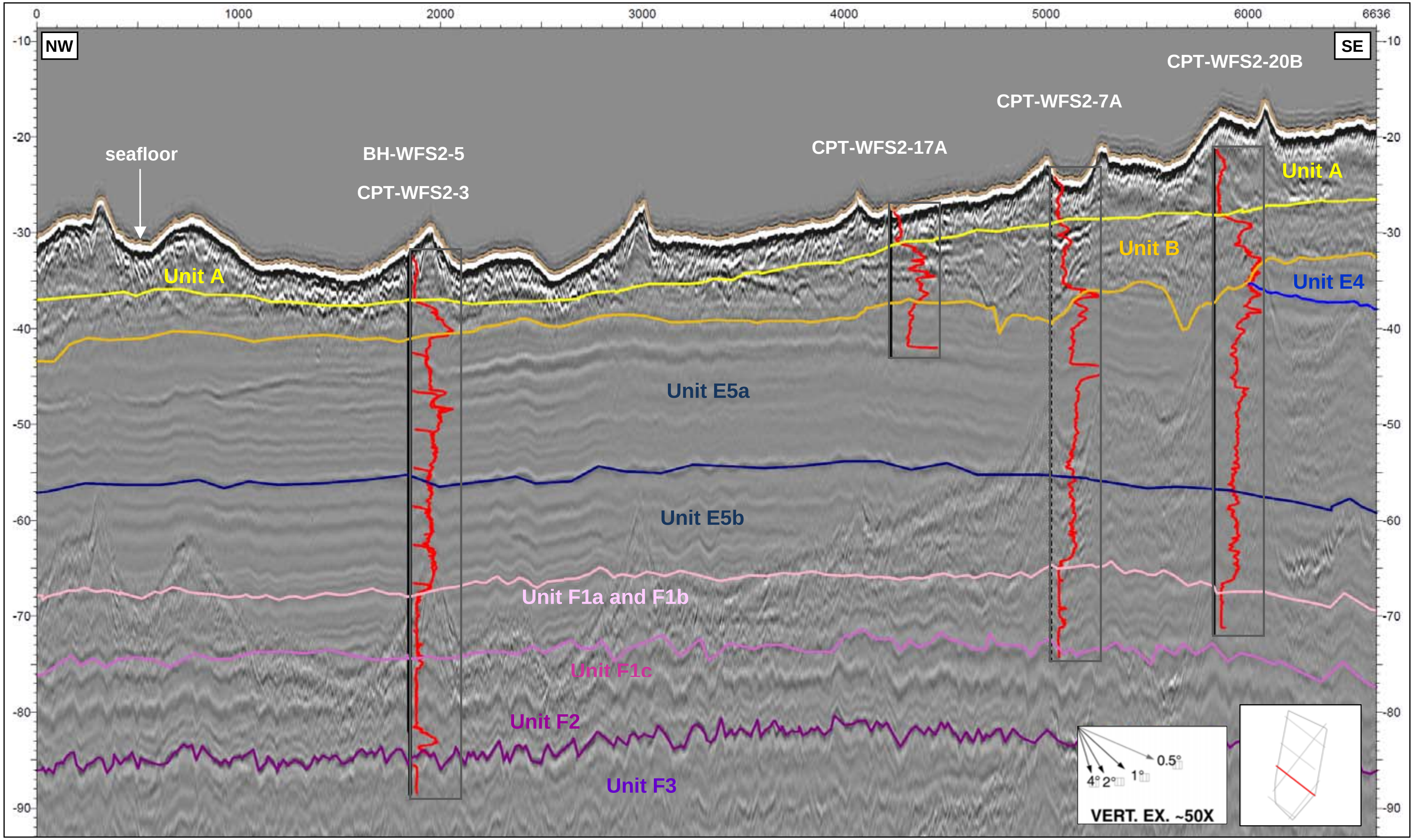


NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE 172-x-0

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

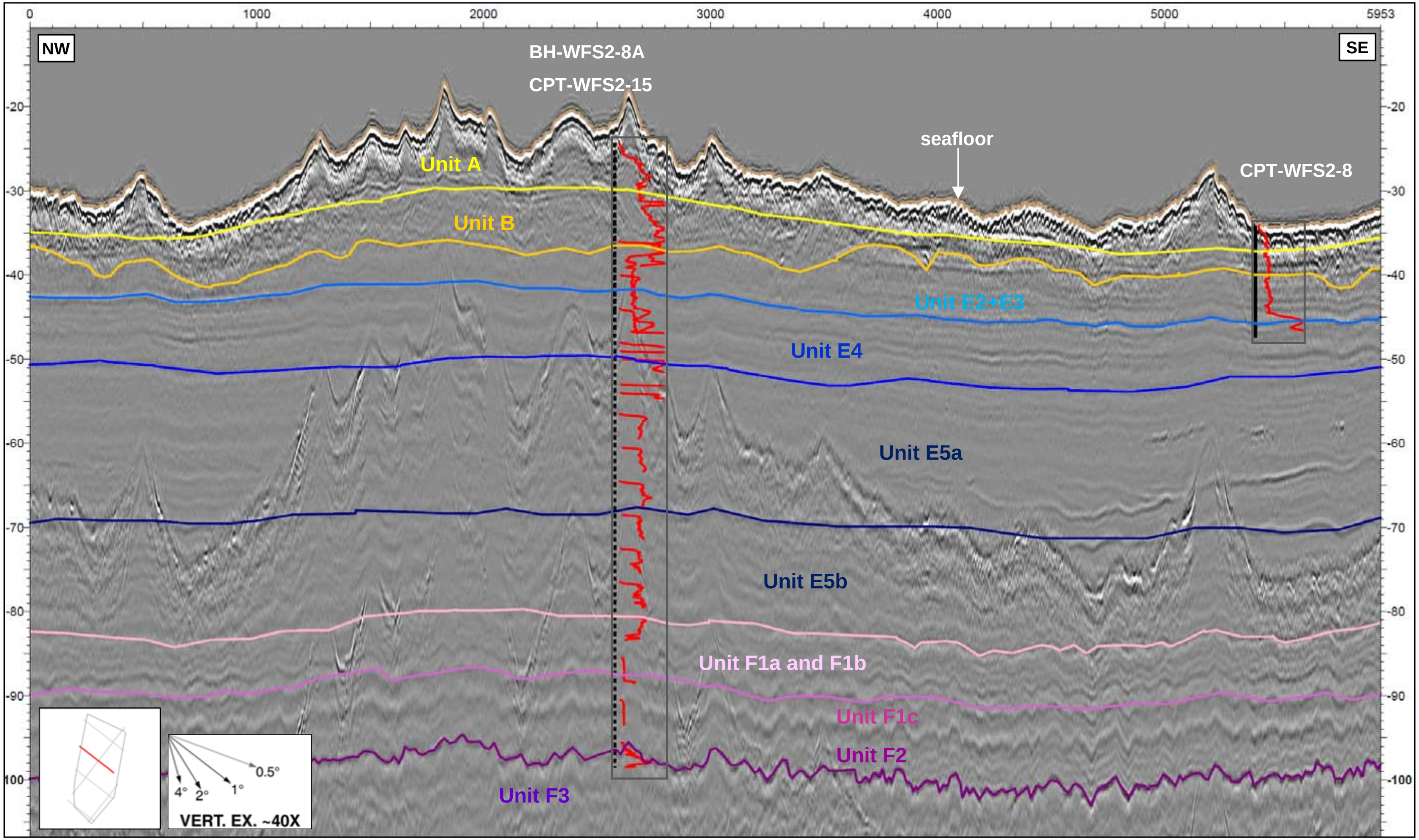
ISSUE 01



NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE 174 x-4000

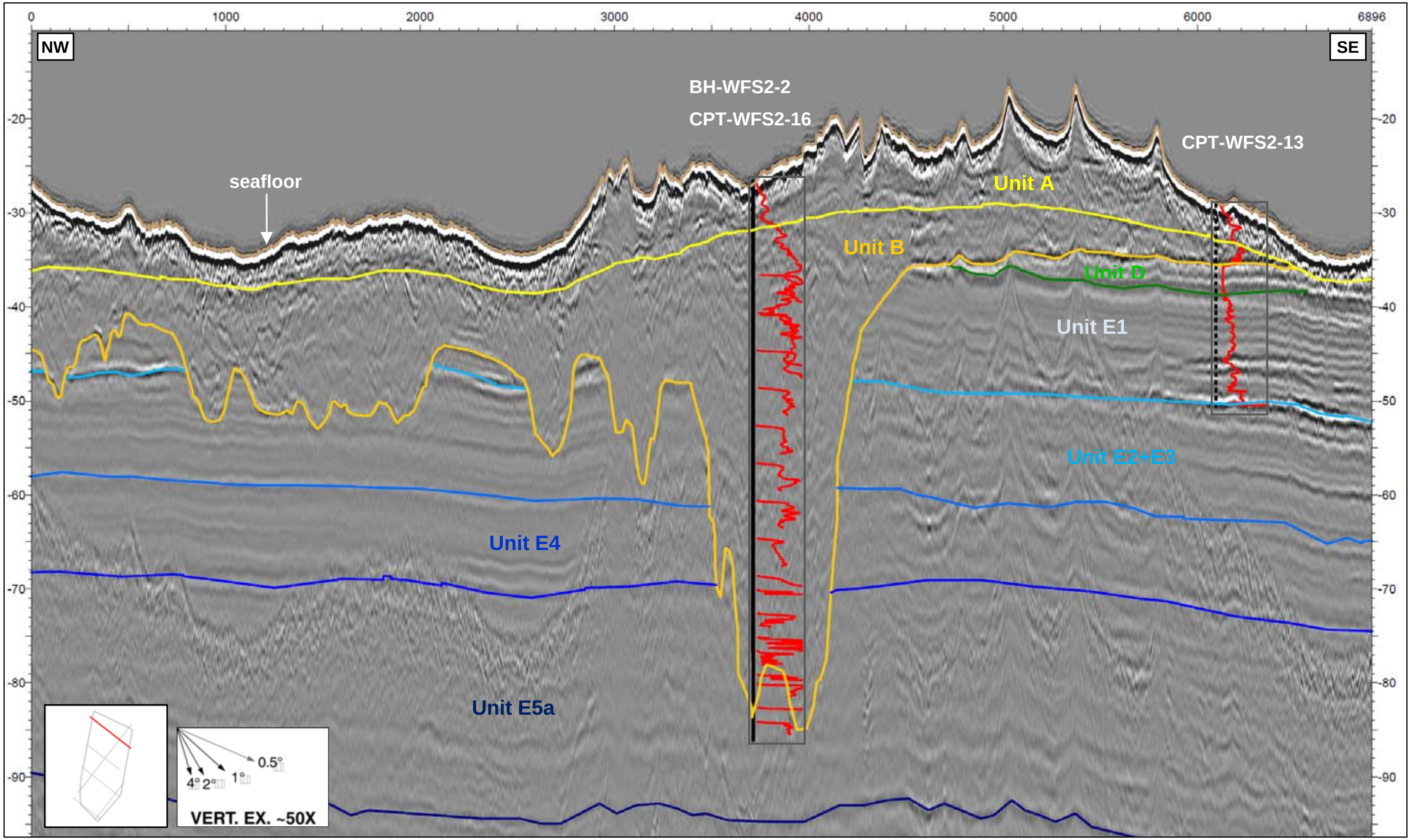
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres). CPT cone resistance data for the geotechnical locations are projected on the seismic profile (CPT-WFS2-15 is located 300 m and CPT-WFS2-8 is located 225 m from the section line; box marks maximum values of 50 MPa). Location of the cross section is shown on Plate 3-6.

CROSS SECTION – SECTION LINE x-in3200

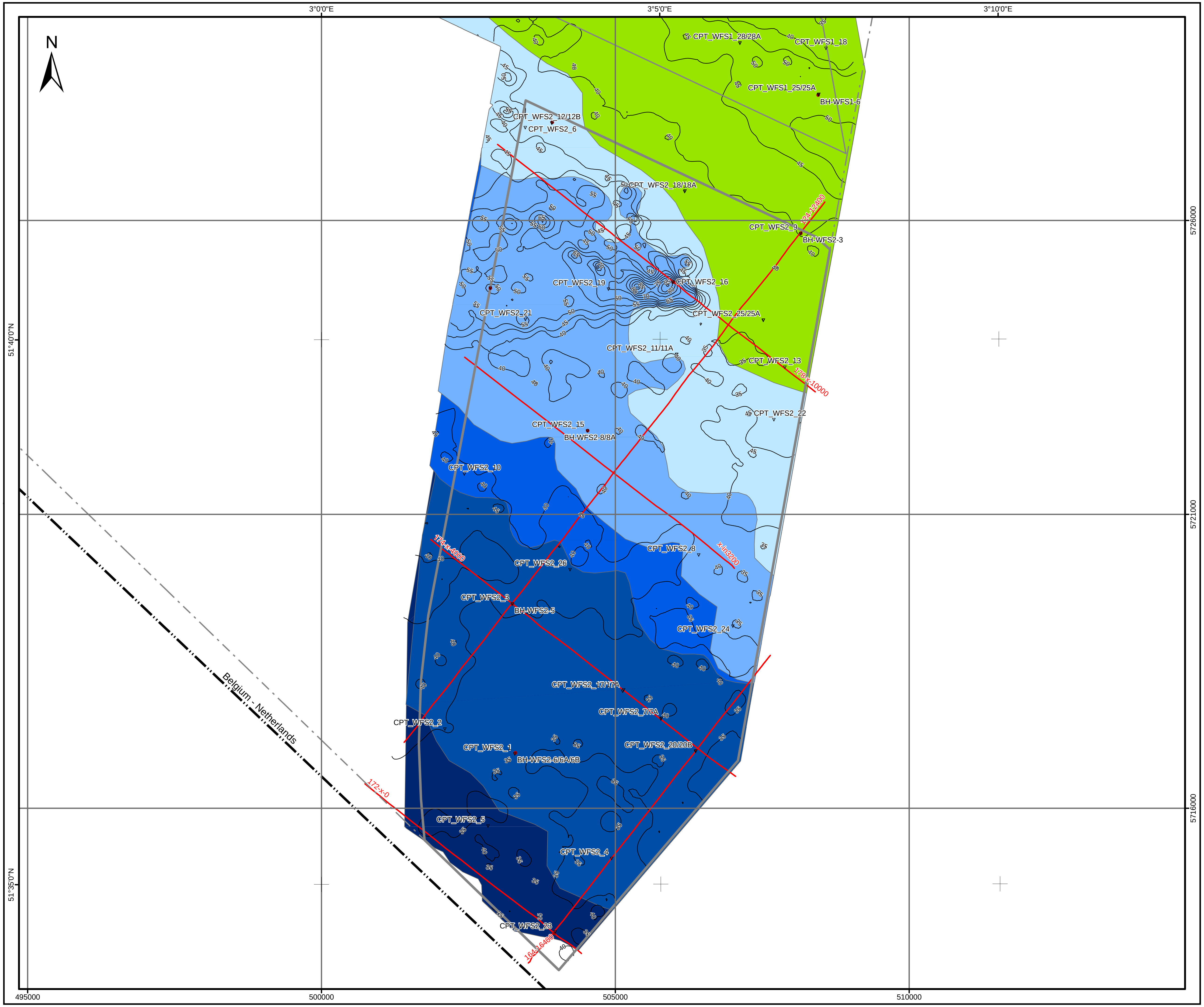
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



NOTE: Example of MCS seismic line (vertical and horizontal scales are in metres).
CPT cone resistance data for the geotechnical locations are projected on the seismic profile (box marks maximum values of 50 MPa).
Location of the cross section is shown on Plate 3-6.

CROSS SECTION - SECTION LINE 178-x-10000

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of depth to base of Unit B [m below LAT]

Subcrop of Tertiary Units

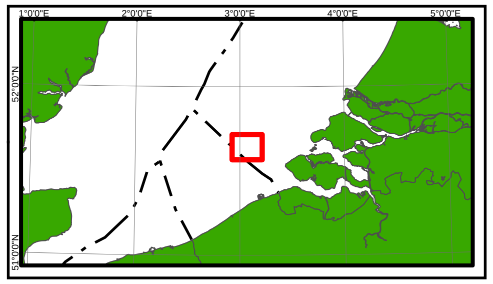
- Unit D (Rupel Clay Mb.)
- Unit E1 (Ruisbroek Sand Mb.)
- Unit E3 (Bassevelde 3 Sand Mb.)
- Unit E4 (Bassevelde 2 Sand Mb.)
- Unit E5a (Bassevelde 1 Sand Mb.)
- Unit E5b (Bassevelde 1 Sand Mb.)

NOTES:

- Base of Unit B (Pleistocene) represents an erosional surface truncating underlying dipping Tertiary strata
- Tertiary units subcropping at base of Unit B are represented, i.e. intersection of unit boundaries with base of Unit B
- Outline of units based on interpretation from Multi-Channel Seismic data

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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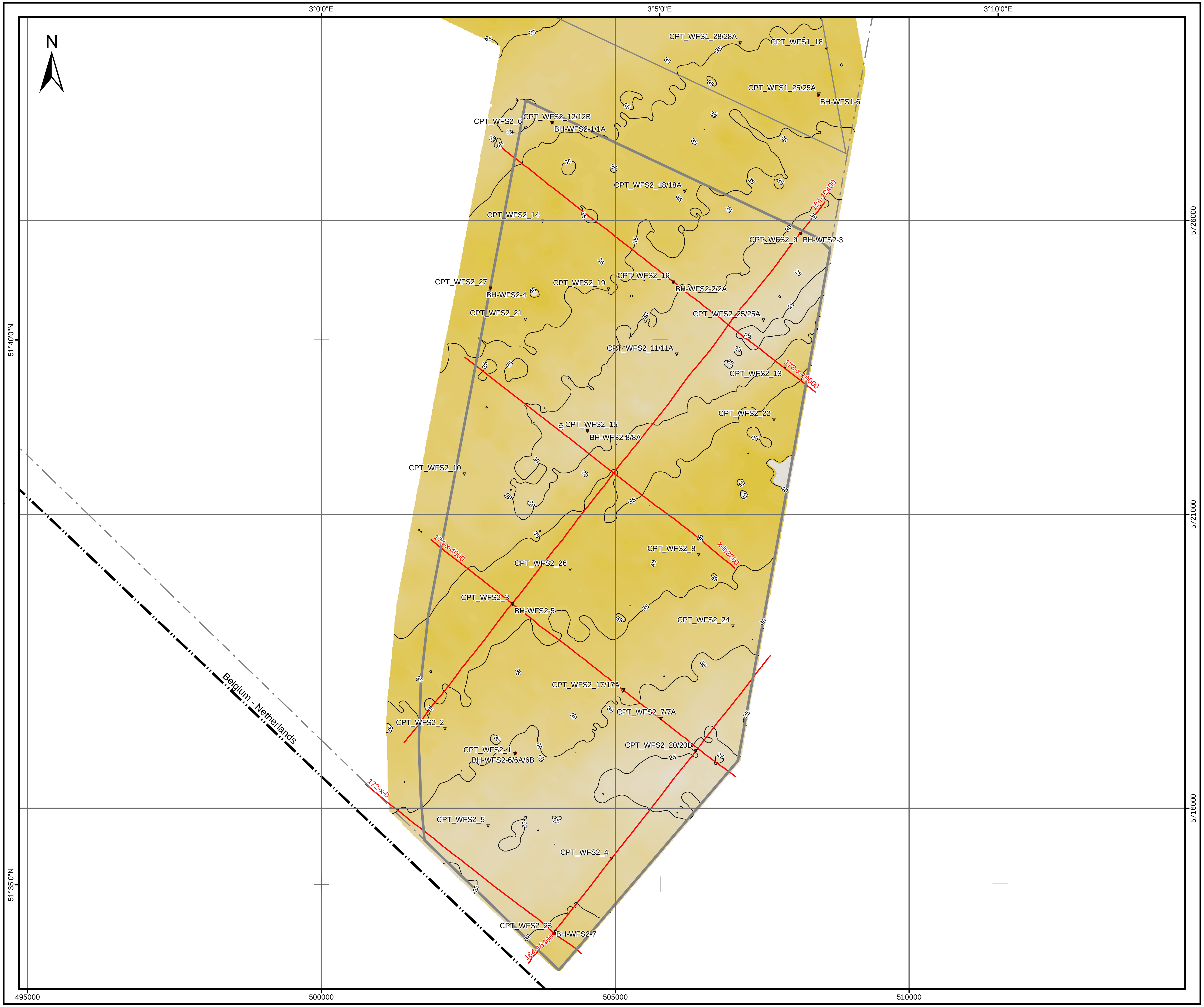
TERTIARY UNITS BELOW UNIT B (KREFTENHEYE FM. / EEM FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-13
Printed: 02/07/2015 22:23:30		Author: BLM



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of depth to base (m below LAT)

Depth to base [m below LAT]

20

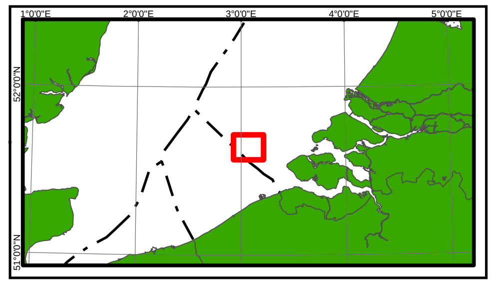
80

140

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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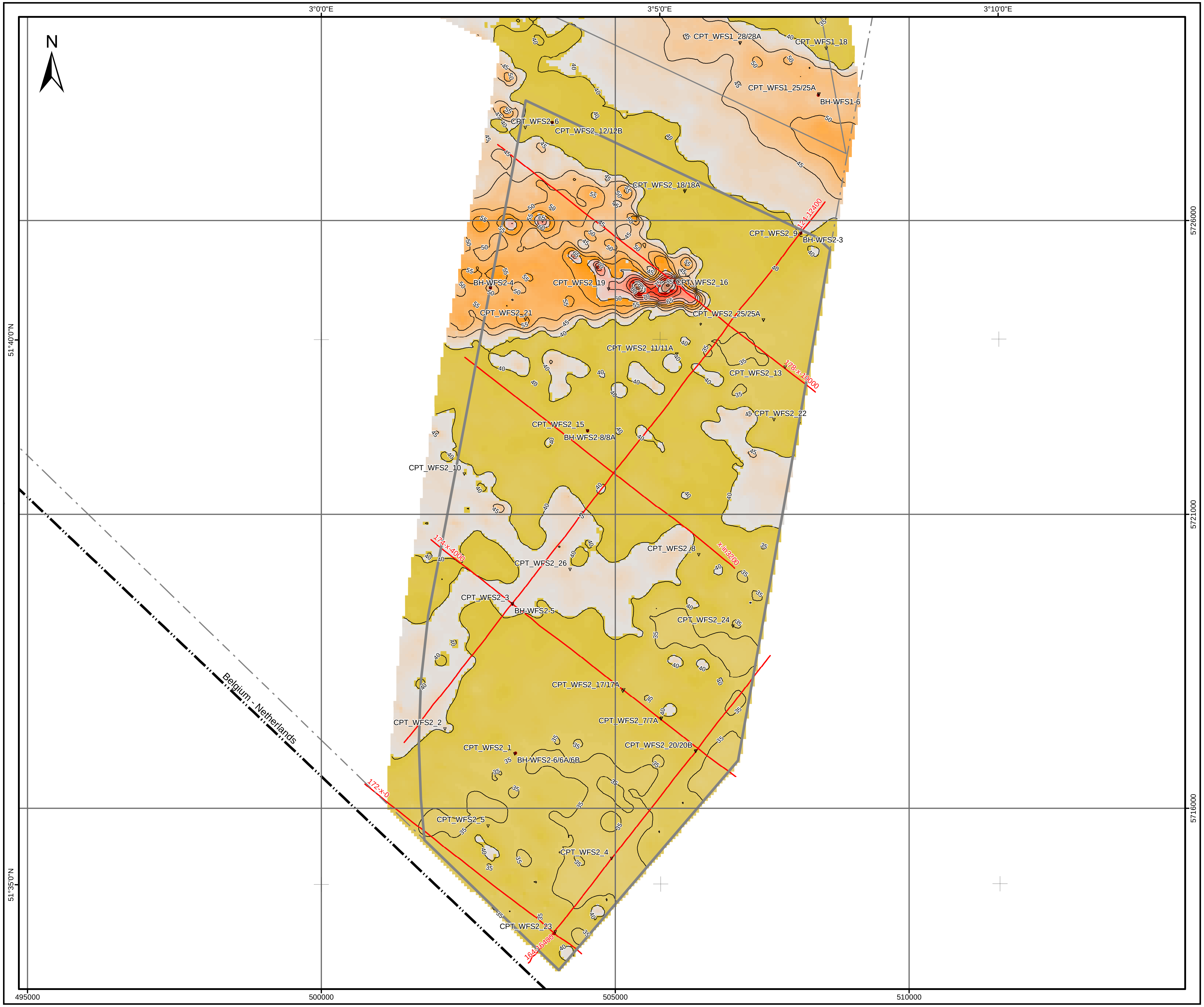
DEPTH TO BASE OF UNIT A (SOUTHERN BIGHT FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-14
Printed: 07/02/15 4:20:40 PM		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20

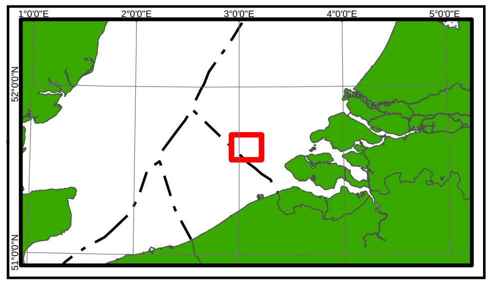
80

140

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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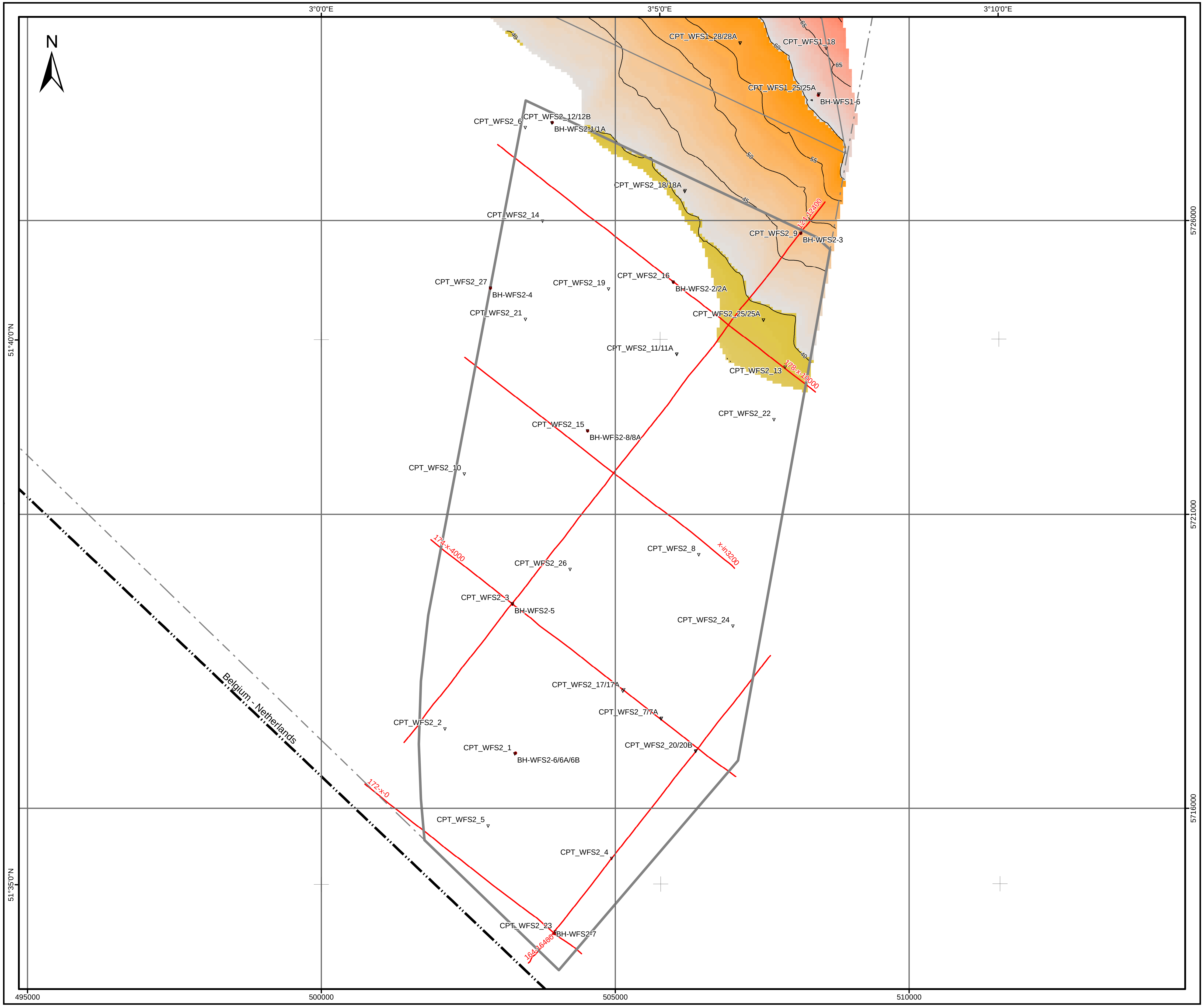
DEPTH TO BASE OF UNIT B (KREFTENHEYE FM./EEM FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 2	Plate 3-15
Printed: 02/07/2015 18:38:23		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line presented in the report
- Contour line of base of Unit D (depth relative to LAT)

Depth to base [m below LAT]

20

80

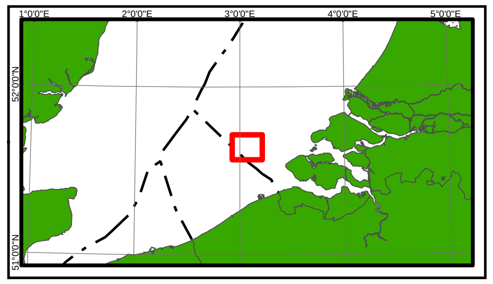
140

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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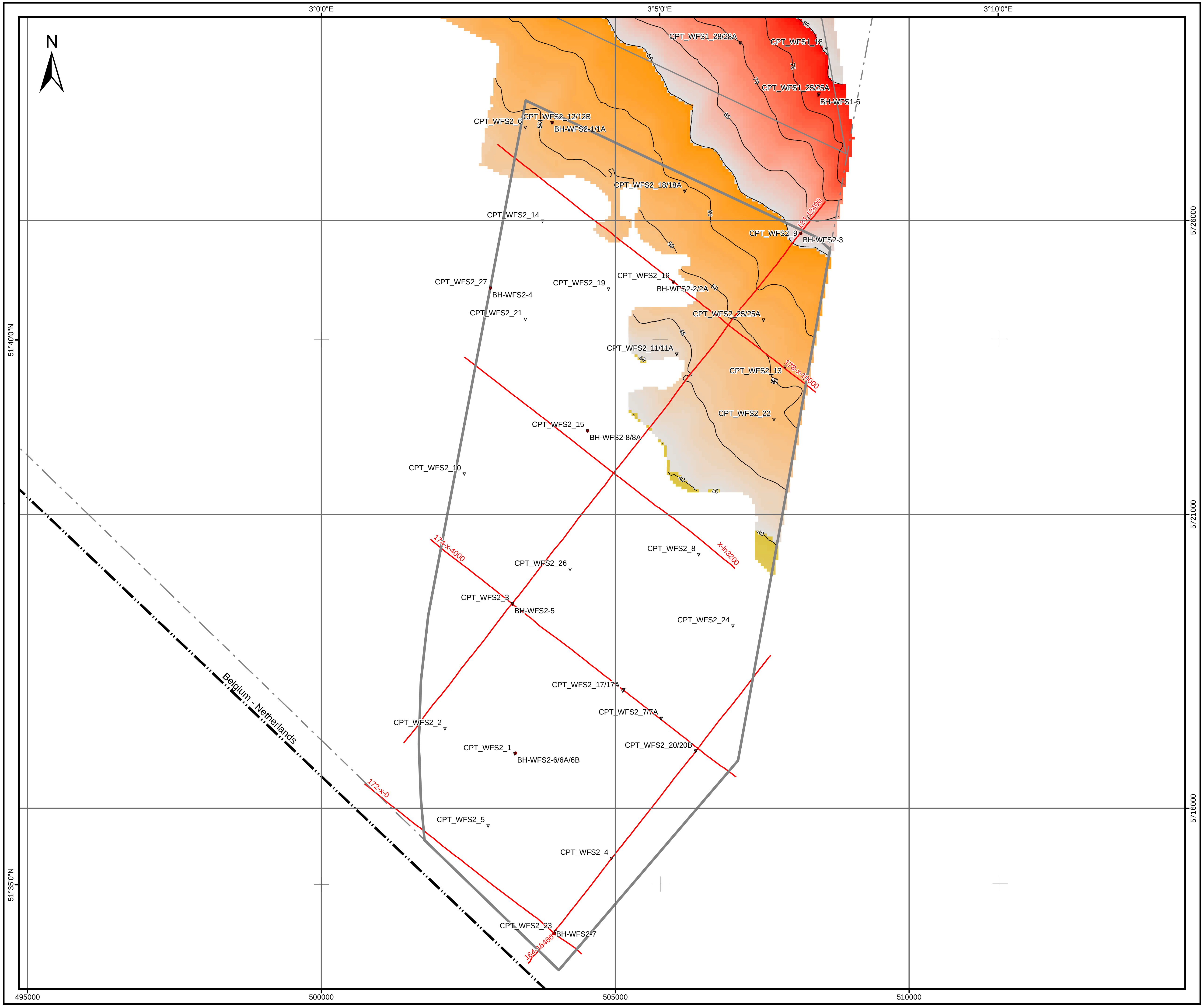
DEPTH TO BASE OF UNIT D (RUPEL CLAY MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-16
Printed: 02/07/2015 18:56:03		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

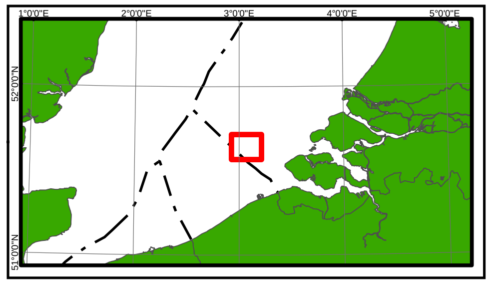
Depth to base [m below LAT]

20
80
140

NOTES:
- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



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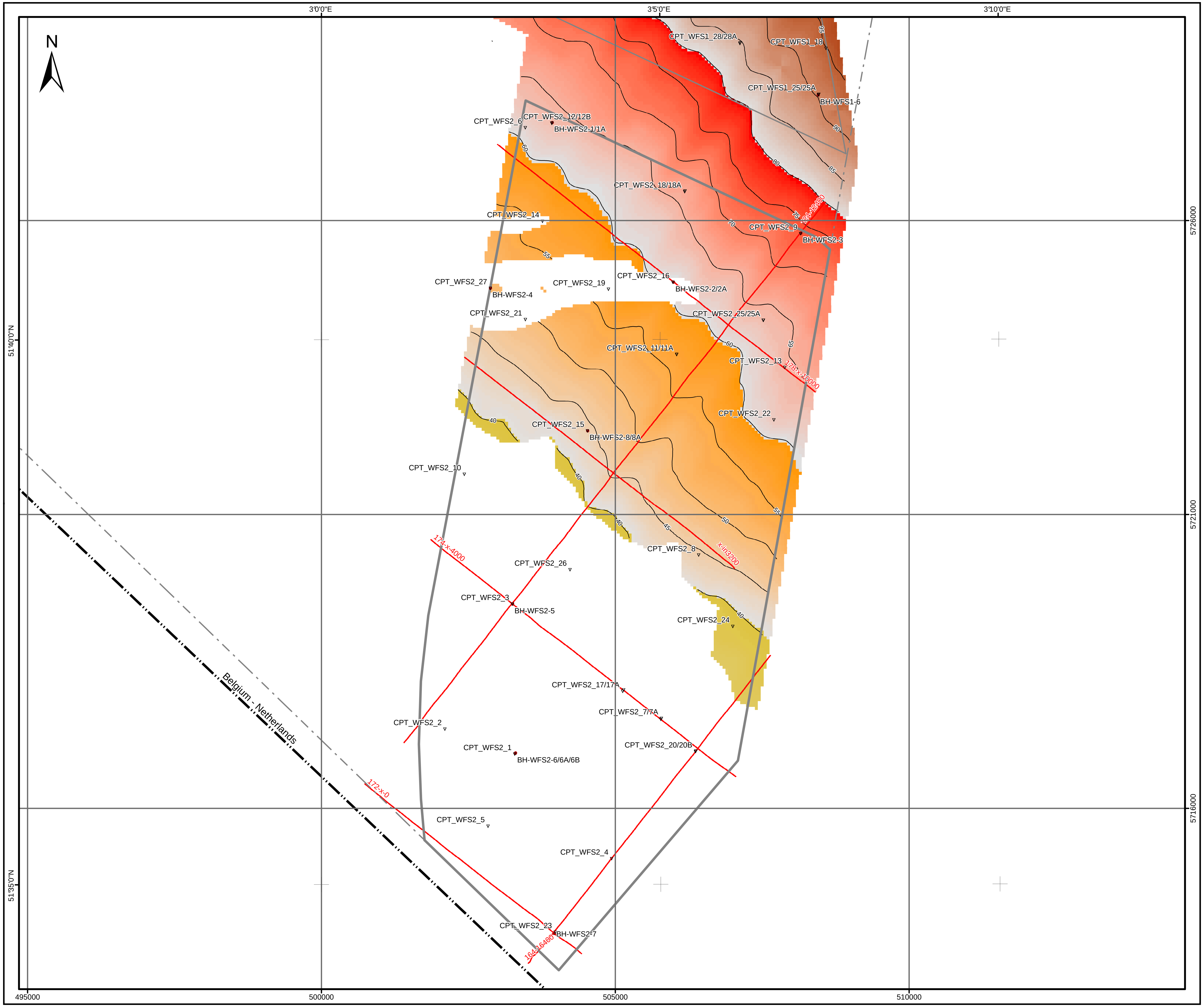
Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

DEPTH TO BASE OF UNIT E1
(RUISBROEK SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-17
Printed: 02/07/2015 17:29:38		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

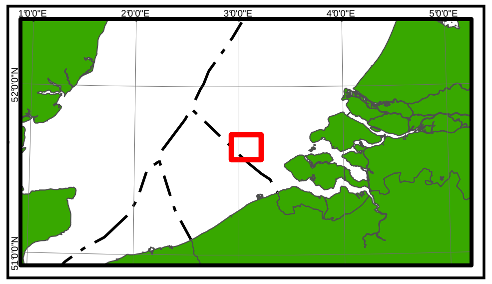
Depth to base [m below LAT]

20
80
140

NOTES:
- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3°00' 00" E
Latitude of Origin	0°00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

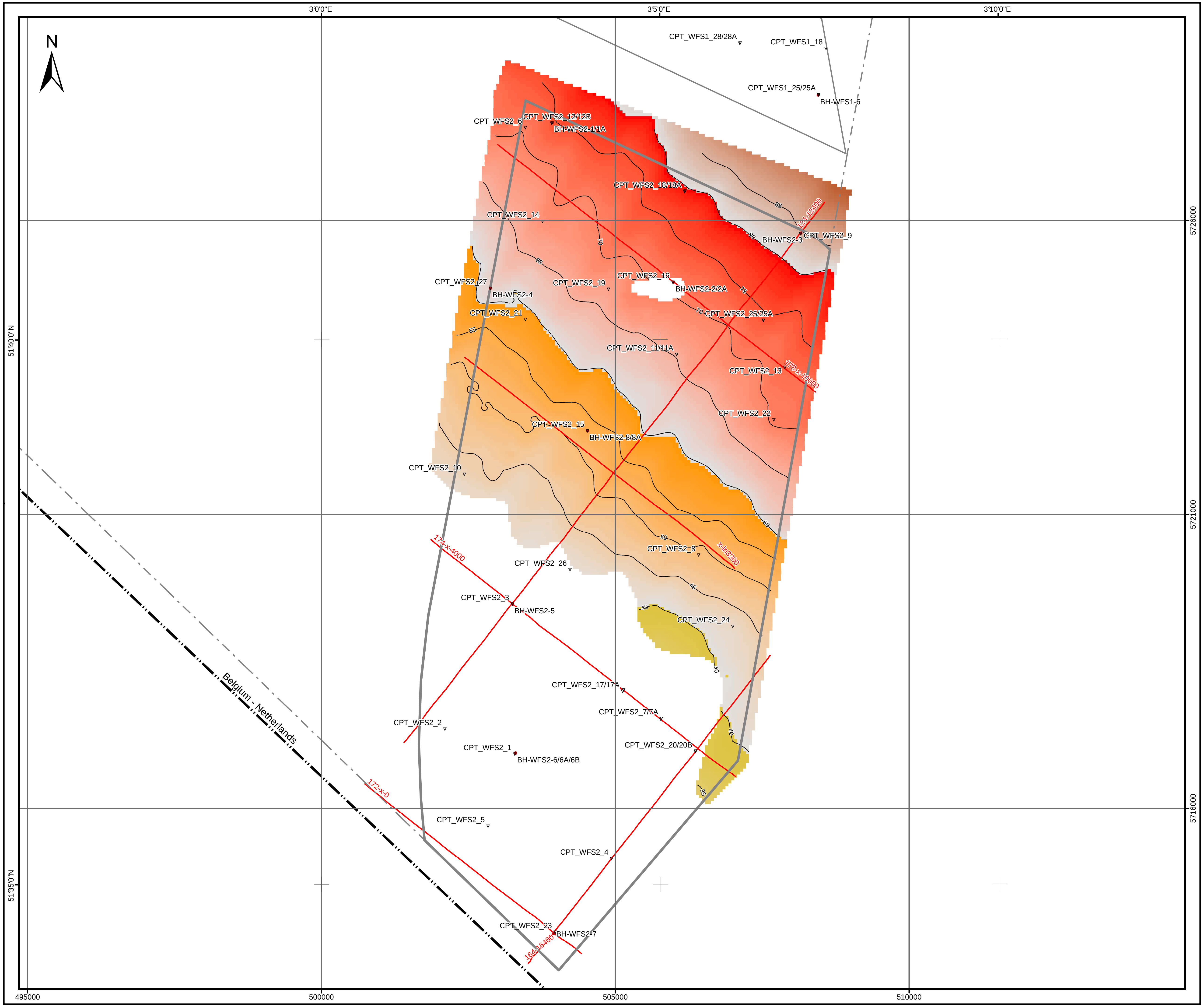
DEPTH TO BASE OF UNIT E3
(BASSEVELDE 3 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 4	Plate 3-18
Printed: 8/3/2015 1:11:42 PM		Author: WVK



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20

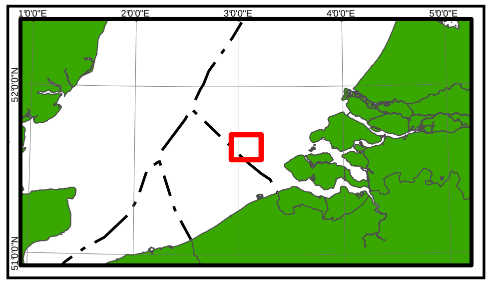
80

140

NOTES:
- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3°00' 00" E
Latitude of Origin	0°00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

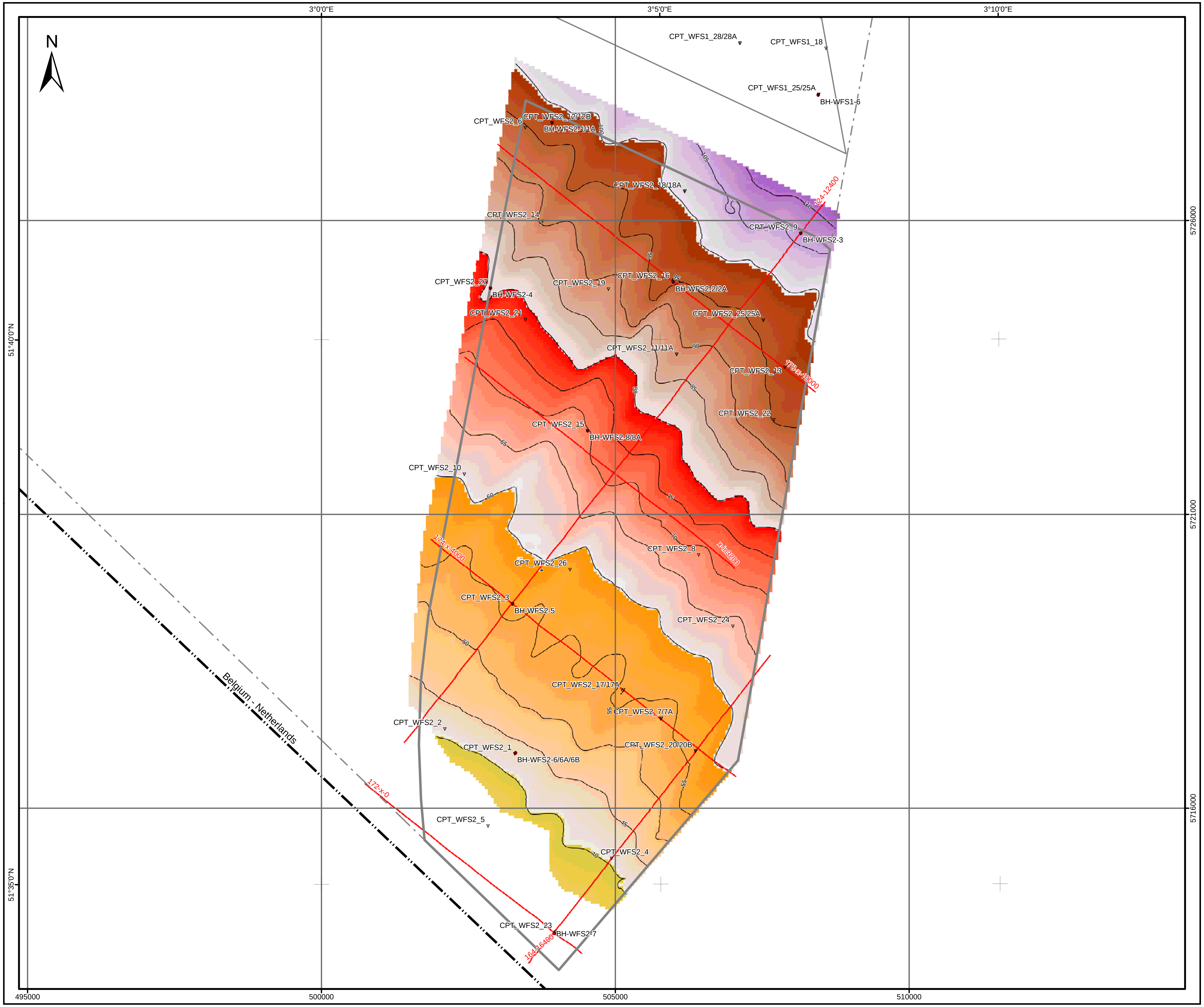
DEPTH TO BASE OF UNIT E4 (BASSEVELDE 2 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 4	Plate 3-19
Printed: 8/3/2015 11:13:14 AM		Author: WVK



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20

80

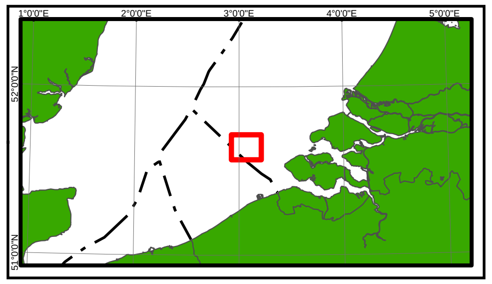
140

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

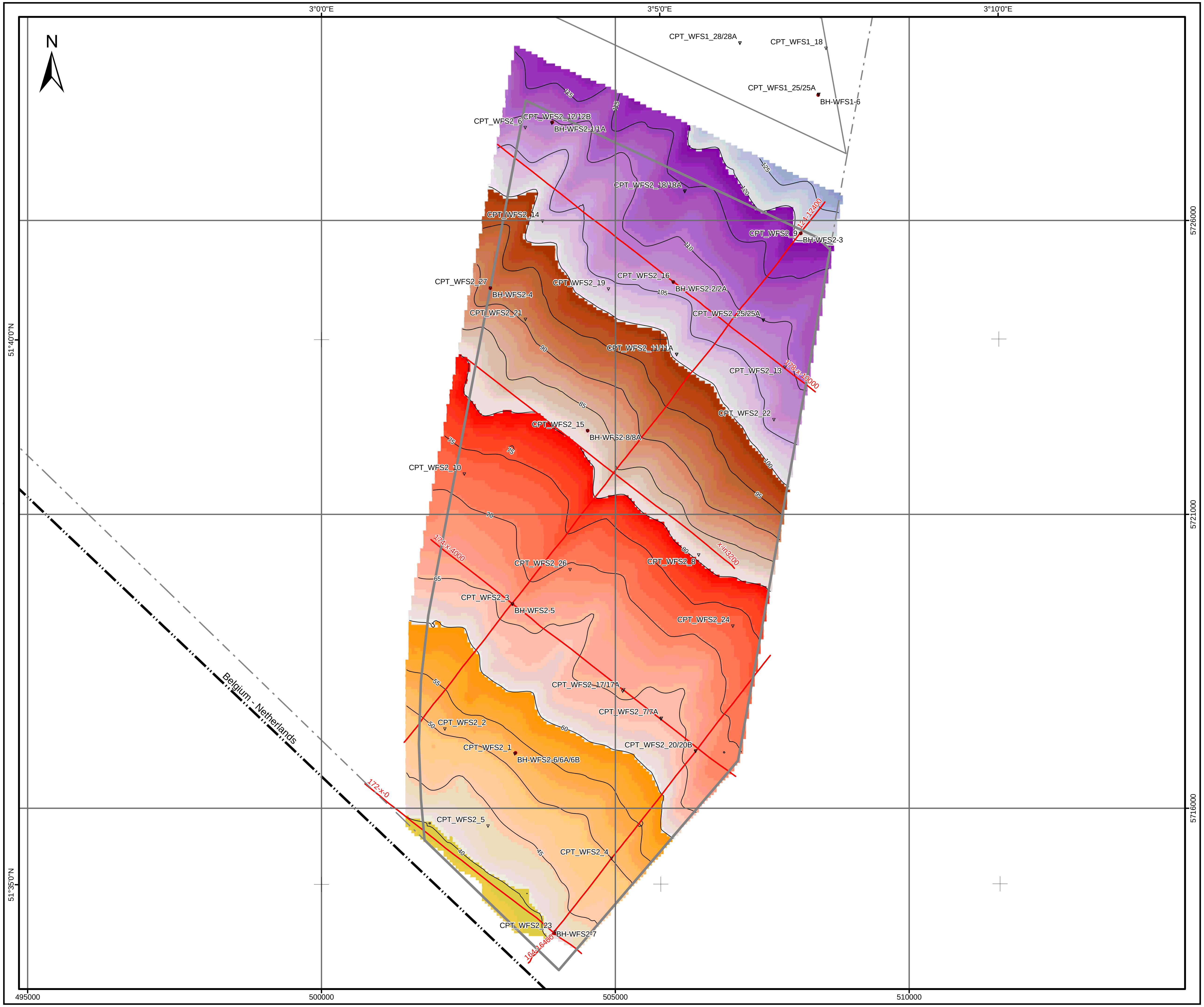
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

DEPTH TO BASE OF UNIT E5A (BASSEVELDE 1 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-20
Printed: 03/07/2015 00:08:42		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20

80

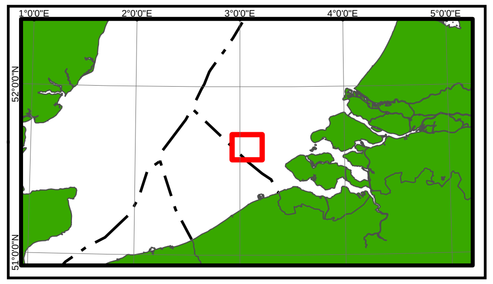
140

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

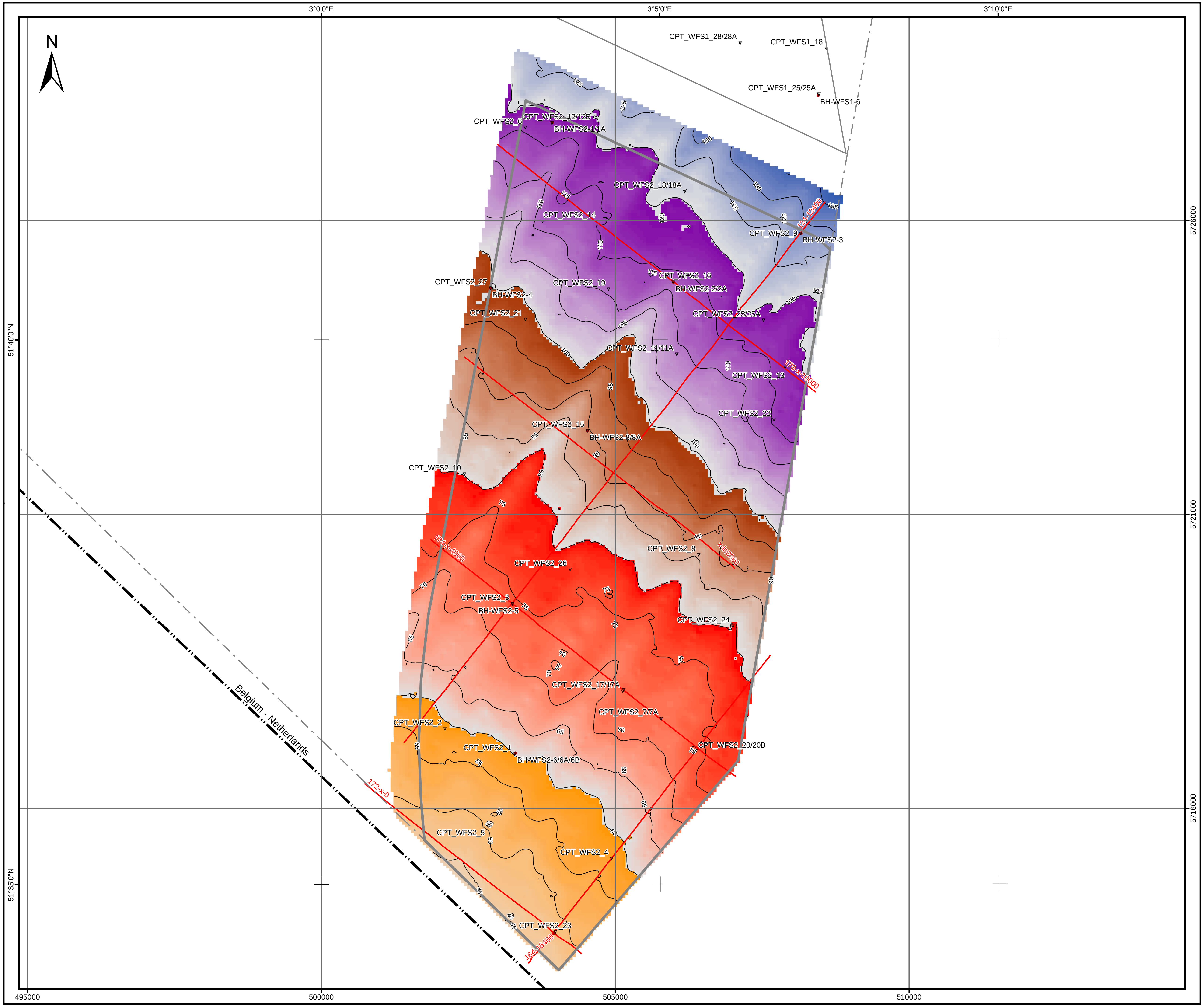
DEPTH TO BASE OF UNIT E5B (BASSEVELDE 1 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 2	Plate 3-21
Printed: 03/07/2015 00:07:49		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20

80

140

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees

Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

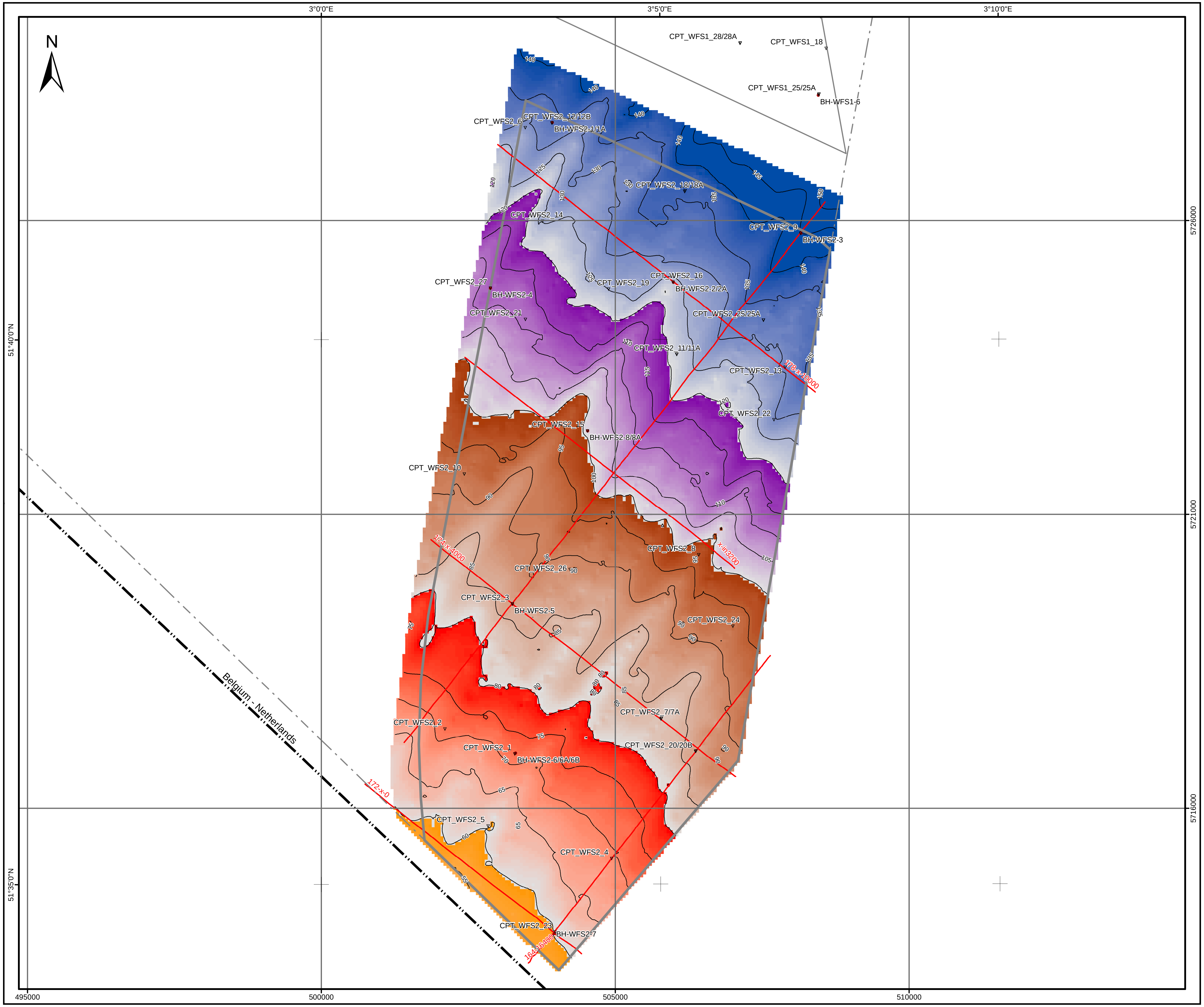
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

DEPTH TO BASE OF UNIT F1B (ONDERDIJKE MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-22
Printed: 02/07/2015 16:26:41		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of depth to base [m below LAT]

Depth to base [m below LAT]

20
80
140

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
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False Northing	000 000 m
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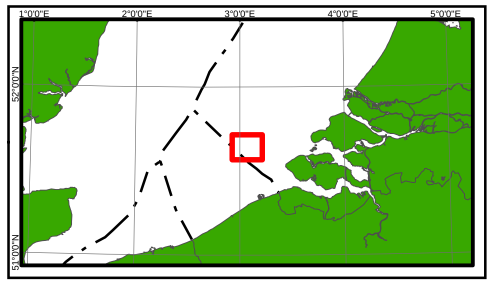
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

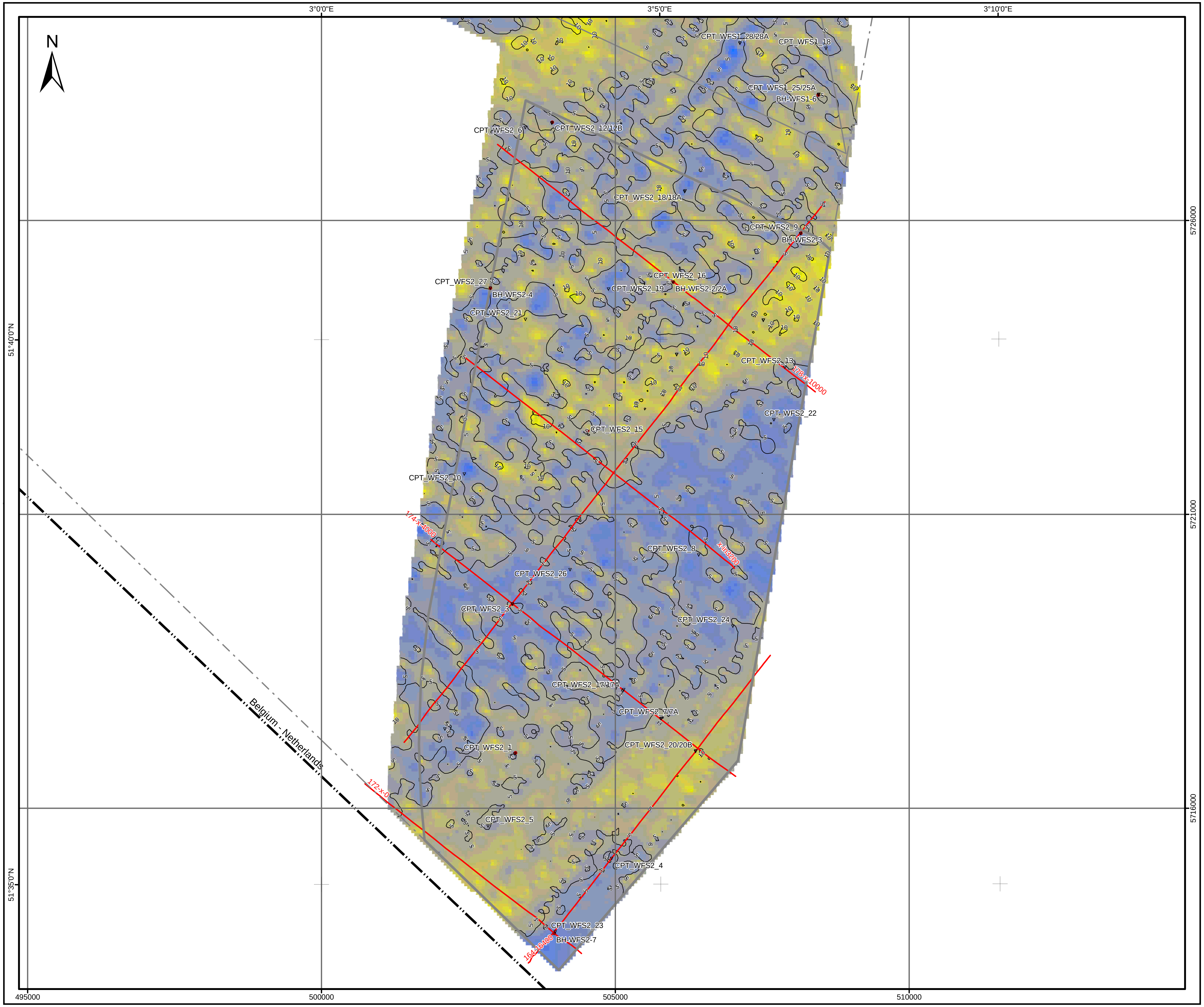
Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

DEPTH TO BASE OF UNIT F2 (BUISPUTTEN MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-23
Printed: 02/07/2015 16:19:24		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

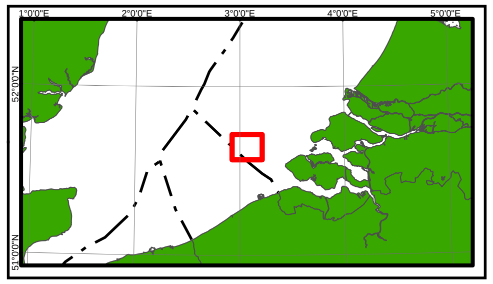
32

0

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

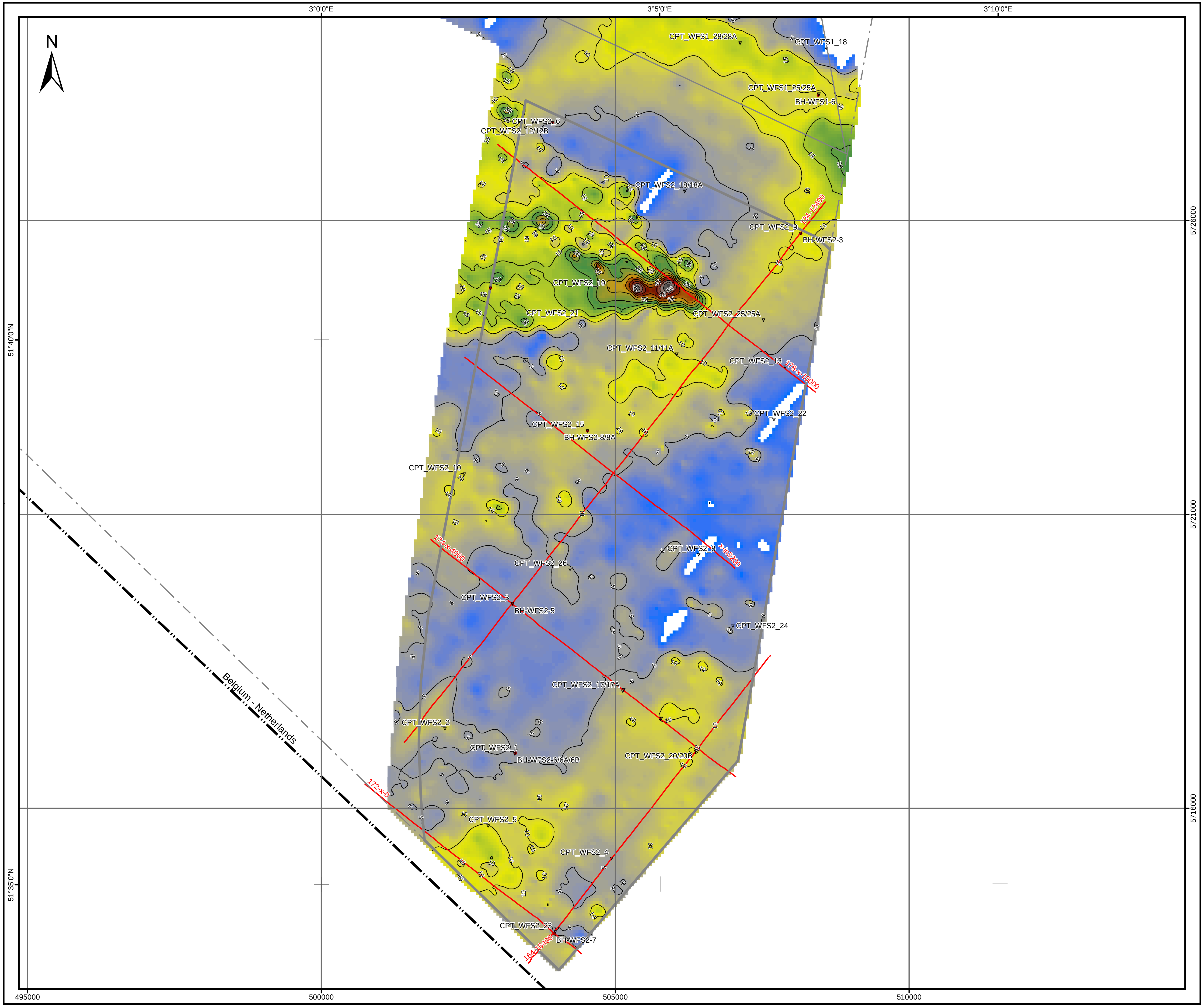
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT A (SOUTHERN BIGHT FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-24
Printed: 02/07/2015 15:24:24		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

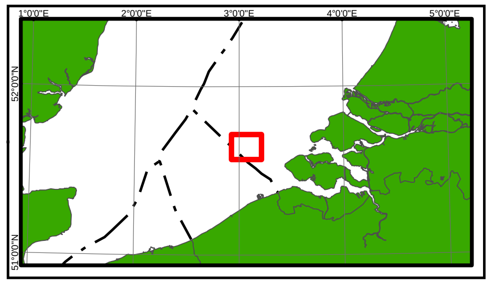
32

0

NOTES:
- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

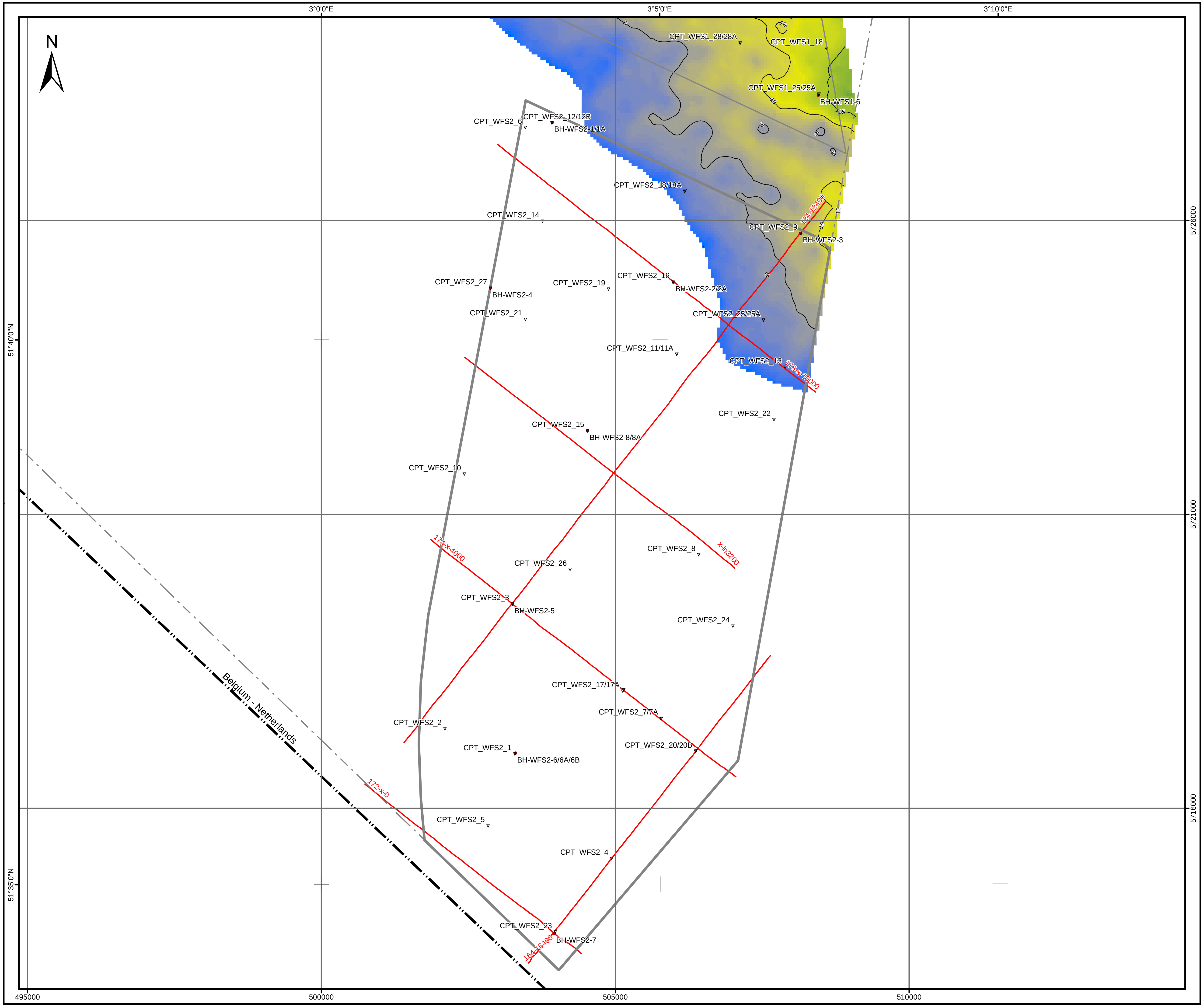
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT B (KREFTENHEYE FM./EEM FM.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-25
Printed: 02/07/2015 18:35:59		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

32

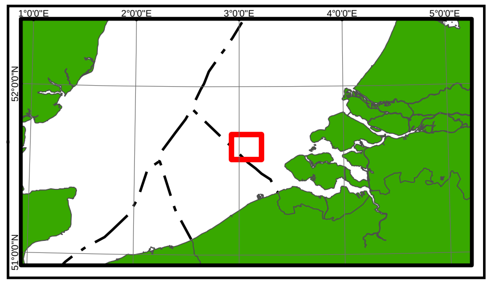
0

NOTES:

- Unit is absent at blank area within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

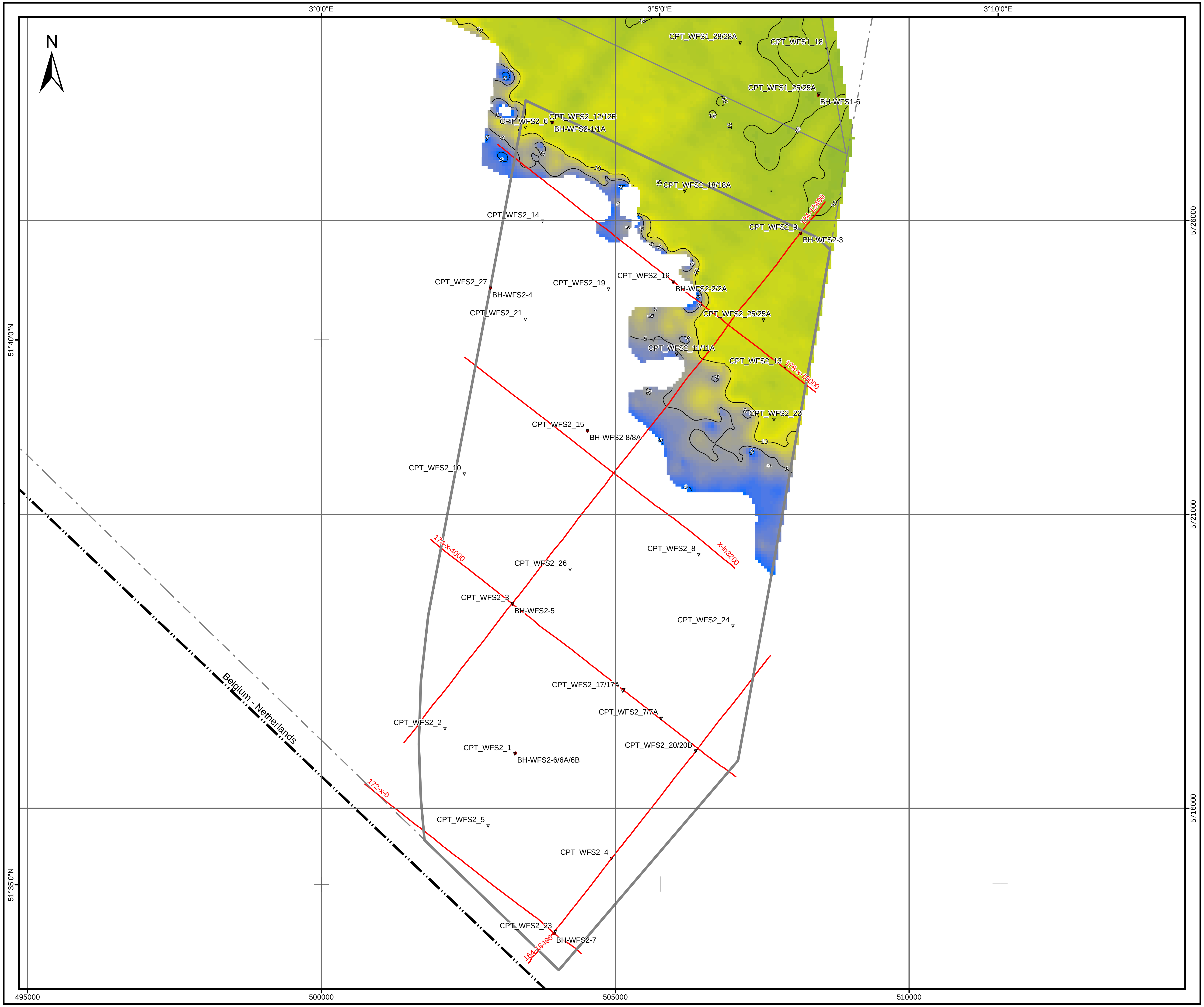
THICKNESS OF UNIT D (RUPEL CLAY MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 2	Plate 3-26
Printed: 07/02/15 1:15:41 PM		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

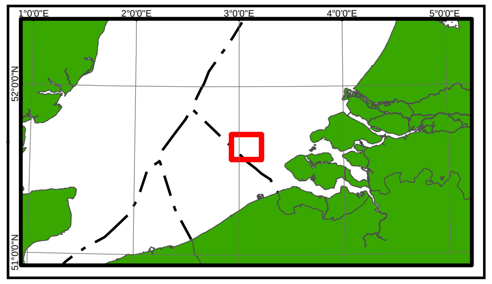
32

0

NOTES:
- Unit is absent at blank area within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

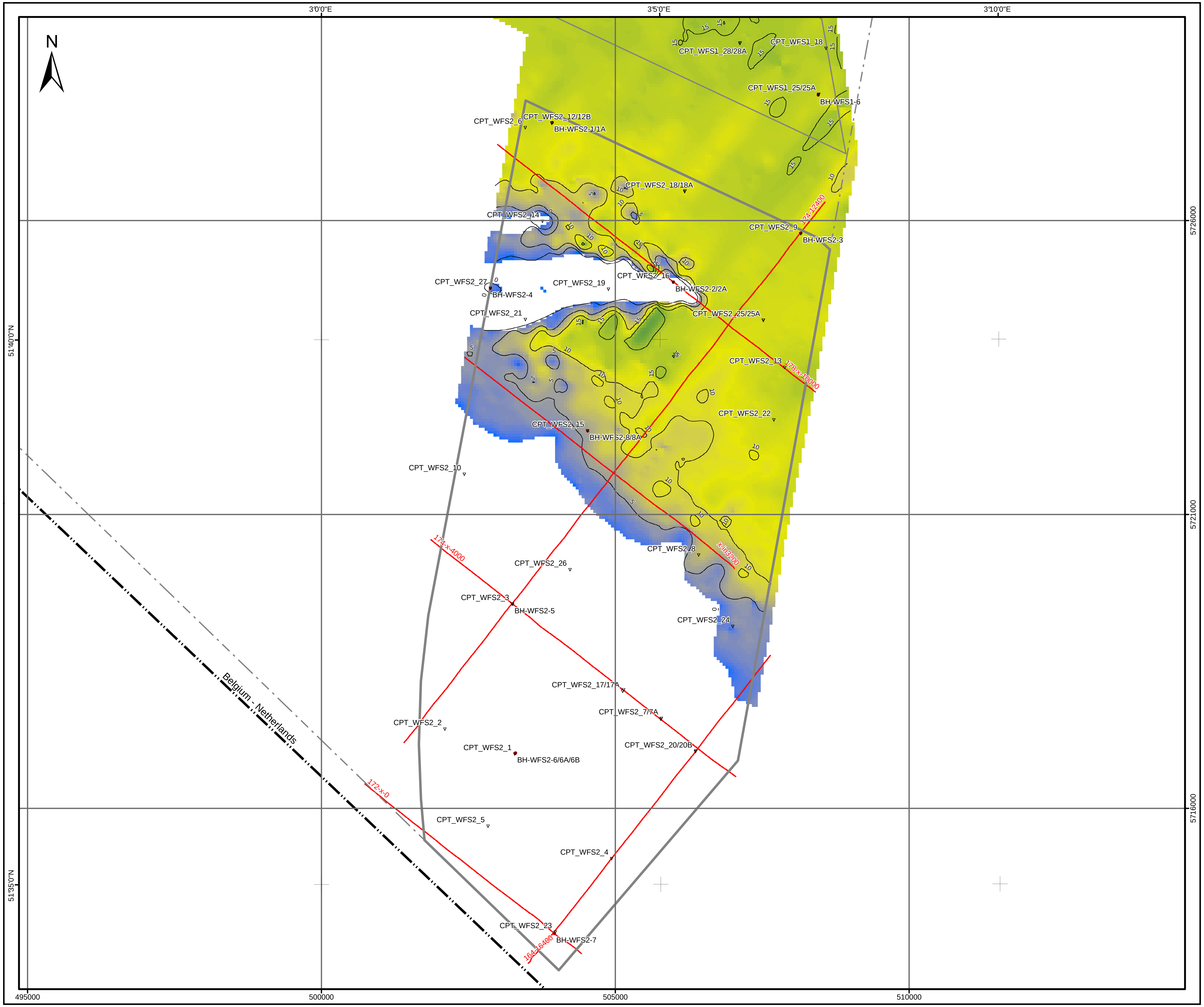
Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT E1 (RUISBROEK SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-27
Printed: 07/01/15 4:46:47 PM		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

32

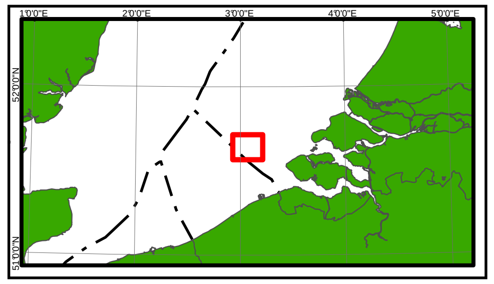
0

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3°00' 00" E
Latitude of Origin	0°00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

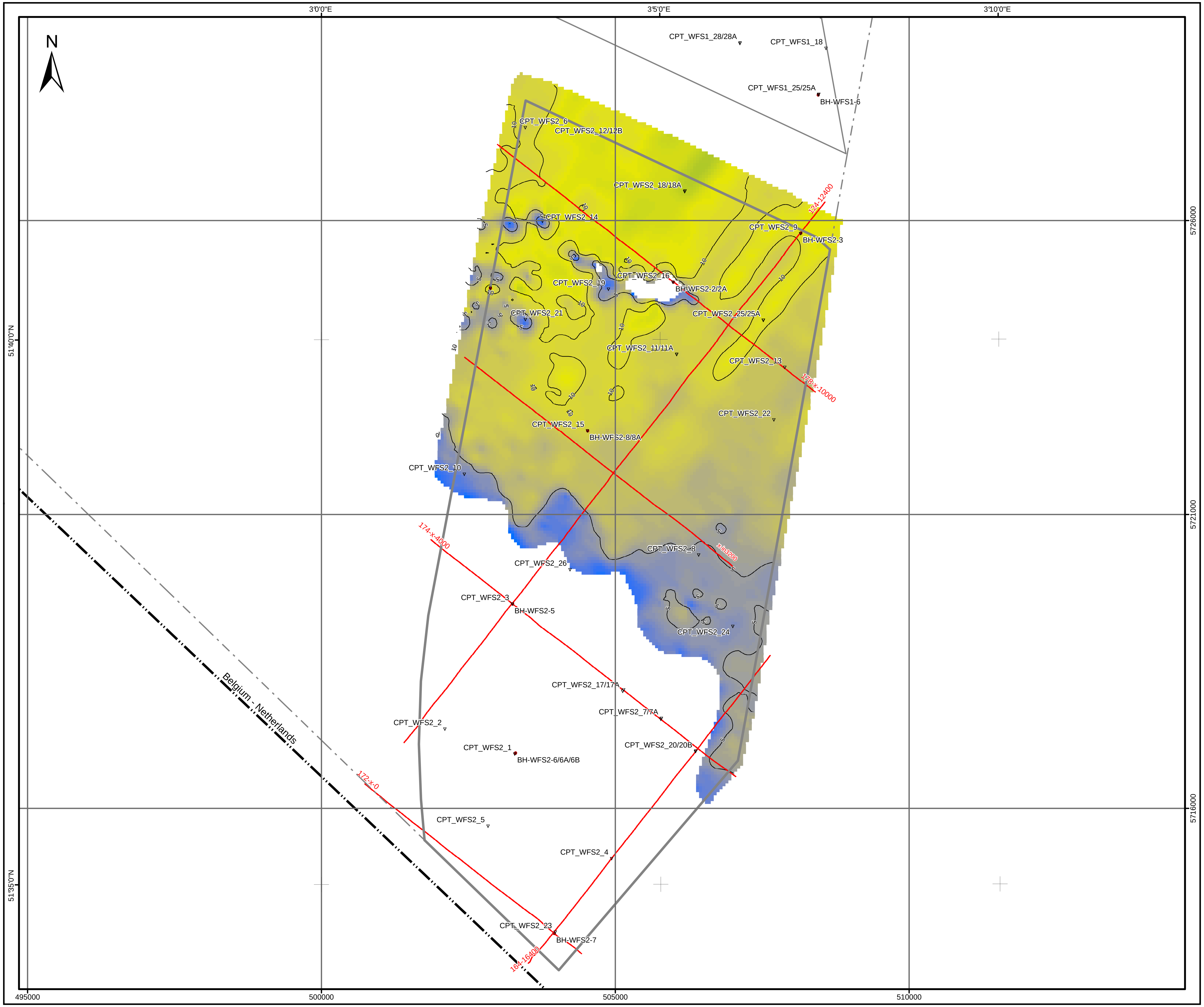
THICKNESS OF UNIT E2+E3
(WATERVLIET CLAY MB. + BASSEVELDE 3 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 4	Plate 3-28
Printed: 8/3/2015 3:38:33 PM		Author: WVK



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

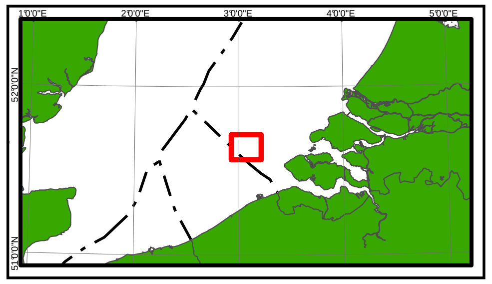
32

0

NOTES:
- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3°00' 00" E
Latitude of Origin	0°00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

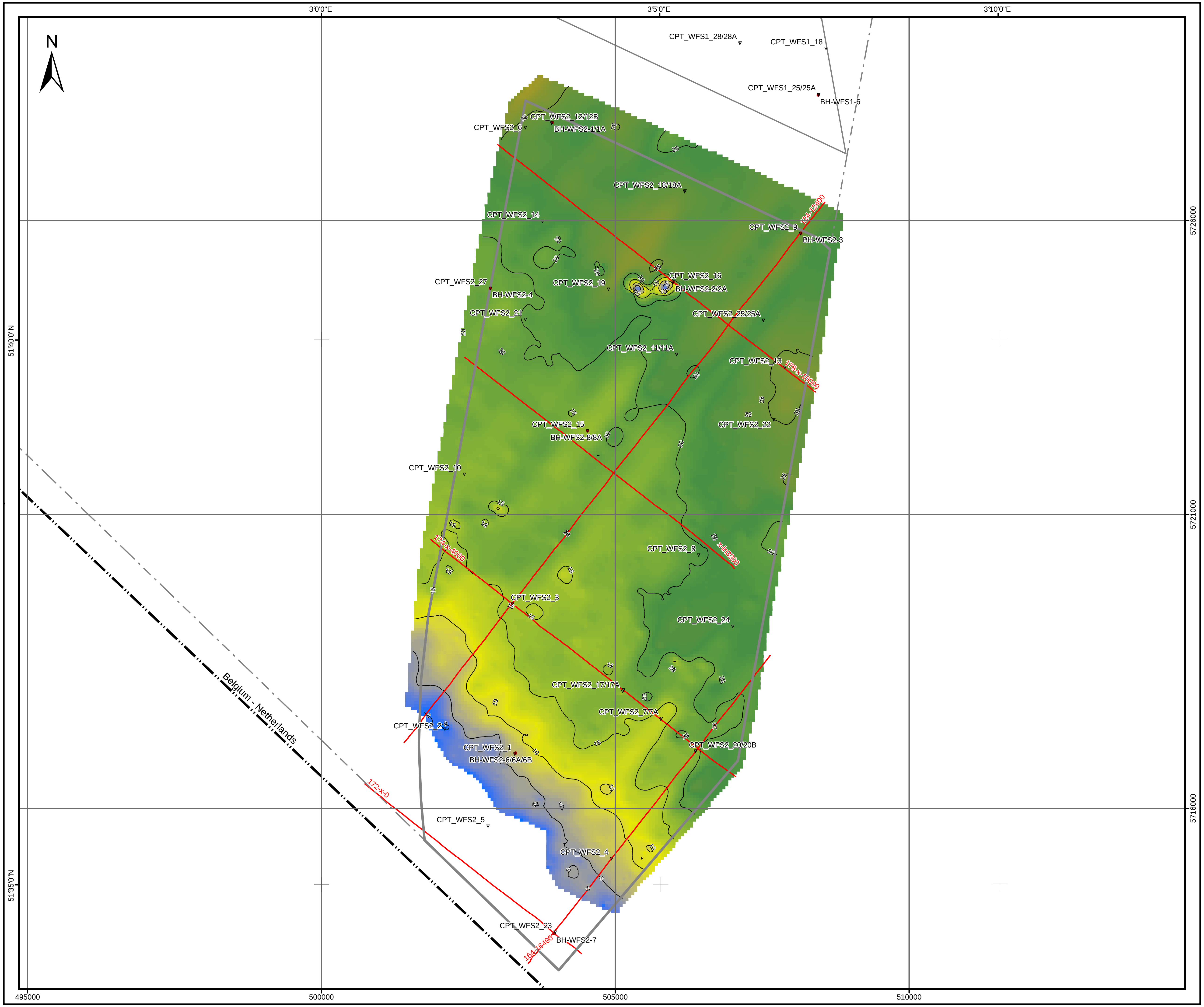
Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT E4 (BASSEVELDE 2 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 4	Plate 3-29
Printed: 8/3/2015 3:00:08 PM		Author: WVK



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

32

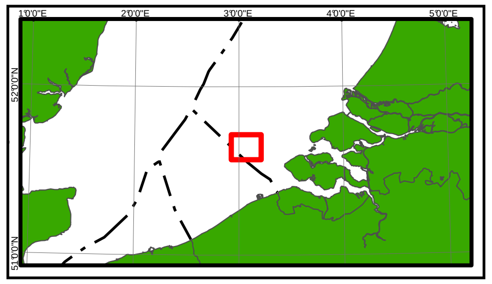
0

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3°00' 00" E
Latitude of Origin	0°00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

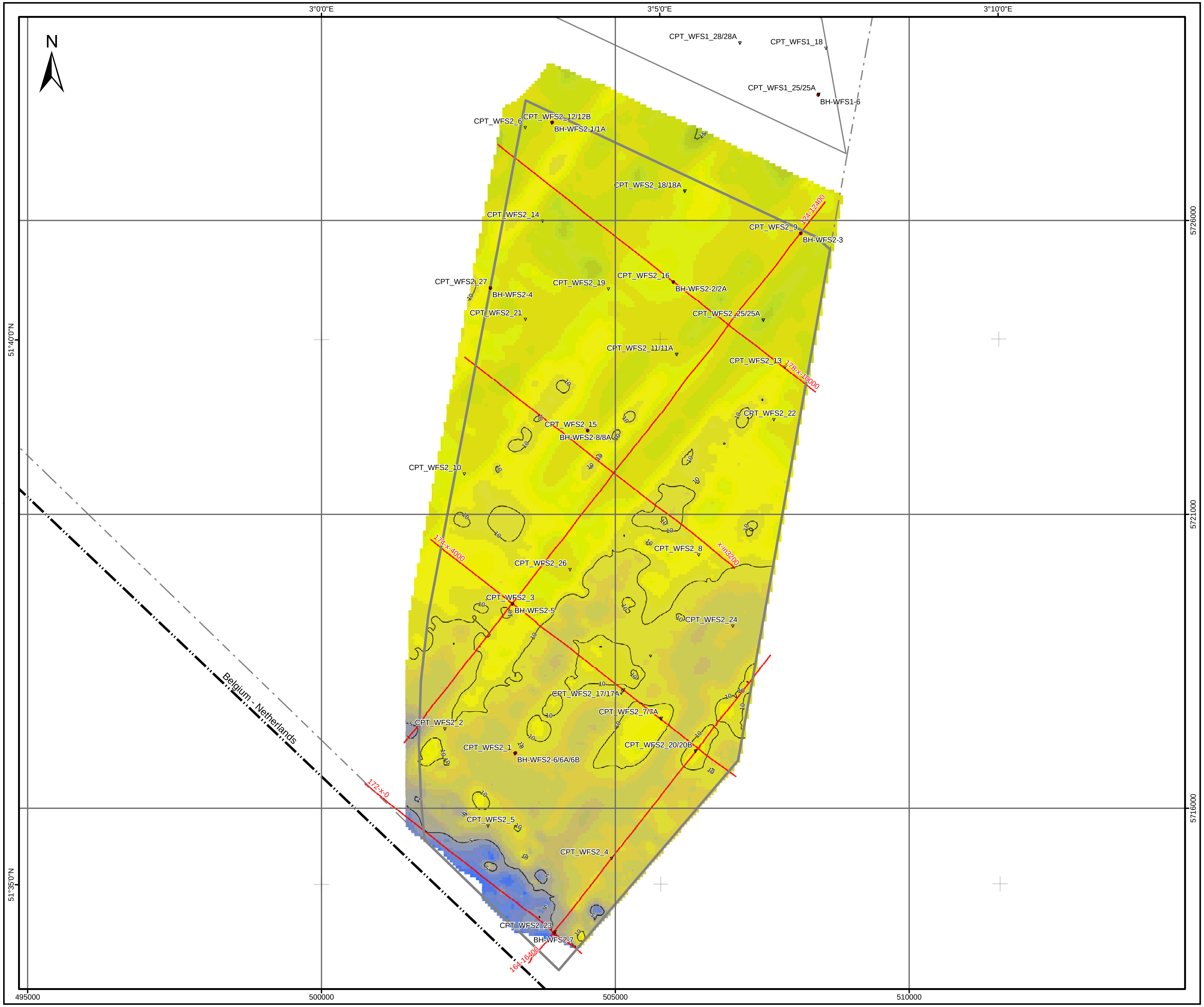
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT E5A (BASSEVELDE 1 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 4	Plate 3-30
Printed: 8/3/2015 3:30:32 PM		Author: WVK



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

32

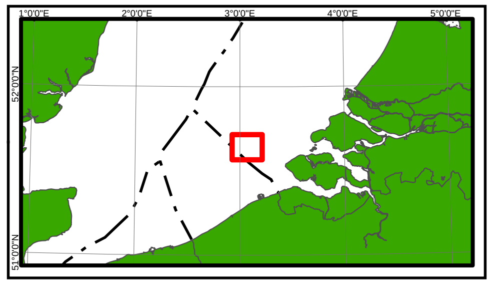
0

NOTES:

- Unit is absent at blank areas within WFS II

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

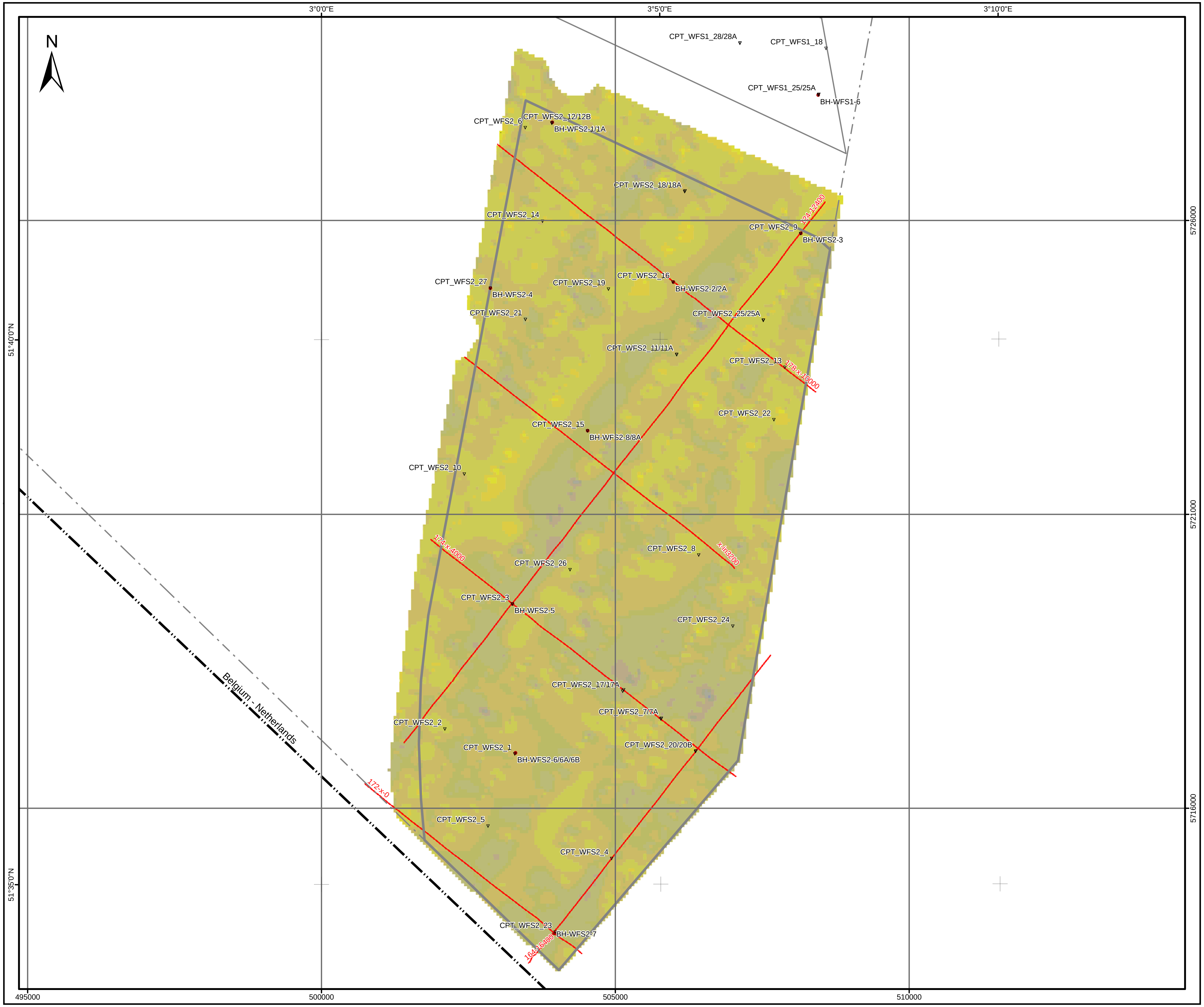
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

THICKNESS OF UNIT E5B (BASSEVELDE 1 SAND MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 3-31
Printed: 03/07/2015 00:35:00		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report
- Contour line of thickness [m]

Thickness [m]

65

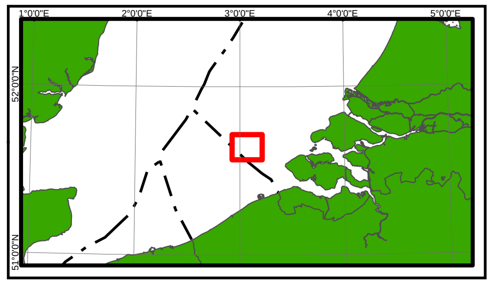
32

0

NOTES:

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
Central Meridian (CM)	3° 00' 00" E
Latitude of Origin	0° 00' 00" N
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)

Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro

Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

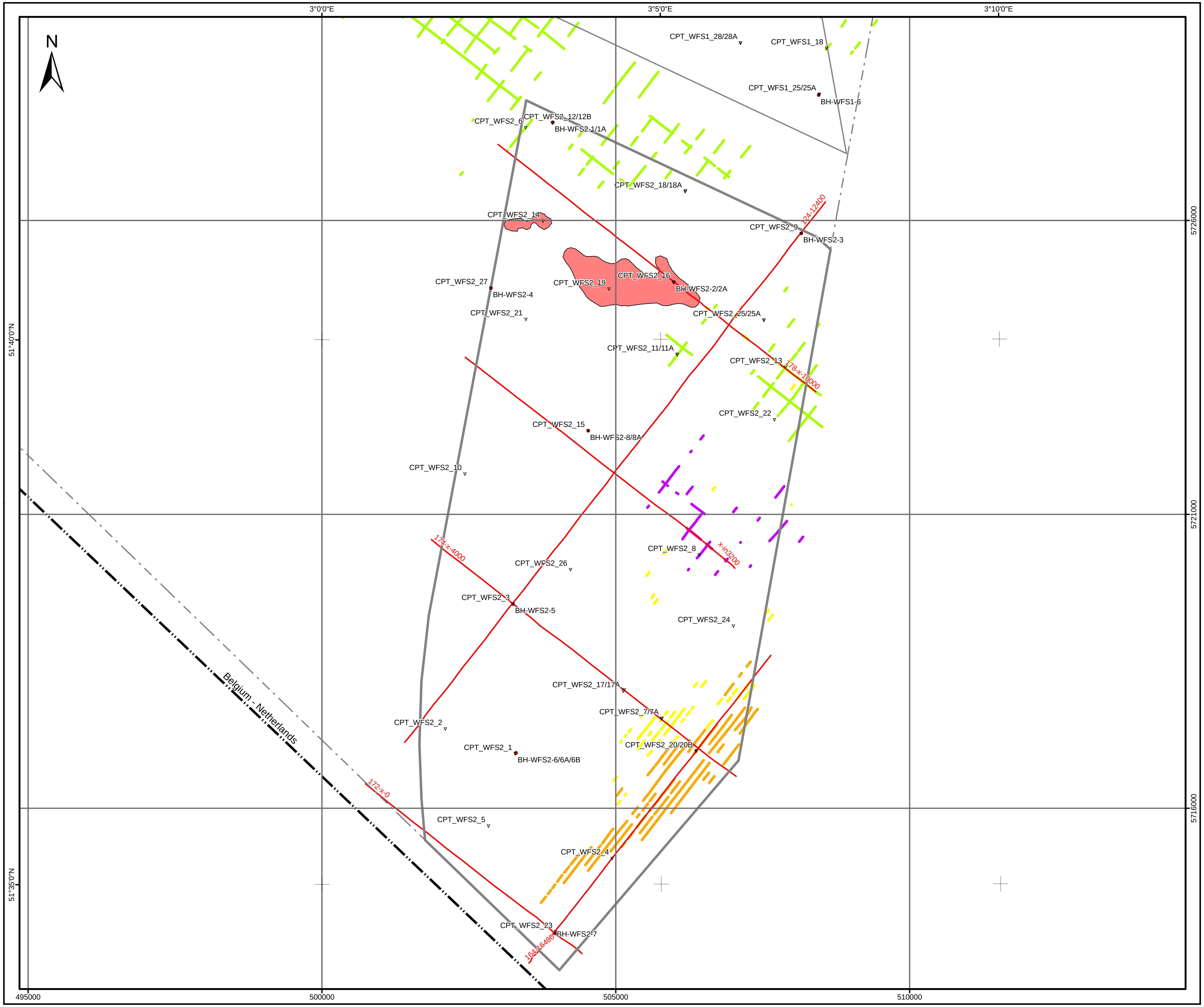
THICKNESS OF UNIT F1a + b (ONDERDIJKE MB. + BUISPUTTEN MB.)

BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

FUGRO

Fugro Report No. N6016/06	Issue 2	Plate 3-32
Printed: 03/07/2015 00:36:28		Author: RTN



LEGEND:

- CPT location
- BH location
- Outline of WFS I
- Outline of WFS II
- Outline of Borssele Wind Farm Zone
- Maritime boundary
- Section line of cross-section presented in the report

Geological Features

- Gravelly Sand (Unit B, Kreftenheye Fm./Eem Fm.)
- Infilled paleo-channel (Unit B, Kreftenheye Fm./Eem Fm.)
- Scour hollow (Unit B, Kreftenheye Fm./Eem Fm.)
- Clay with septarian and pyrite concretions (Units D, Rupel Clay Mb.)
- Lignite (Unit E, Watervliet Clay Mb.)

