Integration and Interpretation Report OWF1 & OWF2

Integration and Interpretation Report OWF1 & OWF2 | Bay of Biscay

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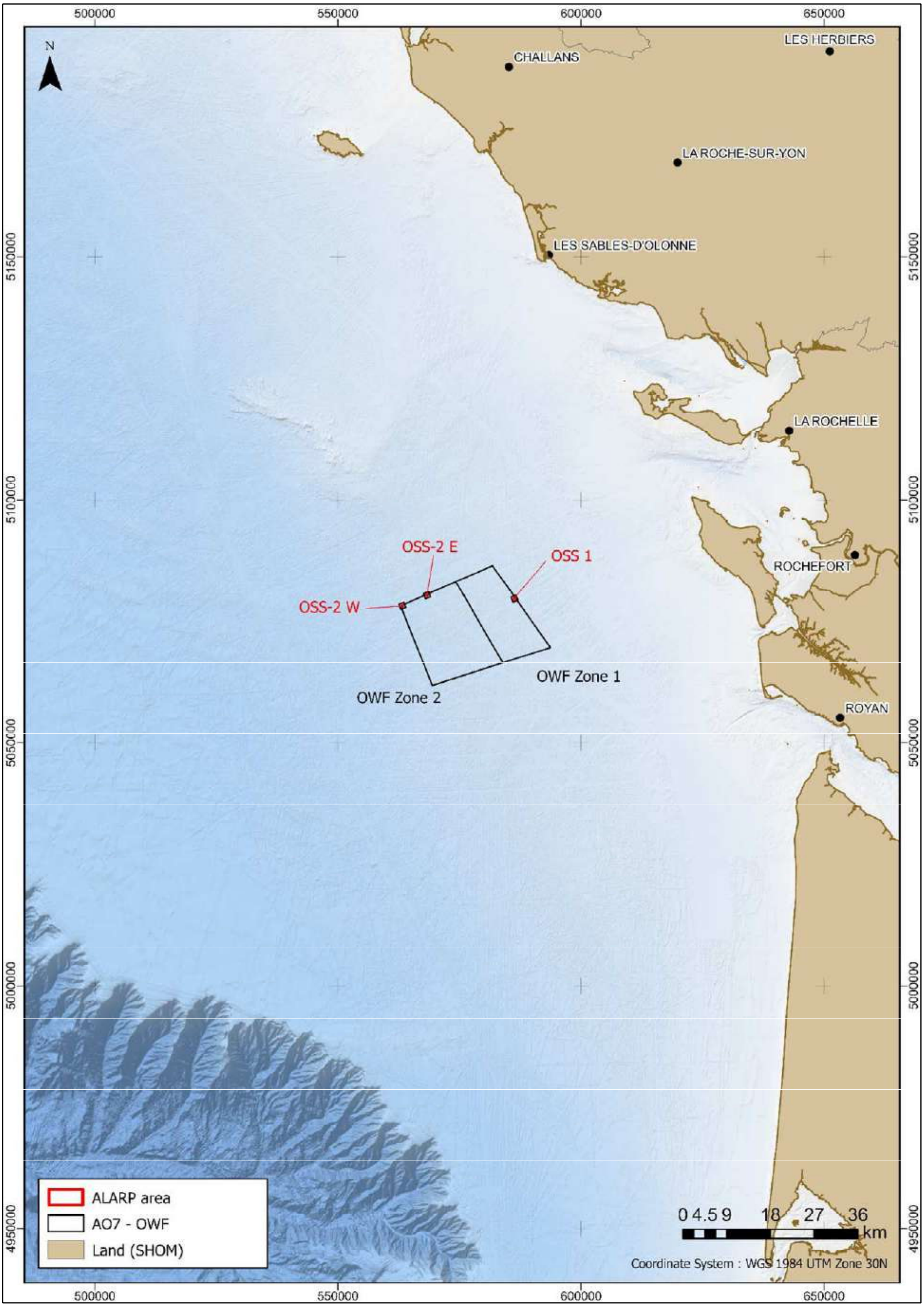
Frontispiece



Executive Summary

To develop offshore wind in France, the Programmation Pluriannuelle de l'énergie (PPE) establishes a schedule and goal for the coming years. For each tender area, "De-risk studies" for offshore windfarms (OWF) are commissioned by Direction Général de l'Energie et du Climat (DGEC). As part of these de-risk studies, Fugro has performed a geotechnical site investigation (SI) over the OWF Zone 1 (OWF1) and OWF Zone 2 (OWF2) located in the Bay of Biscay, offshore France.

The OWF sites are part of the AO7 tender call for OWF (façade Sud Atlantique) located 66 km south-west of La Rochelle and covers an area of 432 km² where in-situ testing and sediment / rock coring at twenty-three (23) locations (sampling and CPT boreholes) were performed (including OSS locations). Onshore laboratory testing results are included in this final integration report.

Geophysical data were provided by DGEC/RTE, notably: seventy-eight (78) 2D UHRS lines; one hundred and eighty-nine (189) SBP lines; and seafloor site investigation data, comprising grab samples with PSD analysis, MBES, backscatter, SSS and magnetometry data. Interpretation results of these data were also provided such as the seafloor nature map, a sediment thickness map and uninterpreted UHRS data. For the sake of ensuring quality of the ground model, Fugro decided to interpret UHRS data as part of the integration work to match geotechnical data acquired as part of the geotechnical SI.

This report presents the seafloor and sub-seafloor conditions over the site, resulting from the interpretation of both geophysical and acquired geotechnical data and it develops an integrated ground model detailing expected soil units along with their geotechnical parameters. Key findings are:

- Seafloor conditions were described:
  - Water depth at OWF site ranges between -54.6 m and -81.9 m HZ and seafloor gradient of 0.4° in average, ranging from 0.0° to 61.5;
  - Seafloor gently dips towards the south-west;
  - Seafloor nature ranges from mud to rock. Sand is dominant across the OWF site
  - Identified seafloor features include rock outcrops, sand dunes, sand ribbons, megaripples, anthropogenic obstructions (shipwrecks) and trawlmarks. Sand dunes are mostly distributed in OWF2 while rock outcrops occur within OWF1.
  - OWF site seafloor is exposed to wave base action during extreme events (storms). Persistent NNE/SSW currents may remobilize sediments forming scours.
- Sub-seafloor conditions are described based on the geophysical and geotechnical data interpretation:
  - Four (4) seismostratigraphic units (SU) were defined and gridded across the OWF site based on available 2D UHRS data;
  - A major fault was mapped across the OWF site;
  - Fifteen (14) Ground Types (GT) have been identified from geotechnical data, including Quaternary (GT1 and GT2) and Miocene sediments (GT3 and GT4), sedimentary rocks (CALCILUTITE, CALCISILTITE; CALCARENITE, CLAYSTONE, SILTSTONE, SANDSTONE; GT5 to

GT11) and residual soils and completely weathered rock related to faults (GT13 and GT14), karsts (GT15), or uncompacted deposits (GT12)

- Integration of geotechnical and geophysical data led to the definition of seven (7) Geotechnical Units and fifteen (15) sub-units. Nine (9) soil profiles were defined, accounting for the observed lateral and vertical variability of the 7 geotechnical units. A soil province map allows to understand the distribution of individual soil profiles. A set of thirteen (13) geotechnical parameters was derived for each sub-unit based on available geotechnical data;
- Geohazard, soil constraint and anthropogenic constraint inventories are provided along with remaining uncertainties and possible mitigations:
  - Six (6) geohazards were observed and on the available data and two (2) are inferred to be feasible at the OWF site;
  - Eight (8) soil constraints were observed and on the available data and two (2) are inferred to be feasible at the OWF site;
  - Anthropogenic constraints include the presence of shipwrecks, a protected area, fishing activity and a shipping route. Full UXO DTS and risk assessment is not included but is recommended.
- Recommendations for additional site investigation as well as general recommendations on foundation pile design and installation for future offshore wind turbines considering predicted soil conditions are provided.

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Appendices

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Abbreviations

AIS	Automatic Identification System
ALARP	As Low As Reasonably Possible
BDSS	Base de Données Sédimentologiques du Shom
BE	Best Estimate
BP	Before Present
BRGM	Bureau de Recherche Géologique et Minière
BSF	Below seafloor
CANDHIS	Centre d'Archivage National de Données de Houle In-Situ
CEREMA	Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement
CFMS	Comité Français de Mécanique des Sols et de Géotechnique
CIRIA	Construction Industry Research and Information Association
CPT	Cone Penetration Testing
DGEC	Direction Générale de l'Energie et du Climat
DTM	Digital terrain model
EMODnet	European Marine Observation and Data Network
H	Horizon
HE	High Estimate
HZ	Hydrographic Zero
IGM	Integrated Ground Model
kyr	Thousand Years
LAT	Lowest Astronomical Tide
LE	Low Estimate
LGM	Last Glacial Maximum
m	metre
MBES	Multi-Beam Echo Sounder
MSL	Mean Sea Level
OSS	Offshore Substation
OWF	Offshore Windfarm
OWT	Offshore Wind Turbine
PLT	Point Load Test
PPE	Programmation Pluriannuelle de l'Energie
PSD	Particle Size Distribution
RC	Rock Core
RéNaSS	Réseau National de Surveillance Sismique
RTE	Réseau de Transport d'Electricité
S	Second
SBP	Sub-Bottom Profiler

SHOM	Service Hydrographique et Océanographique de la Marine
SI	Site Investigation
SSS	Side-Scan Sonar
ST	Soil or Rock Type
SU	Soil or Rock Unit
U	Geological/Seismo-stratigraphic unit
UXO	Unexploded Ordnance
UHRS	Ultra-High Resolution Seismic
VAP	Vendean-Armorican Platform
WIP	Wireline Push Sample

1. Introduction

1.1 Project Background

To develop offshore wind in France, the Programmation Pluriannuelle de l'Energie (PPE) establishes a schedule for the coming years, setting location and maximal power of offshore wind tenders. For each tender, 'De-risk' studies are conducted by DGEC for the development of wind farm sites. Among these de-risk studies, geophysical and geotechnical survey were performed to understand the main characteristics of the project location and enable the tender candidates to estimate project costs.

DGEC and RTE jointly contracted Fugro to carry out a geotechnical site investigation (SI) and provide detailed soil information at the offshore substation (OSS) locations of the two planned AO7 offshore windfarm (OWF) sites: AO7 Zone 1 (OWF1) and AO7 Zone 2 (OWF2). The three OSS sites are OSS1 in OWF1, OSS2-E and OSS2-W both in OWF2.

The geotechnical SI was performed onboard of the geotechnical vessel MV Fugro Quest from the 2nd of July 2023 to the 12th of September 2023.

1.2 Purpose of Report

The aim of this integration study is to inform DGEC and bidders for the tender call to help their future decisions making in the planning and design of the AO7 OWF1 and OWF2 development. Acquired data alongside Fugro experience, client provided data, and publicly available datasets were integrated, providing comprehensive commentary on ground conditions for foundation / anchoring solution selection.

The integrated ground model (IGM) integrates geophysical and geotechnical data from de-risk studies as enacted in Section 5.5 of Recommendations for planning and designing foundations of offshore wind turbines, Comité Français de Mécanique des Sols et de Géotechnique (CFMS, 2020). IGM provides a state of knowledge document and digital deliverables relating to the geotechnical site conditions for windfarm development.

1.3 Scope of Work

1.3.1 Integrated Ground Model

The main purpose of this report is to integrate geotechnical data acquired during the geotechnical SI with client-provided geophysical data; Fugro experience; and publicly available data to provide details on the soil conditions at the AO7 OWF1 and OWF2 sites. More specifically, the report scope is to:

- Interpret geophysical profiles to understand the stratigraphic framework and soil unit lateral and vertical variability to the foundation depth of interest (60 metres below the seafloor (m BSF));
- Describe the seafloor and sub-seafloor conditions based on available data;

- Develop an engineering geological ground model derived from the integration of geophysical and geotechnical data results to a depth of 60 m BSF;
- Provide a review of identified geohazards, soil constraints and anthropogenic constraints;
- Provide comments and recommendations on any possible geotechnical issues with respect to the design and installation of the future OWFs considering predicted soil conditions.

This revision includes the input and relevant updates based on geotechnical laboratory data.

1.3.2 Area of Interest

OWF1 and OWF2 are located within AO7 tender call area, 66 km south-west of La Rochelle. The area of interest for this report covers an area of 432 km² and correspond to both OWF1 and OWF2 areas and will be referred to as "OWF site" in the report.

The boundary coordinates of OWF1 and OWF2 are indicated in Table 1.1, and Figure 1.1, and made available as a GIS package. Plate 1.1 provides a larger scale vicinity map.

Table 1.1: Boundary coordinates for OWF area

Points	Easting (m)	Northing (m)
A	581745.74	5086450.71
B	593722.87	5069590.01
C	583920.12	5066435.75
D	569429.21	5061772.61
E	562940.98	5078145.61
F	574268.38	5083124.98
Notes: Datum = WGS 84/UTM Zone 30N		

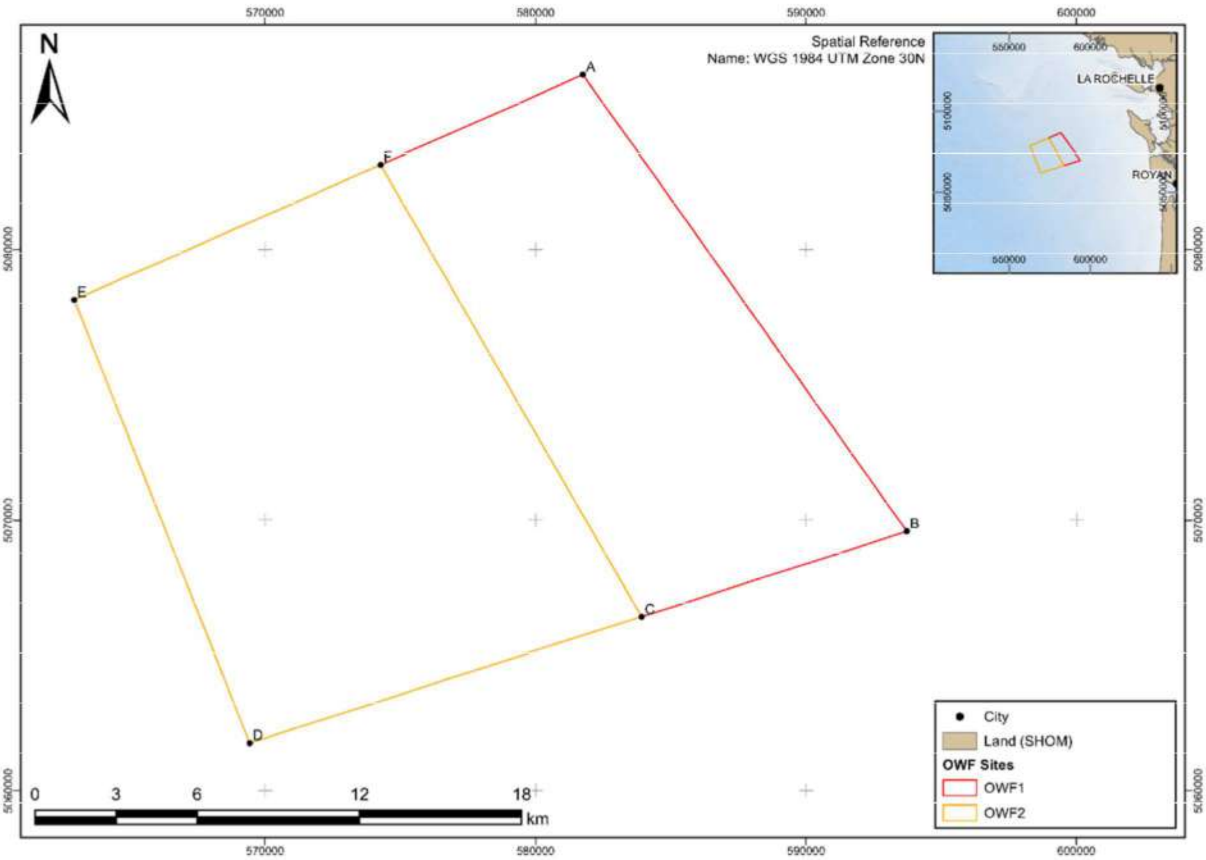


Figure 1.1: OWF site location map

1.3.3 Depth of Interest

The depth of interest for the OWF1 and OWF2 integration report is 60 m BSF. This depth range provides correlation with the extent of the geotechnical datasets and the geophysical investigation data.

1.4 Geodetic Parameters and Vertical Datum

The parameters of the coordinate system used in this report, charts and GIS database are WGS 84 UTM zone 30N, (EPSG code: 32630), as summarised Table 1.2.

All elevation provided as part of this report are reduced to the Hydrographic Zero (HZ) using the Bathyelli v2.0 model (https://diffusion.shom.fr/donnees/references-verticales/surface-zero-hydrographique-bathyelli-20.html#) calibrated using the Sables d'Olonnes tide gauge and (when stated) the lowest astronomical tide (LAT). Depth of soil units are provided in meters below seafloor (m BSF).

Table 1.2: Project Coordinate Reference System Parameters

Geodetic Datum	
EPGS Code	EPSG: 32630
Geographic Coordinate System	WGS 84 / UTM zone 30N
Datum	World Geodetic System 1984
Spheroid	WGS 1984
Semi-major axis	a = 6 378 137.0 m
Inverse flattening	$^1/_f$ = 298.257223563
Prime Meridian	Greenwich (0,0)
Geodetic Datum - Projected	
Projection	Transverse Mercator
Grid system	UTM zone 30N
Central meridian	-3,0
Latitude of origin	0.0
False easting	500 000 m
False northing	0.0 m

1.5 Guidelines on Use of the Report

Appendix A outlines the limitations of this report in terms of a range of considerations including, but not limited to, its purpose, its scope, the data on which it is based, its use by third parties, possible future changes in design procedures, and possible changes in the conditions at the sites with time. It represents a clear exposition of the constraints which apply to all reports issued by Fugro. It should be noted that the guidelines do not in any way supersede the terms and conditions of the contract between Fugro and DGEC/RTE.

2. Data Review

2.1 Overview

This section details the data that was integrated to inform site conditions and the IGM at the OWF site. These data include:

- Fugro acquired data;
- Client provided data;
- Additional publicly available data.

The plates associated with this section are Plate 2.1 which shows the locations of Fugro's acquired geotechnical data across the OWF site and Plate 2.2 which shows available 2D UHRS data.

2.2 2023 Site Investigation - Fugro Data

This integration work follows a geotechnical SI performed onboard of the geotechnical vessel MV Fugro Quest from the 2nd of July 2023 to the 12th of September 2023.

A total of twenty-three (23) geotechnical locations are considered as part of this report:

- One (1) Cone Penetration Testing (CPT) boreholes;
- Twelve (12) sampling boreholes;
- Ten (10) composite CPT and sampling boreholes.

Four (4) of the above were performed at the OSS1 location, one (1) at the OSS2-E location, one (1) at the OSS2-W location and seventeen (17) across the OWF site. Details on the individual boreholes such as coordinates, water depth and final penetration are detailed in Table 2.1.

Table 2.1: Fugro Geotechnical Data acquired during Geotechnical SI

Location	Type	Zone	Easting (m)	Northing (m)	Water Depth* (m LAT)	Final Penetration (m BSF)
OSS1_BH1	Sampling	OSS1	586305.00	5079670.96	59.7	70.3
OSS1_BH2	CPT and Sampling	OSS1	586330.40	5079610.43	59.8	60.6
OSS1_BH3	Sampling	OSS1	586265.72	5079619.98	59.8	62.1
OSS1_BH4	CPT and Sampling	OSS1	586294.18	5079630.47	59.7	61.0
OSS2-E_BH4	CPT and Sampling	OSS2-E	568351.12	5080319.85	74.1	70.1
OSS2-W_BH4	CPT and Sampling	OSS2-W	563280.11	5078139.44	78.6	70.1
OWF_BH01	Sampling	OWF1	581179.19	5083840.35	61.0	60.2
OWF_BH03	Sampling	OWF1	581370.07	5079100.57	64.6	60.2
OWF_BH04	CPT and Sampling	OWF1	584365.02	5075420.68	63.5	60.4
OWF_BH05	Sampling	OWF1	588228.54	5073669.79	61.0	3.3

Location	Type	Zone	Easting (m)	Northing (m)	Water Depth* (m LAT)	Final Penetration (m BSF)
OWF_BH05a	Sampling	OWF1	588228.04	5073666.05	61.1	60.4
OWF_BH06	CPT and Sampling	OWF1	583684.03	5068750.28	67.1	23.1
OWF_BH06a	CPT and Sampling	OWF1	583683.89	5068745.31	66.7	60.7
OWF_BH07	Sampling	OWF1	587019.81	5068409.63	64.4	35.0
OWF_BH08	Sampling	OWF2	570487.58	5078189.67	73.7	37.9
OWF_BH10	CPT and Sampling	OWF2	572951.28	5075910.30	72.7	30.3
OWF_BH11	CPT	OWF2	568403.97	5070979.30	78.1	9.8
OWF_BH11a	CPT and Sampling	OWF2	568399.43	5070980.91	78.1	61.0
OWF_BH14	Sampling	OWF2	578753.79	5073299.65	70.0	15.0
OWF_BH14a	Sampling	OWF2	578754.23	5073303.17	69.6	60.5
OWF_BH16	CPT and Sampling	OWF2	577010.41	5069429.57	72.7	60.5
OWF_BH17	Sampling	OWF2	570527.03	5065371.13	78.5	60.3
OWF_BH18	Sampling	OWF2	581408.95	5066279.73	69.3	60.5

Notes:
Geodetic Datum: WGS 84/UTM Zone 30N
* Water Depth from CTD readings, reduced to LAT
BSF Below Seafloor
CPT Cone Penetration testing
LAT Lowest Astronomic Tide

Geotechnical borehole locations are displayed in Figure 2.1 and presented in Plate 2.1.

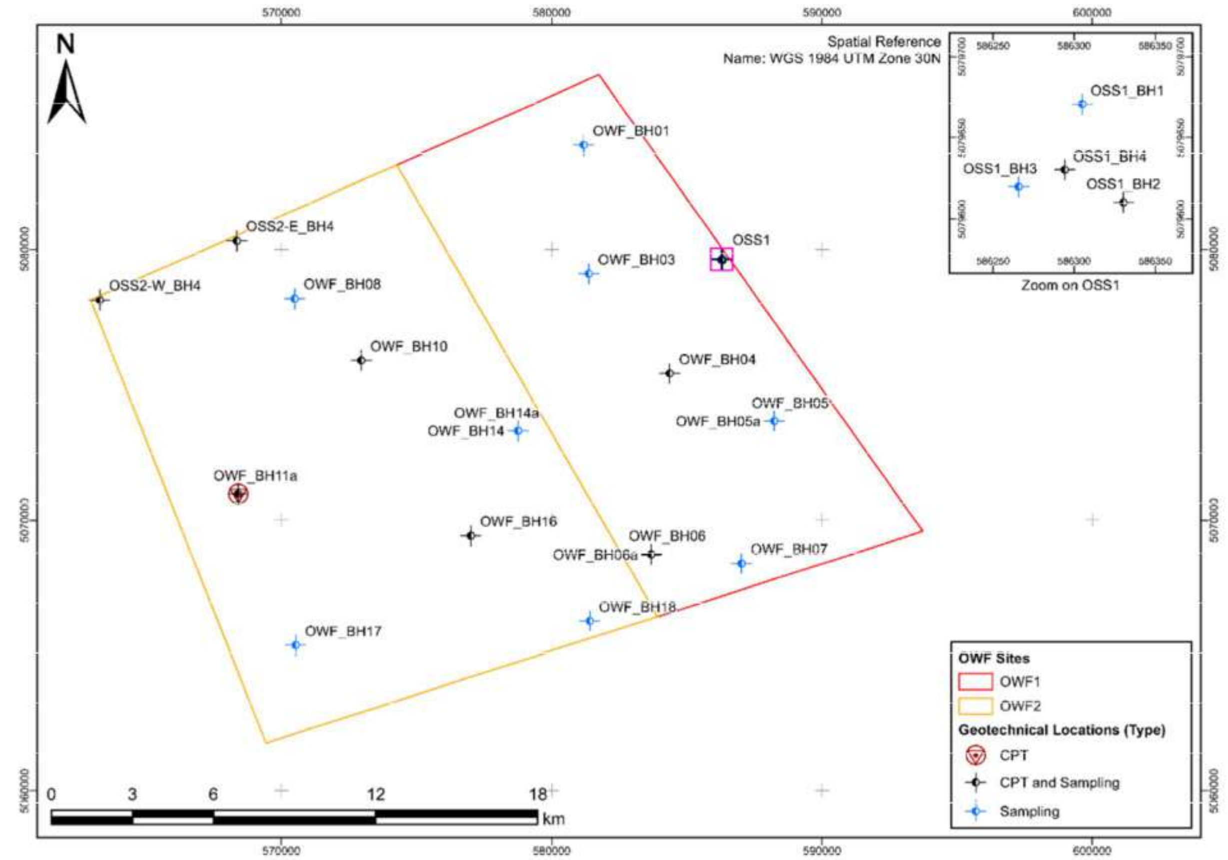


Figure 2.1: Geotechnical borehole location map

Geotechnical data, including geotechnical logs and offshore laboratory data, were extracted from different Fugro reports, which references are detailed in Table 2.2.

Table 2.2: Fugro reports delivered as part of the geotechnical SI at the date of present report delivery

Title	Report Reference	Issue Date
Field Operations and Preliminary Results Report – AO7 Oléron OWF and OSS Geotechnical Site Investigation *(Fugro, 2023a)*	F210748-REP-001_DGEC-RTE-AO7	03/10/2023
Measured and Derived Geotechnical Parameters Report – AO7 – OWF – Geotechnical Site Investigation *(Fugro, 2023b)*	F210748-REP-004_DGEC-A07-OWF	26/03/2023
Measured and Derived Geotechnical Parameters Report – AO7 – OSS – Geotechnical Site Investigation *(Fugro, 2023c)*	F210748-REP-003_RTE-A07-OSS	26/03/2023
Note: *Italic* Reference used in text		

2.2.1 In Situ Test Data

In situ test data details and methods are detailed in the Section 3 of Fugro reports (Fugro, 2023a,b,c).

2.2.2 Sampling Data

Sampling data details and methods are detailed in the Section 4 of Fugro reports (Fugro, 2023a,b,c).

2.2.3 Laboratory Test Data

Laboratory test data details and methods are detailed in the Section 4 of Fugro reports (Fugro, 2023a,b,c).

2.3 Client Provided Data

This section details the data provided by DGEC as part of the study. These data were compiled or acquired by SHOM and/or TECNOAMBIENTE as part of early de-risking studies commissioned by DGEC.

2.3.1 Geophysical Data

2.3.1.1 Regional Bathymetry

DGEC provided a Digital Terrain Model (DTM) as a raster file with the regional Bathymetry from SHOM (Service Hydrographique et Océanographique de la Marine). This DTM covers the entire French Atlantique façade with a grid resolution of 111 m and is the result of a compilation of 18 bathymetric databases acquired between 1951 and 2015 by SHOM and compiled in 2015 as part of the HOMONIM project (SHOM, 2022a,b). The water depth of this data is provided in metres relative to the lowest astronomic tide (m LAT). The resulting map is displayed in Figure 2.2.

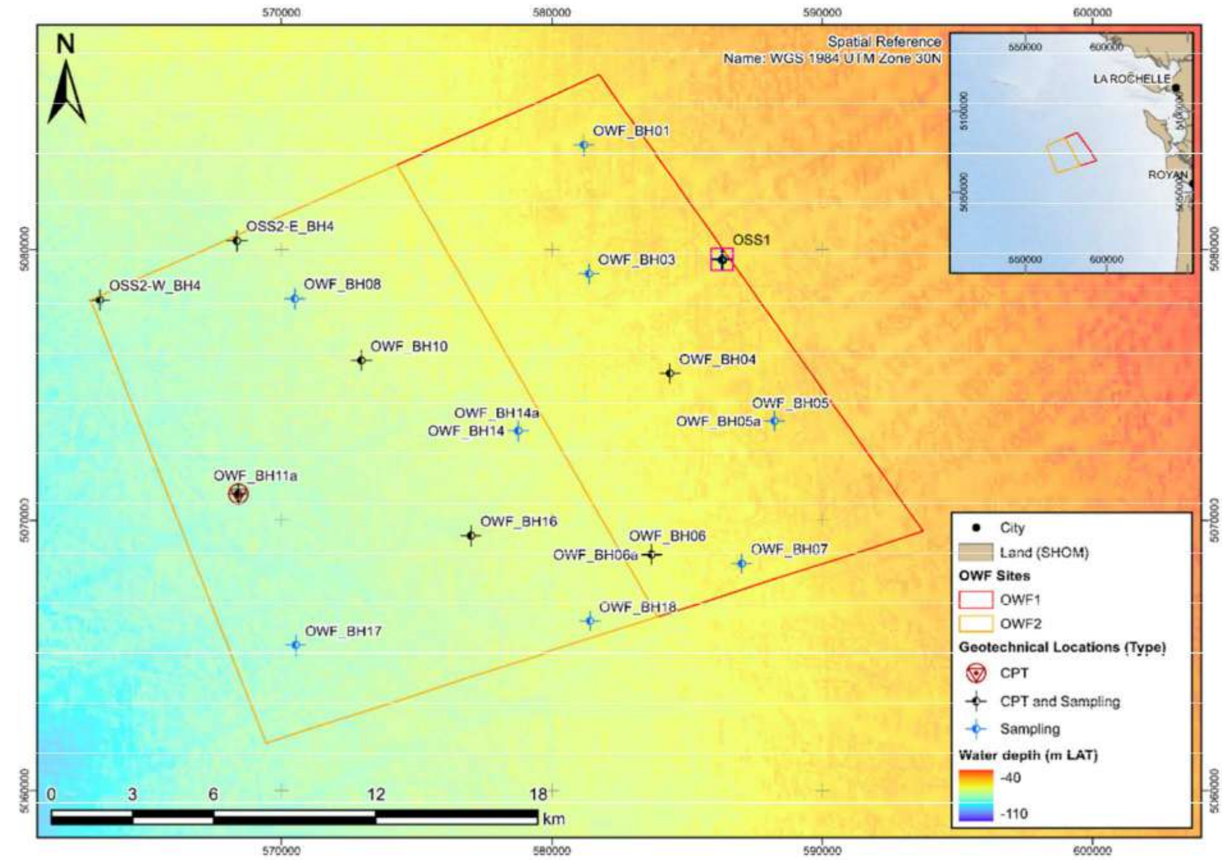


Figure 2.2: HOMONIM bathymetric data across the Bay of Biscay

Across the OWF site, the HOMONIM data presents a poor quality due to source data that had acquired from 1960's to 1970's as sparse sounding measurements leading to high uncertainties (vessel positioning, tide corrections).

2.3.1.2 Multi-Beam Echosounder

To reduce uncertainties, SHOM acquired multi-beam echosounder (MBES) data across the OWF site between March and October 2022 using several geophysical vessels at different period of times (SHOM, 2023a, b). Two parameters were recorded using MBES:

- Bathymetry, provided in m HZ;
- Seafloor backscatter (or reflectivity).

The resulting data was compiled into DTMs with 1 m of grid resolution (SHOM, 2023e, f). The resulting backscatter map is displayed in Figure 2.3.

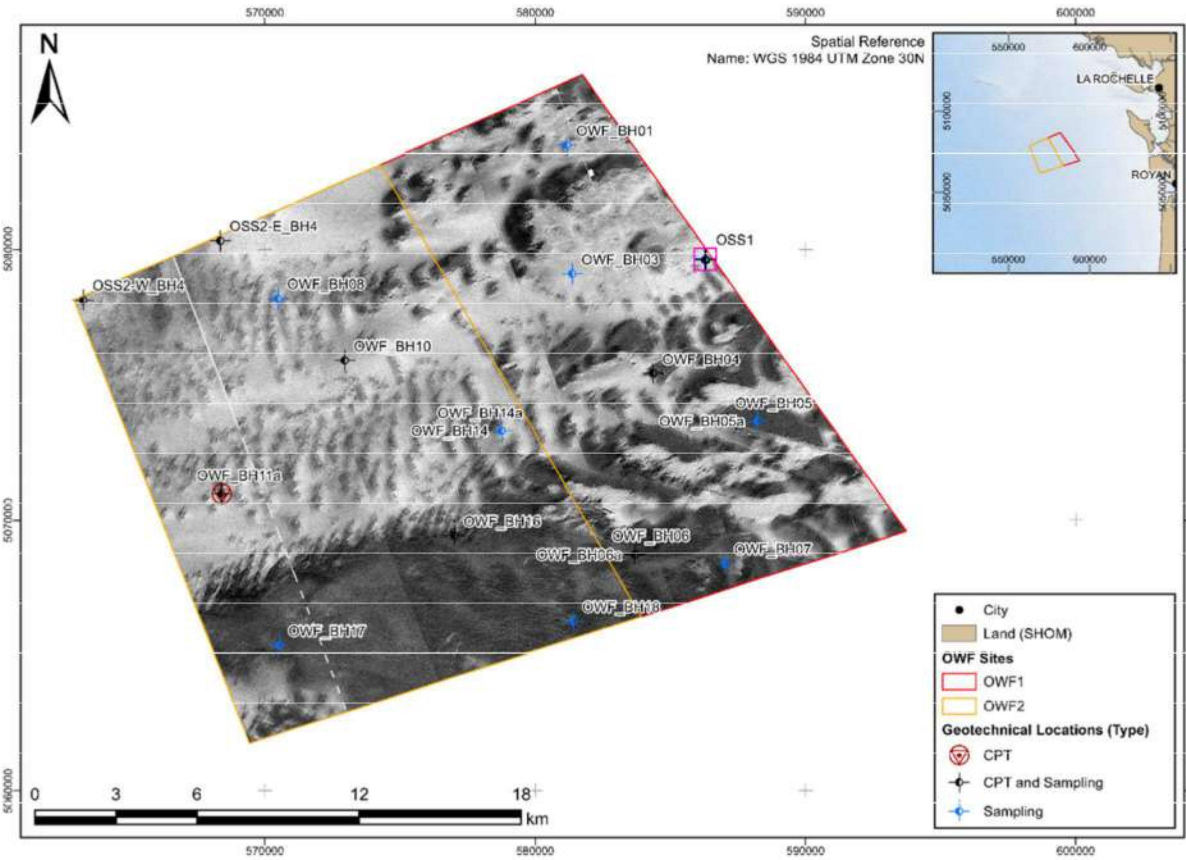


Figure 2.3: MBES backscatter data at the OWF site

2.3.1.3 Side Scan Sonar

SHOM acquired side scan sonar (SSS) data across the OWF site between March and October 2022 using several geophysical vessels at different period of times (SHOM, 2023e, f). Only part of the OWF site was covered due to technical issues with SSS devices. The resulting data was provided as raster files with 1.6 m of grid resolution. The resulting SSS map is displayed in Figure 2.4.

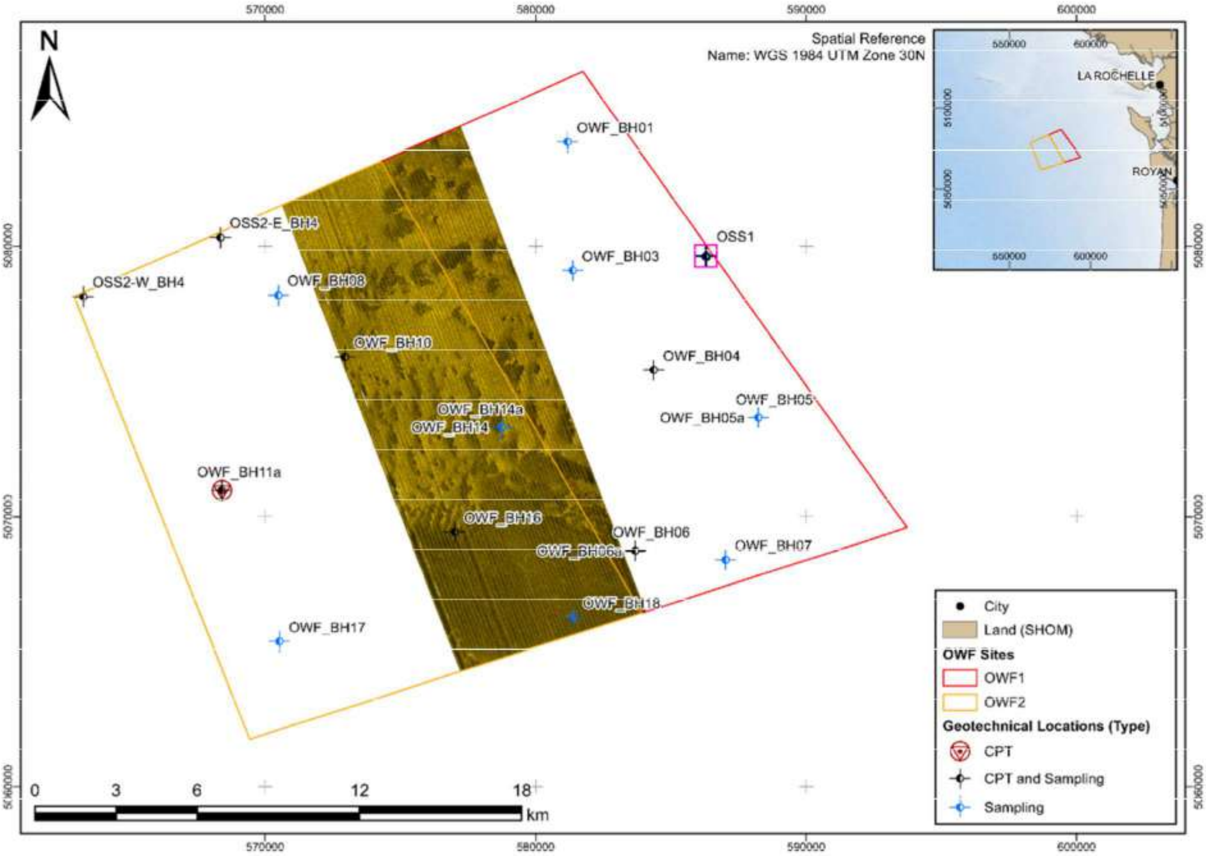


Figure 2.4: SSS data at the OWF site

2.3.1.4 Sub-bottom Profiler

SHOM acquired sub-bottom profiler (SBP) data across the OWF site between March and October 2022 using several geophysical vessels at different periods of time (SHOM, 2023e, f). The resulting data were provided as SEG files along with navigation files. A shapefile with the SBP profile traces was also provided.

A total of 2207 km of SBP profiles were acquired at the OWF site, with a spacing varying between 150 m and 400 m (SHOM, 2023e, f). Figure 2.5 shows the traces of the SBP data acquired across the OWF site.

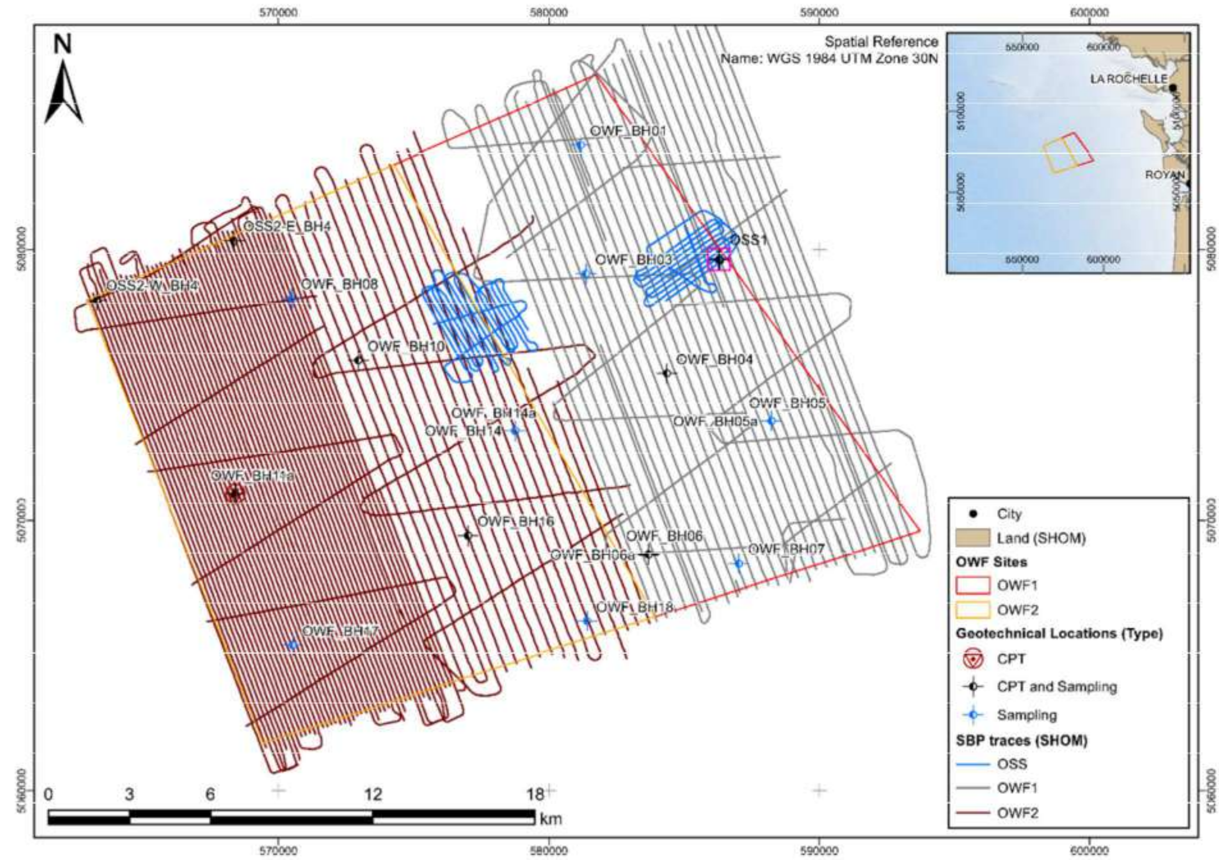


Figure 2.5: SBP data at the OWF site

2.3.1.5 Magnetometer Data

SHOM acquired magnetometer data across the OWF site between March and October 2022 using several geophysical vessels at different periods of time. These allowed calculation of magnetic anomalies across the OWF site using the global models IGRF 2021 as reference and by filtering Earth magnetic field related high frequency values using observations from a reference station at "Pointe de Grave (SHOM, 2023e, f).

Data were provided as XYZ data (text files) and were compiled and interpolated (kriging method) by Fugro. The resulting map is displayed in Figure 2.6.

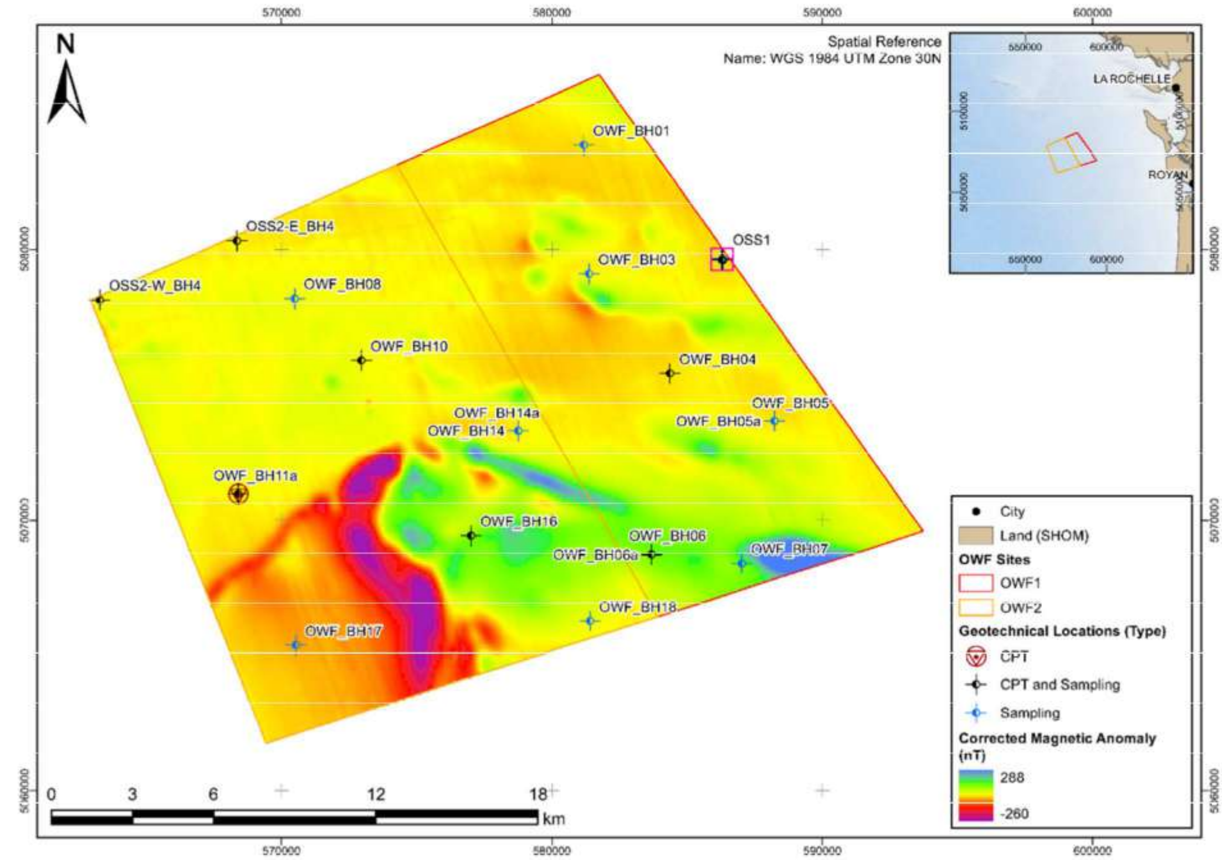


Figure 2.6: Corrected and filtered magnetometry anomaly across the OWF site

2.3.1.6 Ultra-High Resolution Seismic Data

TECNOAMBIENTE acquired ultra-high resolution seismic (UHRS) data as part of the de-risking studies commissioned by DGEC at the OWF site between 2022 and 2023. In a first stage, DGEC provided a total of seventy-eight (78) 2D UHRS lines. The associated Kingdom project with TECNOAMBIENTE's interpretation was subsequently provided to Fugro by DGEC. No interpretation report was provided. After reviewing the data, Fugro concluded that the interpretation was incomplete and did not fit the geotechnical data. Therefore, it was agreed with DGEC that Fugro would perform a reinterpretation to allow a better integration process between geophysical and geotechnical data.

Seismic interpretation presented as part of this report was performed by Fugro using S&P Global Kingdom™ software.The traces of available 2D UHRS lines are displayed in Figure 2.7 and in Plate 2.2. Properties of the seismic data made available are based on an internal seismic quality control using S&P Global Kingdom™ software and are detailed in Table 2.3.

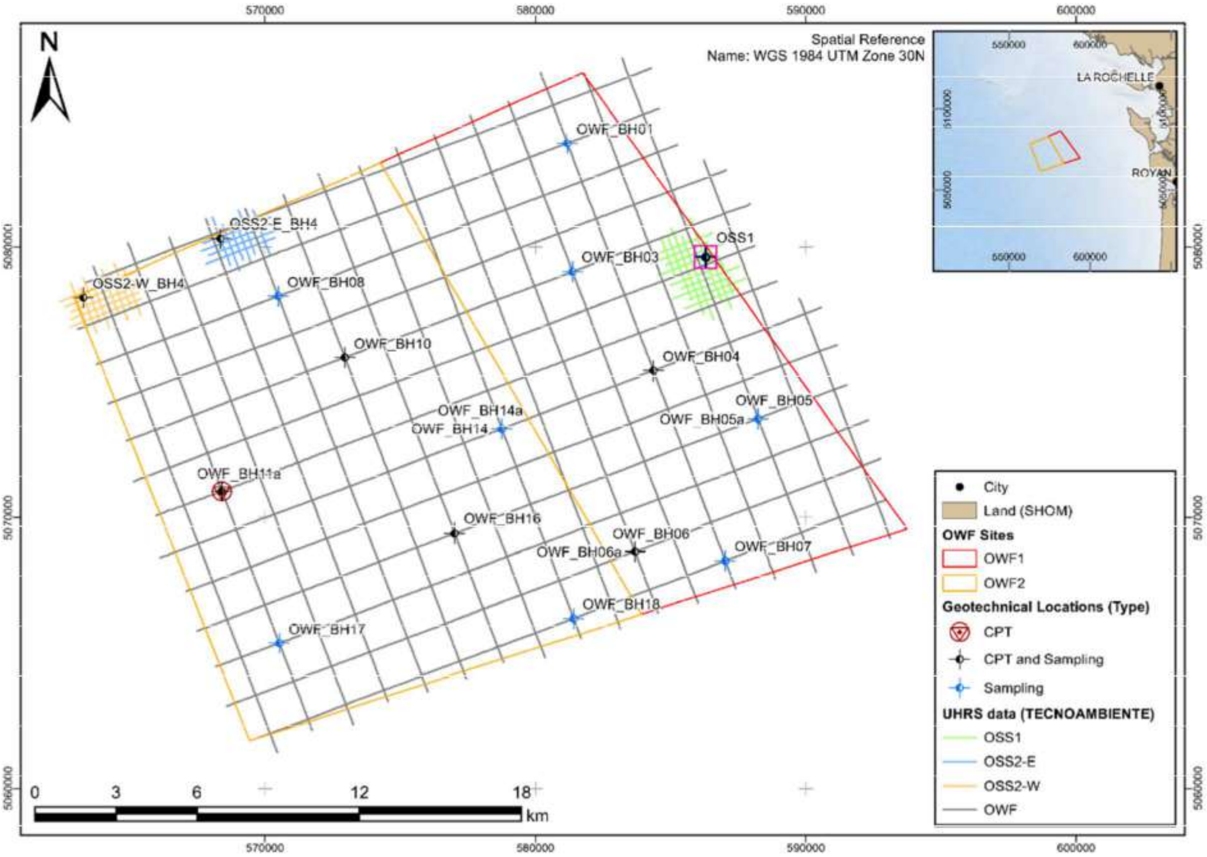


Figure 2.7: 2D UHRS data available over OWF site

Table 2.3: Summary of the 2D UHRS geophysical properties

Properties	Details
Line spacing	NNW-SSW: 250 m WSW-ENE: 250 m
Source	Sparker
Channel Number	48 channels
Sample interval Record length	0.0625 ms 280 ms
Bandwidth (50%dB)	258-2850 Hz
Vertical resolution (λ /4, 1500m/s; λ /4 2000m/s)	0.3 – 0.4 m
Horizontal resolution (λ /10, 1500m/s; λ /10 2000m/s)	0.1 – 0.2m
Notes: λ: Wavelength	

2.3.2 Geotechnical Data

2.3.2.1 Grab Samples

DGEC provided particle size distribution (PSD) analysis data including:

- Ten (10) extracted from historical SHOM database (BDSS - Base de Données Sédimentologiques du Shom; SHOM , 2022c,d);
- Eighty-seven (87) from Shipek grab samples acquired during SHOM reconnaissance surveys (SHOM, 2023e,f).

Data was provided as two shapefiles and are plotted in Figure 2.8.

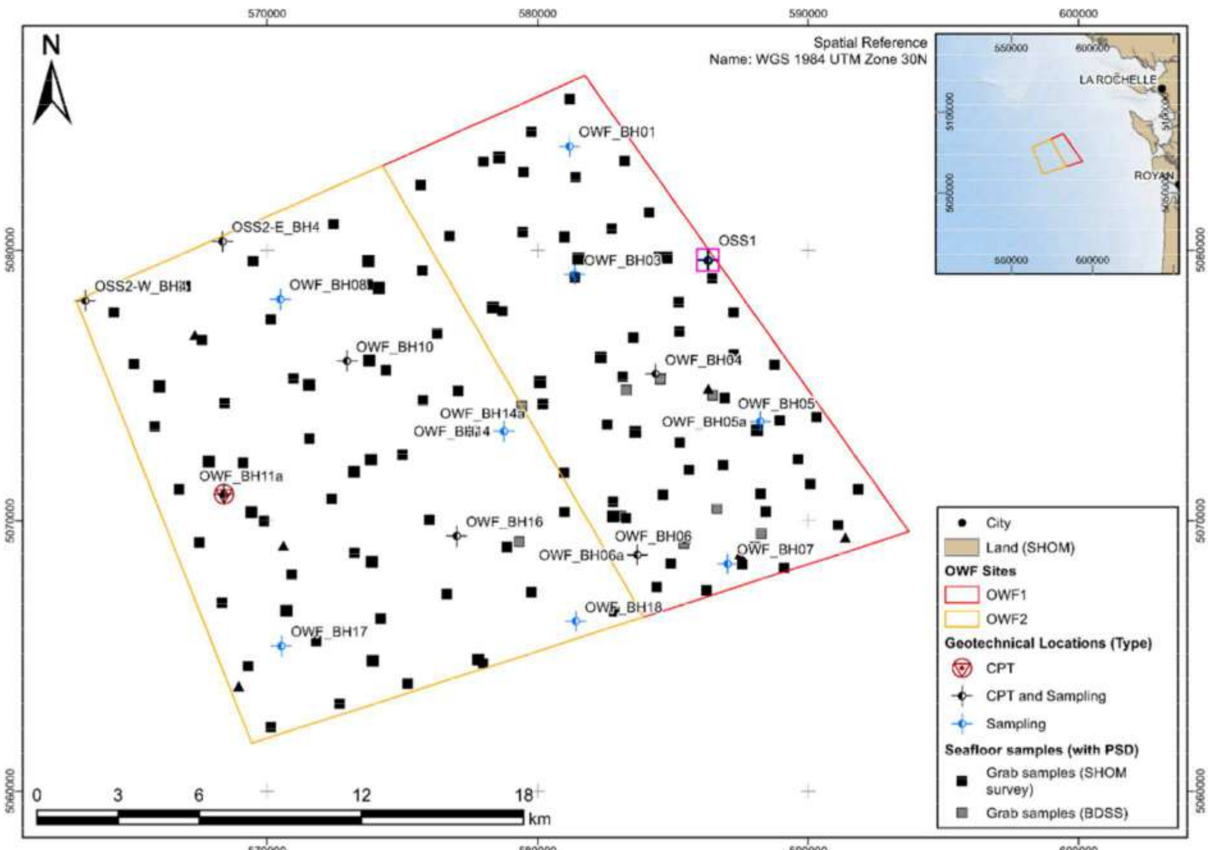


Figure 2.8: Seafloor samples with PSD analysis data across OWF site

PSD analysis results of the 87 Shipek grab samples are detailed in SHOM (2023i,j).

2.3.3 Processed Data and Others

2.3.3.1 Interpreted Maps

As part of DGEC provided data, several interpreted maps were provided, including:

- A seafloor nature map from SHOM (SHOM, 2023g,h), derived based on PSD analysis (Section 2.3.2.1), MBES data (Section 2.3.1.2), and SSS data (Section 2.3.1.3); and
- A sediment thickness map from SHOM (SHOM, 2023g,h), based on the interpretation of SBP data (Section 2.3.1.4) and converted from two-way travel time (TWTT) to depth using

a P-wave velocity of 1640 m/s, average value calculated based on SHOM internal sedimentological parameters (SHOM, 2023g, h).

Maps were provided in shapefile formats.

2.3.3.2 Anthropogenic Feature Data

DGEC provided data regarding expected anthropogenic features across or close to the OWF. These include:

- Shipwrecks extracted from SHOM historical database;
- Anthropogenic seafloor obstructions as identified on MBES data (Section 2.3.1.2);
- Buoys, in particular Metocean buoys that were utilized to derive swell or current parameters. These were compiled by Fugro based on SHOM reports (SHOM, 2022e, 2023a, b, c, d). Most of Metocean buoys are decommissioned and do not represent seafloor obstructions.

This information was provided by DGEC in the form of shapefiles, text files or reports.

2.3.3.3 Metocean Data

Metocean information compiled or measured by SHOM were provided by DGEC for the study. They include:

- Data on currents (SHOM, 2022e, 2023c, d);
- Data on swell (SHOM, 2023a, b); and
- Data on tides (SHOM, 2021a, b)

Data were provided in different format. As part of the study, main results and observations were extracted from reports.

2.3.3.4 UXO Desk Study

An UXO Threat and Risk Assessment and Risk Mitigation study performed by 6-alpha Associates (6-alpha, 2023) was provided by DGEC. The report was reviewed to provide information on potential UXO risk at the OWF sites.

The study is based on multiple historical data sources and public databases (refer to 6-alpha, 2023) and mitigation options provided in the report are focused on geotechnical investigation solely based on United Kingdom's Construction Industry Research and Information Association (CIRIA, 2016).

2.4 Publicly Available Data

This section details additional publicly available data that was consulted and integrated as part of this study by Fugro.

2.4.1 Published Research Articles

A number of published research articles were consulted and synthesised to provide a geological setting of the OWF site region (Section 4). The article references are listed in Section 9.3.

2.4.2 Geotechnical and Geophysical Data

2.4.2.1 From Published Literature.

Huerta et al. (2010) provide a geological map based on interpreted seismic lines and using rock drag samples as chrono-stratigraphic proxy. Two of the interpreted lines presented in this scientific paper are close to the considered zones and were used to help the interpretation of UHRS seismic profiles (Figure 2.9).

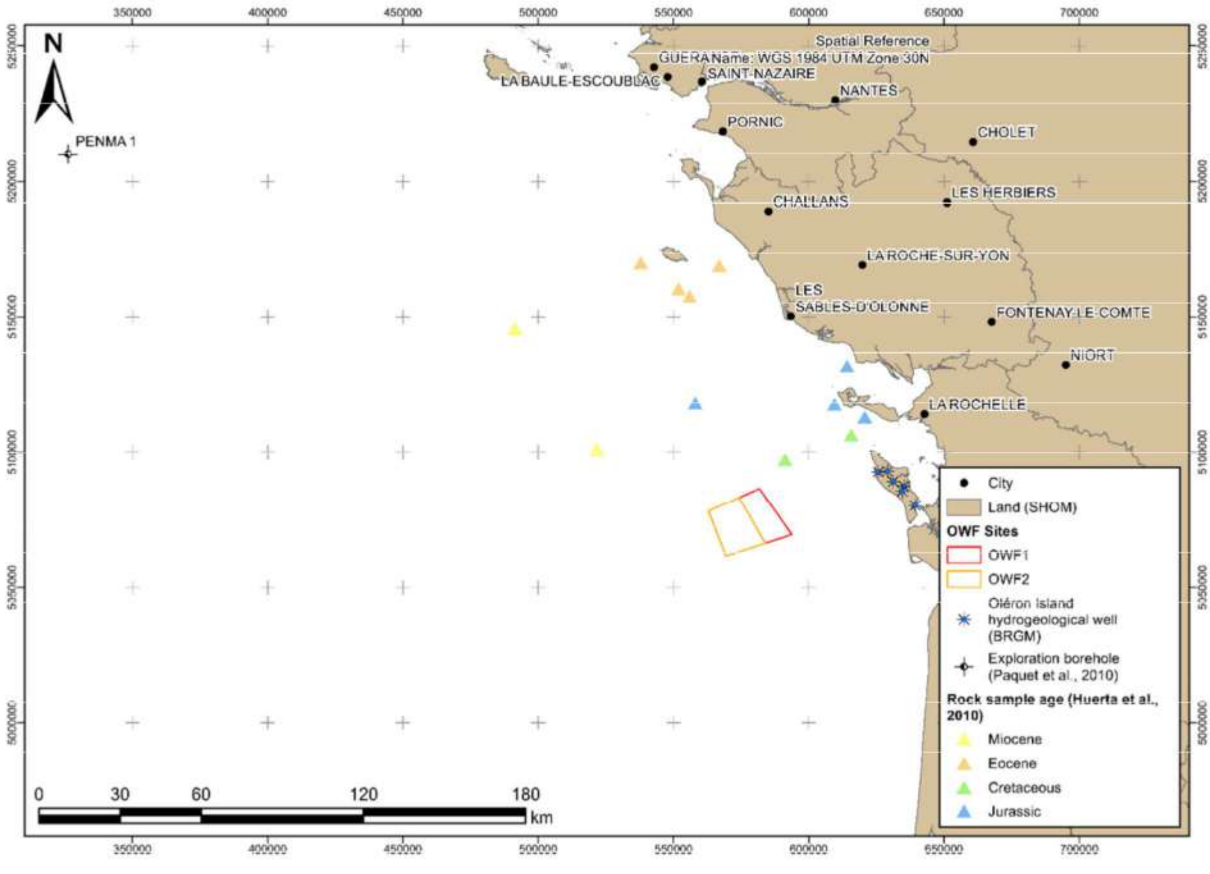


Figure 2.9: Available rock samples or boreholes across the Bay of Biscay from Huerta et al. (2010)

Furthermore, PENMA-1 deep exploration borehole was drilled 271 km to the north-west of the studied zones (see Figure 2.9 for location). Paquet et al. (2010) provide a synthetic log of this borehole (Figure 4.2). This log provides a seismostratigraphic framework for the Bay of Biscay.

2.4.2.2 Bureau de Recherche Géologique et Minière (BRGM)

BRGM database includes fifty one (51) seafloor samples located across the OWF site (Figure 2.10). The samples consist of grab samples and drag samples. Particle size distribution (PSD) information is provided for twenty three (23) samples.

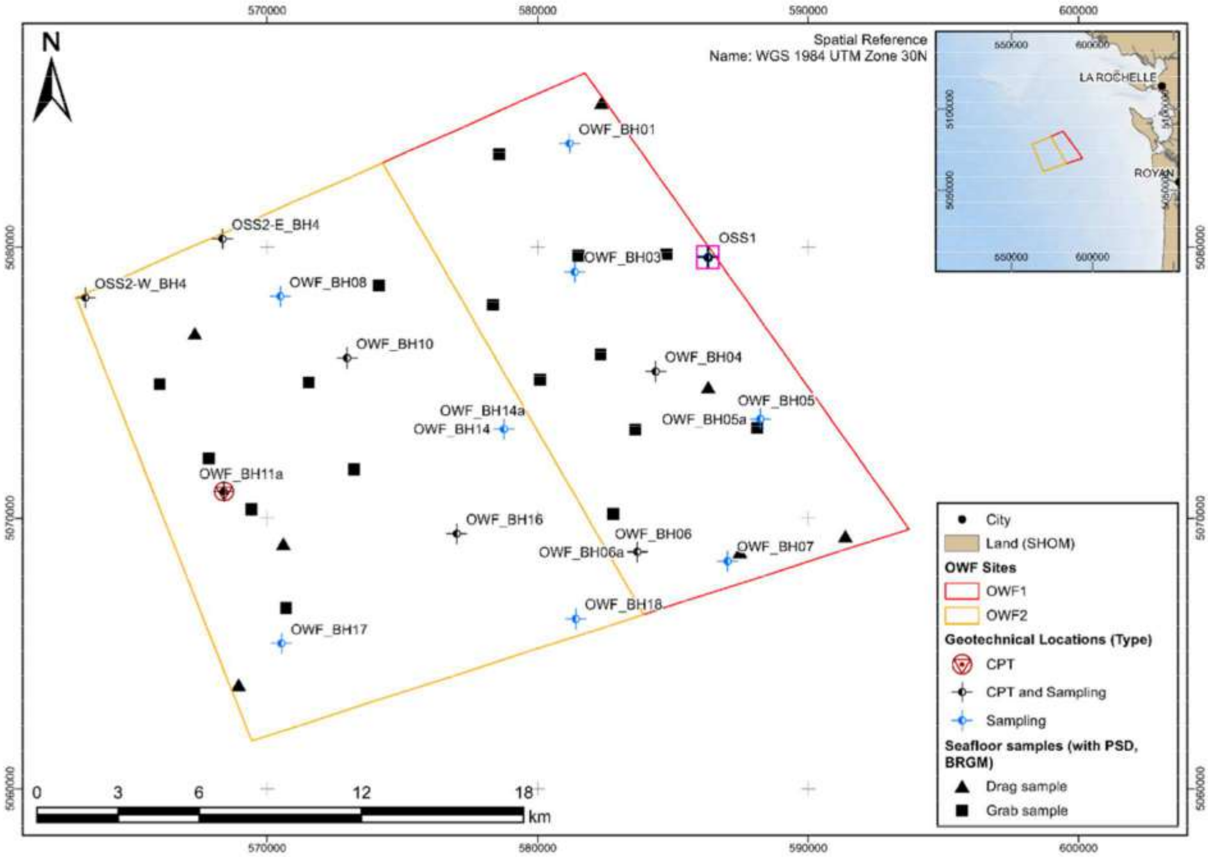


Figure 2.10: BRGM seafloor and sub-seafloor geotechnical locations

The Subsurface Database (BSS) from BRGM provides information on hydrogeological wells. Eight (8) wells on the Oléron Island (Figure 2.9) were extracted from the database and include synthetic geological logs with descriptions and stratigraphic ages of the drilled formations. These data were useful to increase confidence in the stratigraphic framework.

2.4.3 Geological Maps

The geology of the central Bay of Biscay is well documented, with various regional-scale maps available from several sources. Table 2.4 details the publicly available geological maps reviewed and used within this study. These data sources aided the interpretation of seabed conditions and sub-seabed geology across the two zones.

Table 2.4: Publicly available geological data sources

Data	Author	Date	Scale	Data Format	Derived Information	Website or DOI
Geological map of France	Chantraine et al.	1996	1: 1 000 000	Georeferenced map and WMS service	Pre-Quaternary geology and paleo-valleys	http://infoterre.brgm.fr/viewer/
Geological map of Aquitaine Region	Bourbon et al.	2019	1: 250 000	PDF and Technical Note	Quaternary and Pre-Quaternary geology	https://sigesaqi.brgm.fr/Une-carte-geologique-de-l-Aquitaine-au-1-250000-un-support.html
Geological Map of the Vendean-Armorican platform (VAP)	Huerta et al.	2010	1: 250 000	Georeferenced map	Pre-Quaternary geology	https://doi.org/10.2113/gssgfbull.181.1.37
Geological Map of the Oléron Island	Bourgueil et al.	1976	1: 50 000	WMS service and webmap, Technical Note	Quaternary and Pre-Quaternary geology	http://ficheinfoterre.brgm.fr/Notices/0657N.pdf
Map of surficial sediments of the septentrional part of the continental shelf of the Bay of Biscay	Bouysse et al.	1986	1: 500 000	Georeferenced map, WMS service and shapefiles	Surficial sediments and outcrops	https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/ea0b61b0-71c6-11dc-b1e4-000086f6a62e
Seafloor nature map	SHOM	1992 (2016 [(1)])	1: 50 000	WMS service and shapefiles	Surficial sediments and outcrops (nearshore)	https://services.data.shom.fr/geonetwork/srv/fre/catalog.search#/metadata/HOM_GEOL_NATURES_FOND_50.xml
Seafloor nature map of the Aquitaine shelf	Cirac et al.	2016	1: 250 000	WMS service and webmap	Surficial sediments	https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/602a30c5-c338-4e75-a591-baccb8ba1f79
Seafloor nature map of the Aquitaine shelf	Bourillet et al.	2017	1: 50 000	WMS service and webmap	Surficial sediments	https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/2efa6d8b-7caf-444f-813a-c4178215b2ce
Marine aggregate resources South Brittany sheet. Thickness of soft sediments	Augris et al.	2013	1: 250 000	Georeferenced maps, WMS, and shapefiles	Quaternary sediment thickness, paleo-valleys extent, and thickness	https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/c841ca37-b414-4c51-ad6a-16bc34e8cf6f

Note:
(1) Revision date under brackets

2.4.4 Other

Other useful information was derived from publicly available data sources, including:

- Anthropogenic activity from EMODnet (European Marine Observation and Data Network) and SHOM databases;
- Earthquake catalog from Réseau National de Surveillance Sismique (ReNaSS); and
- Metocean data from CANDHIS (Centre d'Archivage National de Données de Houle In-Situ), allowing to retrieve swell and wave data close to the OWF site.

3. Integration Methodology

3.1 Overview

This section details the method of interpretation of the datasets listed in Section 2 and interpreted in Section 5, and how they are prepared and integrated to derive IGM presented in Section 6.

3.2 Integration Workflow

Integration of datasets was carried out in accordance with ISO 19901-10:2021. Figure 3.1 shows the integration process.

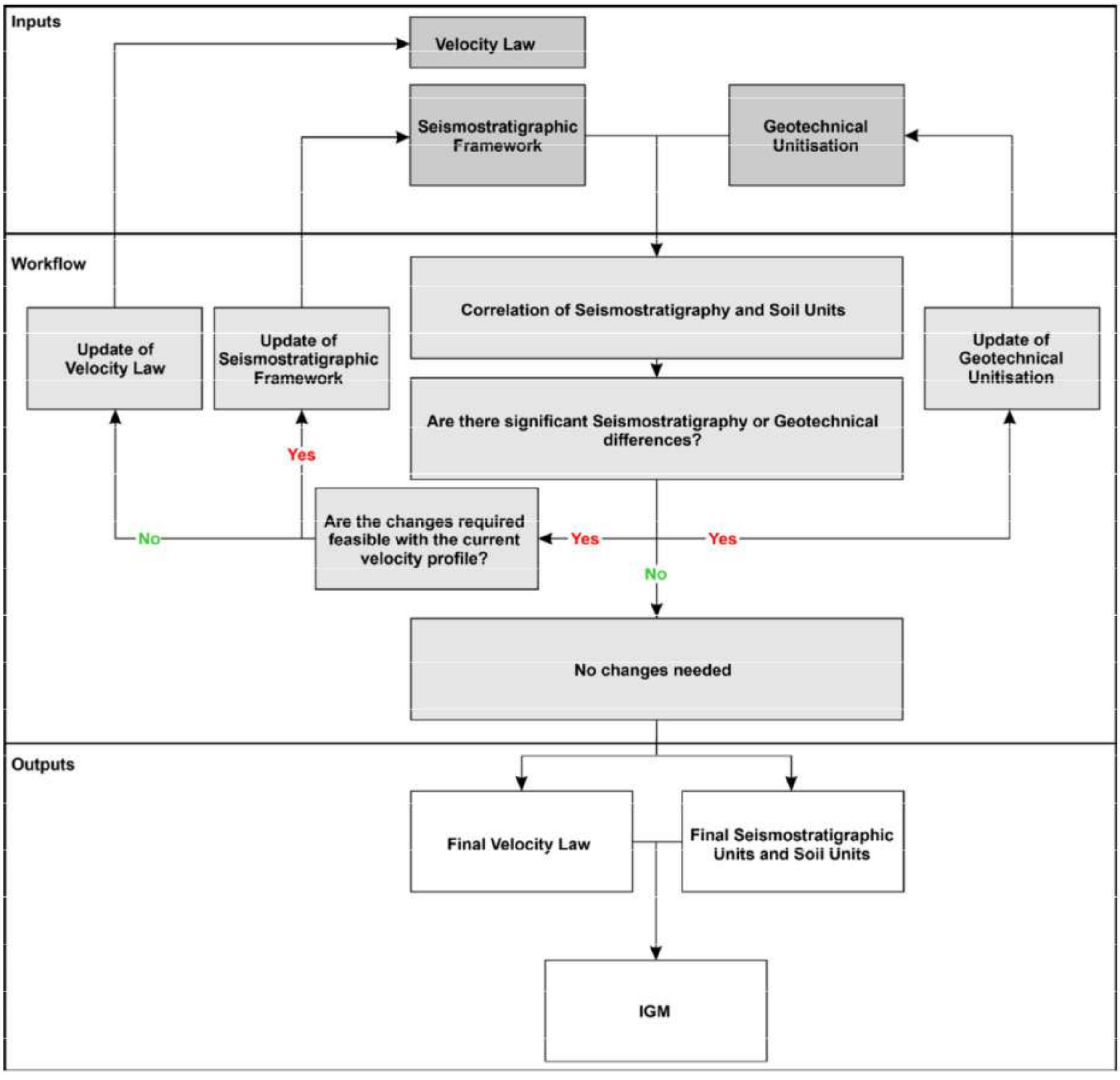


Figure 3.1: Integration workflow and decision tree for the OWF site

Seismostratigraphic units (identified with "SU#" in tables and figures) at the OWF site were interpreted by Fugro from the 2D UHRS data (Section 2.3.1.6).

Soil and rock ground types (identified with "GT#" in tables and figures) were delineated from geotechnical data from Fugro (Section 2.2) by identifying significant changes of geotechnical properties and/or lithologies.

The seismostratigraphic units and geotechnical ground types defined and discussed in Section 5.3.2 and Section 5.3.3 respectively were compared and correlated (Section 6), with the intention to highlight soil characteristics variability at the OWF site. Geophysical reflectors where soil or rock type changes occurred were considered significant for mapping and inclusion in the IGM as a bounding horizon.

The ground types were also reviewed against the seismostratigraphy to ensure the full range of geotechnical properties was captured for each of the seismostratigraphic units. Where appropriate, the geotechnical unitization was updated.

Where significant changes in geotechnical properties were observed without a previously existing seismostratigraphic unit, new and original interpretation was performed to identify and map on the geophysical data these geotechnically significant units.

This iterative approach correlated the ground types with the seismostratigraphic units and enabled the development of the OWF site IGM with definition of soil or rock units (identified with "SU#" in tables and figures) for which geotechnical properties were defined by extrapolating geotechnical data across areas with similar inferred soil conditions.

3.3 Seismic Interpretation Methodology

3.3.1 Interpretation Methodology

Seismic interpretation required as part of the integration process (Section 2.3.1.6) was done in S&P Global Kingdom™ Seismic and Geological Interpretation Software in the time domain.

Seismostratigraphic mapping was undertaken by picking amplitude peaks or troughs reflectors in-between areas of similar acoustic character with the geotechnical changes at the investigation locations, along the survey lines.

Resulting seismic horizons were then converted to grid (isochrone) maps using a flex gridding algorithm to resolve seismostratigraphy across the OWF site.

3.3.2 Time-depth Conversion

Correlation of ground types (identified with "GT#") from the geotechnical boreholes in depth below seafloor (m BSF) with seismic horizons from the seismic dataset in two-way travel time (TWTT, s) required a time-depth conversion law.

Borehole formation tops (i.e. "GT#" tops in m BSF) thought to be correlated with seismic horizons (in TWTT, s) were paired. Interval velocity between two pairs was calculated at each borehole. Any formation (i.e. seismostratigraphic unit, "SU#") with an interval velocity thought to be unrealistic or unrepresentative was adjusted by adapting the horizon picking or removed from the final selection. Where interpretation could be adjusted, revised time-depth pairs were created which in turn generated updated interval velocities. This iterative process resulted in a good correlation between the soil units and the seismic horizons (Section 5.3.2.1).

This iterative detailed review was undertaken for all boreholes locations resulting in three (3) estimated interval velocities. Each interval velocity was compared between boreholes. Variations exist for a same interval between the different boreholes, these are in ranges of velocities encounter in the literature.

Due to the observed range in-between boreholes for a same interval, the mean velocity per interval for the whole boreholes (excluding unrealistic values due to e.g. thickness under the seismic resolution or significant distance between boreholes and seismic data) were used to convert all interpreted horizons from TWTT (s) to depth in m BSF.

These depth horizons were then used to produce gridded thickness maps (i.e. seismostratigraphic units - "SU#").

This approach was considered the most reliable considering velocity uncertainties due to the absence of waves (i.e. compression -P and shear -S) velocity measurements at boreholes.

3.4 Geotechnical Data Methodology

3.4.1 Geotechnical Descriptions

Soil descriptions provided in the geotechnical model are based on ISO 14688-1:2018 (ISO, 2018a). Rock descriptions provided in the report are based on ISO 14689:2018 (2018c).

The undrained shear strength terms from ISO 14688-2:2018 (ISO,2018b), presented in Table 3.1, are utilised throughout this report.

Table 3.2 details the relative density terms for the description of sand units based on relative density ranges (Lambe & Whitman, 1969).

Effective angles of internal friction values were checked ranges obtained from API RP 2A-WSD (2000) (Table 3.3) based on soil description and relative density terms.

Table 3.4 details the terms for the description of rock strength based on field identification and providing corresponding Uniaxial compressive strength (UCS) ranges. Table 3.5 provides the sedimentary rock types relevant for the study area. These terms are based on ISO 14689:2018, (ISO, 2018c). As part of this revision, field descriptions were updated based on UCS data.

Table 3.1: Consistency terms for undrained shear strength (ISO, 2018a,b)

Strength Term (BS5930:2010)	Undrained Shear Strength [kPa]
Extremely low	< 10
Very low	10 to 20
Low	20 to 40
Medium	40 to 75
High	75 to 150
Very high	150 to 300
Extremely high	300 to 600
Ultra-high	> 600

Table 3.2: Ranges of relative density for the description of sand units (Lambe & Whitman, 1969)

Relative Density Term	Relative Density [%]
Very Loose	0 to 15
Loose	15 to 35
Medium Dense	35 to 65
Dense	65 to 85
Very Dense	85 to 100

Table 3.3: Effective Angle of Internal Friction values relative to soil type and relative density based on API RP 2A-WSD (2000)

Relative Density Term	Soil Type	Effective Angle of Internal Friction * [°]
Very Loose Loose Medium	Sand Sand-Silt Silt	20
Loose Medium Dense	Sand Sand-Silt Silt	25
Medium Dense	Sand Sand-Silt	30
Dense Very Dense	Sand Sand-Silt	35
Dense Very Dense	Gravel Sand	40

Table 3.4: Terms of description of rock strength based on ISO (2018c)

Term	Field Identification	Uniaxial Compressive Strength (MPa)
Extremely weak	Can be indented by thumbnail. Gravel-sized lumps crush between finger and thumb	0.6 – 1.0
Very weak	Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife	1 – 5
Weak	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with the point of geological hammer	5 – 12.5
Moderately Weak	Can be scratched with difficulty by pocket knife. Hand-held specimens can be broken with single firm blow of geological hammer	12.5 – 25
Medium strong	Cannot be scraped with pocket knife. Can be fractured with a single firm blow of geological hammer	25 – 50
Strong	Requires more than one blow of geological hammer to fracture	50 – 100
Very strong	Requires many blows of geological hammer to fracture	100 – 250
Extremely strong	Can only be chipped with geological hammer	> 250

Table 3.5: Sedimentary rock types relevant for the study area modified from ISO (2018c)

Grain size	Siliceous	Biogenic	
		Low porosity	Porous
>20 mm	Conglomerate Breccia	Limestone or dolomite	Calcirudite
6.3 mm to 20 mm			
2 mm to 6.3 mm			
0.63 mm to 2 mm	Sandstone Greywacke		Calcarenite
0.2 mm to 0.63 mm			
63 µm to 200 µm			
2 µm to 63 µm	Siltstone		Calcisiltite Chalk
<2 µm	Claystone Mudstone		Calcilutite
Crypto-crystalline	Flint Chert	NA	NA

Note:
NA Not applicable

3.4.2 Geotechnical Parameters

Table 3.6 details the parameters that are derived for the OWF IGM based on Fugro geotechnical data (Section 2.2.1).

Table 3.6: Geotechnical parameters derived as part of the OWF integrated ground model

Symbol	Geotechnical Parameter	Unit	Type of Soil	Utilised Data [(1)]	Report version [(2)]
w	Water content	%	All	Offshore laboratory data	Intermediate and updated in Final
γ	Wet Unit weight	kN/m^3	All	Offshore laboratory data	Intermediate and updated in Final
ρ_s	Particle density	-	All	Onshore laboratory testing	Final
q_c	Cone tip resistance	MPa	All	CPT data	Intermediate and updated in Final
s_u	Undrained shear strength	kPa	Cohesive soils	CPT data	Intermediate and updated in Final
Dr	Relative density	%	Non-cohesive soils	CPT data	Intermediate and updated in Final
ϕ'	Effective angle of internal friction	°	Non-cohesive soils	Intermediate: ranges based on API RP 2A-WSD (2000) (Table 3.3) and Fugro experience Final: onshore laboratory testing	Intermediate and updated in Final
ε_{50}	Axial strain at 50% of the maximum deviator stress	%	Cohesive soils	Onshore laboratory data	Final
TR	Thermal Resistivity	m.K/W	All (first 6 m BSF)	Offshore laboratory testing	Intermediate and updated in Final
RQD	Rock Quality Designation	%	Rocks	Offshore description logs	Intermediate and updated in Final
$Is(50)$	Point Load Strength Index	MPa	Rocks	Offshore laboratory testing	Intermediate and updated in Final
UCS	Uniaxial Compressive Strength	MPa	Rocks	Onshore laboratory testing and correlation with I_s50	Final
E	Young's Modulus of Elasticity (axial)	GPa	Rocks	Onshore laboratory testing	Final

Notes:
- No unit
(1) Data used in deriving individual parameters
(2) Report version for which parameters were derived or updated

3.5 Soil Profile and Province Map Approach

As part of the IGM, soil profiles are created to depict each soil unit occurrence and variability in thickness observed from available data (Fugro geotechnical data and client-provided geophysical data). Soil profiles are represented as stick logs to differentiate individual soil units.

Where and when relevant, based on the expected soil condition variability, a soil province map is then generated to depict the spatial extent of each predicted soil profile. Soil province maps allow the lateral variability between soil units to be better understood.

4. Geological Setting

4.1 Overview

An understanding of the regional geological history and features of the Offshore Oléron region is required to predict geological and geotechnical conditions and to identify geohazards and constraints within the OWF site. The geology of the Offshore Oléron region comprises:

- Crystalline bedrock dated from Palaeozoic;
- Jurassic to Miocene sedimentary rocks and sediments;
- Quaternary sediments including infilled paleo-valleys.

The information provided in the following sections are mainly derived from published literature.

4.2 Geodynamic Evolution

Vanney (1977) and Huerta et al. (2010) both describe the geodynamic evolution of the Bay of Biscay. This is synthesised into five main stages from Late Palaeozoic to the present-day, and summarised in Figure 4.1:

- Late Palaeozoic: the present-day Vendean-Armorican platform (VAP) is part of the Armorican-Iberic tectonic plate (Stage 1 in Figure 4.1);
- Triassic to Jurassic: marine transgression flooding the Armorican and Iberic crystalline bedrock (Stage 1 in Figure 4.1);
- Late Jurassic: marine regression leading to the formation of the continental slope and shelf. Carbonate ramp platform environment dominated the VAP. No deposition occurred in the VAP region during Early Cretaceous as the region was probably uplifted and thus exposed (Stage 2 in Figure 4.1);
- Late Cretaceous to Miocene: intense tidal-influence sedimentation linked to various marine transgression events. Opening of the Bay of Biscay and initiation of Pyrenean compression. VAP area was folded and faulted (Stage 3 in Figure 4.1);
- Early Pliocene to present-day: successive glacio-eustatic variations leading to erosion during relative sea-level low stands, sometimes down to crystalline bedrock, and fluvio-deltaic to marine sediments deposition during sea transgression. Generation of paleo-valley networks at several paleo-river mouths (e.g. Gironde and Charente Rivers) (Stage 4 in Figure 4.1). Last paleo-incisions date from the last glacial maximum (LGM) 20-21 thousand years before present (kyr BP) and were infilled during the subsequent widespread marine transgression where sea levels increased by up to 120 m over the last 20 kyr BP (Menier, 2004).

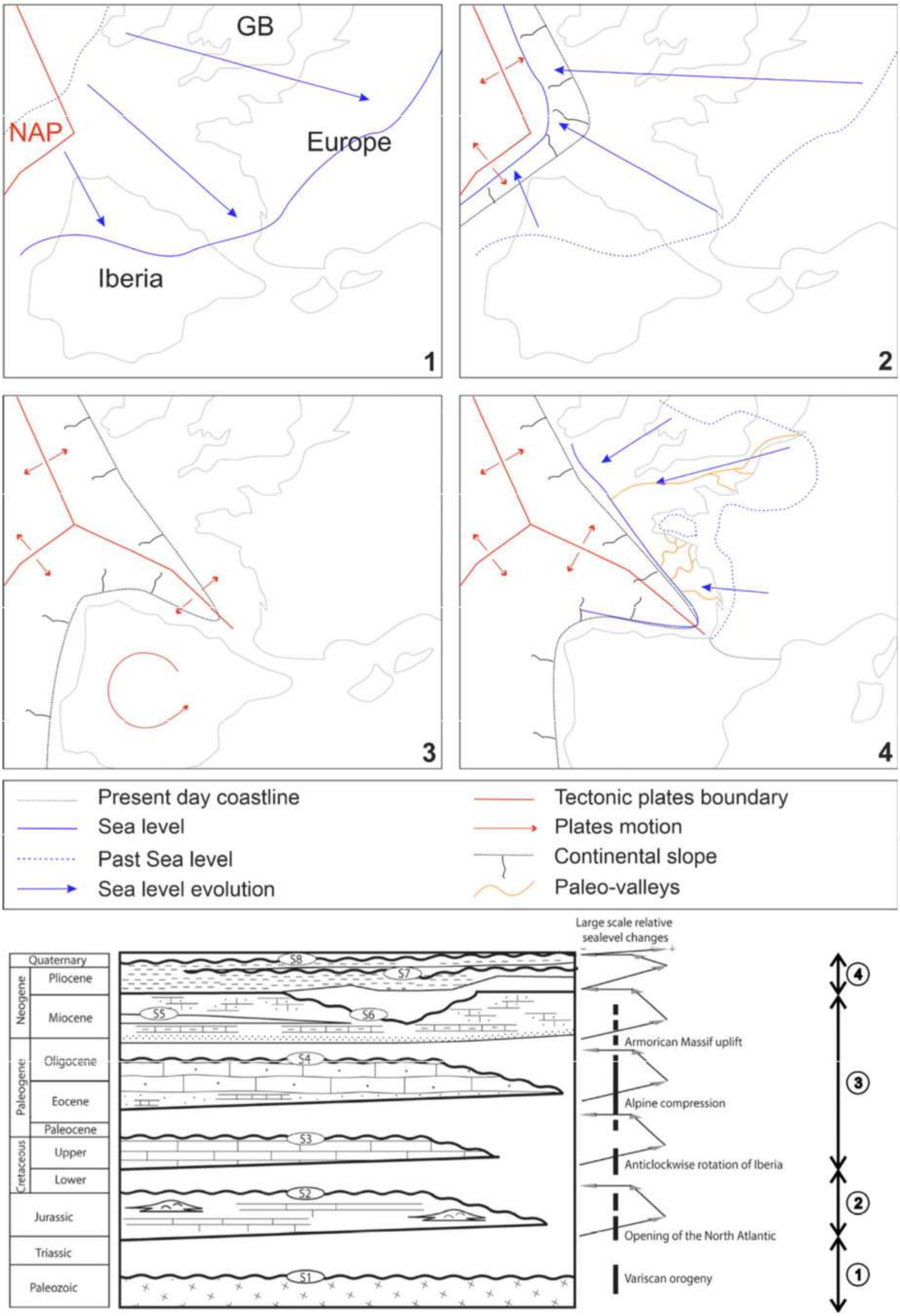


Figure 4.1: Geodynamic evolution of the Bay of Biscay. Top: Conceptual sketches showing the Bay of Biscay geodynamic and morphological evolution. Bottom: Chronostratigraphic scheme of the seismic stratigraphy of the VAP (modified from Huerta et al., 2010). NAP = North American Plate; GB = Great Britain

4.3 General Stratigraphy

Table 4.1 synthesises available information on expected seismic stratigraphy and lithology based on:

- Chantraine et al. (1996);
- Huerta et al. (2010);
- Paquet et al. (2010);
- Bourgueil et al. (1976), for Upper Jurassic;
- Augris et al. (2013), Menier et al. (2010) and Chaumillon et al. (2008, 2010) for Plio-Pleistocene sequence.
- Bouysse et al. (1986), Cirac et al. (2000) and Augris et al. (2013) for Holocene sediments.

Figure 4.2 shows the geological map from Chantraine et al. (1996). This map shows the expected distribution of the main pre-Quaternary units.

PENMA-1 description log from Paquet et al. (2010) is displayed for reference in Figure 4.2. However, the exploration borehole is located 271 km to the north-west of the OWF site, outside of the VAP and within the outer shelf. Its geological setting is therefore different from the OWF site and units are likely to have different lithologies in the considered VAP area. PENMA-1 should only be considered for stratigraphic correlation purpose.

Table 4.1: Seismic stratigraphy and descriptions of Pre-Quaternary strata from Huerta et al. (2010)

Age	Seismic units (Huerta et al., 2010)	Lithological description	Lateral extent	Geometry of seismic units	Thickness
Palaeozoic (Devonian to Carboniferous)	Ub	Crystalline basement (orthogneiss and other undifferentiated metamorphic rocks)	Rochebonne High area (outcropping and sub cropping)	NA	NA
Upper Jurassic	U1	Thin-and poorly bedded, marly limestones transitioning upwards to interbedded marls and limestones	Between Rochebonne High to the W and Les Sables d'Olonne to the NE	Faulted and folded and delimits an NNW-oriented, broad syncline with a periclinal termination to the NW	Thickness over 200 ms TWTT (tabular)
Upper Cretaceous	U2	Interbedded limestones and marls and glauconitic sandstones	Between the Rochebonne High in the W and Ré Island in the E	Faulted and folded and constitutes the core of the syncline	Thickness up to 230 ms TWTT (tabular)
Eocene to Oligocene	U3	Mudstones (with sand bars and channel fills) transitioning upwards to siliciclastic limestones	In the SE and in the NW of the Rochebonne High, and close to Ile d'Yeu	Folded and faulted and dips gently southward	Thickness of 50 to 100 ms TWTT increasing drastically to the SW, towards the shelf margin
Early to Middle Miocene	U4	Light-grey glauconitic and bioclastic sandstones transitioning upwards to fine-grained sediments alternating with bioclastic limestones and dolomitized sediments	Parallel to the coastline and the shelf margin with NW to SE direction at the SW of Rochebonne High	Faulted and gently tilted towards the SW	Maximum of 75 to 100 ms TWTT in the S
Plio-Pleistocene	U5	■ Fluvial sands and gravels (low stand system tract, in paleo-incisions) ■ Estuarine clays to sands (transgressive system tract). ■ Clayey sands to marine clays, often shell-rich (high stand system tract).	Everywhere, except at rock outcrops. Paleo-valleys distribution unknown across the OWF site (Figure 4.4)	U-shaped features with erosive basal surface (paleo-incisions) Dune-shaped features Wedge-shaped	Generally, less than 10 m Up to 25 m along paleo-incision axis
Holocene	NA	Normally graded sequence of coarse sand to fine sand, often shell-rich	Everywhere, except at rock outcrops	Continuous layer	Less than 1 m

Notes:

ms TWTT: milliseconds Two-Way Travel Time

NA: Not Applicable

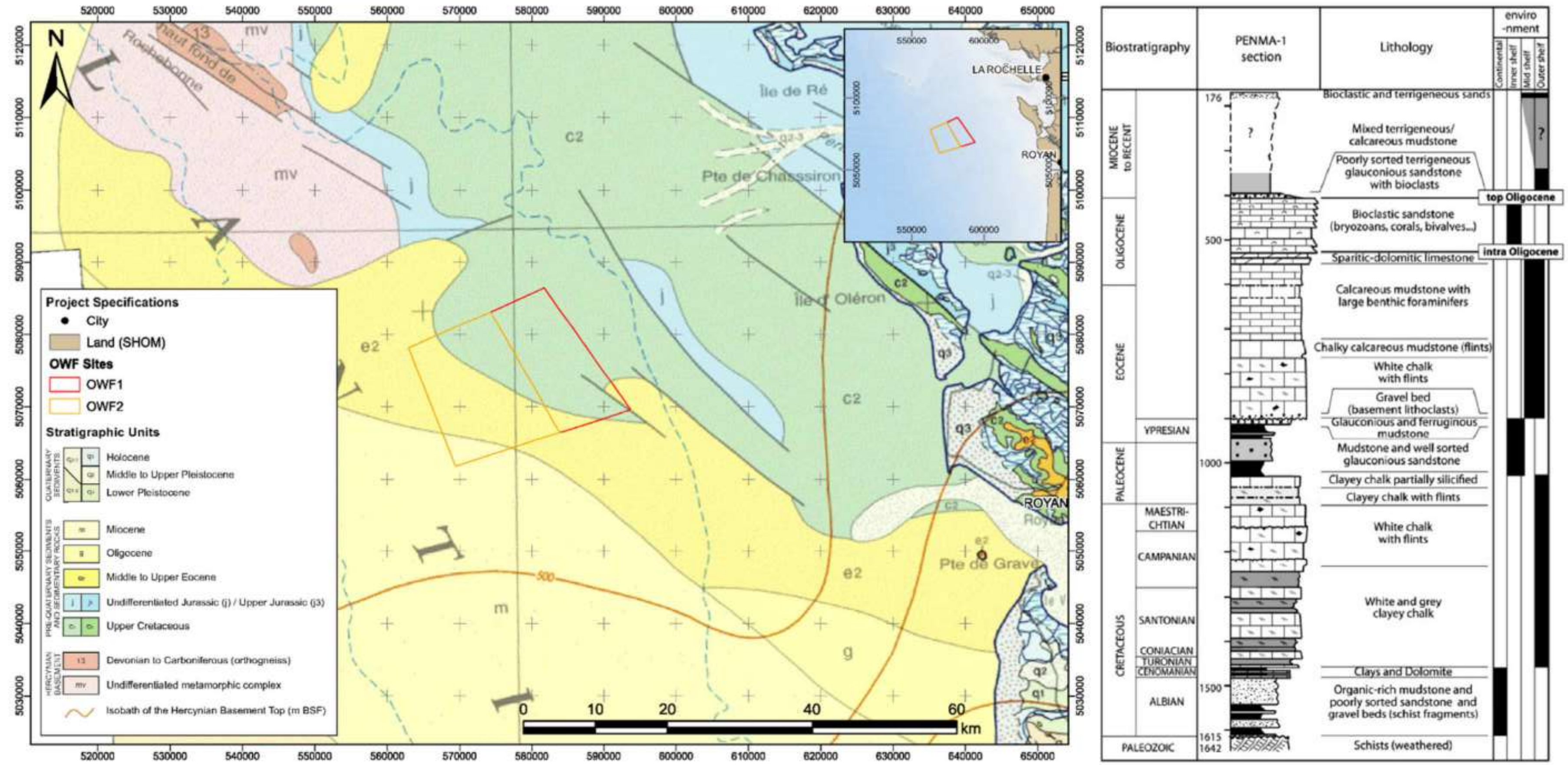


Figure 4.2: Regional Geological Map (Chantraine et al., 1996) and PENMA-1 descriptive log (Paquet et al., 2010)

4.4 Expected Geological Features

This section identifies from publicly available data and literature any specific geological features.

