Neptun Deep Project

Final Geotechnical Interpretative Report Pelican Drill Center

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Neptun Deep Project

Final Geotechnical Interpretative Report Pelican Drill Center

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FUGRO

Pelican Drill Center Geotechnical Interpretive Report
Neptun Deep Survey

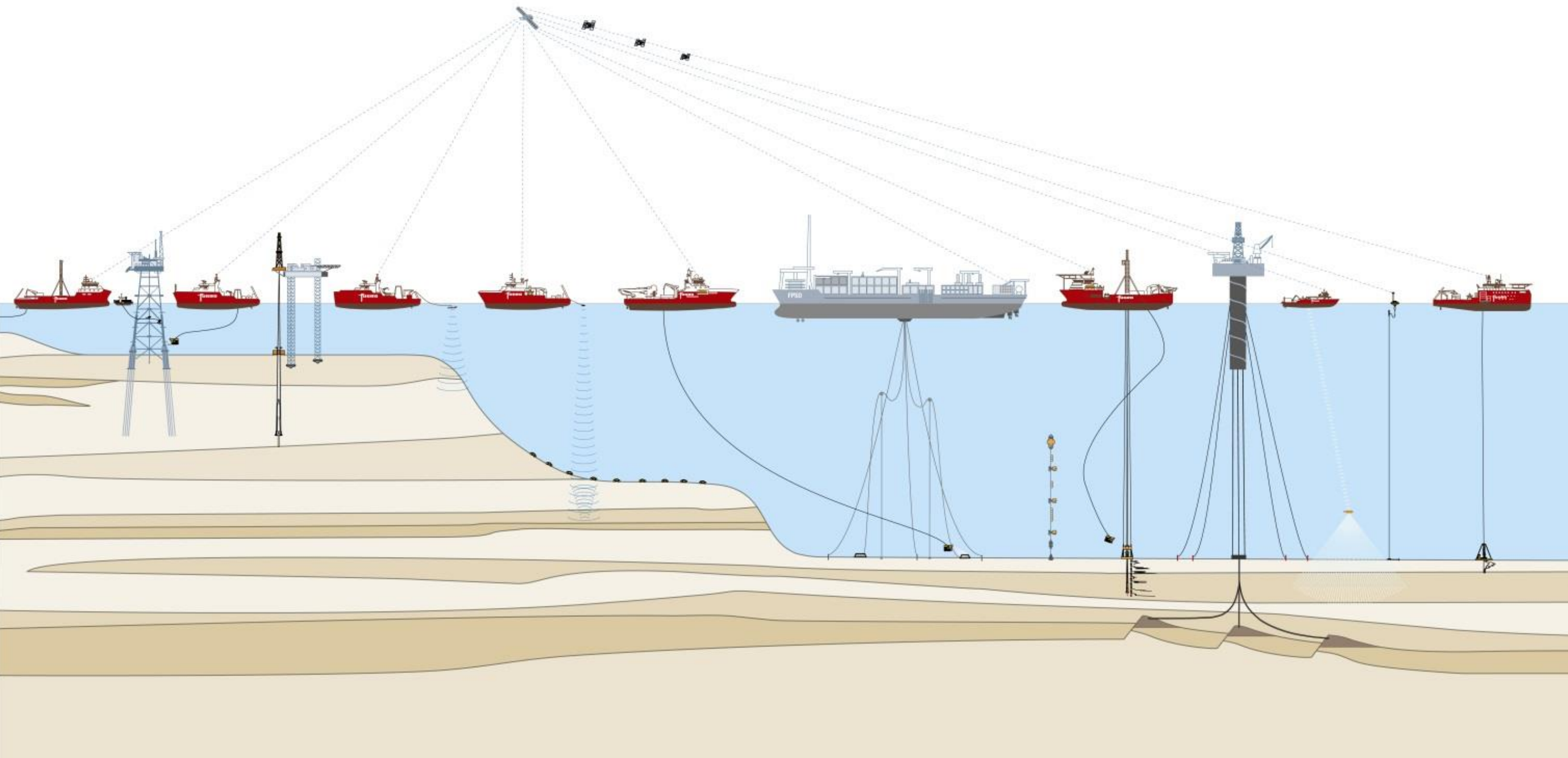
Pelican South Field

Black Sea, Romania

Fugro Document No.: 173570-05a(02)
Issue Date: 5 June 2018

ExxonMobil Exploration and Production Romania Limited

Final Report



FUGRO

Pelican Drill Center Geotechnical Interpretive Report
Neptun Deep Survey
Pelican South Field
Black Sea, Romania

Fugro Document No: 173570-05a (02)

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Date: 5 June 2018

ExxonMobil Exploration and Production Romania Limited
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Bucharest
Romania

Dear Yvonne Moret and Patrick Lee,

Neptun Deep Survey
Pelican South Field, Black Sea, Romania

We have the pleasure of submitting the Pelican Drill Center Geotechnical Interpretive Report for the Neptun Deep Survey. This report presents the interpreted geotechnical soil parameters for mudmat foundation assessment at the Pelican South Drill Center.

This report was prepared by Martin Gichura and Charles Bloore under the supervision of Mike Rattley.

We hope that you find this report to your satisfaction; should you have any queries, please do not hesitate to contact us.

Yours sincerely,
Fugro GB Marine Limited

Martin Gichura
Geotechnical Engineer

Distribution: One electronic copy to Yvonne Moret and Patrick Lee

QUALITY ASSURANCE RECORD

Section	Prepared By	Checked By	Approved By
Main text	MG	DR/LMC	MR
Plates following the main text	MG	DR	MR
Appendix A – Guidelines On Use Of Report	Fugro	Fugro	Fugro

Notes:
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REPORT ISSUE LOG

Issue No.	Status	Reason for Issue/Reissue	Comments on Content	Date
01	Draft	First issue to client	Awaiting client comments	15 May 2018
02	Final	Update in response to client comments	Updated for client comments	5 June 2018

FRONTISPIECE

EXECUTIVE SUMMARY

Introduction

ExxonMobil Exploration and Production Romania Limited (ExxonMobil) is developing the Pelican South field and Domino field in the Romanian sector of the Black Sea.

ExxonMobil requested Fugro GB Marine Limited (Fugro) to perform a geotechnical site investigation to provide soils information at the Pelican South field and Domino field. The fieldwork was performed from the MV Fugro Synergy from 28 December 2017 to 8 February 2018.

This report contains interpreted geotechnical soil parameters derived from the in situ and laboratory test data at the Pelican South Drill Center.

Geotechnical Data

Fugro (2018a) presents results of the in situ and laboratory testing from boreholes at the Pelican drill center location. Table S.1 summarises the borehole data used for assessment of geotechnical parameters.

Table S.1: Summary of Borehole Data at the Pelican Drill Center Location

Borehole Name	Easting[a] [mE]	Northing[a] [mN]	Water Depth [m MSL]			Termination Depth [m BML]	Comment
			Pressure Sensor	EchoSounder	Drill String		
DP-BH-01	548 044	4 878 185	124.7	124.5	123.9	29.9	Sampling only BH
DP-BH-03	548 084	4 878 177	124.9	124.7	124.5	29.3	CPT-and sampling BH
DP-CPT-02	548 067	4 878 233	124.6	124.7	123.8	30.0	CPT-only BH
L-CPT-11	547 708	4 877 703	124.4	124.7	N/A	4.5	CPT-only BH
DP-PH-01	548 067	4 878 180	124.6	124.7	124.7	33.0	Pilot hole

Notes:
a = Co-ordinate system WGS84 TM 30E
MSL = Mean sea level
BML = Below mudline
BH = Borehole
CPT = Cone penetration test

Geological Setting

The planned Pelican Drill Center location is situated between 123.8 m and 124.5 water depth on the edge of the Romanian Continental Shelf. This location was sensitive to changes in sea level throughout the quaternary.

At the planned Pelican South Drill Center locations, no signs of shallow gas including bubbles around the drill string at the seabed frame were observed (Fugro, 2018a). The samples from the Pelican south drill center locations were subsampled for headspace gas analysis which identifies the composition and concentration of gas trapped within the sediment. The number of samples that could be taken was limited due to the sandy silty nature of the soil.

The sediments of Unit II sampled boreholes at the Pelican South Drill Center show highly structured clay fabrics similar to the sediments at Platform G (Fugro, 2018b). The resulting soil fabrics are interpreted to represent changes in the post-depositional history of the sediment, including the presence or previous occurrence of gas within the sediment. The soil fabric may affect the strength of the sediment, depending on the specimen orientation and mode of shearing. Due to these soil structure variations there is a significant variance between index strength measurements, and the interpreted CPT and onshore laboratory test strength test measurements.

Design Soil Parameters

Fugro understands that, at the Pelican South Drill Center location, mudmat foundations are to be installed to support manifolds and tree protection structures. Derivation of the geotechnical soil parameters for preliminary mudmat design is discussed in this report and presented on plates following the main text of this report. The following design soil parameters were derived:

i. Water Content (w)
ii. Total Unit Weight (γ)
iii. Cone penetration test (CPT) Cone Resistance (q_c)
iv. Undrained Shear Strength (s_u)
v. Relative Density (D_r)
vi. Friction Angle ($\emptyset'$)
vii. Overconsolidation Ratio (OCR)
viii. Remoulded Strength (s_{ur})
ix. Strength Sensitivity (S_t)

Low estimate (LE), best estimate (BE) and high estimate (HE) design soil profiles were derived to the depth of investigation.

Discussion and Recommendations on Mudmat Foundations

Fugro understands that at the Pelican drill center location mudmats are planned to be installed to support manifolds and tree protection structures. The following foundation design risks were identified:

Shallow Gas: The presence of shallow gas may lead to a reduction in soil strength and stiffness within the soil. Shallow gas may also lead to accelerated corrosion of the foundation;

Seismicity: Formal unity checks on seismic stability should be performed as it may have an impact on structure operability may often lead to increased or reduced foundation sizes relative to unity checks;

Strong shallow soils: Strong shallow soils close to seafloor may provide challenges during the installation of the mudmats.

Fugro recommends that the mudmat analyses to be performed at the Pelican drill center location should consider the following in the detailed design as a minimum:

i. Structure-location specific design soil parameterisation as far as is possible with the available dataset;
ii. Quantifying the effects of shallow gas on key design soil parameters (e.g. s_u, compression parameters);
iii. Consideration of mudmat skirt installation constraints;
iv. Rate effects on s_u.

It is recommended that these effects are quantified and considered in detailed during detailed design in accordance with any specific ExxonMobil design basis requirements.

CONTENTS

APPENDICES

TABLES IN THE MAIN TEXT

FIGURES IN THE MAIN TEXT

PLATES FOLLOWING THE MAIN TEXT

ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BC	Boxcore
BE	Best estimate
BHA	Bottom-hole assembly
BML	Below mudline
BP	Before present
CAU	Anisotropically consolidated undrained triaxial
CID	Isotropically consolidated drained
CM	Central meridian
CPT	Cone penetration test
CRS	Constant Rate of Strain Oedometer
DSS	Direct Simple Shear
ERP	Emergency Response Plan
ExxonMobil	ExxonMobil Exploration Production Romania Ltd
FC	Fall cone
HE	High estimate
ISO	International Standards Organization
Ka BP	Thousand years before present

LAT	Lowest Astronomical Tide
LDPC	Large Diameter Piston Core
LE	Low estimate
LGM	Last Glacial Maximum
LV	Laboratory vane
LVr	Remoulded laboratory vane
WC	Water content
MSL	Mean Sea Level
MV	Marine Vessel
NE	North East
OCR	Overconsolidation ratio
OD	Outer Diameter
OED	Incremental oedometer
PC	Piston Core
PEP	Project Execution Plan
PP	Pocket penetrometer
PSHA	Probabilistic Seismic Hazard Analysis
SBF	Seabed Frame
SD	Standard deviation
SGMP	Shallow Gas Management Plan
SH	Shear wave
SRA	Site Response Analysis
SRD	Soil Resistance to Driving
SSHE	Safety, Security, Health and Environment Plan
TM	Transverse Mercator
TN	Technical Note
TV	Torvane
ULS	Ultimate Limit State
UTC	Coordinated universal time
UTM	Universal Transverse Mercator
UU	Unconsolidated undrained triaxial
UUr	Remoulded unconsolidated undrained triaxial
VHMT	Vertical, Horizontal, Moment and Torsion Loading
WC	Water content
WGS	World geographic system

1. INTRODUCTION

1.1 Project Setting

The Neptun Deep development area is located within the Neptun Block, Black Sea, offshore Romania. The proposed development comprises of the Pelican Drill Centre located in approximately 124 m water depth and 1.3 km from the proposed Platform G location. Platform G is located on the shelf in approximately 123 m water depth with ties to deep water drill centers. The proposed Domino Drill Centers are in approximately 900 m water depth, 23 km south-east of the proposed Platform G location and Pelican South Drill Center. The Domino Drill Centers are tied back to the Platform on the shelf by a flowline. A second flowline runs from the Pelican Drill Center to the Platform. A production pipeline runs from the planned platform location to shore. Figure 1.1 presents an overview of the planned development.