NOTES:

- Geological features interpreted from MCS and SBP seismic reflection data
- Seismic reflection data acquired by Deep (2015)
- Refer to Section 5 of Main Text for explanation of the geological features

GEODETIC PARAMETERS:

DATUM	ETRS89
Ellipsoid	GRS80
Semi major axis	a = 6 378 137.000
Inverse flattening	1/f = 298.257222101
PROJECTION	UTM, Zone 31 North
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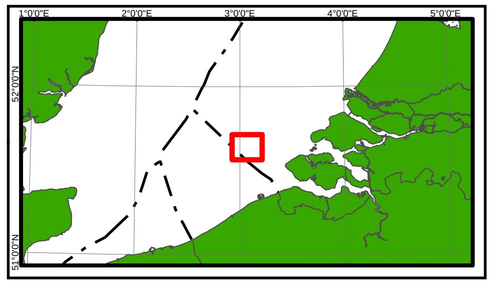
False Easting	500 000 m
False Northing	000 000 m
Scale factor	0.9996
Units	metres/degrees



Rijksdienst voor Ondernemend Nederland (RVO)
Croeselaan 15, 3521 BJ, Utrecht - THE NETHERLANDS

Fugro
Prismastraat 4, 2631 RT, Nootdorp - THE NETHERLANDS

GEOLOGICAL FEATURES

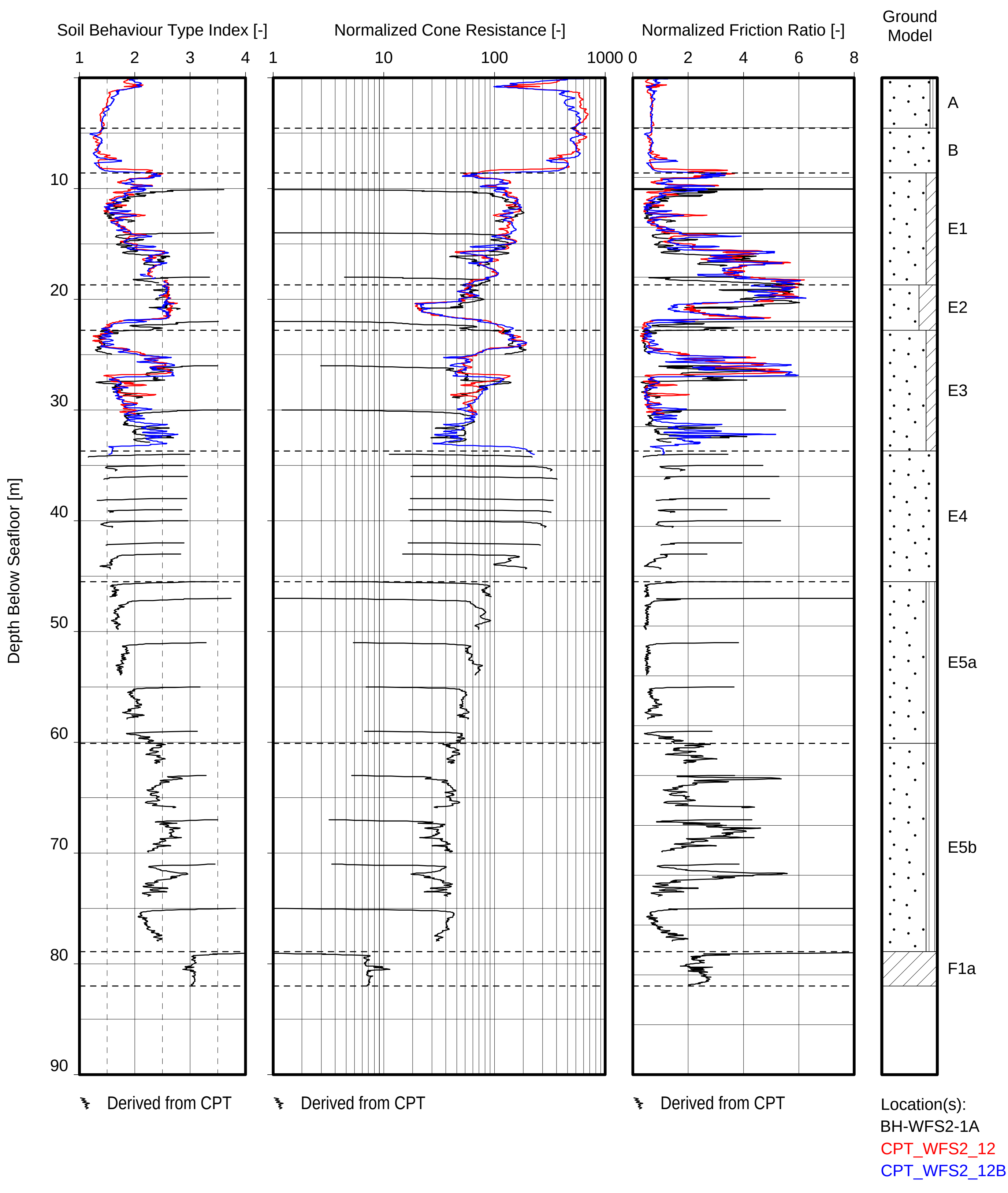
BORSSELE WIND FARM ZONE, WFS II
DUTCH SECTOR, NORTH SEA

0 500 1,000 1,500 2,000 metres

Fugro Report No. N6016/06	Issue 2	Plate 5-1
Printed: 02/07/2015 23:42:12		Author: BLM

SECTION A: GEOTECHNICAL PARAMETERS PER BOREHOLE LOCATION

LIST OF PLATES IN SECTION A: Plate

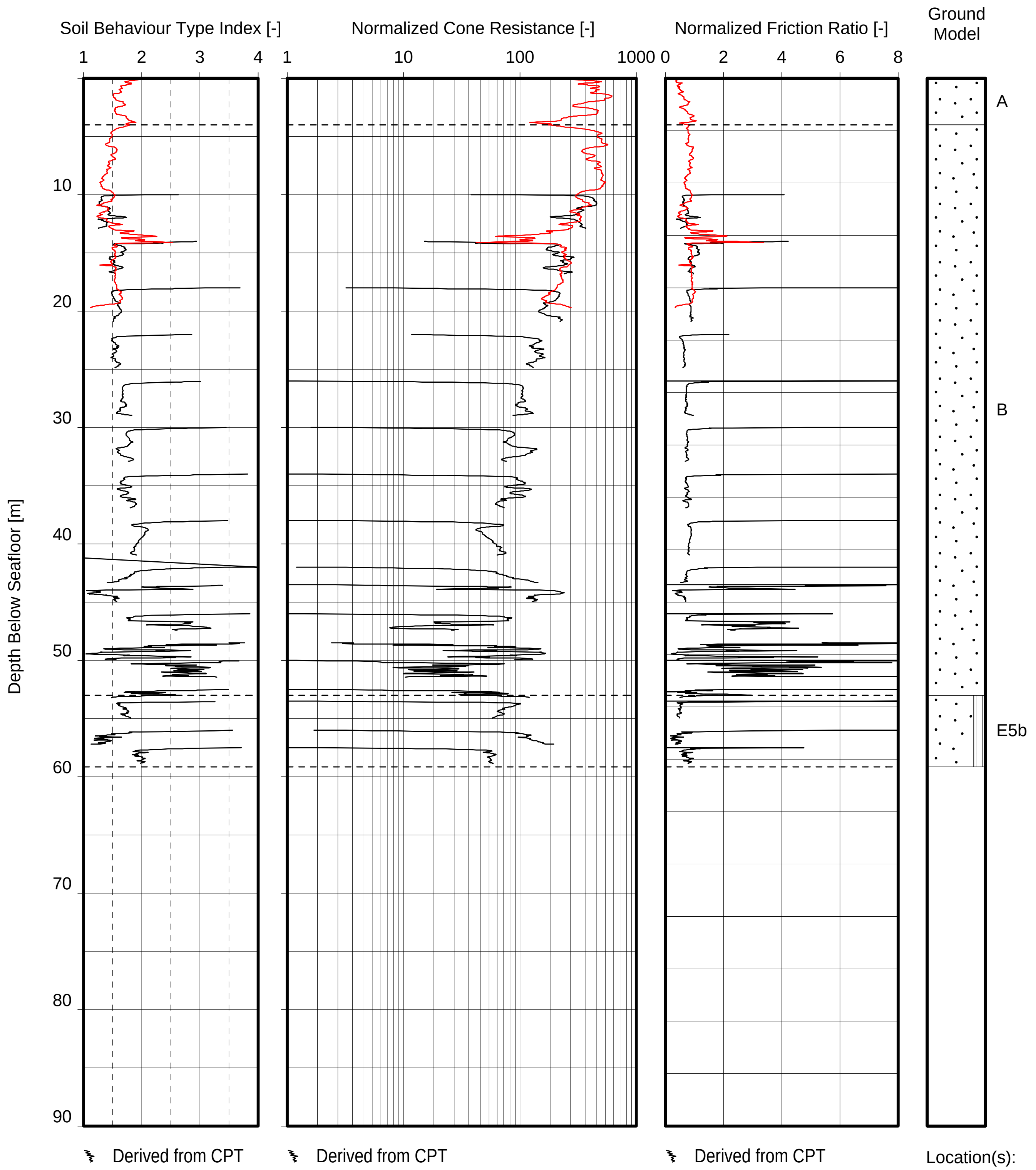


GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:08:07

Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



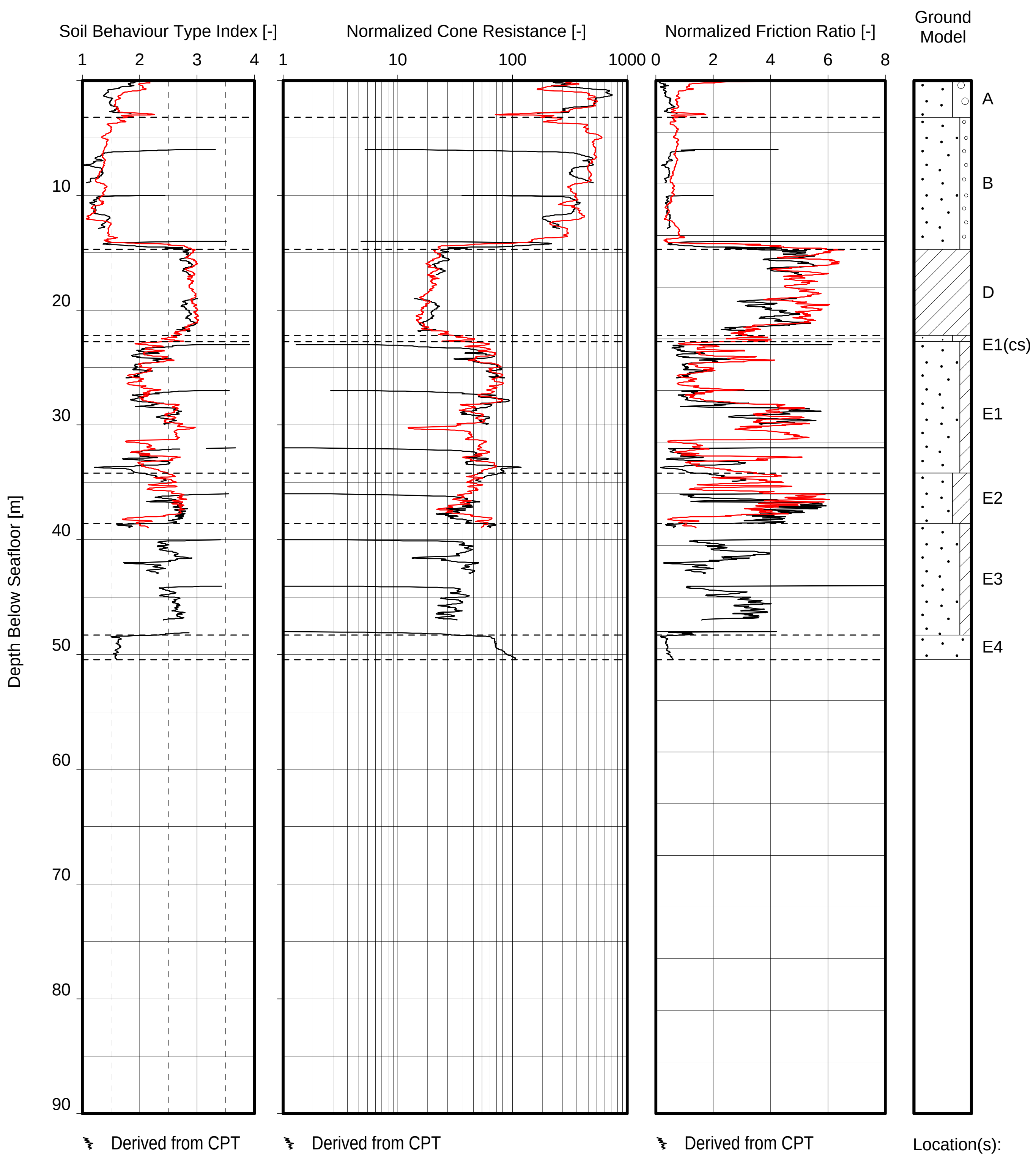
Location(s):
BH-WFS2-2A
CPT_WFS2_16

GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:23:32

Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

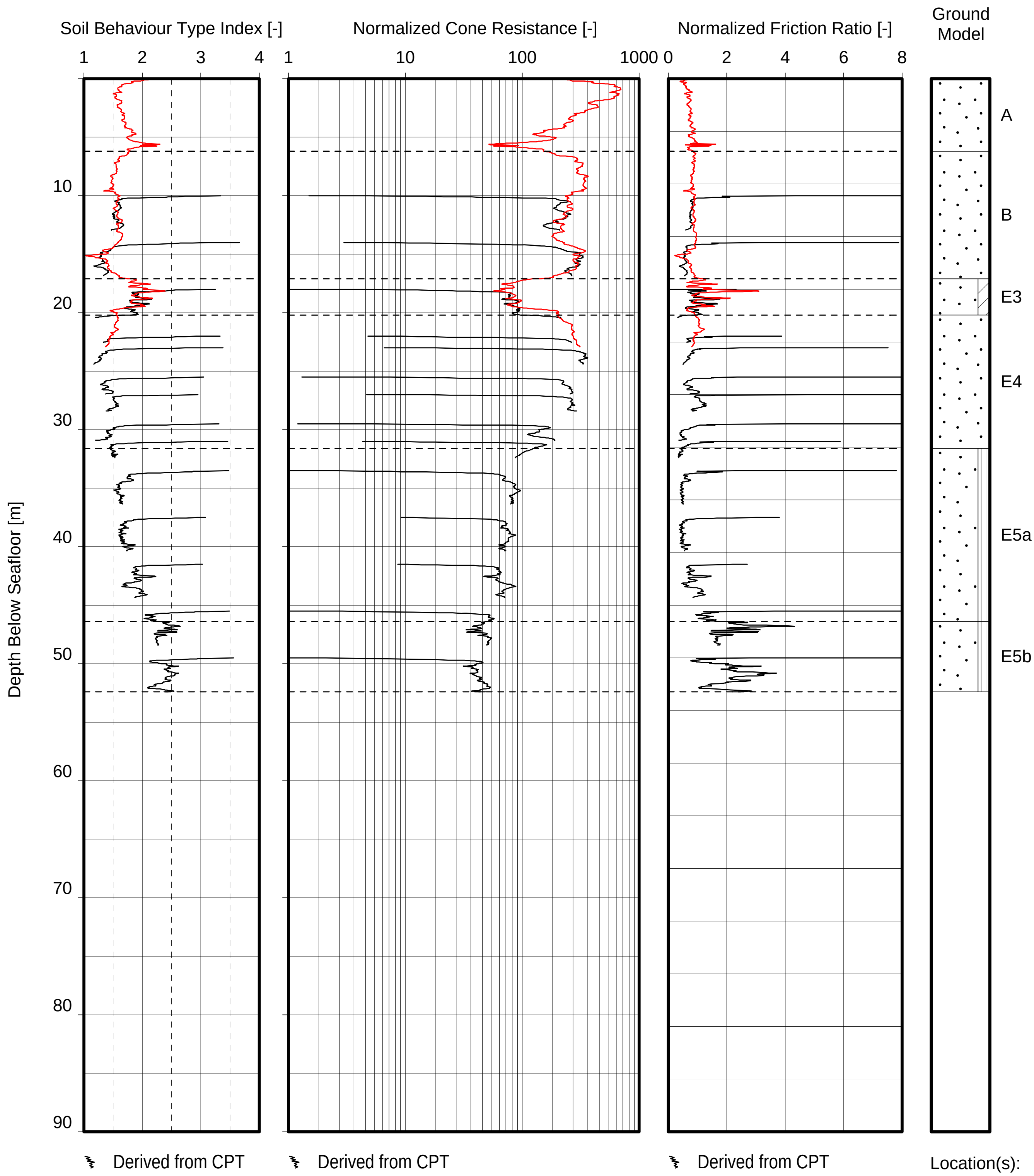


Location(s):
BH-WFS2-3
CPT_WFS2_9

Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



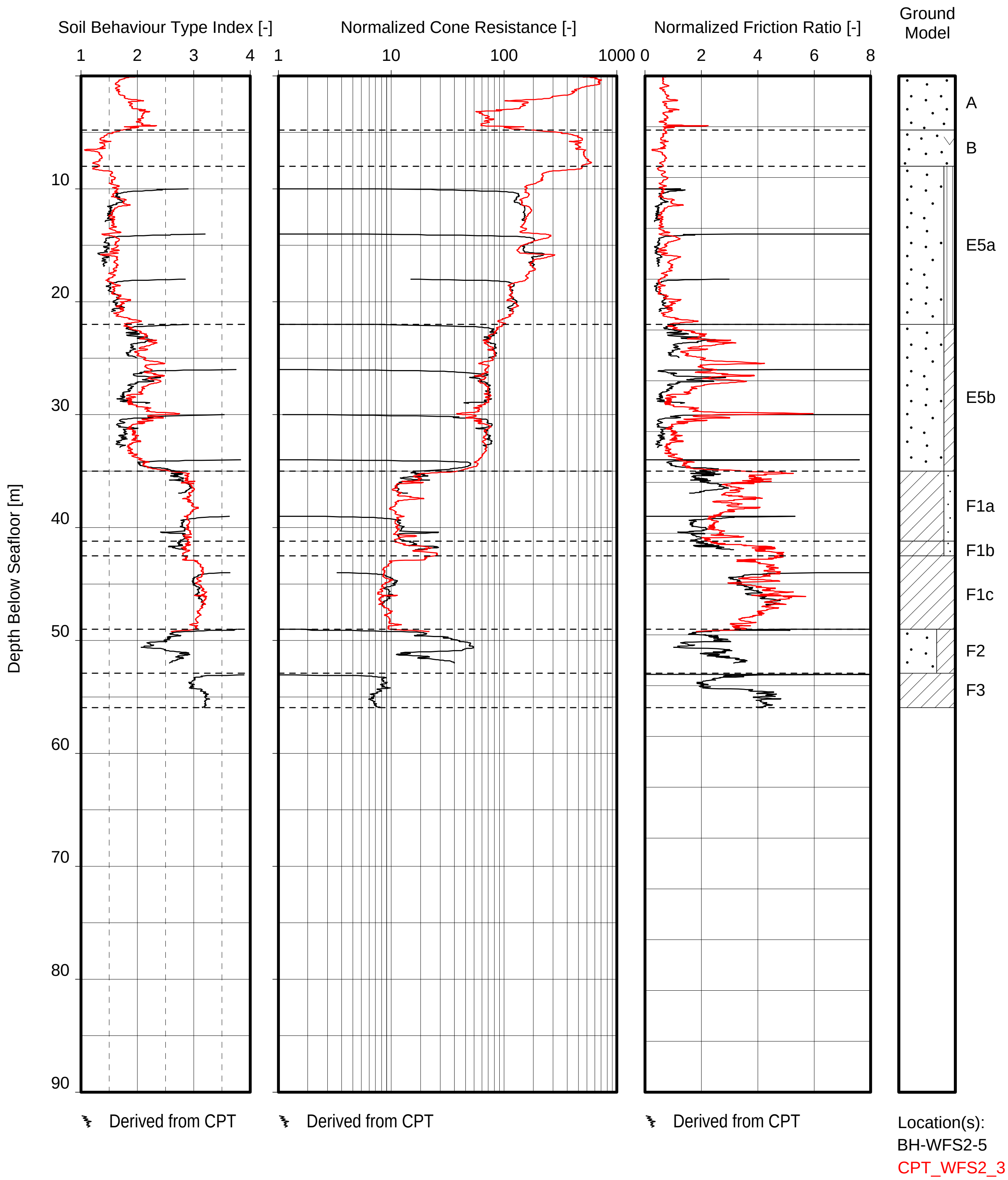
Location(s):
BH-WFS2-4
CPT_WFS2_27

Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:42:02

NORMALIZED CPT PARAMETERS VERSUS DEPTH

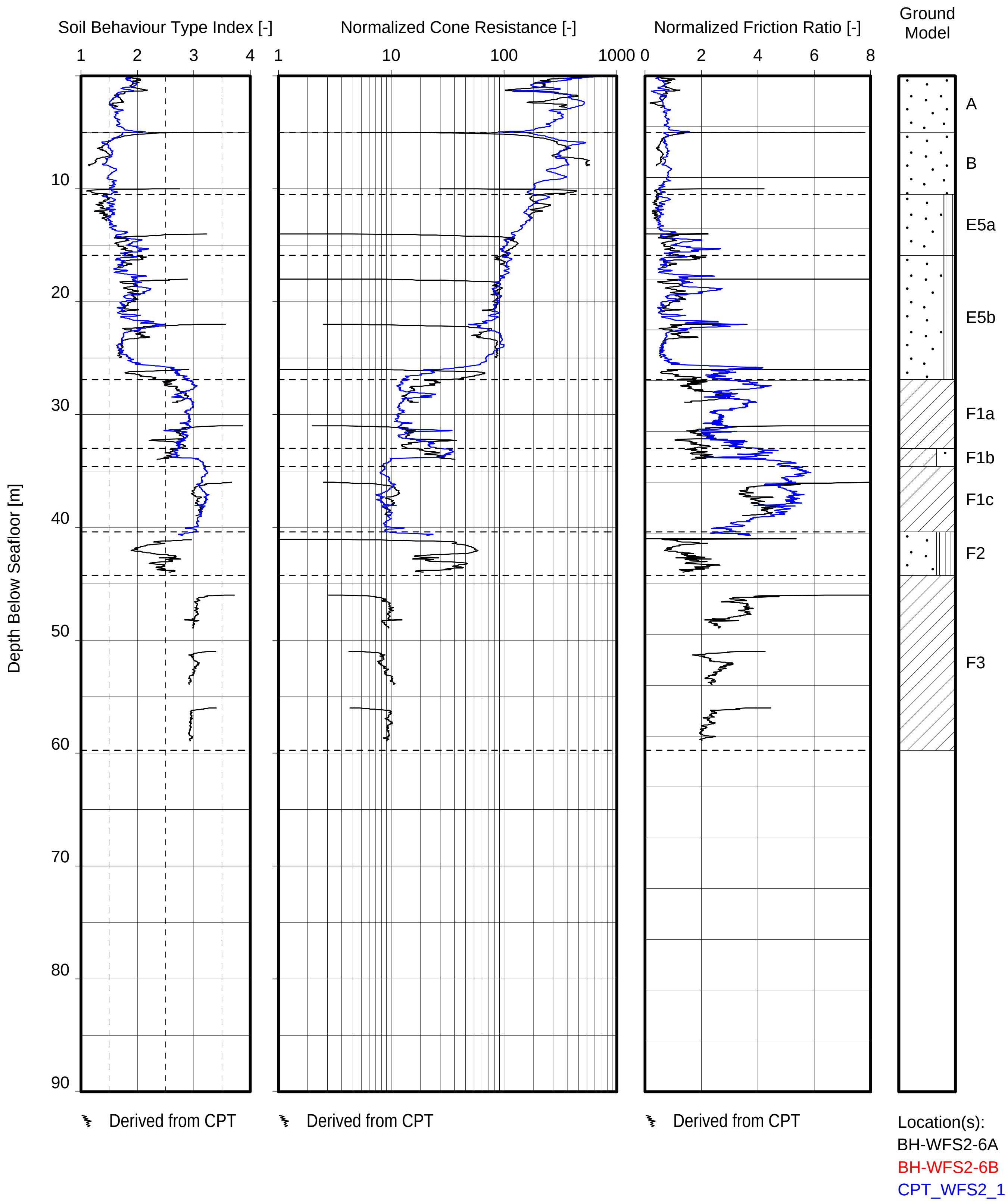
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

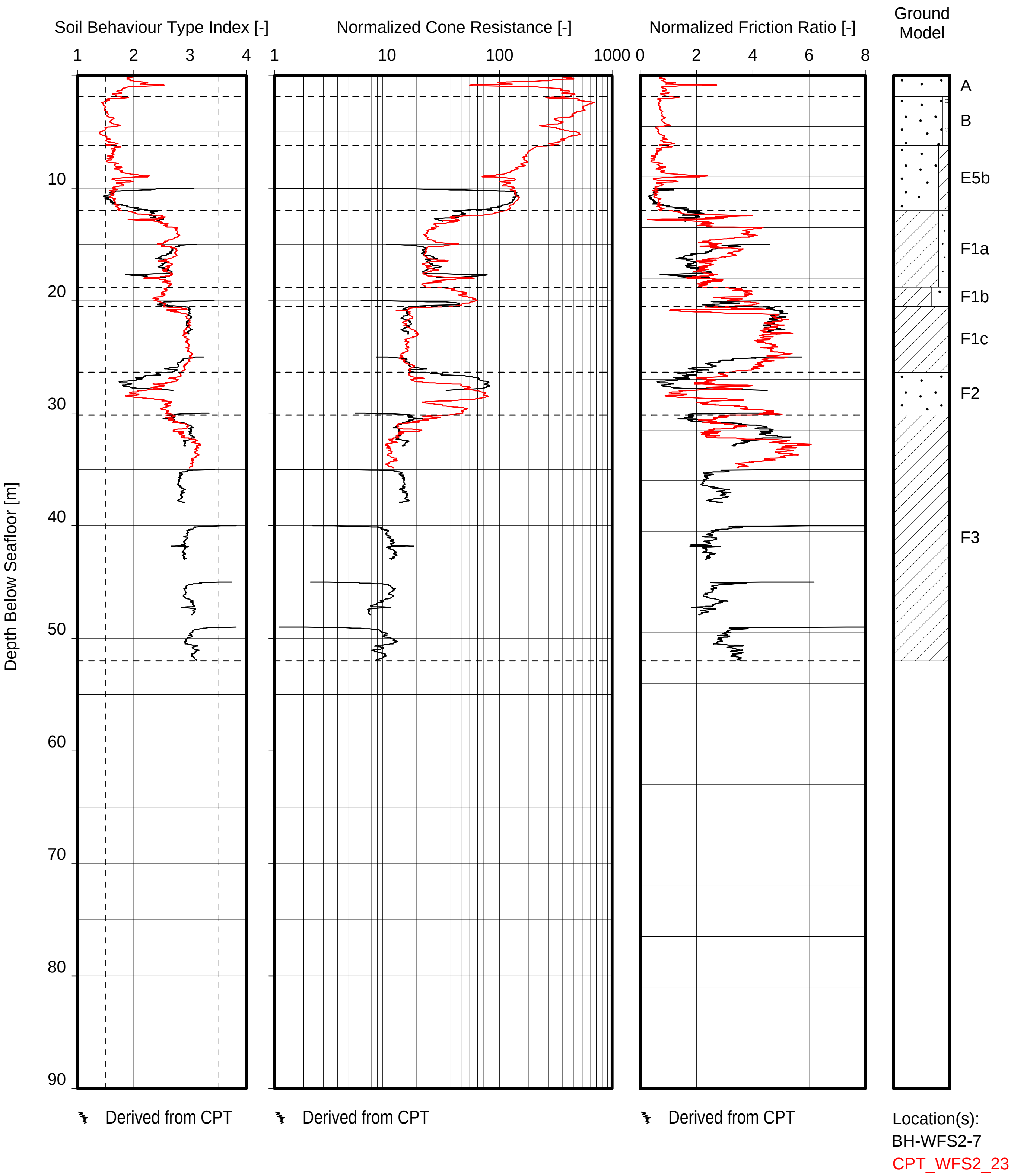


Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:05:04

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

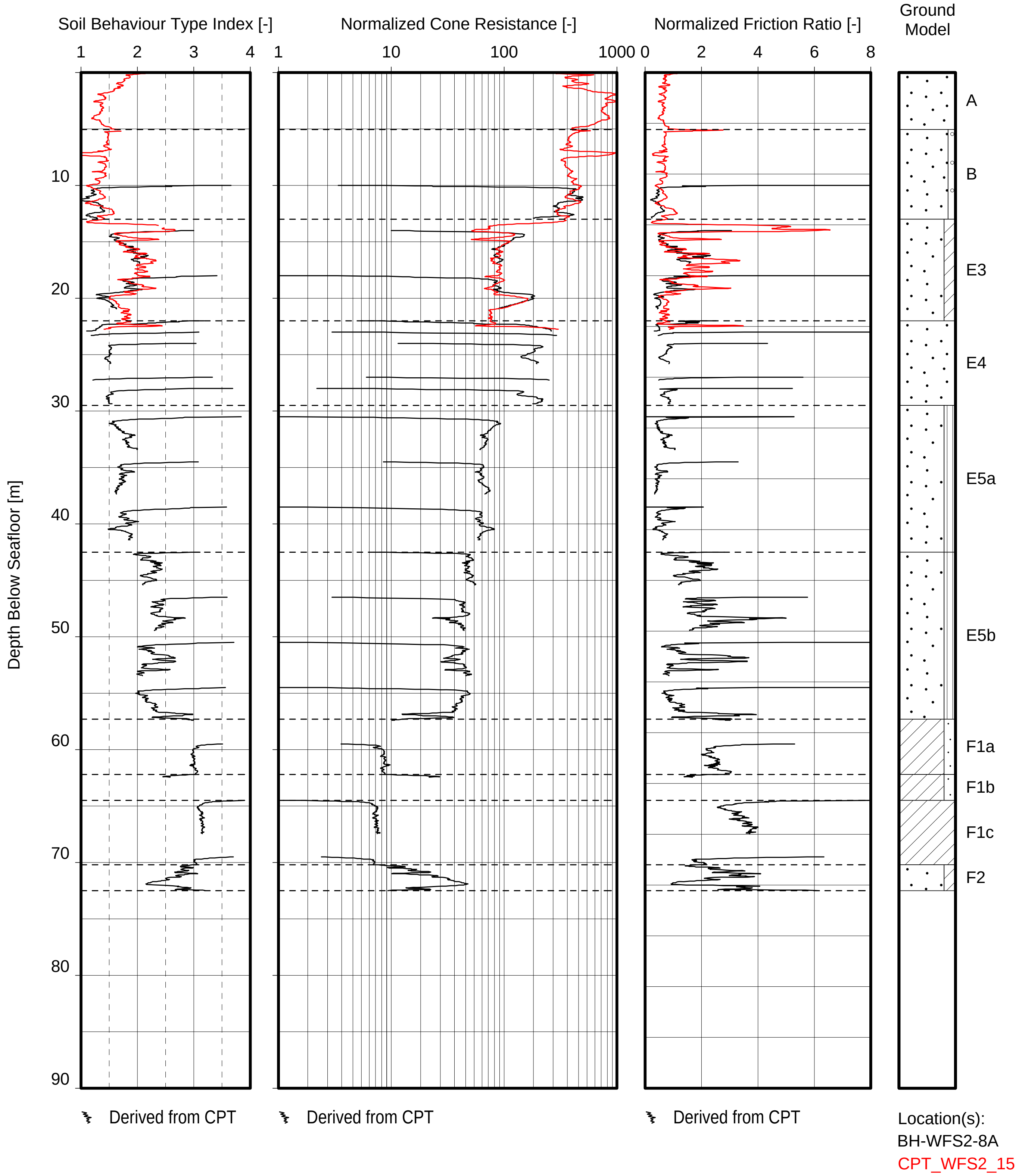


GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:24:34

Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

NORMALIZED CPT PARAMETERS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/Normalized CPT Parameters versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:28:27

NORMALIZED CPT PARAMETERS VERSUS DEPTH

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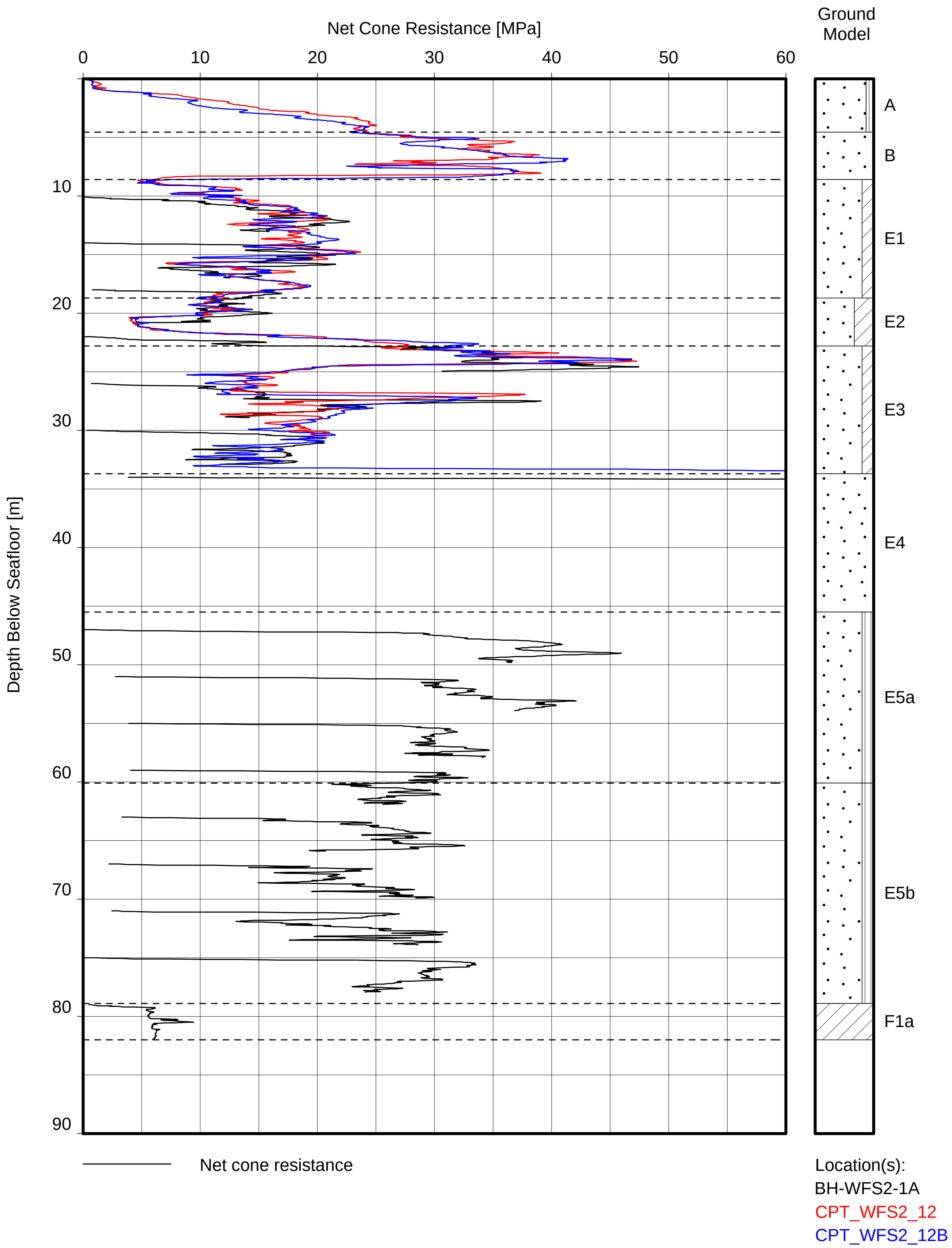

GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:08:24

NET CONE RESISTANCE VERSUS DEPTH

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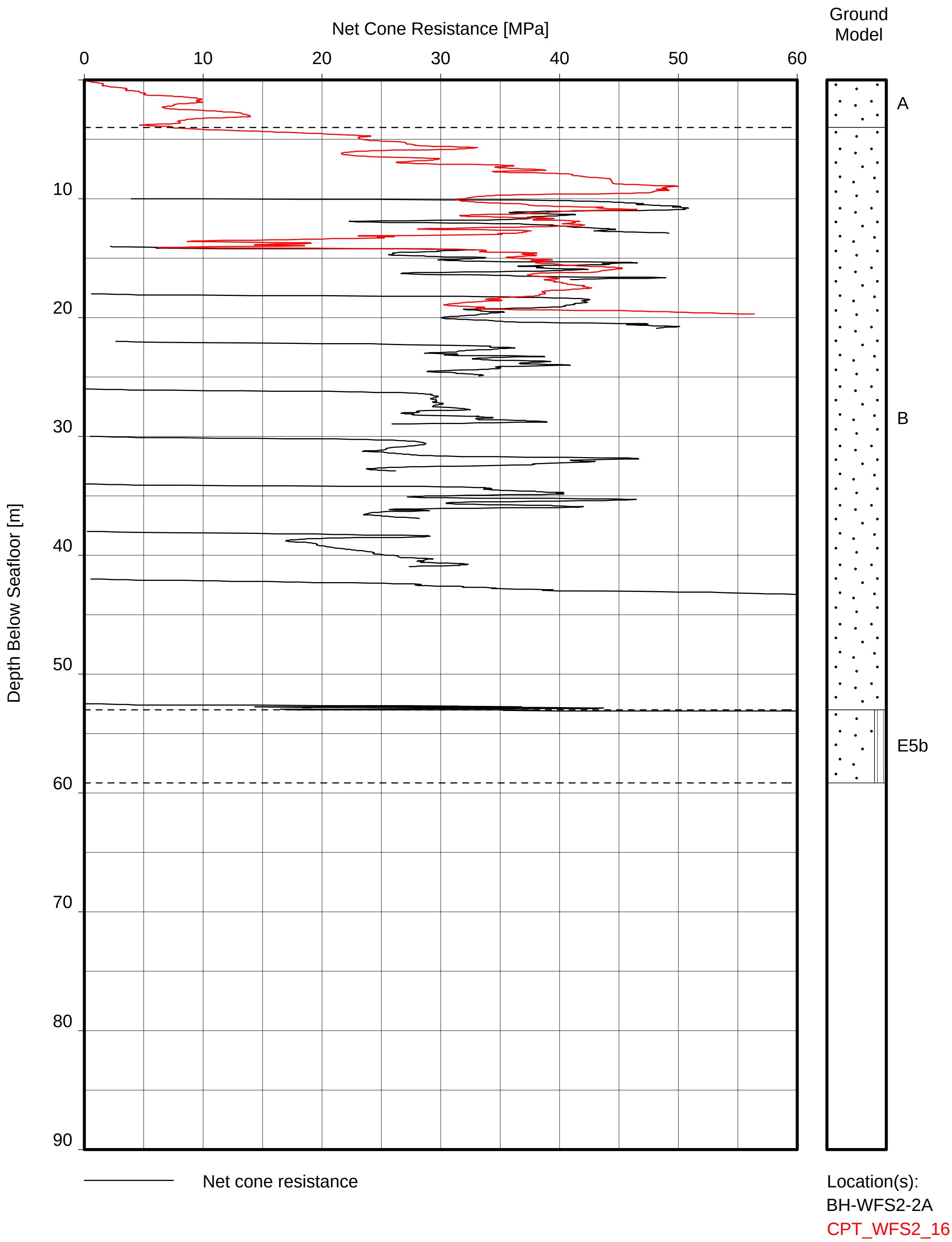

GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:24:15

NET CONE RESISTANCE VERSUS DEPTH

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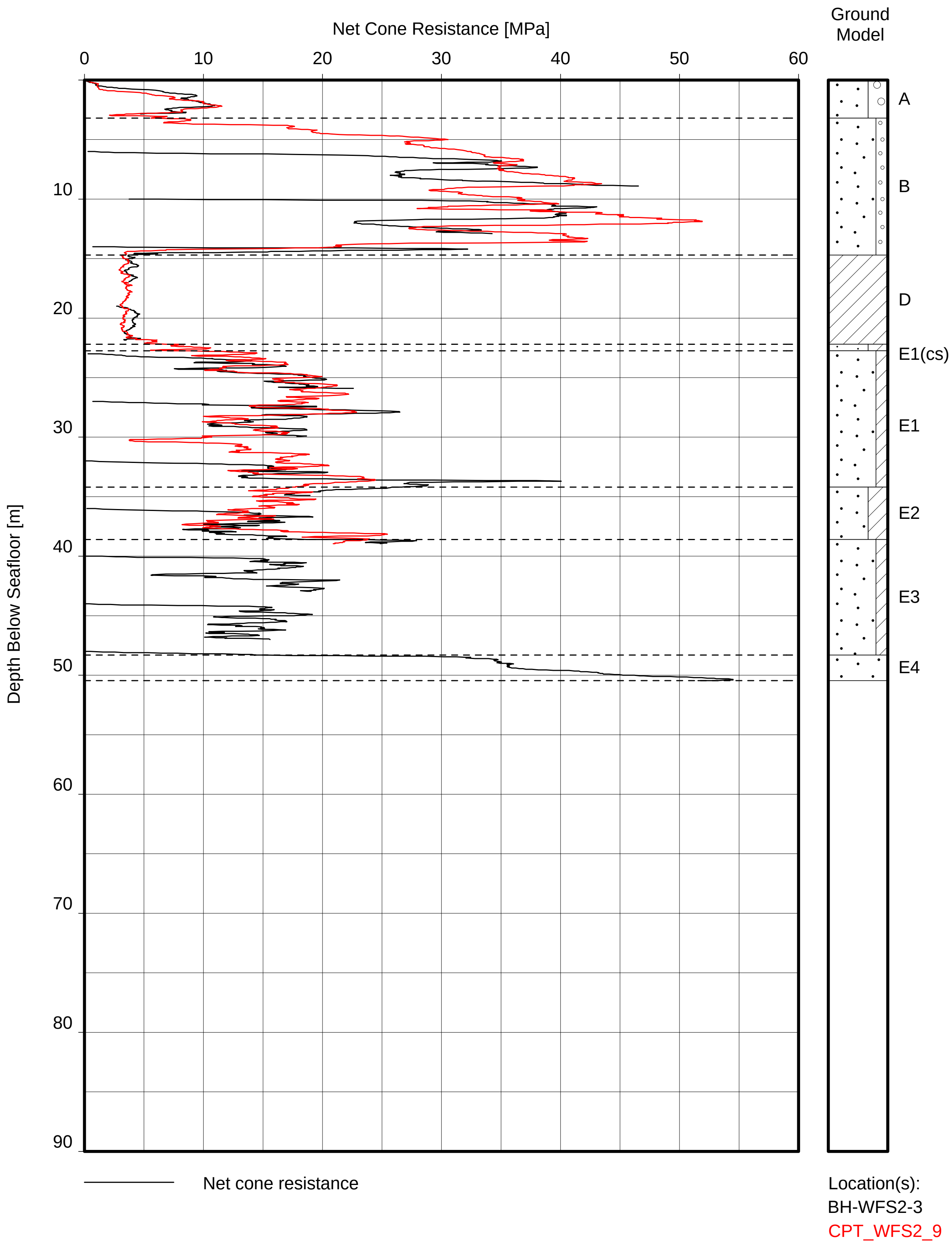
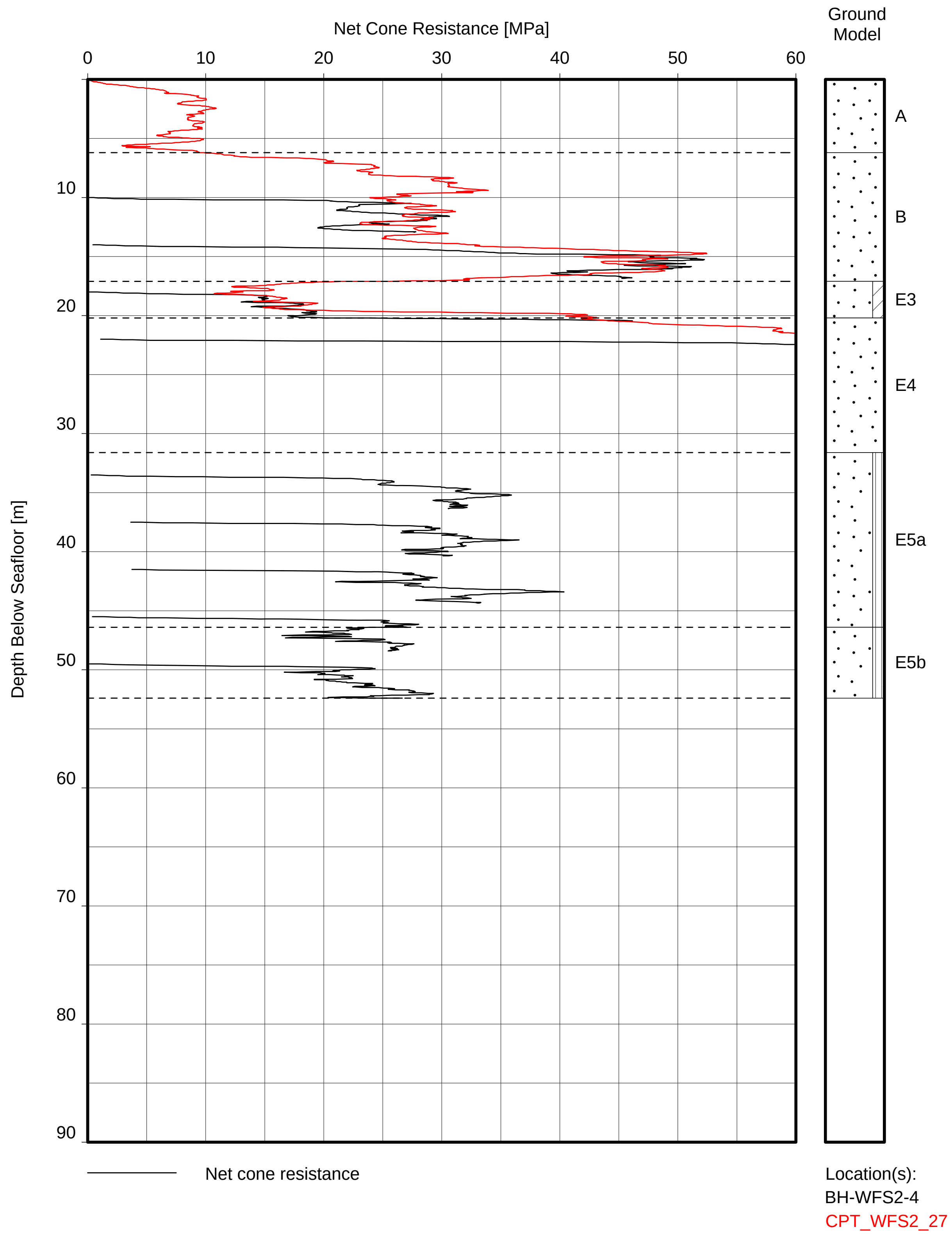


GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:34:17

NET CONE RESISTANCE VERSUS DEPTH

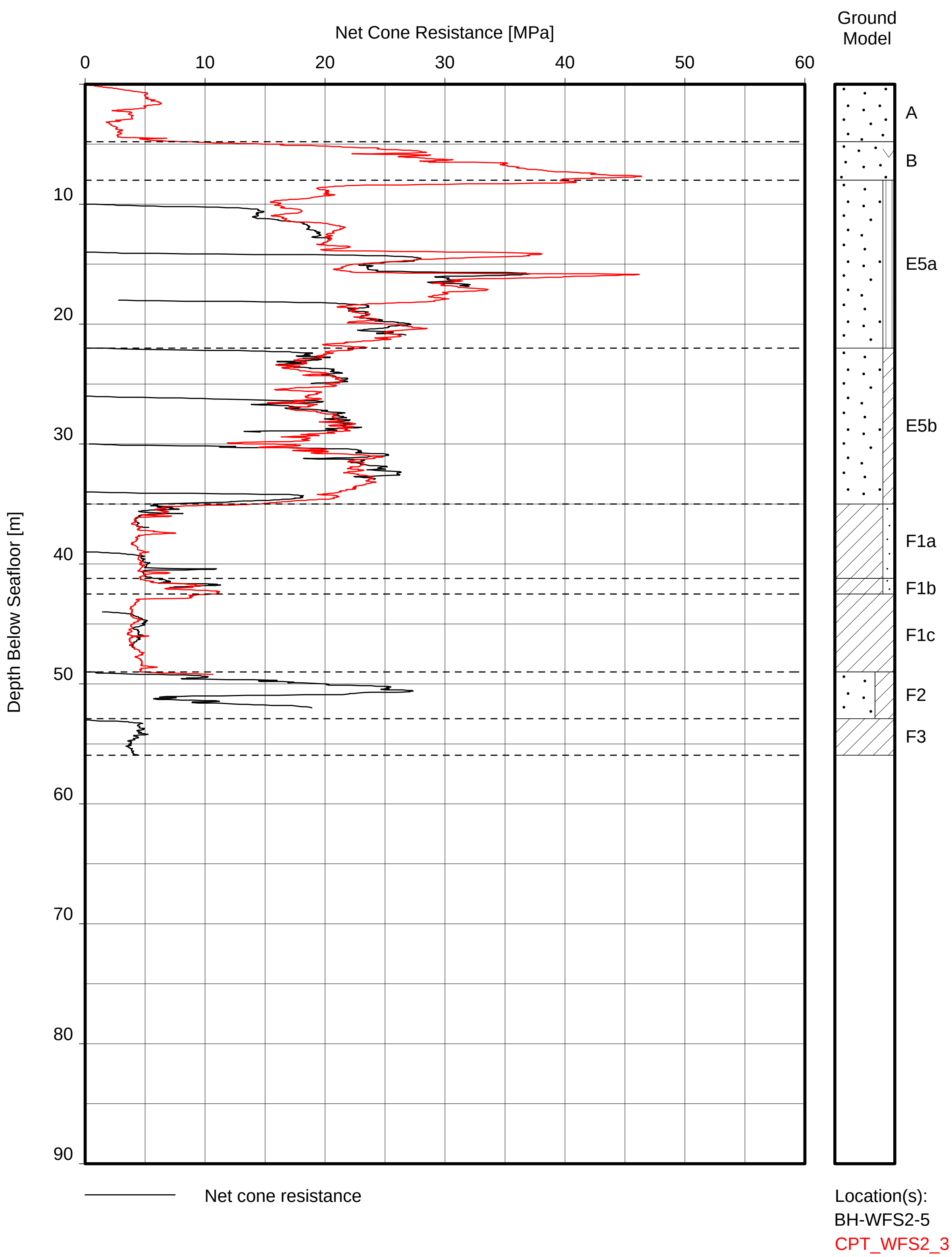
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:42:25

NET CONE RESISTANCE VERSUS DEPTH

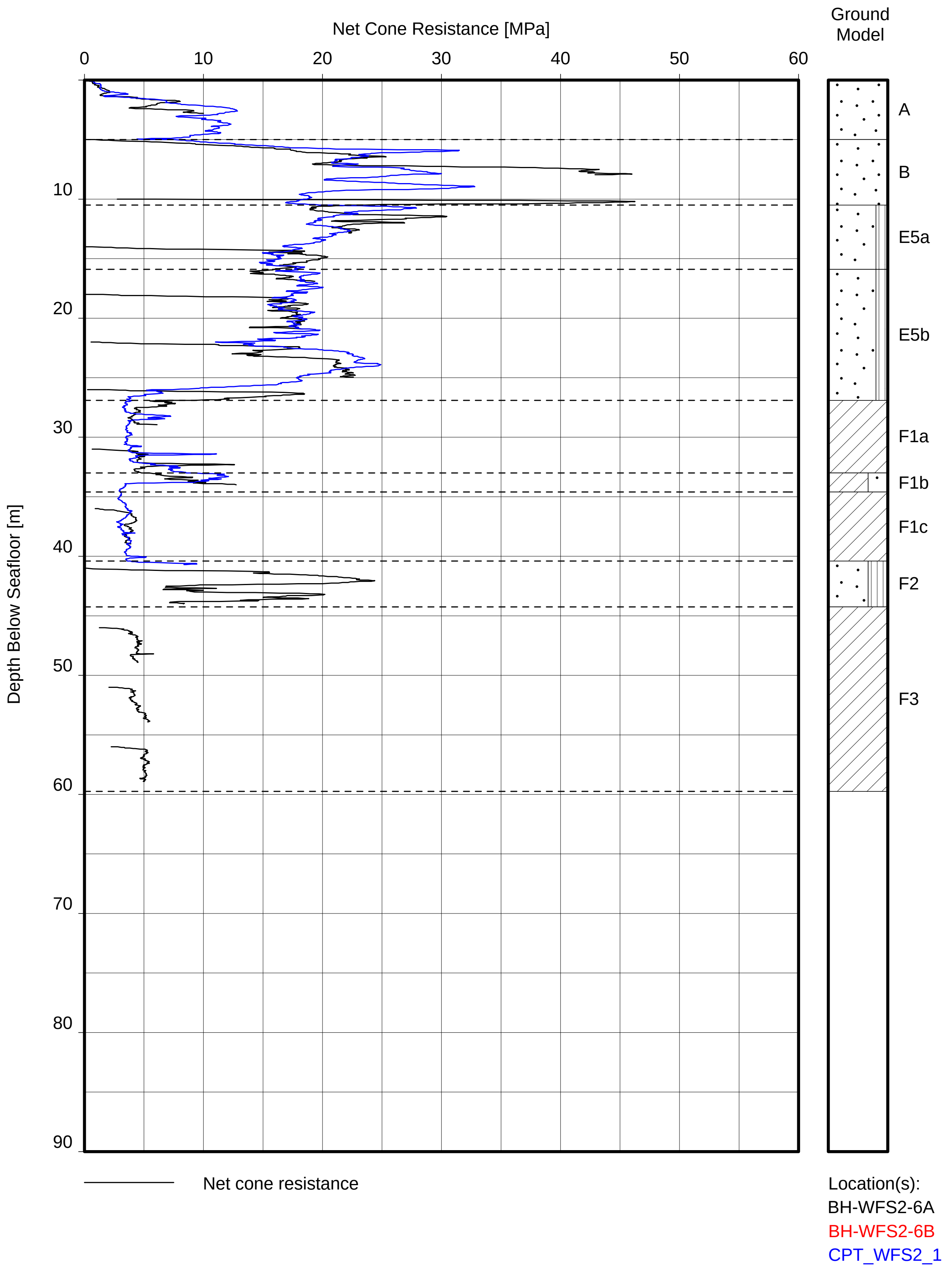
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:39:25

NET CONE RESISTANCE VERSUS DEPTH

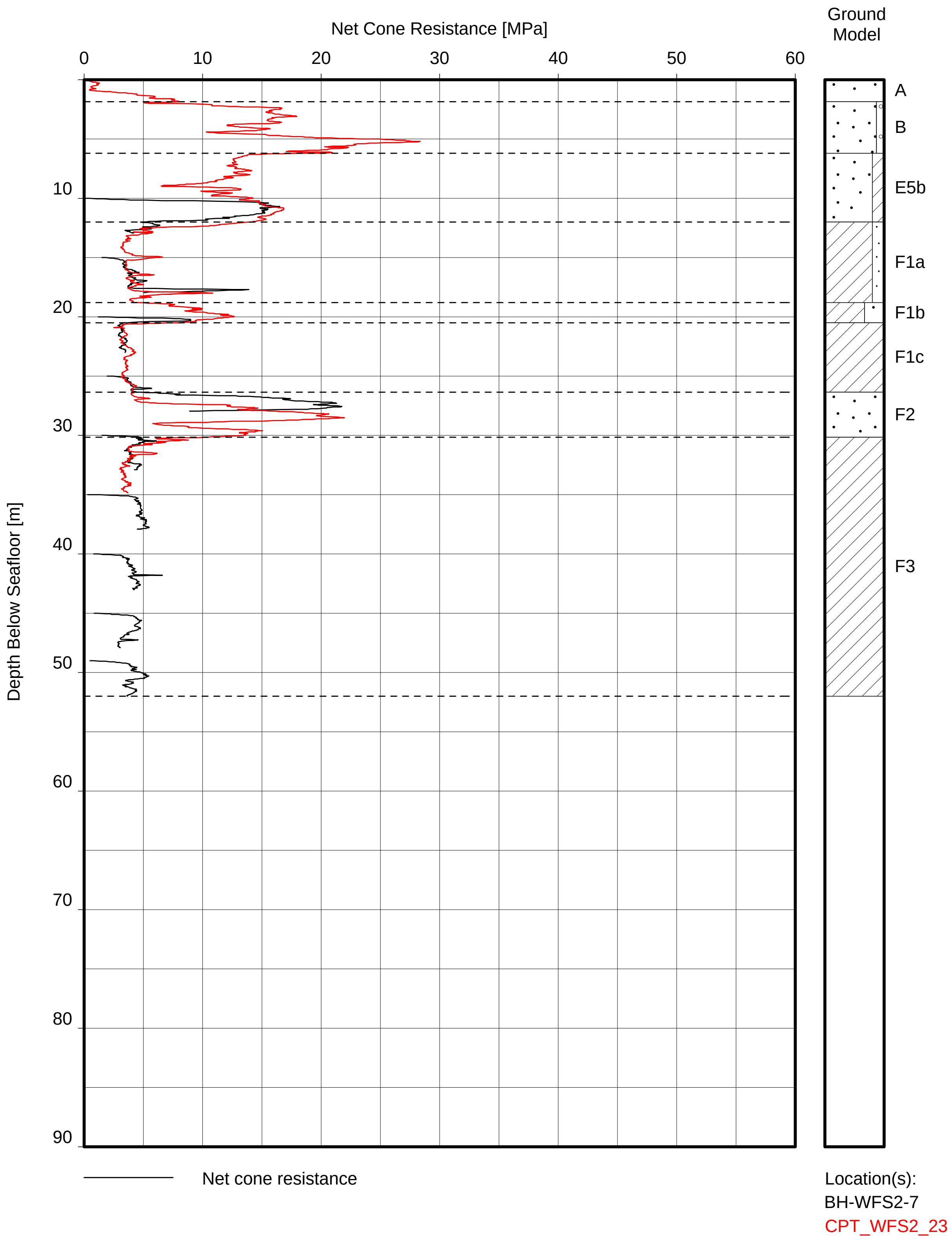
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:05:48

NET CONE RESISTANCE VERSUS DEPTH

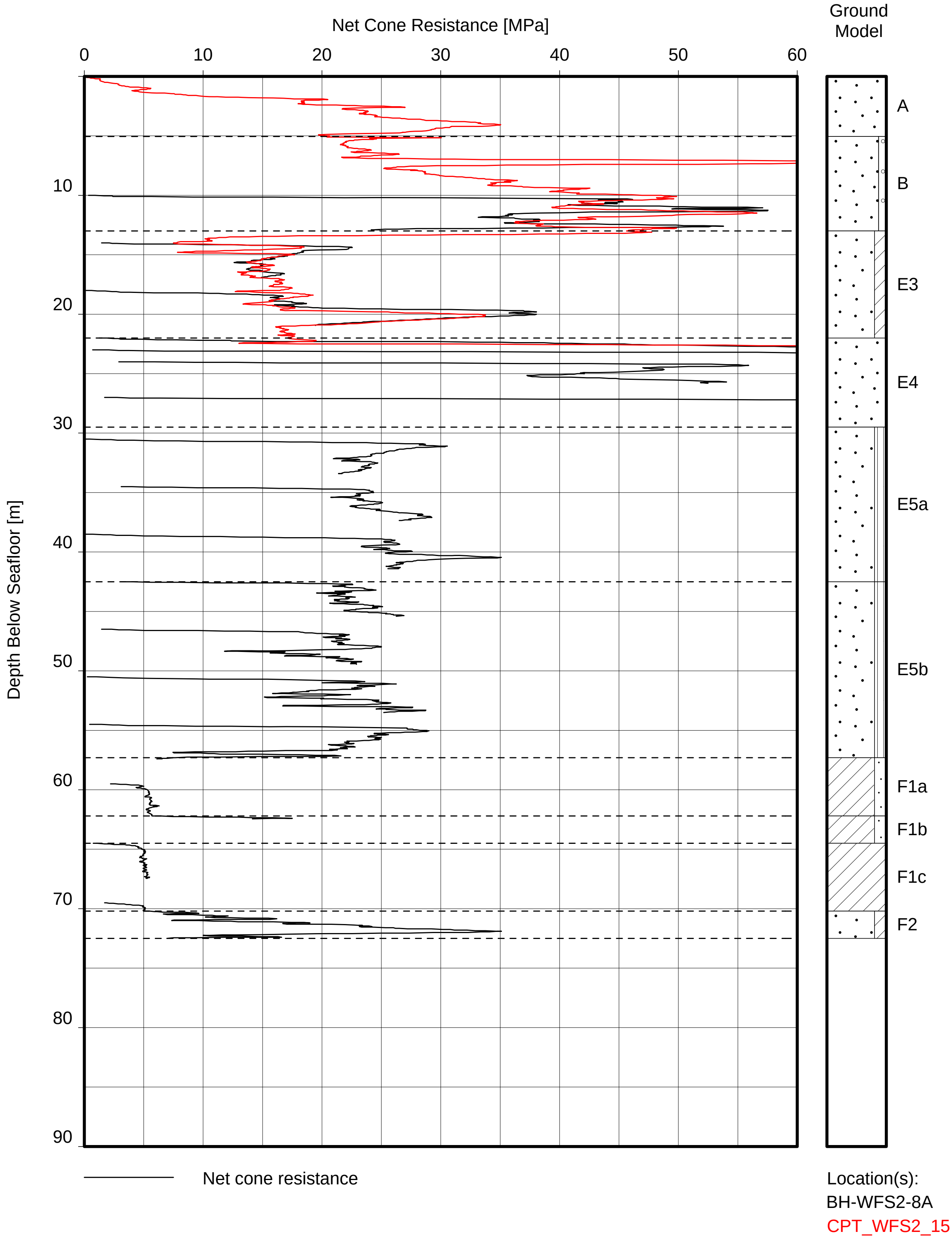
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:25:02

NET CONE RESISTANCE VERSUS DEPTH

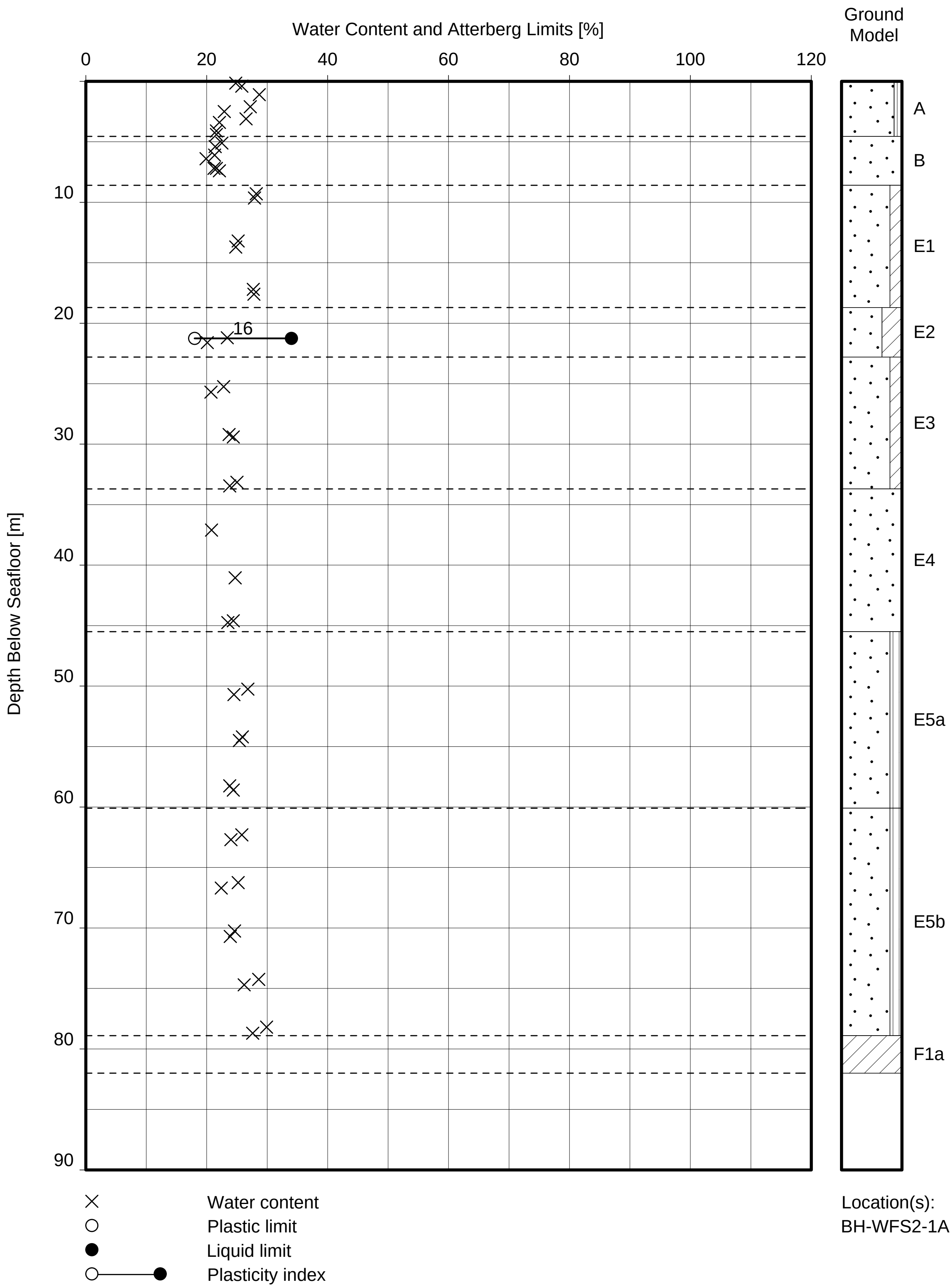
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Net Cone Resistance versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:28:55

NET CONE RESISTANCE VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 15:06:43

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

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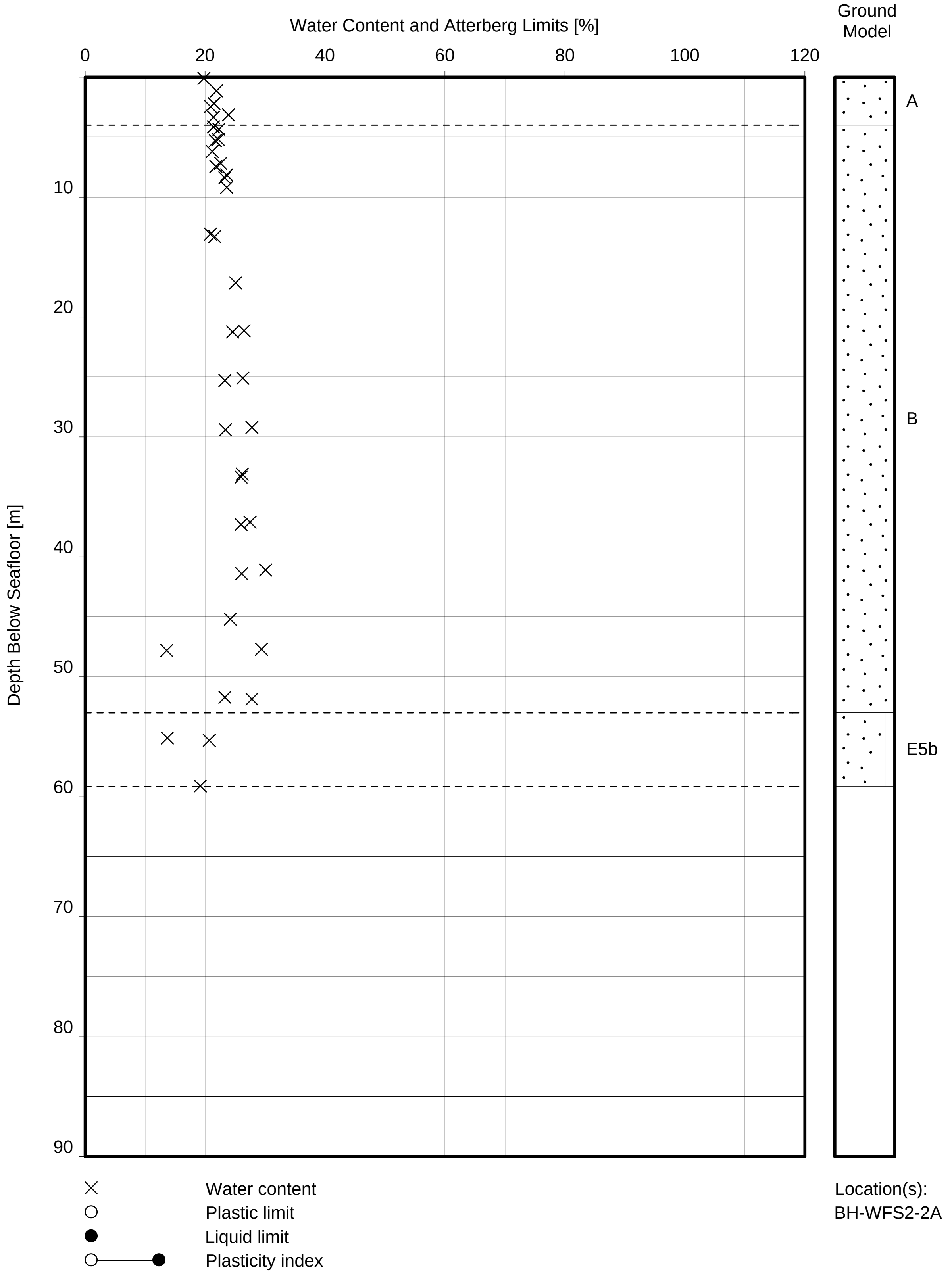
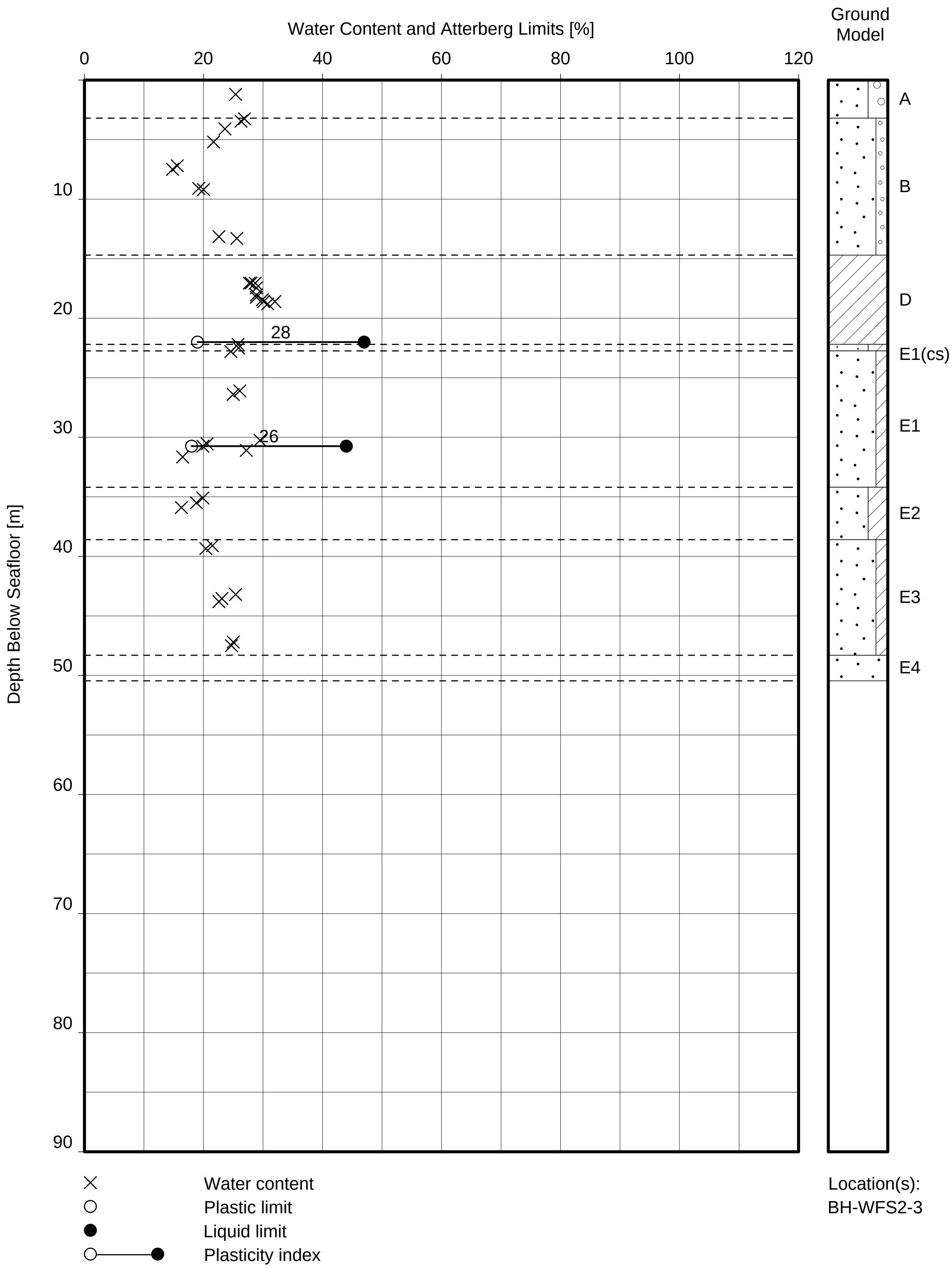


GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 15:11:02

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

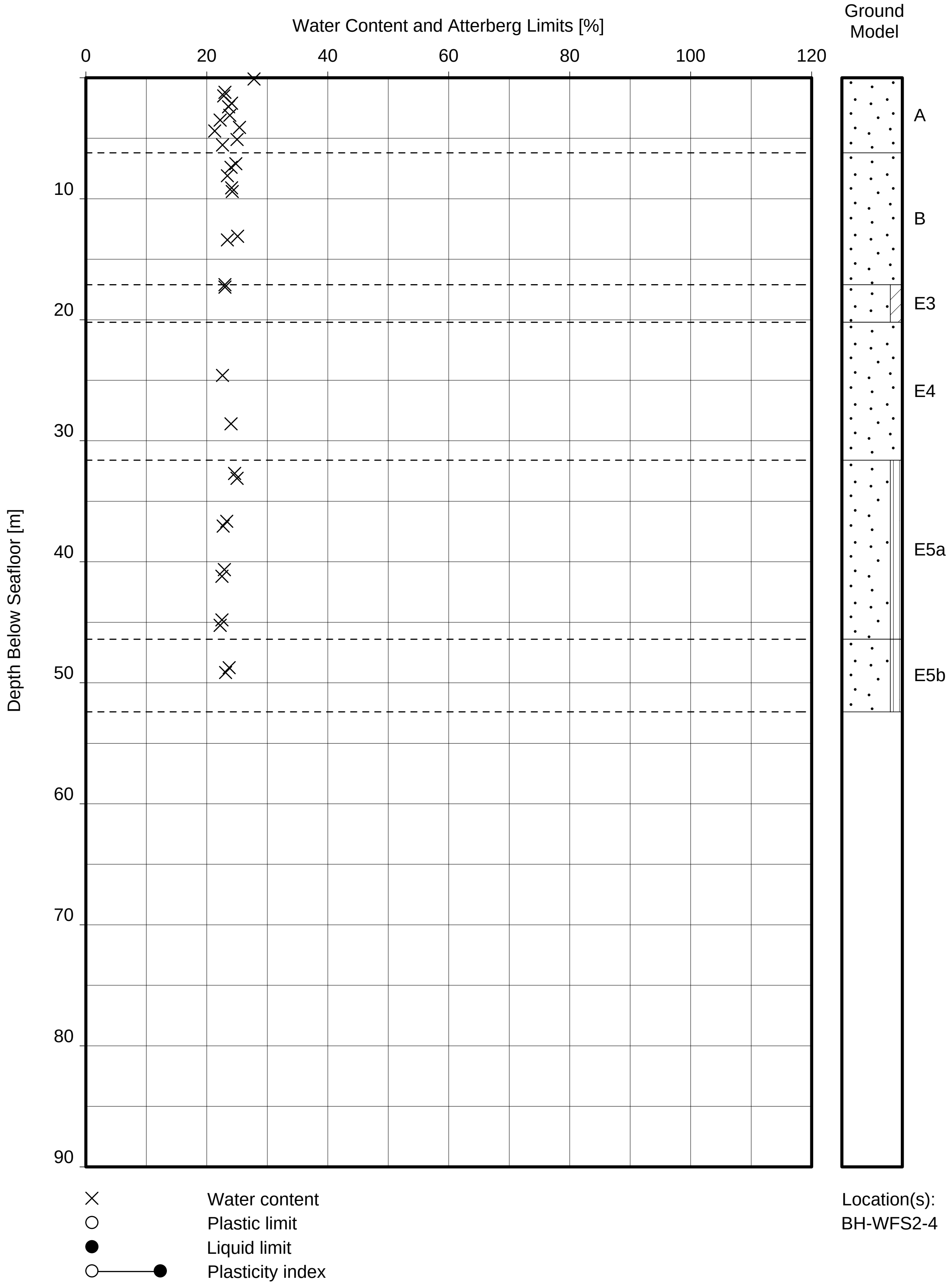
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 16:32:40

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

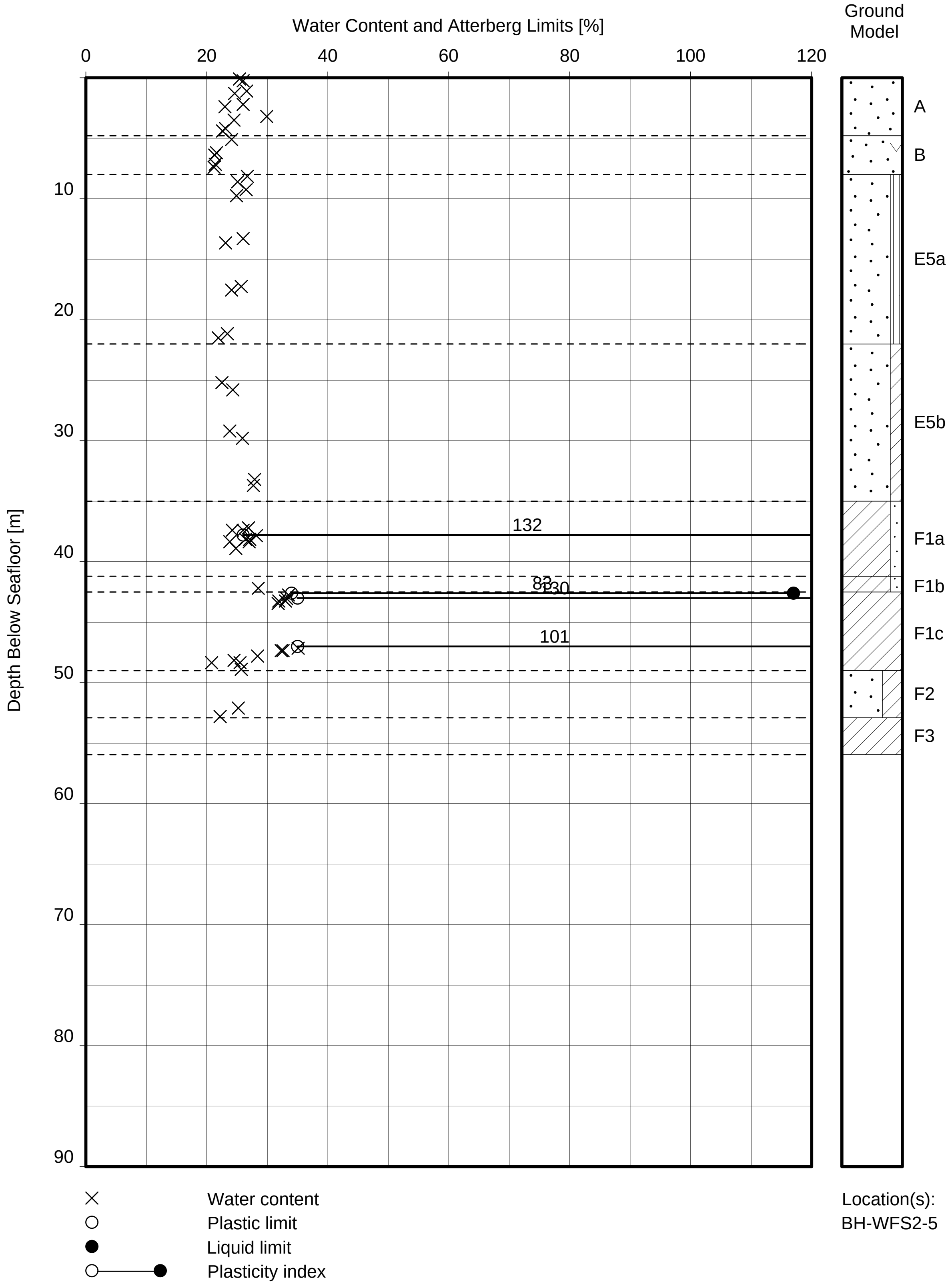
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 15:39:45

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

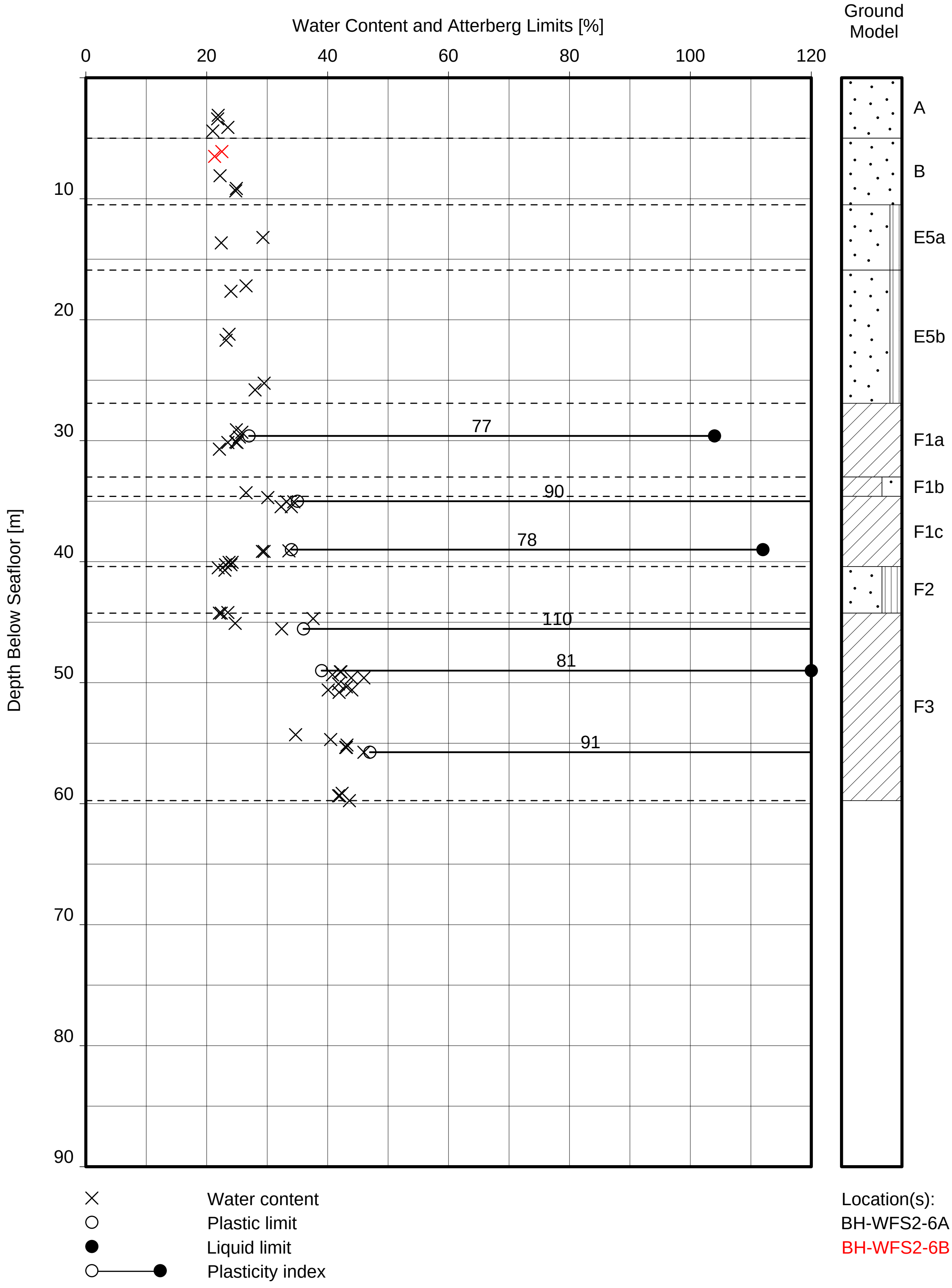
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 16:37:56

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

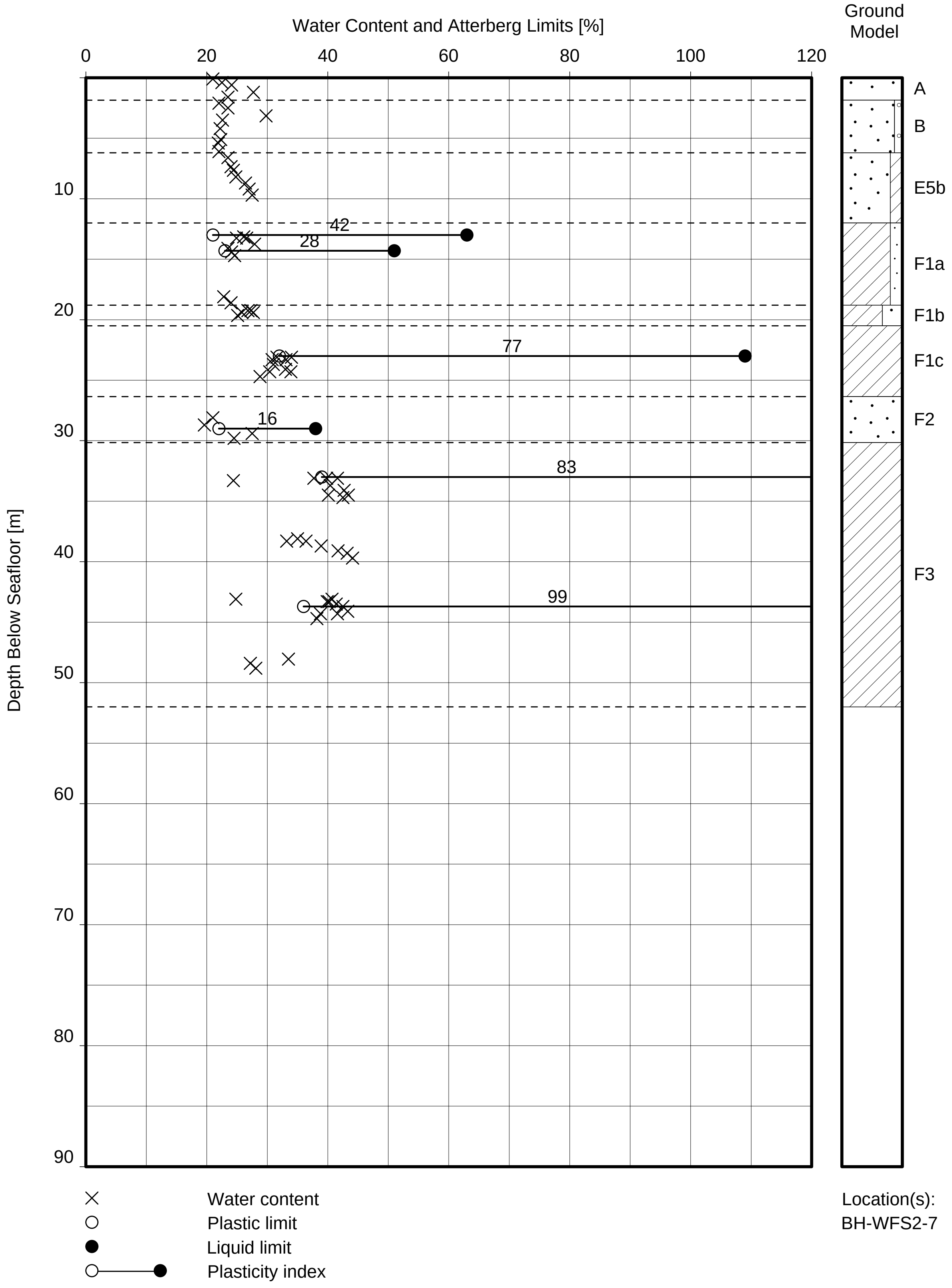
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 16:03:26

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

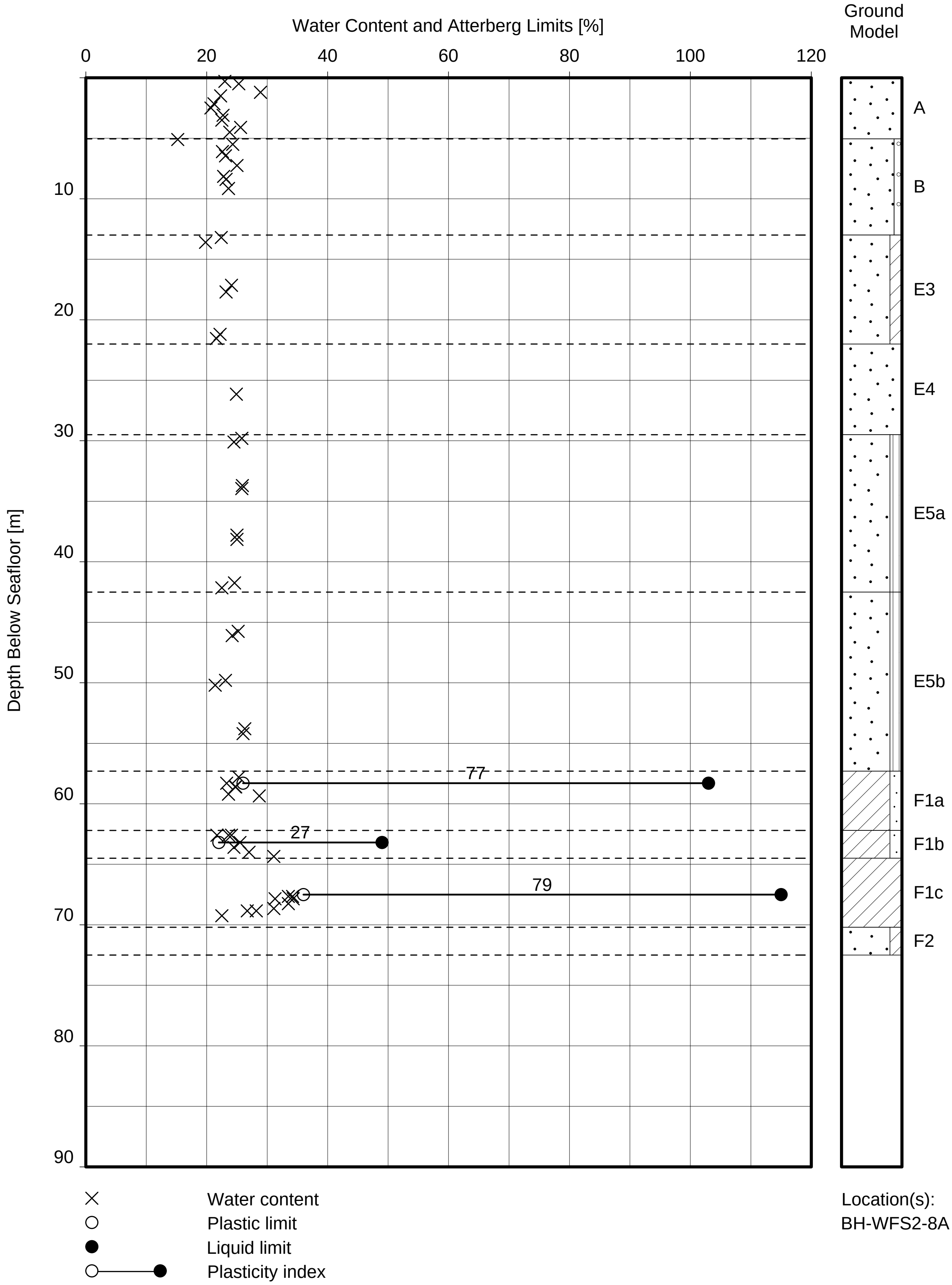


Location(s):
BH-WFS2-7

GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 16:23:43

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

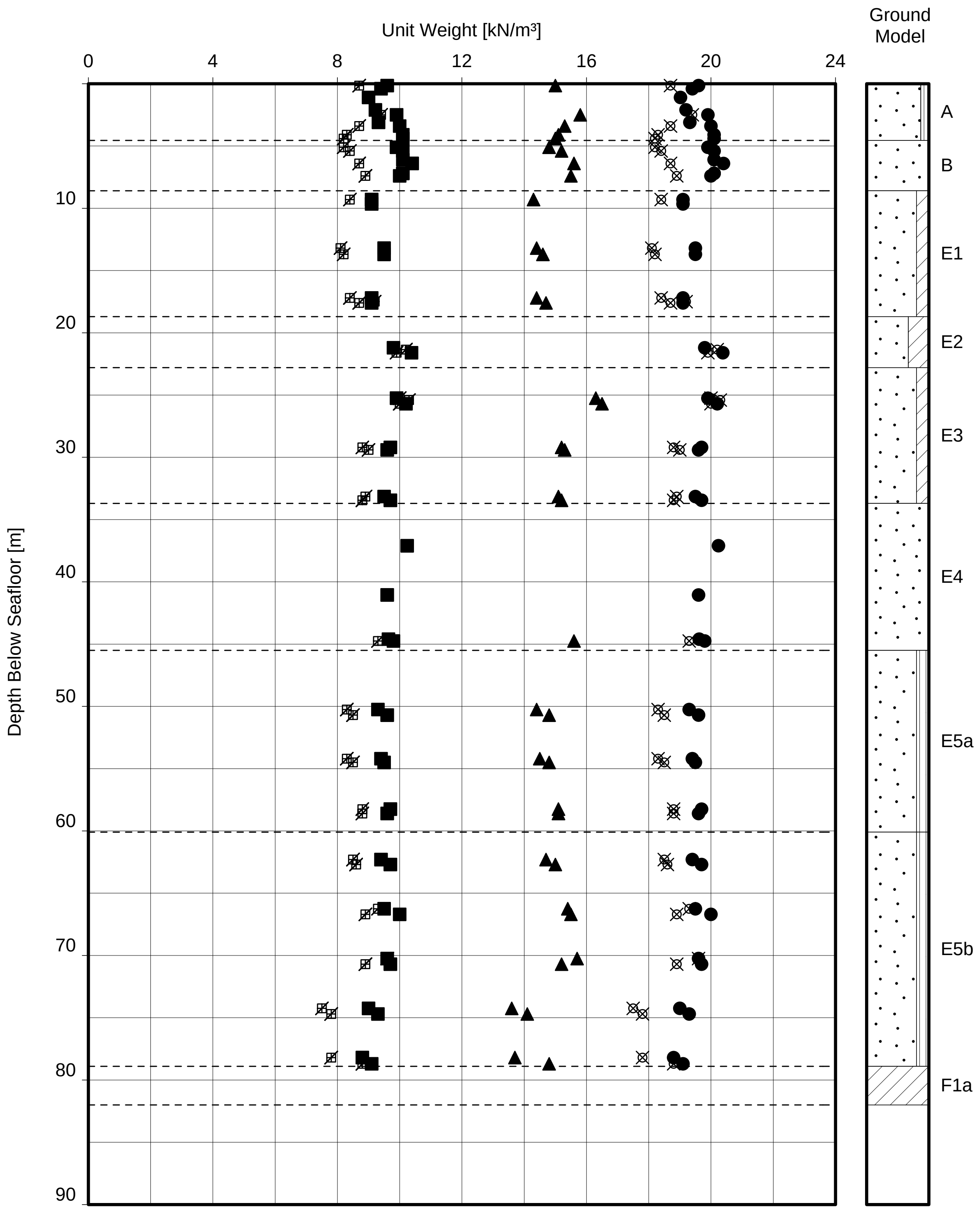
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Water Content and Atterberg limits vs Depth (all UNITS, incl. GM),GLO/2015-07-01 16:27:10

WATER CONTENT AND ATTERBERG LIMITS VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

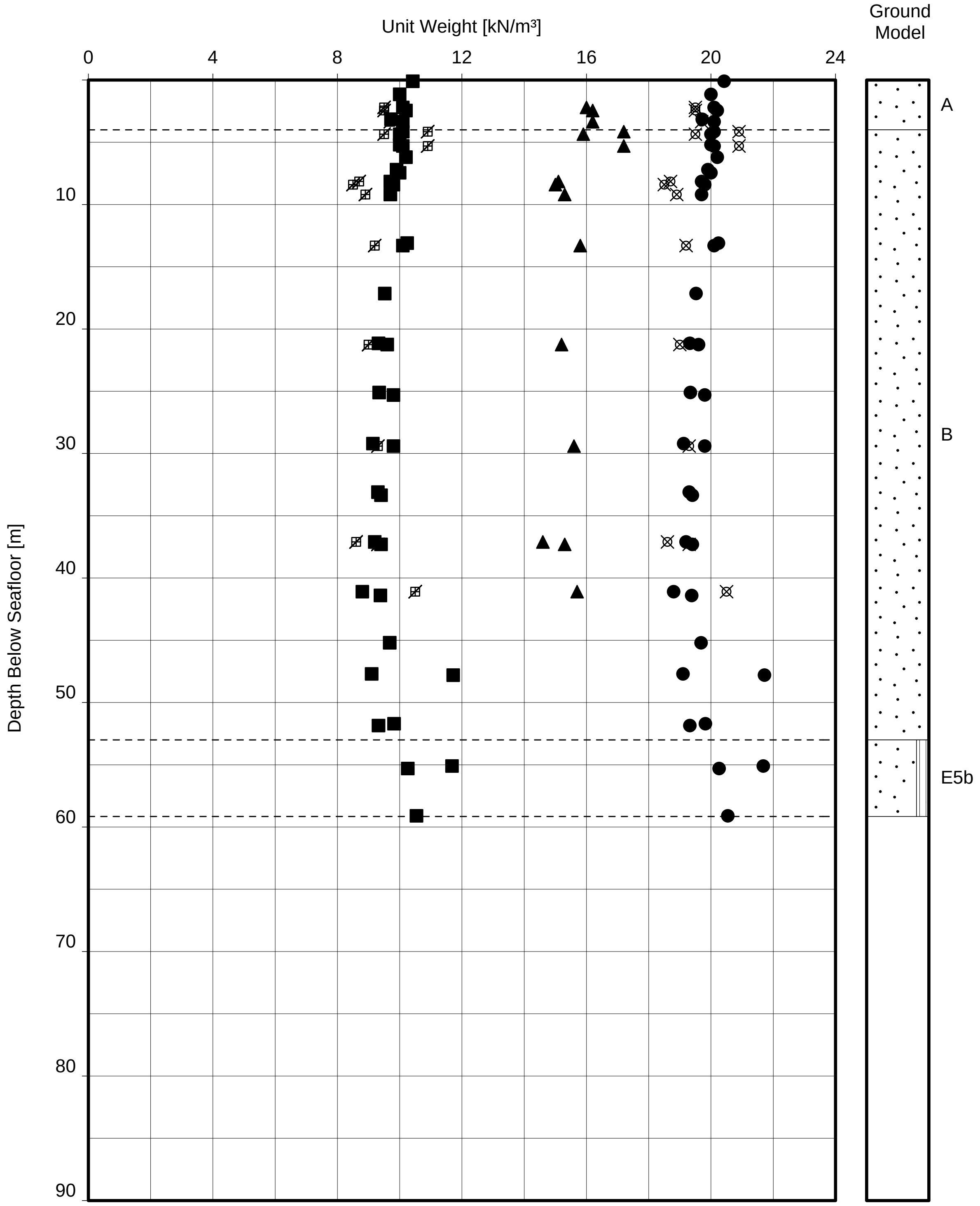
Location(s):
BH-WFS2-1A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:07:12

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- ● Unit weight derived from water content and particle density
- Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

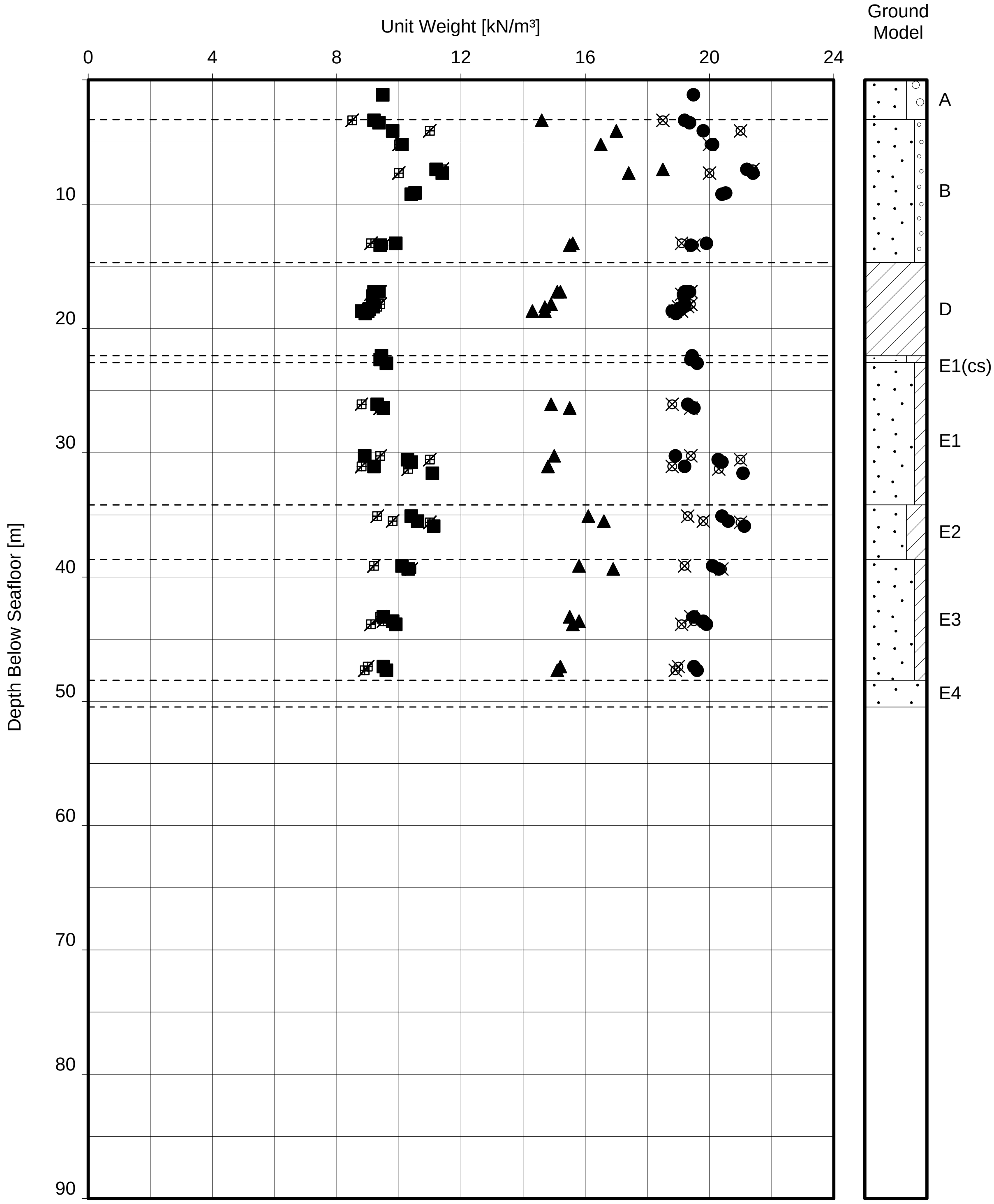
Location(s):
BH-WFS2-2A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:11:26

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- ● Unit weight derived from water content and particle density
- ⊠ Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- ⊠ Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

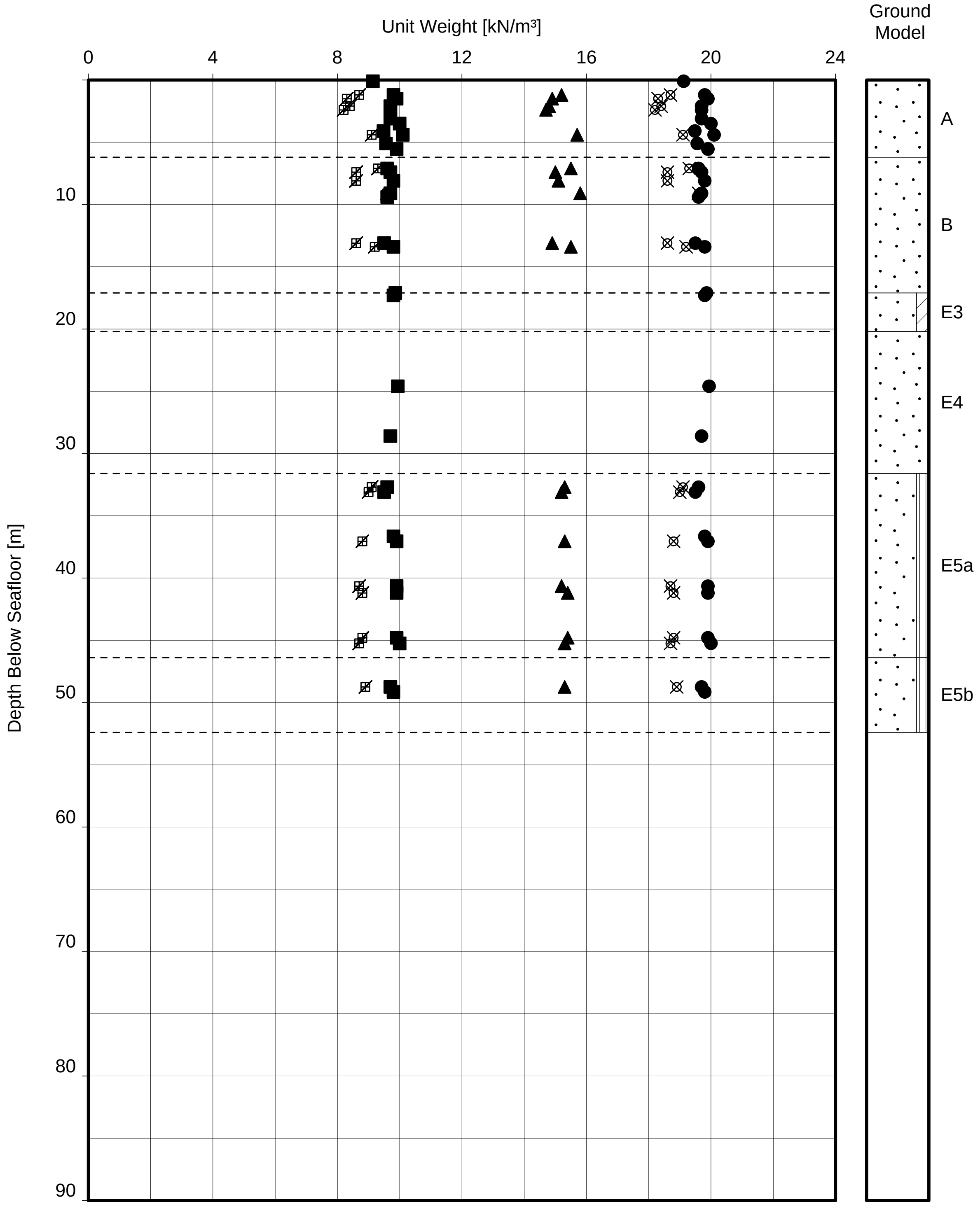
Location(s):
BH-WFS2-3

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:33:02

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

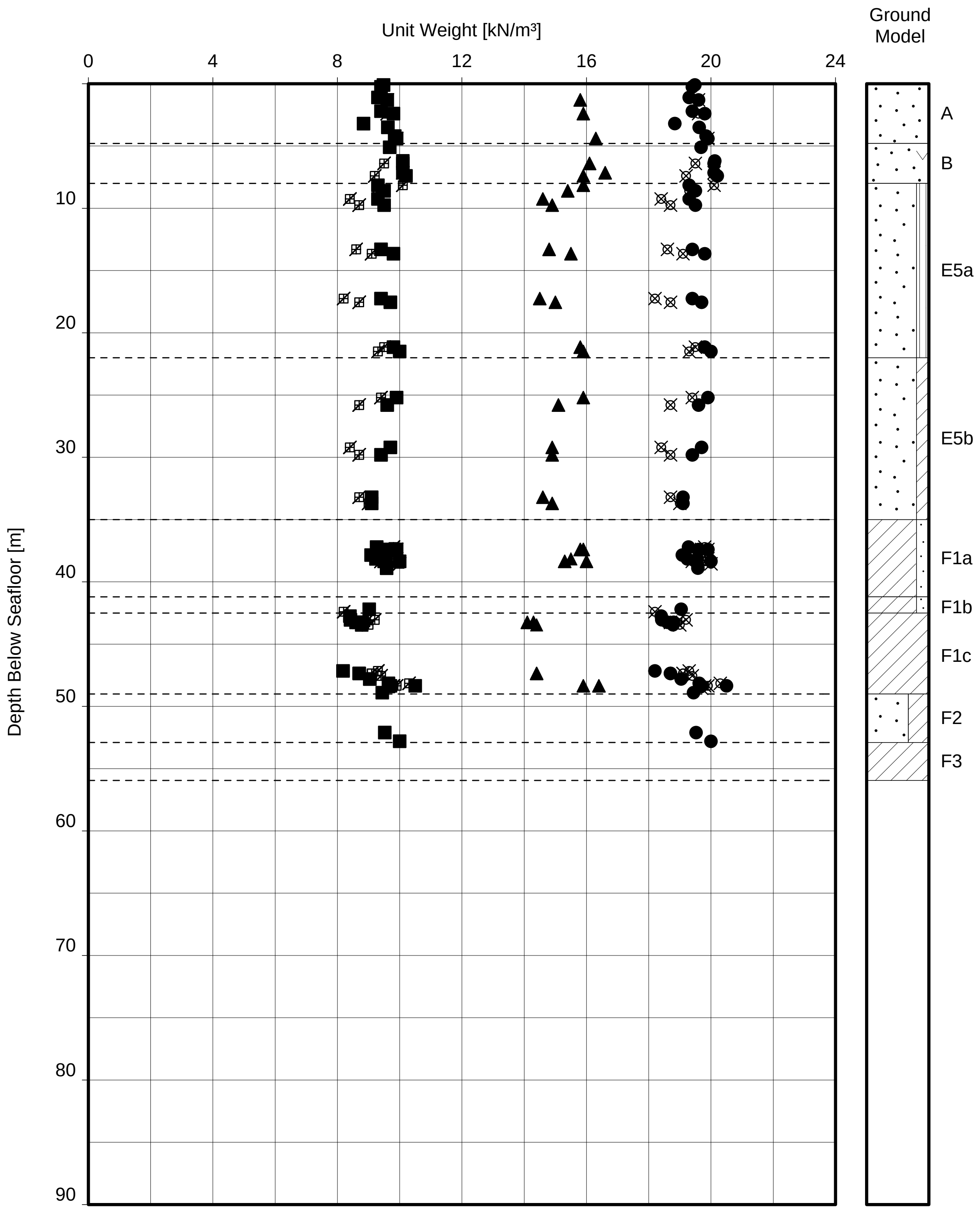
Location(s):
BH-WFS2-4

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:40:17

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- ● Unit weight derived from water content and particle density
- ⊠ Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- ⊠ Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