4.4.1 Tectonic Features

Huerta et al. (2010) interpreted the presence of numerous faults as well as folded strata across the VAP based on seismic data (see descriptions in Table 4.1). Chantraine et al. (1996) geological map shows the potential presence of faults to the south-east of the OWF site (Figure 4.2).

4.4.2 Paleo-valleys

The VAP has hosted different river systems from the Neogene period up until the present day (Figure 4.3). During glacial periods where the sea level was low, these river systems have incised the pre-existing sedimentary rocks and crystalline basement creating a network of incised valleys. As the sea-level rose during the Holocene marine transgression that took place following the LGM (20-21 kyr BP), these incised valleys were infilled with sediments and subsequently buried to form the paleo-valleys identified in geophysical data today (Menier, 2004; Chaumillon et al., 2008; Chaumillon et al., 2010).

Published literature (Menier et al., 2010; Chaumillon et al., 2008) suggest three main units, with facies classified from proximal to distal environments:

- Fluvial sands and gravels (lowstand system tract);
- Estuarine clays to sands (transgressive system tract). Internal tidal ravinement surface may occur and the unit is topped by a wave ravinement surface;
- Clayey sands to marine clays, often shell-rich (highstand system tract).

From Fugro experience of paleo-valley deposits, important lateral and vertical variability in soil conditions must be expected within paleo-valley deposits. Several of these sequences may be stacked vertically and laterally, internal erosions (tidal and wave ravinement surfaces) are frequent.

Paleo-valleys of the VAP region were mainly studied closer to the shore (Weber et al., 2004; Chaumillon et al., 2008; Chaumillon et al., 2010; Fenies et al., 2010). Therefore, publicly available maps (Chantraine et al., 1996; Weber et al., 2004; Fenies et al., 2010; Augris et al., 2013) only show the presence of paleo-valleys in the inner shelf with varying geometries (Figure 4.3). It is unclear from published literature if paleo-incisions may be encountered within the OWF site.

Publicly available data highlights the thickness of the paleo-valley infill sediments that were mapped in the inner shelf (Augris et al., 2013). Paleo-valley infill sediment thickness is not mapped in publicly available data over the OWF site (Figure 4.3). However, the map highlights those infilling sediments are generally less than 10 m thick but may reach up to 25 m within the central axis of the paleo-incision.

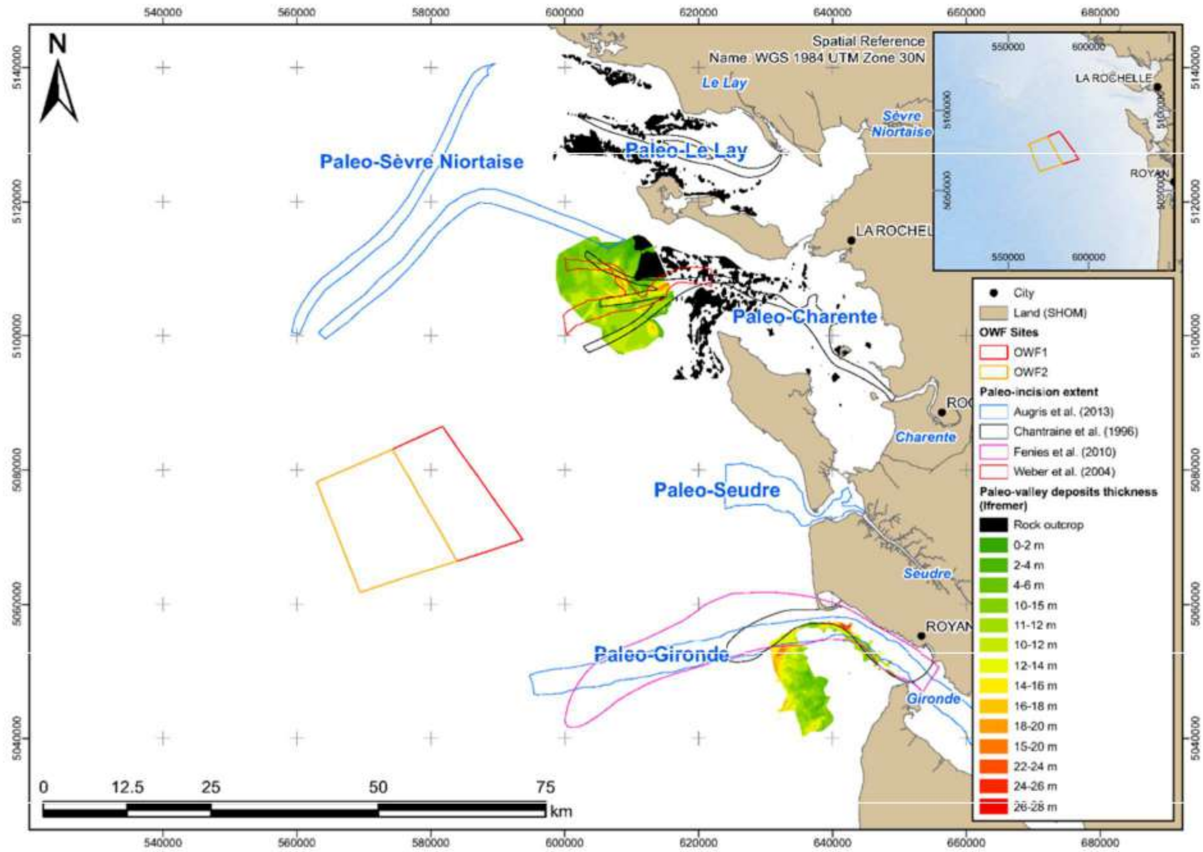


Figure 4.3: Paleo-valley extent and thickness across the VAP (modified from multiple sources)

4.4.3 Bedrock Outcrops

Figure 4.4 show that rock outcrops are distributed across the central VAP. The Rochebonne High represents one example of large outcrop area, but smaller individual outcrops are expected to be present but were not captured due to map resolution.

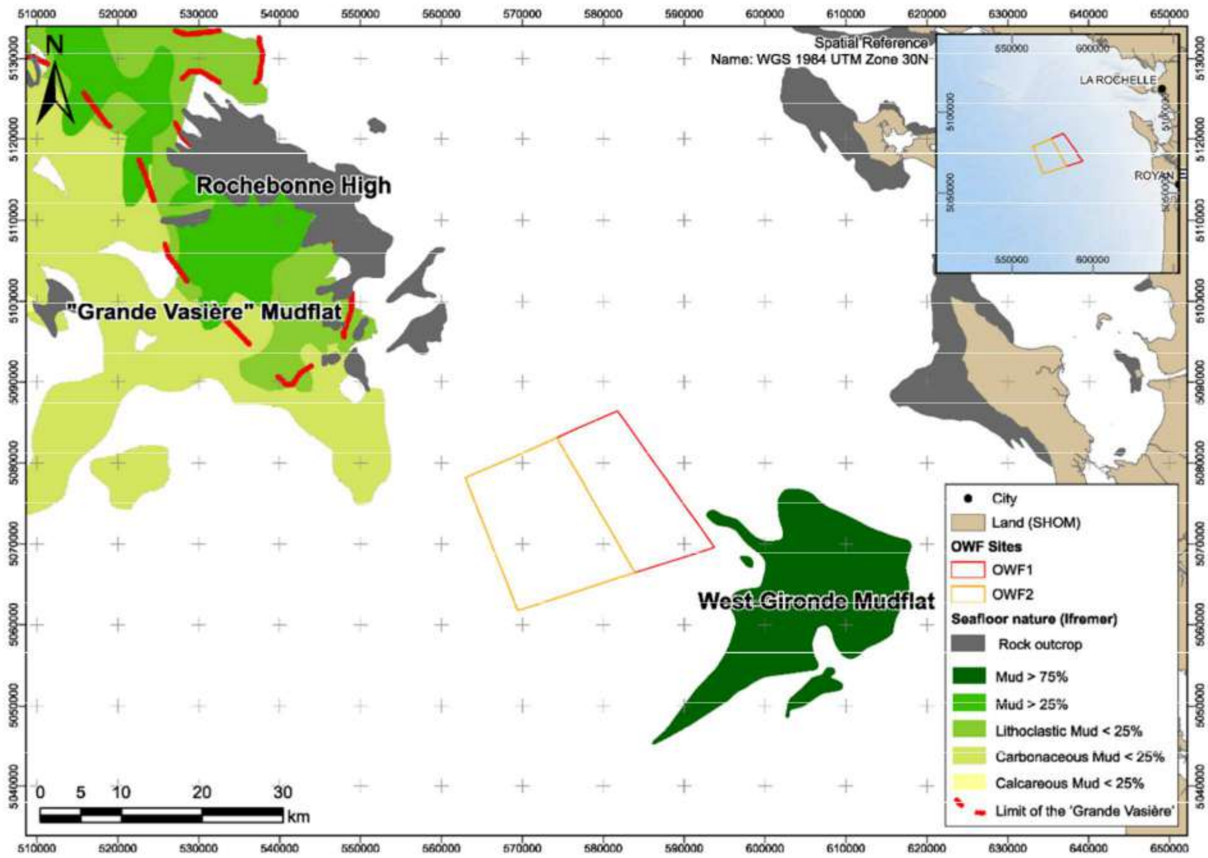


Figure 4.4: Rock outcrops and mudflats in the vicinity of the OWF site (modified from Ifremer and Bourillet et al., 2005)

4.4.4 Mudflats

Sediment dispersal in the Armorican and Aquitaine shelf is governed by fluvial sediment input mainly from the Vilaine, Loire, Charente, and Gironde rivers and spread by shelf currents. Fine-grained sediments are deposited at the seafloor along mudflats.

The VAP is surrounded by different mudflats. To the north and to the west of Rochebonne High, "La Grande Vasière" extends along the continental shelf from Penmarc'h in the north-west to Royan in the south-east (Pinot, 1966; Glémarec, 1969; Jouanneau et al., 1999; Dubrulle et al., 2007). This sedimentary system is 250 km long and 30 km wide and is situated in water depths ranging between -50 m HZ to -120 m HZ (Glémarec, 1969; Lesueur et al., 1991; Bourillet et al., 2004; Dubrulle et al., 2007).

Similarly, to the south-east corner of the OWF site, the Gironde mudflat is visible from the seafloor nature map (Jouanneau et al., 1999) (Figure 4.4). Based on Figure 4.4, none of these mudflats are expected to be present across the OWF site. However, smaller fine sediments accumulations may be expected in sheltered areas as water depths expected at the OWF site are similar to the range where the main mudflats are observed.

Mudflats are described as active sedimentary systems, their areas and thicknesses being controlled by a hydrographic regime (e.g. currents, swell, tides) as well as anthropogenic factors such as trawling and fishing activities.

For instance, the surface of "La Grande Vasière" is affected by seasonal remobilisation and sedimentation processes; deposition mainly takes place between April and September (fluvial sediment input), while remobilisation occurs in winter, resulting from storms (Lesueur et al., 1991; Rimaud, 2014; Bourillet et al., 2004; Dubrulle et al., 2007; Mengual et al., 2016).

Mudflats are described by several authors as the clay-fraction within the recent Holocene interval affected by remobilization processes (Pinot, 1966; Glémarec, 1969; Bourillet et al., 2004; Dubrulle et al., 2007). This finer fraction has the potential of being remobilised more easily, within the first half metre of sediments.

4.4.5 Bedforms

Turcq et al. (1986) and Berné (1999) have described coarse substrate at a water depth of -30 m HZ to -90 m HZ over the Aquitaine shelf and Cirac et al. (2000) mention several types of bedforms across the North Aquitaine Shelf. They were interpreted from side-scan sonar data (SSS) and sediment core data. These include:

- Erosive furrows with lateral sand banks parallel to the shoreline (linked to storm-induced bottom currents; -30 m HZ to -60 m HZ). Erosion through bottom currents may explain the presence of coarser material at seafloor (Section 5.2.4);
- Megaripples (-50 m HZ);
- Lineations observed on the outer shelf (-80 m HZ).

Coarser (sands, gravels, and cobbles) sediments are considered less mobile than mudflats. Nevertheless, Mazières et al. (2015) described mobile sandy (fine to coarse) sediments at -25 m HZ to -50 m HZ in the inner part of the shelf, south of Bay of Arcachon.

The area surrounding OWF site is less understood; however, Bourillet et al. (2017) indicates the presence of coarse sediments related to possible bedforms at depths of -76 m HZ up to -100 m HZ. Thus, the presence of bedforms at the OWF site cannot be excluded.

4.5 Oceanographic Setting

In the Bay of Biscay, long-term Metocean measurements are lacking for the shelf (Armorican and Aquitaine shelf), mostly because the shelf is the site of intense fishing activity, particularly by numerous trawlers. Long-term moorings have therefore been avoided.

Nevertheless, long-term current measurement surveys (from 2 to 6 weeks) were carried out by Le Cann (1982), at depths from -40 m HZ to -100 m HZ showing a persistent north-westerly flow, with typical mean speeds of 3 cm/s that occurred coastally along the Armorican shelf (Pingree and Le Cann, 1989). These currents are thought to be weaker in the south over the Aquitaine Shelf (Le Cann, 1982).

Tidal characteristics were investigated by Le Cann (1990); the semi-diurnal components (M_2; e.g. the most energetic), shows velocities of 20-30 cm/s over the shelf with peak around 50 cm/s in the north-western outer part of the shelf.

Wind driven currents on the shelf are highly variable. Wind induced circulation generates currents of typically 10 cm/s and locally 20-30 cm/s (Koutsikopoulos and Le Cann 1996).

5. Site Conditions

5.1 Overview

This section presents the site conditions that are predicted based on the interpretation and integration of data listed in Section 2. Relevant integration and interpretation methods are detailed in Section 3.

5.2 Seafloor Conditions

5.2.1 Overview

This section details the seafloor conditions at the OWF site based on Fugro's analysis and interpretation of SHOM data provided by DGEC (Section 2.3).

Plates associated with this section are listed below:

- Plate 3.1 presenting the shaded relief bathymetry at OWF site;
- Plate 3.2 presenting the seafloor gradient map at OWF site;
- Plate 3.3 presenting the seafloor nature map at OWF site;
- Plate 3.4 presenting the seafloor features map at OWF site;

5.2.2 Bathymetry

SHOM MBES bathymetry (see Section 2.3.1.2) illustrates in detail (grid resolution of 2 m) the expected water depth across the OWF site.

Details on the water depth values per OWF site (OWF1 and OWF2) are provided in Table 5.1.

Table 5.1: Water depth values across the OWF sites

Site	Minimum [m HZ]	Maximum [m HZ]	Average [m HZ]
OWF1	-69.44	-54.56	-63.60
OWF2	-81.88	-66.00	-74.44
OWF site (all)	-81.88	-54.56	-69.93

Based on the shaded-relief bathymetric map displayed in Figure 5.1, water depth across the OWF site regularly deepens from east to west, towards the shelf break, with a maximum of -54.56 m HZ to the East and a minimum of -81.88 m HZ to the West.

The seafloor appears irregular within OWF1 where numerous positive bathymetric features (up to 5 m high) are observed and are interpreted as rock outcrops (Section 5.2.5). Elongated depressions can be observed between these bathymetric highs.

Within OWF2, the seafloor appears more regular than at OWF1. Regularly spaced elongated bathymetric features are imaged with less than 1 m in height and are interpreted as sand dunes (Section 5.2.5). These features are found along the elongated depressions that continue within OWF2.

Shaded-relief bathymetry map is also provided as Plate 3.1.

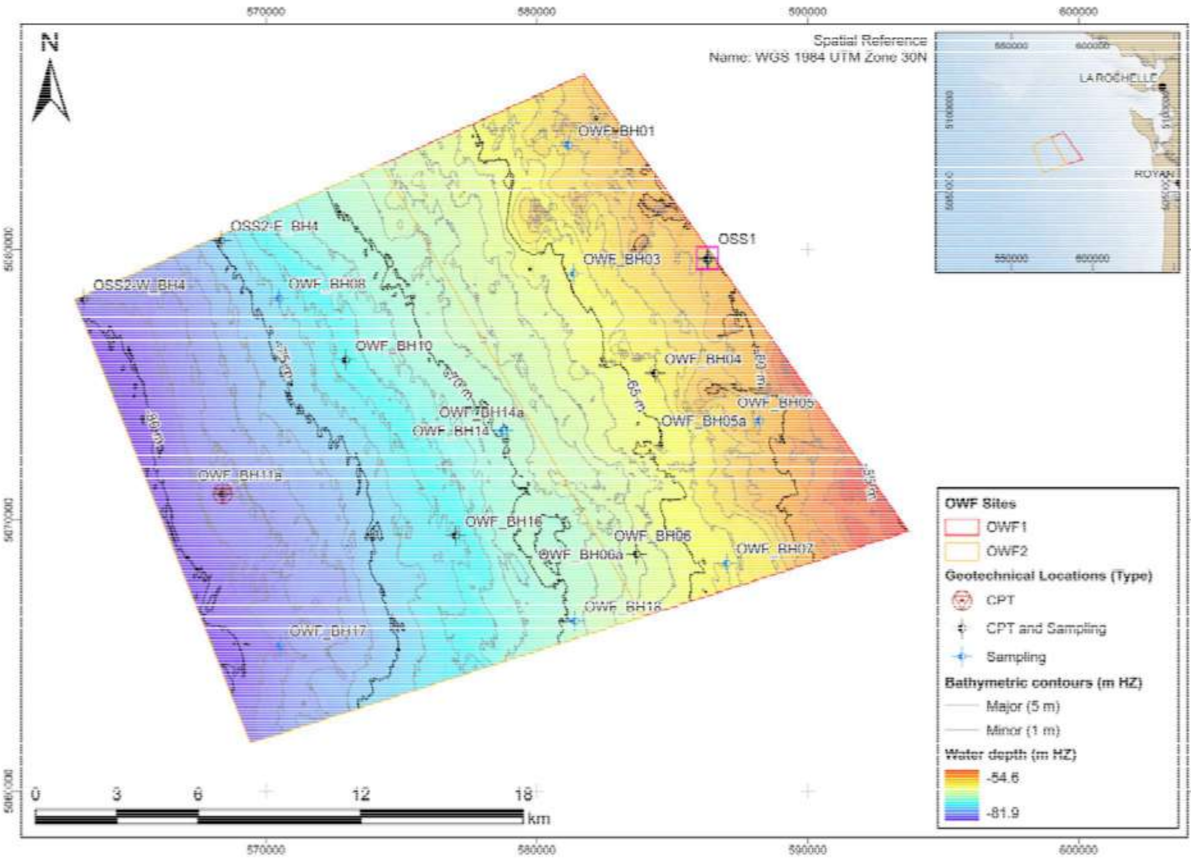


Figure 5.1: SHOM MBES shaded-relief bathymetry across the OWF site

5.2.3 Seafloor Gradients

Seafloor gradients were calculated based on SHOM MBES bathymetry. Values range between 0 and 61.52° but the average value is 0.41° showing that slope angles are generally low. Details per OWF site are provided in Table 5.2.

Table 5.2: Seafloor gradient values across the OWF sites

Site	Minimum [°]	Maximum [°]	Average [°]
OWF1	0.00	42.44	0.44
OWF2	0.00	61.52	0.37
OWF site (all)	0.00	61.52	0.41

Figure 5.2 displays the resulting seafloor gradient map across the OWF site. Most of the area presents slope angles lower than 0.5°. Higher values are expected in OWF1 and are associated with rock outcrops along the eastern part of the site. This is in accordance with the higher average observed at OWF1 compared to OWF2 (Table 5.2). High values at OWF2 are generally associated with sand dunes where slopes can reach 5°. However, OWF2 highest value (61.52°) is associated to localized seafloor features identified by SHOM as anthropogenic obstructions.

Seafloor gradient map is also provided as Plate 3.2.

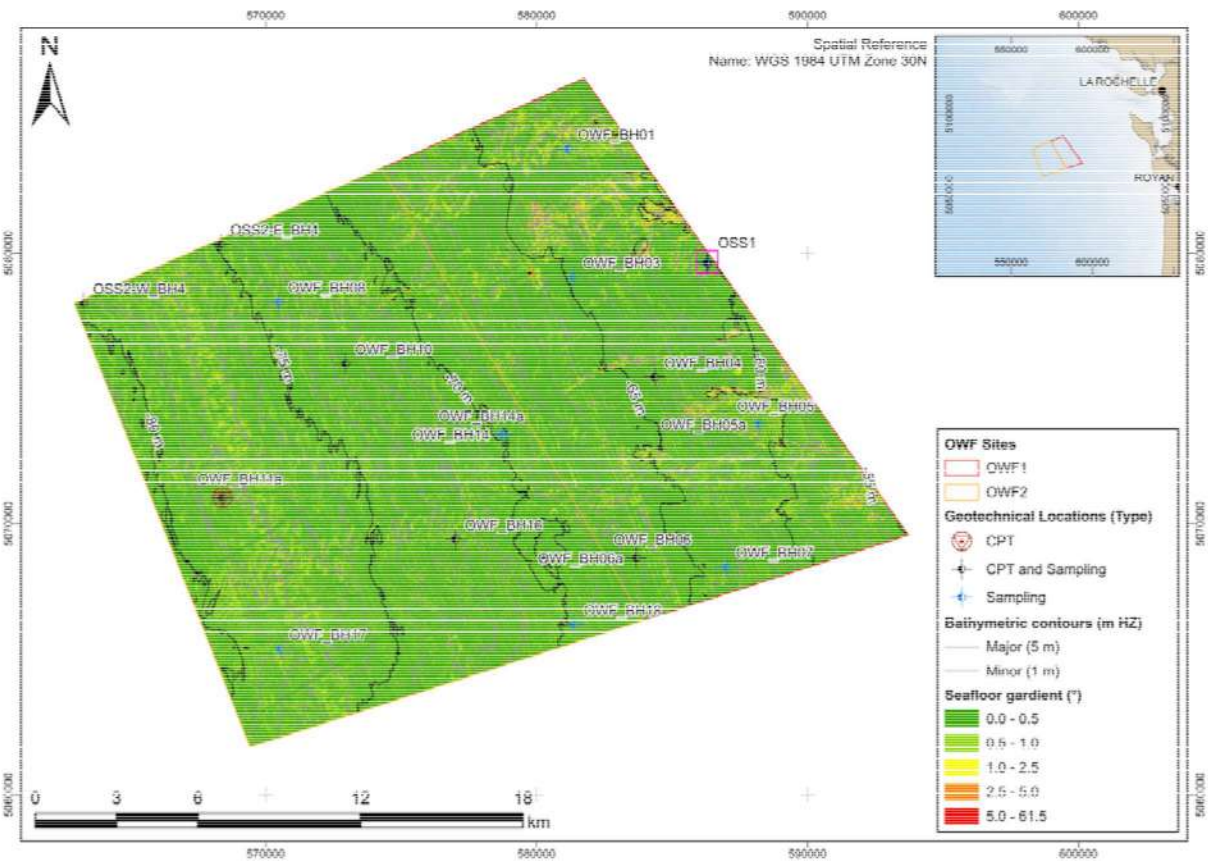


Figure 5.2: SHOM MBES seafloor gradient across the OWF site

5.2.4 Seafloor Nature

SHOM produced a seafloor nature map across the OWF site based on MBES backscatter (Section 2.3.1.2) and PSD analysis performed on seafloor samples (Section 2.3.2.1).

Figure 5.3 displays the seafloor nature map along with the different PSD analysis available across the site. Except for a small number of points, the seafloor nature map shows a good correlation with available PSDs. The seafloor at the OWF site consists of:

- Mud;
- Muddy fine sand;
- Fine sand;
- Sand;
- Rock.

Rock outcrops (Rock in Figure 5.3) are mainly distributed within OWF1. Mud is only found in water depth greater than -70 m HZ and on the proximal side of outcrops where hydrodynamic conditions are likely more favourable to the deposition of fine-grained sediments. The rest of the site consist of fine sand to sand. Fine sand is mostly expected where dunes are observed on MBES data. Muddy fine sand may be expected at very localized areas of the seafloor showing that a finer fraction may be expected in surficial sands.

Seafloor nature map is also provided as Plate 3.3.

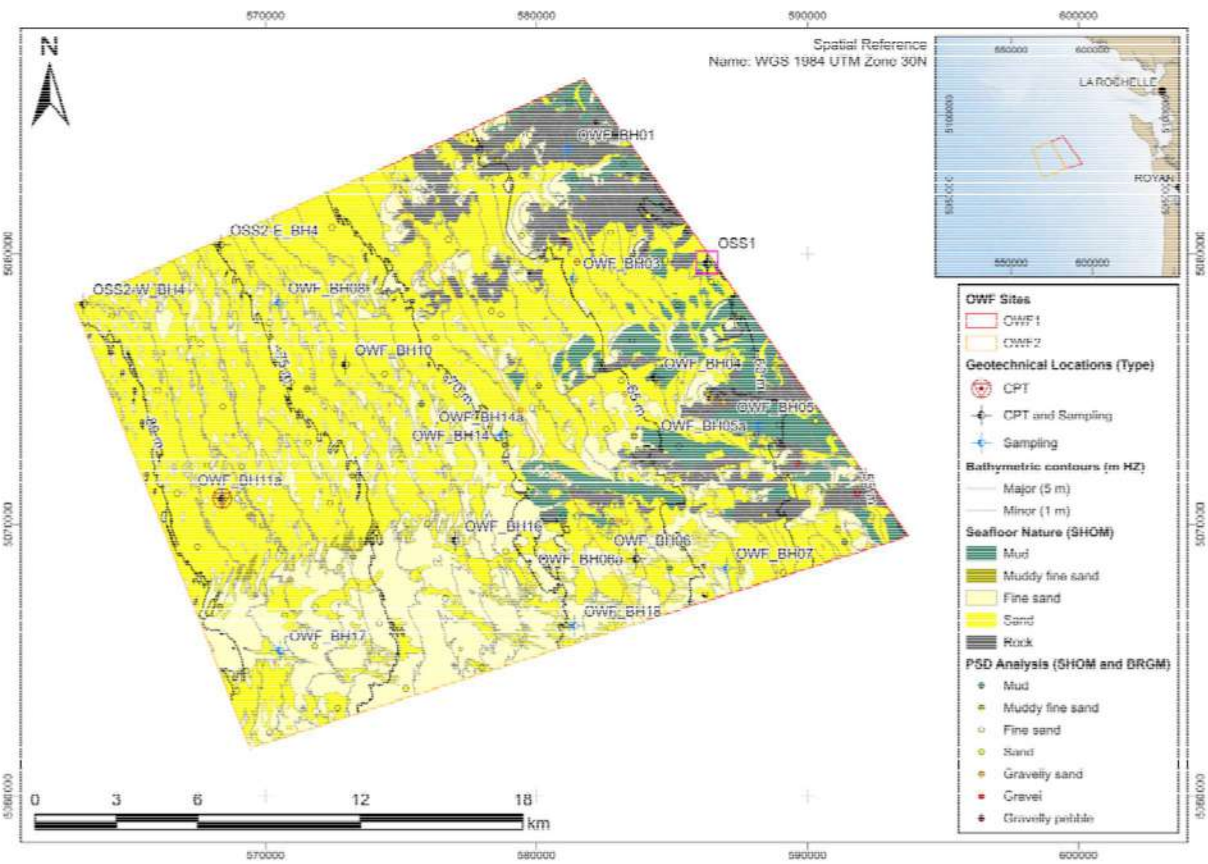


Figure 5.3: SHOM seafloor nature map with main soil types from PSD results on seafloor samples

5.2.5 Seafloor Features

Based on observations made on the MBES data (bathymetry, seafloor gradient and backscatter) and on the seafloor nature map from SHOM, Fugro identified and mapped a number of seafloor features. The resulting map is displayed in Figure 5.4. Identified seafloor features are:

- Rock outcrops;
- Sand dunes;
- Ribbons;
- Megaripples;
- Anthropogenic obstructions;
- Trawlmarks.

Seafloor features map is also provided as Plate 3.4.

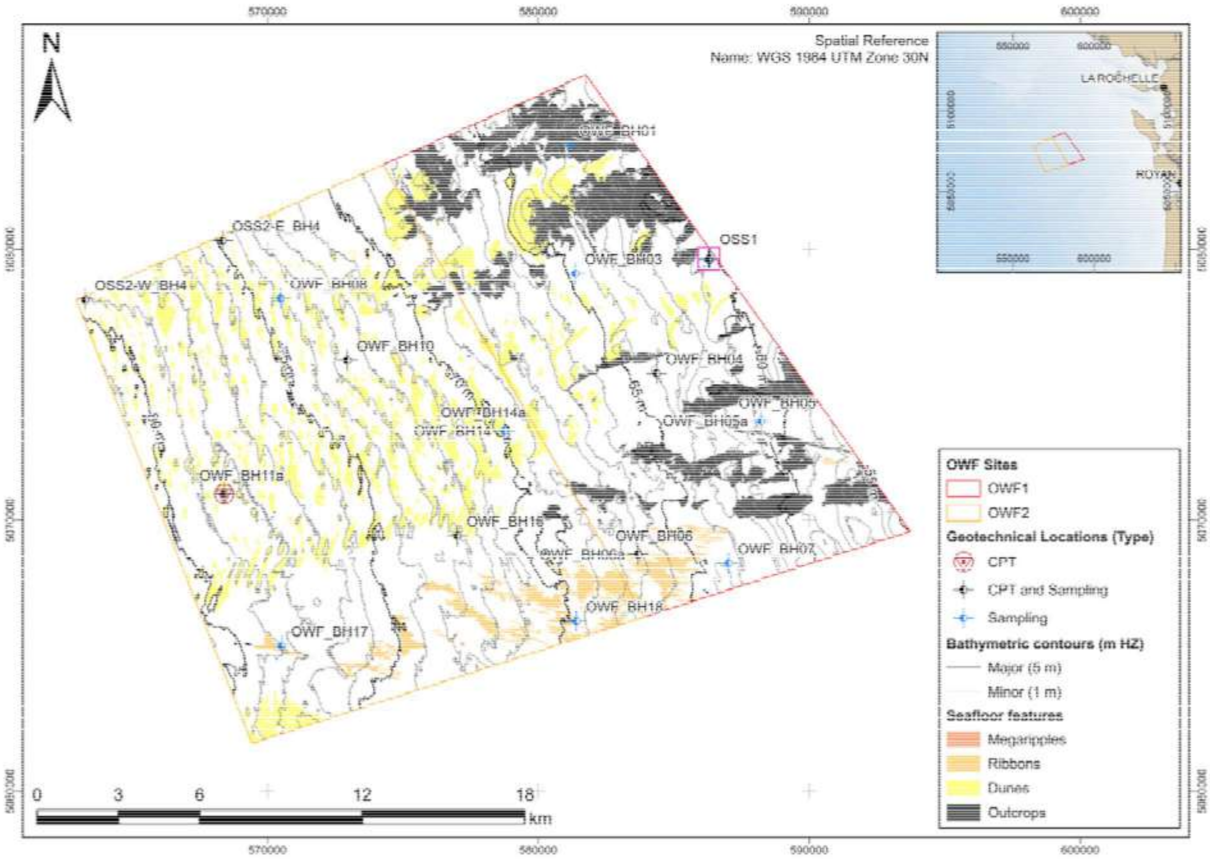


Figure 5.4: Seafloor features across the OWF site

5.2.5.1 Rock Outcrops

Rock outcrops are directly derived from SHOM seafloor nature map (Figure 5.3). Their characteristics are:

- Irregular seafloor with bathymetric changes of up to 5 m (Figure 5.1);
- High seafloor gradients (greater than 5°);
- High seafloor backscatter (reflectivity) value.

An example of rock outcrop showing typical seafloor gradients and seafloor backscatter is provided as Figure 5.5.

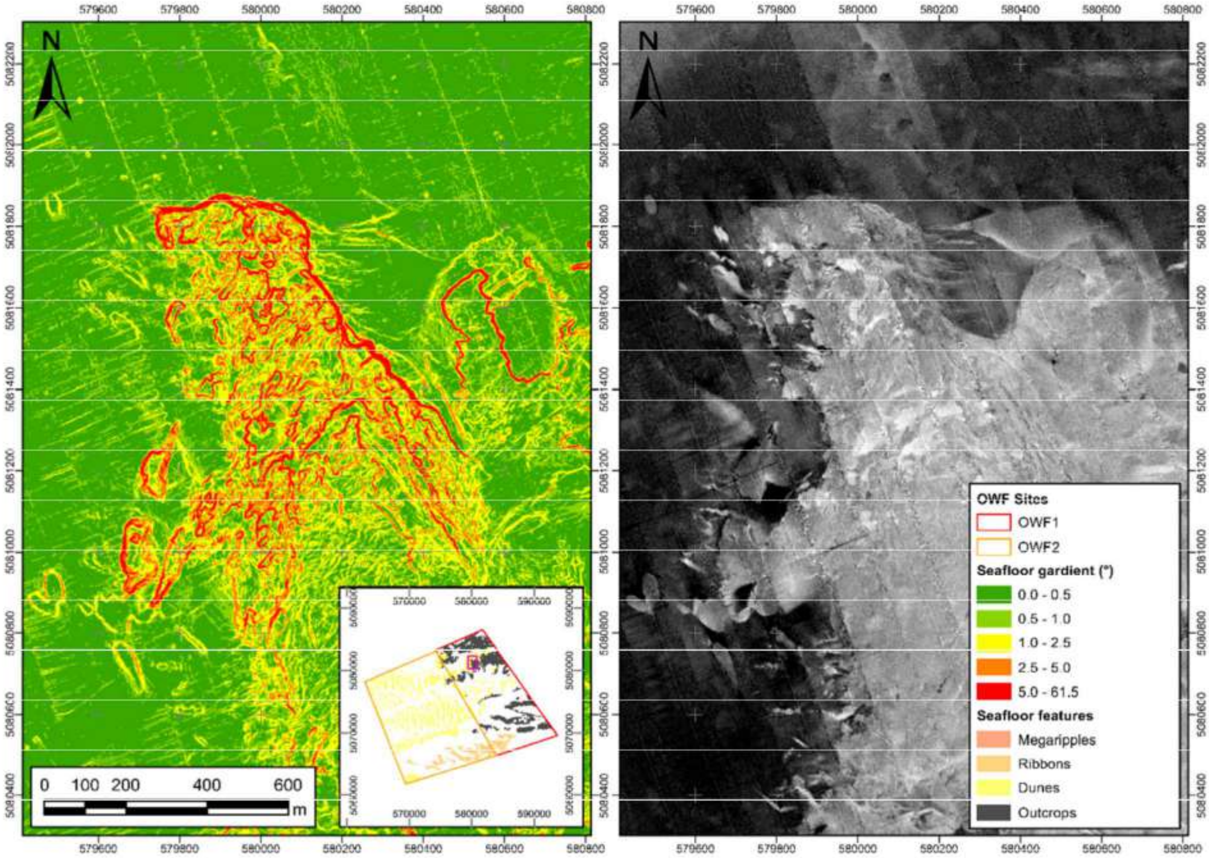


Figure 5.5: Example of rock outcrops. Left: seafloor gradients; right: backscatter

5.2.5.2 Sand Dunes

Sand dunes observed on MBES data (Figure 5.1, Figure 5.2 and Figure 2.3) correlates with the presence of fine sand on the seafloor nature map from SHOM (Figure 5.3). Fugro extracted the fine sand from the map and only kept the areas corresponding to observable dunes. Sand dunes were recognized based on:

- Elongated bathymetric highs with height reaching 1 m (Figure 5.1);
- Seafloor gradients up to 5° along the edges of the dunes;
- Low seafloor backscatter (reflectivity) value corresponding to the presence of fine sand.

An example of sand dunes showing typical seafloor gradients and seafloor backscatter is provided as Figure 5.6.

Sand dunes observed at the OWF site present the following characteristics as demonstrated by the bathymetric profile displayed in Figure 5.7:

- Height ranging from 0.5 m to 1 m;
- Elongated in a south-south-west to north-north-east direction;
- Aligned along a west-south-west to east-north-east direction;
- Length is variable with smaller dunes being less than 100 m long, and longer reaching 4 km. Width varies between less than 50 m and 1 km;
- Spacing varies between 200 m and 1 km.

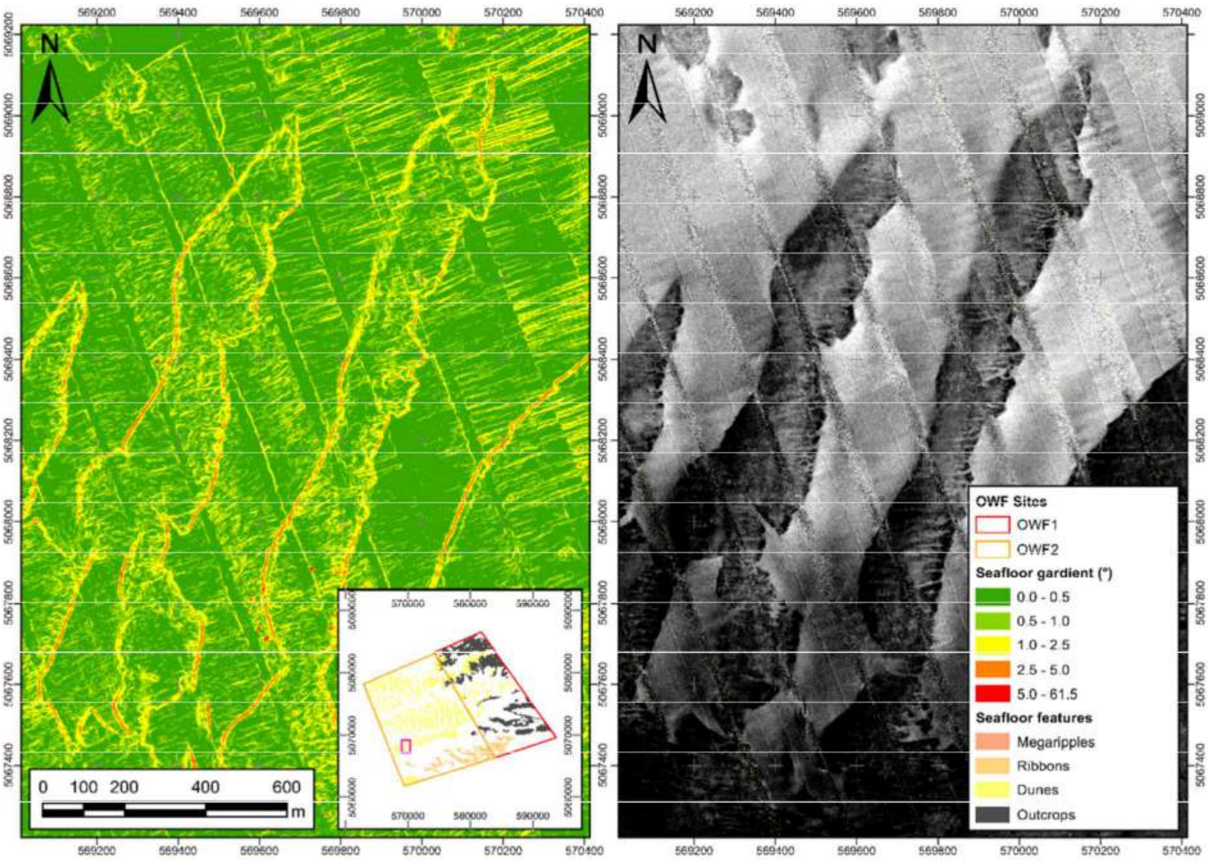


Figure 5.6: Example of sand dunes. Left: seafloor gradients; right: backscatter

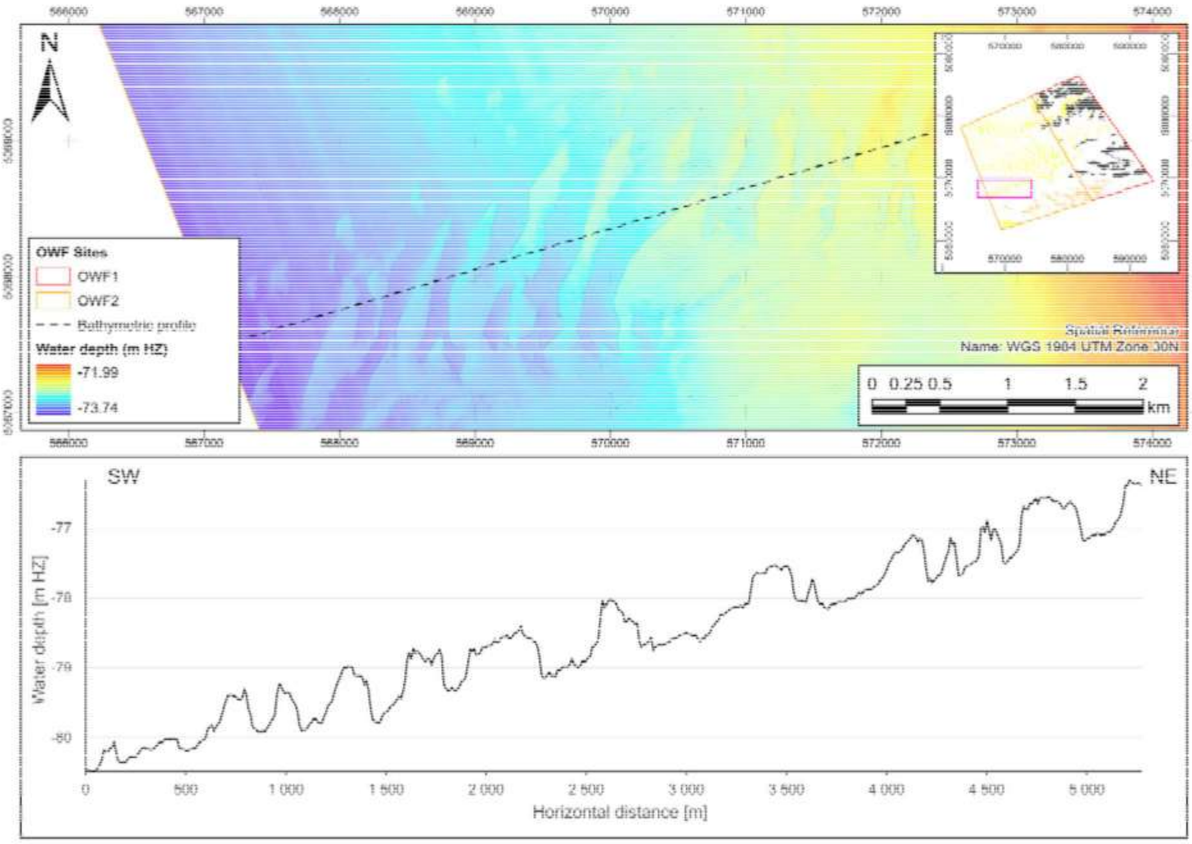


Figure 5.7: Bathymetric profile across a sand dune field at the OWF site

Sand dunes are distributed in different dune fields all extending within bathymetric depressions extending from east to west and likely related to the absence of rock outcrops (Figure 5.4). Their possible mobility is assessed in Section 5.2.6.

5.2.5.3 Ribbons

Ribbons are observed on the seafloor backscatter showing slightly higher reflectivity than the background sediments (Figure 5.8). SHOM seafloor nature map (Figure 5.3) shows these features are related to the presence of sand at seafloor in an area mostly covered by fine sand. Those features are not associated with any bathymetric or seafloor gradient changes and are therefore interpreted as being a very fine veneer of sand (sand ribbons) or the result of the local remobilization of fine sand through the action of bottom currents.

These features elongate along a south-east to north-west axis (Figure 5.8) and develops within a bathymetric depression as observed in Figure 5.1.

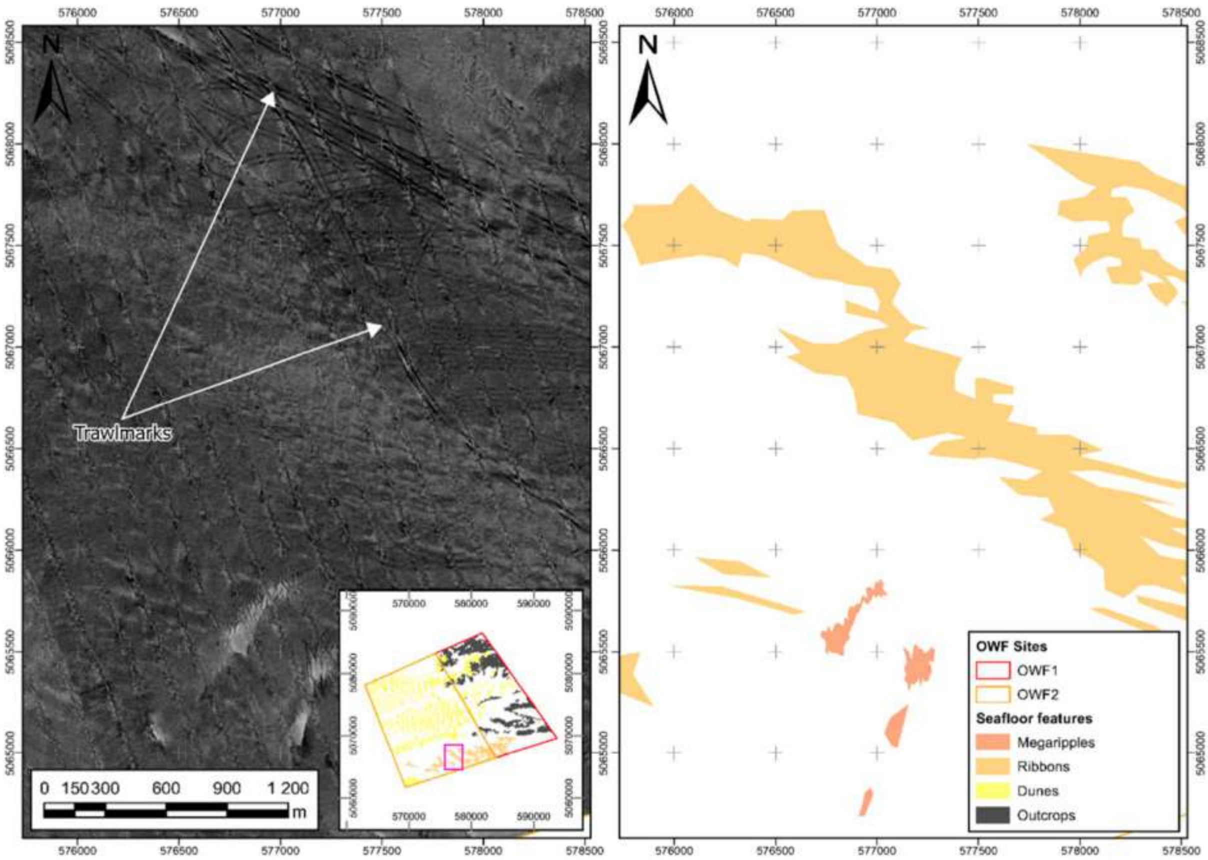


Figure 5.8: Example of ribbons, megaripples and trawlmarks. Left: backscatter; right: interpretation

5.2.5.4 Megaripples

Small patches presenting wavy geometries are visible on backscatter data as higher reflectivity zones (Figure 5.8). These patches are therefore associated with coarser sand and occur within localized small bathymetric depressions. These features are likely related to localized bottom current conditions.

Megaripples observed at the OWF site present the following characteristics as demonstrated by the bathymetric profile displayed in Figure 5.9:

- Height comprised between 10 cm and 25 cm;
- Wavelength of 20 m;
- Elongated in a north-south direction;
- Aligned an east to west axis.

Their possible mobility is assessed in Section 5.2.6.

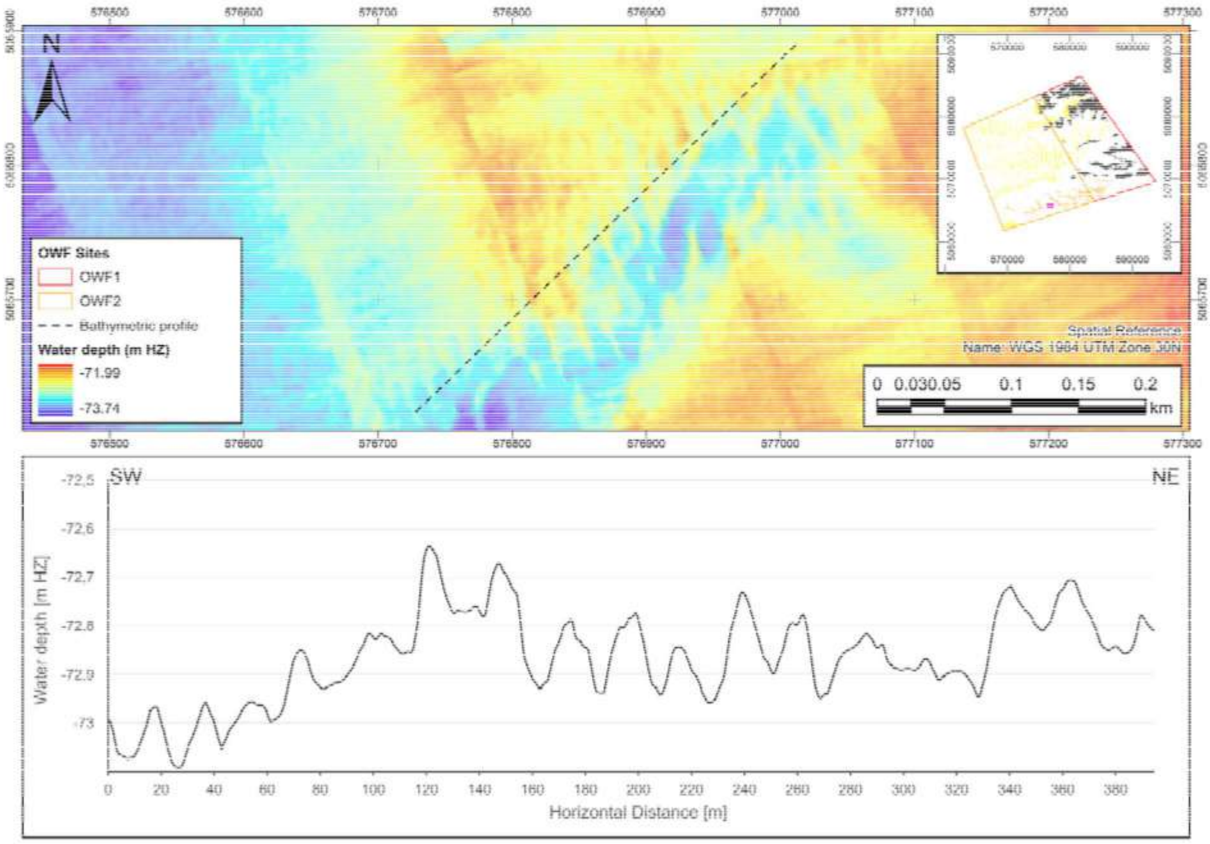


Figure 5.9: Bathymetric profile across a megaripple field at the OWF site

5.2.5.5 Anthropogenic Features

Two (2) anthropogenic seafloor obstructions were identified on MBES data by SHOM. Those are displayed in Figure 5.10 (as a and b) and are likely associated with shipwrecks. Scours (seafloor depression), that relate to the erosion of seabed sediments, occur in the northern edge of the obstructions, likely related to a SSW-oriented current flow regime.

SHOM historical database highlights the possible presence of two wooden shipwrecks sunk in 1917 (fishing vessels, Dundee type) caused by underwater mine explosions (Gourong and Leplat, 2001). No detailed information is available on those ships and it is therefore difficult to conclude if the seafloor obstructions observed in Figure 5.10 are those two wooden fishing vessels.

Magnetic anomalies might be associated with both seafloor obstructions highlighting the potential presence of metallic elements within the shipwrecks.

Another potential shipwreck is visible at seafloor but was not identified by SHOM. This obstruction (c in Figure 5.10) appears to be partially buried but is elongated like the two others. This obstruction is potentially another shipwreck. No magnetic anomaly is associated with this obstruction, indicating that no metallic pieces are expected.

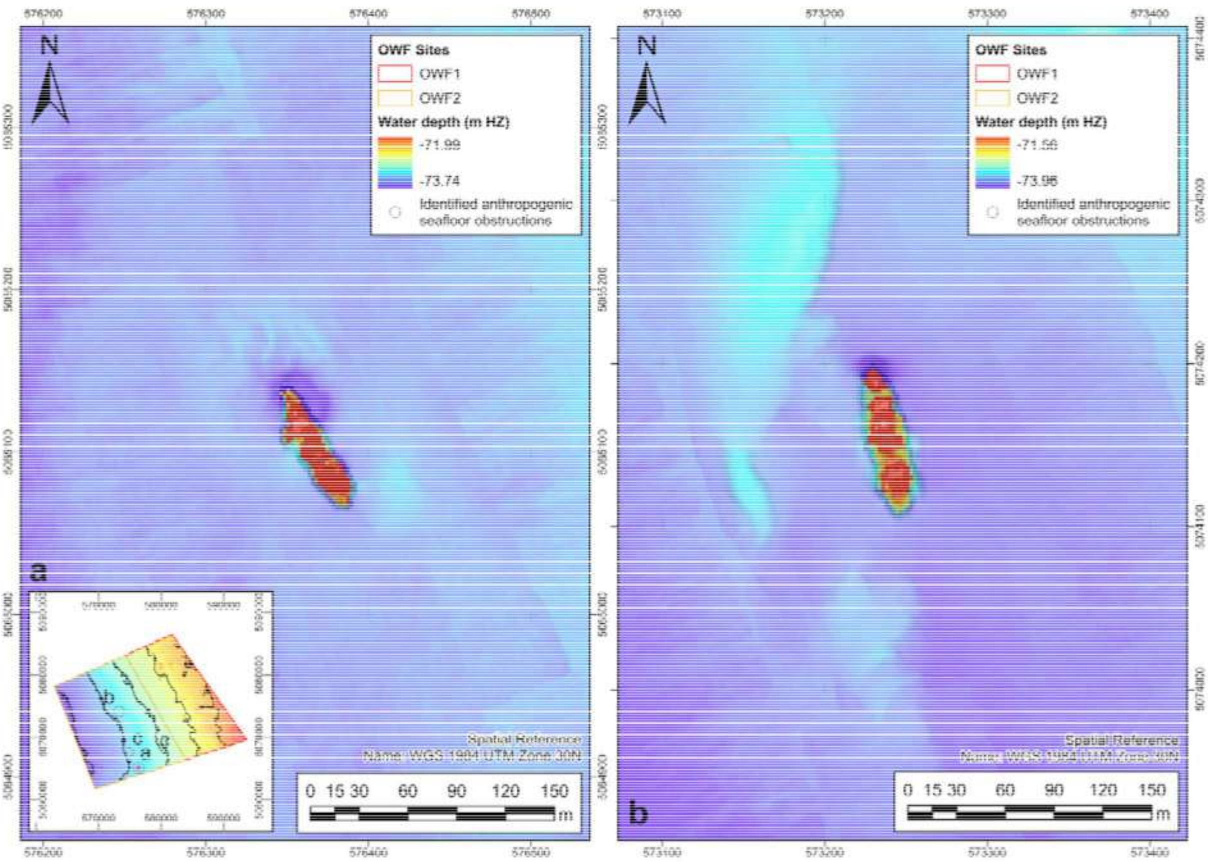


Figure 5.10: Examples of seafloor obstructions identified at the OWF site seafloor

Trawlmarks were also noticed at different areas of the OWF site, in particular along the southern border as highlighted in Figure 5.8. These are evidence for fishing activity across the OWF site.

5.2.6 Hydro-sedimentary Conditions

Wave base, the depth beneath a water mass below which wave action ceases to disturb the sediments, is approximately equal to half the wavelength of the surface waves. A major storm identified at buoy 01704 (e.g. 30 Janv. 2021) shows a mean wave period of 10.4 seconds (Kergadallan, 2022). From the buoy Windsea 14, the maximum mean wave period recorded from June 2021 to June 2022 is 12.4 seconds (SHOM, 2022e). The maximum mean period of waves modelized in the period 1979-2021 is 14.63 seconds (SHOM, 2022f, g).

The wavelength (L) being calculated using the formula (1)

(1) $L = gT^2/(2\pi)$

where g=9.8 m/s^2 and T is wave period in seconds.

The wave-base action could be comprised between -79 m HZ and -156 m HZ during major storms. Thus, sediment mobility could occur in the water depths of the whole OWF site.

ADCP current velocities near the seabed (-31 m HZ) from June 2021 to June 2022 of the buoy Windsea 14 shows that currents are at maximum around 35 cm/s and oriented NE/SW (SHOM, 2022e). From SHOM Lot 2 Currents data (SHOM, 2023c, d), ADCP current velocities of station F0760 between March and June 2017 at -29 m HZ indicate maximum velocities of 26 cm/s in NNE/SSW direction.

Based on these data, remobilisation of the seabed deposits including the sand fraction is likely possible with the deposition of ripples, especially during major storms. However, flow velocity for the deposition of bedforms such as dunes, ribbons, and megaripples as identified in Sections 5.2.5.2, 5.2.5.3 and 5.2.5.4, respectively, should be above around 40 cm/s according to the paper of Rebesco et al. (2014). Therefore, most of these bedforms are likely relict-features and not active.

This should be confirmed by a specific hydro-sedimentary study.

5.3 Sub-seafloor Conditions

5.3.1 Overview

This section details the subsurface geological conditions at the OWF site based on Fugro's acquired geotechnical data (Section 2.2) and on Fugro's interpretation of TECNOAMBIENTE UHRS data (Section 2.3.1.6).

Plates associated with this section are listed below:

- Plate 3.5 to 3.7 present three examples of interpreted seismic lines;
- Plate 3.8 presents the sediment thickness map from SHOM based on the interpretation of SBP data (Section 2.3.1.4);
- Plate 3.9 to Plate 3.11 present the gridded thickness maps for individual seismostratigraphic units picked as part of the study on 2D UHRS data (Section 2.3.1.6);
- Plate 3.12 present the gridded Depth to Top SU4 Map picked as part of the study on 2D UHRS data (Section 2.3.1.6);
- Plate 3.13 shows a map displaying ground types per borehole;

5.3.2 Seismostratigraphic Units

5.3.2.1 Time-depth Conversion of Seismostratigraphic Units

Following the methodology described in Section 3.3.2, time-depth pairs were created at each borehole and summarized in Table 5.3 .

Table 5.3: Time to depth pairs

Borehole name	Time-depth pair 1			Time-depth pair 2			Time depth pair 3			Time depth pair 4		
	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]
OSS1_BH01	0.0007	1.5213	11571*	-	-	-	-	-	-	0.0015	1.5213	5324*
OSS1_BH02	0.0010	1.4971	7300*	-	-	-	-	-	-	0.0015	1.4971	4876*
OSS1_BH03	0.0007	1.4425	6714*	-	-	-	-	-	-	0.0014	1.4425	3258*
OSS1_BH04	0.0008	1.5213	10000*	-	-	-	-	-	-	0.0015	1.5213	5259*
OSS2-E_BH04	0.0084	9.8919	2083	-	-	-	-	-	-	0.0099	9.8919	1769
OSS2-W_BH04	0.0152	25.4541	1796	0.0095	8.7875	2705*	-	-	-	0.0255	25.4541	2082
OWF_BH01	-	-	-	-	-	-	-	-	-	-	-	-
OWF_BH03	0.0013	0.1470	308*	-	-	-	-	-	-	0.0001	0.147	2721
OWF_BH04	0.0066	9.4103	1970	-	-	-	0.0052	6.1100	2212	0.0094	9.4103	1381
OWF_BH05	0.0036	3.9378	2972	-	-	-	0.0352	41.3600	2403	0.0040	3.9378	2717
OWF_BH05a	0.0037	3.9378	2892	-	-	-	0.0350	41.1250	2417	0.0040	3.9378	2717
OWF_BH06	0.0102	10.1751	2216	-	-	-	-	-	-	0.0102	10.1751	2221
OWF_BH06a	0.0101	10.1751	2238	-	-	-	-	-	-	0.0102	10.1751	2221
OWF_BH07	0.0080	8.0345	1625	-	-	-	-	-	-	0.0080	8.0345	1618
OWF_BH08	0.0101	11.4327	2495	-	-	-	-	-	-	0.0114	11.4327	2204
OWF_BH10	0.0064	8.2905	1859	-	-	-	-	-	-	0.0083	8.2905	1435
OWF_BH11	0.0140	29.5835	1857	0.0184	17.0200	1891	-	-	-	0.0296	29.5835	2055
OWF_BH11a	0.0140	29.5835	1857	0.0188	17.3900	1851	-	-	-	0.0296	29.5835	2055
OWF_BH14	0.0017	1.2175	2000	-	-	-	0.0054	6.3450	4926*	0.0012	1.2175	2793
OWF_BH14a	0.0016	1.2175	2125	-	-	-	0.0055	6.4625	4836*	0.0012	1.2175	2793
OWF_BH16	0.0099	10.4637	1515	-	-	-	-	-	-	0.0105	10.4637	1434

Borehole name	Time-depth pair ❶			Time-depth pair ❷			Time depth pair ❸			Time depth pair ❹		
	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]	Time [s TWTT]	Depth [m BSF]	Velocity [m.s^{-1}]
OWF_BH17	0.0157	30.2336	1618	0.0201	18.5925	1801	-	-	-	0.0302	30.2336	2037
OWF_BH18	0.0129	12.9483	1674	-	-	-	-	-	-	0.0129	12.9483	1668
AVERAGE	-	-	2047	-	-	1848	-	-	2344	-	-	2107
MINIMUM	-	-	1515	-	-	1801	-	-	2212	-	-	1381
MAXIMUM	-	-	2972	-	-	1891	-	-	2417	-	-	2793
Std. DEVIATION	-	-	419	-	-	45	-	-	115	-	-	490

Notes:

❶ Fugro's SU1 from seismic data in the time domain (s TWTT) paired with GT1,2 from geotechnical data in the depth domain (m BSF)

❷ Fugro's SU2 from seismic data in the time domain (s TWTT) paired with GT3,4 from geotechnical data in the depth domain (m BSF)

❸ Fugro's SU3 from seismic data in the time domain (s TWTT) paired with GT5,6 from geotechnical data in the depth domain (m BSF)

❹ SHOM's sediment cover from seismic data in the time domain (s TWTT) paired with GT1,2,3,4 from geotechnical data in the depth domain (m BSF)

* Velocities not used for the estimation of average, minimum, maximum, and standard deviations statistics

Three (3) seismostratigraphic units (i.e. SU1, SU2, and SU3), bounded by a top and a base horizon, as well as the sediment cover map of the SHOM time-converted using SHOM velocities of 1,640 m/s, were paired with ground types observed at boreholes.

Average velocities were calculated per units excluding:

- OSS1_BH01, _BH02, _BH03, and _BH04 time-depth pairs for Fugro's seismostratigraphic unit 1 (SU1) and SHOM sediment cover;
- OWF_BH03 time-depth pair for Fugro's seismostratigraphic unit 1 (SU1);
- OSS2-W_BH04 time-depth pair for Fugro's seismostratigraphic unit 2 (SU2); and
- OWF_BH14 and _BH14a time-depth pairs for Fugro's seismostratigraphic unit 3 (SU3).

Exclusion of these values are either due to seismic gridding algorithms limits or seismic resolution limits.

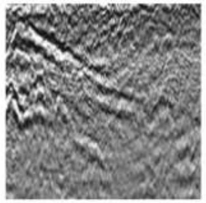
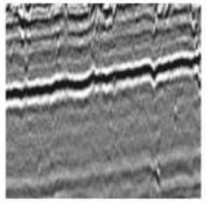
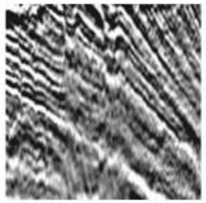
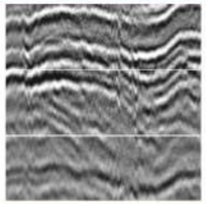
Average velocities were applied to seconds two-way travel time gridded maps to depth-convert them in metres below seafloor using 2050 m/s for SU1, 1850m/s for SU2, 2350 m/s for SU3, and 2100 m/s for the SHOM sediment cover map.

5.3.2.2 Overview

Four (4) seismostratigraphic units (SU) were differentiated on the 2D UHRS data (Section 2.3.1.6). Table 5.4 synthetizes the seismic properties and characteristics of these SU.

Thicknesses in metres were obtained by converting TWTT thicknesses using acoustic velocities detailed in Table 5.3.

Table 5.4: Seismostratigraphic units (SU) at OWF site

SU	Top / Base Horizon	TWTT thickness [s]		Velocity [m/s]	Thickness (1) [m]		Seismic facies example	Seismic Facies Description [configuration; continuity; amplitude]	Depositional environments	Age (2)
		Min	Max		Min	Max				
SU1	H01 / H02	0.000	0.023	2050	0.2 *	24.3		Chaotic, discontinuous, low amplitude seismic reflectors.	Shallow marine deposits (U5 in Table 4.1).	Plio-Quaternary
SU2	H02 / H03	0.000	0.0368	1850	0.0	34.0		Parallel, continuous, low to moderate amplitude seismic reflectors.	Marine deposits (U4 in Table 4.1).	Miocene
SU3	H01 or H02 / H04	0.000	0.054	2350	0.4 *	62.9		Oblique, semicontinuous, moderate to high amplitude seismic reflectors.	Shallow marine deposits (U2 in Table 4.1).	Paleogene
SU4 *	H01, H02, or H03 / NA	- **	- **	-	- **	- **		Semi-parallel, oblique, or contorted to mound-shaped, continuous to discontinuous, low to high amplitude seismic reflectors.	Shallow marine to marine deposits (U1 and U3 in Table 4.1).	Mesozoic

Notes:
* Limited by vertical resolution of seismic data
** SU4 thickness is not calculated as the base of SU4 could not be picked on 2D UHRS data.
H01: Seafloor
(1) Thickness data are calculated from the TWTT thickness using acoustic velocities obtained following the time-depth conversion results detailed in Table 5.3.
(2) Assumed age based on published literature (Huerta et al., 2010)

Examples of interpreted seismic sections showing the relationships between each unit across the OWF site are provided as Plates 3.5 to 3.7.

The characteristics (i.e. geometries, facies and distribution) of individual SUs and of major structural elements are detailed in the following sub-sections.

5.3.2.3 Seismostratigraphic Unit 1 (SU1)

Seismostratigraphic unit 1 (SU1) is characterised by chaotic and discontinuous seismic facies with low amplitude reflectors. The unit is bounded at its base by an erosive surface (horizon H02) and at its top by the seafloor horizon (H01). An acoustic velocity of 2050 m/s was applied to SU1, rounded value based on borehole data (Table 5.3).

SU1 is distributed across the entire OWF site with thicknesses ranging from 0 m and 24 based on the gridded thickness map (Figure 5.11). Maximum thickness is observed towards the west while the minimum thickness is located east, where rock outcrops are observed at seafloor, thus where SU3 or SU4 are outcropping at the seabed surface. At outcrop locations, SU1 is absent.

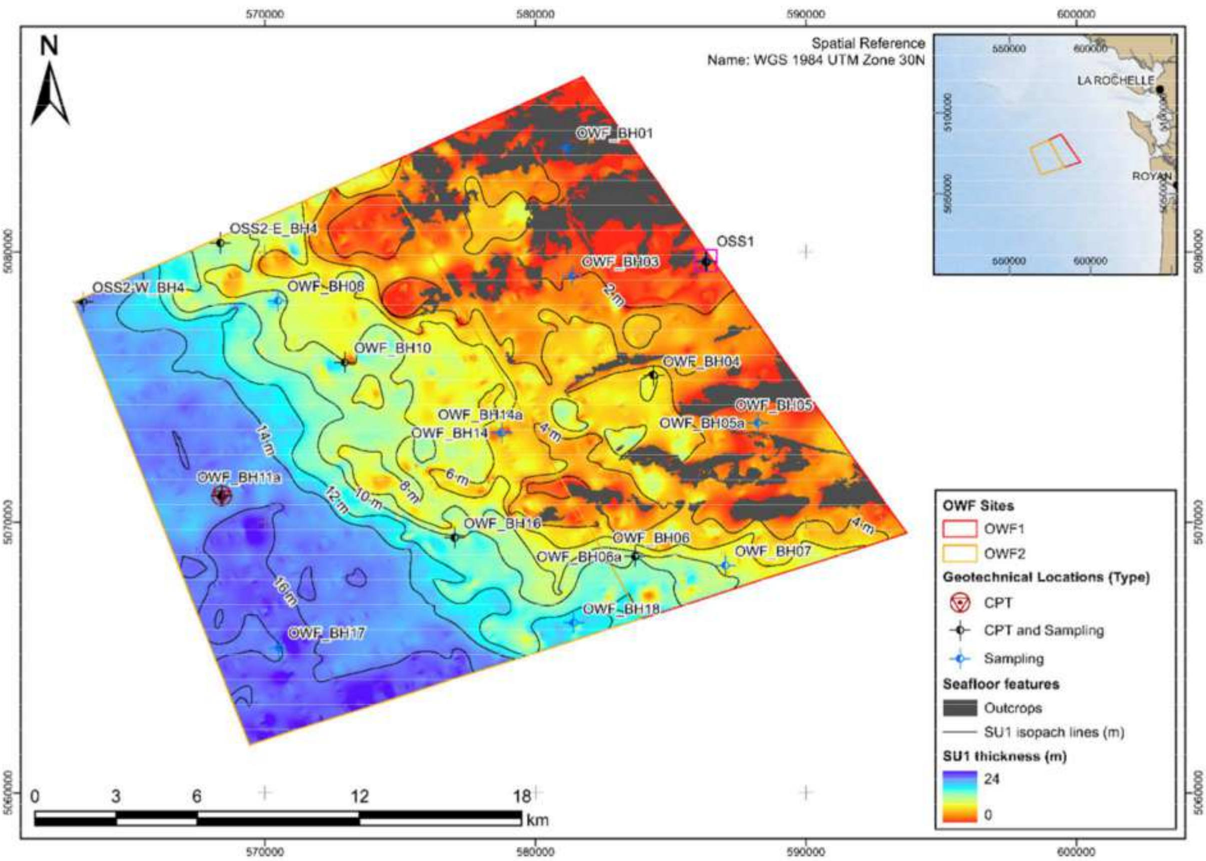


Figure 5.11: SU1 thickness map using an acoustic velocity of 2050 m/s

Based on Section 4.3, SU1 is likely associated with Plio-Quaternary deposits (Plio-Pleistocene and Holocene).

SHOM completed a sediment cover thickness map based on the interpretation of SBP data (SHOM, 2023g, h). The sediment cover does not differentiate between sedimentary units and therefore captures SU1 and part of SU2 thickness. To the south-west of the OWF site, SHOM interpretation was likely limited by signal penetration and their map underestimates sediment cover thickness to the south-west.

The map was provided as a shapefile in metres converted from TWTT using a seismic velocity of 1640 m/s, average value calculated based on SHOM internal sedimentological parameters (SHOM, 2023g, h). Based on sediment sampled at the AO7 during the geotechnical SI, this velocity seems underestimated. The time-depth conversion process detailed in Section 5.3.2.1 was utilized to derive a new velocity for sedimentary cover of 2100 m/s , rounded value based on borehole data (Table 5.3). This new velocity was used to correct the SHOM map. The resulting map is displayed in Figure 5.12.

Sediment cover thickness varies between 0 m where rock outcrops are present at seafloor, and 35 m to the south-west of the OWF site. 35 m likely represents the penetration limit of SBP signal. At OWF2, the sediment cover is the addition of SU1 and SU2 and should reach more than 50 m locally (refer to Figure 5.11 and Figure 5.13).

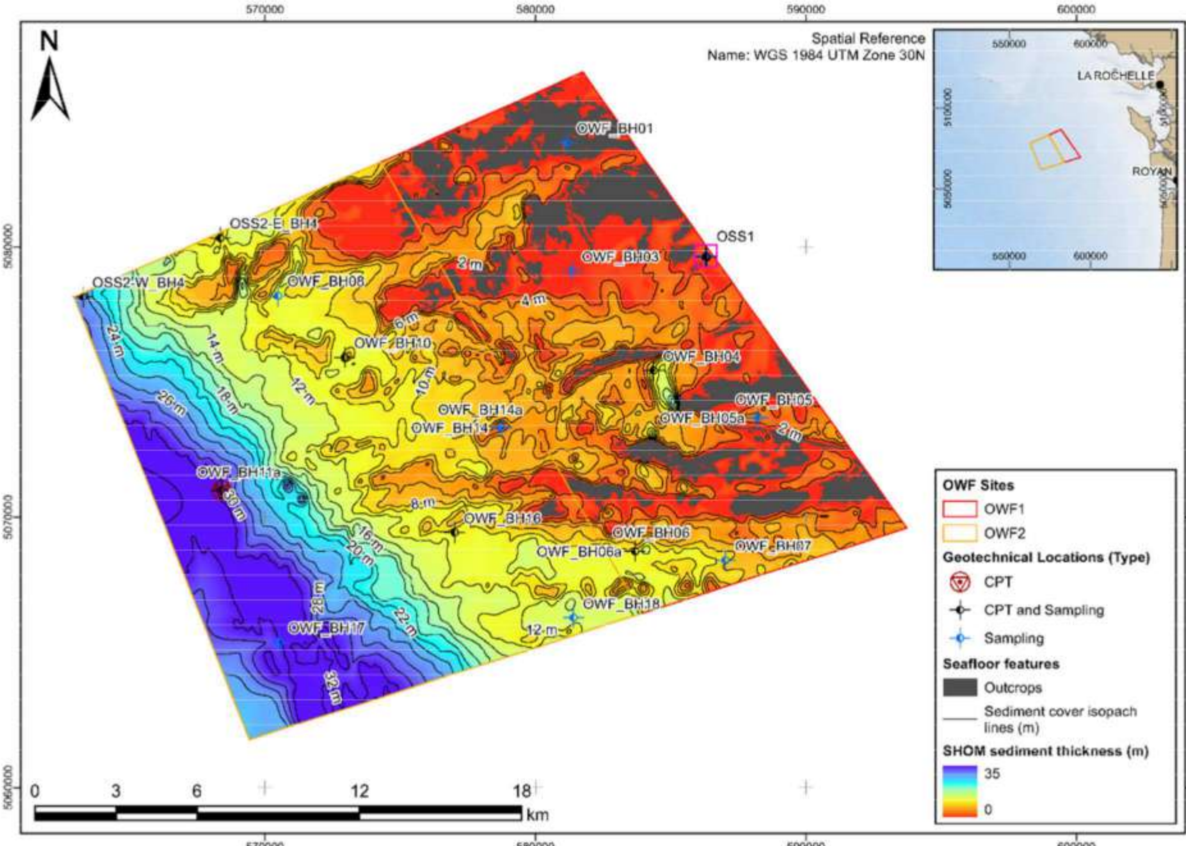


Figure 5.12: Sediment cover thickness map modified from SHOM (2023g,h) using an acoustic velocity of 2100 m/s

5.3.2.4 Seismostratigraphic Unit 2 (SU2)

Seismostratigraphic unit 2 (SU2) is characterised by parallel and continuous seismic facies with low to moderate amplitude reflectors. The unit is bounded at its base by an erosive surface (horizon H03) and at its top by the horizon H02 truncating SU2. An acoustic velocity of 1850 m/s was applied to SU2, rounded value based on borehole data (Table 5.3).

SU2 is distributed across the western part of the OWF site with thicknesses ranging from 0 m and 34 m based on the gridded thickness map (Figure 5.13). Maximum thickness is observed towards the west while the minimum thickness is located east, where SU2 is pinching out.

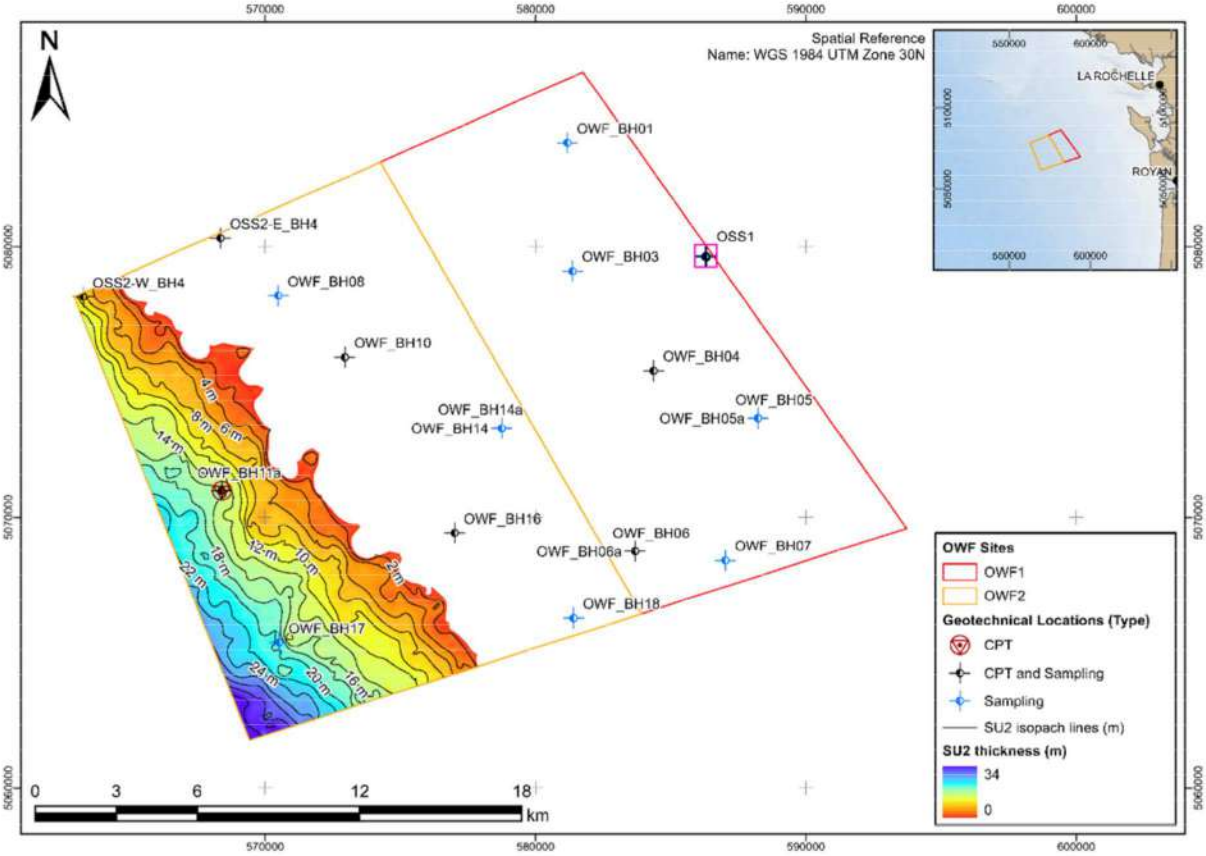


Figure 5.13: SU2 thickness map using an acoustic velocity of 1850 m/s

Based on the geological setting (Section 4.3), and in particular based on Chantraine et al. (1996) (see Figure 4.2), SU2 is likely associated with Miocene deposits.

5.3.2.5 Seismostratigraphic Unit 3 (SU3)

Seismostratigraphic unit 3 (SU3) is characterised by oblique and semicontinuous seismic facies with moderate to high amplitude reflectors. The unit is bounded at its base by a conformable surface (horizon H04) where internal reflectors are downlapping on H04 and at its top by the horizon H02 or the seabed (H01), both truncating SU3. An acoustic velocity of 2350 m/s was applied to SU3 (Table 5.3). SU3 internal reflectors dips to the south.

SU3 is distributed across the eastern part of the OWF site, north of a major fault, with thicknesses ranging from 0 and 63 m (Figure 5.14). Maximum thickness is observed along the fault plane while the minimum thickness is located north where SU3 is eroded (truncation surface).

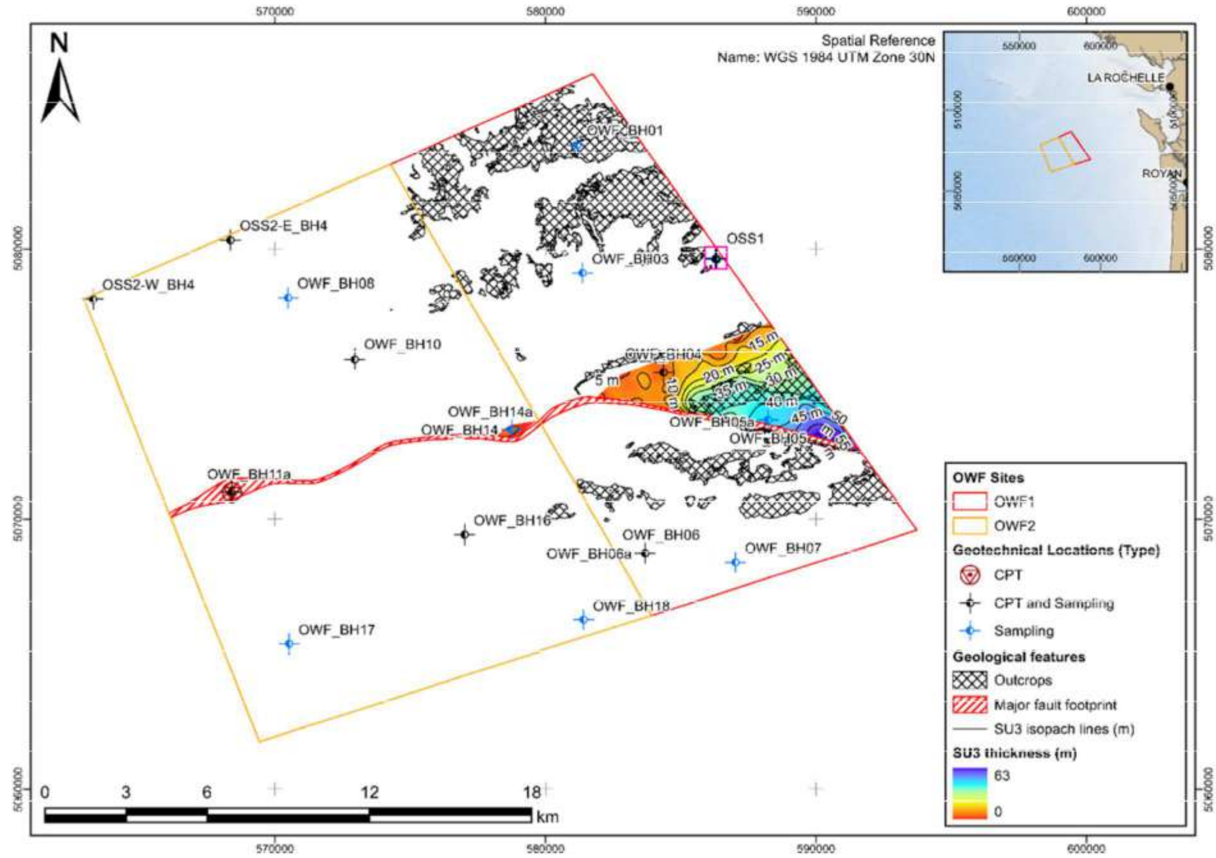


Figure 5.14: SU3 thickness map using an acoustic velocity of 2350 m/s

Based on the geological setting (Section 4.3), SU3 is likely associated with Paleogene deposits.

5.3.2.6 Seismostratigraphic Unit 4 (SU4)

Seismostratigraphic unit 4 (SU4) is characterised by various seismic facies; semi-parallel and continuous, oblique and semicontinuous, and contorted to mound shaped and discontinuous. Reflectors are low to high amplitude and generally dipping to the south. The base of the unit is unidentified due to the penetration limit of the 2D UHRS data, and its top is truncated by H01, H02, and H03 and concordant with H03. Top SU4 depth map was calculated using the thicknesses of SU1, SU2 and SU3 (Figure 5.11, Figure 5.13 and Figure 5.14 respectively). The resulting map is provided as Figure 5.15.

SU4 is distributed across the entire OWF site (Figure 5.15). Its top increases regularly from the north-east to the south-west of OWF2, ranging from 0 m and 45 m BSF. Top SU4 depth is more consistent across OWF1 with values generally lower than 5 m BSF, locally reaching more than 10 m BSF to the South of OWF1. Along the major fault at OWF1, top SU4 is deepening very quickly, from less than 5 m BSF to 68 m BSF along the fault plane. This is associated with the presence of SU3 at this location.

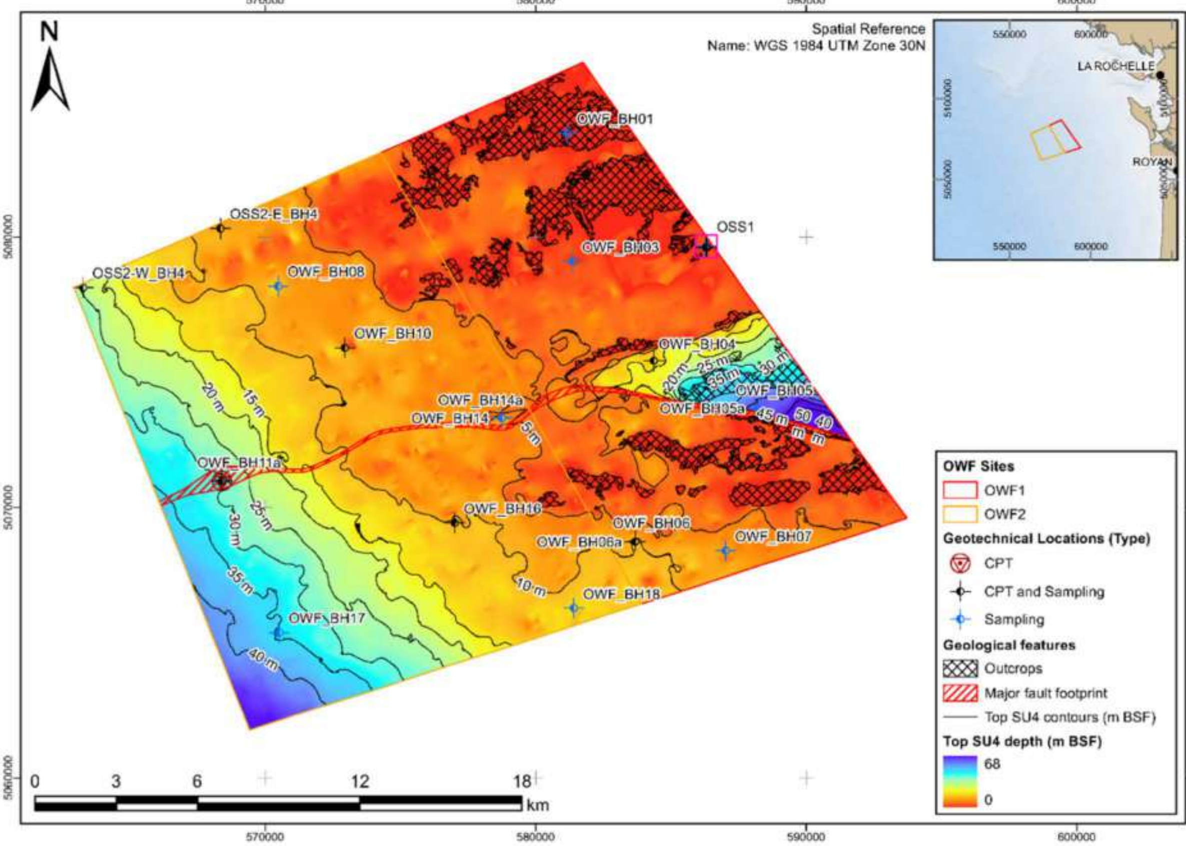


Figure 5.15: Depth to Top SU4 using acoustic velocities detailed in Table 5.3

Based on the geological setting (Section 4.3), within the study depth of interest SU4 is likely associated with Mesozoic deposits (Cretaceous to Jurassic).

5.3.2.7 Major Fault

The distribution of SU3 suggests the existence of a local displacement surface (fault plane) trending WSW-ENE in the OWF site. The fault axis can be interpreted by the existence of an area of transparent seismic facies, likely representing the fault zone area where highly weathered and fractured rock occur (sampled at OWF_BH11/11a).

This area was gridded and mapped across the OWF site and is displayed in Figure 5.14 and Figure 5.15.

Other minor faults were visible but could not be mapped across the OWF site based on 2D UHRS data.

5.3.3 Ground Types

5.3.3.1 Overview

The geotechnical ground type was established based on the geotechnical description and laboratory results taken from Fugro (2023b,c).

Ground types allow identifying and describing the major lithological and soil parameters changes observed at the OWF site geotechnical locations.

Ground types are derived mainly from major lithological changes on geotechnical data. Synthetic descriptions were derived based on tables and references listed in Section 3.4.1. Correlations were then attempted across the OWF site using 2D UHRS data as proxy to understand layers geometry and variability between individual boreholes. A high variability is expected across the site due to layer geometries (dipping reflectors), folds and faults, leading to an overall poor correlation between ground types, especially for older units.

From the available geotechnical data over the OWF site fifteen (15) ground types down to 60 m BSF were interpreted. These ground types along with their description are summarised in the following sub-sections. Figure 5.16 and Plate 3.13 show a map displaying synthetic stick logs detailing ground types expected at each borehole.

The fractures descriptions are highly variable across the OWF site. Their description is therefore not included as part of the integration report. Indication on the fracture state of individual ground types is provided as part of the IGM in the geotechnical parameter table (Section 6.5) through the derivation of the rock quality designation (RQD). Detailed fracture descriptions are available in the factual reports (Fugro, 2023b,c).

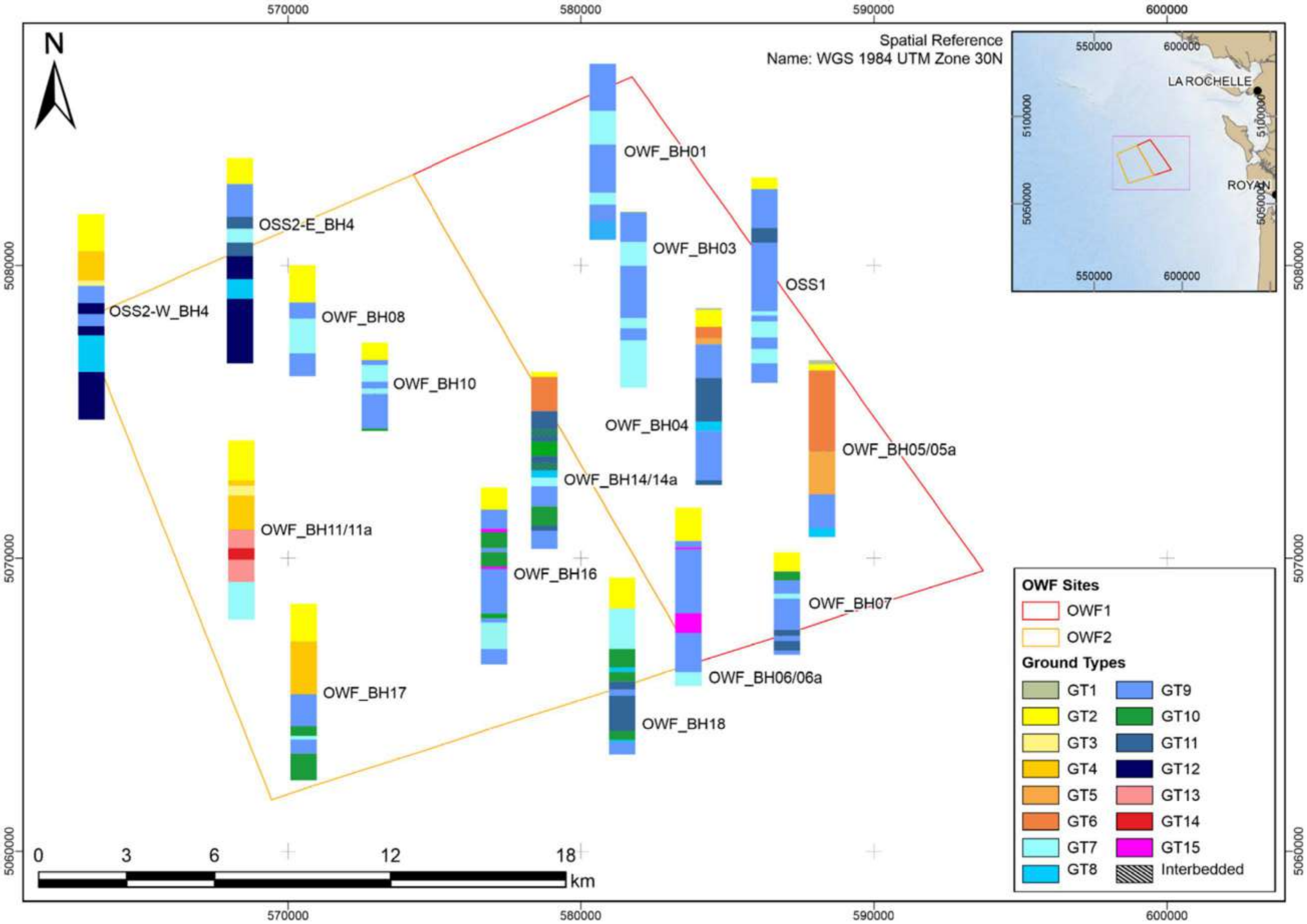


Figure 5.16: Map showing ground type distribution at individual boreholes

5.3.3.2 Ground Type 1 (GT1)

GT1 occurs at two boreholes only (OWF_BH04 and OWF_BH05-05a) and consists of extremely low strength olive grey slightly sandy clayey SILT.

GT1 depth of occurrence and thicknesses are detailed in Table 5.5. GT1 occurrence in Figure 5.16 is in accordance with SHOM seafloor nature map (Figure 5.3) that shows presence of mud at seafloor at both locations.

Table 5.5: GT1 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH04	0.00	0.60	0.60	0.60	1
OWF_BH05	0.00	1.50	1.50	1.50	1
OWF_BH05a	0.00 (1)	2.70	2.70 (1)	2.70 (1)	1
Summary*	**0.00**	**2.70**	**0.60**	**2.70**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes
(1) Start of borehole at 2.50 m BSF, GT1 considered to start at seafloor

5.3.3.3 Ground Type 2 (GT2)

GT2 occurs at all geotechnical locations, except at OWF_BH01, between 0.0 m and 15.2 m BSF with a thickness varying between 0.1 and 12.4 m. Based on Plate 3.13, GT2 thickness tends to increase towards the West of the OWF site (Figure 5.16). GT2 characteristics are detailed in Table 5.6.