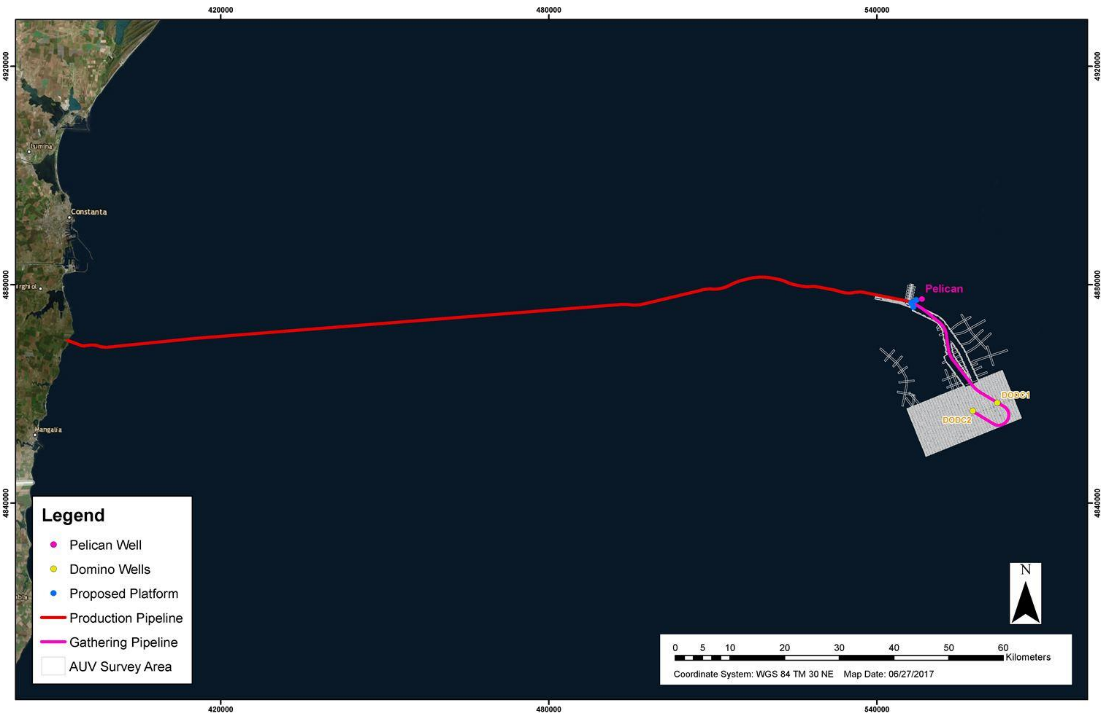


Figure 1.1: Main proposed infrastructure associated with the Neptun Deep development area

1.2 Project Summary

ExxonMobil Exploration Production Romania Ltd (ExxonMobil) contracted Fugro to perform and report on a geotechnical site survey for the proposed Platform G location, flowline route and three drill centres in the Neptun Block, Black Sea, offshore Romania. This work was carried out under Marine Site Survey order A2552390. Call Off 2 Change Order 6.

The scope of work comprised:

- 4 seabed CPTs;
- 7 sampling boreholes,
- 7 CPT boreholes;
- 14 combined sampling boreholes;
- 4 Pilotholes.

The site investigation took place from the MV Fugro Synergy between 28 December 2017 and 08 February 2018.

The geotechnical data were acquired to assess the sub-seafloor conditions and to provide data for input to foundation design. This report forms part of a series of reports for the geotechnical site investigation; these reports are detailed in Table 1.1.

Table 1.1:Reporting Structure

<table>
<tr><th>Type</th><th colspan="2">Deliverable</th></tr>
<tr><td rowspan="5">Engineering / Interpretive</td><td colspan="2">WORK PACKAGE 4
INTERPRETIVE REPORTS</td></tr>
<tr><td>Integrated Report Update
Report Number: 173570-08</td><td>Slope Stability and Debris Flow Run-Out Modelling Update Report
Report Number: 173570-09</td></tr>
<tr><td>Geological Interpretative Report
Report Number: 173570-06</td><td>Site Response Analysis
Report Number: 173570-07</td></tr>
<tr><td>Geotechnical Interpretive Report
Pelican Drill Center
Report Number: 173570-05a</td><td>Geotechnical Interpretive Report Platform
Report Number: 173570-05b</td></tr>
<tr><td>Geotechnical Interpretive Report
Domino Drill Center
Report Number: 173570-05c</td><td>Geotechnical Interpretive Report
Pipeline and Flowlines
Report Number: 173570 -05d</td></tr>
<tr><td rowspan="5">Factual</td><td colspan="2">WORK PACKAGE 3
FACTUAL/LABORATORY REPORT</td></tr>
<tr><td colspan="2">Laboratory and Insitu Testing Data report
Report Number: 173570-04</td></tr>
<tr><td colspan="2">WORK PACKAGE 3
FIELD/RESULTS REPORTS</td></tr>
<tr><td>Operations Report
Report No.: 173570-01</td><td>MMO Report
Report No.: 173570-02</td></tr>
<tr><td colspan="2">Field Data Report
Report No.: 173570-03</td></tr>
<tr><td>Preliminary Data</td><td colspan="2">Preliminary Interpretation Technical Note
TN-173570-05</td></tr>
<tr><td rowspan="2">Execution</td><td>Project Execution Plan
Document No.: 173570-PEP</td><td>Safety, Security, Health and Environmental Plan
Document No.: 173570-SSHE</td></tr>
<tr><td>Emergency Response Plan
Document No.: 173570 -ERP</td><td>Shallow Gas Management Plan
Document No.: 173570-SGMP</td></tr>
</table>

1.3 Scope of Report

This report presents geotechnical soil parameters for each defined geotechnical soil unit at the Pelican South Drill Center location. Fugro understands that mudmat foundations supporting manifolds and/or tree protection structures are the chosen foundation concept for the site. Design soil parameters are therefore provided for preliminary mudmat design.

The following tasks were performed to present the results in this report:

i. Evaluation and interpretation of the geotechnical data at the Pelican South Drill Center from the Laboratory and In Situ Testing Data Report (Fugro, 2018a);
ii. Derivation of representative design soil parameters to the borehole termination depth with consideration given to mudmat foundation assessment.

1.4 Data Sources

This report uses the results of the geotechnical site investigation to assess the soil conditions for the planned Pelican South Drill Center. The data used in the preparation of this report were obtained during an offshore site investigation, including in situ and laboratory testing, and from the subsequent onshore laboratory testing programme. Details of the site investigation are presented in Fugro Document No. 173570-03(02) (Fugro, 2018b) and details of the laboratory testing programme are presented in Fugro Document No. 173570-04(03) (Fugro, 2018a).

1.5 Project Co-ordinate Reference System

Table 1.2 presents the geodetic parameters for this project.

Table 1.2: Project Co-ordinate Reference System Parameters

Geodetic Datum	
Datum	WGS84
Ellipsoid	WGS84
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314245179
Inverse flattening	$^1/_f$ = 298.257223563
Angular unit	Degrees
Map Projection	
Projection system	TM 30 NE
Central meridian	30º 00′ 00.00″ east
Latitude of origin	0º north
False easting	500 000.0 m
False northing	0.0 m
Scale factor on central meridian	0.9996
Linear unit	Metres

1.6 Guidelines on Use of Report

Appendix A (guidelines on use of report) 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 site 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 ExxonMobil.

2. GEOLOGICAL SETTING.

2.1 General

This section details the geological setting for the Pelican South Drill Center. Fugro (2015a) provides a comprehensive geological model of the site based on a literature review and the results of the geohazard core logging (Fugro, 2014b and 2015a). An updated geological setting will be presented in the updated integrated report for the site (Fugro, 2018 (*in press*)).

The planned Pelican Drill Center location is situated between 123.8 m and 124.5 water depth on the edge of the Romanian Continental Shelf.

The north-western Black Sea is characterised by a wide shelf extending approximately 160 km from the Romanian coast. The Romanian continental slope dips gently to the south-east and is incised by a number of canyons. The largest of these canyons, the Viteaz canyon, is located west of the Neptun block. Canyons in the area have been active sediment transport pathways or subject to down-canyon processes during various time periods as a result of changes in sea level, sediment source and the position of the Danube delta.

Geological processes in the Neptun block were controlled by global sea level change during the Quaternary. Figure 2.1 presents the sea level curve for the late Quaternary showing the changing water level in the Black Sea and environmental conditions over the last 40,000 years.

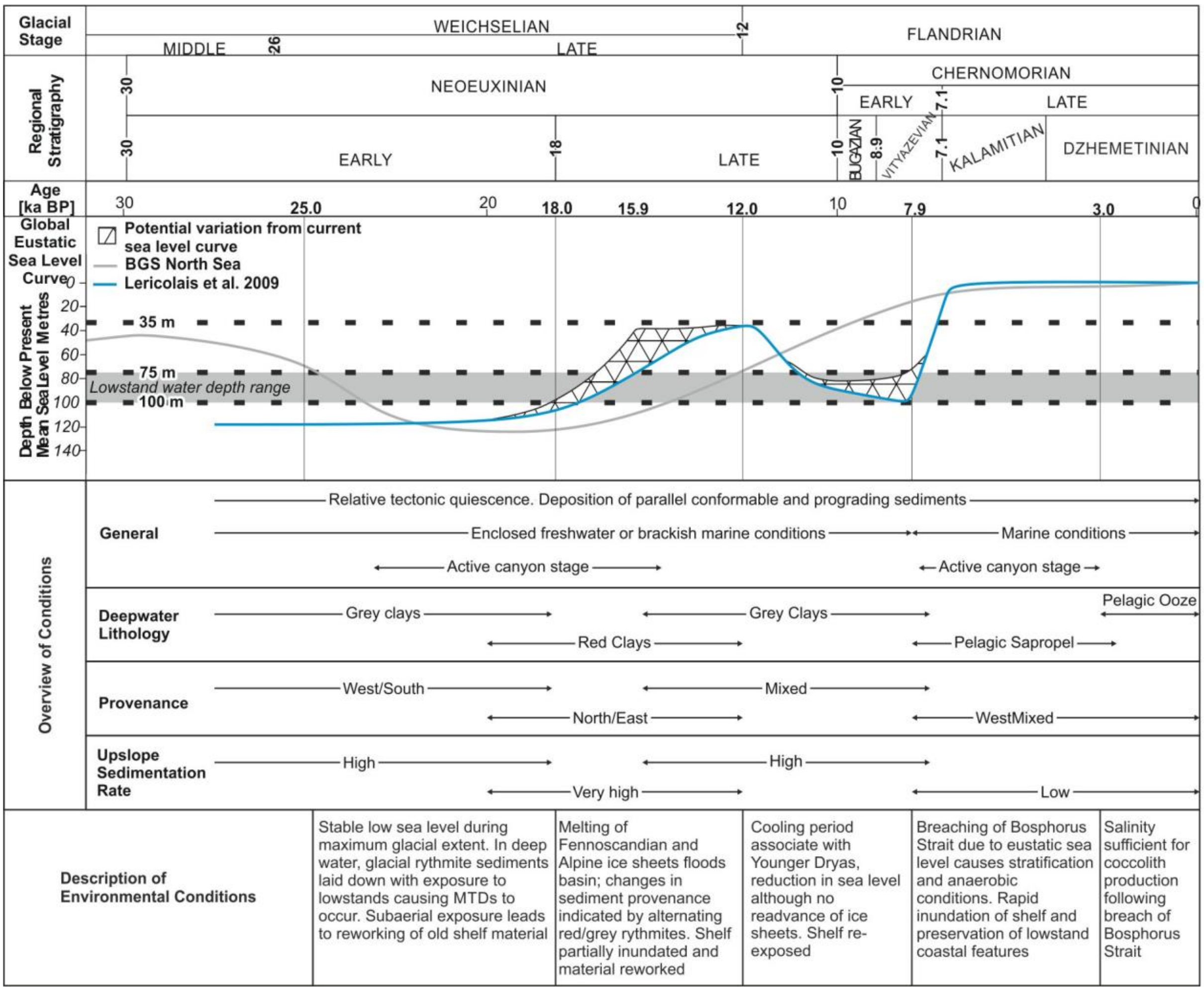


Figure 2.1: Sea level curve for the Neptun Block

Up to 8.0 ka (thousand years BP) the Black Sea was a freshwater lake fed by rivers from across Eastern Europe and Turkey, with its water level controlled by the advance and retreat of ice sheets. During this time, sediment deposition in the deeper-water areas was predominantly lacustrine clay. Global sea level rise at 8 ka and the reconnection of the Bosphorus Strait and the flooding of the Black Sea led to the deposition of organic rich clay (sapropel) and coccolith ooze. The organic rich sapropel is not preserved in water depths of less than 200 m; however, the shell rich surface layer observed at the planned platform location represents the recent marine depositional environment following the flooding of the Black Sea.