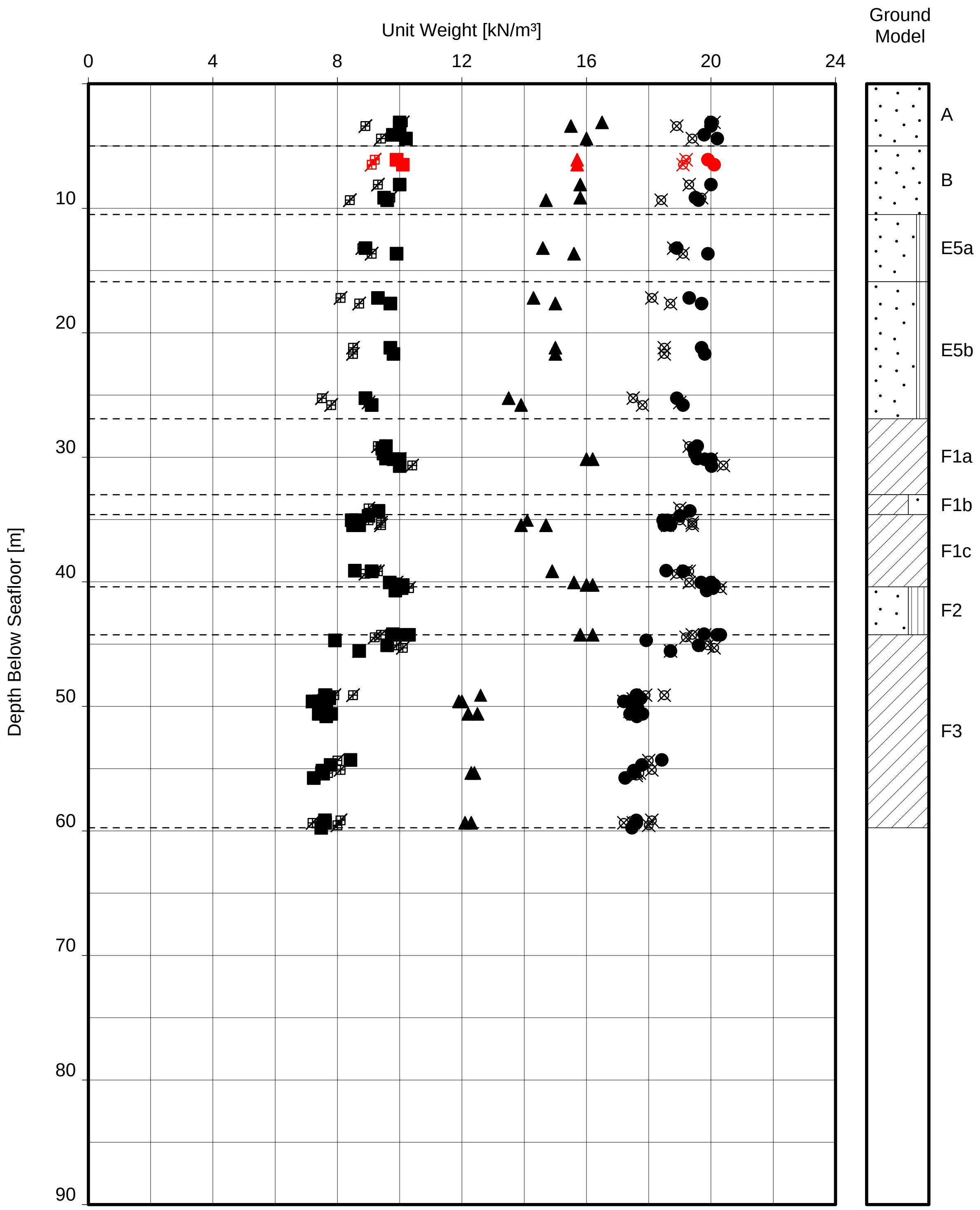
Location(s):
BH-WFS2-5

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM) GLO/2015-07-01 16:38:16

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



● Unit weight derived from water content and particle density

⊠ Unit weight derived from volume mass calculation

■ Submerged unit weight derived from water content and particle density

⊠ Submerged unit weight derived from volume mass calculation

▲ Dry unit weight derived from volume mass calculation

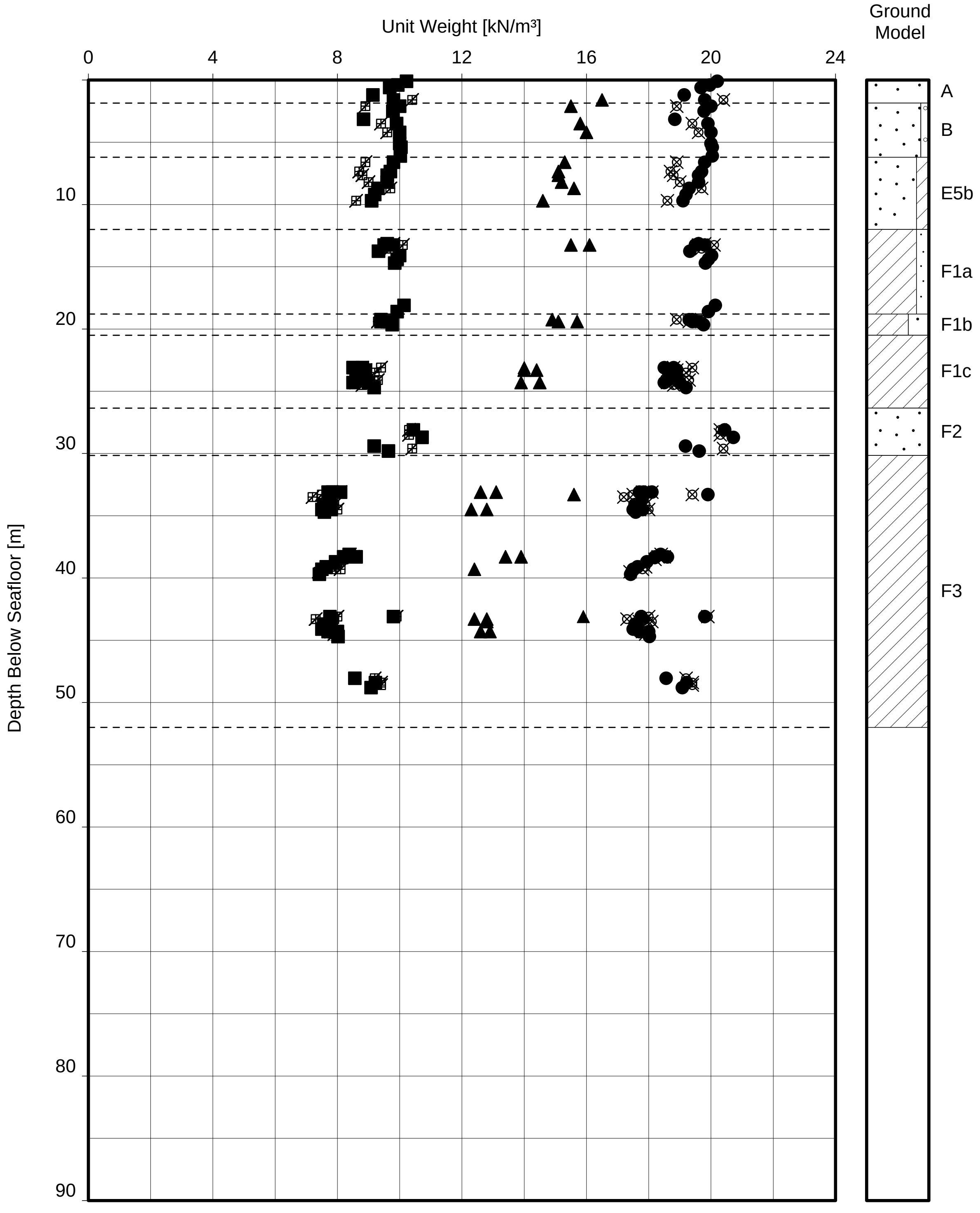
Location(s):
BH-WFS2-6A
BH-WFS2-6B

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:04:03

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- ● Unit weight derived from water content and particle density
- ⊠ Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- ⊠ Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

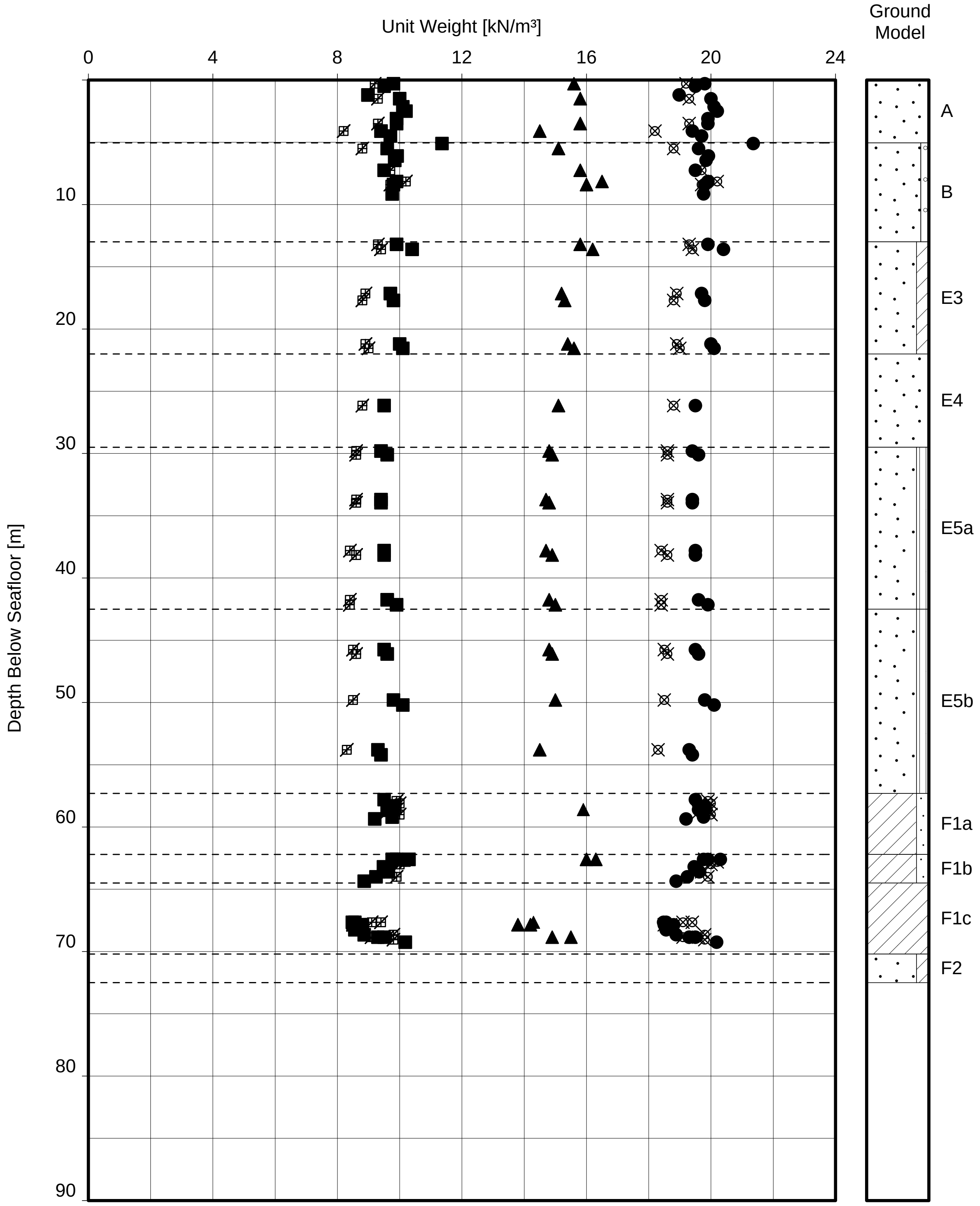
Location(s):
BH-WFS2-7

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:24:05

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- ● Unit weight derived from water content and particle density
- ⊠ Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- ⊠ Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

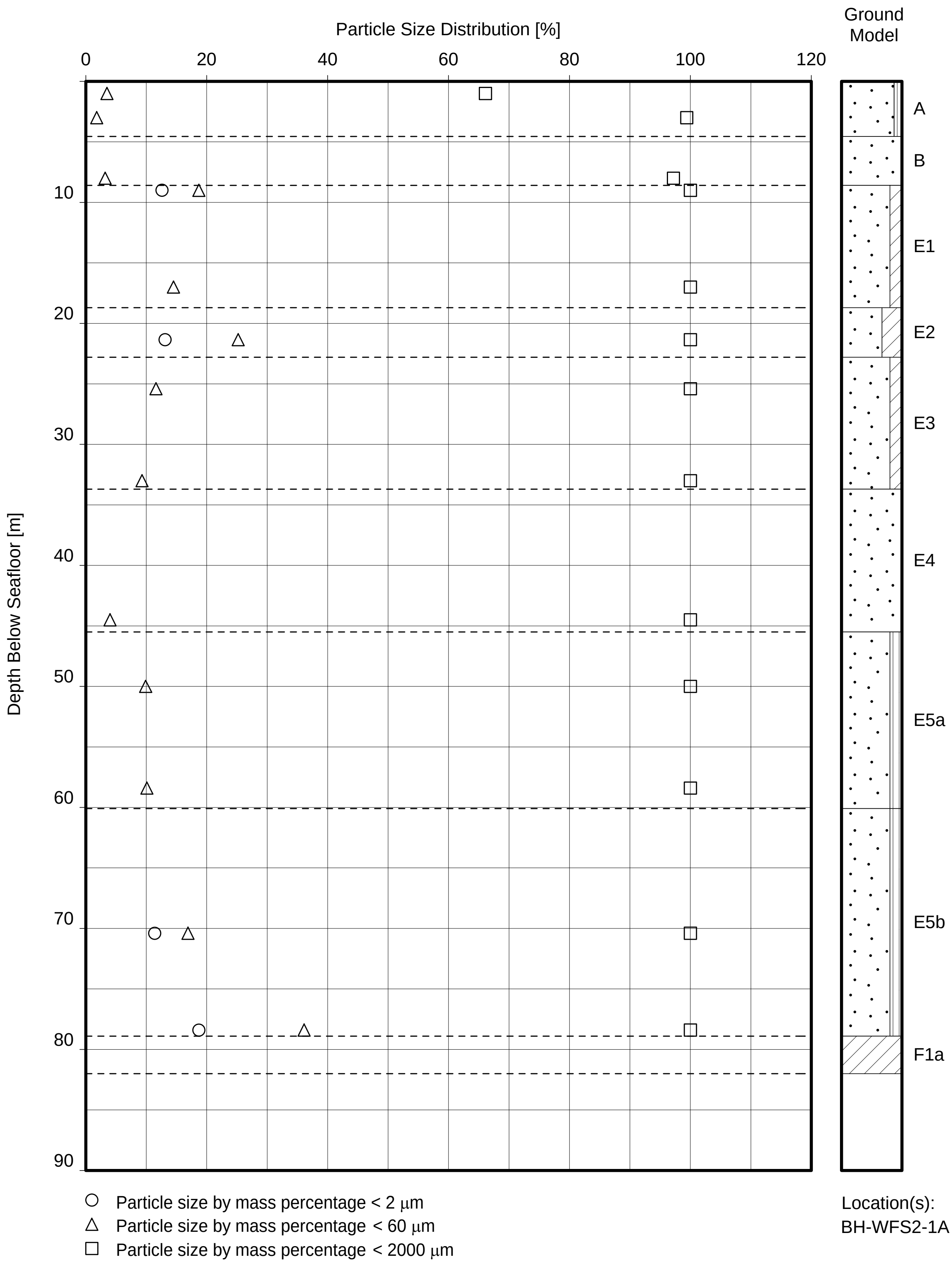
Location(s):
BH-WFS2-8A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Unit Weight, Dry Unit Weight and Submerged Unit Weight versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:27:30

UNIT WEIGHT, DRY UNIT WEIGHT AND SUBMERGED UNIT WEIGHT VERSUS DEPTH

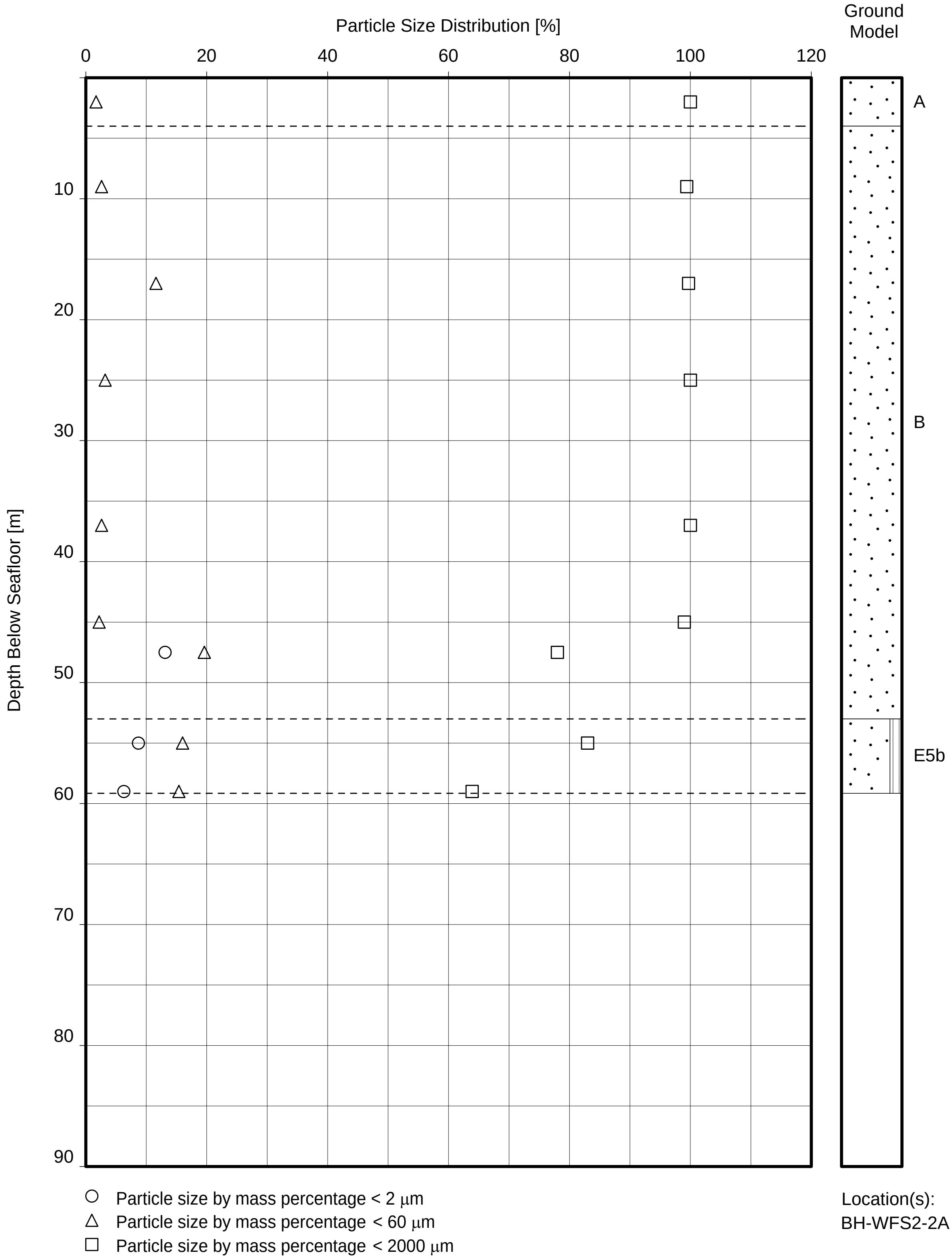
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM),GLO/2015-07-01 15:07:32

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

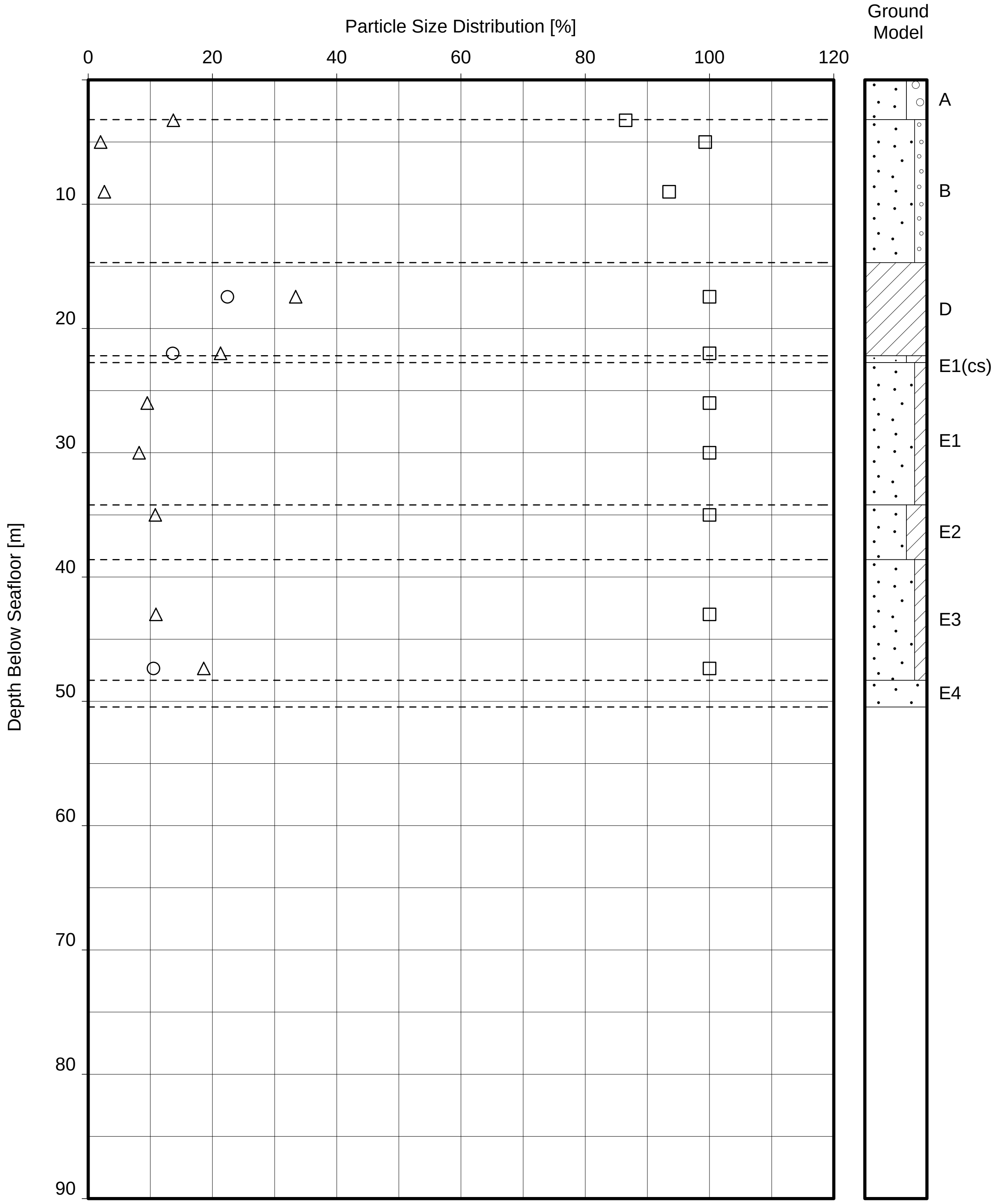
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:13:27

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



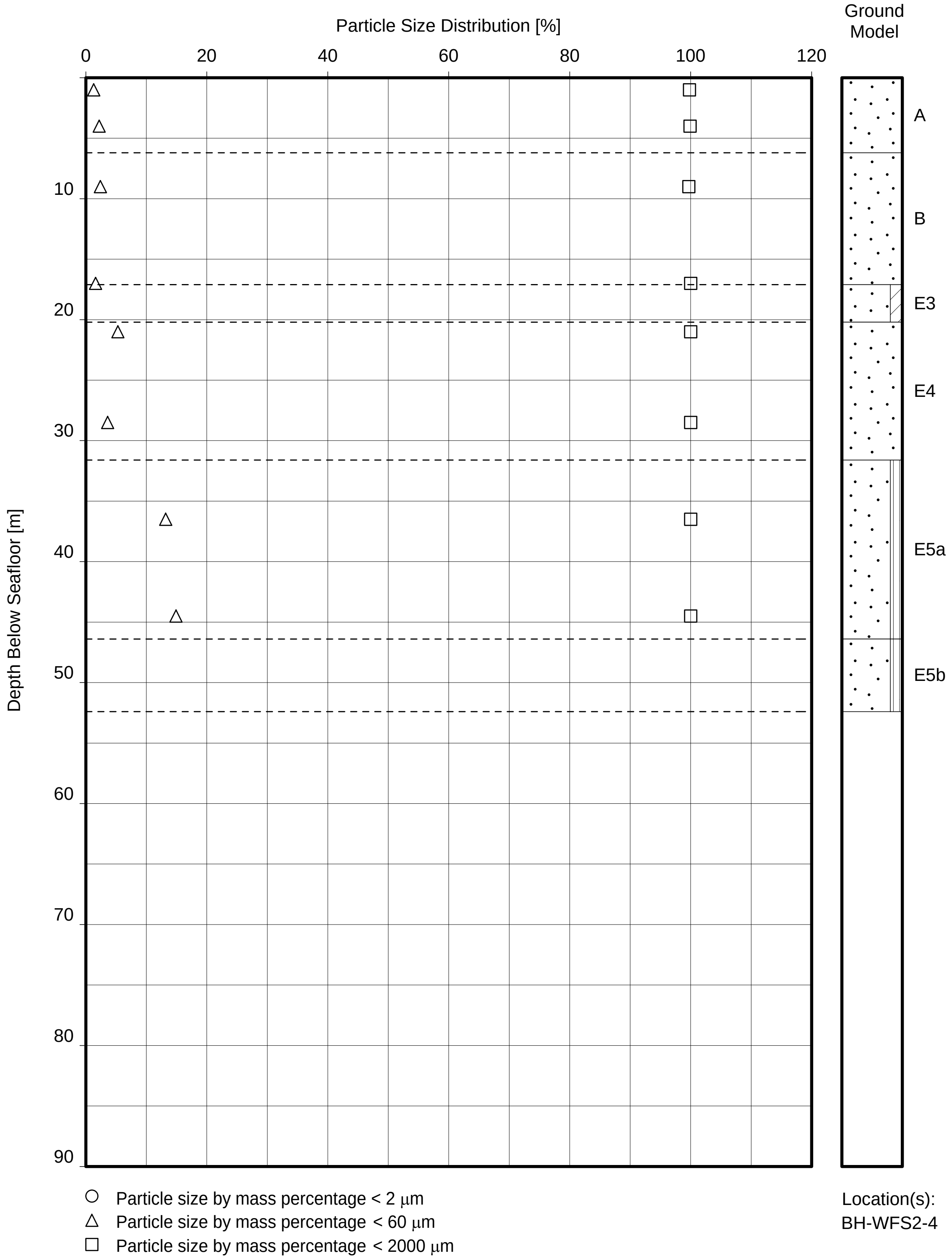
○ Particle size by mass percentage < 2 µm
△ Particle size by mass percentage < 60 µm
□ Particle size by mass percentage < 2000 µm

Location(s):
BH-WFS2-3

GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM),GLO/2015-07-01 16:33:26

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

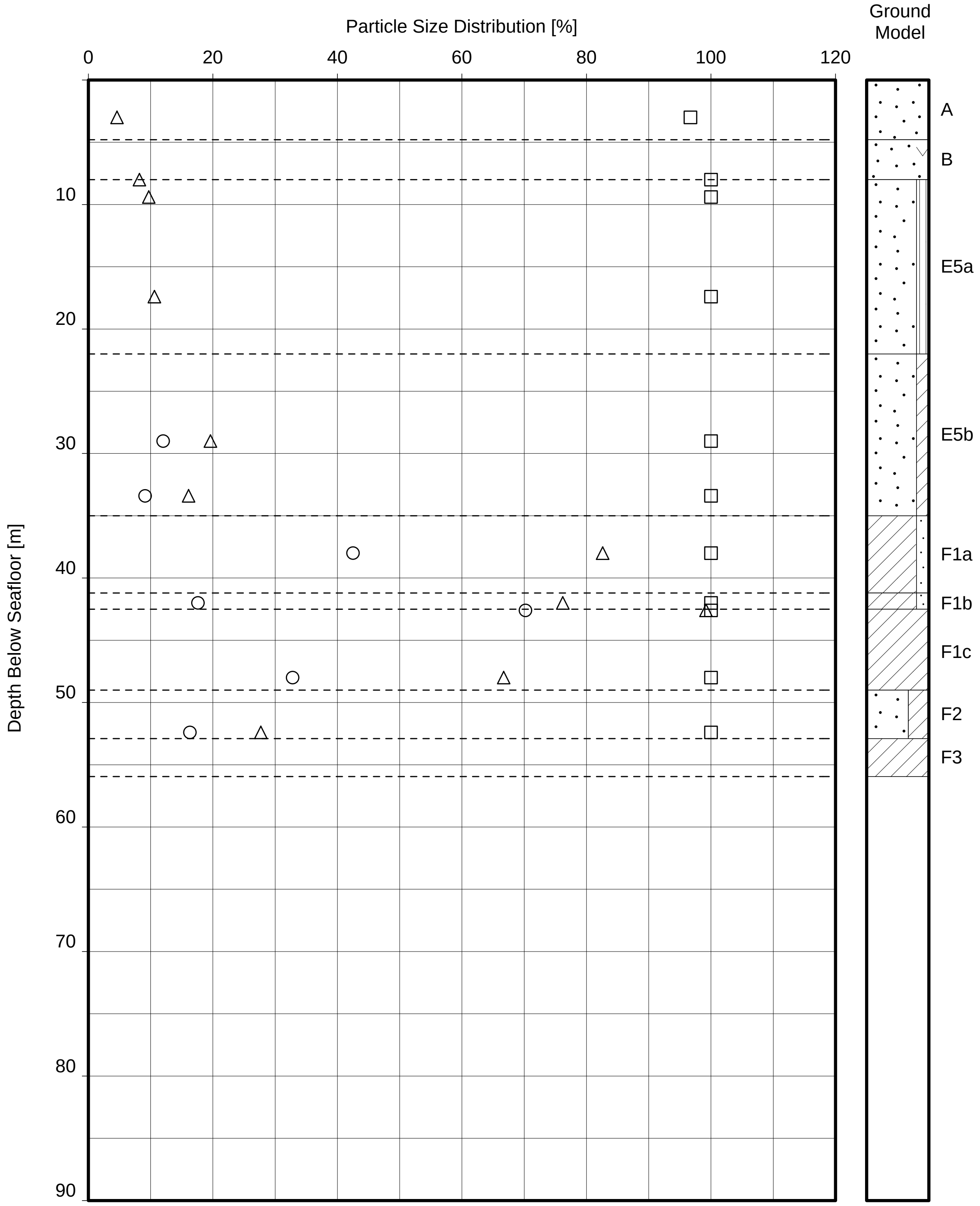
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:40:37

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



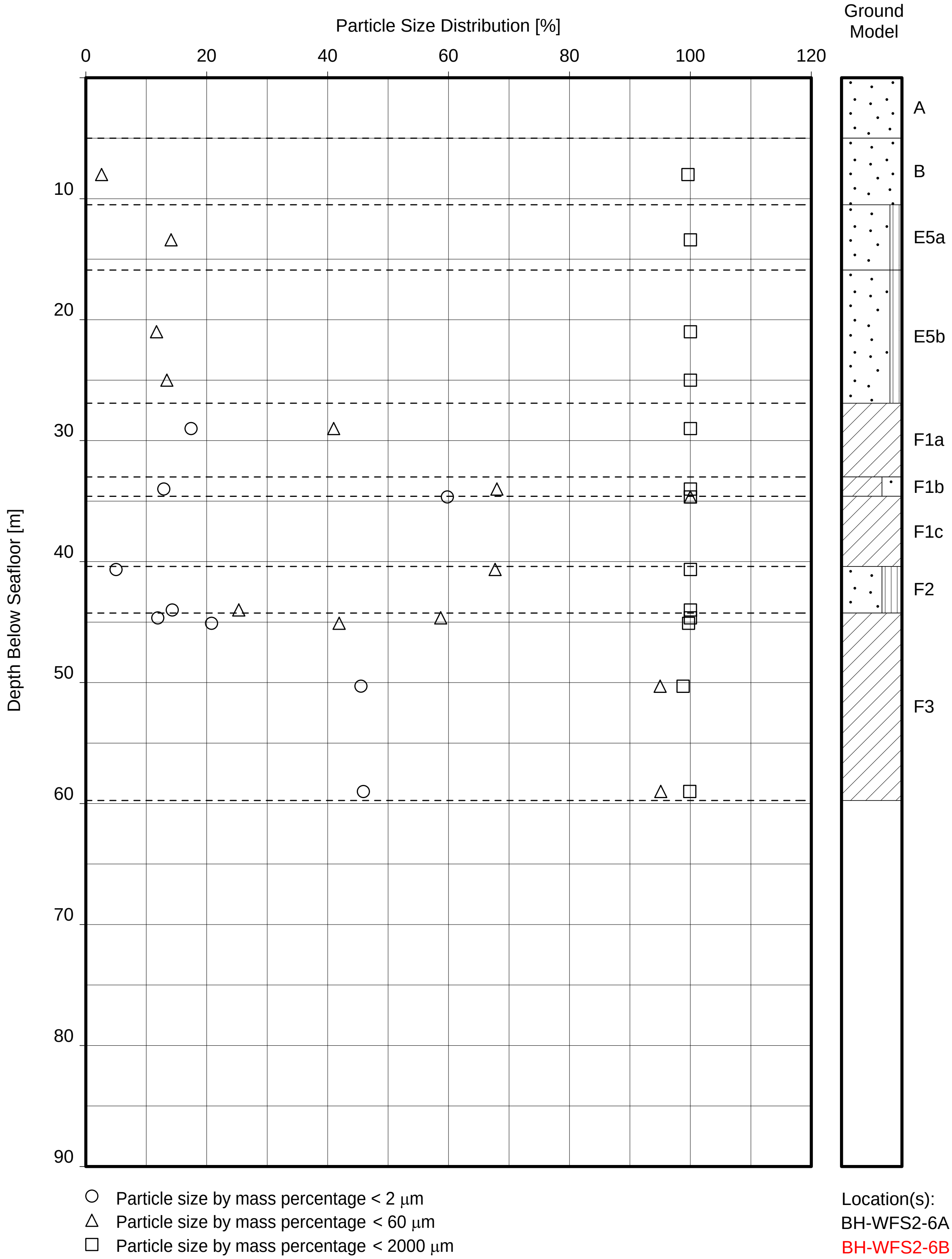
○ Particle size by mass percentage < 2 µm
△ Particle size by mass percentage < 60 µm
□ Particle size by mass percentage < 2000 µm

Location(s):
BH-WFS2-5

GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:38:41

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

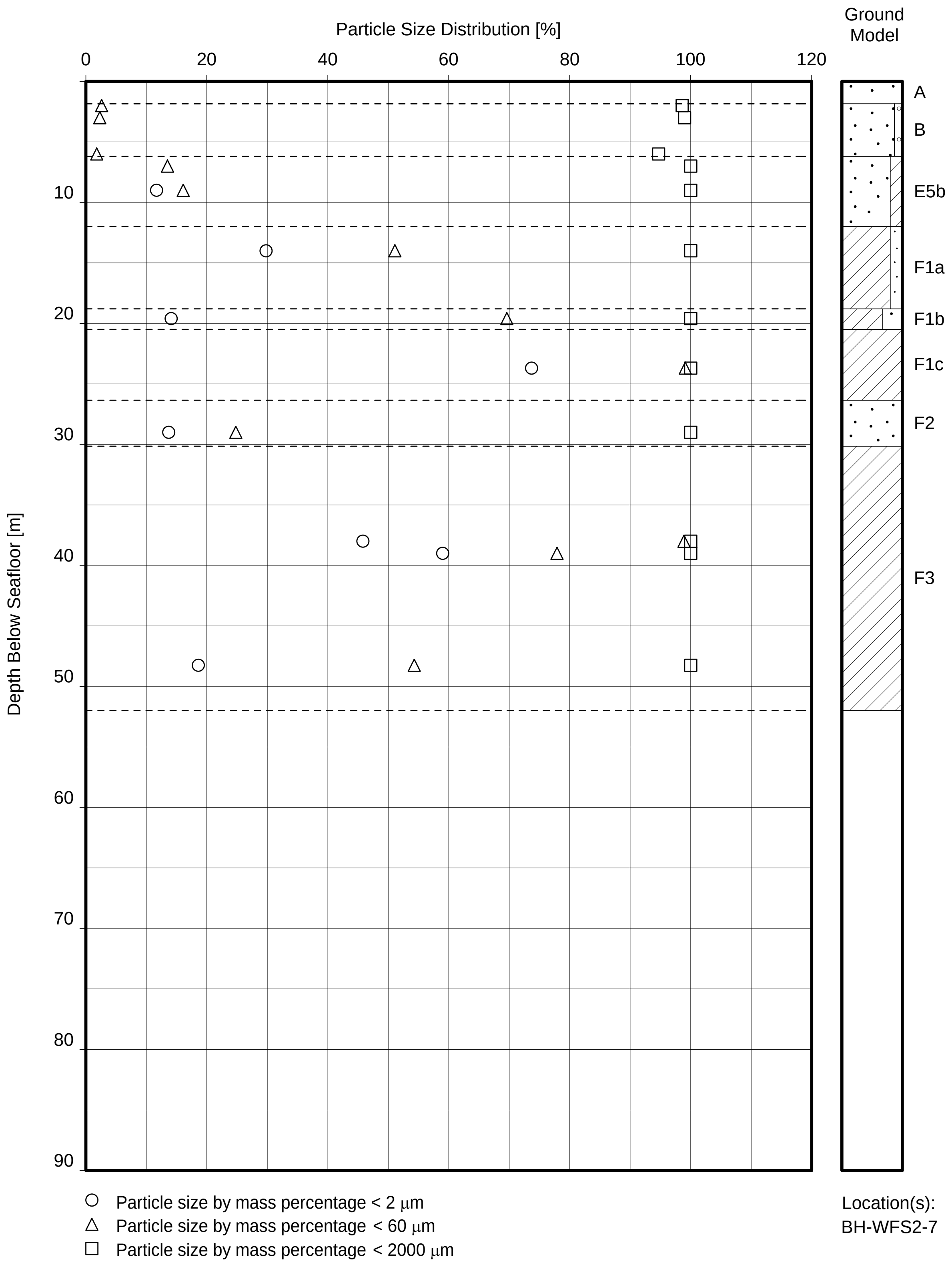
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM),GLO/2015-07-01 16:04:35

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

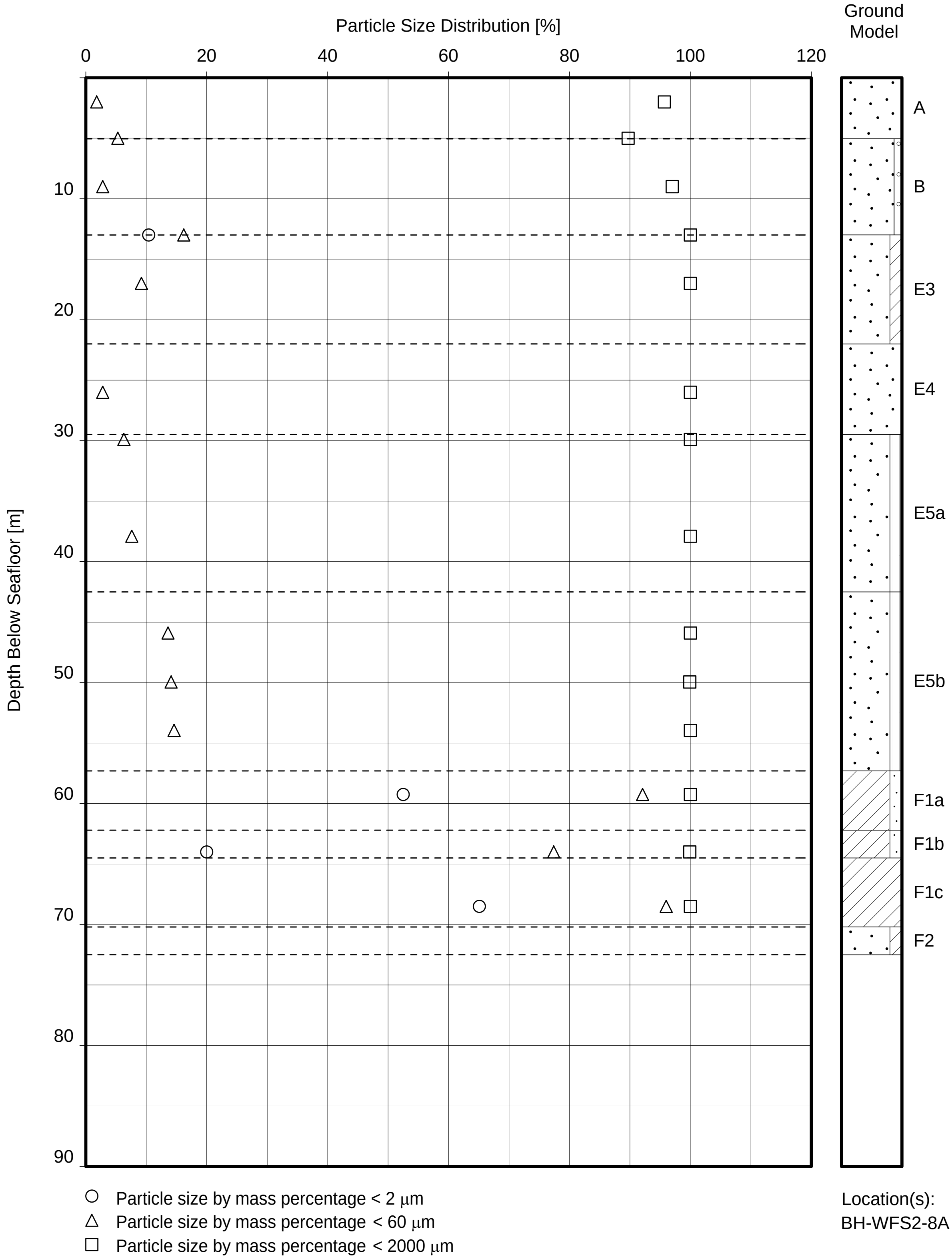
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:23:20

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

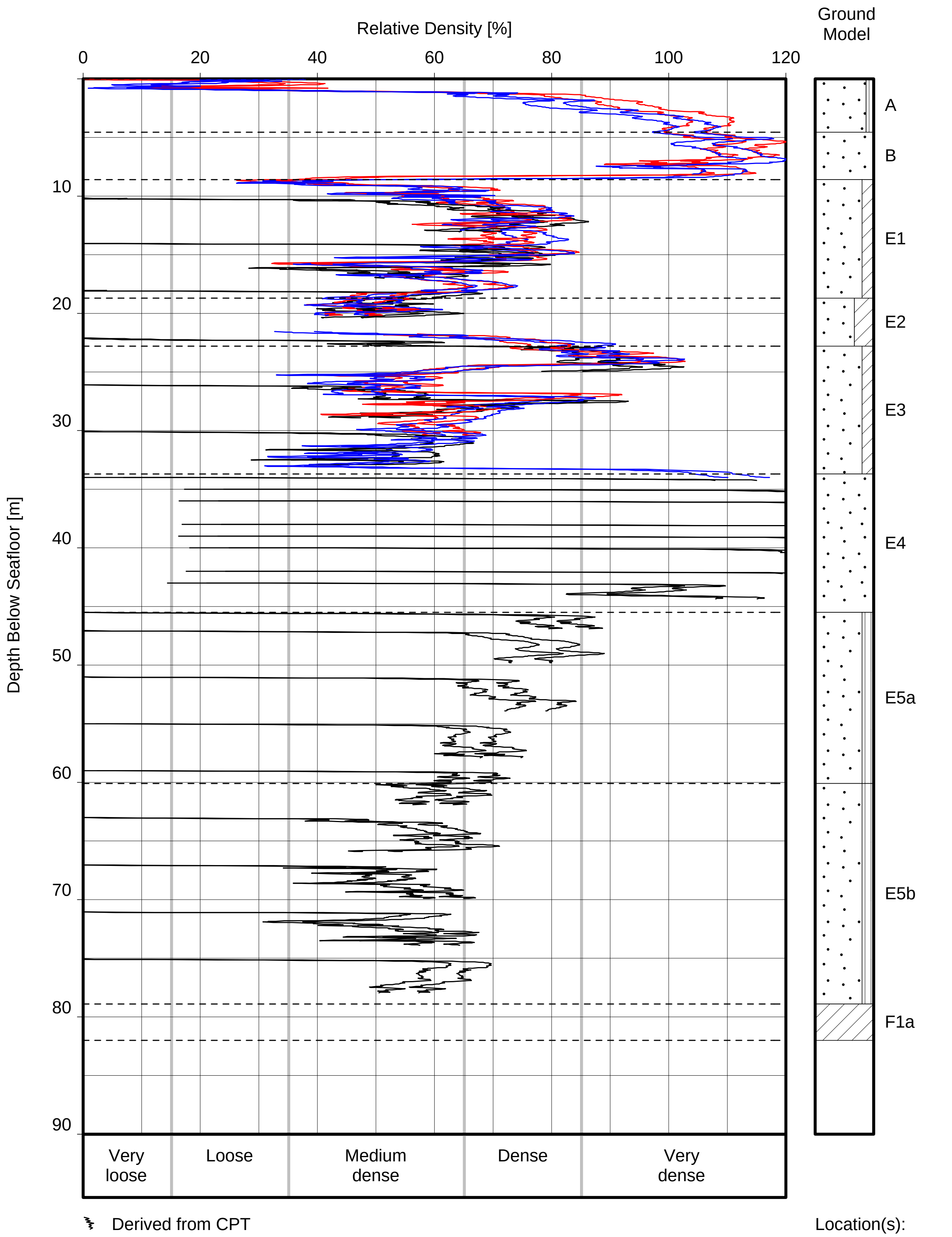
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/Particle Size Distribution versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:28:02

PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

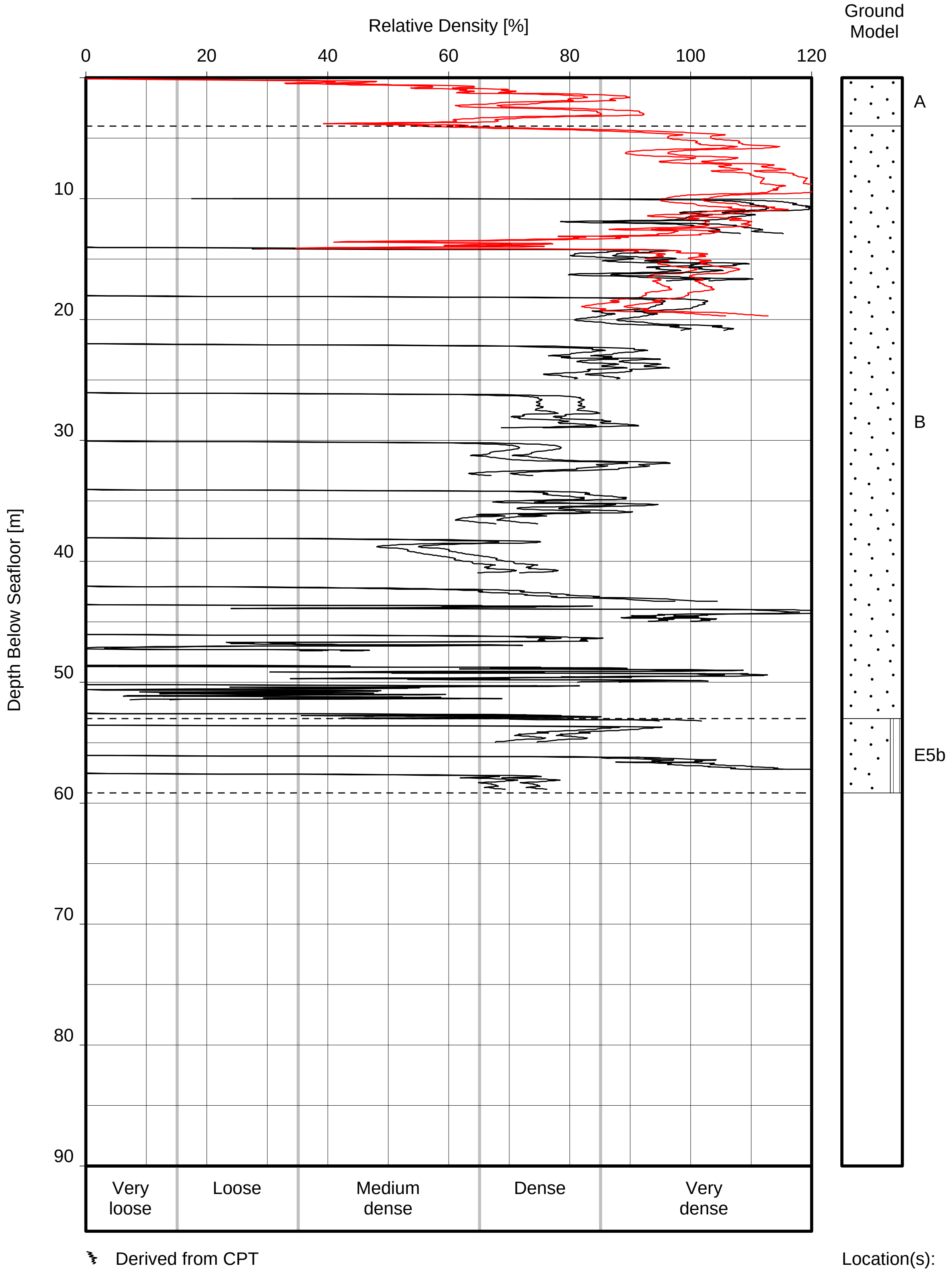


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 15:08:39

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



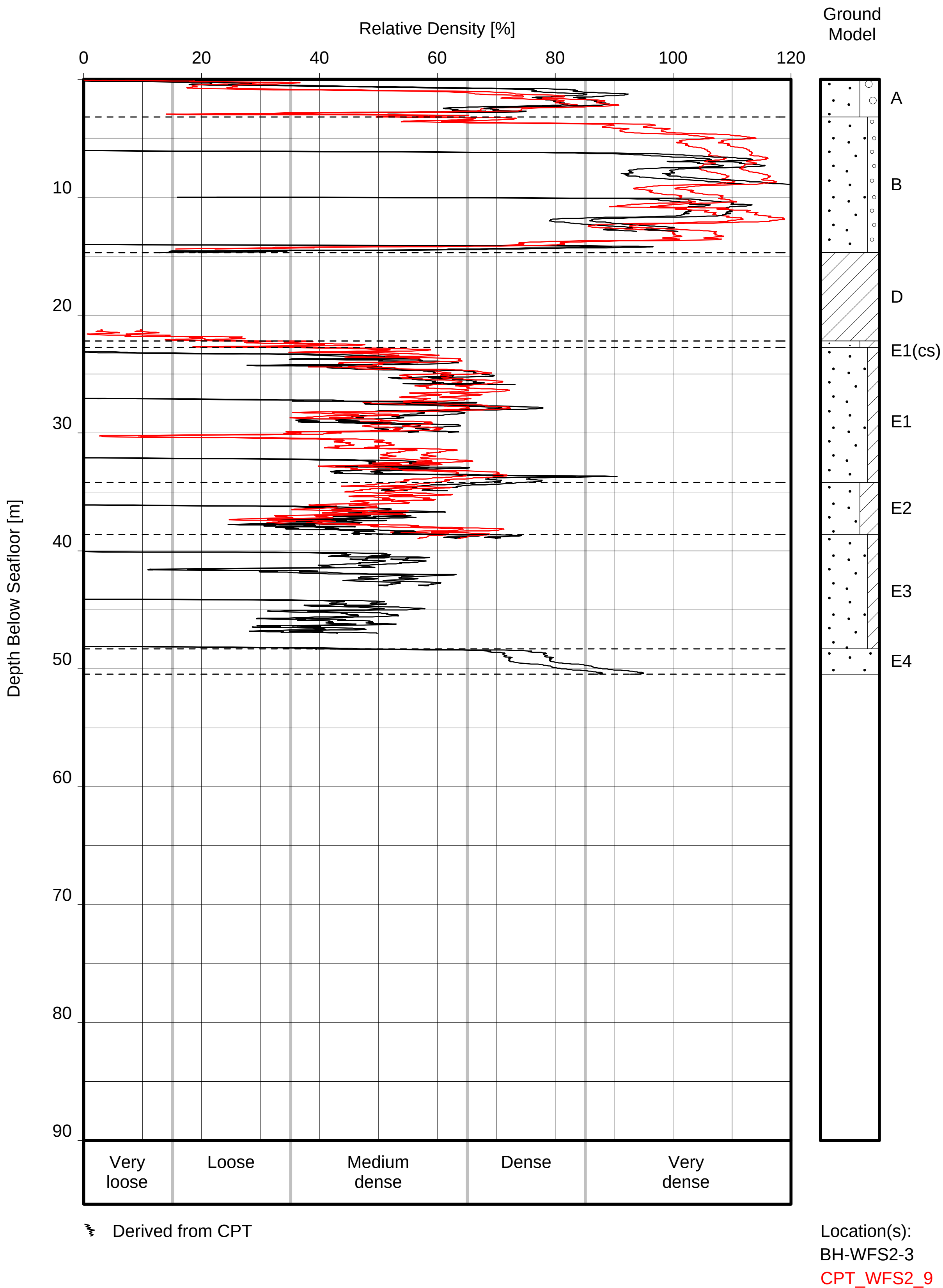
Location(s):
BH-WFS2-2A
CPT_WFS2_16

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 15:24:45

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

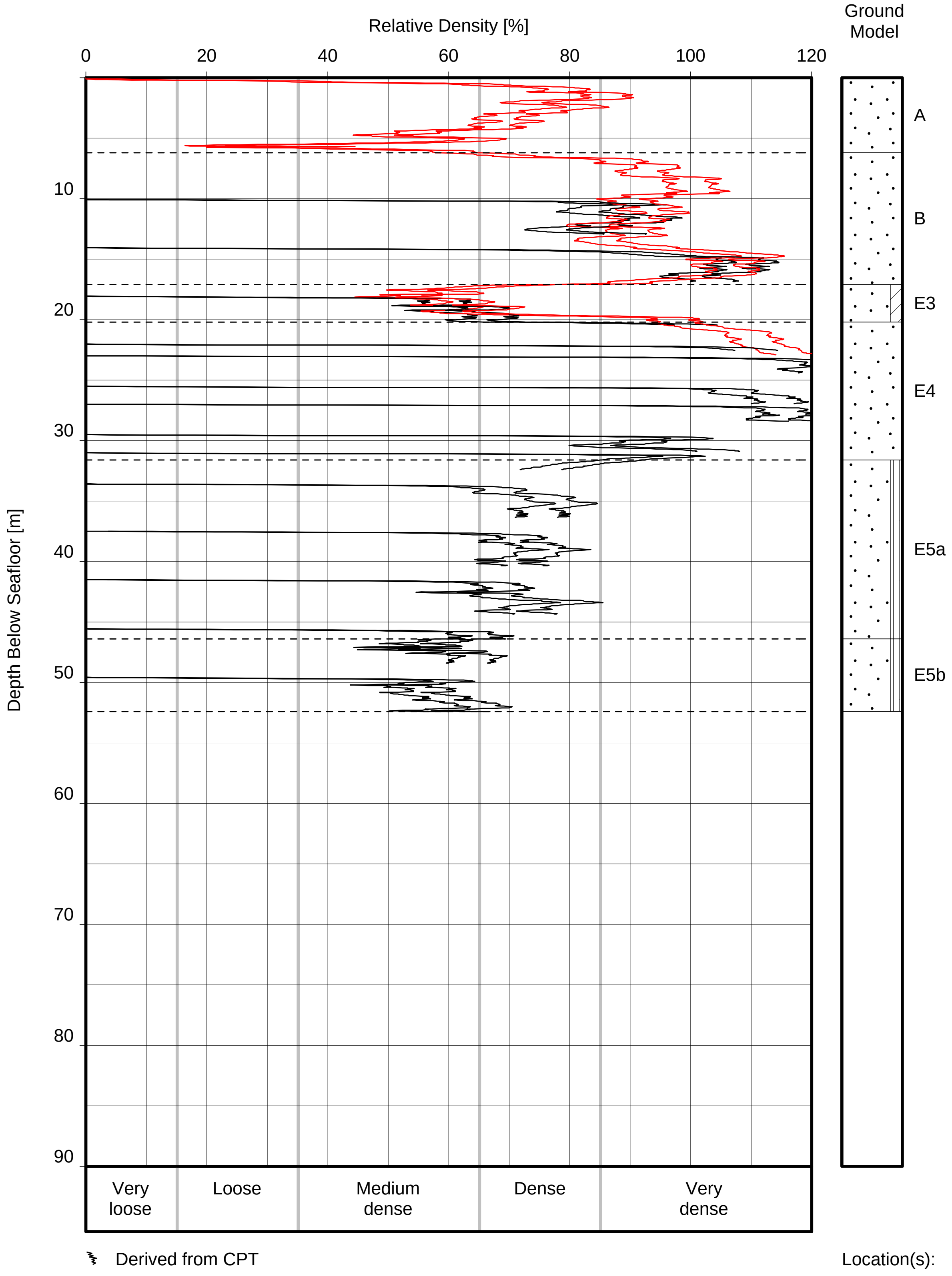


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 16:35:48

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



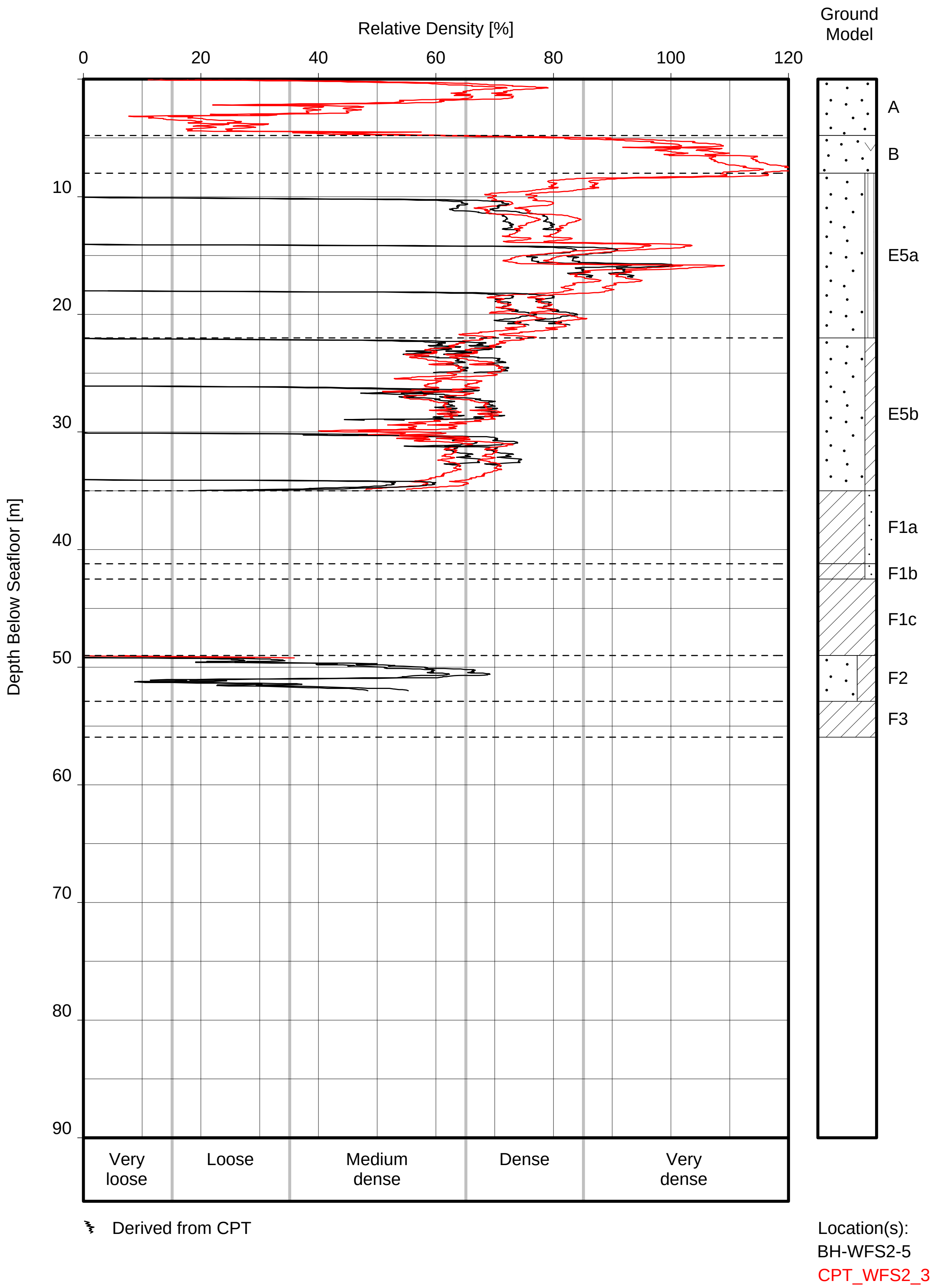
Location(s):
BH-WFS2-4
CPT_WFS2_27

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 15:42:53

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

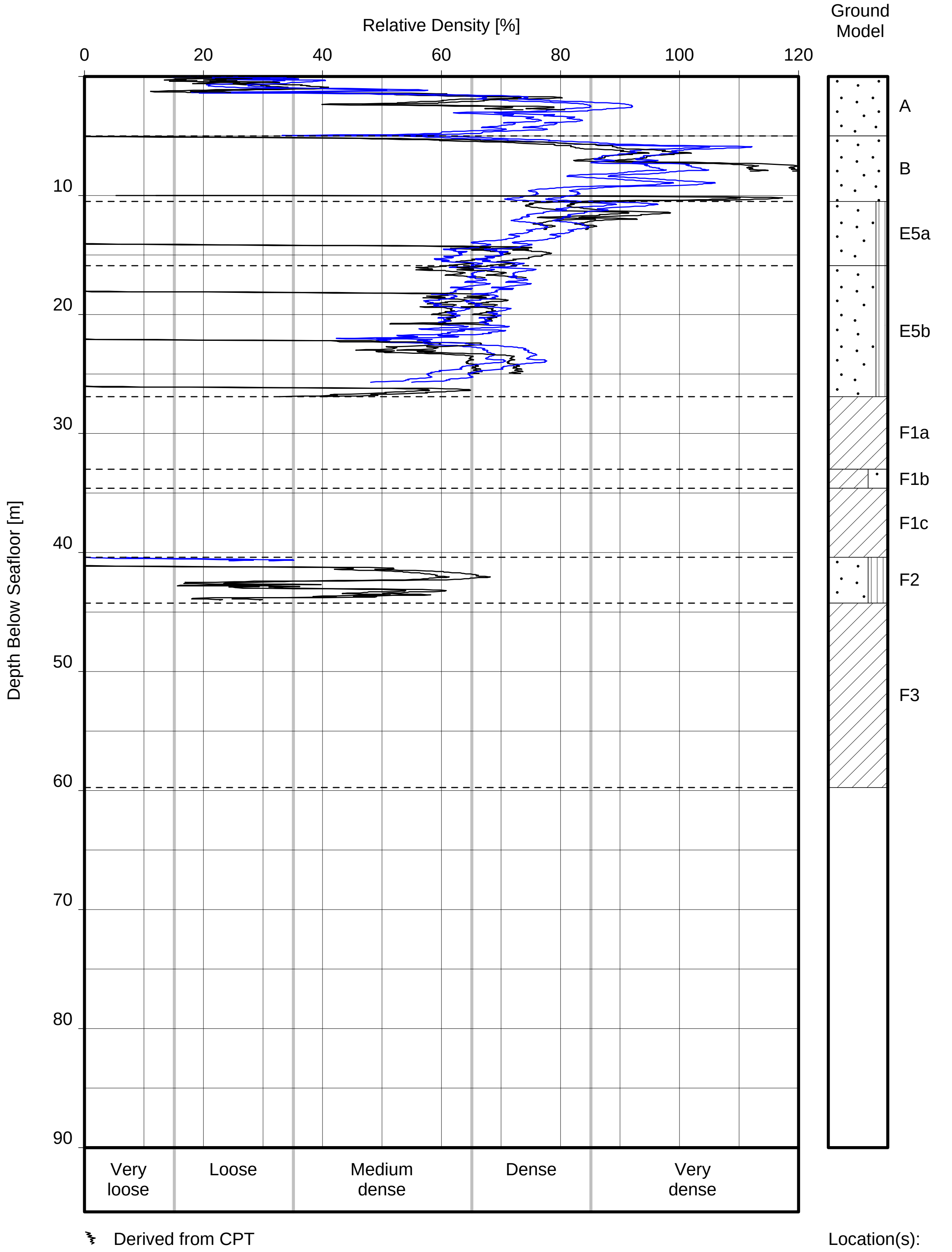


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 16:42:50

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

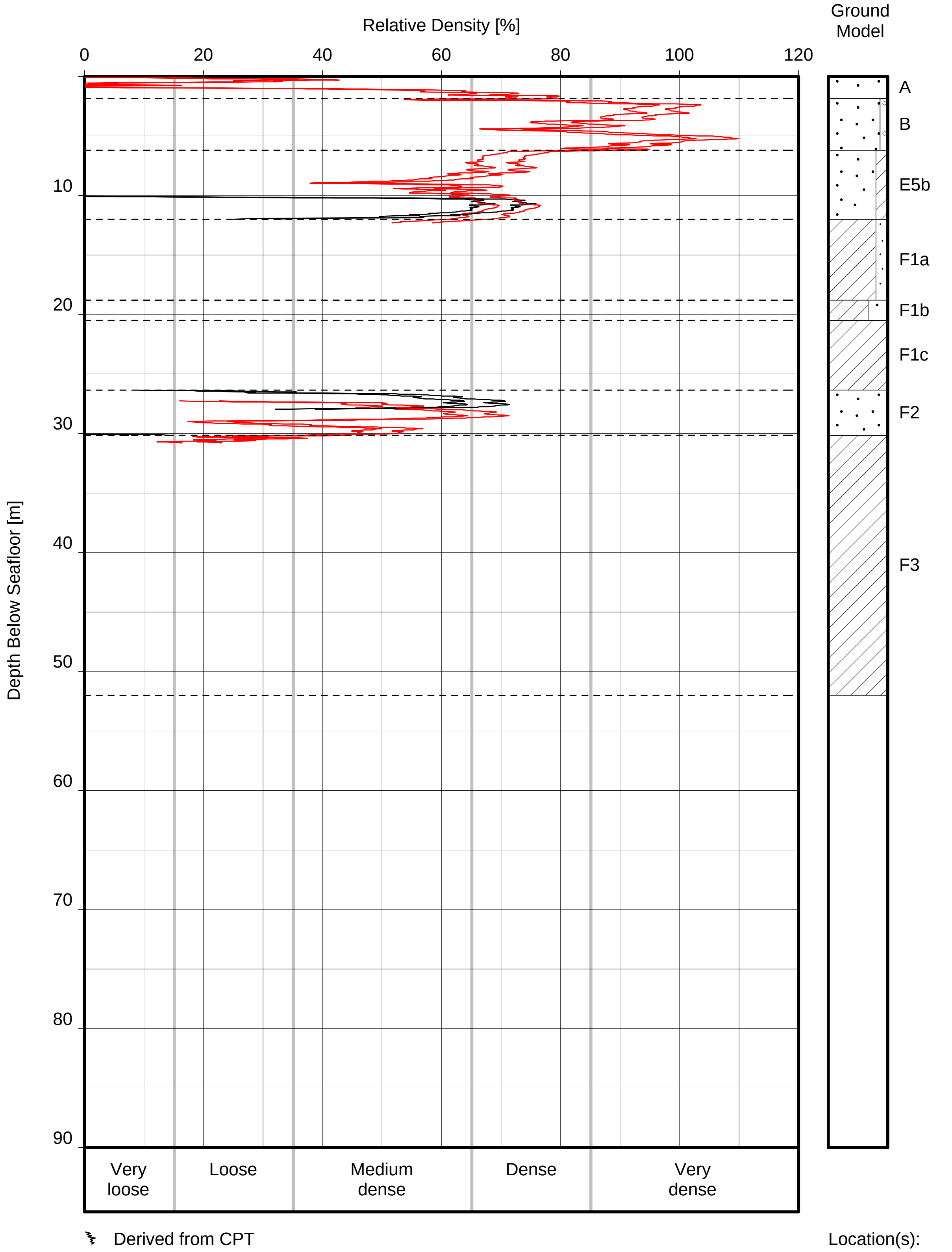


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 16:06:19

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

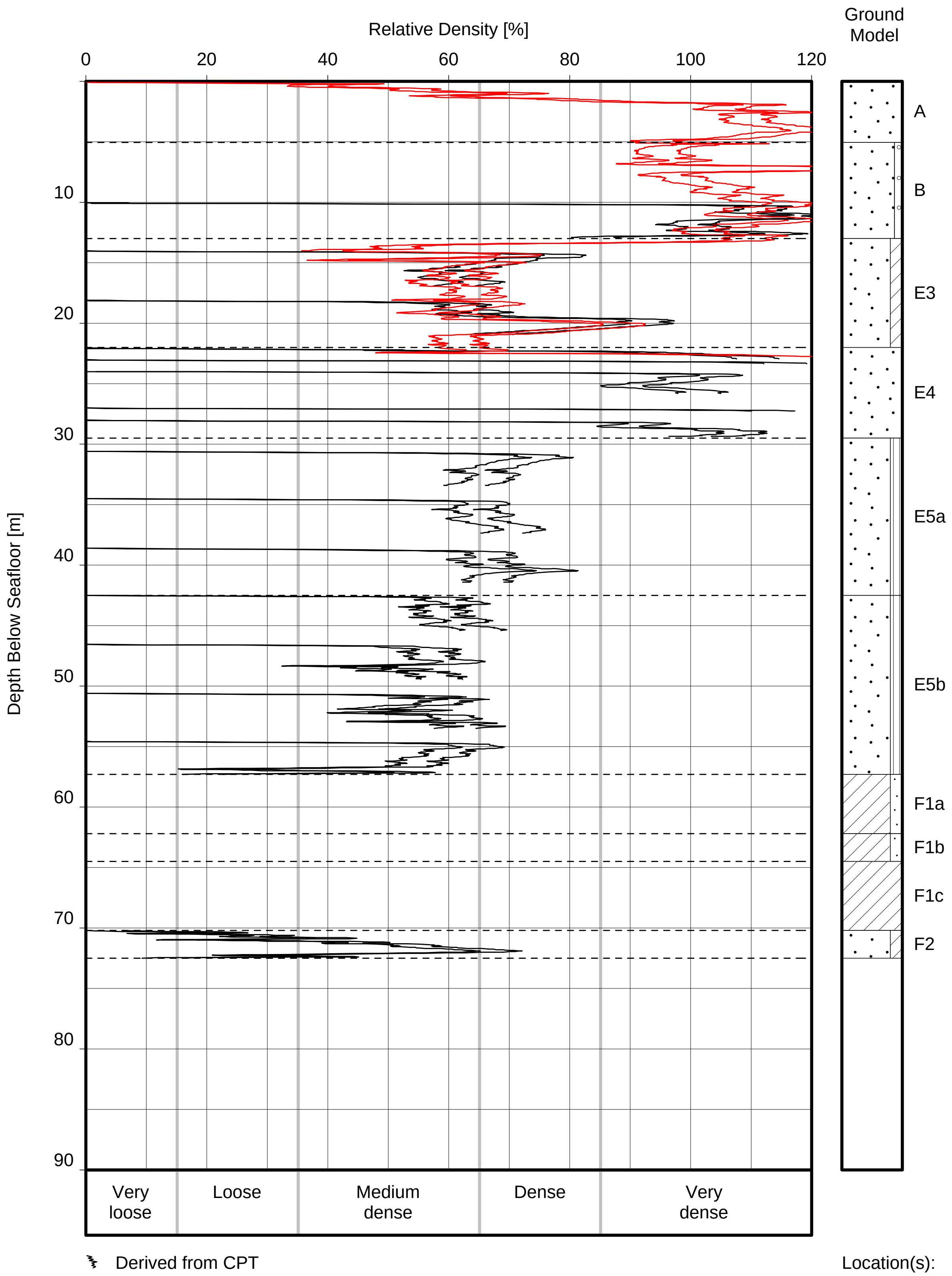


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 16:25:31

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



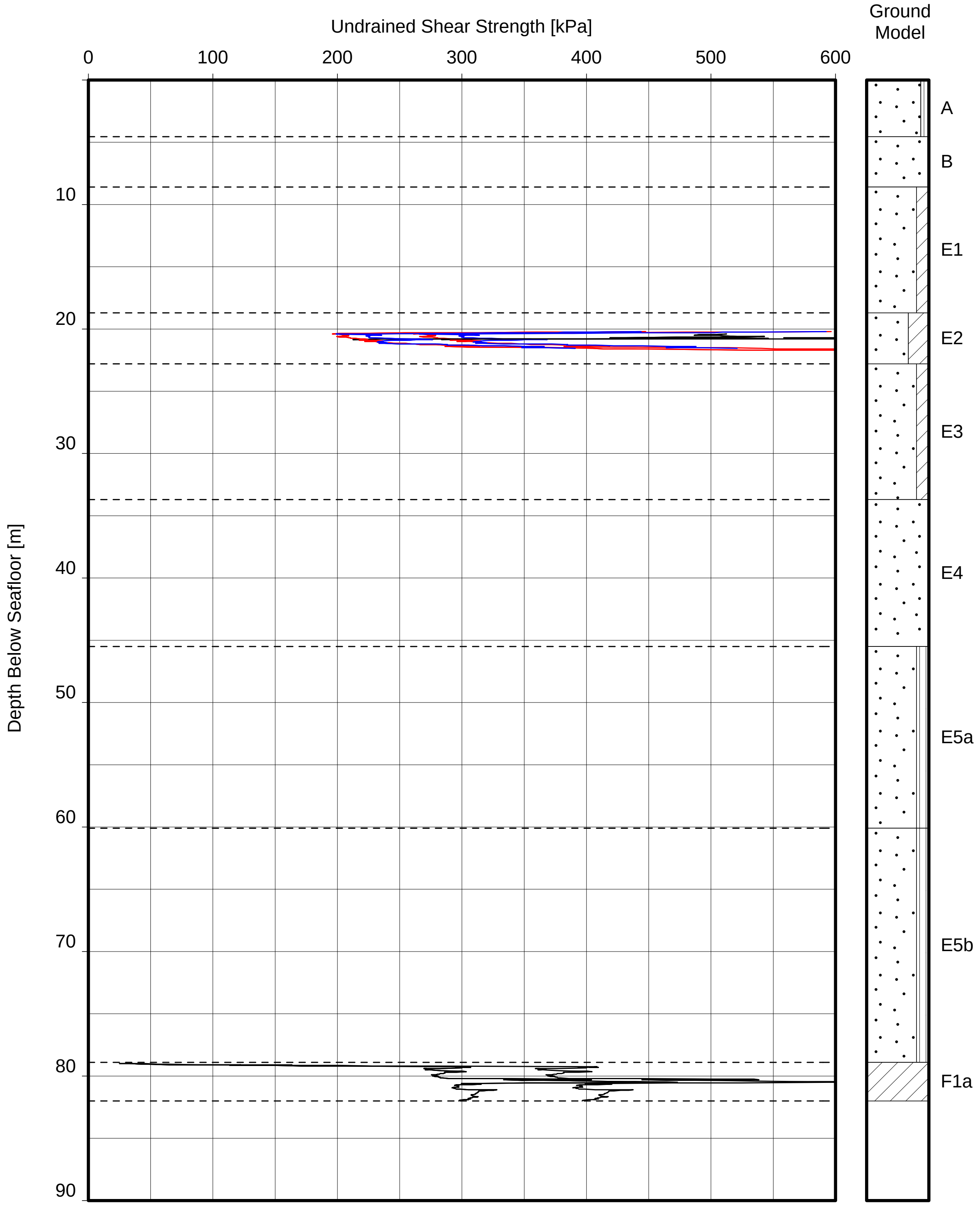
Location(s):
BH-WFS2-8A
CPT_WFS2_15

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT

GeODin/Relative Density versus Depth 0-120 % (all UNITS, incl. GM).GLO/2015-07-01 16:29:26

RELATIVE DENSITY VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



△ Pocket penetrometer
○ Torvane
▽ Fallcone
⊕ Laboratory vane

● UU-triaxial
■ CU-triaxial
◪ Direct simple shear
◆ In situ vane shear
Derived from CPT

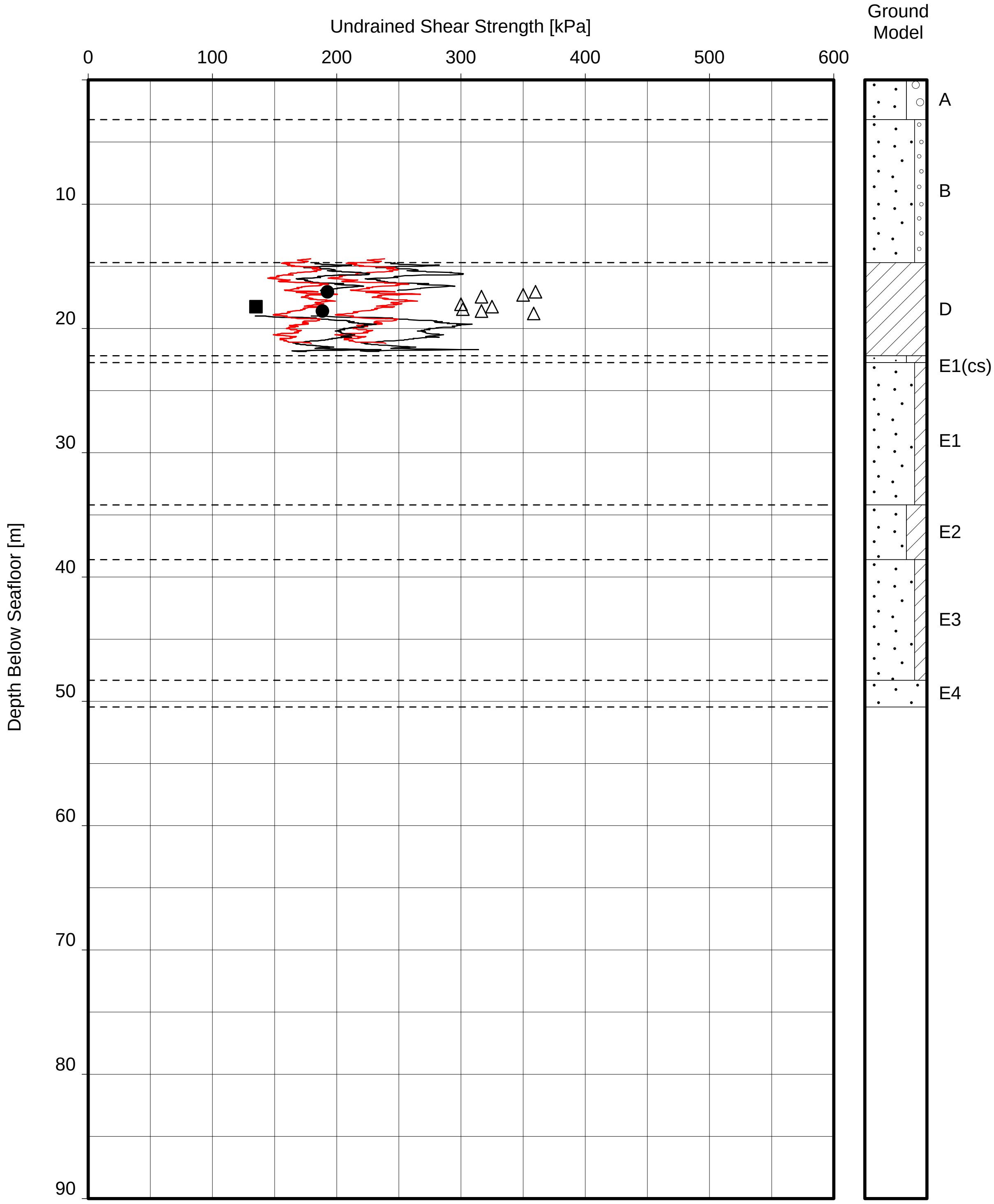
Location(s):
BH-WFS2-1A
CPT_WFS2_12
CPT_WFS2_12B

Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-01 15:08:59

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



△ Pocket penetrometer
○ Torvane
▽ Fallcone
⊕ Laboratory vane
● UU-triaxial
■ CU-triaxial
◪ Direct simple shear
◆ In situ vane shear
Derived from CPT

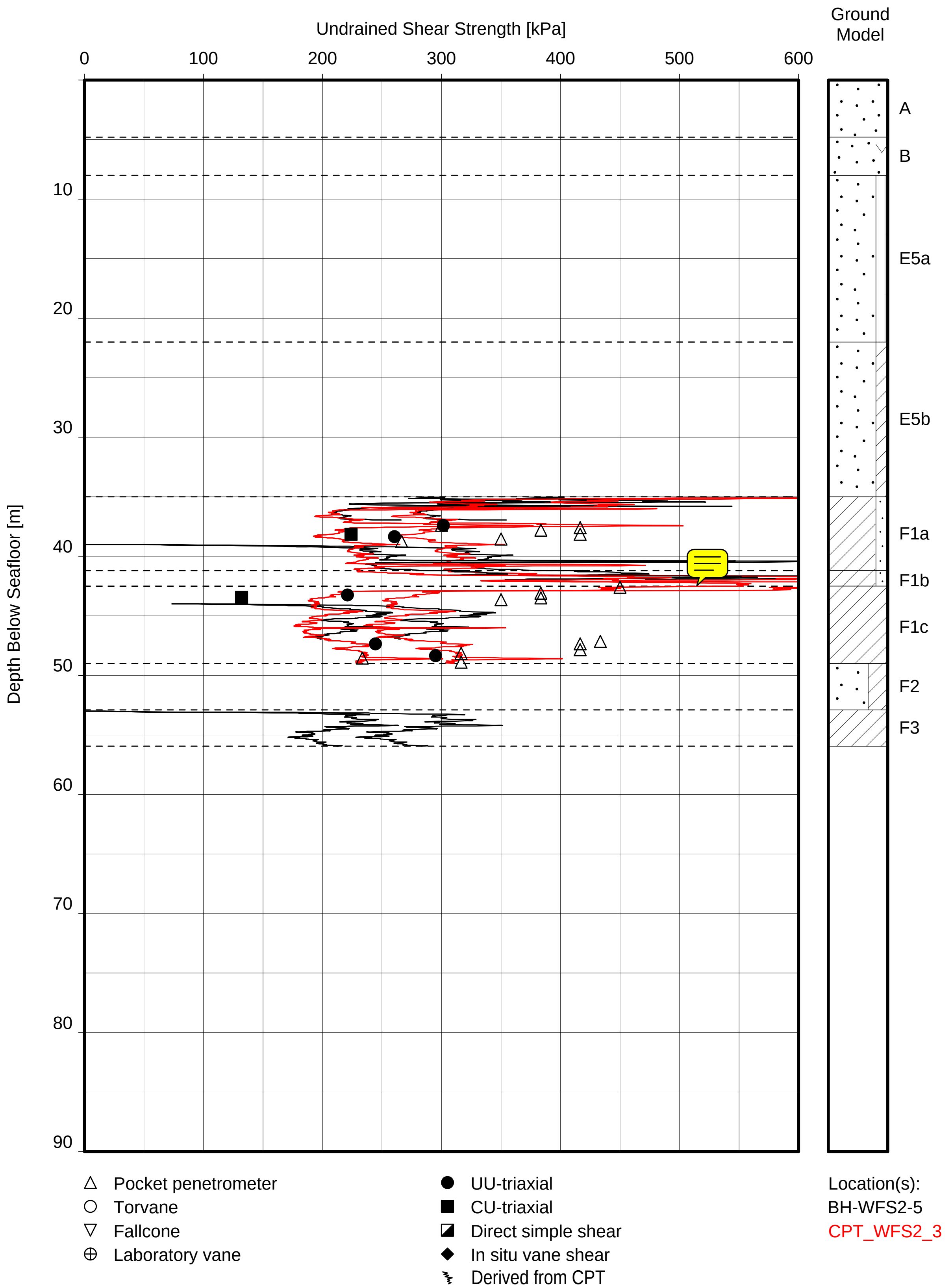
Location(s):
BH-WFS2-3
CPT_WFS2_9

Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-02 11:04:52

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

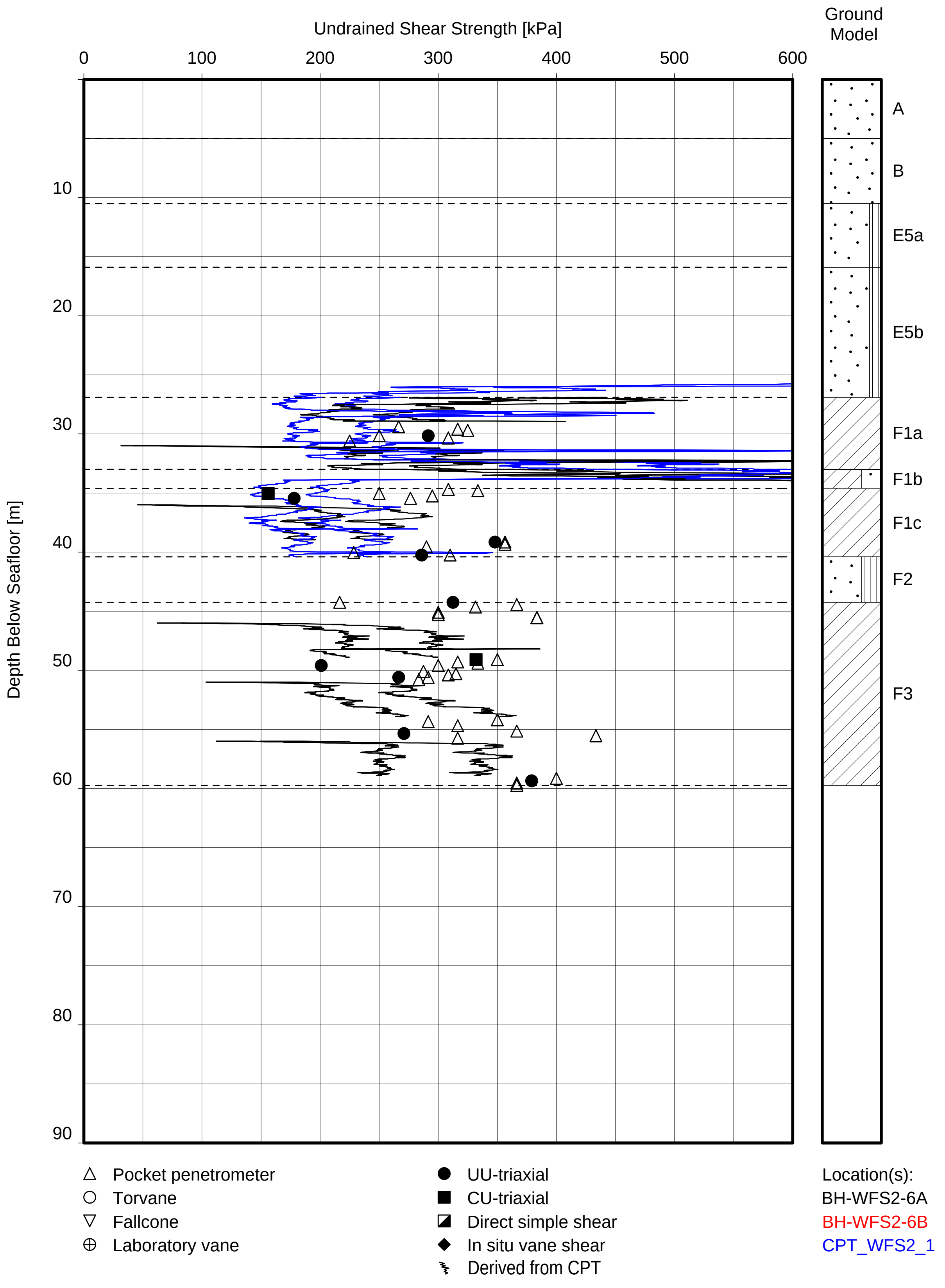


Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-02 11:05:44

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

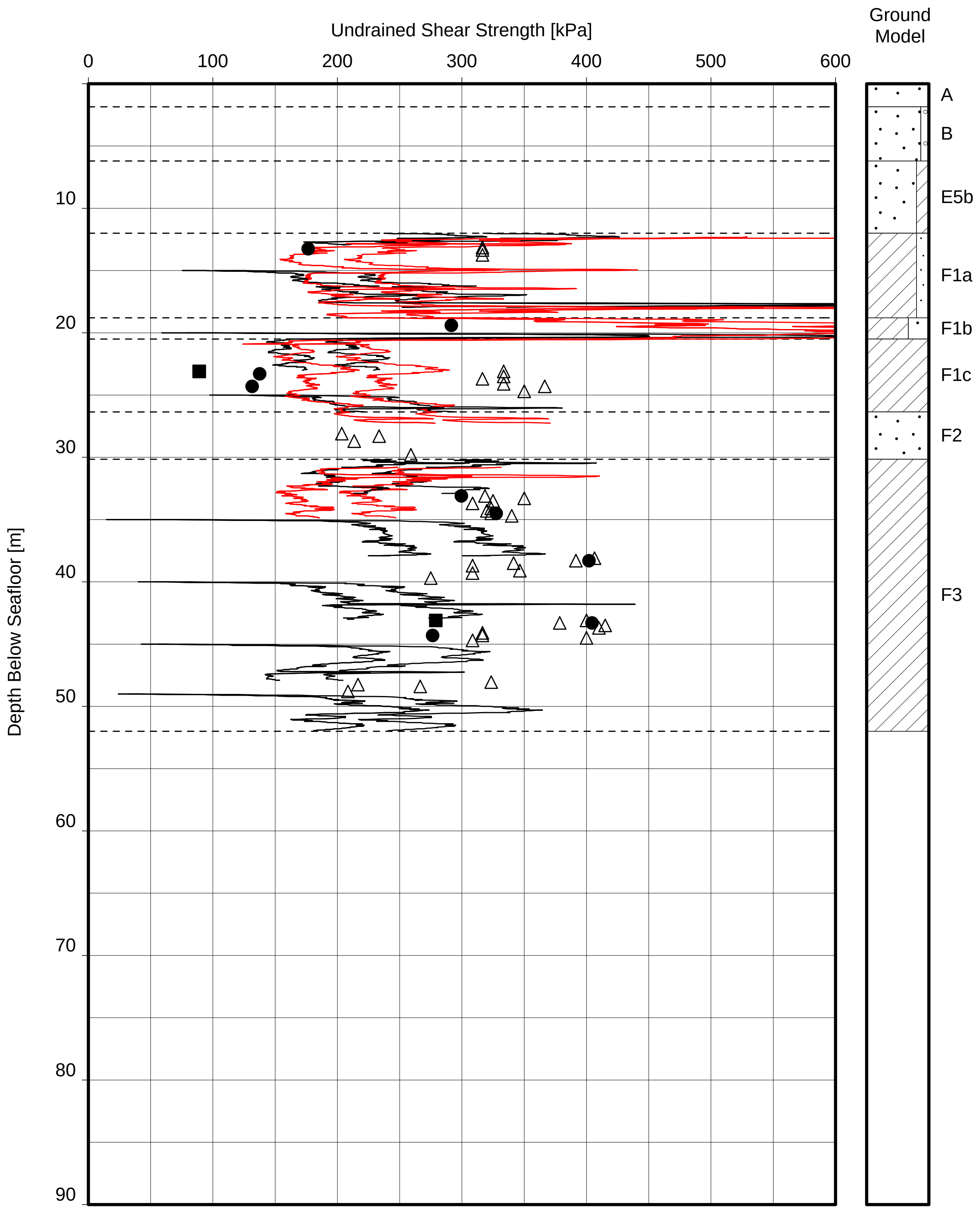


Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-02 11:07:10

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



△ Pocket penetrometer
○ Torvane
▽ Fallcone
⊕ Laboratory vane
● UU-triaxial
■ CU-triaxial
◪ Direct simple shear
◆ In situ vane shear
Derived from CPT

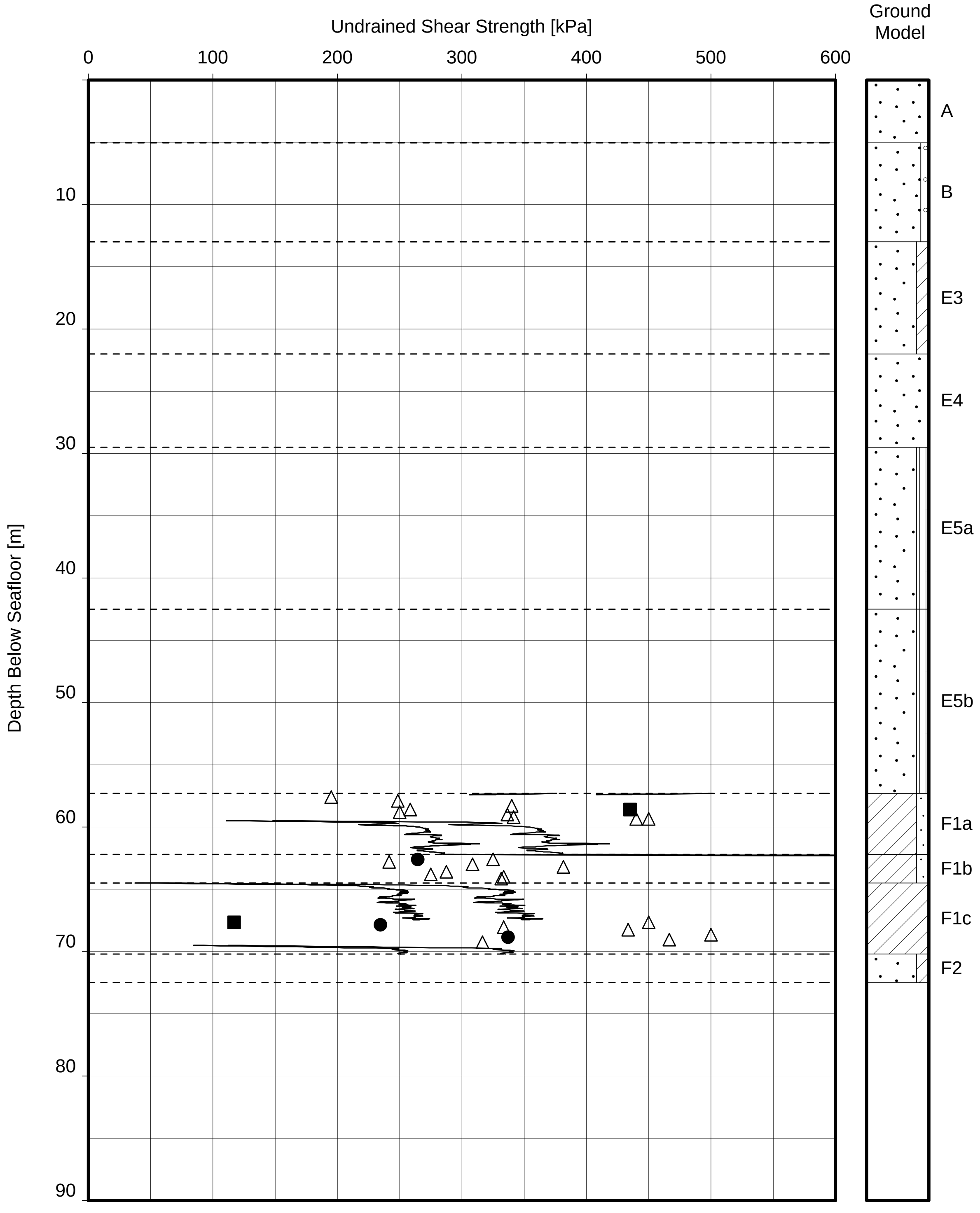
Location(s):
BH-WFS2-7
CPT_WFS2_23

Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-02 11:08:05

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



△ Pocket penetrometer
○ Torvane
▽ Fallcone
⊕ Laboratory vane
● UU-triaxial
■ CU-triaxial
◪ Direct simple shear
◆ In situ vane shear
Derived from CPT

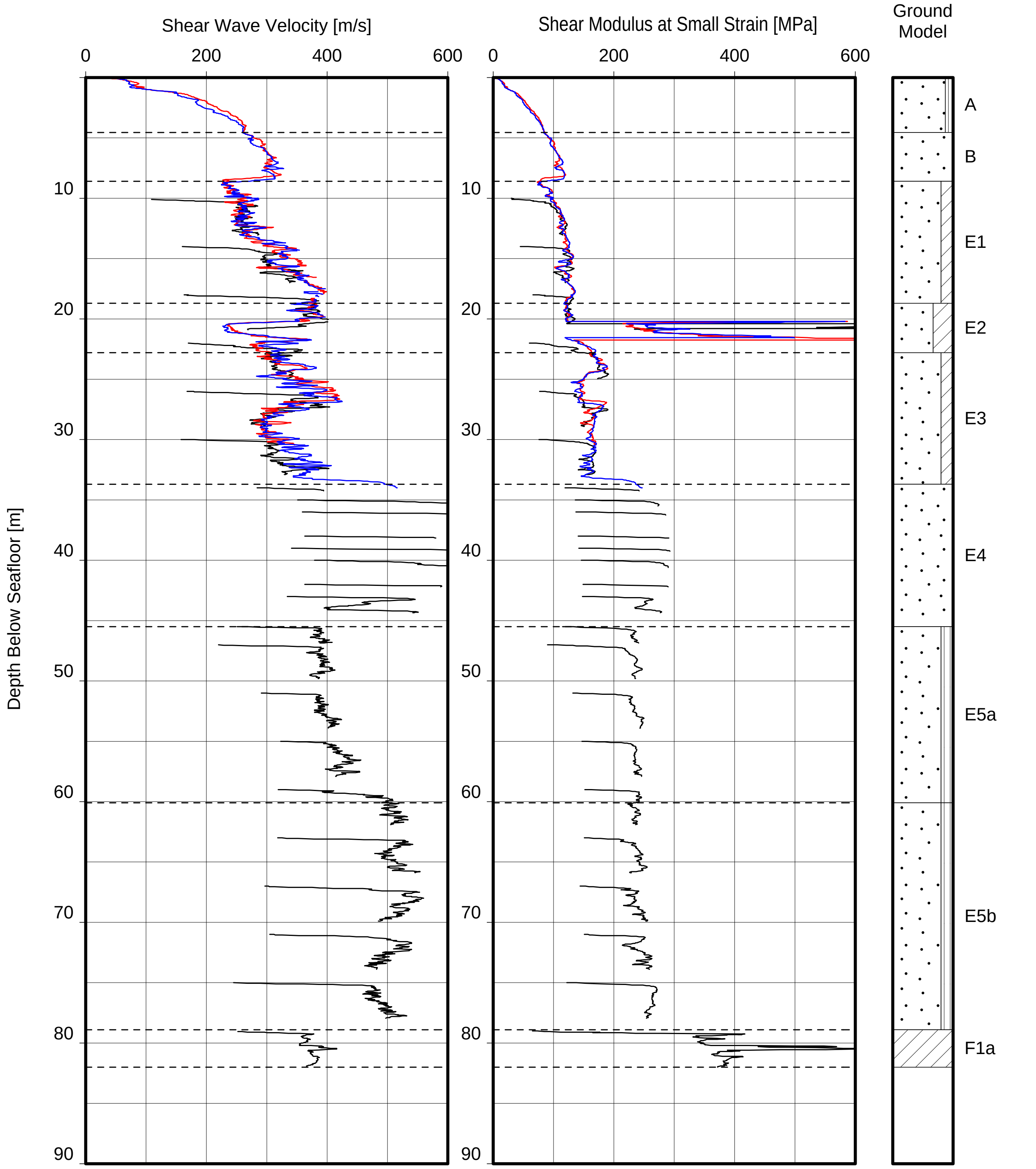
Location(s):
BH-WFS2-8A
CPT_WFS2_15

Note(s):
- N_k = 15 and N_k = 20 are used to derive c_u from CPT

GeODin/Undrained Shear Strength versus Depth (all UNITS, incl. GM).glo/2015-07-02 11:08:39

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array

Shear modulus at small strain (G_{max}) derived from v_s measured

v_s and G_{max} derived from CPT

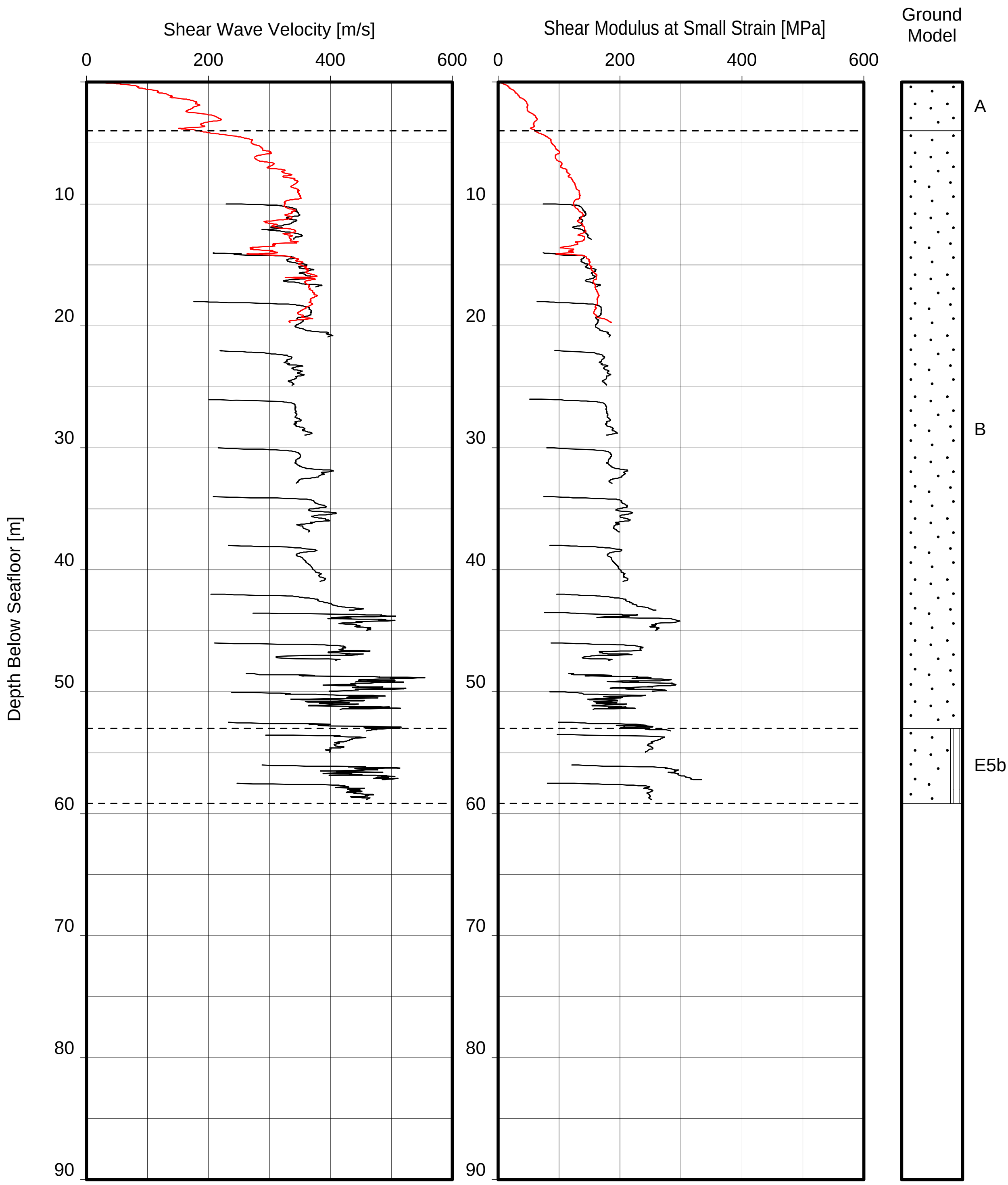
Location(s):
BH-WFS2-1A
CPT_WFS2_12
CPT_WFS2_12B