Table 5.6: GT2 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH1	0.00	4.05	4.05	4.05	1
OSS1_BH2	0.00	3.65	3.65	3.65	1
OSS1_BH3	0.00	2.35	2.35	2.35	1
OSS1_BH4	0.00	4.00	4.00	4.00	1
OSS2-E_BH4	0.00	8.75	8.75	8.75	1
OSS2-W_BH4	0.00	13.65	13.65	13.65	1
OWF_BH03	0.00	0.20	0.20	0.20	1
OWF_BH04	0.60	6.50	5.90	5.90	1
OWH_BH05	1.50	3.25	1.75	1.75	1
OWF_BH05a	2.70	3.55	0.85	0.85	1
OWF_BH06	0.00	11.30	11.30	11.30	1
OWF_BH07	0.00	6.50	6.50	6.50	1

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH08	0.00	12.60	12.60	12.60	1
OWF_BH10	0.00	5.95	5.95	5.95	1
OWF_BH11	0.00	9.84	9.84	9.84	1
OWF_BH11a	9.00	13.50	4.50	4.50	1
OWF_BH14	0.00	1.70	1.70	1.70	1
OWF_BH16	0.00	7.50	7.50	7.50	1
OWF_BH17	0.00	12.70	12.70	12.70	1
OWF_BH18	0.00	10.80	10.80	10.80	1
Summary*	**0.00**	**13.65**	**0.20**	**13.50**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

GT2 can be split between three sub-units, mostly depending on the density of SAND:

- GT2a: very loose to loose light yellowish brown to very dark grey slightly gravelly to very gravelly slightly silty sometimes very clayey fine to coarse non calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments;
- GT2b: medium dense to dense light olive brown to very dark grey slightly gravelly to gravelly slightly silty fine to coarse slightly calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments with rare mica crystals;
- GT2c: very dense light yellowish brown to dark greyish brown slightly gravelly slightly silty fine to coarse non calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments with rare mica crystals.

Detailed characteristics of each sub-units are presented in Table 5.7 to Table 5.9. The split was performed based relative density or effective angle of internal friction values.

Table 5.7: GT2a depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH4	0.00	0.20	0.20	0.20	1
OWF_BH04	0.60	0.95	0.35	0.35	1
OWF_BH06	2.50	7.90	5.40	5.40	2
OWF_BH07	0.00	0.20	0.20	0.20	1
OWF_BH08	0.00	0.50	0.50	0.50	1
OWF_BH14	0.00	1.70	1.70	1.70	1
OWF_BH16	0.00	0.30	0.30	0.30	1

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH17	0.00	1.00	1.00	1.00	1
OWF_BH18	0.00	1.00	1.00	1.00	1
Summary*	**0.00**	**7.90**	**0.20**	**5.40**	**1 – 2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

Table 5.8: GT2b depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH2	0.00	2.0	0.5	0.5	2
OSS1_BH4	0.20	2.1	1.9	1.9	1
OSS2-E_BH4	0.00	5.80	5.80	5.80	1
OSS2-W_BH4	0.00	3.80	3.80	3.80	1
OWF_BH04	0.95	3.45	2.50	2.50	1
OWF_BH06	8.80	11.30	2.50	2.50	2
OWF_BH08	0.50	1.00	0.50	0.50	1
OWF_BH10	0.00	0.75	0.75	0.75	1
OWF_BH11	0.00	0.45	0.45	0.45	1
OWF_BH16	0.30	3.10	2.80	2.80	1
OWF_BH17	1.00	8.35	7.35	7.35	1
OWF_BH18	1.00	3.00	2.00	2.00	1
Summary*	**0.00**	**11.30**	**0.45**	**7.35**	**1 – 2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

Table 5.9: GT2c depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH2	0.5	3.65	1	1.65	2
OSS1_BH4	2.1	4.00	1.9	1.9	1
OSS2-E_BH4	5.80	8.75	2.95	2.95	1
OSS2-W_BH4	3.80	13.65	9.85	9.85	1
OWF_BH04	3.45	6.50	3.05	3.05	1
OWH_BH06	0.00	8.80	0.90	2.50	2
OWF_BH07	0.20	6.50	6.30	6.30	1
OWF_BH08	1.00	12.60	11.60	11.60	1

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH10	0.75	5.95	5.20	5.20	1
OWF_BH11	0.45	9.84	9.39	9.39	1
OWF_BH11a	9.00	13.50	4.50	4.50	1
OWF_BH16	3.10	7.50	4.40	4.40	1
OWF_BH17	8.35	12.70	4.35	4.35	1
OWF_BH18	3.00	10.80	7.80	7.80	1
Summary*	**0.00**	**13.65**	**0.90**	**13.05**	**1 – 2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.4 Ground Type 3 (GT3)

GT3 occurs at two geotechnical locations and consists of thinly interlaminated to very thickly interbedded high strength to extremely high strength dark grey slightly gravelly slightly sandy calcareous CLAY and loose to medium dense very dark grey slightly gravelly slightly sandy calcareous SILT with medium to widely spaced beds of siltstone. GT3 only occurs to the west of the OWF site (Figure 5.16).

GT3 characteristics are detailed in Table 5.10.

Table 5.10: GT3 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS2-W_BH4	24.60	26.50	1.90	1.90	1
OWF_BH11a	15.30	18.75	3.45	3.45	1
Summary*	**15.30**	**26.50**	**1.90**	**3.45**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.5 Ground Type 4 (GT4)

GT4 occurs at three geotechnical locations and consists of loose to medium dense white to grey slightly gravelly to gravelly very silty fine to coarse slightly calcareous to highly calcareous sometimes cemented SAND with rare medium sand-sized to coarse sand-sized shell fragments. GT4 only occurs to the West of the OWF site (Figure 5.16).

GT4 characteristics are detailed in Table 5.11.

Table 5.11: GT4 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS2-W_BH4	13.65	24.60	10.95	10.95	1
OWF_BH11a	13.50	30.40	1.80	11.65	2
OWF_BH17	12.70	30.80	18.10	18.10	1
Summary*	**12.70**	**30.80**	**1.80**	**18.10**	**1 – 2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.6 Ground Type 5 (GT5)

GT5 occurs at two geotechnical locations and consists of very weak to weak slightly to moderately weathered light greenish grey to grey CALCILSILTITE with rare fine to medium gravel-sized shell fragments. GT5 only occurs to the east of the OWF site (Figure 5.16).

GT5 characteristics are detailed in Table 5.12.

Table 5.12: GT5 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH4	10.15	12.25	2.10	2.10	1
OWF_BH05a	31.15	45.90	14.75	14.75	1
Summary*	**10.15**	**45.90**	**2.10**	**14.75**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.7 Ground Type 6 (GT6)

GT6 occurs at three geotechnical locations and consists of very weak to moderately weak slightly to completely weathered light greenish grey to grey fine to coarse grained CALCARENITE with occasional to frequent medium sand-sized to coarse gravel-sized shell fragments. GT6 only occurs to the east of the OWF site (Figure 5.16).

GT6 characteristics are detailed in Table 5.13.

Table 5.13: GT6 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH4	6.50	10.15	3.65	3.65	1
OWF_BH05a	3.55	31.15	27.60	27.60	1
OWF_BH14	1.70	13.30	11.60	11.60	1

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
Summary*	**1.70**	**31.15**	**3.65**	**27.55**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.8 Ground Type 7 (GT7)

GT7 occurs at fifteen locations and consists of extremely weak to weak fresh to completely weathered light greenish grey to very dark grey locally glauconitic CALCILUTITE to CALCISILTITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments and with occasional to abundant fine to medium sand-sized mica crystals. GT7 occurs across most of OWF site but is generally more present towards the eastern part of the site (Figure 5.16).

GT7 characteristics are detailed in Table 5.14.

Table 5.14: GT7 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH1	45.80	63.50	1.50	5.40	3
OSS1_BH2	45.50	60.60	1.95	5.35	3
OSS1_BH3	45.25	62.05	1.75	13.30	2
OSS1_BH4	45.25	61.00	1.75	5.70	3
OSS2-E_BH4	23.95	28.70	4.75	4.75	1
OWF_BH01	16.20	48.27	4.12	11.55	2
OWF_BH03	10.20	60.20	3.60	16.40	3
OWF_BH06a	56.20	60.60	4.40	4.40	1
OWF_BH07	14.35	16.10	1.75	1.75	1
OWF_BH08	18.20	29.90	11.70	11.70	1
OWF_BH10	7.7	17.55	1.70	5.85	2
OWF_BH11a	48.10	61.00	12.90	12.90	1
OWF_BH14a	36.05	39.15	3.10	3.10	1
OWF_BH16	46.10	55.10	9.00	9.00	1
OWF_BH17	45.05	46.20	1.15	1.15	1
OWF_BH18	10.80	24.50	13.70	13.70	1
Summary*	**10.20**	**63.50**	**1.15**	**16.40**	**1 – 3**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.9 Ground Type 8 (GT8)

GT8 occurs at seven locations and consists of extremely weak to moderately weak slightly weathered to completely weathered dark grey to black non-calcareous to calcareous MUDSTONE to SILTSTONE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments. Distribution of GT8 does not follow any noticeable trend (Figure 5.16).

GT8 characteristics are detailed in Table 5.15.

Table 5.15: GT8 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS2-E_BH4	41.25	47.95	6.70	6.70	1
OSS2-W_BH4	45.05	52.90	7.85	7.85	1
OWF_BH01 (1)	54.00	60.20	6.20	6.20	>1
OWF_BH04	38.70	42.05	3.35	3.35	1
OWF_BH05a	57.35	60.40	3.05	3.05	1
OWF_BH14a	33.55	36.05	2.50	2.50	1
OWF_BH16	46.10	52.00	5.90	5.90	1
OWF_BH18	30.85	56.25	0.70	1.70	2
Summary*	**7.70**	**60.40**	**0.70**	**7.85**	**1 – 2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes
(1) Thinly to medium interbedded with GT9

5.3.3.10 Ground Type 9 (GT9)

GT9 occurs at all locations except at OWF_BH11 and OWF_BH11a and consists of extremely weak to medium strong fresh to residual soil white to very dark grey fine to coarse grained CALCARENITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments locally with occasional to frequent fine to coarse gravel-sized fossils. Residual soil recovered as pale yellow to light yellowish brown gravelly silty fine to coarse calcareous SAND with occasional to numerous mica crystals and with rare to occasional coarse sand-sized to medium gravel-sized shell fragments. GT9 is the ground type the most represented across the OWF site (Figure 5.16).

GT9 characteristics are detailed in Table 5.16.

Table 5.16: GT9 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH1	4.05	70.30	1.95	23.55	5
OSS1_BH2	3.65	58.40	1.83	23.20	4

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH3	2.35	48.75	1.75	23.55	3
OSS1_BH4	4.00	58.25	1.65	20.00	5
OSS2-E_BH4	8.75	20.05	11.30	11.30	1
OSS2-W_BH4	26.50	41.75	4.65	6.50	2
OWF_BH01 (1)	0.00	60.20	11.93	16.40	>4
OWF_BH03	0.20	43.80	3.90	17.80	3
OWF_BH04	12.25	58.75	11.65	16.70	2
OWF_BH05a	45.90	57.35	11.45	11.45	1
OWF_BH06	11.30	22.45	2.20	8.25	2
OWF_BH06a	22.45	56.20	13.55	13.70	2
OWF_BH07	9.65	35.00	1.50	10.85	4
OWF_BH08	12.60	37.90	5.60	8.00	2
OWF_BH10	5.95	30.30	1.75	11.90	3
OWF_BH14a	39.15	60.50	6.30	6.80	2
OWH_BH16	7.50	60.50	1.40	15.45	5
OWH_BH17	30.80	50.95	4.75	11.05	2
OWH_BH18	38.25	60.50	2.15	4.25	2
Summary*	**0.00**	**70.30**	**1.50**	**23.55**	**1 – 5**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes
(1) Thinly to medium interbedded with GT8

5.3.3.11 Ground Type 10 (GT10)

GT10 occurs at six locations and consists of extremely weak to moderately weak slightly to completely weathered light greenish grey to dark greenish grey glauconitic fine to coarse grained CALCARENITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments with frequent coarse sand-sized to coarse gravel-sized brown and orange staining. GT10 occurs predominantly to the south of the OWF site (Figure 5.16).

GT10 characteristics are detailed in Table 5.17.

Table 5.17: GT10 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH07	6.50	9.65	3.15	3.15	1
OWF_BH10	24.95	30.30	0.85	0.85	1
OWF_BH14a (1)	19.55	60.40	2.55	6.45	>4
OWF_BH16	15.20	44.65	1.45	5.55	3

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH17	41.85	60.30	3.20	9.35	2
OWF_BH18	24.50	55.55	3.00	6.35	3
Summary*	**6.50**	**60.30**	**0.85**	**9.35**	**1 – >4**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes
(1) Thickly interlaminated to medium interbedded with GT11

5.3.3.12 Ground Type 11 (GT11)

GT11 occurs at nine locations and consists of extremely weak to moderately weak slightly weathered to residual soil greenish grey to black locally glauconitic fine to coarse grained non-calcareous to calcareous SANDSTONE with rare to abundant medium sand-sized to medium gravel-sized shell fragments with occasional to numerous medium sand-sized mica crystals. Residual soil recovered as dark greenish grey to very dark greenish grey silty to very silty fine to medium calcareous SAND with frequent coarse sand-sized to fine gravel-sized shell fragments and with occasional mica crystals. GT11 occurs mostly to the east of the OWF site (Figure 5.16).

GT11 characteristics are detailed in Table 5.18.

Table 5.18: GT11 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS1_BH1	17.25	22.25	5.00	5.00	1
OSS1_BH2	17.40	22.30	4.90	4.90	1
OSS1_BH3	16.35	21.70	5.35	5.35	1
OSS1_BH4	16.75	43.25	1.15	5.35	2
OSS2-E_BH4	20.05	33.50	3.90	4.80	2
OWF_BH04	23.90	60.40	1.65	14.80	2
OWF_BH07	26.95	33.50	1.35	3.35	2
OWF_BH14	13.30	14.00	1.25	1.25	1
OWF_BH14a (1)	14.00	54.20	1.80	6.25	> 6
OWH_BH18	35.60	52.55	2.65	12.15	2
Summary*	**15.00**	**60.40**	**1.15**	**14.80**	**1 – >6**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes
(1) Thickly interlaminated to medium interbedded with GT10

5.3.3.13 Ground Type 12 (GT12)

GT12 occurs at two locations and consists of medium dense to very dense grey to black slightly gravelly to very gravelly slightly silty to silty locally clayey to very clayey locally glauconitic fine to coarse SAND with occasional to frequent medium to coarse sand-sized mica crystals. GT12 occurs as SAND layers in-between sandstones, siltstones and mudstones to the north-west of the OWF site (Figure 5.16).

GT12 characteristics are detailed in Table 5.19

Table 5.19: GT12 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OSS2-E_BH4	33.50	70.08	7.75	22.13	2
OSS2-W_BH4	33.00	70.55	3.30	17.65	3
Summary*	**33.00**	**70.55**	**3.30**	**22.13**	**2-3**
Notes: Some ground types may occur several times along individual geotechnical locations. * Summary for all boreholes					

5.3.3.14 Ground Type 13 (GT13)

GT13 occurs at one location (OWF_BH11a; Figure 5.16) and consists of very high strength to ultra-high strength CLAY with closely to medium spaced very thin to medium beds of sand and gravel (possibly firmly indurated fine grained carbonate silt with firmly cemented medium grained carbonate sand). GT13 was only observed at OWF_BH11/11a within the major fault footprint (see Figure 5.14 and Figure 5.15) and is likely associated with rocks that were affected by the fault plane rupture and resulting fracturing and weathering. The unit was not sampled and was only measured with CPTs.

GT13 characteristics are detailed in Table 5.20.

Table 5.20: GT13 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWH_BH11a	30.40	48.10	6.25	7.45	2
Summary*	**30.40**	**48.10**	**6.25**	**7.45**	**2**
Notes: Some ground types may occur several times along individual geotechnical locations. * Summary for all boreholes					

5.3.3.15 Ground Type 14 (GT14)

GT14 occurs at one location (OWF_BH11a) and consists of loose to medium dense SAND with closely to medium spaced very thin to thin beds of clay (possibly firmly cemented medium grained carbonate sand with firmly indurated cemented fine grained carbonate silt). GT14 occurs as one bed within GT13 (Figure 5.16). GT14 was only observed at OWF_BH11/11a within the major fault footprint (see Figure 5.14 and Figure 5.15) and is likely associated with rocks that were affected by the fault plane rupture and resulting fracturing and weathering. The unit was not sampled and was only measured with CPTs.

GT14 characteristics are detailed in Table 5.21.

Table 5.21: GT14 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWH_BH11a	36.65	40.65	4.00	4.00	1
Summary*	**36.65**	**40.65**	**4.00**	**4.00**	**1**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.3.16 Ground Type 15 (GT15)

GT15 occurs at two locations and consists of extremely low strength to low strength olive yellow to yellowish brown slightly gravelly sandy calcareous CLAY to medium dense to dense olive yellow to yellowish brown slightly gravelly sandy calcareous SILT with occasional fine gravel-sized to medium gravel-sized shell fragments. Gravel is subangular fine to coarse of highly to completely weathered calcarenite. GT15 is only found in the south of the OWF site (Figure 5.16) and is likely associated with karst deposits.

GT15 characteristics are detailed in Table 5.22.

Table 5.22: GT15 depth/thickness characteristics

Borehole	First depth of occurrence [m BSF]	Last depth of occurrence [m BSF]	Minimum thickness [m]	Maximum thickness [m]	Number of occurrences
OWF_BH06	13.50	14.20	0.70	0.70	1
OWH_BH06a	36.00	42.50	6.50	6.50	1
OWF_BH16	14.00	27.75	0.75	1.20	2
Summary*	**13.50**	**42.50**	**0.70**	**6.50**	**2**

Notes:
Some ground types may occur several times along individual geotechnical locations.
* Summary for all boreholes

5.3.4 Synthesis of Geotechnical Parameters

5.3.4.1 Overview

Parameters detailed in Table 3.5 were measured in situ or during the laboratory testing phase as described in the factual reports (Fugro, 2023b,c). These parameters were classified for each ground type and minimum, maximum values as well as number of tests available are presented in the following sub-section. Further engineering analysis of these parameters is provided and detailed in Section 6.5.

Ground type depths indicated in Table 5.23 to Table 5.37 corresponds to the minimum and maximum observed values at geotechnical locations.

5.3.4.2 Water Content (w)

Water content values per ground type (from GT1 to GT15) are described in Table 5.23.

Table 5.23: Water content (w) per ground type

Ground Type	Depth [m]	Minimum [%]	Maximum [%]	Number of values
GT1	0.40 – 1.20	96.3	100.5	3
GT2	0.00 – 13.00	10.2	70.1	130
GT3	20.60 – 25.60	20.0	30.0	5
GT4	12.80 – 30.45	20.6	35.1	35
GT5	10.90 – 45.40	11.7	25.0	31
GT6	2.65 – 30.35	3.4	40.6	64
GT7	9.15 – 62.95	1.7	31.3	263
GT8	31.60 – 59.70	3.7	46.5	50
GT9	0.0 – 69.45	2.7	47.0	746
GT10	7.05 – 59.65	3.4	32.0	83
GT11	13.60 – 60.10	3.4	52.8	127
GT12	33.60 – 68.65	4.7	39.5	65
GT13	ND	ND	ND	ND
GT14	ND	ND	ND	ND
GT15	14.80 – 37.40	9.5	113.8	9

Notes:
Applicable to cohesive soils, non-cohesive soils and rocks.
ND No data available

5.3.4.3 Wet Unit weight (γ)

Wet unit weight values per ground type (from GT1 to GT15) are described in Table 5.24. The values include derived values based on water content and particle density.

Table 5.24: Wet unit weight (γ) per ground type

Ground Type	Depth [m]	Minimum [kN/m^3]	Maximum [kN/m^3]	Number of values
GT1	0.40 – 1.20	14.2	14.4	4
GT2	0.00 – 13.00	14.5	26.5	223
GT3	20.60 – 25.60	19.3	21.1	10
GT4	12.80 – 30.45	15.9	24.5	66
GT5	10.90 – 45.40	19.3	28.7	43

Ground Type	Depth [m]	Minimum [kN/m³]	Maximum [kN/m³]	Number of values
GT6	2.65 – 30.35	18.1	30.9	102
GT7	9.15 – 62.95	17.1	33.6	407
GT8	31.60 – 59.70	17.0	25.8	81
GT9	0.0 – 69.45	2.4	29.4	1188
GT10	7.05 – 59.65	15.9	30.5	144
GT11	13.60 – 60.10	16.6	28.7	200
GT12	33.60 – 68.65	17.6	26.0	112
GT13	ND	ND	ND	ND
GT14	ND	ND	ND	ND
GT15	14.80 – 37.40	13.9	23.8	12

Notes:
Applicable to cohesive soils, non-cohesive soils and rocks.
ND No data available

5.3.4.4 Particle density (ρs)

Particle density values per ground type (from GT1 to GT15) are described in Table 5.25.

Table 5.25: Particle density (ρs) per ground type

Ground Type	Depth [m]	Minimum [kN/m³]	Maximum [Mg/m³]	Number of values
GT1	0.60	2.75	2.75	1
GT2	0.00 – 10.70	2.65	2.72	17
GT3	25.40 – 26.50	2.74	2.74	2
GT4	16.0 – 30.20	2.70	2.73	6
GT5	ND	ND	ND	ND
GT6	ND	ND	ND	ND
GT7	13.50 – 59.10	2.66	2.79	8
GT8	42.55 – 50.00	2.50	2.73	3
GT9	3.90 – 65.45	2.70	2.74	23
GT10	ND	ND	ND	ND
GT11	17.20 – 32.50	2.64	2.77	6
GT12	33.25 – 67.00	2.58	2.73	11
GT13	ND	ND	ND	ND
GT14	ND	ND	ND	ND
GT15	37.05	3.02	3.02	1

Notes:
Applicable to cohesive soils, non-cohesive soils and rocks.
ND No data available

5.3.4.5 Cone Tip Resistance (q_c)

Net Cone Resistance values per ground type are described in Table 5.26 for soils only (GT1, GT2, GT3, GT4, GT12, GT13, GT14 and GT15). Values of q_c are based on CPT data only. Number of CPTs available per ground type are detailed in Table 5.26.

Table 5.26: Net Cone Resistance (q_c) per ground type

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of CPTs
GT1	0.00 – 0.60	0.0	0.2	1
GT2	0.00 – 13.65	0.5	88.0	59
GT3	13.00 – 26.50	3.0	85.0	8
GT4	13.00 – 30.40	6.0	42.0	23
GT12	35.50 – 70.55	7.0	117.0	41
GT13	30.40 – 48.10	1.0	84.0	17
GT14	36.65 – 40.65	2.8	50.0	4
GT15	14.00 – 42.50	0.1	52.0	7
Notes: Applicable to cohesive soils and non-cohesive soils.				

5.3.4.6 Undrained Shear Strength (s_u)

Undrained Shear Strength values per ground type are described in Table 5.27 for cohesive soils only (GT1, GT3, GT13 and GT15). Values of s_u are based on laboratory data and CPT data. Number of laboratory measurements and number of CPTs available per ground type are detailed in Table 5.27.

Table 5.27: Undrained Shear Strength (s_u) per ground type

Ground Type	Depth [m]	Minimum [kPa]	Maximum [kPa]	Number of values	Number of CPTs
GT1	0.00 – 0.60	0.0	9.5	2	1
GT3	13.00 – 26.50	75.0	950.0	5	8
GT13	30.40 – 48.10	0.0	5500.0	0	17
GT15	14.00 – 42.50	0.0	270.0	1	7
Notes: Applicable to cohesive soils. s_u derived from CPT based on factor of Nk = 15 and 20					

5.3.4.7 Relative Density (Dr)

Relative Density values per ground type are described in Table 5.28 for soils only (GT2, GT3, GT4, GT12 and GT14 and GT15). Values of Dr are based on CPT data only. Number of CPTs available per ground type are detailed in Table 5.28.

Table 5.28: Relative Density (Dr) per ground type

Ground Type	Depth [m]	Minimum [%]	Maximum [%]	Number of CPTs
GT2	0.00 – 13.65	10	140	59
GT3	13.00 – 26.50	18	120	8
GT4	13.00 – 30.40	15	102	23
GT12	35.50 – 70.55	5	118	41
GT14	36.65 – 40.65	0	90	4
GT15	14.00 – 42.50	25	107	7
Notes: Applicable to non-cohesive soils. Dr derived from CPT based on factor of $K0$ = 0.5 and 1.0				

5.3.4.8 Effective Angle of Internal Friction (ϕ')

Effective Angle of Internal Friction values per ground type are described in Table 5.29 for soils only (GT2, GT3, GT4, GT12 and GT14 and GT15). Values of ϕ' are based on laboratory data and CPT data. Number of laboratory measurements and number of CPTs available per ground type are detailed in Table 5.29.

Table 5.29: Effective Angle of Internal Friction (ϕ') per ground type

Ground Type	Depth [m]	Minimum [°]	Maximum [°]	Number of values	Number of CPTs
GT2	0.00 – 13.65	25.2	51.0	35	59
GT3	13.00 – 26.50	27.0	46.0	0	8
GT4	13.00 – 30.40	35.0	45.5	6	23
GT12	35.50 – 70.55	20.0	46.5	27	41
GT14	36.65 – 40.65	28.0	44.0	0	4
GT15	14.00 – 42.50	22.5	46	0	7
Notes: Applicable to non-cohesive soils.					

5.3.4.9 Axial Strain at 50% of the Maximum Deviator Stress (ε_{50})

Axial Strain at 50% of the Maximum Deviator Stress values per ground type are described in Table 5.30 for cohesive soils only (GT1, GT3, GT13 and GT15).

Table 5.30: Axial Strain at 50% of the Maximum Deviator Stress (ε_{50}) per ground type

Ground Type	Depth [m]	Minimum [%]	Maximum [%]	Number of values
GT1	ND	ND	ND	ND
GT3	19.20 – 30.00	0.4	3.8	4
GT13	ND	ND	ND	ND
GT15	ND	ND	ND	ND
Notes:				

Ground Type	Depth [m]	Minimum [%]	Maximum [%]	Number of values
Applicable to cohesive soils. ND No data available				

5.3.4.10 Thermal Resistivity (TR)

Thermal Resistivity values per ground type are described in Table 5.31. TR was only measured within the first 7 m BSF at OSS1 and OSS2 locations.

Table 5.31: Thermal Resistivity (TR) per ground type

Ground Type	Depth [m]	Minimum [(m.K)/W]	Maximum [(m.K)/W]	Number of values
GT1	ND	ND	ND	ND
GT2	0.05 – 5.60	0.381	0.860	11
GT3	ND	ND	ND	ND
GT4	ND	ND	ND	ND
GT5	ND	ND	ND	ND
GT6	ND	ND	ND	ND
GT7	ND	ND	ND	ND
GT8	ND	ND	ND	ND
GT9	2.35 – 6.55	0.450	0.600	4
GT10	ND	ND	ND	ND
GT11	ND	ND	ND	ND
GT12	ND	ND	ND	ND
GT13	ND	ND	ND	ND
GT14	ND	ND	ND	ND
GT15	ND	ND	ND	ND
Notes: Applicable to cohesive soils, non-cohesive soils and rocks. NA No data available				

5.3.4.11 Rock Quality Designation (RQD)

Rock Quality Designation values per ground type are described in Table 5.32. RQD was only measured in rocks. Number of values detailed Table 5.32 correspond to the number of rock cores where the ground type represents more than 50% of the total core length.

Table 5.32: Rock Quality Designation (RQD) per ground type

Ground Type	Depth (1) [m]	Minimum [%]	Maximum [%]	Number of values
GT5	10.25 – 44.40	43.3	100.0	11
GT6	2.50 – 29.50	0.0	100.0	30
GT7	8.00 – 62.80	0.0	100.0	109
GT8	30.50 – 59.30	6.7	100.0	20

Ground Type	Depth (1) [m]	Minimum [%]	Maximum [%]	Number of values
GT9	0.00 – 68.80	0.0	100.0	320
GT10	15.50 – 58.80	0.0	100.0	33
GT11	13.50 – 59.50	0.0	100.0	59

Notes:
Applicable to rocks.
(1) Depths correspond to the top of the shallowest and deepest rock cores where the ground type represents more than 50% of their length

5.3.4.12 Point Load Strength Index (*Is(50)*)

Point Load Strength Index values per ground type are described in Table 5.33. *Is(50)* was only measured in rocks.

Table 5.33: Point Load Strength Index (*Is(50)*) per ground type

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of values
GT5	10.85 – 44.40	0.05	1.96	40
GT6	2.65 – 31.15	0.01	3.60	90
GT7	9.40 – 62.80	0.00	3.04	398
GT8	31.10 – 59.70	0.02	2.55	55
GT9	1.70 – 69.80	0.00	4.60	920
GT10	7.05 – 59.65	0.01	4.09	114
GT11	13.50 – 60.15	0.01	2.26	164

Notes:
Applicable to rocks.

5.3.4.13 Uniaxial Compressive Strength (*UCS*)

Uniaxial Compressive Strength values per ground type are described in Table 5.34. *UCS* was only measured in rocks.

Table 5.34: Uniaxial Compressive Strength (*UCS*) per ground type

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of values
GT5	11.90 – 43.30	3.3	7.8	5
GT6	4.60 – 28.95	2.1	23.4	6
GT7	9.15 – 61.65	0.3	21.4	44
GT8	39.80 – 55.80	0.4	22.6	8
GT9	7.05 – 68.80	0.8	37.1	79
GT10	7.05 – 59.65	0.6	16.8	8
GT11	17.50 – 59.65	0.4	20.3	16

Notes:
Applicable to rocks.

5.3.4.14 Correlation between *Is(50)* and *UCS*

Point load tests (PLTs) were performed offshore during the investigation and onshore after the completion of advanced testing such as UCS.

Direct results are expressed as an index of resistance normalised to a 50 mm diameter sample (*Is(50)*). By itself this measure has no application, but when compared to UCS results to obtain a coefficient *K*, it can be interpreted as Uniaxial compressive strength:

$$UCS = K \times Is(50)$$

Low and high estimate (LE and HE) of *K* factor can be deduced by plotting *UCS* versus *Is(50)* values for specimens tested at the same location and depth. Due to small amount of data available for certain ground types, correlation was performed grouping different ground types together depending on their rock types. Groups are:

- Fine-grained rocks including GT5, GT7 and GT8;
- Calcarenites including GT6, GT9 and GT10;
- Sandstones including GT11.

Resulting correlations are presented in Figure 5.17 to Figure 5.19.

For the assessment of *K* factor, values of PLT performed in all loading directions (axial, diametral and on irregular rock pieces) at the same depth were averaged. In addition, *K* values were filtered in order to remove outlier values. PLT values lower than 0.01 MPa and higher than 5.00 MPa were not considered in the correlation process. Filters selected are specific to each unit and are indicated on Figure 5.17 to Figure 5.19 as the slope of the LE and HE lines. These limit values are based on the average value of all PLT plus or minus a certain percentage of the standard deviation.

The correlation factor *K* applied to each unit is the average of the LE and HE values plotted in Figure 5.17 to Figure 5.19. They are detailed in Table 5.35.

Table 5.35: Synthesis of correlation factor *K* between *Is(50)* and *UCS* applied for each ground type

Ground Type	Rock Type	Graph	*K* (average)
GT5	Fine-grained rock	Figure 5.17	7.00
GT6	Calcarenite	Figure 5.18	17.75
GT7	Fine-grained rock	Figure 5.17	7.00
GT8	Fine-grained rock	Figure 5.17	7.00
GT9	Calcarenite	Figure 5.18	17.75
GT10	Calcarenite	Figure 5.18	17.75
GT11	Sandstone	Figure 5.19	6.50

It should be noted that these correlations were done to provide a first assessment of values to be used to convert *Is(50)* to *UCS* values. Further analysis of data should be performed to refine these correlation values. Particularly, this assessment does not distinguish between different types of fine-grained rocks (GT5, GT7 and GT8) or between different calcarenites (GT6, GT9 and GT10). Correlation for sandstone (GT11) is based on a smaller number of values (Figure 5.19) and a higher degree of uncertainty should be considered on this correlation.

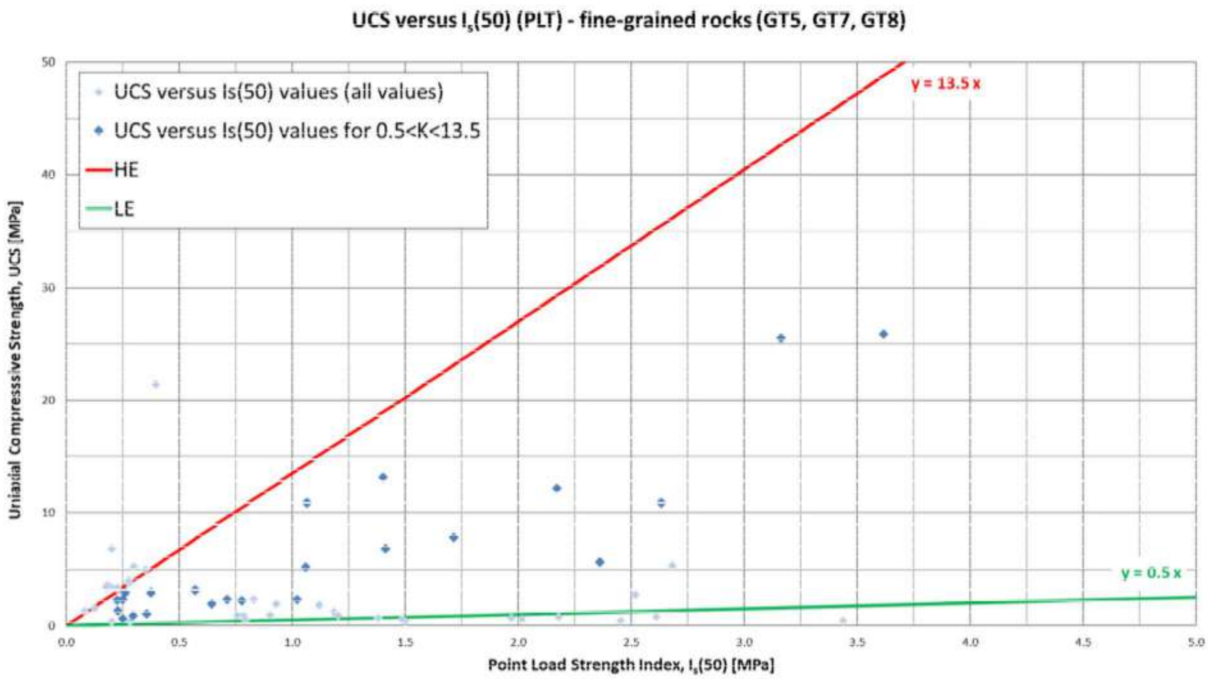


Figure 5.17: Correlation between *Is(50)* and *UCS* for fine-grained rocks

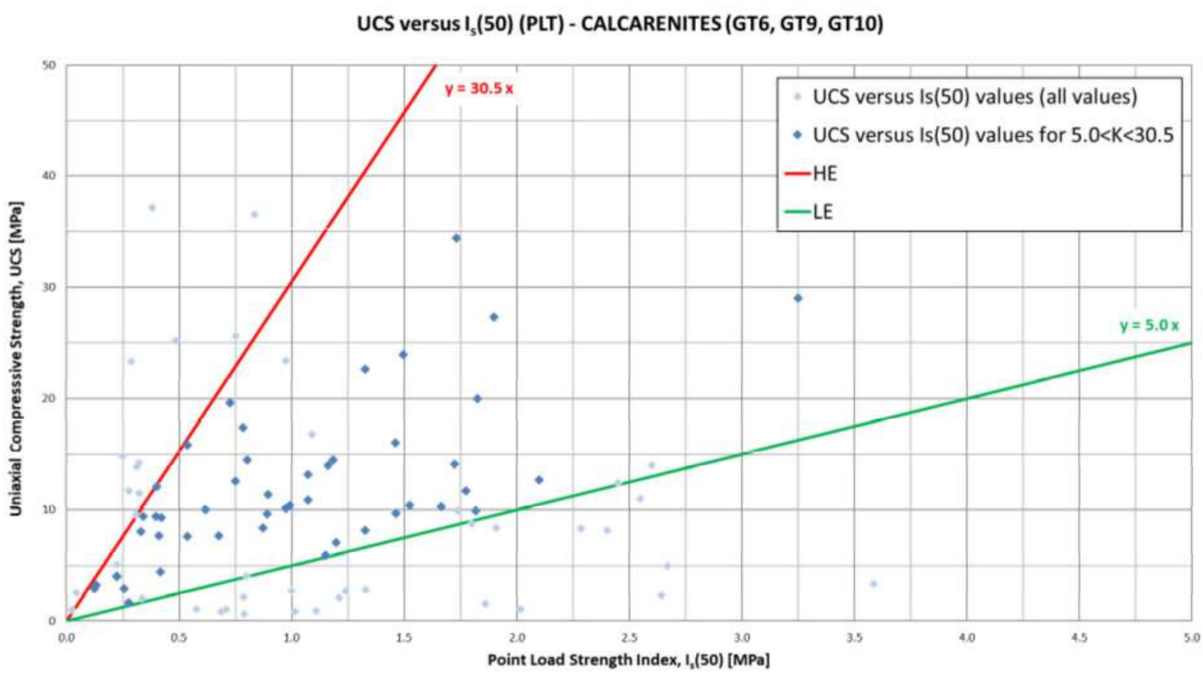


Figure 5.18: Correlation between *Is(50)* and *UCS* for calcarenites

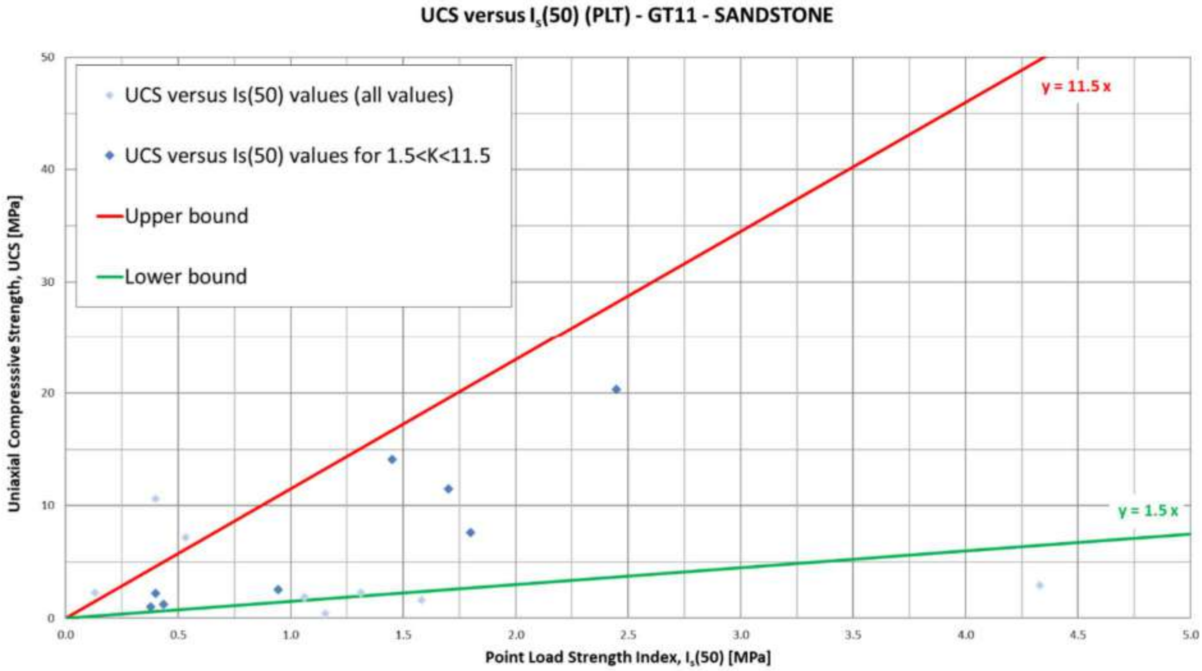


Figure 5.19: Correlation between *Is(50)* and *UCS* for sandstone

UCS values per ground type converted from *Is(50)* values, using average values of *K* provided in Table 5.35, are described in Table 5.36.

Table 5.36: Uniaxial Compressive Strength (*UCS*) per ground type converted from *Is(50)* values using average values of *K* provided in Table 5.35

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of values
GT5	10.85 – 44.40	0.4	13.7	40
GT6	2.65 – 31.15	0.2	63.9	90
GT7	9.40 – 62.80	0.0	21.3	398
GT8	31.10 – 59.70	0.1	17.9	55
GT9	1.70 – 69.80	0.0	81.7	920
GT10	7.05 – 59.65	0.2	72.6	114
GT11	13.50 – 60.15	0.1	14.7	164
Notes: Applicable to rocks.				

5.3.4.15 Young's Modulus of Elasticity (axial) (E)

Young's Modulus of Elasticity (axial) values per ground type are described in Table 5.37. E was only measured in rocks.

Table 5.37: Young's Modulus of Elasticity (axial) (E) per ground type

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of values
GT5	11.90 – 43.30	830	1670	4

Ground Type	Depth [m]	Minimum [MPa]	Maximum [MPa]	Number of values
GT6	7.40 – 20.55	263	25 000	3
GT7	14.40 – 61.65	17	11 600	32
GT8	39.80 – 48.90	37	367	5
GT9	7.05 – 68.80	29	56 000	65
GT10	18.95 – 59.65	23	45 900	4
GT11	17.50 – 53.25	13	13 200	13
Notes: Applicable to rocks.				

6. Integrated Ground Model

6.1 Overview

This section presents the integrated ground model (IGM) at the OWF site derived based on site conditions presented in Section 5 and the geological understanding of the region (Section 4).

Plates associated with this section are Plate 4.1 showing the soil profiles, and Plate 4.2 showing the soil province map.

6.2 Unitization

Correlation of seismostratigraphic units (Section 5.3.2) and ground types (Section 5.3.3) was performed to create geotechnical units and geotechnical sub-units.

Geotechnical units are generally following the seismostratigraphic units and are thus possible to correlate and map across the OWF site to derive soil profiles and soil provinces.

Geotechnical sub-units are only based on ground types and are used to provide geotechnical parameters of the different soils and rocks that were sampled at the OWF site. Ground types were not possible to correlate across the OWF site using seismic data due to high lateral and vertical variability observed between boreholes (Plate 3.13) and on seismic data.

The major fault plane could be mapped across the OWF site from 2D UHRS data but its depth range and thickness range could not be defined except at OWF_BH11a where weathered and fractured material associated with the fault was sampled as two different ground types (Sections 5.3.3.13 and 5.3.3.14). Two geotechnical sub-units were defined associated to the presence of the fault. Thickness and depth ranges provided for these two sub-units (Sub-units VIa and VIb) are directly tied to the two associated ground types tested at OWF_BH11a. Based on 2D UHRS seismic data, the fault terminates at the base horizon of SU1 (H02) and where SU2 is present, at the base horizon of SU2 (H03) (refer to Table 5.4).

GT14 is believed to be associated with presence of karsts which extent is still unknown outside of the two boreholes it was sampled and represent a potential geohazard and soil constraint for foundations. Indeed, two GT14 layers were noticed at OWH_BH06-06a and at OWF_BH16 but resolution and processing of 2D UHRS data mitigates against recognising or differentiating these deposits from surrounding carbonates. The geotechnical unit associated with these karsts (Unit VII) is solely based on the four occurrences of GT14. Depth and thickness for Unit VII are from the two boreholes.

Table 6.1: Description and properties of Geotechnical Units and Sub-Units

Seismo-stratigraphic Unit[1] or geological feature	Ground Type [2]		Geotechnical Unit	Geotechnical Sub-Units	Description	From Boreholes [3] Depth [m BSF] Min.	Depth [m BSF] Max.	Thickness [m] Min.	Thickness [m] Max.	From Seismic [4] Top Depth [m BSF] Min.	Top Depth [m BSF] Max.	Thickness [m] Min.	Thickness [m] Max.	Boreholes with geotechnical units [5]
SU1	GT1		I	I	extremely low strength olive grey slightly sandy clayey SILT	0.0	2.7	0.6	2.7	0.0	0.0	0.2	24.0	OWF_BH04 and OWF_BH05/05a
	GT2	GT2a	II	IIa	very loose to loose light yellowish brown to very dark grey slightly gravelly to very gravelly slightly silty sometimes very clayey fine to coarse non calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments	0.0	7.9	0.2	5.4					All boreholes except OWF_BH01
		GT2b		IIb	medium dense to dense light olive brown to very dark grey slightly gravelly to gravelly slightly silty fine to coarse slightly calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments with rare mica crystals	0.0	11.3	0.5	7.4					
		GT2c		IIc	very dense light yellowish brown to dark greyish brown slightly gravelly slightly silty fine to coarse non calcareous to calcareous SAND with occasional to numerous medium sand-sized to coarse gravel-sized shell fragments with rare mica crystals	0.5	13.7	0.9	13.1					
SU2	GT3		III	IIIa	thinly interlaminated to very thickly interbedded high strength to extremely high strength dark grey slightly gravelly slightly sandy calcareous CLAY and loose to medium dense very dark grey slightly gravelly slightly sandy calcareous SILT with medium to widely spaced beds of siltstone	13.8	26.5	0.5	3.5	9.1	24.3	0.2	34.0	OSS2-W_BH4, OWH_BH11a and OWF_BH17
	GT4			IIIb	loose to medium dense white to grey slightly gravelly to gravelly very silty fine to coarse slightly calcareous to highly calcareous sometimes cemented SAND with rare medium sand-sized to coarse sand-sized shell fragments	12.7	30.8	0.7	9.9					
SU3	GT5		IV	IVa	very weak to weak slightly to moderately weathered light greenish grey to grey CALCILSILTITE with rare fine to medium gravel-sized shell fragments	10.2	45.9	2.1	14.8	0.0	8.9	0.2	63.0	OWF_BH04, OWF_BH05a and OWF_BH14
	GT6			IVb	very weak to moderately weak slightly to completely weathered light greenish grey to grey fine to coarse grained CALCARENITE with occasional to frequent medium sand-sized to coarse gravel-sized shell fragments	1.7	31.2	3.7	27.6					
SU4	GT7		V	Va	extremely weak to weak fresh to completely weathered light greenish grey to very dark grey locally glauconitic CALCILUTITE to CALCISILTITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments and with occasional to abundant fine to medium sand-sized mica crystals	7.7	63.5	1.2	16.4	0.0	67.9	NA[6]		All boreholes
	GT8			Vb	extremely weak to moderately weak slightly weathered to completely weathered dark grey to black non-calcareous to calcareous MUDSTONE to SILTSTONE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments	30.9	60.4	0.7	7.9					
	GT9			Vc	extremely weak to medium strong fresh to residual soil white to very dark grey fine to coarse grained CALCARENITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments locally with occasional to frequent fine to coarse gravel-sized fossils. Residual soil recovered as pale yellow to light yellowish brown gravelly silty fine to coarse calcareous SAND with occasional to numerous mica crystals and with rare to occasional coarse sand-sized to medium gravel-sized shell fragments	0.0	70.3	0.3	23.6					
	GT10			Vd	extremely weak to moderately weak slightly to completely weathered light greenish grey to dark greenish grey glauconitic fine to coarse grained CALCARENITE with occasional to abundant medium sand-sized to coarse gravel-sized shell fragments with frequent coarse sand-sized to coarse gravel-sized brown and orange staining	6.5	60.3	0.9	9.4					

Seismo-stratigraphic Unit [1] / Geological Feature	Ground Type	Geotechnical Unit	Geotechnical Sub-Units	Description	From Boreholes: Depth [m BSF] Min.	From Boreholes: Depth [m BSF] Max.	From Boreholes: Thickness [m] Min.	From Boreholes: Thickness [m] Max.	From Seismic: Top Depth [m BSF] Min.	From Seismic: Top Depth [m BSF] Max.	From Seismic: Thickness [m] Min.	From Seismic: Thickness [m] Max.	Boreholes with ground type
SU4	GT11	V	Ve	extremely weak to moderately weak slightly weathered to residual soil greenish grey to black locally glauconitic fine to coarse grained non-calcareous to calcareous SANDSTONE with rare to abundant medium sand-sized to medium gravel-sized shell fragments with occasional to numerous medium sand-sized mica crystals. Residual soil recovered as dark greenish grey to very dark greenish grey silty to very silty fine to medium calcareous SAND with frequent coarse sand-sized to fine gravel-sized shell fragments and with occasional mica crystals	13.3	60.4	1.2	14.8	0.0	67.9	NA-(6)		All boreholes
	GT12		Vf	medium dense to very dense grey to black slightly gravelly to very gravelly slightly silty to silty locally clayey to very clayey locally glauconitic fine to coarse SAND with occasional to frequent medium to coarse sand-sized mica crystals	33.0	70.6	3.3	22.1					
Fault	GT13	VI	VIa	very high strength to ultra-high strength CLAY with closely to medium spaced very thin to medium beds of sand and gravel (possibly firmly indurated fine grained carbonate silt with firmly cemented medium grained carbonate sand)	30.4	48.1	6.3	7.5	NA [(7)]				OWF_BH11/11a
	GT14		VIb	loose to medium dense SAND with closely to medium spaced very thin to thin beds of clay (possibly firmly cemented medium grained carbonate sand with firmly indurated cemented fine grained carbonate silt)	36.7	40.7	4.0	4.0					
Karsts	GT15	VII	VII	extremely low strength to low strength olive yellow to yellowish brown slightly gravelly sandy calcareous CLAY to medium dense to dense olive yellow to yellowish brown slightly gravelly sandy calcareous SILT with occasional fine gravel-sized to medium gravel-sized shell fragments	13.5	42.5	0.7	6.5	NA [(7)]				OWF_BH06/06a and OWH_BH16

Notes:

(1) Seismostratigraphic units defined from 2D UHRS data in Section 5.3.2
(2) Ground types defined from borehole data in Section 5.3.3
(3) Depth and thickness of getechnical units based on 2D UHRS data interpretation (Section 5.3.2))
(4) Depth and thickness of geotechnical sub-units based on borehole data (Section 5.3.3
(5) List of boreholes where individual geotechnical units were sampled.
(6) Thickness of Geotechnical Unit V not provided. Base of SU4 could not be picked on 2D UHRS data.
(7) Fault and karsts depth and thickness could not be picked on 2D UHRS data.

6.3 Soil Profiles

Soil profiles were produced to predict the lateral and vertical variability of geotechnical units within the considered depth of interest (60 m BSF). Geotechnical sub-units were not correlated across the OWF site due to high lateral and vertical variability of ground types observed between boreholes (Plate 3.13) and on seismic data.

Soil profiles were designed to allow a split between areas:

- With varying sediment cover thickness:
  - 0 m;
  - >0 to 10 m;
  - 10 to 20 m;
  - Above 20 m.
- With presence of absence of individual geotechnical units:
  - Presence of Unit V only;
  - Presence of Unit III and V;
  - Presence of Unit IV and V.

Thickness ranges provided in the soil profiles are derived from associated seismostratigraphic units (Section 6.3). The best estimate (BE) ranges are provided based on the standard deviation of gridded maps of each individual unit. The low estimate (LE) and high estimate (HE) ranges shows the observed minimum and maximum on gridded maps. Geotechnical boreholes generally show depth of units within the BE range.

Unit VI (fault) and Unit VII (karsts) are shown as hatched polygons above each profile where they may occur.

Unit VI can occur at all profiles except SP1d and only affect geotechnical units IV and V. BE thickness ranges between 0 and the maximum thickness observed in borehole data. In a conservative approach, the HE depth of the unit was taken to the depth of interest.

Unit VII was only observed in SP1c. BE thickness range was taken between 0 and the minimum observed thickness at boreholes. The LE range considers the maximum thickness of unit VII at boreholes. Depths correspond to observed depth at boreholes.

A total of nine (9) soil profiles were defined for the AO7 OWF site area. These profiles are displayed in Figure 6.1 and as Plate 4.1.

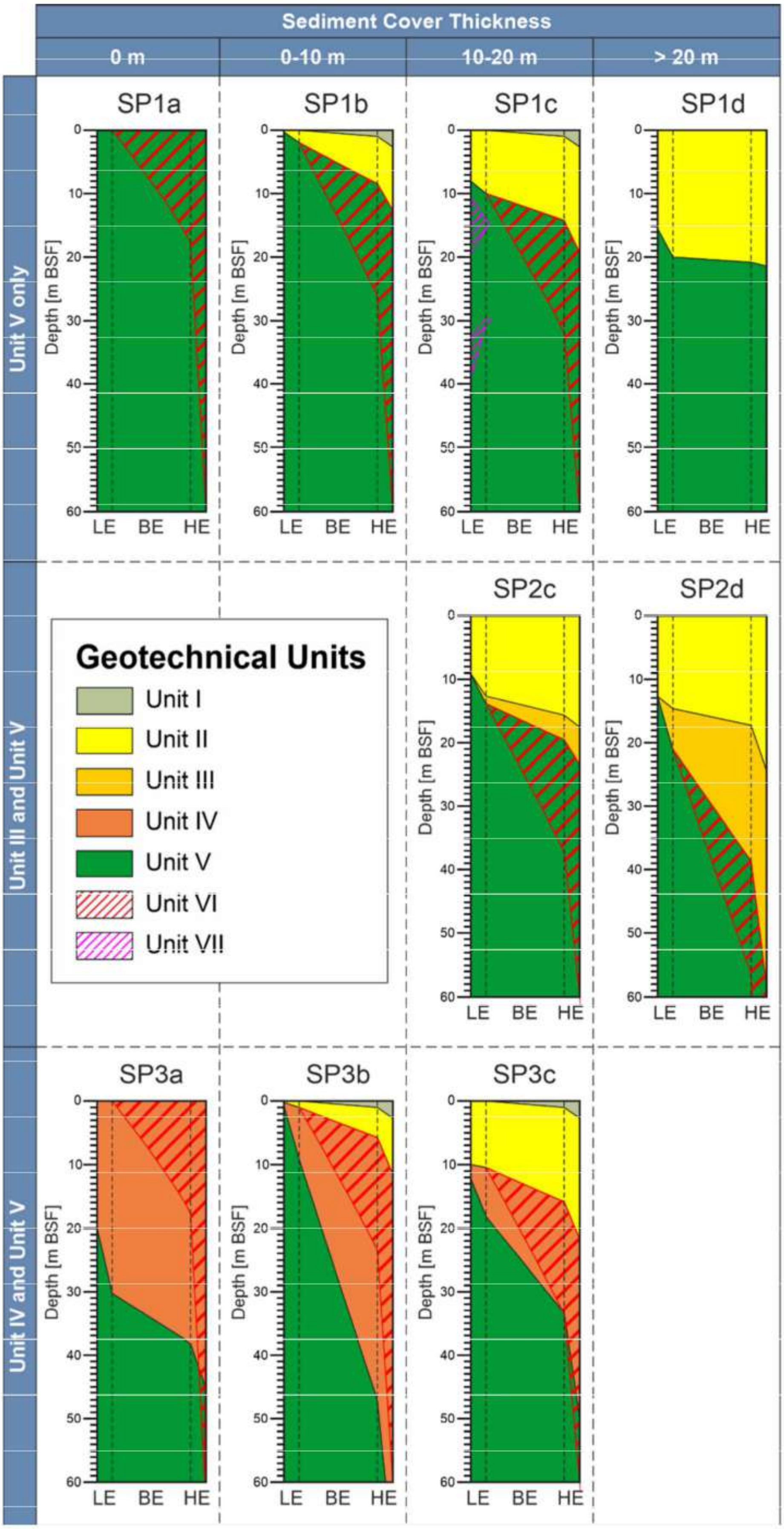


Figure 6.1: Soil profiles derived for AO7 OWF site

6.4 Soil Provinces

Based on SHOM sediment cover thickness and on gridded maps of individual units created upon Fugro's interpretation of 2D UHRS data, a soil province map was created to show the distribution of individual soil profiles (Figure 6.1) across the OWF site.

The soil province map is provided in Figure 6.2 and in Plate 4.2.

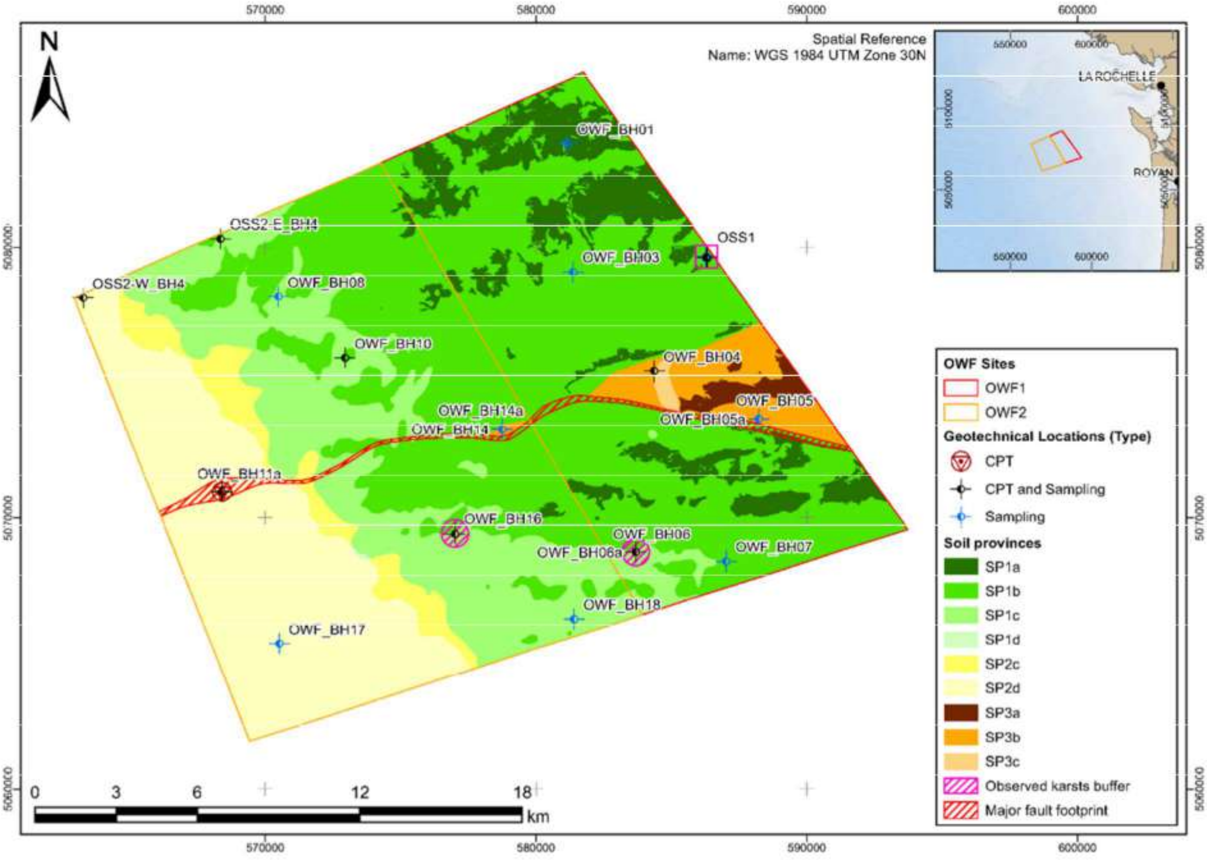


Figure 6.2: Soil province map for the AO7 OWF site

At OWF1, most of the area consist of SP1b. At OWF2, the area is split between SP1c to the north-east and SP2d to the south-west. The distribution of soil provinces is consistent with the presence of thicker Unit II and presence of Unit III to the west, and with the presence of Unit IV along the eastern border of the OWF site.

The major fault footprint as mapped from 2D UHRS data and a 500 m radius buffer around the two locations where Unit VII was sampled are displayed on the map to show the areas where Unit VI and VII are known to occur. However, both units are likely to occur elsewhere in the OWF site:

- Other minor faults were noticed on seismic but 2D UHRS did not allow to map their footprint due to line spacing being too large;
- Available geotechnical data and geophysical data do not provide enough resolution to map karsts across the entire area.

Both units are however displayed in soil profiles where they are most likely to occur (Figure 6.1) and are considered as geohazard and soil constraint in Section 7 where remaining uncertainties and possible mitigations are further discussed.

Table 6.2 shows the area covered by each soil province and the corresponding percentage of the OWF site that it represents. Most of OWF site is expected to consist of SP1b (46 %). SP1c and SP2d respectively cover 18 % and 20 % of the OWF site. SP1d, SP3a and SP3c are however marginal, the three of them representing only 1.2 % of the total OWF site area.

Table 6.2: Area covered by each soil province

Soil Province	Area [km^2]	Percentage of OWF site [%]
SP1a	36.3	8.4
SP1b	197.9	45.8
SP1c	78.4	18.1
SP1d	0.1	0.02
SP2c	15.7	3.6
SP2d	84.3	19.5
SP3a	3.9	0.9
SP3b	14.6	3.4
SP3c	1.2	0.3

6.5 Geotechnical Parameters

Design geotechnical parameters listed in Table 3.5 were derived for each geotechnical sub-units based on available geotechnical data detailed in Section 5.3.4. The parameters are derived at the minimum and maximum depth of occurrence of each sub-unit from boreholes except where enough in-situ continuous testing data show an evolution of parameters with depth.

In order to provide design parameters for engineering purposes, the parameters in this report are either:

- Low Estimate (LE), Best Estimate (BE) and High Estimate (HE) values: provided for strength related parameters (q_c, s_u, Dr, ϕ', RQD, I_s50, UCS);
- Best Estimate (BE) values: provided for general engineering parameters (w, γ, ρs, $\varepsilon 50$, TR, E) and to which the engineering assessments have a generally lower sensitivity to variations.

It is noted that the LE parameters generally govern the engineering capacity and sizing assessments whilst HE parameters are applicable to installation feasibility. BE is strictly indicative and should not be used in engineering calculations (excepting general engineering parameters, see list above).

Design soil parameters presented in Table 6.3 are representative values (ISO, 2019) selected using the available in situ data, laboratory data and engineering judgement, and are intended to be cautious for a feasibility and preliminary foundation design. The range of LE, BE and HE values consider only statistically representative values; outliers were excluded. The engineer in charge of the detailed foundation design should reinterpret the data and select their own geotechnical design profiles in consideration of the selected foundation solution and project specific details (i.e., loads, anticipated pile length, diameter, etc..).

The derivation of some parameters is based on very limited data, for example UCS and Young's Modulus in GT8. In these instances, the range in observed values derived from these limited data appear to be narrow, but it cannot be ruled out that a wider range would exist if more data were available. Conversely, for units where numerous data are available, for example GT9, a very wide range was observed in, for example, UCS and Young's Modulus and likely relates to wide range of weathering observed across the site in these units. Table 5.34 and Table 5.37 show the range in UCS and Young's Modulus observed from laboratory testing for individual units along with the number of measured values. These uncertainties should be considered when using unit-specific parameter values.

Table 6.3 notes provide detailed information and/or limitation on individual parameter values. Corresponding design lines are plotted per ground type and provided in Appendix B.

Table 6.3: Geotechnical parameters at AO7 OWF site

Unit	Sub-unit (GT)	Main Lithology	Depth (1) [m BSF]	w [%]	γ [kN/m^3]	ρs [-]	q_c [MPa]			S_u [kPa]			Dr [%]			ϕ' [°]			$\varepsilon 50$ [%]	TR (2) [m.K/W]	RQD [-]			$Is50$ [MPa]			UCS (6) [MPa]			E [GPa]
				BE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE
I (5)	I (GT1)	CLAY	0.0	97*	14.5*	2.75*	0.02	0.02	0.02	0.5	1.0	1.5		NA			NA		ND	ND		NA			NA			NA		NA
			0.6				0.05	0.08	0.10	1.0	1.8	2.5																		
			2.7				0.11 (3)	0.25 (3)	0.35 (3)	1.3 (3)	2.9 (3)	6.0 (3)																		
II (GT2)	IIa (GT2a)	SAND	0.0	23 (4)	20.0 (4)	2.67 (4)	0.1	0.5	0.8		NA		5	23	35	25	28	35	NA	0.5 (4)		NA			NA			NA		NA
			1.0				0.2	1	2				5	23	35	25	28	35												
			2.3				2	4	6				10	23	35	31	35	39												
			7.9				2	4	6				10	23	35	31	35	39												
	IIb (GT2b)	SAND	0.0	23 (4)	20.0 (4)	2.67 (4)	0.5	2	4		NA		35	50	65	26	38	45	NA	0.5 (4)		NA			NA			NA		NA
			0.5				0.5	2	4				35	50	65	26	38	45												
			0.5				5	15	25				65	75	85	35	43	45												
			4.80				5	15	25				65	75	85	35	43	45												
			10.0				5	15	25				65	75	85	35	43	45												
			11.3				5	15	25				65	75	85	35	43	45												
	IIc (GT2c)	SAND	0.0	23 (4)	20.0 (4)	2.67 (4)	5	10	20		NA		85	95	100	37	45	48	NA	0.5 (4)		NA			NA			NA		NA
			2.0				5	10	20				85	95	100	37	45	48												
			2.0				20	35	55				90	100	100	37	45	48												
			11.5				20	35	55				90	100	100	37	45	48												
			11.5				20	70	85				90	100	100	37	45	48												
			13.7				20	70	85				90	100	100	37	45	48												
III	IIIa (GT3)	CLAY / SILT	13.8	25*	20.3*	2.74*	5	9	13	100	350	550	25*	35*	40*	30	33	35	1.5*	ND		NA			NA			NA		NA
			14.5				5	9	13	100	350	550	25*	35*	40*	30	33	35												
			14.5				5	9	13	100	175	250		ND			ND													
			15.3				5	9	13	100	175	250	30	40	50	35	38	40												
			18.8				5	9	13		ND		30	40	50	35	38	40												
			20.5					ND		100	175	390		ND			ND													
			22.7				13	15	17	100	175	390	45	50	55	35	38	40												
			24.8				13	15	17		ND		45	50	55	35	38	40												
			25.6				13	15	17	-	75*	-	45	50	55	35	38	40												
			26.5				13	15	17	-	75*	-	45	50	55	35	38	40												
	IIIb (GT4)	SAND	12.7	30	19.0	2.71*	5	15	21		NA		30	48	65	35	39	42	NA	ND		NA			NA			NA		NA
			15.3				5	15	21				30	48	65	35	39	42												
			17.0				9	15	21				35	48	65	35	39	42												
			30.8				9	15	21				35	48	65	35	39	42												

Unit	Sub-unit (GT)	Main Lithology	Depth [(1)] [m BSF]	w [%]	γ [kN/m³]	ρs [-]	q_c [MPa]			s_u [kPa]			Dr [%]			ϕ' [°]			$\varepsilon 50$ [%]	TR [(2)] [m.K/W]	RQD [-]			$Is50$ [MPa]			UCS [(6)] [MPa]			E [GPa]
				BE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE
IV	IVa (GT5)	CALCI-SILTITE	10.2	18	21.5	ND		NA			NA			NA			NA		NA	ND	-	43*	-	0.1	0.3	0.5	1.0	2.0	3.5	1.1*
			12.0																		-	43*	-	0.1	0.3	0.5	1.0	2.0	3.5	
			31.2																		62	75	100	0.1	0.3	0.5	1.0	3.5	7.5	
			45.9																		62	75	100	0.1	0.3	0.5	1.0	3.5	7.5	
	IVb (GT6)	CALC-ARENITE	1.7	16	22.5	ND		NA			NA			NA			NA		NA	ND	25	65	95	0.1	0.3	0.6	1.2	2.0	7.0	3.3*
			12.0																		25	65	95	0.1	0.3	0.6	1.2	2.0	7.0	
			12.0																		25	65	95	0.3	1.0	2.0	2.0	12.0	23.0	
			21.0																		25	65	95	0.3	1.0	2.0	2.0	12.0	23.0	
			21.0																		25	65	95	0.1	0.3	0.6	2.0	5.0	10.0	ND
			31.2																		25	65	95	0.1	0.3	0.6	2.0	5.0	10.0	
V	Va (GT7)	CALCILUTITE / CALCI-SILTITE	7.7	17.5	22.0	2.73*		NA			NA			NA			NA		NA	ND	25	80	100	0.1	0.3	1.3	0.4	3.0	11.0	0.8
			31.0	17.5	22.0																25	80	100	0.1	0.3	1.3	0.4	3.0	11.0	
			36.0	10	23.0																25	80	100	0.1	0.3	1.3	0.4	3.0	11.0	
			63.5	10	23.0																25	80	100	0.1	0.3	1.3	0.4	3.0	11.0	
	Vb (GT8)	MUDSTONE / SILTSTONE	30.9	16	22.0	2.66*		NA			NA			NA			NA		NA	ND	25	75	100	0.1	0.3	0.8	0.5	1.5	4.5	0.2*
			43.0	16	22.0																25	75	100	0.1	0.3	0.8	0.5	1.5	4.5	
			43.0	32	20.0																25	75	100	0.1	0.3	0.8	0.5	1.5	4.5	
			49.0	32	20.0																25	75	100	0.1	0.3	0.8	0.5	1.5	4.5	
			53.0	32	20.0																25	75	100		ND			ND		ND
			53.0	16	22.0																25	75	100	0.1	1.3	2.5	0.5	9.0	15.0	
			60.4	16	22.0																25	75	100	0.1	1.3	2.5	0.5	9.0	15.0	
	Vc (GT9)	CALC-ARENITE	0.0	15	23.0	2.71		NA			NA			NA			NA		NA	0.6	25	70	100	0.1	0.5	2.2	0.9	5.0	20.0	14.0
			6.55																	0.6	25	70	100	0.1	0.5	2.2	0.9	5.0	20.0	
			23.0																	ND	25	70	100	0.1	0.5	2.2	0.9	5.0	20.0	
			23.0																		25	70	100	0.1	0.5	2.2	0.9	10.0	40.0	
			70.3																		25	70	100	0.1	0.5	2.2	0.9	10.0	40.0	
	Vd (GT10)	CALC-ARENITE (glauconitic)	6.5	15	22.0	ND		NA			NA			NA			NA		NA	ND	35	70	97	0.1	0.5	1.6	0.8	3.0	13.0	0.1*
			53.0	15	22.0																35	70	97	0.1	0.5	1.6	0.8	3.0	13.0	
			53.0	25	20.5																35	70	97	0.1	0.5	1.6	0.8	3.0	13.0	
			60.3	25	20.5																35	70	97	0.1	0.5	1.6	0.8	3.0	13.0	
	Ve (GT11)	SAND-STONE	13.3	19	20.5	2.72*		NA			NA			NA			NA		NA	ND	35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	1.0
			23.0	19	20.5																35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	
			23.0	16	21.5																35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	
			54.2	16	21.5																35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	
			58.8	10	23.5																35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	ND
			60.4	10	23.5																35	70	100	0.1	0.4	1.6	0.4	2.0	13.0	

Unit	Sub-unit (GT)	Main Lithology	Depth [1] [m BSF]	w [%]	γ [kN/m³]	ρs [-]	q_c [MPa]			s_u [kPa]			Dr [%]			ϕ' [°]			$\varepsilon 50$ [%]	TR [2] [m.K/W]	RQD [-]			$Is50$ [MPa]			UCS [6] [MPa]			E [GPa]
				BE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE	BE	LE	BE	HE	LE	BE	HE	LE	BE	HE	BE
V	Vf (GT12)	SAND	33.0	26	19.5	2.66	40	60	80		NA		50	75	100	31	40	44	NA	ND		NA			NA			NA		NA
			70.6				40	60	80				50	75	100	31	40	44												
VI [5]	VIa (GT13)	CLAY	30.4	ND	ND	ND	10	20	40	300	1000	1500		NA			NA		ND	ND		NA			NA			NA		NA
			36.7				10	20	40	300	1000	1500																		
			40.7				3	7	15	150	300	500																		
			48.1				3	7	15	150	300	500																		
	VIb (GT14)	SAND	36.7	ND	ND	ND	4	15	20		NA		15	35	55	33	37	40	ND	ND		NA			NA			NA		NA
			40.7				4	15	20				15	35	55	33	37	40												
VII [5]	VII (GT15)	CLAY / SILT	13.5	40*	19.0*	3.02*	0.3	7	15	2	20	40	25	38	50	33	38	40	NA	ND		NA			NA			NA		NA
			15.0				0.3	7	15	2	20	40	25	38	50	33	38	40												
			21.0				0.3	1.5	3		ND			ND			ND													
			22.5				0.3	1.5	3																					
			27.0				0.3	1.5	3	2	20	ND		ND			ND													
			27.8				0.3	1.5	3	2	20	40																		
			36.0				0.3	1.5	3	2	20	ND		ND			ND													
			41.3				0.3	1.5	3	2	20	40																		

Notes:

LE Low Estimate: govern the engineering capacity and sizing assessments.
BE Best Estimate: strictly indicative at this stage and should not be used for design calculation.
HE High Estimate: applicable to installation feasibility.
ND No data available to derive parameter at geotechnical unit.
NA Parameter not applicable to soil type or not part of the scope.
LE, BE and HE values provided for strength related parameters (q_c, s_u, Dr, ϕ', RQD, I_s50, UCS).
BE values provided for general engineering parameters (w, γ, ρs, $\varepsilon 50$, TR, E).

(1) Minimum and maximum depth of occurrence of each geotechnical sub-unit or transition depth observed in geotechnical data.
(2) Thermal resistivity only measured within the first 7 m BSF at OSS1 and OSS2 locations.
(3) Extrapolated from trend at shallower depth based on sample description.
(4) w_c, γ and TR derived from sampling boreholes only where Unit II is undifferentiated.
(5) Geotechnical units identified only on a limited number of boreholes. Parameters may vary away from borehole locations.
(6) UCS derived based on laboratory data and values calculated based on Is50 values using correlation presented in Section 5.3.4.14.
\- Parameter value not derived due to insufficient data
* Value based on limited data.

FUGRO

7. Geohazards, Soil Constraints and Anthropogenic Constraints

7.1 Overview

This section presents inventories summarising (1) geohazards, (2) soil constraints and (3) anthropogenic constraints identified across the OWF site based on available data and information.

Table 7.1 defines the qualitative descriptors used in the geohazards and soil constraints inventories tables, giving an estimate on the likelihood of encounter.

Table 7.1: Criteria to estimate geohazards and soil constraints likelihood of encounter

Likelihood	Classification	Description
High	3	Soil condition or geohazard inferred to be feasible and observed within the available data
Moderate	2	Soil condition or geohazard inferred to be feasible and some indicators within the available data
Low	1	Soil condition or geohazard inferred to be feasible but not observed within the available data

Plate 5.1 presents the geohazards and soil constraints that could be identified and mapped from available data.

7.2 Geohazards and Soil Constraints Inventories

Table 7.2 presents the geohazards inventory, while Table 7.3 details soil constraints. These tables qualitatively assess the likelihood of the geohazards and soil constraints being present across the OWF site as defined in Table 7.1. They do not represent a quantitative value or risk ranking. This likelihood assessment is based on the available data only.

With the present knowledge of the OWF site and based on the information obtained on identified geohazards and soil constraints, proposed mitigations in Table 7.2 and Table 7.3 focus on reducing identified uncertainties. Where no uncertainties remain preventive or protective mitigation methods are proposed. The proposed mitigations are following CFMS (2020) and OSIG (2014, 2022) recommendations.

Table 7.2: Geohazards inventory for the OWF site

Geohazards	Description	OWF Site Occurrence	Implication for Surveying, Foundations/Anchors and Cables	Likelihood of Encounter	Uncertainties ❶ and mitigation ❷
Earthquakes	An earthquake occurs when stresses in the Earth's crust, that have gradually build-up, are suddenly released by movements along a fault. The movement generates seismic waves which propagate away from the point of rupture (epicentre).	Earthquakes have been recorded over the last 50 years along the central Bay of Biscay shoreline (none within the OWF site). A maximum magnitude of 5.3 has been recorded in 2023, between Niort and La Rochelle, less than 100 km away from AO7 OWF site ([17/11/2023] https://renass.unistra.fr/fr/zones/france/). The closest event recorded was in 2005 and reached a magnitude of 4.6 and was located offshore, West of Oléron island, 35 km East of AO7 OWF site. The onshore area is categorized as a moderate seismic risk area by the BRGM.	**Surveying:** damage on tools and equipment during operations. **Foundations/Anchors:** reduction or loss of capacity, destabilisation, and damage to offshore wind turbine (OWT) **Cables:** over tension and rupture.	1	❶ Recurrence period of major earthquakes and earthquake-induced ground motions. ❷ Perform a probabilistic seismic hazard assessment study and a site response analysis.
Irregular seafloor topography	Seafloor morphology can be irregular as a result of past or present geological processes. Human activities can also affect the seafloor topography (dredging, trawling).	Seafloor gradient above 5° have been observed, associated with seafloor bedforms, seafloor outcrops, and anthropogenic features (e.g. wrecks) (Section 5.2.2).	**Surveying:** instability and/or damage of seabed tools and equipment, challenging installation, calibration of sampling tools and challenging data acquisition. **Foundations/Anchors:** operational issues and positioning uncertainties during installation. **Cables:** over tension and rupture.	3	❶ NA ❷ Avoid areas of high seafloor gradients when planning OWT and related foundation / anchor locations.
Seafloor bedforms and sediment mobility	A seafloor bedform is a morphological feature formed by interaction of wave action and (tidal) currents with cohesionless sediment (i.e. sand and silt). Bedforms are typically found in sandy areas at a continental shelf. A characteristic of bedforms is their mobility. Sand dunes tend to move slowly (metres per year) or to flex their crests with (tidal) currents while smaller-scale ripples tend to be more mobile, in the order of metres per day.	Seafloor bedforms identified in the OWF site include sand dunes and ribbons (50 to 1000 m in wavelength; Sections 5.2.4.2 and 5.2.4.3) and megaripples (10 to 20 m in wavelength; Section 5.2.4.4).	**Surveying:** no direct implication, see "Irregular seafloor topography" geohazard **Foundations/Anchors**: (mobile bedforms) reduction or loss of capacity (primarily lateral capacity) with resulting destabilisation and possible damage. **Cables:** (mobile bedforms) exposure or burial leading to over tension and rupture, change of thermal conductivity leading to overheating, and exposure to accidental damage from anthropogenic activities.	3	❶ Occurrence of smaller scale bedforms at the seabed (e.g. ripples) and the rate, volume, and extent of sediment remobilisation at the seabed. ❷ Detail image of the seabed using e.g. remotely operated vehicle (ROV); Acquire MBES surveys at different period of the year to capture bedform evolution over time. Perform a sediment mobility hazard assessment study (3D hydrodynamical and morphodynamical modelling).
Rock outcrops and hard seafloor	Rock outcrops and hard seafloor commonly include cemented soils (e.g. cemented aeolian dunes) and outcrops of rocks. Examples are pre-Quaternary sand- and limestone beds and metamorphic rocks exposed at the seabed.	Seafloor outcrops have been observed within the OWF site, associated with pre-Quaternary rocks at the seabed. Expected rocks are geotechnical units IVa,b and Va,b,c,d (Table 6.1). Seafloor outcrops are associated with high seafloor gradients.	**Surveying:** inappropriate data acquisition instruments and/or calibration; instability, early refusal and/or damage on tools and equipment. **Foundations/Anchors:** uneven outcrop can be difficult for levelling of installation equipment. Driven piles may have difficulty in penetrating the substratum and possible pile tip damage. **Cables:** exposure to accidental damage from anthropogenic activities or trenching issues during cable installation; abrasion damage where the cable laid over outcrops.	3	❶ Exact nature of rock outcrops away from geotechnical boreholes ❷ Avoid areas of rock outcrops when planning OWT and related foundation. Detailed, geotechnical SI with boreholes including rock coring at the foundation/anchor location.
Soil liquefaction	Soil liquefaction or cyclic mobility relates to a decrease of soil strength and stiffness caused by a sudden 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.	No direct observation. Examples of natural cyclic and dynamic actions include earthquake shaking, storm wave loading and vortex vibrations due to fluid flow around a structure. Water depth at the OWF site is within the wave-base action and earthquakes were recorded in the region.	**Surveying:** instability and/or damage of seabed tools and equipment. **Foundations/Anchors:** reduction or loss of capacity, destabilisation, and damage. **Cables:** exposure or burial leading to over tension and rupture, change of thermal conductivity leading to overheating, and exposure to accidental damage from anthropogenic activities.	1	❶ Probability, intensity and extent of soil liquefaction. ❷ Perform a soil liquefaction hazard assessment study.

Geohazards	Description	OWF Site Occurrence	Implication for Surveying, Foundations/Anchors and Cables	Likelihood of Encounter	Uncertainties ❶ and mitigation ❷
Wind, waves, and currents	Periods of extreme weather conditions, such as storms, peak wind, waves, and current regimes can cause lateral and cyclic actions on the seafloor and any seabed-supported structure. 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.	Storms are frequent along the French Atlantic coast (e.g. Ciaran the 2nd of November 2023 and Domingos the 4th and 5th of November 2023 with recorded H_{max} of 14.8 m and 18.3 m, respectively) ([13/11/2023]https://candhis.cerema.fr/). The wave-base action can affect the whole OWF site seabed during extreme conditions (Section 5.2.5).	**Surveying:** inaccessibility of the area for surveys (severe weather conditions), vessel layover, need to repeat part of surveys. **Foundations/Anchors:** enhanced lateral loading magnitude and possible cyclic loading requiring a more robust foundation design. Also see "Seafloor bedforms" and "Seafloor scour and sediment mobility" geohazards. **Cables:** no direct implication, see "Seafloor bedforms" and "Seafloor scour and sediment mobility" geohazards.	3	❶ Specific metocean conditions at the OWF site. ❷ Deploy wind LiDAR buoys at the OWF site to measure wind profiles, waves, and current profiles. Monitor Metocean conditions during SI and avoid winter period. Consider extreme conditions in the design of foundations and anchors.
Faults / Fault zones	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. Fault zones are areas where multiple fractures and faults occur in close proximity, with similar movement direction. Rock is generally highly fractured and weathered within the fault zone.	A major fault zone has been mapped from geophysical data in the OWF site (Section 5.3.2.7) and associated weathered and fractured rock was sampled at OWF_BH11-11a location. Other minor faults were imaged but could not be mapped across the OWF site. Faults are not active anymore and terminates below Miocene sediments.	**Surveying:** complex geometries difficult to image on seismic data; areas of weathered rock and fractured material may cause sampling and drilling difficulties. **Foundations/Anchors:** see "Earthquakes" geohazard. Fault zones with weathered rock and fractured material may lead to driven piles installation issues (early refusal, free fall). Collapse of drilling wall during drilled and grouted pile installation. **Cables**: see "Earthquakes" geohazard.	3	❶ Extent of minor faults; depth of the fault zone; nature and geotechnical properties of fractures and weathered material away from OWF_BH11-11a location. ❷ Acquire three-dimensional UHR seismic data across the final development site to map the fault network in details. Avoid fault zones when planning OWT locations. Perform a direct fault rupture hazard assessment study to understand the impact of the fault and its activity on foundation stability.
Seafloor scour	Seafloor 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 locally increasing flow velocities.	Scours are observed around obstacles (examples around wrecks in Section 5.2.4.5) and related to a current flow regime oriented NNE/SSW (Section 5.2.5)	**Surveying:** no implication. **Foundations/Anchors:** loss of lateral support and associated increase bending moment due to lateral loading. Minor reduction in axial capacity. **Cables:** exposure or burial leading to over tension and rupture, change of thermal conductivity leading to overheating, and exposure to accidental damage from anthropogenic activities.	3	❶ Soil/structure/fluid interaction. ❷ Perform a scour hazard assessment study (3D hydrodynamical and morphodynamical modelling).

Note:
NA = non-applicable

Table 7.3: Soil constraints inventory for the OWF site

Soil Constraints	Description	OWF Site Occurrence	Implication for Surveying, Foundations/Anchors and Cables	Likelihood of Encounter	Uncertainties ❶ and mitigation ❷
Weathered rock	Wearing down or breaking of rocks after their deposition. Weathering can be biological, chemical, or physical.	Weathered rocks are frequent in all pre-Quaternary strata. In particular, completely weathered to residual soil layers were observed in geotechnical units IV and V with RQD as low as 0 %(Fugro, 2023c) but especially in units VI (major fault) and VII (karsts) and ground types GT12 to GT14.	**Surveying:** loss of seismic signal in weathered rock; instability and/or damage on tools and equipment; sampling and testing difficulties. **Foundations/Anchors:** localised reduction in soil/rock strengths. Enhanced likelihood of fracturing leading to variable soil conditions. Poor hole stability condition for start of drilling. Reduction of rock strength (anticipated low rock mass factor through the weathered zone). **Cables:** see implications for "Rock outcrops and hard seafloor"	3	❶ Weathering degree/grade of the rock away from boreholes. ❷ Detailed geotechnical SI with boreholes including rock coring to the anticipated foundation depth and at the planned location. Measure of the RQD.
Spatial variability	Lateral and vertical variability of materials (e.g., thickness variability, geotechnical properties variability, etc.).	High spatial and vertical variability is observed on existing data (boreholes, 2D UHRS data) across the OWF site and throughout the overall depth of interest (60 m BSF).	**Surveying:** early refusal and/or damage on tools and equipment; complex tie between geophysical and geotechnical data. **Foundations/Anchors:** may lead to driven piles installation issues (extrusion buckling risks and early refusal). Collapse/instability of drilling wall during drilled and grouted pile installation. **Cables:** cable burial issues (specific trenching tools required), operations could be time-consuming.	3	❶ Spatial variability of the geotechnical units and ground types away from boreholes. ❷ Geotechnical SI with boreholes including soil sampling and rock coring at the foundation/anchor location. Additional CPTs may be required if significant lateral variability is anticipated.
Interbedded soils and rocks	Beds of rocks and soils lying between or alternating with others of different character.	Interbedded soil/rocks were observed at boreholes throughout the overall depth of interest (60 m BSF). In particular at OWF_BH01; OWF_BH04, OWH_BH14a and OWH_BH18.	**Surveying:** instability, early refusal and/or damage on tools and equipment; complex tie between geophysical and geotechnical data. **Foundations/Anchors:** may lead to driven piles installation issues (extrusion buckling risks and early refusal). Collapse/instability of drilling wall during drilled and grouted pile installation. **Cables:** cable burial issues (specific trenching tools required), operations could be time-consuming.	3	❶ Soil/rock layers distribution away from boreholes. ❷ Same to "Spatial variability" mitigation.
Fractured strata	Mechanical ruptures in rocks involving discontinuities within the rock mass with no evidence for significant displacement.	Fractures are frequent within the pre-Quaternary strata (Fugro, 2023c). In particular, highly fractured ground layers were observed in geotechnical units IV and V where RQD as low as 0 % was measured.	**Surveying:** loss of seismic signal in fractured strata; inappropriate data acquisition instruments and/or calibration; instability, refusal and/or damage on tools and equipment. **Foundations/Anchors:** collapse/instability of drilling wall during drilled and grouted pile installation. **Cables:** see implications for "Rock outcrops and hard seafloor"	3	❶ Distribution of fractures within the rock away from boreholes. ❷ Similar to "Weathered rock" mitigation. Detailed fracture logging required.
Cementation	Process of precipitation of cement between minerals in a rock matrix and strengthening the rock mass. Nature of cement may vary depending on pore fluids, temperature and pressure conditions and surrounding rocks.	Localized dolomitized beds associated with peaks in I_s50 and dissolution features, were observed within the pre-Quaternary strata (see geotechnical logs in Fugro, 2023c).	**Surveying:** Rapid changes in seismic velocity leading to imaging issues; early refusal and/or damage on tools and equipment. **Foundations/Anchors:** may lead to driven piles installation issues (extrusion buckling and early refusal risk during driving). **Cables:** cable burial issues (specific trenching tools required)	3	❶ Distribution of cemented layers away from boreholes. ❷ Detailed geotechnical SI with boreholes including rock coring to at the foundation/anchor location. PLT and UCS tests and thin sections analysis in laboratory to confirm cement type.
Variable bedrock	Variable lithology, weathering, strength of rock strata across the OWF site	Rocks were sampled as geotechnical units IV and V (GT5 to GT10) across the OWF site. Descriptions demonstrate a strong variability in lithologies (Unit V was split into 5 sub-units of different lithologies) and in	**Surveying:** early refusal and/or damage on tools and equipment; complex tie between geophysical and geotechnical data.	3	❶ Distribution of the different types of rock away from boreholes.

Soil Constraints	Description	OWF Site Occurrence	Implication for Surveying, Foundations/Anchors and Cables	Likelihood of Encounter	Uncertainties ❶ and mitigation ❷
		weathering state. Strength within sub-units is also highly variable (see I_s50 in Table 6.3). High lateral and vertical variability predicted from seismic data and boreholes (Plate 3.13)	**Foundations/Anchors:** may lead to driven piles installation issues (extrusion buckling and early refusal risk during driving). **Cables:** cable burial issues (specific trenching tools required), abrasion damage where the cable laid over outcrops.		❷ Detailed geotechnical SI with boreholes including rock coring at planned wind turbine / pile location.
Karsts	Void or topography formed from the dissolution of carbonate rock types such as limestone and dolomite.	Karsts are identified at boreholes OWF_BH06-06a and OWF_BH16 as geotechnical unit VII and ground type 14. 4 out of 6 rock types are described as carbonate rocks (CALCILUTITE, CALCISILTITE, CALCARENITE) that could be impacted by karstification processes.	**Surveying:** voids may cause loss of seismic signal; instability, refusal and/or damage on tools and equipment. **Foundations/Anchors:** may lead to driven piles installation issues (free fall, extrusion buckling, early refusal). Silts can also be subject to very low skin frictions. Collapse/instability of drilling wall during drilled and grouted pile installation. **Cables:** NA	2	❶ Distribution, size, and infill of karst cavities away from boreholes. ❷ Acquire three-dimensional UHR seismic data across the final development site to map potential karst network. Geotechnical SI with boreholes including rock coring at the foundation/anchor location.
Organic matter content	Organic fraction of the soil / rock derived from e.g., algal, plant, and microbial materials.	OM layers have been locally found in boreholes BH16 (interval 27.00-27.75 m BSF), BH18 (interval 0.50-10.50 m BSF), and BH08 (intervals 9.75-10.00 m BSF, 12.40-12.45 m BSF).	**Surveying:** no implication. **Foundations/Anchors:** no implication **Cables:** heat dissipation issues for buried cable (OM has very high resistivity).	2	❶ Distribution and thickness of OM layers away from boreholes. ❷ Detailed geotechnical SI with CPTs. Organic content test in laboratory.
Sulphate-reducing bacteria (SRB)	Microorganisms that are able to reduce sulfate or partially oxidized sulfur compounds, such as sulfite and thiosulfate to produce energy in anaerobic conditions.	SRB tests have been performed at the OSS location with heavy contamination (i.e. >100 000 SRB/ml) recorded.	**Surveying:** no implication. **Foundations/Anchors:** microbiologically influenced corrosion (MIC) (electrochemical corrosion influenced by the presence/action of SRB) of piles and anchors. **Cables:** microbiologically influenced corrosion (MIC) (electrochemical corrosion influenced by the presence/action of SRB) of cables	3	❶ SRB presence away from OSS locations. ❷ Sulphate reducing bacteria (SRB) tests during detailed geotechnical SI.
Glauconitic material	Glauconite is an iron potassium phyllosilicate (mica group) mineral of green colour which is very friable and has very low weathering resistance.	GT10 corresponds to glauconitic calcarenite. GT10 occurs predominantly to the south of the OWF site (Figure 5.16). Glauconites are also present as minor constituent in GT7, GT11 and GT12.	**Surveying:** sampling difficulties **Foundations/Anchors:** May lead to driven pile installation issues (early refusal for intact material, loss of capacity in highly weathered material) **Cables:** no implication	3	❶ Exact distribution and mapping of GT10 ❷ Detailed geotechnical SI with rock coring to the anticipated foundation depth. Visual description of rock cores. Consideration of glauconite in the design of foundations.

Note:
NA = non-applicable

7.3 Identified Geohazards and Soil Constraints Map

Based on available data, a number of identified geohazards and soil constraints detailed in Table 7.2 and Table 7.3 were possible to represent in a map to show their predicted or observable distribution. These are:

- Bedforms;
- Rock outcrops;
- Areas of high seafloor gradient (irregular seafloor);
- Major fault;
- Observed karsts;
- Earthquakes from ReNaSS catalog.

The resulting map is Figure 7.1 and in Plate 5.1.