Earlier lowstand events during the Younger Dryas (12.0 ka to 7.9 ka) and the last glacial maximum (25 ka to 30 ka) resulted in periods of higher sediment input which are interpreted to relate to greater canyon activity and slope instability. During these lowstands the Pelican Drill Center location is likely to have been in a nearshore or shallow marine environment.

2.2 Site-Specific Geological Setting

The planned Pelican South Drill Center is located on the shelf break in approximately 124 m water depth. This location was sensitive to changes in sea-level throughout the Quaternary. The variation in the chemical proprieties (Section 4.8) and the presence of shell fragments which indicate the change in sedimentary environment.

The sediment types identified in the boreholes reflect changes in the depositional environment at the shelf location and show the transition between a marine (oxygenated) and lacustrine (anoxic) environment.

Section 3.3 presents the geotechnical soil units sampled and tested at the Pelican South Drill Center. Section 3.4 presents details of the site-specific geological features that are present that need to be considered when designing foundations. Table 2.1 summarises the interpreted depositional environment for each geotechnical unit at the Pelican South Drill Center location.

Table 2.1: Summary of Geotechnical Units interpreted to be present at Pelican South Drill Center

Geotechnical Soil Unit	**Description**	**Interpreted Depositional Environment**
I	Extremely low strength to low strength sandy CLAY with abundant shell fragments	Reworking of underlying sediments following Mediterranean water flooding the Black Sea
II	Low strength to high strength foliated to fissured sandy silty calcareous CLAY with closely spaced partings to thick laminae of silty fine SAND	Transitional marine/deltaic environment with periodic input of sand interpreted to be deposited during last glacial maximum lowstand. The presence of biogenic gas suggests high input organic material breaking down to produce methane.
III	Dense to very dense silty fine to medium SAND	Nearshore high energy environment during a period of sea level fall during the quaternary
Notes: BML = Below mudline		

The sediment types identified in the boreholes reflect changes in the depositional environment at the shelf location and show the transition between a marine (oxygenated) and lacustrine (anoxic) environment.

Section 3.3 presents the geotechnical units sampled and tested at the Pelican South Drill Center location. Section 3.4 presents details of the site-specific geological features that are present that need to be considered when designing foundations. Table 2.1 summarises the interpreted depositional environment for each geotechnical unit at the Pelican South Drill Center location.

3. GEOTECHNICAL PROFILE

3.1 General

This section details the geotechnical soil units observed in the boreholes at the Pelican South Drill Center location. Fugro (2018a) present the geotechnical borehole logs, laboratory data and in situ CPT data at the Pelican South Drill Center location.

3.2 Borehole Data

Four boreholes were drilled at the Pelican South Drill Center location. Table 3.1 presents details of the boreholes used in this study.

Table 3.1: Geotechnical Borehole Data at the Pelican South Drill Center Location

Borehole Name	Easting[a] [mE]	Northing[a] [mN]	Water Depth [m MSL]			Termination Depth [m BML]	Comment
			Pressure Sensor	EchoSounder	Drill String		
DP-BH-01	548 044	4 878 185	124.7	124.5	123.9	29.9	Sampling only BH
DP-BH-03	548 084	4 878 177	124.9	124.7	124.5	29.3	CPT-and sampling BH
DP-CPT-02	548 067	4 878 233	124.6	124.7	123.8	30.0	CPT-only BH
L-CPT-11	547 708	4 877 703	124.4	124.7	N/A	4.5	CPT-only BH
DP-PH-01	548 067	4 878 180	124.6	124.7	124.7	33.0	Pilot hole

Notes:
a = Co-ordinate system WGS84 TM 30E
MSL = Mean sea level
BML = Below mudline
BH = Borehole
CPT = Cone penetration test

3.3 Geotechnical Soil Units

There is good continuity between boreholes at the Pelican South Drill Center with the same geotechnical units observed at similar depths in each of the boreholes. Table 3.2 presents the geotechnical soil units observed and base of unit for each borehole.

Table 3.2: Geotechnical Units Observed at the Pelican South Drill Center Location

Geotechnical Soil Unit	Depth to Base of Unit [m BML]				Description
	DP-BH-01	DP-CPT-02	DP-BH-03	L-CPT-11	
I	0.40	0.72	0.47	0.78	Extremely low strength to low strength sandy CLAY with abundant shell fragments
II	25.20	25.35	25.10	4.45 [a]	Low strength to high strength foliated to fissured sandy silty calcareous CLAY with closely spaced partings to thick laminae of silty fine SAND
III	29.90[a]	30.00[a]	29.34 [a]	-	Dense to very dense silty fine to medium SAND with occasional medium beds of CLAY

Notes:
BML = Below Mudline
BH = Borehole
CPT = Cone penetration test
a = End of borehole

3.4 Geological Considerations

3.4.1 General

The proximity of the Pelican South Drill Center location to the proposed Platform G location at a distance of 1.3 km highlights various geological features that require consideration when developing design soil parameters. Figure 3.1 shows the Pelican drill center location in respect to the Platform G.

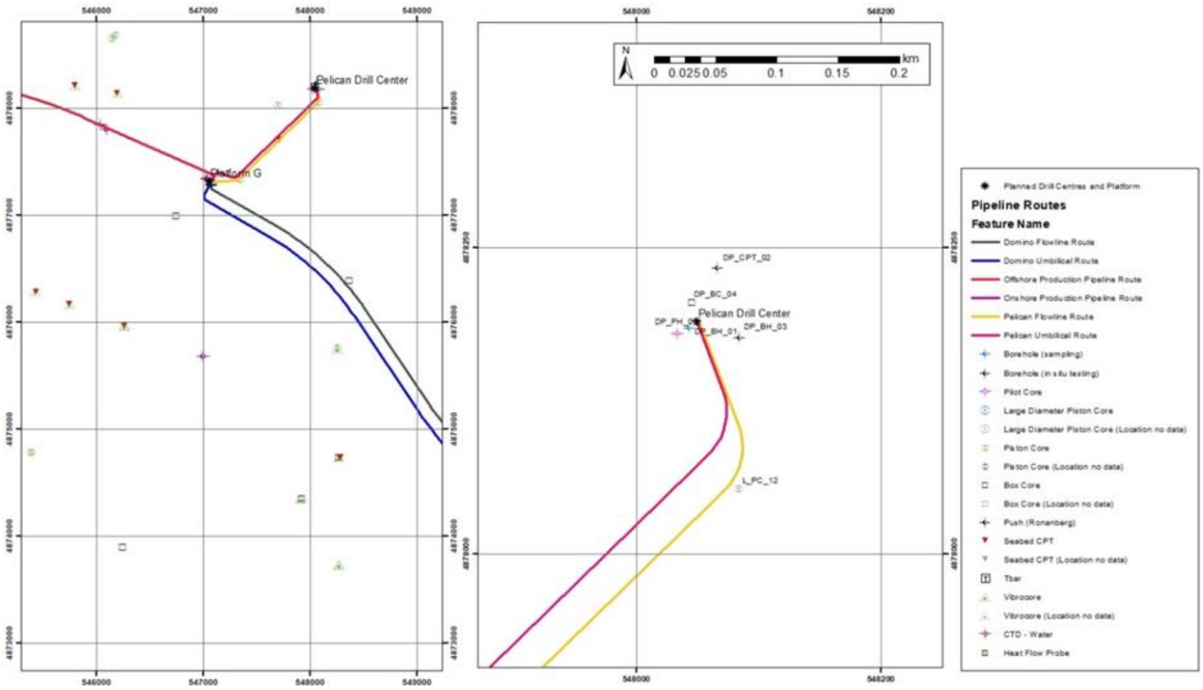


Figure 3.1: Map Showing Location of Pelican South Drill Center Boreholes and proximity to Platform G

Two geological features, as discussed by Fugro (2018c), were considered when deriving soil parameters:

i. Shallow gas;
ii. Soil fabric and structure observations.

Sections 3.4.2 and 3.4.3 discusses the above two geological considerations.

3.4.2 Shallow Gas

During drilling of the pilot hole (DP-PH-01) and boreholes at the Pelican South Drill Center locations, no signs of shallow gas including bubbles around the drill string at the seabed frame were observed (Fugro, 2018a).

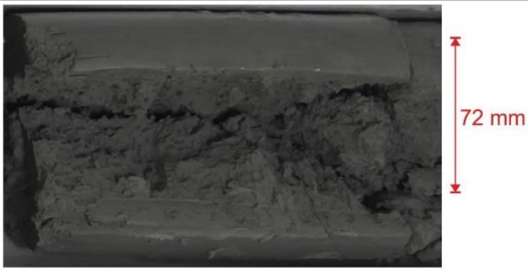
The samples from the Pelican South Drill Center locations were subsampled for headspace gas analysis which identifies the composition and concentration of gas trapped within the sediment. The number of samples that could be taken was limited due to the sandy silty nature of the soil.

When extruding samples in the laboratory from DP-BH-01 and DP-BH-03, the portable gas detector was held close to the sample and did indicate the presence of gas several times at a depth of 15.0 m below mudline (BML). The gas detector indicated that methane was present with concentrations between 13 % and 78 %. This gas dissipated within a few seconds.

3.4.3 Soil Fabric and Structure Observations

The sediments of Geotechnical Soil Unit II sampled from boreholes at the Pelican South Drill Center show highly structured clay fabrics similar to the sediments at the proposed Platform G (Fugro, 2018b) location. These soil fabrics are interpreted to be a result of post-depositional processes and could include the presence or previous occurrence of gas within the sediment. The soil fabric should be considered when interpreting geotechnical test results as these affect the strength, of the sediment depending on the axis along which the sample is tested. Because of this soil structure, there is an observed difference between the shear strength index test results carried out offshore and the shear strengths interpreted from the Cone Penetration Test (CPT) data. Table 1.1 presents a summary of the soil fabrics observed at the Pelican South Drill Center.

Table 3.3: Summary of Soil Fabrics Observed at DP-BH-01 and DP-BH-03

Unit	Depth [m BML]	Observation	Photograph
II	2.00	Structurless sandy silty CLAY with closely spaced thin laminae to medium beds of silty fine sand and with black staining	
II	4.00	Blocky/foliated dark silty CLAY with very closely spaced partings of silty fine sand	
II	5.00	Foliated silty CLAY with very closely to closely spaced thin to thick laminae of silty fine sand	
II	14.00	Foliated dark greenish grey sandy silty CLAY with sub-horizontal fractures	

4. INTERPRETATION AND EVALUATION OF GEOTECHNICAL DATA

4.1 Introduction

This section presents an interpretation and evaluation of the soil parameters at the Pelican South Drill Center locations within the Pelican South field. The soil parameters were derived to the termination depth of the deepest borehole at the Pelican drill center location. Specific consideration is given to mudmat foundation stability and installation analyses when deriving the design soil parameters. The soil parameters discussed in this section have been summarised in plates following the main text of this report. The plates present a selection of individual and/or composite plots with recommended representative low estimate (LE), best estimate (BE) and high estimate (HE) parameter profiles applicable for preliminary mudmat sizing. The parameters profiles were derived statistically according to GL-DNV (2015) where appropriate and engineering judgement.

The soil parameters discussed in this report were evaluated based on the geotechnical soil units unitisation described in Section 3.3.

LE and HE terms are used to represent a credible indication of the low and high distribution of the representative geotechnical parameters of the soil, with engineering judgement applied. It should be noted that the LE and HE terms are not necessarily lower or upper bound soil properties but rather recommended low or high values, which could be used as reference during derivation of soil parameters for preliminary mudmat sizing.

The BE profile for a soil parameter is typically based on a statistical average of the available data from the geotechnical site investigations and subsequent laboratory testing. Experience based engineering judgement is applied as required to provide a representative BE profile.

4.2 Basic Soil Physical Properties

4.2.1 General

This section presents the following basic physical soil properties:

i. Moisture content;
ii. Particle density;
iii. Total unit weight;
iv. Plasticity data;

Sections 4.2.2 to 4.2.5 discuss basic physical soil properties derived from field data and laboratory test data. In general, the basic physical soil properties are relatively consistent within the geotechnical soil units and only minor data scatter is observed.

4.2.2 Moisture Content

Plate 1 presents water content (w) data versus depth. The LE, BE and HE design lines were derived statistically from the available data and using engineering judgement for each geotechnical soil unit. The data presented indicates that:

i. The highest water content range is observed in Geotechnical Soil Unit I with water content ranging from 25 % to 80 %;
ii. Variable water content in Soil Unit II is expected to be a result of the transitional depositional environment for this soil unit, where periodic input of sand and silt soils has resulted in some intervals of lower water content.