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:09:17

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

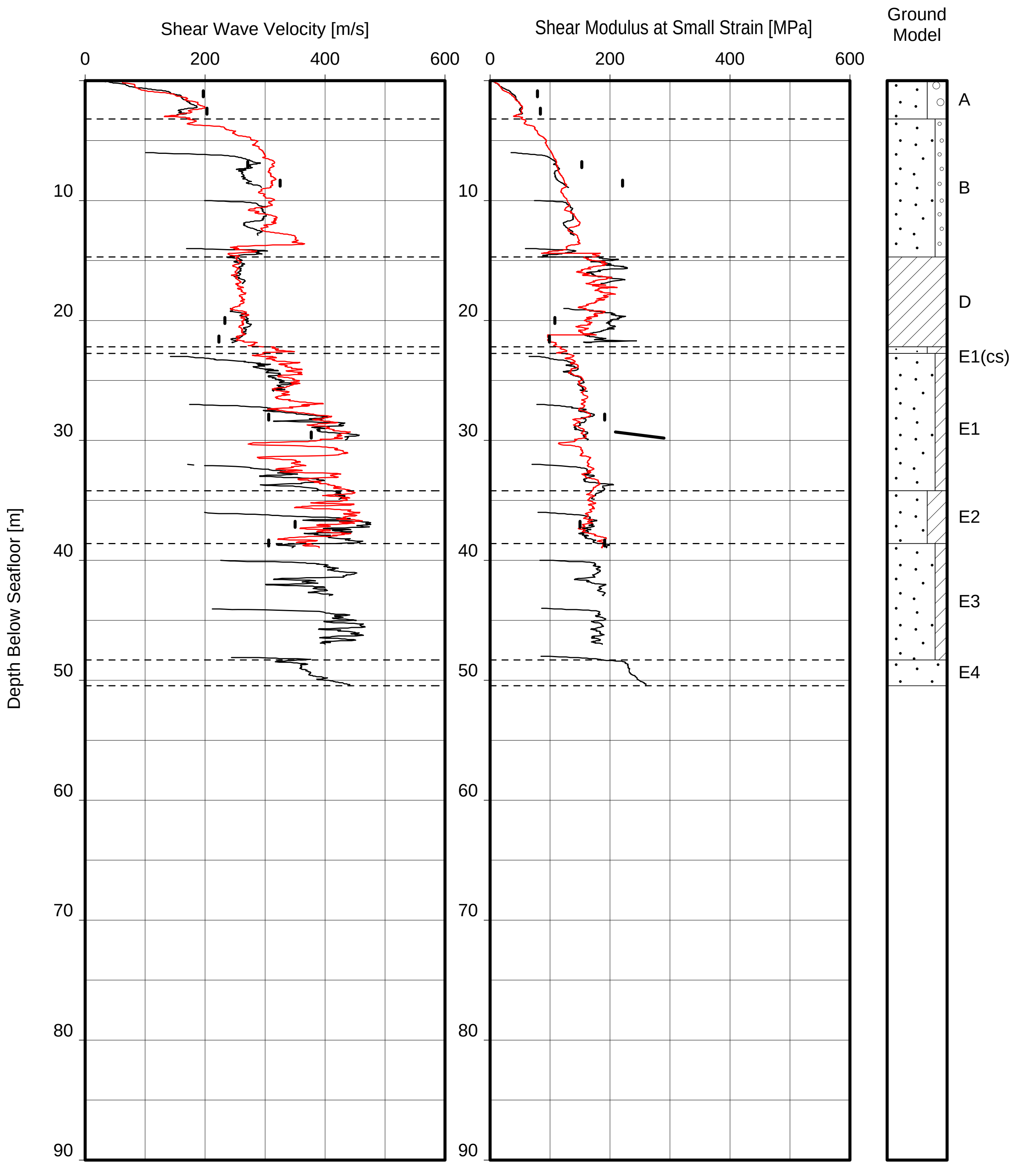
Location(s):
BH-WFS2-2A
CPT_WFS2_16

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:27:12

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

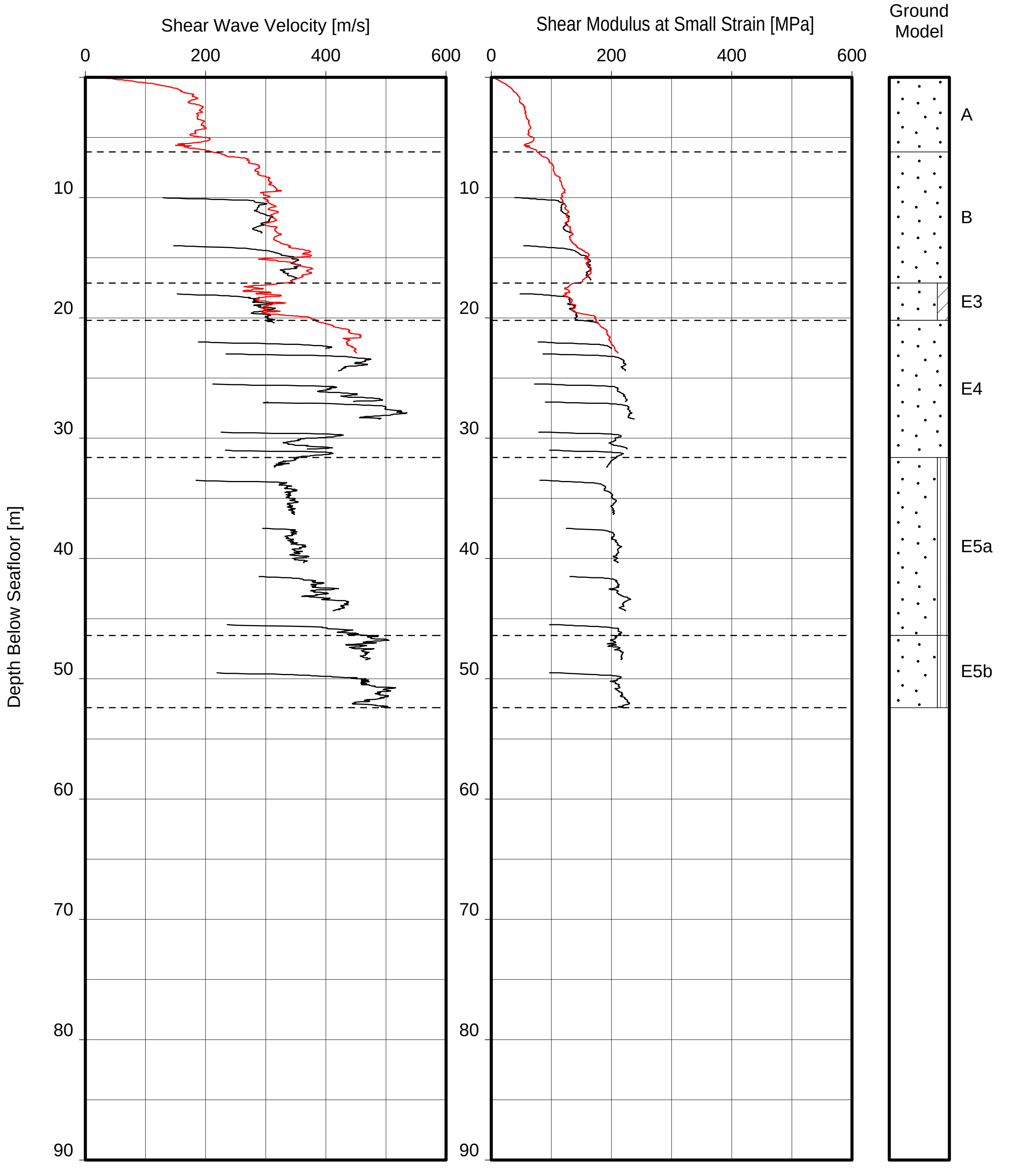
Location(s):
BH-WFS2-3
CPT_WFS2_9

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:36:43

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

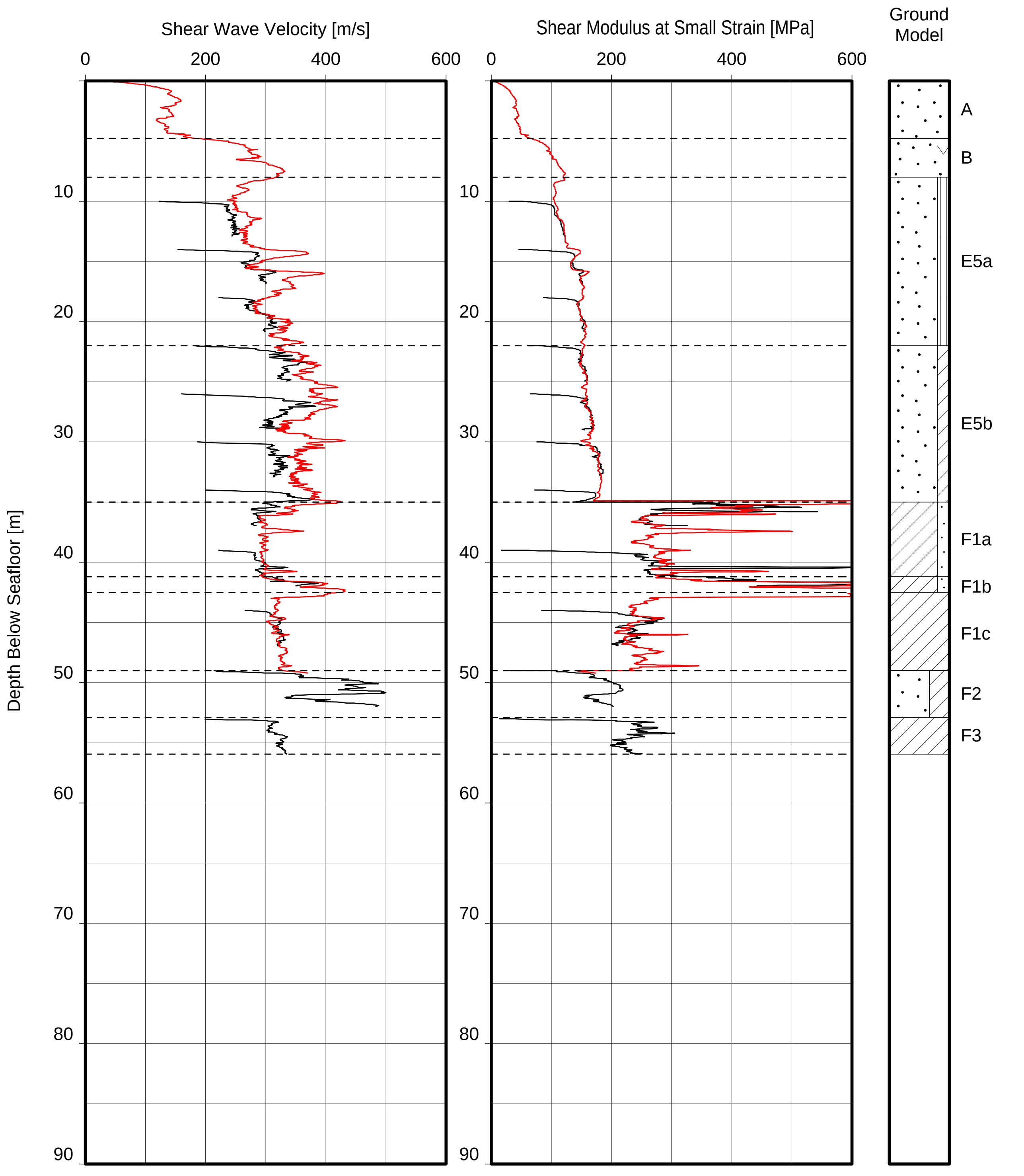
Location(s):
BH-WFS2-4
CPT_WFS2_27

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 15:44:51

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

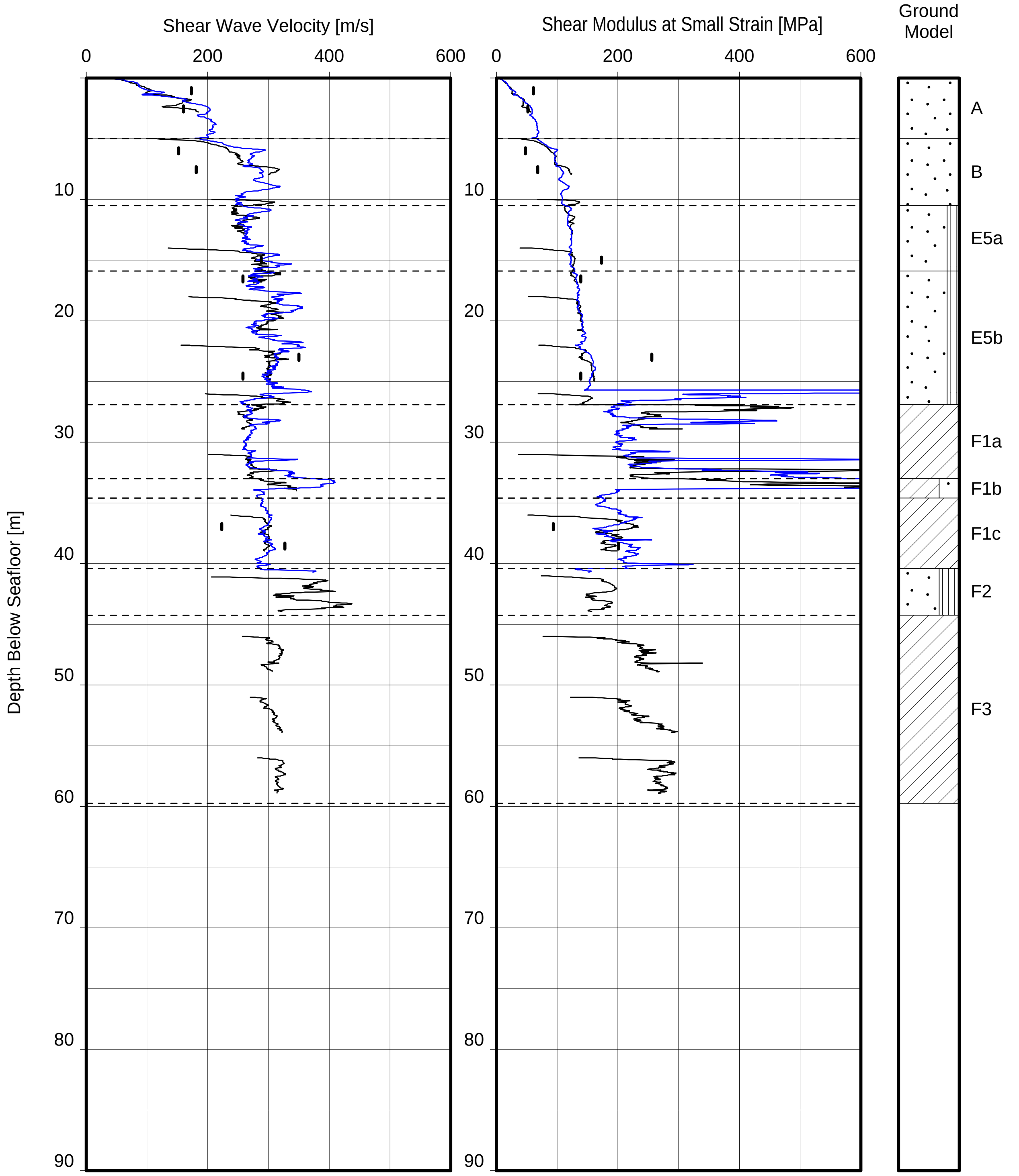
Location(s):
BH-WFS2-5
CPT_WFS2_3

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:45:15

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array

Shear modulus at small strain (G_{max}) derived from v_s measured

v_s and G_{max} derived from CPT

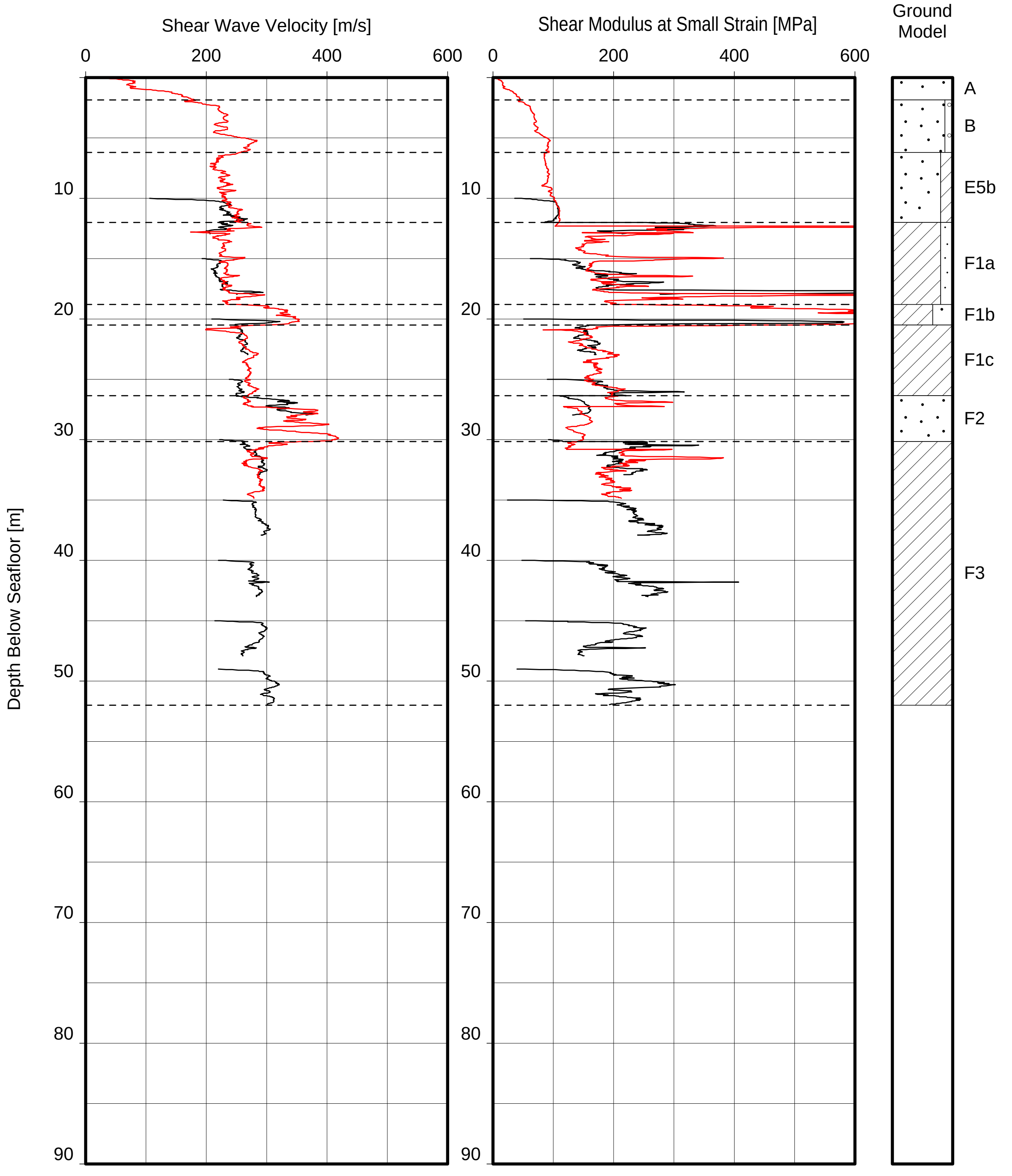
Location(s):
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:08:28

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

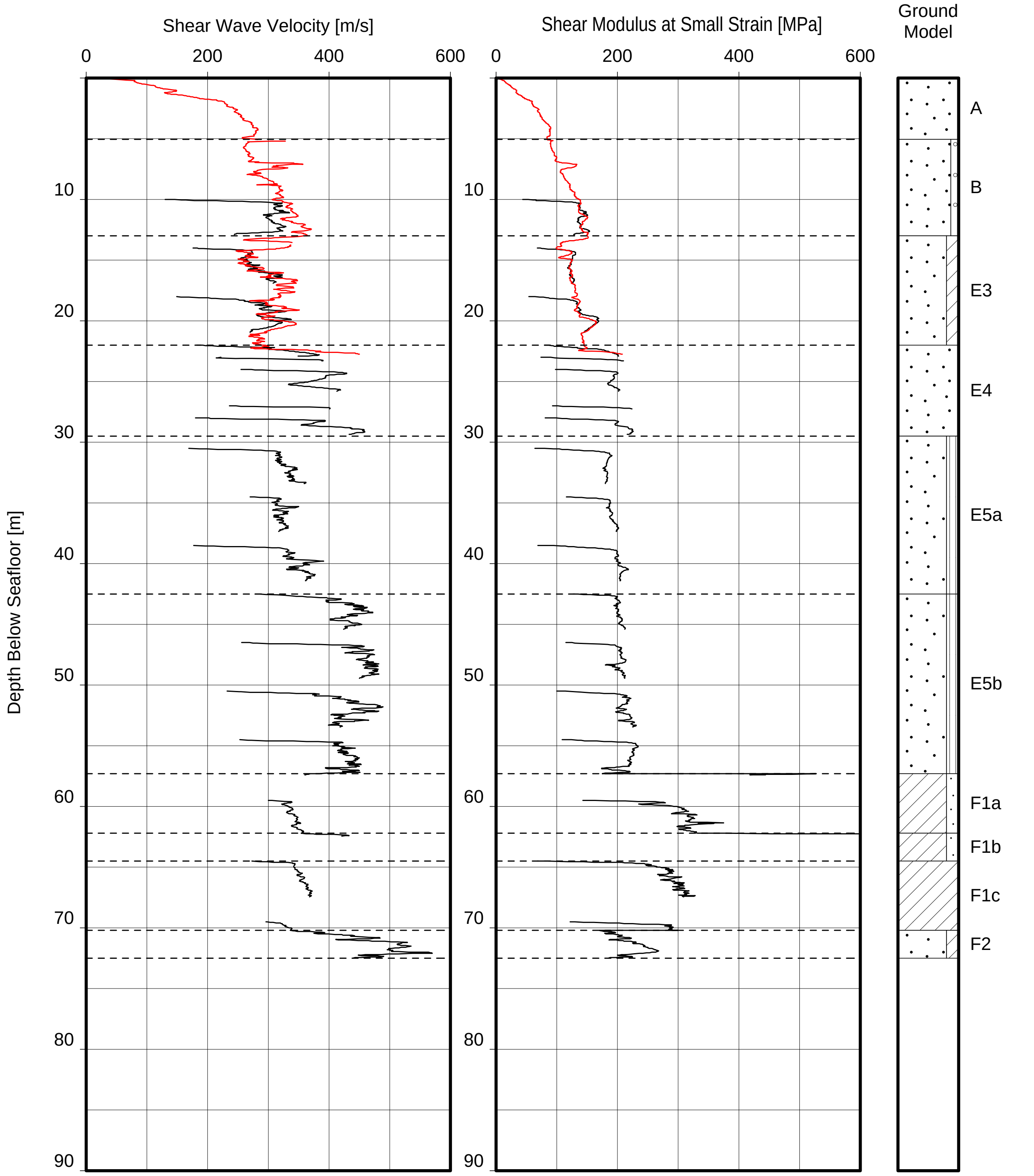
Location(s):
BH-WFS2-7
CPT_WFS2_23

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:26:26

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (all UNITS, incl. GM).GLO/2015-07-01 16:30:37

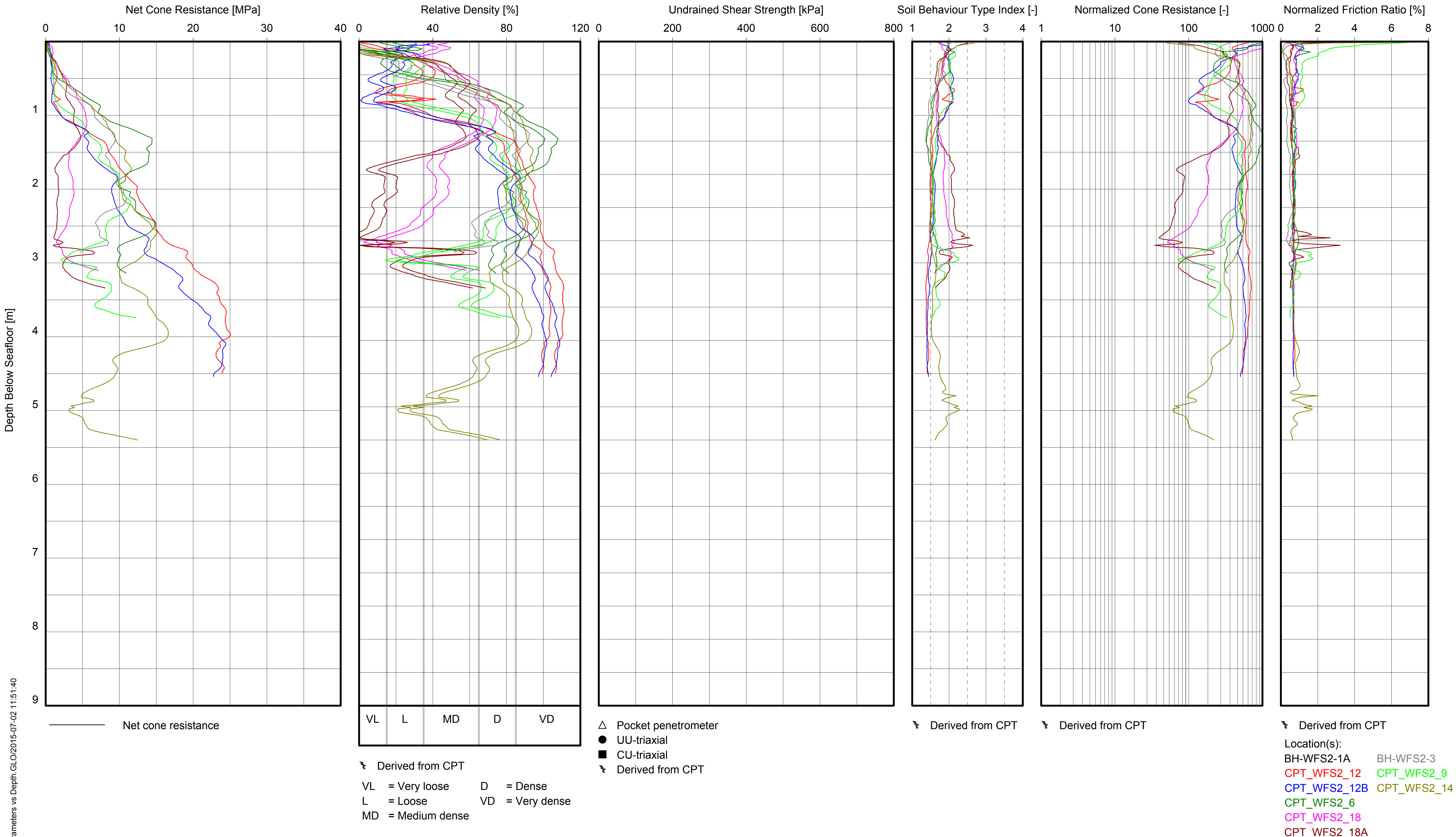
SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

SECTION B: GEOTECHNICAL PARAMETERS – GROUPING PER GEOTECHNICAL UNIT

LIST OF PLATES IN SECTION B

LIST OF PLATES IN SECTION B Plate

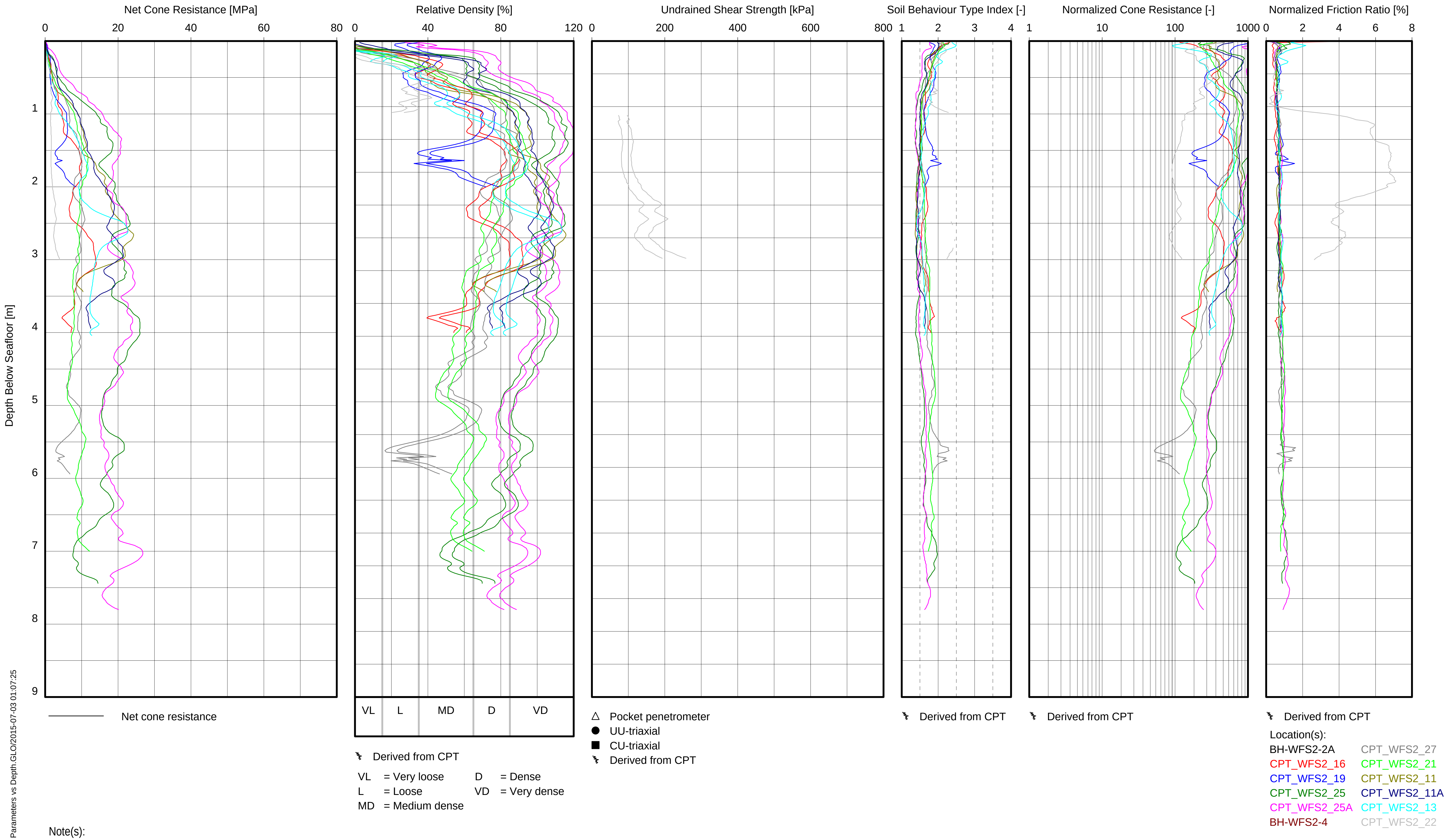


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



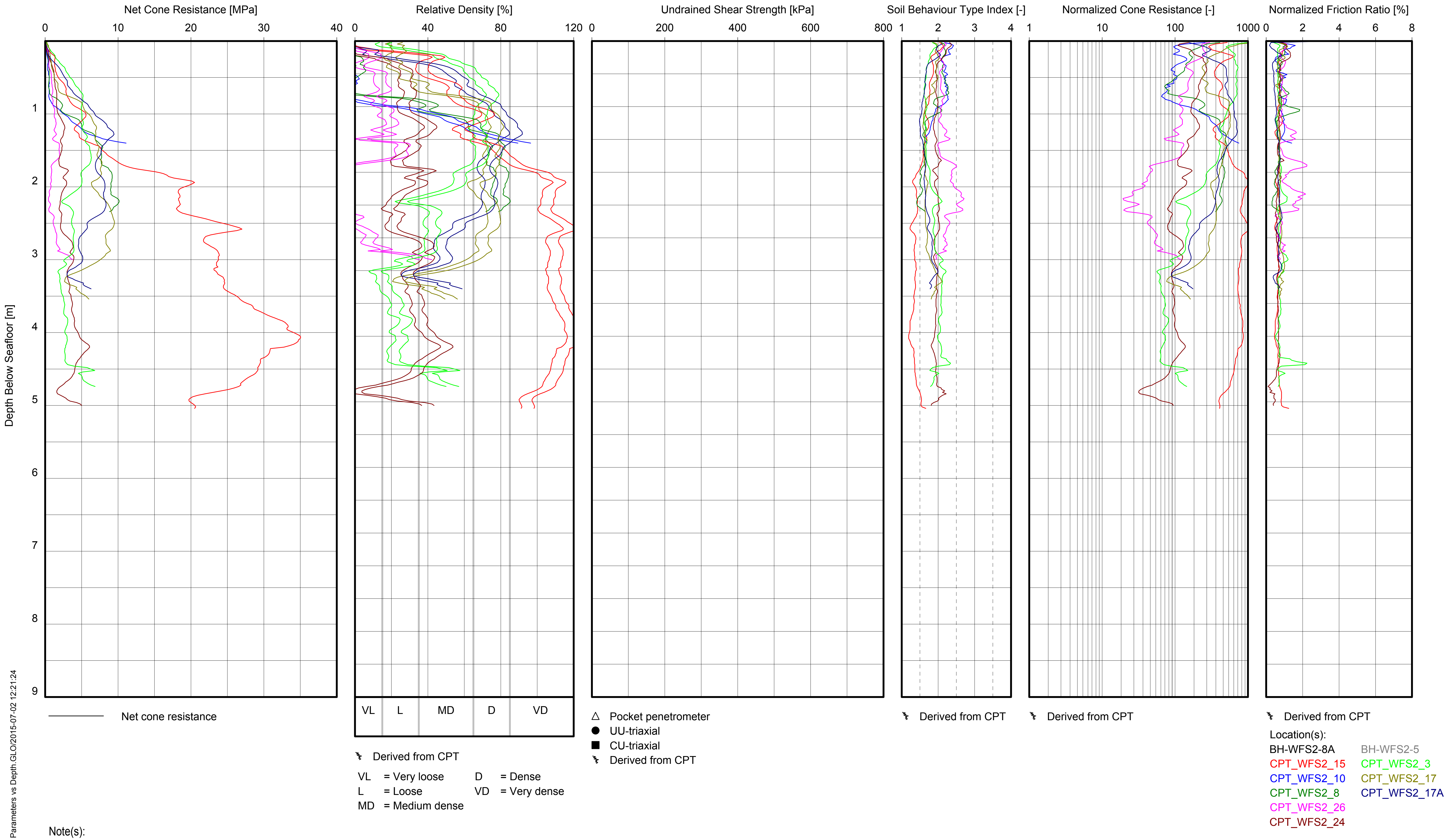
GeODin\CPT Parameters vs Depth.GLO/2015-07-03 01:07:25

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

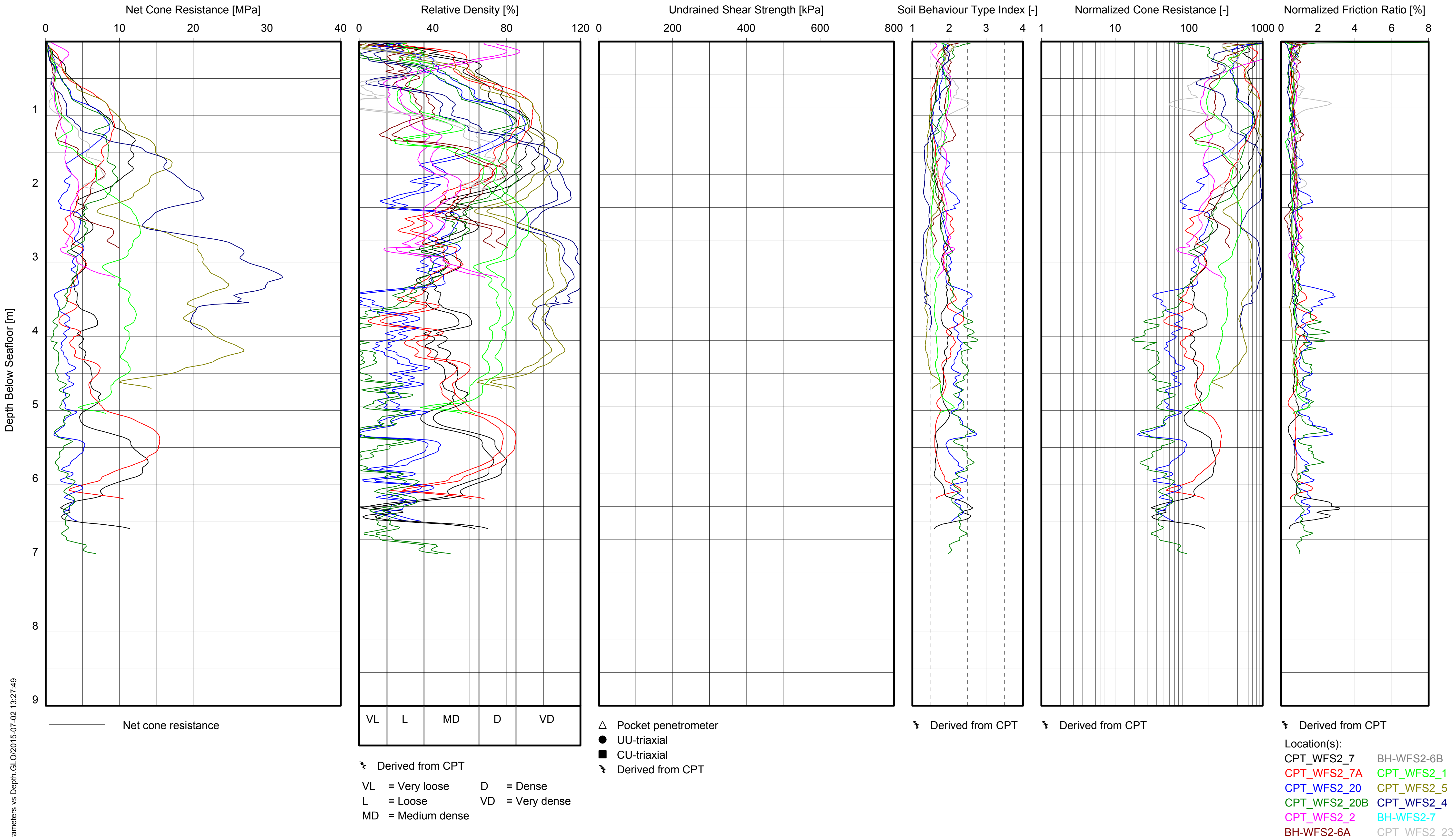
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin\CPT Parameters vs Depth.GLO/2015-07-02 12:21:24

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT A
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

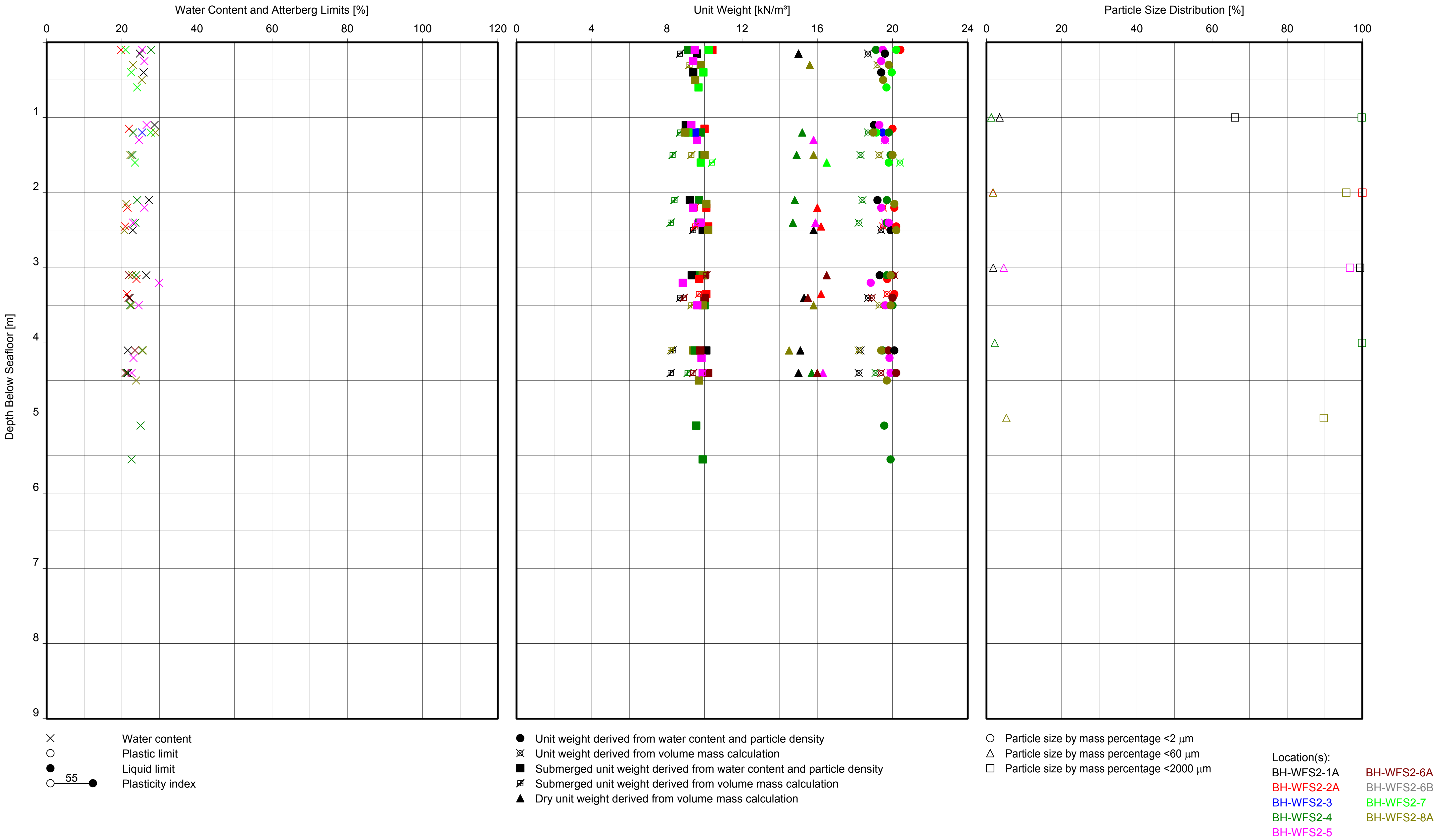


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



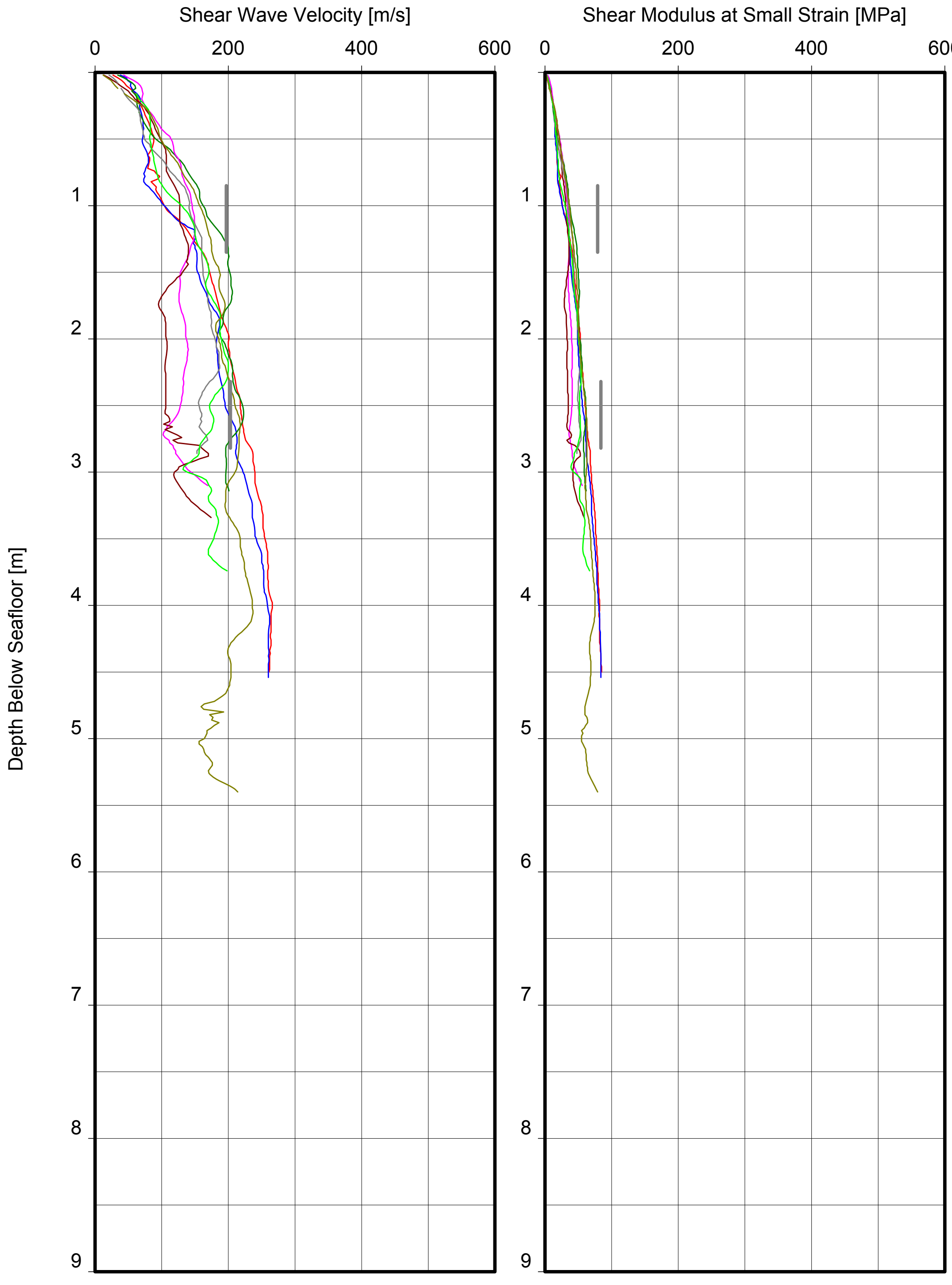
GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:31:49

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

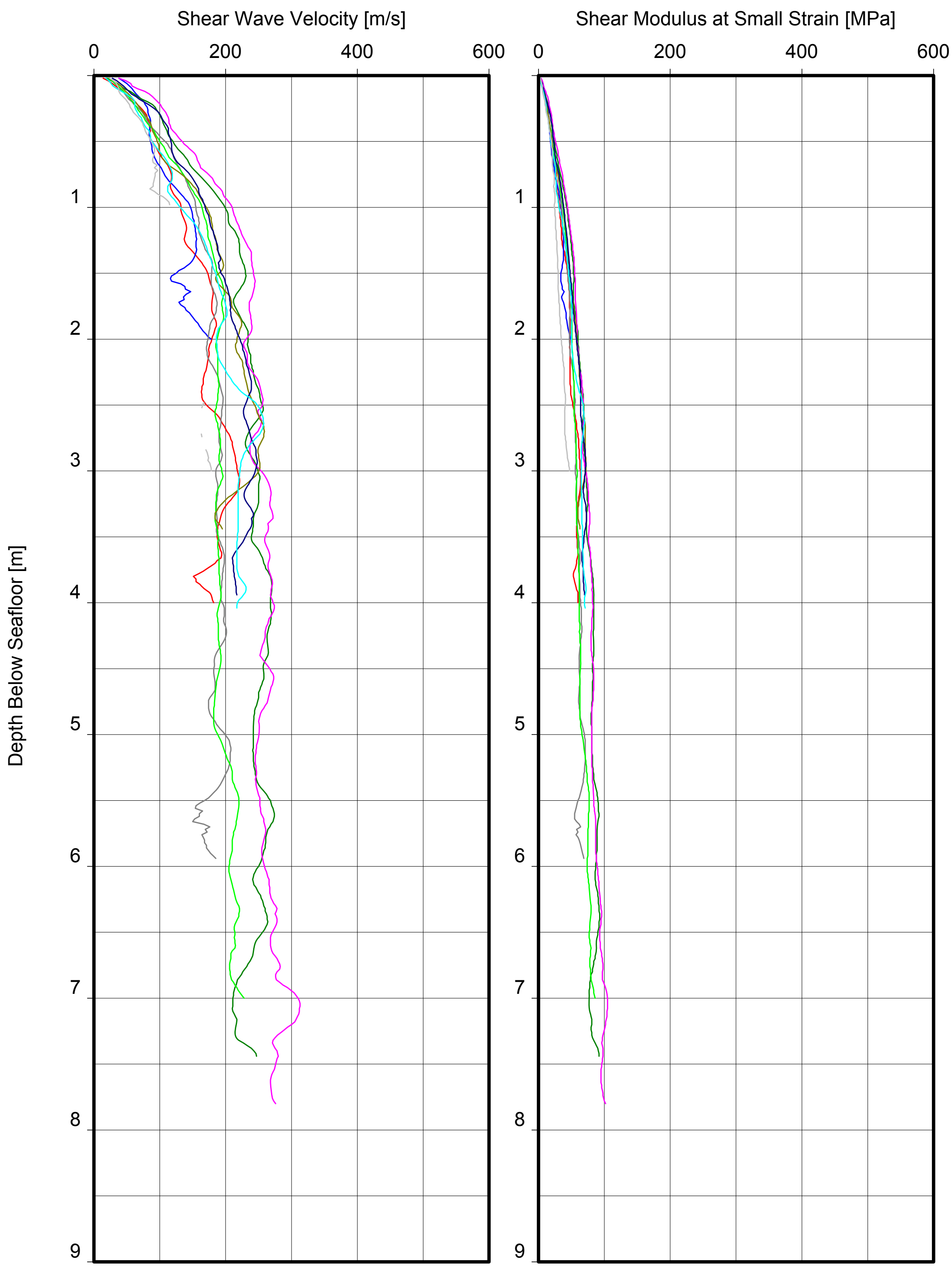
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 14:51:24

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

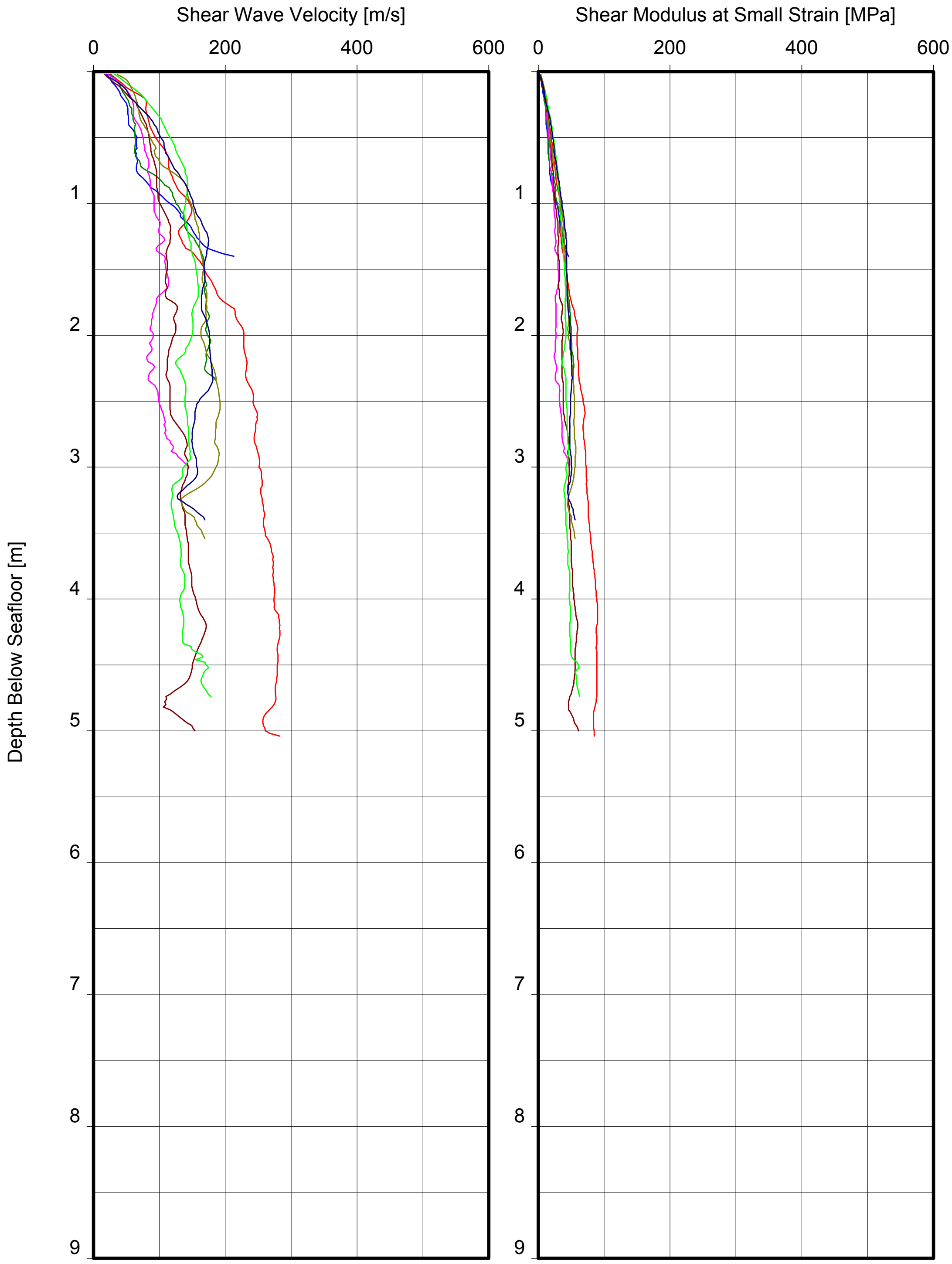
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:18:54

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

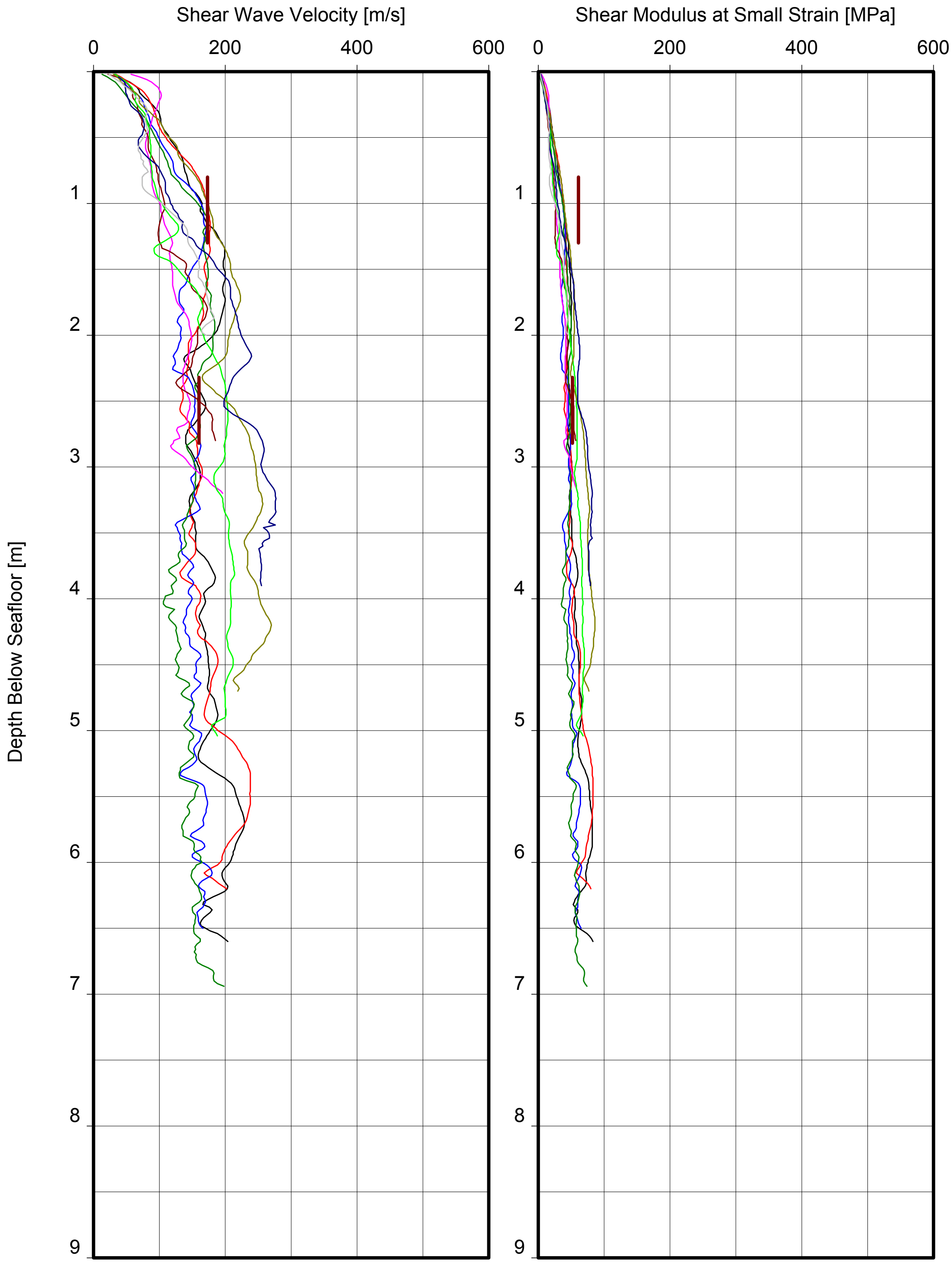
Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



| Shear wave velocity (v_s) measured in-between geophone array
| Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):

CPT_WFS2_7	BH-WFS2-6B
CPT_WFS2_7A	CPT_WFS2_1
CPT_WFS2_20	CPT_WFS2_5
CPT_WFS2_20B	CPT_WFS2_4
CPT_WFS2_2	BH-WFS2-7
BH-WFS2-6A	CPT_WFS2_23

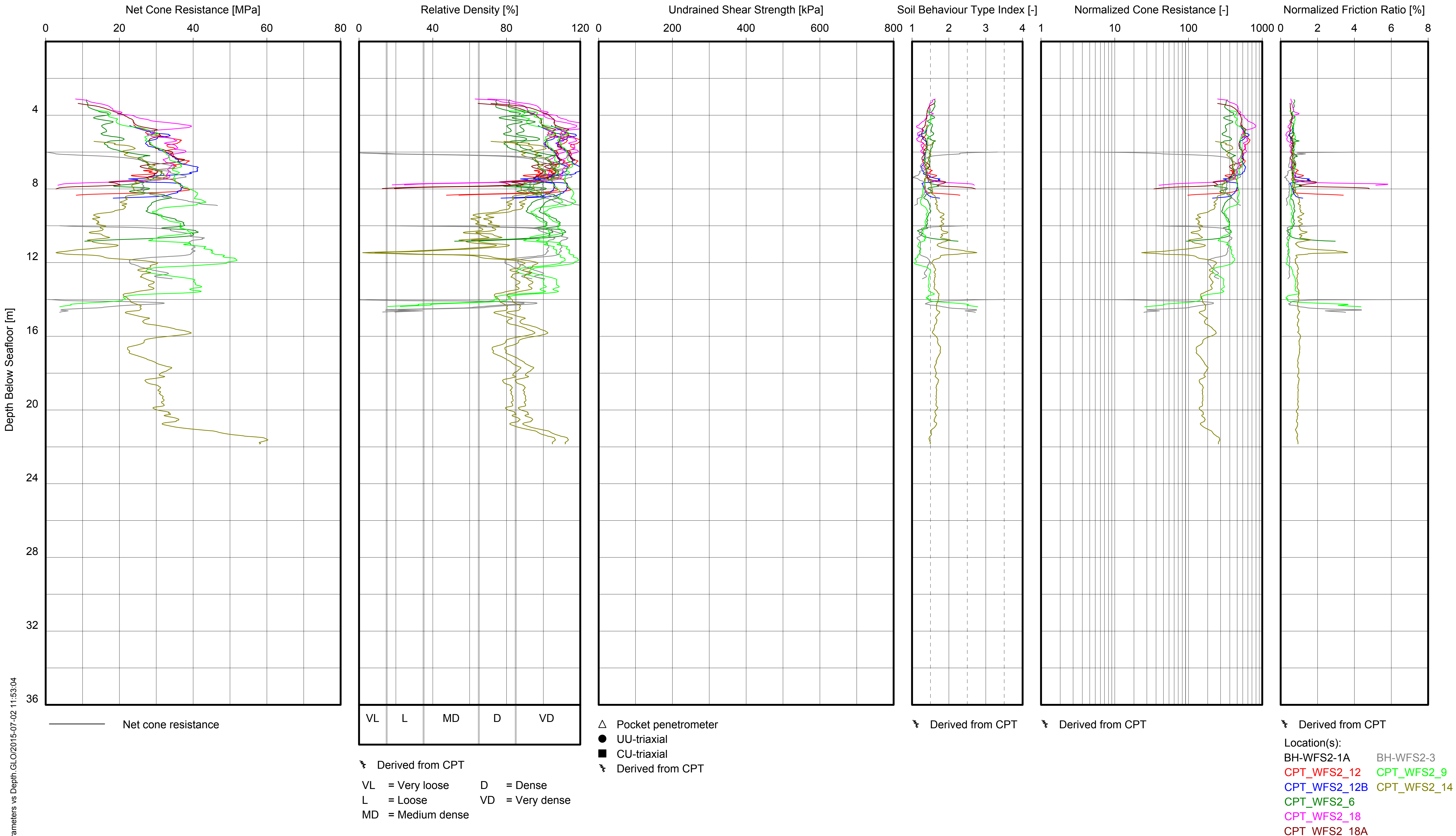
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:47:56

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA

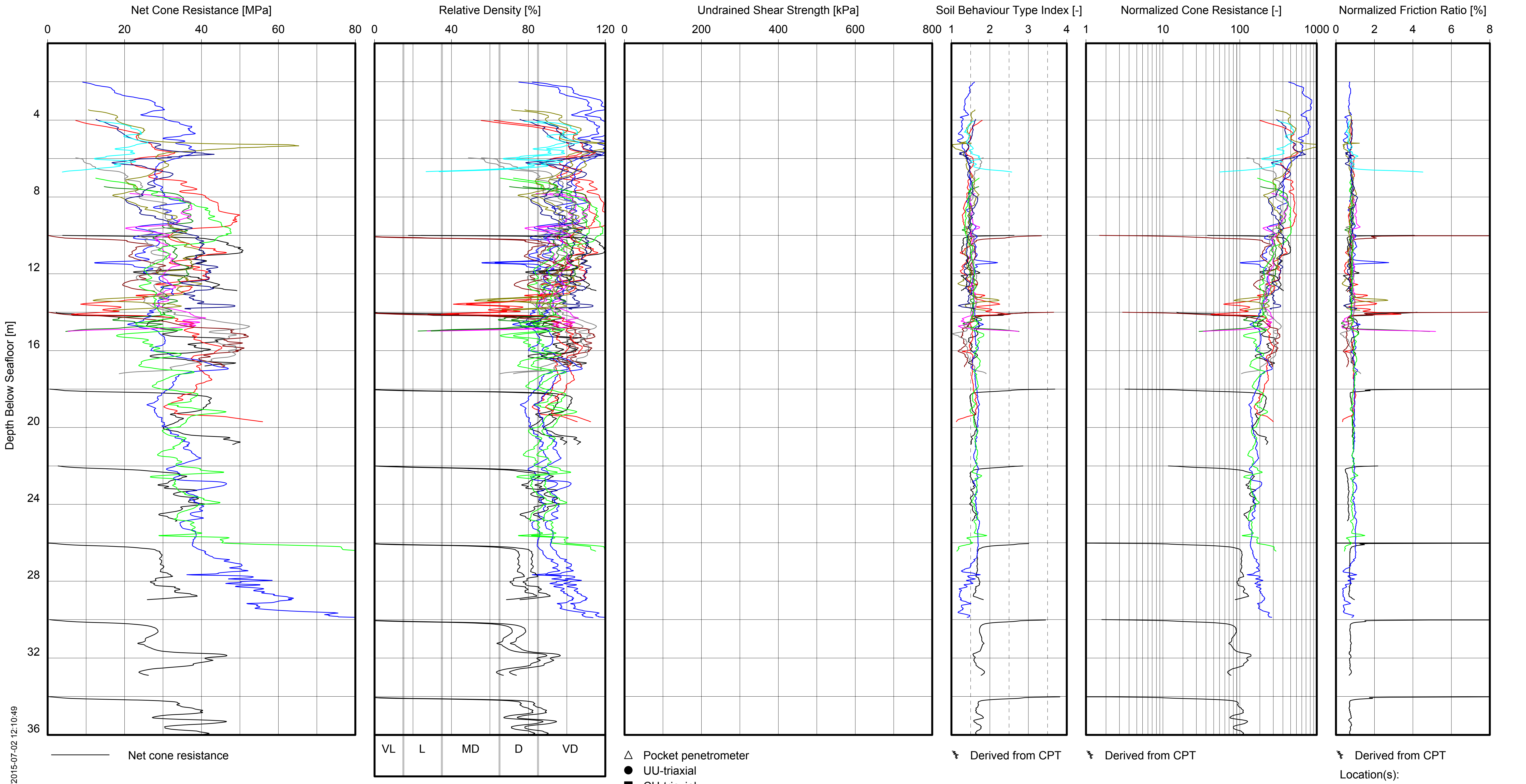


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



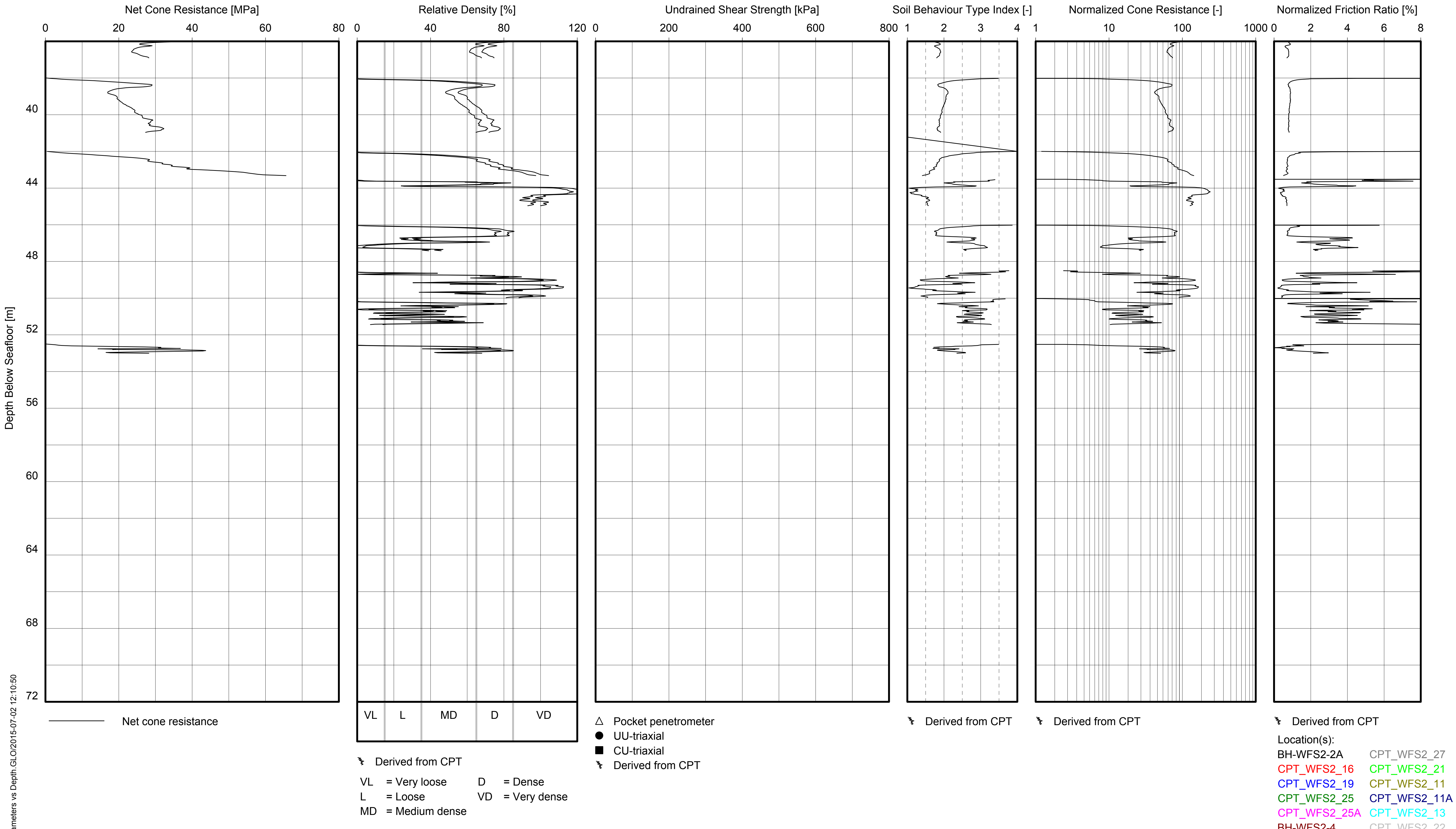
GeODin\CPT Parameters vs Depth.GLO/2015-07-02 12:10:49

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



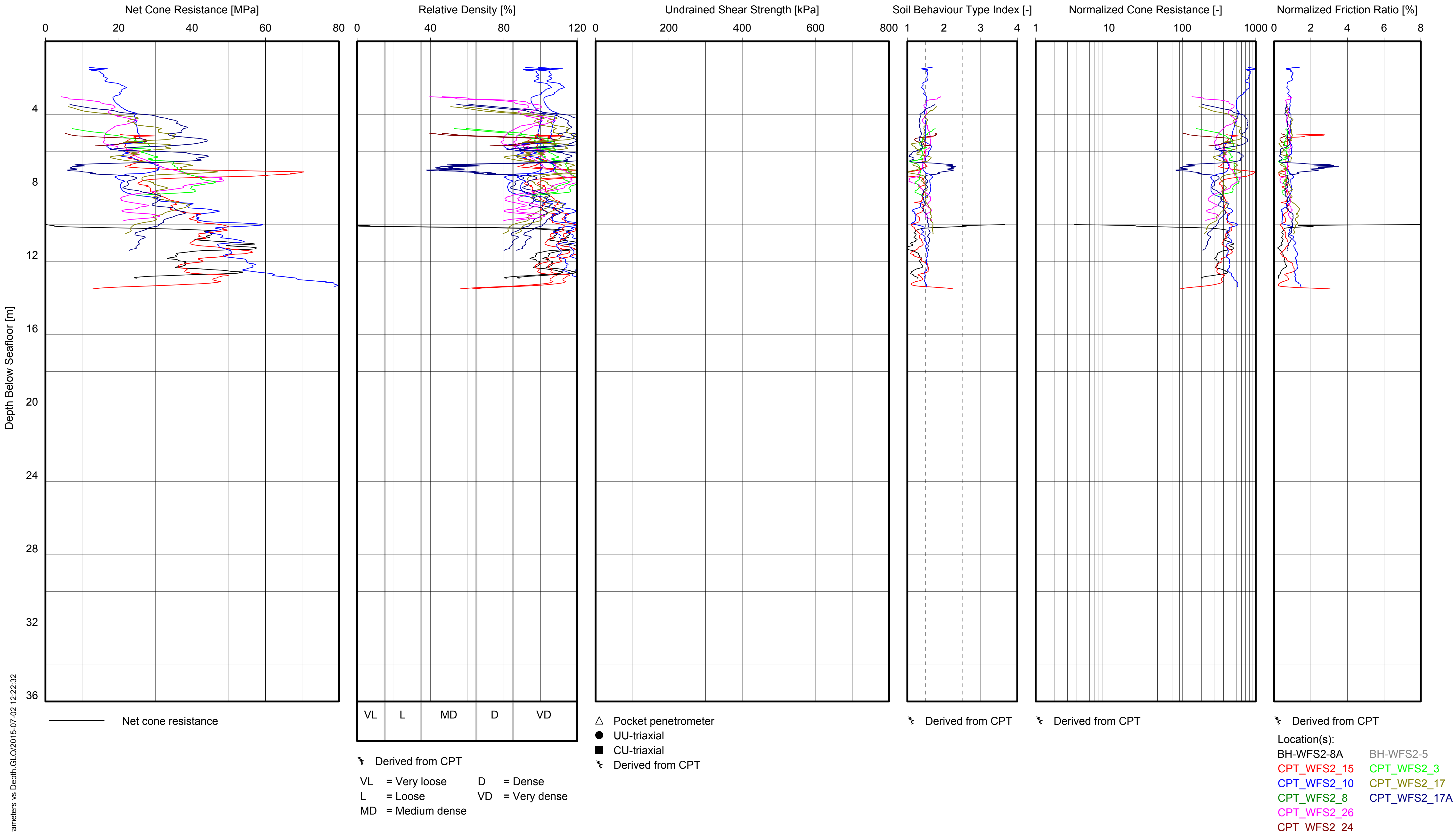
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 12:10:50

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



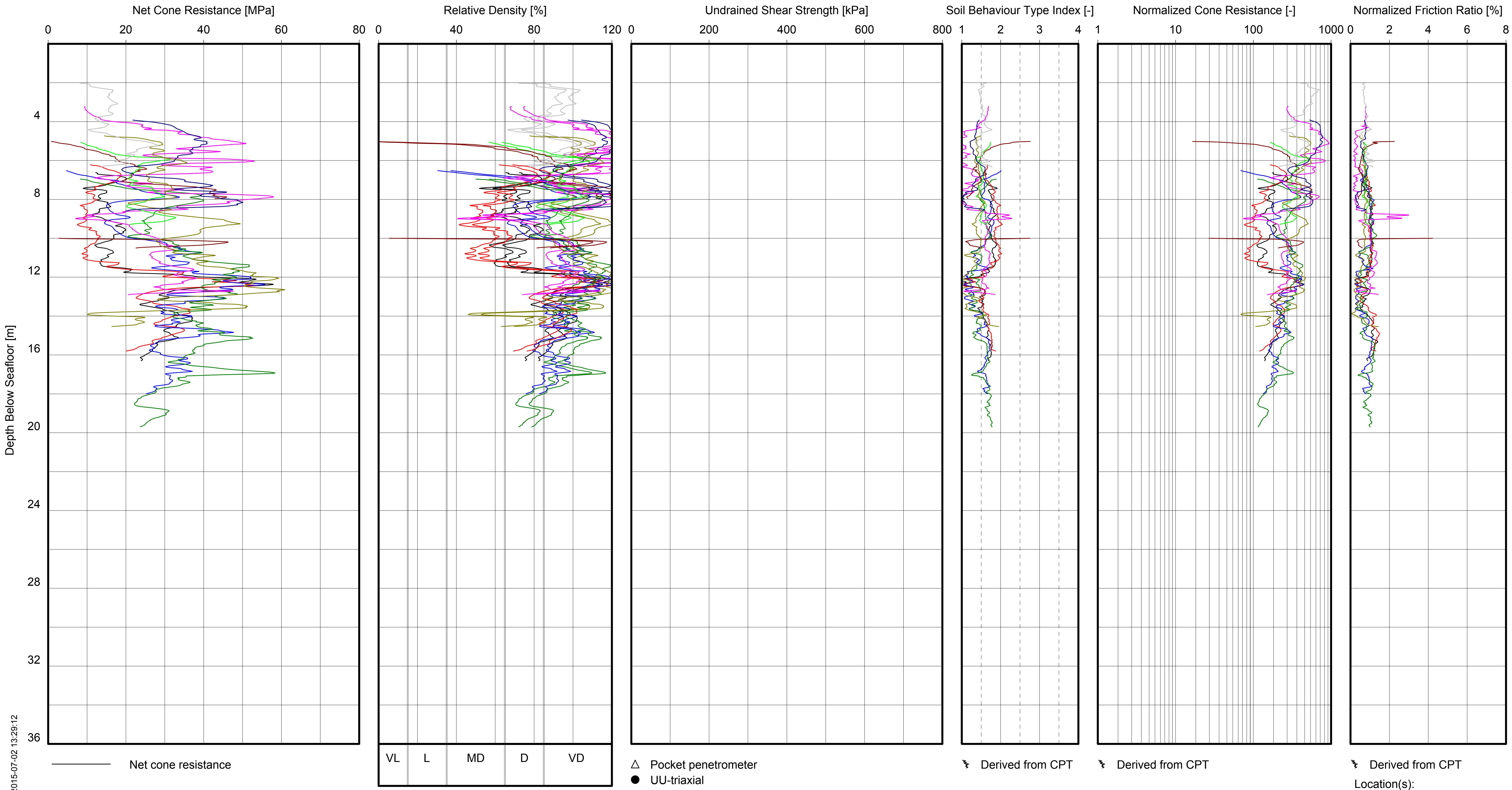
GeODin/CPT Parameters vs Depth GLO/2015-07-02 12:22:32

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

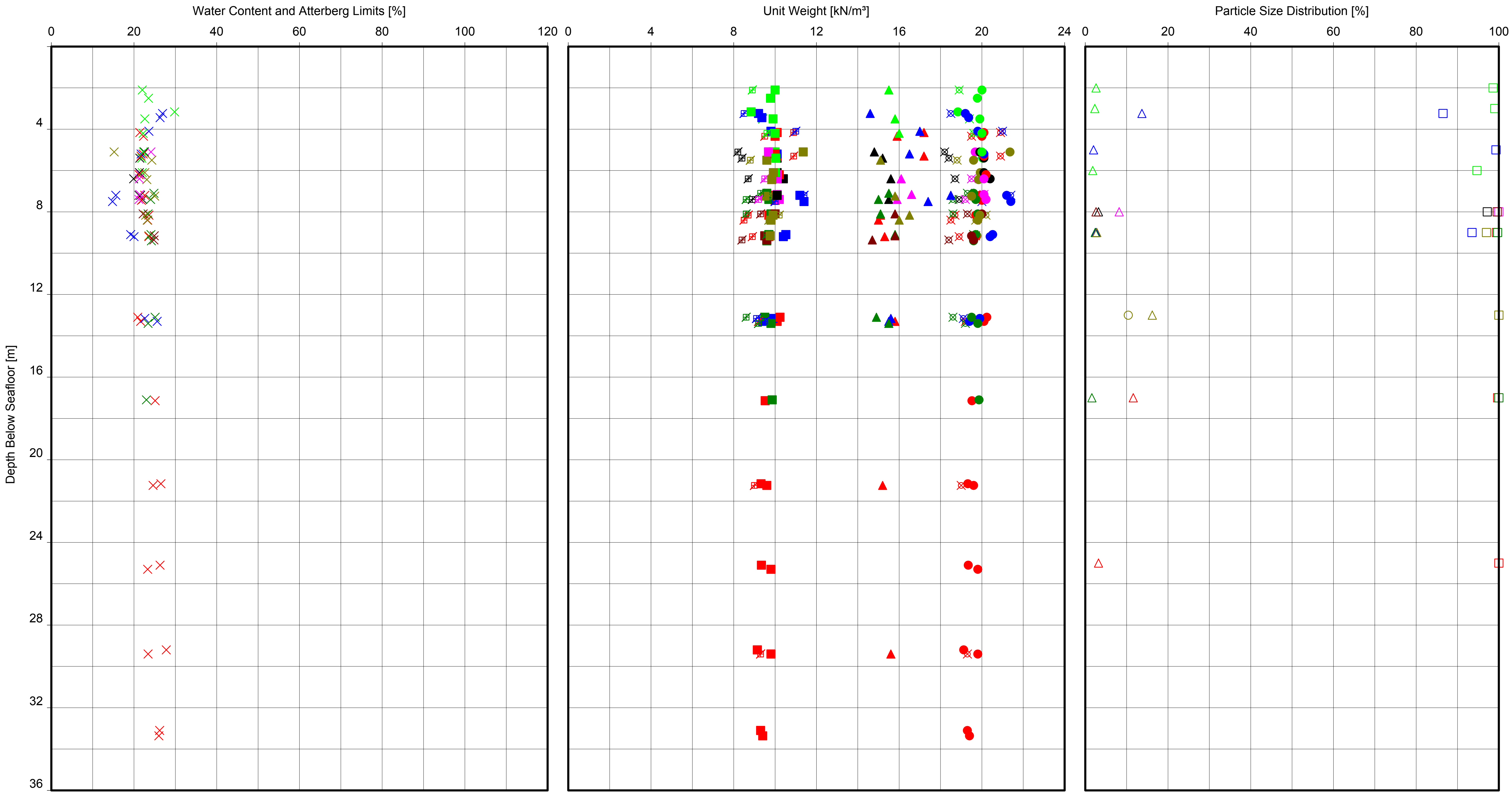
Location(s):

CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:29:12

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT B
BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



× Water content
○ Plastic limit
● Liquid limit
○—55—● Plasticity index

● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

○ Particle size by mass percentage <2 µm
△ Particle size by mass percentage <60 µm
□ Particle size by mass percentage <2000 µm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

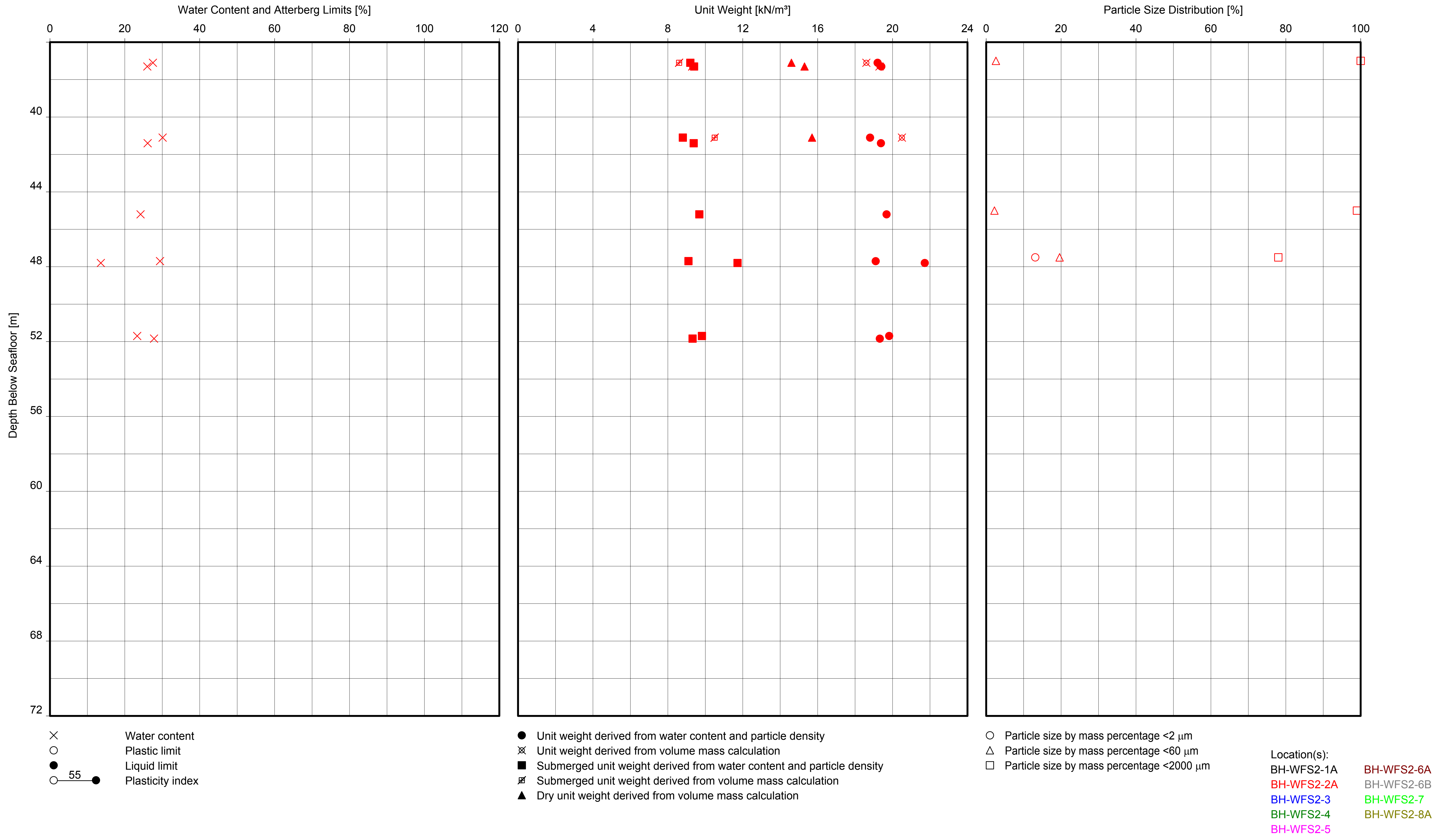
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeoDin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:32:55

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



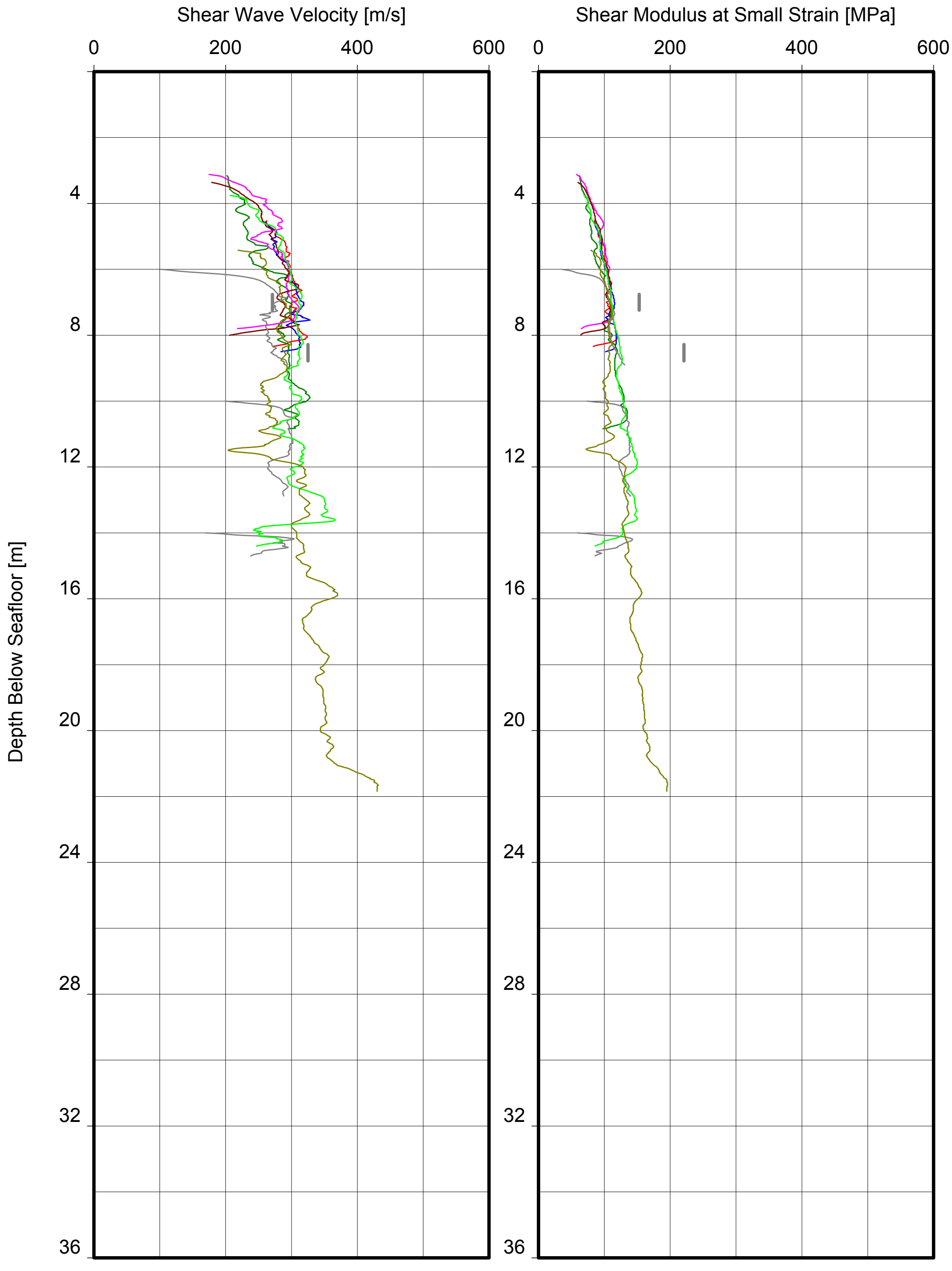
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeoDin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:32:55

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

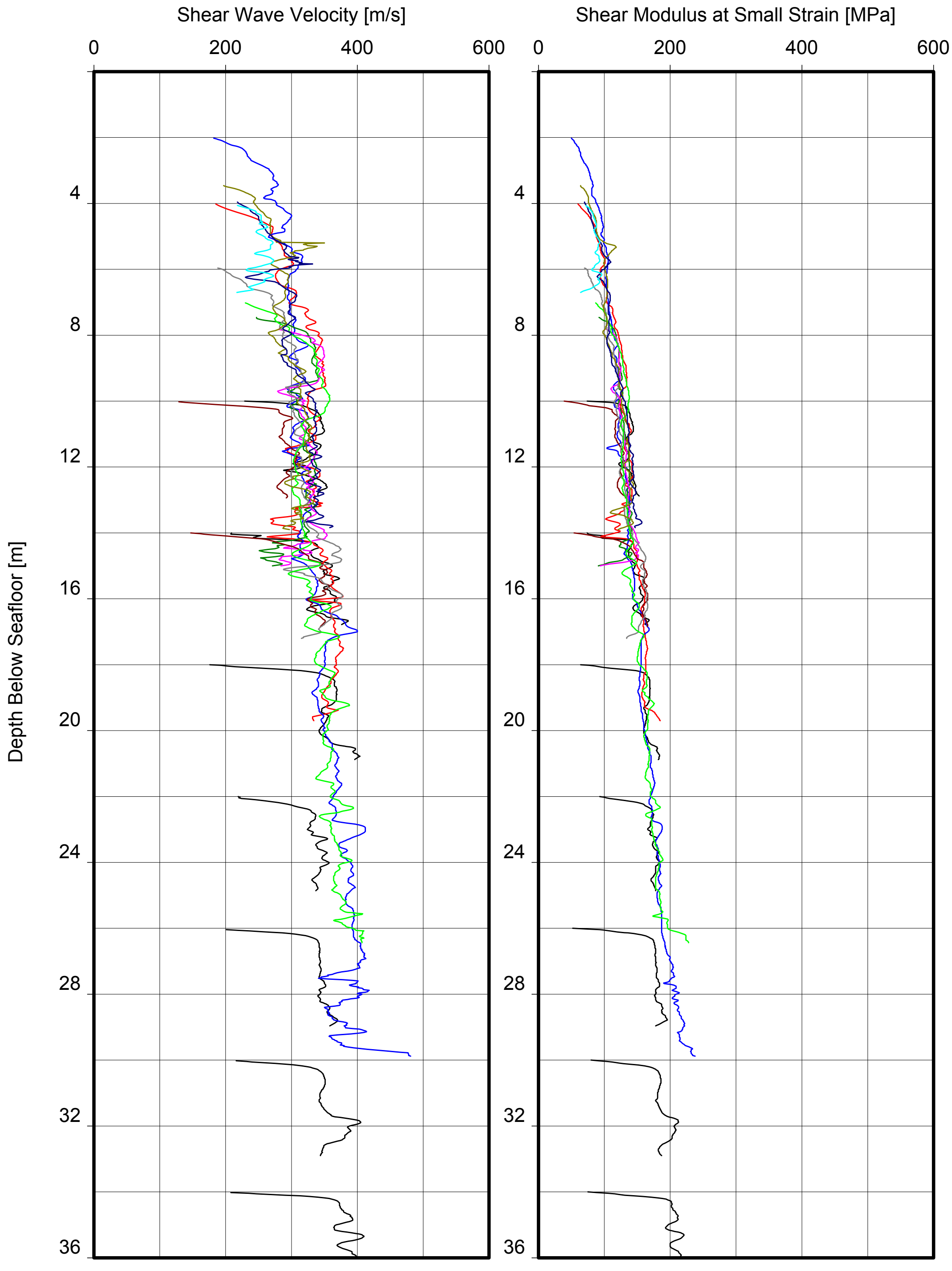
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 14:52:01

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

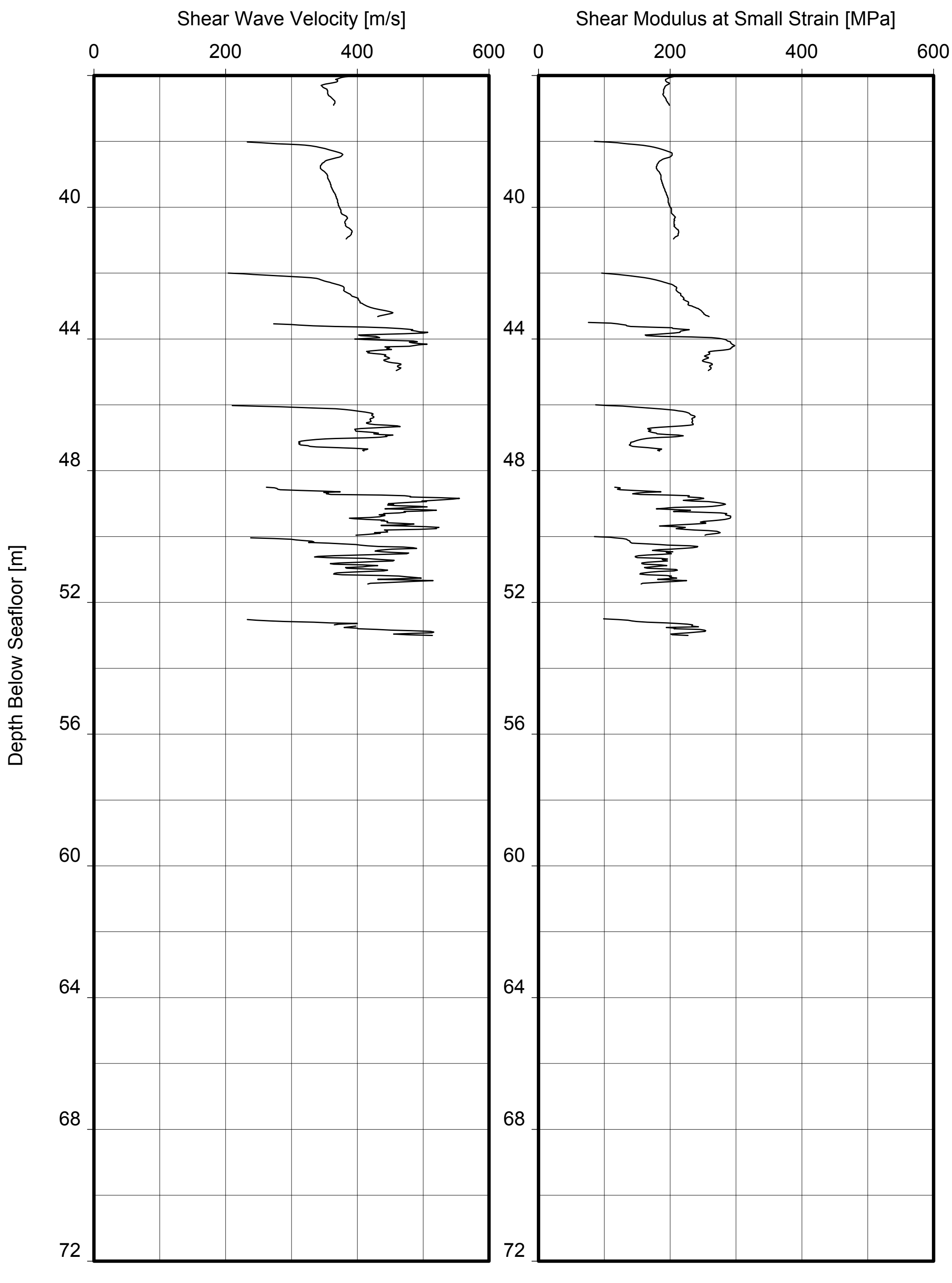
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:19:55

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array

Shear modulus at small strain (G_{max}) derived from v_s measured

v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A, CPT_WFS2_16, CPT_WFS2_19, CPT_WFS2_25, CPT_WFS2_25A, BH-WFS2-4, CPT_WFS2_27, CPT_WFS2_21, CPT_WFS2_11, CPT_WFS2_11A, CPT_WFS2_13, CPT_WFS2_22

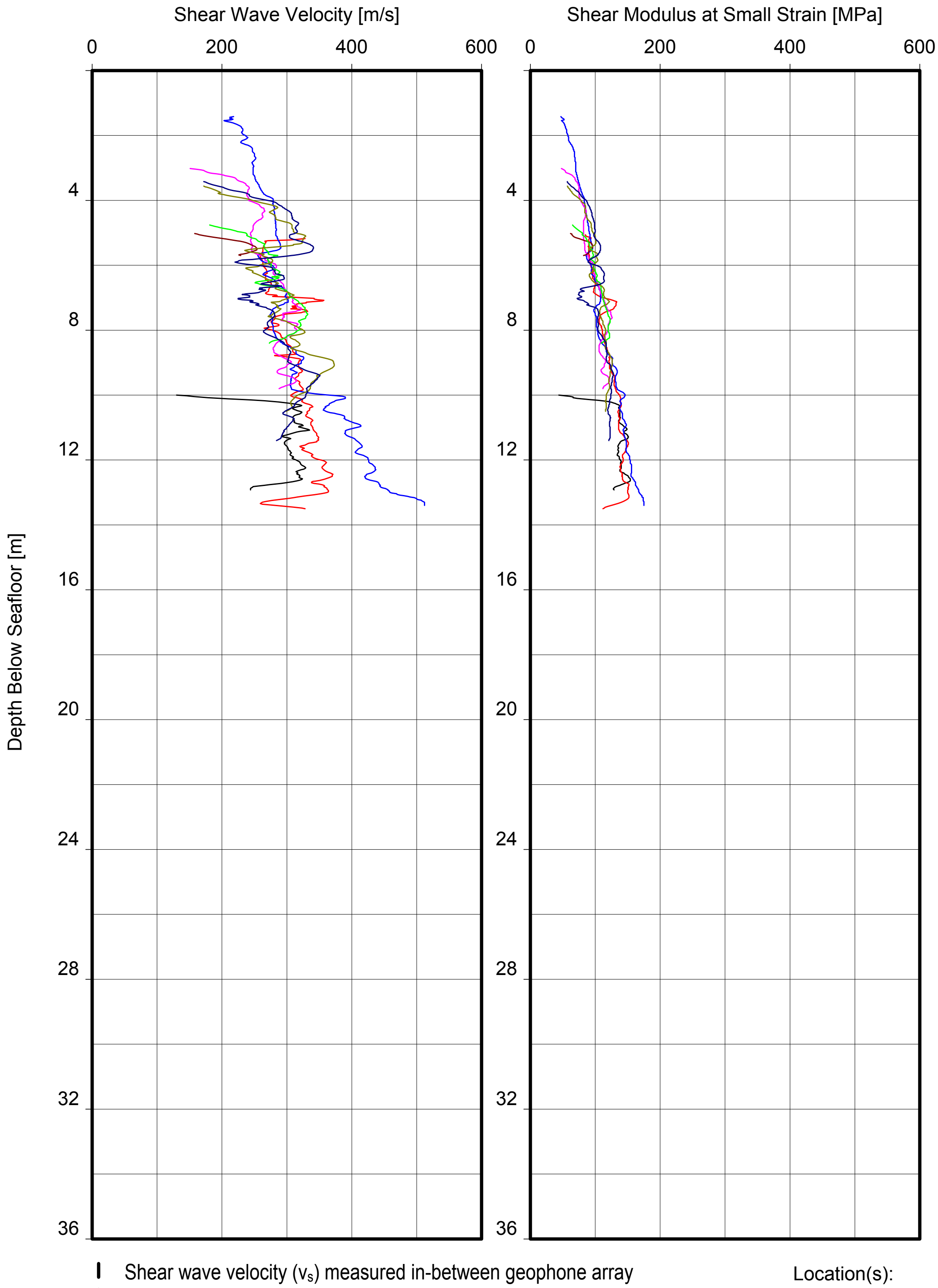
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:19:55

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

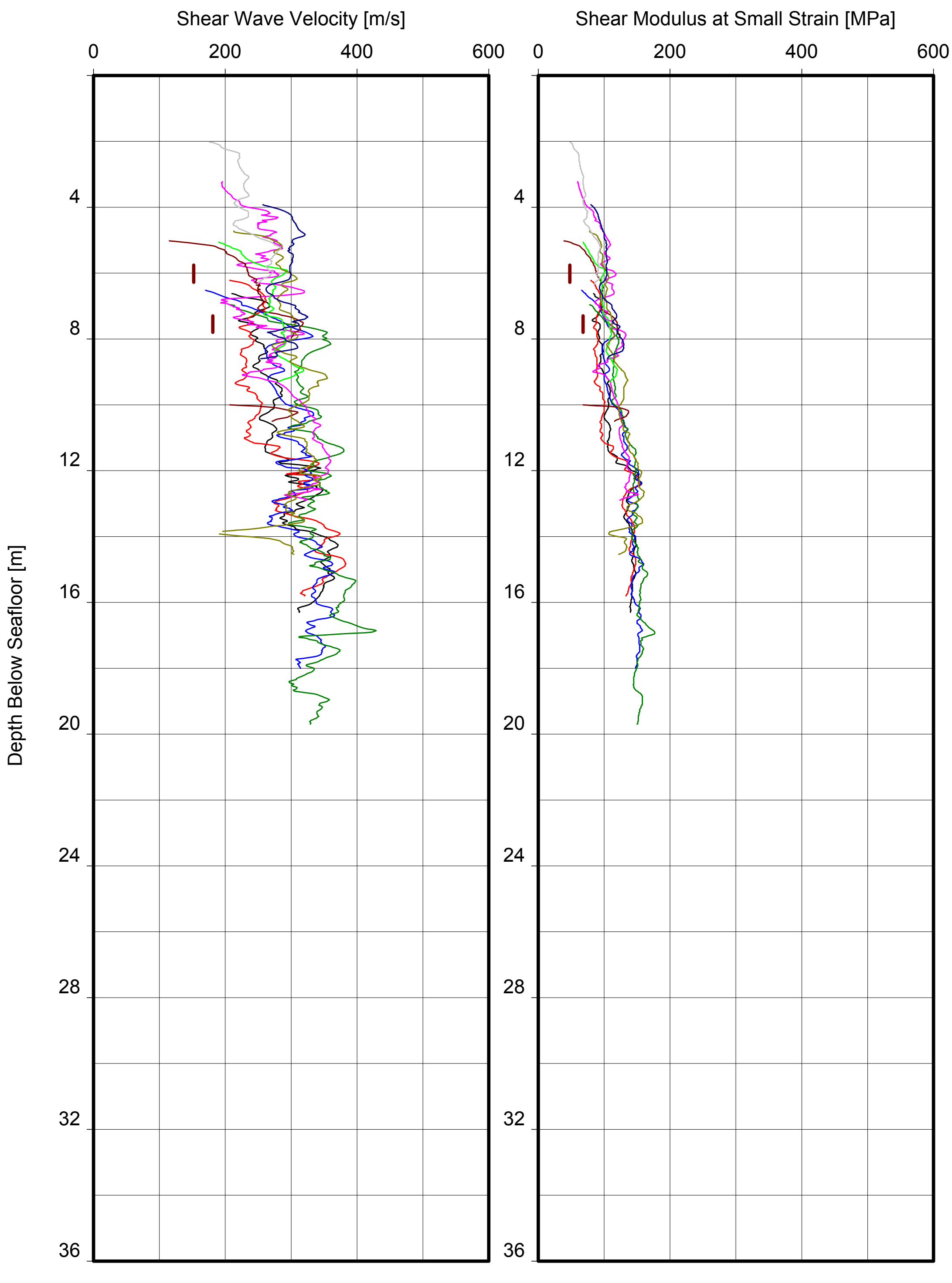
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:36:29

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):

CPT_WFS2_7, CPT_WFS2_7A, CPT_WFS2_20, CPT_WFS2_20B, CPT_WFS2_2, BH-WFS2-6A, BH-WFS2-6B, CPT_WFS2_1, CPT_WFS2_5, CPT_WFS2_4, BH-WFS2-7, CPT_WFS2_23

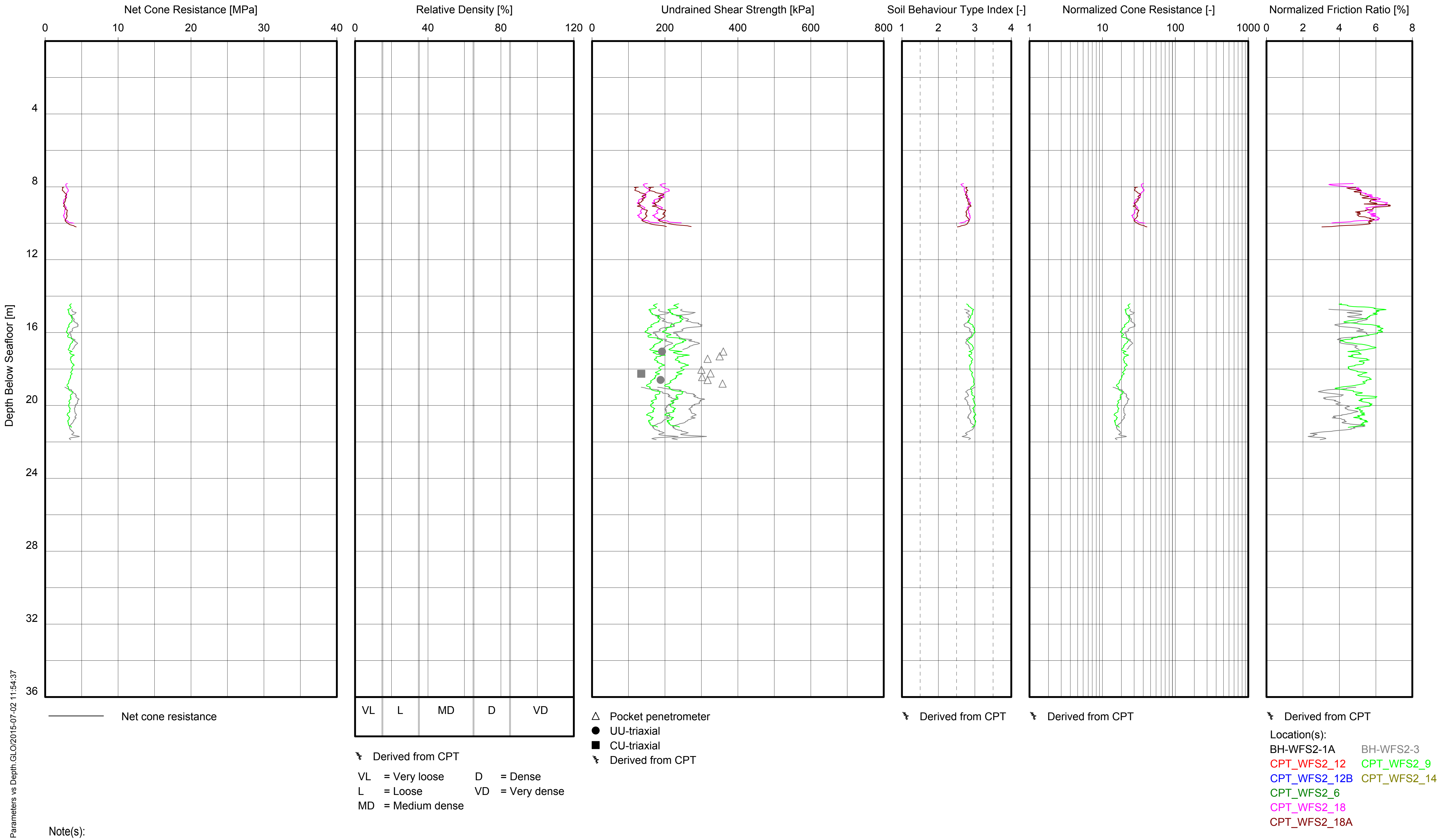
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:49:36

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT B

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



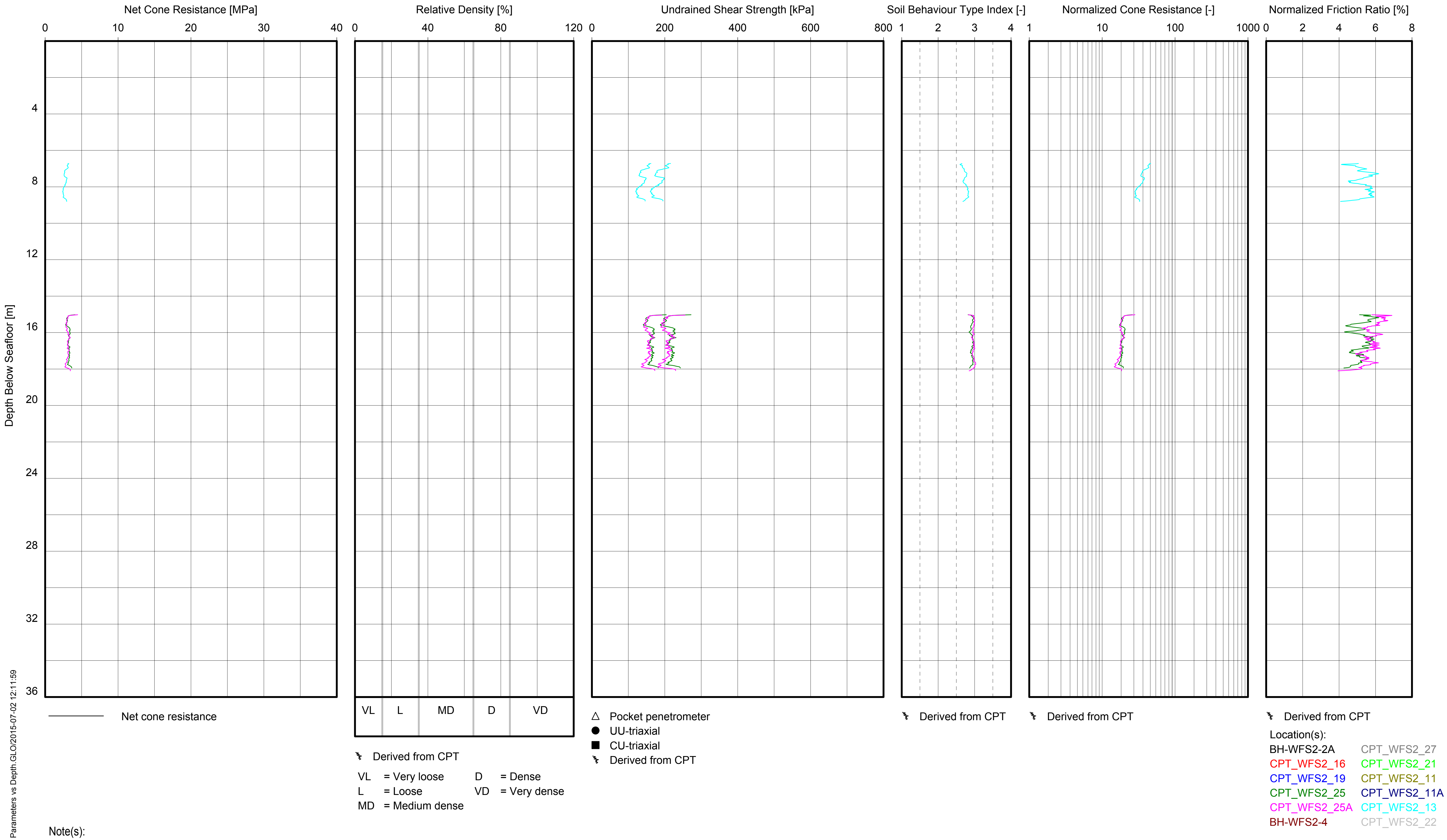
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 11:54:37

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT D

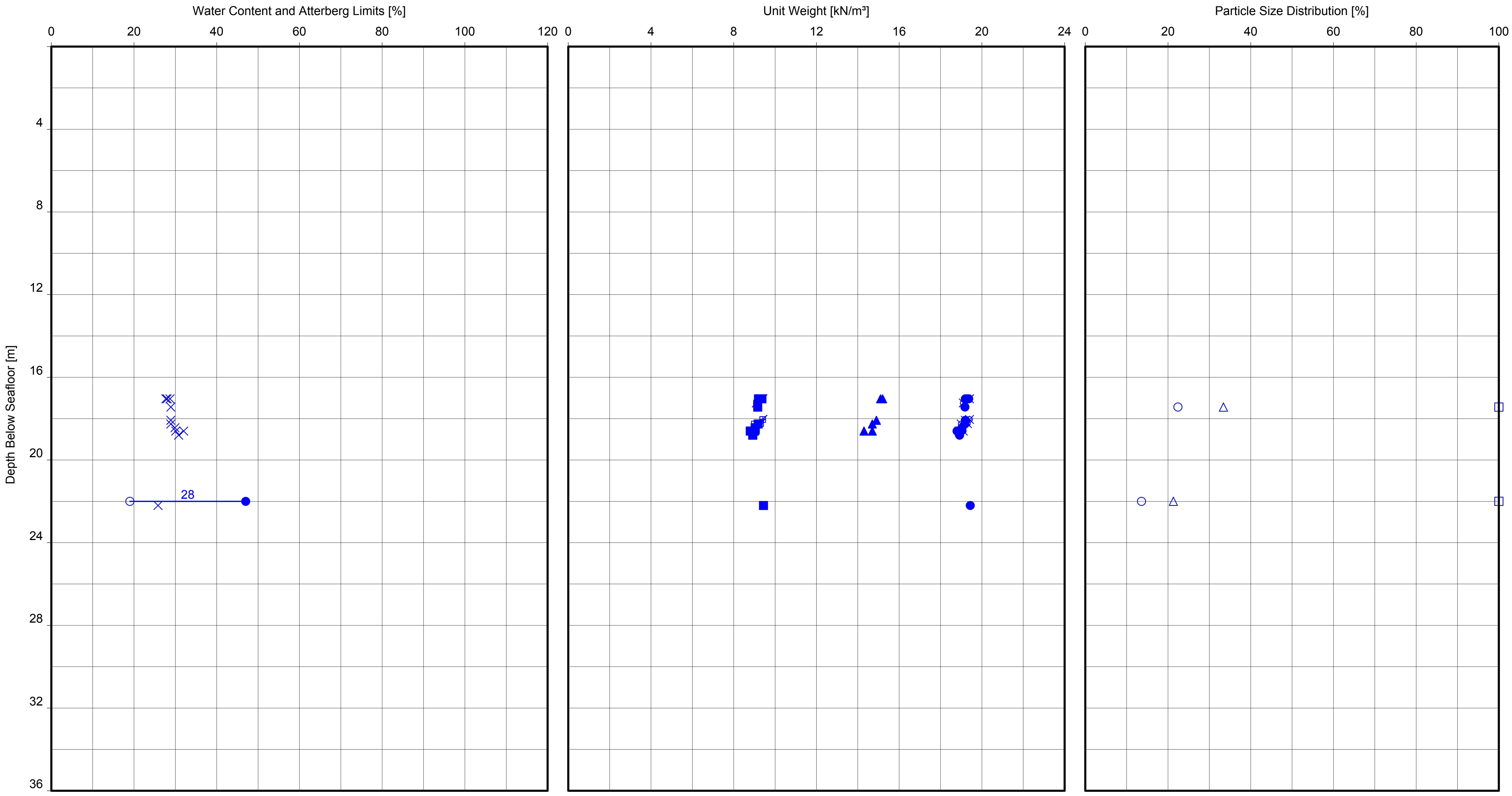
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



GeODin/CPT Parameters vs Depth GLO/2015-07-02 12:11:59

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT D
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



× Water content
○ Plastic limit
● Liquid limit
○—55—● Plasticity index

● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

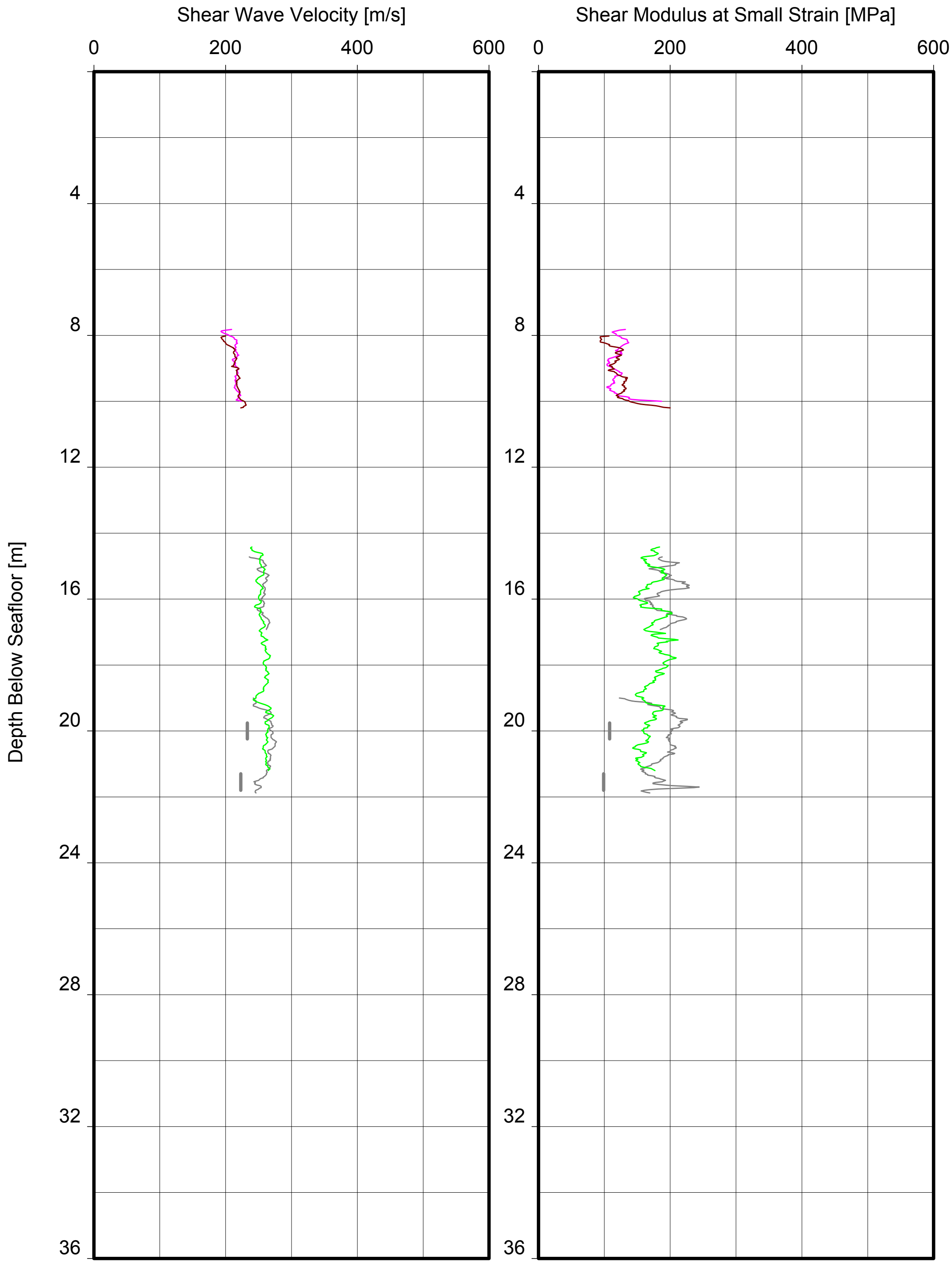
○ Particle size by mass percentage <2 μm
△ Particle size by mass percentage <60 μm
□ Particle size by mass percentage <2000 μm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:33:40