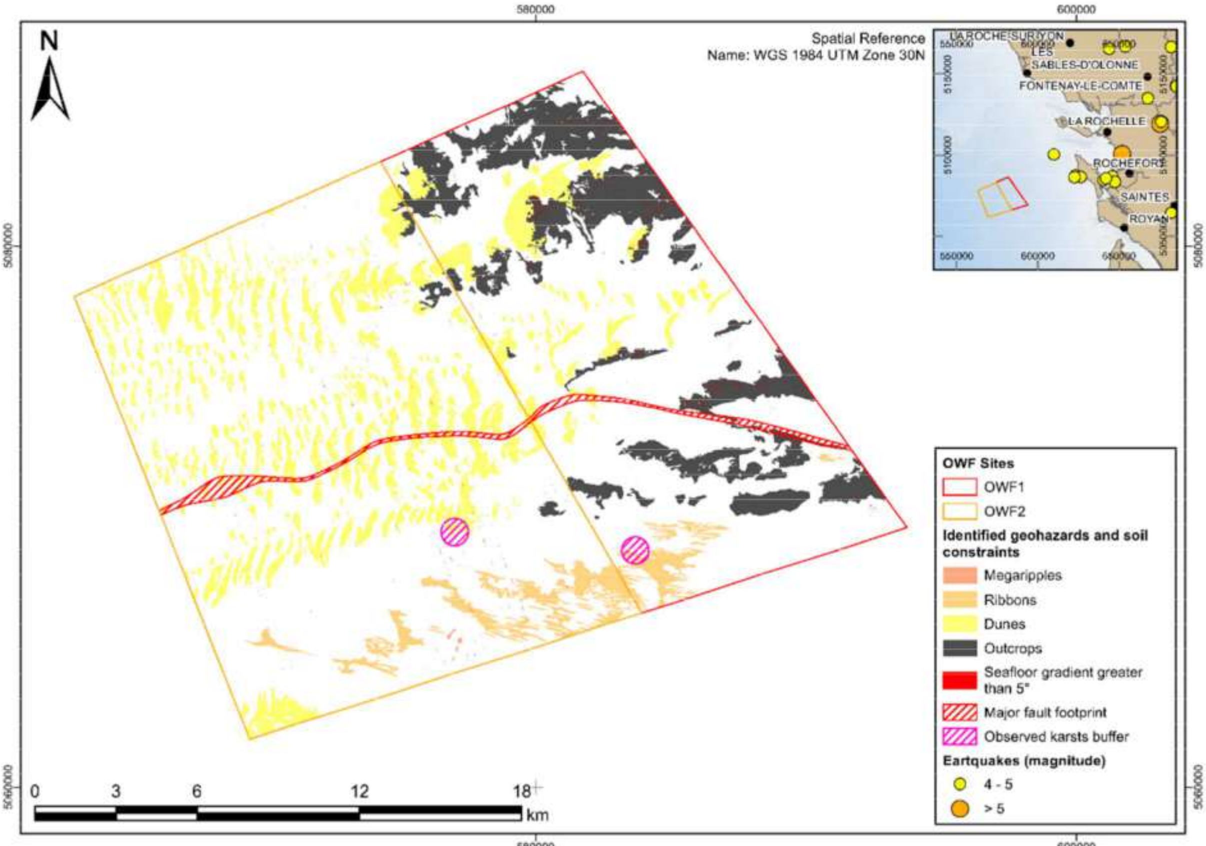


Figure 7.1: Geohazards and soil constraints with predictable or observed distribution

7.4 Identified Anthropogenic Constraints

7.4.1 Overview

Anthropogenic constraints were identified on available data as described in Section 2. The following sub-section list and discuss identified anthropogenic constraints.

7.4.2 Fishing Activities

EMODnet human activities webmaps (https://emodnet.ec.europa.eu/geoviewer/) allow to display fishing density around Europe monthly for the past 5 years (2017-2022). This allows to identify areas and periods of the year where or when fishing activity is the most intense.

Based on these maps, intense fishing activities at or close to the OWF site were recorded between May and September, while December to March show the less intense fishing activity.

Potential hazards from fishing activities are caused by fishing gear coming into contact with the cables, particularly from bottom-engaging fishing. The contact may result in immediate damage/weakening of the cable or even cable failure.

According to Shapiro et al. (1997), of the fishing methods currently in use, trawling is considered the greatest threat to the cables. Bottom set fixed fishing gear and dredges still pose a significant risk to cables. The depth of penetration of trawl gear in the seabed sediment is highly dependent on the soil conditions. No significant penetration is anticipated in areas rock outcrops (SP1a and SP3a in Figure 6.2). In areas where soft sediments are predicted at the surface (e.g. all soil provinces except SP1a and SP3a in Figure 6.2) higher fishing gear penetration is expected, and may typically reach 0.3 m or more.

Trawlmarks were noticed on MBES backscatter data and SSS data as displayed in Figure 5.8, illustrating the impact of these type of fishing gears on the OWF site seafloor.

7.4.3 Shipping Vessel Anchorage

EMODnet human activities webmaps (https://emodnet.ec.europa.eu/geoviewer/) allow to display vessel route density around Europe yearly and per vessel type. This allows to identify types of vessels that are likely to cross an area.

Based on these maps, a tanker and cargo vessel route is currently crossing across the OWF site with densities ranging between 20 and 80 vessel passage per square kilometre and per year. This route crosses the site in a South-East to North-West direction from Gironde Estuary towards the main Bay of Biscay – English Channel shipping lane.

Like fishing activities, shipping vessels can also pose threat to submarine cables due to risk of anchor deployment and drag that may strike on the cable. The likelihood that a cable is snagged and damaged by an anchor will depend on the depth at which it may be buried for protection and is primarily a function of the expected anchor penetration in the anticipated soils, and the density of shipping traffic potentially crossing the cable route.

To understand the spatial distribution and density of marine traffic in vicinity of the export cable routes, Automatic Identification System (AIS) vessel tracking data are required. This dataset should form the basis of a dedicated Cable Burial Risk Assessment study informing the recommendation of cable burial depths.

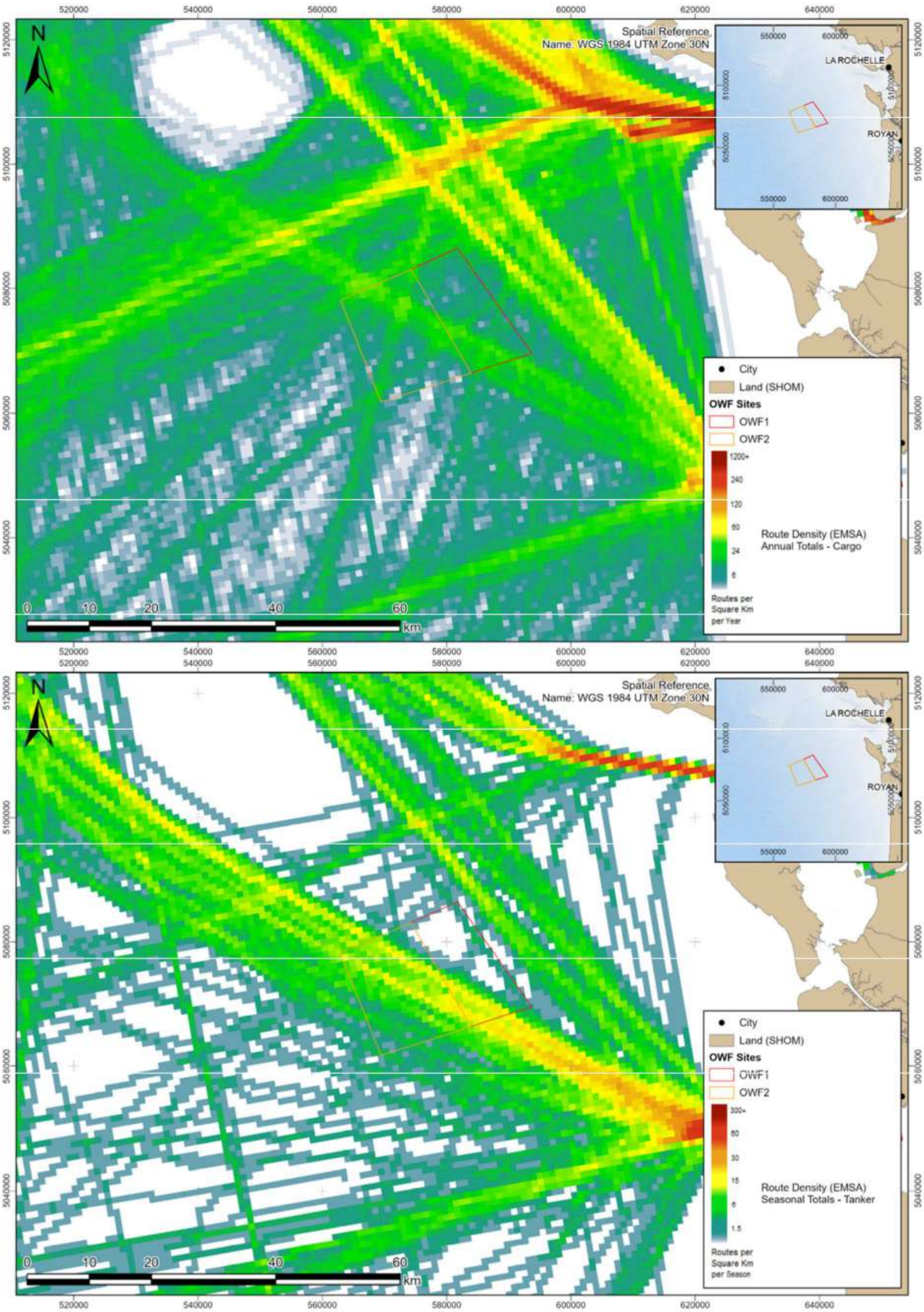


Figure 7.2: Cargo (Top) and tanker (bottom) annual route density from EMODnet

Moreover, the proximity of a major shipping lane increases the probability of vessel collision with an OWT. This may occur when a vessel loses engine capacity and starts drifting away from its route as it happened in German North Sea in April 2023. This risk shall be considered in the design of foundations for OWT as extreme cases scenarios as stated by Moulas & Shafiee (2017).

7.4.4 Protected Areas

Based on EMODnet, a Natura 2000 special protection area following Birds and Habitats European directive and an Oslo-Paris (OSPAR) convention zone referred as « Parc naturel marin de l'estuaire de la Gironde et de la mer des Pertuis » covers the entire OWF site.

The future OWF development shall comply with associated directive and constraints imposed by those two areas.

7.4.5 Shipwrecks

As stated in Section 5.2.5.5, three (3) seafloor obstructions, likely shipwrecks based on MBES data (see Figure 5.10), are present at the OWF site. Based on EMODnet and SHOM databases, two of these shipwrecks are identified as Dundee type shipping vessels sunk by German mines in 1917. The third shipwreck is not identified in SHOM or EMODnet databases.

The actual locations spotted on SHOM MBES data are different from the ones available from EMODnet and SHOM databases. The actual locations are provided in Table 7.4.

Magnetic anomalies are likely associated with two of the shipwrecks showing some metallic elements may be present in the wrecks. The third one is not associated with any visible anomaly and is likely non-metallic.

Table 7.4: Identified shipwrecks actual locations and possible characteristics

Shipwreck number (1) (Figure 5.10)	Easting [m]	Northing [m]	Metallic elements (2)	Possible identification (3)
a	573239	5074153	Likely	Dupleix, Dundee type shipping vessel. Sunk in 1916 by a German mine
b	576369	5065097	Likely	Redempteur, Dundee type shipping vessel. Sunk in 1916 by a German mine
c	574746	5067626	Unlikely	Unknown

Notes:
(1) Letters used in Figure 5.10 and in Section 5.2.5.5 to identify seafloor obstructions on MBES data
(2) Likelihood based on magnetic anomaly visible on SHOM magnetometric data close to the shipwreck locations
(3) Possible identification of vessel based on SHOM historical database and actual locations of the shipwrecks

7.4.6 UXO risk

Two of the shipwrecks were sunk by German mines dropped during the First World War. This observation shows that UXO risk is not null across the OWF site and shall be carefully considered prior to any site survey and before installation operations.

6-alpha Associates UXO threat and risk assessment report (6-alpha, 2023) describes the OWF sites as having a low UXO risk. It is recommended to follow 6-alpha (2023) mitigation recommendations and perform recommended additional studies prior to any future site investigation and offshore operations. UXO risks should in any case be reduced to As Low As Reasonably Possible (ALARP) through specific geophysical surveying (magnetometer and seafloor imaging) across reduced areas around planned future geotechnical location or foundation/anchor location.

8. Recommendations

8.1 Main Integrated Ground Model Uncertainties

As stated in the site conditions and in the geohazards and soil constraints inventory, a high lateral and vertical variability was observed at boreholes (ground types and/or geotechnical sub-units) and on 2D UHRS data (seismostratigraphic units and/or geotechnical units) and is therefore expected across the OWF site.

The soil profiles (Figure 6.1) and soil province map (Figure 6.2) provide a high-level control on expected geotechnical units and their thickness and was designed to help decision making between main foundation or anchor solutions. It mainly differentiates between areas with varying sediment thickness, areas where geotechnical units (associated to seismostratigraphic units) are present or absent, and areas of identified soil constraints such as faults and karsts (identified as geotechnical units VI and VII).

Some geotechnical units are then divided into sub-units (such as Unit V, including 5 sub-units) consisting of different rock types and soils. These sub-units could not be correlated based on available data due to:

- High lateral and vertical variability compared to data density;
- Poor 2D UHRS data penetration in carbonates.

Each sub-unit is associated to a set of geotechnical parameters derived to the observed depth range of the sub-unit on geotechnical data.

Other uncertainties were highlighted along the report sections. They are listed along with possible mitigations in Section 7.2.

8.2 Recommendations for Future Geotechnical Surveys

8.2.1 Second Reconnaissance Survey

Based on CFMS (2020), and with respect to observed and expected variable ground conditions at the OWF site which covers an area of 432 km^2, Fugro recommends that once reduced development areas are selected (based on the present integrated ground model and any other parameters and constraints, e.g. operational or financial), another set of geotechnical locations should be performed to improve the ground model.

The number of locations shall correspond to at least 10% of the number of wind turbines planned to be installed in case. This number is a lower bound considering expected variability. Selecting locations should be performed by some who is aware of the future requirements for integration across the site.

The purpose of the additional reconnaissance survey is to reduce uncertainties (in particular uncertainties related to variable ground conditions discussed in Section 8.1) across a reduced development site and therefore improve and update the present IGM. In order to do so, it is highly recommended to perform at least one borehole including P-wave velocity logging (using wireline tools). This will allow to improve the time to depth conversion of seismic through direct seismic to borehole tie and would therefore improve correlations of ground types between boreholes (through the definition of new seismostratigraphic units).

8.2.2 Detailed Geotechnical Survey

CFMS (2020) and OSIG (2022) recommends a detailed geotechnical survey to be performed prior to final design and dimensioning of foundations. The main objective of this detailed geotechnical survey is to define a geotechnical parameters profile applicable for each wind turbine. To do so it is required to perform at least one representative borehole at each future wind turbine location, regardless of the considered foundation type.

However, this number may be reduced in case it was demonstrated that the development site is homogeneous enough to interpolate geotechnical parameters in-between locations. Based on the present study, the observed and expected variability of ground conditions is very high, in particular with respect to:

- Geotechnical sub-units across the OWF site;
- Geotechnical parameters within individual units.

For more details on the number of locations and methods to be applied per foundation solution, please consult Table 5.11 of CFMS (2020).

8.2.3 Recommendations on Drilling Techniques

Based on Fugro's experience on this geotechnical SI, it is recommended to re-assess and decide the drilling technique depending on the investigation scope. For all locations where thick sedimentary layers have been identified, they could be performed using two separate drilling tools:

- API mode to characterize sediments;
- Piggy-back mode to characterize rocks;

This is in particular relevant for OWF2 site where thicker sedimentary cover was observed and is predicted based on the IGM.

These could be performed with two separate vessels or with one vessel during two legs to allow switching tools. This would improve efficiency of drilling, avoiding issues related to sediments being stuck in the drilling pipes. Sediment characterization should be performed first until refusal in API mode, and then a drill-out to base of sediments should be considered at the same location in piggy-back mode.

8.3 Recommendations On Detailed Geophysical Surveys

Based on CFMS (2020), detailed geophysical survey should be performed to complement preliminary reconnaissance data (presented and used in the present study). The main objectives are:

- provide more accurate data (bathymetry, seafloor morphology, obstructions) at the OWT locations;
- complement the existing seismic reflection data below the planned locations, with specific objectives of penetration and resolution;
- provide additional data using geophysical engineering methods (seismic refraction, surface waves, electrical resistivity, depending on objectives).

Table 8.1 presents recommended programme for detailed geophysical surveys as per CFMS (2020).

Table 8.1: Recommended programme of detailed geophysical survey (CFMS, 2020)

Objective	Method	Grid	Penetration	Notes
Seafloor topography	Multibeam bathymetry (MBES)	Coverage of each structure location with overlap of 100%	NA	Area covered depends on the type of structure to be installed
Seafloor morphology and obstructions	Side Scan Sonar (SSS)	Coverage of each structure location with overlap of 100%	NA	Area covered depends on the type of structure to be installed
Stratigraphy	Single or multi-trace seismic reflection Source: ▪ boomer or sparker for significant penetrations (1) ▪ chirp for small shallow penetrations	Two perpendicular lines for each structure	Depending on the type of foundation and on specific objectives	
Measurement of the velocity of compression waves Vp by seismic refraction	Refraction (dragged on the seafloor or static)	On structures locations: to be defined according to objectives. Cable route: continuous profile	5 m to 20 m depending on objectives. Cable route: 5 m	
Measurement of shear wave velocity Vs by surface waves	MASW	On structures locations: to be defined according to objectives.	5 m to 15 m depending on objectives.	

Notes:
Table modified from CFMS (2020)
NA Not applicable
(1) Sparker leads to better vertical resolution but lower penetration. Boomer leads to greater penetration and lower vertical resolution.

The 2D multichannel UHRS data (sparker source) typically provided good data to the top of the carbonate sequence but limited penetration below that. To improve penetration below the top of the carbonate sequence, a lower frequency source would likely be required. One option could be to acquire 2D multichannel UHRS using a boomer source rather than a sparker source, as boomers can generate lower frequencies than sparkers. Another option could be to use a mini-airgun source in either a single channel or multichannel configuration. It is considered that these alternative systems, if used, should be trialled along a small number of lines and should be additional to, rather than a replacement for, the 2D multichannel UHRS data (sparker source).

8.4 General Recommendations on Foundation Pile Design and Installation for Future OWTs

8.4.1 General

It is understood that a piled foundation/anchor solution is the preferred option for the future offshore wind turbines (OWT) and offshore substations (OSS) at the AO7 site.

The feasibility of a pile foundation tends to depend upon the installation with the two main methods being:

- Driven Piles; and
- Drilled and Grouted Piles.

Driven piles tend to be more prevalent in the offshore industry on account of their generally easier and more rapid installation, however, are typically only feasible in clays, sands and weak rock formations (UCS<5 MPa). It is additionally noted that in areas with weakly cemented carbonates (i.e. calcarenites), carbonate sandy material and low plasticity silts, driving may be feasible but mobilizable frictions can be very low and there exists the risk of pile damage due to highly cemented nodules. In rocks with a uniaxial compressive strength (UCS) above 5 MPa, the driving process becomes difficult with a high risk of premature refusal and/or pile buckling. Additional details are provided in Section 8.4.2.

In competent rock, a drilled and grouted pile represents the traditional solution. In general terms, this consists in drilling an oversized hole; installing a steel tubular casing into the hole and grouting the annulus between the rock and the steel wall. Installing piles by drilling and grouting is typically more expensive and time consuming than driving. Additional details are provided in Section 8.4.3.

It is noted that this Section 8.4 represents a feasibility, general screening of piled foundation solutions only. Alternative foundation/anchoring solutions may be possible and are recommended to be explored in a separate scope, particularly as contingency should piled solutions prove challenging due to local ground conditions (i.e., considering the local state of rock weathering). Such verifications and uncertainties on the pile feasibility (discussed in the following sections) are anticipated to be better defined in future project stages following planned detailed geotechnical site investigations (on limited areas). Regarding gravity-based structure (GBS) solutions, there is no explicit geotechnical reasoning for exclusion as a potential solution at the AO7 site (noting the generally sandy/rocky seabed), however additional considerations such as the Bay of Biscay Metocean conditions, water depth and operational costs and challenges should be carefully considered for a holistic comparison.

8.4.2 Driven Pile Feasibility

The following Sections discuss the feasibility of driven piles within the anticipated soil units of the AO7 OWF1 and OWF2 sites.

8.4.2.1 Sand deposits

Soil Unit SU1 (Geotechnical Unit II) and Soil Unit SU2 (Geotechnical Unit III) are expected to comprise very loose to very dense SAND. Pile driving is considered a generally routine process in such material.

It is important to note that depending upon the metocean conditions, SAND deposits are susceptible to seabed scour which is detrimental to the foundation capacity (particularly the lateral capacity) and should be considered in any future engineering assessments.

8.4.2.2 Weak and Competent Rocks

The driving feasibility in cemented rock units including Calcarenite, Calcisiltite, Calcilutite, Claystone, Mudstone, Siltstone and Sandstone of the AO7 units SU3 (Geotechnical Unit IV) and SU4 (Geotechnical Unit V) depend on their rock strength.

Pile driving is typically feasible in cemented sands or weak rock formations (UCS<5.0 MPa) (Puech et al., 1990). During an installation scenario in weak rock, the rock in the vicinity of the pile tip becomes heavily fractured and may form a cohesionless annulus of material along the pile shaft which may be likened to a sand in regard to the pile response under axial loading.

In rocks with an Uniaxial compressive strength (UCS) above 5 MPa, the driving process is generally considered unfeasible. This is due to a number of reasons including but not limited to:

- likely early driving refusal from a high Soil Resistance to Driving (SRD);
- slow rates of penetration factoring into high installation timings and therefore cost; and
- high risks of pile damage.

At the AO7 OWF1 and OWF2 sites, the measured UCS can be in excess of 5 MPa, for example within GT9 where there are a considerable number of recordings up to order of 40 MPa. This is generally considered to preclude the use of a driven pile at this site due to the very high risk of pile damage and early refusal. Bespoke, detailed studies investigating pile damage during installation would be necessary should a driven pile solution be pursued.

In some units, for example GT9, where a lot of data was acquired, a wide range in UCS values was observed, indicating a wide range in weathering of the rock. It is therefore difficult to adequately quantify the strength of the rock on a unit basis and requires location specific data. The presence of glauconites will increase the variability between weak and competent rocks through variable levels of weathering of the rock mass. This will also amplify uncertainty and possible driving or capacity issues.

8.4.2.3 Carbonate Sand and Cemented Carbonates

All SAND units in AO7 are described as calcareous, whilst CALCARENITE is identified in SU3 and SU4.

Uncemented or weakly cemented carbonate sands require a separate consideration of their engineering response (as compared to non-carbonate sands) since large strain shearing in carbonates tends to either crush (coarse grained) or remould (fine-grained) the material (ARGEMA, 1992; Watson et al. 2019), resulting in potentially very low mobilised shaft frictions (order of 5 - 20 kPa; CFMS (2020)).

Additionally, cyclic loads applied during dynamic pile driving may liquefy the surrounding soils, further reducing the available shaft friction. This can lead to a risk of uncontrolled pile penetration during installation termed 'pile runs' or 'free-falls' (Watson et al. 2019).

Use of driven piles in carbonate sands is often limited to cases where loads are compressive and a hard bearing layer exists, with pile embedments tending to be quite large. Skin frictions tend to be too low to support tensile, uplift loading. Crucial soils data (including the carbonate content and the carbonate compressibility index) can indicate the degree to which pile skin friction may deteriorate - there is a distinction in behaviour between 'calcareous' sand and 'carbonate' sand.

Calcarenite is considered to be analogous to carbonate sand with a high to very high degree of cementation (CFMS, 2020).

Driving through cemented carbonate layers can lead to installation difficulties as the degree of cementation can be highly variable. There exist risks of:

- early refusal on localised hard layers;
- pile tip damage;
- uncontrolled pile runs due to punch-through of a cemented layer and subsequent low end bearing and shaft friction (Watson et al. 2019); and
- while a pile may pass through a hard layer, there still exists a risk of 'extrusion buckling'.

Pile monitoring can be effectively used to aid in the optimisation of pile design in carbonate materials, although as indicated in Section 8.4.2.2, the high UCS (often in excess of 5 MPa) is considered to preclude the use of a driven pile at this site due to the very high risk of pile damage and early refusal, coupled with the potential for very low skin frictions.

8.4.2.4 Driven Piles Discussion

It is anticipated that outcropping or shallow rock will have a UCS that will likely prevent the deep installation of driven piles. Coupled with potentially low skin frictions from carbonate sands/low plasticity silts, it is the current opinion of Fugro that a driven pile solution is not the optimal solution for taut or tension (uplift) loaded anchors or compressive loaded foundations where the rock horizon is shallower than about 10 to 15 pile diameters, noting that the lateral loading effects of a pile are generally confined to this region.

Thicker extents of cohesionless material more amenable to a driven pile installation are anticipated in SP1d and SP2d, although these will still suit primarily compressive loaded foundations or catenary loaded anchors due to the low anticipated pile skin friction.

SP1d may have a sufficient thickness of cohesionless sediment to support the lateral/catenary loading of pile anchors, though it is noted the extent of Soil Province SP1d is expected to be minimal (only 0.02% of the OWF site).

SP2d represents a significant proportion of the OWF site (19.5%), with a cohesionless sediment thickness expected to vary from about 20 m to 40 m BSF. Should a high carbonate content in the SAND and/or the plasticity of the Unit IIIa SILT prove low, then low skin frictions may not be suitable for tension or taut loaded anchors, and compressive foundations might require longer piles with end-bearing on underlying rock units. However, a driven pile solution within this province is generally expected to be feasible for compressive loaded foundations and catenary loaded anchors. The feasibility of tension or taut anchors will depend upon the magnitude of the loading.

8.4.3 Drilled and Grouted Pile Feasibility

Drilled and grouted piles are the traditional installation method used in competent rock.

Soil Provinces of outcropping rock include SP1a and SP3a (representing 8.4% and 0.9% of the total OWF area respectively). These provinces are expected to be good candidates for a drilled and grouted pile solution.

The soil units SU3 and SU4 (Geotechnical Unit IV and V respectively) indicate best estimate RQD values of 'fair to good' rock quality which are of low risk to hole instability. However, potential pockets of cohesionless sand within rock units (i.e. sub-unit Ve), and the possibility of weathered or heavily faulted/fractured rock can still pose a risk. It is recommended that these hole stability aspects be reviewed on a per foundation/anchor basis if pursuing a drilled and grouted solution.

The main challenge of a drilled and grouted pile in AO7 is in those remaining Soil Provinces (i.e. not outcropping rock) with an extent of surficial sand. A surficial cohesionless sand is less adapted to an installation procedure using an open shaft. It is possible to use drilling mud to aid in the shaft stability but most likely the detailed design and installation procedure would be more akin to a hybrid pile as follows:

- a driven or vibro-installed sacrificial casing through SU1 (Geotechnical Unit I and cohesionless Unit II) and SU2 from mudline to the rock horizon;
- drilling through and below this casing to the required depth for axial and lateral capacity;

- removal of cuttings from the shaft and cleaning of the sacrificial casing internal wall;
- insertion of a steel insert casing;
- grouting between the insert casing and drilled shaft wall (i.e. rock-grout interface) and between the sacrificial and insert casing in the upper pile region; and
- waiting a sufficient period of time for curing of the grout prior to the application of loads.

The sacrificial-insert casing combination in the upper pile region results in a composite pile section of much greater stiffness which is beneficial for resisting lateral loads.

Other than large extents of cohesionless units (SU1 and SU2) which may be better suited to a driven pile or require a sacrificial casing, and potential hole stability concerns (to be verified on a per foundation basis) there are no overt elements at the AO7 site which preclude the use of drilled and grouted piles.

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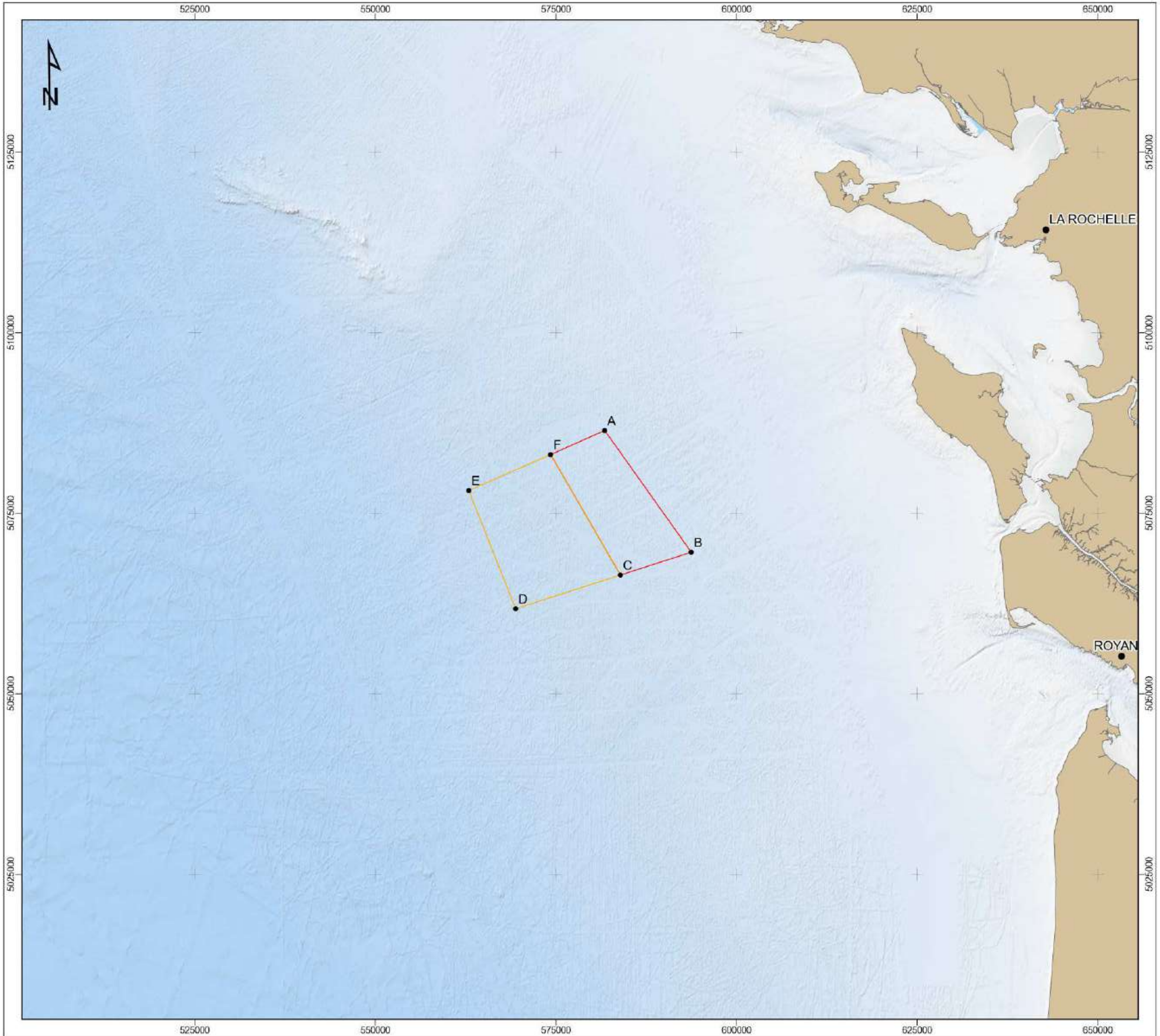
List of Plates



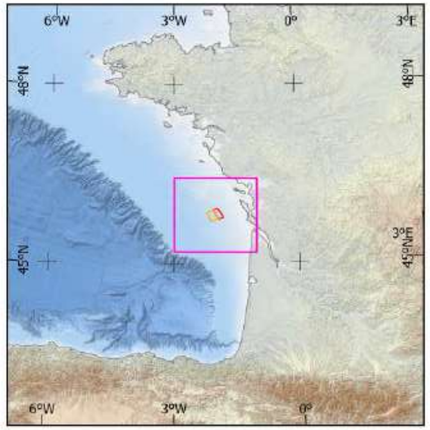
Legend

- City
- Land (SHOM)

OWF Sites

- OWF1
- OWF2

Notes:



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0 2.5 5 10 15 20 Miles

Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

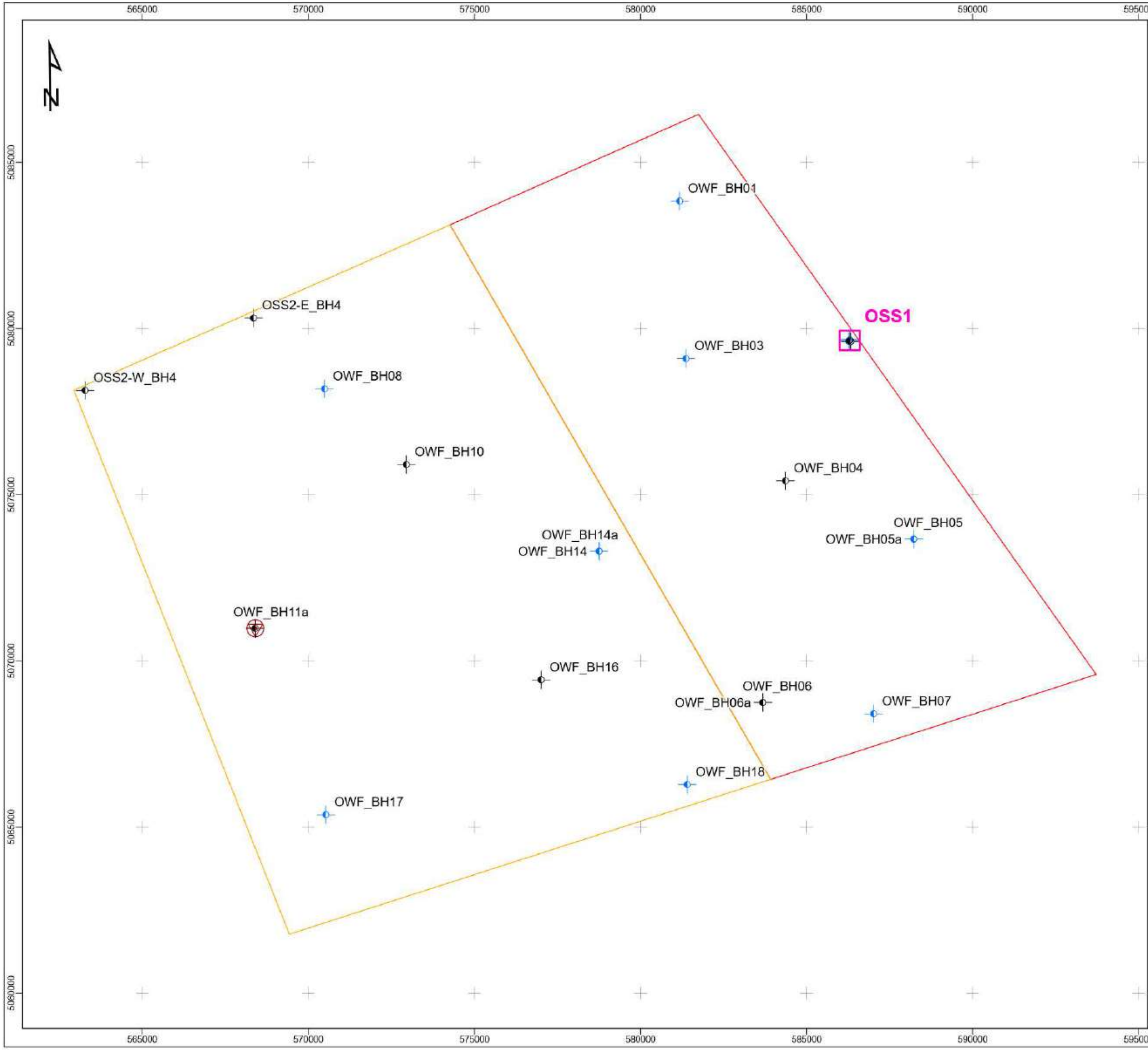
FUGRO

Title: **AO7 OWF Geotechnical SI**
Vicinity Map

Plate 1.1

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	GGB	JPI



Legend

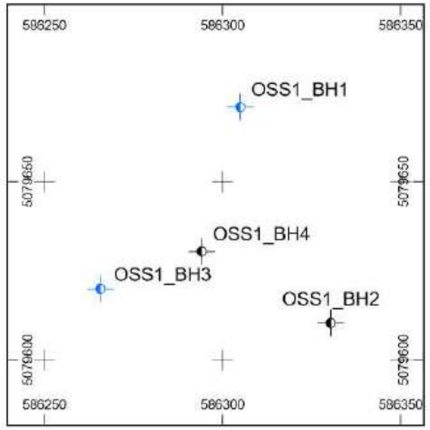
OWF Sites

- OWF1
- OWF2

Geotechnical Locations (Type)

- CPT
- CPT and Sampling
- Sampling

Notes:
Inset map shows a zoom on OSS1 locations



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0 0.5 1 2 3 4 Miles

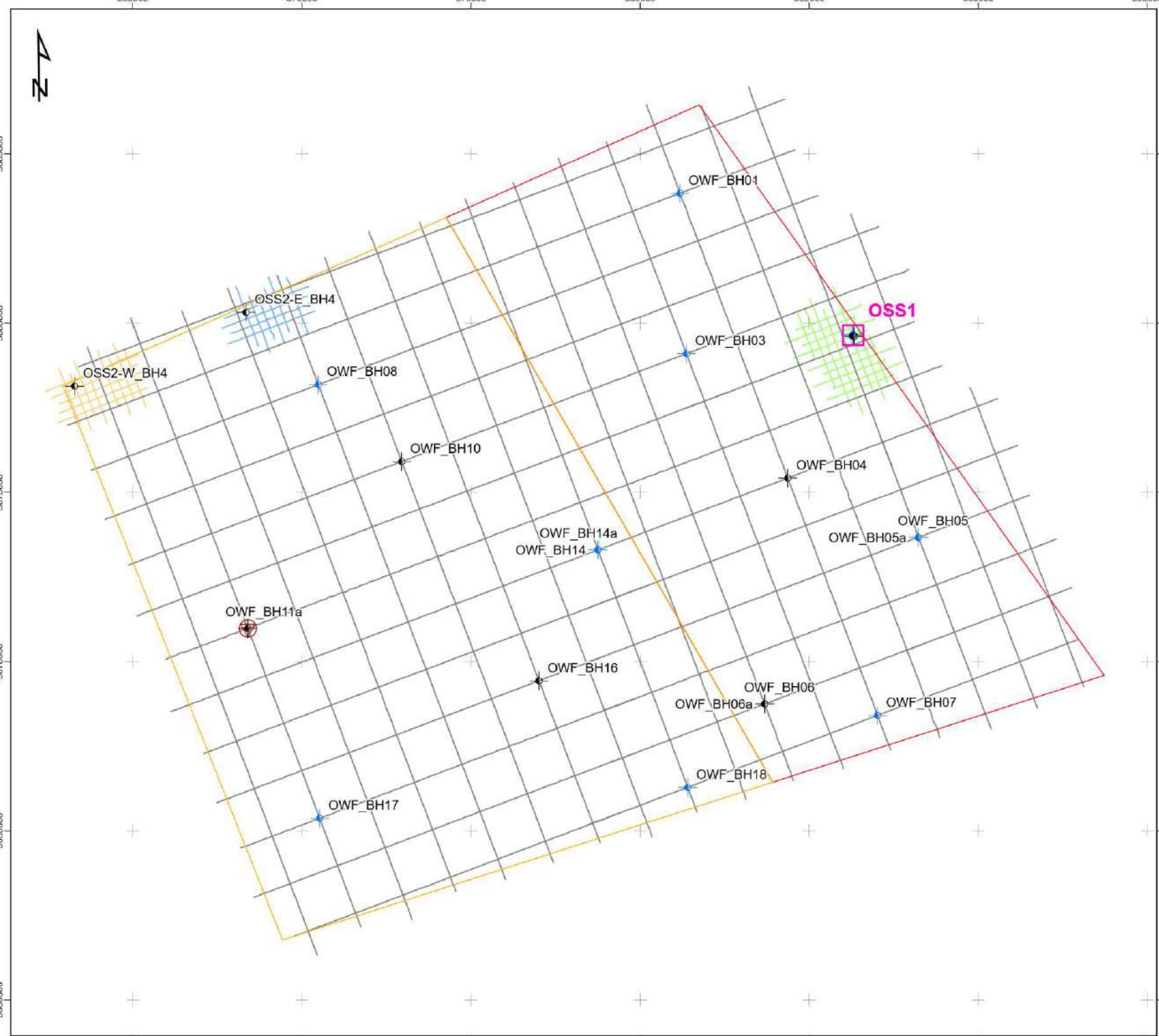
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

Title: AO7 OWF Geotechnical SI
Geotechnical Location Map

Plate 2.1

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



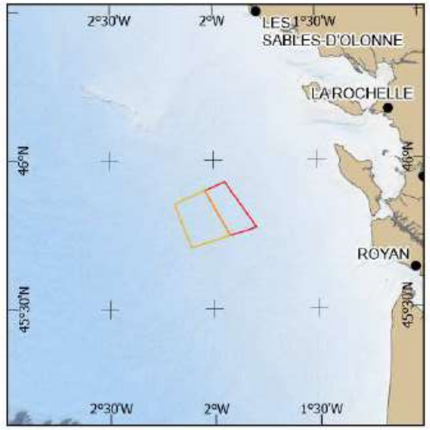
Legend

OWF Sites
- OWF1
- OWF2

Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

UHRS data (TECNOAMBIENTE)
- OSS1
- OSS2-E
- OSS2-W
- OWF

Notes:
2D UHRS data acquired by TECNOAMBIENTE and provided by DGEC for integration purpose



Coordinate System : WGS 1984 UTM 30N

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0 0.5 1 2 3 4 Miles

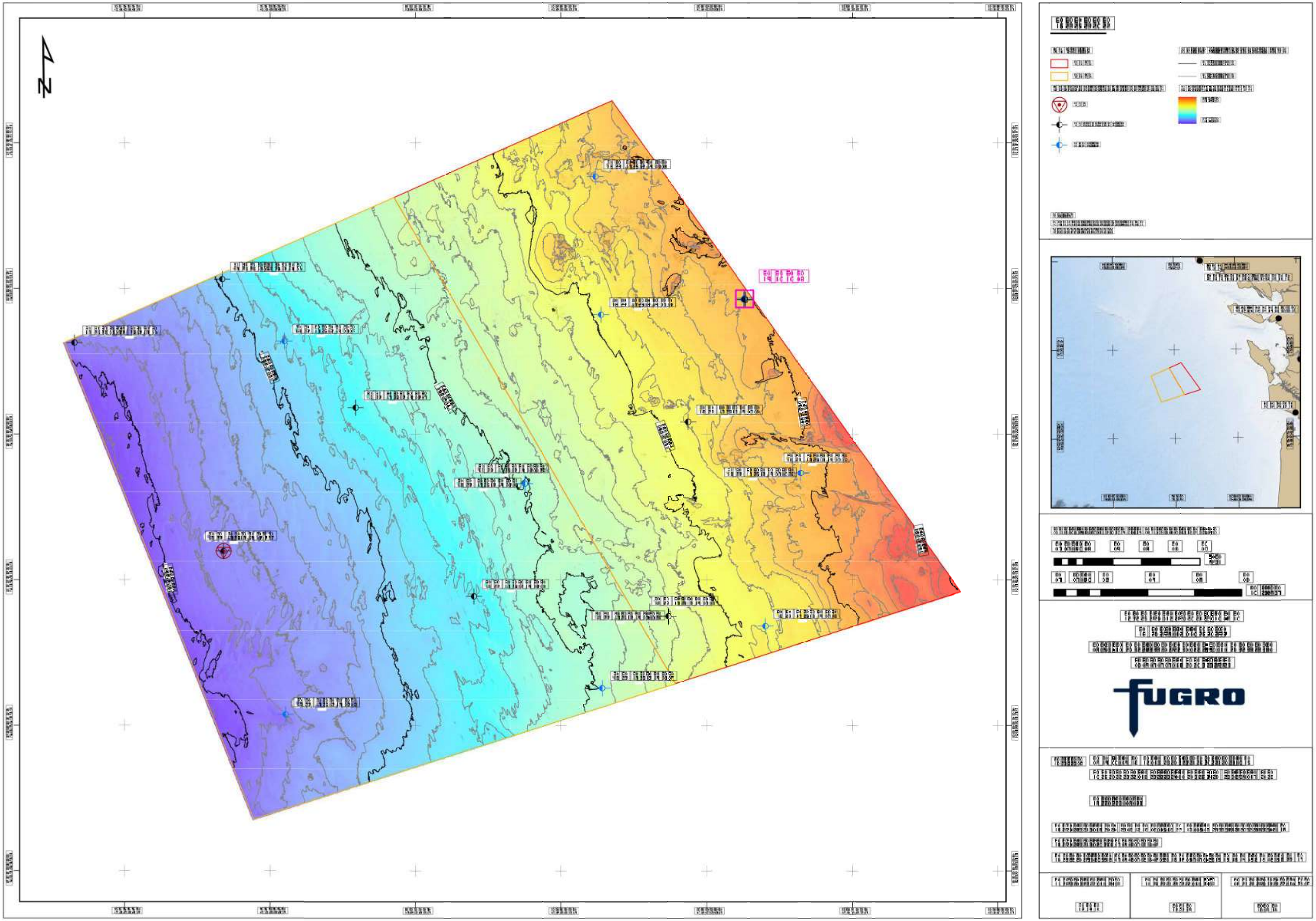
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

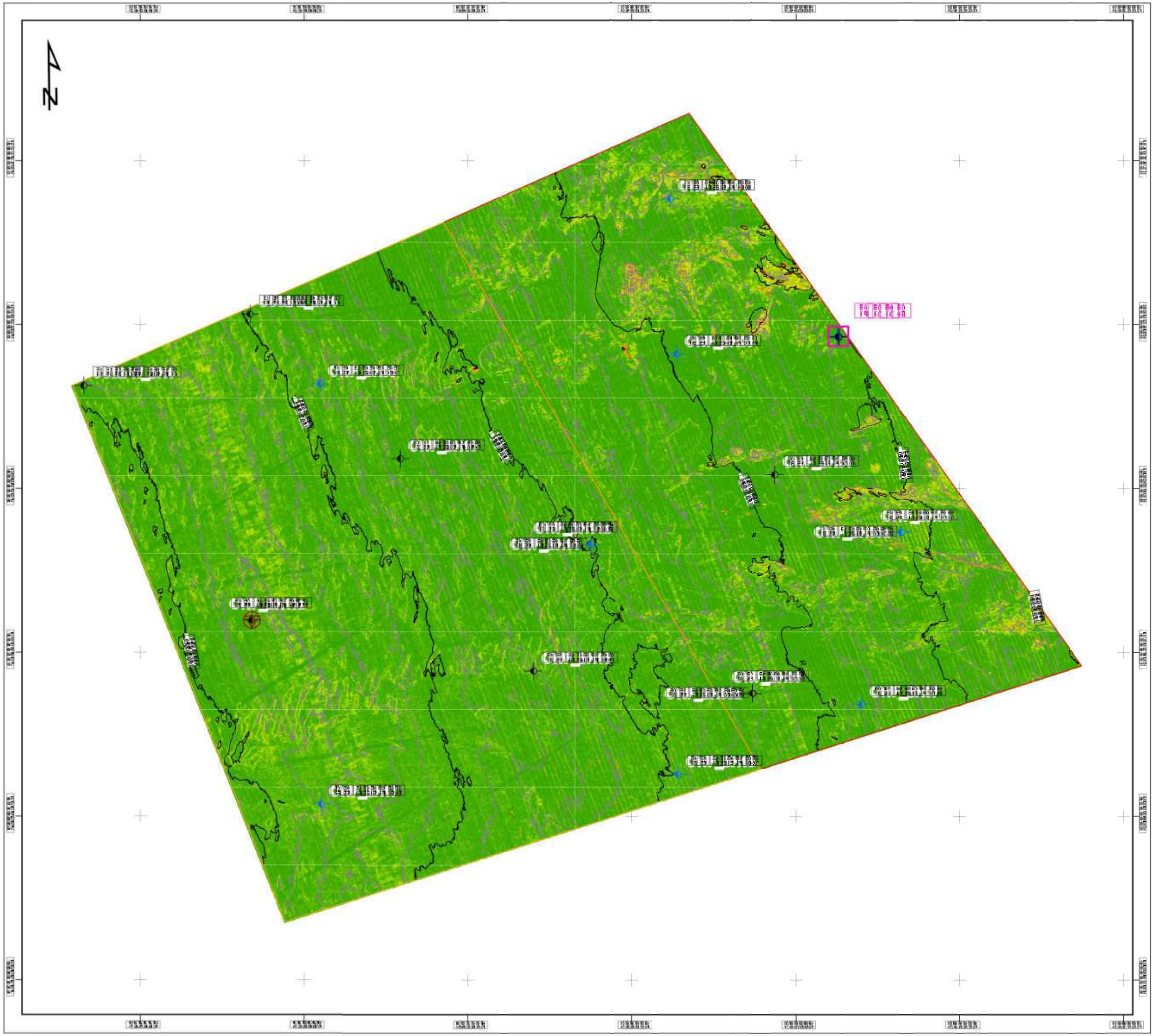
Title: **AO7 OWF Geotechnical SI**
2D UHRS Profiles Location Map

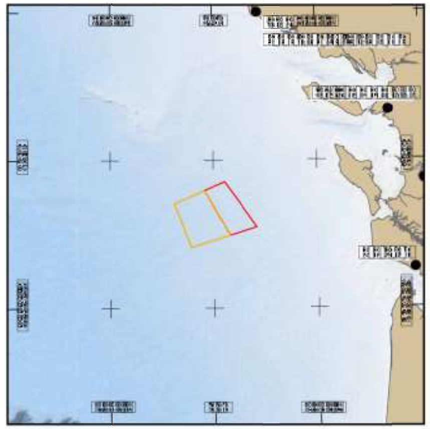
Plate 2.2

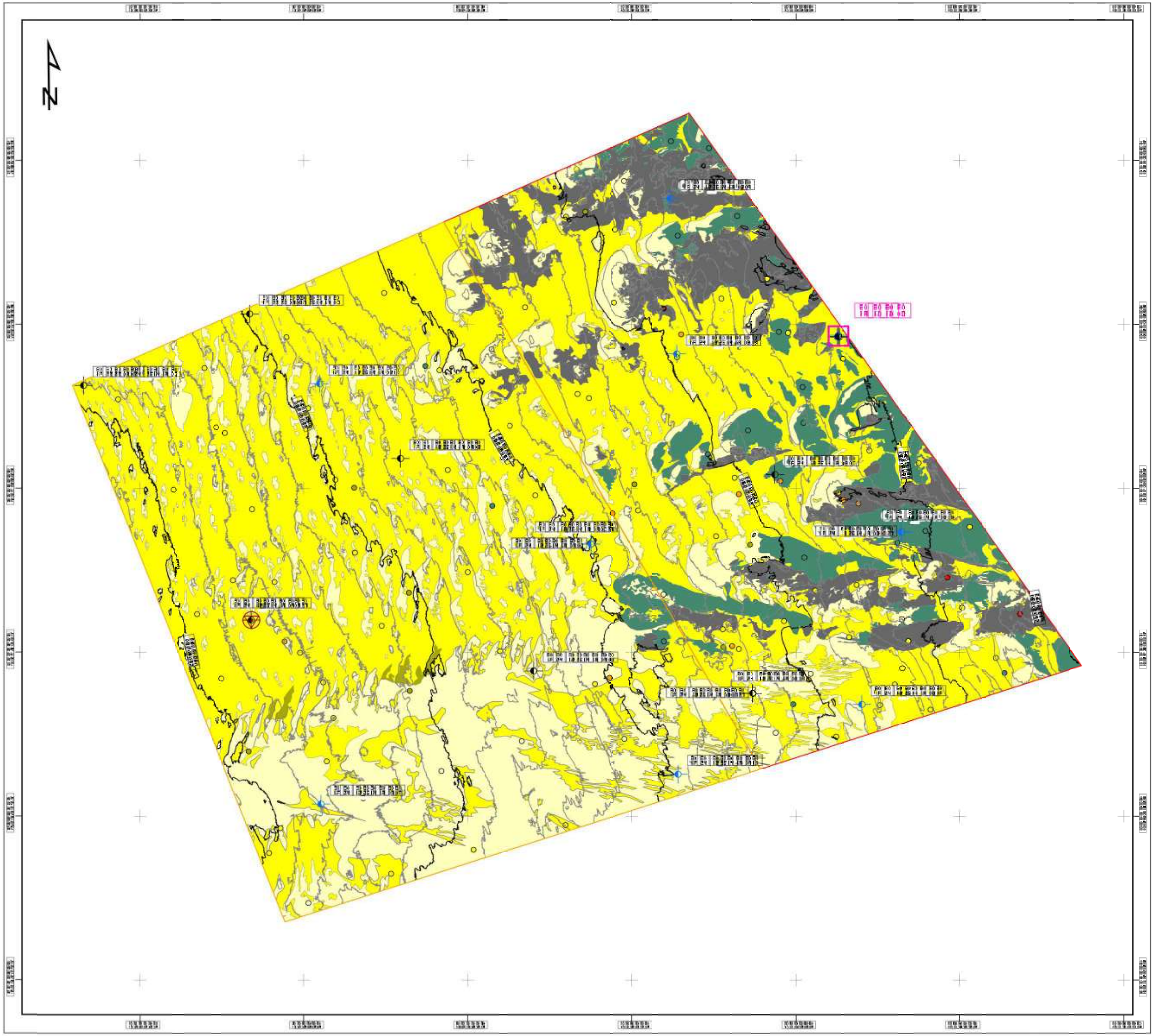
Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

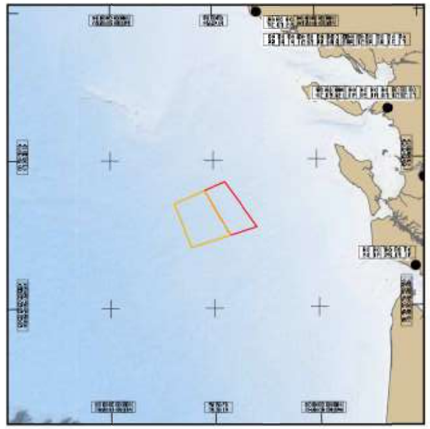
Created By:	Checked By:	Approved By:
ABL	ATH	LOL

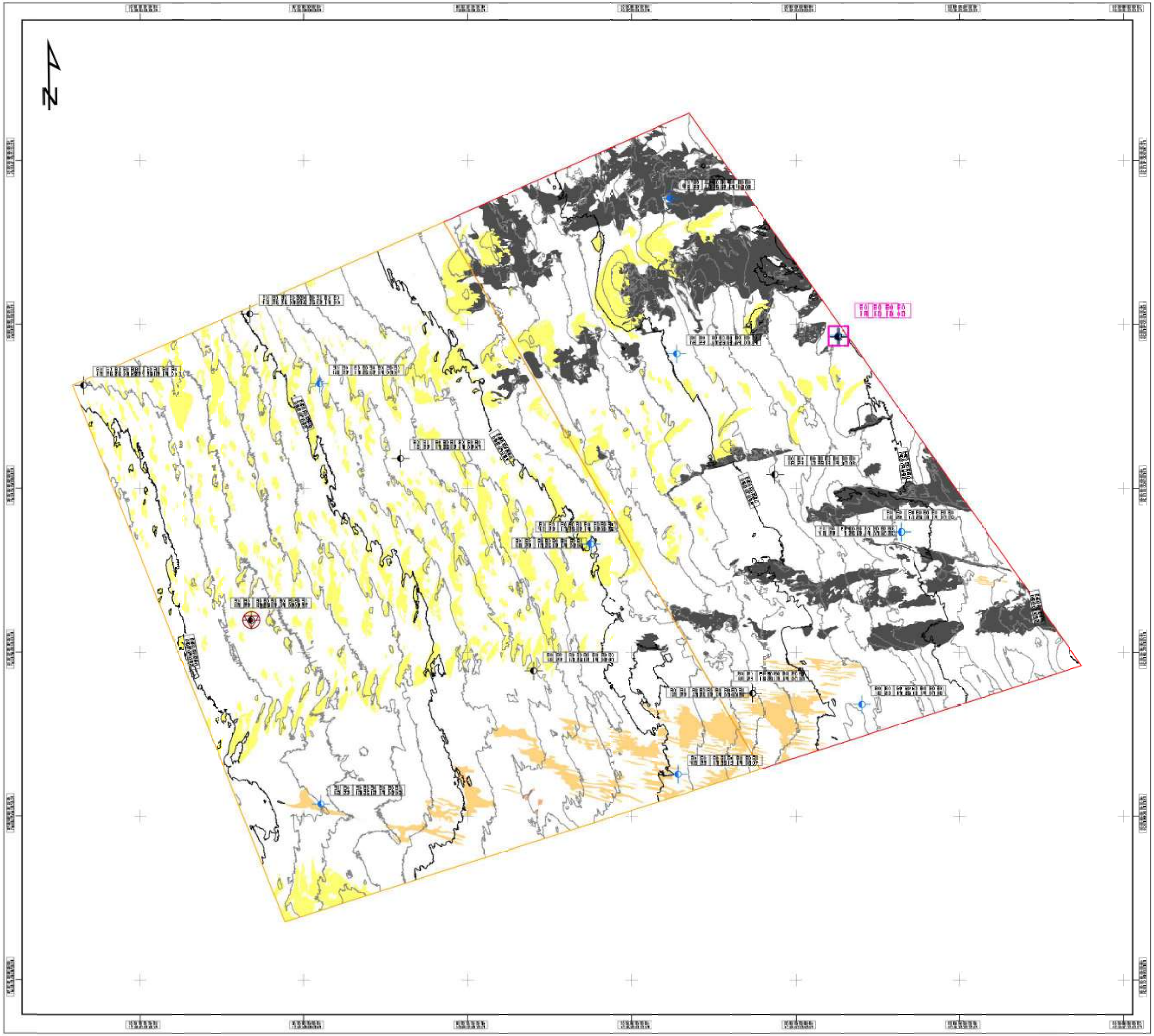


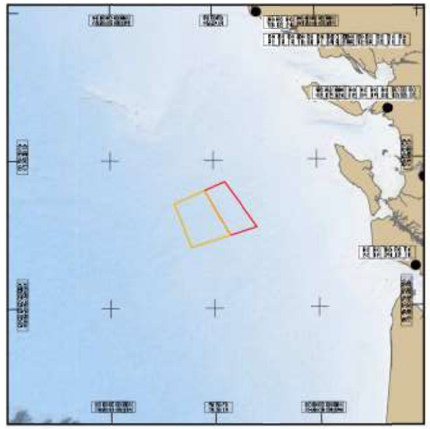


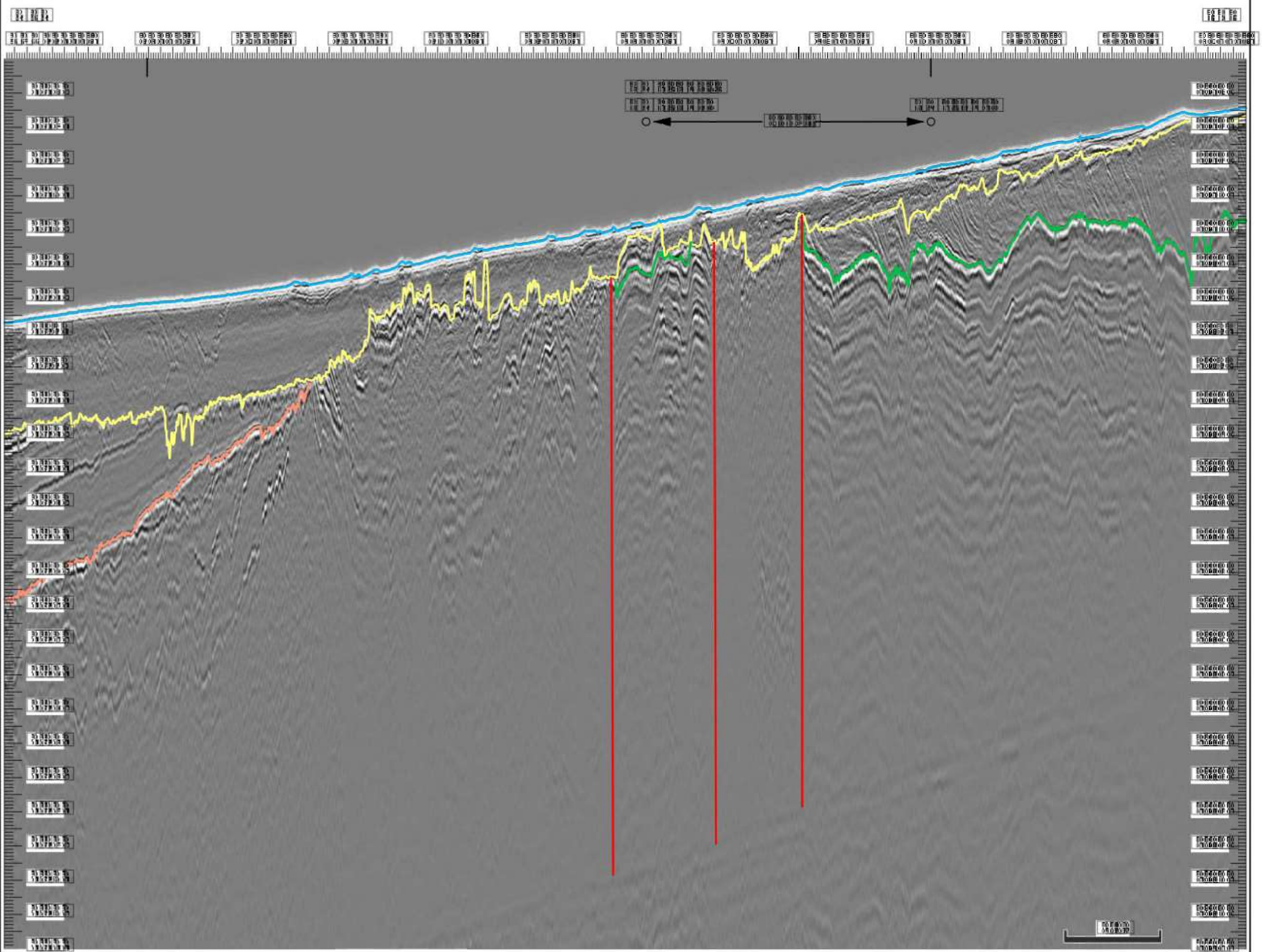


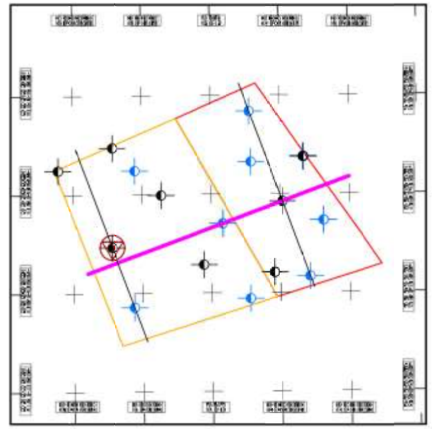


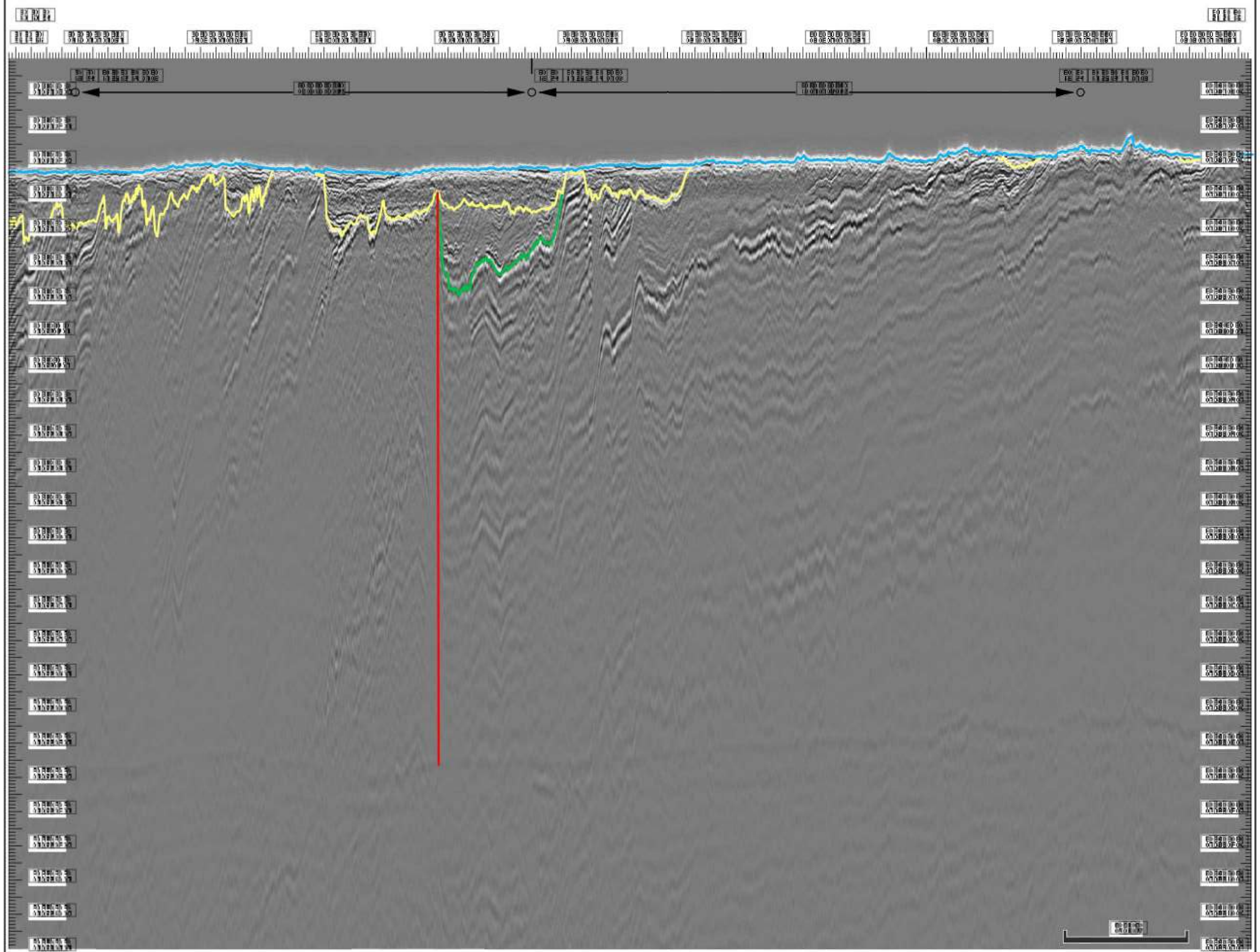


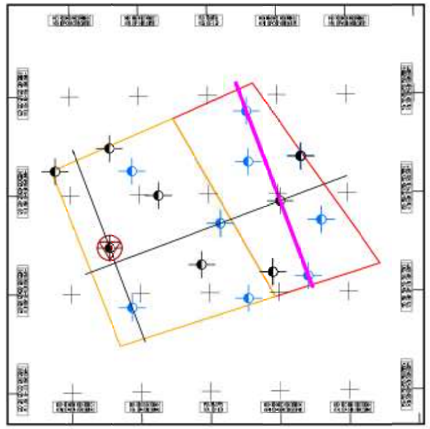


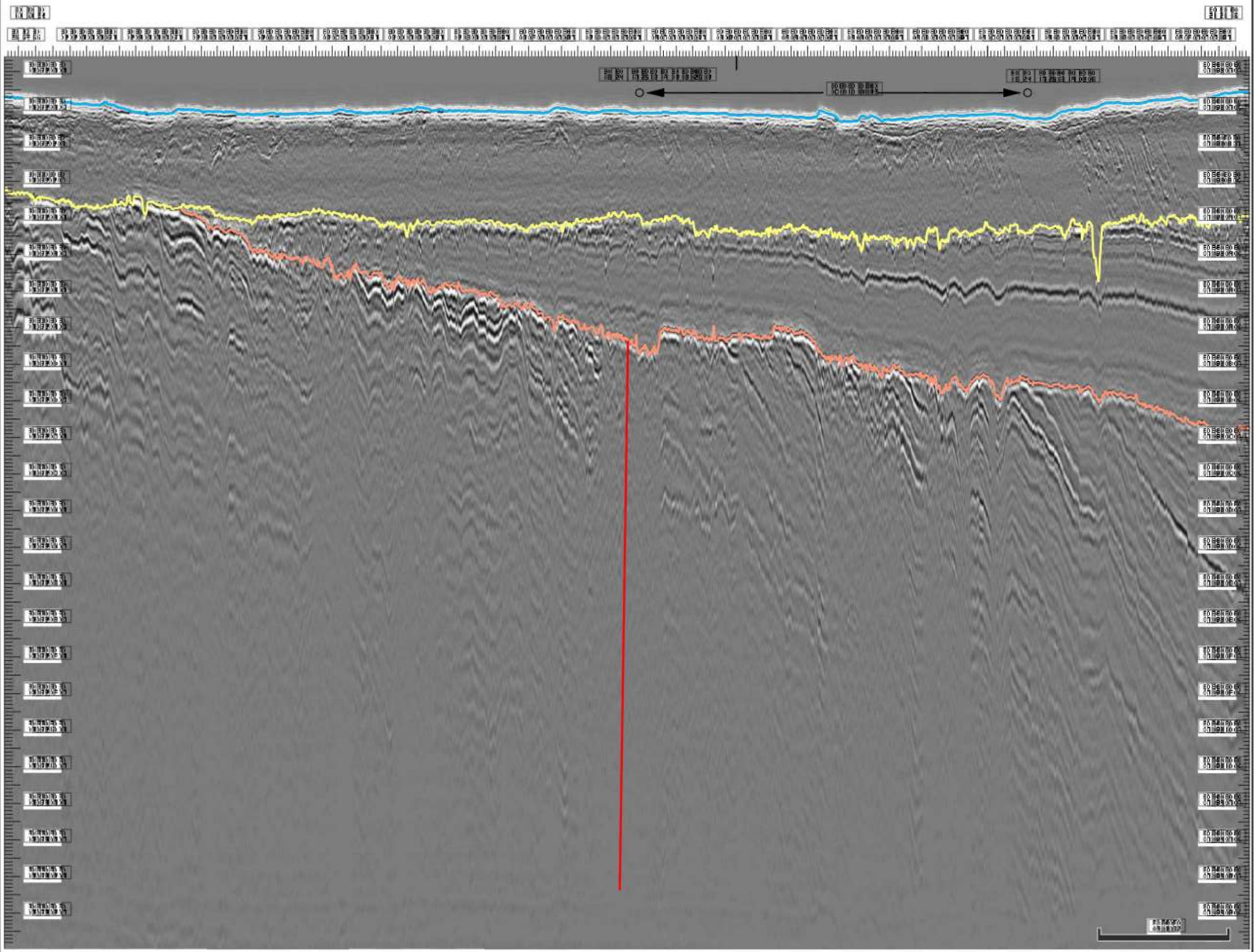


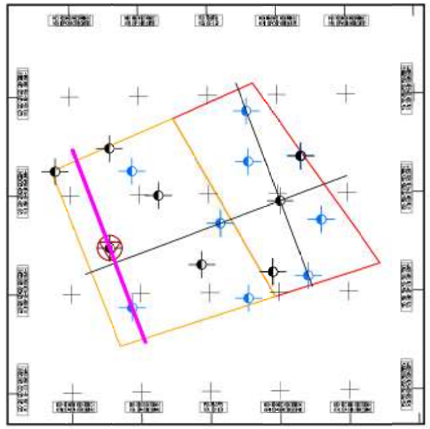


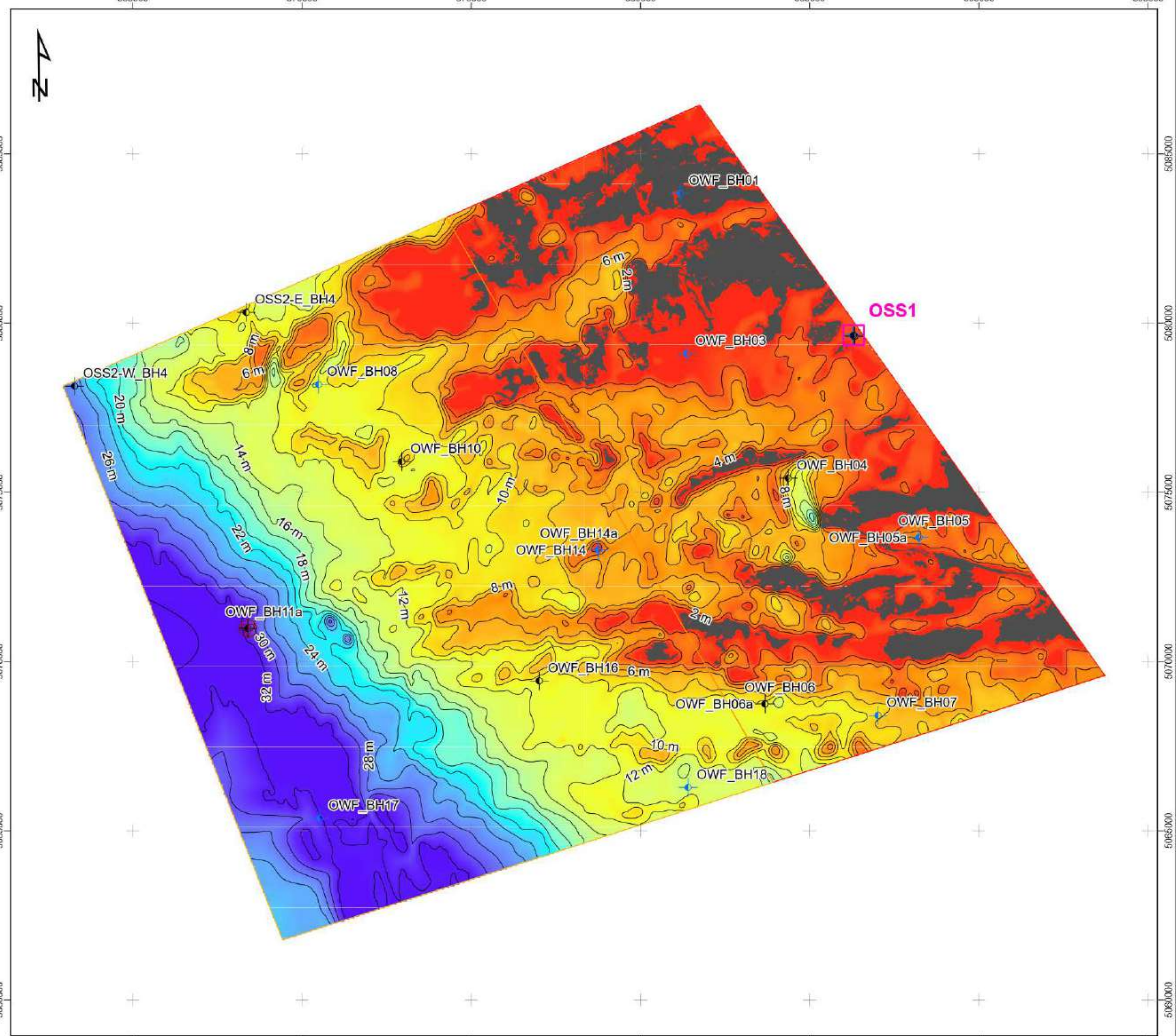












Legend

OWF Sites
- OWF1
- OWF2

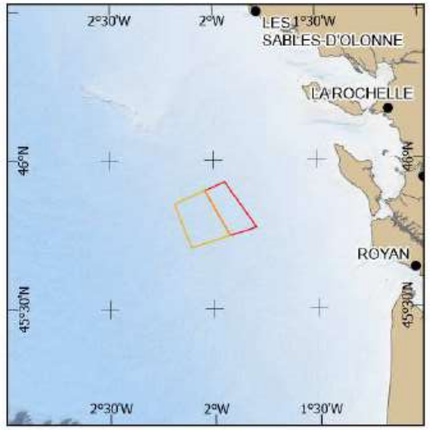
Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

Sediment cover isopach lines (m)

Seafloor features
- Outcrops

SHOM sediment thickness (m)
35
0

Notes:
Gridded map based on SHOM's interpretation of SBP data
Converted by Fugro using a velocity of 2100 m/s



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

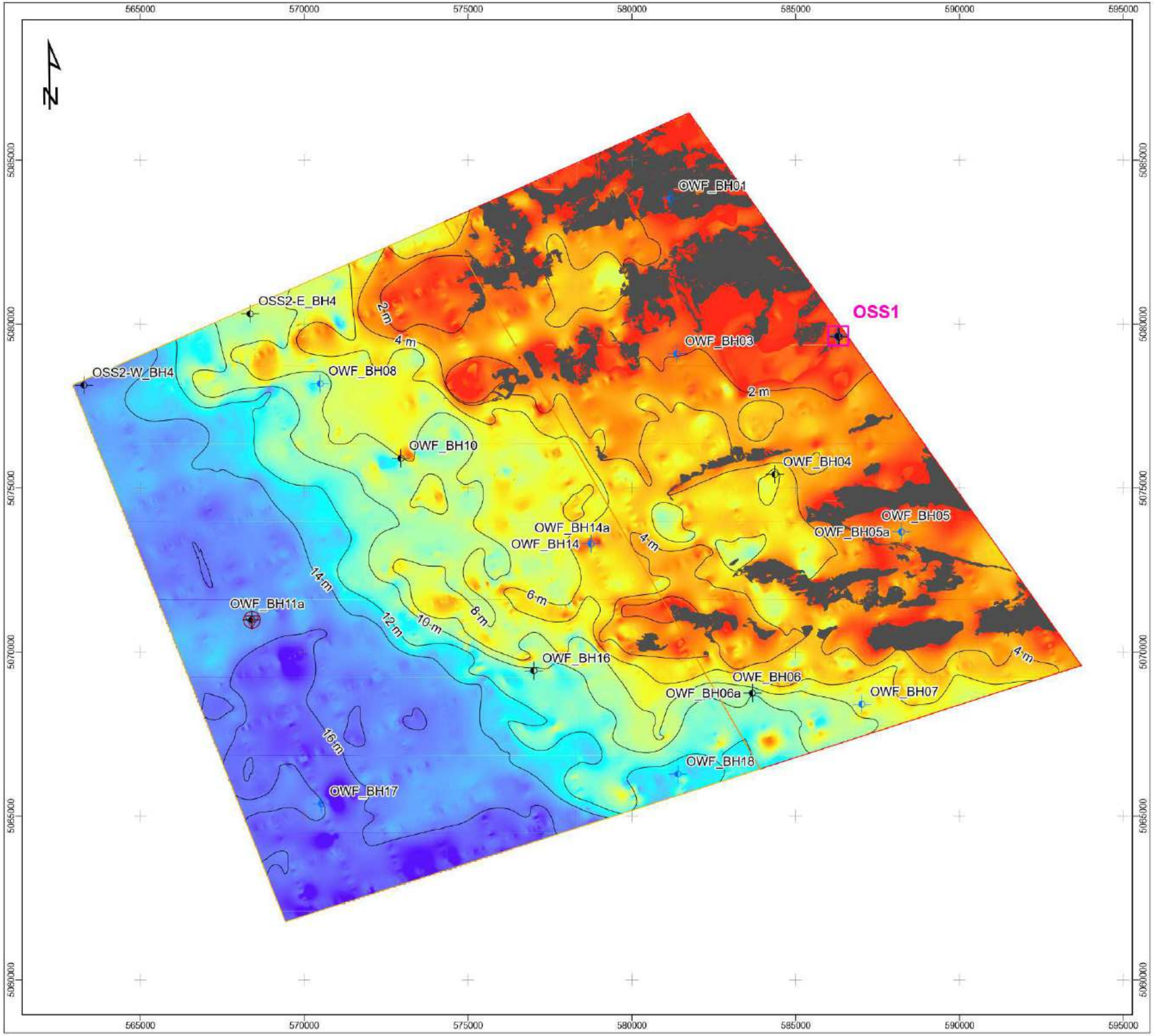
FUGRO

Title: AO7 OWF Geotechnical SI
Sediment Thickness Map (SHOM)

Plate 3.8

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



Legend

OWF Sites

- OWF1
- OWF2

Geotechnical Locations (Type)

- CPT
- CPT and Sampling
- Sampling

SU1 isopach lines (m)

Seafloor features

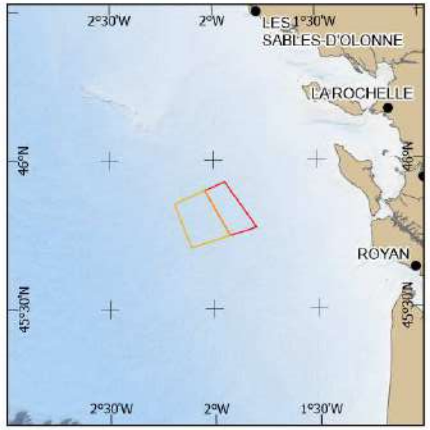
- Outcrops

SU1 thickness (m)

24

0

Notes:
Gridded map based on Fugro's interpretation of TECNOAMBIENTE 2D UHRS data (Plate 2.2)



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

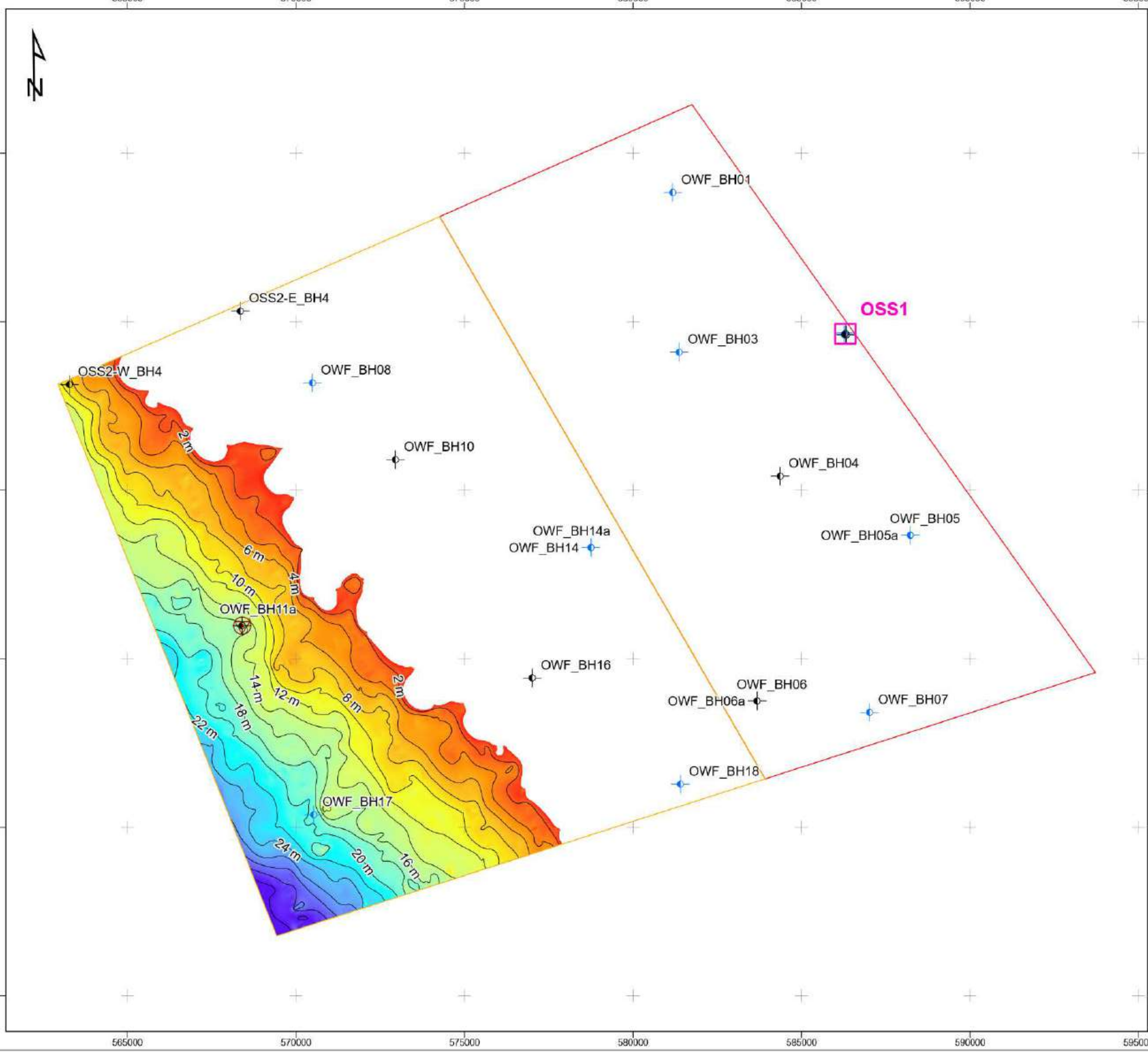
FUGRO

Title: AO7 OWF Geotechnical SI
SU1 Gridded Thickness Map (Fugro)

Plate 3.9

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



Legend

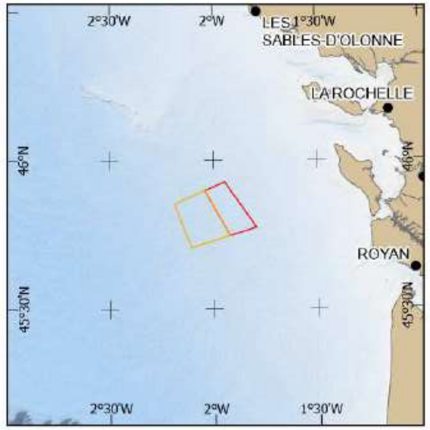
OWF Sites
- OWF1
- OWF2

Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

SU2 isopach lines (m)

SU2 thickness (m)
34
0

Notes:
Gridded map based on Fugro's interpretation of TECNOAMBIENTE 2D UHRS data (Plate 2.2)



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

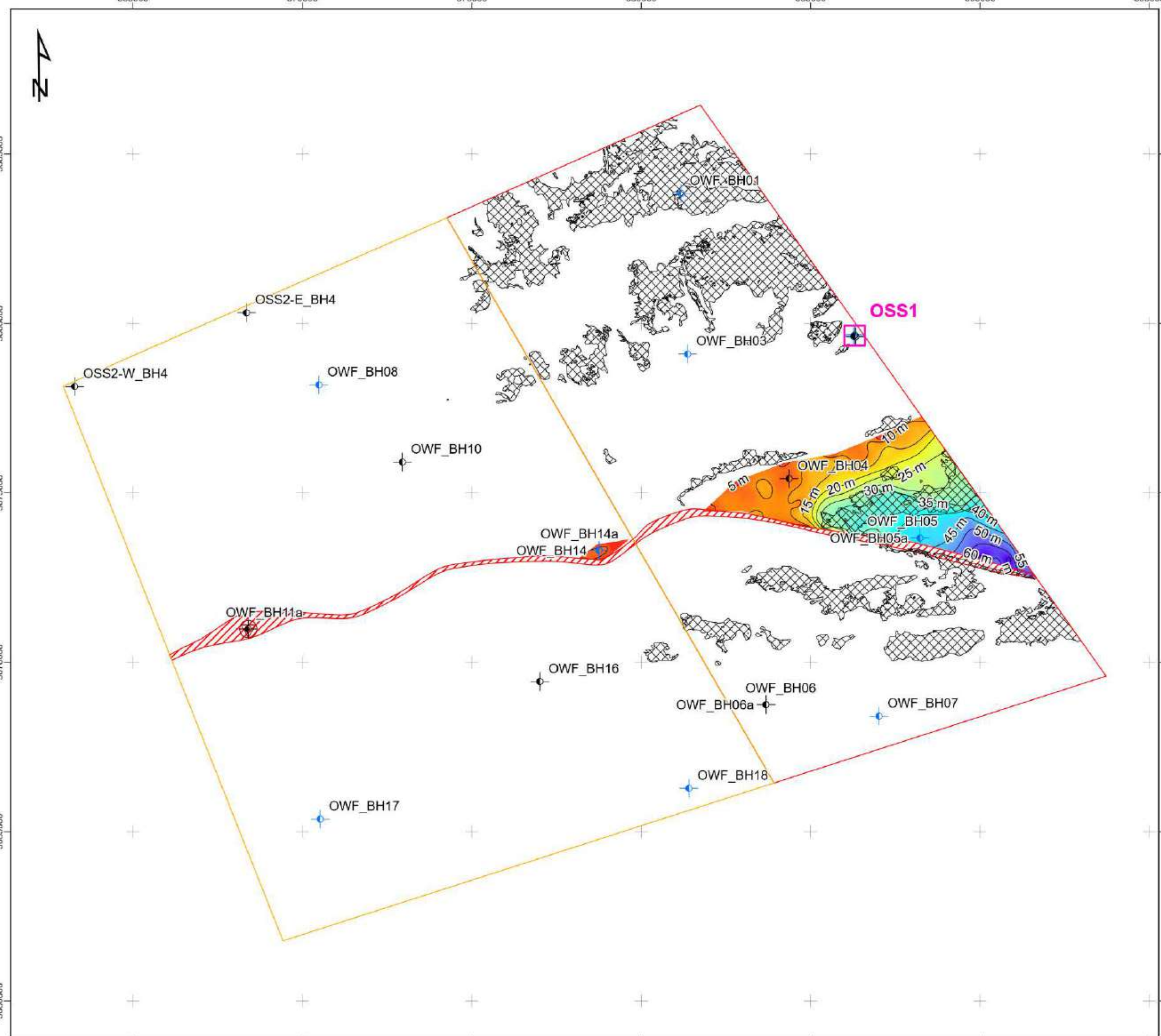
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

Title: **AO7 OWF Geotechnical SI**
SU2 Gridded Thickness Map (Fugro)

Plate 3.10

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



Legend

OWF Sites
- OWF1
- OWF2

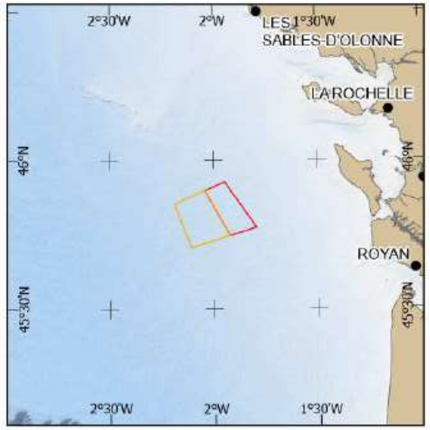
Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

SU3 isopach lines (m)

Geological features
- Outcrops
- Major fault footprint

SU3 thickness (m)
63
0

Notes:
Gridded map based on Fugro's interpretation of TECNOAMBIENTE 2D UHRS data (Plate 2.2)



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

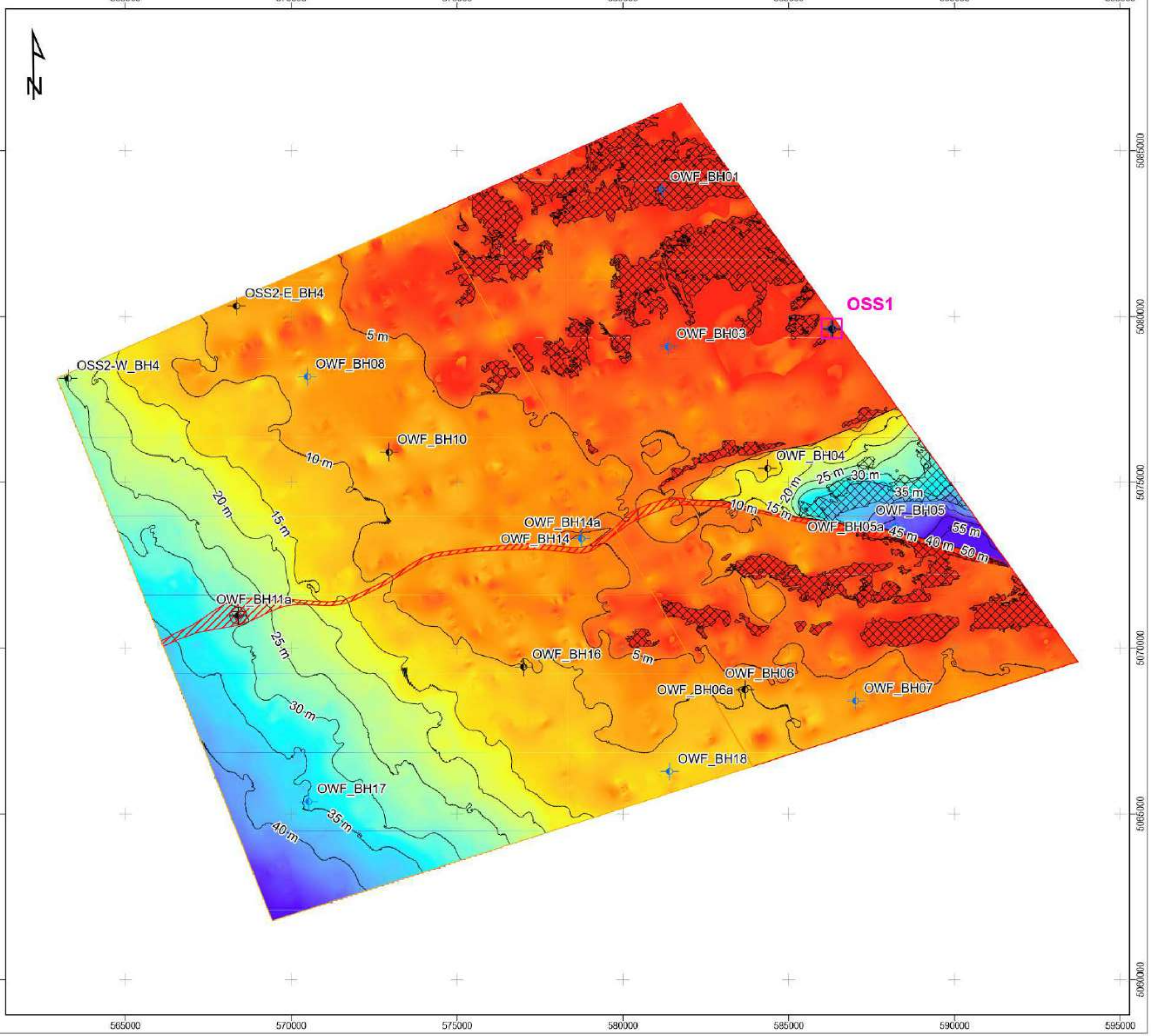
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

Title: AO7 OWF Geotechnical SI
SU3 Gridded Thickness Map (Fugro)

Plate 3.11

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



Legend

OWF Sites
- OWF1
- OWF2

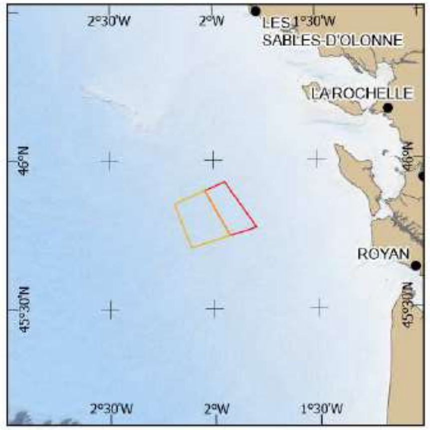
Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

— Top SU4 contours (m BSF)

Geological features
- Outcrops
- Major fault footprint

Top SU4 depth (m BSF)
- 68
- 0

Notes:
Gridded map based on Fugro's interpretation of TECNOAMBIENTE 2D UHRS data (Plate 2.2)



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

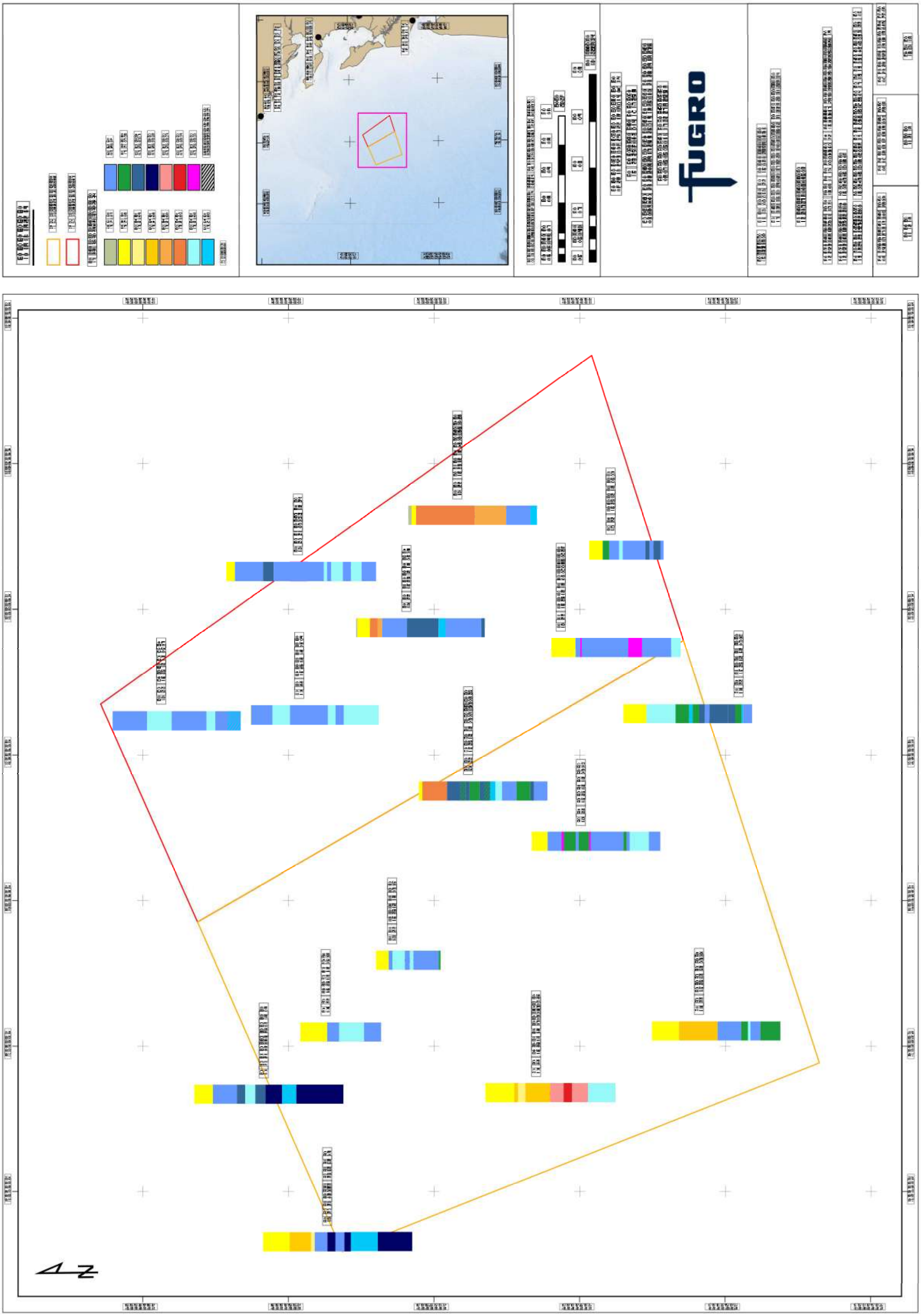
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

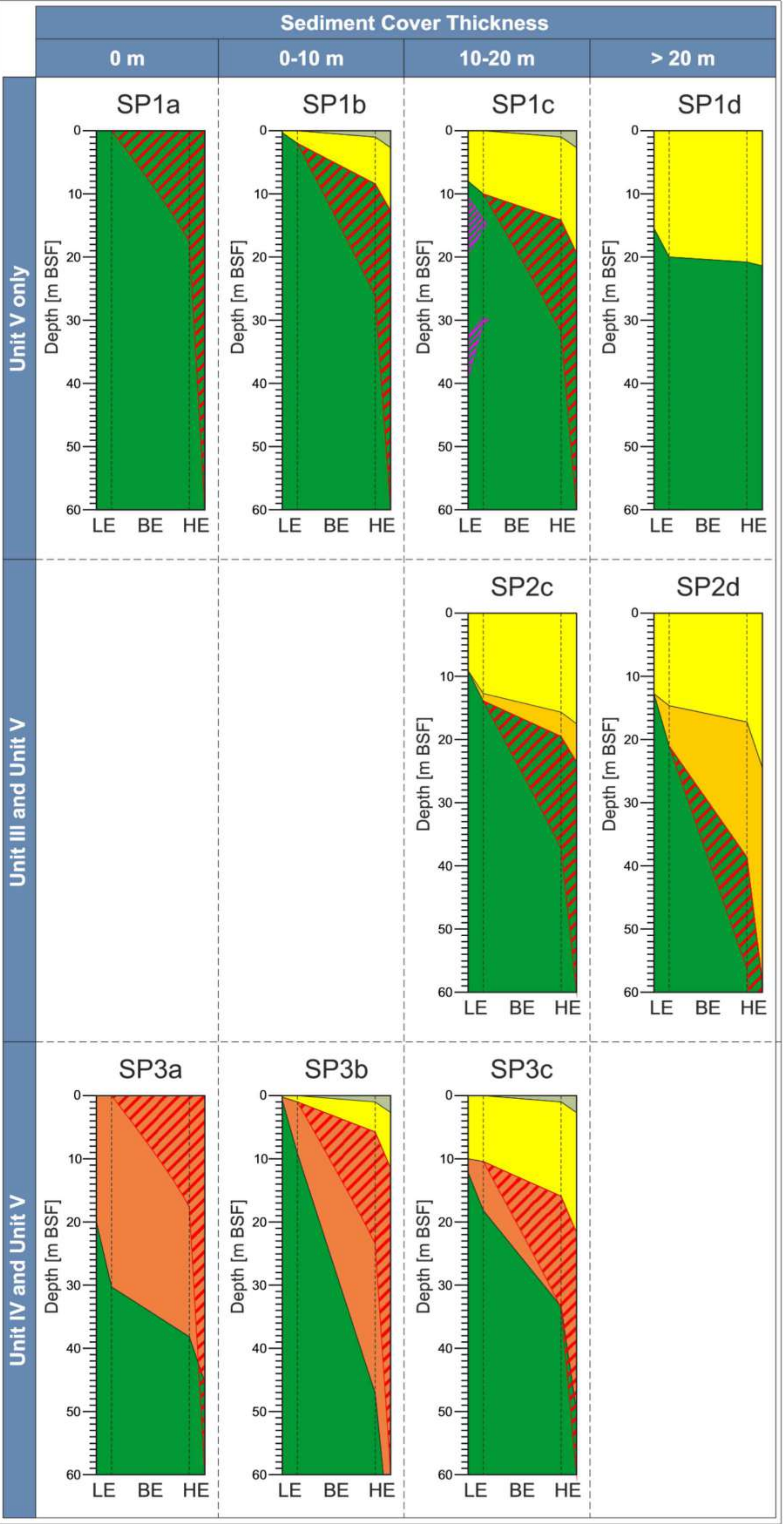
Title: **AO7 OWF Geotechnical SI**
Top SU4 Gridded Depth Map (Fugro)

Plate 3.12

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL





Legend

Map:

OWF Sites

- OWF1
- OWF2

Geotechnical Locations (Type)

- CPT
- CPT and Sampling
- Sampling

Soil provinces

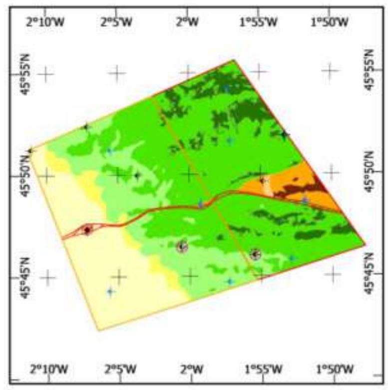
- SP1a
- SP1b
- SP1c
- SP1d
- SP2c
- SP2d
- SP3a
- SP3b
- SP3c
- Observed karsts buffer
- Major fault footprint

Profiles:

Geotechnical Units

- Unit I
- Unit II
- Unit III
- Unit IV
- Unit V
- Unit VI
- Unit VII

Notes:
LE: Low Estimate
BE: Best Estimate
HE: High Estimate
Thickness ranges statistically derived using geophysical mapping and borehole data. BE based on standard deviation.
Soil profile distribution displayed in soil province map (inset map below and Plate 4.2)
Geotechnical units VI and VII may occur on several soil profiles, where fault-related fractured/weathered strata is exepceted (unit VI) and where karsts deposits occurs (unit VII).
Thickness range of units VII and VI are derived from borehole observation.
Unit VI is expected along the major fault plane (see soil province map Plate 4.2 and inset map). Other minor faults may be associated with unit VII but could not be mapped absed on available data.
Unit VII is confirmed at two boreholes (OWF_BH06-06a and OWF_BH16) but may occur elsewhere. Buffer of 500 m around boreholes was considered as a conservative approach.