4.2.3 Particle Density

Plate 2 presents the particle density versus depth profile. The LE, BE and HE soil profiles were determined by engineering judgement and experience from the proposed Platform G location boreholes.

The particle density data are limited, with only one measurement in Soil Unit I and three measurements in Soil Unit II. No measurements were performed in Soil Unit III. However, the available data generally fall within the bounds established for the same soils unit based on data from the proposed Platform G location boreholes and the design profiles are taken to be consistent with those proposed for the Platform G location. The BE particle density profile was used to derive unit weight from water content data.

4.2.4 Unit Weight

Plate 3 presents the unit weight (γ) data versus depth. Unit weight data were determined from:

i. Volume-mass calculations from undisturbed samples;
ii. Measured water content and unitised BE particle density values.

Measured water content unit weights were generally higher than the volume-mass unit weights. The volume-mass unit weights may have been affected by the presence of shallow gas in the sand and silt partings as noted in Section 3.4.1. Therefore, unit weight design lines were generally biased to data calculated from measured water content and particle density measurements. In addition, volume-mass unit weights were typically considered non-representative in Soil Unit III, due to the elevated influence of sample disturbance on cohesionless soils.

4.2.5 Plasticity Data

Composite plots of plastic limit (W_p) and liquid limit (W_L) data were delineated into soil units and used to determine representative parameter profiles of plasticity index (I_p). The LE, BE and HE design lines for I_p were derived from the available data for each soil unit.

Plate 4 presents the W_p and W_L data and Plate 5 presents I_p versus depth. Equation 4.1 describes the calculation of I_p from the $W_p$and W_L.

$$I_p = W_L - W_p$$

Equation 4.1

Plate 6 presents the BS5930 plasticity chart. Soil Unit II at the Pelican South Drill Center location is determined to be of intermediate plasticity.

In the top 5.0 m BML within Soil Unit II a lower soil plasticity is inferred from the measured data which is generally consistent with lower water content values measured across the same depth range. Although the plasticity data is limited, it is expected that the presence of silt layers, as noted in the borehole logs, will have affected the plasticity of the soils across this depth interval. This is reflected in the design profiles provided. Below 5.0 m BML in Soil Unit II, variations in soil plasticity typically follow changes in water content and are expected to be a result of the transitional depositional environment for this soil unit, where periodic input of sand and silt soils will have affected the classification properties of the soil.

At 28.0 m BML within Geotechnical Soil Unit III a plasticity index test was performed on a sample taken from a clay bed. The plasticity index of this clay bed was 11 %.

Liquidity index (I_L) was derived from the plasticity data and water content (w). It relates the water content of a fine-grained soil to its plasticity data. Equation 4.2 describes the calculation of I_L:

$$I_L = \frac{w - W_P}{I_P}$$

Equation 4.2

Plates 7 presents I_L versus depth. The I_L plot shows that the I_L is generally uniform with depth within Soil Unit II. The I_L values observed are generally not indicative of a potential for extreme sensitivity or extremely low remoulded strength in in Soil Unit II, however instances of reasonably low remoulded strength were observed within Soil Unit II (see Section 4.4.4).

4.3 In Situ Testing

4.3.1 General

Downhole CPT data acquired in the boreholes at the Pelican South Drill Center location were used in deriving cone resistance (q_c) and sleeve friction (f_s) profiles. Correlations to CPT test data were also used to derive indicative undrained shear strength (s_u), relative density (D_r), overconsolidation ratio (OCR) and soil strength sensitivity (S_t) data.

4.3.2 Measured Cone Resistance

Measured cone resistance data were derived from CPT data presented in Fugro (2018b). Plate 8 presents the unitised q_c data and the determined LE, BE and HE q_c design profiles. Plate 9 presents the unitised q_c data on an enhanced scale. The design profiles were determined based on engineering judgement.

The measured q_c data was used to derive OCR as described in Section 4.5.2.

The large variation of q_c in the upper 5.0 m BML and below 18.25 m BML within Soil Unit II reflects the influence of higher sand and silt content across the same depth interval and it consistent with variations in the water content, plasticity and particle size distribution measurements across the same depth range. BE profiling is subject to some uncertainty within this depth range and should be carefully reviewed based on the objectives of the engineering analysis for which it is being considered.

Within Geotechnical Soil Unit III only LE and HE q_c design profiles are provided. These profiles represent the strength variation through the interbedded sand and clay units and highlight the limits of the unit response characteristics. In the upper part of Geotechnical Soil Unit III, to 28.50 m BML, the LE q_c design profile is considered to reflect of the occurrence clay beds in this soil unit and represents a predominantly clay (undrained) response. The HE q_c profiles represent a predominantly sand (drained) response. Other design profile variations within Soil Unit III, including a BE profile, are specific to the engineering analysis considered and should be derived based on the objectives of the analysis being performed. Hence these are not included in this report.

4.3.3 Sleeve Friction

Plate 10 presents the CPT sleeve friction with depth and a BE design profile derived using engineering judgement. The f_s data was used as a reference in deriving remoulded undrained shear strength and strength sensitivity (see Section 4.4.4 and Section 4.4.5, respectively).

The variation of f_s in the upper 5.0 m BML of Soil Unit II reflects the influence of higher sand and silt content across the same depth interval and it consistent with variations in the water content, plasticity and particle size distribution measurements across the same depth range. BE profiling is subject to some uncertainty within this depth range and should be carefully reviewed based on the objectives of the engineering analysis for which it is being considered.

4.4 Monotonic Undrained Shear Strength

4.4.1 General

This section details the methods used to determine the monotonic undrained shear strength (s_u). LE, BE and HE s_u profiles were derived based on engineering judgement.

A LE design line of the s_u data was derived for soil capacity analysis, considering the potential uncertainty in the cone factors applied and the inherent variability in the datasets. A HE design line of the s_u data was derived for installation analysis. Plate 11 presents the s_u data and the derived LE, BE and HE design profiles.

Dependent on the nature of the engineering analyses being undertaken, the upper part of Geotechnical Soil Unit III, to 28.50 m BML, which consists of interbedded sand and clay layers may be modelled as clay (undrained) or sand (sand). Where the soil response is to be modelled as undrained the CPT q_c should be carefully reviewed to define an appropriate design profile.

The variation of s_u in the upper 5.0 m BML and below 18.25 m BML within Soil Unit II reflects the influence of higher sand and silt content across the same depth interval and it consistent with variations in the water content, plasticity and particle size distribution measurements across the same depth range. Design profiling is subject to some uncertainty within these depth ranges and should be carefully reviewed based on the objectives of the engineering analysis for which it is being considered. For the purposes of this report the BE design line was biased toward the characteristic BE of the consolidated laboratory test measurements. This profile is expected to reflect a soil strength which is not subject to significant shear dilation effects, which can occur due to increased sand and silt content of the soil. The LE profile provided reflects the lower limits to measurements of strength for the same response. The HE profile provided generally reflects an upper limit to the available laboratory data and is expected to be representative of the increases in strength which may occur due to increases in shear induced dilation.

4.4.2 Undisturbed Strength from Laboratory Data

The s_u data were obtained from laboratory vane (LV) and unconsolidated undrained (UU) triaxial tests performed in the offshore laboratory. Direct simple shear (DSS) test, UU and consolidated anisotropically undrained (CAU) triaxial tests from the onshore laboratory testing were also used in determining s_u in Soil Unit II.

Index strength test data from pocket penetrometer (PP) and torvane (TV) data were not considered representative of the soil strength in Geotechnical Soil Unit II. A generally lower s_u was obtained from index tests (PP and TV) and LV, than from DSS, UU and CPT. This is interpreted to be due to the high silt content and well developed sub-horizontal to vertical fissures within Geotechnical Soil Unit II. Further soil fabric observations are noted by Fugro (2018b), see Section 3.4.3. Therefore, PP and TV measurements were not generally considered in deriving the s_u design profiles provided.

4.4.3 Undisturbed Strength from Cone Penetration Test Data

Undrained shear strength (s_u) was measured directly from laboratory testing and was also inferred from CPT data using Equation 4.3:

$$s_u = q_n / N_{kt}$$

Equation 4.3

Where:

q_n = Net cone resistance [kPa]

N_{kt} = Empirical factor relating cone resistance to undrained shear strength

N_{kt} factors of 15 to 20, were used to derive characteristic s_u values from q_c data for input to engineering analyses. These N_{kt} factors are general values based on Fugro experience in similar soils. Further review of the N_{kt} factors and detailed calibration of these values may be required for strength profiling in Soil Unit II as part of foundation detailed design.

4.4.4 Remoulded Undrained Shear Strength

The remoulded s_u (s_{uR}) was measured using remoulded LV (LVr) and remoulded UU (UUr) tests. Plate 12 presents the s_{uR} plot for all geotechnical units.

The residual LV test is prepared using the vane to remould the soil after the undisturbed test, as outlined in ASTM D4648 (1982). The LVr test procedure requires removal of the soil from the sample tube, physically remoulding the soil with a spatula, replacing the remoulded soil into a suitable container and testing as outlined in ExxonMobil G004 (2015).

Values of s_{uR} were also calculated from I_L according to Wroth (1979). Equation 4.4 presents the calculation of s_{ur} from I_L.

$$s_{ur} = 1.7\left[10^{2(1-I_L)}\right]$$

Equation 4.4

Values of s_{uR} were also determined from CPT f_s. According to Lunne et al., (1997) f_s from an electric cone is approximately equal to the s_{uR}. In this report s_{uR} was considered to be inferred from 2/3 f_s based on Fugro experience.

A large degree of variability is observed in the LV data in Soil Unit II. Some low values of s_{uR} were observed from LV tests which are not consistent with the CPT sleeve friction measurements over the same interval. The latter is considered to be a better indicator of remoulded strength for the purpose of shallow foundation design, due to the mechanisms related to remoulding the soil around the CPT being broadly similar to remoulding of soil around a foundation skirt. The BE s_{uR} design profile was biased toward the CPT sleeve friction data for this reason. Generally, the results from UUr tests plot towards the upper bound of the dataset and were typically used to define the HE design line. Four LV tests were observed to have sensitivities greater than 10. These high sensitives of the LV are considered to be due to the realignment of the sand and silt particles during remoulding leading to a loss of structure and hence significantly lower remoulded shear strength results.

4.4.5 Strength Sensitivity

Strength sensitivity (S_t) is calculated from the ratio of s_u to s_{ur}. S_t was assessed by using undisturbed and remoulded LV and UU test results. Equation 4.5 was used to derive S_t from CPT data based on the recommendations of Schmertmann (1978).

$$S_t = {}^{N_s}\!/_{R_f}$$

Equation 4.5

Where:
N_s = Factor relating S_t to R_f
R_f = Friction ratio as determined from q_c and f_s

N_s factors of 3.5 and 9 were considered for derivation of S_t within Soil Unit II, given observations of low remoulded strength within this unit.

Plate 13 presents the strength sensitivity data and LE, BE and HE design profiles. The S_t profiles derived from CPT data generally match well with the lower and upper bounds inferred from the laboratory test results. For Soil Units II S_t profiles were selected using engineering judgement. The LE S_t. was based on the UU while the HE S_t was tentatively based on a review of the LV tests results, although some higher values were omitted from this review based on comparison to CPT sleeve friction data and noting that preferential failures can develop for lab vanes tests performed on specimens with high sand and silt contents (i.e. friable soils) i.e. some very low remoulded laboratory vane results were discounted.

4.5 In Situ Stresses and Stress History

4.5.1 General

This section presents the inferred stress history parameters for the Pelican South Drill Center. Constant rate of strain consolidation tests were performed to determine the stress history characteristics of the soil.

4.5.2 Overconsolidation Ratio

Overconsolidation ratio (OCR) was derived from the preconsolidation pressure (p'_c) or maximum additional overburden pressure ($\Delta p'$) and estimated effective overburden pressure (p'_0). Equation 4.6 describes the calculation of OCR.

$$OCR = \frac{p'_c}{p'_0} = \frac{(p'_0 + \Delta p)}{p'_0}$$

Equation 4.6

The one-dimensional consolidation tests were used to derive p'_c based on the Casagrande (1936) method. p'_0 was determined from the BE submerged unit weight assuming fully saturated soils and hydrostatic soil conditions.

In addition to the CRS testing, OCR was also indirectly assessed from p'_0 and s_u determined from UU, CAU and DSS tests. Equation 4.7 describes the relationship used to estimate OCR, from s_u and p'_0 (Mayne, 1980):

$$OCR = \left(\frac{\left({s_u}/{p'_o} \right)_{oc}}{\left({s_u}/{p'_o} \right)_{nc}} \right)^{1/\lambda_0}$$

Equation 4.7

Where:

s_u = Undrained shear strength [kPa]
p'_0 = Effective overburden pressure [kPa]
$(s_u/p'_0)_{OC}$ = Ratio for overconsolidated soil
$(s_u/p'_0)_{NC}$ = Ratio for normally consolidated soil (taken as ~0.25)
λ_0 = 0.85

The strength ratio for normally consolidated soil of 0.25 was selected based on general review of the available laboratory strength data.