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH
UNIT D
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

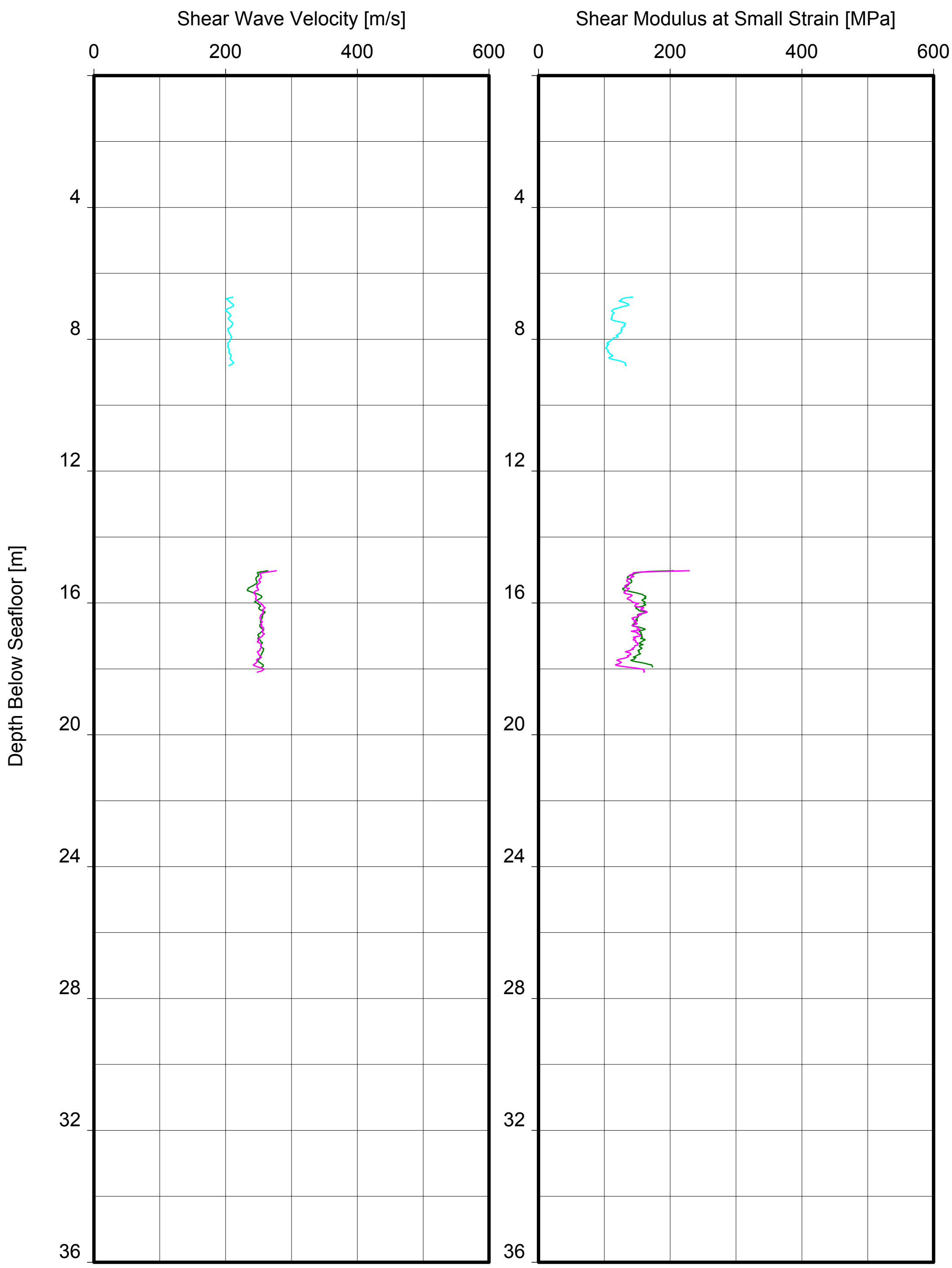
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 14:52:57

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT D

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

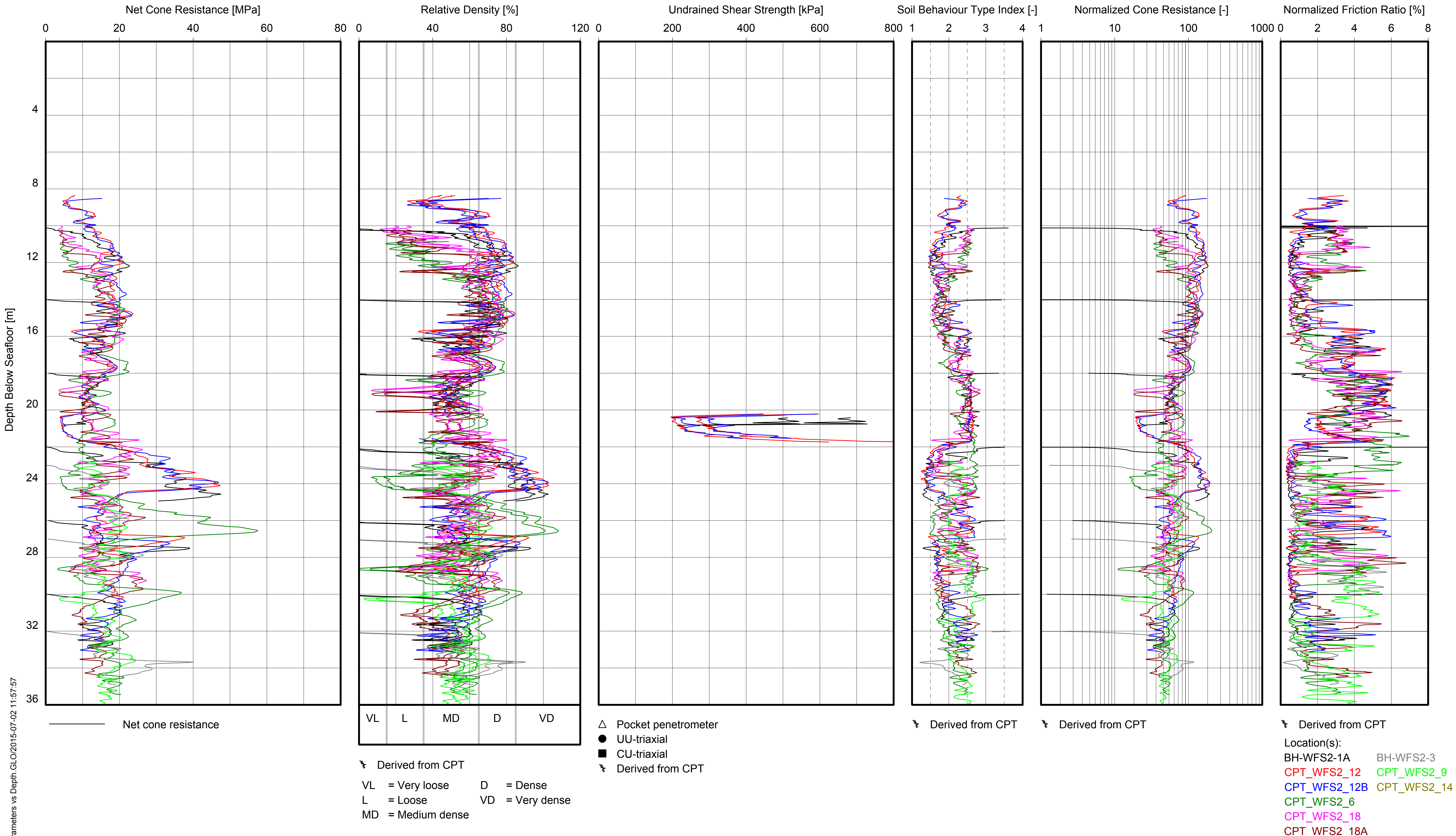
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:20:48

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT D

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

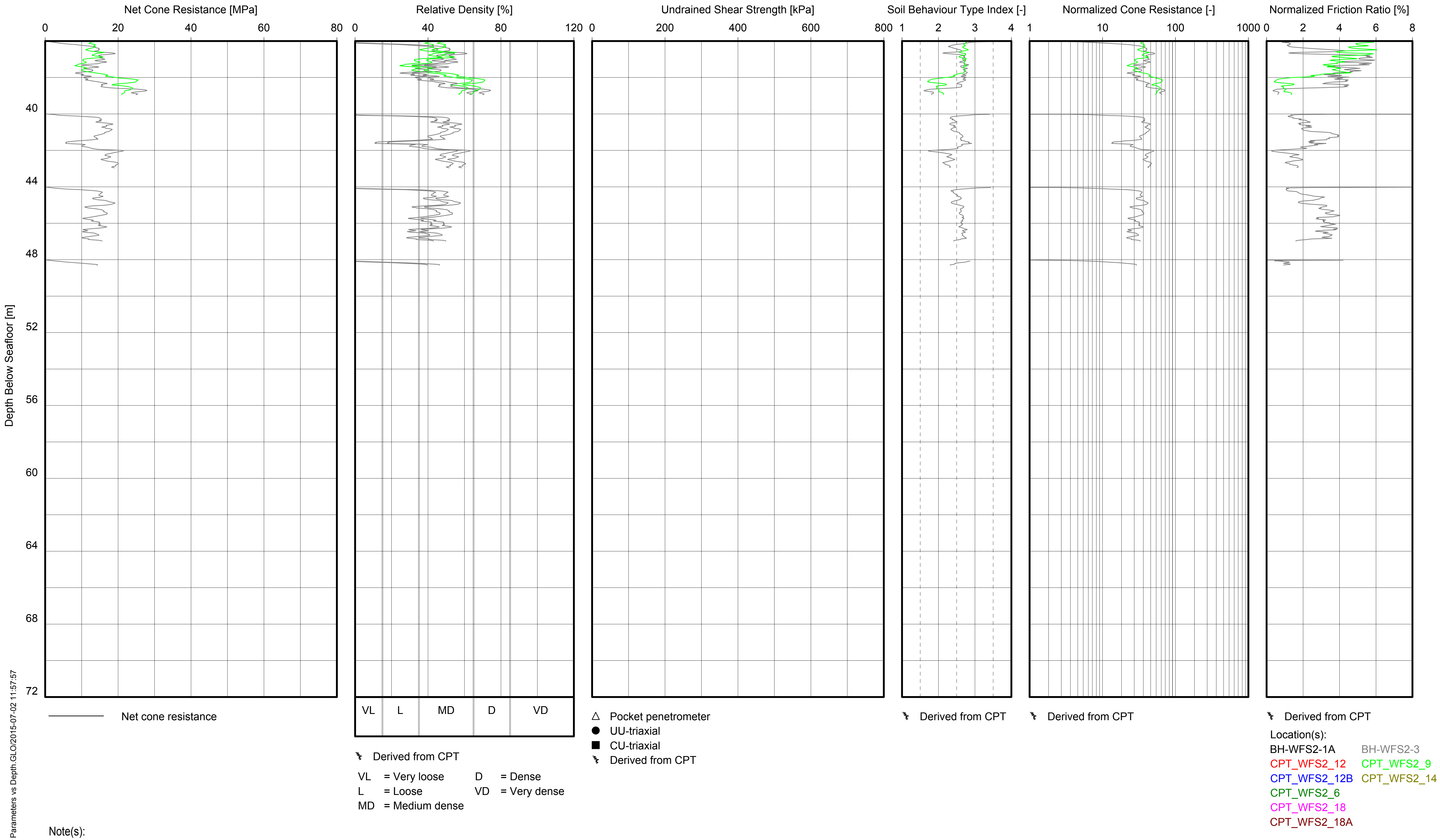


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



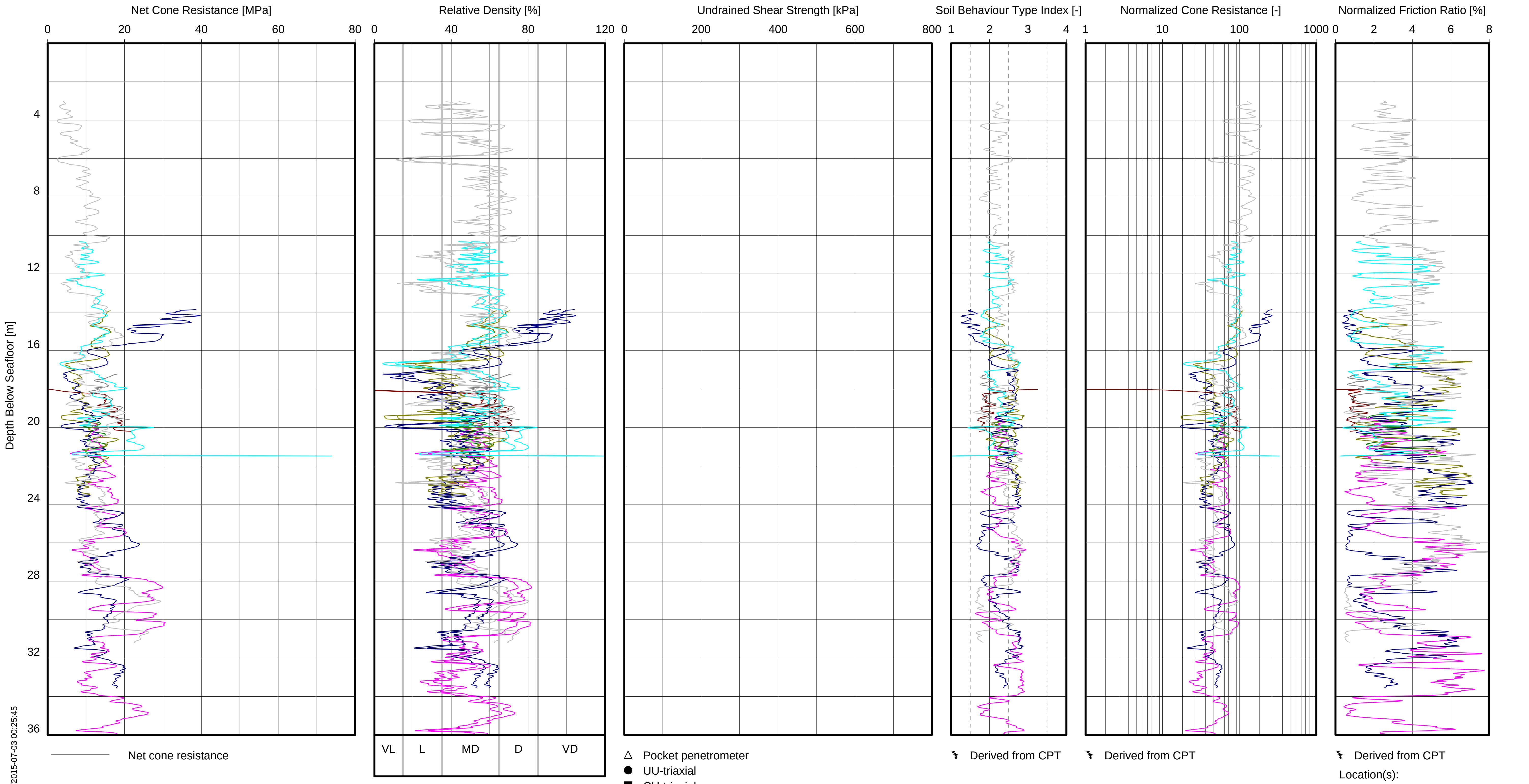
GeODin\CPT Parameters vs Depth.GLO\2015-07-02 11:57:57

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



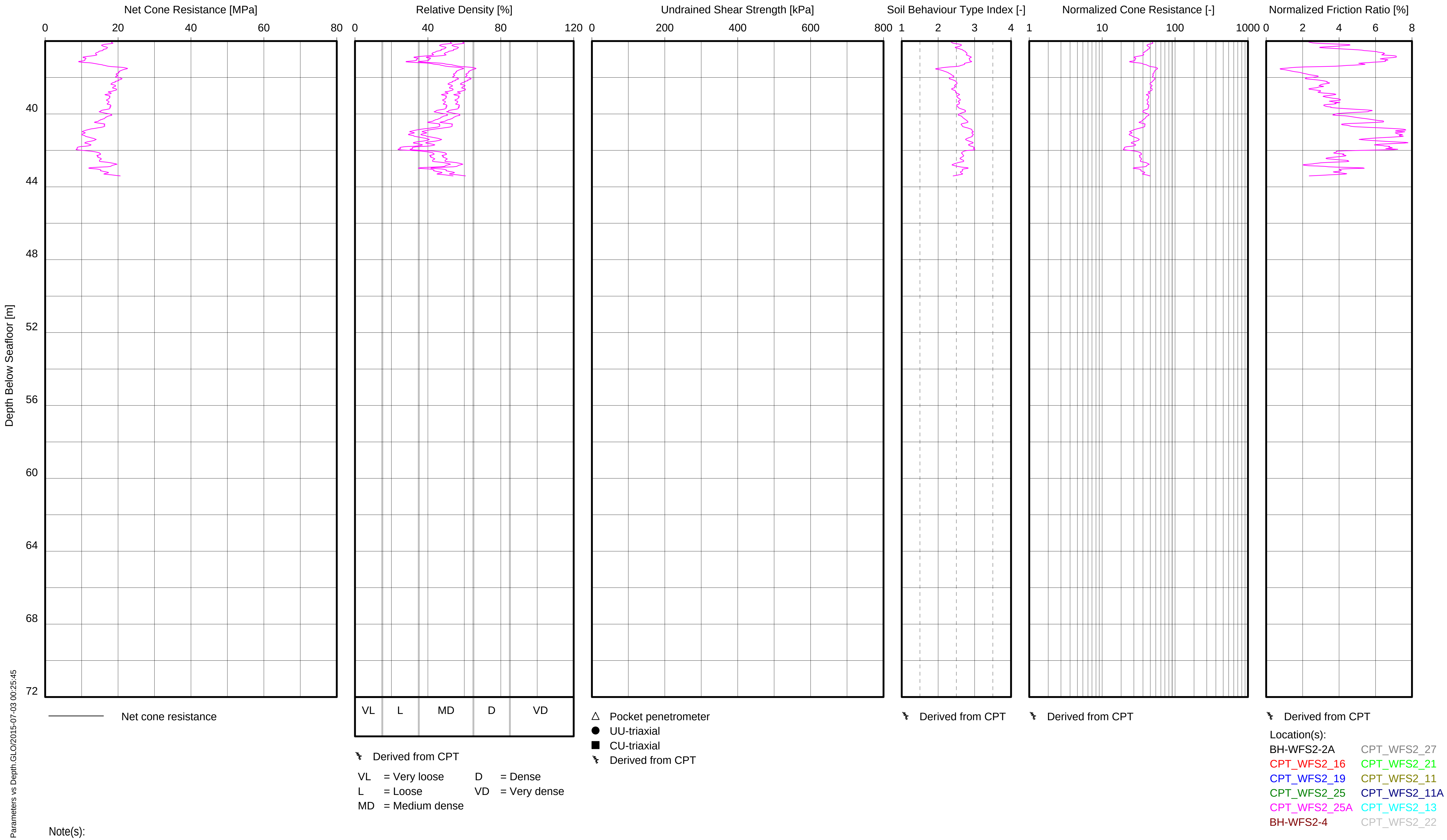
Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin\CPT Parameters vs Depth.GLO/2015-07-03 00:25:45

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



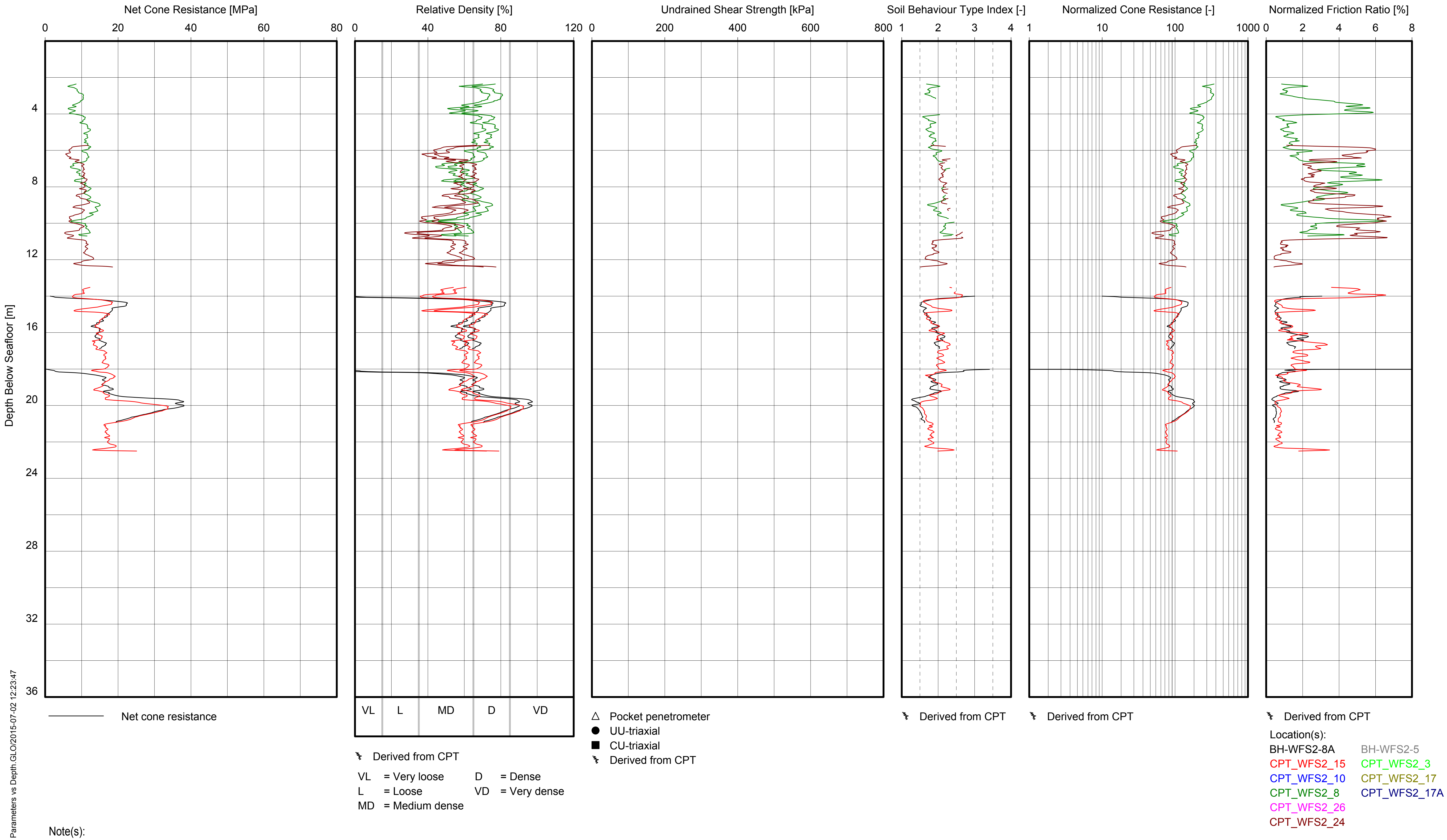
GeODin\CPT Parameters vs Depth.GLO/2015-07-03 00:25:45

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

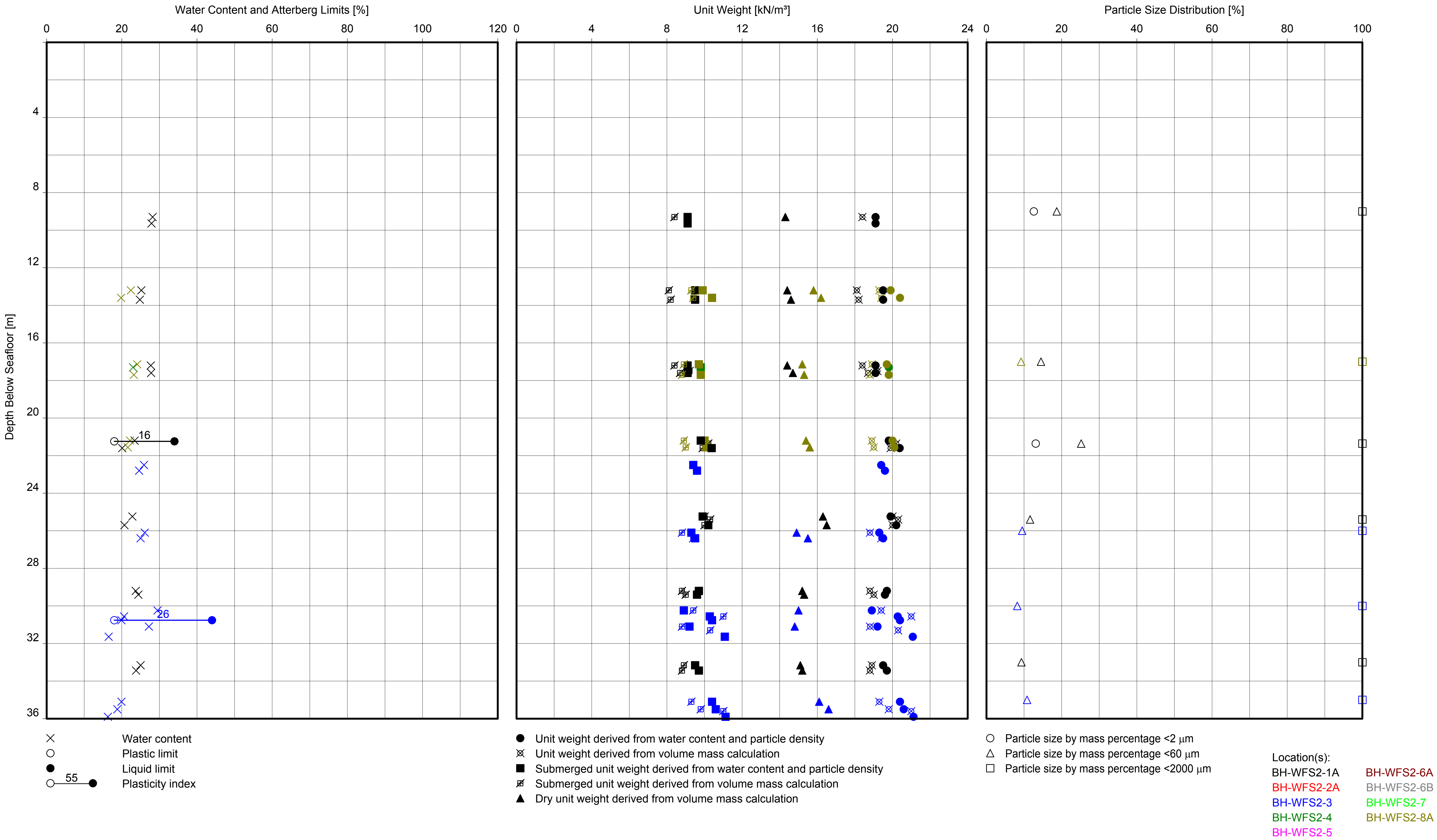
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin\CPT Parameters vs Depth GLO\2015-07-02 12:23:47

CPT PARAMETERS VERSUS DEPTH
UNIT E1-E3
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



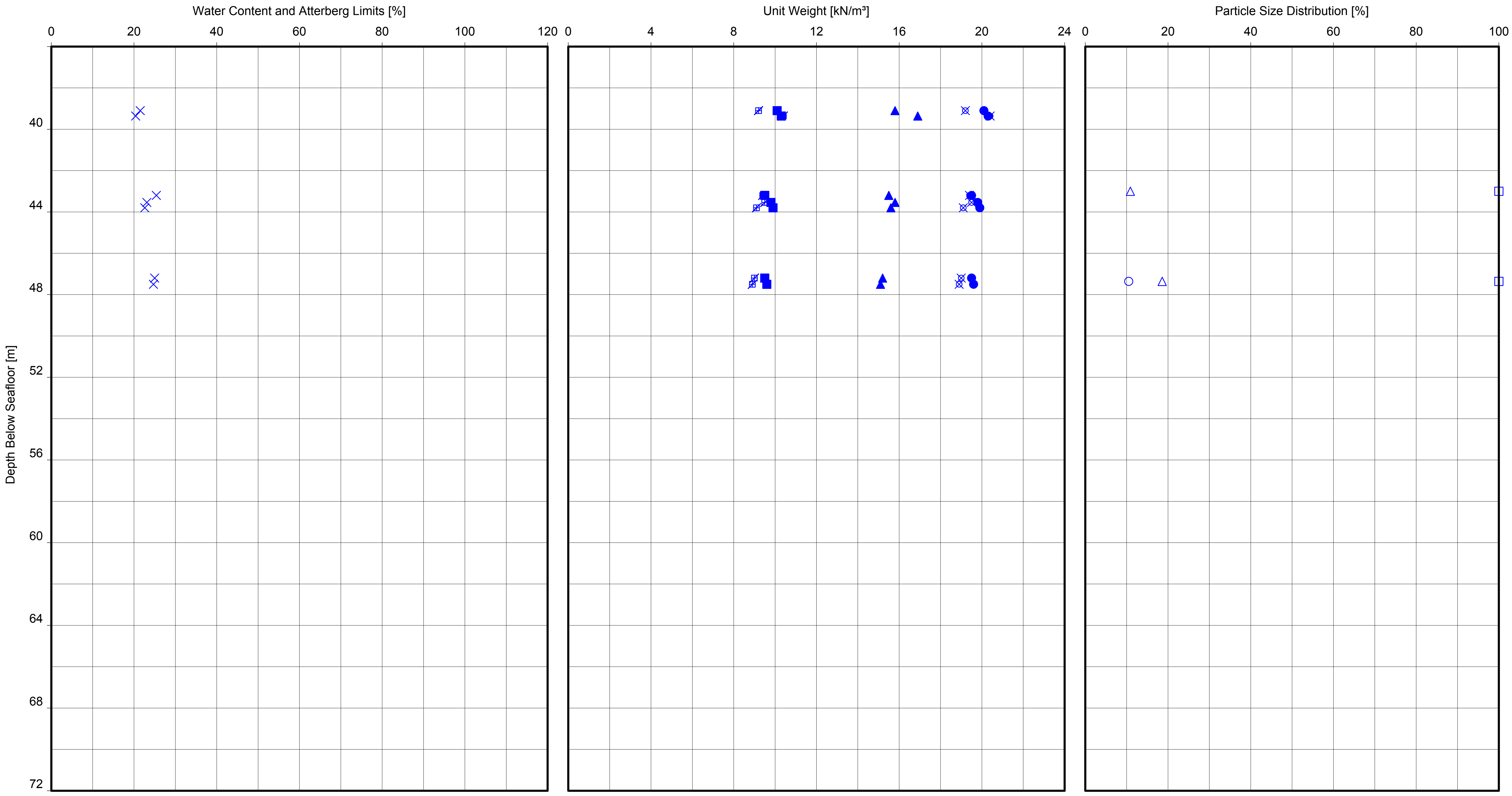
GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:34:36

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



× Water content
○ Plastic limit
● Liquid limit
○—55—● Plasticity index

● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

○ Particle size by mass percentage <2 μm
△ Particle size by mass percentage <60 μm
□ Particle size by mass percentage <2000 μm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

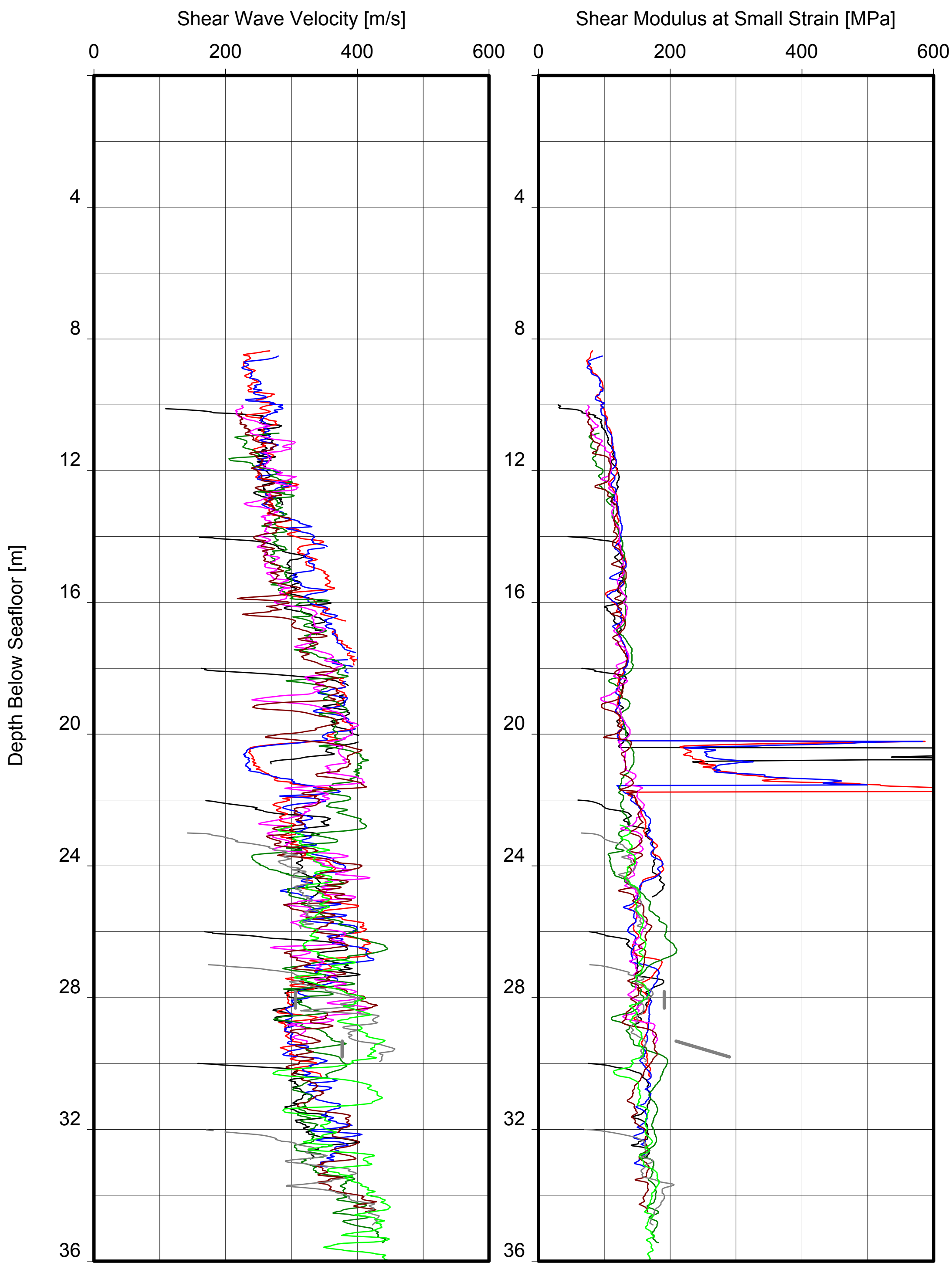
GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:34:37

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



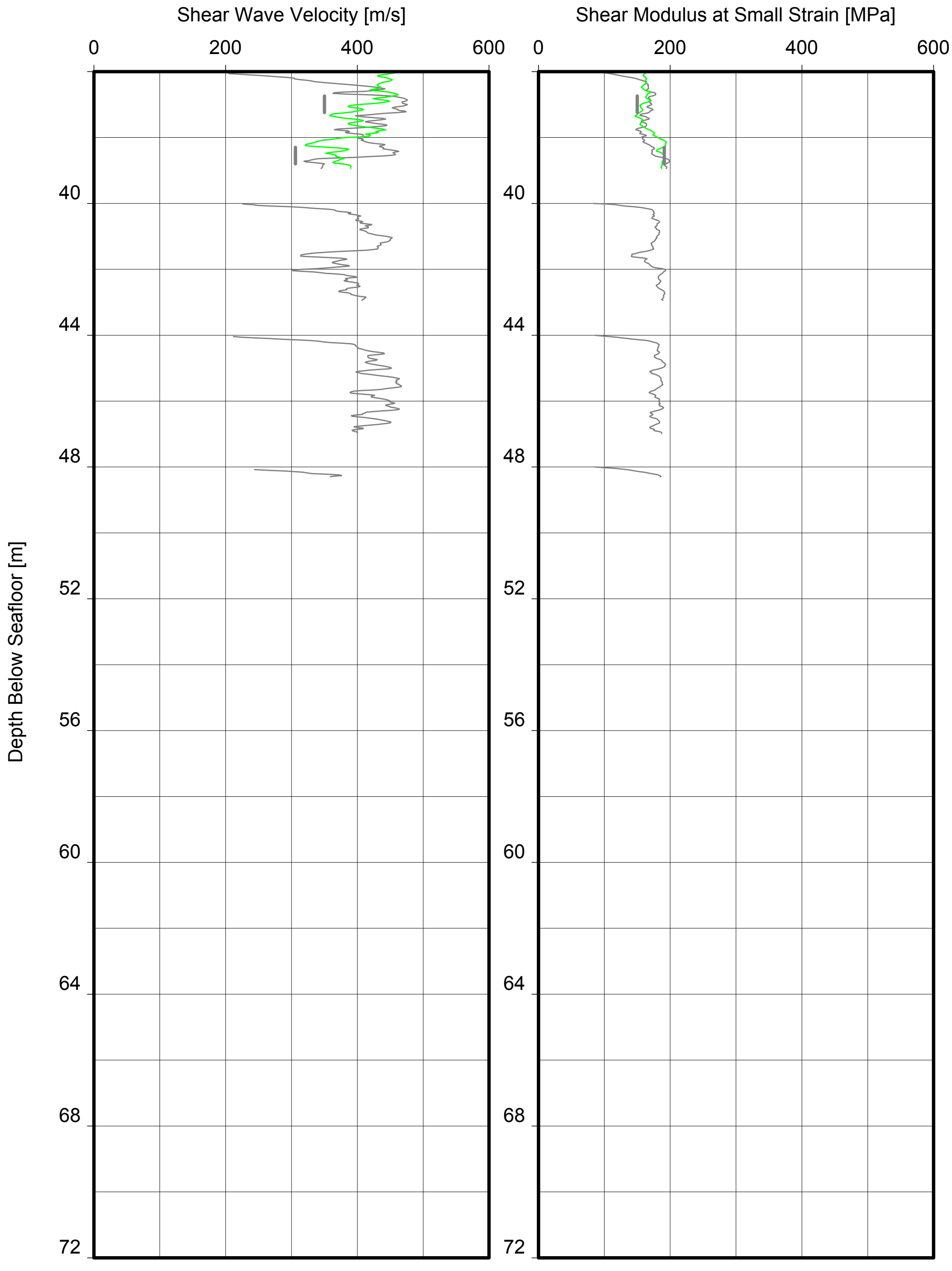
Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
CPT_WFS2_12
CPT_WFS2_12B
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A
BH-WFS2-3
CPT_WFS2_9
CPT_WFS2_14

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:39:23

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH
UNIT E1-E3
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

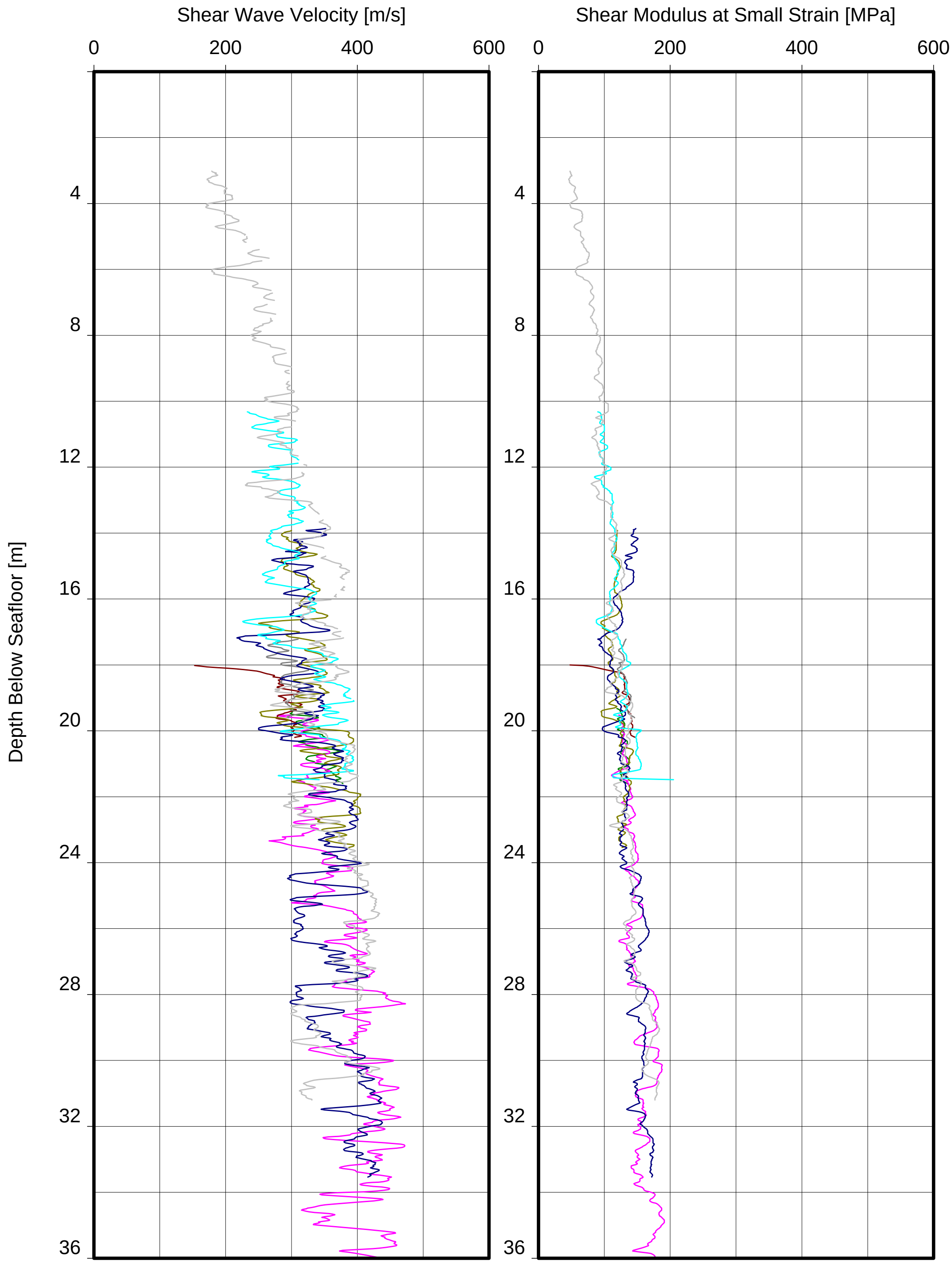
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:39:23

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

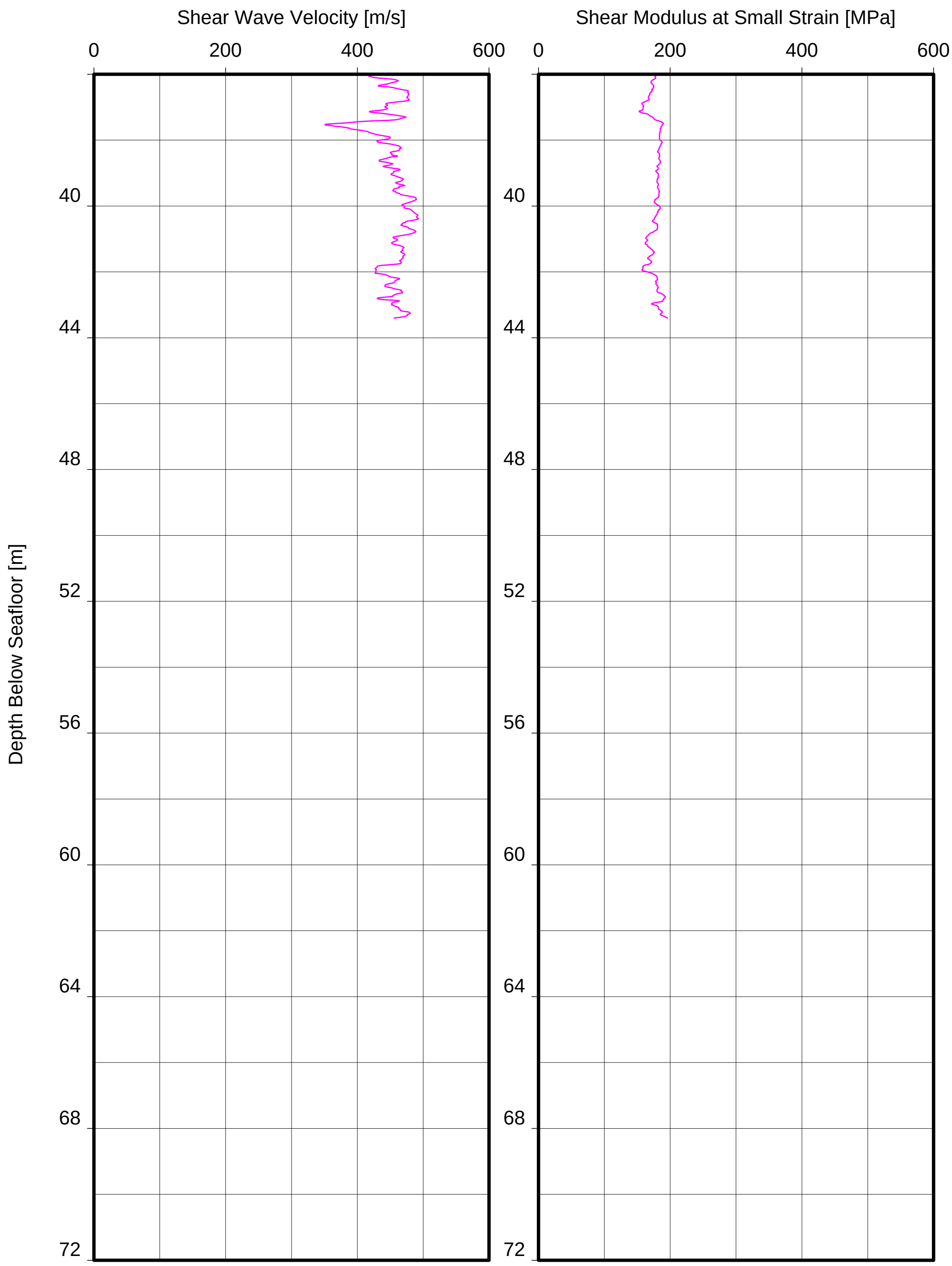
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-03 00:31:13

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

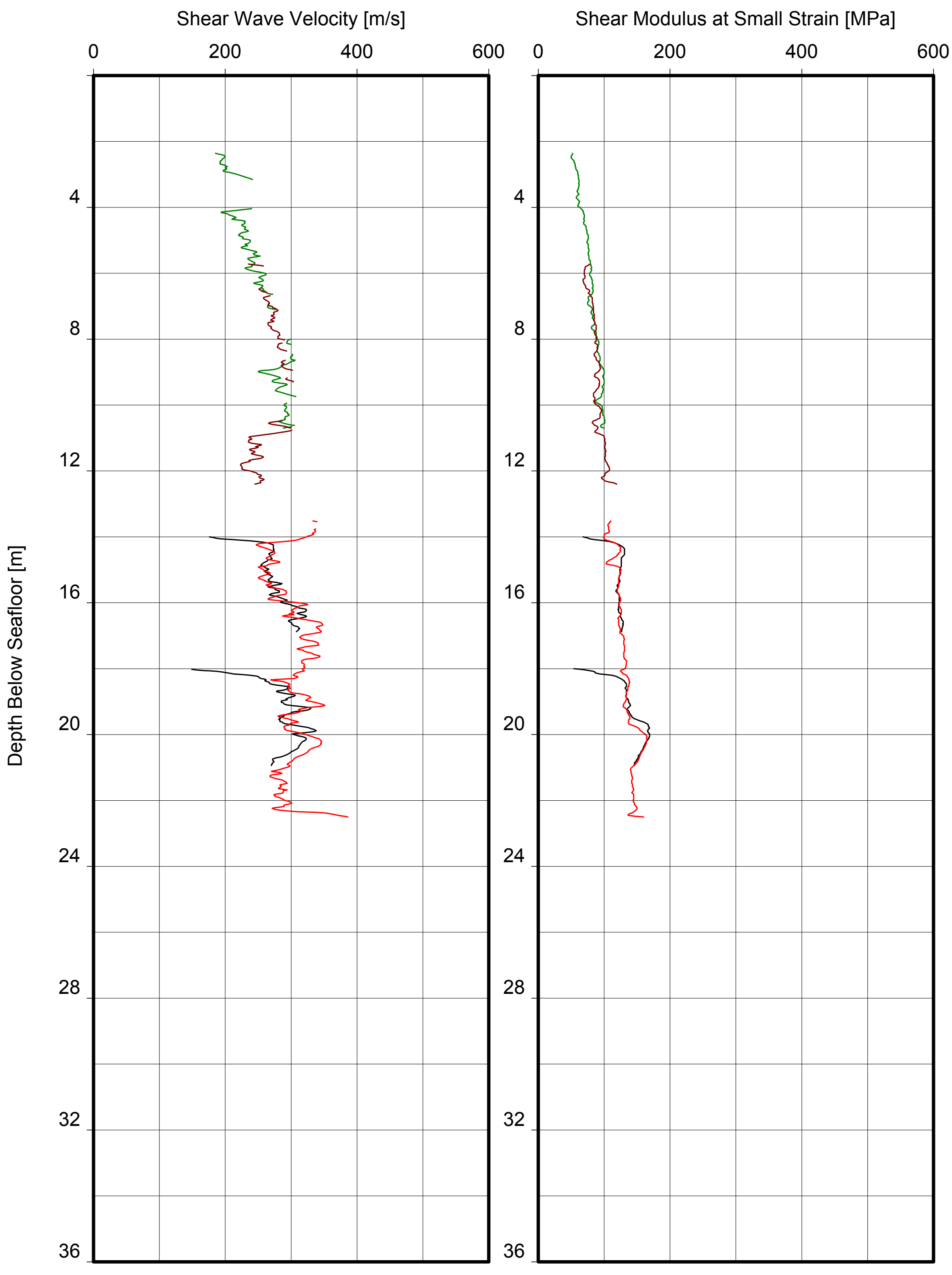
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-03 00:31:13

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

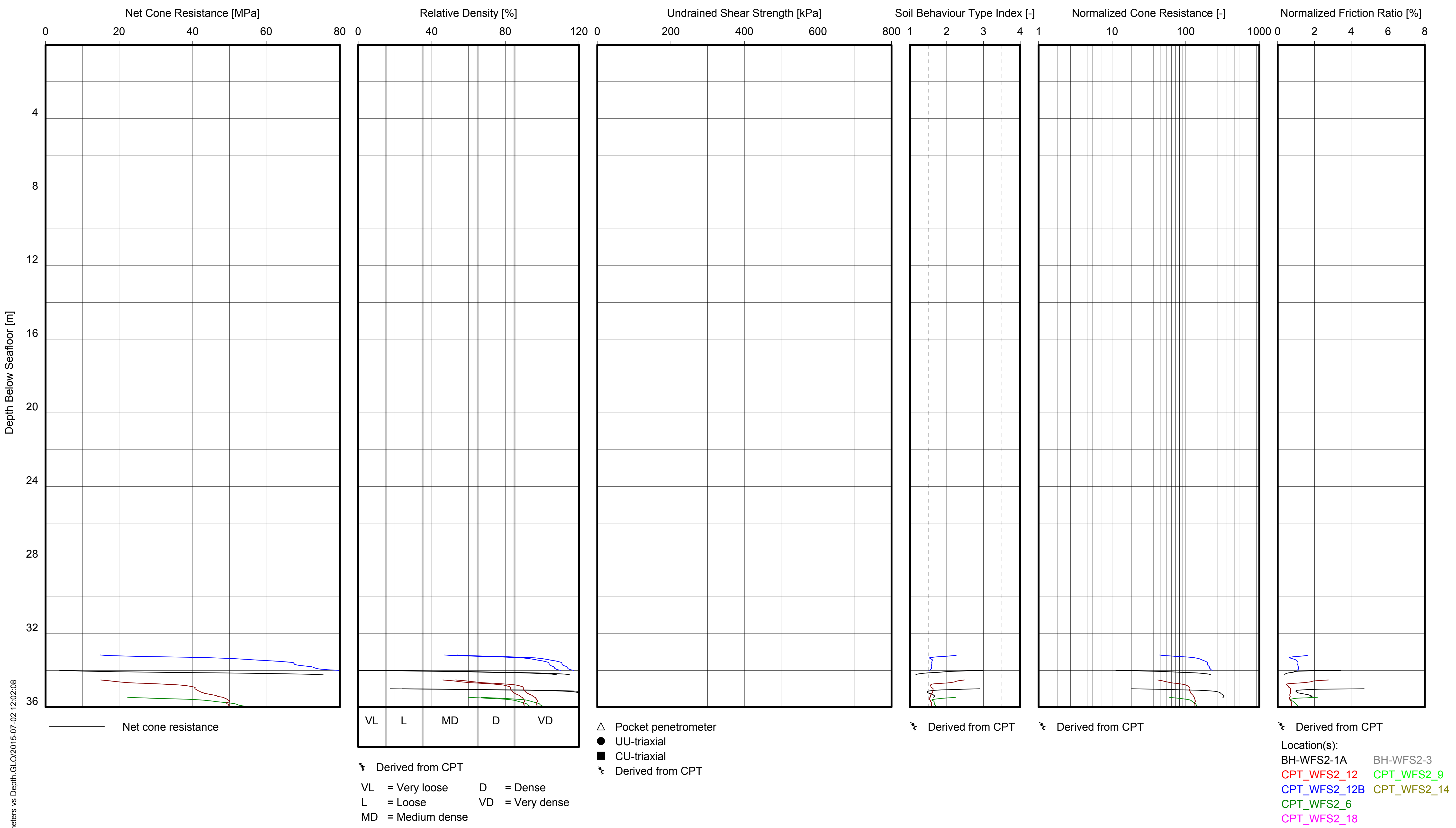
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:38:49

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E1-E3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



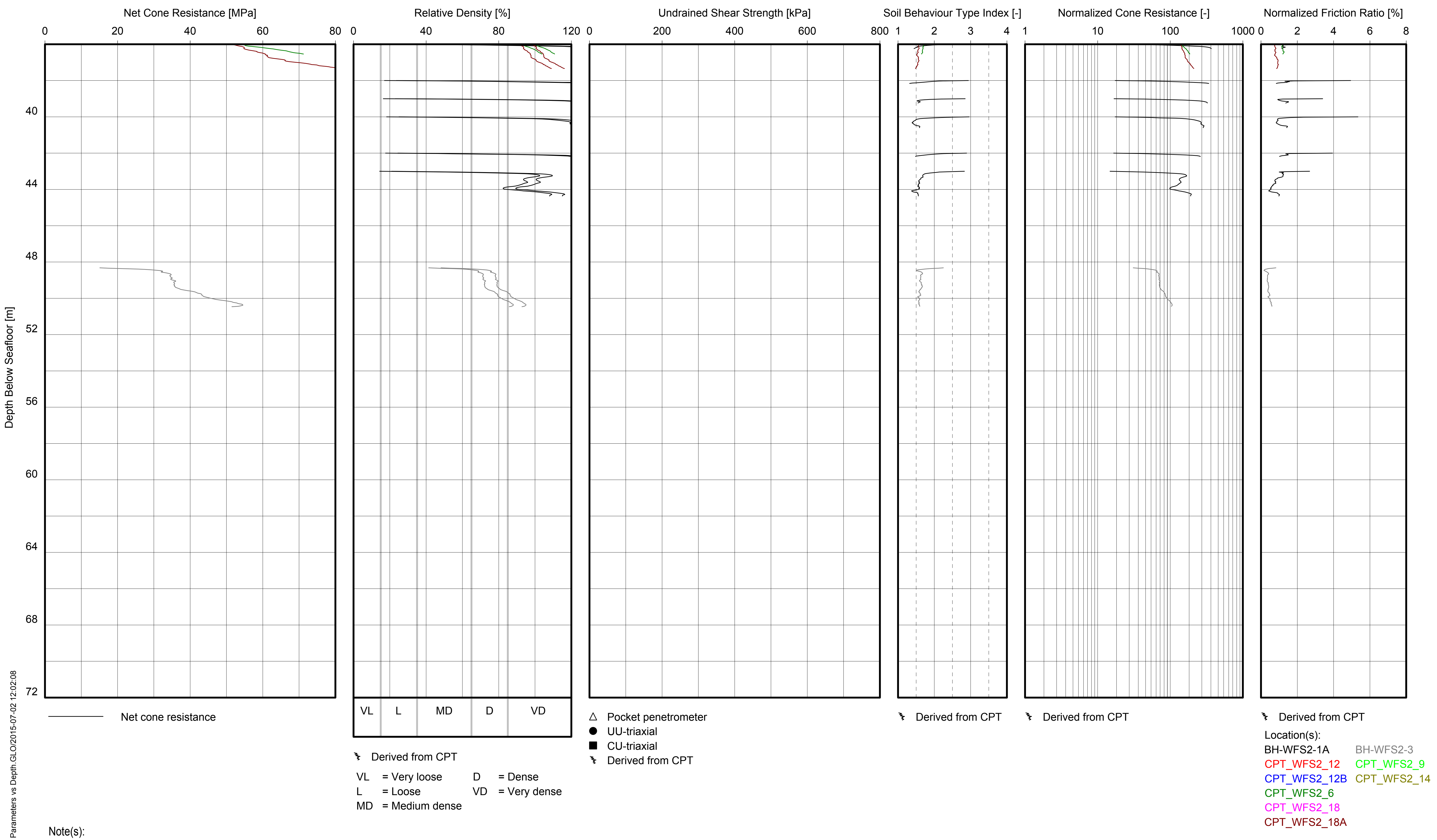
GeODin/CPT Parameters vs Depth GLO/2015-07-02 12:02:08

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



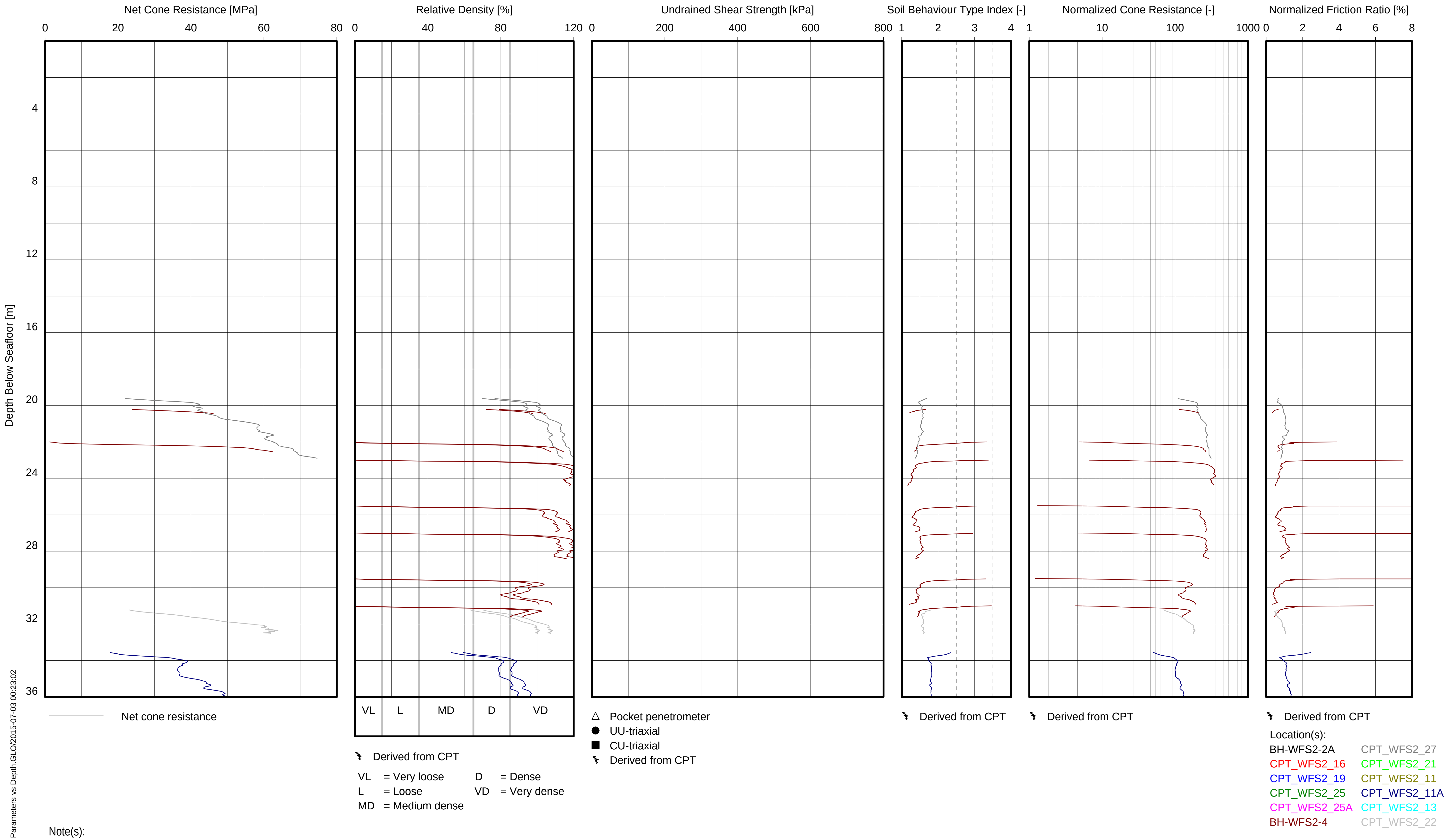
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 12:02:08

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



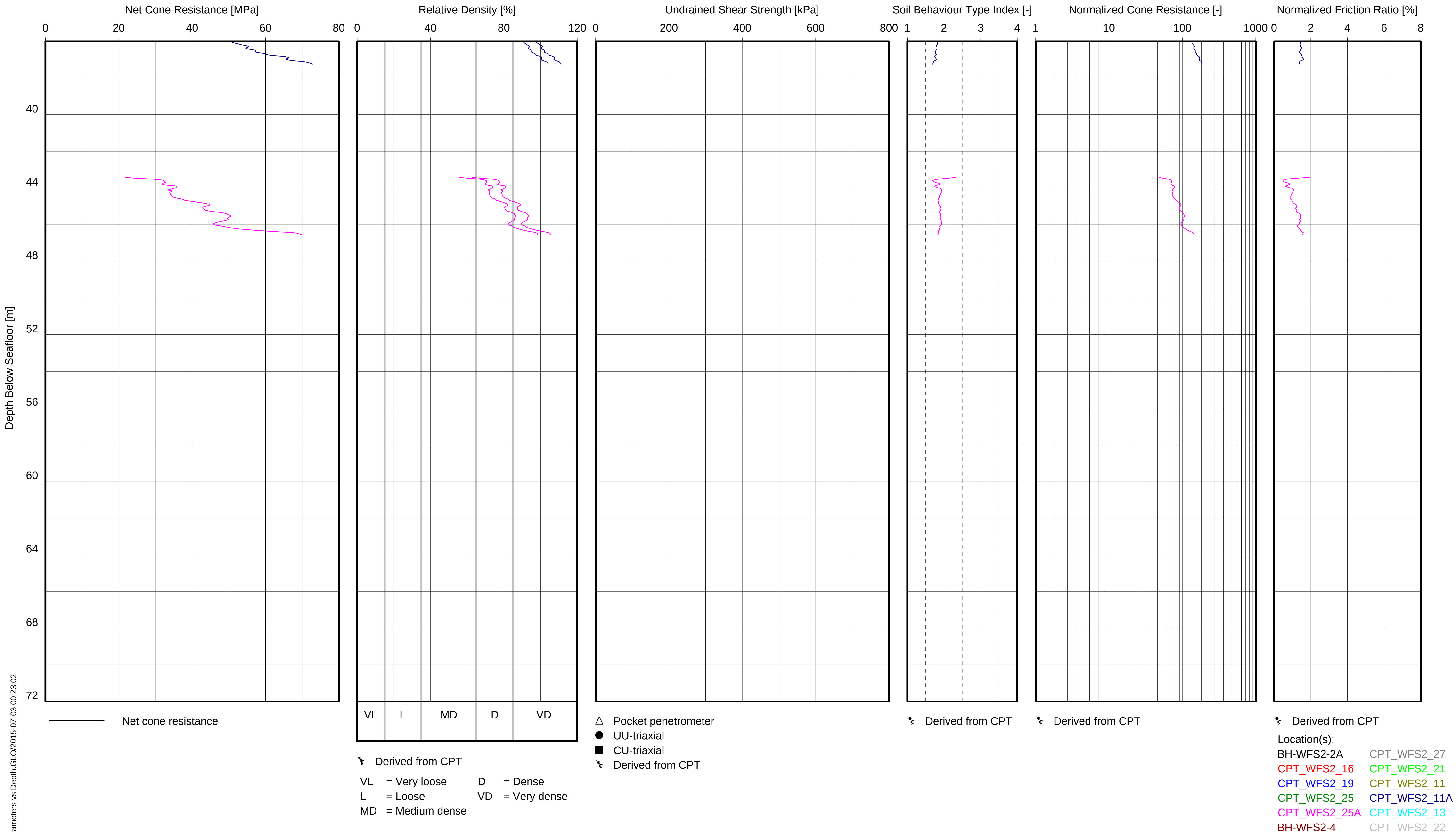
GeODin\CPT Parameters vs Depth.GLO/2015-07-03 00:23:02

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

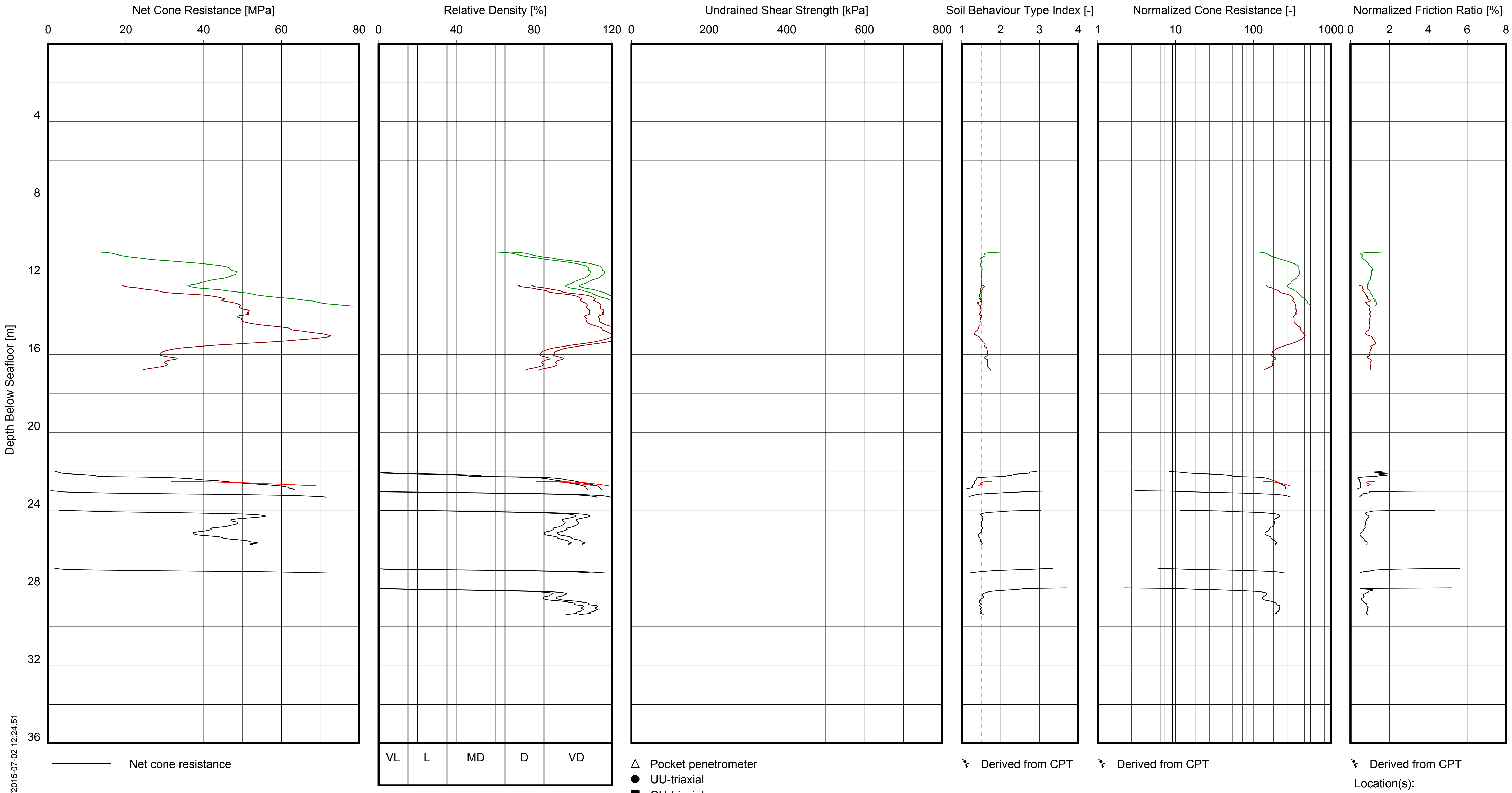


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

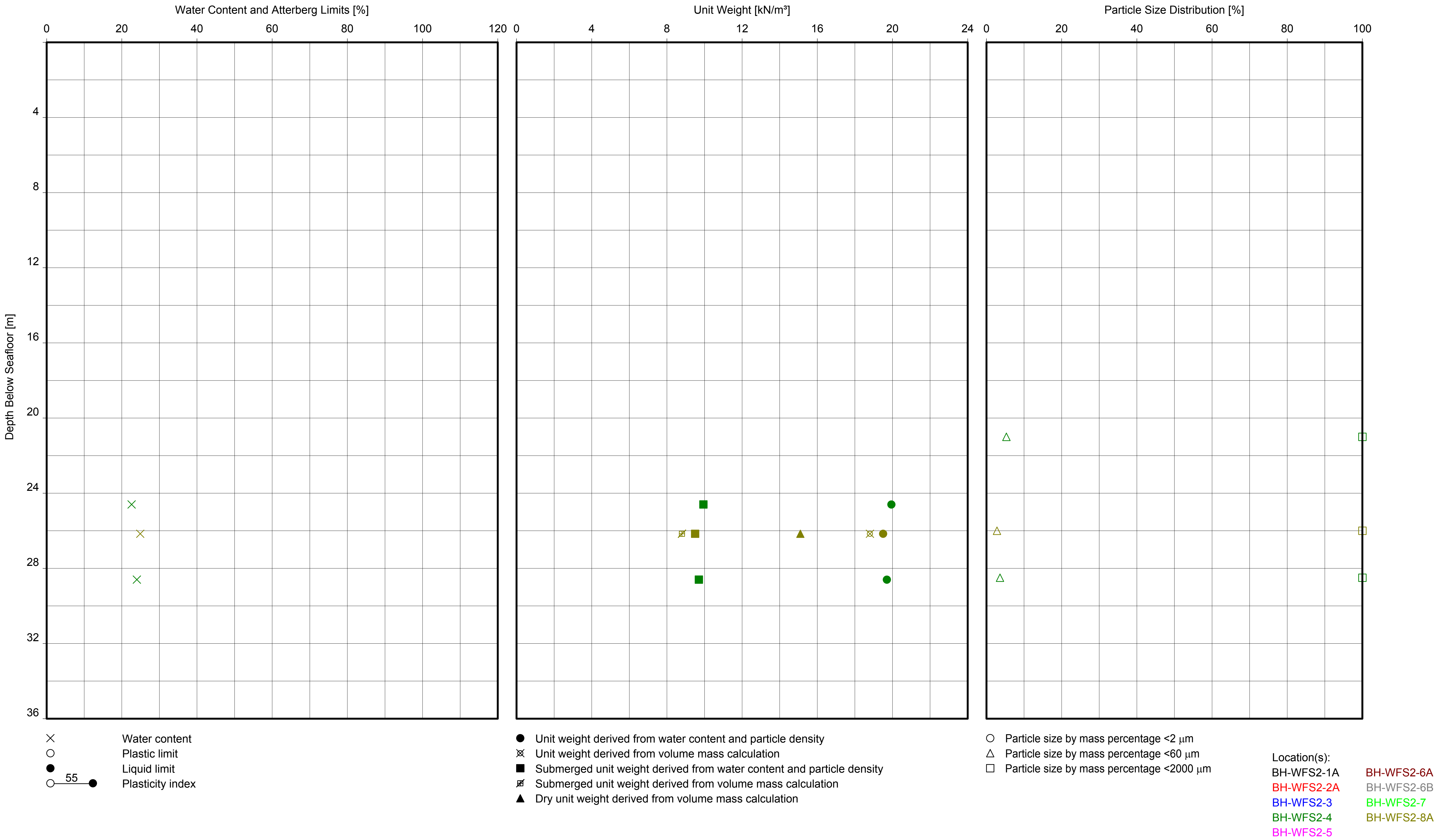
GeODin/CPT Parameters vs Depth GLO/2015-07-02 12:24:51

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



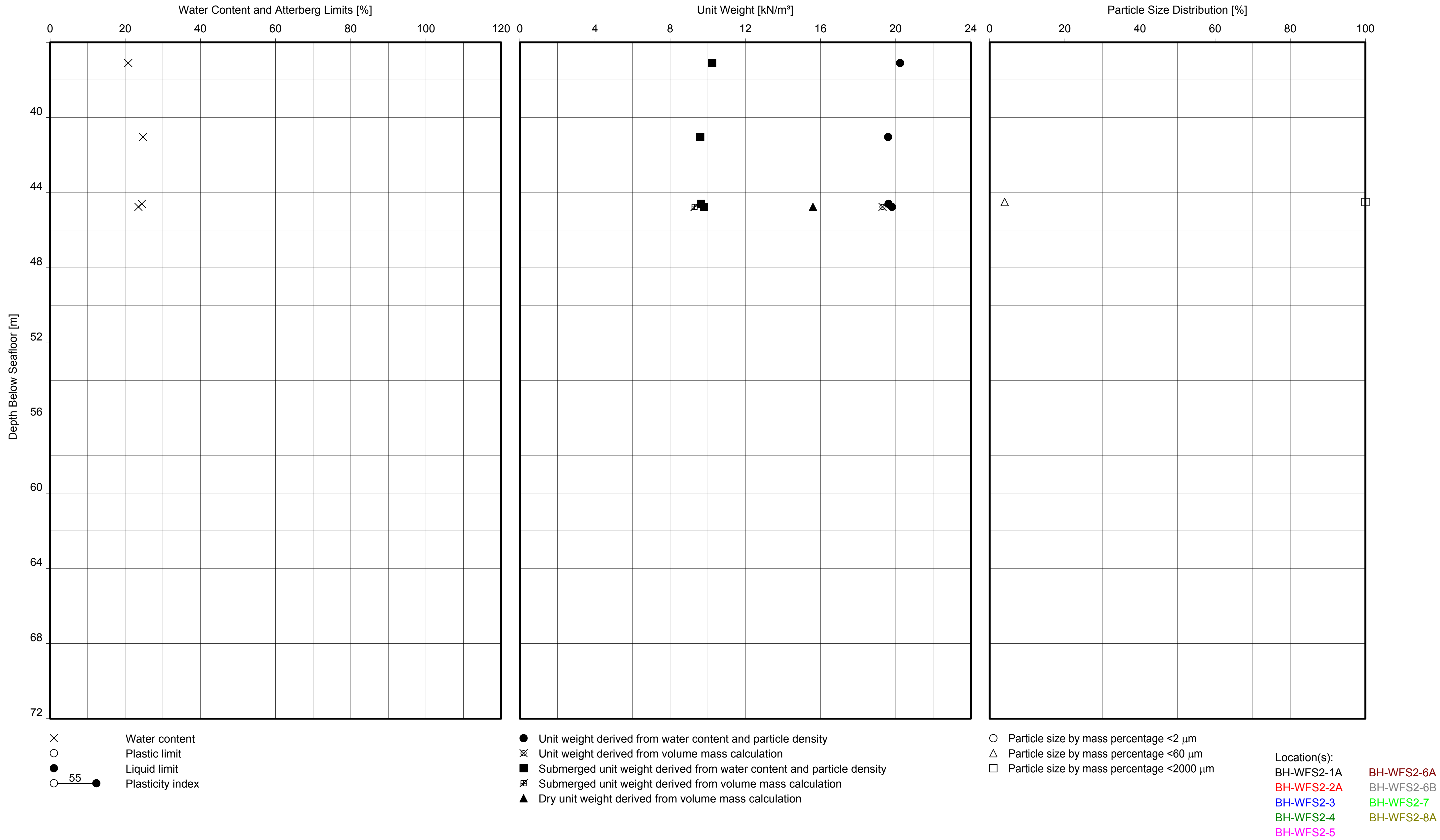
GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:35:38

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



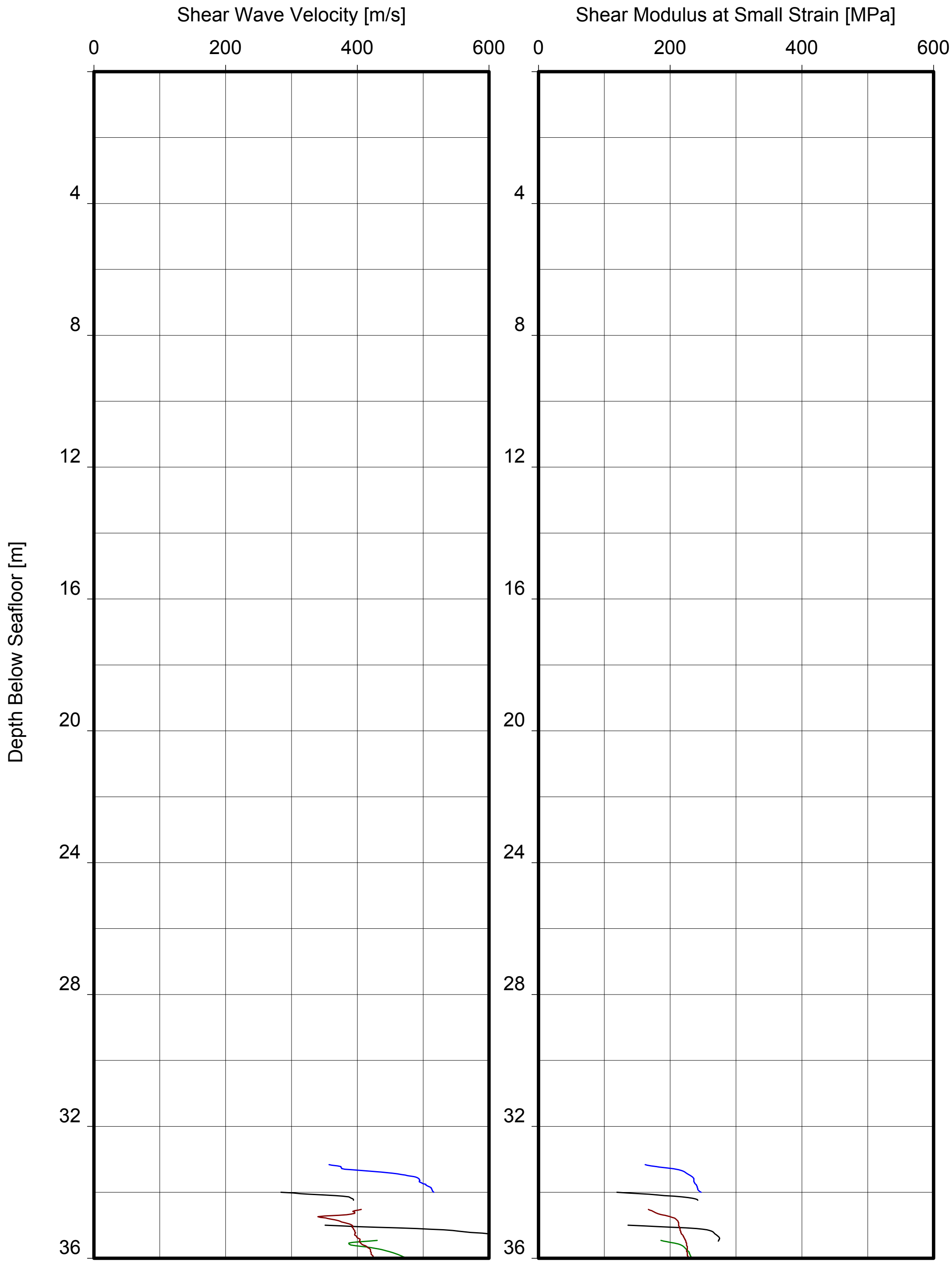
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:35:38

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

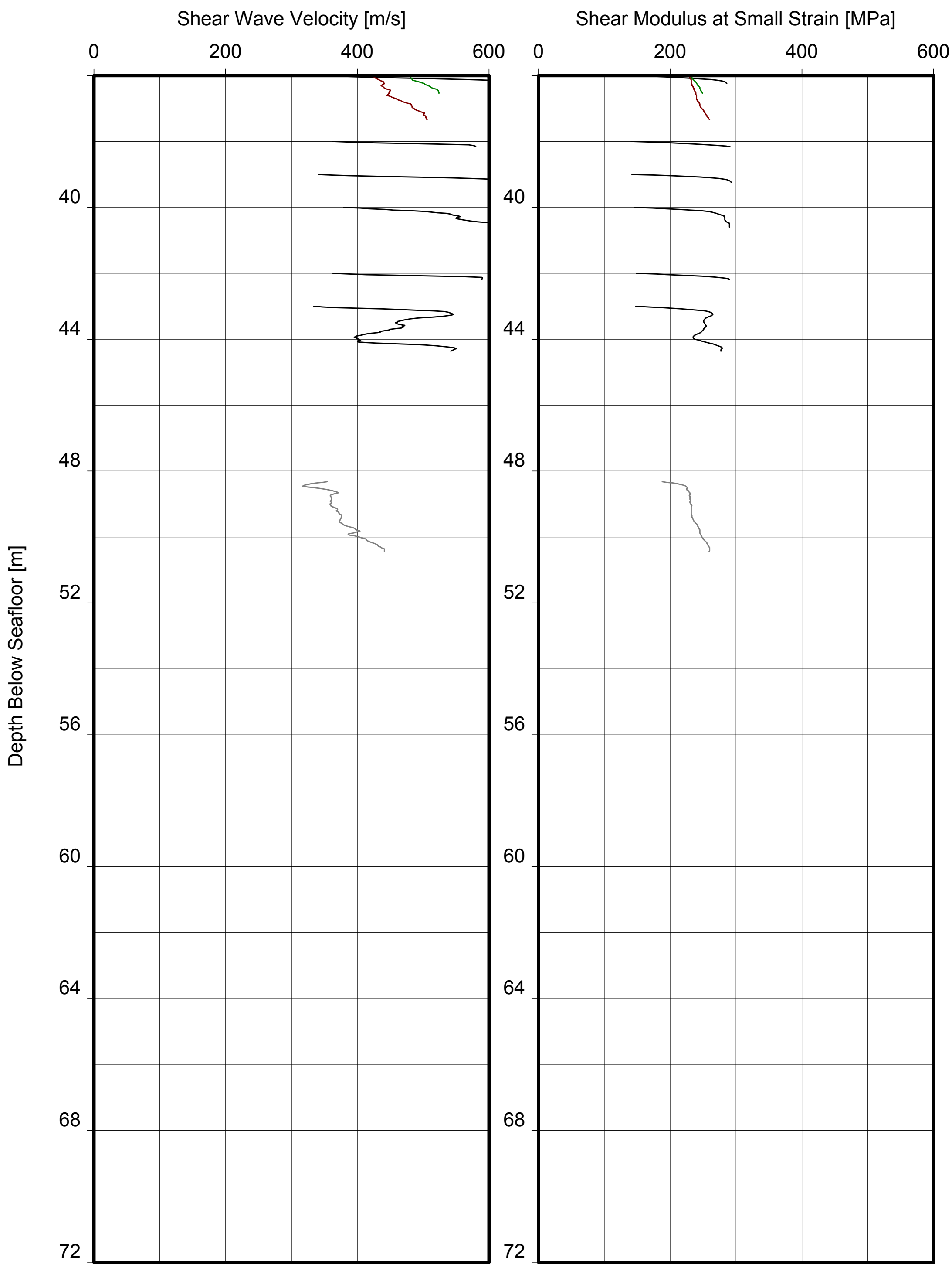
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:40:19

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

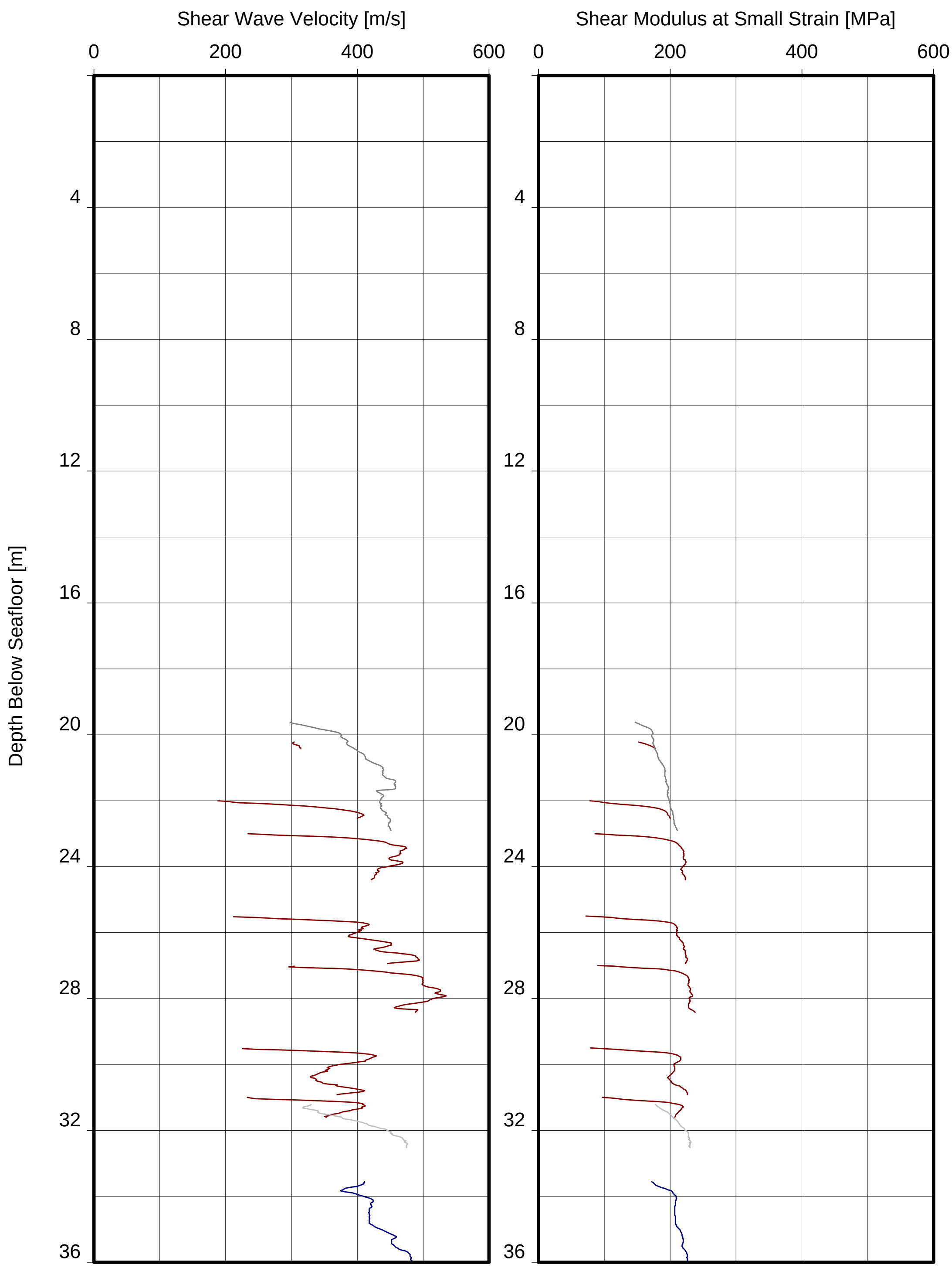
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:40:19

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

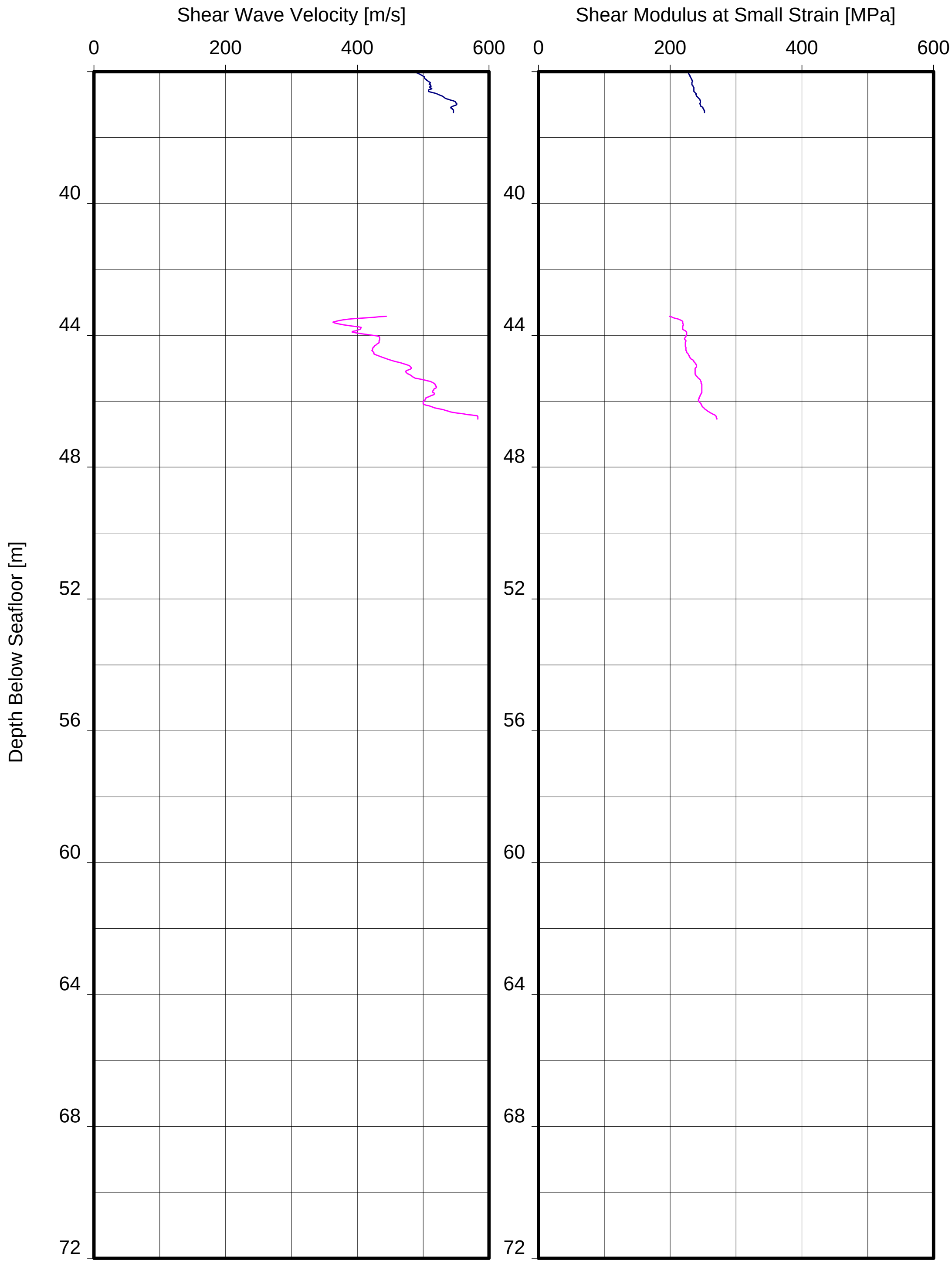
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-03 00:33:45

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

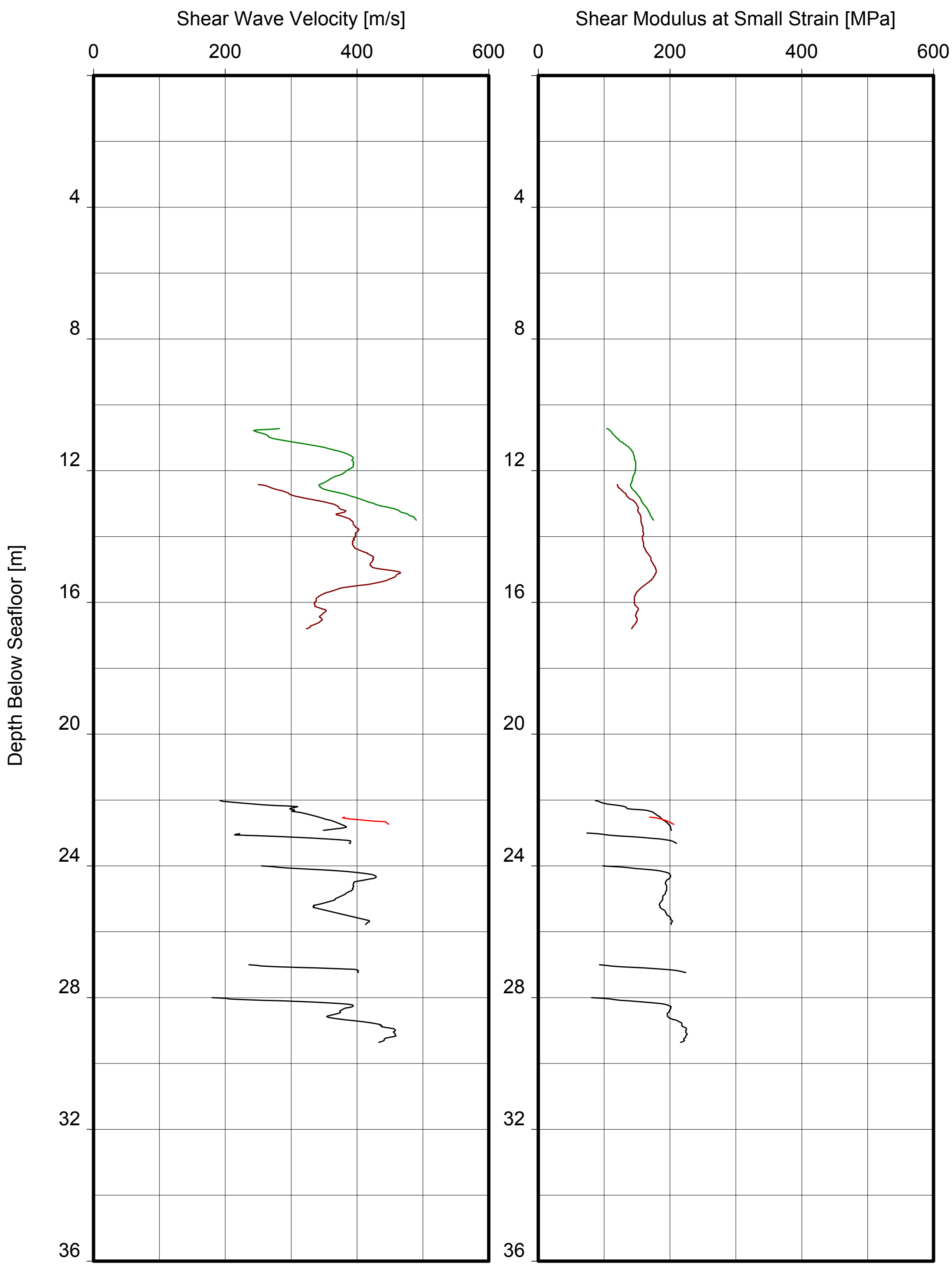
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-03 00:33:45

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT A

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

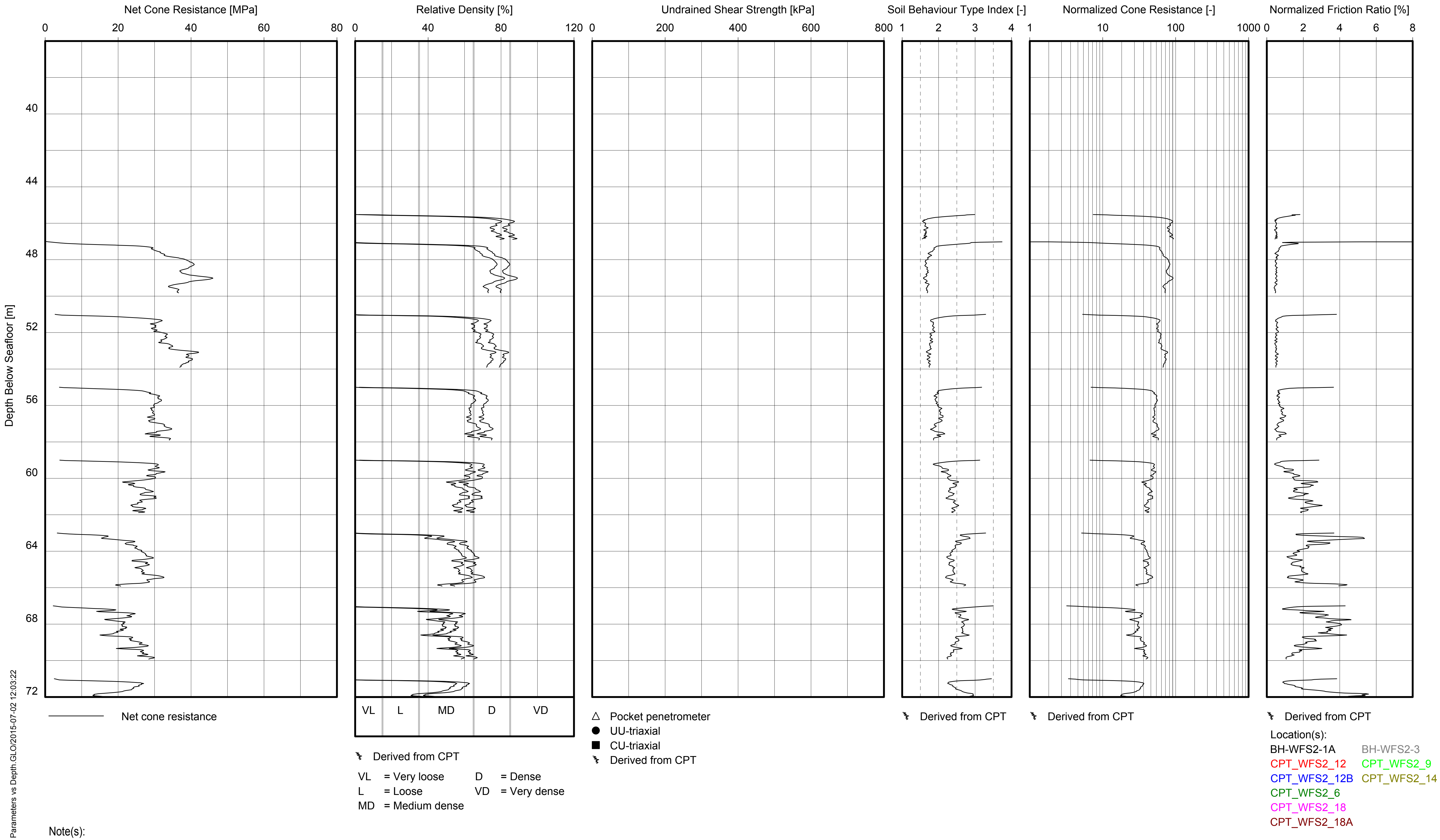
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:39:46

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

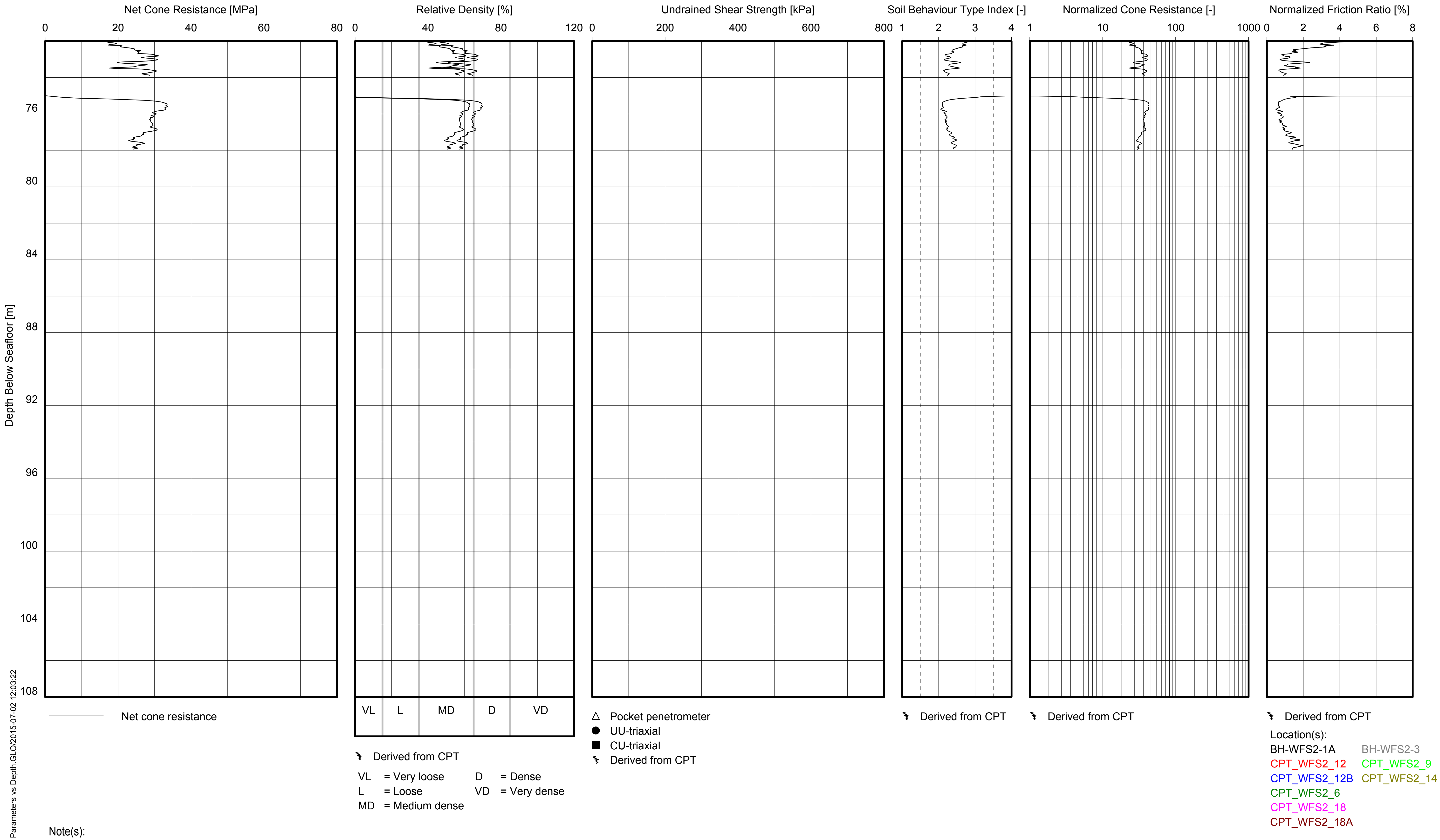
UNIT E4

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT E5
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



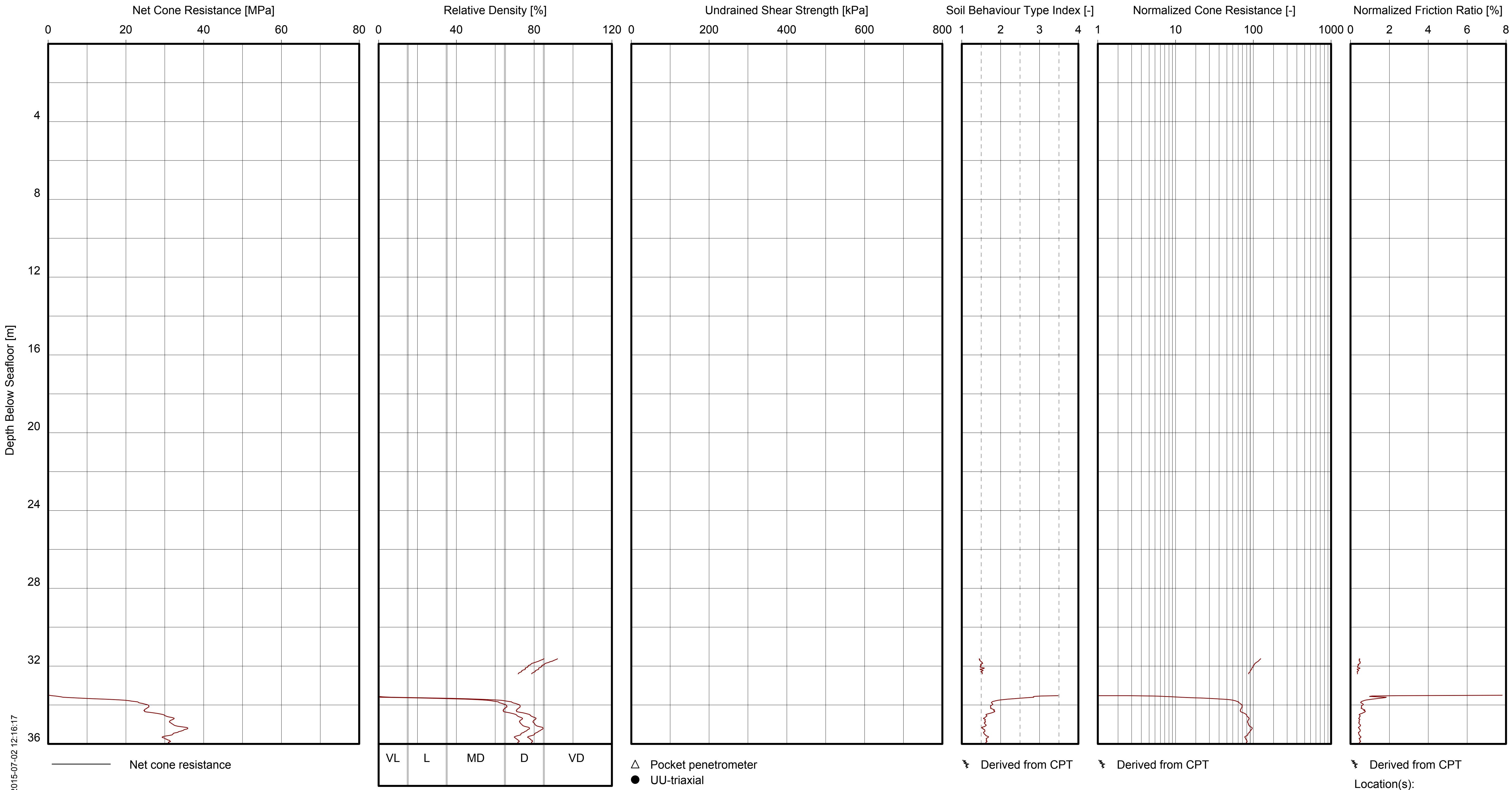
Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/CPT Parameters vs Depth.GLO/2015-07-02 12:03:22

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

Pocket penetrometer
UU-triaxial
CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):

BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

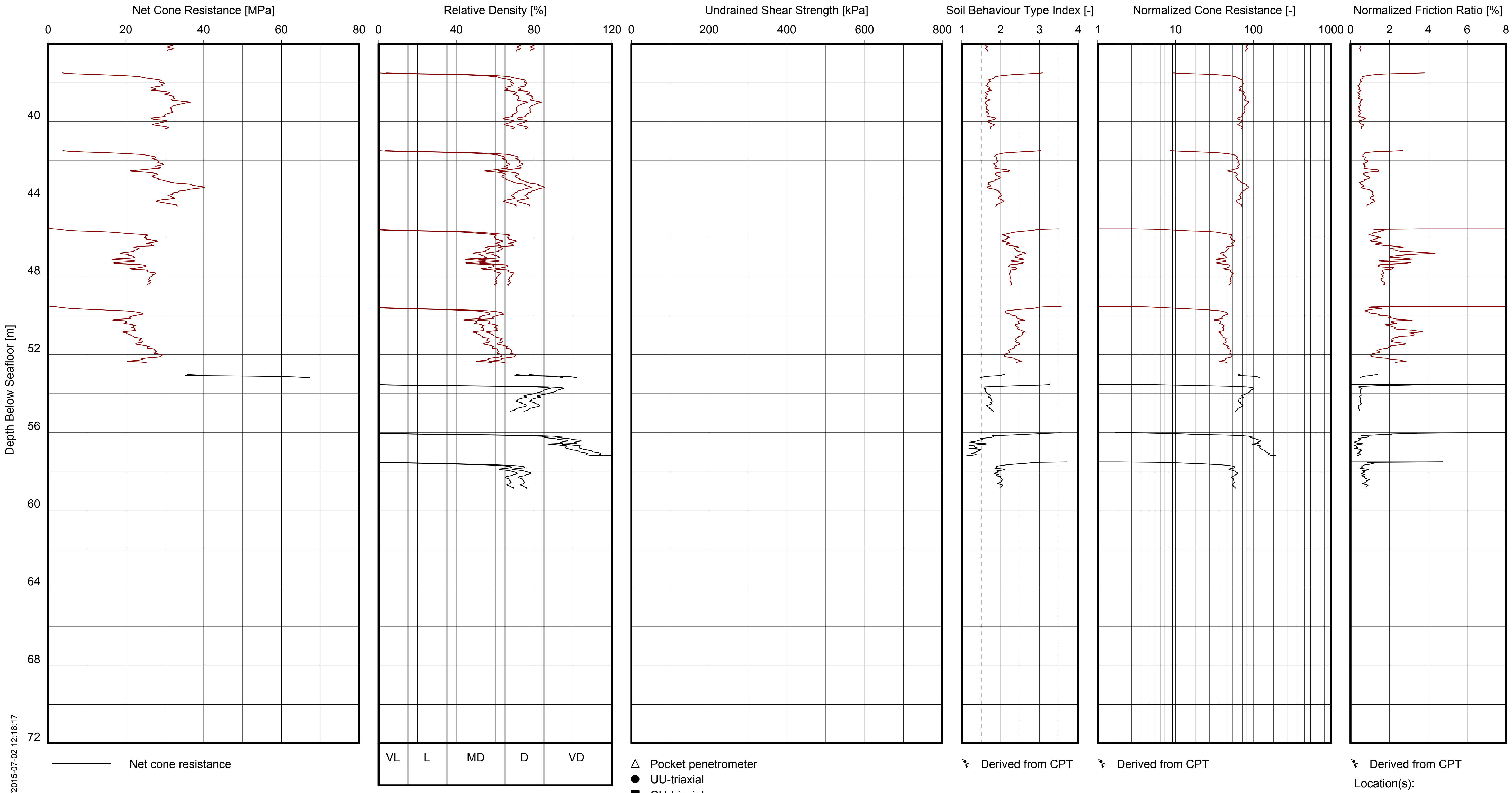
GeODin/CPT Parameters vs Depth GLO/2015-07-02 12:16:17

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):

BH-WFS2-2A, CPT_WFS2_27, CPT_WFS2_16, CPT_WFS2_21, CPT_WFS2_19, CPT_WFS2_11, CPT_WFS2_25, CPT_WFS2_11A, CPT_WFS2_25A, CPT_WFS2_13, BH-WFS2-4, CPT_WFS2_22

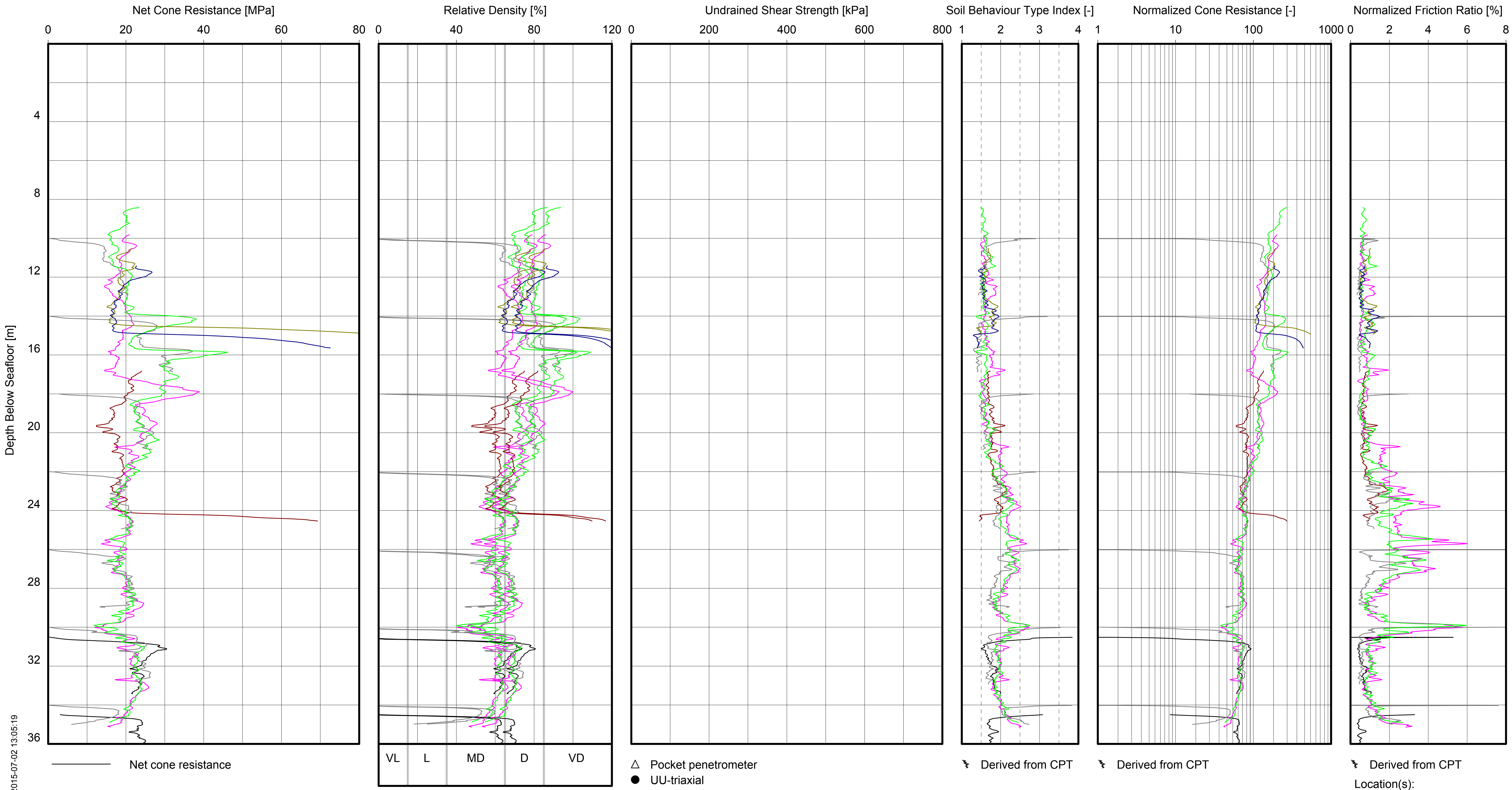
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 12:16:17

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

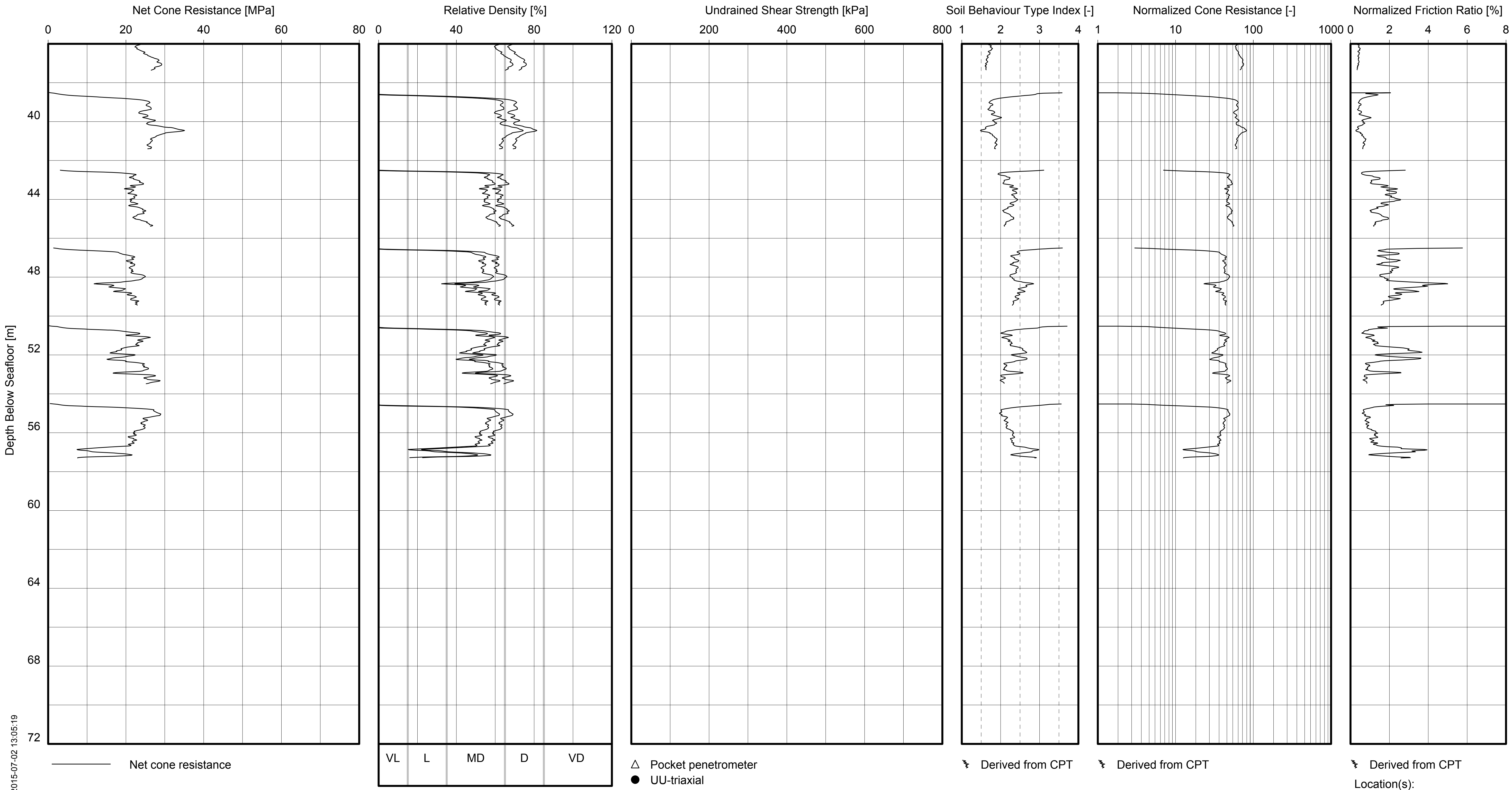
Derived from CPT

Derived from CPT

Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT E5
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

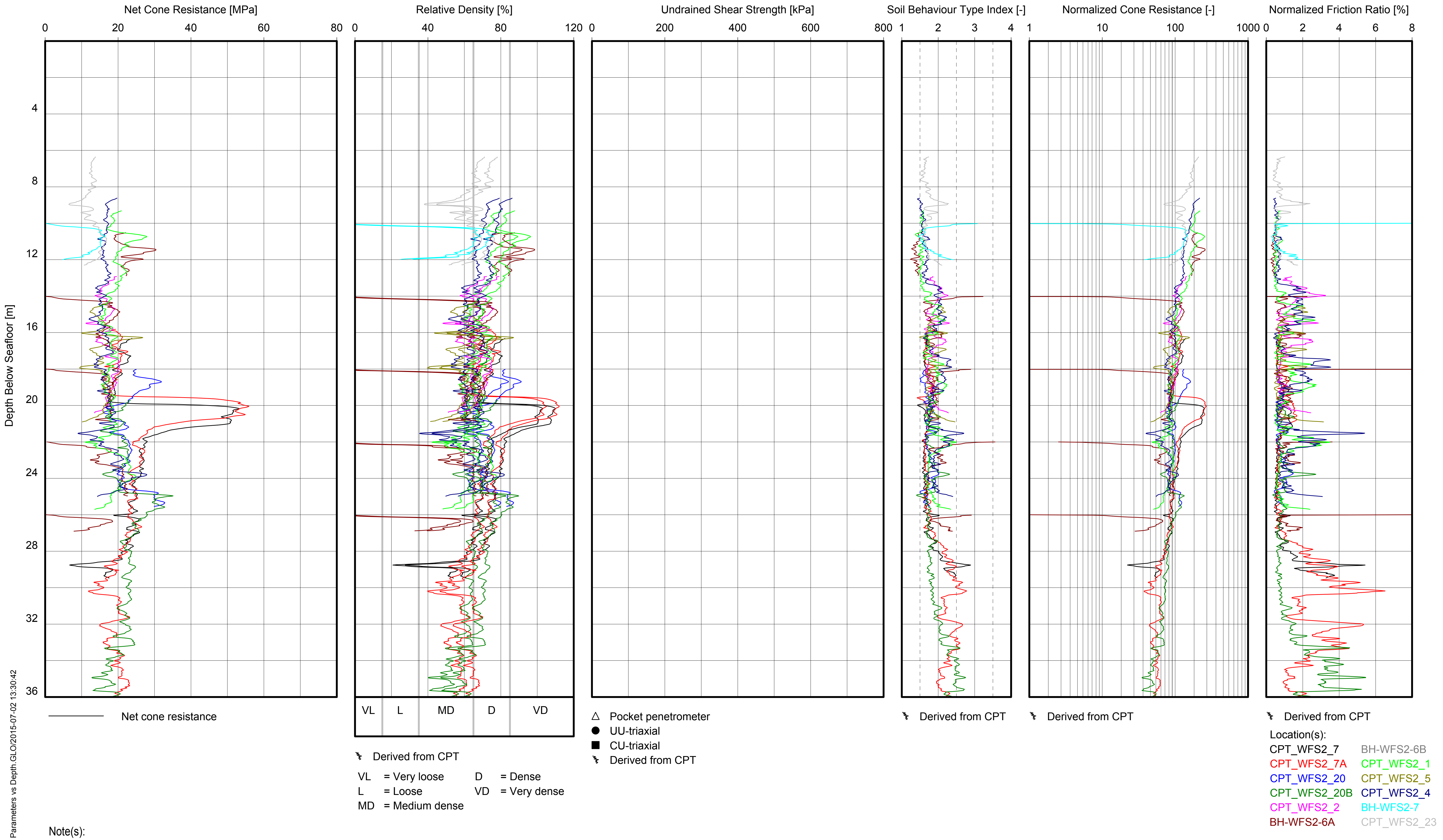
Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:05:19

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



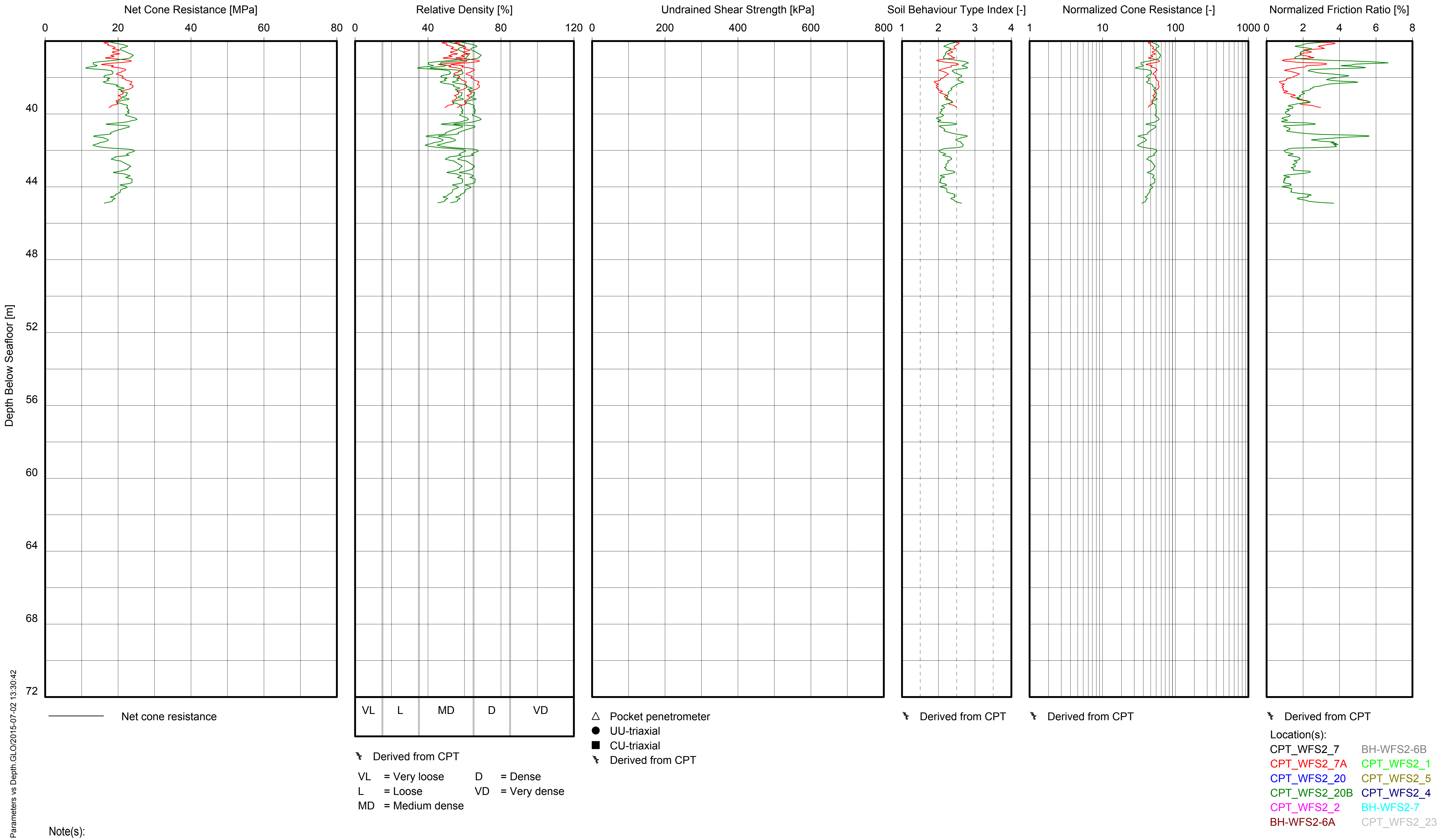
Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin\CPT Parameters vs Depth.GLO/2015-07-02 13:30:42

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA

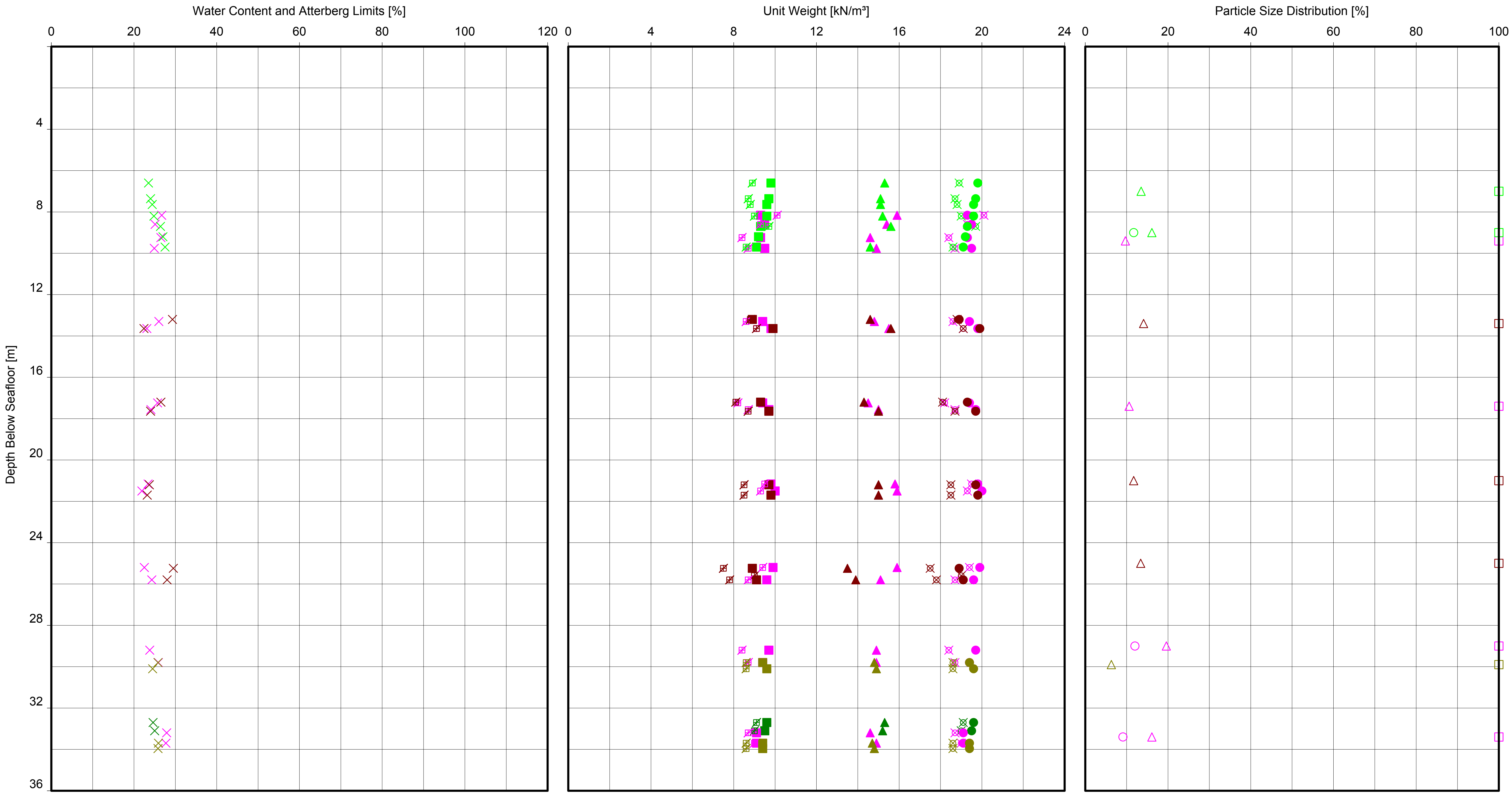


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



× Water content
○ Plastic limit
● Liquid limit
○—55—● Plasticity index

● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

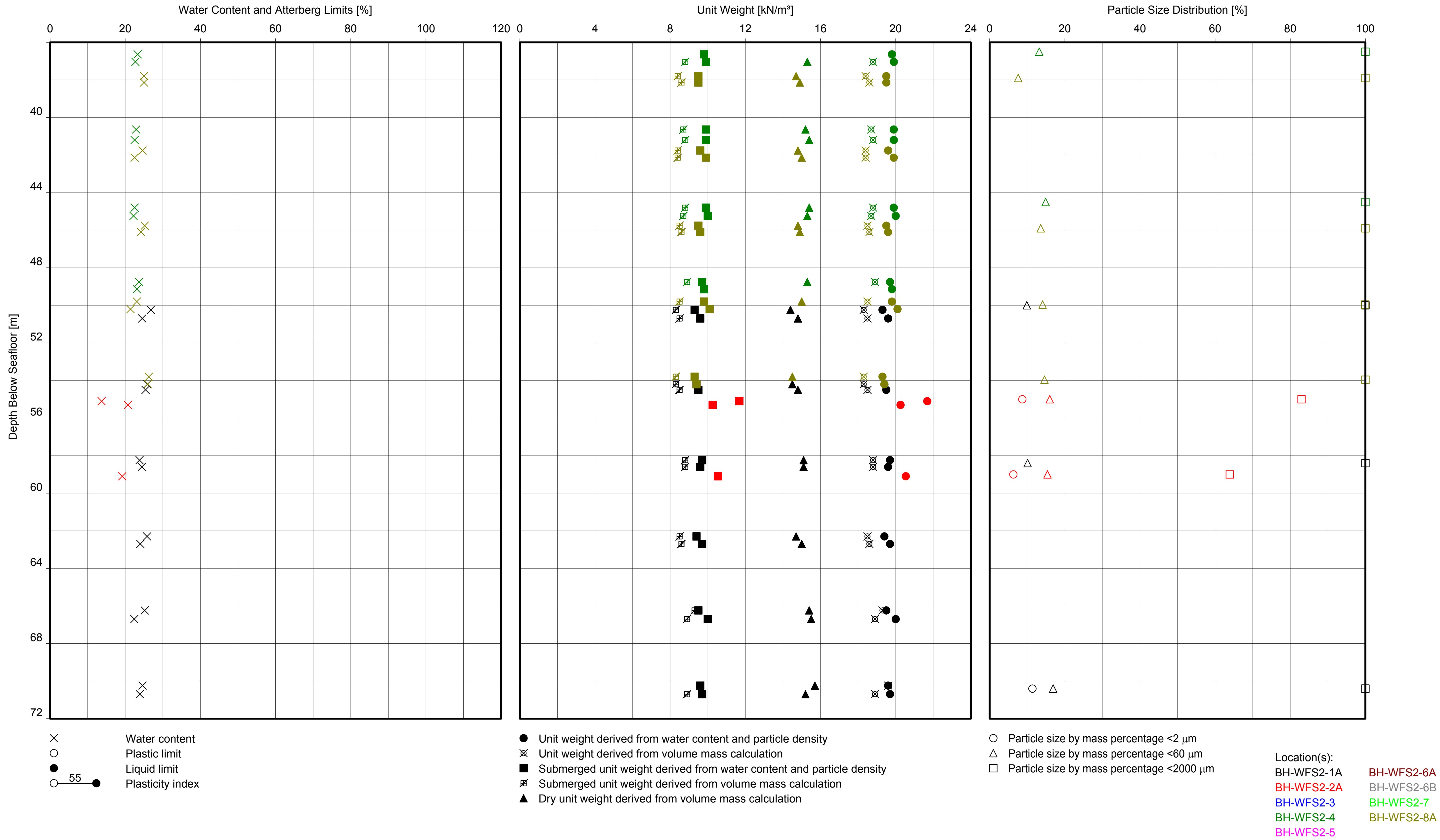
○ Particle size by mass percentage <2 µm
△ Particle size by mass percentage <60 µm
□ Particle size by mass percentage <2000 µm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:40:42

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH
UNIT E5
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

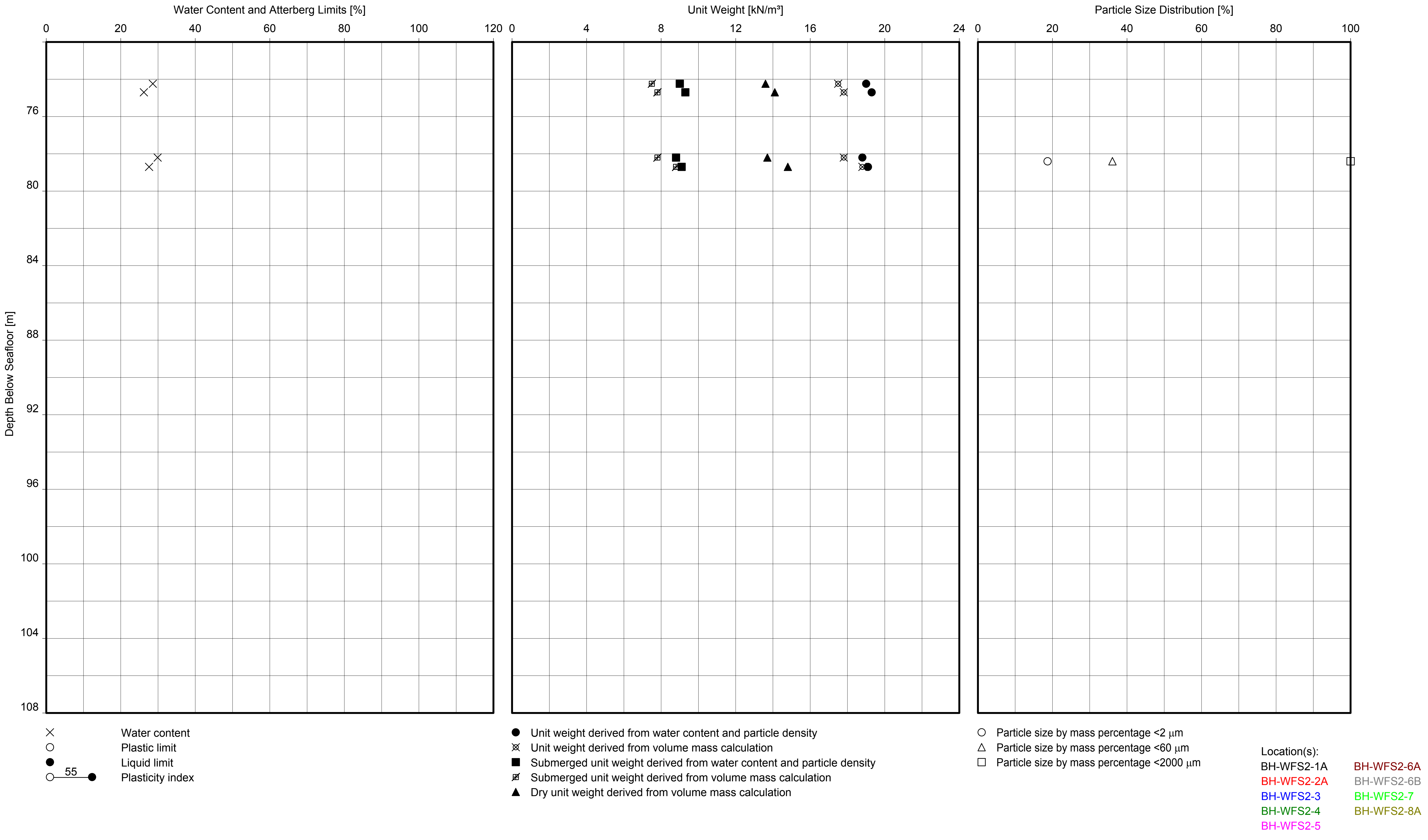


Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



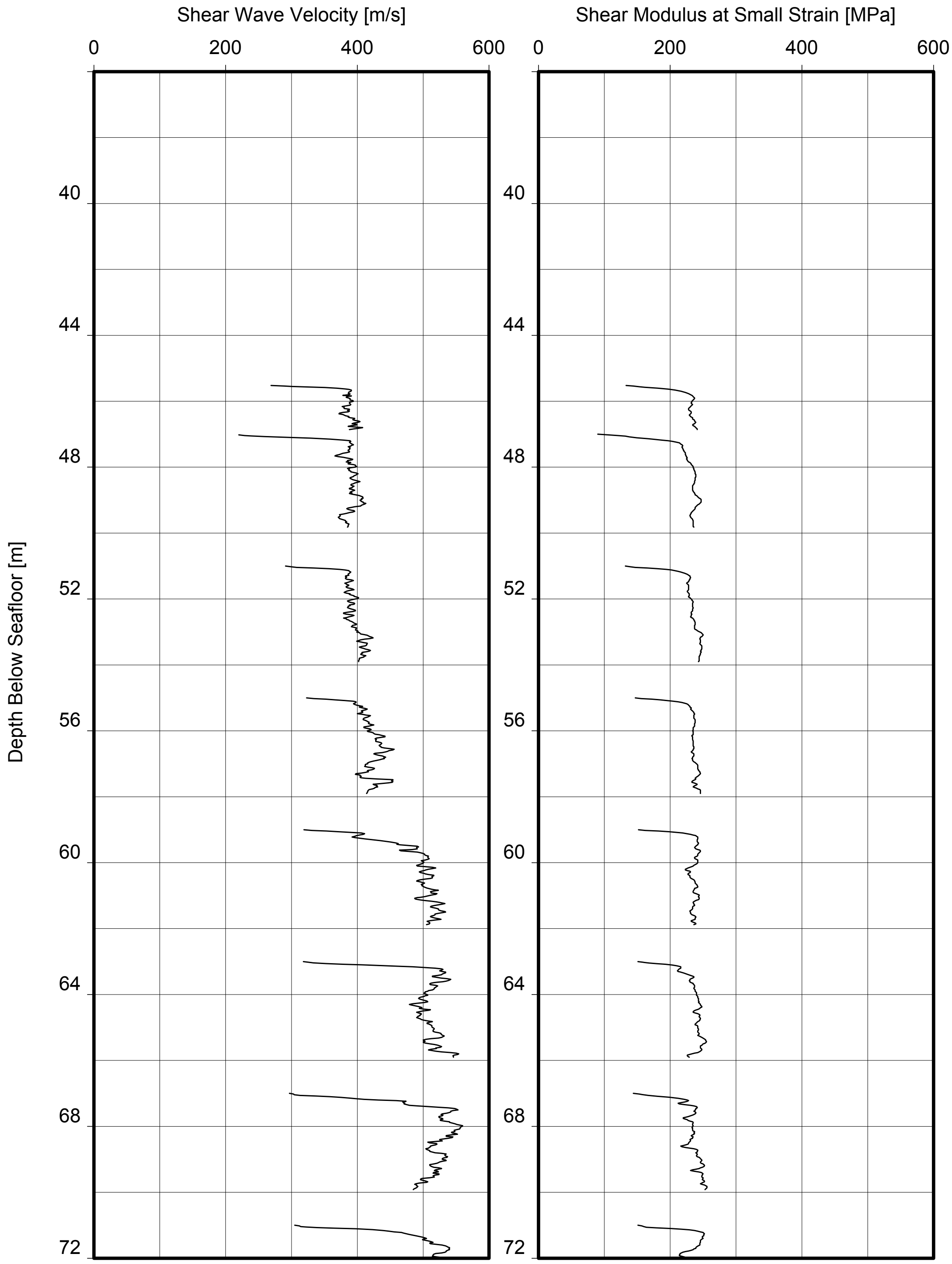
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:40:42

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

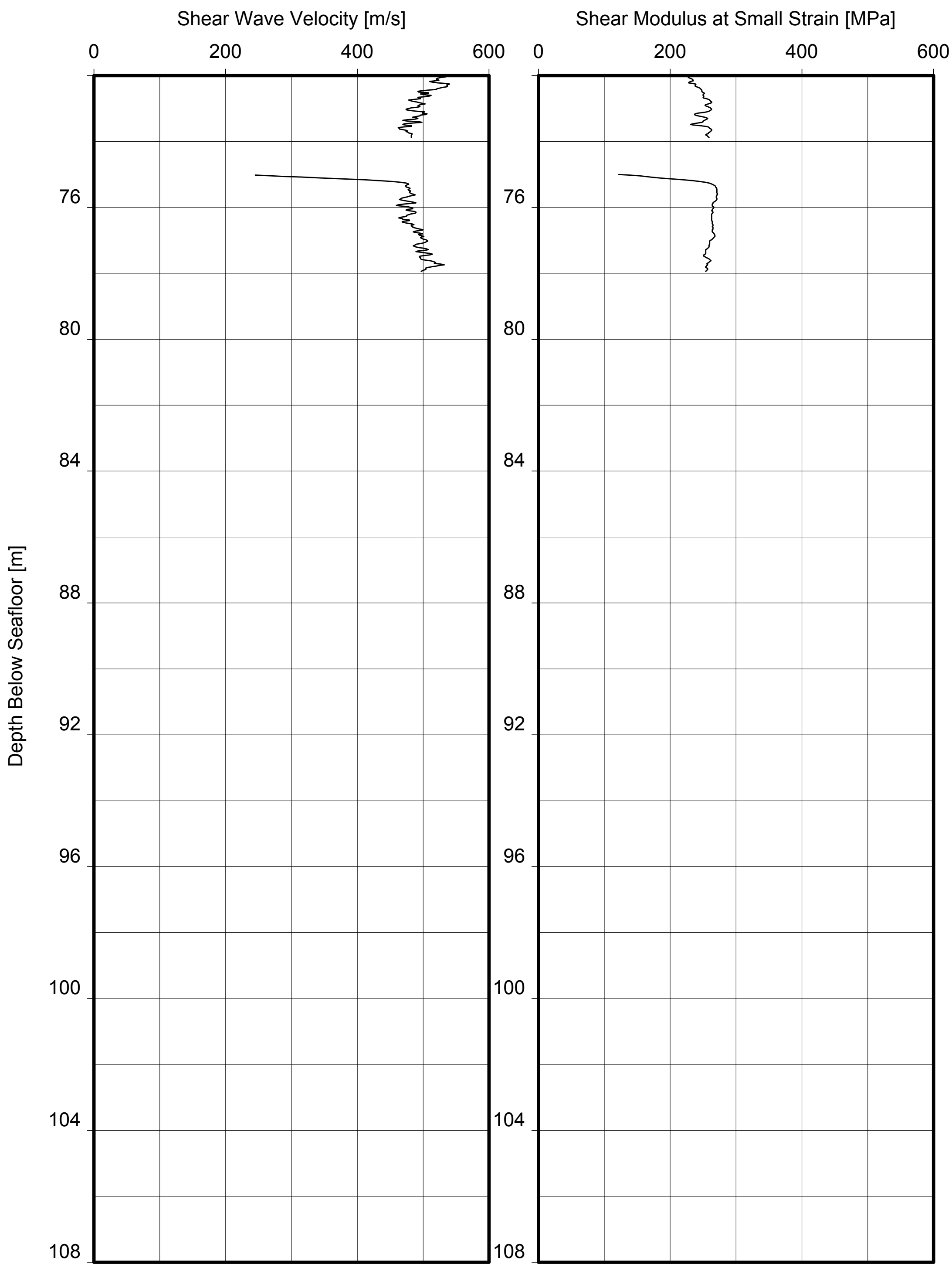
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:30:15

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

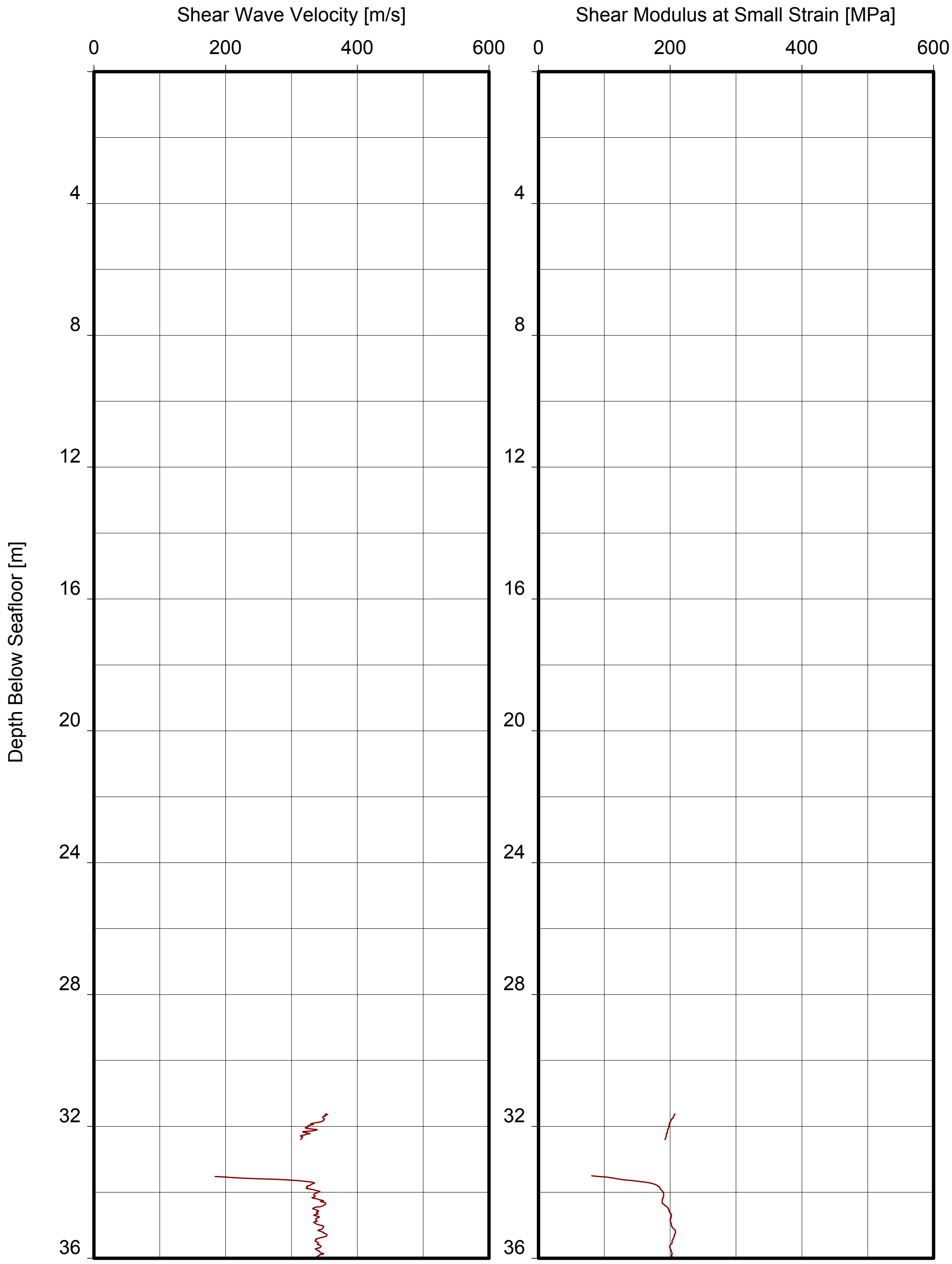
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:30:15

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

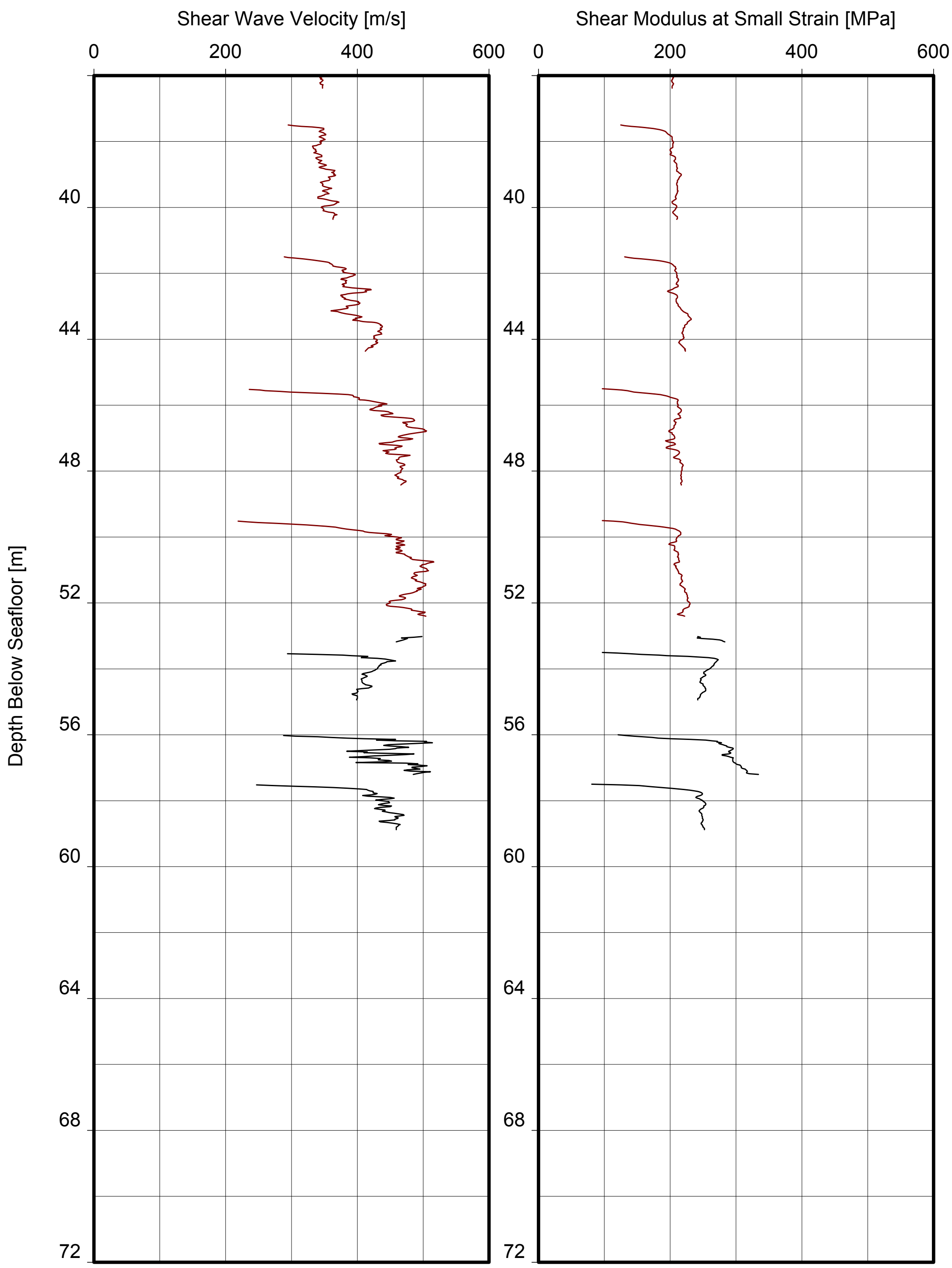
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:26:53

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-2A
CPT_WFS2_16
CPT_WFS2_19
CPT_WFS2_25
CPT_WFS2_25A
BH-WFS2-4
CPT_WFS2_27
CPT_WFS2_21
CPT_WFS2_11
CPT_WFS2_11A
CPT_WFS2_13
CPT_WFS2_22

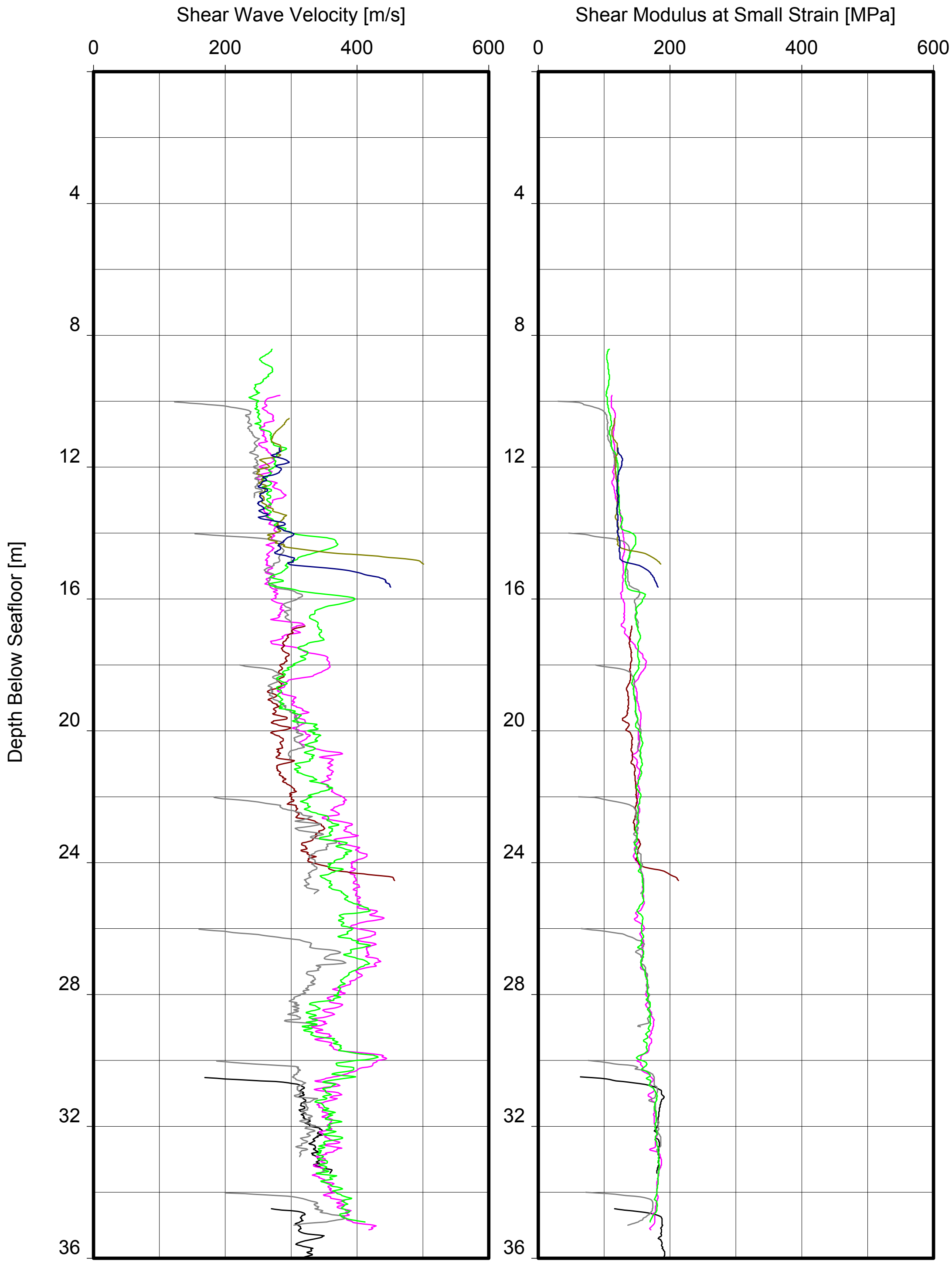
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:26:54

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array

Shear modulus at small strain (G_{max}) derived from v_s measured

v_s and G_{max} derived from CPT

Location(s):

BH-WFS2-8A, BH-WFS2-5, CPT_WFS2_15, CPT_WFS2_3, CPT_WFS2_10, CPT_WFS2_17, CPT_WFS2_8, CPT_WFS2_17A, CPT_WFS2_26, CPT_WFS2_24

Note(s):

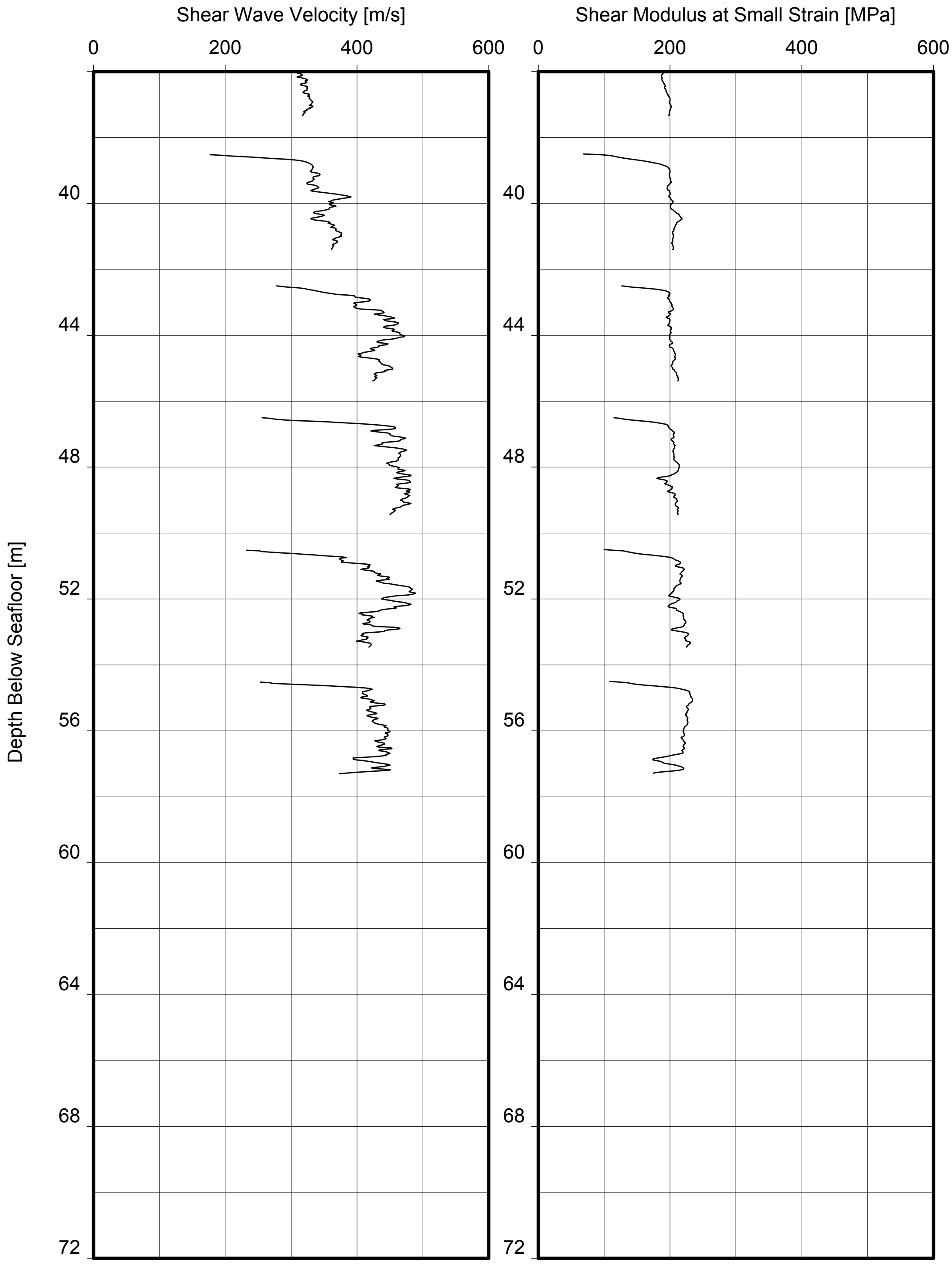
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:43:53

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

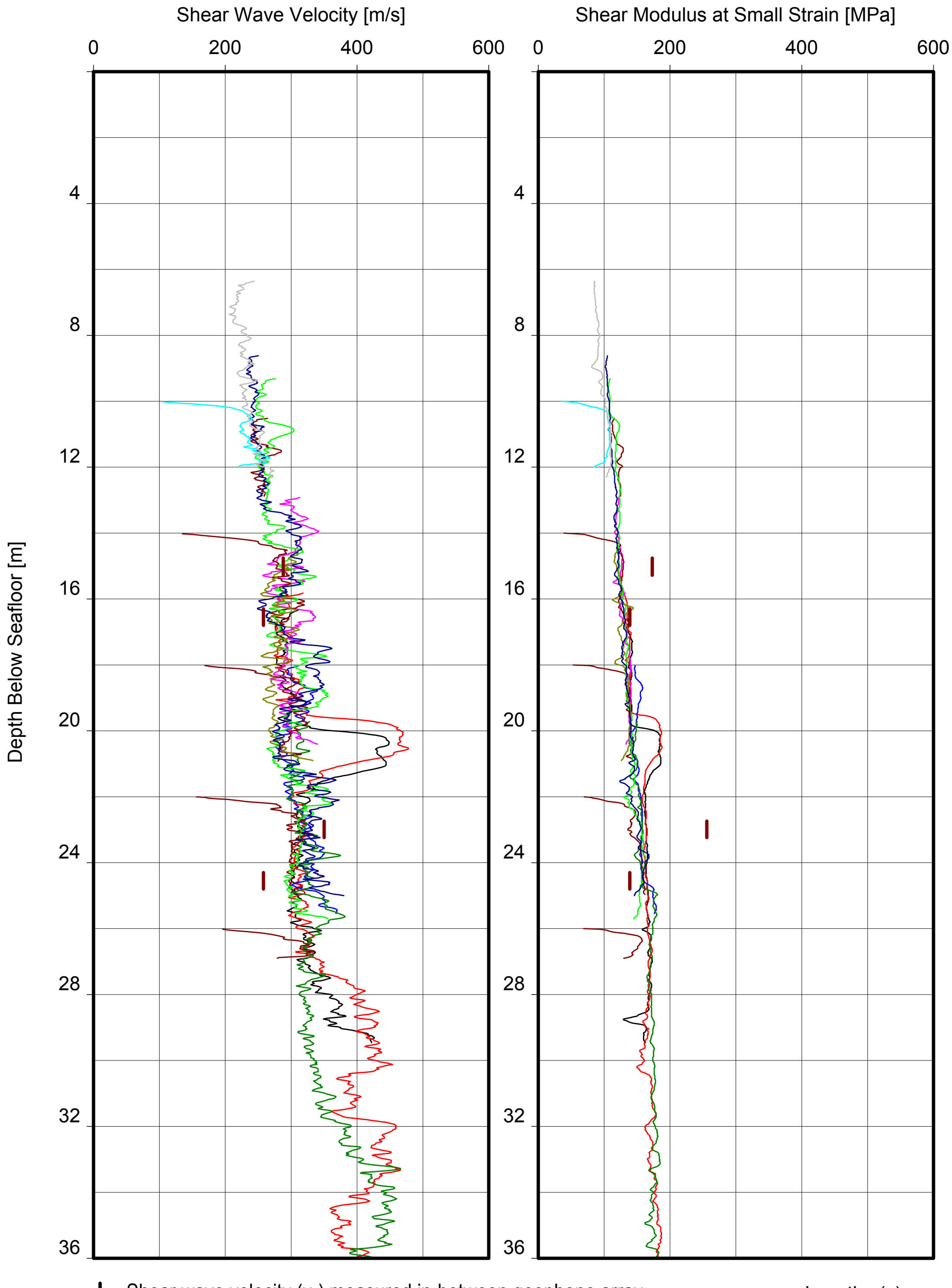
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:43:54

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

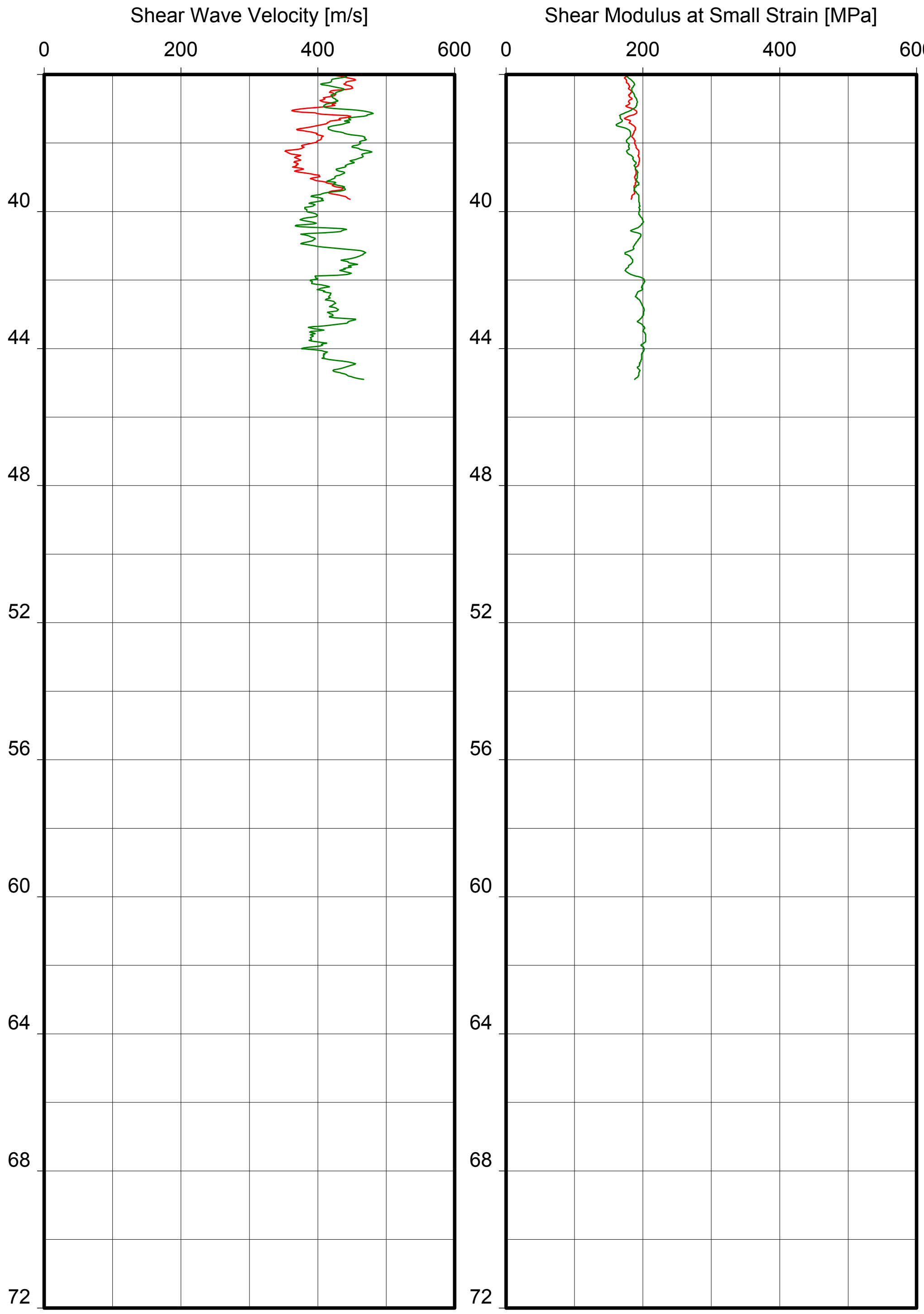
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:52:03

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

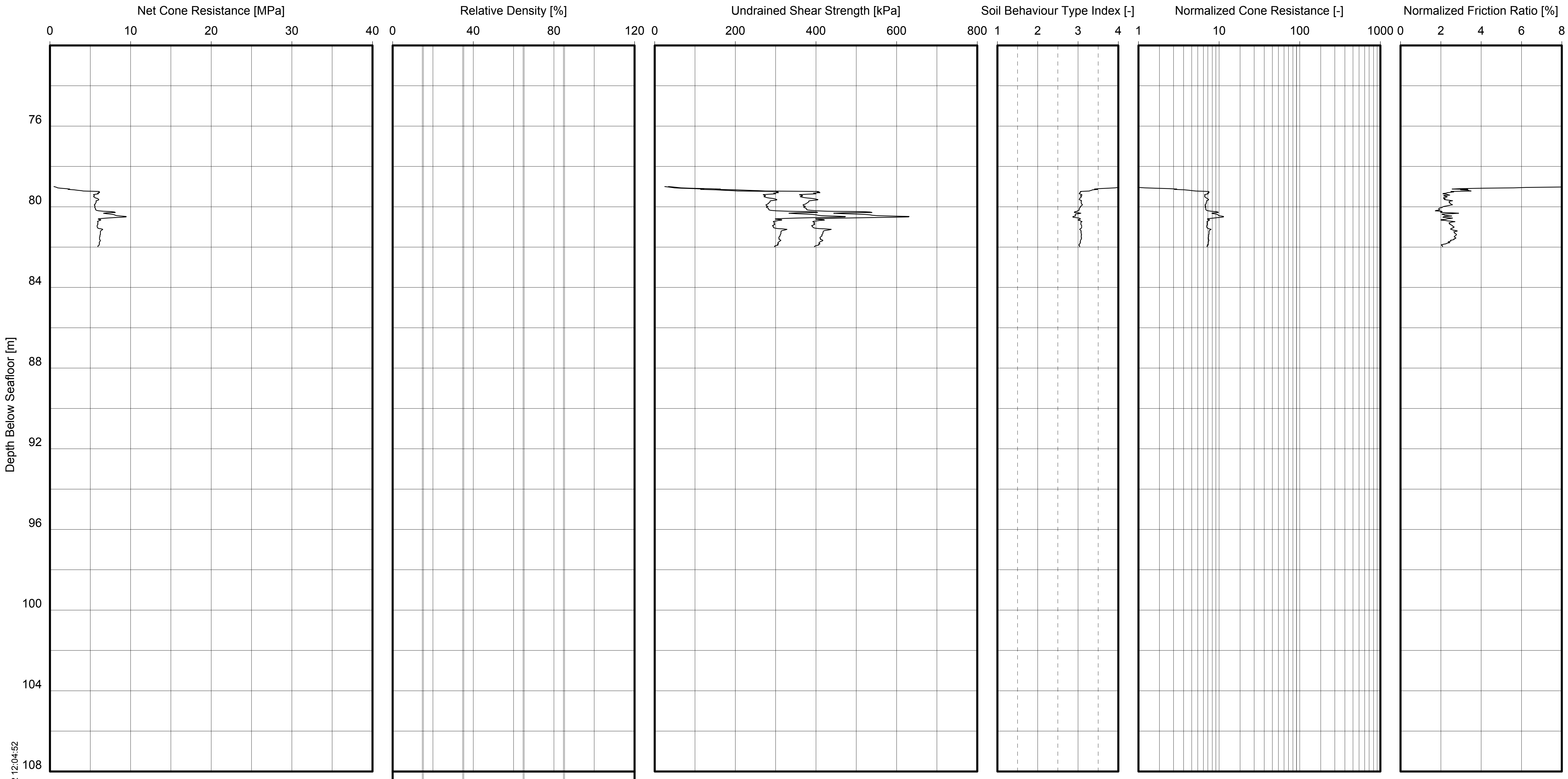
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:52:03

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT E5

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

Pocket penetrometer
UU-triaxial
CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

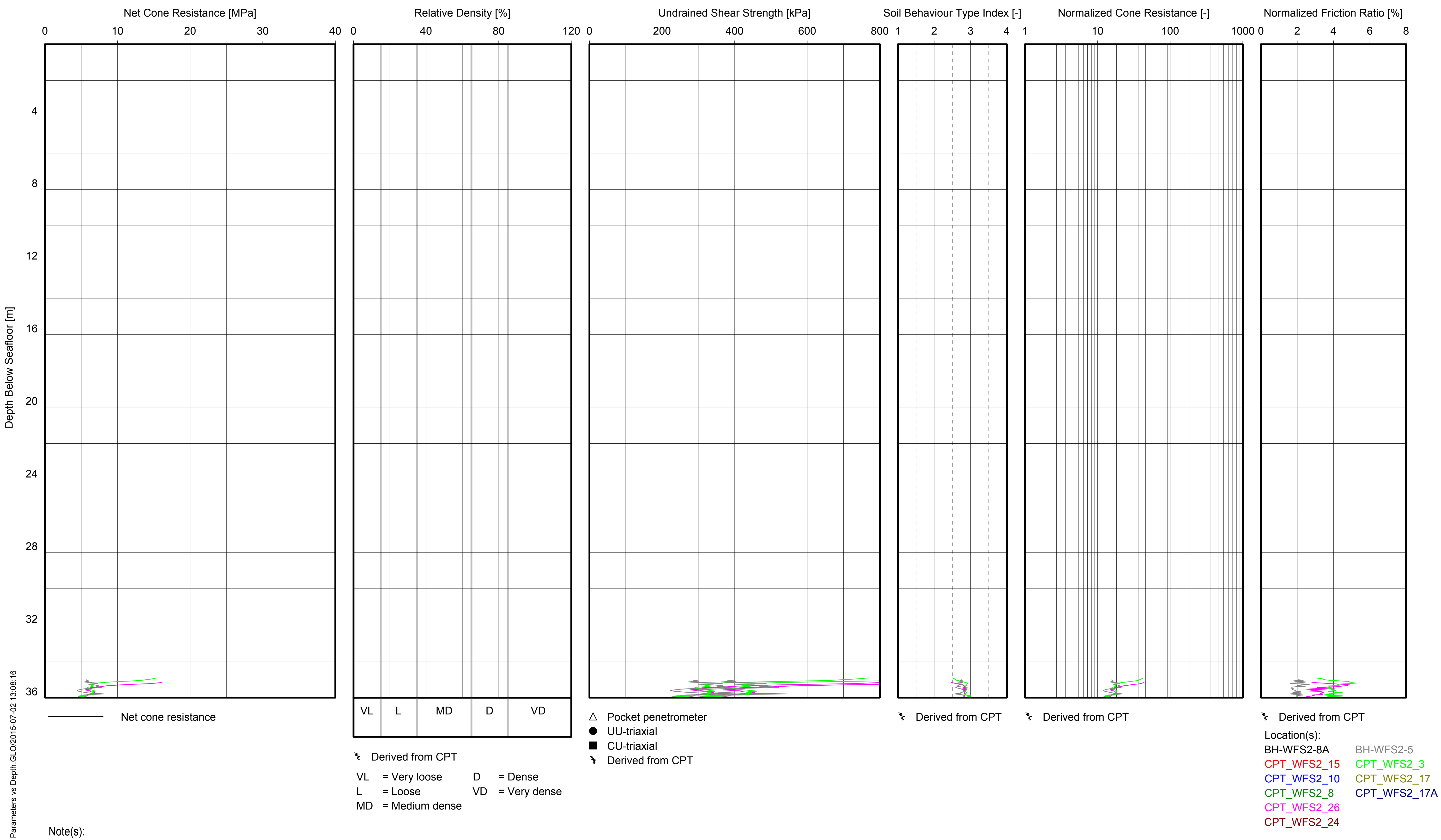
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 12:04:52

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



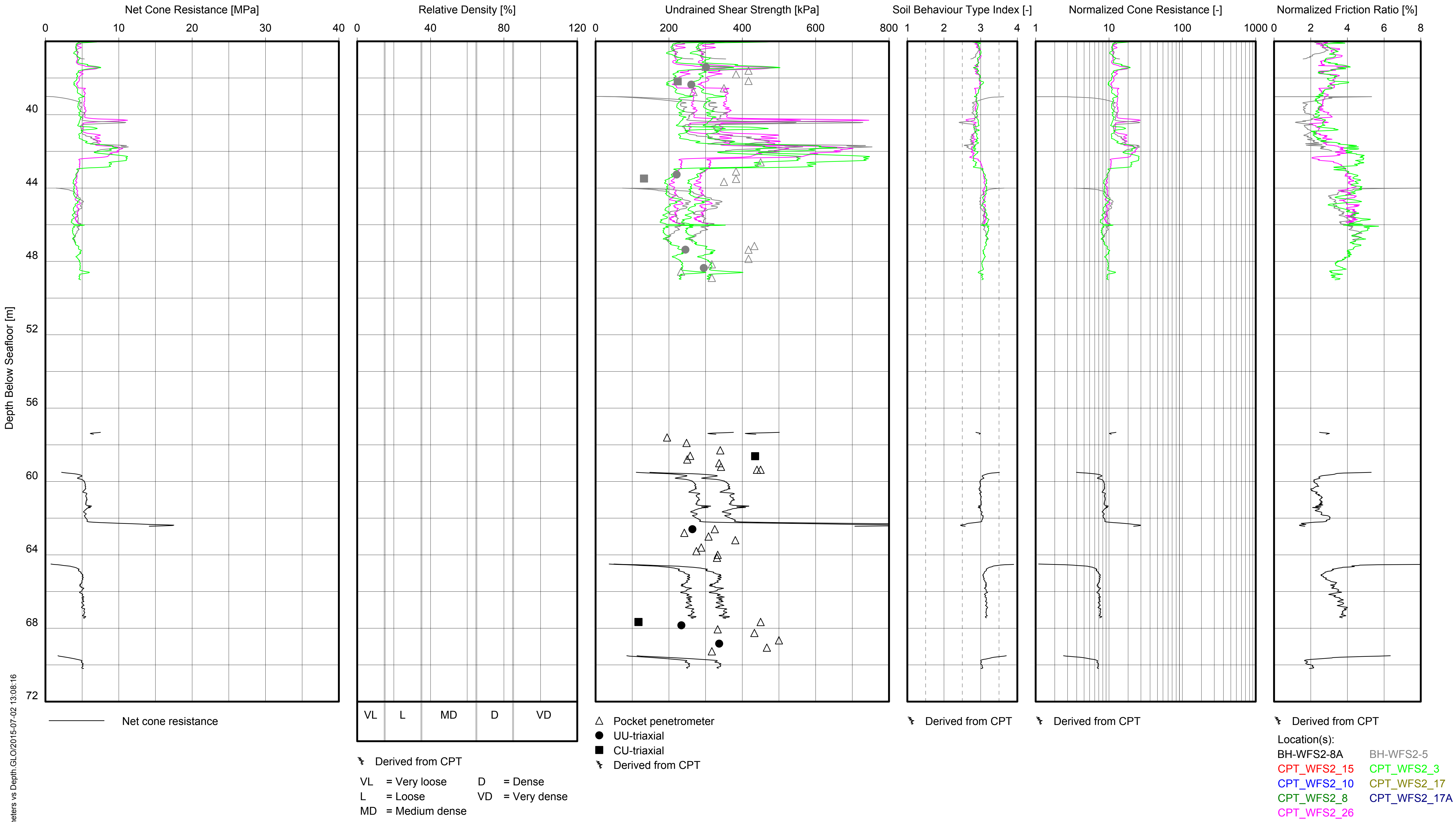
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:08:16

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



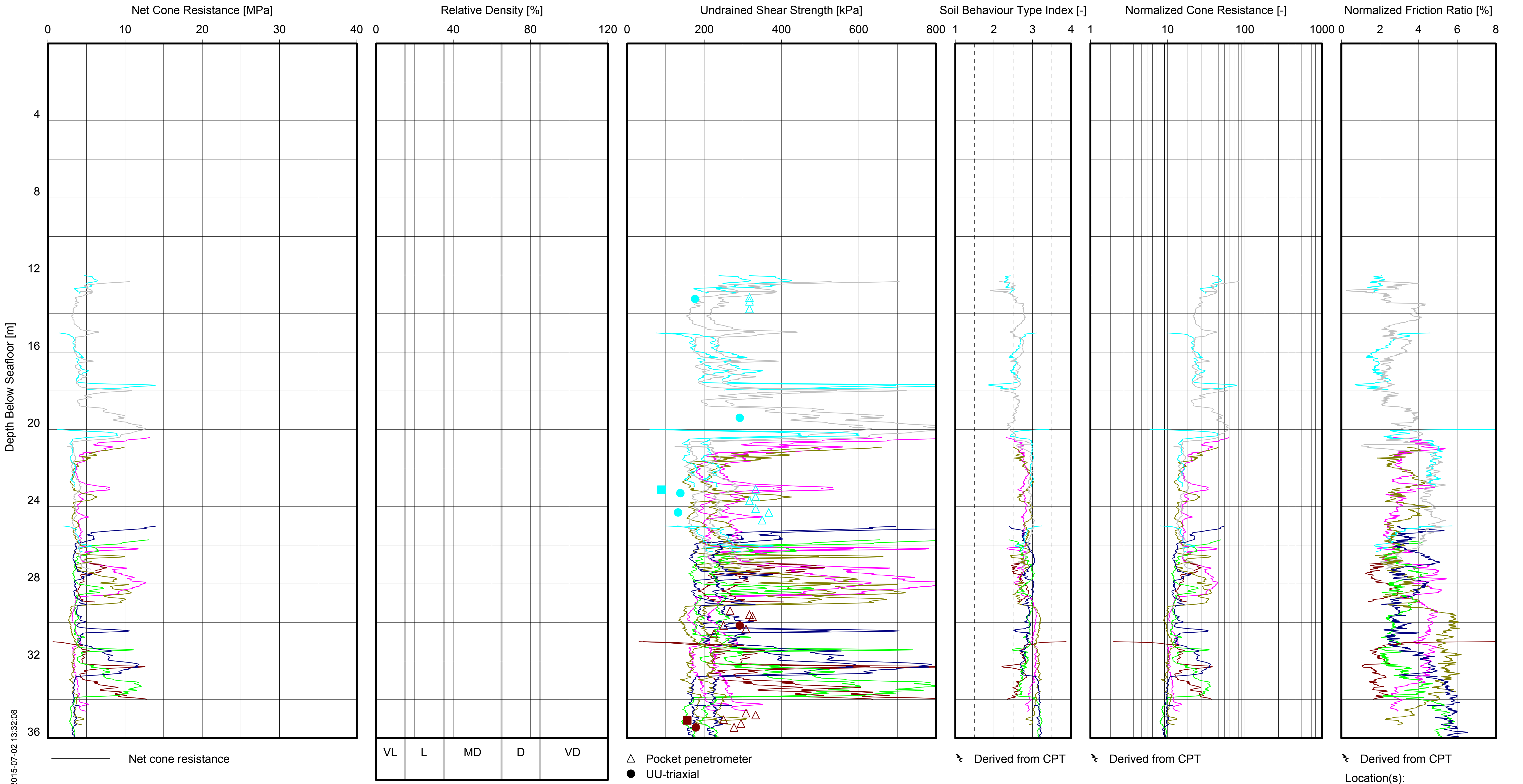
GeODin\CPT Parameters vs Depth.GLO/2015-07-02 13:08:16

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

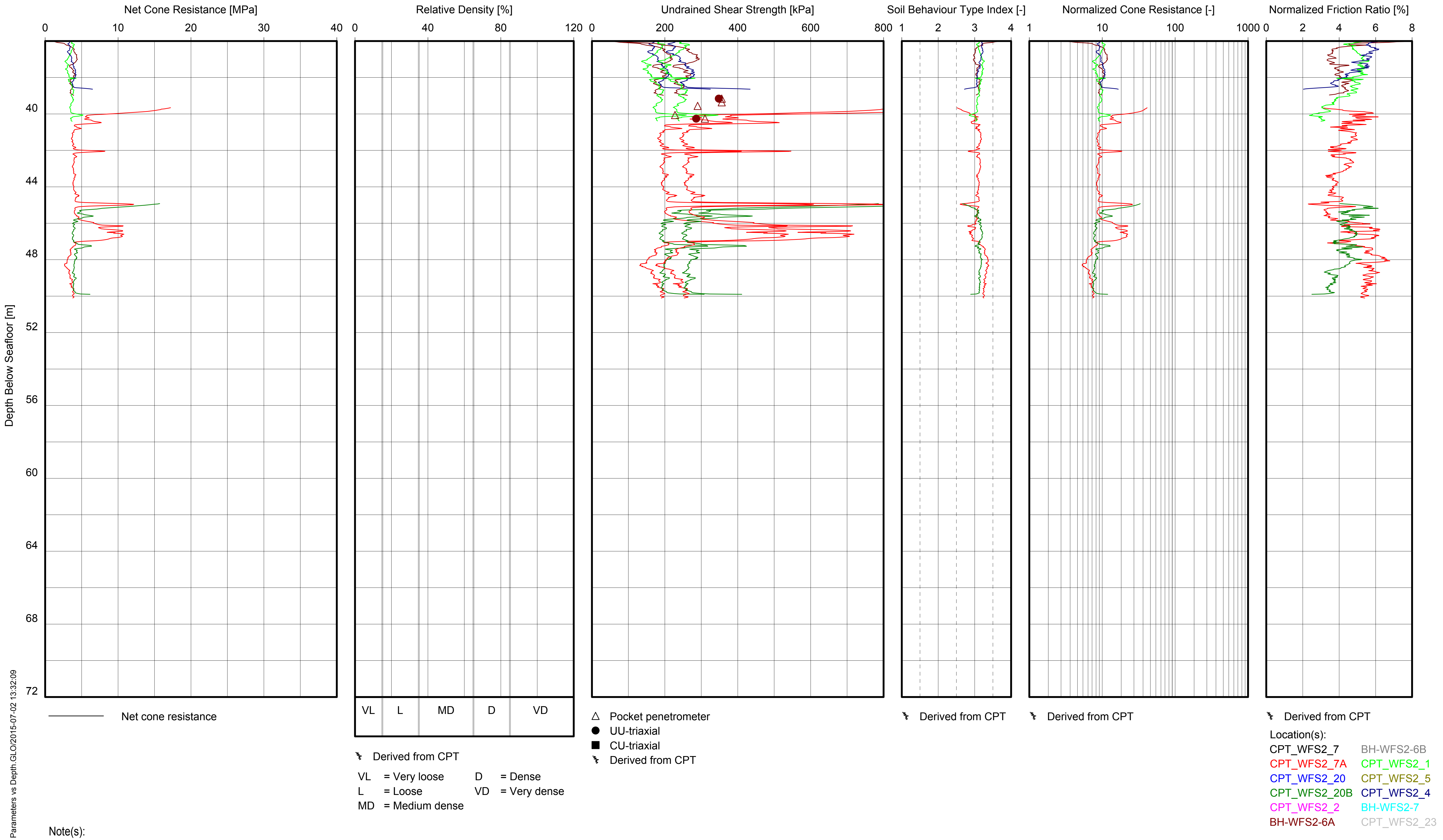
UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT F1
BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



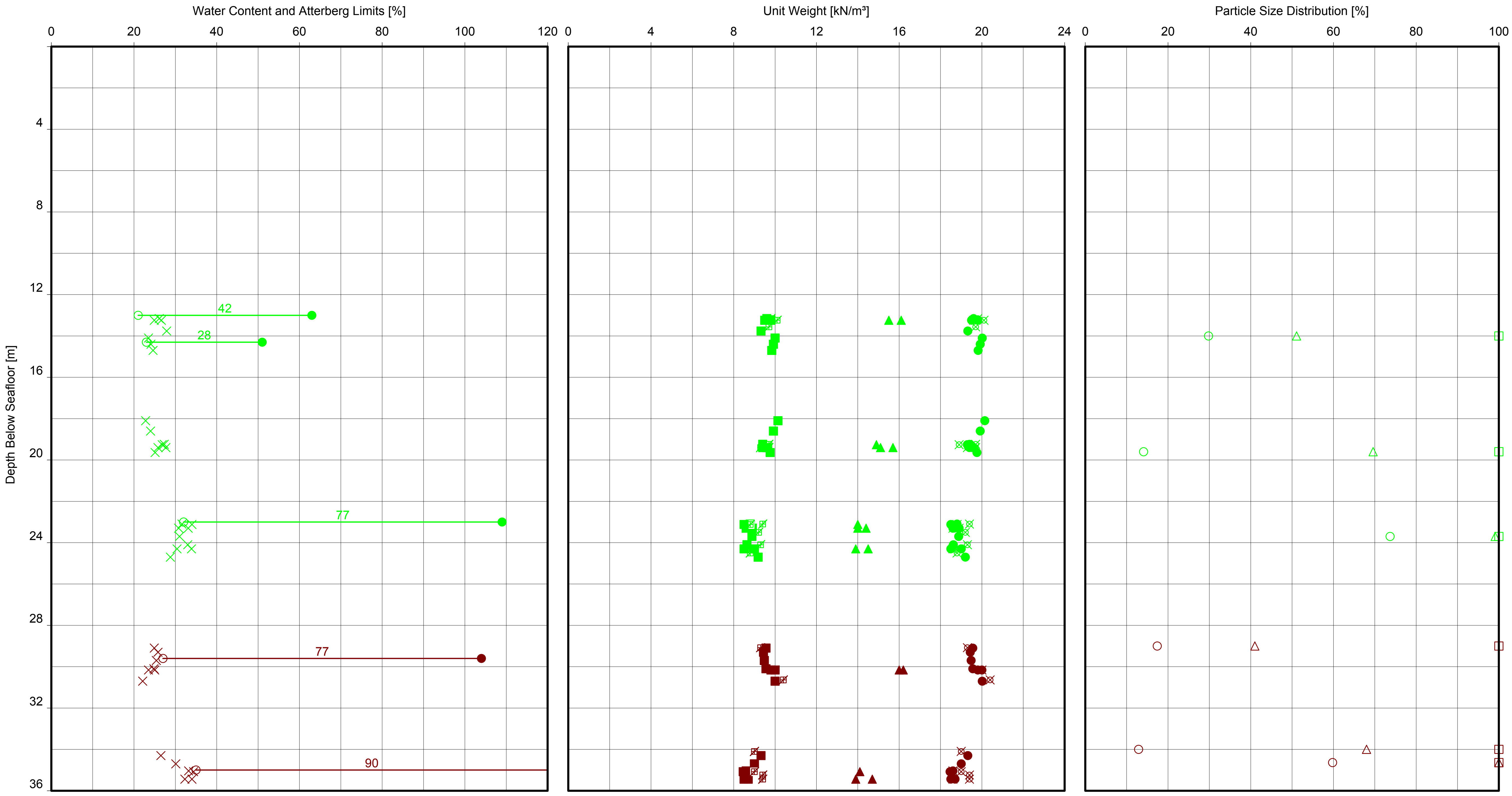
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:32:09

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



× Water content
○ Plastic limit
● Liquid limit
○—55—● Plasticity index

● Unit weight derived from water content and particle density
⊠ Unit weight derived from volume mass calculation
■ Submerged unit weight derived from water content and particle density
⊠ Submerged unit weight derived from volume mass calculation
▲ Dry unit weight derived from volume mass calculation

○ Particle size by mass percentage <2 µm
△ Particle size by mass percentage <60 µm
□ Particle size by mass percentage <2000 µm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

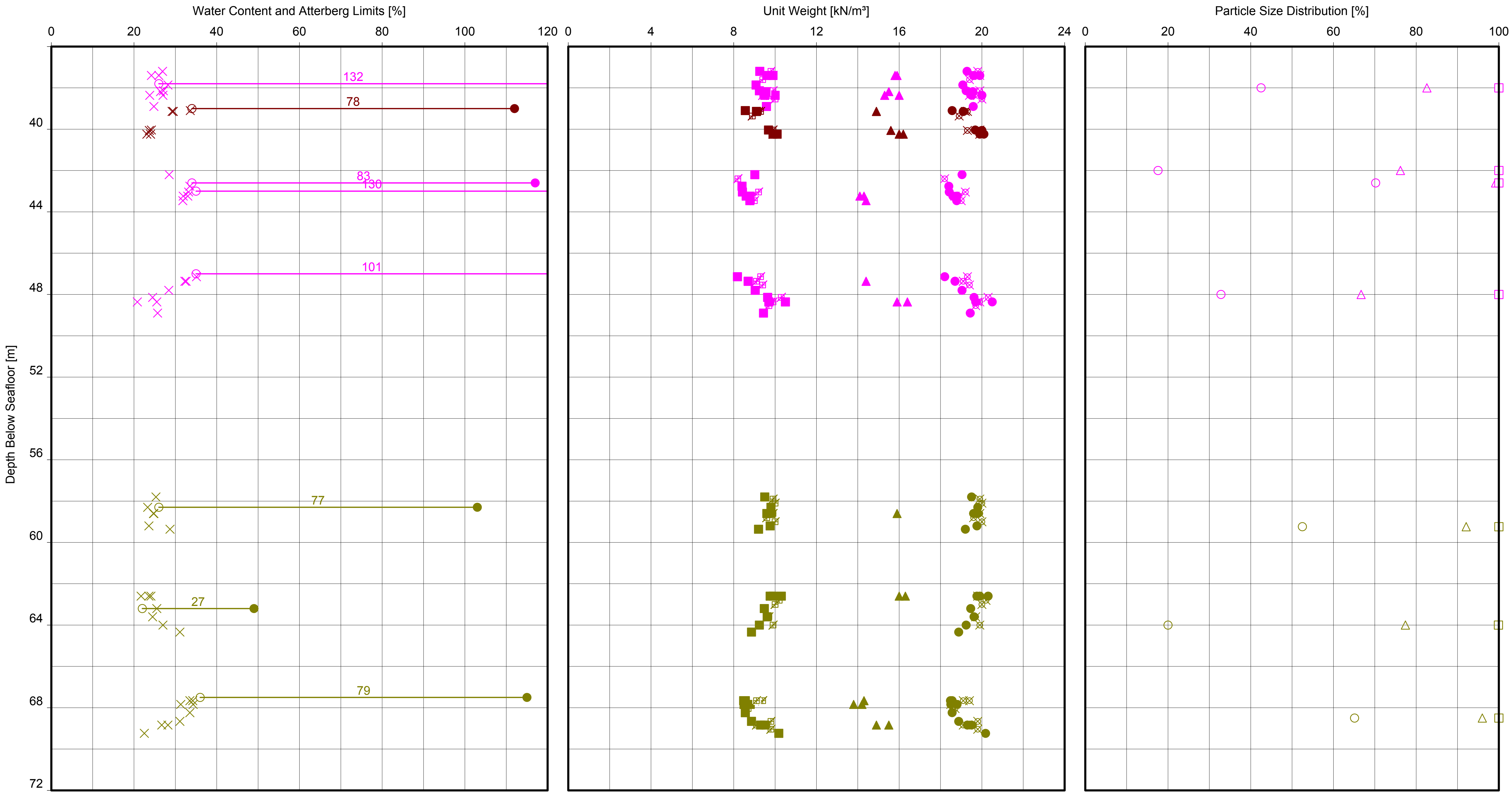
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:42:04

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



×	Water content
○	Plastic limit
●	Liquid limit
○—55—●	Plasticity index

- ● Unit weight derived from water content and particle density
- ⊠ Unit weight derived from volume mass calculation
- ■ Submerged unit weight derived from water content and particle density
- ⊠ Submerged unit weight derived from volume mass calculation
- ▲ Dry unit weight derived from volume mass calculation

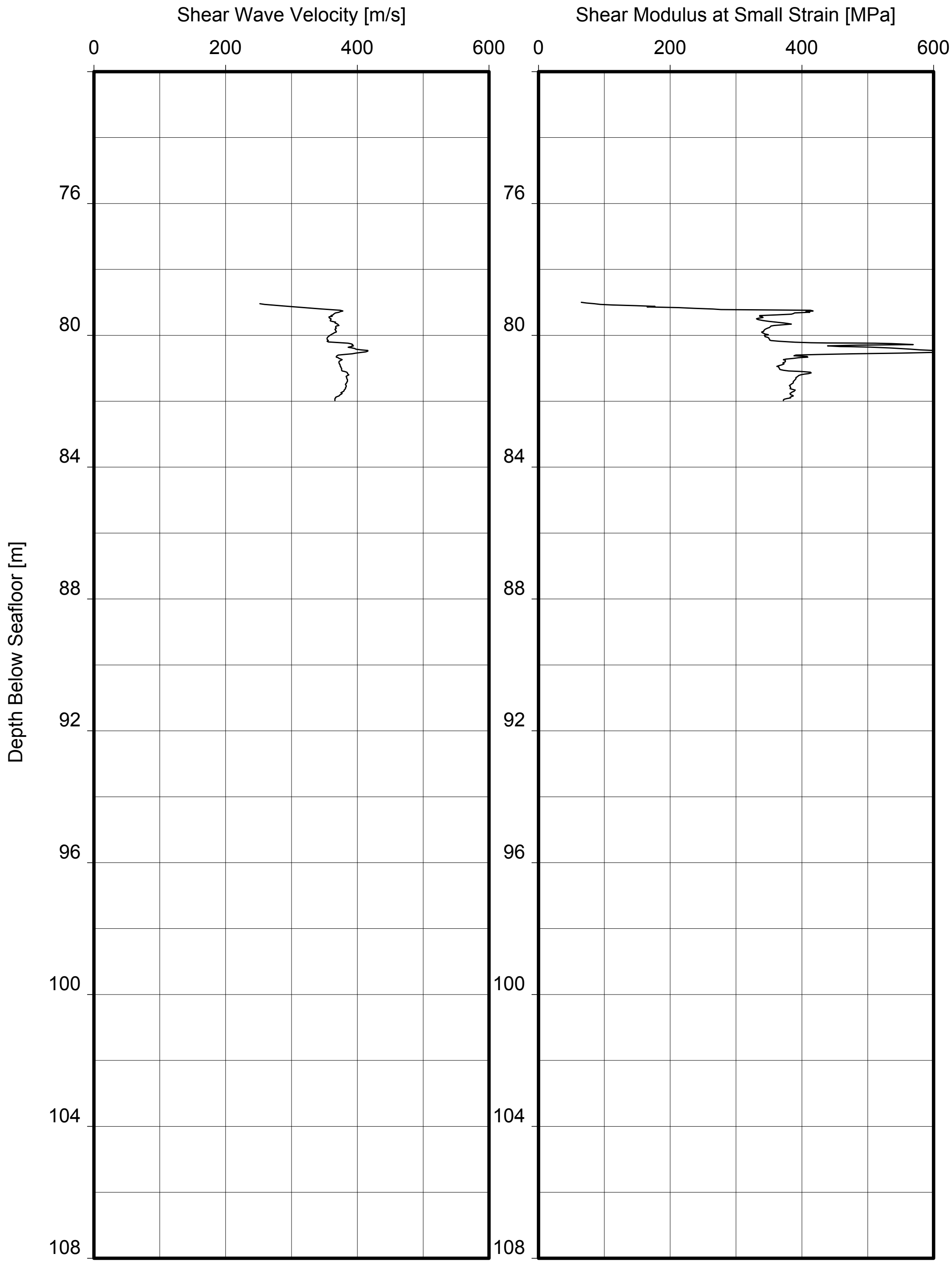
- ○ Particle size by mass percentage <2 µm
- △ Particle size by mass percentage <60 µm
- □ Particle size by mass percentage <2000 µm

Location(s):
BH-WFS2-1A, BH-WFS2-2A, BH-WFS2-3, BH-WFS2-4, BH-WFS2-5, BH-WFS2-6A, BH-WFS2-6B, BH-WFS2-7, BH-WFS2-8A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:42:04

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH
UNIT F1
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-1A
BH-WFS2-3
CPT_WFS2_12
CPT_WFS2_9
CPT_WFS2_12B
CPT_WFS2_14
CPT_WFS2_6
CPT_WFS2_18
CPT_WFS2_18A

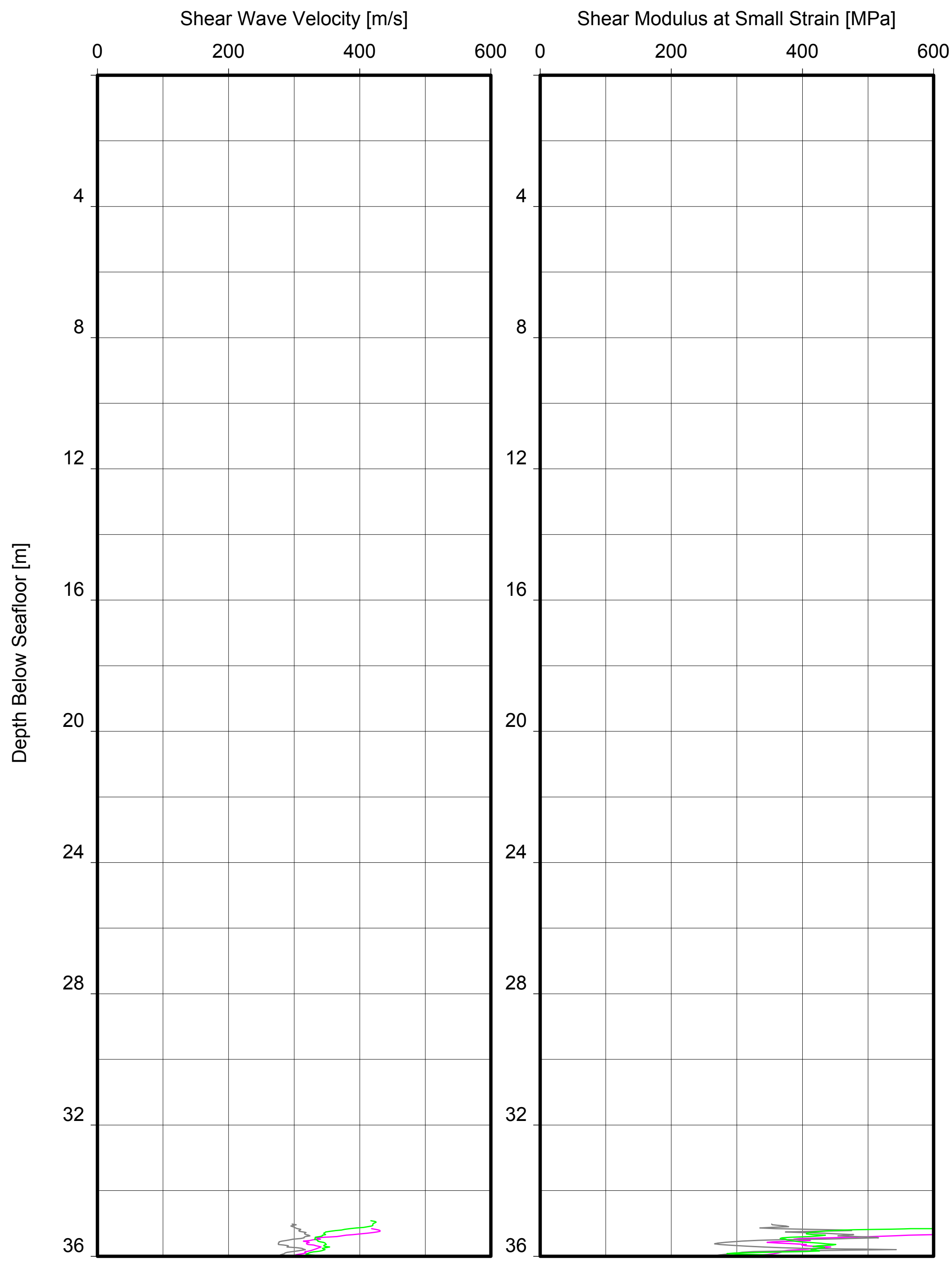
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:01:29

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

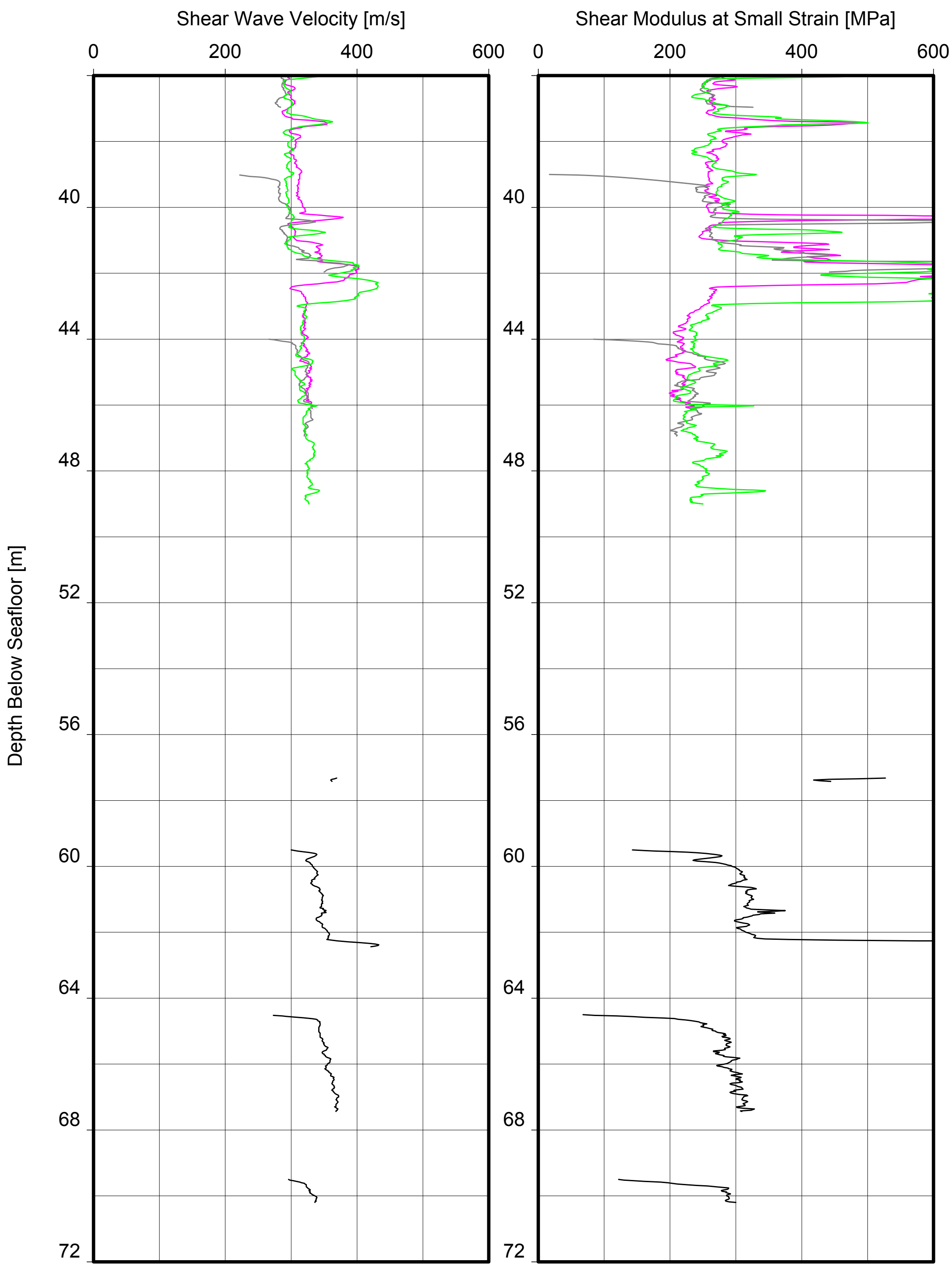
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:46:01

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

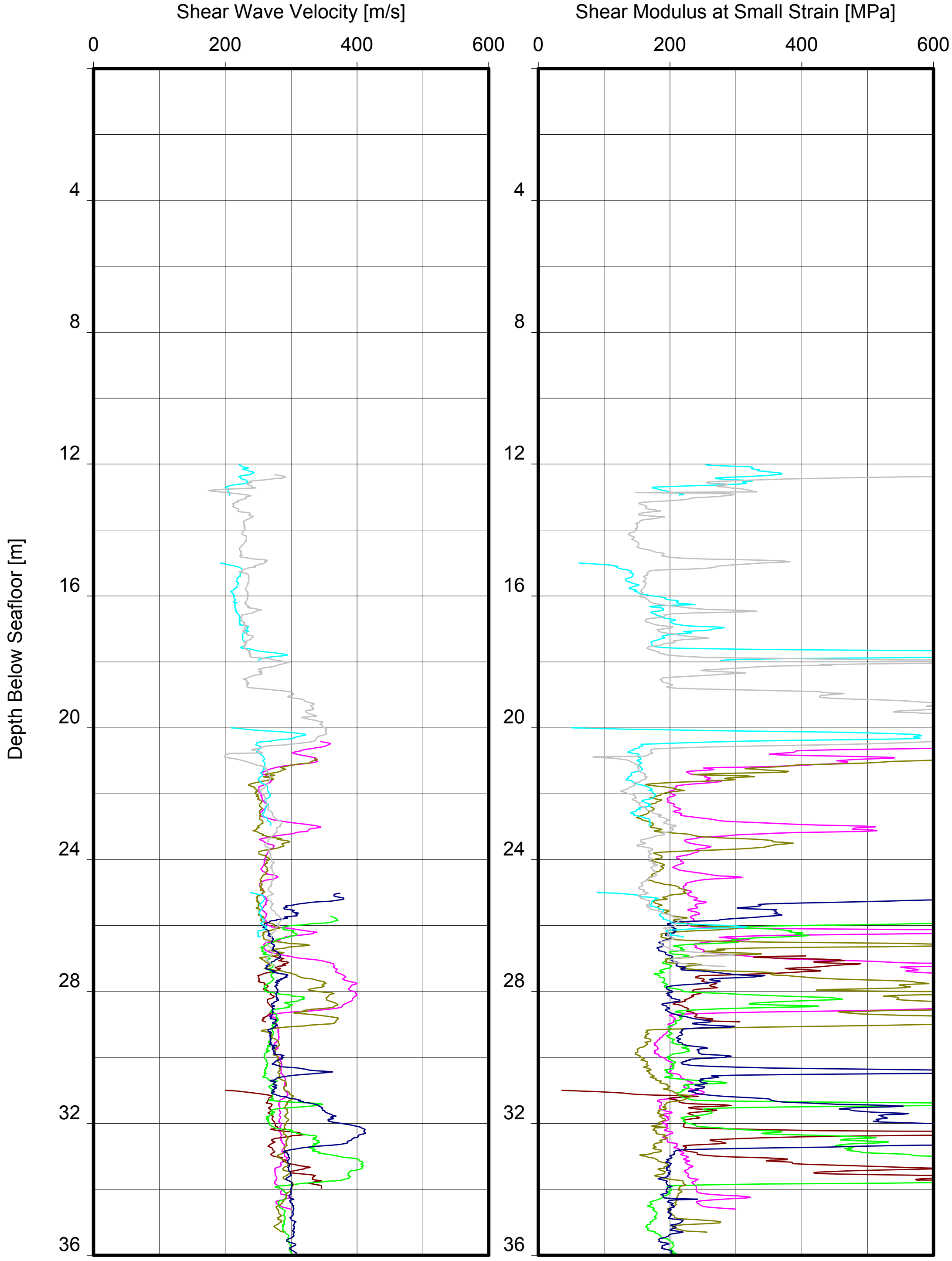
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:46:01

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- Shear wave velocity (v_s) measured in-between geophone array
- Shear modulus at small strain (G_{max}) derived from v_s measured
- v_s and G_{max} derived from CPT

Location(s):

CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

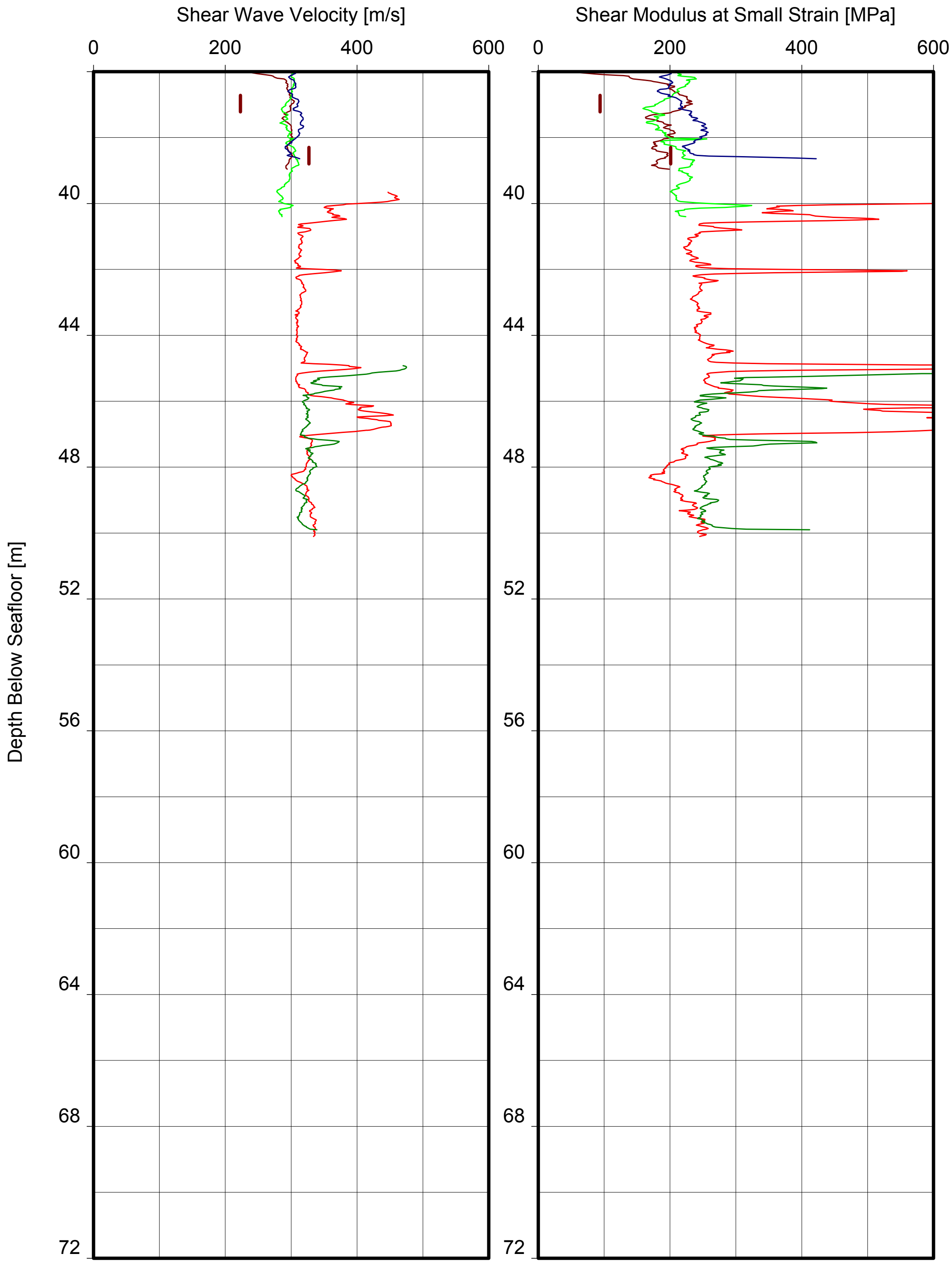
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:53:21

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Shear wave velocity (v_s) measured in-between geophone array

Shear modulus at small strain (G_{max}) derived from v_s measured

v_s and G_{max} derived from CPT

Location(s):

CPT_WFS2_7, CPT_WFS2_7A, CPT_WFS2_20, CPT_WFS2_20B, CPT_WFS2_2, BH-WFS2-6A, BH-WFS2-6B, CPT_WFS2_1, CPT_WFS2_5, CPT_WFS2_4, BH-WFS2-7, CPT_WFS2_23