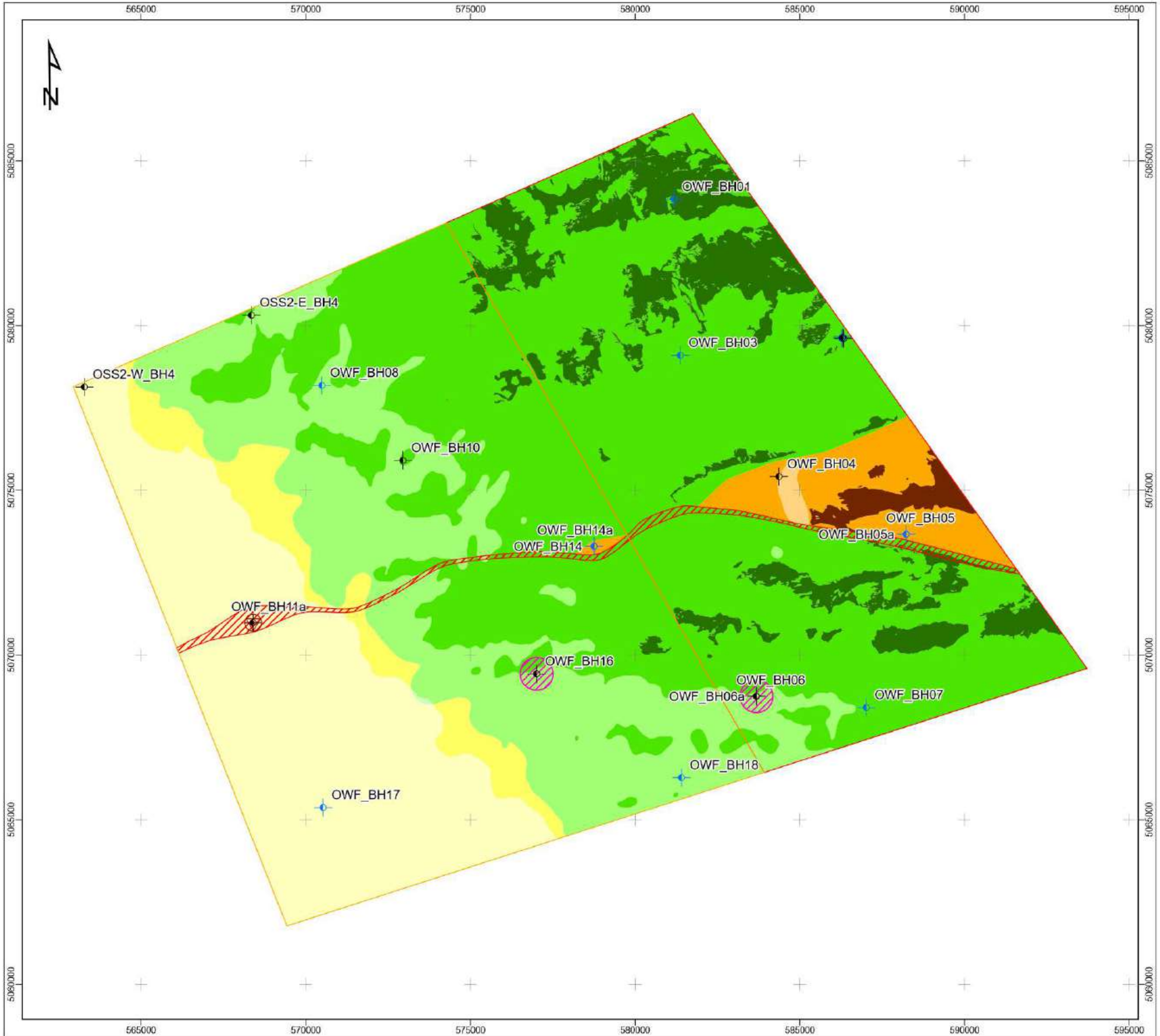
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

Title: **AO7 OWF Geotechnical SI**
Soil Profiles

Plate 4.1

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



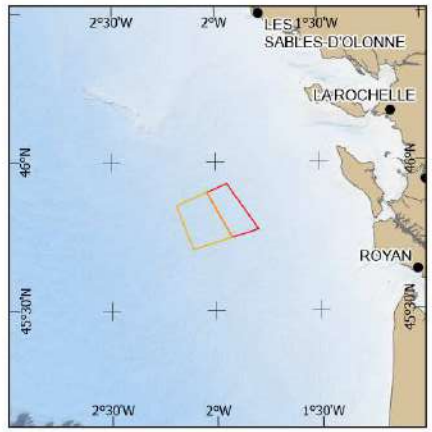
Legend

OWF Sites
- OWF1
- OWF2

Geotechnical Locations (Type)
- CPT
- CPT and Sampling
- Sampling

Soil provinces
- SP1a
- SP1b
- SP1c
- SP1d
- SP2c
- SP2d
- SP3a
- SP3b
- SP3c
- Observed karsts buffer
- Major fault footprint

Notes:
Soil provinces associated to soil profiles presneted in Plate 4.1



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

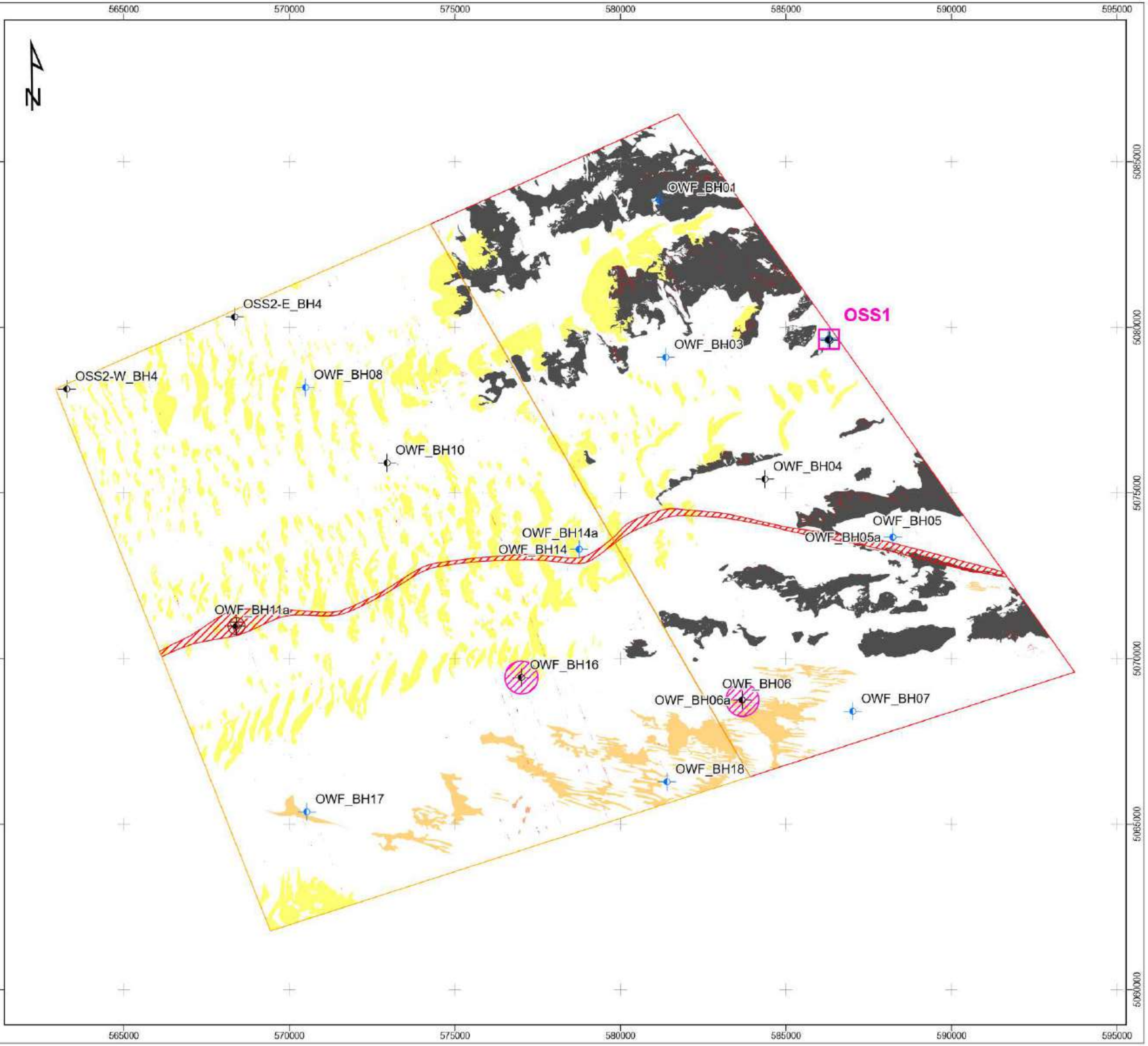
Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

Title: **AO7 OWF Geotechnical SI**
Soil Province Map

Plate 4.2

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL



Legend

OWF Sites

- OWF1
- OWF2

Geotechnical Locations (Type)

- CPT
- CPT and Sampling
- Sampling

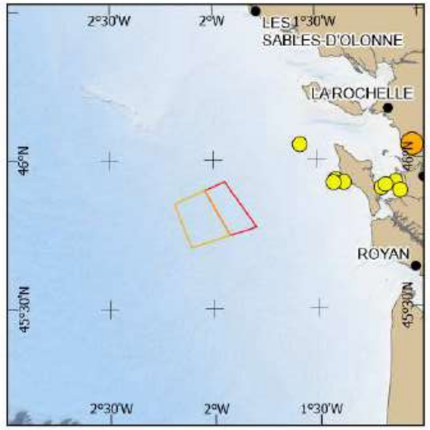
Eartquakes (magnitude)

- 4 - 5
- > 5

Identified geohazards and soil constraints

- Megaripples
- Ribbons
- Dunes
- Outcrops
- Observed karsts buffer
- Major fault footprint
- Seafloor gradient greater than 5°

Notes:
Identified Geohazards and Soil Constraints based on available data and Fugro's interpretation



Coordinate System : WGS 1984 UTM 30N

0 0.5 1 2 3 4 5 km

0 0.5 1 2 3 4 Miles

Fugro France SAS
Work & Share
3-5 Boulevards des Bouvets
92000 Nanterre

FUGRO

Title: AO7 OWF Geotechnical SI
Geohazards and Soil Constraints

Plate 5.1

Project Name: AO7 - OWF - Geotechnical SI
Project n°: F210748
Report n°: F210748-REP-006_DGEC-AO7-OWF

Created By:	Checked By:	Approved By:
ABL	ATH	LOL

[illegible]

[illegible]

[illegible]

[illegible] [illegible]

[illegible]

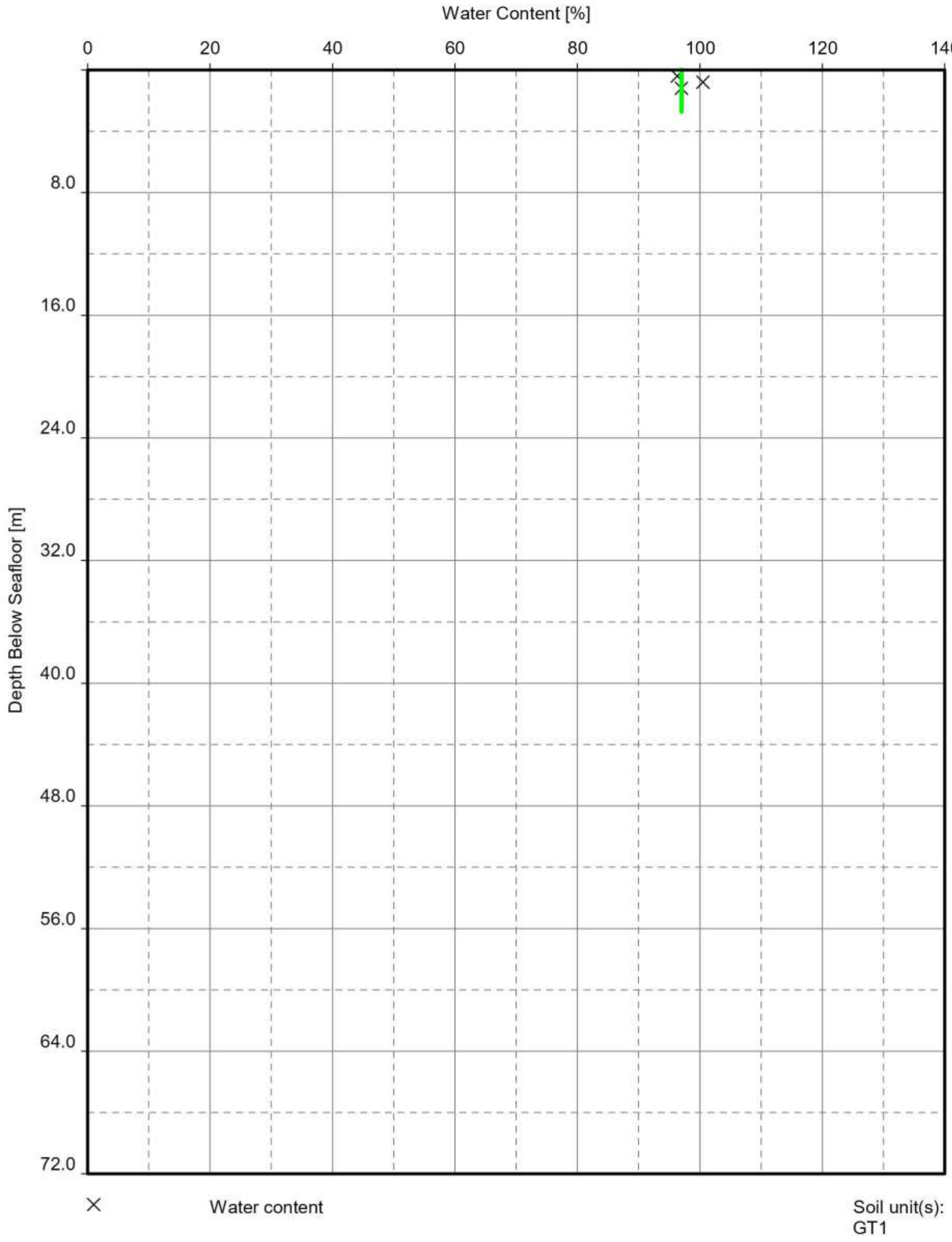
Appendix B

Design Lines per geotechnical parameters and ground types

B.1 Design Lines per geotechnical parameters and soil types

Plates per ground types are supplied in the following order of geotechnical parameters declination:

- Water Content (w);
- Wet Unit Weight (γ);
- Particle soil density (ρs);
- Cone resistance (qc);
- Undrained Shear Strength (s_u);
- Relative Density (Dr);
- Effective angle of internal friction (ϕ');
- Axial strain at 50% of the maximum deviator stress (ε_{50});
- Thermal Resistivity (TR);
- Rock Quality Designation (RQD);
- Point Load Strength Index ($Is50$);
- Uniaxial Compressive Strength (UCS);
- Young's Modulus of Elasticity (axial) (E).

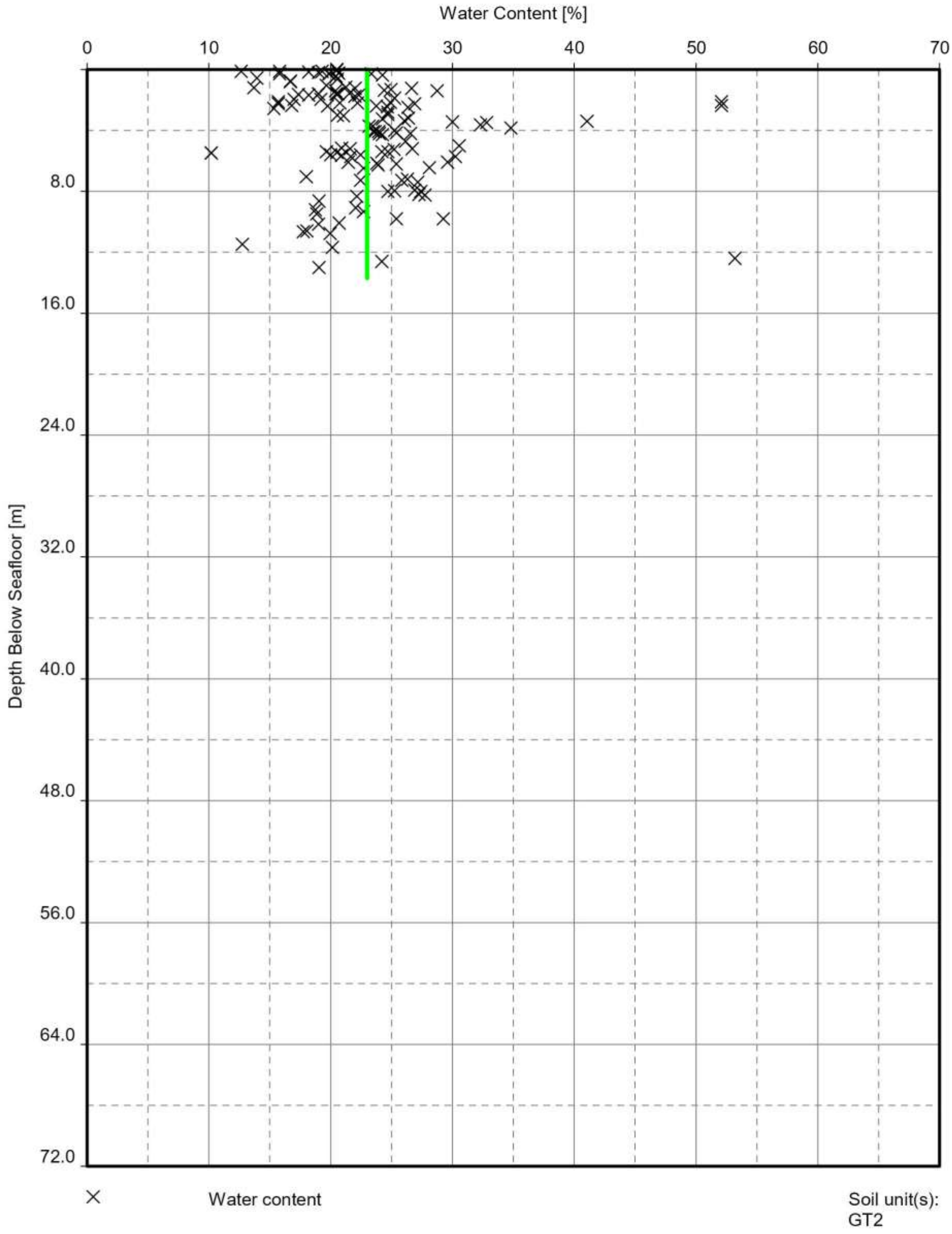


GeODin / Water content vs depth.GLO / 2024-05-06 @ 11:44:37

WATER CONTENT VERSUS DEPTH

OWF

[redacted]

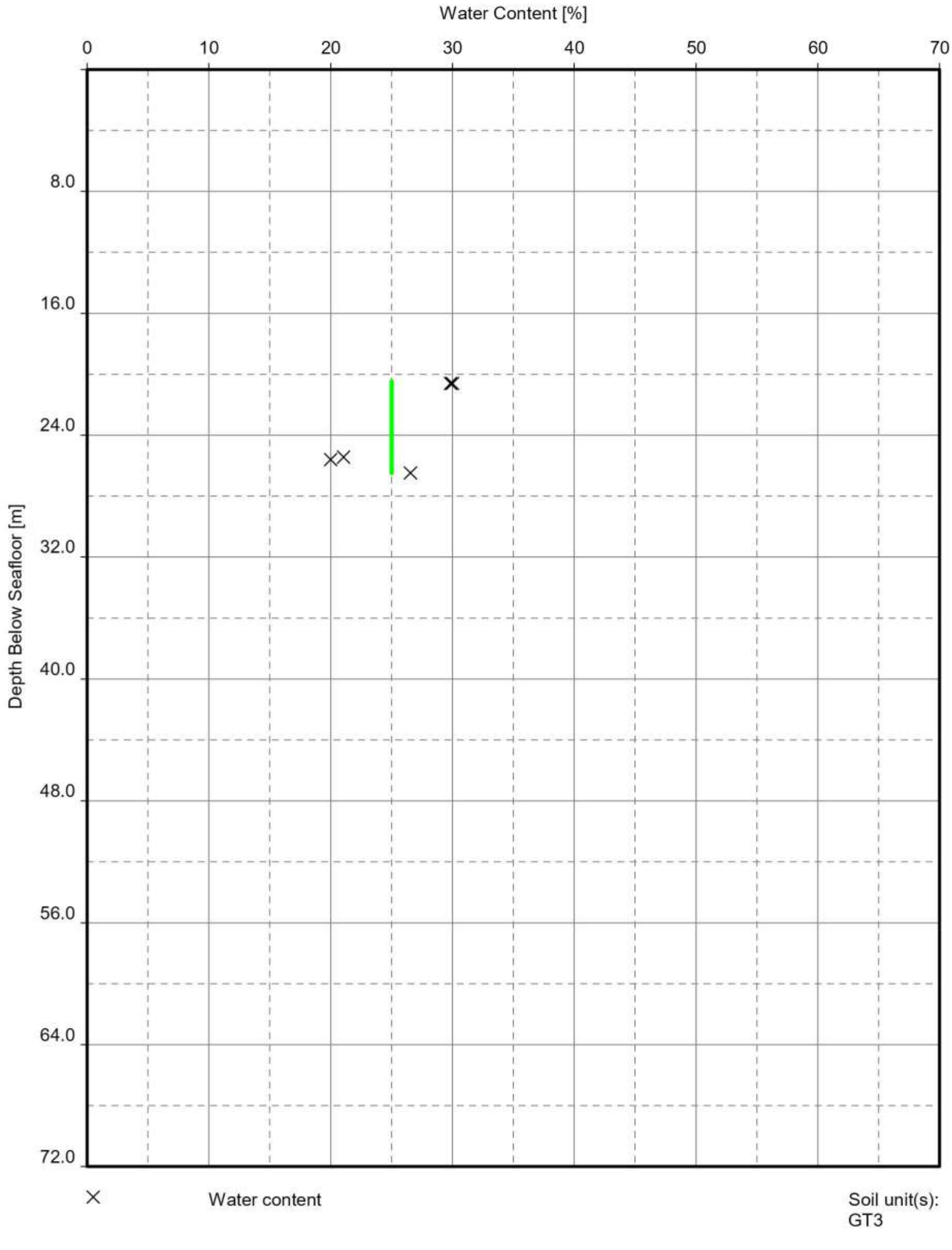


GeODin / Water content vs depth.GLO / 2024-05-06 @ 11:42:00

WATER CONTENT VERSUS DEPTH

OWF

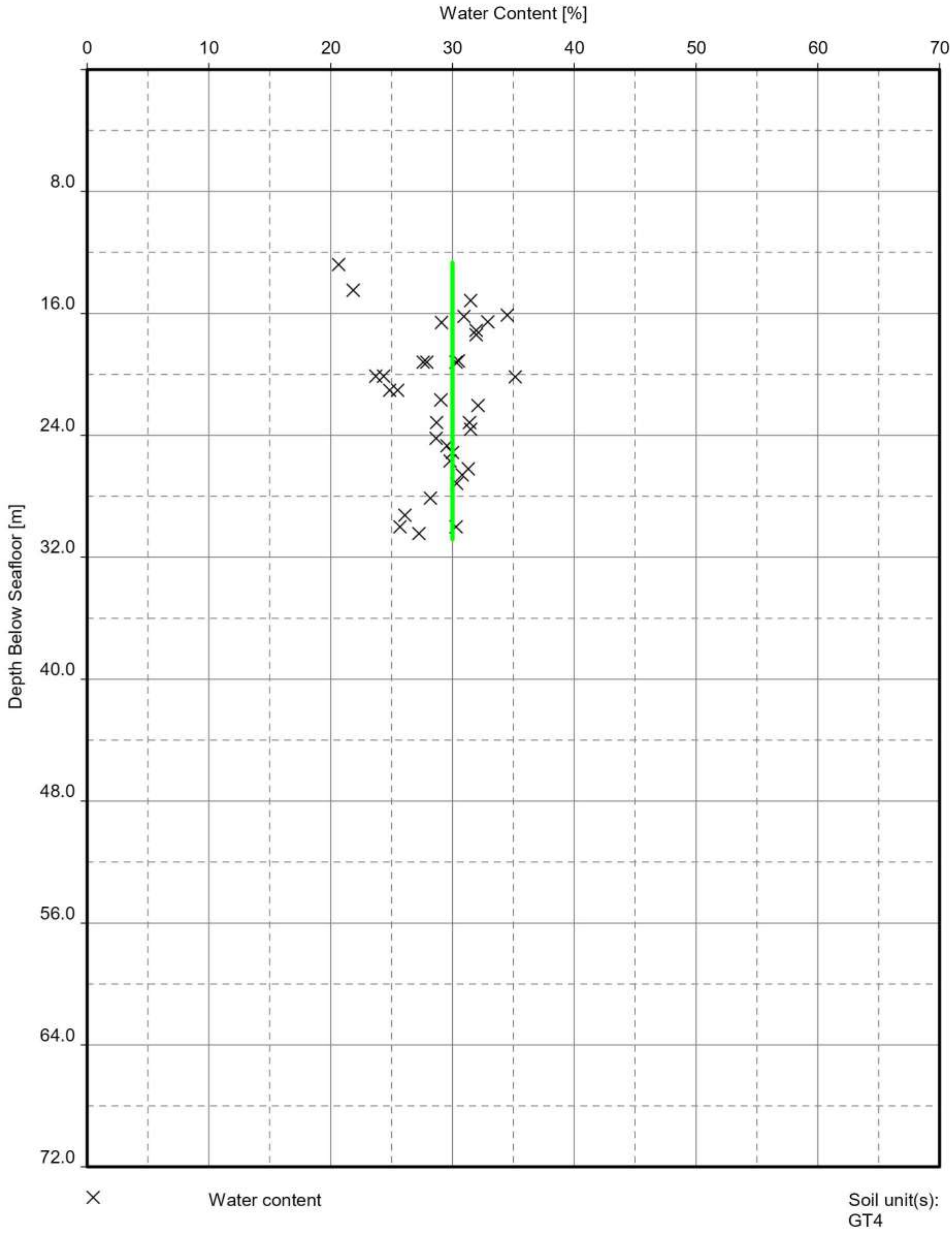
[redacted]



GeODin / Water content vs depth.GLO / 2024-05-06 @ 09:54:11

WATER CONTENT VERSUS DEPTH

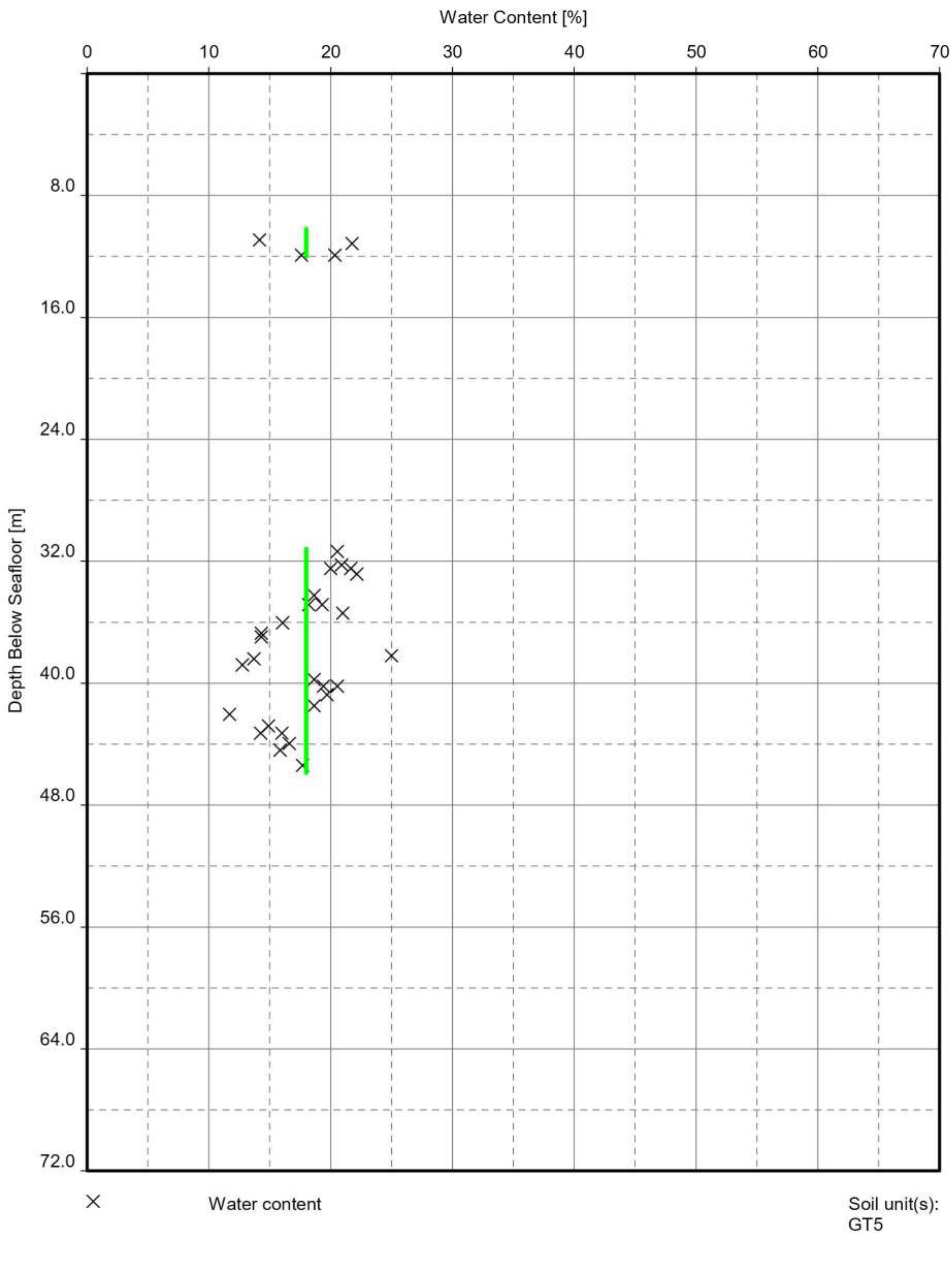
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:14:36

WATER CONTENT VERSUS DEPTH

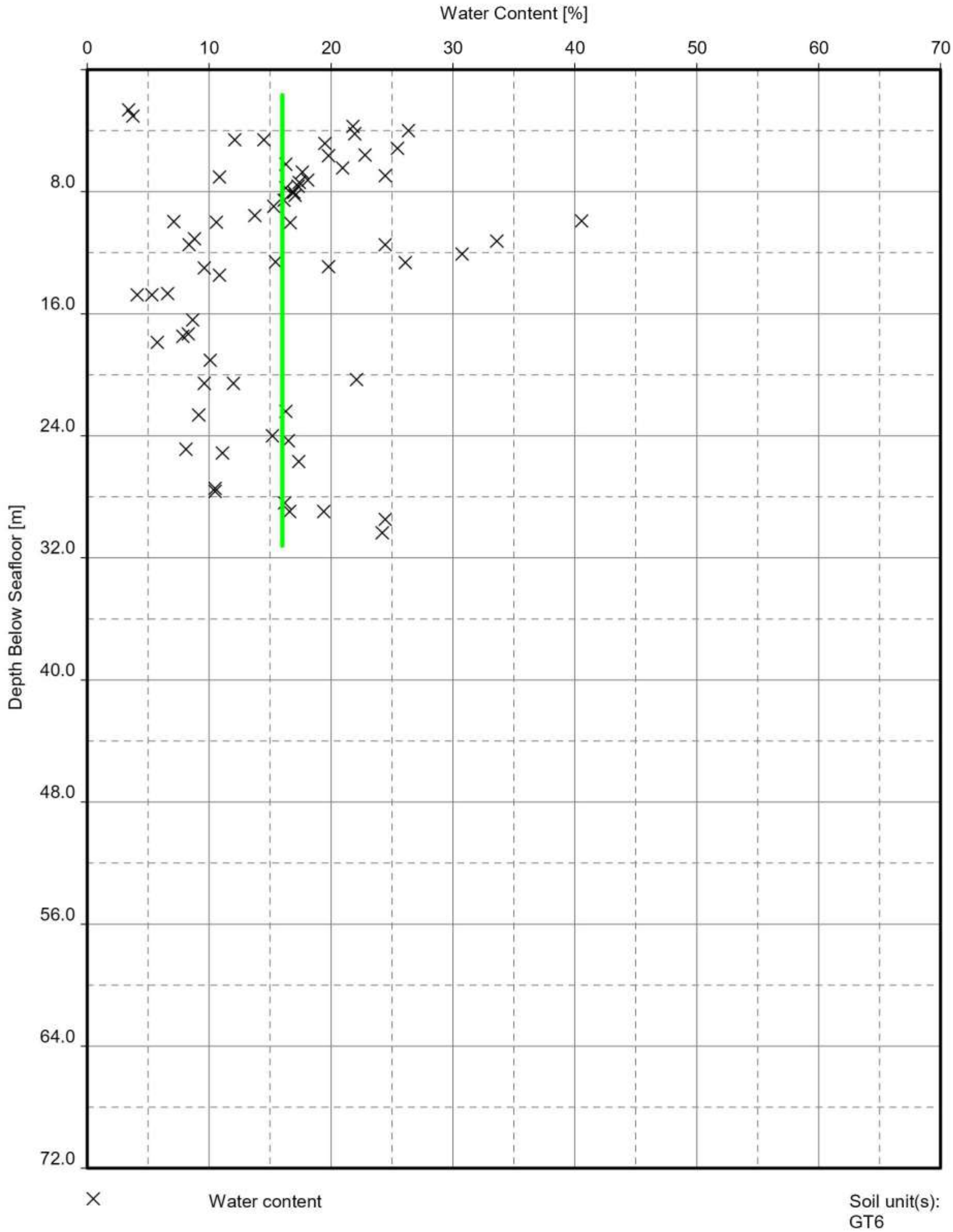
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:18:42

WATER CONTENT VERSUS DEPTH

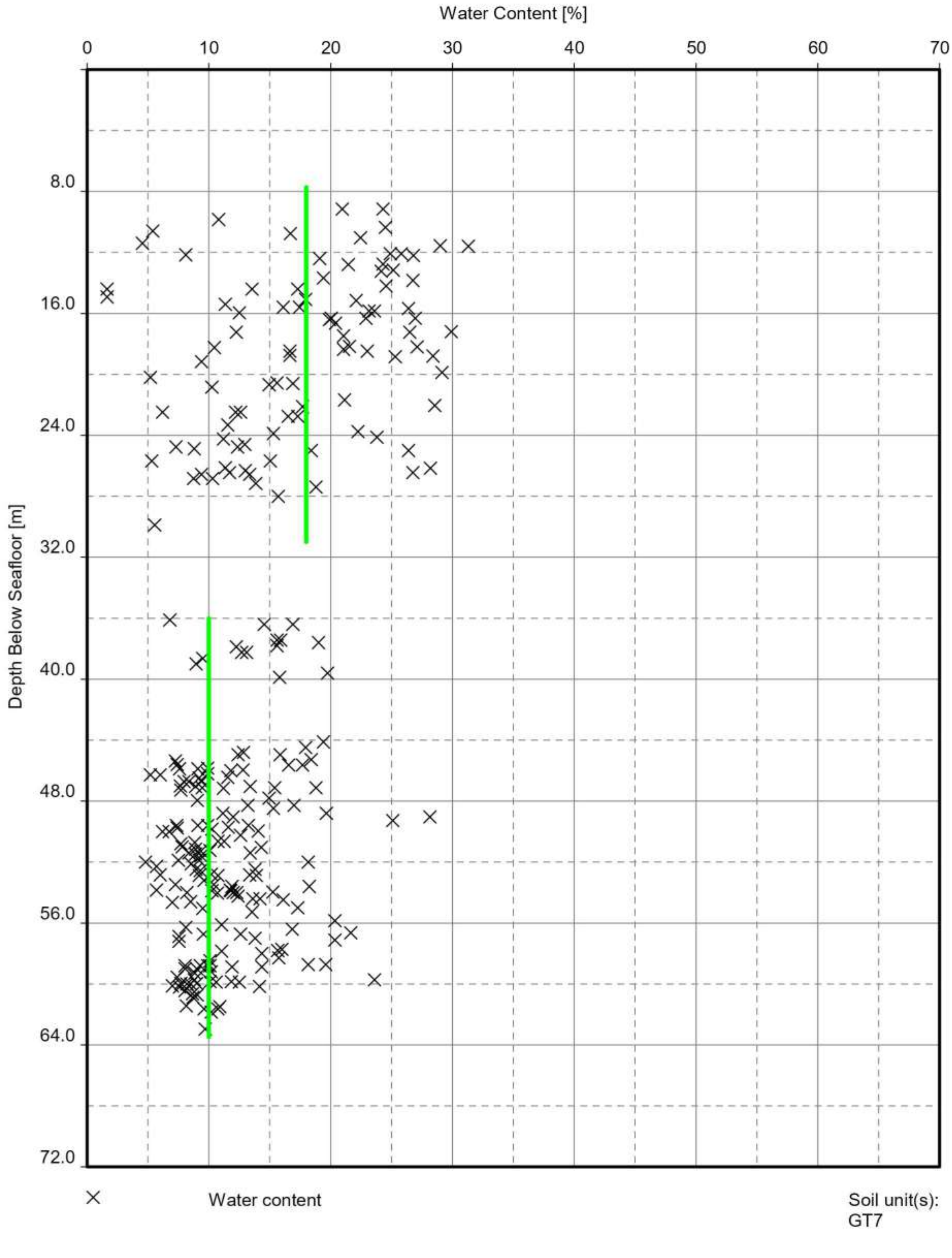
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:25:51

WATER CONTENT VERSUS DEPTH

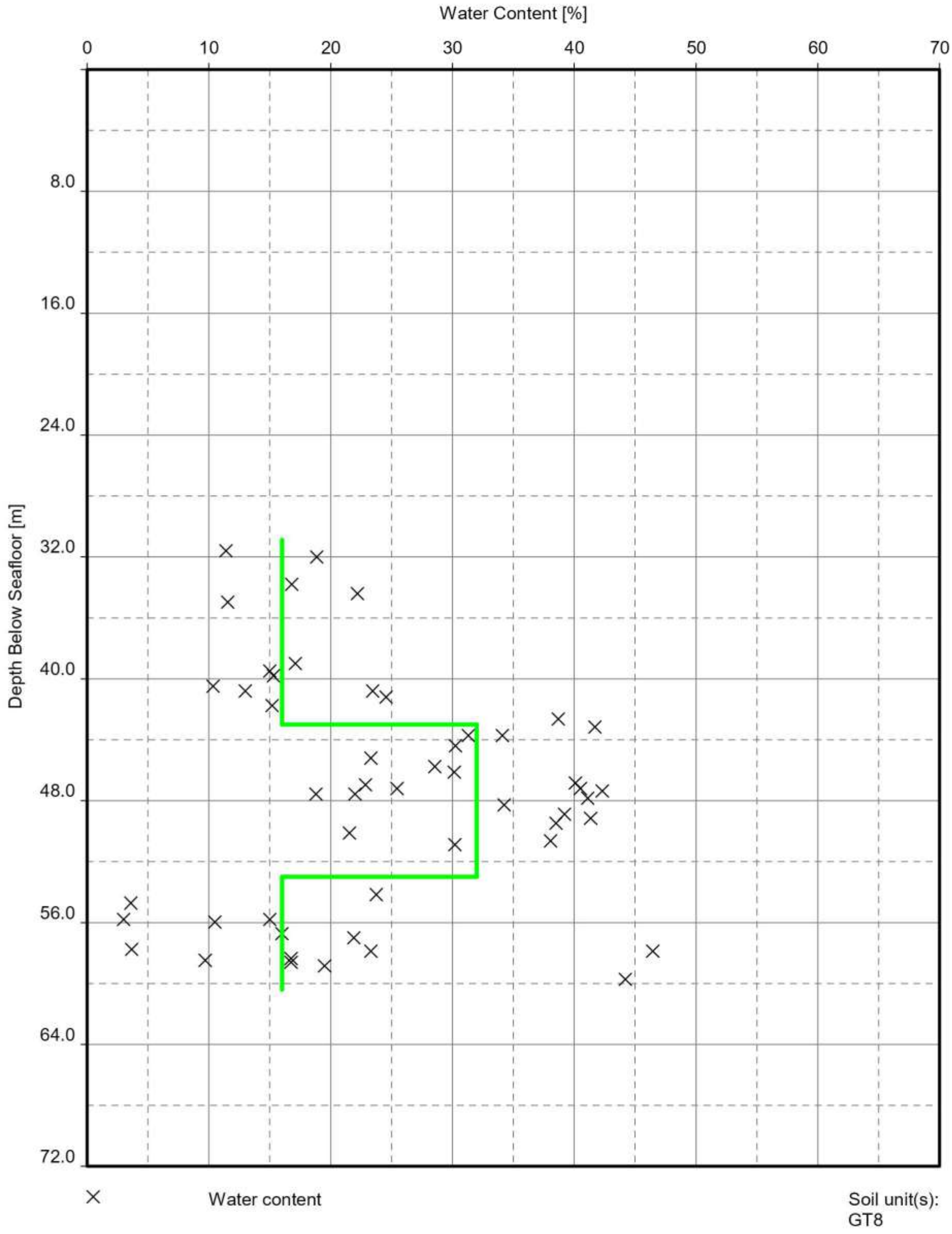
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:30:48

WATER CONTENT VERSUS DEPTH

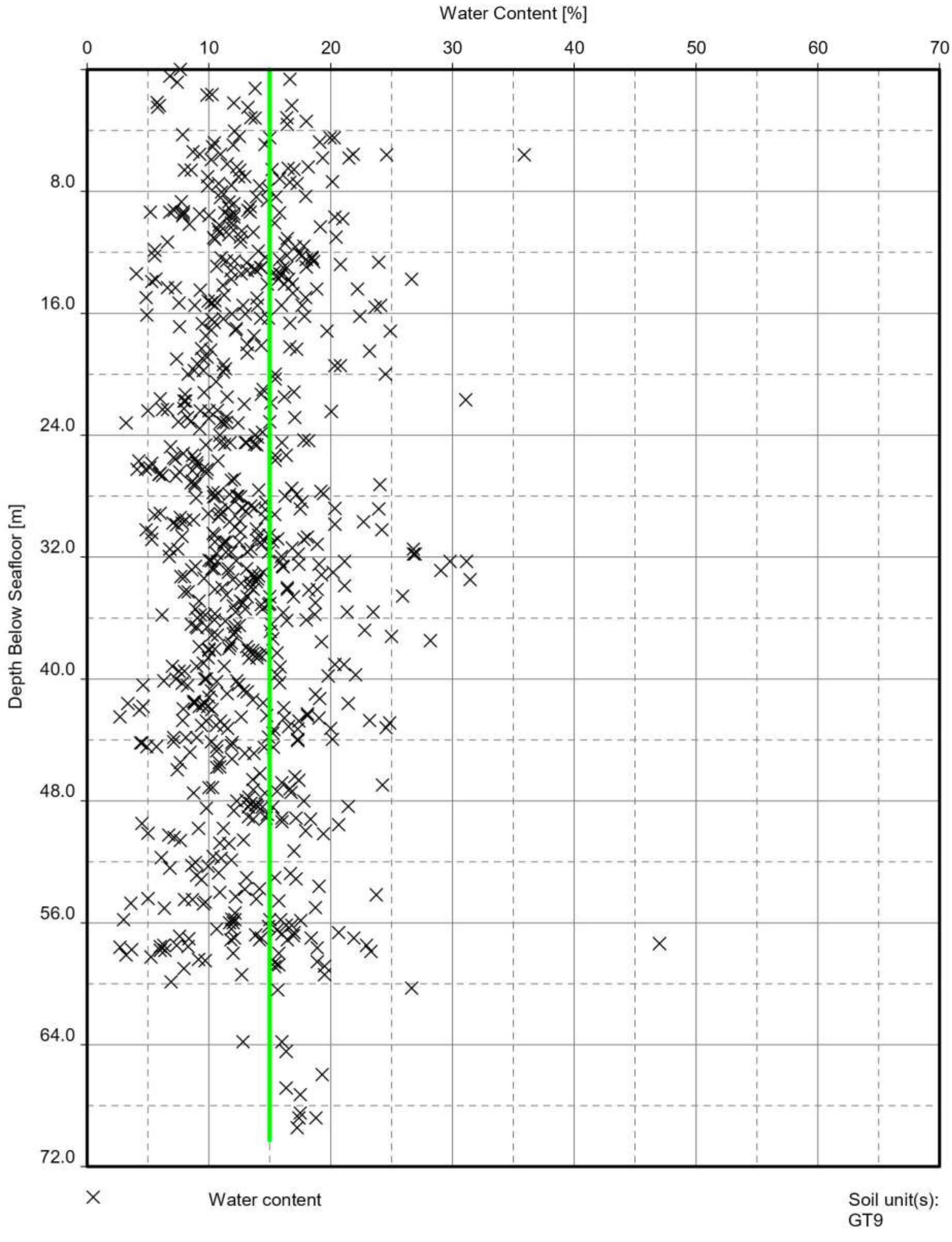
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:36:27

WATER CONTENT VERSUS DEPTH

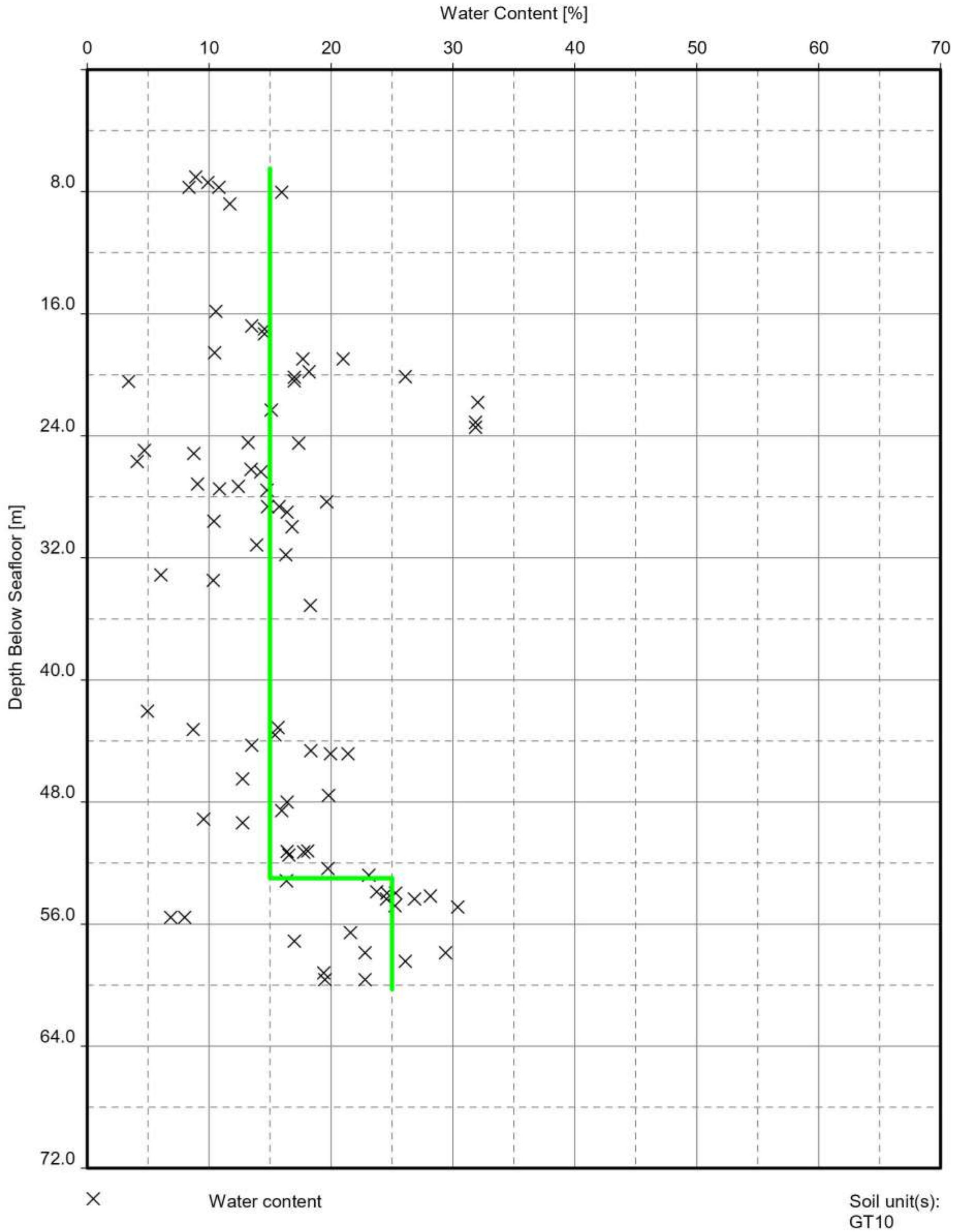
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:46:52

WATER CONTENT VERSUS DEPTH

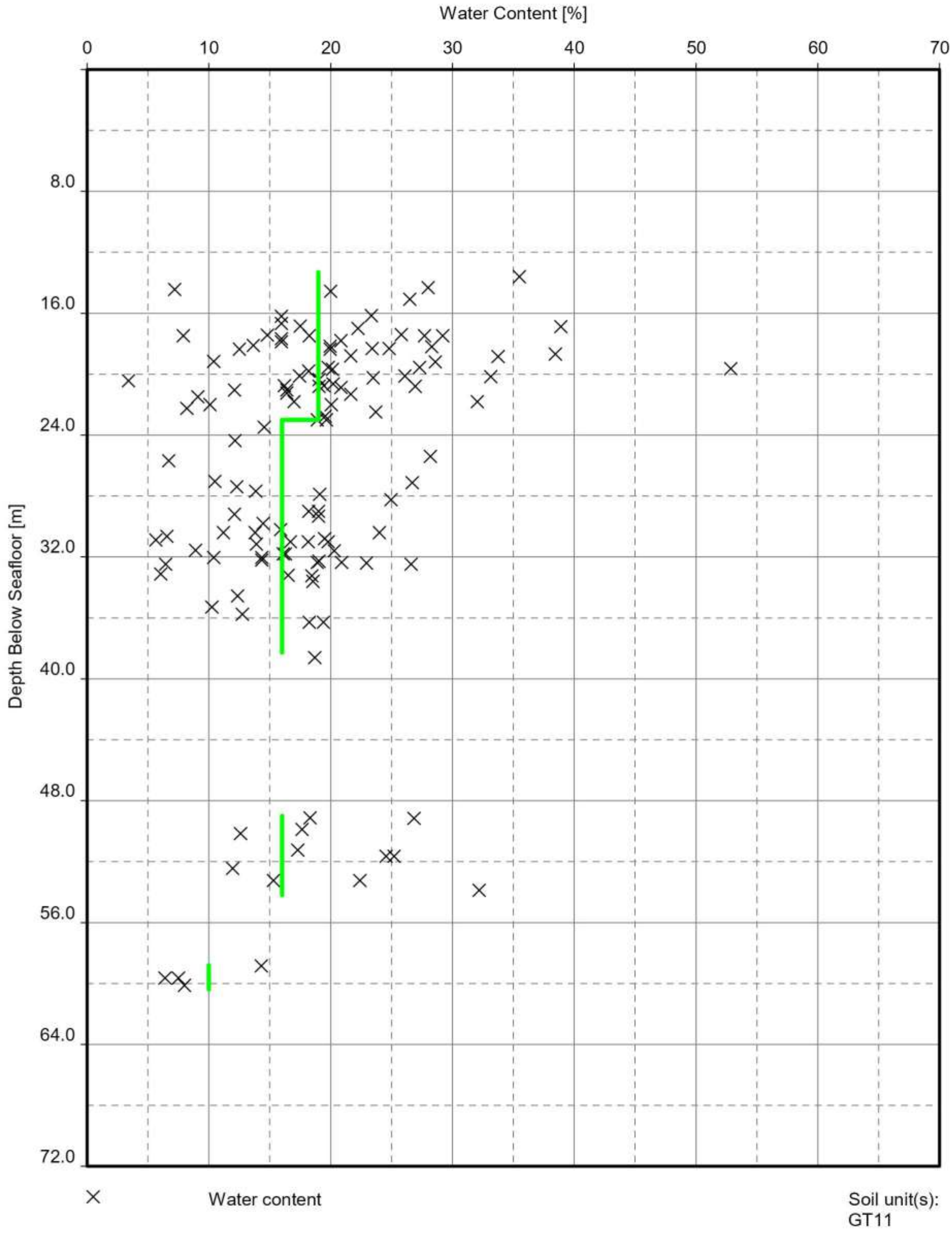
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:49:11

WATER CONTENT VERSUS DEPTH

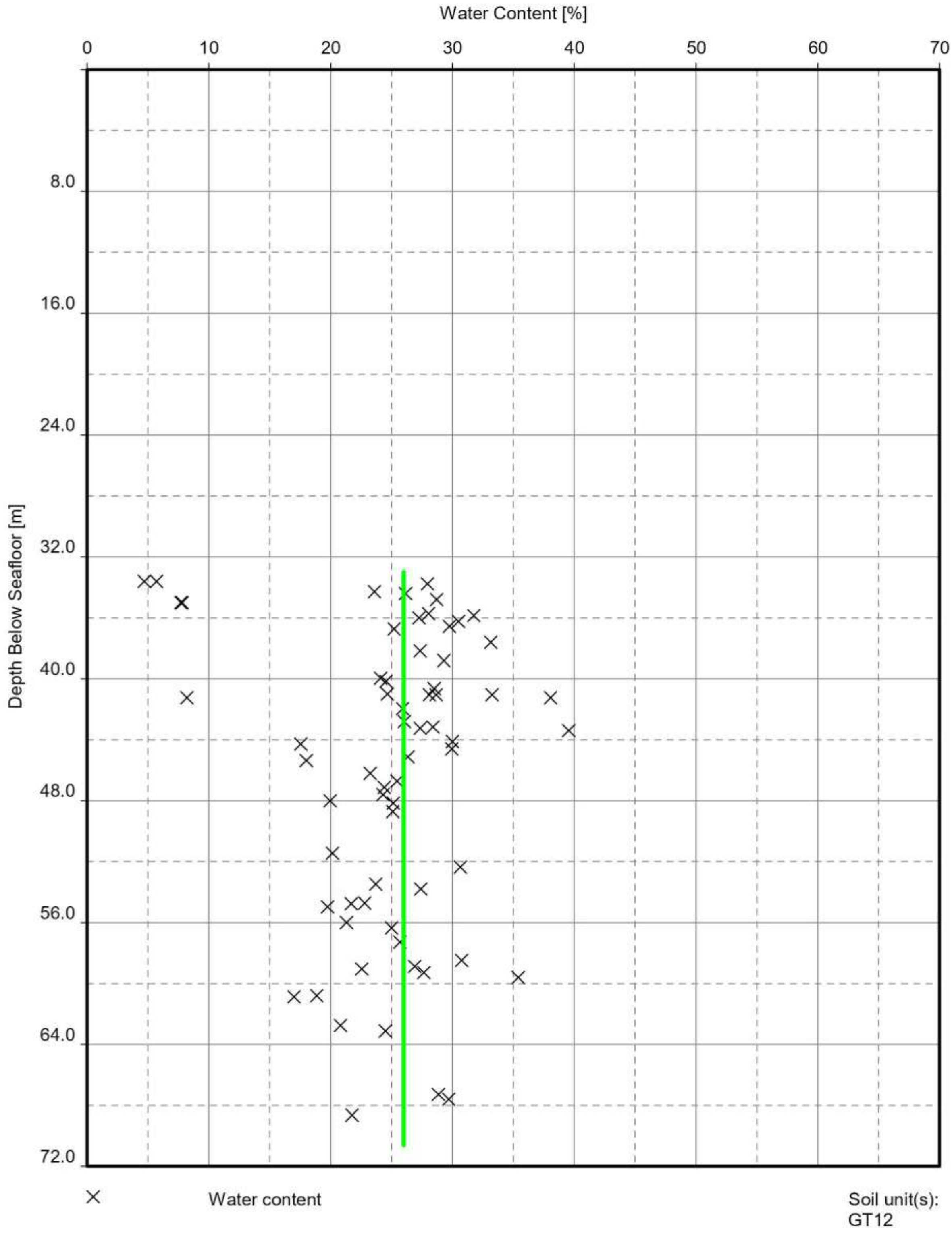
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:51:34

WATER CONTENT VERSUS DEPTH

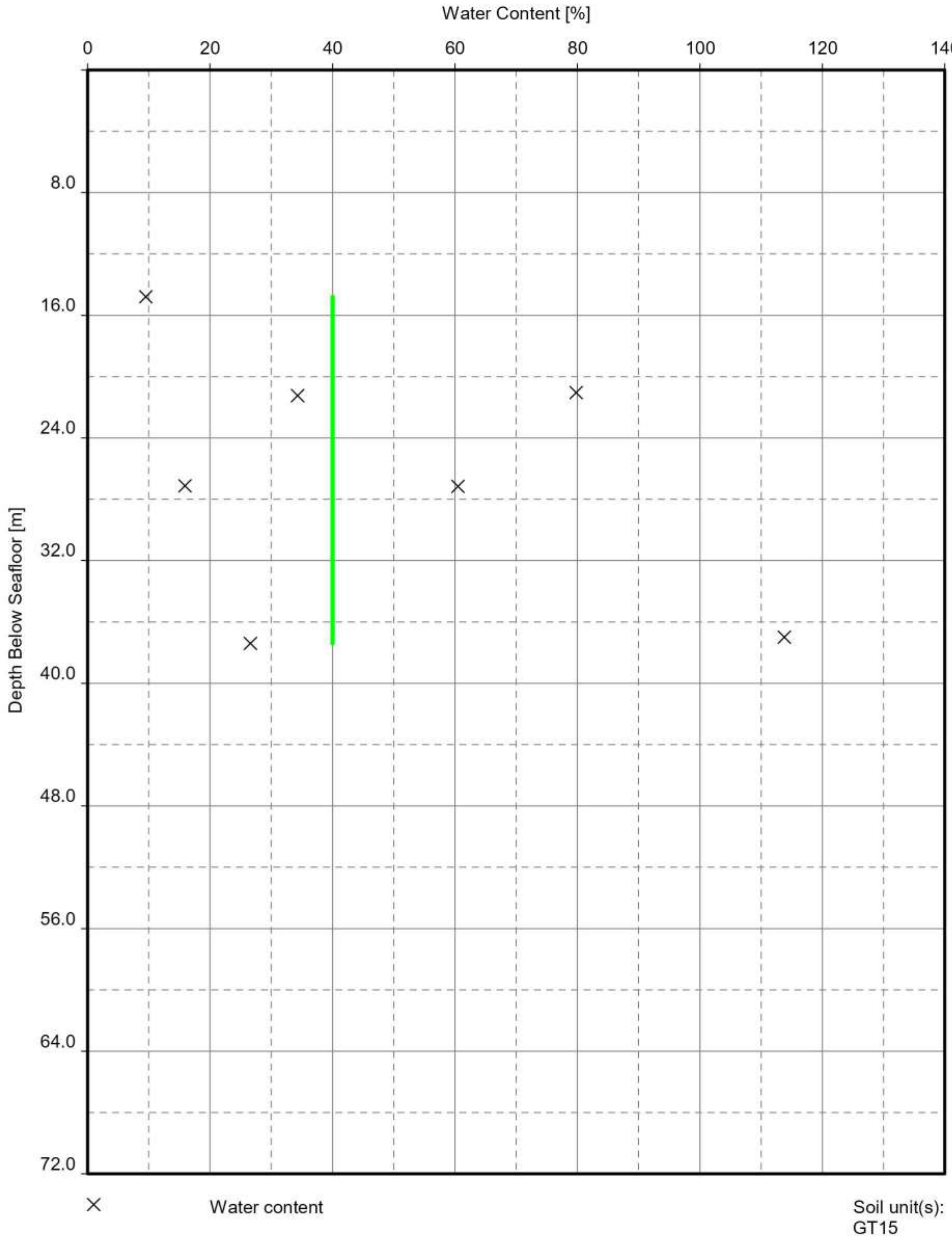
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 10:54:12

WATER CONTENT VERSUS DEPTH

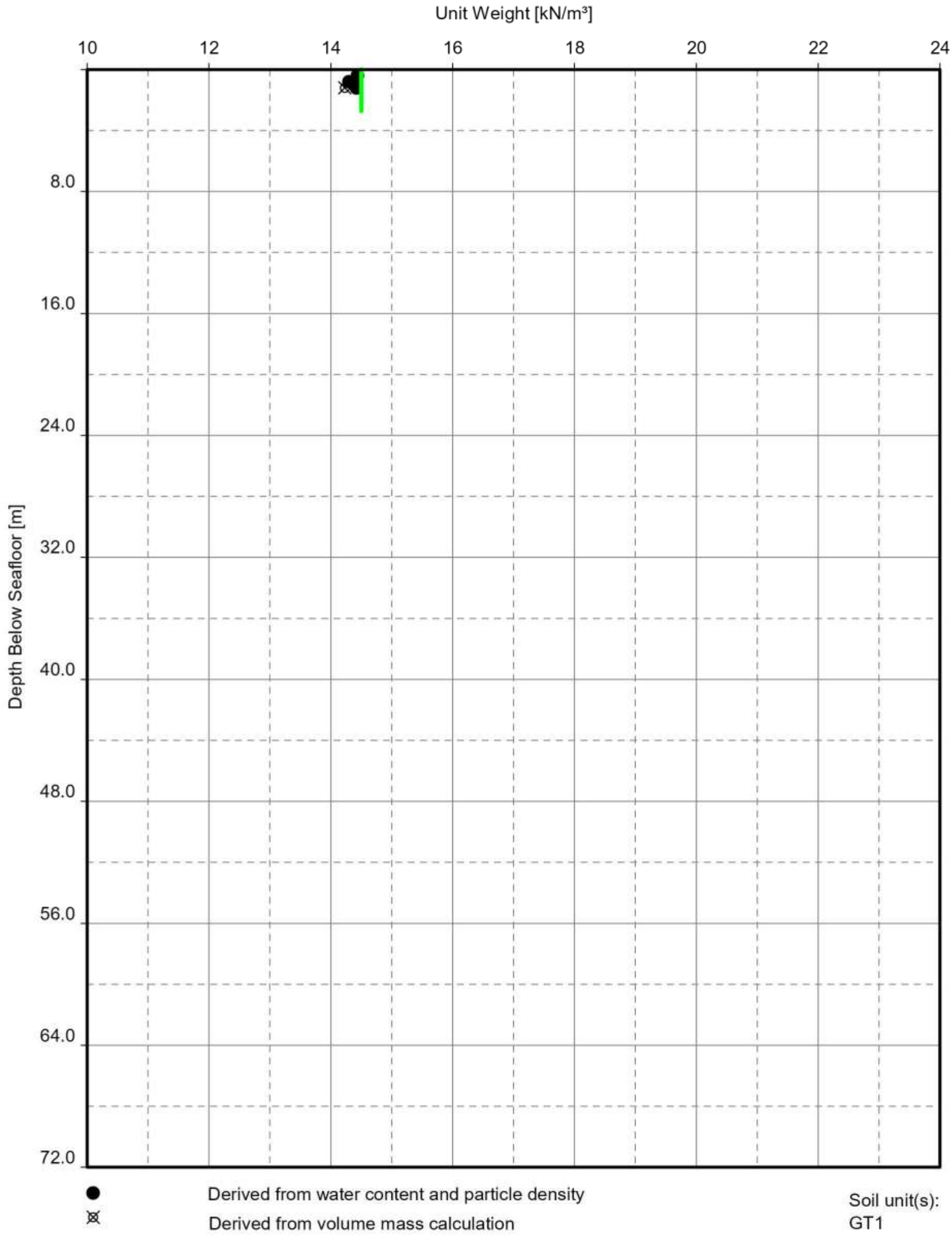
OWF



GeODin / Water content vs depth.GLO / 2024-05-06 @ 11:10:59

WATER CONTENT VERSUS DEPTH

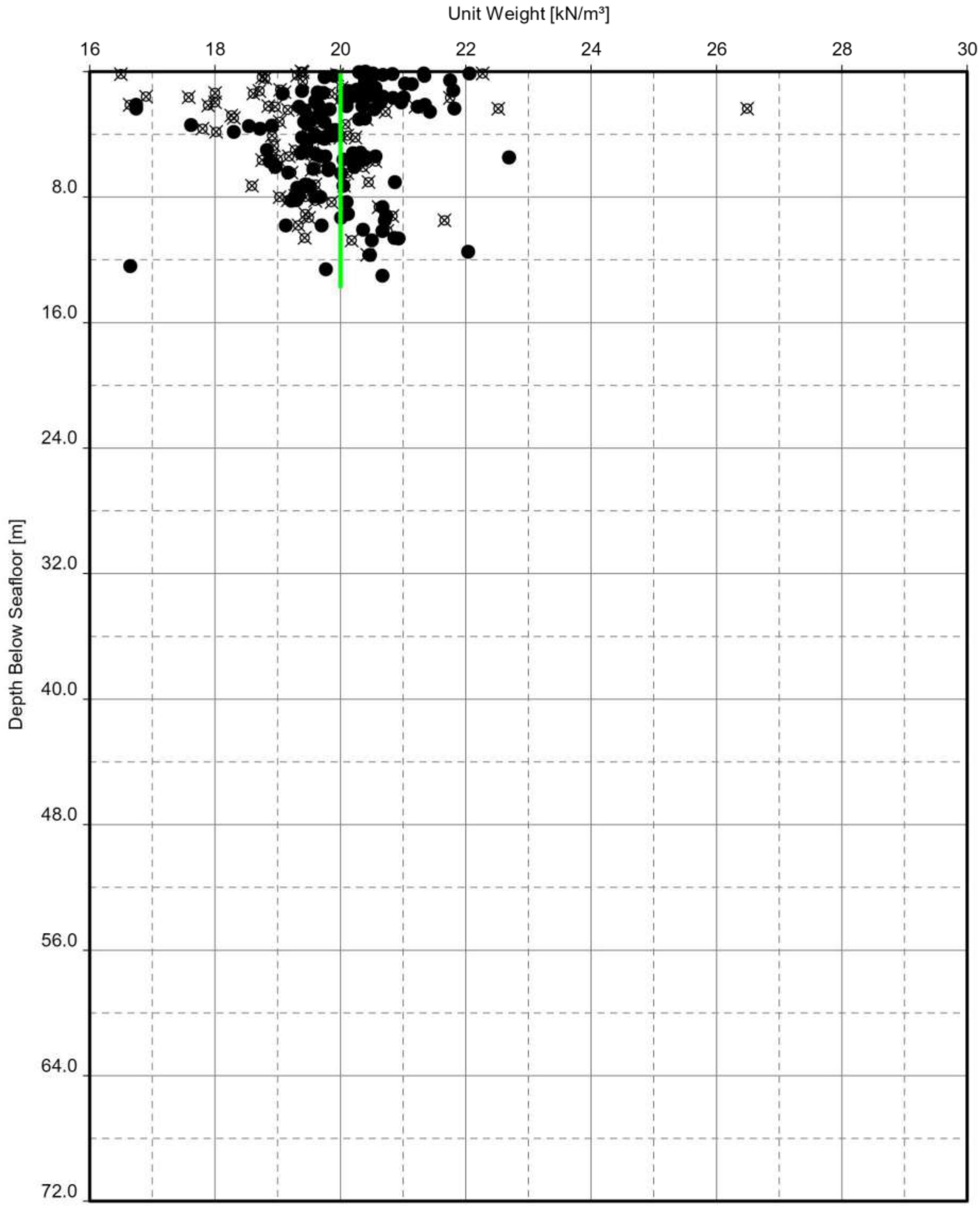
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 11:54:19

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF



● Derived from water content and particle density

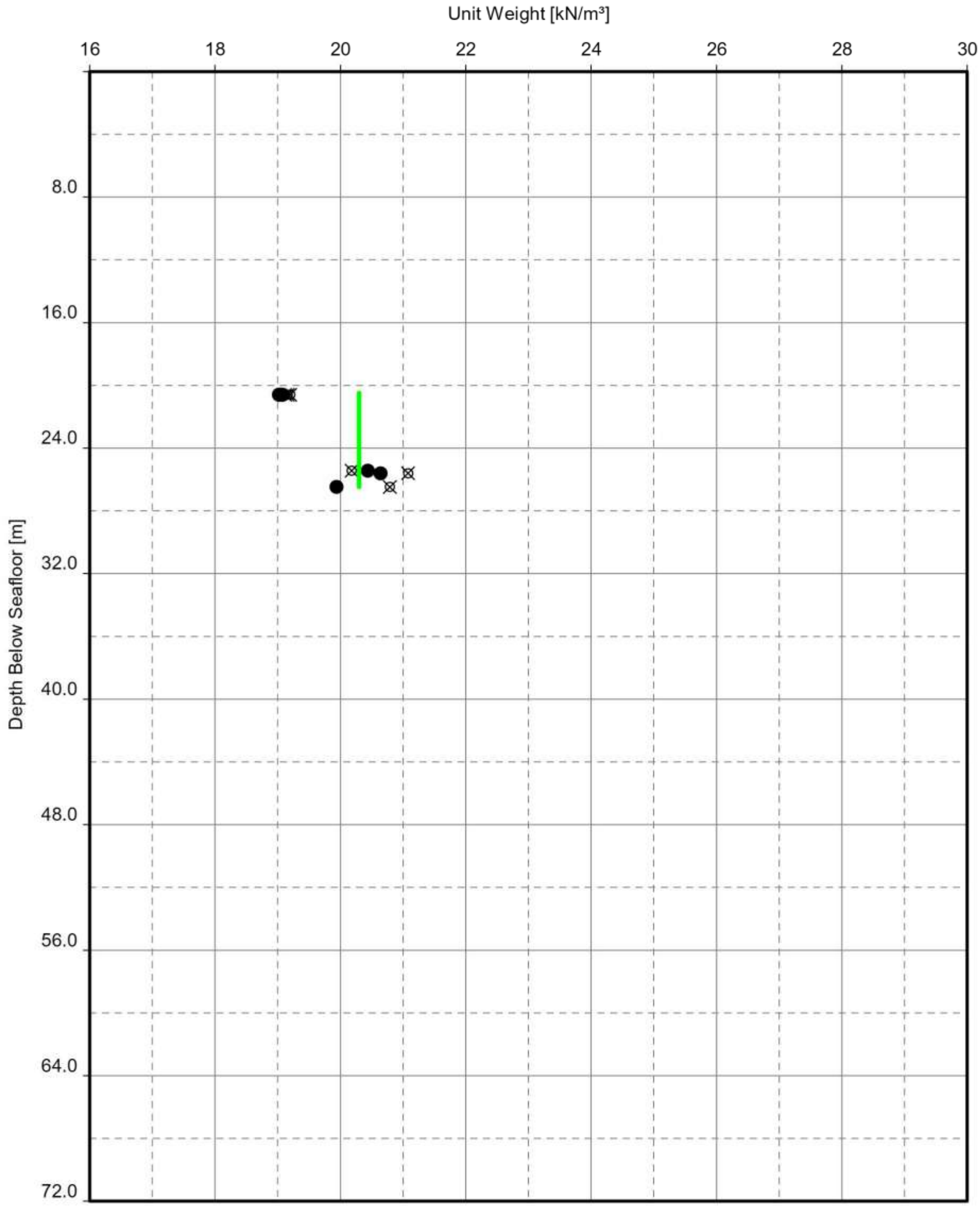
⊠ Derived from volume mass calculation

Soil unit(s):
GT2

GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 11:58:30

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF



● Derived from water content and particle density

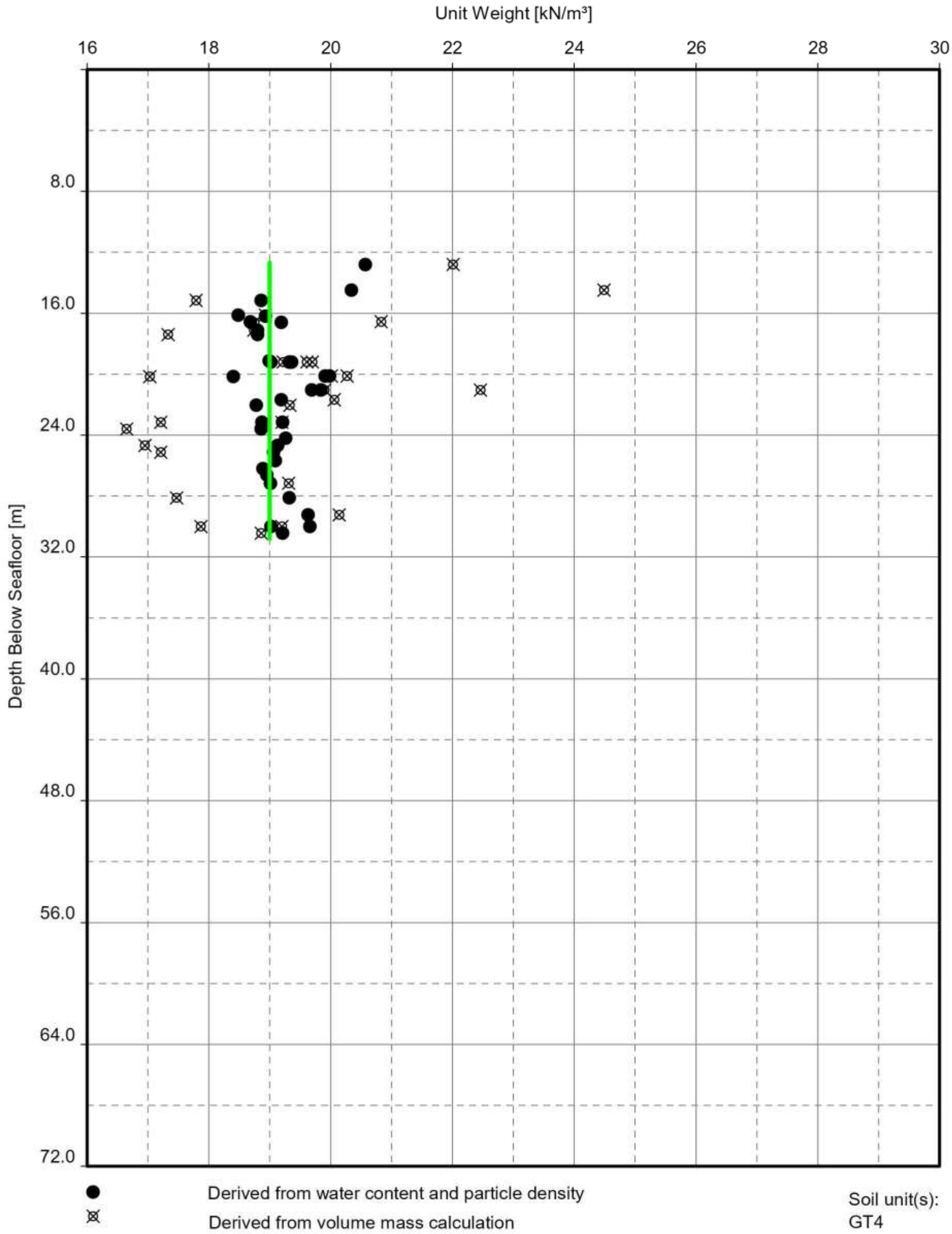
⊠ Derived from volume mass calculation

Soil unit(s):
GT3

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF

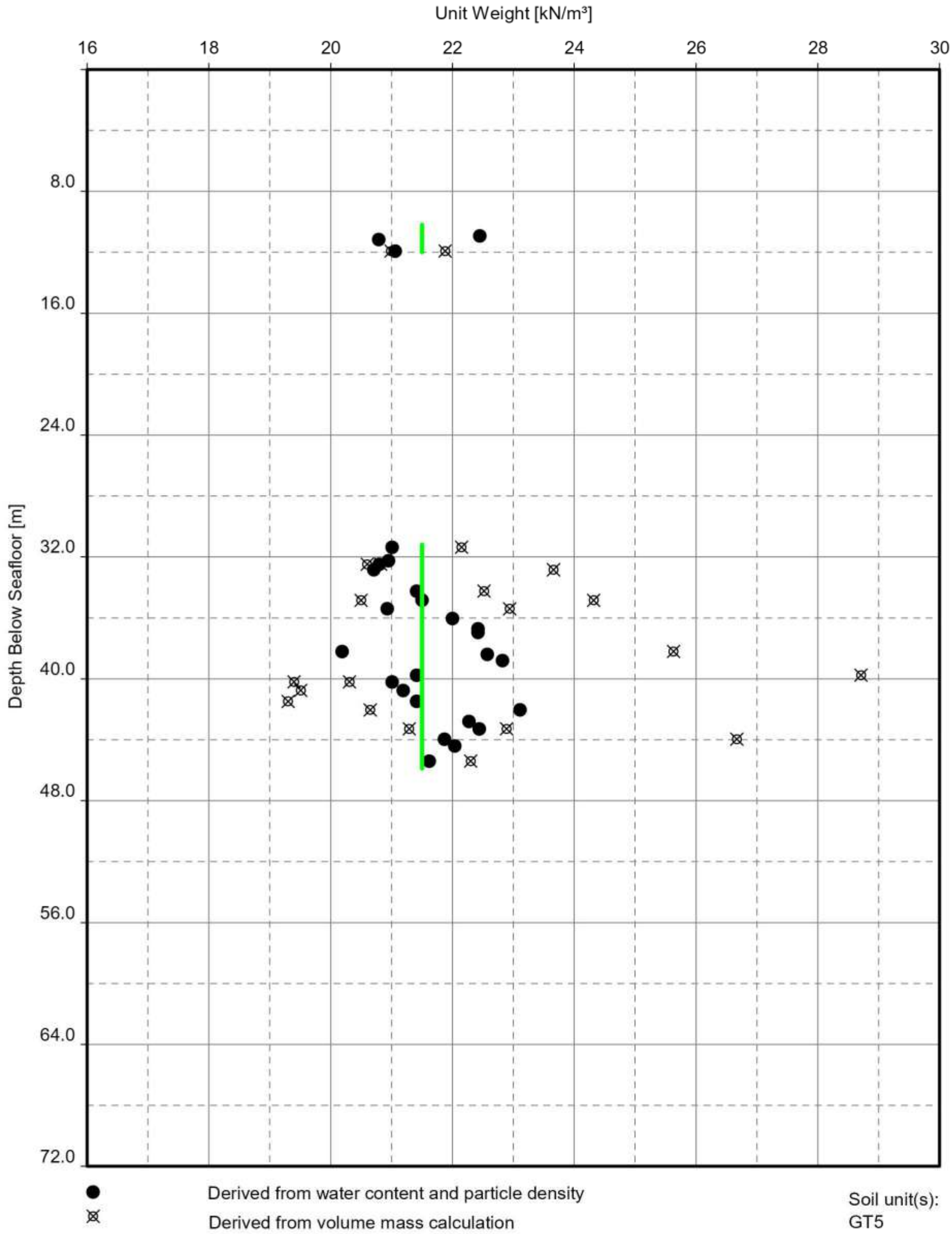
FUGRO



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 12:53:11

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

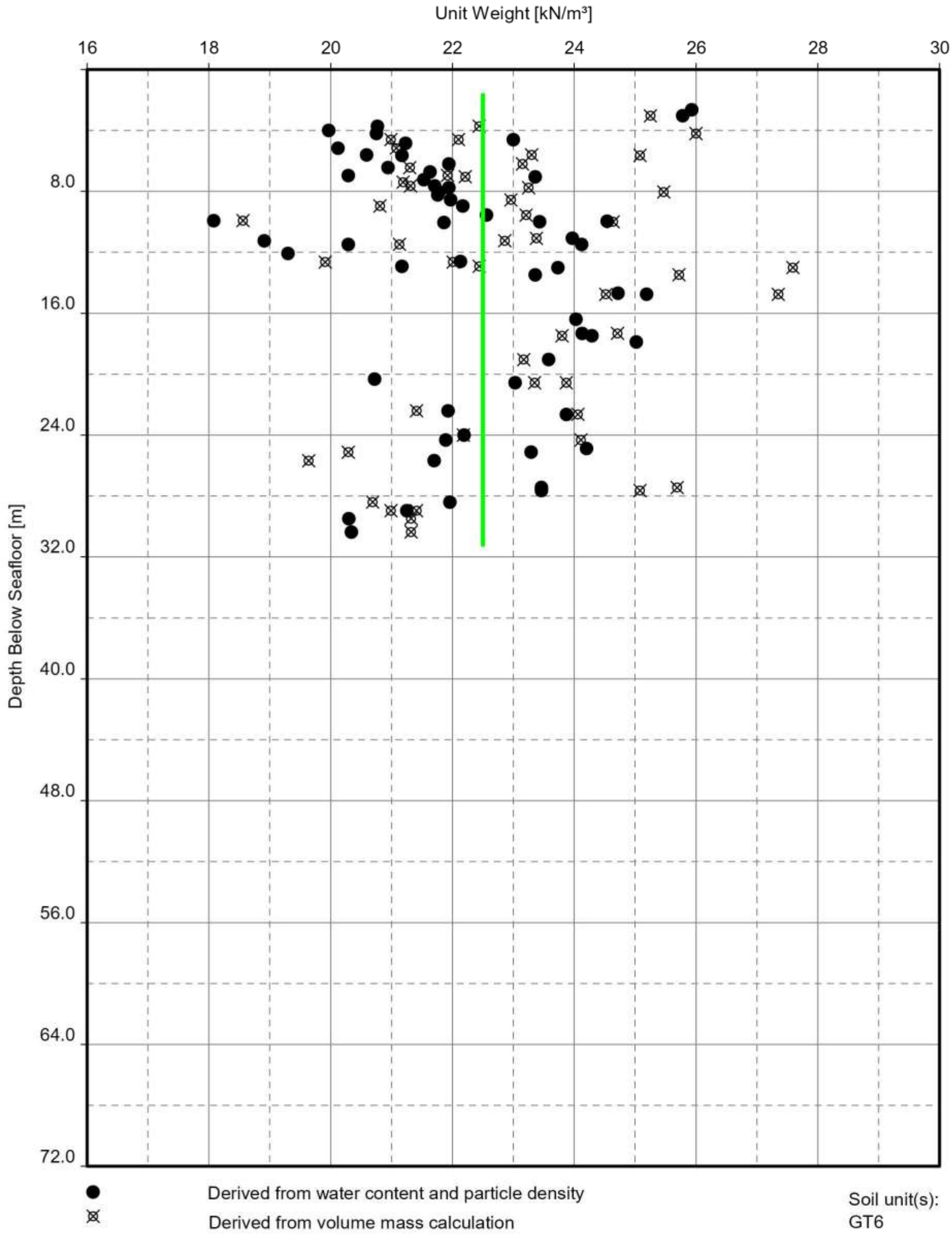
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 12:56:14