OCR was also inferred from CPT data using the method outlined by Powell et al. (1988), where the shape of the normalised cone resistance (Q_t) profile is described by Equation 4.8. Equation 4.9 describes the calculation of OCR according to Powell et al. (1988).

$$Q_t = \left(\frac{q_t - \sigma_{vo}}{\sigma'_{vo}} \right)$$

Equation 4.8

Where:

q_t = Total cone resistance [MPa]
σ_{v0} = Total overburden pressure [kPa]
σ'_{v0} = Effective overburden pressure [kPa]

$$OCR = Q_t \times k$$

Equation 4.9

Where:

OCR = Overconsolidation ratio

k = An empirical constant [~0.2 to 0.22]

Plate 14 presents the measured and derived apparent OCR using the above methods and the recommended representative parameter profile. The BE design line was biased toward data from CRS consolidation tests and is broadly consistent with the inferred geological stress history of Soil Unit II. It should be noted that OCR values determined based on CRS consolidation test data may be subject to some uncertainty depending on the rate dependency characteristics of the soil. That is, the OCR predicted from CRS test data increases with increasing strain rate (Sheahan et al., 1996). For Soil Unit II these effects may be anticipated to be relatively low, although detailed review and comparison with the results of incremental oedometer testing is recommended to examine the consolidation rate dependency of the soil.

4.6 Relative Density

Relative density (D_r) was interpreted in the sand present in Geotechnical Soil Unit III. Interpretation of D_r was also made in the upper 5.0 m BML and below 23.0 m BML within Soil Unit II to highlight the influence of intervals of elevated sand content within this soil unit. D_r was determined from q_c using the Jamiolkowski et al. (2003) method for saturated sands. Plate 15 presents the D_r data.

The derived LE, BE and HE D_r design lines are representative for clean sand intervals within Geotechnical Soil Unit III and therefore do not consider the very low values indicated within the clay beds. D_r was used to infer internal friction angle ranges and skin friction limits according to API (2011) guidance.

4.7 Friction Angle

Internal friction angles (ϕ') were inferred from CID test data and from D_r based on general API (2011) recommendations. Plate 16 presents the ϕ data and LE and HE design profiles. The design profiles were derived based on engineering judgement.

In Geotechnical Soil Unit III the LE ϕ' profiles were reduced by 5° based on the recommendations of API (2011) to account for the high fines content within this interbedded unit, as noted in the borehole descriptions and observed in the PSD test results.

4.8 Chemical Composition

The chemical composition and salinity content tests were generally performed in accordance with the procedures presented in BS 1377. Table 4.1, Table 4.2 and Table 4.3 summarise the chemical content results per geotechnical soil unit. The results of the chemical composition are briefly discussed in this report. Where these tests can be used to further update the geological model for the site they will be discussed in the updated integrated report for the site (Fugro,2018, *in press*).

The observed changes in chemistry are interpreted to have been caused by multiple transitions from freshwater to marine environments, the trends identified agree with the geological model for the Neptun Block.

Table 4.1: Carbonate Content and Organic Content Test Results

Geotechnical Soil Unit	Carbonate Content [%]		Organic Content [%]	
	Result Range	Number of Tests	Result Range	Number of Tests
I	5.9	1	-	-
II	7.5 – 11.1	5	0.5 – 1.2	4
III	5.2	1	0.2	1

Notes:
- = No test performed

Table 4.2: Chloride Content Test Results

Geotechnical Soil Unit	Chloride Content [mg/l]	
	Result Range	Number of Tests
I	-	-
II	100 – 890	7
III	100	1

Notes:
- = No test performed

Table 4.3: pH and Sulphate Content Test Results

Geotechnical Soil Unit	pH [-]		Sulphate Content [%]	
	Result Range	Number of Tests	Result Range	Number of Tests
I	-	-	-	-
II	7.8 – 8.3	6	22 – 65	5
III	9.0	1	16	1

Notes:
- = No test performed

4.8.1 Carbonate Content

Plate 17 present the composite carbonate content versus depth plot for all geotechnical soil units. Carbonate content tests were performed with the results expressed as a percentage by mass of carbonate CO_3. The results range from 5.2 % to 11.1 %. Values are all considered low, with only small variations seen with depth. Geotechnical Soil Unit II shows relatively uniform carbonate content with depth. Table 4.1 summarises the carbonate content results.

As stated above, low carbonate contents were observed from the test results and no cemented beds were identified from offshore testing. Therefore, the impact of these carbonate contents on the soil response and related foundation analyses is expected to be low.

4.8.2 Organic Content

Plate 18 and Table 4.1 present the results of total organic content testing. Total organic content ranges from 0.2 % to 1.2 %. Based on the BS 5930 (2015) soil classification, the measured range indicates that the samples tested are inorganic.

The inorganic nature of the sediments suggests that the sediments were deposited in an oxygenated shallow water environment without the stratification that is present in the Black Sea now. The highest organic content value was observed in Geotechnical Soil Unit II at 16.0 m BML was 1.2 %.

4.8.3 Chloride Content

Plate 19 present a composite plot of chloride content versus depth for locations at the Pelican south drill center location. Eight tests were performed, seven within Geotechnical Soil Unit II and one in Geotechnical Soil Unit III.

A large degree of scatter is observed in the results. However, the general trend shows a decrease in chloride content with depth. This decrease in chloride content is consistent with the sediments of Geotechnical Soil Unit II deposited in a freshwater lacustrine environment. The uppermost sediments show an elevated chloride content due to the influx of higher salinity seawater following the breach of the Bosphorus Strait and the migration of chloride-rich porewater through the sediment column over the past 8200 years (Riboulot et al., 2018). Table 4.2 summarises the chloride content results.

Chloride can cause an accelerated corrosion of steel. Results of the laboratory testing shows a general decrease in chloride content with depth. Measures to mitigate corrosion of steel due to chloride corrosion should be applied such as use of high yield steel.

4.8.4 Sulphate Content and pH

Plate 20 presents the sulphate content at the Pelican South drill center location. Sulphate content for Geotechnical Soil Unit II is highly variable and range from 16 % to 65 %. Table 4.3 summarises the sulphate content.

Sulphate values are interpreted to be elevated in Geotechnical Soil Unit II close to seafloor as a result of the influx of saline-rich pore-water from the higher salinity seawater following the breach of the Bosphorus Strait. Sulphates can cause corrosion of steel. Sulphates must be in solution to cause corrosion. Therefore, soil permeability and ground water mobility will have the greatest bearing on the severity of corrosion by sulphates. The mudmats are expected to be placed at seafloor with skirts penetrating into seafloor. Therefore, mitigation measures should be put in place to reduce the effect of corrosion of steel due to sulphates such as use of high yield steel

Plate 21 presents the pH at the Pelican South drill center location. The pH ranges between 7.8 and 8.3 across all the samples; this is consistent with samples deposited in a freshwater to marine environment. pH testing was only performed within Geotechnical Soil Unit II. Table 4.3 summarises the pH content.

4.9 Headspace Gas And Carbon Isotope Analysis.

Headspace gas analysis was carried out on 11 samples at the Pelican South drill center location. Table 4.4 summarises the test results. Plate 22 presents the headspace gas results versus depth.

Table 4.4: Headspace Gas Analysis and Carbon Isotope Analysis Test Results

Geotechnical Soil Unit	Headspace Gas Analysis (Methane C1) [ppm]		Carbon Isotope Ratio (Methane C1) [13C versus 12C, δ13C]	
	Result Range	Number of Tests	Result Range	Number of Tests
II	64 to. 41651	11	-66.3 to -77.9	6

The headspace gas values show that methane (C1) is present in Geotechnical Soil Unit II. There is a high degree of scatter for the volume of gas, the lowest results were taken in sandier layers where gas is interpreted to have escape; following extrusion from the sample. The volumes of gas observed in the sediment are similar to those observed in samples obtained during the 2014 geotechnical site investigation (Fugro, 2015b) and at the Planned Platform G location (Fugro, 2018a).

The carbon isotope ratio is calculated from the ratio of methane ethane and propane and is used to provide an origin for the gas (Equation 4.10).

$$C1/(C2 + C3)$$

Equation 4.10

Where:
$C1$ = Methane
$C2$ = Ethane
$C3$ = Propane

The carbon isotope ratio suggests that the methane in the sediment is biogenic. The limited range in the measured carbon isotope ratio suggests that all of the methane tested has undergone the same process. Figure 4.1 shows the relationship between the carbon isotope and the origin of the gas.

Previous testing carried out on samples from Neptun block (Fugro 2015b) suggested biogenesis for the samples; this is supported by recent data from scientific surveys adjacent to the Neptun Block (Ifremer, 2015).

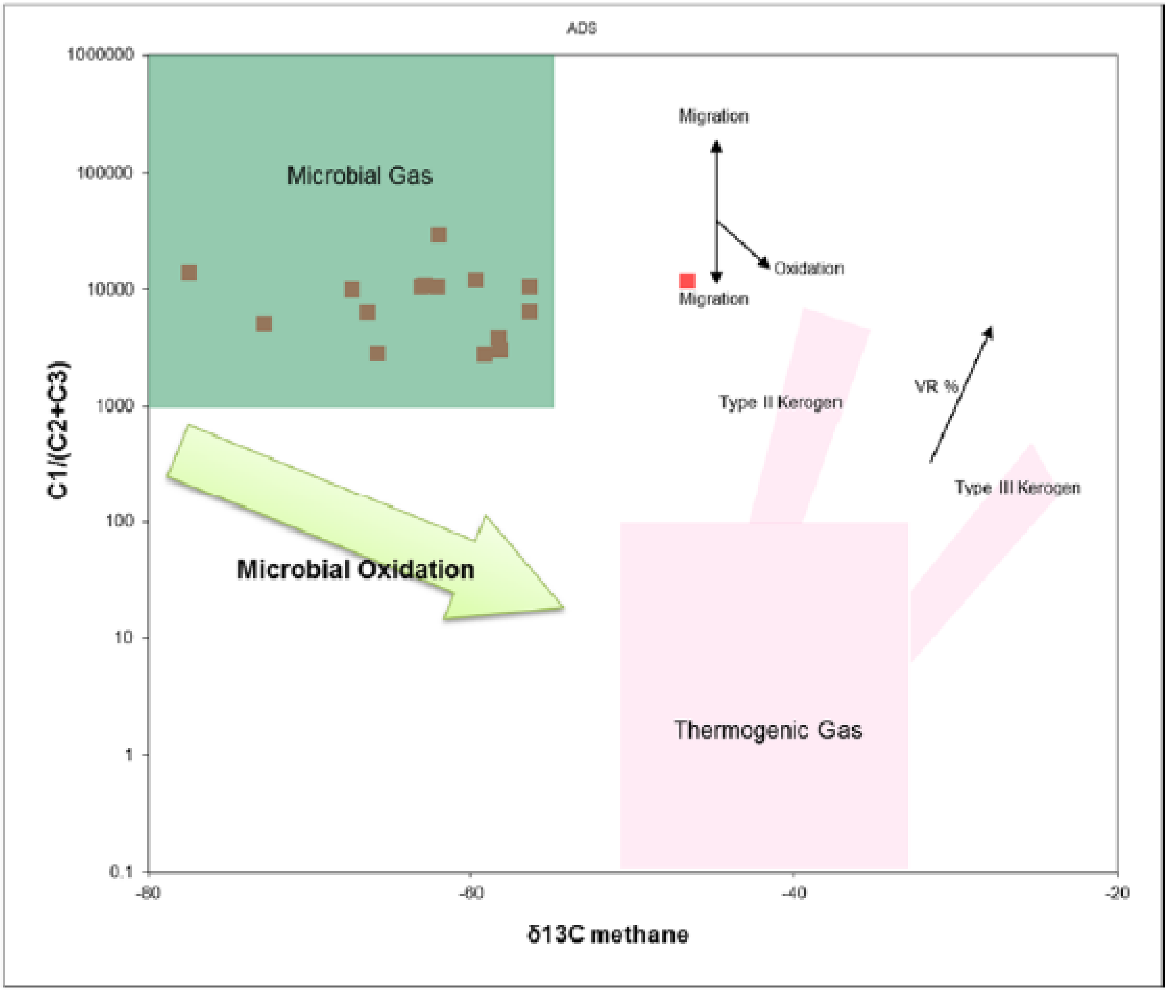


Figure 4.1: Carbon isotope characterisation, (Bernard Diagram) from Fugro 2015b Results of Analysis plot in top left corner of diagram within green polygon and shaow that the methane is biogenic in origin

5. MUDMAT DESIGN

5.1 General

Fugro understands that mudmat foundations supporting manifolds and/or tree protection structures are the chosen foundation concept for the Pelican Drill Center location. Section 4 discusses the design soil parameters derived for preliminary mudmat design. This section provides a brief discussion of and provides recommendations for mudmat foundation analysis at the Pelican Drill Center location.