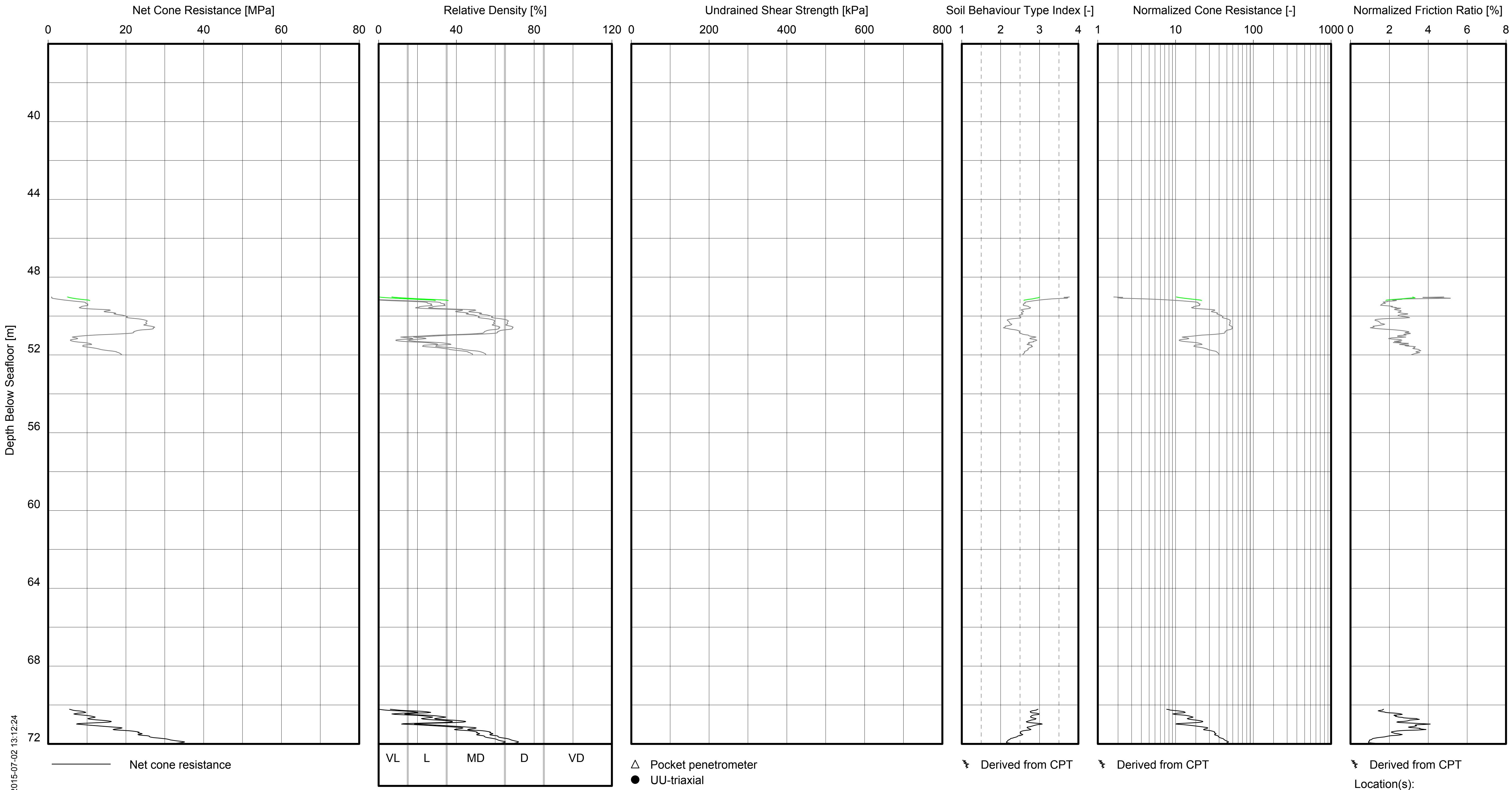
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:53:22

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F1

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

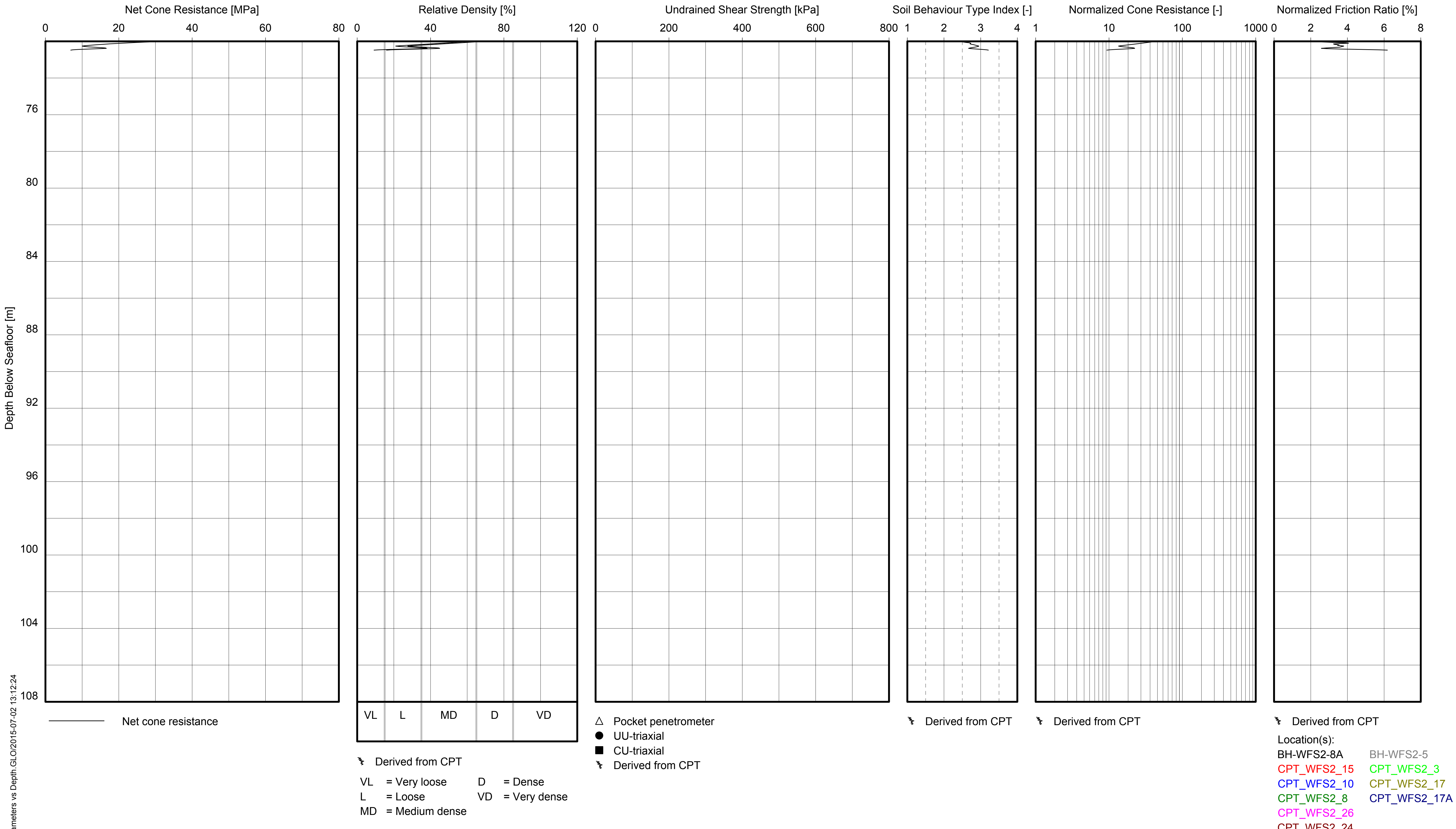
Derived from CPT

Derived from CPT

Location(s):
BH-WFS2-8A
BH-WFS2-5
CPT_WFS2_15
CPT_WFS2_3
CPT_WFS2_10
CPT_WFS2_17
CPT_WFS2_8
CPT_WFS2_17A
CPT_WFS2_26
CPT_WFS2_24

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH
UNIT F2
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA

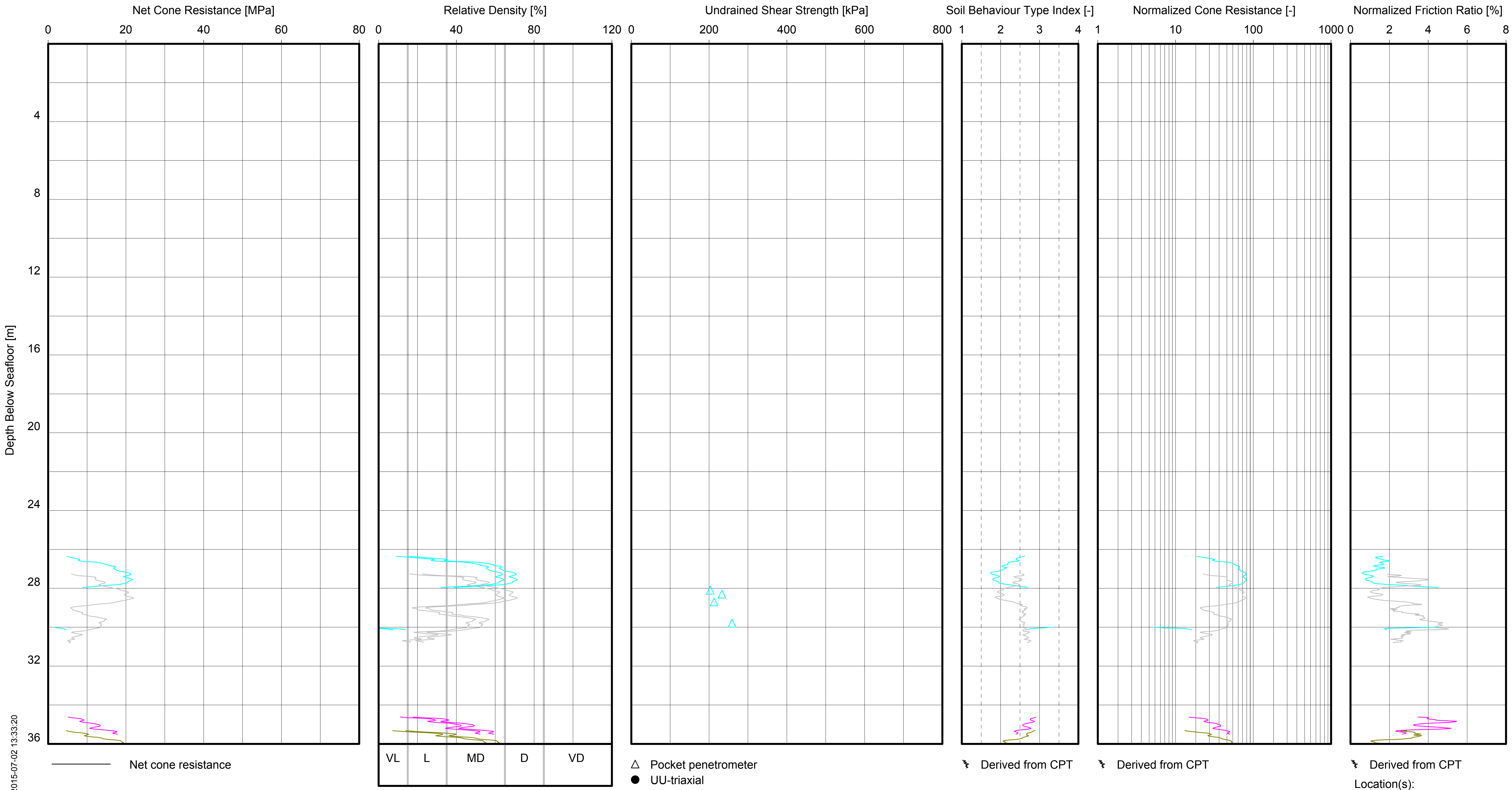


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

△ Pocket penetrometer
● UU-triaxial
■ CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

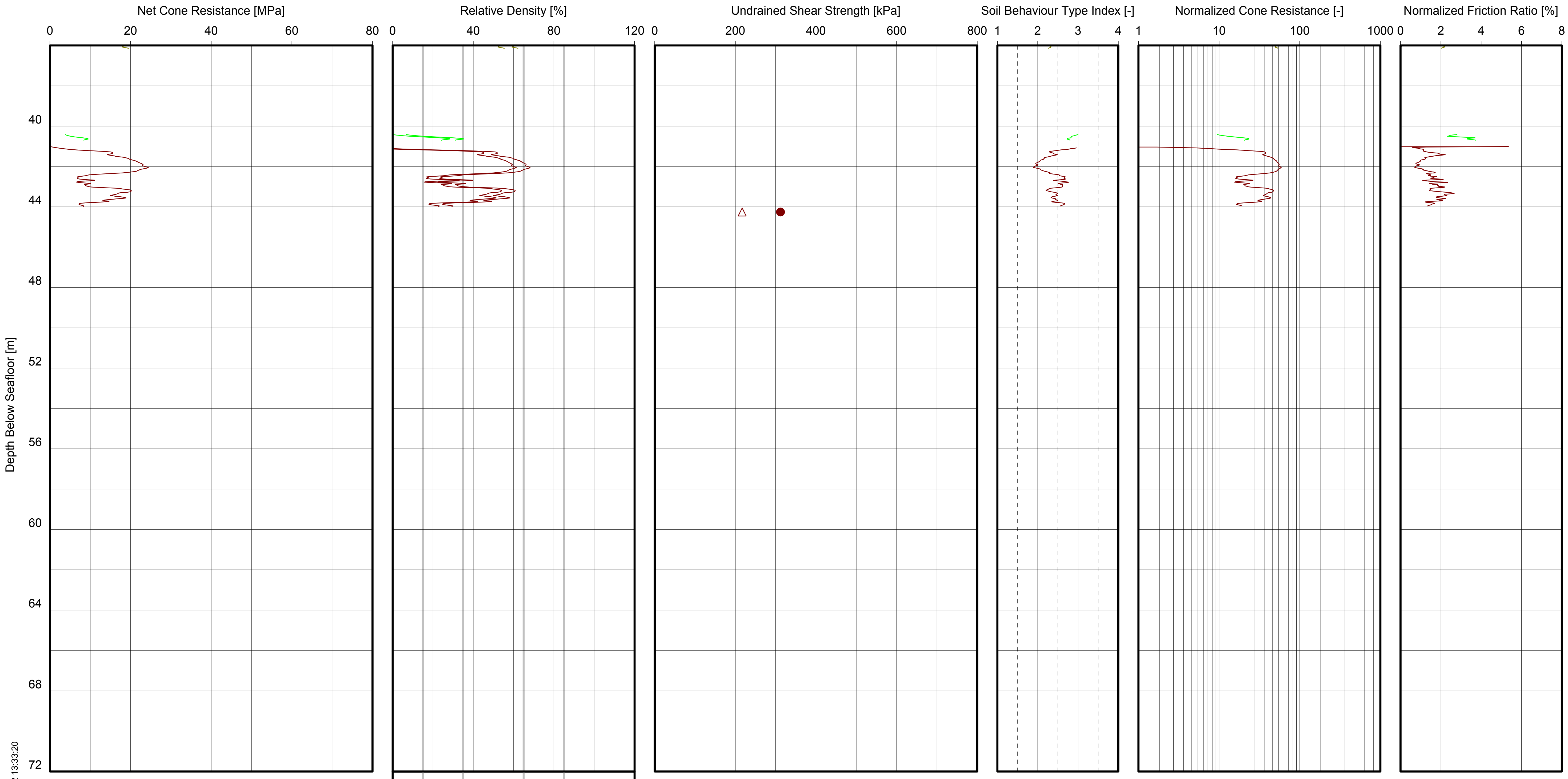
Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

GeODin/CPT Parameters vs Depth GLO/2015-07-02 13:33:20

CPT PARAMETERS VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Net cone resistance

Derived from CPT

VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

Pocket penetrometer
UU-triaxial
CU-triaxial
Derived from CPT

Derived from CPT

Derived from CPT

Derived from CPT

Location(s):
CPT_WFS2_7
BH-WFS2-6B
CPT_WFS2_7A
CPT_WFS2_1
CPT_WFS2_20
CPT_WFS2_5
CPT_WFS2_20B
CPT_WFS2_4
CPT_WFS2_2
BH-WFS2-7
BH-WFS2-6A
CPT_WFS2_23

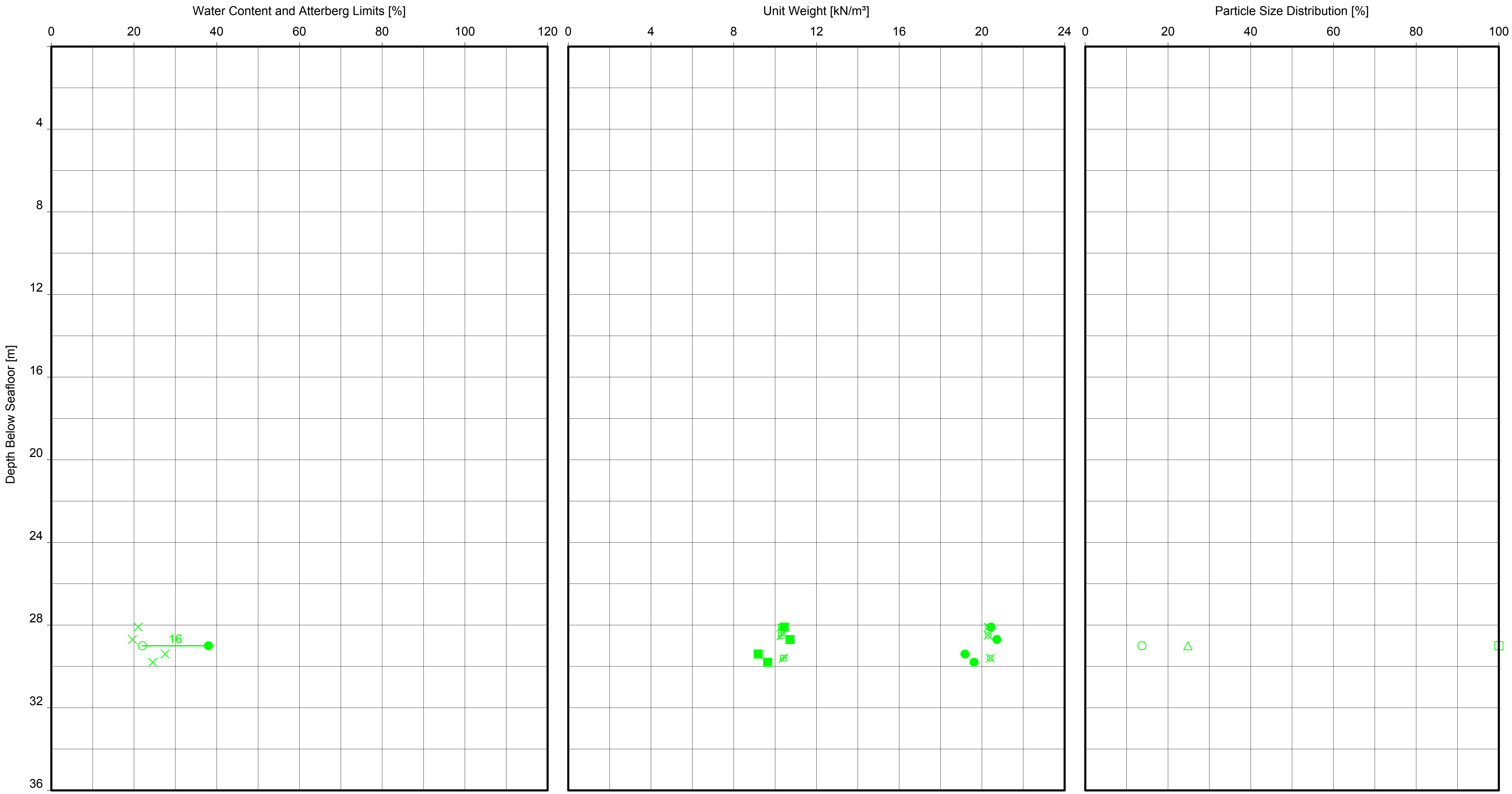
GeODin/CPT Parameters vs Depth GLO/2015-07-02 13:33:20

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



×	Water content
○	Plastic limit
●	Liquid limit
○—55—●	Plasticity index

●	Unit weight derived from water content and particle density
⊠	Unit weight derived from volume mass calculation
■	Submerged unit weight derived from water content and particle density
⊠	Submerged unit weight derived from volume mass calculation
▲	Dry unit weight derived from volume mass calculation

○	Particle size by mass percentage <2 µm
△	Particle size by mass percentage <60 µm
□	Particle size by mass percentage <2000 µm

Location(s):

BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

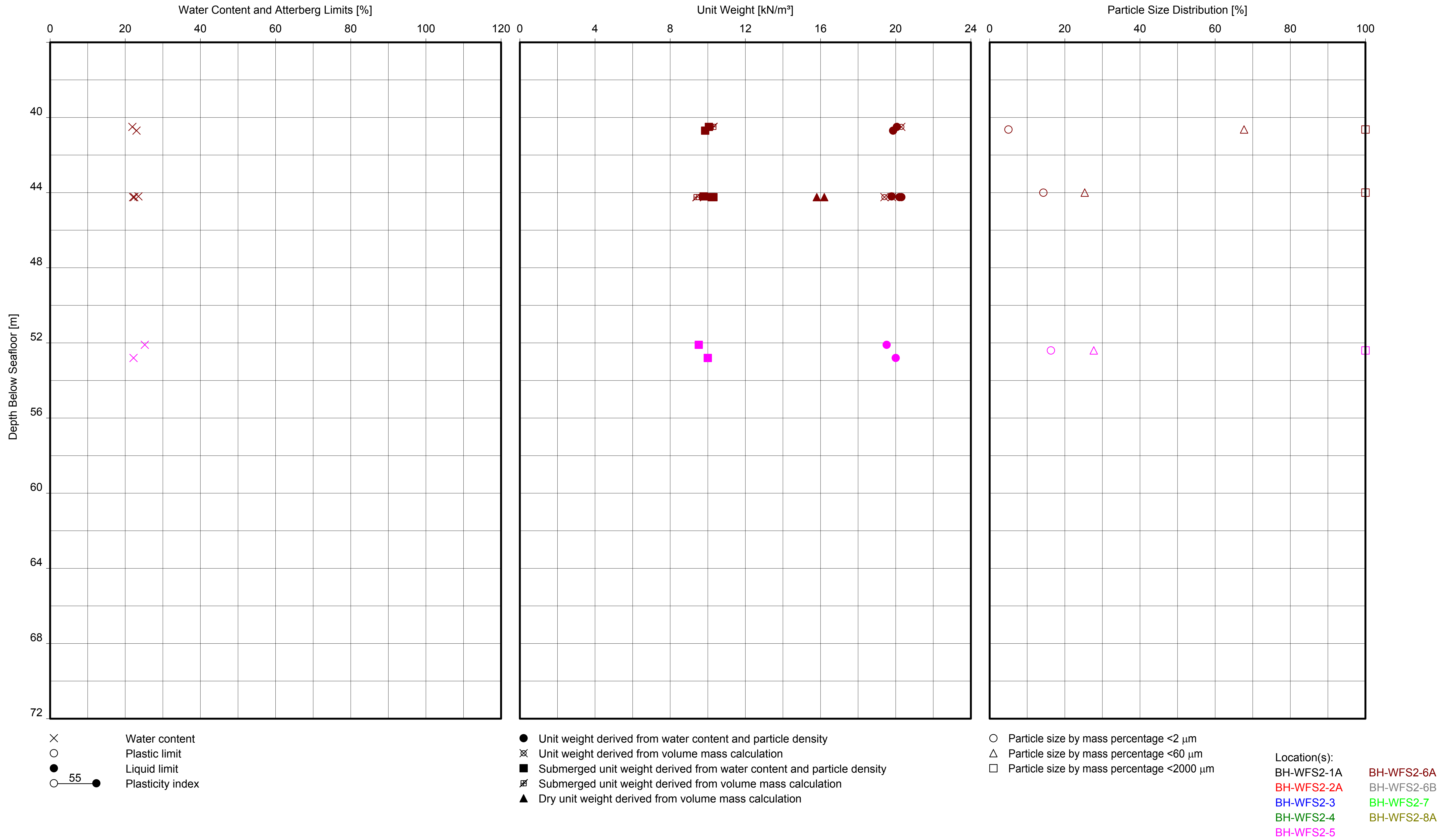
Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:44:49

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT F2

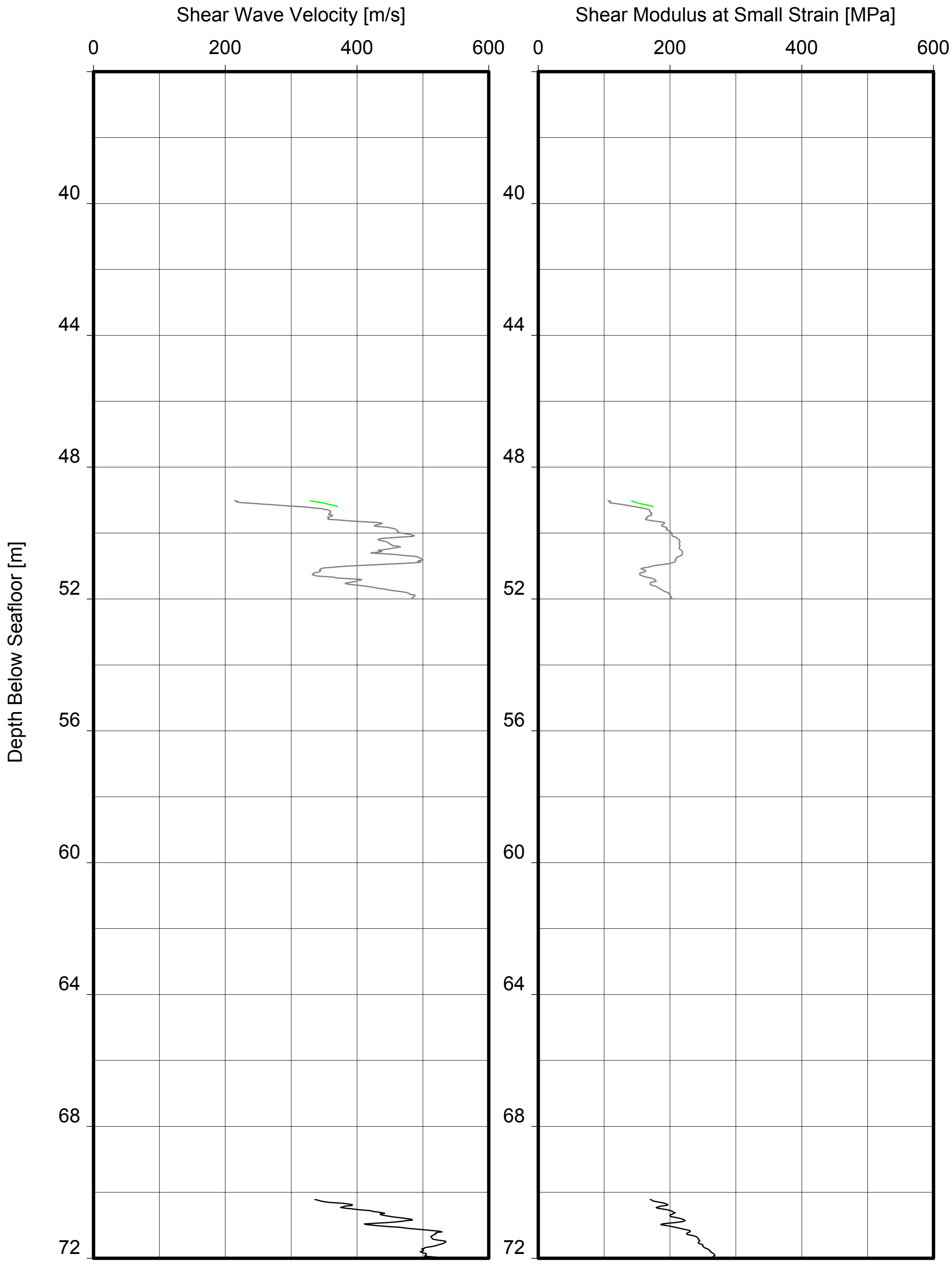
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:44:49

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH
UNIT F2
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

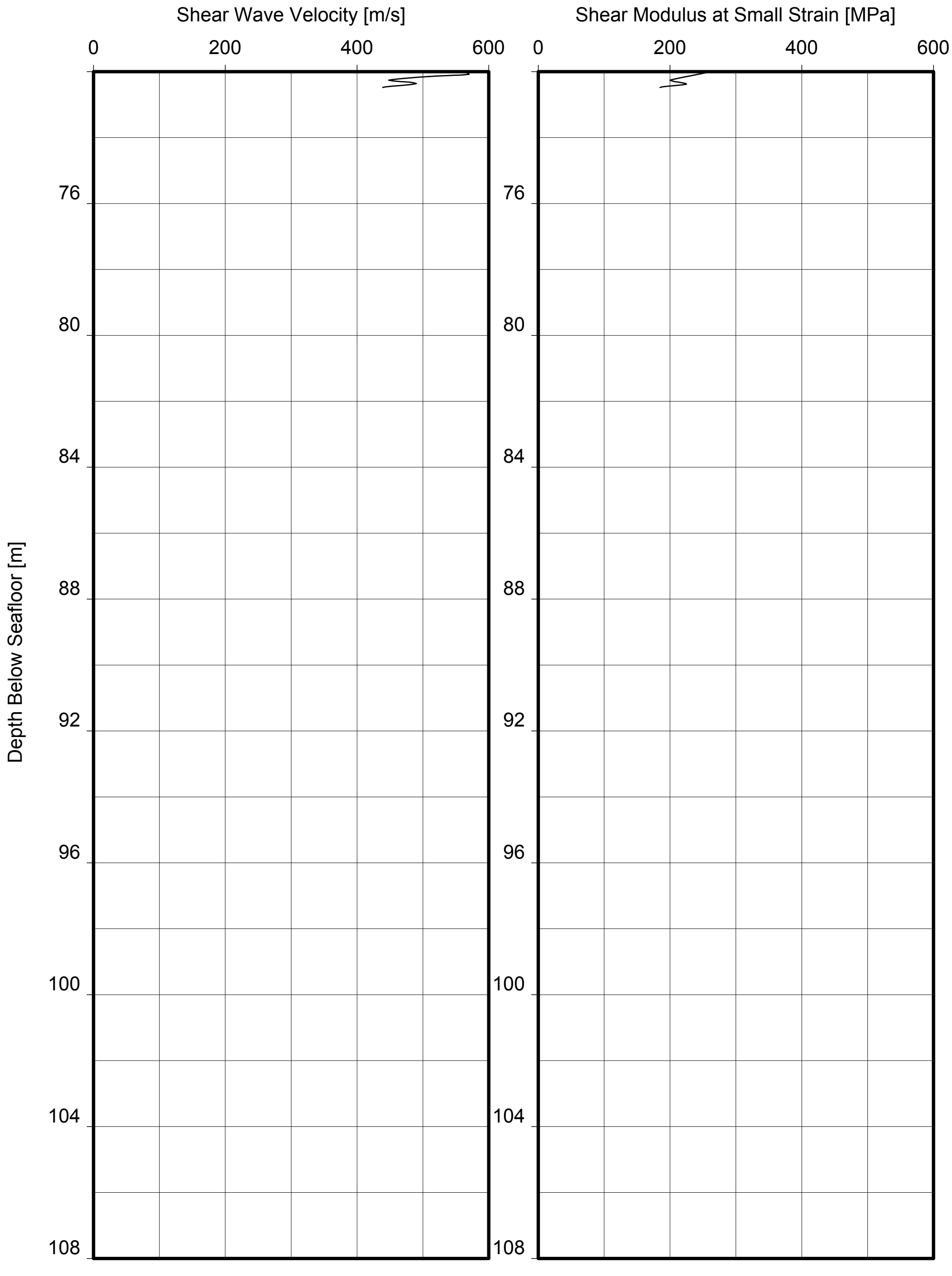
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:48:07

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



- Shear wave velocity (v_s) measured in-between geophone array
- Shear modulus at small strain (G_{max}) derived from v_s measured
- v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

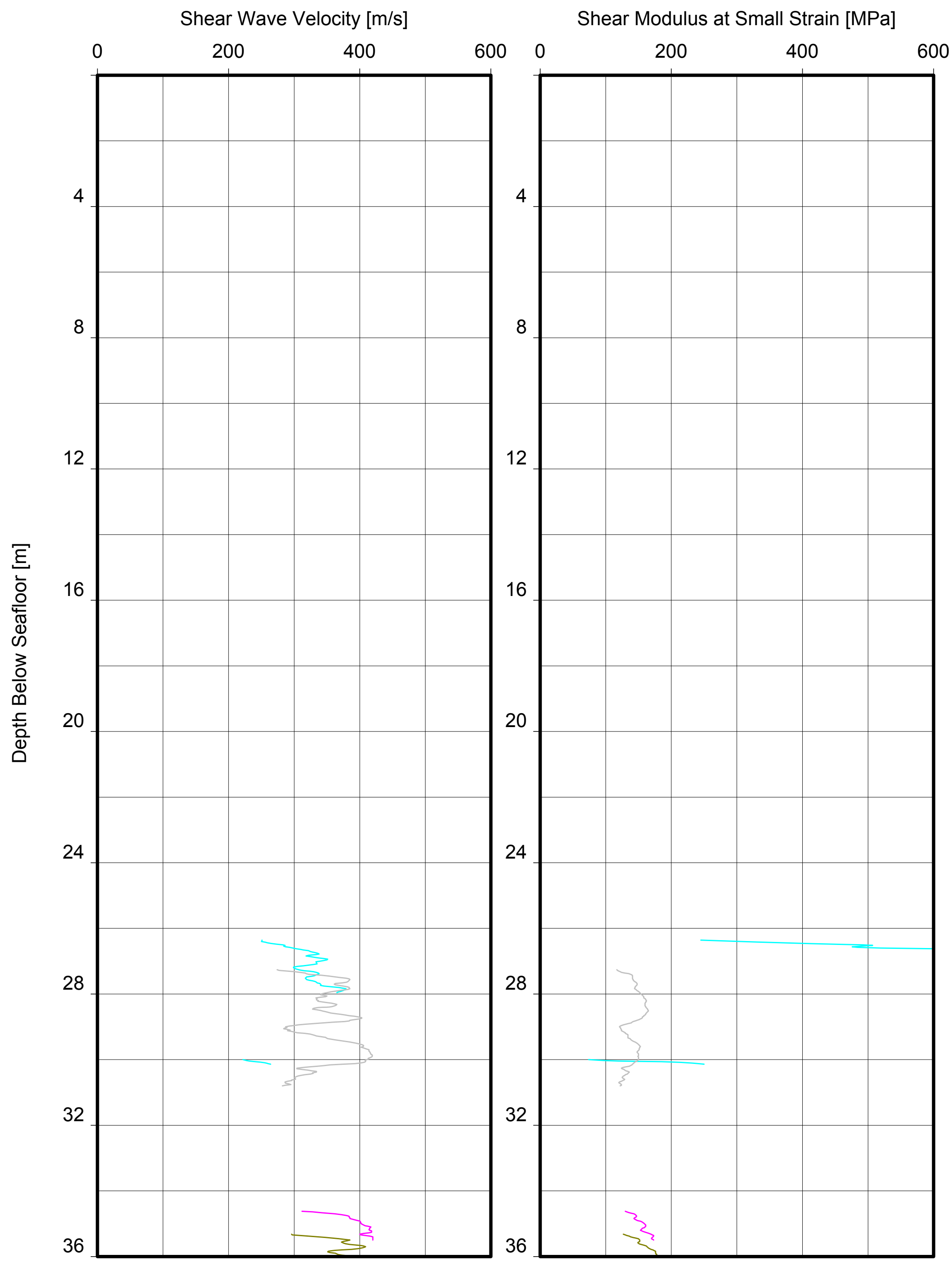
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:48:07

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

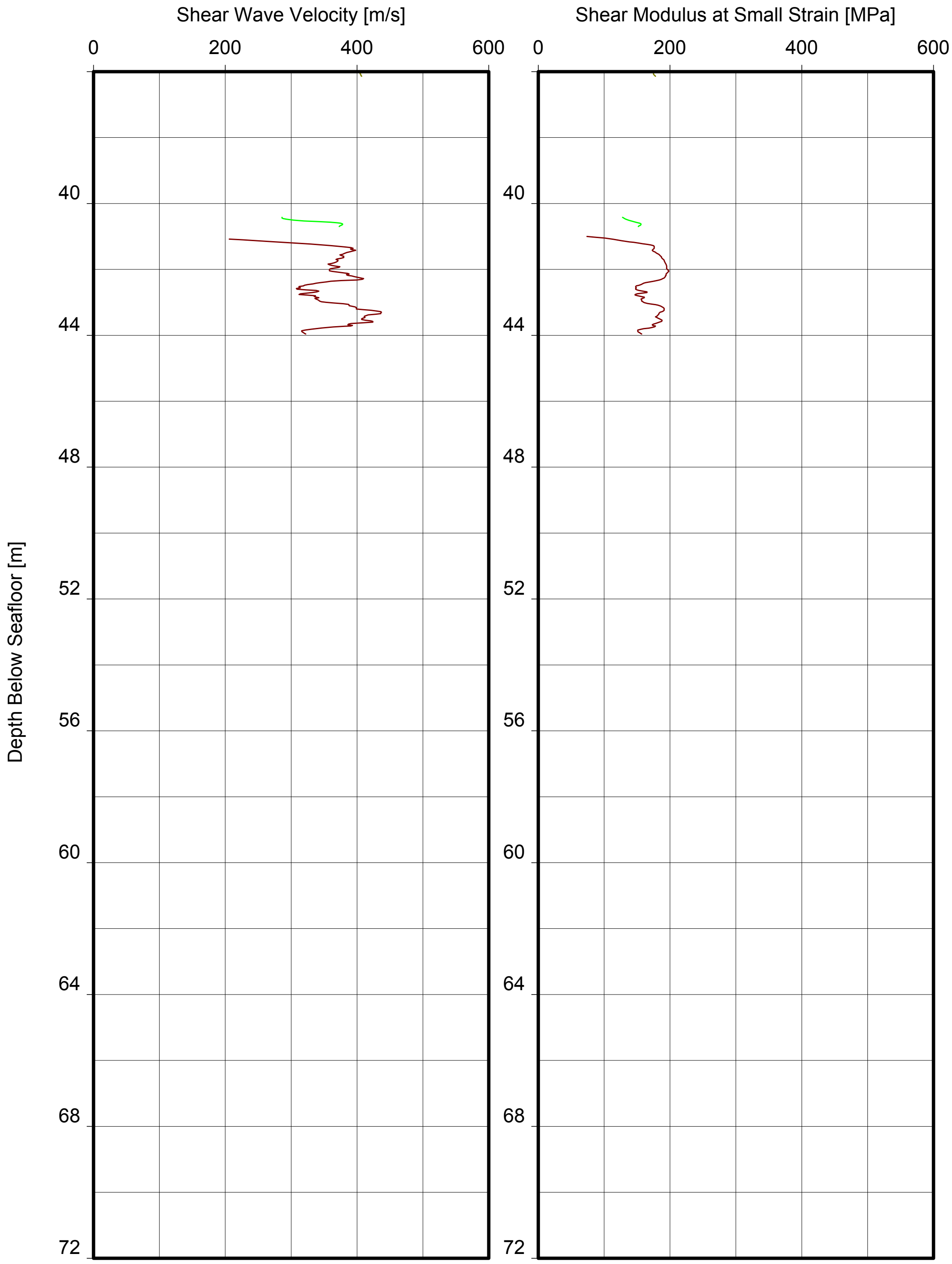
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:54:55

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

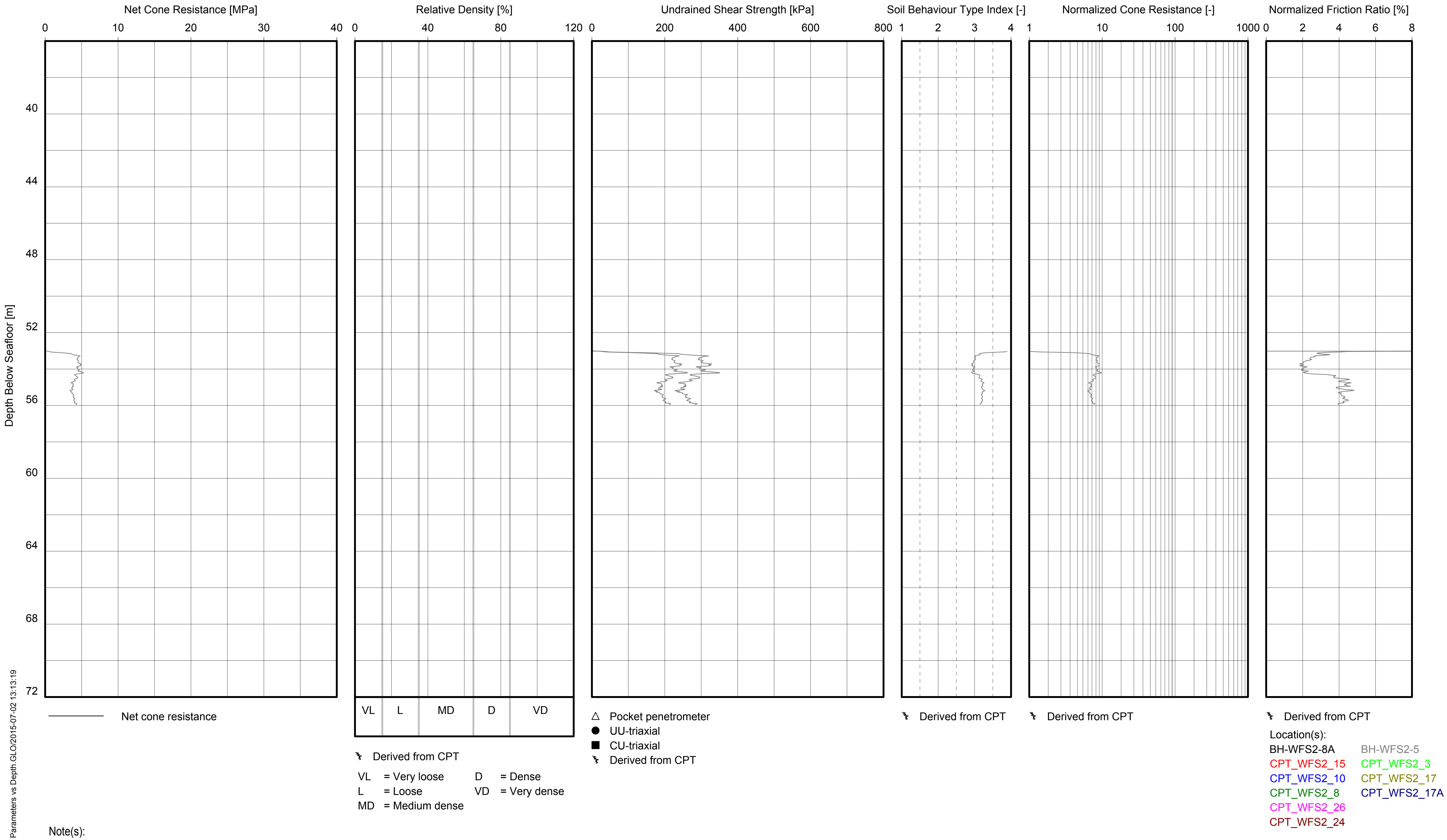
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:54:55

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F2

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA

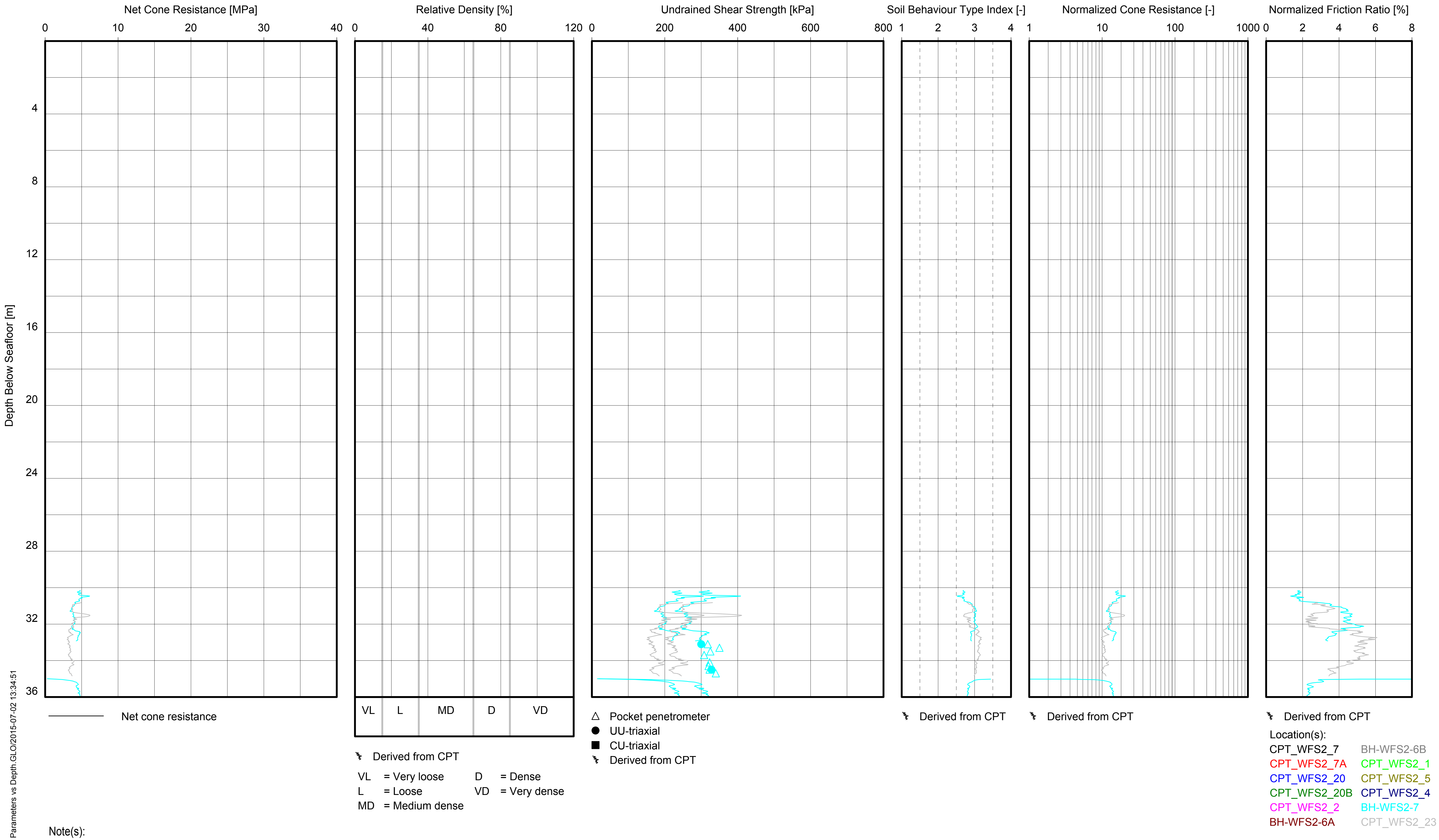


Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



VL = Very loose
L = Loose
MD = Medium dense
D = Dense
VD = Very dense

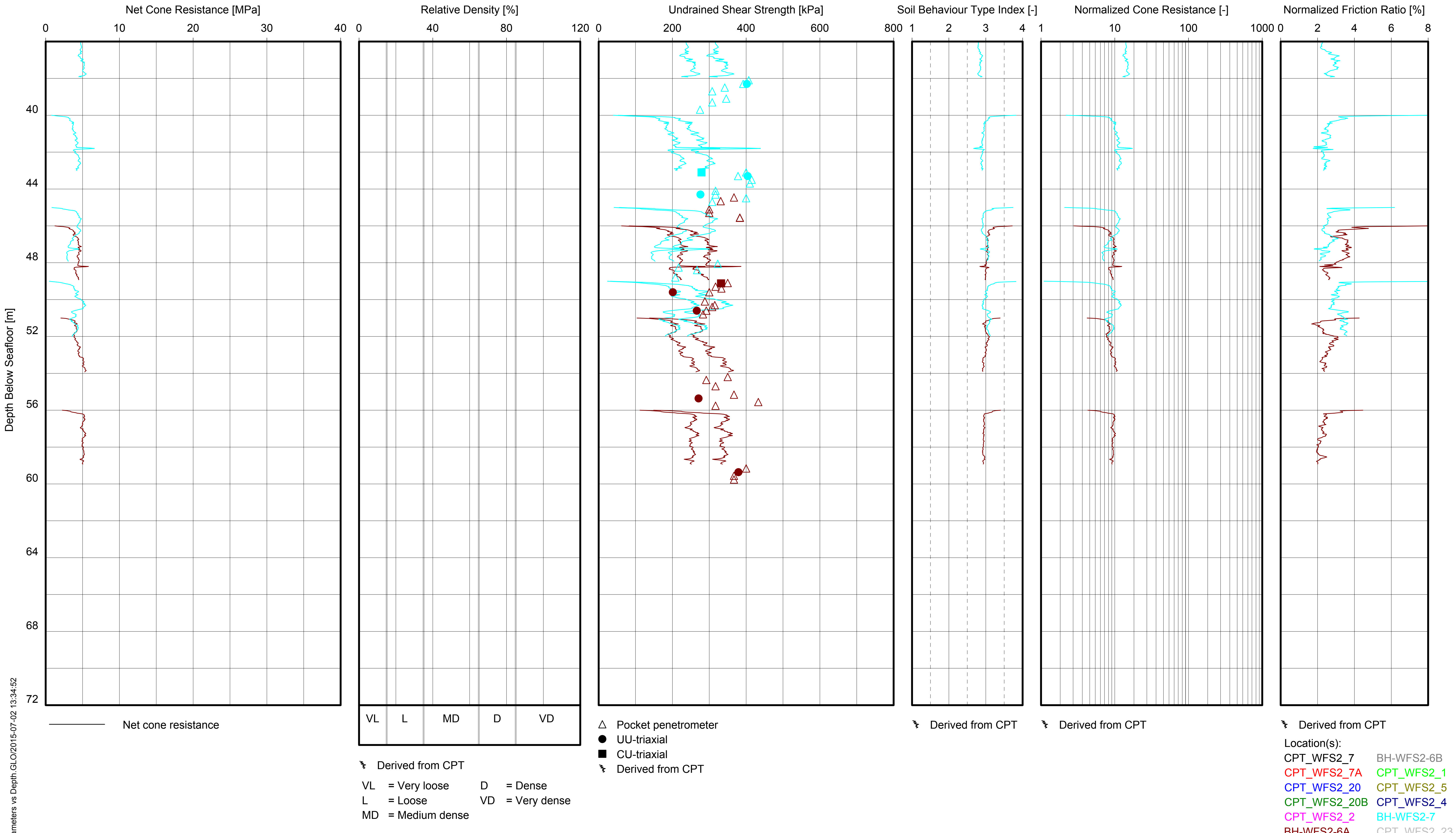
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:34:51

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



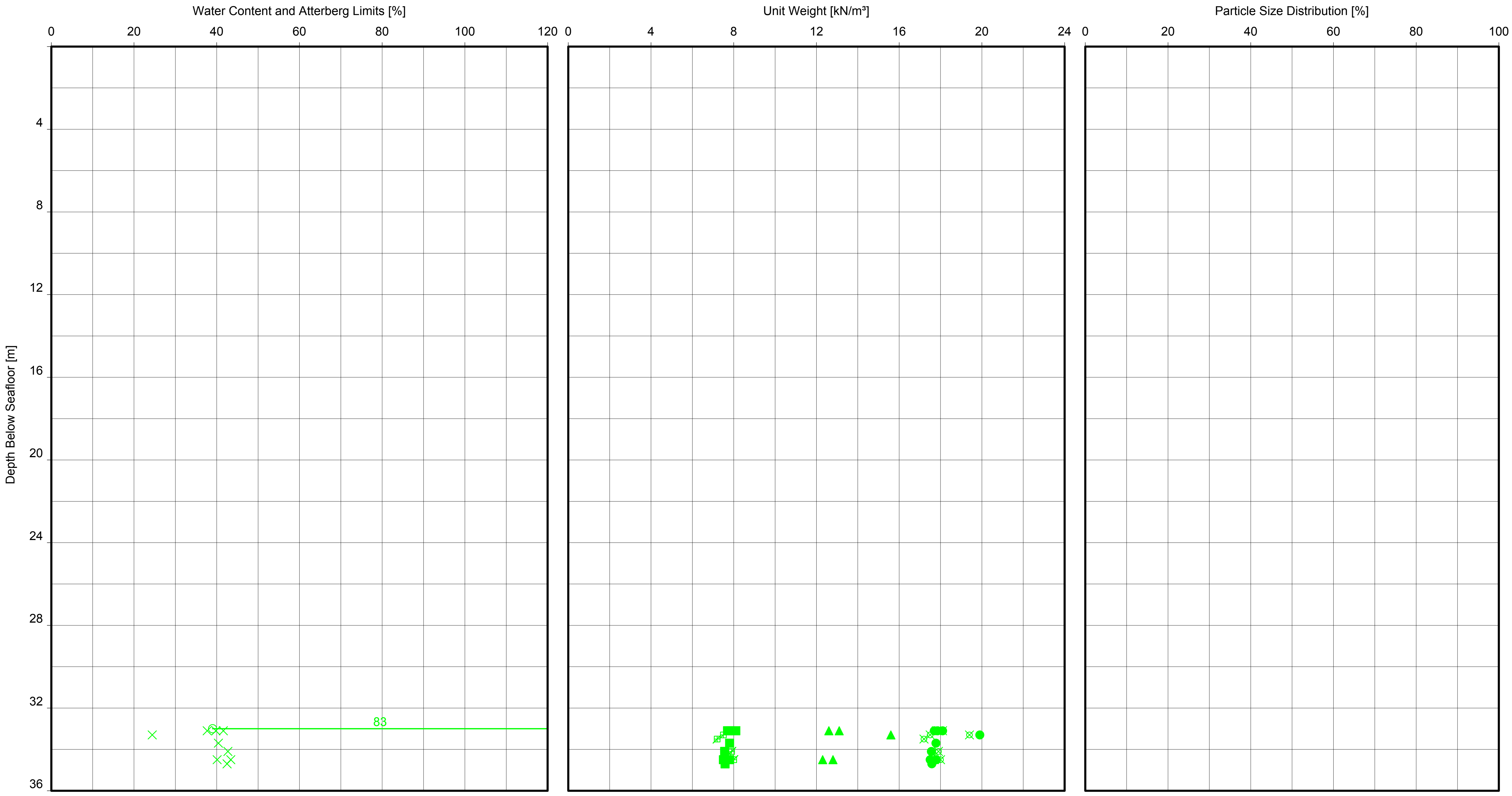
GeODin/CPT Parameters vs Depth.GLO/2015-07-02 13:34:52

Note(s):
- K_0 = 0.5 and K_0 = 1.0 are used to derive relative density from CPT
- N_k = 15 and N_k = 20 are used to derive c_u from CPT
- Soil Behaviour Type Index is according to Robertson (2009), refer to Appendix 1, document titled "Cone Penetration Test Interpretation"

CPT PARAMETERS VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Water content
Plastic limit
Liquid limit
55 Plasticity index

Unit weight derived from water content and particle density
Unit weight derived from volume mass calculation
Submerged unit weight derived from water content and particle density
Submerged unit weight derived from volume mass calculation
Dry unit weight derived from volume mass calculation

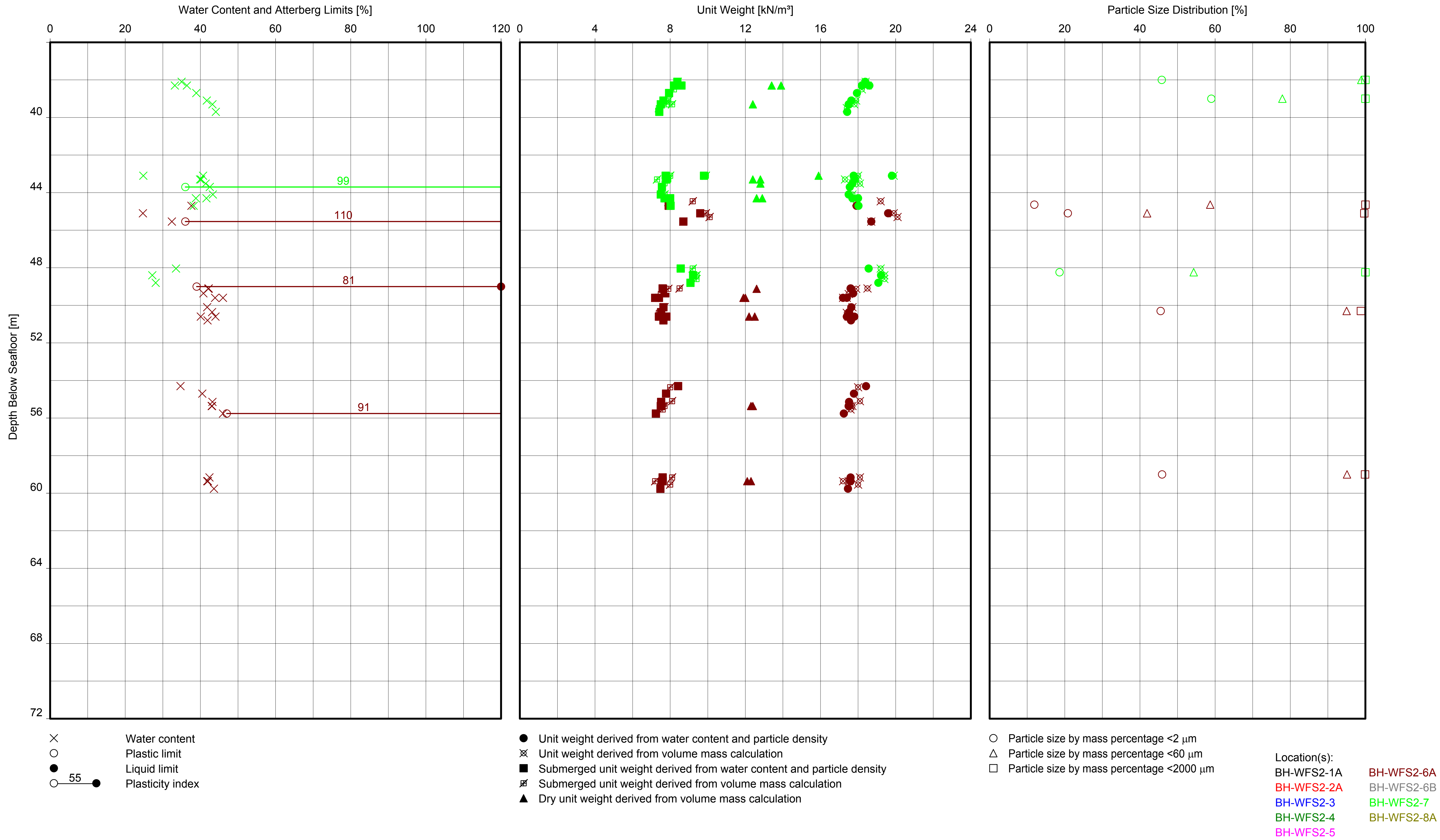
Particle size by mass percentage <2 µm
Particle size by mass percentage <60 µm
Particle size by mass percentage <2000 µm

Location(s):
BH-WFS2-1A
BH-WFS2-2A
BH-WFS2-3
BH-WFS2-4
BH-WFS2-5
BH-WFS2-6A
BH-WFS2-6B
BH-WFS2-7
BH-WFS2-8A

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:46:09

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH
UNIT F3
BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



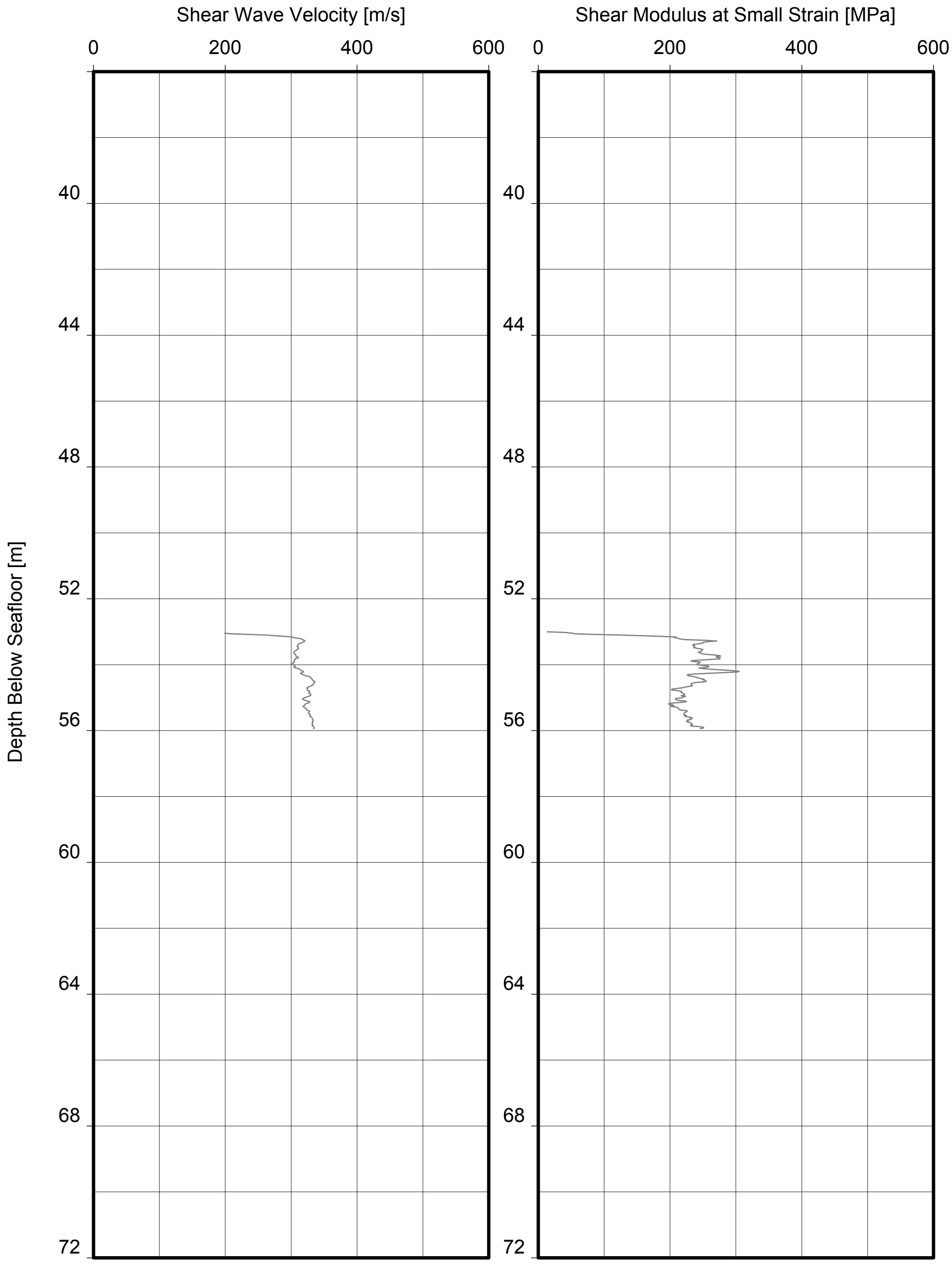
GeODin/Water Content, Unit Weight And Particle Size Distribution vs Depth GLO/2015-07-01 15:46:09

Note(s):
- In case a unit weight is derived from volume mass calculation by weighing a sub sample prior to waxing, no dry unit weight is available.

WATER CONTENT, UNIT WEIGHT AND PARTICLE SIZE DISTRIBUTION VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
BH-WFS2-8A
CPT_WFS2_15
CPT_WFS2_10
CPT_WFS2_8
CPT_WFS2_26
CPT_WFS2_24
BH-WFS2-5
CPT_WFS2_3
CPT_WFS2_17
CPT_WFS2_17A

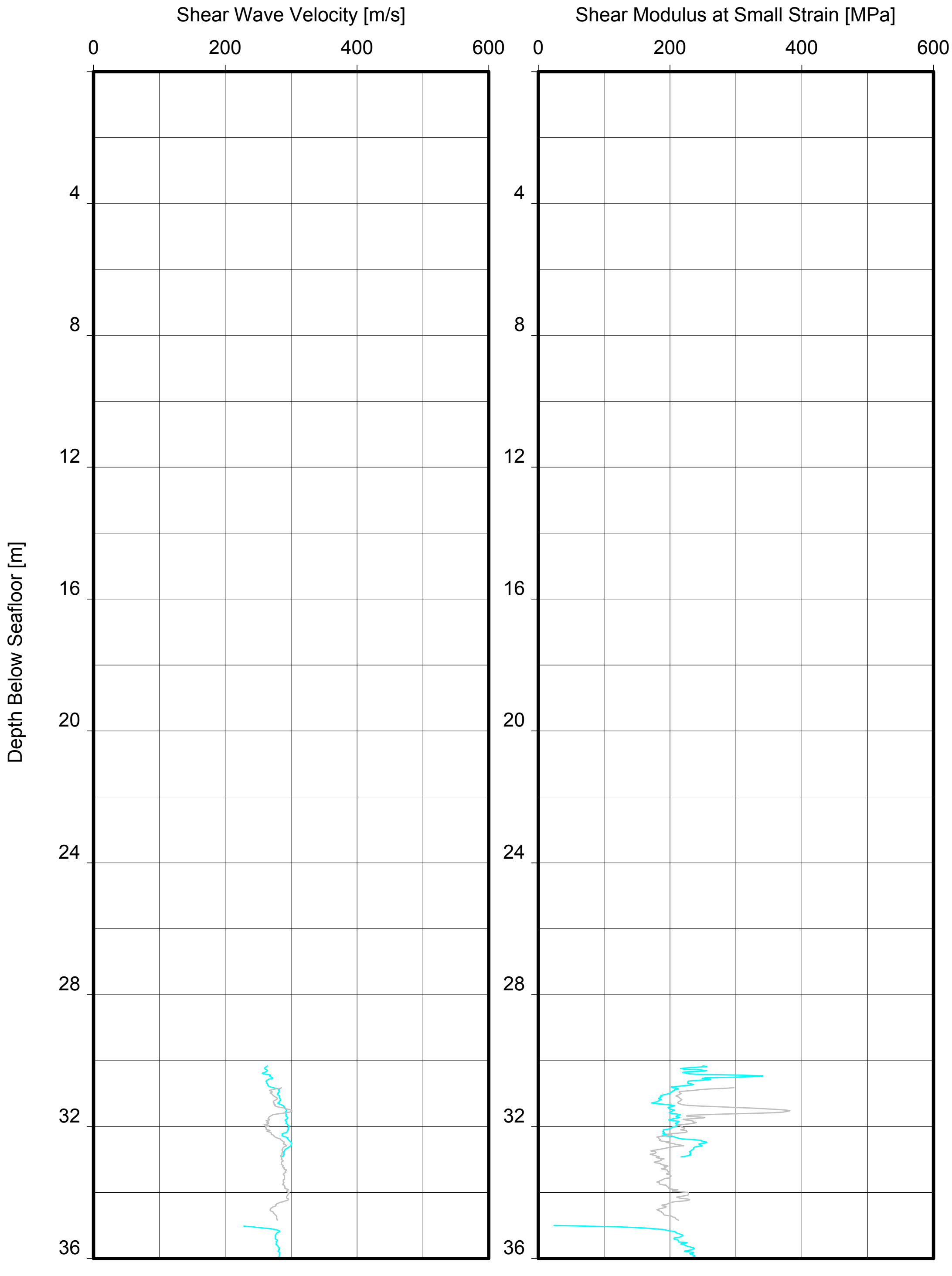
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 16:49:41

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II – DUTCH SECTOR, NORTH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

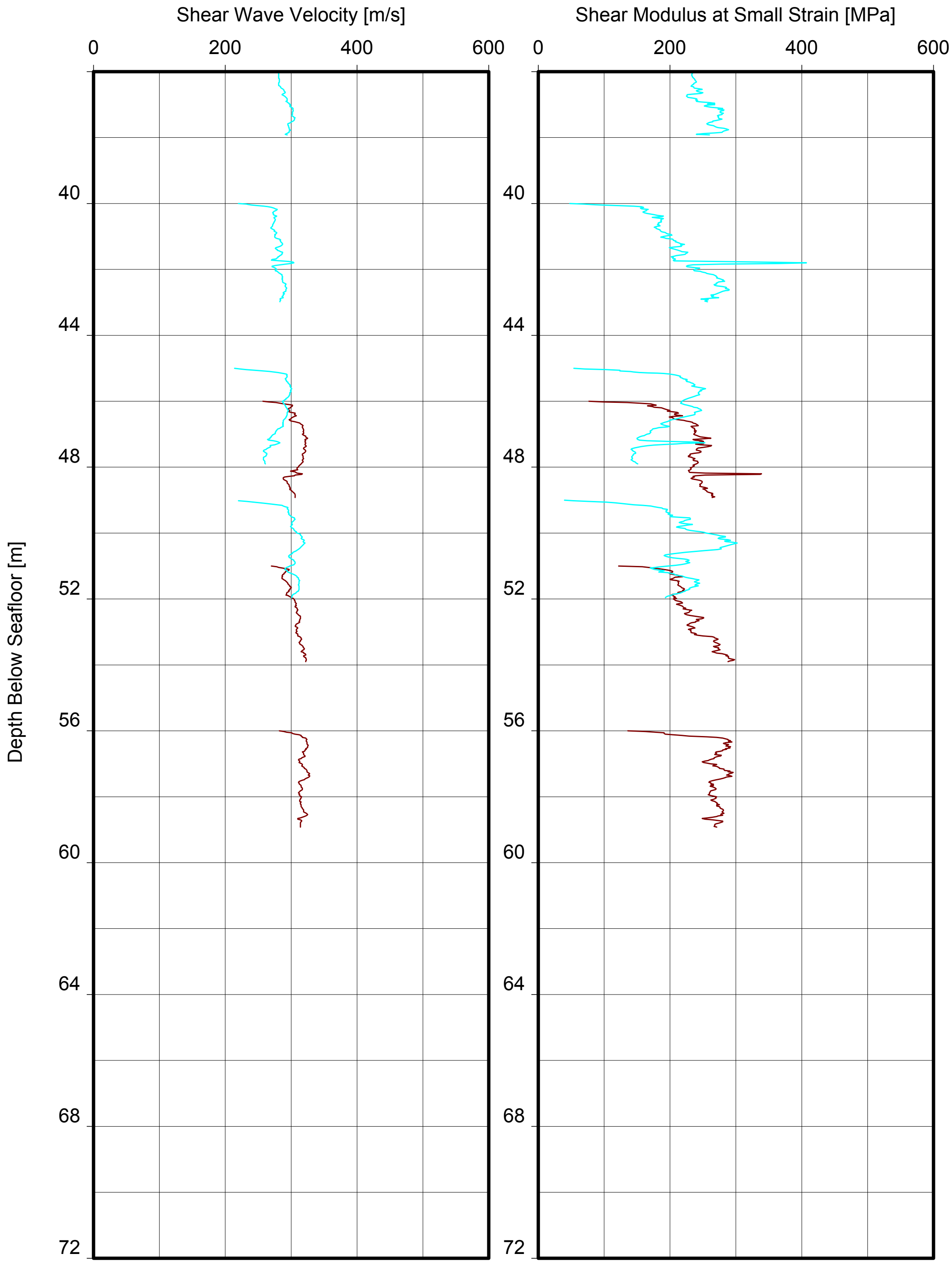
Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
- G_{max} for sands derived from CPT based on Rix and Stokoe (1991)

GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:55:47

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA



Shear wave velocity (v_s) measured in-between geophone array
Shear modulus at small strain (G_{max}) derived from v_s measured
v_s and G_{max} derived from CPT

Location(s):
CPT_WFS2_7
CPT_WFS2_7A
CPT_WFS2_20
CPT_WFS2_20B
CPT_WFS2_2
BH-WFS2-6A
BH-WFS2-6B
CPT_WFS2_1
CPT_WFS2_5
CPT_WFS2_4
BH-WFS2-7
CPT_WFS2_23

Note(s):
- v_s derived from CPT based on Robertson and Cabal (2010)
- G_{max} for clays derived from CPT based on Mayne and Rix (1993)
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GeODin/Shear Wave Velocity and Shear Modulus at Small Strain versus Depth (single UNIT, excl. GM).GLO/2015-07-01 15:55:47

SHEAR WAVE VELOCITY AND SHEAR MODULUS AT SMALL STRAIN VERSUS DEPTH

UNIT F3

BORSSELE WIND FARM ZONE, WFS II - DUTCH SECTOR, NORH SEA

SECTION C: GUIDELINES FOR USE OF REPORT

CONTENTS Reference

INTRODUCTION

This document provides guidelines, recommendations and limitations regarding the use of information in this report.

The cost of geotechnical data acquisition, interpretation and monitoring is a small portion of the total cost of a construction project. By contrast, the costs of correcting a wrongly designed programme or mobilising alternative construction methods are often far greater than the cost of the original investigation. Attention and adherence to the guidelines and recommendations presented in this guide and in the geotechnical report can reduce delays and cost overruns related to geotechnical factors.

This guide applies equally to the use of geotechnical and multi-disciplinary project information and advice.

REQUIREMENTS FOR QUALITY GEOTECHNICAL INVESTIGATIONS

Fugro follows ISO 9001 quality principles for project management. Project activities usually comprise part of specific phases of a construction project. The quality plan for the entire construction project must incorporate geotechnical input in every phase - from the feasibility planning stages to project completion. The parties involved must do the following.

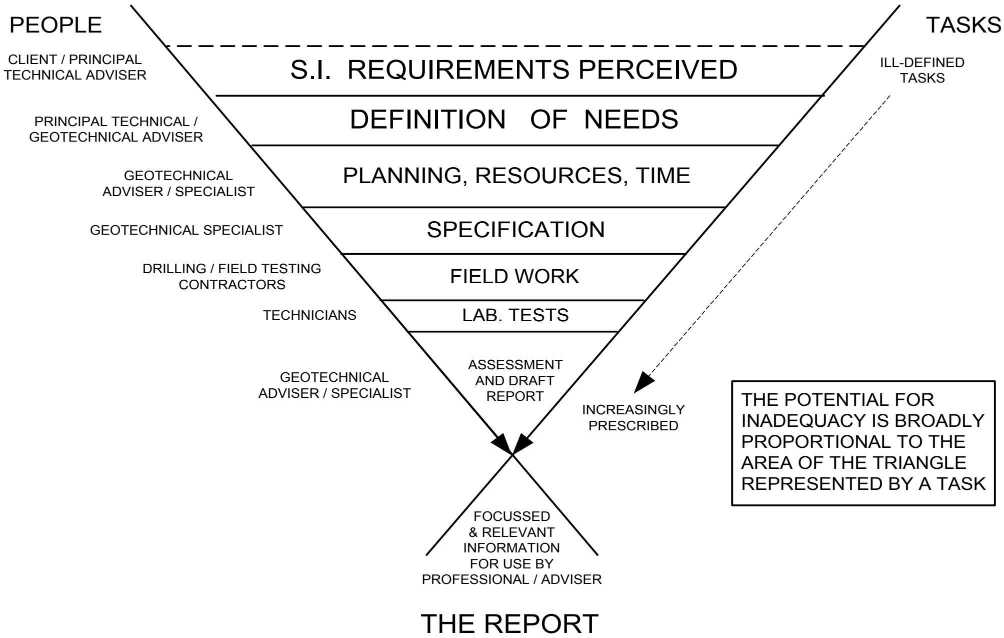
- Provide complete and accurate information necessary to plan an appropriate geotechnical site investigation.
- Describe the purpose(s), type(s) and construction methods of planned structures in detail.
- Provide the time, financial, personnel and other resources necessary for the planning, execution and follow-up of a site investigation programme.
- Understand the limitations and degree of accuracy inherent in the geotechnical data and engineering advice based upon these data.
- During all design and construction activities, be aware of the limitations of geotechnical data and geotechnical engineering analyses/advice, and use appropriate preventative measures.
- Incorporate all geotechnical input in the design, planning, construction and other activities involving the site and structures. Provide the entire geotechnical report to parties involved in design and construction.
- Use the geotechnical data and engineering advice for only the structures, site and activities which were described to Fugro prior to and for the purpose of planning the geotechnical site investigation or geotechnical engineering analysis programme.

AUTHORITY, TIME AND RESOURCES NECESSARY FOR GEOTECHNICAL INVESTIGATIONS

To ensure compliance with these requirements, there must be adequate designation of authority and accountability for geotechnical aspects of construction projects. This way, an appropriate investigation can be performed, and the use of the results by project design and construction professionals can be optimised.

Figure 1 illustrates the importance of the initial project phases in ensuring that adequate geotechnical information is gathered for a project. The initial phases, when site investigation requirements are defined and resources are allocated, are represented by more than 50% of the Quality triangle (Figure 1). Decisions and actions made during these phases have a large impact of the outcome and thus the potential of the investigation to meet project requirements.

Figure 1: Quality of Geotechnical Site Investigation (adapted from SISG[1]).



DATA ACQUISITION AND MONITORING PROGRAMMES

Geotechnical investigations are operations of discovery. Investigation should proceed in logical stages. Planning must allow operational adjustments deemed necessary by newly available information. This observational approach permits the development of a sound engineering strategy and reduces the risk of discovering unexpected hazards during or after construction.

GEOTECHNICAL INFORMATION – DATA TYPES AND LIMITATIONS

1. RELIABILITY OF SUPPLIED INFORMATION

Geotechnical engineering can involve the use of information and physical material that is publicly available or supplied by the Client. Examples are geodetic data, geological maps, geophysical records, earthquake data, earlier borehole logs and soil samples. Fugro endeavours to identify potential anomalies, but does not independently verify the accuracy or completeness of public or Client-supplied information unless indicated otherwise. This information, therefore, can limit the accuracy of the report.

2. COMPLEXITY OF GROUND CONDITIONS

There are hazards associated with the ground. An adequate understanding of these hazards can help to minimize risks to a project and the site. The ground is a vital element of all structures which rest on or in the ground. Information about ground behaviour is necessary to achieve a safe and economical structure. Often less is known about the ground than for any other element of a structure.

3. GEOTECHNICAL INVESTIGATION - SPATIAL COVERAGE LIMITATIONS

Geotechnical investigations collect data at specific test locations. Interpretation of ground conditions away from test locations is a matter of extrapolation and judgement based on geotechnical knowledge and experience, but actual conditions in untested areas may differ from predictions. For example, the interface between ground materials may be far more gradual or abrupt than a report indicates. It is not realistic to expect a geotechnical investigation to reveal or anticipate every detail of ground conditions. Nevertheless, an investigation can reduce the residual risk associated with unforeseen conditions to a tolerable level. If ground problems do arise, it is important to have geotechnical expertise available to help reduce and mitigate safety and financial risks.

1 Site Investigation Steering Group SISG (1993), "Site Investigation in Construction 2: Planning, Procurement and Quality Management", Thomas Telford, London.

ISSUE 10

4. ROLE OF JUDGEMENT AND OPINION IN GEOTECHNICAL ENGINEERING

Geotechnical engineering is less exact than most other design disciplines, and requires extensive judgement and opinion. Therefore, a geotechnical report may contain definitive statements that identify where the responsibility of Fugro begins and ends. These are not exculpatory clauses designed to transfer liabilities to another party, but they are statements that can help all parties involved to recognise their individual responsibilities and take appropriate actions.

COMPLETE GEOTECHNICAL REPORT SHOULD BE AVAILABILE TO ALL PARTIES INVOLVED

To prevent costly construction problems, construction contractors should have access to the best available information. They should have access to the complete original report to prevent or minimize any misinterpretation of site conditions and engineering advice. To prevent errors or omissions that could lead to misinterpretation, geotechnical logs and illustrations should not be redrawn, and users of geotechnical engineering information and advice should confer with the authors when applying the report information and/or recommendations.

GEOTECHNICAL INFORMATION IS PROJECT-SPECIFIC

Fugro's investigative programmes and engineering assessments are designed and conducted specifically for the Client described project and conditions. Thus this report presents data and/or recommendations for a unique construction project. Project-specific factors for a structure include but are not limited to:

- location
- size and configuration of structure
- type and purpose or use of structure
- other facilities or structures in the area.

Any factor that changes subsequent to the preparation of this report may affect its applicability. A specialised review of the impact of changes would be necessary. Fugro is not responsible for conditions which develop after any factor in site investigation programming or report development changes.

For purposes or parties other than the original project or Client, the report may not be adequate and should not be used.

CHANGES IN SUBSURFACE CONDITIONS AFFECT THE ACCURACY / SUITABILITY OF THE DATA

Ground is complex and can be changed by natural phenomena such as earthquakes, floods, seabed scour and groundwater fluctuations. Construction operations at or near the site can also change ground conditions. This report considers conditions at the time of investigation. Construction decisions must consider any changes in site conditions, regulatory provisions, technology or economic conditions subsequent to the investigation. In general, two years after the report date, the information may be considered inaccurate or unreliable. A specialist should be consulted regarding the adequacy of this geotechnical report for use after any passage of time.

APPENDIX 1: DESCRIPTIONS OF METHODS AND PRACTICES

CONTENTS Reference

This appendix presents method statements and terminology that are generally familiar to expert users of the information.

INTRODUCTION

Fugro employs a range of industry-standard classification systems with additional refinements. The more important systems are:

- British Standard 5930 (BS, specifically Section 6 Paragraphs 41 to 43 on Description of soils) published in 1999.
- American Society for Testing and Materials (ASTM) Standards D 2487-11 (Classification of soils for Engineering Purposes) and D 2488-09a (Description and Identification of Soils – Visual-Manual Procedure).
- International Standard ISO 14688-1:2002 (Geotechnical Investigation and Testing - Identification and Classification of Soil: Identification and Description) and International Standard ISO 14688-2:2004 (Principles for a Classification).

The standards are similar, as they are (1) based on the Unified Classification System (Casagrande, 1948), (2) rely on a range of relatively simple visual and manual observations and (3) classify soils according to particle-size distribution and plasticity. Laboratory particle-size distribution and Atterberg limits tests are used to confirm the observations. In addition, the standards include organic soils characterization under soil particle type description.

Significant differences between the standards include the particle-size boundaries and the degree to which plasticity is used as a basis for description. Other differences include the format and order of the soil description.

This document describes a classification convention that is consistent with either the BS or ASTM standard, and that produces soil descriptions, which can be converted to the other standard. In addition, to describe calcareous soils, Fugro has integrated the carbonate classification system outlined by Clark and Walker (1977) with both British Standard and ASTM systems (Landva et al., 2007). No further information is given about the ISO standards.

British Standard and ASTM systems apply primarily to common terrestrial soils in temperate climates. However, construction activities in coastal areas and offshore can also encounter major carbonate soil deposits. The engineering characteristics of carbonate soil deposits can differ substantially from those of silica-based soil deposits, primarily because of cementation and differences in void ratios (Kolk, 2000).

Appropriate description is necessary. A commonly accepted procedure for calcareous soil deposits is the Clark and walker system, originally developed for the Middle East. This considers particle size, carbonate content and material strength. The particle size classification fits both BS and ASTM system. The carbonate content is an additional feature and the material strength classification relates to common post-depositional alteration of calcareous soil.

This document does not include rock description or specific engineering geological classification systems, such as those for the detailed identification of peat, chalk or micaceous sand.

The main steps of the soil description system are:

1. Measure or estimate particle type as silica-based, organic, or calcareous.
2. For soils that are predominantly silica-based and organic, select BS 5930:1999 or ASTM D 2487 based on local geotechnical practice or project requirements, and follow the appropriate descriptive procedure. For calcareous soils, use the process described by Peuchen et al. (1999).
3. Measure or estimate the particle-size distribution and Atterberg limits (plasticity) for use in defining the principal and secondary soil fractions.
4. Measure or estimate soil strength according to one of the following: (1) relative density of coarse-grained soil, (2) consistency of fine-grained soil, (3) cementation of cemented soil, or (4) lithification of soil undergoing diagenesis.
5. Complete the description using the additional terms for the soil mass characteristics and other features such as bedding, colour, and particle shape.

CALCAREOUS SOIL DESCRIPTION

The procedure considers particle size, carbonate content and material strength. The particle-size classification follows the Unified Soil Classification System. The carbonate content is an additional feature and the material strength classification relates to common post-depositional alteration of calcareous soil.

PARTICLE TYPE

The first determinant for soil description is particle type using Table 1. It mainly differentiates between silica and carbonate soil compositions with organic content of less than 1% of the dry weight. Organic soils are further described in the soil description procedures for BS and ASTM (Table 4).

TABLE 1 - PARTICLE TYPE

Clay soil	Other Soils	Carbonate Content (by dry weight)	Reaction with HCl (10%)
--	Silica	< 10 %	In clays: no bubbles, or slowly forming bubbles. In sands: reaction often limited to some individual particles, or particle surface Residue - Nearly all soil remaining
Calcareou s	Calcareous silica	10 to 50	In clays: clearly visible, prolonged reaction and foaming. In sand: violent reaction Residue - Large part of soil remaining
Carbonate	Siliceous carbonate	50 to 90	Violent reaction Residue - Only small part of soil remaining
Carbonate	Carbonate	> 90	Violent reaction Residue - Hardly any soil remaining

The description method does not distinguish between types of carbonate material, and assumes that non-carbonate particles are siliceous.

CEMENTATION AND LITHIFICATION

Cementation is the process by which a binding material precipitates in the voids between the grains or minerals. Lithification is the process by which a soil is hardened due to pressure solution and transformation or new grain or mineral growth. Both processes contribute to the formation of rock.

The descriptions for cementation follow the equivalent rock strength classification in Table 2:

TABLE 2 - CEMENTATION

Cementation	Equivalent Rock Strength	
	Description	Uniaxial Compressive Strength σ_c [MPa]
Slightly cemented	very weak	0.3 to 1.25
Moderately cemented	Weak	1.25 to 5.0
Well cemented	Moderately weak	5.0 to 12.5

The term "well cemented" in Table 2 applies to soil, which also shows sublayers with little or no cementation. In case of further lithification, the soil description becomes a rock description using Table 3. The rock strength is only indicative.

TABLE 3 - LITHIFICATION

Carbonate content [%]	Dominant fraction						σ_c [MPa]
	Clay	Silt	Sand	Gravel	Cobbles	Boulders	
incomplete lithification							
< 10	CLAYSTONE	SILTSTONE	SANDSTONE	CONGLOMERATE	CONGLOMERATE or BRECCIA		0.3 to 12.5
10 to 50	Calcareous CLAYSTONE	Calcareous SILTSTONE	Calcareous SANDSTONE	Calcareous CONGLOMERATE			
50 to 90	Clayey CALCILUTITE	Siliceous CALCISILTITE	Siliceous CALCARENITE	Conglomeratic CALCIRUDITE			
> 90	CALCILUTITE	CALCISILTITE	CALCARENITE	CALCIRUDITE			
complete lithification							
< 50	CLAYSTONE	SILTSTONE	SANDSTONE	GRAVEL CONGLOMERATE	CONGLOMERATE or BRECCIA		>12.5
> 50	Fine-grained Argillaceous LIMESTONE	Fine-grained Siliceous LIMESTONE	Medium grained LIMESTONE	Conglomeratic LIMESTONE			

The Clark and Walker system does not include reef limestone (biolithite). **Reef limestone** represents an in-situ accumulation of biological origin (e.g. coral reef) and consists largely of carbonate skeletal material of colonising organisms. The carbonate content normally exceeds 90%. Classification of strength follows rock description procedures.

SOIL DESCRIPTION USING BS 5930:1999

In the following sections, each of the main characteristics is described in the order most commonly used for soil identification, with some portions of the text quoted (shown within quotation marks) or paraphrased from the BS 5930.

SOIL GROUP (BS)

The soil group subdivides the soils into very coarse, coarse, fine, and organic soils.

Very coarse soils consist of cobbles and boulders, with particles larger than 60 mm in diameter. These soil particles are rarely sampled using standard soil sampling techniques. They are described separately, and not included when determining the proportions of the other soil components.

The initial classification of silica soils as coarse or fine is based on the percentage of fine particles after the very coarse particles are removed. In BS 5930, the boundary between coarse (i.e. sands and gravels) and fines (i.e. silts and clays) is 0.060 mm (60 µm). When the soil contains approximately 35% or more fines, it is described as a fine soil; further classification of the fine soil as a clay or silt depends on the plasticity of the soil. When the soil contains less than about 35% fine material, it is usually described as a coarse soil. “The boundary between fine and coarse soils is approximate, as it depends on the plasticity of the fine fraction and the grading of the coarse fraction.”

Organic soils contain usually small quantities of dispersed organic matter that can have a significant effect on soil plasticity. Organic soil descriptions in BS 5930 are based on an organic content by weight determined by loss on ignition. Where organic matter is present as a secondary constituent, the following terms are used:

TABLE 4 - ORGANIC SOIL DESCRIPTIONS

Term	Organic content [% by weight]	Typical colour
Slightly organic clay or silt Slightly organic sand	2 to 5 1 to 3	Grey Same as mineral
Organic clay or silt Organic sand	5 to 10 3 to 5	Dark grey Dark grey
Very organic clay or silt Very organic sand	> 10 > 5	Black Black

Soils with organic contents up to approximately 30% by weight and water contents up to about 250% behave as mineral soils and are described using the terms given in the lower portion of Table 4.

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Peat consists predominantly of plant remains, is usually dark brown or black, and has a distinctive smell. It is generally classified according to the degree of decomposition (fibrous, pseudo-fibrous, or amorphous) and strength (firm, spongy, or plastic). When encountered, reference can also be made to the classification given in ASTM Standard Procedure D 4427.

PRINCIPAL SOIL TYPE AND PARTICLE SIZE (BS)

Coarse-Grained Soils

The principal soil type in coarse-grained soils is sand if the dry weight of the sand fraction (0.06 mm to 2 mm particle sizes) exceeds that of the gravel fraction (2 mm to 60 mm particle sizes), and vice versa for gravel.

As an addition to the BS 5930 classification, coarse-grained soils are described as well-graded or poorly-graded based on the grain-size distribution curve, using the coefficient of uniformity (C_U) and, to a lesser extent, the coefficient of curvature (C_C), as follows:

– Sands with ≤12% fines are well-graded when $C_U \geq 6$ and C_C is between 1 and 3.
– Sands are poorly-graded for other values of C_U and C_C.
– Gravels with ≤12% fines are well-graded when $C_U \geq 4$ and C_C is between 1 and 3.
– Gravels are poorly-graded for other values of C_U and C_C.

For coarse-grained soils with fines contents > 12%, these terms are not used.

Sands and gravels are sub-divided into coarse, medium, and fine, as defined in Table 5.

TABLE 5 - SIZE FRACTION DESCRIPTIONS FOR COARSE-GRAINED SOILS

Soil	Particle diameter range [mm]		
	Coarse	Medium	Fine
Gravel	60 to 20	20 to 6	6 to 2
Sand	2 to 0.6	0.6 to 0.2	0.2 to 0.06

Fine-Grained Soils

Fine-grained soils are classified as clay or silt according to the results of Atterberg limits tests. A fine-grained soil is classified as clay if:

$$I_P \geq 6 \text{ and } I_P \geq 0.73(w_L\text{-}20)$$

where:
I_P = plasticity index [%]
w_L = liquid limit [%]

Otherwise the dominant soil fraction is silt. The equation $I_P = 0.73(w_L-20)$ represents the "A-line" in a plasticity chart. The plasticity chart may also show a “U-line” defined as $I_P = 0.9\,(w_L-8)$ and $w_L \geq 16$, according to Casagrande (1948). The U-line represents an approximate upper limit of correlation between plasticity index and liquid limit for natural soils.

The following additional descriptors (as used in the ASTM soil description procedure) are added:

– Clays with liquid limits of 50% or higher are described as “fat.”
– Clays with liquid limits below 50% are described as “lean.”
– Silts with liquid limits of 50% or higher are termed “elastic silt.”
– Silts with liquid limits below 50% are simply “silts.”

The term “silty clay” is not used, since BS 5930 explicitly states that silt and clay “are to be mutually exclusive.”

Particle Shape

The description of particle shape includes terms for form, angularity, and surface texture. These terms are the same for BS 5930 as for ASTM D 2488. Reference should be made to the corresponding ASTM section of this document.

COMPOSITE (SECONDARY) SOIL TYPES (BS)

BS 5930 defines procedures for assigning secondary soil fractions to coarse-grained soils that are identical for sand and gravel, except that the secondary soil type is sandy when the principal soil type is gravel and vice versa. For fine-grained soils (silt and clay) there is a single procedure for assigning secondary soil fractions. The ranges for the percentages of the secondary constituents are similar to, though different from, those defined by ASTM.

If the principal soil type is sand, secondary soil fractions may be gravelly and silty or clayey (e.g. silty sand). Similarly, if the principal soil type is clay, secondary soil fractions may be sandy or gravelly. Table 6 (from BS 5930) gives the terms to be used for ranges of secondary constituents.

TABLE 6 - DESCRIPTIVE TERMS AND RANGES FOR SECONDARY CONSTITUENTS

Term	Principal soil type	Approximate proportion of secondary constituent	
		Coarse soil	Fine soil
Slightly clayey or silty	SAND and/or GRAVEL		< 5%
Clayey or silty			5% to 20%
Very clayey or silty			> 20% (1)
Slightly sandy or gravelly		< 5%	
Sandy or gravelly		5% to 20%	
Very sandy or gravelly		> 20%	
Slightly sandy and/or gravelly	SILT or CLAY	< 35%	
Sandy and/or gravelly		35% to 65%	
Very sandy and/or gravelly		> 65% (2)	

Notes: (1) or can be described as fine soil depending on engineering behaviour
(2) or can be described as coarse soil depending on engineering behaviour.

COLOUR (BS)

Soil colours are described using the Munsell Soil Colour Charts (Gretag-Macbeth, 2000).

The Munsell colour is arranged according to three variables known as Hue, Value and Chroma. The Hue notation of a colour indicates its relation to red, yellow, green, blue and purple. The Value notation indicates the relative lightness. The Chroma notation indicates the intensity of the colour.

BEDDING/STRATIGRAPHY (BS)

Layers of different soil types within a stratum are called bedding units, and are described in terms of the unit thickness. In an otherwise homogeneous soil, these can be identified as bedding planes or as colour changes, and not necessarily as discontinuities.

Table 7 (from BS 5930) gives terms for bedding/stratigraphy.

TABLE 7 - DESCRIPTIVE TERMS FOR BEDDING/STRATIGRAPHY

Stratified	Bedding	Interbedded	Thickness [mm]
Very thick beds	Very thick bedded	Very thickly interbedded	>2000
Thick beds	Thickly bedded	Thickly interbedded	600 to 2000
Medium beds	Medium bedded	Medium interbedded	200 to 600
Thin beds	Thinly bedded	Thinly interbedded	60 to 200
Very thin beds	Very thinly bedded	Very thinly interbedded	20 to 60
Thick laminae	Thickly laminated	Thickly interlaminated	6 to 20
Thin laminae	Thinly laminated	Thinly interlaminated	<6

Strata with alternating or different beds or laminations can be described as interbedded or interlaminated. Where the soil types are approximately equal, both terms can be used (e.g. thinly interlaminated SAND and CLAY).

Partings are bedding surfaces that separate easily, and typically are laminae of no appreciable thickness. The spacing between partings is described in the same terms as for spacing of discontinuities (Table 8).

DISCONTINUITIES/STRUCTURE (BS)

Discontinuities include fissures and shear planes, and the descriptor refers to the mean spacing between such discontinuities in a soil mass. A soil is “fissured” when it breaks into blocks along unpolished discontinuities, and “sheared” when it breaks into blocks along polished discontinuities (which is equivalent to a slickensided soil). The spacing description ranges from extremely closely spaced (less than 20 mm) to very widely spaced (over 2000 mm). No other descriptive terms are used. An example would be: Firm grey very closely fissured fine sandy calcareous CLAY with many silt partings.

The spacing terms are also used for distances between partings, isolated beds or laminae, desiccation cracks, rootlets, etc.

TABLE 8 - SPACING OF DISCONTINUITIES

Term	**Mean spacing range [mm]**
Very widely	Over 2000
Widely	600 to 2000
Medium	200 to 600
Closely	60 to 200
Very closely	20 to 60
Extremely closely	Under 20

DENSITY/COMPACTNESS OF GRANULAR SOILS (BS)

Usually, soil description offers little evidence about the density condition of coarse-grained cohesionless (granular) soil samples. The reason for this is the substantial sampling disturbance incurred during conventional sampling operations such as push sampling, percussion sampling, and vibrocoring. Complementary investigation techniques, such as Cone Penetration Tests (CPT), are usually necessary. The strength of a cohesionless soil is normally measured as a function of its relative density (also termed compactness or density index). Relative density is the ratio of the difference between the void ratios of a cohesionless soil in its loosest state and existing natural state to the difference between its void ratio in the loosest and densest states.

Relative density (compactness) is referred to in BS 5930:1999 only in terms of N-values obtained by the Standard Penetration Test (which is not conducted in offshore site investigations). Rather than using SPT-based values, it is common practice to interpret relative density on the basis of CPT results. Ranges of relative density are given in Table 9. These ranges are in common use in the industry. They were originally given in Lambe and Whitman (1979) and in the API RP 2A guidelines generally used for offshore pile design. These terms also apply to cohesionless fine-grained soils.

TABLE 9- RANGE OF RELATIVE DENSITY OF GRANULAR SOILS

Term	**Range of relative density [%]**
Very loose	Less than 15
Loose	15 to 35
Medium dense	35 to 65
Dense	65 to 85
Very dense	Greater than 85

STRENGTH OF COHESIVE SOILS (BS)

The strength of cohesive soils is given in terms of undrained shear strength, using the terms and ranges given in Table 10, with an additional level to cover “very hard” soils.

TABLE 10 - UNDRAINED SHEAR STRENGTH SCALE FOR COHESIVE SOILS (BS 5930:1999)

Term	**Undrained shear strength**	
	[kPa]	**[ksf] (1)**
Very soft	Less than 20	Less than 0.4
Soft	20 to 40	0.4 to 0.8
Firm	40 to 75	0.8 to 1.5
Stiff	75 to 150	1.5 to 3.0
Very stiff	150 to 300	3.0 to 6.0
Hard	300 to 600	6.0 to 12.0
Very hard (2)	Greater than 600	Greater than 12.0

Notes: (1) Unit conversion added to table
(2) Added for global practice.

MINOR CONSTITUENTS (BS)

Percentages of minor constituents within the soil, such as shell or wood fragments, or small soil inclusions (such as partings or pockets), can be quantified using the terms “with trace”, “with few”, “with” and “with many” (in increasing order). These terms are usually added at the end of the main soil description (e.g. with many shell fragments, with silt pockets, etc.); exceptions are terms such as “shelly”, which are more appropriate before the soil group name. For beds of material within a soil matrix, the terminology for spacing and thickness of beds is used. For individual particles of soil or material within a soil matrix, the terms “partings” and “pockets” are used.

SOIL ODOUR (BS)

Describing the odour from soil samples as they are retrieved or extruded on board ship can be useful. Terms used to describe the odour are H_2S, “musty”, “putrid” and “chemical”. It must be emphasised that soil odour descriptions are unlikely to be fully consistent, because of factors such as variations in sample handling, ambient conditions at time of sample description, and strong dependence on a person’s ability to detect and identify odour.

SOIL DESCRIPTION USING ASTM D 2487 AND D 2488

The identification and description of silica soils in the ASTM system consists primarily of a group name and symbol, which are based on the particle-size distribution and the Atterberg limits test results, and the results of other laboratory classification tests.

The main standard for soil description, D 2487 Classification of Soils for Engineering Purposes, is applicable to naturally-occurring soils passing a 3-in. (75-mm) sieve, and identifies three major soil types: coarse-grained, fine-grained, and highly organic soils. The major soil types are further subdivided into 15 specific basic soil groups.

An accompanying Standard, D 2488, outlines the Description and Identification of Soils using a Visual-Manual Procedure. This standard is used primarily in the field, where full particle-size distribution curves and Atterberg limits values are not available. It gives guidance for detailed descriptions of soil particles and soil conditions (e.g. colour, structure, strength, cementation, etc), which are not included in D 2487.

Soil types with particles larger than 75 mm (i.e. cobbles and boulders) are not included in the Standards, but are identified.

SOIL TYPES (ASTM)

The initial classification of silica soils as coarse-grained or fine-grained is based on the percentage fines, expressed as the percentage of dry weight of the total sample after the very coarse particles are removed, as with BS 5930. However, ASTM has defined the coarse-fine boundary as 0.075 mm (75 µm).

The soil is coarse-grained (sand or gravel) if the percentage fines is 50% or less. Otherwise, the soil is fine-grained (silt or clay) – the classification is not based on plasticity.

Coarse-grained soils are classified further as either sand or gravel using the results of particle-size distribution tests.

Fine-grained soils are classified further as silt or clay on the basis of the liquid limit and plasticity index (from Atterberg limits tests).

The soil is an organic soil if it contains sufficient quantities of dispersed organic matter that it has an influence on the liquid limits of the fines component after oven-drying, as outlined in the BS Section. The definition of peat is similar to that in BS 5930 and it is generally classified according to the degree of decomposition and strength. When encountered, reference should be made to the classification given in ASTM D 4427.

SOIL GROUP NAME AND SYMBOL (ASTM)

Coarse-Grained Soils

For coarse-grained soils, the dominant soil fraction is sand if the dry weight of the sand fraction, i.e. particle sizes from 0.075 mm to 4.75 mm, exceeds that of the gravel fraction, i.e. particles ranging from 4.75 mm to 75 mm, and vice versa for gravel.

Coarse-grained soils with ≤12% fines are also described as well-graded or poorly-graded based on the particle-size distribution curve, using the coefficient of uniformity (C_U) and, to a lesser extent, the coefficient of curvature (C_C) as follows:

- Sands are well-graded when $C_U \geq 6$ and C_C is between 1 and 3.
- Sands are poorly-graded for other values of C_U and C_C.
- Gravels are well-graded when $C_U \geq 4$ and C_C is between 1 and 3.
- Gravels are poorly-graded for other values of C_U and C_C.

For coarse-grained soils with fines contents >12%, these terms are not used.

Sands and gravels are also sub-divided into coarse, medium, and fine, as defined in Table 11.

TABLE 11 - SIZE FRACTION DESCRIPTIONS FOR COARSE-GRAINED SOILS

Soil	Particle diameter range [mm]		
	Coarse	Medium	Fine
Gravel	75 to 19	-	19 to 4.75
Sand	4.75 to 2.0	2.0 to 0.425	0.425 to 0.075

The predominant size fractions present are identified, and the absence of size range descriptors means that fine, medium, and coarse fractions are all present in roughly equal proportions.

Fine-Grained Soils

Fine-grained soils are classified as clay or silt according to the results of Atterberg limits tests. A soil is inorganic clay if: $I_P \geq 6$ and $I_P \geq 0.73(w_L-20)$

where:
I_P = plasticity index [%]
w_L = liquid limit [%]

The A-line and U-line in a plasticity chart are as described in the BS section.

Clays with liquid limit $w_L < 50$ and plasticity index $I_P > 7$ are further classified as lean clay, and given the group symbol “CL”. Clays with liquid limits $w_L \geq 50$ are further classified as fat clay, and are given the group symbol “CH”.

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A soil is classified as a silt when it plots below the A-line or the plasticity index $I_P < 4$. Silts with liquid limit $w_L < 50$ are given the group symbol "ML". Silts with liquid limits $w_L \geq 50$ are further classified as elastic silt, and are given the group symbol "MH".

Soils are classified as silty clay where the liquid limit versus plasticity index plots on or above the A-line but where the plasticity index falls within the range $4 \leq I_P \leq 7$, i.e. the hatched zone in the lower left-hand corner of the plasticity chart. Silty clays are given the Group Symbol "CL-ML".

Organic Soils

For both clay and silt, or the fines component of a coarse-grained soil, the additional term organic applies if the ratio of the liquid limit of a sample (or the fines portion of the sample) after oven drying at 105° C to the liquid limit without oven drying is less than 0.75.

Organic soils are classified in a manner similar to that for inorganic soils for plots of the liquid limit (not oven dried) versus plasticity index with respect to the A-line. Organic clays and silts with liquid limit $w_L < 50$ are given the same group symbol "OL". Organic clays and silts with liquid limits $w_L \geq 50$ are given the group symbol "OH".

Coarse-grained soils containing fine organic material are described using the term "with organic fines".

SECONDARY SOIL TYPE (ASTM)

Secondary soil type descriptions follow the ranges given in Table 12. No other terms are used, though combinations of these terms are.

TABLE 12 - DESCRIPTIVE TERMS AND RANGES FOR SECONDARY CONSTITUENTS

Term	Principal soil type	Term	Approximate proportion of secondary constituent	
			Coarse soil	Fine soil
	SAND and/or GRAVEL(1)			< 5%
	SAND and/or GRAVEL(1)	with clay or silt		5% to 12%
Clayey or Silty	SAND and/or GRAVEL(1)			> 12%
	SAND and/or GRAVEL(1)		<15% gravel or sand	
	SAND and/or GRAVEL(1)	with gravel or sand	≥15% gravel or sand	
	SILT or CLAY		< 15%	
	SILT or CLAY	with sand or gravel(1)	15% to 29%	
Sandy and/or gravelly(1)	SILT or CLAY		≥30%	

Note: (1) choice depends on which has higher percentage.

PARTICLE SHAPE (ASTM)

The description of particle shape includes references to form, angularity, and surface texture. These terms are normally used only for gravels, cobbles, and boulders, though in some cases for coarse sands.

The form (or shape) of coarse particles is described as flat, elongated, or both.

Flat: Width/Thickness > 3
Elongated: Length/Width > 3
Flat and elongated meets both criteria. These terms are not used if the criteria are not strictly met.

Angularity terms are usually only applied to particles gravel-size and larger (Table 13, from ASTM D 2488).

TABLE 13 - ANGULARITY OF COARSE-GRAINED PARTICLES

Term	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

The surface texture of coarse particles are described as rough or smooth.

COLOUR (ASTM)

As noted for BS 5930 (BS section), soil colours are described using the Munsell Soil Colour Charts (Gretag-Macbeth, 2000).

SOIL ODOUR (ASTM)

The same descriptive terms suggested for BS 5930 (BS Section) are used with the ASTM Standards. It must be emphasised that soil odour descriptions are unlikely to be fully consistent, because of factors such as variations in sample handling, ambient conditions at time of sample description, and strong dependence on a person's ability to detect and identify odour.

STRENGTH OF COHESIVE SOILS (ASTM)

Descriptions of cohesive soil strength are not part of the ASTM classification system; however soil strength is incorporated whenever available from laboratory or in situ test results and interpretation. The boundaries for undrained shear strength ranges in current use in North American practice are given in Table 14. These boundaries are lower than those used with BS 5930.

TABLE 14 - UNDRAINED SHEAR STRENGTH SCALE FOR COHESIVE SOILS (1)

Term	**Undrained shear strength**	
	[kPa]	**[ksf] (2)**
Very soft	Less than 12.5	Less than 0.25
Soft	12.5 to 25	0.25 to 0.50
Firm	25 to 50	0.50 to 1.0
Stiff	50 to 100	1.0 to 2.0
Very stiff	100 to 200	2.0 to 4.0
Hard	200 to 400	4.0 to 8.0
Very hard (3)	Greater than 400	Greater than 8.0

Notes: 1) from Terzaghi and Peck (1967)
2) ksf used primarily for US projects
3) the upper boundary for "Hard", and the "Very hard" range have been added.

DENSITY/COMPACTNESS OF GRANULAR SOILS (ASTM)

Tables of recommended values and descriptors for relative density are not provided in the ASTM Standards, but in practice relative density is often interpreted on the basis of cone penetration test results. The same ranges of relative density (compactness) as those recommended for use with BS 5930 (see BS Section) are used.

DISCONTINUITIES/STRUCTURE (ASTM)

Criteria for describing soil structure are provided in ASTM D 2488, and in Table 15 along with additional terms in use in the geotechnical industry.

TABLE 15 - DESCRIPTIVE TERMS FOR SOIL STRUCTURE

Term	**Description**
Slickensided	Fracture or shear planes (or planes of weakness) that appears slick and glossy.
Fissured	Cohesive soil that breaks into blocks along unpolished planes (discontinuities), often filled with a different material. The fill material is noted.
Blocky	Cohesive soil that breaks into small angular lumps along polished planes (discontinuities) which resist further breakdown.
Gassy	Soil has a porous nature and there is evidence of gas, such as blisters.
Expansive	Visibly expands after sampling. Degree of expansion is estimated and noted.
Platy	A stratified appearance when the soil can be broken into thin horizontal plates.
Cemented	Material grains bound together forming an intact mass.

The distance between the fissures, shear planes, and expansion cracks is noted using the terms in Table 8.

BEDDING/STRATIGRAPHY (ASTM)

The terminology for bedding thickness and stratigraphic description used in North American offshore practice is more detailed than outlined in ASTM D 2488, and is different from BS 5930. In Table 16, the descriptive terms have been further defined and integrated with BS 5930 terminology.

TABLE 16 - DESCRIPTIVE TERMS FOR BEDDING THICKNESS AND INCLUSIONS

Term	Bedding thickness	
	[mm]	[inch]
Pocket	Inclusion of material of different texture that is smaller than the diameter of the sample	
Parting	< 3	1/8
Lamina	3 to < 6	1/8 to < 0.25
Laminated(1)	Alternating partings or laminae of different soil types in equal proportion	
Lens	6 to < 20	0.25 to < 0.75
Seam	20 to < 76	0.75 to < 3
Layer	Greater than 76	Greater than 3
Stratified(2)	Alternating lenses, seams or layers of different soil types in equal proportion	
Intermixed	Soil sample composed of pockets of different soil types, and laminated or stratified structure is not evident	

Notes: (1) Equivalent to “Interlaminated” term used in BS 5930:1999
(2) Equivalent to “Interbedded” term used in BS 5930:1999.

MINOR CONSTITUENTS (ASTM)

Minor constituents within a soil, such as shell or wood fragments, or small quantities of soil particles (not secondary soil types), are typically more relevant to the site geology or to laboratory testing procedures than to soil behaviour. Since the terms and percentages are not defined in either BS 5930 or ASTM D 2487/8, the terms “with trace”, “with few”, “with”, “with many” are used as a guide.

WRITTEN SOIL DESCRIPTIONS

Although soils are classified in the order of the characteristics described in the preceding sections, written descriptions are given in a different order in both Standards. To bring as much consistency as possible to the soil descriptions, Fugro selected a single preferred order of terms, which most closely resembled the majority of the descriptions used in Fugro offices around the world.