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

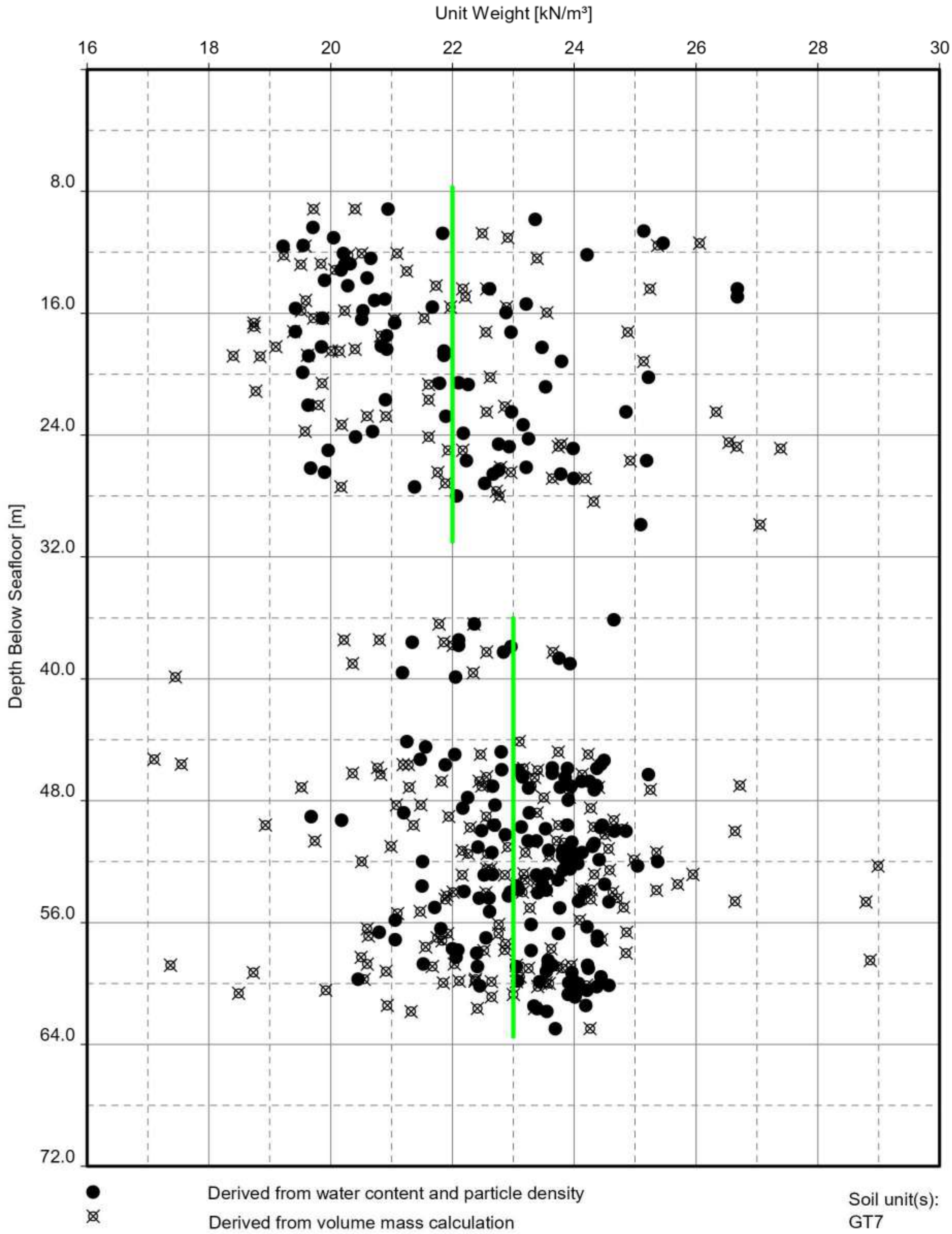
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:02:19

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

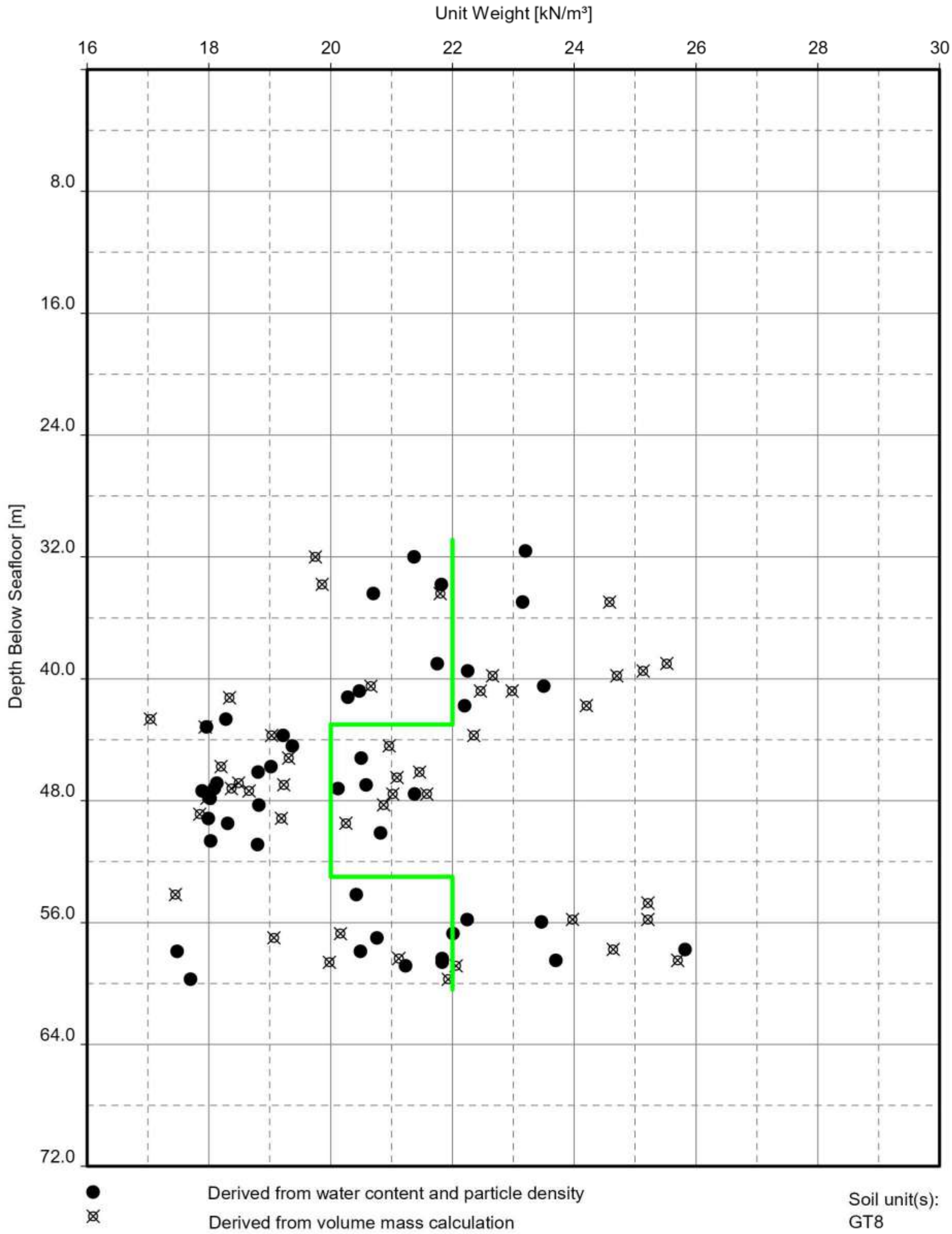
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:05:35

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

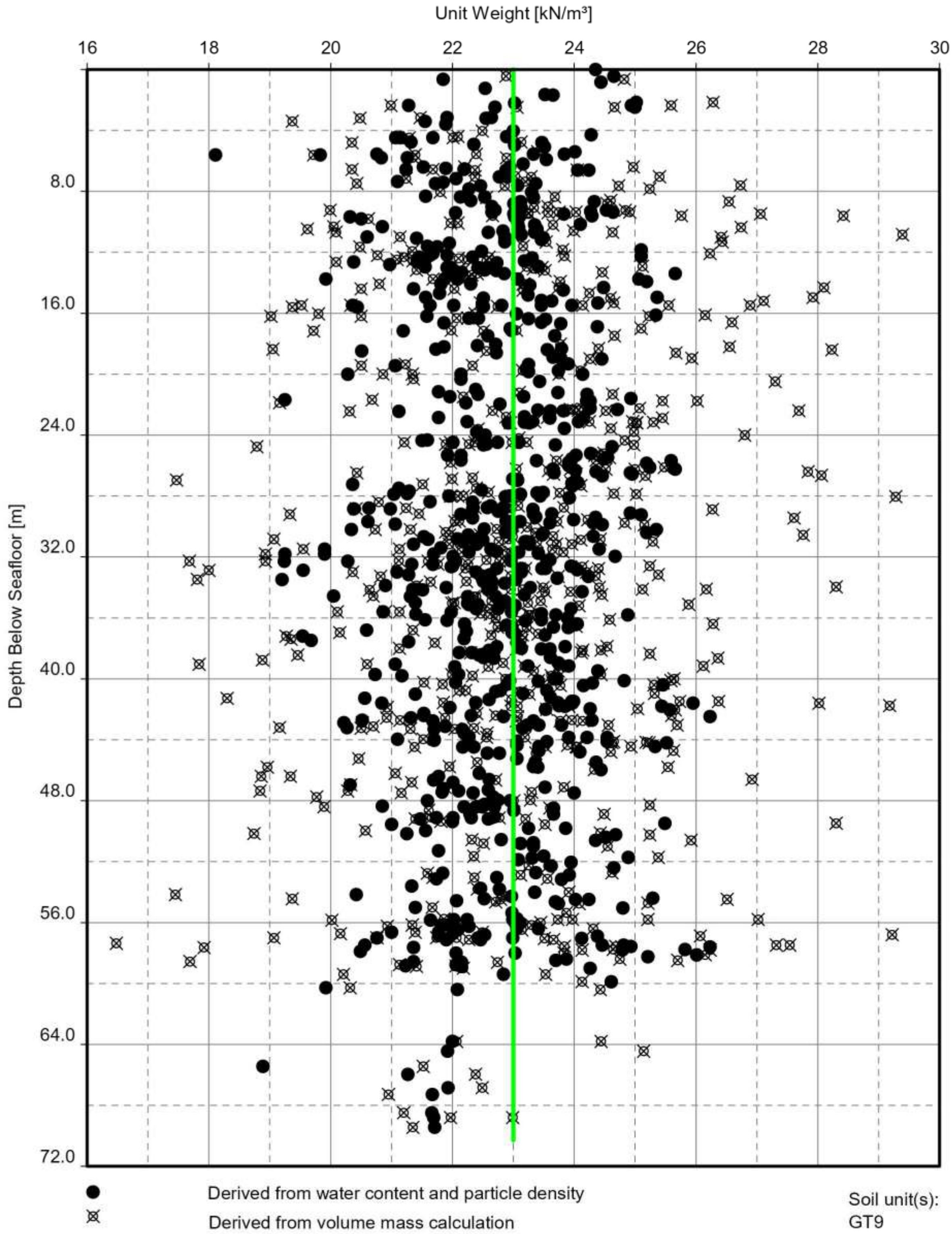
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:10:10

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

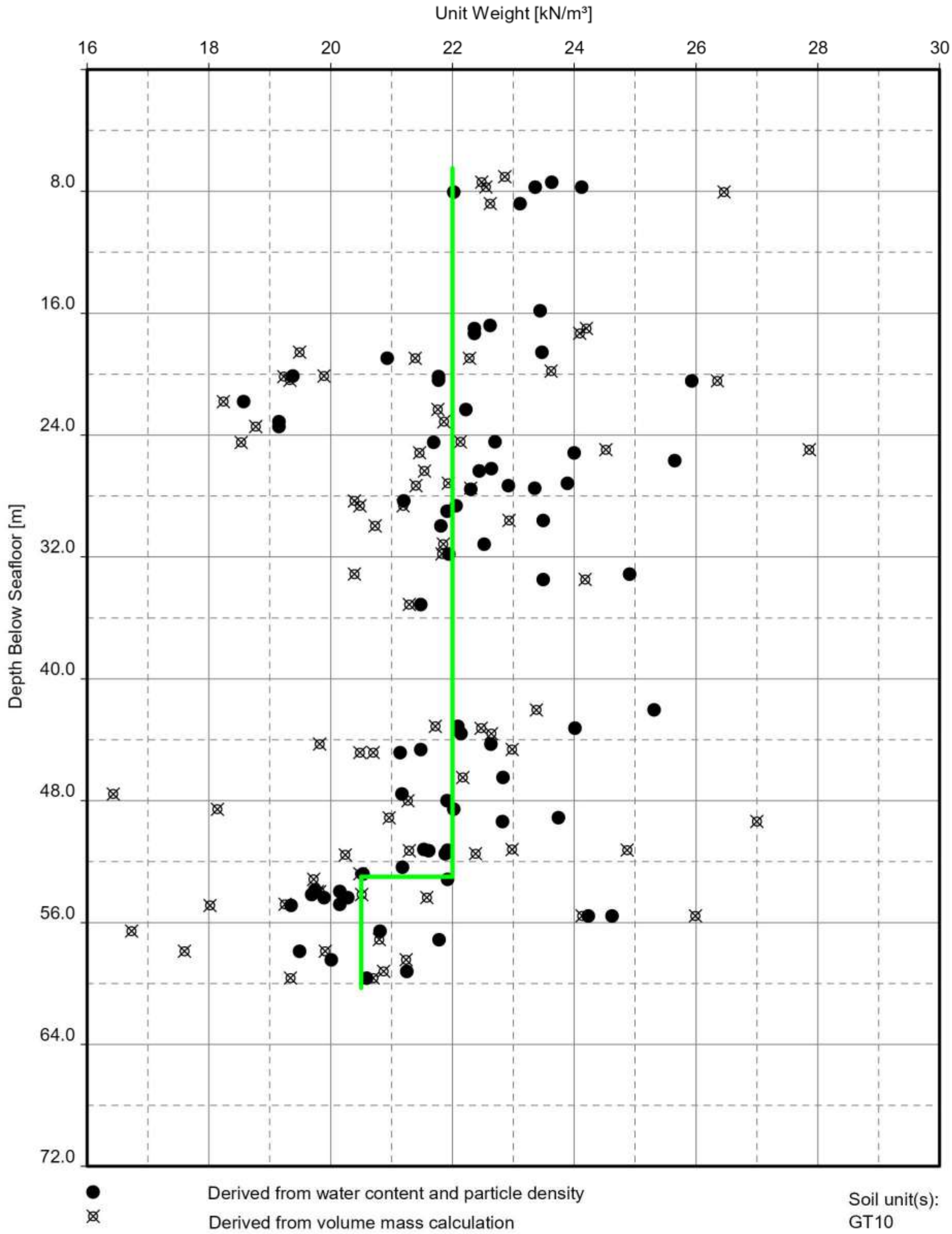
OWF



GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:15:14

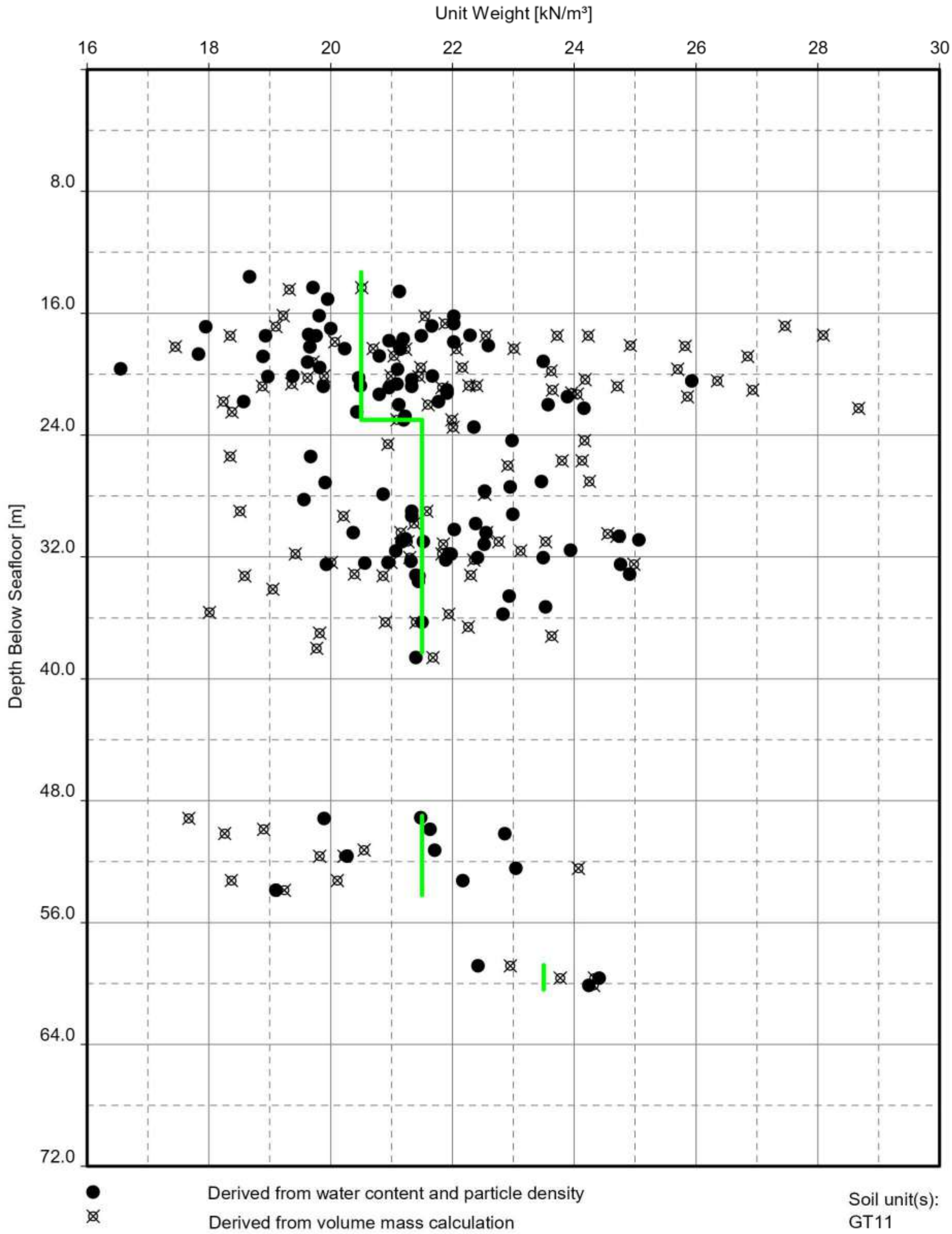
WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF



WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF

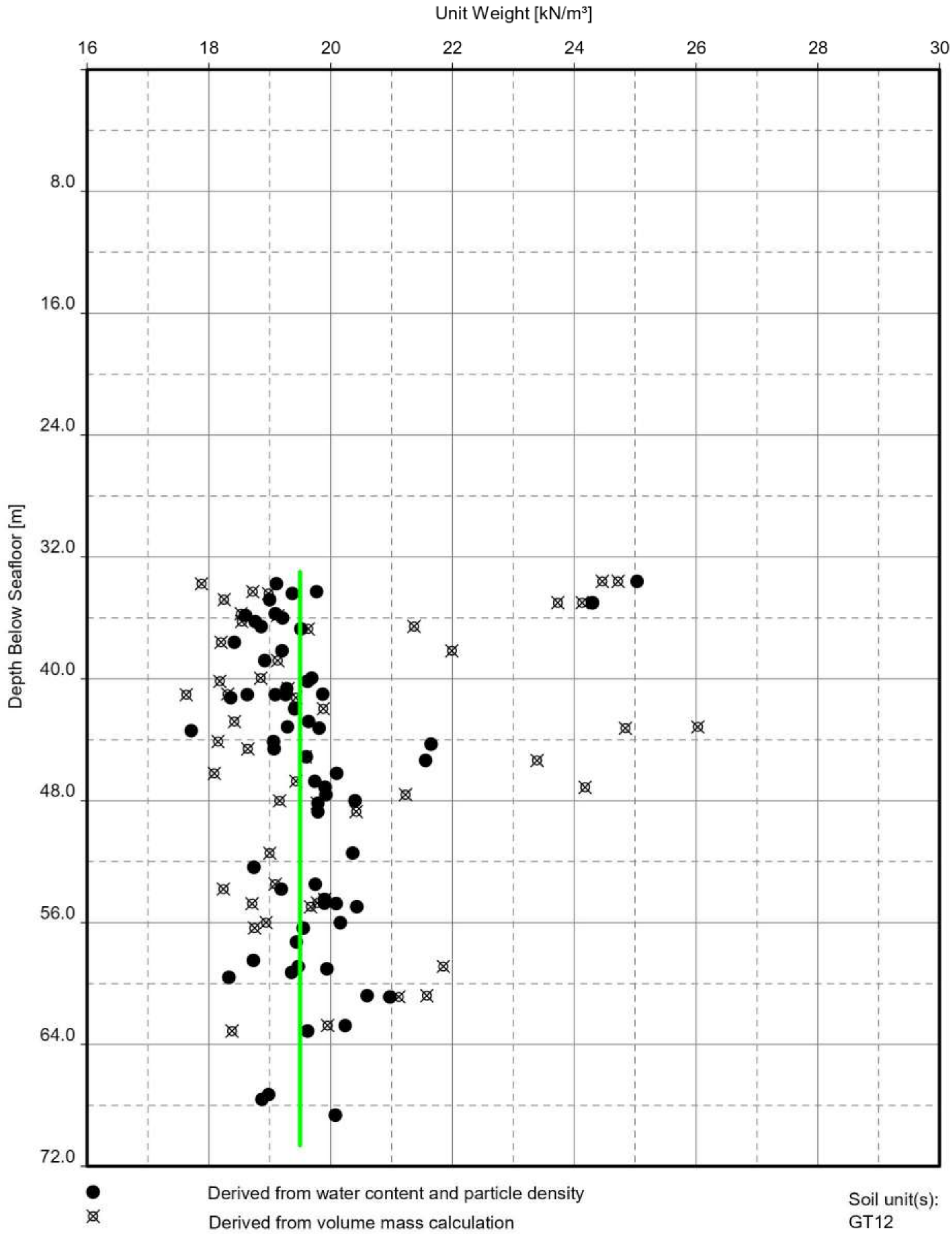


GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:22:56

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

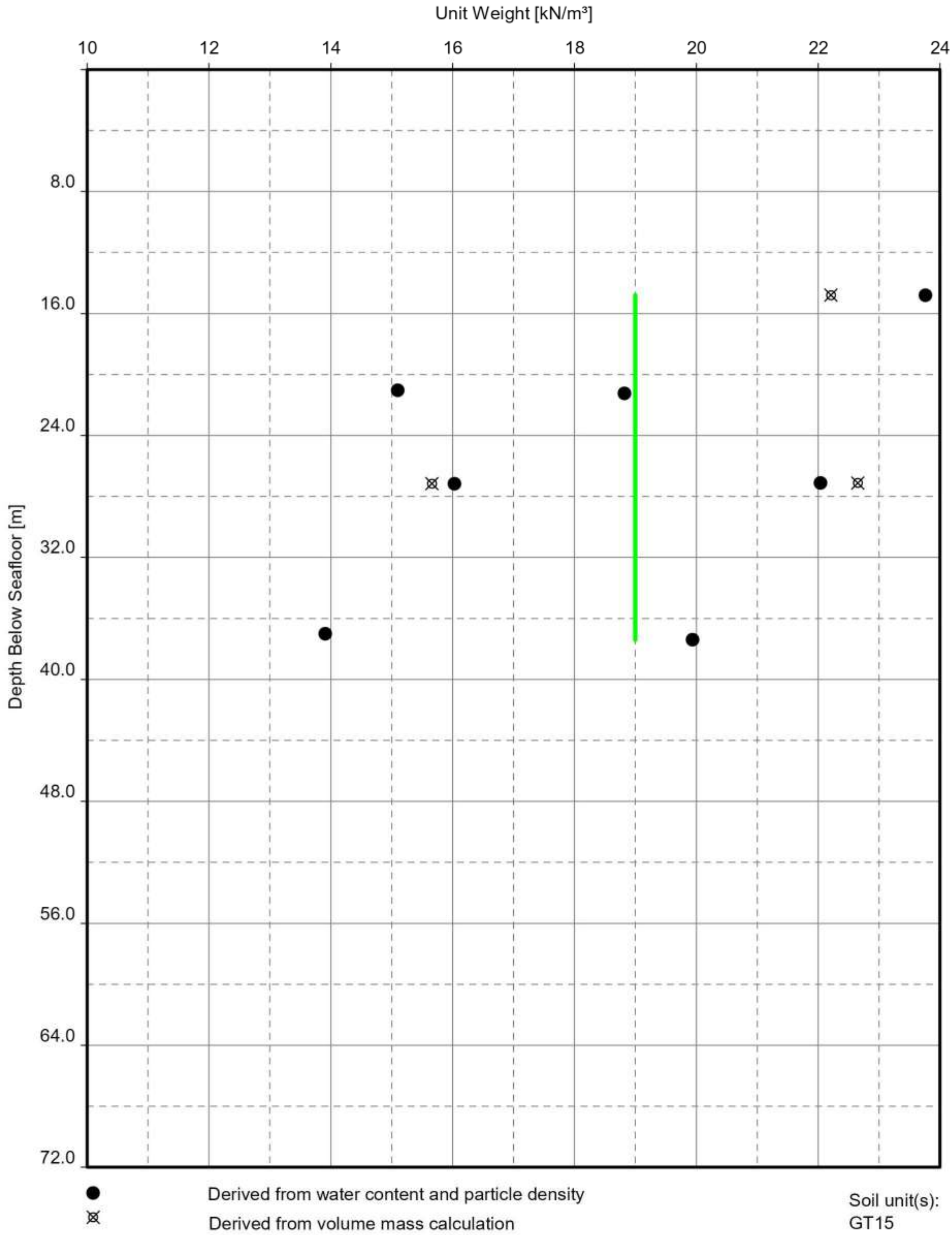
OWF

FUGRO



WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF

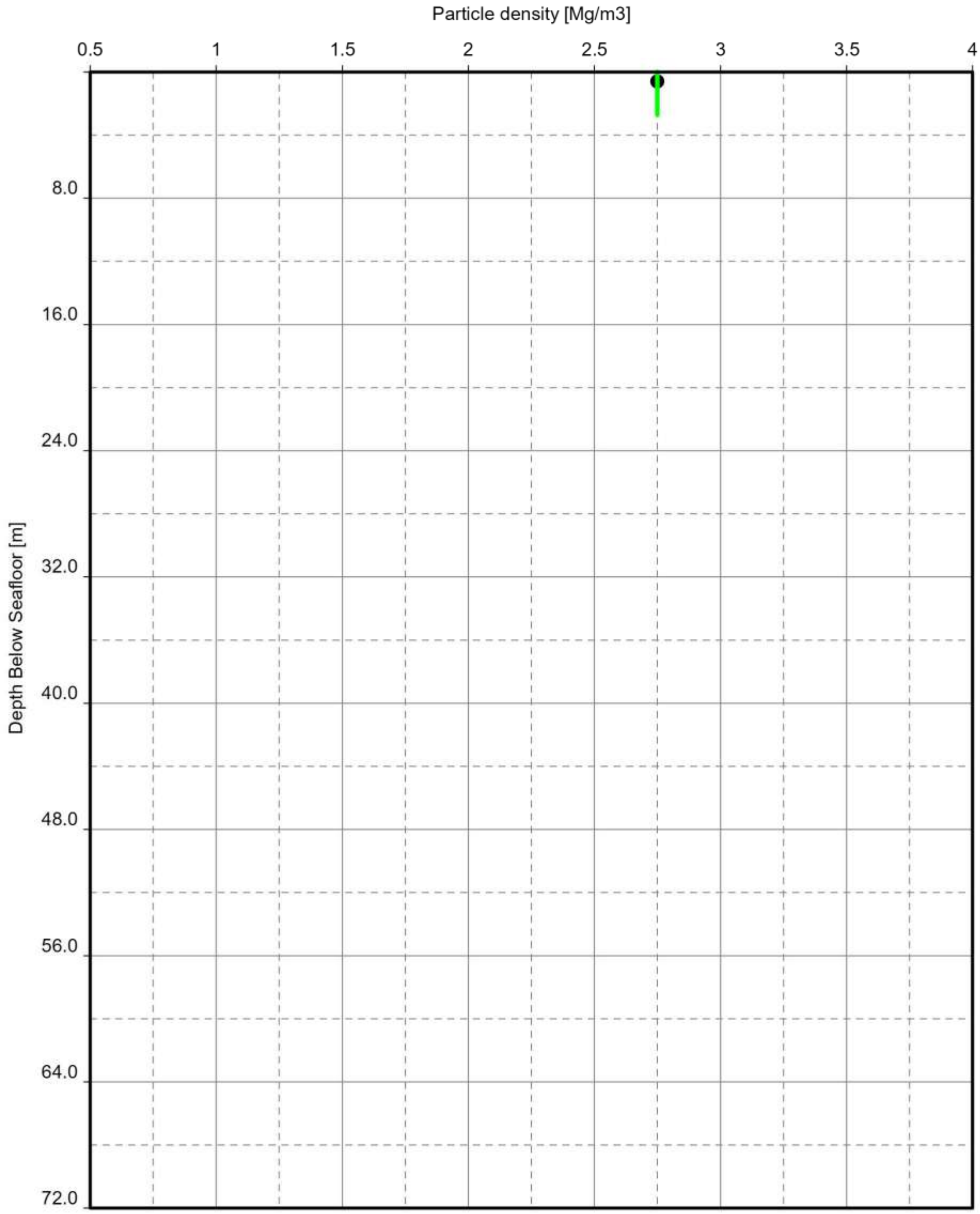


GeODin / Wet unit weight vs depth.GLO / 2024-05-06 @ 13:40:10

WET UNIT WEIGHT VERSUS DEPTH (TOTAL UNIT WEIGHT)

OWF

FUGRO

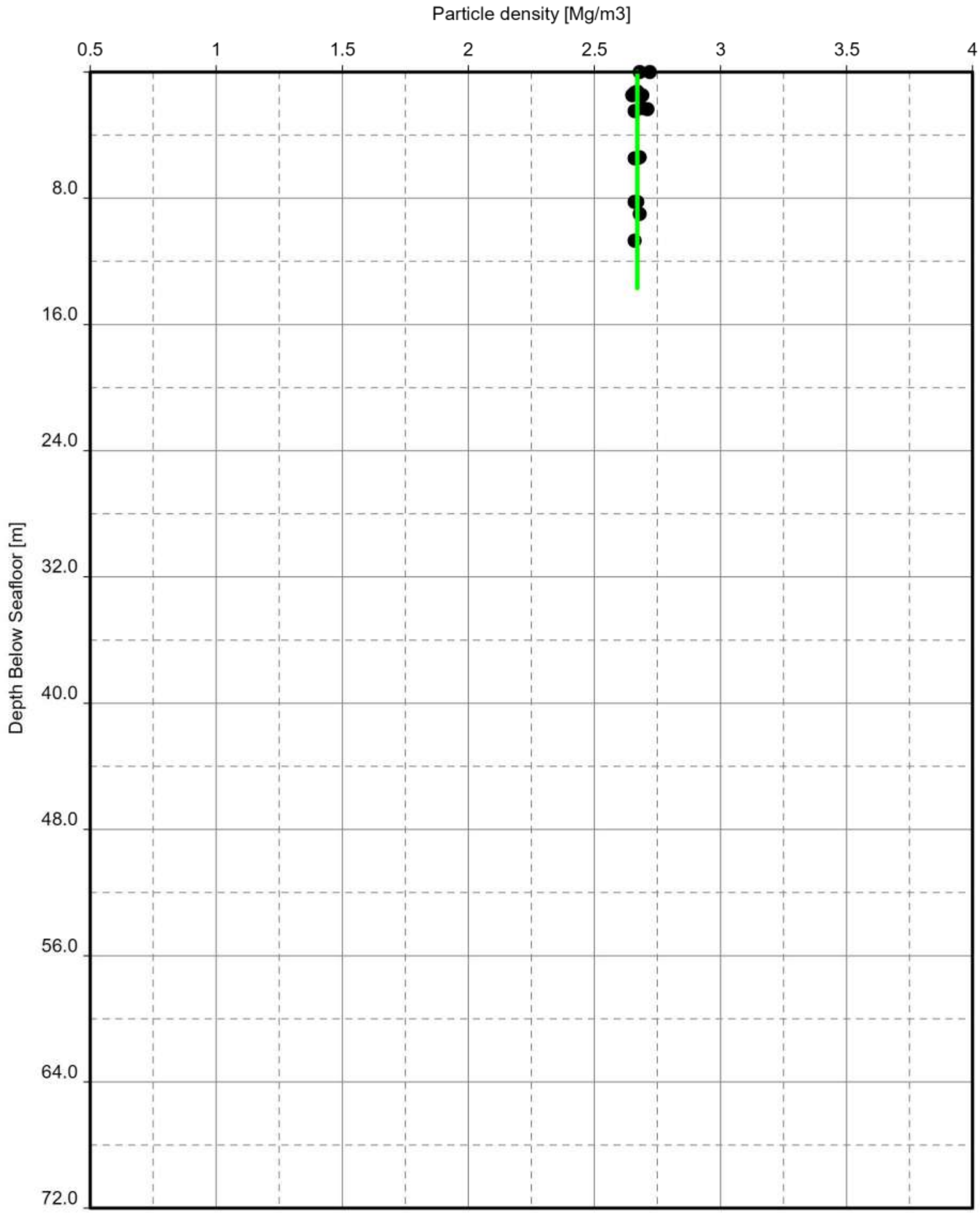


Soil unit(s):
GT1

OWF

PARTICLE DENSITY VERSUS DEPTH

OWF



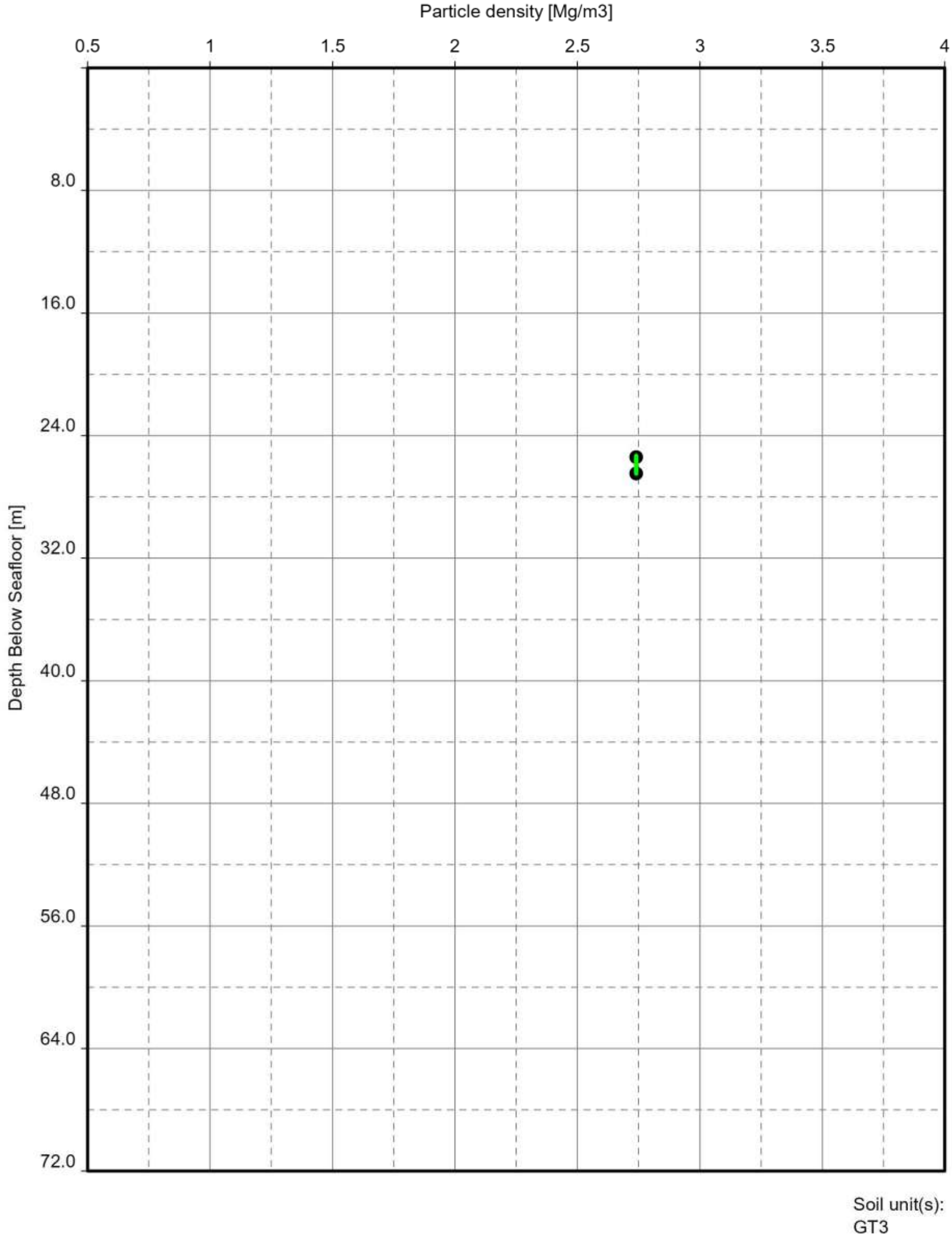
Soil unit(s):
GT2

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:09:57

PARTICLE DENSITY VERSUS DEPTH

OWF



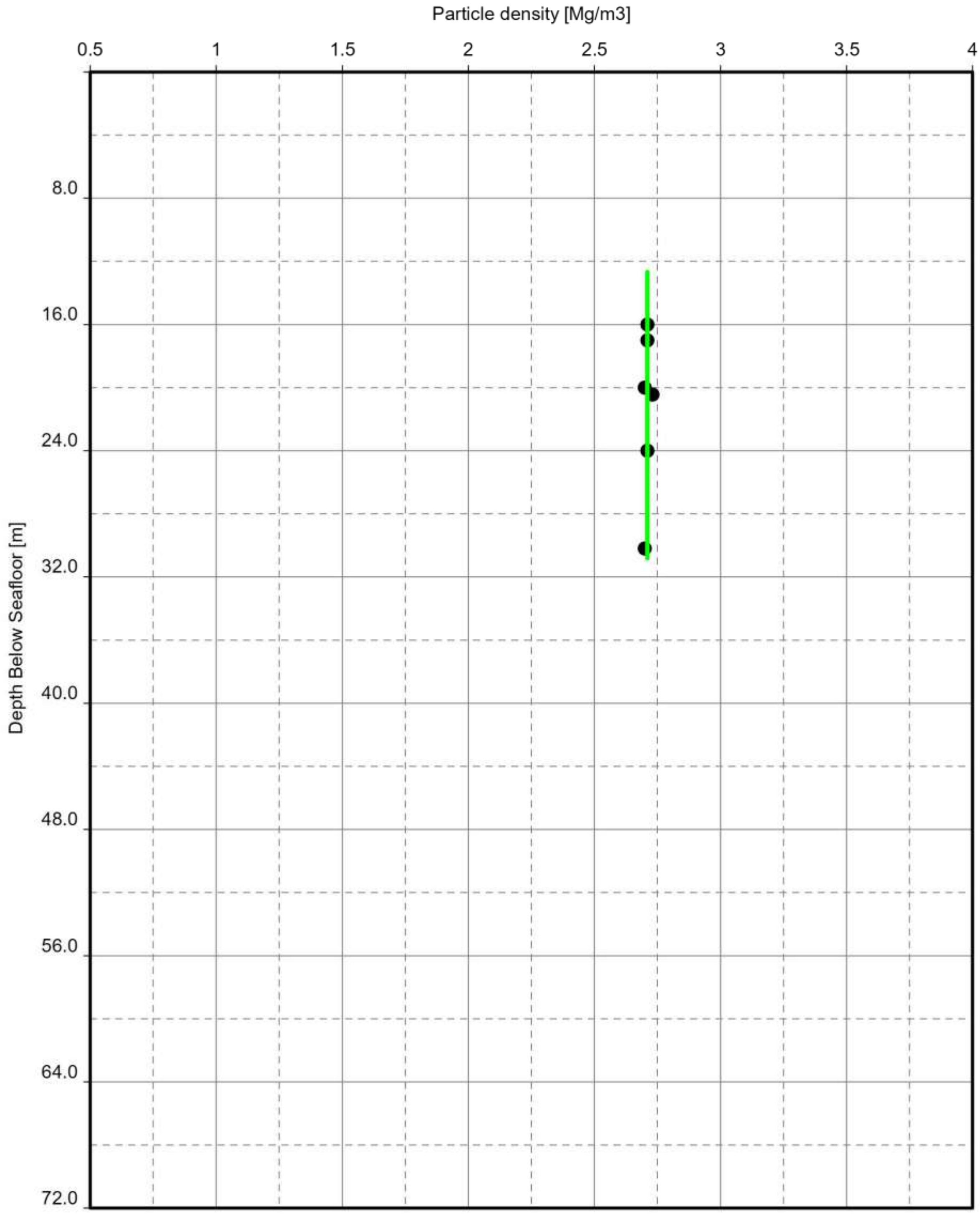
Soil unit(s):
GT3

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:09:06

PARTICLE DENSITY VERSUS DEPTH

OWF



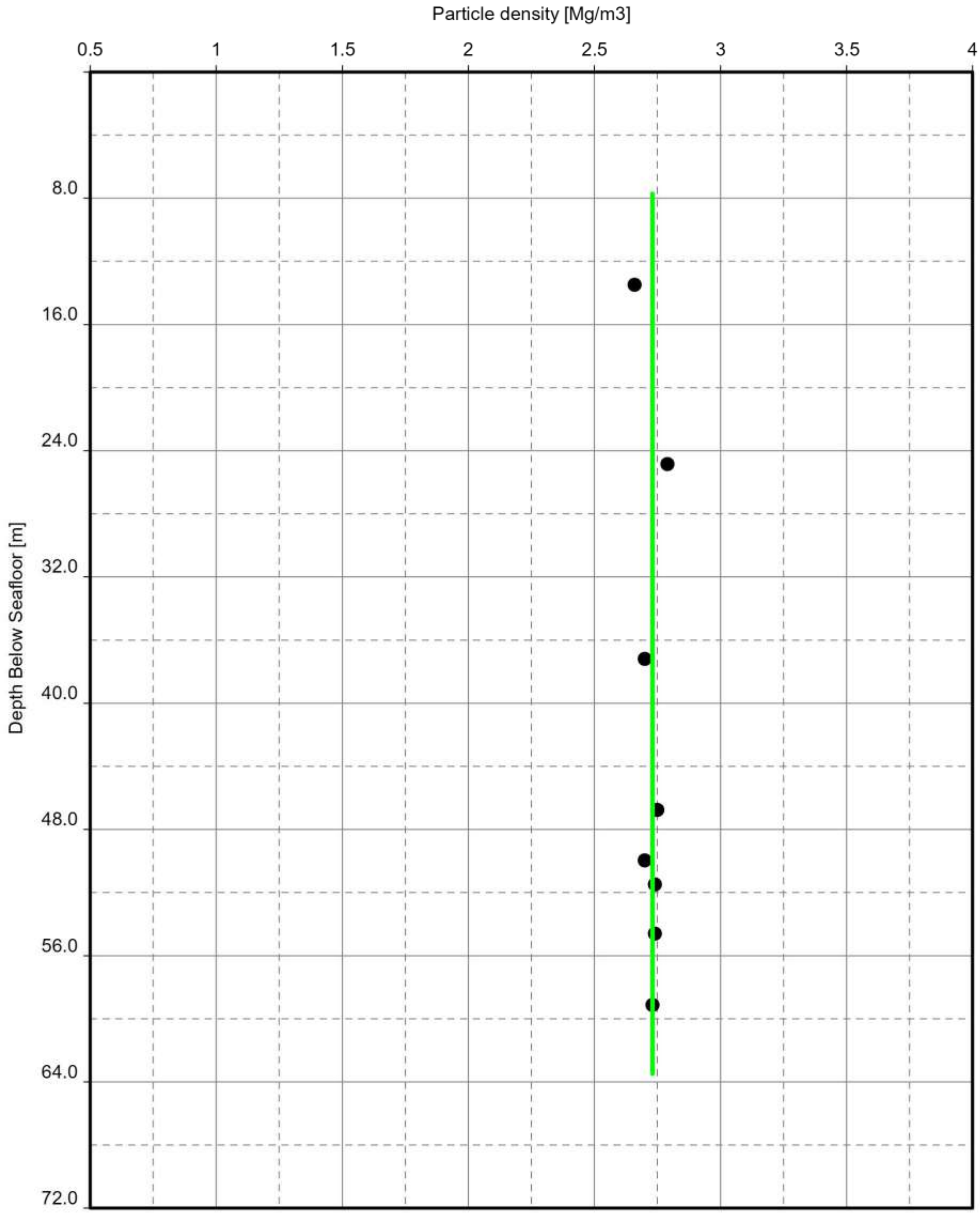
Soil unit(s):
GT4

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:11:32

PARTICLE DENSITY VERSUS DEPTH

OWF



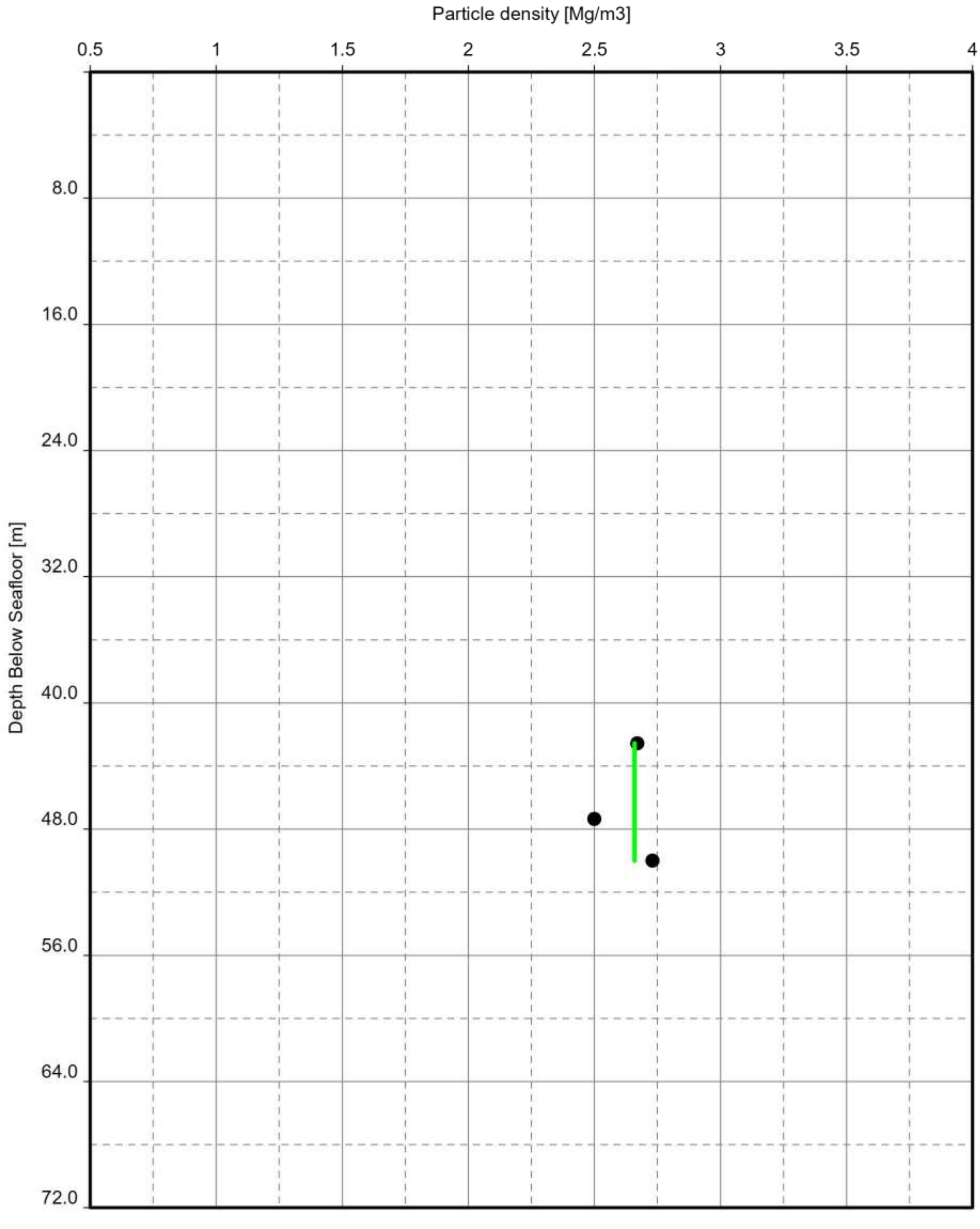
Soil unit(s):
GT7

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:13:07

PARTICLE DENSITY VERSUS DEPTH

OWF



Soil unit(s):
GT8

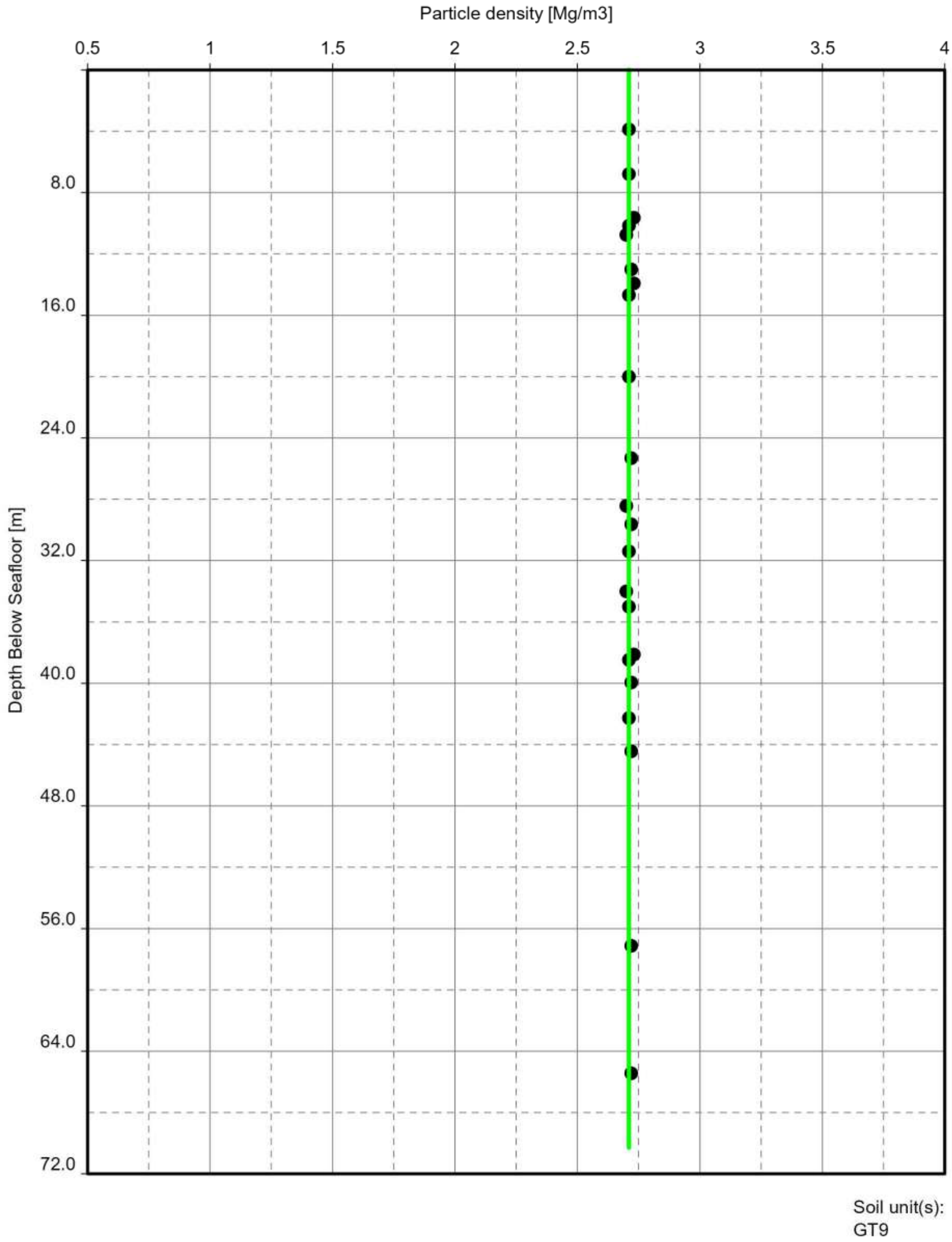
OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:15:53

PARTICLE DENSITY VERSUS DEPTH

OWF

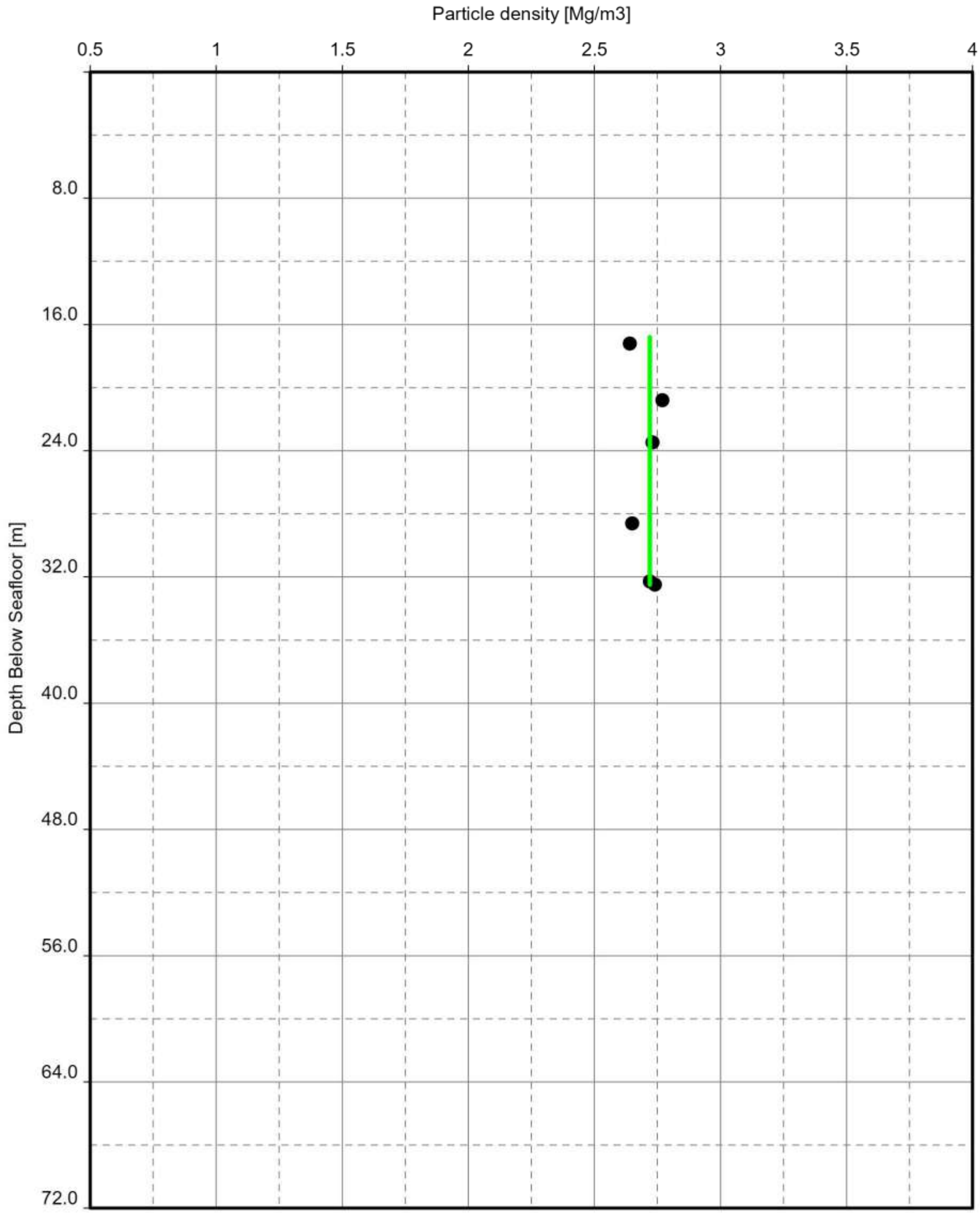
FUGRO



OWF

PARTICLE DENSITY VERSUS DEPTH

OWF



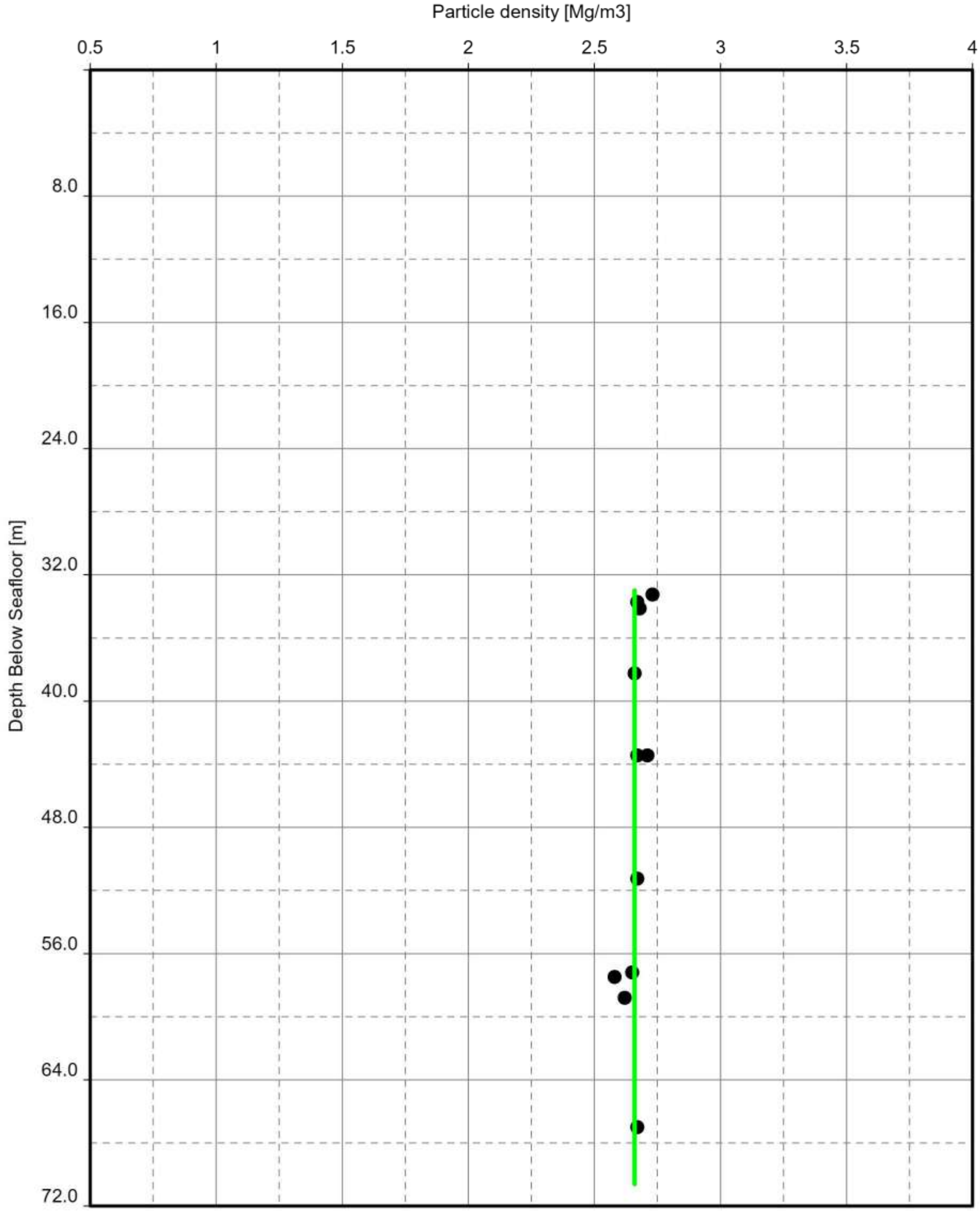
Soil unit(s):
GT11

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:17:55

PARTICLE DENSITY VERSUS DEPTH

OWF



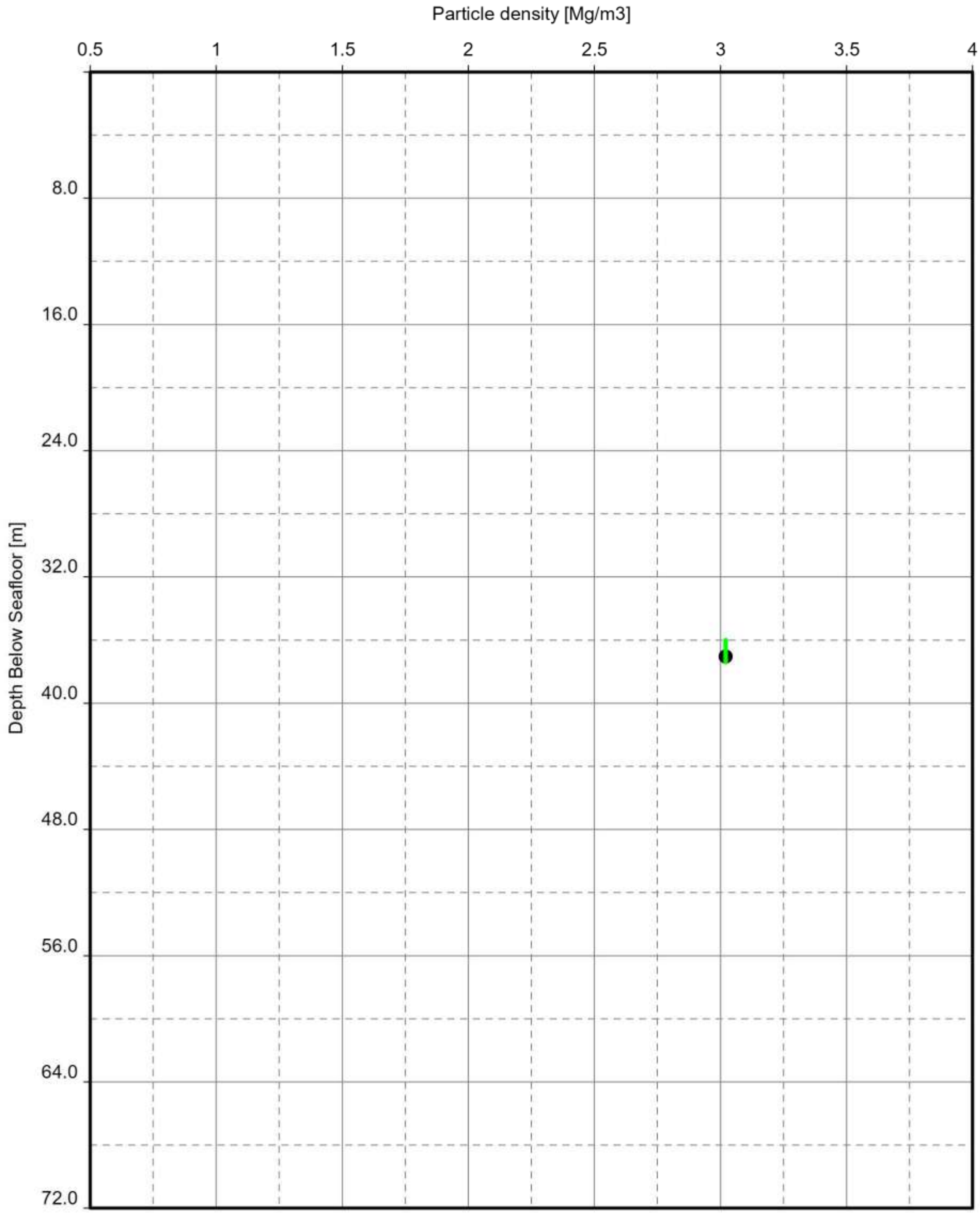
Soil unit(s):
GT12

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:18:32

PARTICLE DENSITY VERSUS DEPTH

OWF



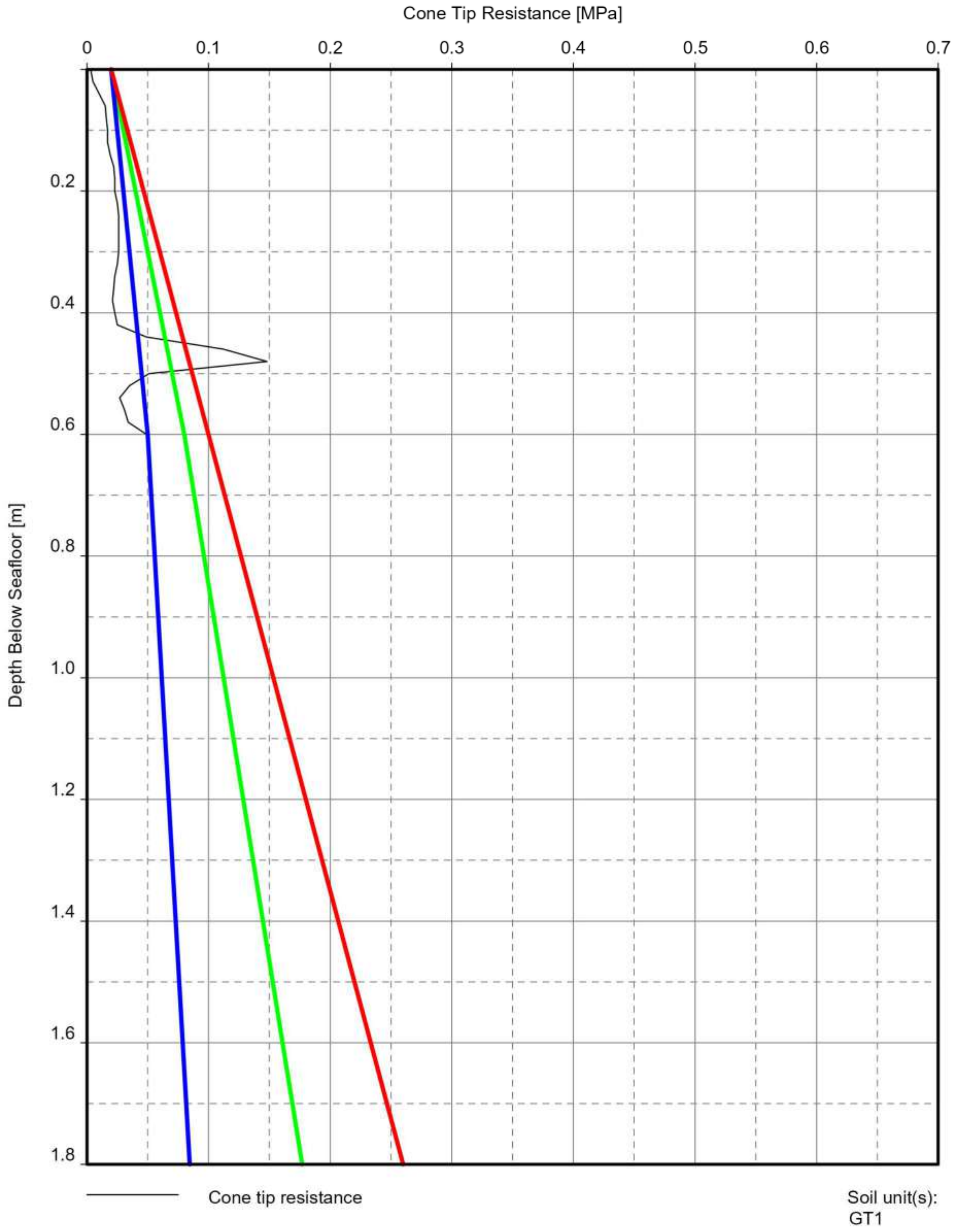
Soil unit(s):
GT15

OWF

GeODin / Particle density vs depth.GLO / 2024-05-06 @ 14:20:37

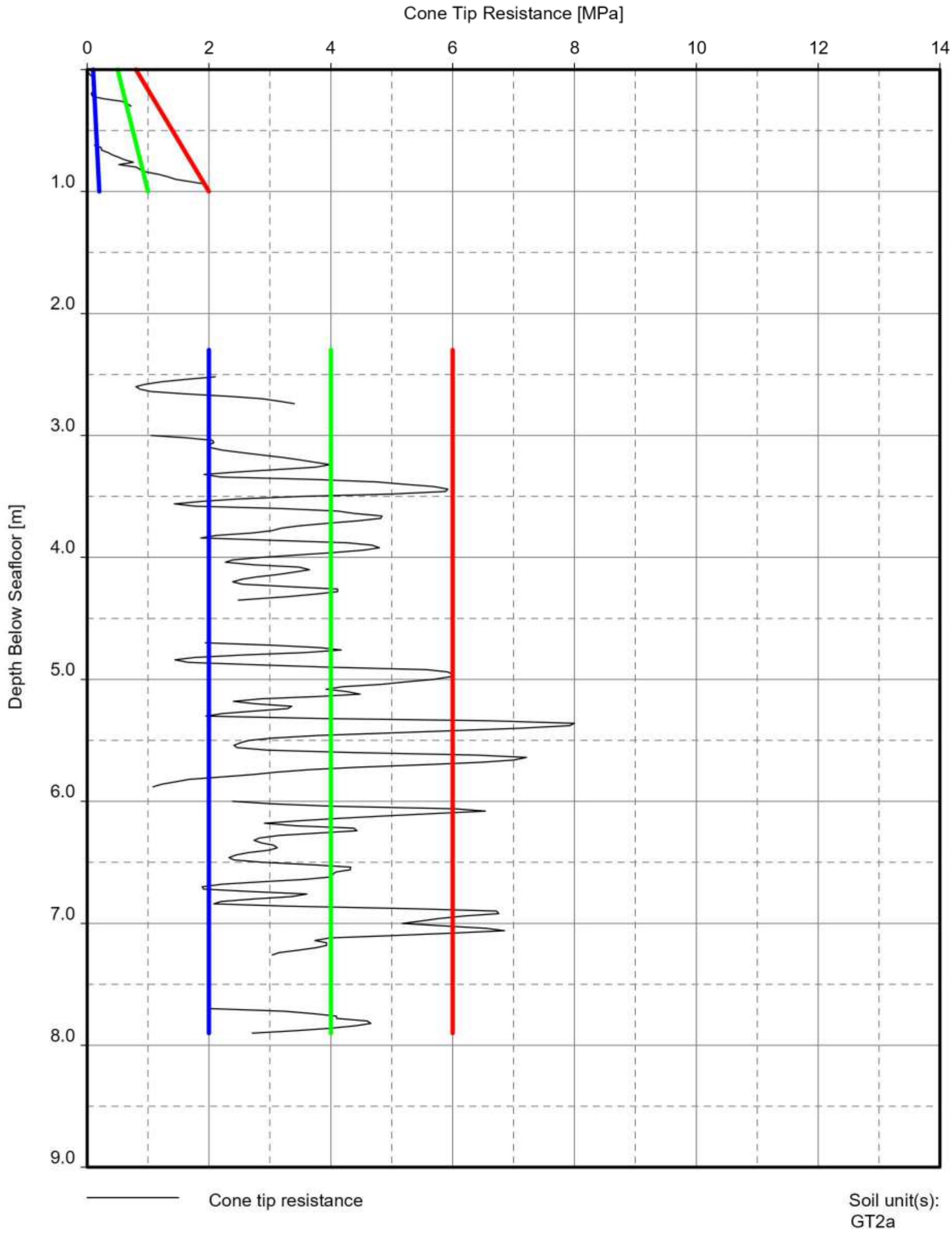
PARTICLE DENSITY VERSUS DEPTH

OWF



CONE TIP RESISTANCE VERSUS DEPTH

OWF

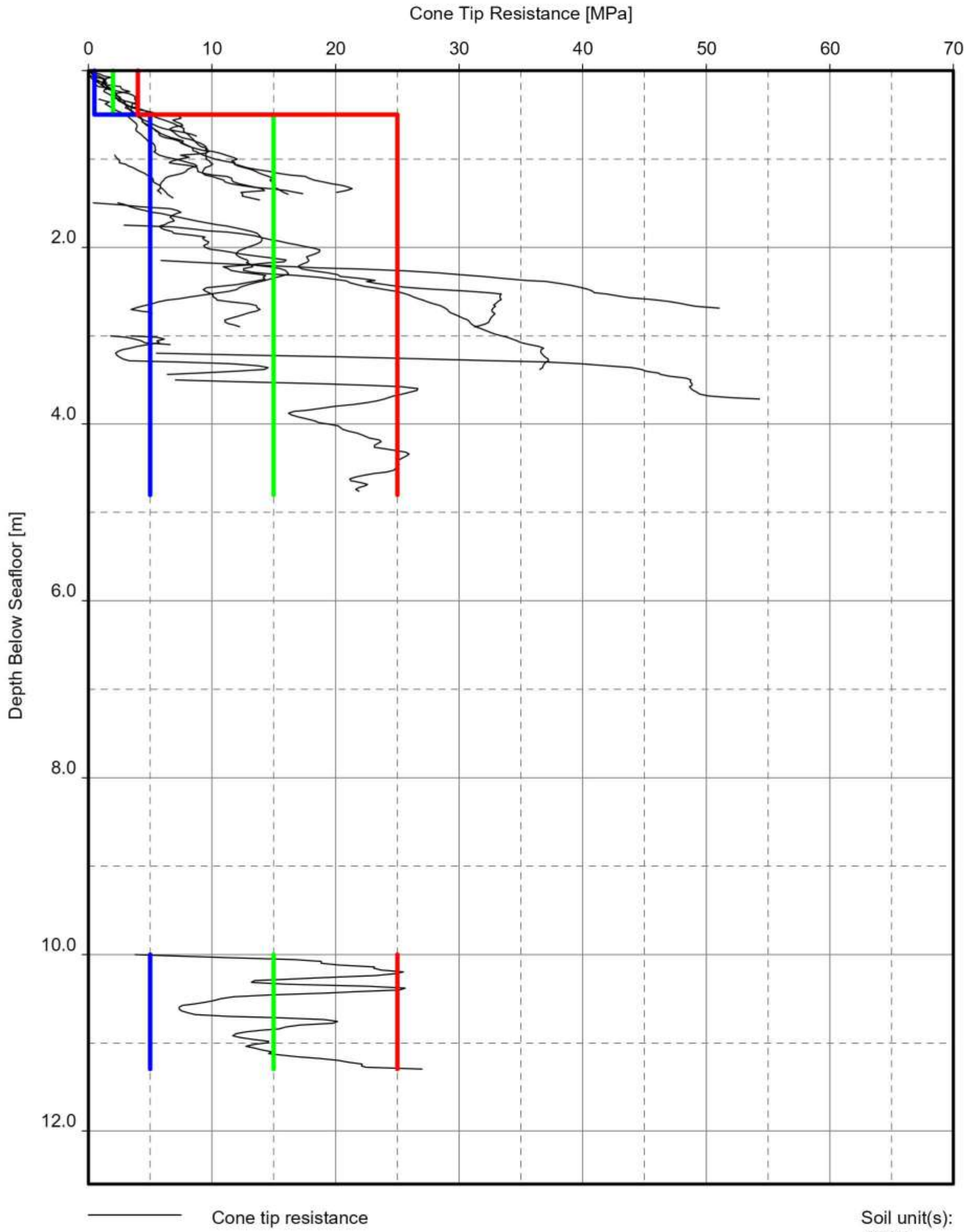


GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:27:24

CONE TIP RESISTANCE VERSUS DEPTH

OWF

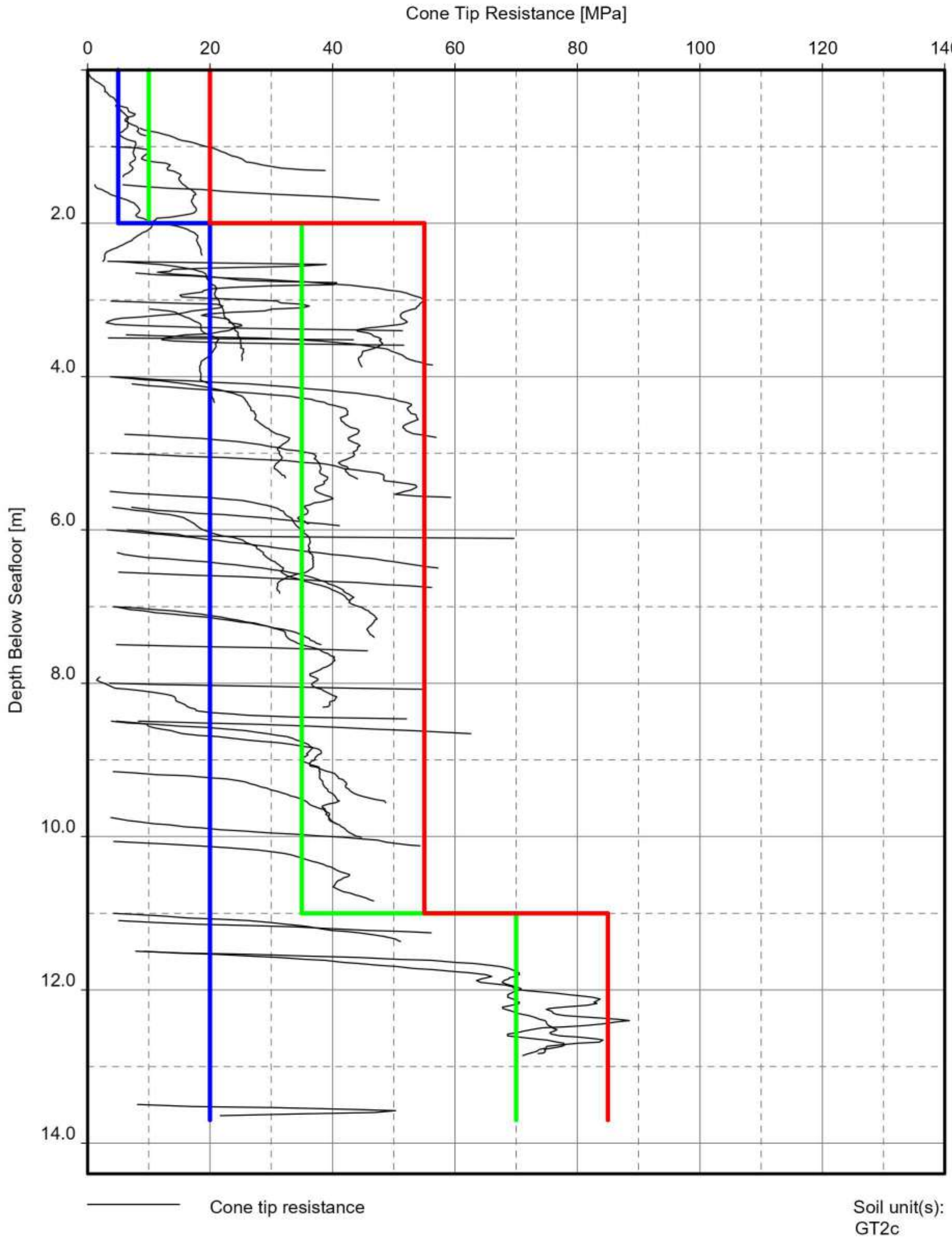
FUGRO



GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:33:10

CONE TIP RESISTANCE VERSUS DEPTH

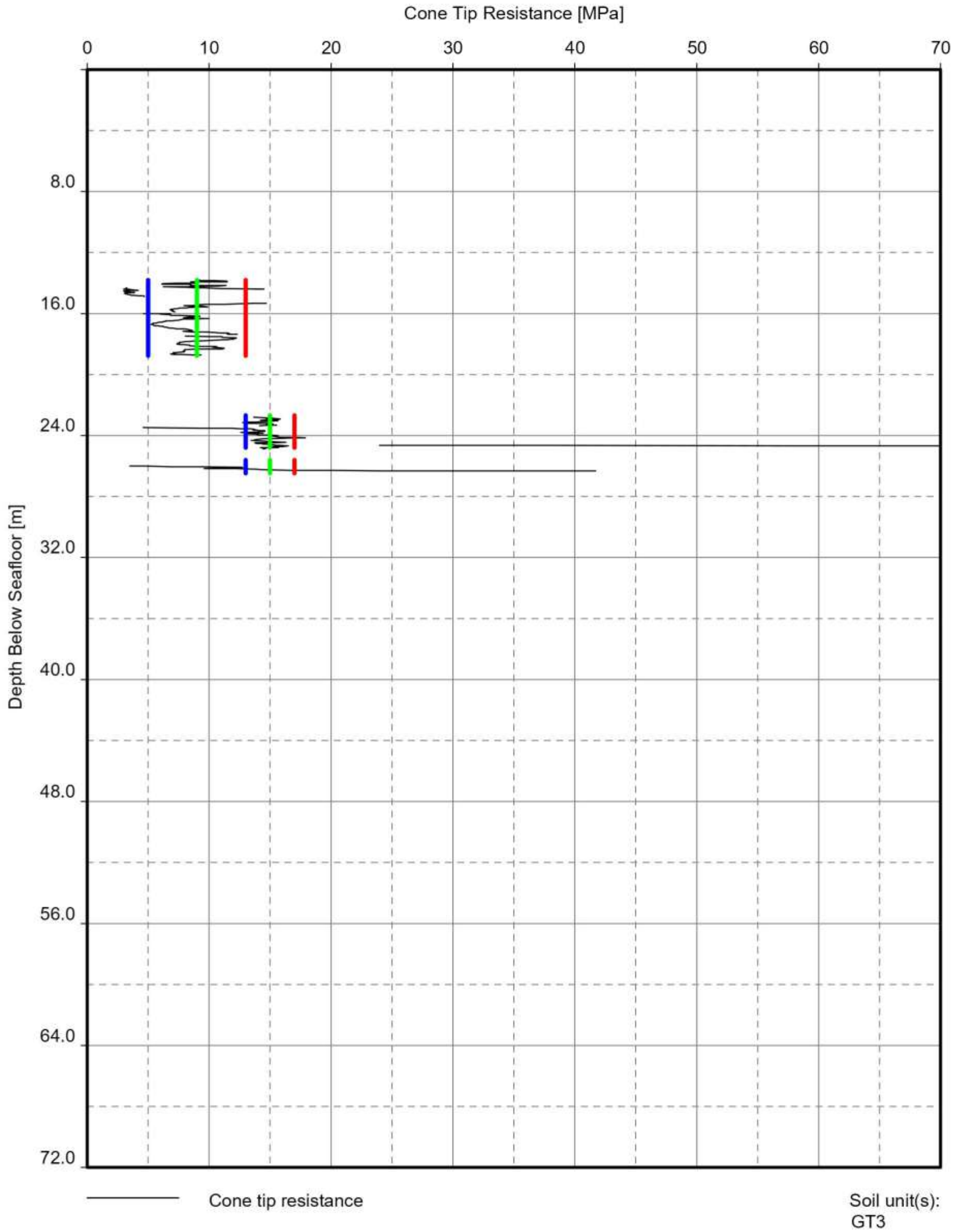
OWF



GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:32:08

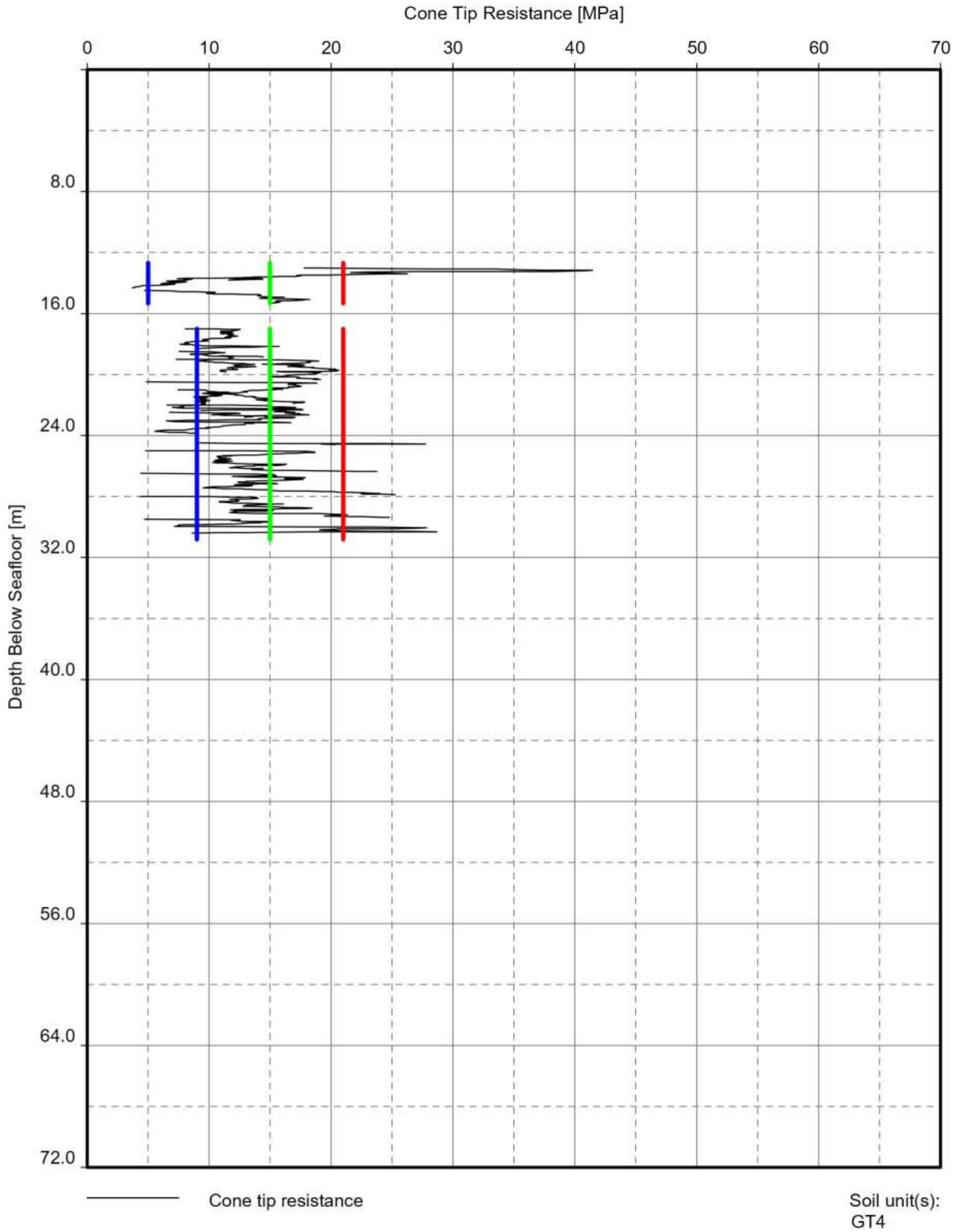
CONE TIP RESISTANCE VERSUS DEPTH

OWF



CONE TIP RESISTANCE VERSUS DEPTH

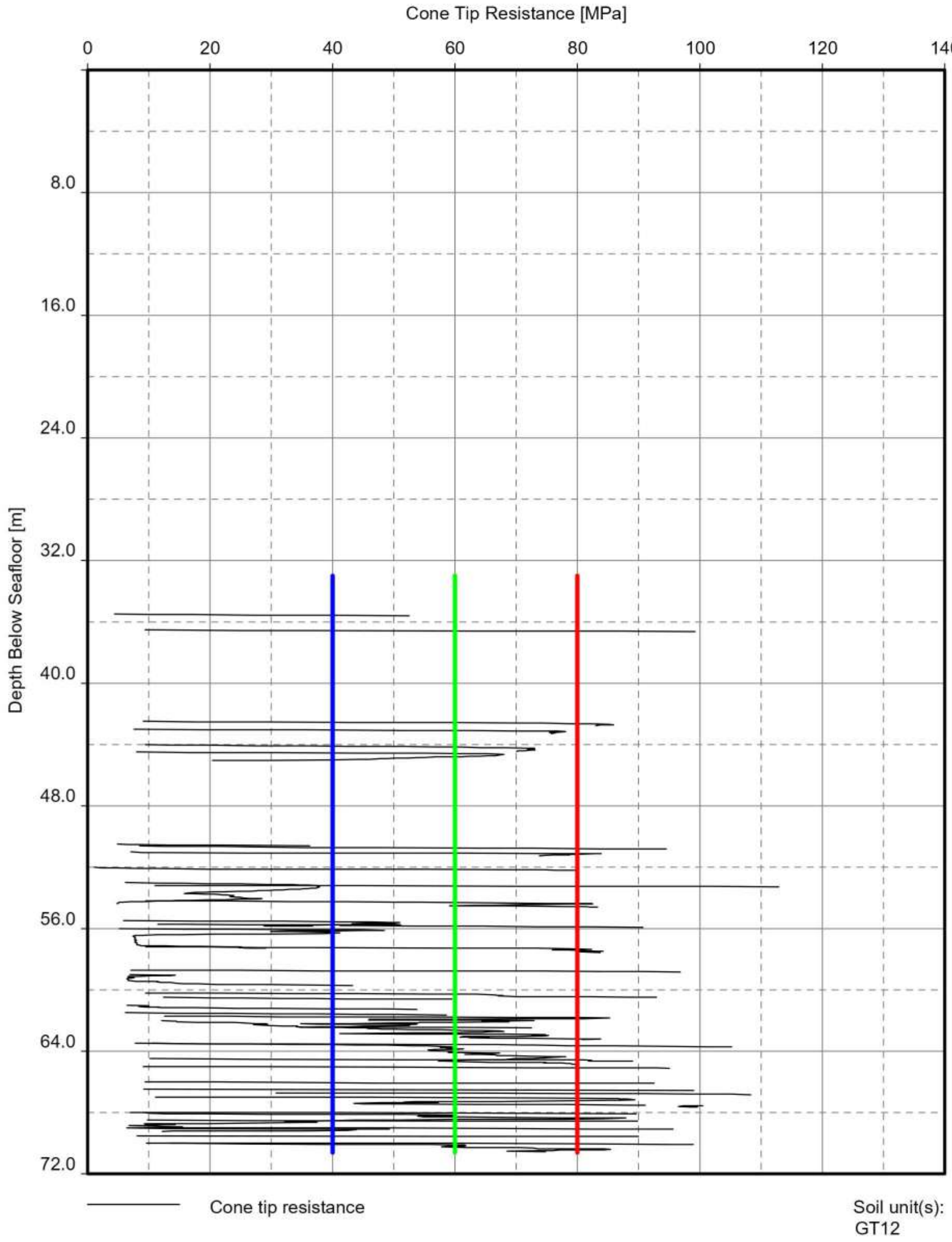
OWF



GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:36:11

CONE TIP RESISTANCE VERSUS DEPTH

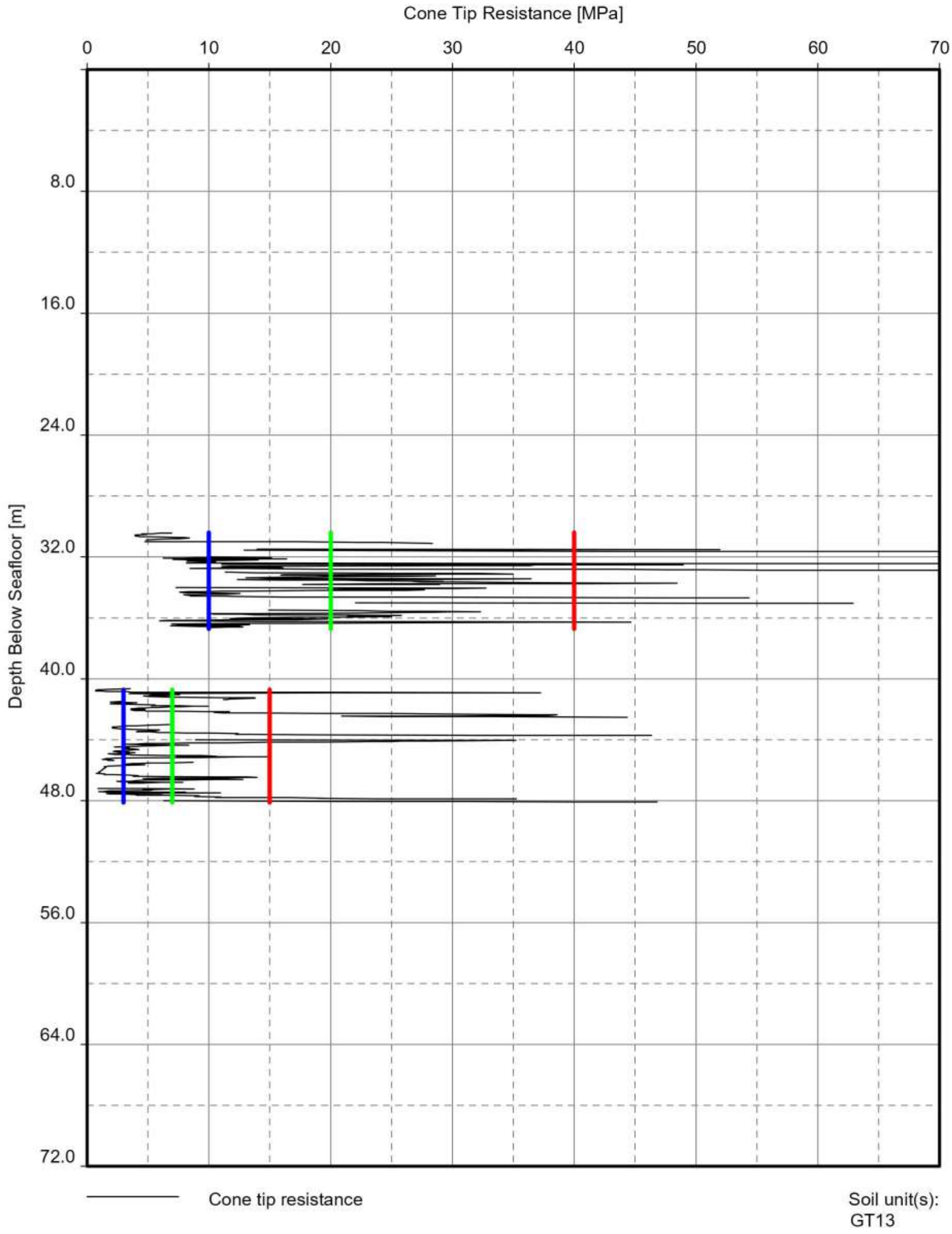
OWF



GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:38:10

CONE TIP RESISTANCE VERSUS DEPTH

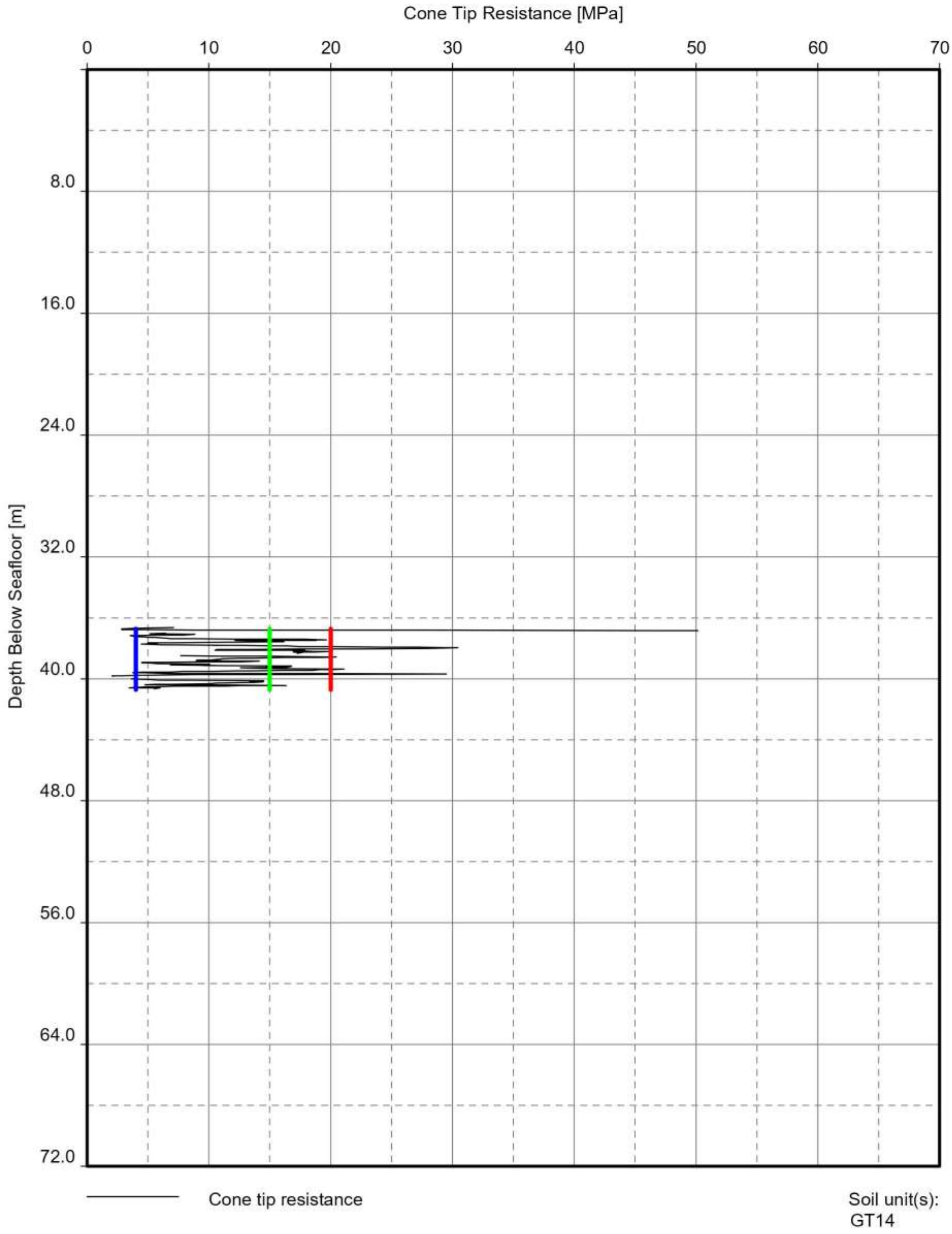
OWF



GeODin / cone tip resistance vs depth.GLO / 2024-05-06 @ 14:39:15

CONE TIP RESISTANCE VERSUS DEPTH

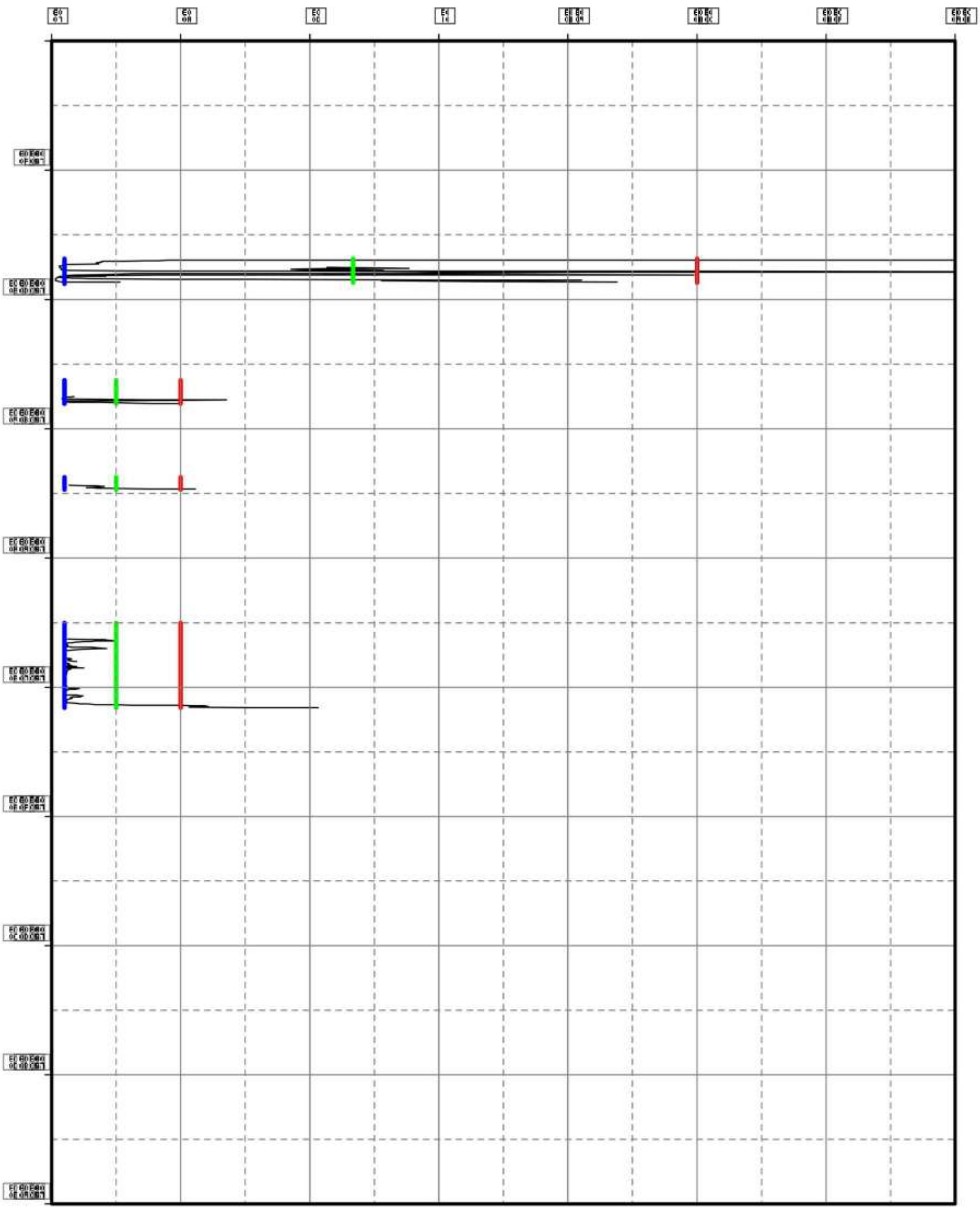
OWF

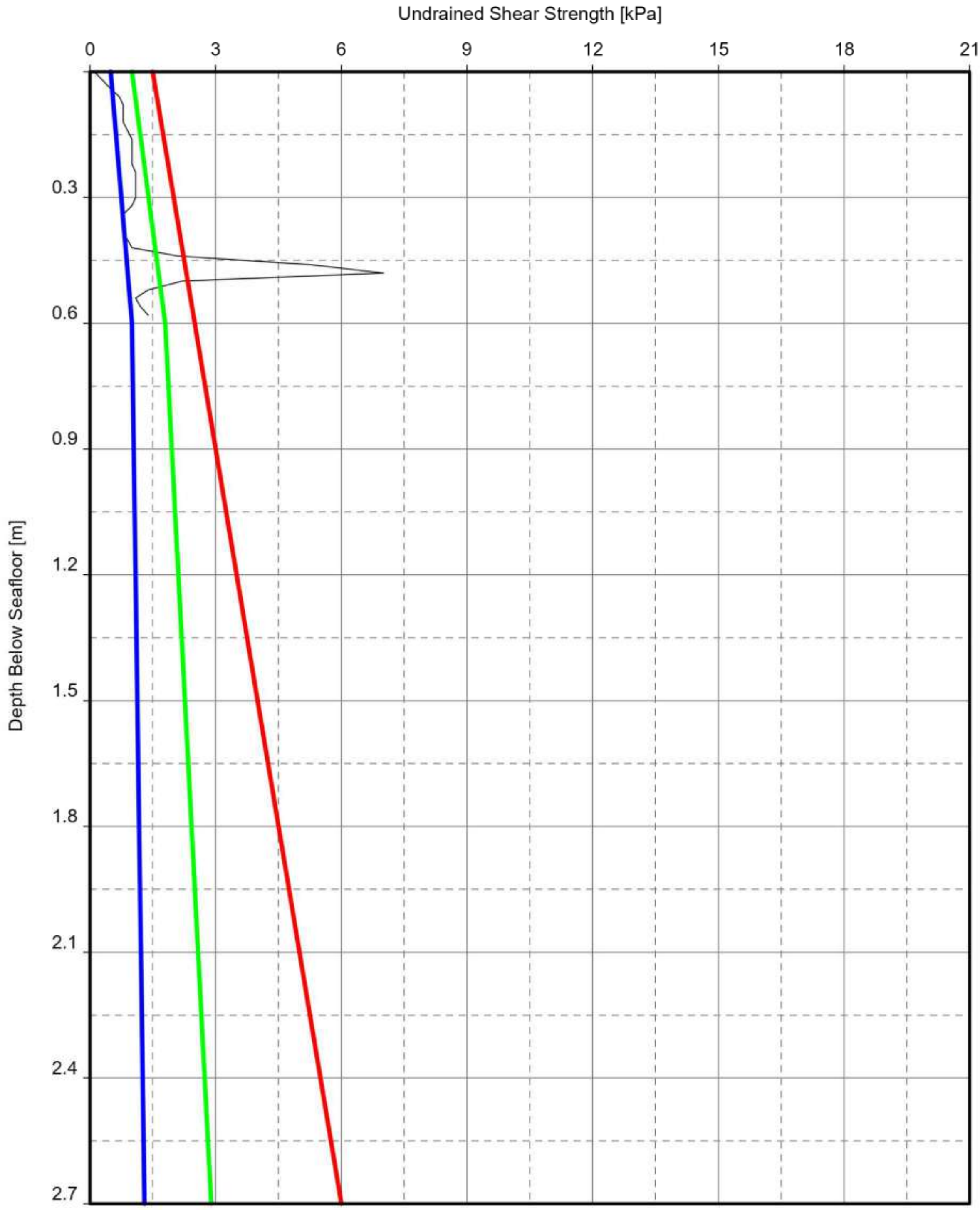


CONE TIP RESISTANCE VERSUS DEPTH

OWF

FUGRO





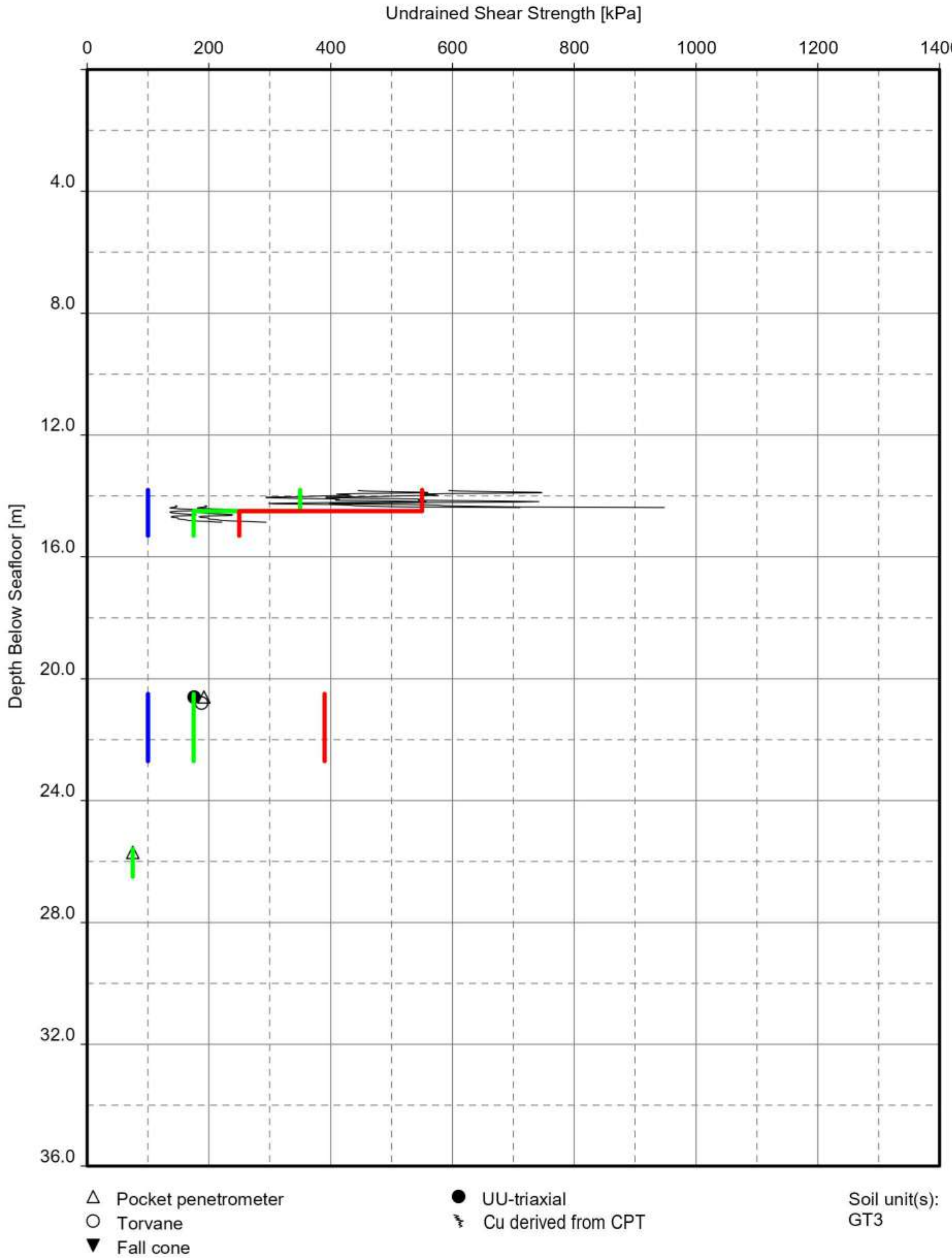
△ Pocket penetrometer
○ Torvane
▼ Fall cone
● UU-triaxial
Cu derived from CPT