5.2 Foundation Design Risks

The following foundation design risks are identified at the Pelican drill center location which may have an impact on the foundation design analysis:

i. Shallow gas;
ii. Seismicity;
iii. Strong shallow soils (installation).

5.2.1 Shallow Gas

Shallow gas was not observed during drilling of the pilot hole and boreholes at the Pelican South Drill Center locations, (Fugro, 2018a). However, the presence of gas was detected during extrusion of the samples (Section 3.4.2) and headspace gas analysis (Section 4.9). Based on the headspace test results the shallow gas at the Pelican drill center was determined to be biogenic.

The presence of shallow gas may lead to:

i. Increased pore pressure in low permeability soils and increase water content. In turn, these effects may significantly reduce the strength and stiffness of the soil and therefore reduce the vertical, horizontal and moment resistance offset by the soil;
ii. Acceleration of foundation corrosion due to changes in the pore-water chemistry.

In the mudmat foundation analyses, a cautionary 10 % reduction to the undrained shear strength is recommended in Geotechnical Soil Units I and II to account for escape of shallow gas trapped within the sand and silt layers. A detailed review regarding the effects of shallow gas on the soil geotechnical properties and mudmat foundation is recommended during detailed design.

5.2.2 Seismicity

Seismic stability, post-seismic stability and post-seismic settlement checks may be required for the Pelican drill centre locations using site-specific probabilistic seismic hazard analysis (PSHA) and site response analysis (SRA).

Formal unity checks on seismic stability may result in excessive foundation dimensions. An alternative approach considering evaluation of foundation displacements under seismic loading and the associated impact on structure operability may often lead to a reduced foundation size relative to unity checks.

5.2.3 Strong Shallow Soils

Strong shallow soils close to seafloor may provide challenges during the installation of the mudmats At the Pelican drill center location, the high estimate s_u profile is observed to rapidly increase in strength at 0.3 m BML. Due to the rapid increase in strength, it may be expected that mudmat skirts greater than 0.3 m may experience challenges when installing under self-weight. However, a detailed analysis should be performed to determine the skirt height that may be feasibly installed at the Pelican drill center location.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 General

ExxonMobil requested Fugro to provide geotechnical soil parameters at the Pelican South Drill Center location to be used for preliminary mudmat design.

6.2 Geological Setting

At the planned Pelican South Drill Center locations, no signs of shallow gas including bubbles around the drill string at the seabed frame were observed (Fugro, 2018a). The samples from the Pelican south drill center locations were subsampled for headspace gas analysis which identifies the composition and concentration of gas trapped within the sediment. The number of samples that could be taken was limited due to the sandy silty nature of the soil.

The sediments of Unit II sampled boreholes at the Pelican South Drill Center show highly structured clay fabrics similar to the sediments at Platform G (Fugro, 2018b). The resulting soil fabrics are interpreted to represent changes in the post-depositional history of the sediment, including the presence or previous occurrence of gas within the sediment. The soil fabric may affect the strength of the sediment, depending on the specimen orientation and mode of shearing. Due to these soil structure variations there is a significant variance between index strength measurements, and the interpreted CPT and onshore laboratory test strength test measurements

6.3 Geotechnical Data

Geotechnical data from four boreholes at the planned Pelican South Drill Center location were used to derive the design soil parameters. Low estimate (LE), best estimate (BE) and high estimate (HE) design soil profiles were derived to the depth of investigation.

The following design soil parameters were derived:

i. Water Content (w)
ii. Total Unit Weight (γ)
iii. Cone penetration test (CPT) Cone Resistance (q_c)
iv. Undrained Shear Strength (s_u)
v. Relative Density (D_r)
vi. Friction Angle ($\emptyset'$)
vii. Overconsolidation Ratio (OCR)
viii. Remoulded Strength (s_{ur})
ix. Strength Sensitivity (S_t)

6.4 Discussion and Recommendations on Mudmat Foundations

Fugro understands that at the Pelican drill center location mudmats are planned to be installed to support manifolds and tree protection structures. The following foundation design risks were identified:

i. Shallow Gas: The presence of shallow gas may lead to a reduction in soil strength and stiffness within the soil. Shallow gas may also lead to accelerated corrosion of the foundation;

ii. Seismicity: Formal unity checks on seismic stability should be performed as it may have an impact on structure operability may often lead to increased or reduced foundation sizes relative to unity checks;
iii. Strong shallow soils: Strong shallow soils close to seafloor may provide challenges during the installation of the mudmats.

Fugro recommends that the mudmat analyses to be performed at the Pelican drill center location should consider the following in the detailed design as a minumum:

i. Structure-location specific design soil parameterisation as far as is possible with the available dataset;
ii. Quantifying the effects of shallow gas on key design soil parameters (e.g. s_u, compression parameters);
iii. Consideration of mudmat skirt installation constraints;
iv. Rate effects on s_u.

It is recommended that these effects are quantified and considered in detailed during detailed design in accordance with any specific ExxonMobil design basis requirements.

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LIST OF PLATES

APPENDICES

A. GUIDELINES ON USE OF REPORT

A. GUIDELINES ON USE OF REPORT

This report (the “Report”) was prepared as part of the services (the “Services”) provided by Fugro GB Marine Limited (“Fugro”) for its client (the “Client”) under terms of the relevant contract between the two parties (the “Contract”). The Services were performed by Fugro based on requirements of the Client set out in the Contract or otherwise made known by the Client to Fugro at the time.

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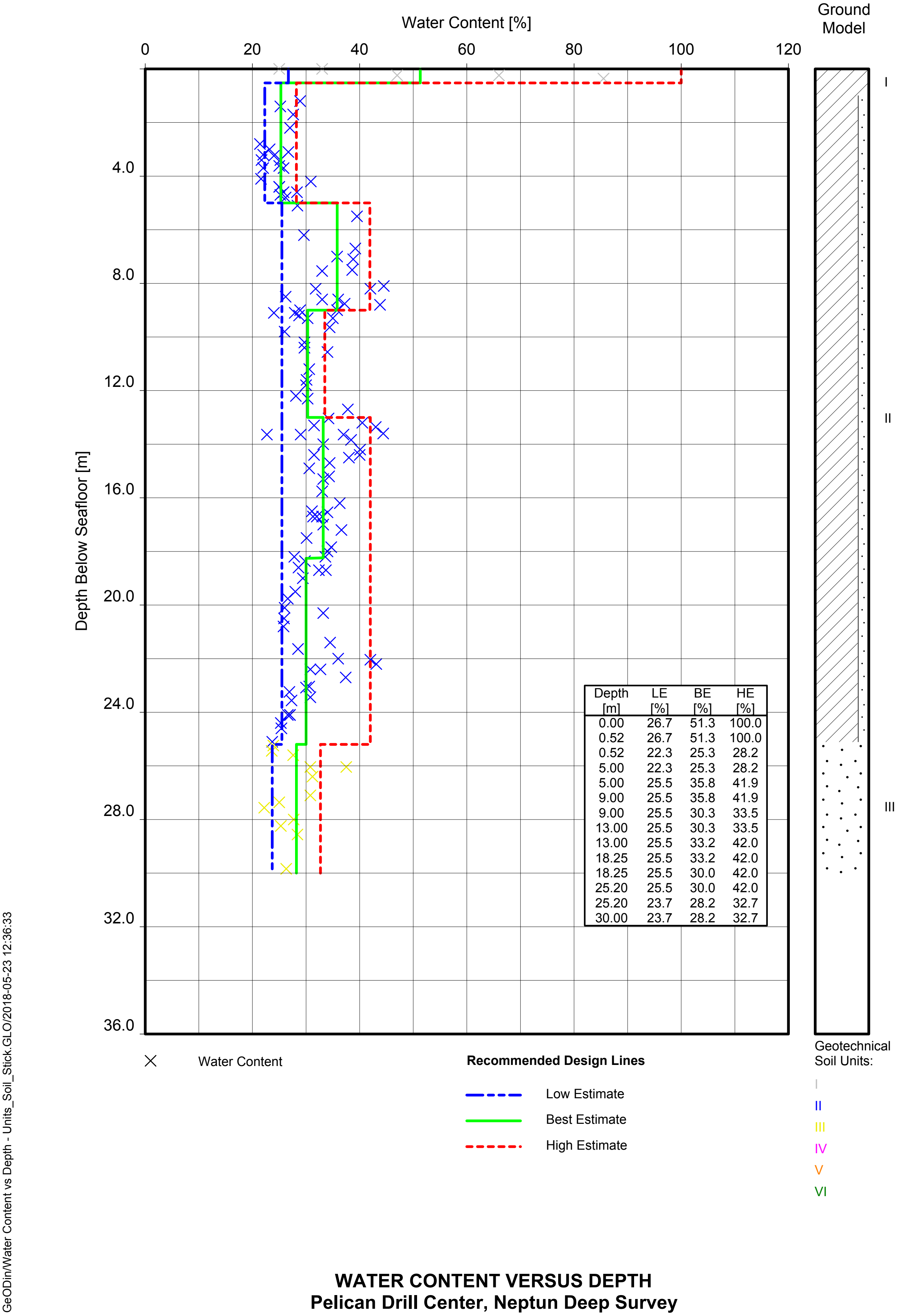

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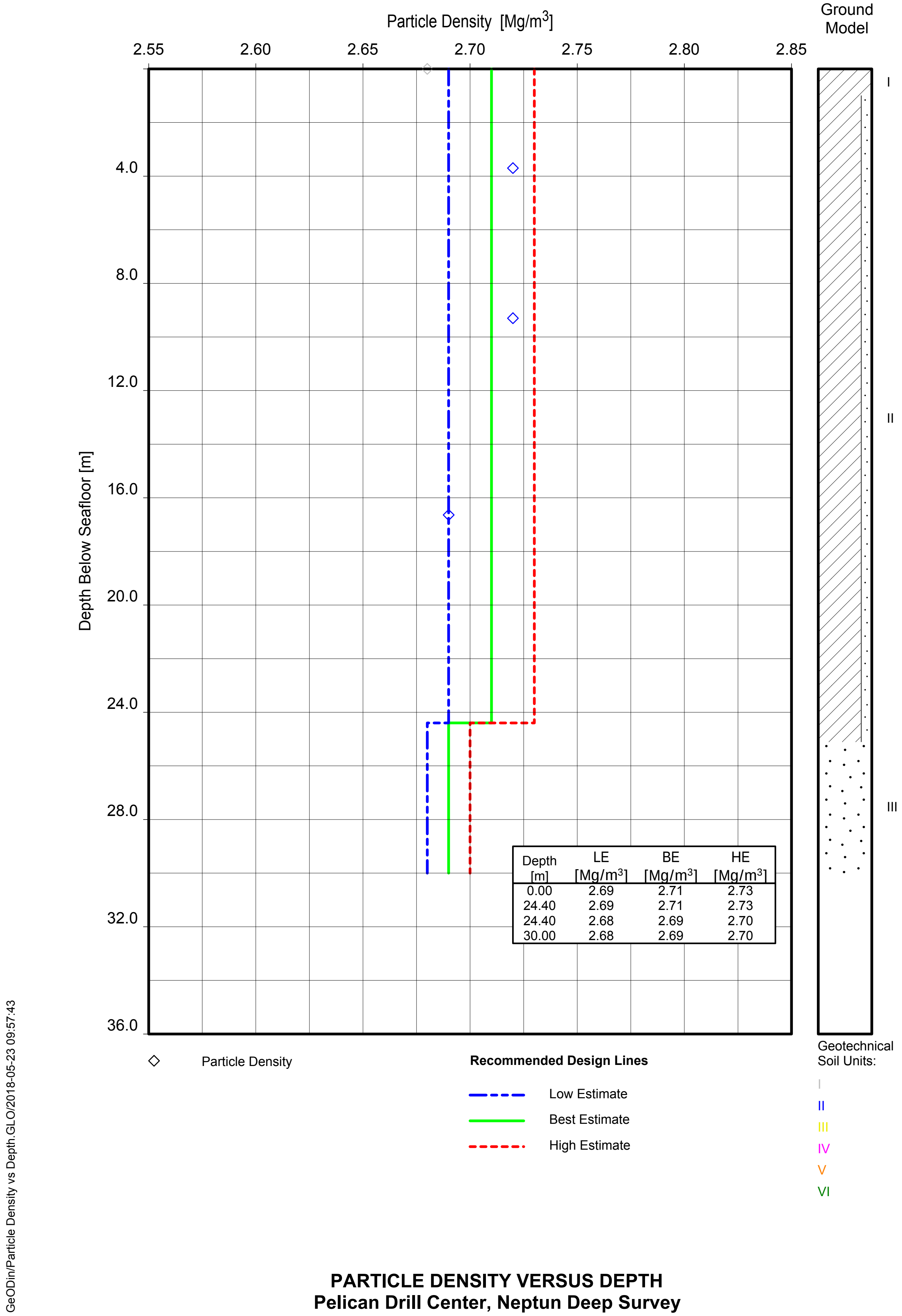
5.00	22.3	25.3	28.2
5.00	25.5	35.8	41.9
9.00	25.5	35.8	41.9
9.00	25.5	30.3	33.5
13.00	25.5	30.3	33.5
13.00	25.5	33.2	42.0
18.25	25.5	33.2	42.0
18.25	25.5	30.0	42.0
25.20	25.5	30.0	42.0
25.20	23.7	28.2	32.7
30.00	23.7	28.2	32.7