In this description, the principal soil type is given last as the soil name, with most other terms written as adjectives. The principal soil type is given in upper-case.

The preferred order of terms for a soil description are:
1. Density/compactness/strength.
2. Discontinuities.
3. Bedding.
4. Colour.
5. Secondary (composite) soil types.
6. Particle shape.
7. Particle size.
8. PRINCIPAL SOIL TYPE.

with:
9. Minor constituents (can be inserted in front of the principal soil type, such as “shelly”).
10. Soil odour.

For example: Firm closely-fissured dark olive grey sandy calcareous CLAY with few silt pockets. Where used, the Group Symbol is part of the soil description, e.g. loose poorly-graded fine to medium SAND with silt (SP-SM).

PARTICULATE DEPOSITS

The geological origin of a single particle type allows the following descriptions (optional):

Clastic: sediment transported and deposited as grains of inorganic origin. Typical clastic particles are:

- quartz grains: clear or milky white and ranging from very angular to very rounded; commonly a frosted surface for wind-blown grains
- feldspar grains: varying in colour from milky white to light yellowish brown
- mica flakes: varying in colour from gold-coloured to dark brown
- dark mineral grains: usually of igneous or metamorphic origin with undetermined mineralogy
- silicate grains: undetermined mineralogy
- rock fragments: including fragments of carbonate rock
- debris: deposit of rock fragments of a variety of particle sizes which may include sand and finer fractions; typical examples are rock debris and coral debris

Organic: remains of plants and animals that consists mainly of carbon compounds

Bioclastic: sediment transported and deposited as grains of organic origin. Examples of bioclastic particles are:

- Calcareous algae: crustal or nodular growths or erect and branching forms produced by lime-secreting algae; microstructures include layered, rectangular structures and internal fine tube-like structures.
- Foraminifera: hard sediment test (external skeleton) consisting of calcite or aragonite and produced by unicellular organisms; commonly less than 1 mm in diameter, multi-chambered and intact.
- Sponge spicules: spicules of siliceous sponges in a variety of rayed shapes; dimensions ranging from less than 1 mm to over 1 cm in length but usually less than 1 mm in width.
- Corals: commonly consisting of small fibres set perpendicular to the walls and septal surfaces; mainly aragonite composition for relatively recent forms; conversion of aragonite to calcite for earlier corals, usually with consequent loss of original structural details.
- Echinoids: hard part of echinoids consisting of a plate or skeletal element forming a single crystal of calcite; five-rayed internal symmetry for spines of echinoids; typical widths ranging from several mm to a few cm.
- Bryozoans: chambered cell-like structures that are considerably coarser than those of calcareous algae; either aragonite or calcite composition; possible cell in-fill consisting of clear calcite and/or micrite.
- Bivalves and Gastropods: Mollusk shells, chiefly of aragonite composition; inner layer of aragonite protected by an outer layer of calcite for some bivalve shells and gastropods.

Oolitic: sediment consisting of solid, round or oval, highly polished and smooth coated grains, which may or may not have a nucleus. The coating consists of chemically precipitated aragonite, possibly converted to calcite. Ooliths have concentric structures and may also have radial structures. The grains are generally less than 2 mm diameter.

Pelletal: sediment consisting of well rounded grains of ellipsoidal shape and no specific internal structure. The composition is clay to silt-sized carbonate material, which is probably the excretion product of sediment eating organisms. Pellets may have an oolitic crust. The grains are generally less than 2 mm diameter.

STRUCTURE OF NON PARTICULATE DEPOSITS

Reef: soil or rock formed by in-situ accumulation or build-up of carbonate material by colonial organisms such as polyps (coral), algae (algal mats or balls) and sponges.

Orthochemical: orthochemical components precipitated during or after deposition. These components can include: (1) pyrite spherulites and grains, (2) crystal euhedra of anhydride or gypsum, (3) replacement patches and nodular masses of anhydrite and gypsum. Single grains are rare.

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GEOLOGICAL INFORMATION

Specific geological terms can assist the geotechnical soil description by providing information on stratigraphy, origin (genesis) or regional significance (optional). Examples are:

- time stratigraphy, such as Eemian and Pleistocene,
- lithostratigraphy, such as Yarmouth Roads Formation
- depositional environment, such as Marine, Glacio-lacustrine and Residual Soil
- regional significance, such as Chalk and Mud.

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INTRODUCTION

This document presents a summary of interpretation methods for Cone Penetration Test (CPT) results. The project-specific selection of methods depends on the agreed project requirements. Some of the methods suit computer-based interpretation of CPT data records.

Interpretation of Cone Penetration Test results helps provide parameters for geotechnical models. Conventional models are typically based on plasticity theory for ultimate limit states, and on elasticity theory and consolidation theory for serviceability limit states. Features of these geotechnical models are:

- analysis of either drained (sand model) behaviour or undrained (clay model) behaviour for plasticity models
- analysis for the ultimate limit state differs from that for the serviceability limit state.

CPT interpretation methods are mostly based on empirical correlations with limited theoretical backing. Data integration with other, complementary investigation techniques (such as drilling, sampling and laboratory testing) improves confidence levels.

The interpretation techniques discussed below are subject to limitations such as:

- The majority of interpretation methods apply to "conventional" sands and clays. Conventional methods may not be appropriate for silts, sand/clay/gravel mixtures, varved or layered soils, gassy soils, underconsolidated soils, peats, carbonate soils, cemented soils and residual soils. These non-conventional soils warrant a more specific approach.
- Empirical correlations use reference parameters such as the undrained shear strength determined from a laboratory single-stage Isotropically Consolidated Undrained triaxial test (CIU) on an undisturbed specimen obtained by means of push sampling techniques (Van der Wal et al., 2010). The reference parameter may not be appropriate for the selected geotechnical model, and adjustment may be necessary. Also, adjustment for test conditions may be necessary, for example in situ temperature versus laboratory temperature.
- The cone penetration test offers limited direct information on serviceability limit states (deformation), as the penetration process imposes large strains in the surrounding soil. In comparison to ultimate limit states, better complementary data will usually be required.
- CPT interpretation techniques are often indirect. Usually, interpretation requires estimates of various other parameters. This is consistent with an integrated geotechnical investigation approach. Inevitably, this approach also includes some redundancy of data.
- Drained or undrained behaviour for the geotechnical analysis at hand may or may not coincide with respectively drained or undrained behaviour during fixed-rate penetration testing. This interpretation difficulty remains largely unresolved at this time.
- The interpretations apply to conditions as encountered at the time of the geotechnical investigation. Geological, environmental and construction/operational factors may alter as-found conditions.

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PENETRATION BEHAVIOUR

Soil behaviour during cone penetration testing shows large displacements in the immediate vicinity of the penetrometer, and small elastic displacements further away from the penetrometer. Density/structure, stiffness and in situ stress conditions significantly affect the measured parameters.

The measured cone resistance (q_c) includes hydrostatic water pressures as well as stress-induced pore pressures. The pore pressures are usually negligible for clean sand because the ratio of effective stress to pore pressure is high. This ratio is, however, low for penetration into clay. Knowledge of pore pressures around the penetrometer can thus be important. CPT parameters that take account of pore pressure effects include total cone resistance (q_t), net cone resistance (q_n) and pore pressure ratio (B_q). These parameters can be calculated if Piezo-cone Penetration Test (PCPT or CPTU) data are available. The influence of pore pressures on sleeve friction f_s is relatively small. It is common to ignore this influence. Calculation of friction ratio R_f (defined as f_s/q_c) includes no allowance for pore pressure effects.

The penetration rate with respect to soil permeability determines whether soil behaviour is primarily undrained, drained or partially drained. In general, soil behaviour during cone penetration testing is drained in clean sand (no measurable pore pressures as a consequence of soil displacements) and undrained in clay (significant pore pressure changes). Partially drained behaviour occurs in soils with intermediate permeability, such as sandy silt. The following sections mostly consider interpretation of drained soil behaviour (sand) and undrained soil behaviour (clay).

SOIL BEHAVIOUR IDENTIFICATION

Identification of soil stratigraphy in terms of general soil behaviour (and to a lesser degree soil type) is a more important feature of CPT than other investigation technique.

Figures 1 to 3 show soil behaviour identification according to procedures given by Robertson (2009) and Ramsey (2002). Robertson (2009) represents an update of Robertson (1990), by exchange of Q_t with Q_{tn}. The procedures consider a normalised soil behaviour classification that provides general guidance on likely soil type (silty sand for example) and a preliminary indication of parameters such as angle of internal friction φ', overconsolidation ratio (OCR) and clay sensitivity (S_t). The procedures require piezo-cone test data:

$$Q_{tn} = [(q_t - \sigma_{vo})/P_a]\,(P_a/\sigma'_{vo})^n \qquad Q_t = \frac{q_t - \sigma_{vo}}{\sigma'_{vo}} \qquad F_r \text{ or } nR_f = \frac{f_s}{q_t - \sigma_{vo}} 100\% \qquad B_q = \frac{u - u_0}{q_t - \sigma_{vo}}$$

where:

Q_{tn} = normalised cone resistance with variable stress exponent
Q_t = normalised cone resistance
q_t = corrected cone resistance
σ_{vo} = total in situ vertical stress
σ'_{vo} = effective in situ vertical stress
P_a = atmospheric pressure
n = stress exponent
f_s = measured sleeve friction
u = measured pore pressure
u_0 = theoretical hydrostatic pore pressure.

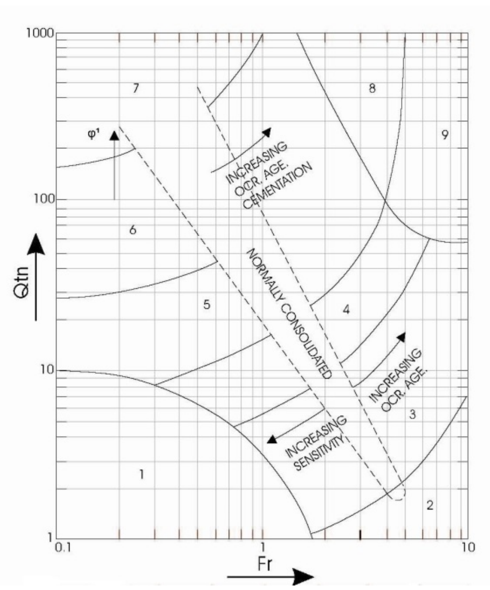
Zhang et al. (2002) defined stress exponent n as follows:

$$n = 0.381\,(I_c) + 0.05\,(\sigma'_{vo} / P_a) - 0.15 \text{ where } n \leq 1$$

Robertson and Wride (1998) defined soil behaviour type index I_c (Figure 3) as follows:

$$I_c = [(3.47 - \log Q_{tn})^2 + (\log F_r + 1.22)^2\,]^{0.5}$$

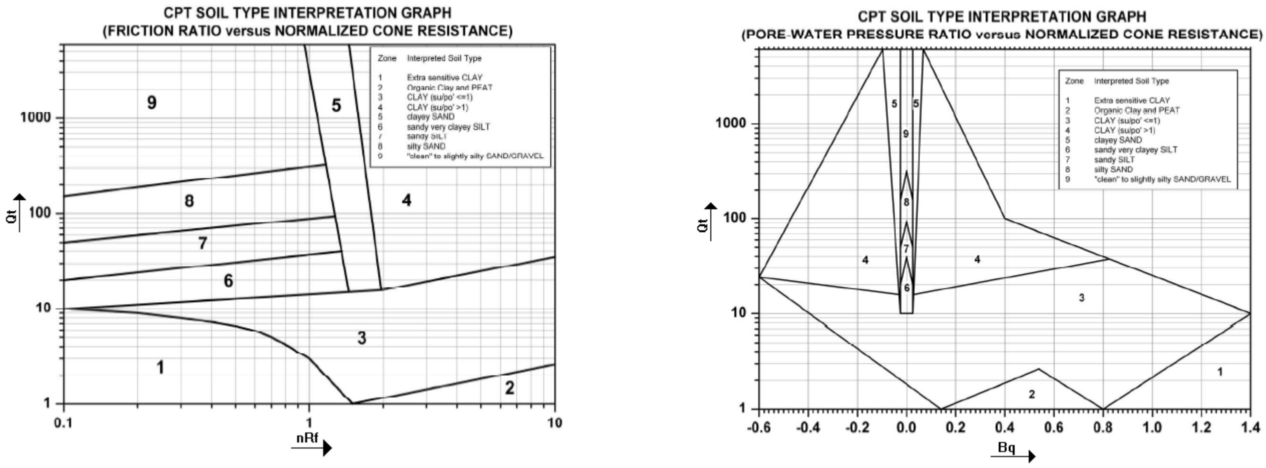
Soils with $I_c < 2.5$ are generally cohesionless, coarse grained, where cone penetration is generally drained and soils with $I_c > 2.7$ are generally cohesive, fine grained, where cone penetration is generally undrained (Robertson, 1990). Cone penetration in soils with $2.5 < I_c < 2.7$ is often partially drained.



1. Sensitive, fine grained
2. Organic soils - peats
3. Clays- clay to silty clay
4. Silt mixtures – clayey silt to silty clay
5. Sand mixtures – silty sand to sandy silt
6. Sands – clean sand to silty sand
7. Gravelly sand to sand
8. Very stiff sand to clayey sand*
9. Very stiff, fine grained*

(*) Heavily overconsolidated or cemented

Figure 1, Classification chart Robertson (2009)



1. Extra sensitive clay
2. Organic clay and peat
3. Clay (c_u/σ'_{vo} <= 1)
4. Clay (c_u/σ'_{vo} > 1)
5. Clayey sand
6. Sandy very clayey silt
7. Sandy silt
8. Silty sand
9. “Clean” sand/gravel

Figure 2, Classification charts Ramsey (2002)

Classification is only possible for certain combinations of Q_{tn}, Q_t , F_r, nR_f and B_q, as shown below.

Classification Limits	
Robertson	**Ramsey**
$1 \le Q_{tn} \le 1000$	$1 \le Q_t \le 6000$
$0.1 \le F_r \le 10$	$0.1 \le nR_f \le 10$
$-0.2 \le B_q \le 1.4$	$-0.6 \le B_q \le 1.4$

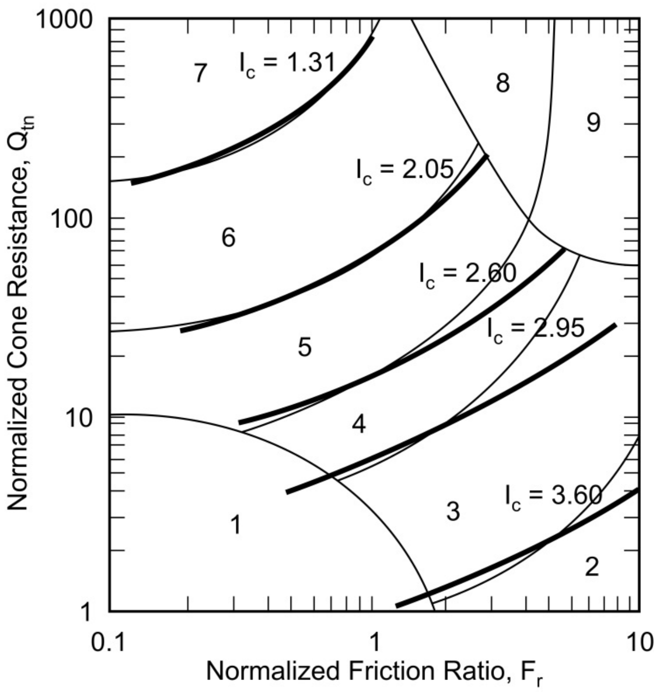


Figure 3, Soil behaviour type index I_c superimposed on Robertson (2009) classification chart

Figure 4 presents a classification chart for friction cone data according to Robertson (2010). This procedure requires no pore pressure input. A non-normalised soil behaviour type index, I_{SBT} applies:

$$I_{SBT} = [(3.47 - \log(q_c/P_a))^2 + (\log R_f + 1.22)^2]^{0.5}$$

I_{SBT} is similar to I_c. Values for I_{SBT} and I_c are typically comparable for effective in situ vertical stress between 50 kPa and 150 kPa.

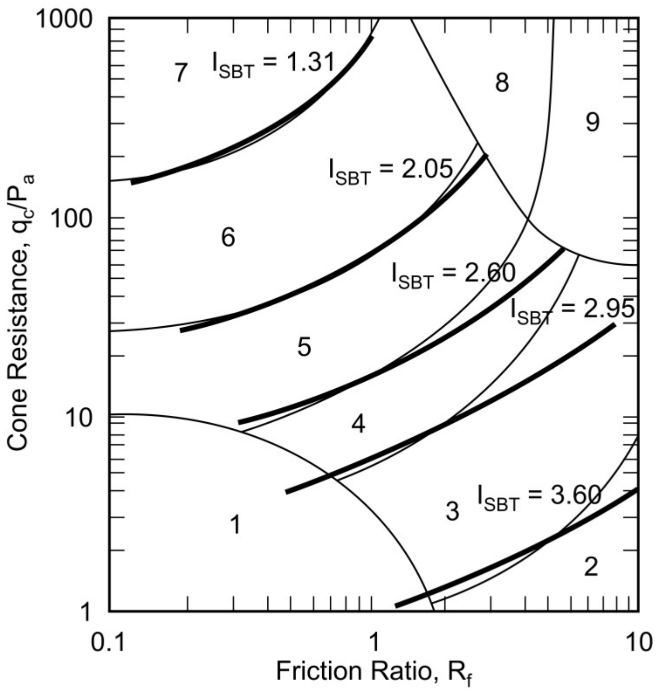


Figure 4, Robertson (2010) classification chart including I_{SBT}

SAND MODEL

Unit Weight – Sand

Unit weight of uncemented (silica) sand, silt and clay soils may be derived according to Mayne et al. (2010):

$$\gamma = 1.95\,\gamma_w \left(\frac{\sigma'_{vo}}{P_a}\right)^{0.06} \left(\frac{f_t}{P_a}\right)^{0.06}$$

where total unit weight γ and unit weight of water γ_w are in kN/m^3 and effective in situ vertical stress σ'_{vo} is in kPa. The symbol f_t refers to sleeve friction corrected for pore pressures acting on the end areas of the friction sleeve, with units in kPa. Atmospheric pressure P_a is in kPa.

In Situ Stress Conditions - Sand

A knowledge of in situ stress conditions is required for estimation of parameters such as relative density D_r and angle of internal friction of a sand deposit φ'. The effective in situ vertical stress σ'_{vo} may be calculated with a reasonable degree of accuracy but the effective in situ horizontal stress $\sigma'_{ho} = K_o\sigma'_{vo}$ is generally unknown. Usually, it is necessary to consider a range of conditions for K_o (coefficient of earth pressure at rest). The range considers overconsolidation as inferred from a geological assessment, pre-consolidation pressures of intermediate clay layers and/or theoretical limits of K_o.

Geological factors concerning overconsolidation include ice loading, soil loading and groundwater fluctuations. Possible subdivisions for these factors are mechanical, cyclic and ageing consolidation.

K_o may be directly correlated to Overconsolidation Ratio (OCR), as follows:

$$K_o = 0.4 \sqrt{(OCR)}$$

Mayne and Kulhawy (1982) investigated mechanical overconsolidation of reconstituted laboratory specimens for over 170 different soils. A K_0 OCR correlation requiring effective angle of internal friction as input was found to provide a reasonable match. It can be shown that the $K_o = 0.4 \sqrt{(OCR)}$ equation provides similar statistics to the Mayne and Kulhawy correlation.

No laboratory study can fully capture in situ behaviour. Particularly, K_o may be underestimated if effects such as ageing and cyclic loading are relevant.

In general, in situ K_o values are limited to the range $K_o = 0.5$ to $K_o = 1.5$. For many situations, K_o values are believed to be relatively low at greater depths (say $K_o < 1$ for depths exceeding 50 m). Jamiolkowski et al. (2003) recommend using a limiting value $K_o = 1$ in practice.

Relative Density - Sand

Procedures for estimation of in situ density condition (loose, dense, etc.) consist of:
(a) Estimation of in situ stress conditions σ'_{vo} and σ'_{ho}
(b) Empirical correlation of relative density D_r (or density condition) with q_c, σ'_{vo} and σ'_{ho}.

Estimation of stress conditions has been discussed above.

Common relationships between q_c and D_r are based on Cone Penetration Tests carried out in sand samples reconstituted in laboratory calibration chamber tests. Such tests are carried out as part of general geotechnical research projects and are subject to a number of limitations, such as:

- soil type dependence
- inaccuracies in determination of laboratory D_r
- limited range of stress levels and K_o values
- sample preparation and soil stress history simplifications.

Jamiolkowski et al. (2003) proposes the following relationship between q_c and D_r for normally and overconsolidated silica (dry) sands:

$$D_{r(dry)} = \frac{1}{2.96} \ln \left[\frac{\frac{q_c}{P_a}}{24.94 \left(\frac{\sigma'_{vo}\left(\frac{1+2K_o}{3}\right)}{P_a} \right)^{0.46}} \right]$$ and for saturated sands: $$D_{r(sat)} = \left(\frac{-1.87 + 2.32 \ln \frac{q_c}{(P_a * \sigma'_{v0})^{0.5}}}{100} + 1 \right) \frac{D_r(dry)}{100}$$

where relative density D_r is a fraction. The correlation for saturated sands results in relative densities that can be up to about 10% higher compared to the correlation for dry sands.

Determination of laboratory minimum and maximum index dry unit weights (γ_{dmin} and γ_{dmax}) forms the basis for the relative density concept (loose, dense sand, etc.). As yet, there is no internationally agreed procedure. Hence, laboratory test procedure dependence applies. Also, it is unlikely that any of the procedures consistently provide the "lowest" γ_{dmin} or the "highest" γ_{dmax}. In situ soil unit weights may therefore fall outside laboratory ranges. The relative density concept is necessary to provide a link between field investigations and laboratory testing on reconstituted specimens, as undisturbed sampling of sands is expensive.

Calibration chamber test results apply to a limited range of stress conditions only; typically:

$$50 \text{ kPa} < \sigma'_{vo} < 400 \text{ kPa}$$
$$0.4 < K_o < 1.5$$

Sample preparation for laboratory chamber tests is usually by means of dry pluviation. Soil stress history application is by mechanical overconsolidation.

Angle of Internal Friction - Sand

The effective shear strength parameter φ' is not a true constant. It depends on factors such as density, stress level, shearing mode and mineralogy. There is evidence that overconsolidation ratio, method of deposition and in situ stress anisotropy is less important.

Correlation of angle of internal friction φ' to cone resistance q_c may be done at various levels of sophistication. Simple procedures rely on a conservative assessment of soil behaviour classification. A more sophisticated empirical correlation consists of:
(a) Estimation of in situ stress conditions σ'_{vo} and σ'_{ho}
(b) Estimation of relative density D_r
(c) Empirical correlation of angle of internal friction φ' with D_r, σ'_{vo} and σ'_{ho}.

Estimation of stress conditions and relative density has been discussed above.

The empirical procedure proposed by Bolton (1986 and 1987) is used for estimation of φ'. This correlation applies to clean sands and considers peak secant angle of internal friction in Isotropically Consolidated Drained triaxial compression (CID) of reconstituted sand. This procedure requires estimation of the dilatancy index and the critical state angle of internal friction.

Kulhawy and Mayne (1990) determined an equation based upon 20 data sets obtained from calibration chamber tests. This equation is almost identical to the empirical formula determined earlier by Trofimenkov (1974) which was based on mechanical cone data. Mayne (2007) validated the use of total cone resistance q_t instead of cone resistance q_c used in the equation from Kulhawy and Mayne (1990).

$$\varphi' = 17.6 + 11.0 \log\left(\left(\frac{q_t}{P_a}\right) / \left(\frac{\sigma'_{vo}}{P_a}\right)^{0.5}\right)$$ (Mayne, 2007)

Undrained Shear Strength - Sand

Undrained shear strength of cohesionless soil can be important for assessment of cyclic mobility and liquefaction potential. Geotechnical procedures other than the conventional limit state models are employed.

Compressibility - Sand

Correlations between CPT data and compressibility parameters are indicative only. Further developments in interpretation techniques may offer improvement in the future.

Elasticity theory is commonly employed for analysis of drained soil deformation behaviour. Secant moduli are adopted. A common guideline is an empirical correlation given by Baldi et al. (1989). The correlation is for silica-based sand and considers cone resistance q_c, in situ stress conditions and secant Young's modulus for drained stress change E'. The ratio of E'/q_c typically ranges from about 3 to 5 for recently deposited normally consolidated sands up to about E'/q_c = 6 to 25 for overconsolidated sands. The correlation has been inferred from laboratory conditions; including CPT tests in a calibration chamber and conventional triaxial compression tests on reconstituted sand samples. It takes account of the degree of deformation and overconsolidation. In this regard, it is noted that secant deformation moduli are strongly dependent on strain level: the elastic modulus increases with decreasing strain to an upper limit at about 10^{-4}% strain.

For estimation of initial (small strain) or dynamic shear moduli, ratios of G_{max}/q_c of between about 4 and 20 are considered, in accordance with Baldi et al. (1989).The basis for this correlation is similar to that of secant Young's modulus, except that laboratory resonant column tests serve as reference instead of triaxial compression tests. Results of limited in situ seismic cross-hole and downhole tests provide an approximate check of this correlation.

Constrained Modulus M - Sand

Kulhawy and Mayne (1990) derived two formulas for the determination of the constrained modulus for both normally consolidated and overconsolidated sands by indicating that the modulus is a function of relative density. The determination of relative density can be done with, for example, the methods indicated previously.

$$M = q_c * 10^{1.09-0.0075D_r}$$ (Normally consolidated sands, Kulhawy and Mayne, 1990)

$$M = q_c * 10^{1.78-0.0122D_r}$$ (Overconsolidated sands, Kulhawy and Mayne, 1990)

where D_r is in %, and q_c and M in kPa respectively.

Shear Wave Velocity v_s – Sand

If no in situ measurements of shear wave velocities (v_s) are available, then empirical correlation with CPT parameters may be considered. Hegazy and Mayne (2006) published a statistical correlation derived from 73 sites worldwide representing a range of soil types including sands, clays, soil mixtures and mine tailings (Figure 5). The correlation considers a normalized cone resistance (q_{c1N_hm}) and a soil behaviour type index (I_{c_hm}) as follows:

$$v_s = 0.0831 q_{c1N\_hm} (\sigma'_{vo} / P_a)^{0.25} \; e^{(1.786 \, I_{c\_hm})}$$ (Hegazy and Mayne, 2006)

where shear wave velocity v_s is in m/s and q_{c1N_hm} and I_{c_hm} are dimensionless. Calculations for q_{c1N_hm} and I_{c_hm} require iteration, and consider measured cone resistance q_c or corrected cone resistance q_t, measured sleeve friction f_s, total in situ vertical stress σ_{vo}, effective in situ vertical stress σ'_{vo} and atmospheric pressure P_a.

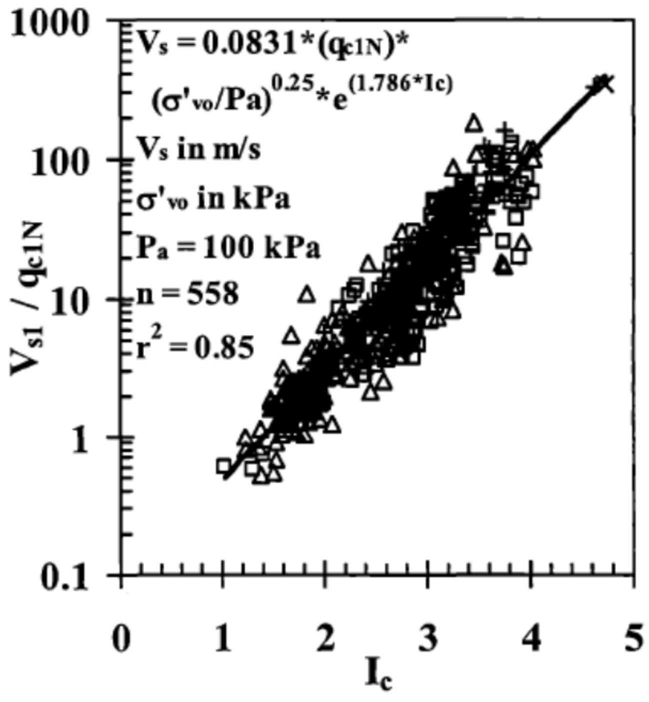


Figure 5, v_s – q_c correlation according to Hegazy and Mayne (2006)

Robertson and Cabal (2010) present a v_s correlation incorporating net cone resistance q_n (= $q_t - \sigma_{vo}$) and soil behaviour type index (I_c) as defined by Robertson and Wride (1998):

$$v_s = [\alpha_{vs}(q_t - \sigma_{v0}) / P_a]^{0.5} \text{ where } \alpha_{vs} = 10^{(0.55 I_c + 1.68)}$$ (Robertson and Cabal, 2010)

where shear wave velocity v_s is in m/s and total cone resistance q_t, total in situ vertical stress σ_{vo} and atmospheric pressure P_a are in kPa. The method can be applied to a wide range of soil behaviour types, notably uncemented Holocene to Pleistocene age soils. Older deposits could have a higher shear wave velocity. Exceptions are Zones 1, 8 and 9 of Robertson (1990 and 2009).

Baldi et al. (1989) derived a correlation between shear wave velocity v_s and cone resistance q_c for uncemented silica sands. This correlation is based on data from CPT, cross-hole and Seismic Cone Penetration Tests (SCPT) performed in quaternary deposits of the predominantly silica Po river sand and Gioia Tauro sand with gravel.

$$v_s = 277 q_c^{0.13} \sigma'_{vo}{}^{0.27} \quad \text{(Baldi et al., 1989)}$$

where shear wave velocity v_s is in m/s and cone resistance q_c and effective in situ vertical stress σ'_{vo} are in MPa.

Shear wave velocity may be normalised according to Robertson and Cabal (2010):

$$v_{s1} = v_s \cdot (P_a / \sigma'_{vo})^{0.25} \quad \text{(Robertson and Cabal, 2010)}$$

Shear Modulus G_{max} - Sand

Interpretation of low-strain shear modulus can be considered by using the modified correlation proposed by Rix and Stokoe (1991) in which data from calibration test measurements is compared to the correlation obtained between G_{max} and q_c by Baldi et al. (1989).

$$G_{max} = 1634 (q_c)^{0.25} (\sigma'_{vo})^{0.375} \quad \text{(Rix and Stokoe, 1991)}$$

where G_{max}, q_c and σ'_{vo} are in kPa.

CLAY MODEL

Unit Weight – Clay

Empirical correlation between unit weight of clay and CPT parameters is as described in "Unit Weight – Sand" above.

In Situ Stress Conditions - Clay

Similar to sand, a knowledge of in situ stress conditions is generally necessary for estimation of other parameters such as consistency (soft, stiff, etc.) of a clay deposit and compressibility.

Calculation of the effective in situ vertical stress σ'_{vo} is reasonably accurate. A more approximate estimate applies to the effective in situ horizontal stress σ'_{ho}, or, more particular, K_o as $\sigma'_{ho} = K_o \sigma'_{vo}$.

Direct correlations for interpretation of the coefficient of earth pressure at rest K_o are uncommon.

For normally consolidated clays and silts, K_{onc} may be correlated with angle of internal friction, in accordance with Jaky (1944), or more simply in accordance with Mayne and Kulhawy (1982). The reference angle of internal friction is that obtained from a straight-line approximation of the Mohr-Coulomb failure envelope determined from Isotropically Consolidated Undrained (CIU) triaxial compression tests on undisturbed specimens.

For overconsolidated clays, K_{ooc} may be correlated with angle of internal friction and overconsolidation ratio, in accordance with Mayne and Kulhawy (1982). The plasticity index together with OCR may also be used for preliminary estimates of K_{ooc} as indicated by Brooker and Ireland (1965).

$$K_o = (1 - \sin\varphi') OCR^{\sin\varphi'} \quad \text{(Mayne and Kulhawy, 1982)}$$

Overconsolidation Ratio - Clay

Overconsolidation ratio is defined as: OCR = σ'_p/σ'_{vo} where σ'_p is the pre-consolidation pressure considered to correspond with the maximum vertical effective stress to which the soil has been subjected, and σ'_{vo} is the current effective in situ vertical stress. The pre-consolidation pressure approximates a stress level where relatively small strains are separated from relatively large strains occurring on the virgin compression stress range. The reference OCR is usually based on laboratory oedometer tests carried out on undisturbed samples, and may thus be influenced by factors such as sample disturbance, strain rate effects and interpretation procedure.

Various analytical and semi-empirical models for interpretation of pre-consolidation pressure from piezo-cone test data are available. Sandven (1990) presents a summary. The procedures are mostly "experimental" and as yet uncommon in practice. Chen and Mayne (1996) presented a direct correlation between net cone resistance and overconsolidation ratio for 205 clay sites around the world, as follows:

$$OCR = 0.317\ Q_t \qquad \text{(Chen and Mayne, 1996)}$$

The overconsolidation ratio may also be inferred from a geological assessment and from undrained strength ratios.

Geological factors concerning overconsolidation have been discussed under "in situ stress conditions - sand". An empirical procedure for estimation of OCR based on undrained strength ratio c_u/σ'_{vo} is given by Wroth (1984). The procedure uses the strength rebound parameter Λ. Guidance for selection of Λ and normally consolidated undrained strength ratio is given by Mayne (1988). Historically, much use has also been made of the Skempton (1957) relationship between normally consolidated undrained strength ratio and plasticity index I_p. This equation is useful for preliminary estimates, considering that I_p probably relates to φ' in some complex manner.

Undrained Shear Strength - Clay

No single undrained shear strength exists. The in situ undrained shear strength c_u depends on factors such as mode of failure, stress history, anisotropy, strain rate and temperature.

Various theoretical and empirical procedures are available to correlate q_c with c_u. Theoretical approaches use bearing capacity, cavity expansion or steady penetration solutions, all of which require a number of simplifying assumptions. Empirical approaches are more common in engineering practice because of difficulties in realistic soil modelling. An empirical correlation for soft to stiff, intact and relatively homogeneous clays is given by Battaglio et al. (1986) as follows:

$$c_u = (q_c - \sigma_{vo})/N_c$$

where c_u, σ_{vo} and q_c are in kPa. N_c is an empirical factor that ranges between 10 and 25, with the higher N_c factors applying to clays with a relatively low plasticity index, and vice versa. The reference undrained shear strength is that determined from in situ vane test results. The term σ_{vo} (total in situ vertical stress) becomes insignificant for stiff clays at shallow depth so that the equation reduces to $c_u = q_c/N_c$.

For specific design situations, a different c_u reference strength should be used. For example, offshore axial pile capacity predictions in accordance with API (2000) recommend c_u to be based on undrained triaxial compression tests, which are likely to yield lower c_u values than in situ vane tests. A site-specific or regional approach should generally be preferred. For example, N_c factors of 15 to 20 have been commonly used for firm to hard North Sea clays. They give reasonable strength estimates for c_u values determined from pocket penetrometer, torvane and Unconsolidated Undrained triaxial tests (UU) on Shelby tube samples obtained by hammer sampling and push sampling techniques. Lower N_c factors are generally appropriate for soft clays and higher factors for heavily overconsolidated clays.

If piezo-cone test data are available, then improved correlations are feasible because of the pore pressure information. Empirical correlations of piezo-cone test results with CIU undrained shear strengths are given by Rad and Lunne (1988), as follows:

$$c_u = q_n/N_k$$

N_k ranges typically between 8 and 30 with the higher N_k factors applying to heavily overconsolidated clays.

Low et al. (2010) recommend N_k = 10 to 14 with a mean value of 12 for correlation with laboratory triaxial compressive strength and N_k = 11.5 to 15.5 with a mean value of 13.5 for correlation with average undrained shear strength defined as the average of laboratory triaxial compression, simple shear and triaxial extension. These recommendations apply to high plasticity, normally consolidated to slightly overconsolidated clays with q_n values of typically less than 1.5 MPa.

Clay Sensitivity

The sensitivity of a clay (S_t) is the ratio of undisturbed undrained shear strength to remoulded undrained shear strength. Sensitivity may be assessed from the CPT friction ratio R_f, in accordance with Schmertmann (1978):

$$S_t = N_s/R_f$$

where N_s is a correlation factor typically ranging between 5 and 10. The correlation is expected to be inaccurate for sensitive clays where uncertainty in very low values for sleeve friction may dominate results.

The reference S_t value is often taken to be that determined from undisturbed and remoulded laboratory unconsolidated undrained triaxial tests. This reference S_t value may differ from that determined from other tests, for example laboratory miniature vane tests. This is partly related to the definition of sensitivity. For vane tests, several measurements of undrained shear strength are possible:

- Intact (I) = undisturbed undrained shear strength as measured on an intact/undisturbed specimen.
- Intact-Residual (I-R) = measured post peak during initial shearing of the intact specimen.
- Intact-Vane Remoulded (I-VR) = measured after multiple-quick rotations of the vane after completion of the intact test.
- Hand Remoulded (HR) = steady state (post-peak if exists) resistance of hand remoulded test specimen.
- Hand Remoulded – Vane Remoulded (HR-VR) = steady state resistance of hand remoulded specimen measured after applying multiple-quick vane rotations.

Skempton and Northey (1952) present a correlation of sensitivity and laboratory liquidity index I_L. This correlation may allow a check on CPT-based interpretation of sensitivity.

Effective Shear Strength Parameters - Clay

Measurement of pore water pressures during penetration testing has led to development of interpretation procedures for estimation of effective stress parameters of cohesive soils. Background information may be found in Sandven (1990). Currently available procedures are evaluated to be "experimental" and are as yet not commonly adopted.

In general, CPT interpretation of effective shear strength parameters for clay and silt relies on soil behaviour-type classification.

It is noted that significant silt and sand fractions in a clay deposit will increase φ', while a significant clay fraction in silt will decrease φ'.

Masood and Mitchell (1993) provide an equation for the determination of φ' by combining sleeve friction with the Rankine earth-pressure theory. The equation is based on the following assumptions:

- Unit adhesion between soil and sleeve is negligible.
- Friction angle between soil and sleeve = $\varphi'/3$.
- Lateral earth pressure coefficient during penetration is equal to the Rankine coefficient of lateral earth pressure under passive conditions.

$$\frac{f_s}{\sigma'_{vo}} = \tan^2(45^\circ + \frac{\varphi'}{2})\tan(\frac{\varphi'}{3}) \qquad \text{(Masood and Mitchell, 1993)}$$

Mayne (2001) proposed an approximation of the Masood and Mitchell equation, as follows:

$$\varphi' = 30.8\left[\log(\frac{f_s}{\sigma'_{vo}}) + 1.26\right] \qquad \text{(Mayne, 2001)}$$

Mayne (2001) also proposed the following approximation of friction angle φ' based on pore pressure ratio B_q and the cone resistance number N_m (Senneset, Sandven and Janbu, 1989):

$$\varphi' = 29.5B_q^{0.121}(0.256 + 0.336B_q + \log N_m) \qquad \text{(Mayne, 2001)}$$

where

$$N_m = \frac{q_t - \sigma_{vo}}{\sigma'_{vo} + a}$$

where the cone resistance number N_m is dimensionless, total cone resistance q_t, total in situ vertical stress σ_{v0} and effective in situ vertical stress σ'_{v0} are in kPa.

Senneset et al. (1989) use the attraction value [a] as a function of soil type. In general the attraction value ranges from 5 to > 50 for both sands and clays and may be estimated directly from CPT results. The correlation is valid if the angle of plastification β is zero. In general a plastification angle of zero applies to medium sands and silts, sensitive clays and highly compressible clays.

Compressibility – Clay

Correlations between CPT data and compressibility parameters are viewed as indicative only, as discussed for sand compressibility.

The use of elasticity theory is common for analysis of undrained soil deformation behaviour. The adopted procedure is as follows:

(a) Estimation of undrained shear strength c_u from CPT data, as outlined above.
(b) Estimation of secant Young's moduli for undrained stress change E_u in general accordance with correlations based on c_u, as presented by Ladd et al. (1977).

Laboratory undrained triaxial tests carried out on undisturbed clay specimen form the basis for the E_u versus c_u correlations. Typical E_u/c_u ratios at a shear stress ratio of 0.3 range between about 300 and 900 for normally consolidated clays and E_u/c_u = 100 to 300 for heavily overconsolidated clay. Higher E_u/c_u ratios would apply to lower shear stress ratios, and vice versa.

Mitchell and Gardner (1976) present an approximate correlation of cone resistance with constrained modulus M (or coefficient of volume compressibility m_v, where $M = 1/m_v$). Typical ratios of M/q_c range between 1 and 8 for silts and clays. Refinements include q_c ranges and soil type (silt, clay, low plasticity, high plasticity, etc.). The correlation relies on the results of conventional laboratory oedometer tests carried out on undisturbed clay and silt samples. The constrained modulus can also be related (approximately) to secant Young's modulus E' and shear modulus G'.

It is noted that laboratory soil stiffness may differ from in situ stiffness because of inevitable sampling disturbance (in particular soil structure disturbance). In general, this implies that laboratory stiffness will usually be less than in situ stiffness.

Constrained Modulus M

Kulhawy and Mayne (1990) correlated constrained modulus M in clays with net cone resistance data. This relationship is based on data from 12 different test sites, with constrained moduli up to 60 MPa. The published standard deviation is 6.7 MPa.

$$M = 8.25\, q_n \qquad \text{(Kulhawy and Mayne, 1990)}$$

Shear Wave Velocity v_s – Clay

Hegazy and Mayne (2006) and Roberson and Cabal (2010) present empirical correlations between shear wave velocity and CPT parameters for a wide range of soils including clays, as described in “Shear Wave Velocity v_s – Sand” above. The Hegazy and Mayne correlation is sensitive to use of q_c or q_t. It should be used with caution for soils showing undrained or partially drained CPT response.

Mayne and Rix (1995) derived a correlation between shear wave velocity v_s and cone resistance q_c for intact and fissured clays. A database from Mayne and Rix (1993) was used including 31 different clay sites.

$$v_s = 1.75 q_c^{0.627} \qquad \text{(Mayne and Rix, 1995)}$$

where shear wave velocity v_s is in m/s and cone resistance q_c is in kPa.

Shear Modulus G_{max}

Mayne and Rix (1993) determined a relationship between G_{max} and q_c by studying 481 data sets from 31 sites all over the world. G_{max} ranged between about 0.7 MPa and 800 MPa.

$$G_{max} = 2.78\, q_c^{1.335} \qquad \text{(Mayne and Rix, 1993)}$$

where G_{max} and q_c are in kPa.

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INTRODUCTION

Site characterisation may be defined as a fit-for-purpose model of seabed conditions at a geographical location in a sea or ocean. Seabed is the ground below seafloor, including pore fluid and gas. The model is fundamental to managing ground risks and optimizing opportunities. The model is a prediction and a reduction of reality:

- Providing sound information with which to define and assess the suitability of a site for proposed facilities
- Detecting and assessing the possible effects of geohazards and changes in seabed conditions with time
- Choosing parameter values for assessment of limit states and assess the feasibility of building/ installing, operating and/or decommissioning a structure.

Other terms used in practice for (parts of) site characterisation include integrated study, integrated geosciences, desk study, seabed characterisation.

Site characterisation can also refer to the activities required to create the model of seabed conditions (e.g. Evans, 2010; Peuchen, 2014).

The terms seabed and seafloor are according to ISO (2003):

- Seabed comprises materials below the sea in which a structure is founded, whether of soils such as sand, silt or clay, cemented materials or, of rock
- Seafloor is defined as the interface between the sea and the seabed.

This document focuses on offshore projects. Site characterisation is an integral part of offshore structure design and operation according to reliability principles covered by standards and codes of practice; for instance API (2000, 2009 and 2011), BWEA (2011), CEN (2004 and 2011); ISO (2002, 2003, 2004, 2009, 2012 and 2013), Osborne et al. (2011) and SNAME (2008).

The following sections provide further information.

SITE HAZARDS

TYPES OF HAZARDS, RISK AND MITIGATION

Site hazards may be grouped into:

- natural geohazards
- man-made hazards.

Natural geohazards are commonly referred to as geohazards or geological hazards. They are about past geological processes and events have shaped the seafloor and seabed. Some of these processes may still be active today. The resulting seafloor topography, and geological and geotechnical conditions within the seabed can be hazardous when installing offshore structures including infrastructure (e.g. Clayton and Power, 2002; OGP, 2009; API, 2011).These processes.

Man-made hazards include shipwrecks, fallen objects, seafloor debris and unexploded ordnance. Within the context of this document, man-made hazards exclude accidental events such as vessel impact, sabotage, well drilling problems and fishing activities.

In relation of offshore activities, geohazards can be defined as local and/or regional site and soil conditions having a potential of developing into a condition (e.g. irregular seafloor topography) or process (e.g. currents, submarine slides) that could cause loss of life or damage to health, environments and/or assets. The event-triggering sources can be ongoing geological processes or human induced changes (OGP, 2009). Figure 1 presents a schematic overview of offshore geohazards.

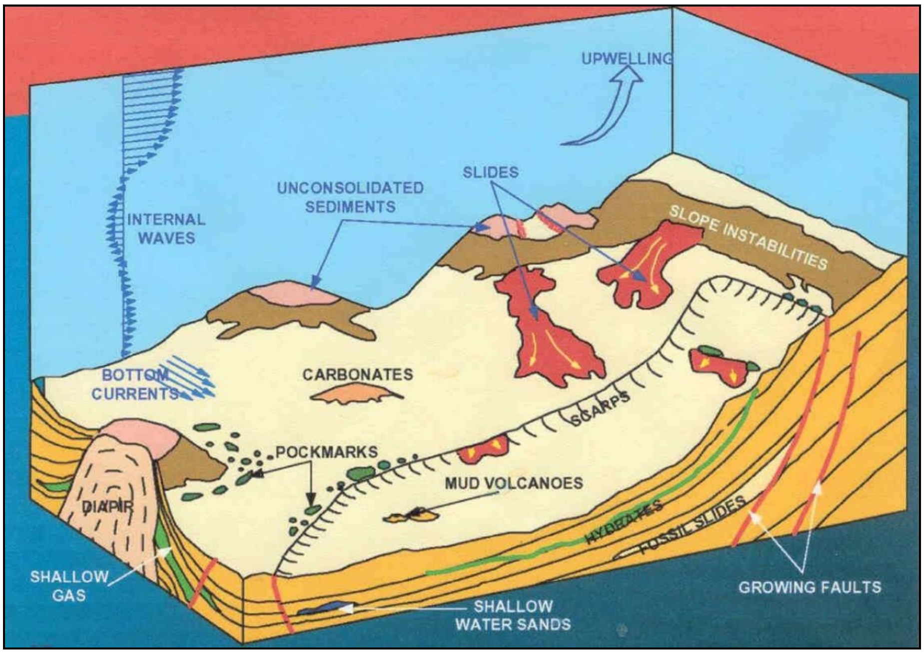

Figure 1: Offshore natural geohazards in deep water settings (modified after Campbell et al., 1986)

The damage potential of site hazards can range from, for example, local effects on pipelines and subsea structures to complete loss of all installations in a license areas and 3rd party losses (OGP, 2009).

The table below presents an overview of potential impacts and/or consequence associated with natural geohazards (and man-made hazards) occurring offshore.

Table 1: Potential Impact/Consequence Associated with Site Hazards

Impact / Consequence	Natural Geohazards and Man-made Hazards															
	Irregular Seafloor Topography	Seafloor Bedforms	Seafloor Outcrops and Hard Seafloor	Soil Liquefaction	Shallow Gas & Gassy Soils	Gas Hydrates	Gas and Fluid Seepage	Diapirs (e.g. Mud /Salt) and Mud Volcanoes	Earthquakes	Faults	Tsunami	Slope Failure	Submarine Mass Movement	Wind, Waves and Currents	Seafloor Scour and Sediment Mobility	Man-Made Hazards
Uneven support (foundation instability)		x				x				x	x				x	
Loss of support (structural stresses)				x			x		x		x	x	x			
Spanning (pipeline & flowlines)	x	x	x							x						
Increased foundation settlements, reduced access				x	x											
Burial / embedment leading to additional loading and reduced access		x		x									x		x	
Reduced soil strength and bearing resistance				x	x		x									

Impact / Consequence	Natural Geohazards and Man-made Hazards															
	Irregular Seafloor Topography	Seafloor Bedforms	Seafloor Outcrops and Hard Seafloor	Soil Liquefaction	Shallow Gas & Gassy Soils	Gas Hydrates	Gas and Fluid Seepage	Diapirs (e.g. Mud /Salt) and Mud Volcanoes	Earthquakes	Faults	Tsunami	Slope Failure	Submarine Mass Movement	Wind, Waves and Currents	Seafloor Scour and Sediment Mobility	Man-Made Hazards
Lateral loading of structure leading to overstressing of foundation / structure components									x		x	x	x	x		x
Structure displacement and structural damage				x					x	x	x	x	x			x
Increased potential for soil liquefaction					x	x	x		x		x			x		
Increased potential for shallow soil instability and submarine sliding					x	x	x	x	x		x			x	x	
Foundation and structure installation difficulties	x	x	x		x	x	x									x
Steel abrasion, gouging and denting; excessive wear trenching equipment			x													
Gas and fluid migration (excess pore pressures)					x	x	x	x		x	x			x		
Corrosion of steel structures, pipelines, flowlines					x		x	x								
Well (borehole) instability					x	x	x			x						
Mud losses (well/borehole drilling)										x						
Damage to casing string and pile foundations										x						
Presence of environmentally protected chemosynthetic communities					x		x	x								
Explosions leading to changed site conditions																x

Site hazards can generally not be treated on a statistical basis applying solely historical data. The nature of a hazard is often site and time dependent. In addition, natural geohazards are often interrelated. This may be due to a common trigger mechanism (e.g. earthquake, slope failure), or that one geohazard occurrence or process forms a trigger for other geohazards.

For instance:

- Earthquakes will induce dynamic actions on a structure and may induce elevated pore pressures leading to increased susceptibility to soil liquefaction;
- Slope failures and their deposits may result in irregular seafloor topography;
- Mud and salt diapirs are commonly associated with radial fault patterns, and continuous diapirism may result in (shallow) slope failures.

Table 2 highlights some relations between natural geohazards.

Table 2: Related Offshore Natural Geohazards

	Irregular Seafloor Topography	Seafloor Bedforms	Seafloor Outcrops and Hard Seafloor	Soil Liquefaction	Shallow Gas & Gassy Soils	Gas Hydrates	Gas and Fluid Seepage	Diapirs (e.g. mud /salt) and Mudvolcanoes	Earthquakes	Faults	Tsunamis	Slope Failure	Submarine Mass Movement	Wind, Waves and Currents	Seafloor Scour and Sediment Mobility
Irregular Seafloor Topography		x	x							x		x	x	x	x
Seafloor Bedforms	x													x	x
Seafloor Outcrops and Hard Seafloor	x				x		x	x				x			x
Soil Liquefaction					x	x	x	x	x					x	
Shallow Gas & Gassy Soils			x	x		x	x	x		x		x	x		
Gas Hydrates				x	x		x					x	x		
Gas and Fluid Seepage			x	x	x	x		x		x		x	x		
Diapirs (e.g. mud /salt) and Mudvolcanoes			x	x	x		x			x		x			
Earthquakes				x						x	x	x	x		
Faults	x				x		x	x	x		x	x	x		
Tsunamis									x	x		x	x	x	x
Slope Failure	x		x		x	x	x	x	x	x	x		x	x	x
Submarine Mass Movement	x				x	x	x		x	x	x	x		x	x
Wind, Waves and Currents	x	x		x							x	x	x		x
Seafloor Scour and Sediment Mobility	x	x	x								x	x	x	x	

Assessment of hazard probability of occurrence and frequency can be based on geomechanical modelling taking into account uncertainty in modelling of site conditions, soil parameter values, ongoing geological processes, actions and applied analysis methods (Clayton and Power, 2002; OGP, 2009).

The risk of a site hazard is the sum of the product of the probability of a hazard event affecting a structure and damage consequence. The damage consequence can depend on factors such as structure robustness and vulnerability. The information in this document covers the nature of hazards and their potential implications, not the risk. Power et al. (2005) and Galavazi et al. (2006) describe risk analysis methodology.

Risk mitigation can include avoidance (e.g. a certain standoff distance to avoid structure interaction) and design for robustness.

IRREGULAR SEAFLOOR

Seafloor morphology can be irregular as a result of past or present geological processes. Human activities can also affect the seafloor topography. Irregular seafloor may be caused by (or be associated with) a number of natural and man-made phenomena. These include:

- Canyons and channels
- Boulders (e.g. drop stones)
- Spudcan footprints
- Anchor scars
- Trawl marks and scars
- Drill cuttings.

The scale of morphological features varies (e.g. scour marks, submarine canyons). The impact can differ per structure type and geometry.

SEABED SCOUR AND SEDIMENT MOBILITY

Seabed scour relates to the erosion of seabed sediments. Such erosion can occur under normal metocean conditions or can be enhanced as a result of a structure or multiple structures interrupting a natural flow regime above seafloor, thereby increasing flow velocities. Scour can be enhanced or initiated by secondary processes such as rocking of a structure.

Especially non-cohesive sandy (and silty) sediments are susceptible to scour. Erosion and transport of fine sand can start at a flow velocity in excess of 0.2 m/s. Local scour pits (or scour holes) can form shortly after installation of a structure. Their dimensions will usually vary in time depending on the flow regime.

Scour can occur in any water depth (from shoreline to deep sea). The flow regime due to wave- and tidal-influence is generally stronger in shallow water than in deep water (Soulsby, 1997; Sumer & Fredsoe, 2002). In general, tide- and wave-action, in combination with fluvial discharge of fresh water determine the natural flow regime in coastal areas. Deepwater bottom current activity may result from density differences between water masses and from global thermohaline ocean circulation. Resulting sedimentary accumulations are known as contourite drifts (Faugeres et al., 1999).

Seafloor variation can usually be characterized as some combination of the following Whitehouse (1998):

- Local scour and sedimentation; usually a steep sided scour pit around a structure or structural element
- Global (or general) scour; a (shallow) scoured basin of large extent around a structure, possibly due to overall structure effects, multiple structure interaction, or wave-soil-structure interaction
- Overall seabed movement; erosion, deposition, bedform migration that would also occur in the absence of a structure (i.e. regional scour).

SEAFLOOR BEDFORMS

A seafloor bedform is a morphological feature formed by interaction of wave-action and (tidal-) currents and cohesionless sediment (i.e. sand/silt). Bedforms are typically found on sandy areas of continental shelves.

Bedforms can be grouped into:

- Ripples: wave length about 0.3 m to 0.6 m, height up to 0.05 m
- Mega ripples: wave length 0.3 m to 1 m, height 0.05 m to 0.2 m
- Sand waves (dunes): wave length 30 m to several hundreds of metres, height between 1 m to 2 m and 10 m to15 m
- Sand banks: wave length 1 km to tens of km, width 0.5 km up to 10 km, height up to tens of metres.

A characteristic of bedforms is their mobility. Sand waves tend to move slowly (metre per year) or flex their crests with tidal currents. Ripples tend to be more mobile, in the order of a metre per day (Morelissen et al., 2003).

For structure design it is important to identify which part of the seabed and/or the bedforms is actually mobile. The rate at which bedforms recover after having been modified by, for example, cable trenching mainly depends on sediment transport rate and supply of sediment.

SEAFLOOR OUTCROPS AND HARD SEAFLOOR

Seafloor outcrops and hard seafloor ground conditions commonly include:

- Shell and coral banks, reefs, which are common in shallow waters in the tropical zones.
- Local patches of cemented soil (e.g. hard ground, cap rock). Examples are authigenic carbonates around pockmarks, Kurkar ridges (cemented aeolian dunes) in the eastern Mediterranean Sea, beach rocks (cemented beach sediments) in the Caribbean Sea, sabkha deposits (evaporitic-tidal floodplain deposits) in the Arabian/Persian Gulf and Gulf of Suez.
- Crust composed of precipitated metalsulphides associated with hydrothermal activity (e.g. black and white smokers) in vicinity of tectonic plate boundaries and faults.
- Outcrops of rock. Examples are pre-Quaternary sand- and limestone beds offshore West Africa, sedimentary and metamorphic rocks exposed in the Irish Sea.

It should be noted that seafloor outcrops and hard seafloor may have environmental protection status or legislative implications.

Cementation of soil may result from sub-marine cementation processes. Cementation may also have resulted from past sub-aerial exposure of a continental shelf during low sea level stands under arid climate conditions. Cementation generally occurs in carbonate-rich and hyper-saline environments.

DIAPIRS AND MUD VOLCANOES

A diapir is a domal upwelling of sediment, rock or salt that forms in response to tectonic forces, density differences and high overburden pressures. Diapirs can pierce through a stratigraphic overburden and create an envelope of overconsolidated soils, deformed rock and sediments around a diaper core (e.g. salt). Generally, a circular dome-shaped topographic feature develops when a diapir approaches the seafloor. Diapirs are commonly associated with radial faulting patterns and locally increased seafloor slopes.

Salt diapirs are known to be present in, for example, the Gulf of Mexico, offshore Brazil and West Africa, and the North Sea.

Mud diapirs and mud volcanoes are usually associated with rapidly-deposited sediments and in situ pore pressure conditions significantly higher than hydrostatic (overpressured). Additionally, high vertical and horizontal stresses typically apply, caused by faulting, folding and uplift processes.

Mud diapirs and mud volcanoes occur mostly in (historic) delta areas: Nile Delta (offshore Egypt), Absheron Ridge (offshore Azerbaijan, Caspian Sea), Makran Ridge (offshore Iran, Arabian Sea), Niger Delta (offshore Nigeria).

Release of pressure is commonly provided by faults and folding of the strata. Sediments mixed with over-pressured fluid and gas (mud) migrate upward through the stratigraphic overburden in vertical columnar zones (diapirs). Usually the over-pressured muds enter fault planes, thus causing diapirism along faults. A mud volcano can form when a mud diapir breaks the seafloor.

In general, mud volcanoes are conical, as tall as 65 m and up to 2 km across. The size and shape of a mud volcano depends on the frequency of expulsion and the type of material ejected. This can be unconsolidated soils, overconsolidated material, fractured rock (e.g. breccia), oil, gas and water (Snead, 1972; Newton et al., 1980; Delisle et al., 2002; Delisle, 2004; Delisle, 2005). Not all offshore mud volcanoes are active. Eruptions are believed to be episodic.

SHALLOW GAS & GASSY SOILS

Gas may be present (trapped) in the seabed (e.g. gassy soils). Shallow gas can comprise a mixture of different gases, such as carbon dioxide, hydrogen sulphide, ethane and methane. In general, the gases originate from bacterial decay of organic matter (biogenic gases) within a few metres of the seafloor. Gas may also come from sources much deeper in the stratigraphy and migrate upwards through pores and cracks in the soil and rock (petrogenic gases).

Shallow gas may be present dissolved in pore water, as free gas in gas-filled voids or bubbles, and as gas hydrates. Over time, gas in soil may increase the in-situ pore pressures and result in excess pore pressures.

Migration of gas in soil can result in accumulation of gas in seabed below a foundation. Shallow gas in the pore water can have a serious effect on foundation behaviour.

In addition, shallow gas can be toxic to humans, can combust and explode.

Soil property measurements on geotechnical samples containing shallow gas may not be representative of in situ properties.

GAS HYDRATES

Gas hydrates are ice-like crystalline solids composed of water molecules surrounding a molecule of gas, generally methane. Gas hydrates can only form when gas is over-saturated in water. Gas hydrates are stable under high pressure and low temperature conditions, and may be present at seafloor and in shallow sediments, generally in deep water environments in excess of 500 m below Mean Sea Level (Rastogi et al., 1999; Von Rad et al., 2000).

Stable gas hydrate acts as cement and increases strength and rigidity of soil.

Natural gas hydrates are regarded as a geohazard when they dissociate, start “melting”. Both water and gas are released into soil when gas hydrates dissociate. This can result in formation of “gassy soils”. The addition of water and gas may decrease soil strength and form a weak layer (Orange and Breen, 1992; Judd and Hovland, 2007). Gas hydrate dissociation may be initiated by human activities, e.g. flow of “hot” hydrocarbons through well production casings, pipelines and flowlines.

Gas hydrates may for as a result of human activity. Gas hydrates can be a by-product of hydrocarbon production, forming hydrate plugs in the wellbore, around leaking joints and in pipelines. If a deep water exploration or production well is leaking, gas introduced into the shallow soils may react with water molecules to form hydrate layers or nodules.

GAS AND FLUID SEEPAGE

Gas and fluid seepage at seafloor is commonly associated with pockmarks. Pockmarks are roughly circular or conical depressions in the seafloor, generally 1 m to 350 m wide and up to 35 m deep (Newton et al., 1980; Von Rad et al., 2000; Judd and Hovland, 2007).

Pockmarks form by disruption of a pore pressure environment. This disruption may be triggered by natural or human causes, and can form on time scales of less than a year. Pockmarks can be intermittently active over long periods of time or can grow with explosive eruption events. The sediments in a pockmark are generally variable and may be overconsolidated.

When gas seeps continue over a long period of time, biological processes may cause cementation of the seabed sediments. Formation of authigenic carbonates can take place around the seeps (Judd and Hovland, 2007; Ding, 2008). In some cases, unique ecological habitats form in and around pockmarks. Such habitats may be protected by environmental legislation.

Authigenic carbonates may form thin crusts of weakly cemented sediments (hard grounds). They can be continuous over distances of several hundreds of metres (Von Rad et al., 2000). Locally more massive, competent layers of authigenic carbonates can be present as hard cemented layers or ‘lenses’. They may form large build-ups and seafloor mounts (Judd and Hovland, 2007).

Apart from natural seeps, gas seepage may also be induced by drilling activities (e.g. geotechnical drilling, hydrocarbon exploration drilling). The drilling process may cause fracturing of soil and rock, when drilling mud pressures exceed the fracture pressure of the soil or rock (i.e. hydraulic fracturing). These fractures may form pathways for fluid and gas migration into the wellbore and up to seafloor. A wellbore or leaking well casing may form a pathway to the surrounding rock and soil formations, introducing gas into sand layers in the shallow subsurface. Overtime, the introduced gas may affect the geotechnical properties of a soil and have serious effects on foundation behaviour.

Drilling-induced fluid flows (e.g. shallow water flows) occur when a pressurised sand body (aquifer) encapsulated in clay is penetrated by the drilling process. Shallow water flows are common offshore large river deltas, such as the Mississippi Delta (Gulf of Mexico) and the Nile Delta (offshore Egypt). The sandbodies are commonly derived from sediment deposition out of turbidity currents.

EARTHQUAKES

An earthquake, or seismic event, occurs after stresses in the earth's crust that have gradually built up, are suddenly released by movements along a fault. The movement generates seismic waves which propagate away from the earthquake epicentre. Most earthquakes occur along tectonic plate boundaries.

The location, magnitude and frequency (recurrence) of earthquakes cannot be reliably predicted. The probability of seismic events can be assessed on the basis of historic records of earthquake activity.

Seismic impact depends on geotechnical conditions at the site and structure design. Seismic activity may induce faulting, soil liquefaction, slope failure, and tsunamis.

SOIL LIQUEFACTION

Two types of liquefaction may be distinguished:
- gravitational (sometimes called static or flow) liquefaction, usually occurring in submerged slopes;
- cyclic liquefaction, usually generated through strong cyclic forces.

Soil liquefaction or cyclic mobility represents a decrease of soil strength and stiffness caused by an increase in pore water pressure in saturated soil. Soil liquefaction usually occurs in response to sudden change in stress condition, causing it to behave like a liquid. Examples of cyclic and dynamic actions include earthquake shaking, storm wave loading, structure displacements upon cyclic load application, pile installation by driving and vortex vibrations due to fluid flow around a structure.

Liquefaction potential can be significant for loose cohesionless soils present close to ground surface (seafloor) and below the water table. Dense sands, loose unsaturated sands and some sensitive cohesive materials can also liquefy under some conditions. In addition, the presence of gas in loose sands can change soil behaviour and may potential for liquefaction (Grozic, 2003).

FAULTS

A fault is a planar fracture or discontinuity in a volume of soil or rock along which significant vertical and/or horizontal displacement has occurred (Figure 2) (i.e. faulting). Fault zones are areas where multiple fractures and faults occur in close proximity, with similar moment direction.

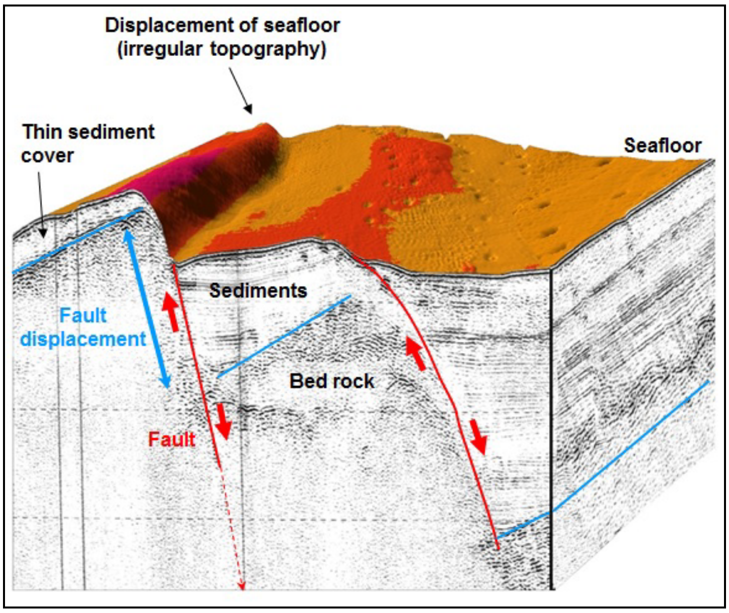

Figure 2: Surface and subsurface expression of fault displacement

Faults can be associated with:

- Tectonic activity (e.g. at tectonic plate boundaries, earthquake zones);
- Laterally variable soil subsidence and compaction;
- Soil contractions (e.g. polygonal faulting in North Sea and West African seabed sediments);
- Diapirism (e.g. radial faulting);
- Slope failure (e.g. headwall scarp, failure planes, tension cracks).

Movement along the fault plane (and hence soil displacement) is a semi-continuous process acting on time scales ranging from years to millions of years. Faults are commonly considered to be in-active if there has been no observed movement or evidence of seismic activity during the last 10,000 years. In this case a faults can be covered by a uniform layer of soil (i.e. without a clear discontinuity surface being present). Depending on crustal stresses and changes therein, apparently in-active faults may be reactivated causing further soil displacements and even seismic events.

Faults may result in a displaced, stepped seafloor and/ or irregular linear topographic features on the seafloor (e.g., headwall scarps). In addition, stratigraphic sequences are displaced in the seabed.

Deep-seated faults, with lengths of 100's to 1000's of metres, may be associated with earthquakes. The build-up of stresses due to differential movement in the earth's crust may be released along these deep-seated faults, whereby large amounts of energy move through rock and soils in the form of pressure waves and shear waves. These deep-seated, earthquake generating, faults are sometimes referred to as seismic faults.

TSUNAMIS

A tsunami (or surge wave) is a series of ocean waves of long wave lengths, which are created when a large volume of water is suddenly displaced by a submarine earthquake, landslide or volcanic eruption (Figure 3). In the open ocean, tsunami waves travel at high speeds (in excess of 800 km/h) with heights of, say, less than 0.05 m. As they approach the coast, the velocity decreases (to approximately 50 km/hr) and the wave height increases up to several metres or tens of metres. At the coastline, the force of a tsunami wave can cause loss of life, damage to buildings and infrastructure, large scale erosion (scour) and flooding of low-lying areas.

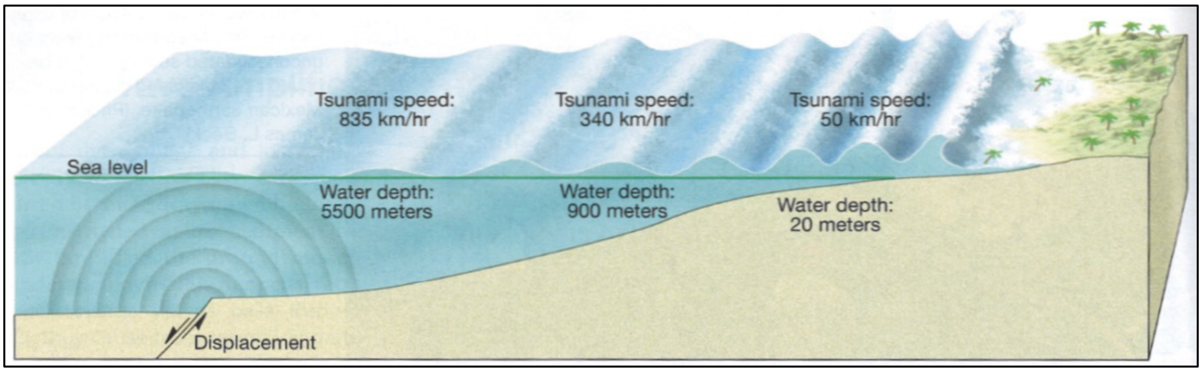

Figure 3 Tsunami generated by fault displacement offshore

SLOPE FAILURE

Slope failure occurs when downslope driving forces acting on seabed exceed resistance. In general, slope failure results in the down-slope movement of a soil mass (see section titled Submarine Mass Movements). Slopes may be unstable at any water depth.

Slopes may develop due to tectonics, high sedimentation rates or incision and erosion by seafloor currents and flows.

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Slope failure can be triggered by earthquakes, strong currents, storms (wave actions), tsunamis, volcanism and human activity (Hampton et al., 1996; Mulder and Cochonat, 1996; Locat and Lee, 2005; Judd and Hovland, 2007; Rogers and Goodbred, 2010).

Usually, a combination of two or more factors influence slope failure, e.g. presence of shallow gas and an earthquake (Orange and Breen, 1992; Judd and Hovland, 2007). Slopes can be unstable due to low shear strength and overpressured strata (e.g. shallow gas). Seabed may fail on slight slopes as little as 0.5˚ (Hampton et al., 1996; Judd and Hovland, 2007).

Failure scarps and oversteepened slopes are commonly associated with past slope failures. Past slope failures may be reactivated if a trigger (e.g. pore pressure build-up, earthquake) is present. The seafloor morphology resulting from a slope failure may be irregular and undulating (see section titled Irregular Seafloor Topography).

SUBMARINE MASS MOVEMENTS

A submarine mass movement is a displacement of seabed material driven directly by gravity or other body forces, rather than stresses associated with fluid flow. The deposits of submarine mass movements are commonly referred to as mass transport deposits, MTDs.

Submarine mass movements commonly follow from slope failures and include the following processes (Figure 4) (Lee et al., 2007):

- Slides:
  - Translational slide
  - Rotational slide
- Mass flows:
  - Debris flow
  - Debris avalanche
  - Mud flow
  - Liquefaction flow
  - Turbidity current

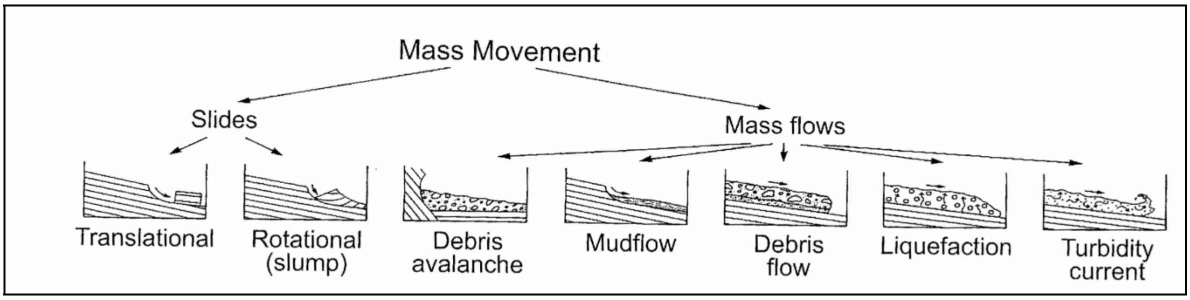


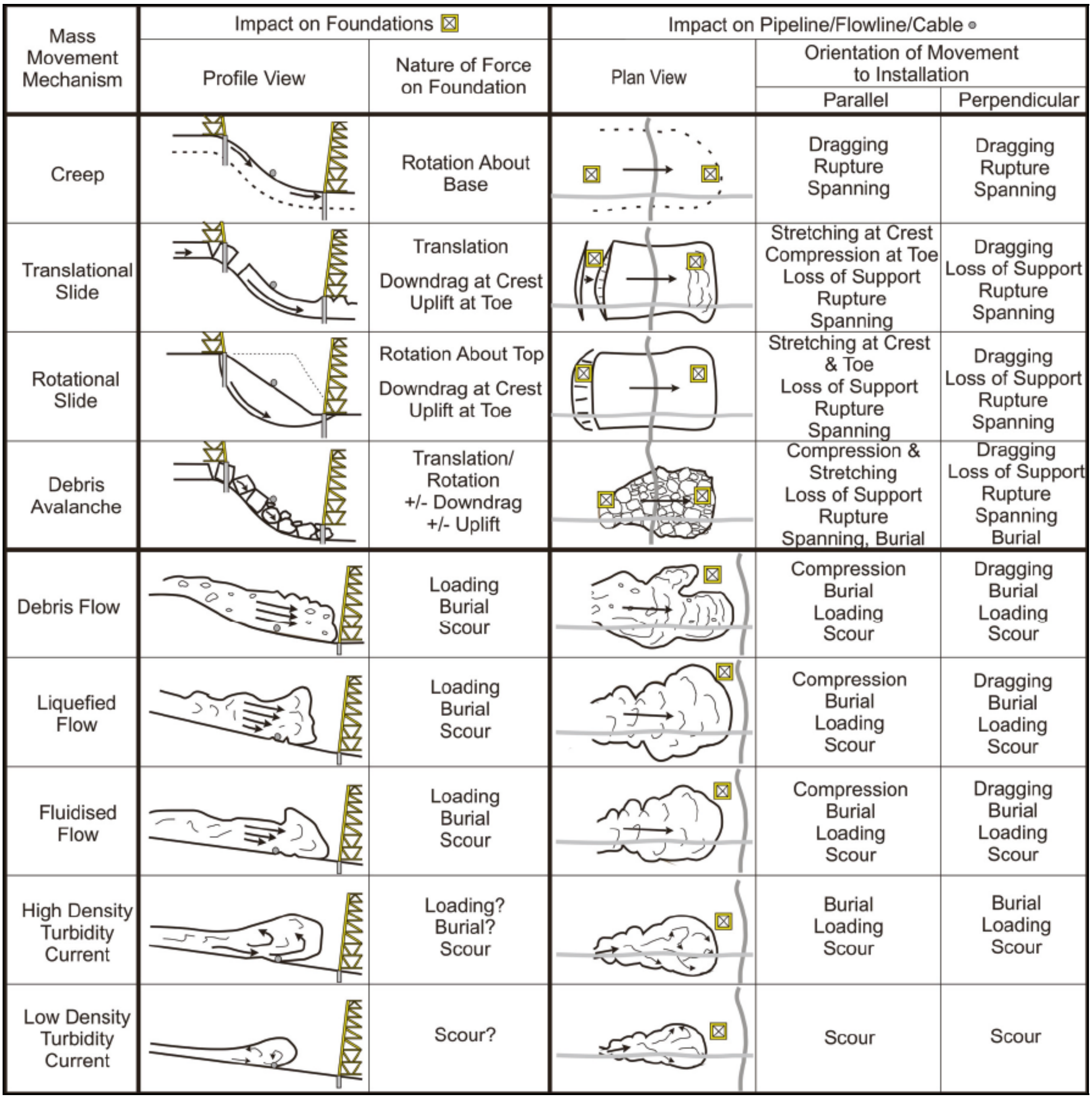
Figure 4: Submarine mass movement classification (after Lee et al., 2007)

Slides are movements of essentially rigid, undeformed masses along discrete failure/slip planes. If slip occurs along a planar surface the slide is referred to as a translational slide. If slip occurs along a curved failure plane and the rigid mass shows rotation, the slide is referred to as rotational.

If moving sediments take a form of viscous fluid, the feature is referred to as mass flow or gravity flow. Mass flow deposits show considerable internal deformation with many invisible or short-lived internal slip surfaces. Submarine slides can become mass flows as the failed material progressively disintegrates, gets entrained with surrounding water and moves downslope.

Debris flows are mass flows in which sediments are heterogeneous and may include larger clasts supported by a fine-grained soil matrix. Mud flows involve predominantly fine-grained (mud) sediments. Turbidity currents involve downslope transport of a relatively dilute suspension of sediment grains that are supported by an upward component of fluid turbulence. Turbidity currents often evolve from disintegration and dilution of debris and mud flows. Liquefaction flows occur when loosely packed sandy sediments collapse under environmental conditions (e.g. cyclic actions by waves or earthquakes; see section titled Soil Liquefaction. Debris avalanches occur where slides collapse and disintegrate into smaller pieces. They move rapidly without following pre-existing channels or valleys.

The potential impact of submarine mass movements on a structure depends upon the location or orientation of the structure in relation to the movement direction (Figure 5).



Mass Movement Mechanism	Impact on Foundations ⊠		Impact on Pipeline/Flowline/Cable ∘		
	Profile View	Nature of Force on Foundation	Plan View	Orientation of Movement to Installation: Parallel	Orientation of Movement to Installation: Perpendicular
Creep		Rotation About Base		Dragging Rupture Spanning	Dragging Rupture Spanning
Translational Slide		Translation Downdrag at Crest Uplift at Toe		Stretching at Crest Compression at Toe Loss of Support Rupture Spanning	Dragging Loss of Support Rupture Spanning
Rotational Slide		Rotation About Top Downdrag at Crest Uplift at Toe		Stretching at Crest & Toe Loss of Support Rupture Spanning	Dragging Loss of Support Rupture Spanning
Debris Avalanche		Translation/ Rotation +/- Downdrag +/- Uplift		Compression & Stretching Loss of Support Rupture Spanning, Burial	Dragging Loss of Support Rupture Spanning Burial
Debris Flow		Loading Burial Scour		Compression Burial Loading Scour	Dragging Burial Loading Scour
Liquefied Flow		Loading Burial Scour		Compression Burial Loading Scour	Dragging Burial Loading Scour
Fluidised Flow		Loading Burial Scour		Compression Burial Loading Scour	Dragging Burial Loading Scour
High Density Turbidity Current		Loading? Burial? Scour		Burial Loading Scour	Burial Loading Scour
Low Density Turbidity Current		Scour?		Scour	Scour

Figure 5: Potential impacts of submarine mass movements on platform foundation and pipeline (modified after Thomas et al., 2009)

WIND, WAVES, CURRENTS AND TIDES

Periods of extreme weather conditions, such as (tropical) storms, monsoons, peak wind, waves and current regimes, can cause lateral and cyclic actions on the seafloor and any seabed-supported structure. In addition, adverse weather conditions may complicate structure installation activities.

Peak wave and (seafloor/bottom) current regimes can also cause changes in seafloor conditions due to scour and burial (i.e. sediment remobilisation), winnowing of seafloor sediments (i.e. removal of fine/clay-size materials) and development of irregular seafloor topography.

Tidal variation and atmospheric pressure fluctuations as a result of storms are known to change pore pressures conditions in the seabed, potentially creating circumstances leading to soil failure and liquefaction.

Estimation of environmental actions is relatively inaccurate. It normally involves statistical data for a specific geographic region and various procedures for modelling the interaction of a structure and its environment.

MAN-MADE HAZARDS

Human activities and anthropogenic (i.e. man-made/man-induced) features, debris or obstructions can have an adverse effect on an offshore structure.

Seafloor features and objects have been left by human activities since the dawn of mankind. Ship wrecks can form archaeological sites, war graves, enhance ecological diversity and may be restricted areas.

In addition, offshore energy activities, such as drilling, (jack-up) platform installation and decommissioning and resulting footprints may alter seafloor topography and/or potentially alter seabed conditions (e.g. drill spoils, gas charging as a result leaking exploration wells).

Commonly encountered man-made hazards include:
- Unexploded ordnance (UXO);
- Existing energy facilities (e.g. fixed platforms, pipelines, manifolds, wellheads, power cables etc.);
- Telecommunication cables;
- Ship wrecks;
- Fallen objects (e.g. shipping containers).

These hazards may complicate structure installation and design if not identified at an early stage.

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INTRODUCTION

A geotechnical design situation or a re-assessment of an existing structure requires geotechnical analysis, including evaluation of hazards and verification of relevant limit states. Geotechnical analysis follows design philosophies included in standards and codes of practice, where available. All consider that the resistance (or capacity) of a geotechnical system must be greater than the actions (demands or loads) on the system for an acceptable or required level of safety or reliability (ISO 2394, 1998).

HAZARD EVALUATION

Hazards are situations or events with potential to cause damage (ISO 2000, 2013). Hazard evaluation typically includes classification, estimation of probability of occurrence and measures for countering the hazard. Examples of hazards are abnormal environmental events, accidental events, geohazards and man-made site hazards. Note that event probability differs from risk, where risk is defined as the product of probability and consequence.

In many geotechnical situations, hazard evaluation will not be complete and exact. It will be necessary to draw on so-called tacit expert knowledge. This means senior expertise, with access to geotechnical knowledge and experience. Judgement and opinion are inevitable and a senior expert or a team of senior experts is more likely to arrive at a correct understanding and an appropriate way forward. Judgement is qualitative and subjective. Table 1 shows probability expressions intended for a context of approximate and subjective probability of the occurrence of a hazardous event or phenomena during a defined exposure period (Peuchen et al., 2015).

Table 1. Expressions for approximate and subjective probability

Term	Verbal descriptor	Approximate probability for exposure period
Negligible	unlikely, although the possibility cannot be ruled out completely	0 to 0.01
Low	not probable, although uncertain	0.01 to 0.1
High	credible, possibility can be described with reasonable confidence by known physical conditions or processes	0.1 to 1

Measures for countering a hazard include source elimination, avoidance, implementation of a barrier, minimising consequences and design for the hazard.

LIMIT STATES

Limit states may be grouped into Ultimate Limit States (ULS, for example structure stability), Serviceability Limit States (SLS, for example for avoiding excessive settlement), Fatigue Limit States (FLS) and Accidental Limit States (ALS). Verification of a limit state usually involves one or more of the following approaches:
- calculation models
- prescriptive measures
- experimental models and load tests
- observational method.

Features of a calculation model include:
- method of analysis typically including simplifications and modification of the results where necessary to improve accuracy or to allow for uncertainty and systematic error
- actions, such as (a sequence of) imposed loads or imposed displacements
- geometrical data, such as the shape of a geotechnical structure, geometry of the ground surface, water levels and interfaces between ground strata
- characteristic values of geotechnical parameters of ground (soil, rock, pore fluid, pore gas) and other materials
- limiting values of, for example, deformations and vibrations
- partial factors or safety factors.

The common analytical models rely on semi-empirical and direct methods of analysis.

Prescriptive measures generally involve (1) conventional and conservative details in the design and (2) attention to specification and control of materials, workmanship, protection and maintenance procedures. Their use is often applicable where calculation models are not available or not necessary. Examples are prescriptive measures for ensuring durability against chemical attack or frost action.

Experimental models and load tests can help to justify a design approach. Important considerations for evaluation of the results include differences in ground conditions, time effects and scale effects.

Prediction of geotechnical behaviour is often difficult. The observational method allows carefully planned monitoring during construction and includes planned contingency measures where necessary. Assessment of the monitoring results takes place at appropriate stages.

DESIGN PHILOSOPHIES

Design philosophies typically incorporate geotechnical calculation models and corresponding (partial) factors. These partial factors or safety factors may vary depending on the specific design scenario.

Design philosophies for the ULS may be grouped as follows:
1. Working Stress Design (WSD).
2. Partial Factor Design (PFD) or Limit State Design (LSD).
    a. Factored material properties.
    b. Factored resistance.

The WSD method uses global safety factors applied to characteristic values (or ultimate values) of resistance.

The PFD methods use partial action factors and partial factors applied to resistance. The partial action factors are applied to characteristic or representative values of actions. This results in design values for actions. The factored material properties and factored resistance methods differ by their calculation of resistance. The method for factored material properties applies partial material factors to characteristic values of material properties such as undrained shear strength of soil. The factored values are then used in the calculation model to obtain a design value for resistance (factored resistance). The factored resistance method uses characteristic values of material properties in the calculation model and then applies a partial resistance factor to obtain a design value for resistance. An additional factor γ_d can be considered to account for model uncertainty or other uncertainties not covered by other partial factors (ISO, 2013).

API Recommended Practice RP 2A-WSD (API, 2000) is an example of the WSD approach. Eurocode 7 Geotechnical Design (CEN, 2004; 2007), ISO 19900 (2012), ISO 19901-4 (2003) and API RP 2GEO Geotechnical and Foundation Design Considerations (API, 2011 and 2014) provide design principles according to the PFD approaches.

Design philosophies for the ALS, SLS and FLS are similar. Global safety factors and partial factors will differ from the ULS.

GEOTECHNICAL PARAMETER VALUES

DESIGN PROCESS

Assignment of geotechnical parameter values or soil property values is according to the following steps:
1. Site characterisation and stratigraphic schematisation.
2. Evaluation of derived values of geotechnical parameters.
3. Selection of characteristic values of geotechnical parameters and application in a calculation model.

The selection of characteristic values of geotechnical parameters takes place within the context of a calculation model and thus includes consideration of limit states, actions, geometry, limiting values and partial factors or safety factors. Divorcing the selection of characteristic values from the actual use and evaluation of a calculation model may lead to errors.

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STRATIGRAPHIC SCHEMATISATION

General site characterisation is necessary before selection of geometrical data for the ground and before evaluation of the results of specific tests and observations. Such site characterisation comprises a general assessment of the character and basic constituents of the ground (soil and rock classification) and their possible change in time.

Typical parameters for soil classification include particle size distribution, water content, carbonate content, Atterberg limits, unit weight, relative density and undrained shear strength. Typical parameters for rock classification include mineralogy, water content, unit weight and uni-axial compressive strength.

Stratigraphic schematisation depends on the nature of the actions, geometrical quantities of the structure that interacts with the ground, volume of ground that represents the domain of influence with respect to the limits state, spatial ground variability, simplification of ground conditions, e.g. undrained versus drained foundation response.

Two competing factors apply to spatial ground variability: (1) the spatial averaging of properties over a potential failure surface, which reduces the coefficient of variation of property values (i.e. with respect to that for the location under consideration) and (2) the tendency for a failure surface to follow the path of least resistance.

Stratigraphic schematisation can include evaluation of:
- basic parameters such as undrained shear strength and relative density on the basis of derived values of geotechnical parameters (refer following section)
- geological and hydro-geological setting
- results of a geophysical survey
- hazards such as potential instability of the ground
- water levels
- aggressiveness of ground and ground water.

DERIVED VALUES OF GEOTECHNICAL PARAMETERS

A derived value of a geotechnical parameter or coefficient is obtained from test results by theory, correlation or empiricism. In situ test and laboratory test measurements and other relevant data provide a basis for obtaining derived values of geotechnical parameters.

Laboratory test standards often specify procedures for obtaining derived values, in particular where it is possible to obtain a derived value by means a of a conversion model or theory. Such derived values are thus part of the laboratory test report. An example is the unconsolidated undrained triaxial compression test. Normalised load and displacement data are the basic measured values. The measured values and the use of theory allow the calculation of a derived value of undrained shear strength by consideration of principal stress conditions and a theoretical deformation model.

Standards for in situ tests usually require reporting of (normalised) measured values only. Examples of measured values are cone resistance and sleeve friction for a Cone Penetration Test (CPT). Measured values can serve as input for some calculation models that rely on empirical relationships. An example is the use of CPT cone resistance for the calculation of axial pile resistance. A more common approach is to obtain derived values of geotechnical parameters from in situ tests on the basis of empiricism or (simplified) theory or a combination thereof. Evaluation of derived values of geotechnical parameters will usually comprise undrained shear strength (c_u) and relative density (D_r) according to a single interpretation method, where appropriate.

Many empirical correlations and theoretical interpretation models are available for obtaining specific derived values of geotechnical parameters from the results of laboratory and in situ tests. Evaluation of various sets of derived values by engineering judgement or statistical methods can be considered, whereby one method is selected as reference.

Measured values and derived values may be represented by low estimate, best estimate and high estimate values. In statistical terms, a best estimate value aims to represent a mean value of a geotechnical parameter for a stratum or multiple soil layers. Low and high estimates aim for the quantile associated with the 5% fractile. Comments are as follows:

- Low, best and high estimates usually consider a reference method or procedure, if values from multiple methods or procedures are combined. This is because a test result or a derived value can depend on the method(s) selected to obtain the parameter value. For example, a value of undrained shear strength derived from a triaxial test can depend on the sampling method, sample handling practice, laboratory test procedure and whether undrained shear strength is derived from maximum deviator stress or maximum principal stress ratio.
- Low, best and high estimates can include judgement and opinion, particularly for a limited quantity or absence of test results and derived values. This implies that outliers may be ignored and that a bias may be introduced relative to the available data. Judgement and opinion consider physically credible values, comparison of data with results from other tests and *a priori* knowledge such as geological setting and comparable experience.
- A wide spread of data can indicate spatial variability of soil. This means that averaging of test results and derived values can obscure a weaker or stronger zone.
- A calculation model can require specific schematisation of soil stratigraphy and model-specific selection of parameter values. This is not covered by low, best and high estimates.

CHARACTERISTIC VALUES OF GEOTECHNICAL PARAMETERS

A characteristic value of a geotechnical parameter represents a ***cautious estimate*** for the value affecting the occurrence of a limit state (CEN, 2004). The selection of a characteristic value takes account of possible differences between derived values of geotechnical parameters and geotechnical parameters representative of the behaviour of a geotechnical structure. Reasons for differences can include non-homogeneity of the ground, extent of the zone governing a particular limit state, uncertainties in geometrical data and analytical model, time effects, brittle or ductile response of the ground, influence of construction activities.

Characteristic values may be lower values, which are less than the most probable value, or upper values, which are greater. Each calculation requires the most unfavourable combination of lower and/or upper values for independent geotechnical parameters.

Statistical methods may be appropriate for selection of a characteristic value (Hicks, 2013; Baecher and Christian, 2003). Usually, they should allow for incorporation of a-priori knowledge of comparable experience with geotechnical parameters, for example by Bayesian methods, as necessary. Selection of a statistical characteristic value is typically such that the calculated probability of a worse value governing the occurrence of a limit state is not greater than 5%. Variance reduction methods may be applied where appropriate.

In principle, spatial ground variability affects:

- The mean (X_m), Standard Deviation (SD) and probability density function (pdf) of the ground property for the location under consideration, including any depth trend.
- The scale of fluctuation (θ) of the ground property, which is the distance over which the property values are significantly correlated; the scale of fluctuation in the (near) horizontal plane is often much larger than in the vertical direction, i.e. $\theta_h >> \theta_v$, for example due to the process of deposition.
- The limit state under consideration, particularly relating to the geometrical quantities of the structure that interacts with the ground, the nature of the applied actions and the volume of ground that represents the domain of influence with respect to the limit state.

The pdf required for the characteristic value should take account of the spatial variability of ground property values and the limit state under consideration, and thus may differ considerably from the underlying pdf for the location under consideration (Figure 1). If the domain of influence is represented by the dimension D, the characteristic value will be a function of the ratio θ/D and will generally lie within the following limits:

- For relatively large values of θ/D, there may be considerable uncertainty regarding the property value governing the structure response. Specifically, although the occurrence of the limit state will generally be governed by the “local” mean, there will be uncertainty about what that mean actually is. The characteristic value may then be represented by the 5 percentile of the underlying pdf. (Figure 1a)
- For intermediate values of θ/D, the characteristic value may be estimated from a pdf with a reduced variance to account for averaging of properties. However, account should also be taken of any apparent

reduction in the property mean due to the tendency for failure to follow the path of least resistance. (Figure 1b)

– For small values of θ/D, there is considerable averaging of property values over potential failure surfaces and the response of the structure may be reasonably represented by a cautious estimate of the mean over the failure surface. For the assumption of a normal distribution of X, this is equivalent to a cautious estimate of X_m, the mean of the underlying distribution. (Figure 1c)

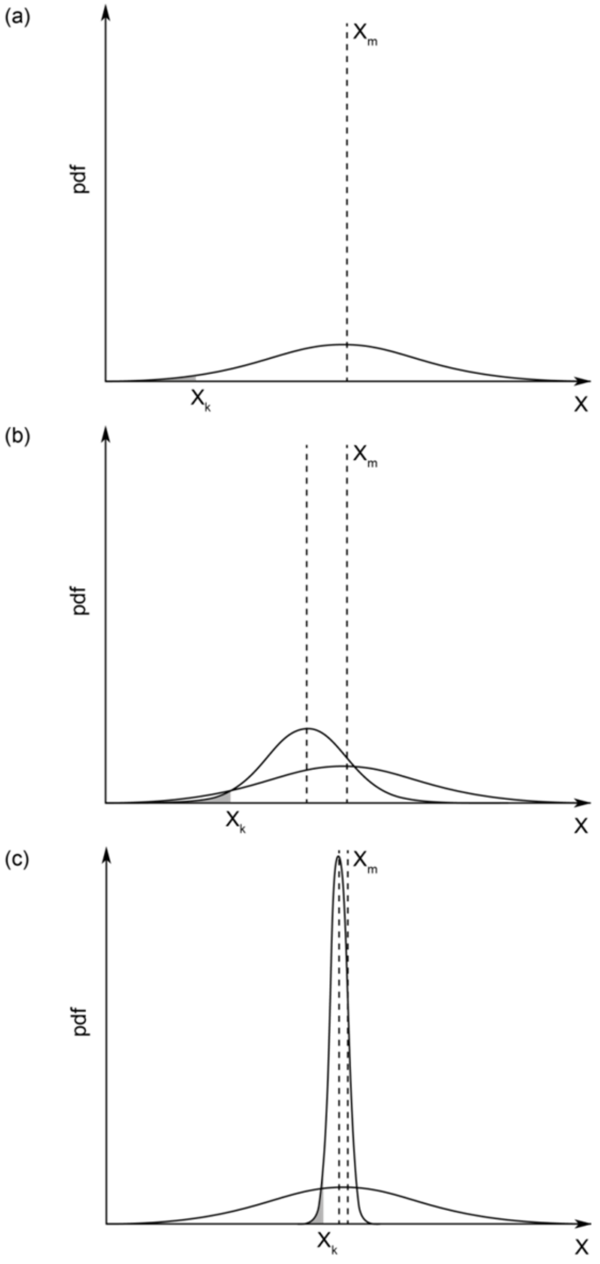

Figure 1. Estimation of characteristic value and pdf (after Hicks, 2012): (a) X_k based on underlying pdf (for large θ/D); (b) X_k based on modified pdf (for intermediate θ/D); (c) X_k based on modified pdf (for small θ/D)

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Symbol	Unit	Quantity
I - GENERAL		
L	m	Length
B	m	Width
D	m	Diameter
d	m	Depth
h	m	Height or thickness
z	m	Penetration or depth below reference level (usually ground surface)
A	m^2	Area
V	m^3	Volume
W	kN	Weight
t	s	Time
v	m/s	Velocity
a	m/s^2	Acceleration
g	m/s^2	Acceleration due to gravity ($g = 9.81\ m/s^2$)
m	kg	Mass
ρ	kg/m^3	Density
π	-	Mathematical constant (= 3.14159)
e	-	Base of natural logarithm (= 2.71828)
ln	-	Natural logarithm
log	-	Logarithm base 10
II - STRESS AND STRAIN		
P_a	kPa	Atmospheric pressure
u	MPa	Pore water pressure
u_o	MPa	Hydrostatic pore pressure relative to seafloor or phreatic surface
σ	kPa	Total stress
σ'	kPa	Effective stress
τ	kPa	Shear stress
t	kPa	Shear stress in s'-t space [$= (\sigma'_1 - \sigma'_3)/2$] or [$= (\sigma_1 - \sigma_3)/2$]
$\sigma_1,\sigma_2,\sigma_3$	kPa	Principal stresses
σ'_{ho}	kPa	Effective in situ horizontal stress
σ_{vo}	kPa	Total in situ vertical stress relative to ground surface or phreatic surface
σ'_{vo}	kPa	Effective in situ vertical stress (or p'_o)
σ'_h	kPa	Effective horizontal stress
σ'_v	kPa	Effective vertical stress
r_u	-	Pore pressure ratio [$= u/\sigma_{vo}$]
p'	kPa	Mean effective stress [$= (\sigma'_1 + \sigma'_2 + \sigma'_3)/3$]
q	kPa	Principal deviator stress [$= \sigma'_1 - \sigma'_3$] or [$= \sigma_1 - \sigma_3$]
s'	kPa	Mean effective stress in s'-t space [$= (\sigma'_1 + \sigma'_3)/2$]
ε	-	Linear strain
$\varepsilon_1,\varepsilon_2,\varepsilon_3$	-	Principal strains
ε_v	-	Volumetric strain
γ	-	Shear strain
ν	-	Poisson's ratio
ν_u	-	Poisson's ratio for undrained stress change
ν_d	-	Poisson's ratio for drained stress change
E	MPa	Modulus of linear deformation (Young's modulus)
E_u	MPa	Modulus of linear deformation (Young's modulus for undrained stress change)
E_d	MPa	Modulus of linear deformation (Young's modulus for drained stress change)
G	MPa	Modulus of shear deformation (shear modulus)
G_{max}	MPa	Shear modulus at small strain
I_r	-	Rigidity index [$= G/\tau_{max}$ or G/s_u]
K	MPa	Modulus of compressibility (bulk modulus)
M	MPa	Constrained modulus [$= 1/m_v$]
μ	-	Coefficient of friction
η	kPa.s	Coefficient of viscosity

III - PHYSICAL CHARACTERISTICS OF GROUND

(a) Density and Unit weights

Symbol	Unit	Quantity
γ	kN/m^3	Unit weight of ground (or bulk unit weight or total unit weight)
γ_d	kN/m^3	Unit weight of dry ground
γ_s	kN/m^3	Unit weight of solid particles
γ_w	kN/m^3	Unit weight of water
γ_{pf}	kN/m^3	Unit weight of pore fluid
γ_{dmin}	kN/m^3	Minimum index (dry) unit weight
γ_{dmax}	kN/m^3	Maximum index (dry) unit weight
γ' or γ_{sub}	kN/m^3	Unit weight of submerged ground
ρ	Mg/m^3 [= t/m^3]	Density of ground
ρ_d	Mg/m^3 [= t/m^3]	Density of dry ground
ρ_s	Mg/m^3 [= t/m^3]	Density of solid particles
ρ_w	Mg/m^3 [= t/m^3]	Density of water
D_r	-, %	Relative density [= $I_D = \gamma_{dmax} (\gamma_d - \gamma_{dmin})/\gamma_d(\gamma_{dmax} - \gamma_{dmin}) = (e_{max} - e)/(e_{max} - e_{min})$]
v	-	Specific volume [= 1+e]
e	-	Void ratio
e_o	-	Initial void ratio
e_{max}	-	Maximum index void ratio
e_{min}	-	Minimum index void ratio
I_D	-, %	Density index [= D_r]
R_D	-, %	Dry density ratio [= γ_d/γ_{dmax}]
n	-, %	Porosity
w	%	Water content
S_r	%	Degree of saturation
r	-, g/kg	Salinity of pore fluid [= ratio of mass of salt to mass of pore fluid]
R	g/l	Salinity of fluid [= ratio of mass of salt to volume of distilled water]
s	g/l	Salinity of fluid [= ratio of mass of salt to volume of fluid]
S	g/kg	Salinity of seawater [= ratio of mass of salt to mass of seawater]

(b) Consistency

Symbol	Unit	Quantity
w_L	%	Liquid limit
w_P	%	Plastic limit
I_P	%	Plasticity index [= $w_L - w_P$]
I_L	%	Liquidity index [= $(w - w_P)/(w_L - w_P)$]
I_C	%	Consistency index [= $(w_L - w)/(w_L - w_P)$]
A	-, %	Activity [= ratio of plasticity index to percentage by weight of clay-size particles]

(c) Particle size

Symbol	Unit	Quantity
D	mm	Particle diameter
D_n	mm	n percent diameter [n% < D]
C_u	-	Uniformity coefficient [= D_{60}/D_{10}]
C_c	-	Curvature coefficient [= $(D_{30})^2/D_{10}D_{60}$]

(d) Dynamic Properties

Symbol	Unit	Quantity
v_p	m/s	P-wave velocity (compression wave velocity)
v_s	m/s	S-wave velocity (shear wave velocity)
v_{s1}	m/s	S-wave velocity normalised to 100 kPa in situ vertical stress
D	-, %	Damping ratio of ground

Symbol	**Unit**	**Quantity**

(e) Hydraulic properties

k	m/s	Coefficient of permeability
k_v	m/s	Coefficient of vertical permeability
k_h	m/s	Coefficient of horizontal permeability
i	-	Hydraulic gradient

(f) Thermal and Electrical properties

T	°C	Temperature
k	W/(m·K)	Thermal conductivity
a_L	1/°C	Thermal expansion coefficient (linear)
α	m^2/s	Thermal diffusion coefficient
ρ	Ω.m	Electrical resistivity
K	S/m	Electrical conductivity

(g) Magnetic properties

B	T	Magnetic flux density (or magnetic induction)

(h) Radioactive properties

γ	CPS	Natural gamma ray

IV - MECHANICAL CHARACTERISTICS OF GROUND

(a) Cone Penetration Test (CPT)

q_c	MPa	Cone resistance
q_{c1}	MPa	Cone resistance normalised to 100 kPa effective in situ vertical stress
f_s	MPa	Sleeve friction
f_t	MPa	Sleeve friction corrected for pore pressures acting on the end areas of the friction sleeve
R_f	%	Ratio of sleeve friction to cone resistance
R_{ft}	%	Ratio of sleeve friction to corrected cone resistance (f_s/q_t or f_t/q_t)
u_1	MPa	Pore pressure at the face of the cone
u_2	MPa	Pore pressure at the cylindrical extension above the base of the cone or in the gap between the friction sleeve and the cone
u_2*	MPa	Pore pressure u_2, but derived rather than measured
u_3	MPa	Pore pressure immediately above the friction sleeve or in the gap above the friction sleeve
K	-	Adjustment factor for ratio of pore pressure at u_1 to u_2 location
q_n	MPa	Net cone resistance
q_t	MPa	Corrected cone resistance (or total cone resistance)
B_q	-	Pore pressure ratio
Q_t	-	Normalized cone resistance [= q_n/σ'_{vo}]
F_r	%	Normalized friction ratio [= f_t/q_n]
N_c	-	Cone factor between q_c and s_u
N_k	-	Cone factor between q_n and s_u
I_c	-	Soil behaviour type index

(b) Standard Penetration Test (SPT)

N	Blows/0.3 m	SPT blowcount
N_{60}	Blows/0.3 m	SPT blowcount normalised to 60% energy
$N_{1,60}$	Blows/0.3 m	SPT blowcount normalised to 60% energy and to 100 kPa effective in situ vertical stress

Symbol	Unit	Quantity
(c) Strength of soil		
s_u	kPa	Undrained shear strength (or c_u)
s_u/σ'_{vo}	-	Undrained strength ratio
κ	kPa/m	Rate of increase of undrained shear strength with depth (linear)
c'	kPa	Effective cohesion intercept
φ'	°(deg)	Effective angle of internal friction
φ'_{cv}	°(deg)	Effective angle of internal friction at large strain
ε_{50}	%	Strain at 50% of peak deviator stress (or ε_c)
E_{50}	MPa	Young's modulus at 50% of peak deviator stress
$s_{u;r}$	kPa	Undrained shear strength of remoulded soil
$s_{u;ar}$	kPa	Undrained shear strength of aged remoulded soil
s_R	kPa	Undrained residual shear strength
S_t	-	Sensitivity [= $s_u/s_{u;r}$ or s_u/s_R]
T_x	-	Thixotropy strength ratio [$T_x(t) = s_{u;ar}(t)/s_{u;r}$]
σ'_c	kPa	Effective consolidation pressure
M	-	Gradient of critical state line when projected onto a constant volume plane
A	-	Pore pressure coefficient for anisotropic pressure increment
B	-	Pore pressure coefficient for isotropic pressure increment
(d) Strength of rock		
$I_{s(50)}$	MPa	Point load strength index
σ_c	MPa	Uni-axial compressive strength
(e) Consolidation (one dimensional)		
σ'_p	kPa	Effective preconsolidation pressure (or effective vertical yield stress in situ)
σ^*_{ve}	kPa	Effective vertical stress on ICL at e_0
σ'_{vy}	kPa	Effective vertical yield stress in situ (or effective preconsolidation pressure)
C_c	-	Compression index
C^*_c	-	Intrinsic compression index [= e^*_{100} - e^*_{1000}]
C_s	-	Swelling index (or re-compression)
CR	-	Primary compression ratio [= $C_c/(1+e_0)$]
RR	-	Recompression ratio [= $C_s/(1+e_0)$]
e_0	-	Void ratio at σ'_{vo}
e_L	-	Void ratio at liquid limit w_L
e^*_{100}	-	Void ratio at σ'_v = 100 kPa during one-dimensional intrinsic compression
e^*_{1000}	-	Void ratio at σ'_v = 1000 kPa during one-dimensional intrinsic compression
C_α	-	Coefficient of secondary compression (primary compression)
$C_{\alpha s}$	-	Coefficient of secondary compression (swelling/re-compression)
c_v	m^2/s	Coefficient of consolidation
H	m	Drainage path length
ICL	-	Intrinsic compression line (Burland 1990)
I_v	-	Void index [= $(e_0 - e^*_{100})/C^*_c$]
m_v	m^2/MN	Coefficient of volume compressibility
M	MPa	Constrained modulus [= $1/m_v$]
p	kPa	Vertical pressure
OCR	-	Overconsolidation ratio [= σ'_p/σ'_{vo}]
SCC	-	Sedimentation compression curve
SCL	-	Sedimentation compression line (Burland 1990)
S_σ	-	Stress sensitivity [= $\sigma'_{vy}/\sigma^*_{ve}$]
YSR	-	Yield stress ratio [= $\sigma'_{vy}/\sigma'_{vo}$]

V - GEOTECHNICAL DESIGN

(a) Partial factors

γ_m	-	Material factor (partial safety factor)
γ_f	-	Load factor (partial action factor)

(b) Seismicity

a_g	m/s^2	Effective peak ground acceleration (design ground acceleration)
d_g	m	Peak ground displacement
α	-	Acceleration ratio [= a_g/g]
τ_c	kPa	Seismic shear stress

(c) Compaction

ρ_{dmax}	Mg/m^3 [= t/m^3]	Maximum dry density
ρ_{max}	Mg/m^3 [= t/m^3]	Maximum density
w_{opt}	%	Optimum moisture content

(d) Earth pressure

δ	°(deg)	Angle of interface friction (between ground and foundation)
K	-	Coefficient of lateral earth pressure
K_a	-	Coefficient of active earth pressure
K_{ac}	-	Coefficient of active earth pressure for total stress analysis
K_p	-	Coefficient of passive earth pressure
K_{pc}	-	Coefficient of passive earth pressure for total stress analysis
K_o	-	Coefficient of earth pressure at rest
K_{onc}	-	K_o for normally consolidated soil
K_{ooc}	-	K_o for overconsolidated soil

(e) Foundations

A	m^2	Total foundation area
A'	m^2	Effective foundation area
B'	m	Effective width of foundation
E_s	MN/m^3	Modulus of subgrade reaction
k	MPa/m	Rate of change of modulus of subgrade reaction E_s with depth z
L'	m	Effective length of foundation
H	MN	Horizontal external force or action
V	MN	Vertical external force or action
M	MN.m	External moment
T	MN.m	External torsion moment
Q	MN	Total vertical resistance of a foundation/pile
Q_p	MN	End-bearing of pile
Q_s	MN	Shaft resistance of pile
q_p	MPa	Unit end-bearing
q_{lim}	MPa	Limit unit end-bearing
f	kPa	Unit skin friction (or q_s)
f_{lim}	kPa	Limit unit skin friction
p	MN/m	Lateral resistance per unit length of pile
p_{lim}	MN/m	Limit lateral resistance per unit length of pile
s	m	Settlement
t	MN/m	Skin friction per unit length of pile
y	mm	Lateral pile deflection
z	mm	Axial pile displacement
α	-	Adhesion factor between ground and foundation (= f/s_u)
β	-	Adhesion factor between ground and foundation (= f/σ'_v or f/σ'_{vo})
δ	°(deg)	Angle of interface friction (between ground and foundation)

Symbol	Unit	Quantity
δ_{cv}	°(deg)	Constant volume or critical-state angle of interface friction (between ground and foundation)
N_c, N_q, N_γ	-	Bearing capacity factors
K_c, K_q, K_γ	-	Bearing capacity correction factors for inclined forces or actions, foundation shape and depth of embedment
i_c, i_q, i_γ	-	Bearing capacity correction factors for external force inclined from vertical shape
s_c, s_q, s_γ	-	Bearing capacity correction factors for foundation shape
d_c, d_q, d_γ	-	Bearing capacity correction factors for foundation embedment

Signs:
- A "prime" applies to effective stress.
- A "bar" above a symbol relates to average properties.
- A "dot" above a symbol denotes derivative with respect to time.
- The prefix "Δ" denotes an increment or a change.
- A “star” after a symbol denotes value corrected for pore fluid salinity.

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Contacts
Netherlands Enterprise Agency (RVO.nl)
Croeselaan 15 | 3521 BJ | Utrecht
P.O. Box 8242 | 3503 RE | Utrecht
www.rvo.nl / http://english.rvo.nl

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