Soil unit(s):
GT1

Note(s):
- Cu derived from CPT base on factor of Nk = 15 and 20

UNDRAINED SHEAR STRENGTH VERSUS DEPTH

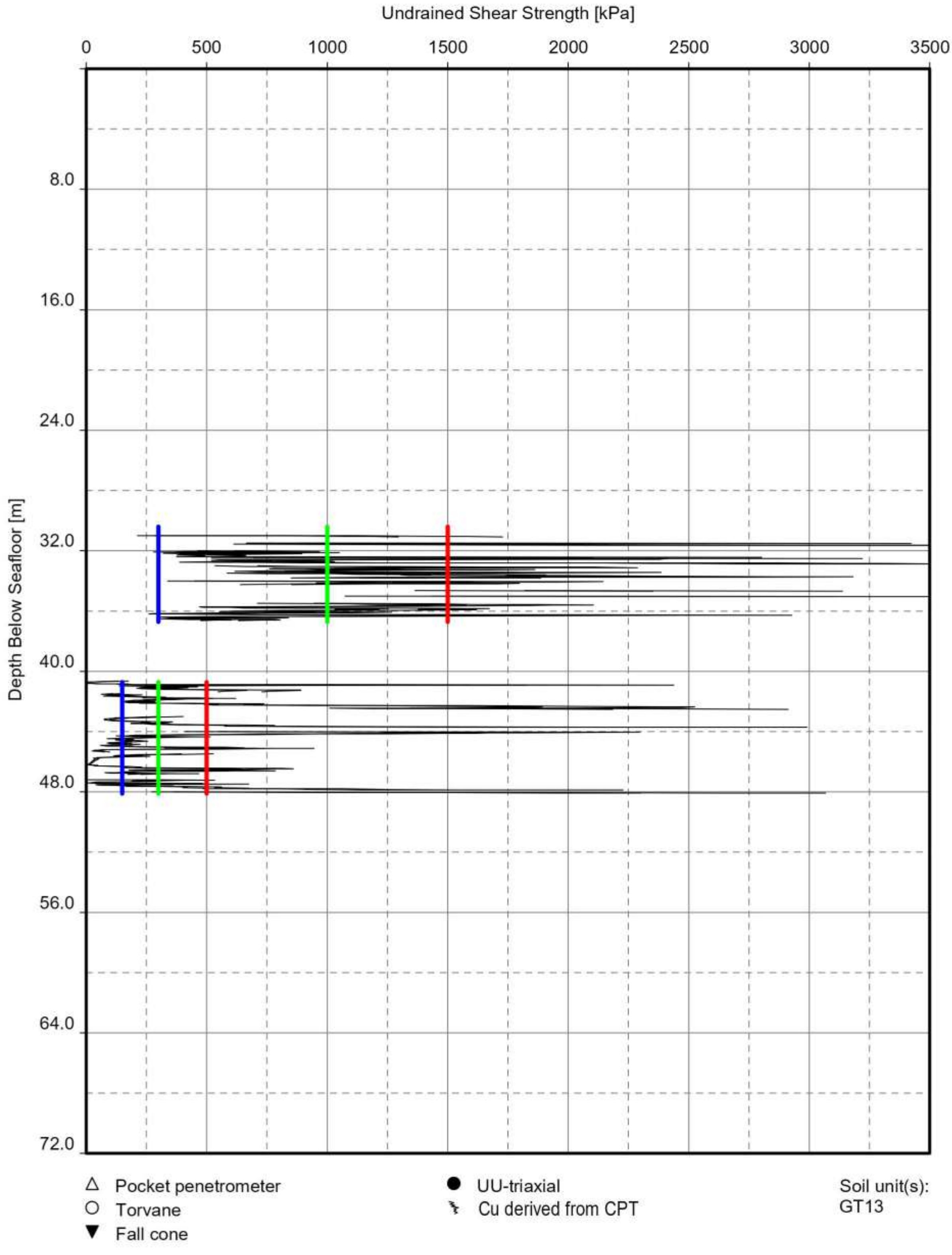
FUGRO



Note(s):
- Cu derived from CPT base on factor of Nk = 15 and 20

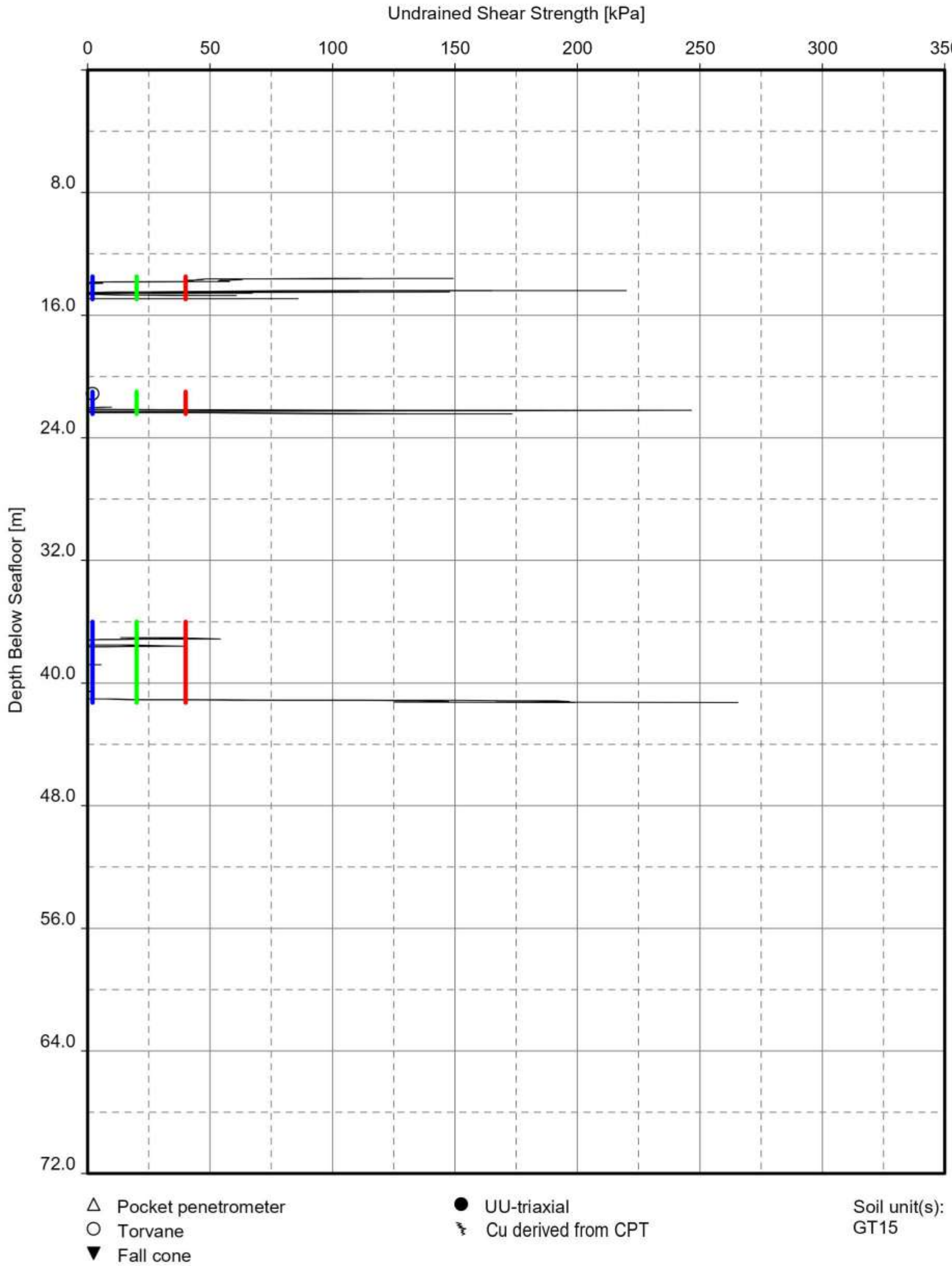
GeODin / Undrained shear strength vs depth.GLO / 2024-05-06 @ 15:51:31

UNDRAINED SHEAR STRENGTH VERSUS DEPTH



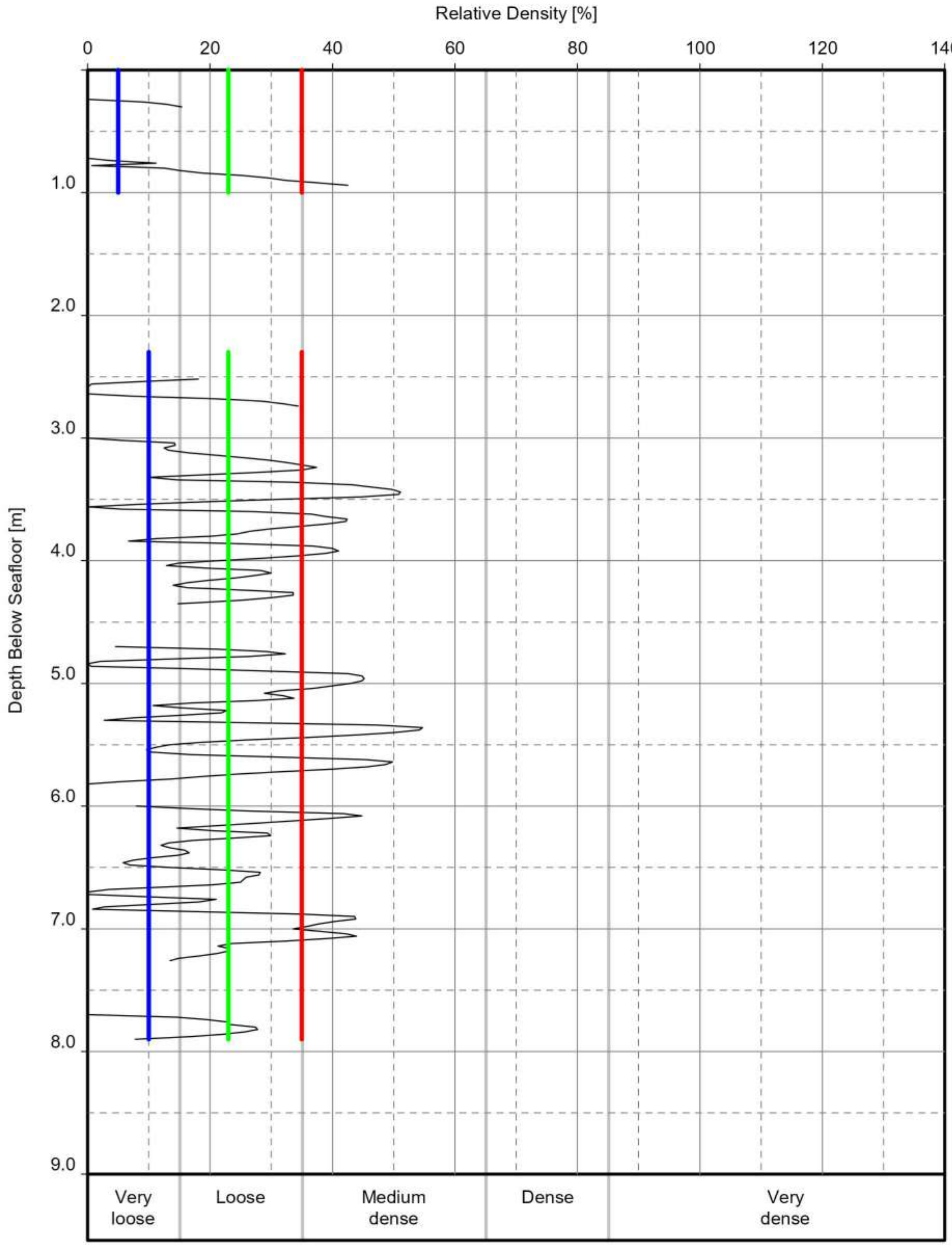
Note(s):
- Cu derived from CPT base on factor of Nk = 15 and 20

UNDRAINED SHEAR STRENGTH VERSUS DEPTH



Note(s):
- Cu derived from CPT base on factor of Nk = 15 and 20

UNDRAINED SHEAR STRENGTH VERSUS DEPTH



Derived from CPT (with K0=0.5 and K0=1.0)

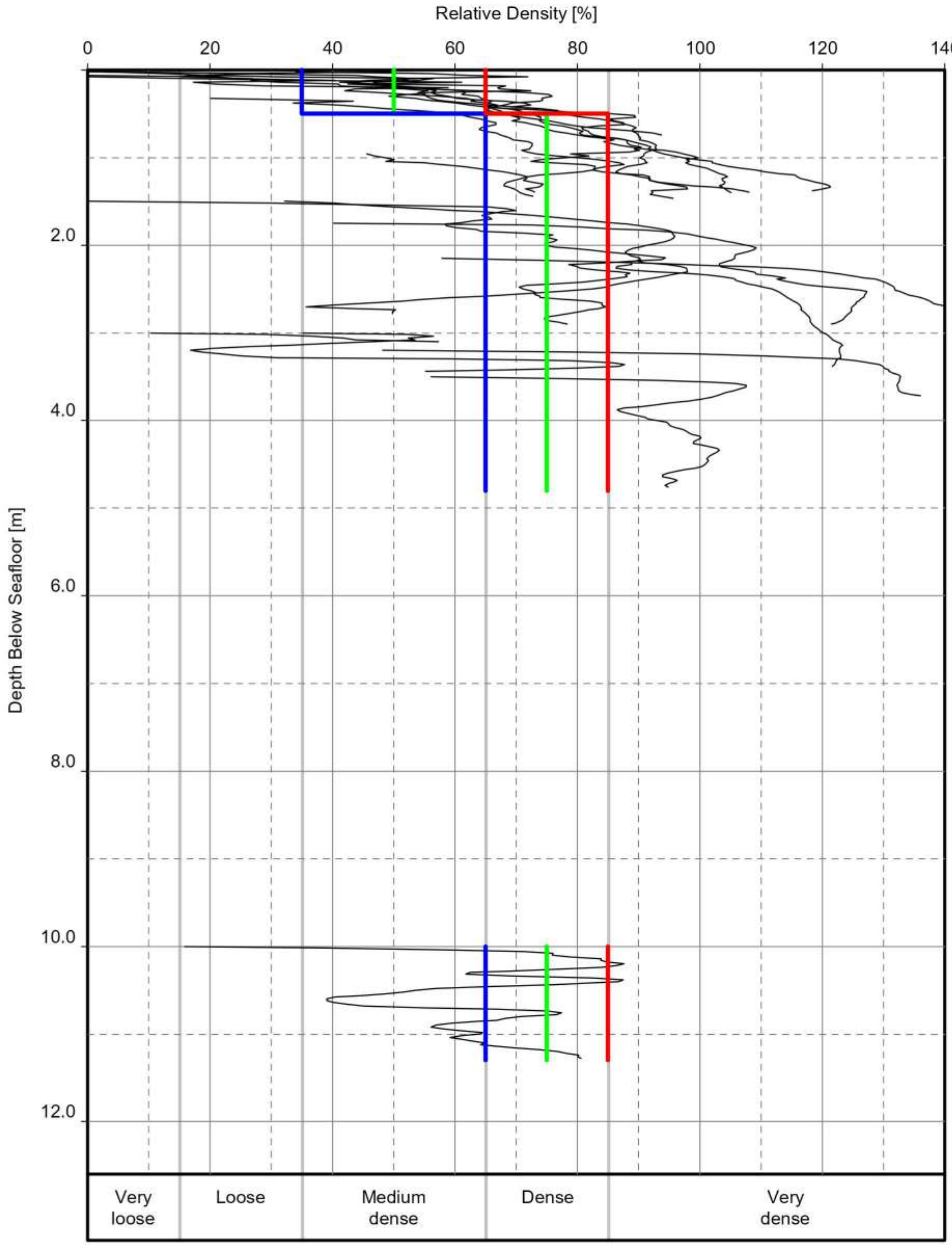
Soil unit(s):
GT2a

GeODin / Relative density vs depth.GLO / 2024-05-06 @ 16:29:06

RELATIVE DENSITY VERSUS DEPTH

OWF

FUGRO



Derived from CPT (with K0=0.5 and K0=1.0)

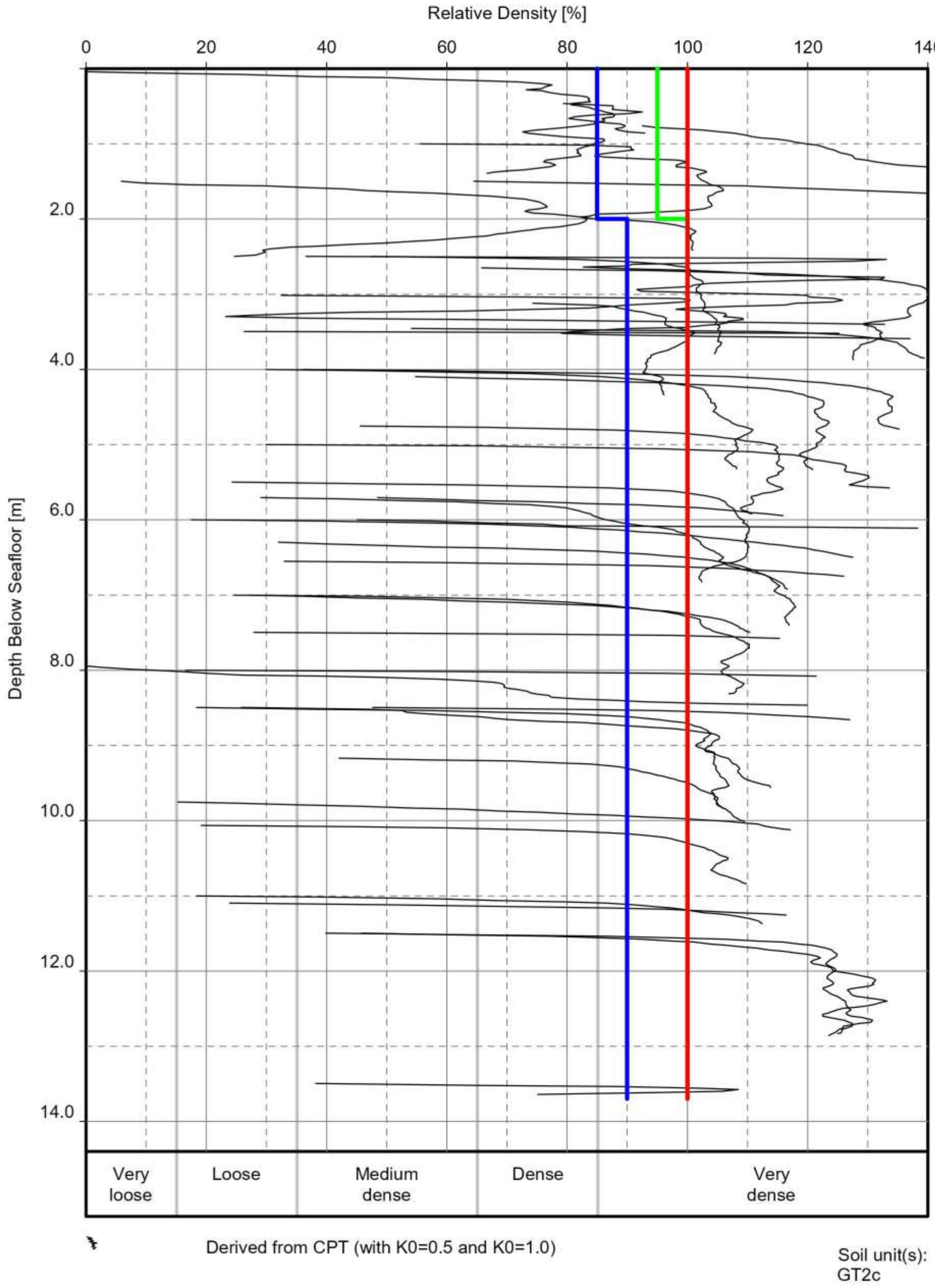
Soil unit(s):
GT2b

GeODin / Relative density vs depth.GLO / 2024-05-06 @ 16:30:06

RELATIVE DENSITY VERSUS DEPTH

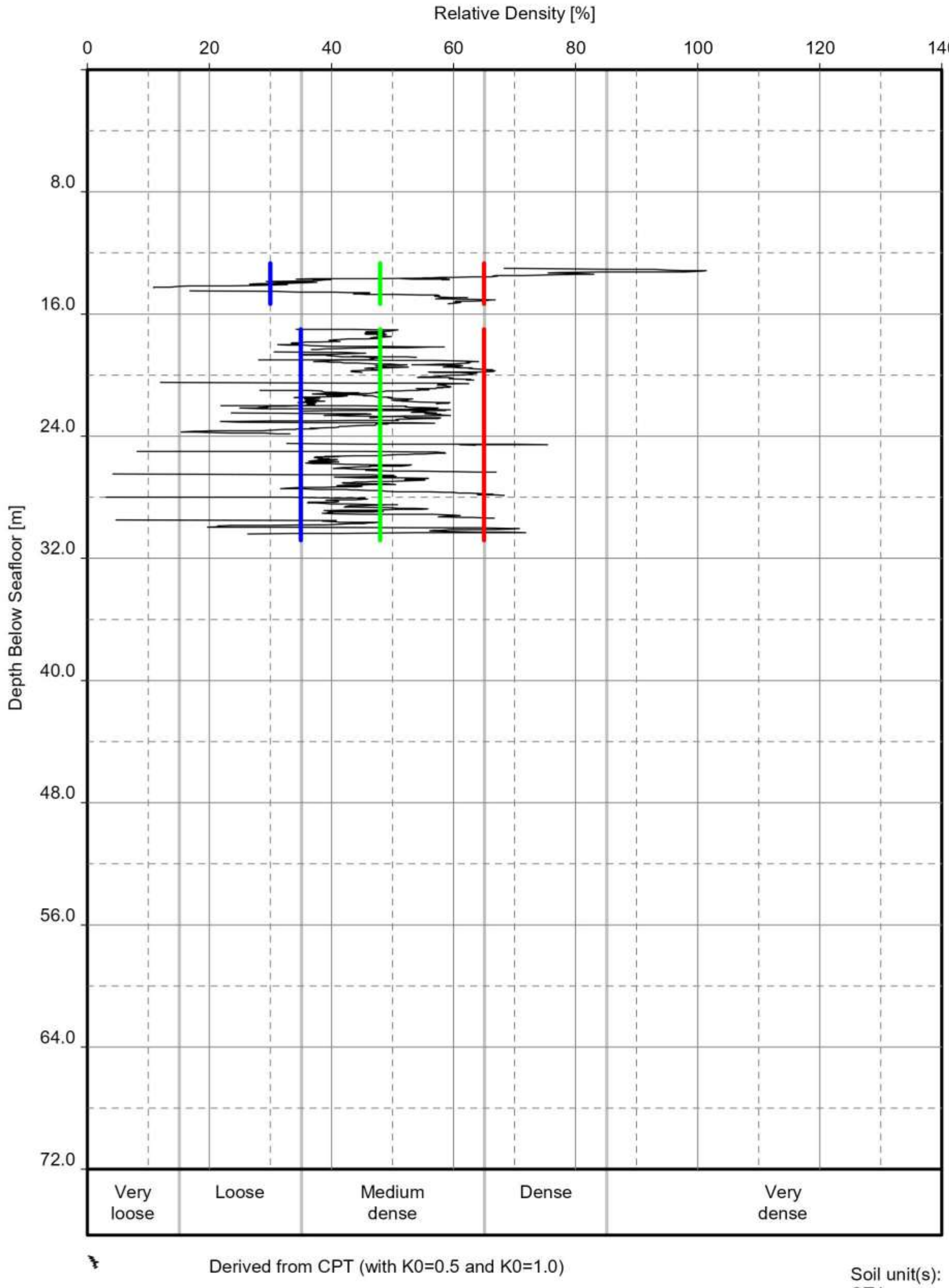
OWF

FUGRO



RELATIVE DENSITY VERSUS DEPTH

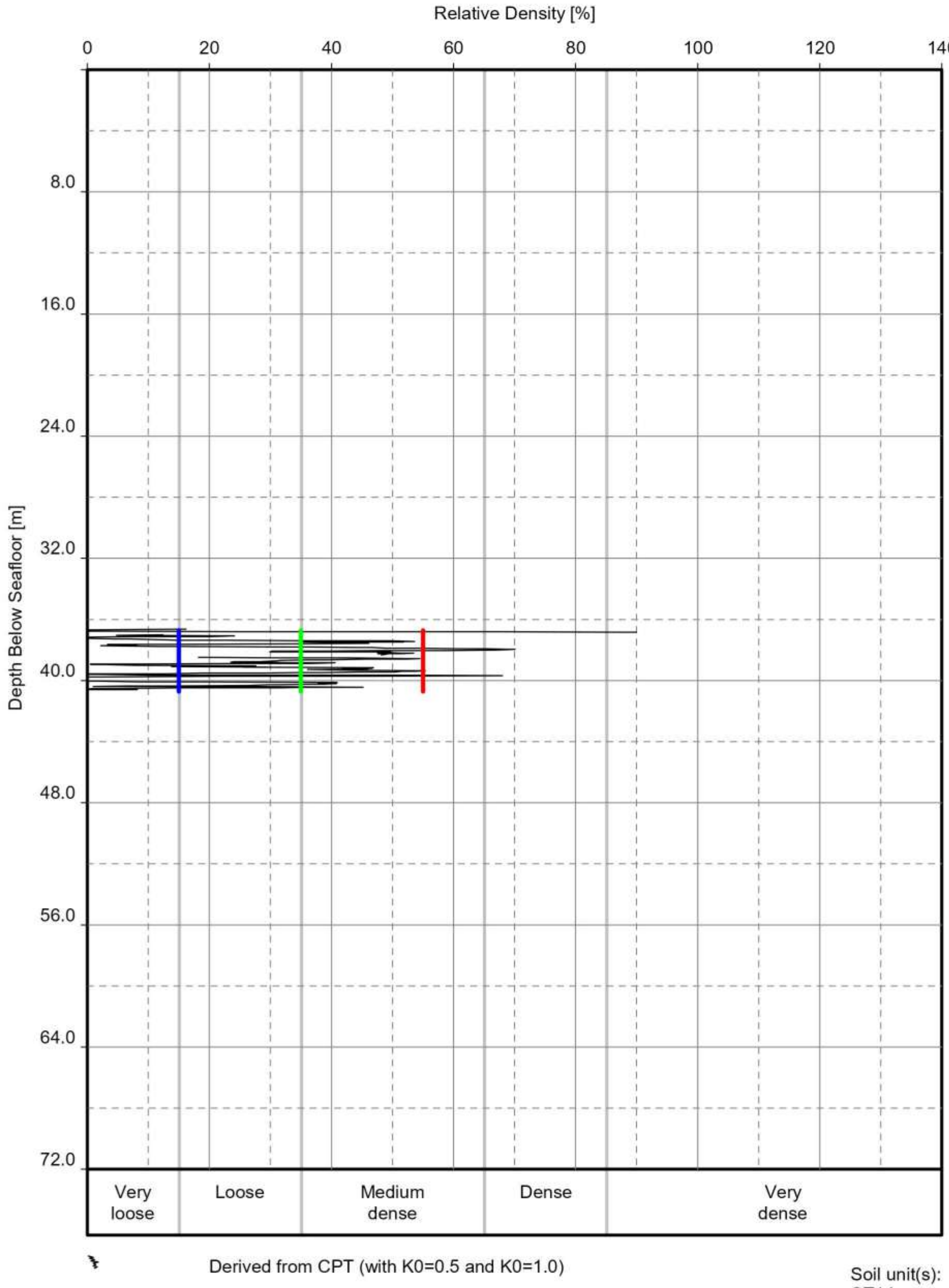
OWF



Soil unit(s):
GT4

RELATIVE DENSITY VERSUS DEPTH

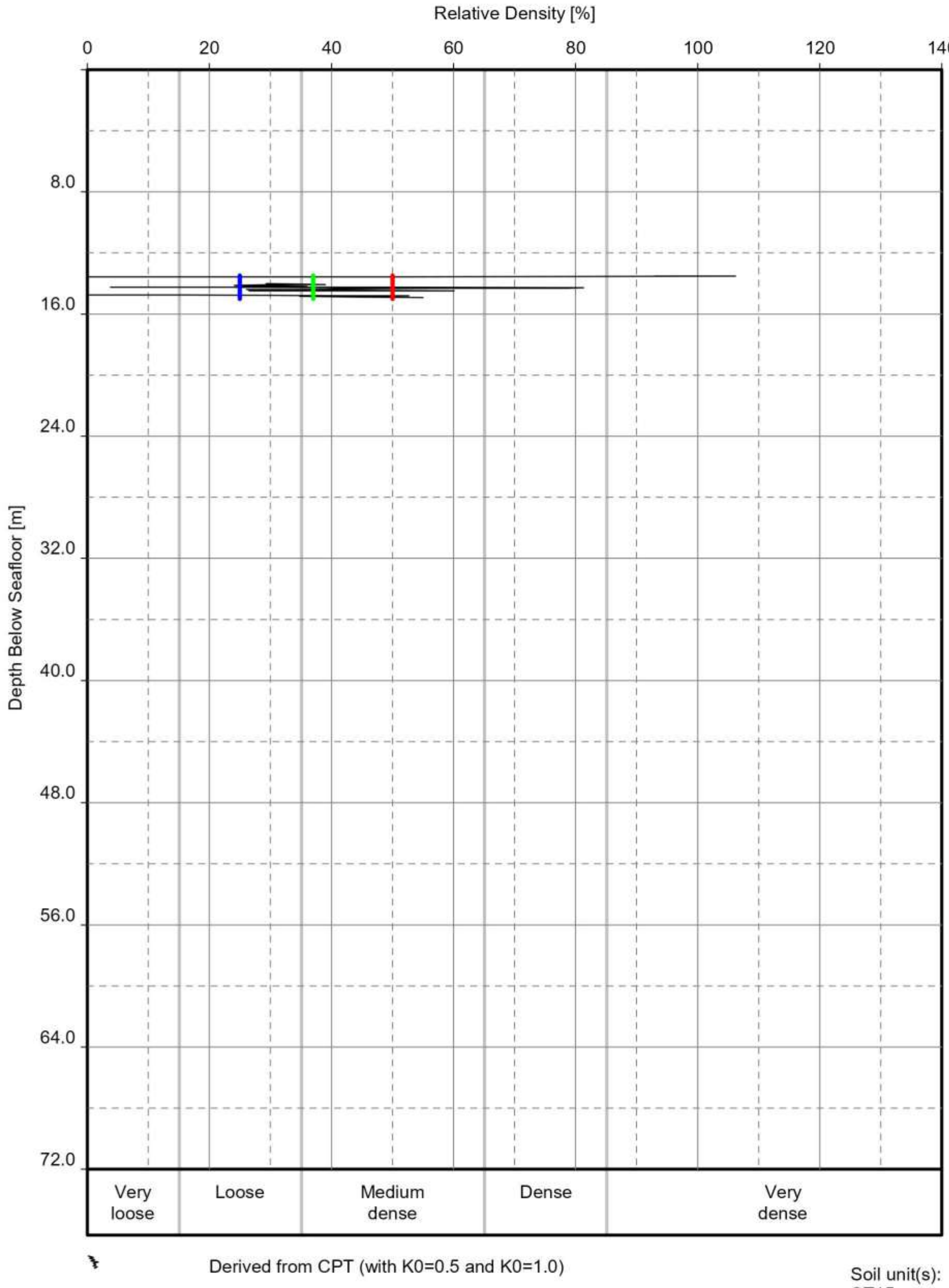
OWF



Soil unit(s):
GT14

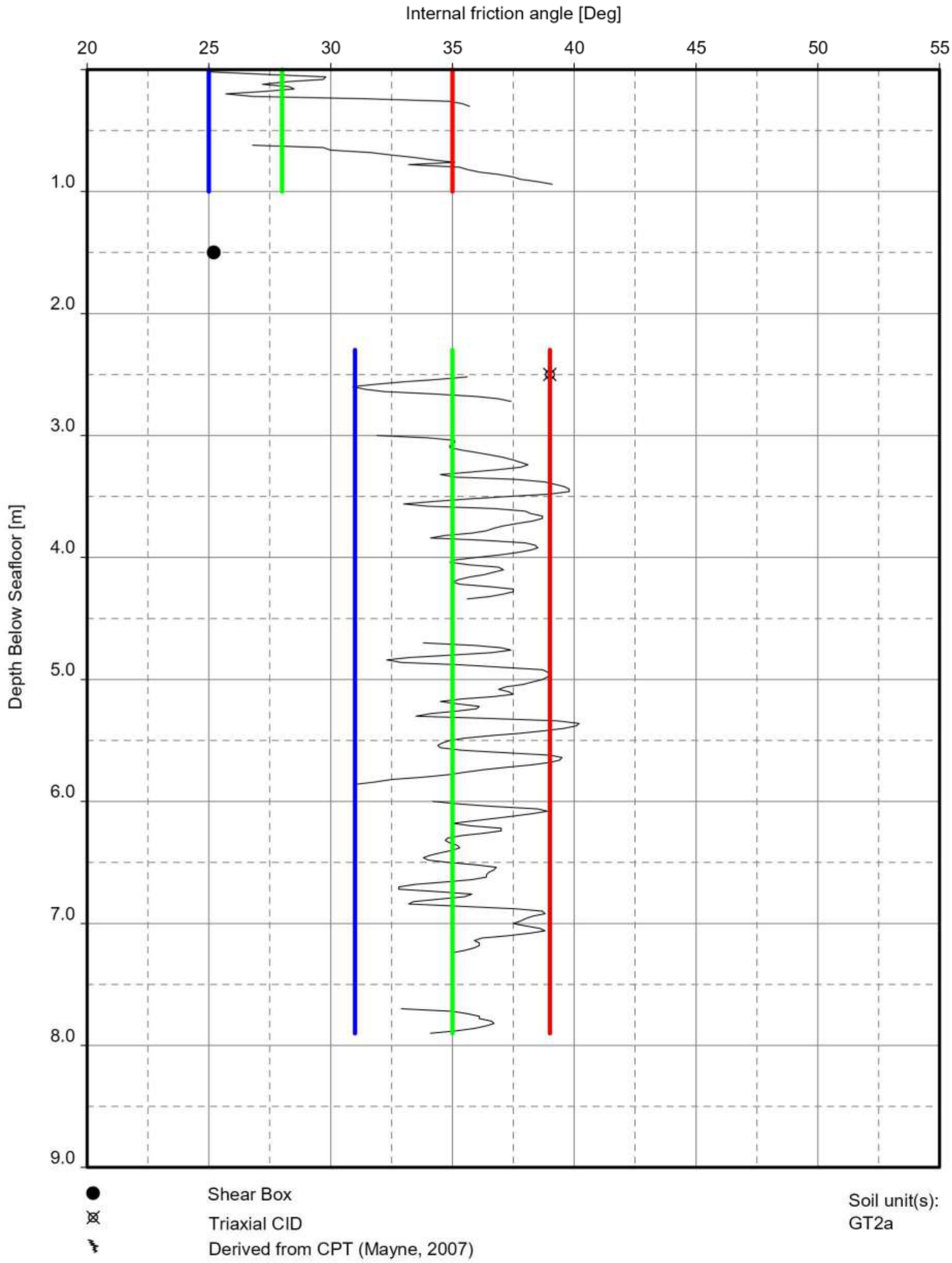
RELATIVE DENSITY VERSUS DEPTH

OWF



RELATIVE DENSITY VERSUS DEPTH

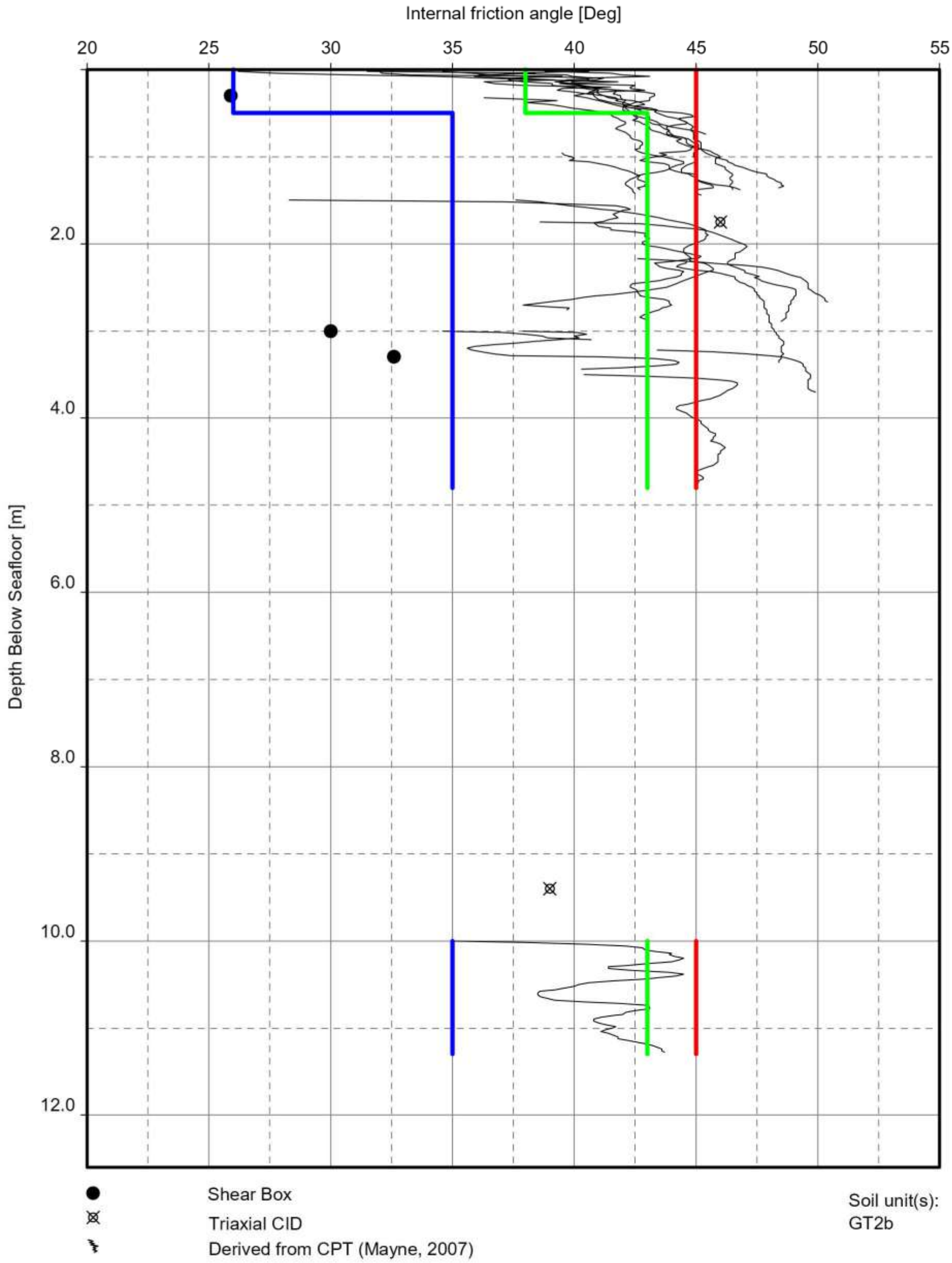
OWF



INTERNAL FRICTION ANGLE VERSUS DEPTH

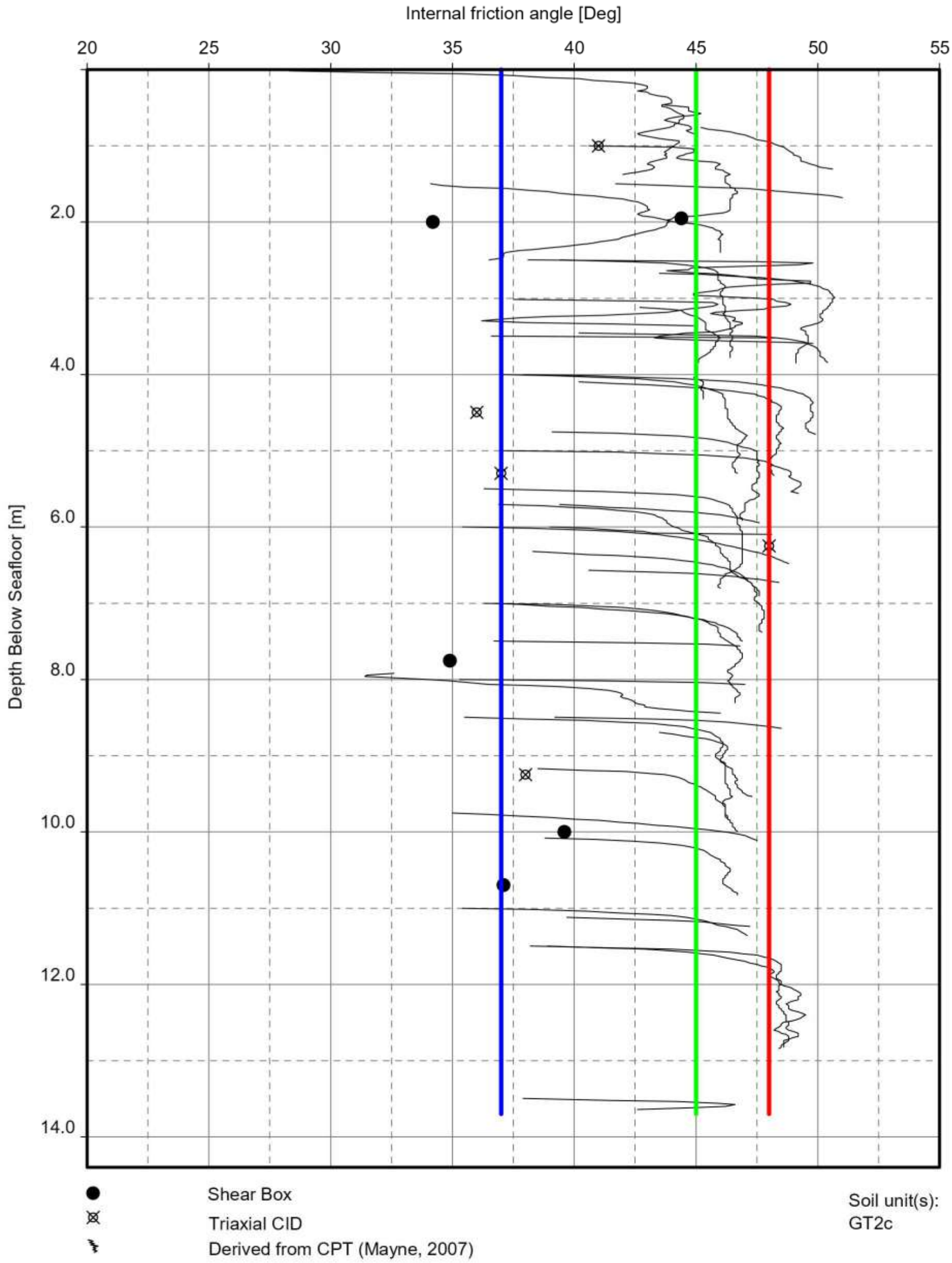
OWF

FUGRO



INTERNAL FRICTION ANGLE VERSUS DEPTH

OWF

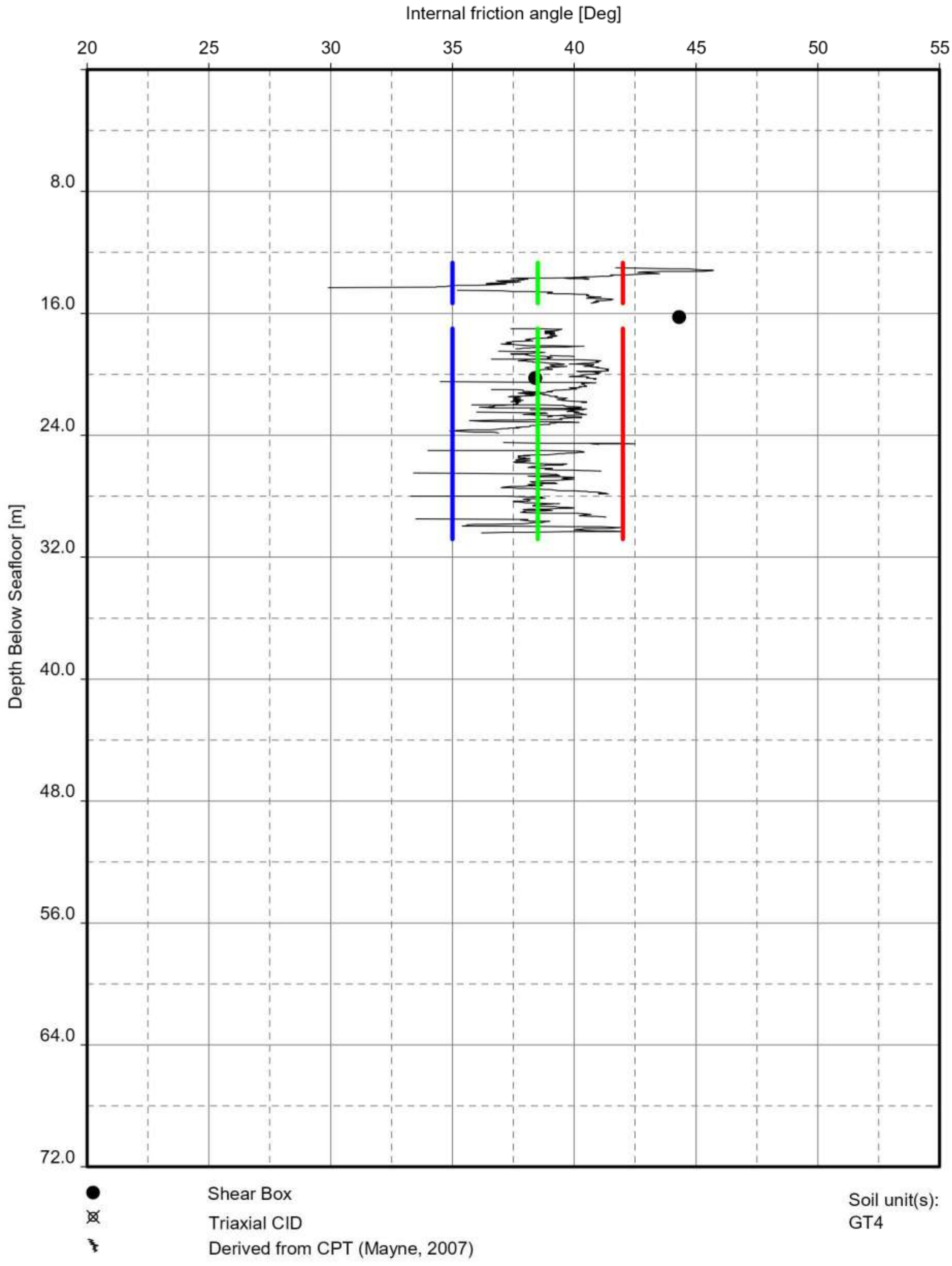


GeODin / Friction angle vs depth.GLO / 2024-05-06 @ 16:58:33

INTERNAL FRICTION ANGLE VERSUS DEPTH

OWF

FUGRO

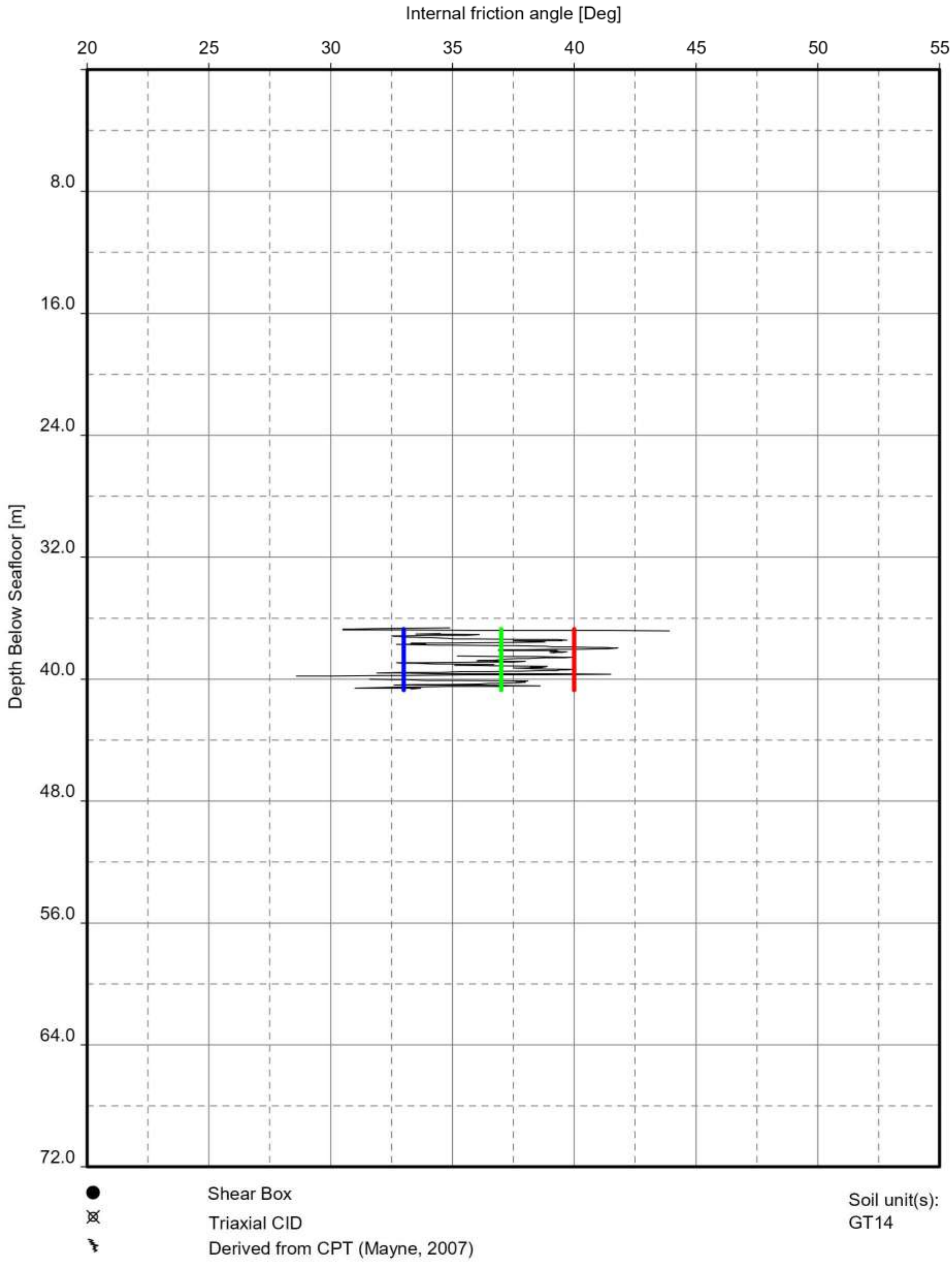


GeODin / Friction angle vs depth.GLO / 2024-05-06 @ 17:03:12

INTERNAL FRICTION ANGLE VERSUS DEPTH

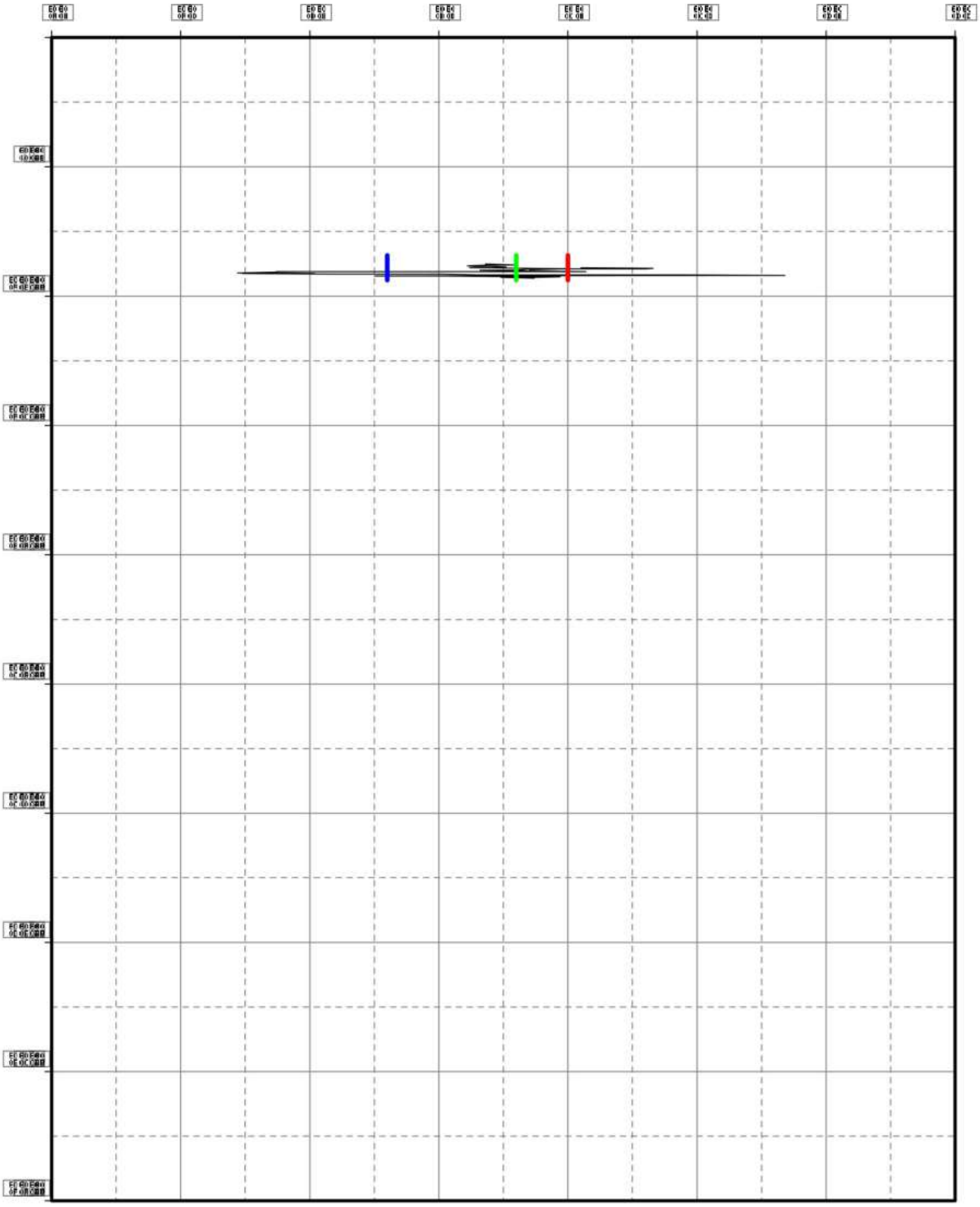
OWF

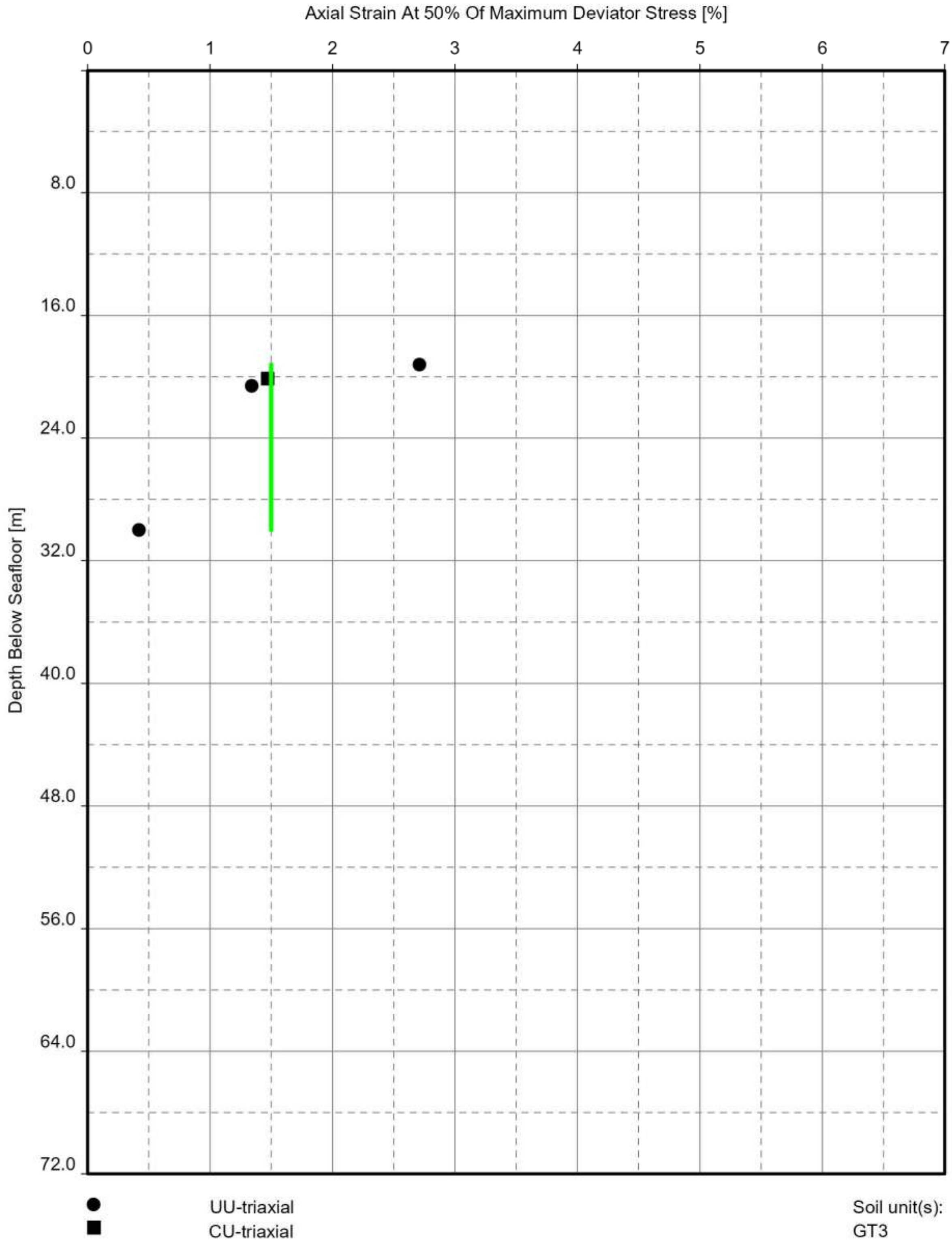
FUGRO



INTERNAL FRICTION ANGLE VERSUS DEPTH

OWF



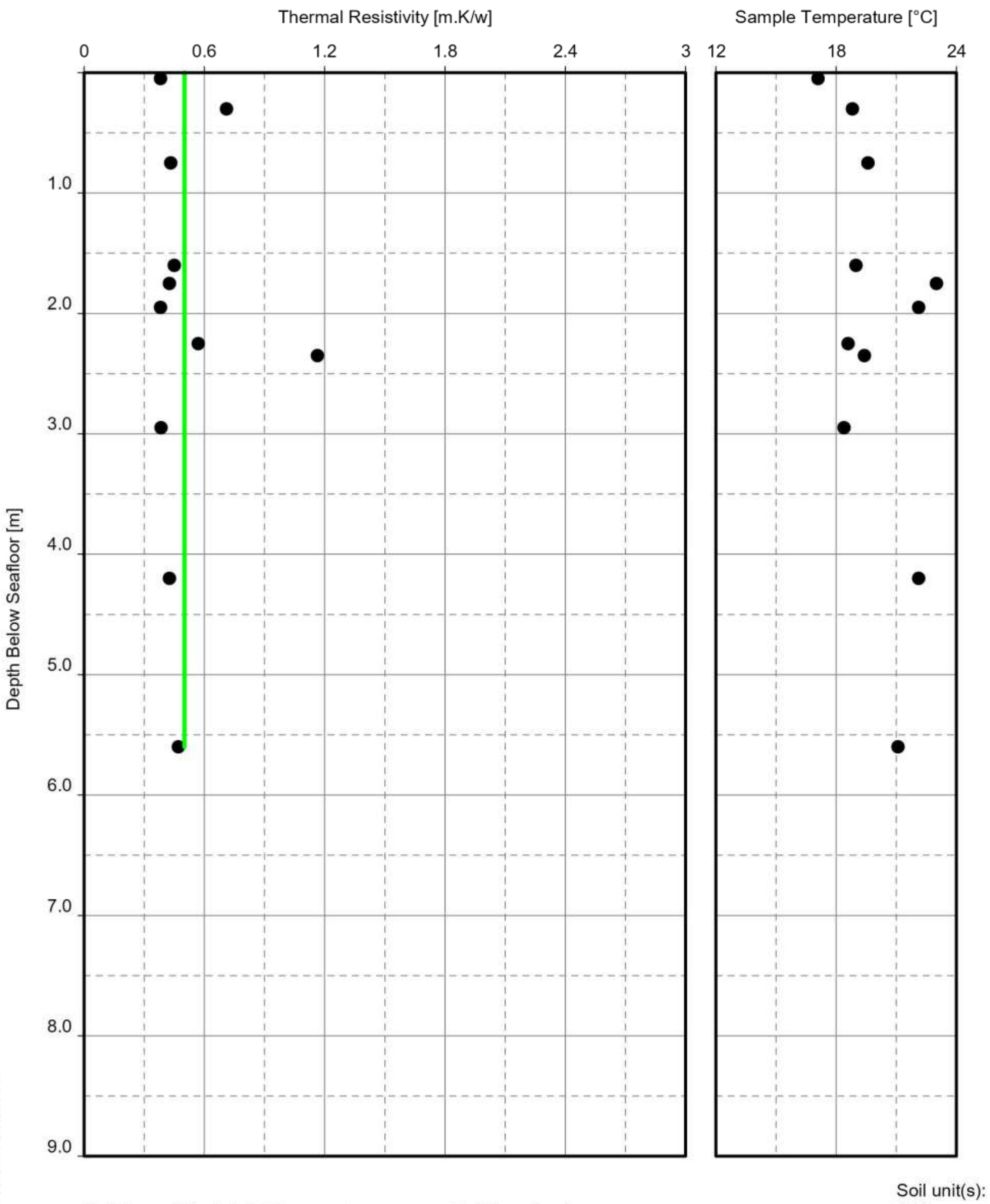


GeODin / Axial strain at 50% of maximum deviator stress vs depth.GLO / 2024-05-06 @ 17:39:17

AXIAL STRAIN AT 50% OF MAXIMUM DEVIATOR STRESS VERSUS DEPTH

OWF

FUGRO



● Thermal Resistivity/ Temperature measured offshore in situ
■ Thermal Resistivity/ Temperature measured onshore