WATER CONTENT VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [Mg/m³]	BE [Mg/m³]	HE [Mg/m³]
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24.40	2.68	2.69	2.70
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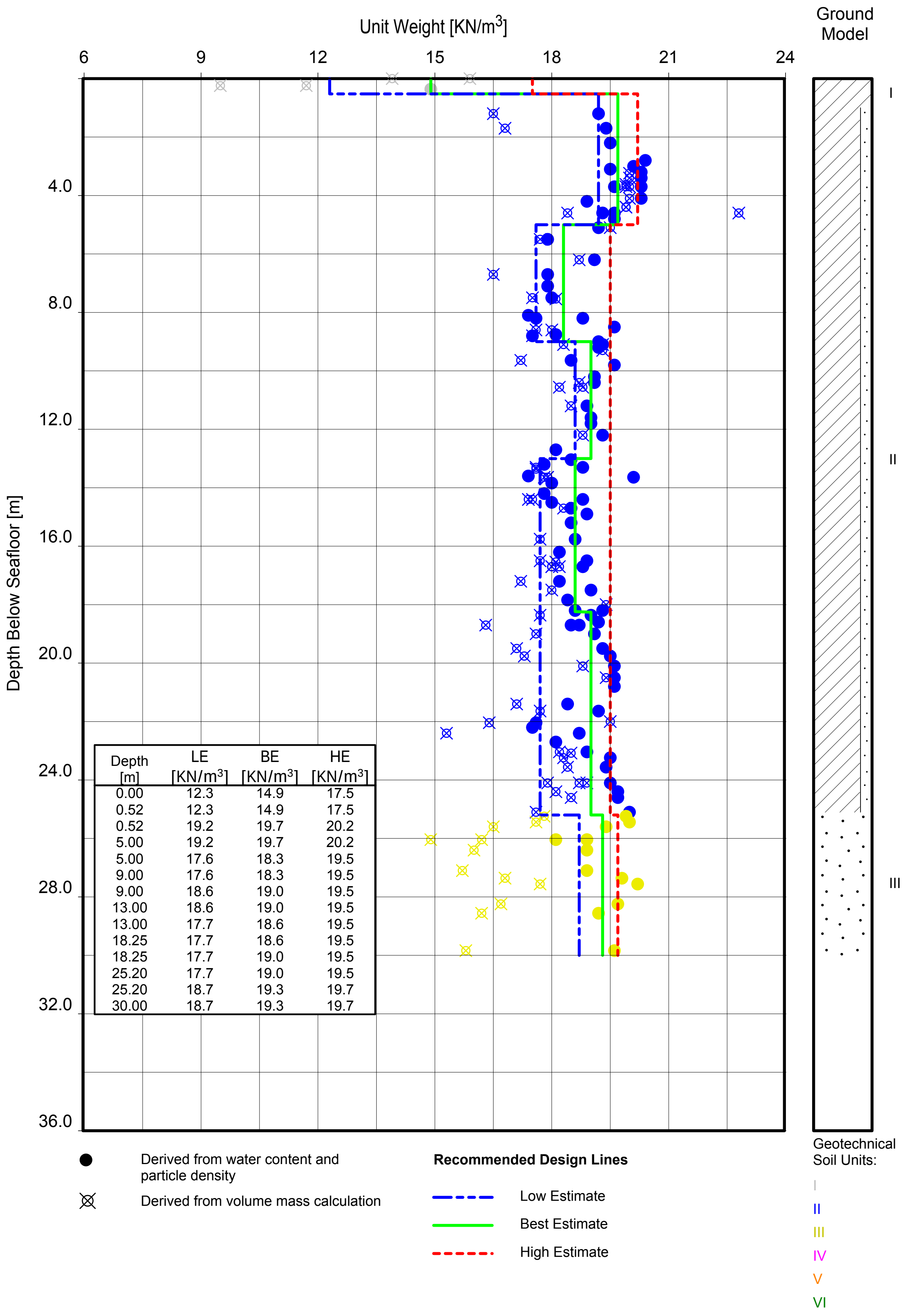
PARTICLE DENSITY VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [KN/m³]	BE [KN/m³]	HE [KN/m³]
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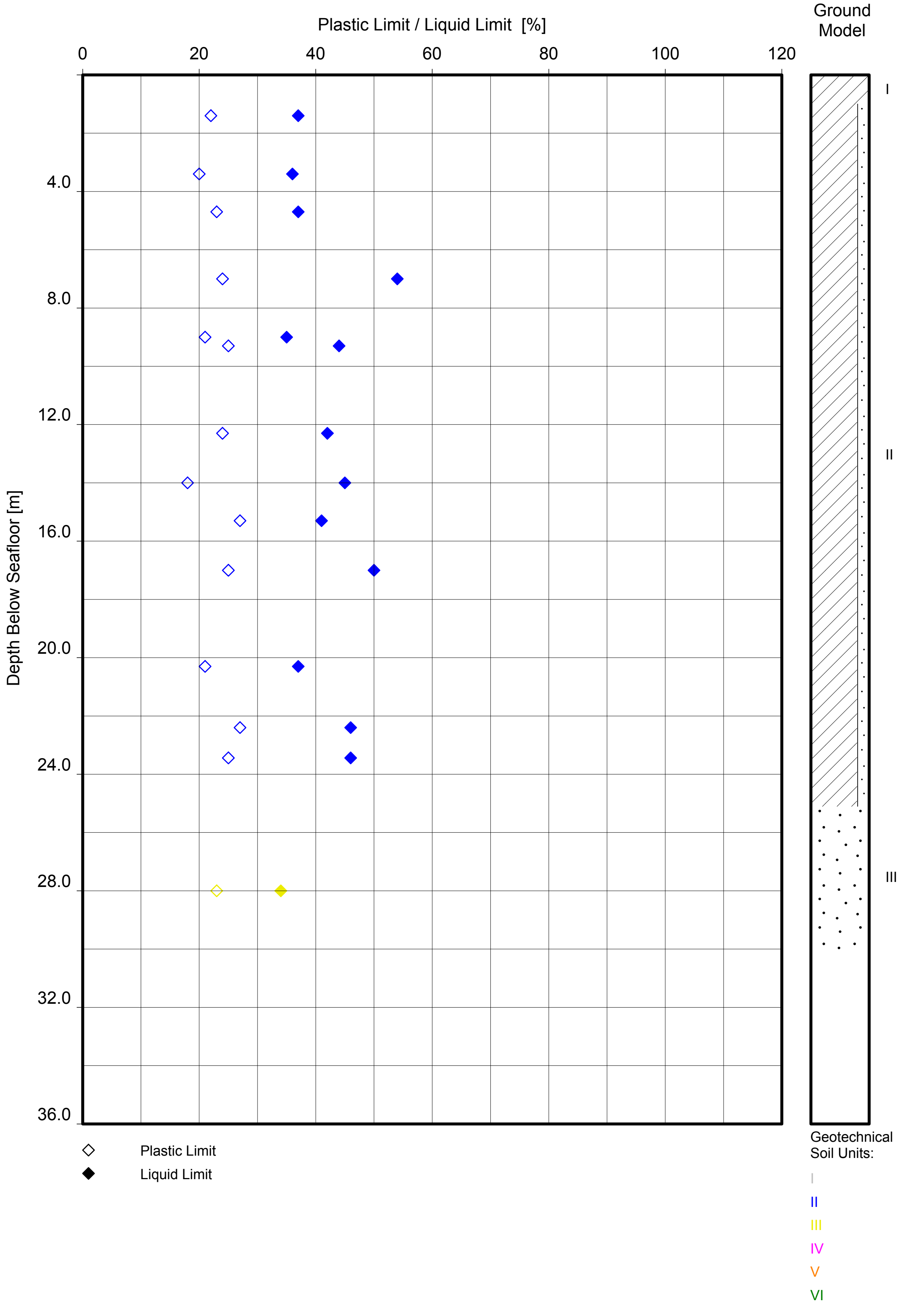
0.52	19.2	19.7	20.2
5.00	19.2	19.7	20.2
5.00	17.6	18.3	19.5
9.00	17.6	18.3	19.5
9.00	18.6	19.0	19.5
13.00	18.6	19.0	19.5
13.00	17.7	18.6	19.5
18.25	17.7	18.6	19.5
18.25	17.7	19.0	19.5
25.20	17.7	19.0	19.5
25.20	18.7	19.3	19.7
30.00	18.7	19.3	19.7

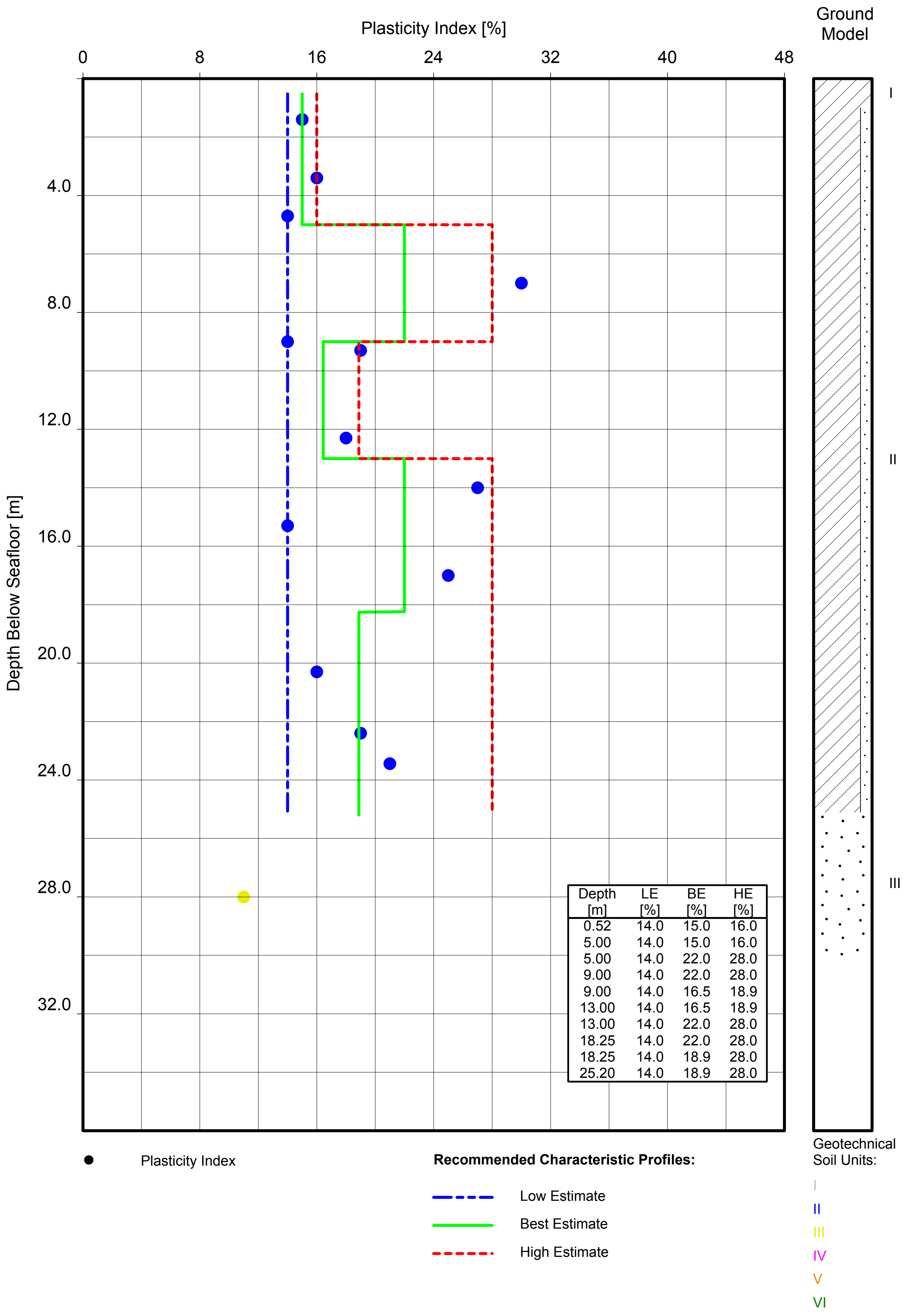
GeODin/Unit Weight versus Depth - Units_Soil-Stick.GLO/2018-05-23 12:37:08