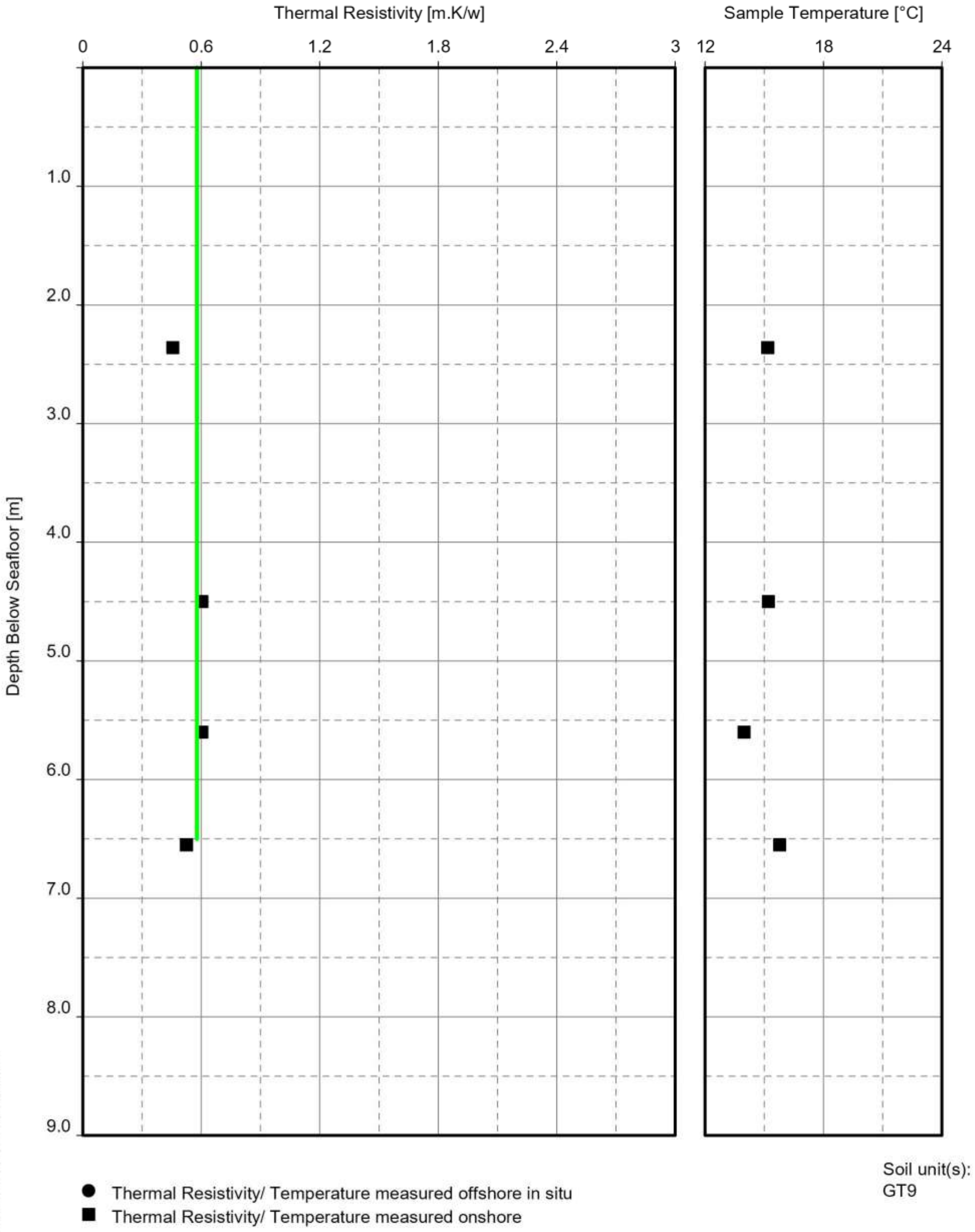
Soil unit(s):
GT2

GeODin / Thermal Resistivity vs depth.GLO / 2024-05-06 @ 17:43:44

THERMAL RESISTIVITY AND SOIL TEMPERATURE VERSUS DEPTH

OWF

FUGRO

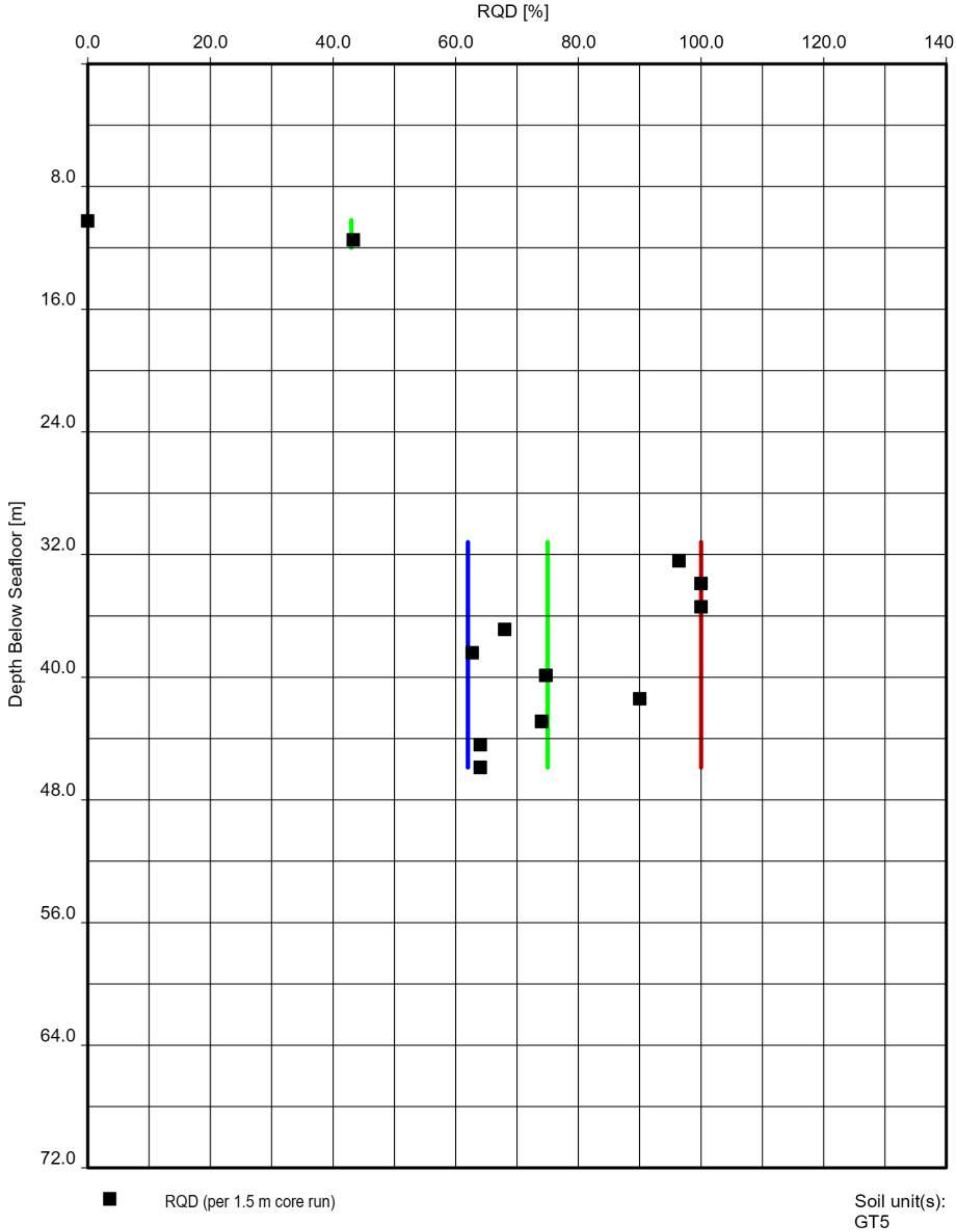


GeODin / Thermal Resistivity vs depth.GLO / 2024-05-06 @ 17:44:57

THERMAL RESISTIVITY AND SOIL TEMPERATURE VERSUS DEPTH

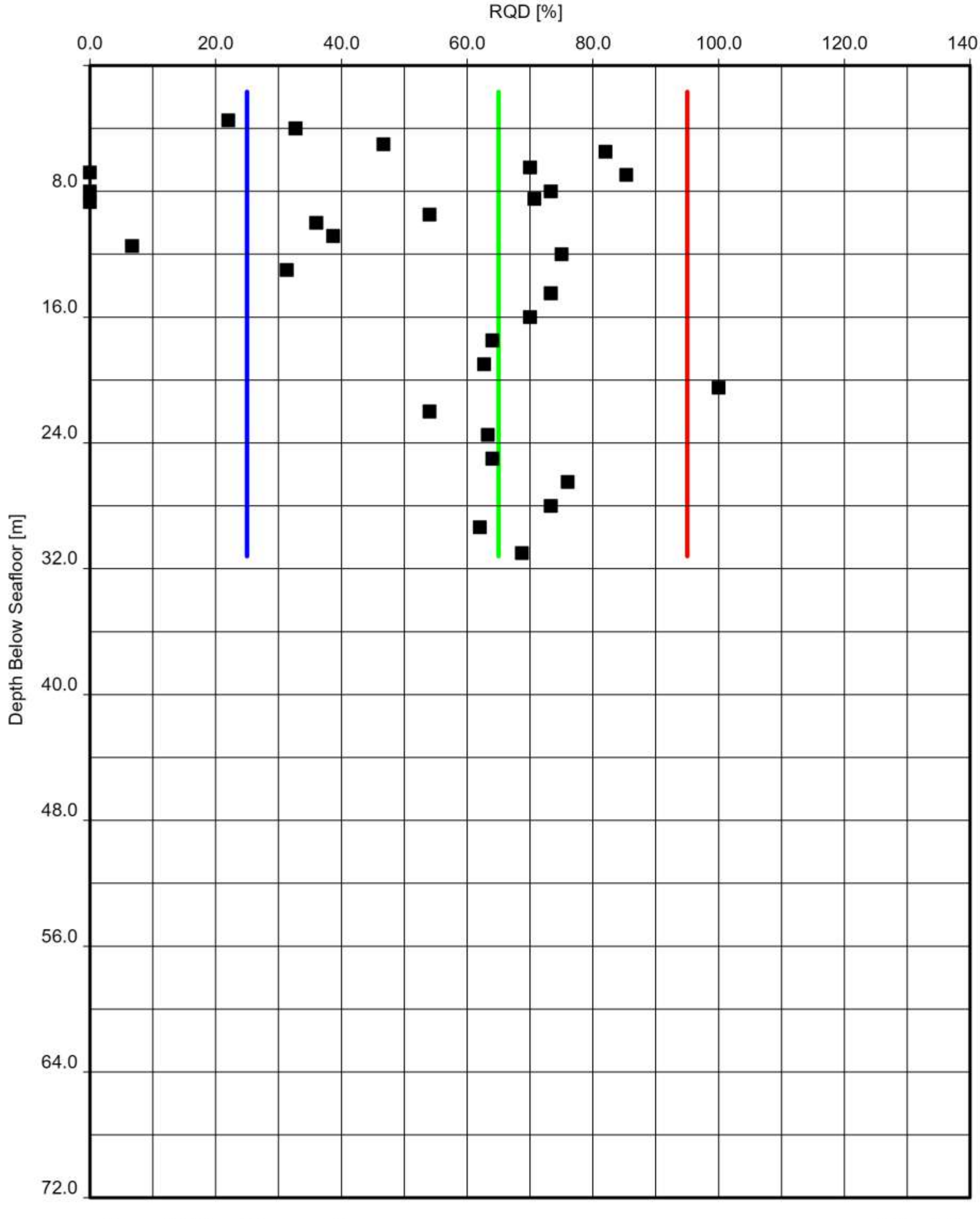
OWF

FUGRO



ROCK QUALITY DESIGNATION VERSUS DEPTH

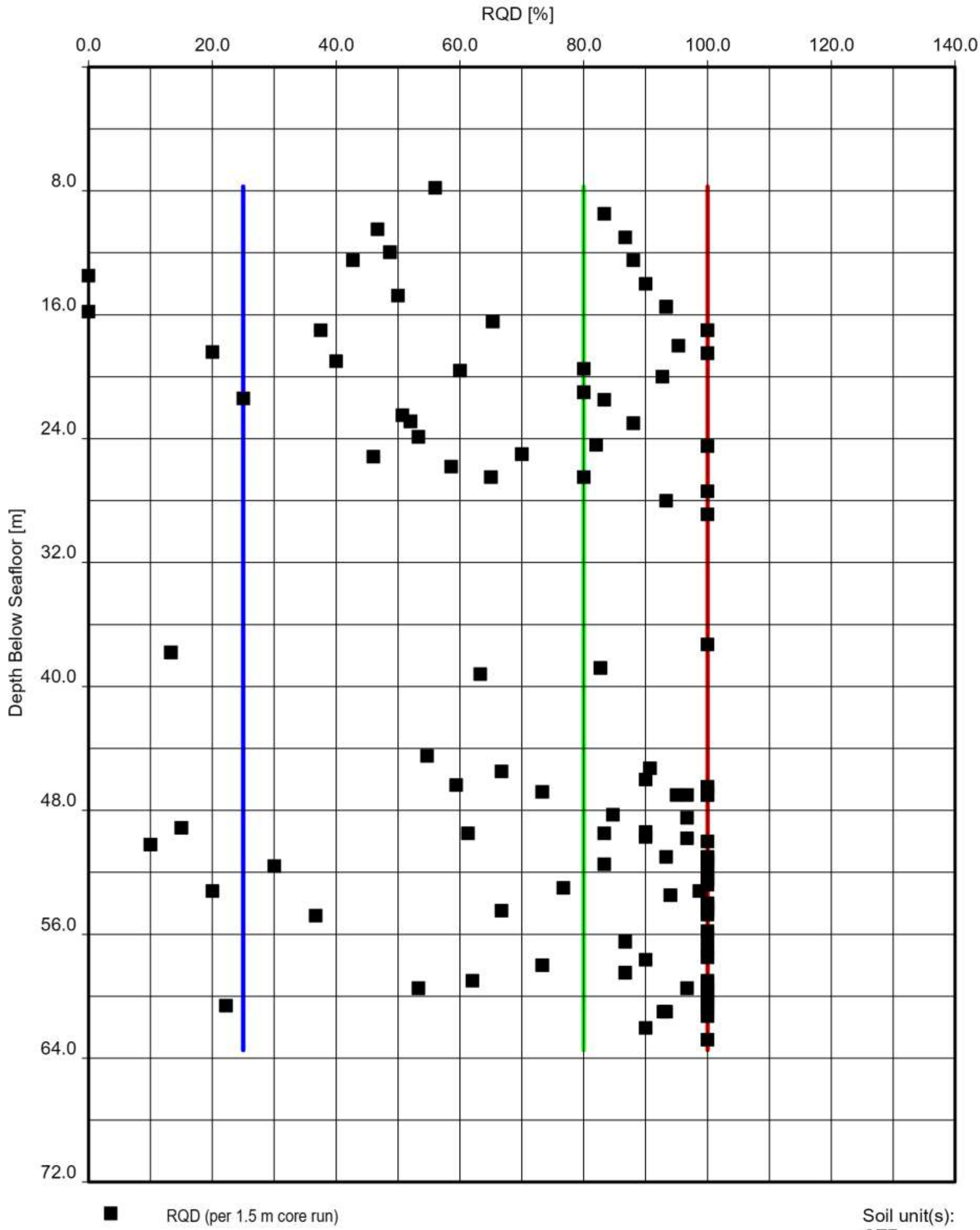
OWF



Soil unit(s):
GT6

ROCK QUALITY DESIGNATION VERSUS DEPTH

OWF

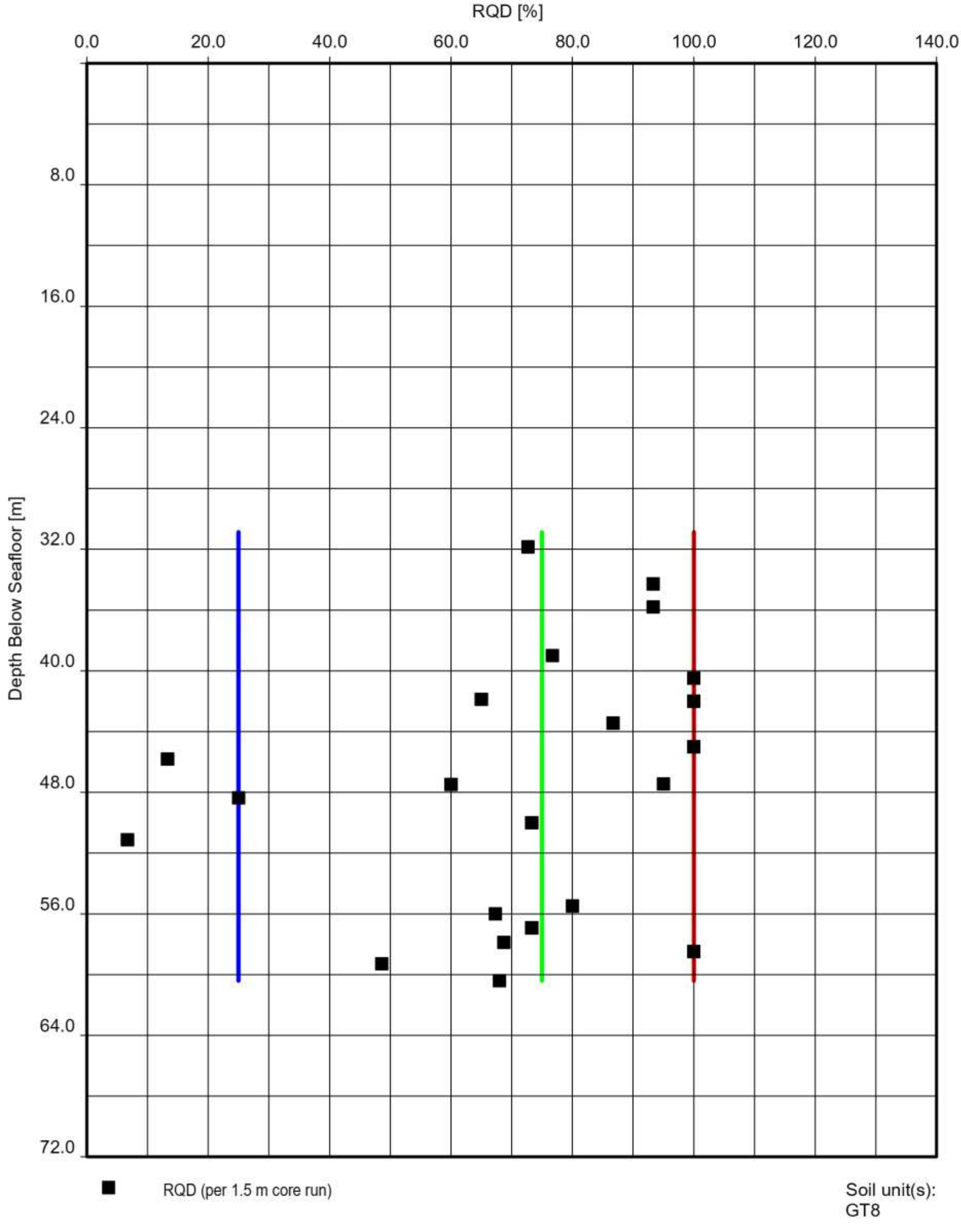


Soil unit(s):
GT7

GeODin / RQD vs depth.GLO / 2024-05-06 @ 17:50:52

ROCK QUALITY DESIGNATION VERSUS DEPTH

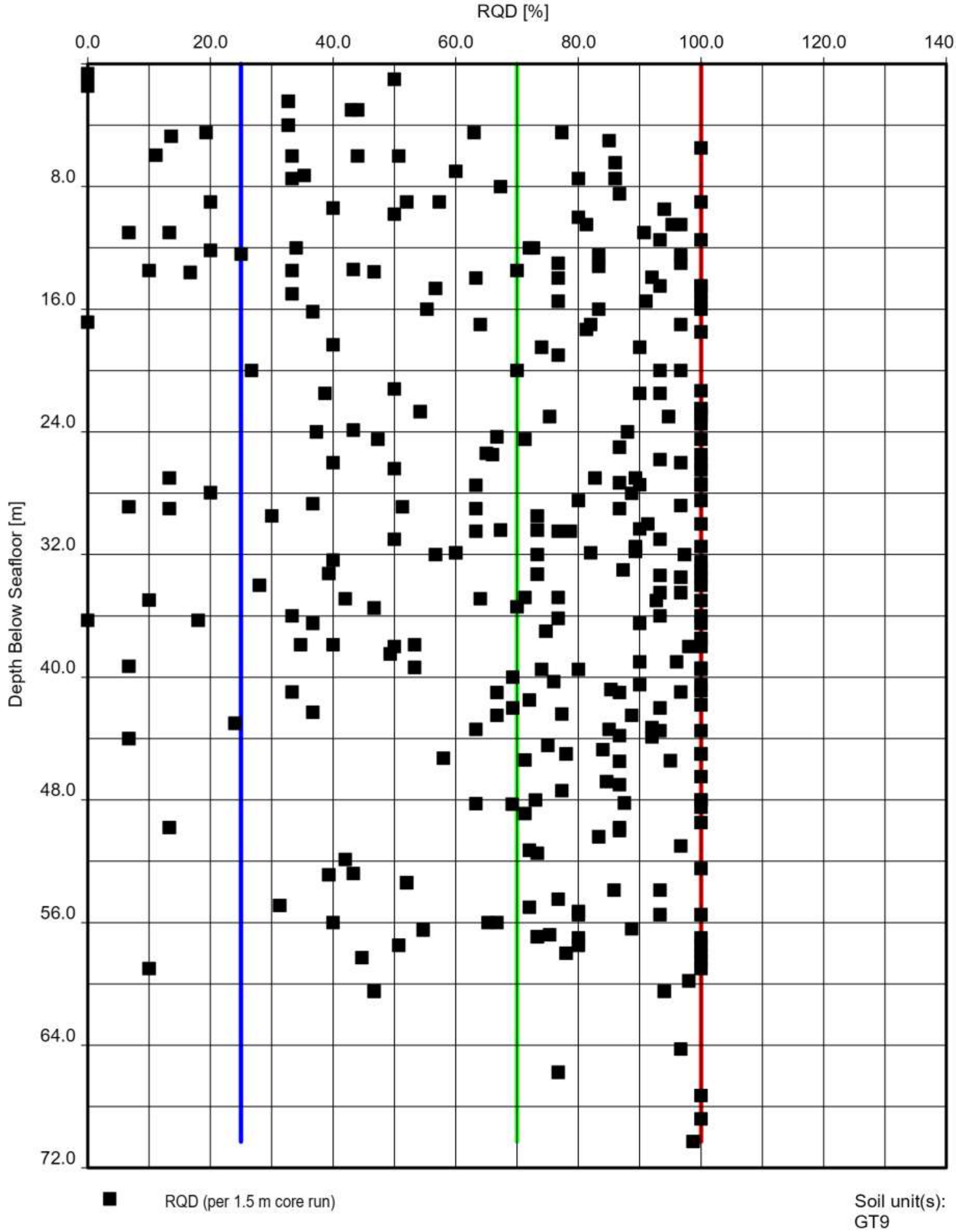
OWF



GeODin / RQD vs depth.GLO / 2024-05-06 @ 17:51:44

ROCK QUALITY DESIGNATION VERSUS DEPTH

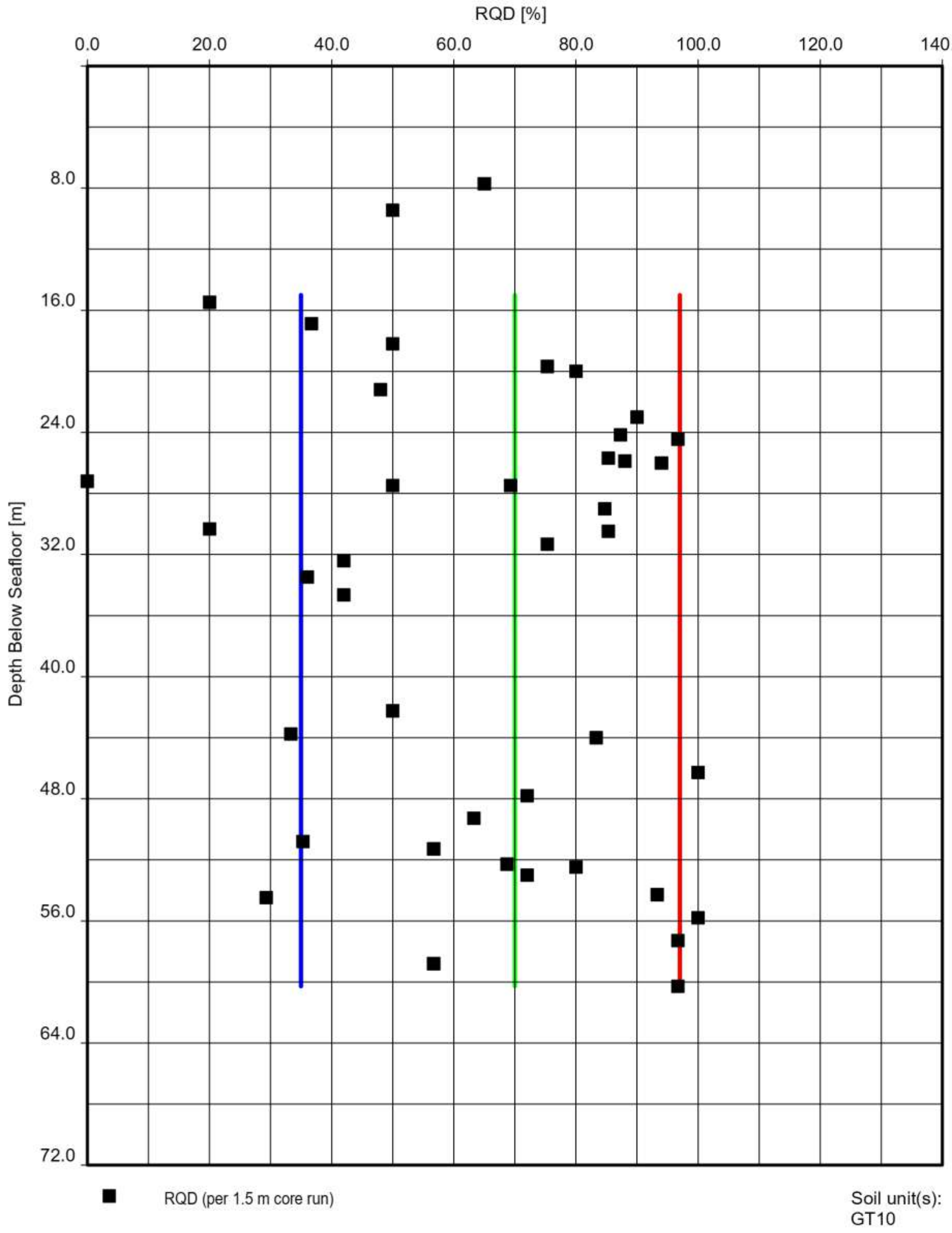
OWF



ROCK QUALITY DESIGNATION VERSUS DEPTH

OWF

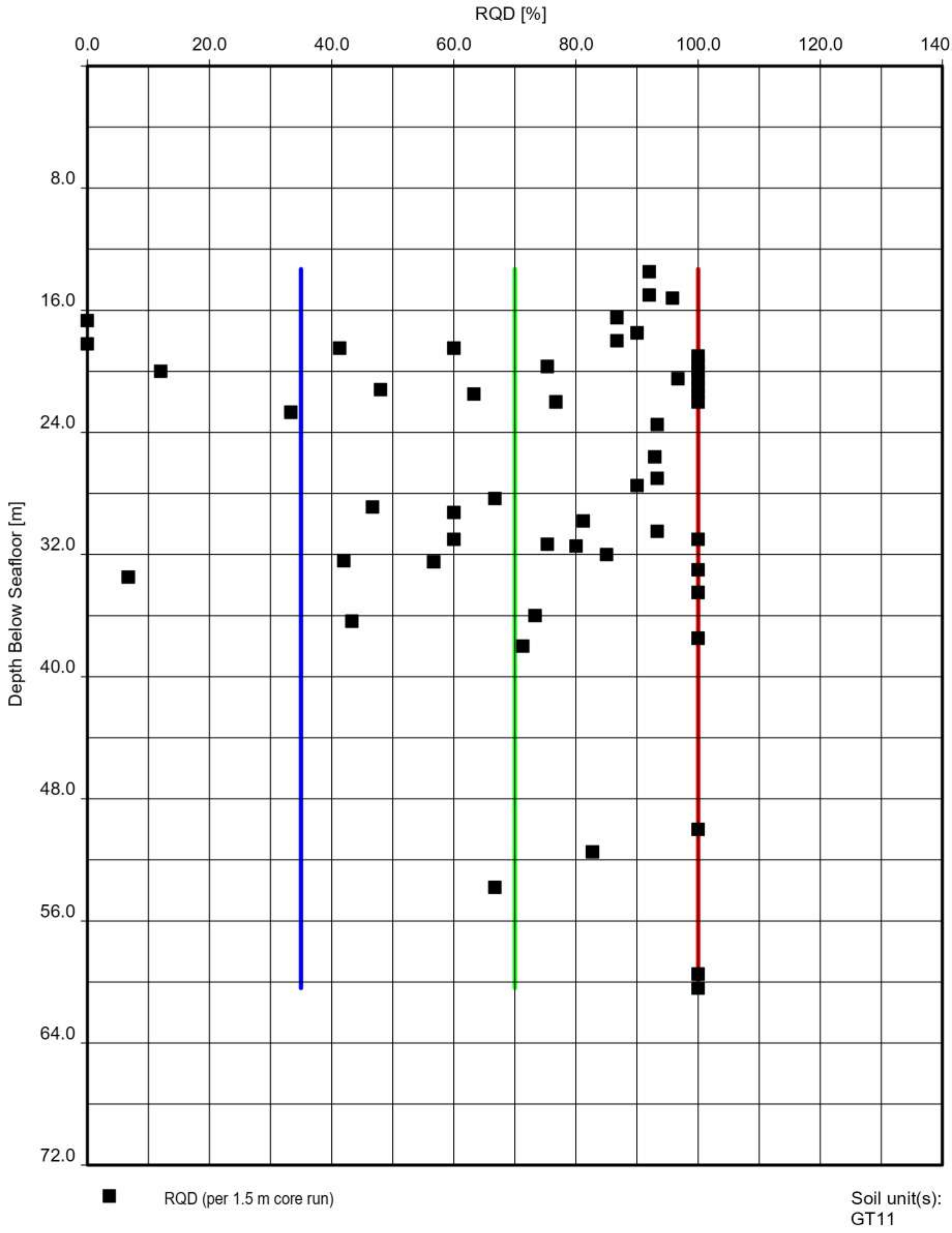
FUGRO



ROCK QUALITY DESIGNATION VERSUS DEPTH

OWF

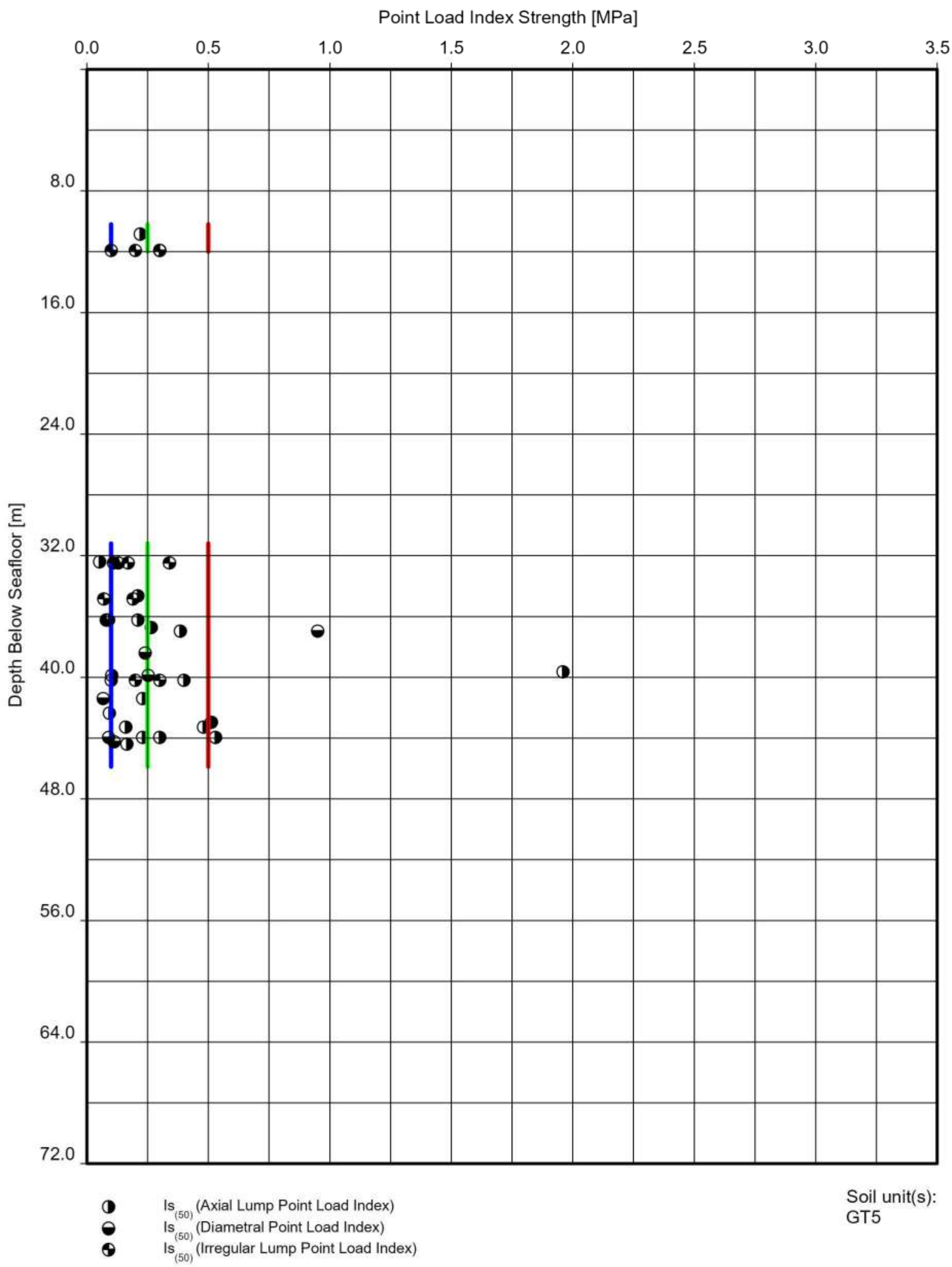
FUGRO



GeODin / RQD vs depth.GLO / 2024-05-06 @ 17:53:34

ROCK QUALITY DESIGNATION VERSUS DEPTH

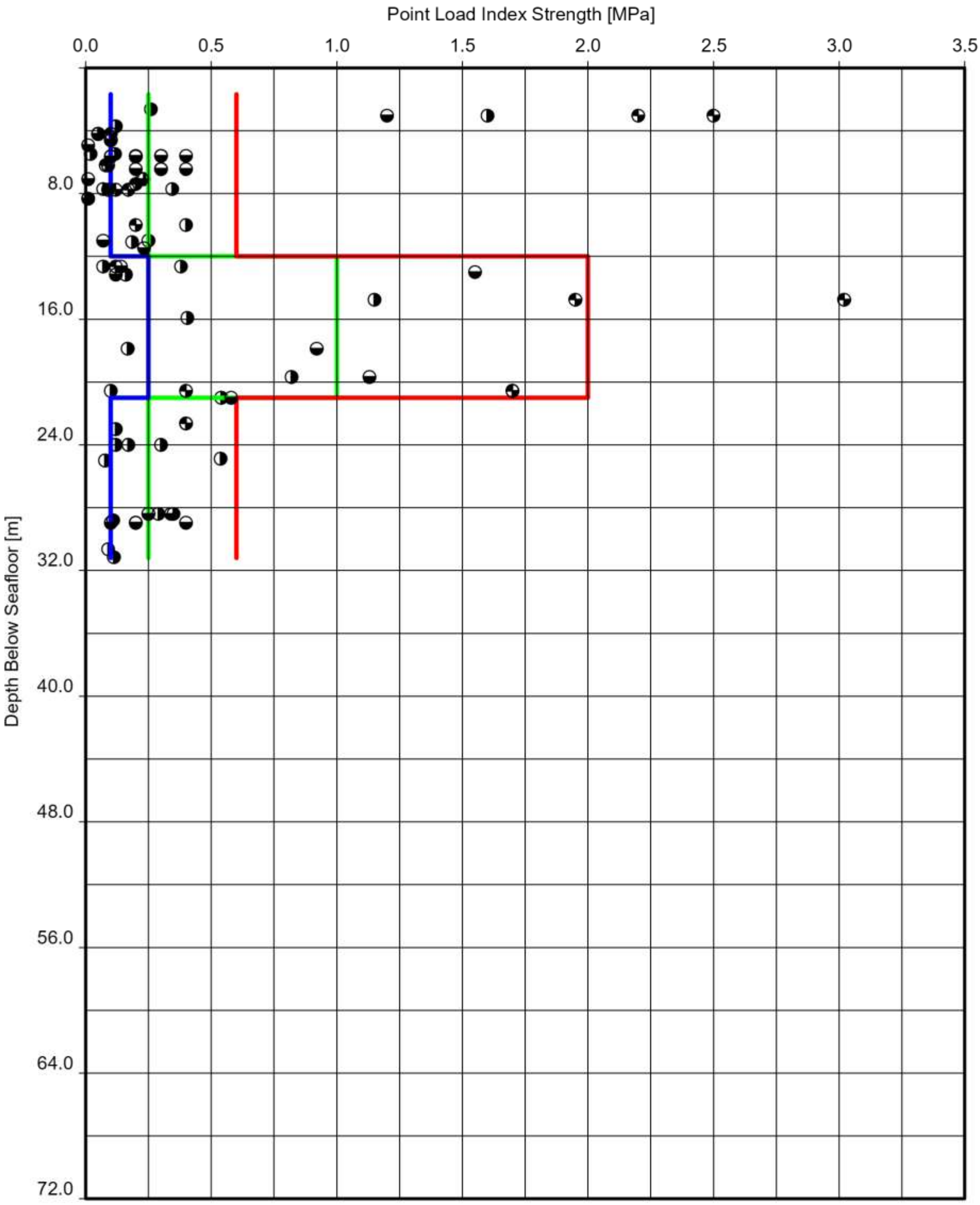
OWF



GeODin / Is(50) vs depth.GLO / 2024-05-06 @ 17:55:08

POINT LOAD INDEX VERSUS DEPTH

OWF

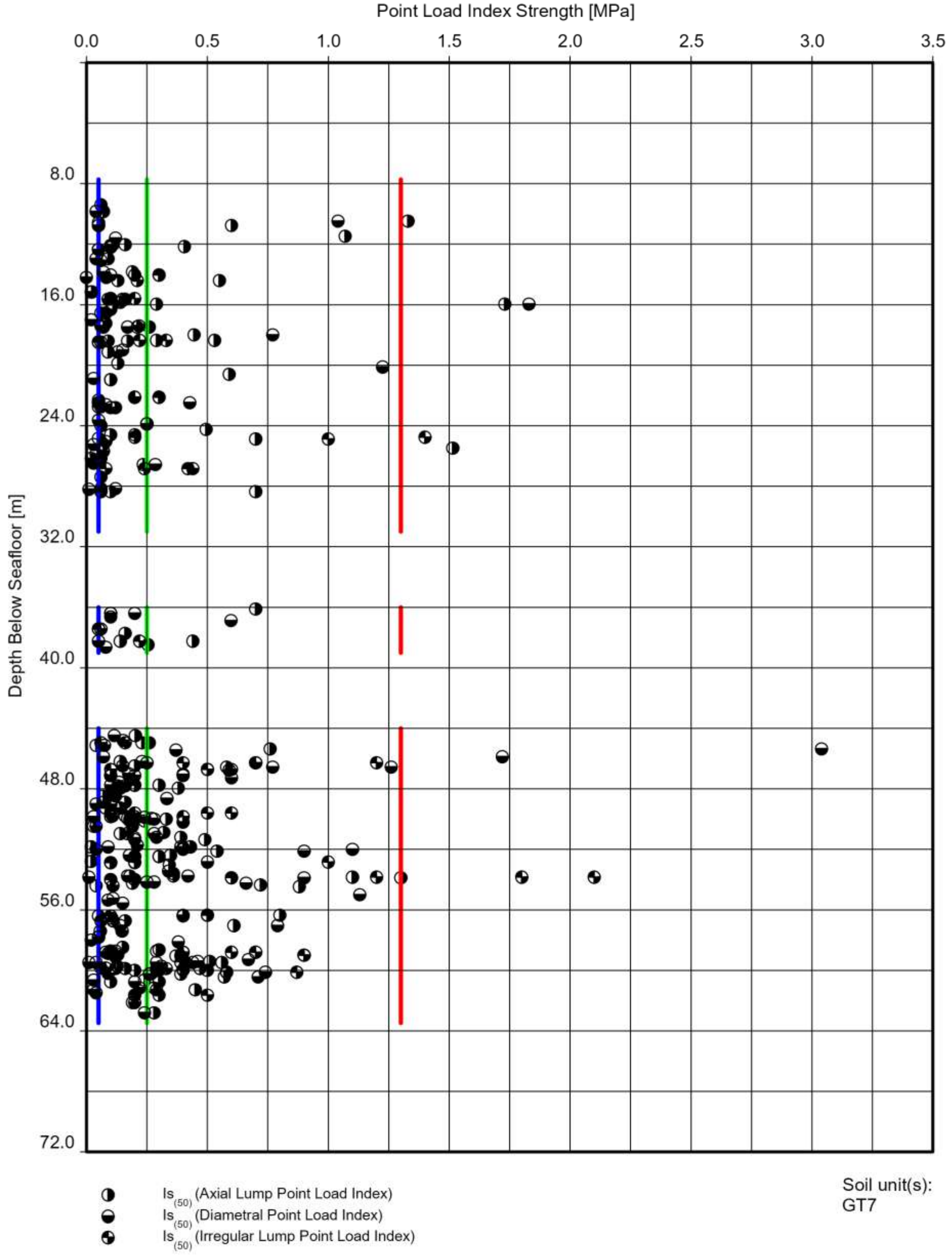


Is(50) (Axial Lump Point Load Index)
Is(50) (Diametral Point Load Index)
Is(50) (Irregular Lump Point Load Index)

Soil unit(s):
GT6

POINT LOAD INDEX VERSUS DEPTH

OWF

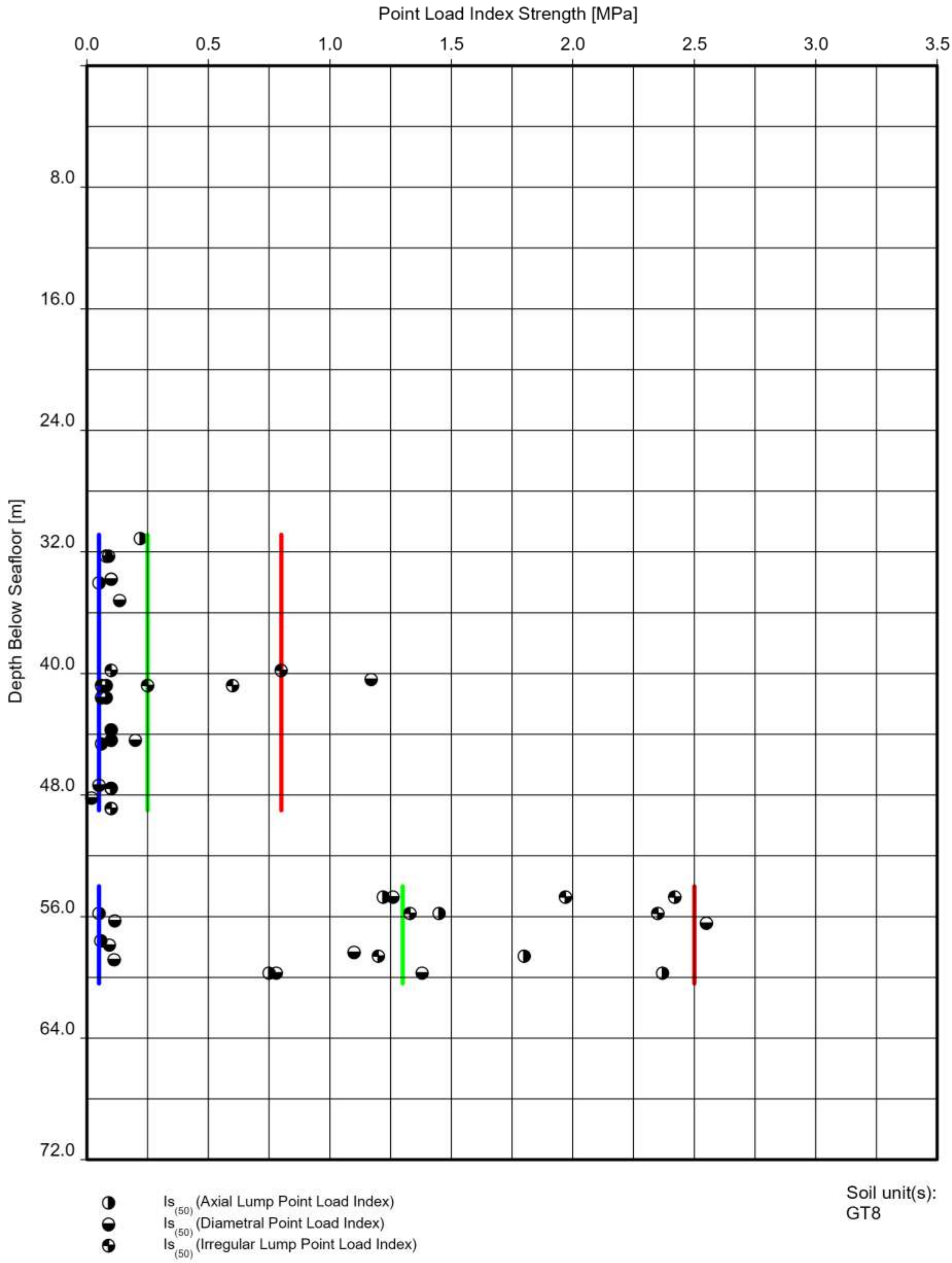


GeODin / Is(50) vs depth.GLO / 2024-05-06 @ 17:57:36

POINT LOAD INDEX VERSUS DEPTH

OWF

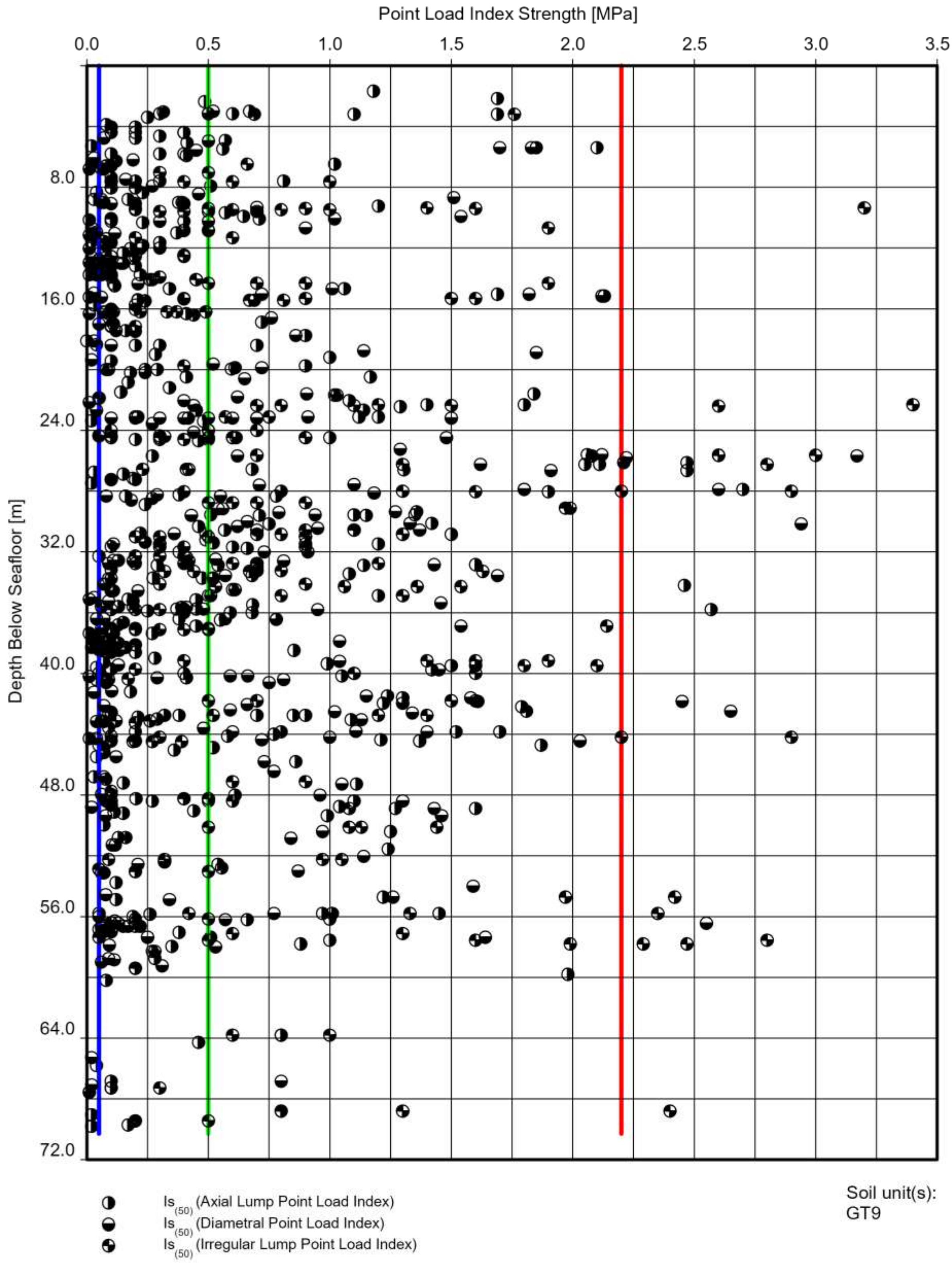
FUGRO



GeODin / Is(50) vs depth.GLO / 2024-05-06 @ 17:58:50

POINT LOAD INDEX VERSUS DEPTH

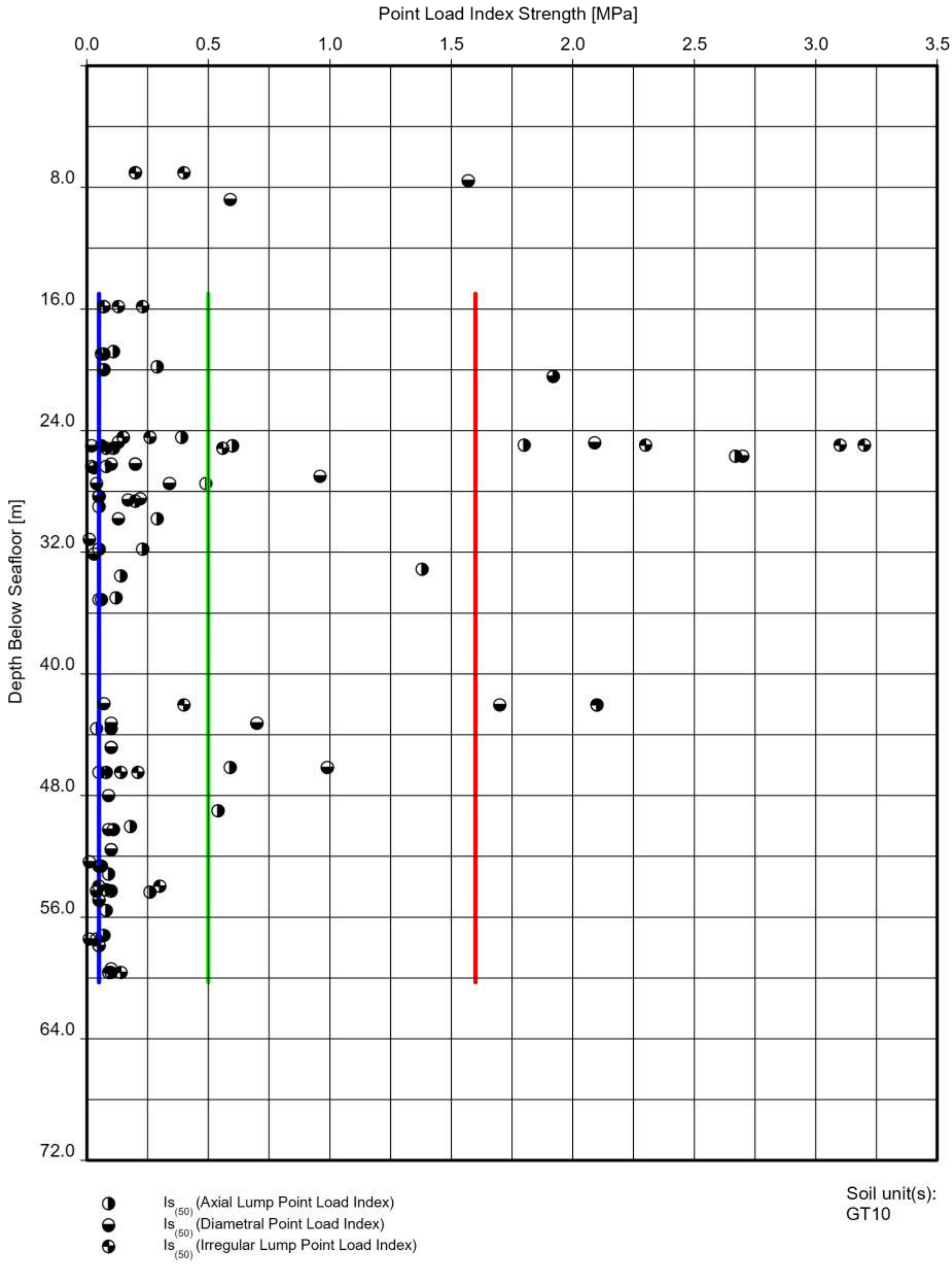
OWF



Soil unit(s):
GT9

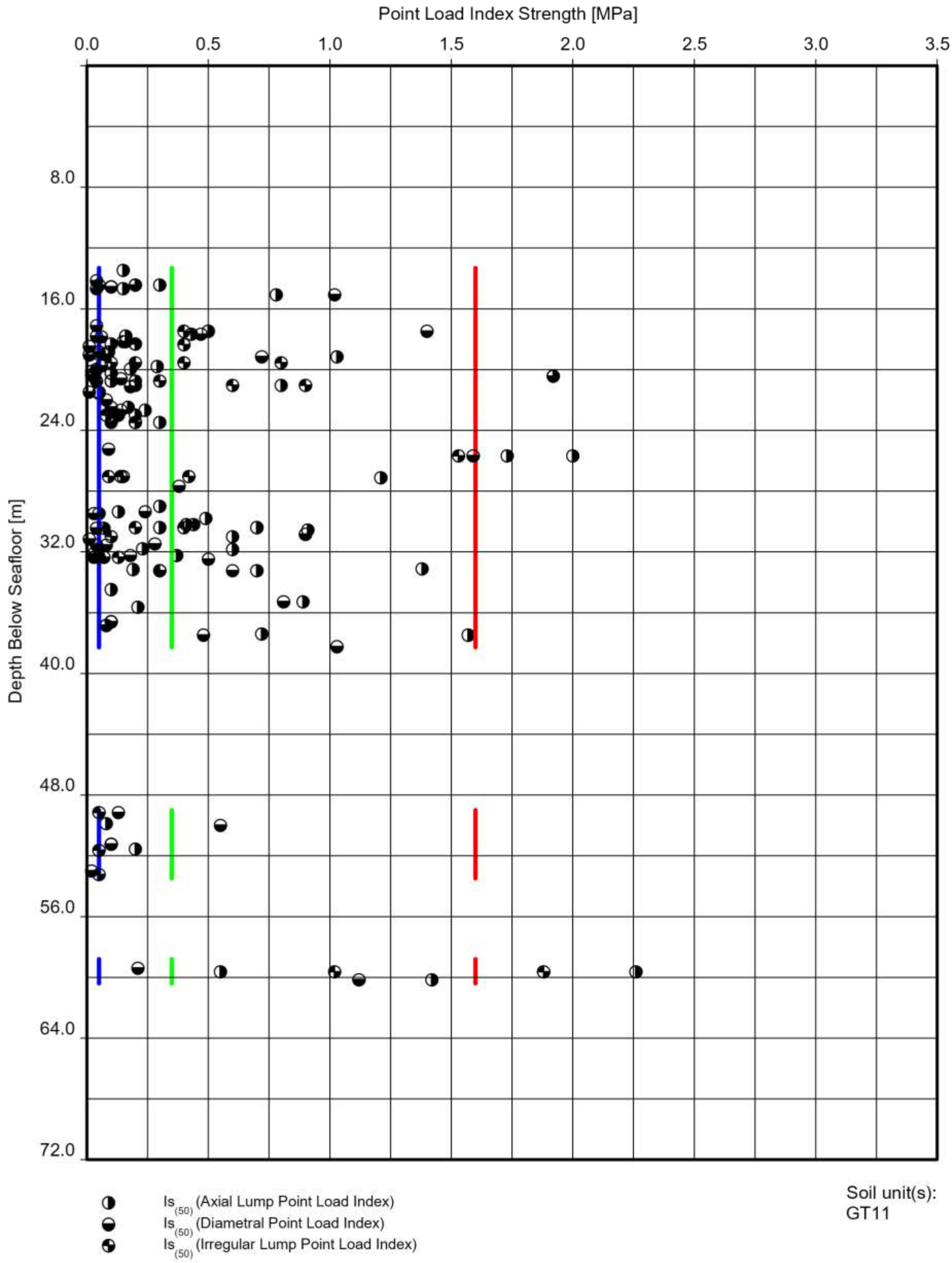
POINT LOAD INDEX VERSUS DEPTH

OWF



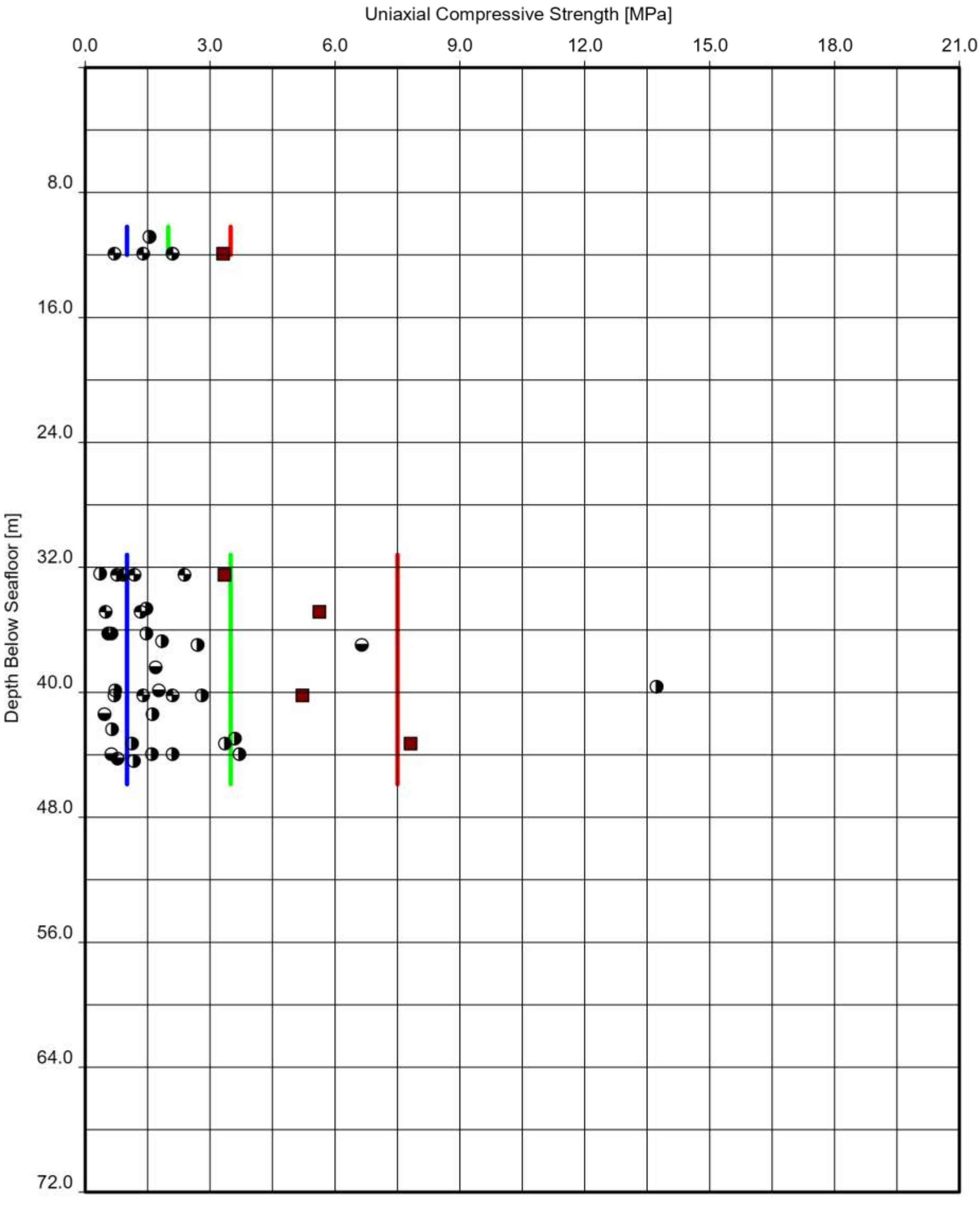
POINT LOAD INDEX VERSUS DEPTH

OWF



POINT LOAD INDEX VERSUS DEPTH

OWF



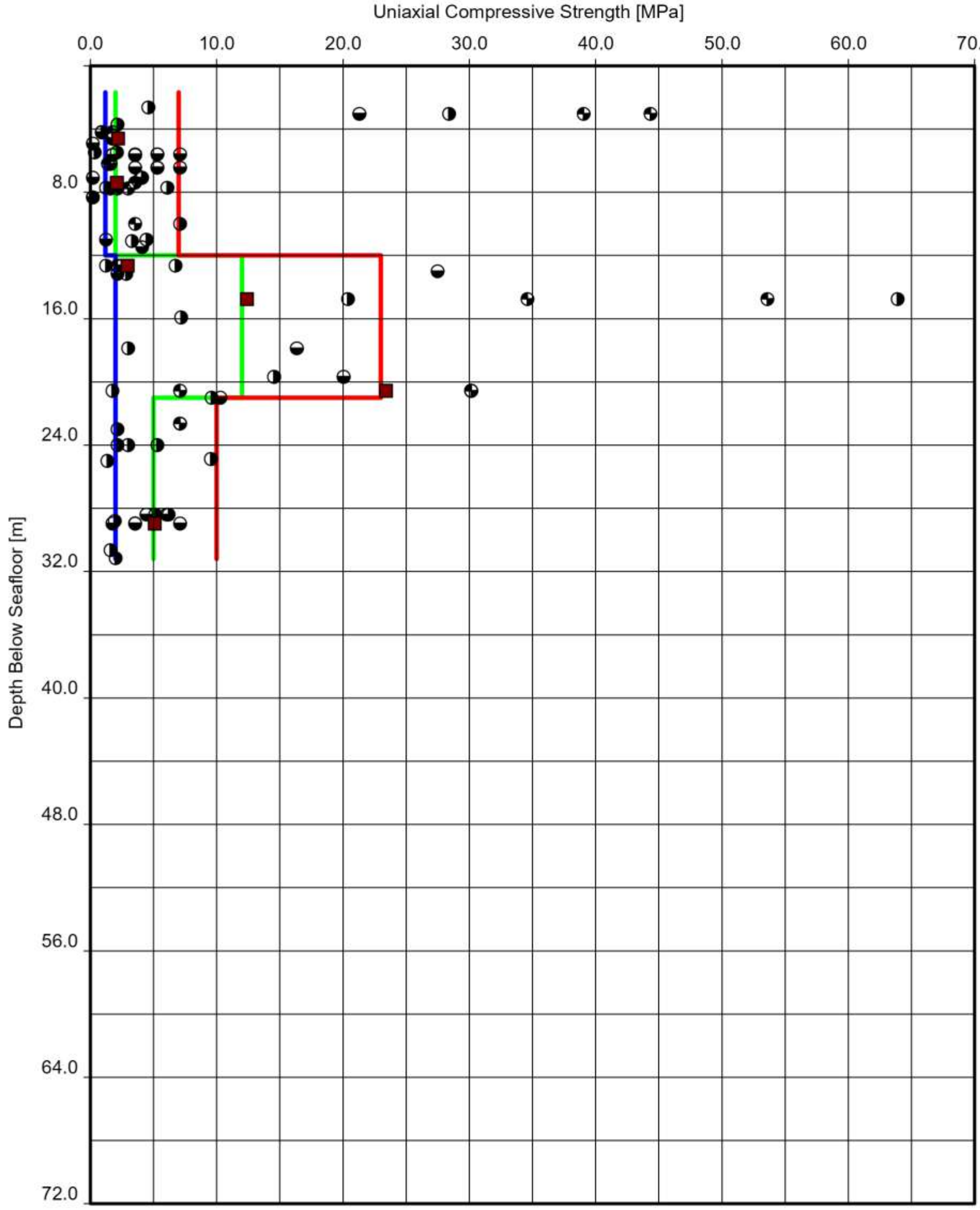
Derived from $Is_{(50)}$ using average K factor (Axial Lump Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Diametral Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Irregular Lump Point Load Index)
UCS tests

Soil unit(s):
GT5

GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:48:19

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF



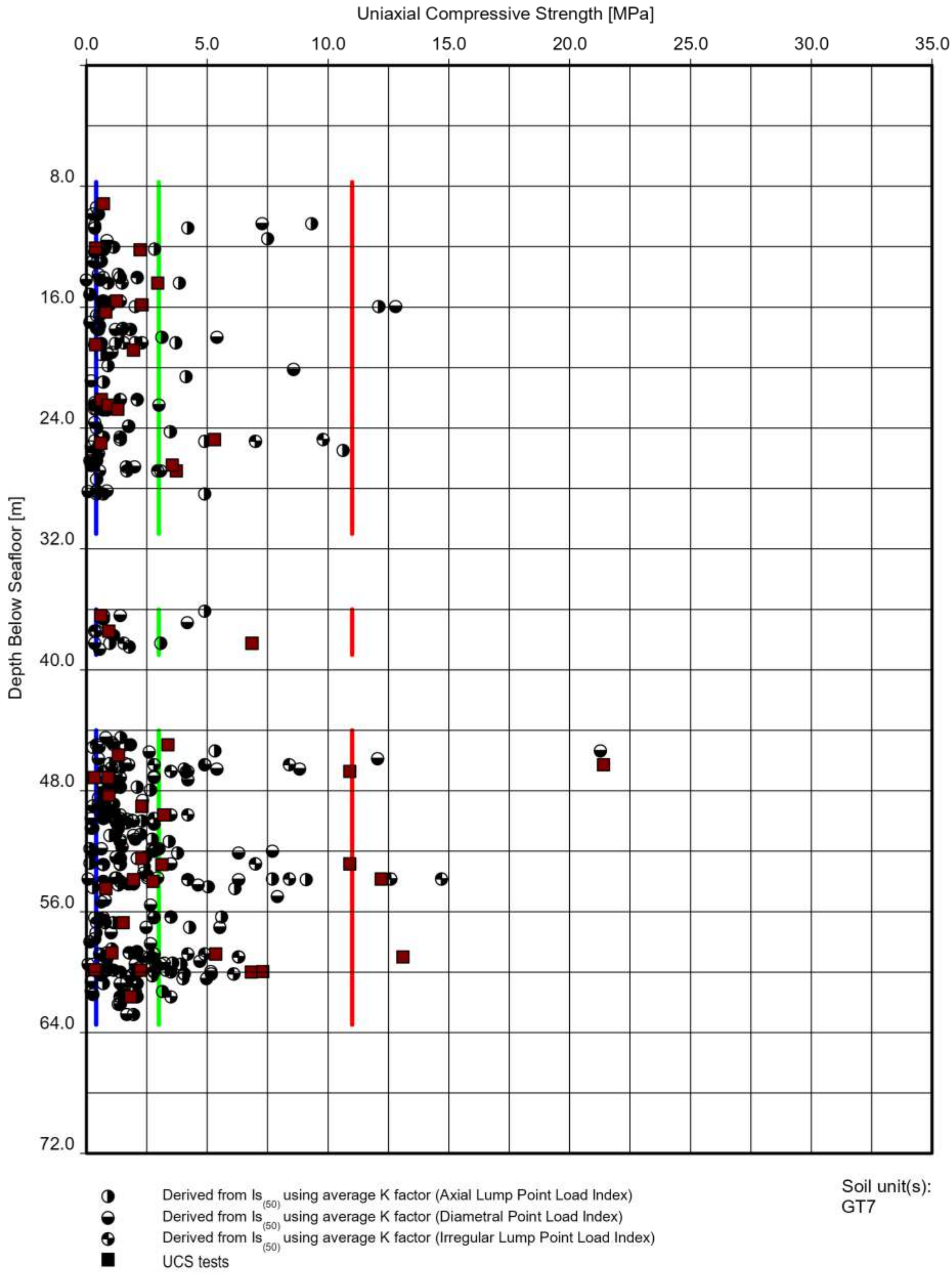
Derived from $Is_{(50)}$ using average K factor (Axial Lump Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Diametral Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Irregular Lump Point Load Index)
UCS tests

Soil unit(s):
GT6

GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:49:29

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF

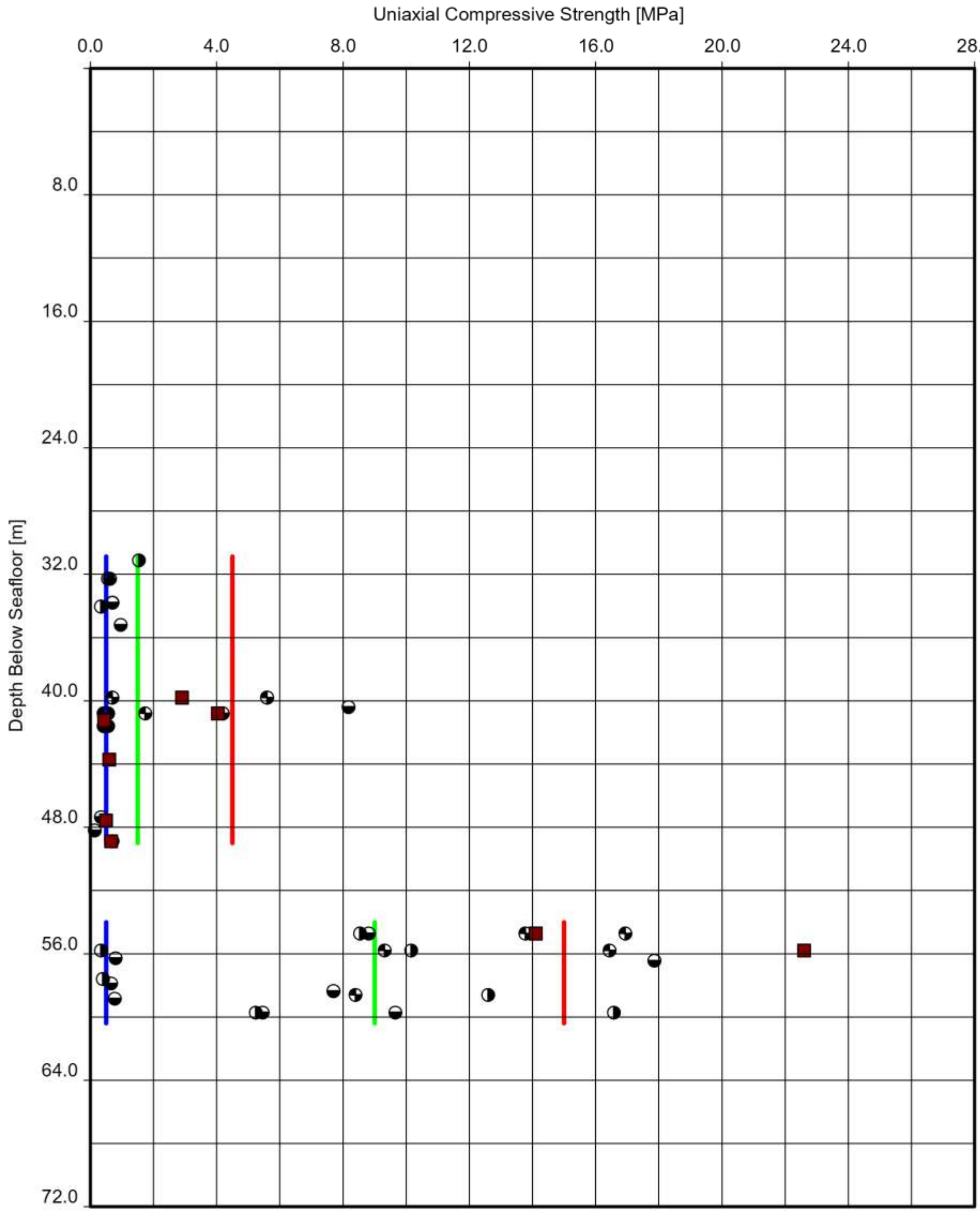


GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:51:11

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF

FUGRO



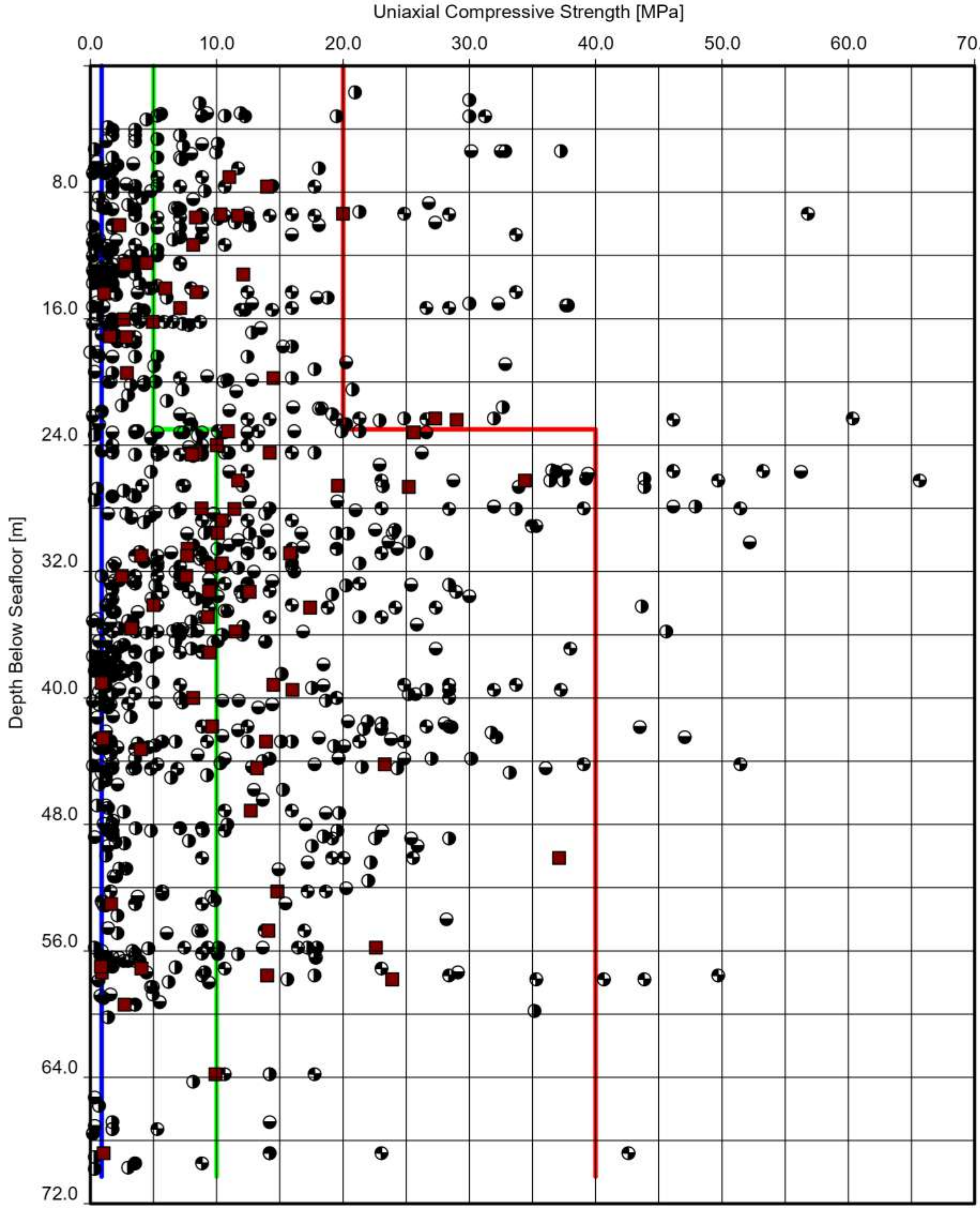
Derived from $Is_{(50)}$ using average K factor (Axial Lump Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Diametral Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Irregular Lump Point Load Index)
UCS tests

Soil unit(s):
GT8

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF

FUGRO



Derived from $Is_{(50)}$ using average K factor (Axial Lump Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Diametral Point Load Index)
Derived from $Is_{(50)}$ using average K factor (Irregular Lump Point Load Index)
UCS tests

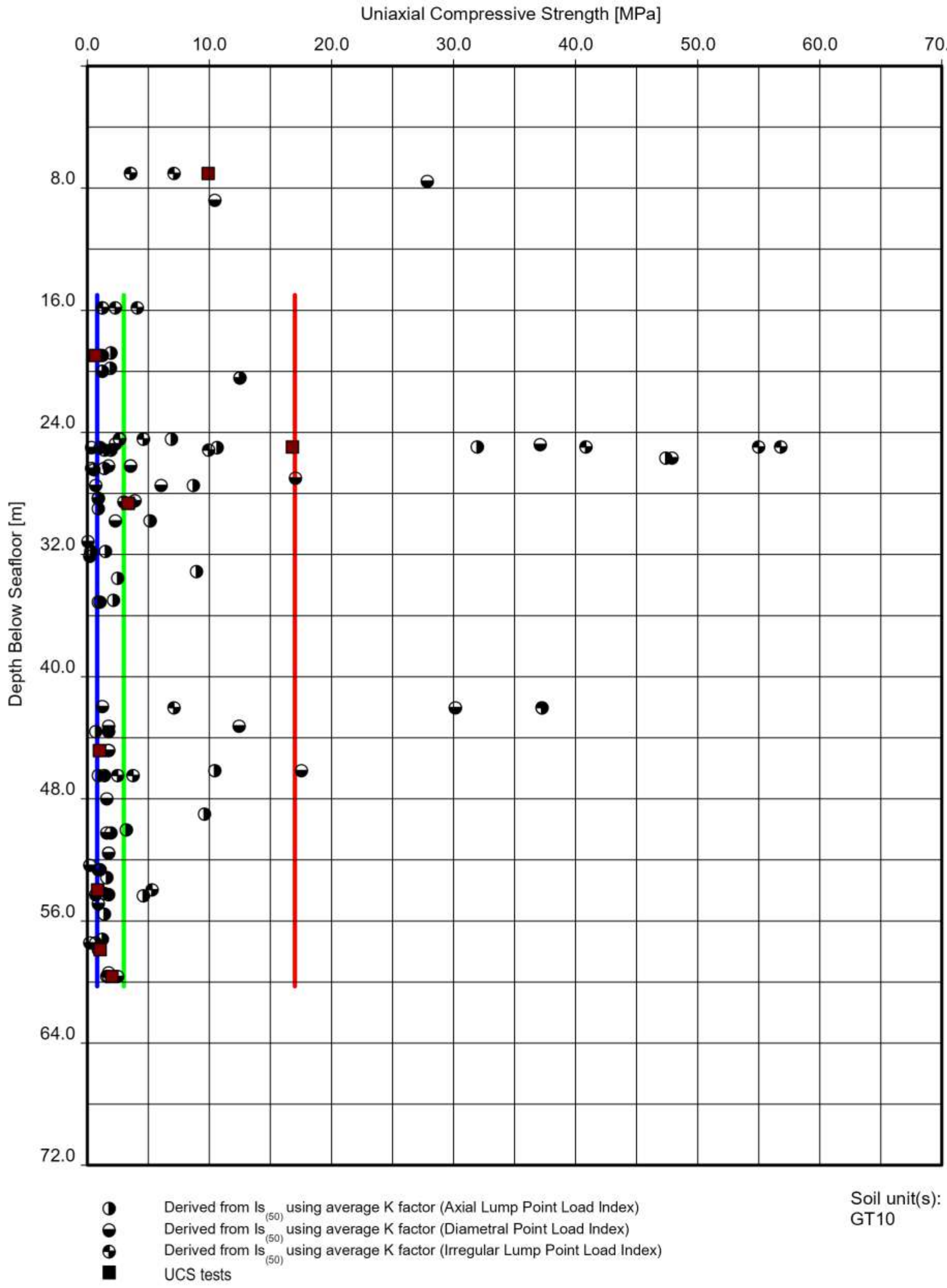
Soil unit(s):
GT9

GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:56:03

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF

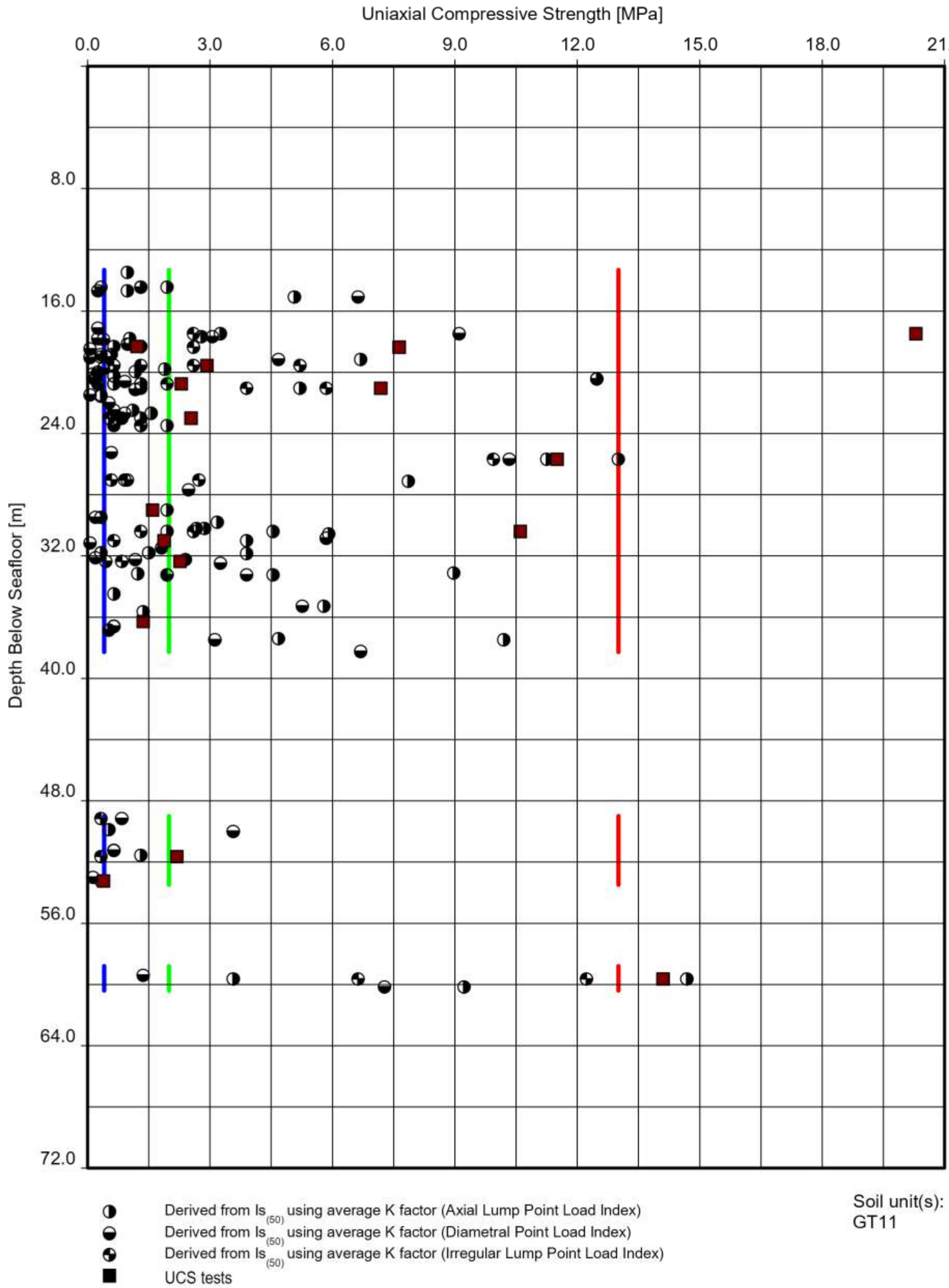
FUGRO



GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:58:13

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

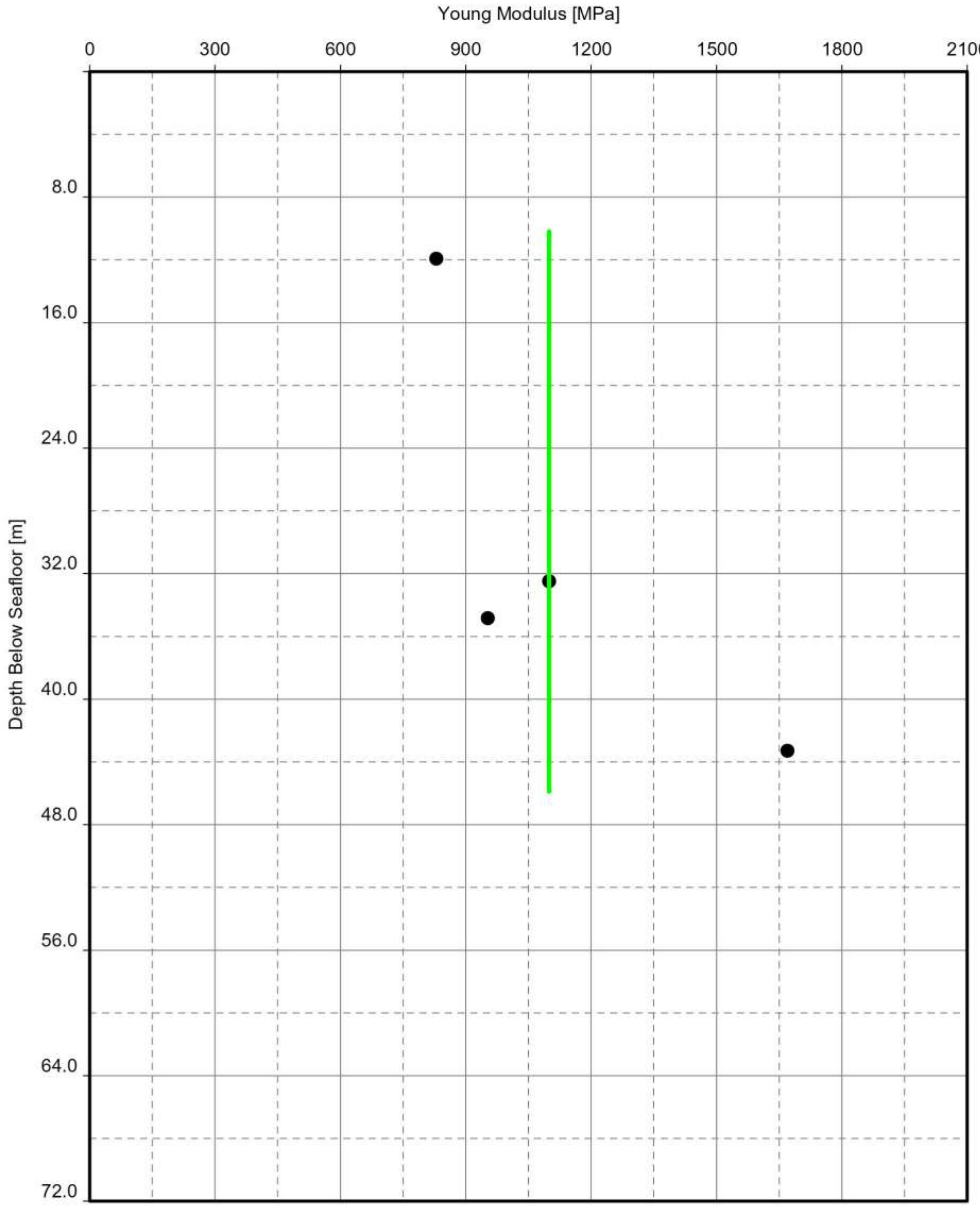
OWF



GeODin / UCS vs depth.GLO / 2024-05-06 @ 19:59:32

UNIAXIAL COMPRESSIVE STRENGTH VERSUS DEPTH

OWF

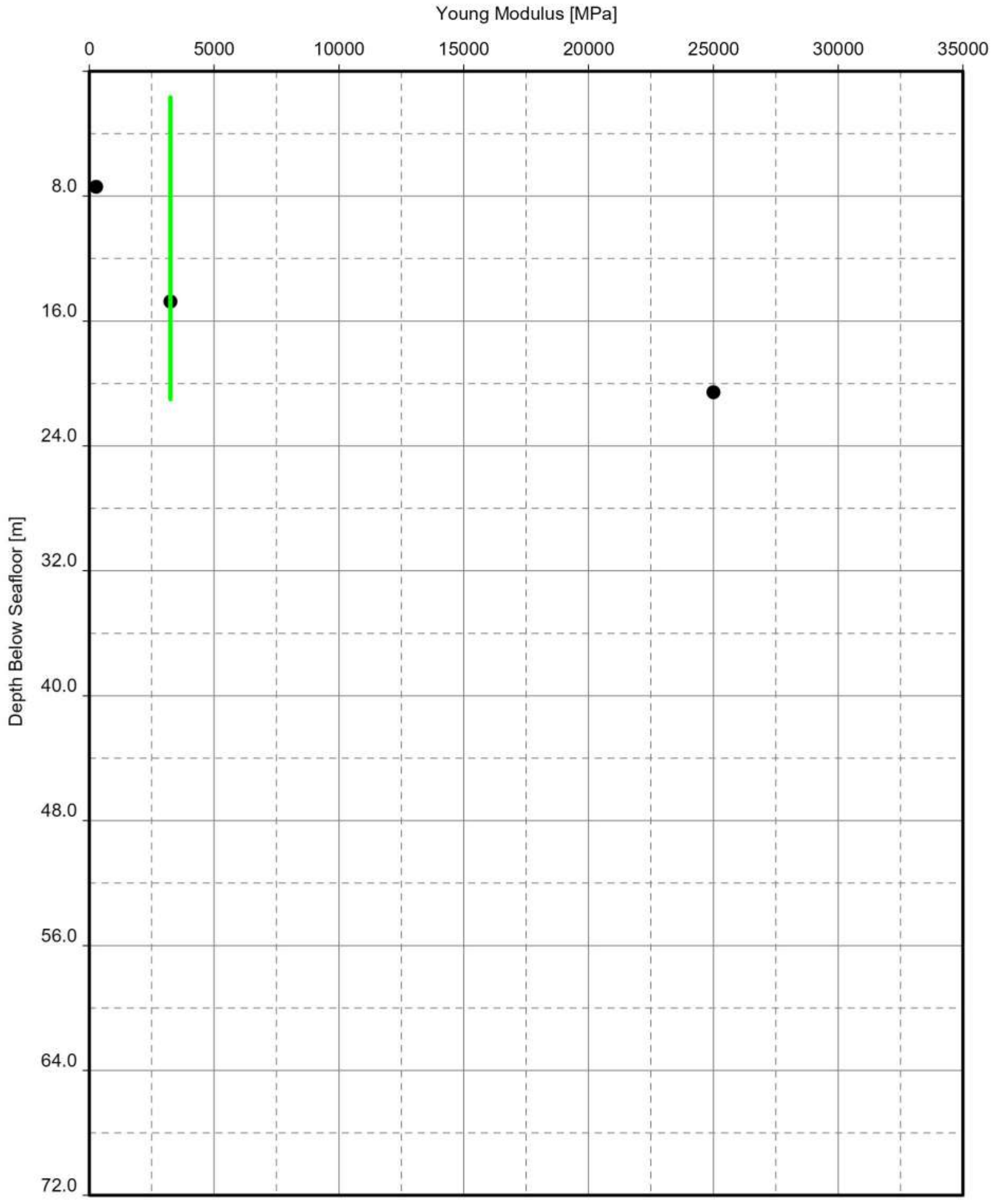


Soil unit(s):
GT5

GeODin / Young modulus vs depht.GLO / 2024-05-06 @ 20:07:04

YOUNG MODULUS VERSUS DEPTH

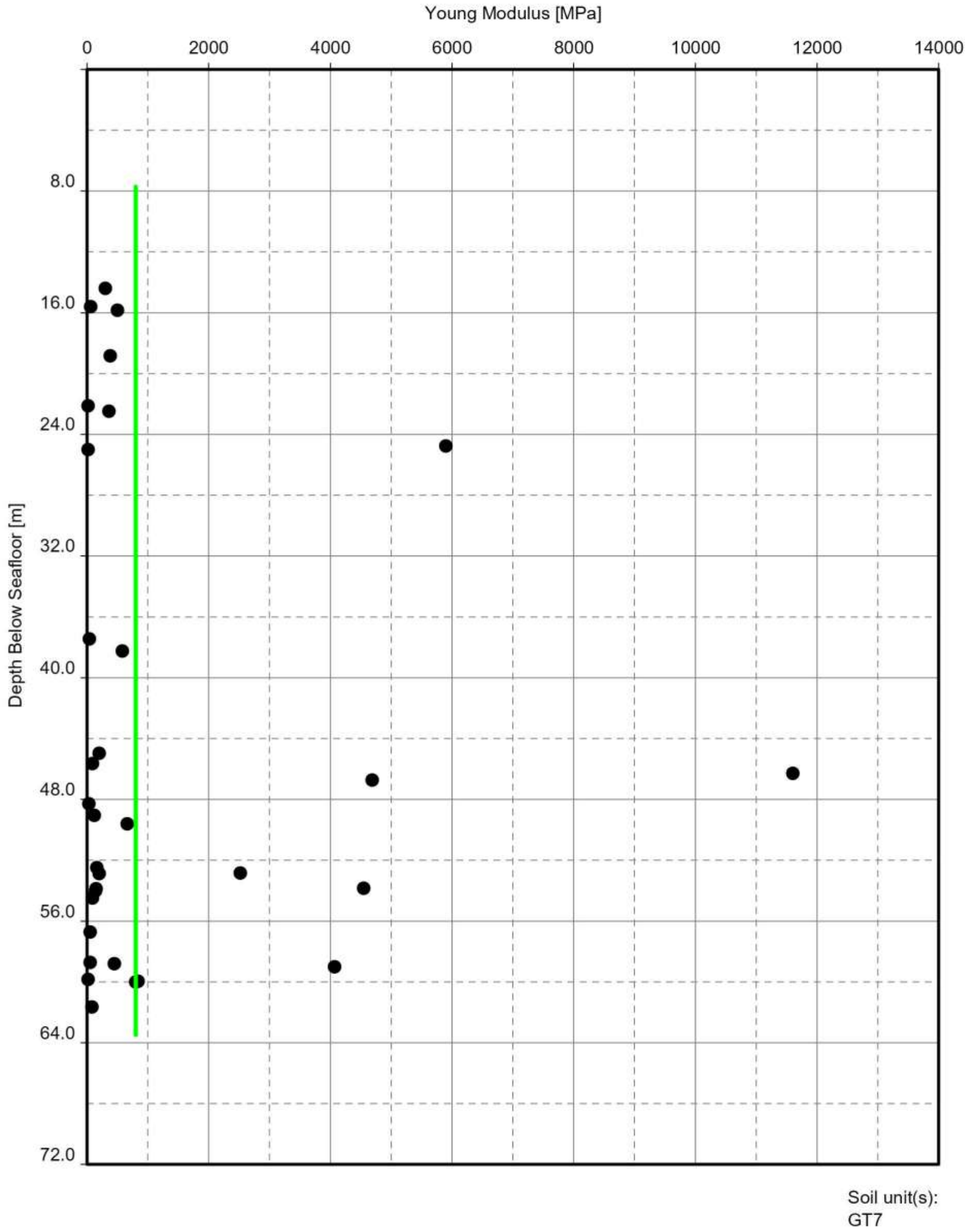
OWF



Soil unit(s):
GT6

YOUNG MODULUS VERSUS DEPTH

OWF

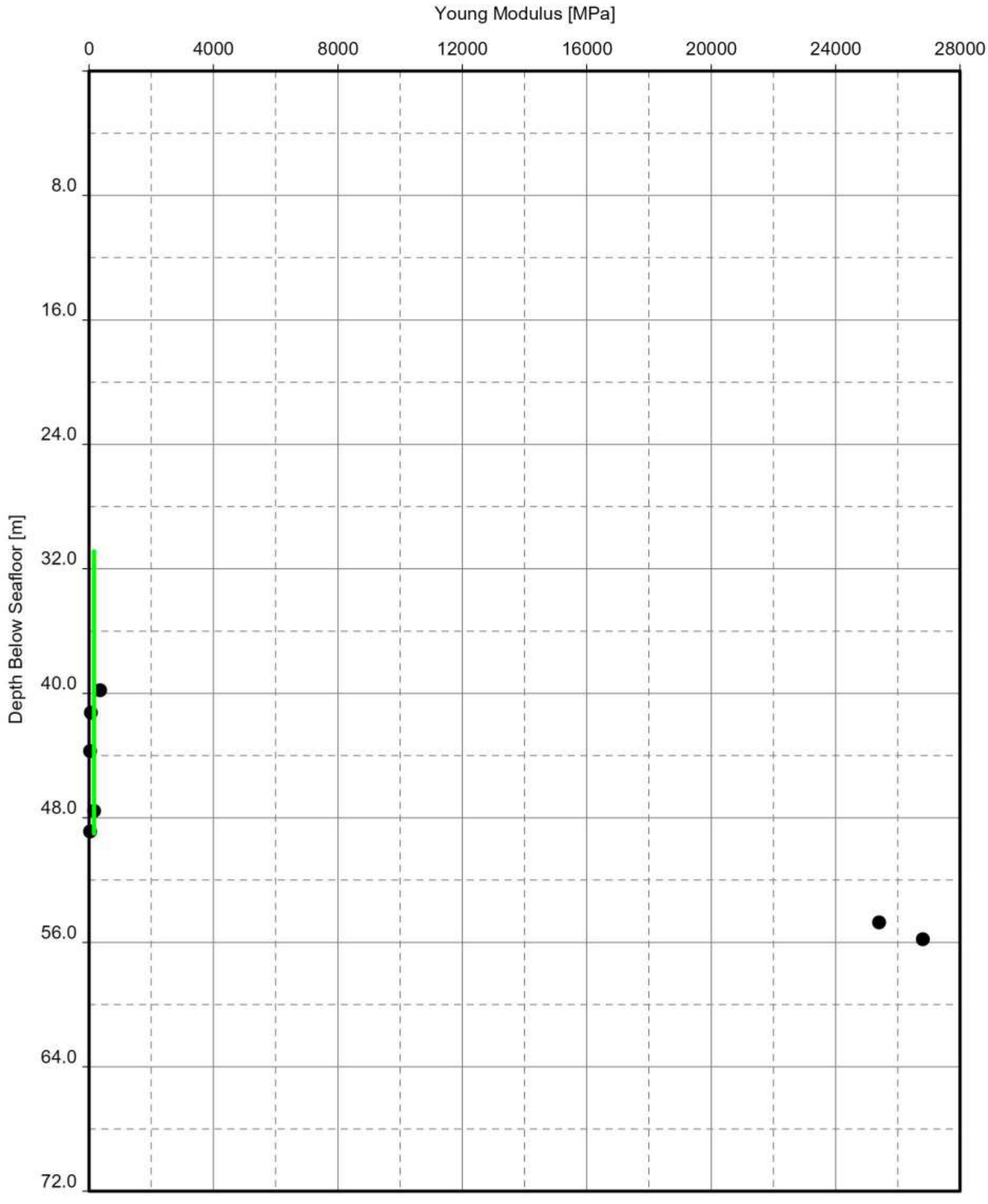


GeODin / Young modulus vs depht.GLO / 2024-05-06 @ 20:04:21

YOUNG MODULUS VERSUS DEPTH

OWF

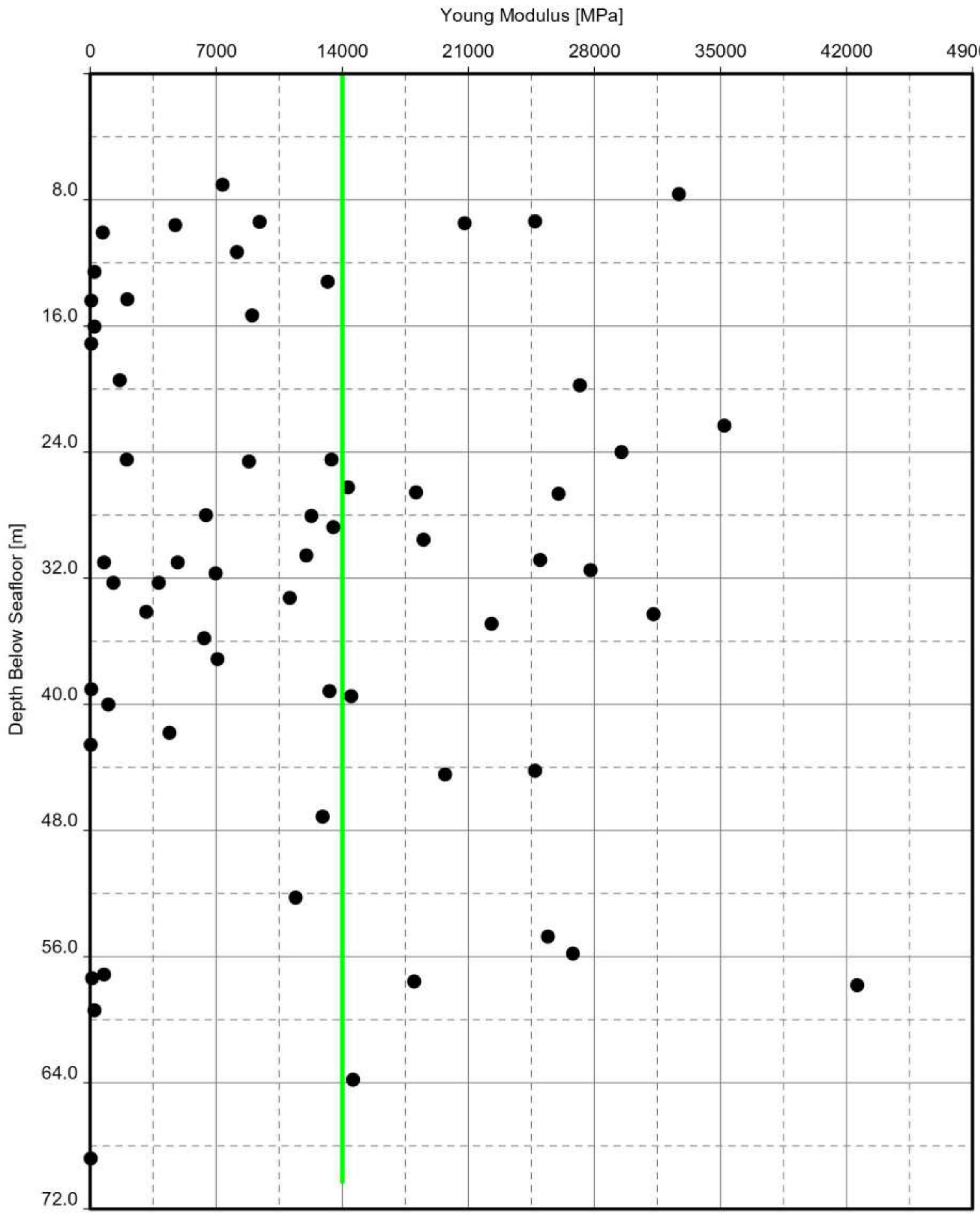
FUGRO



Soil unit(s):
GT8

YOUNG MODULUS VERSUS DEPTH

OWF

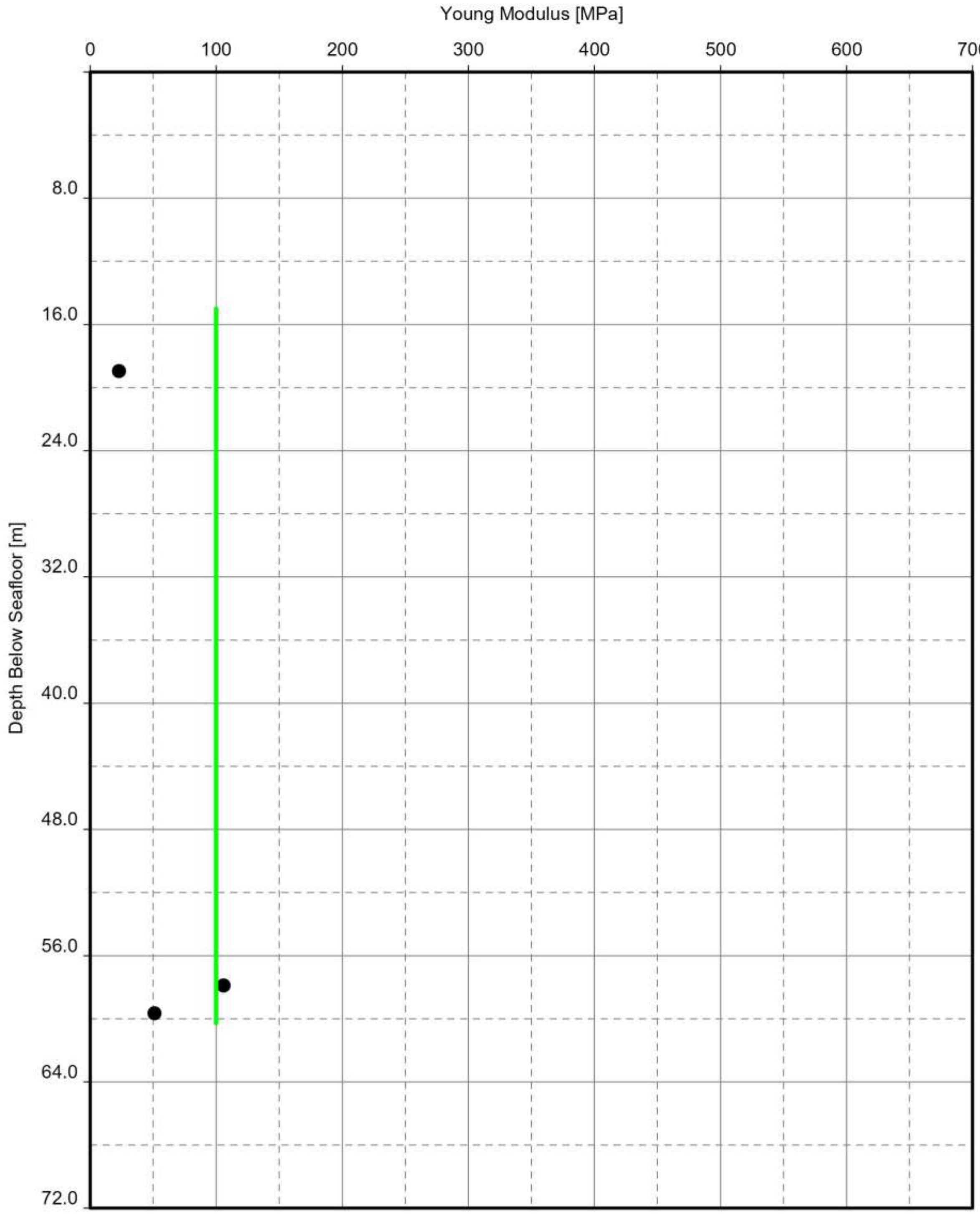


Soil unit(s):
GT9

YOUNG MODULUS VERSUS DEPTH

OWF

GeODin / Young modulus vs depht.GLO / 2024-05-06 @ 20:02:16

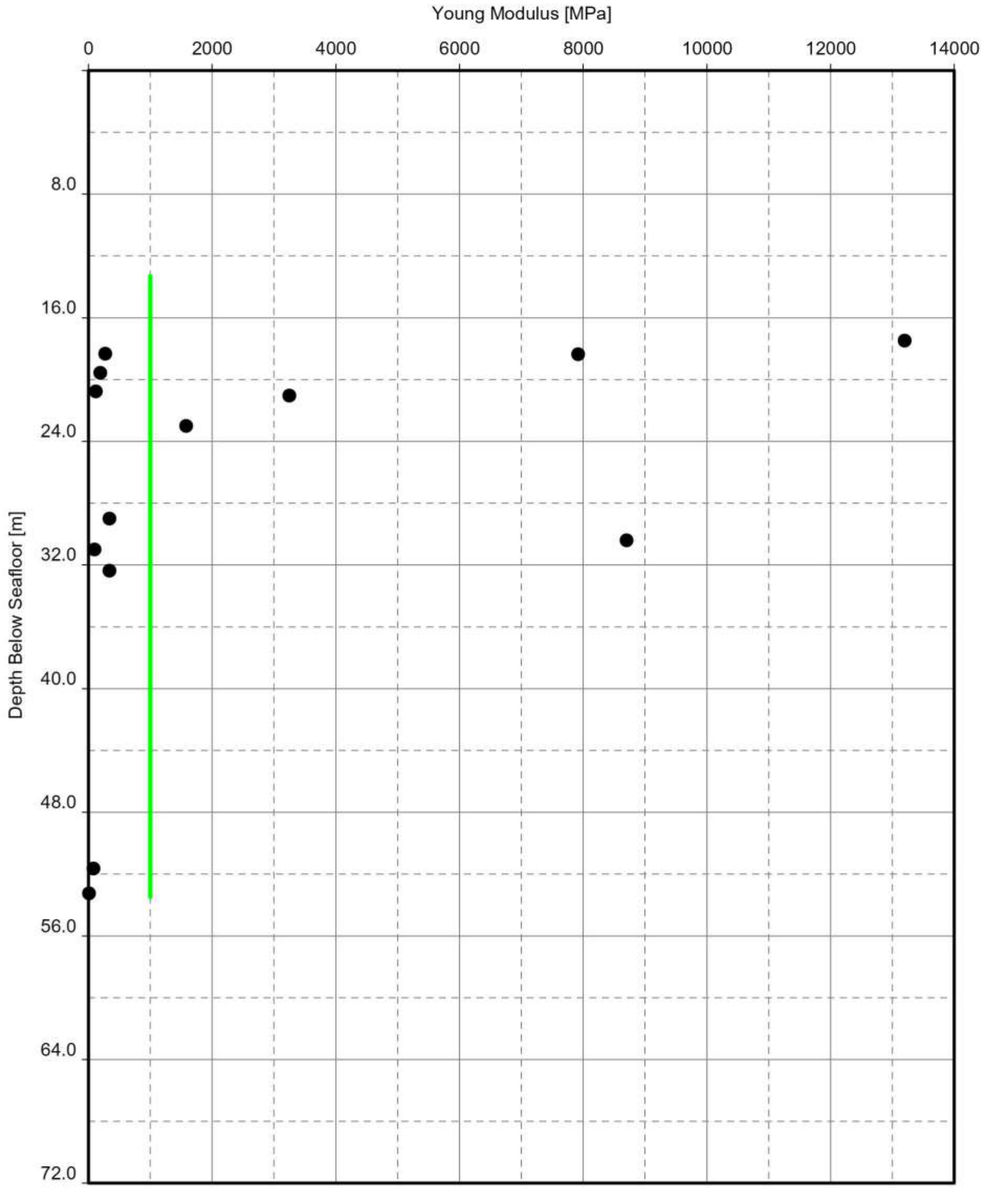


Soil unit(s):
GT10

GeODin / Young modulus vs depht.GLO / 2024-05-06 @ 20:01:12

YOUNG MODULUS VERSUS DEPTH

OWF



Soil unit(s):
GT11

GeODin / Young modulus vs depht.GLO / 2024-05-06 @ 20:00:26

YOUNG MODULUS VERSUS DEPTH

OWF