UNIT WEIGHT VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



GeODin/Plastic Limit _ Liquid Limit vs Depth - Units.GLO/2018-05-23 09:48:17

PLASTIC LIMIT / LIQUID LIMIT VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [%]	BE [%]	HE [%]
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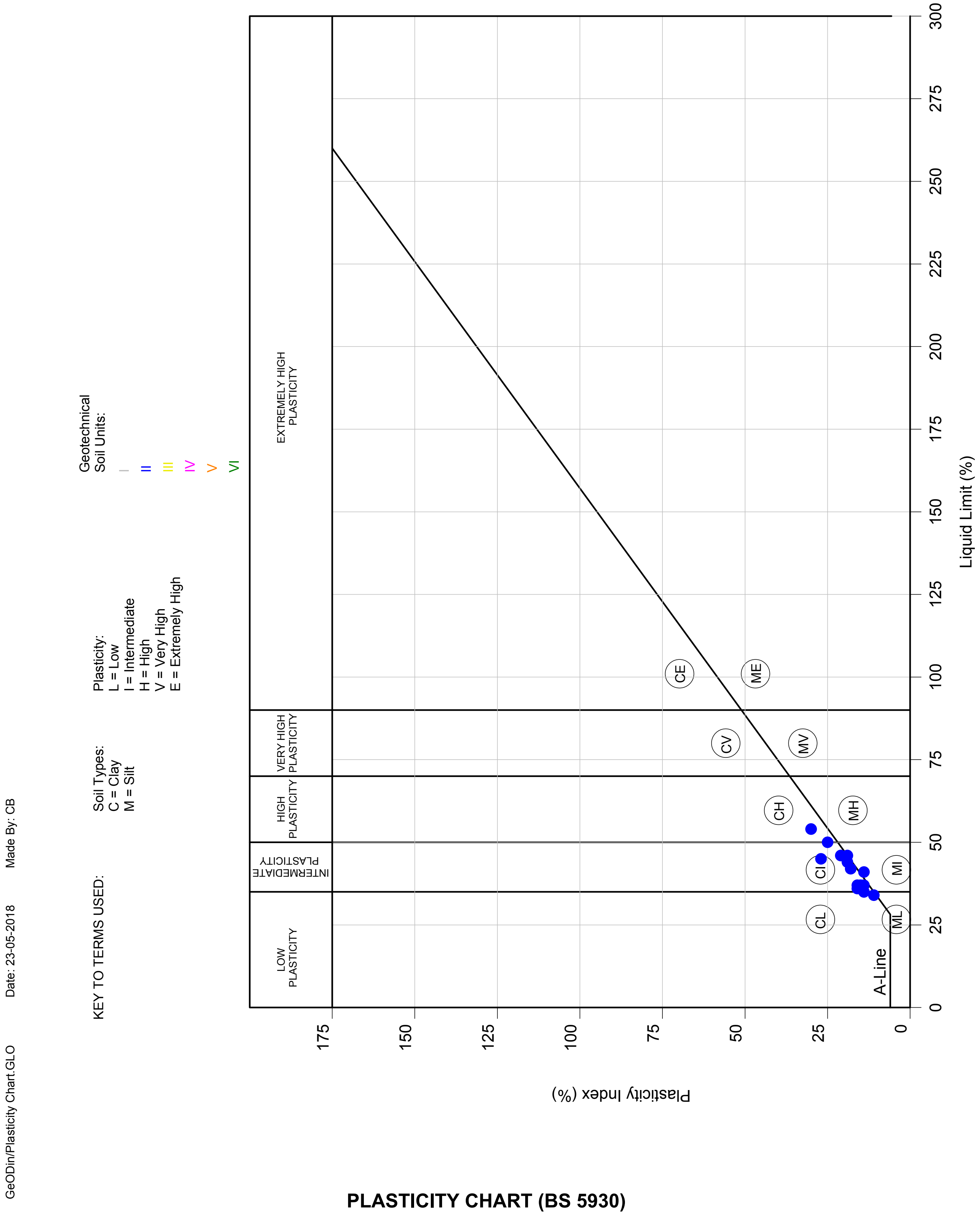
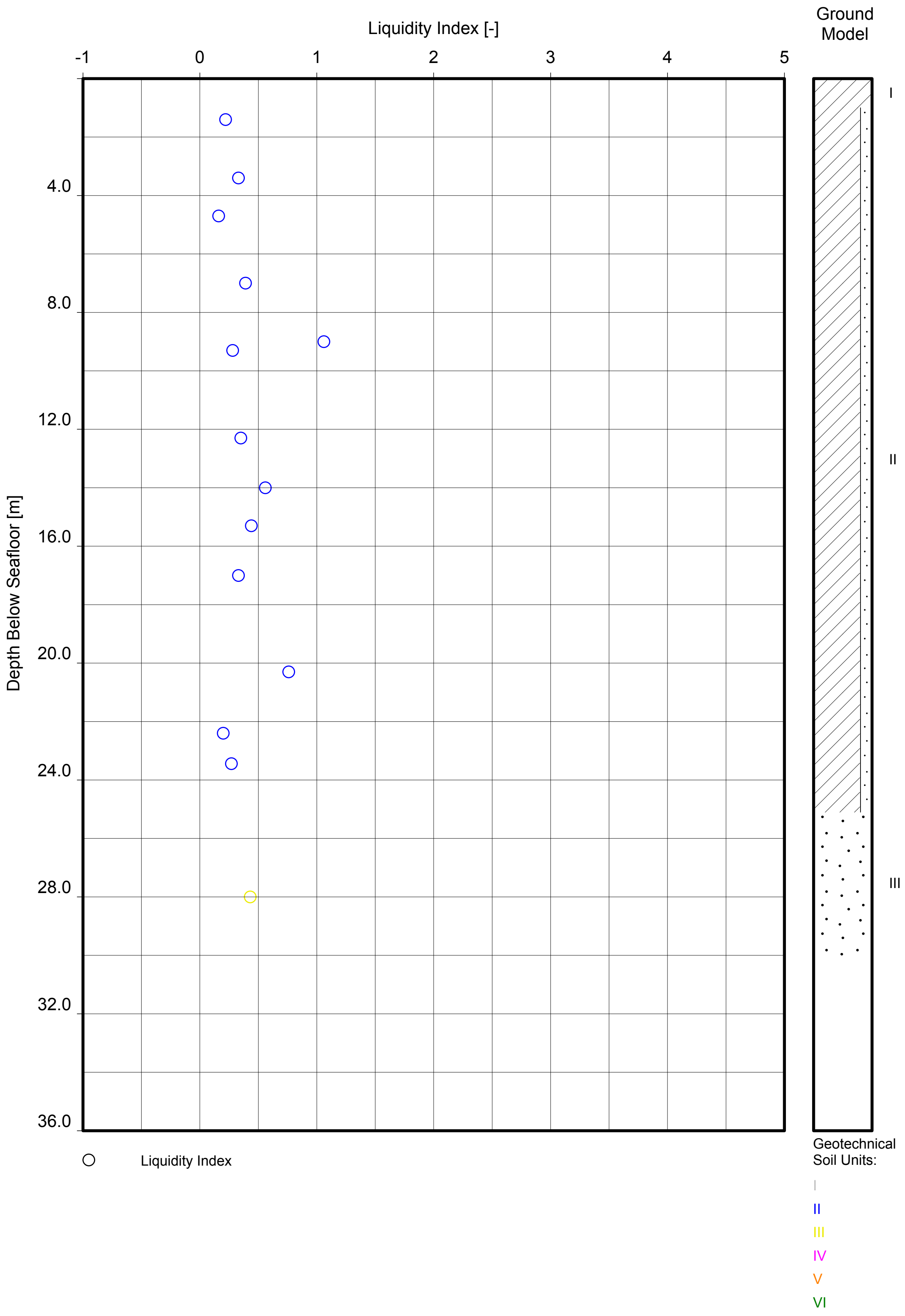
5.00	14.0	15.0	16.0
5.00	14.0	22.0	28.0
9.00	14.0	22.0	28.0
9.00	14.0	16.5	18.9
13.00	14.0	16.5	18.9
13.00	14.0	22.0	28.0
18.25	14.0	22.0	28.0
18.25	14.0	18.9	28.0
25.20	14.0	18.9	28.0

GeODin/Plasticity Index vs Depth - Units .GLO/2018-05-23 09:45:46

PLASTICITY INDEX VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey

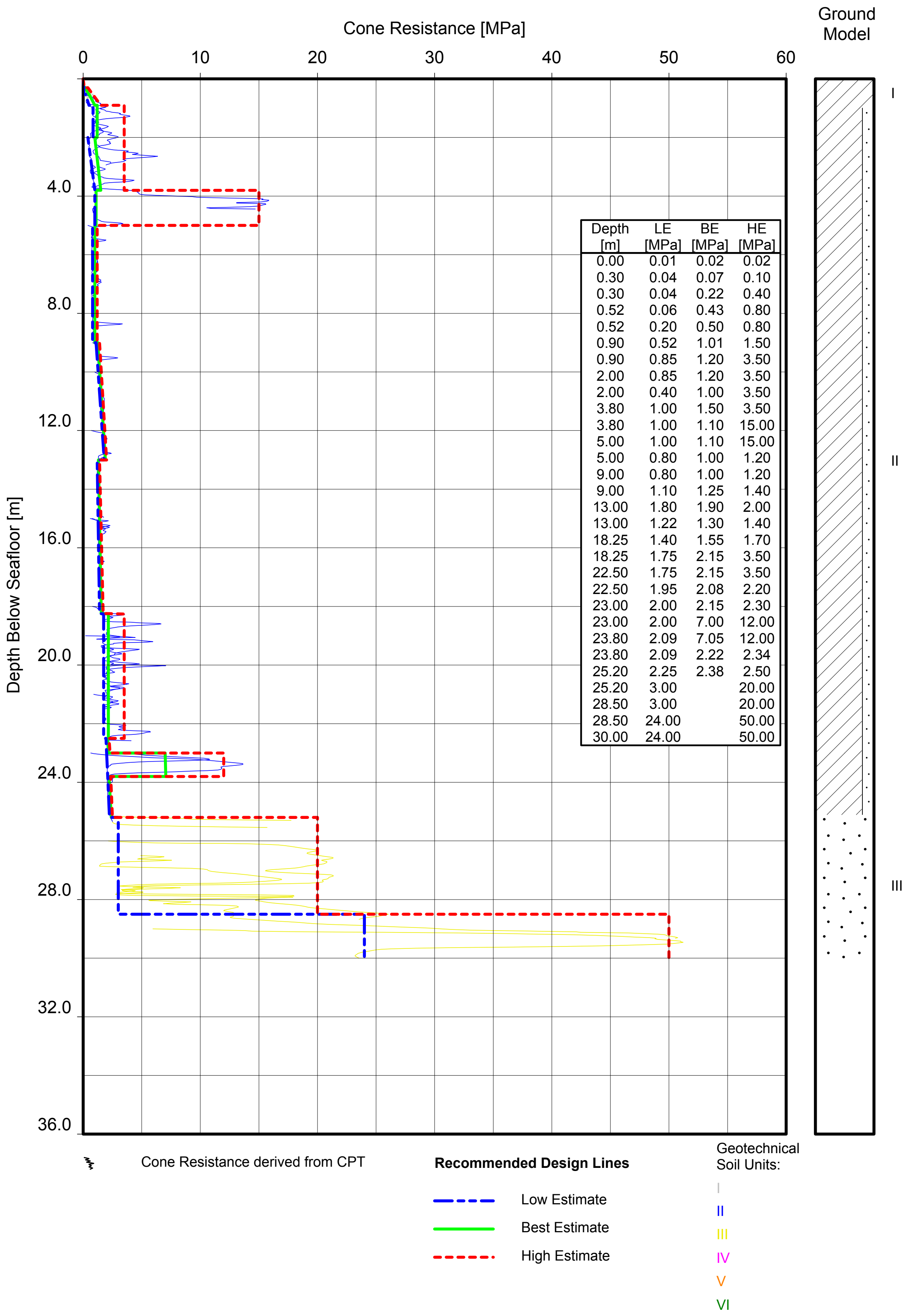


PLASTICITY CHART (BS 5930)
Pelican Drill Center, Neptun Deep Survey



GeODin/Liquidity Index vs Depth - Units.GLO/2018-05-23 09:40:47

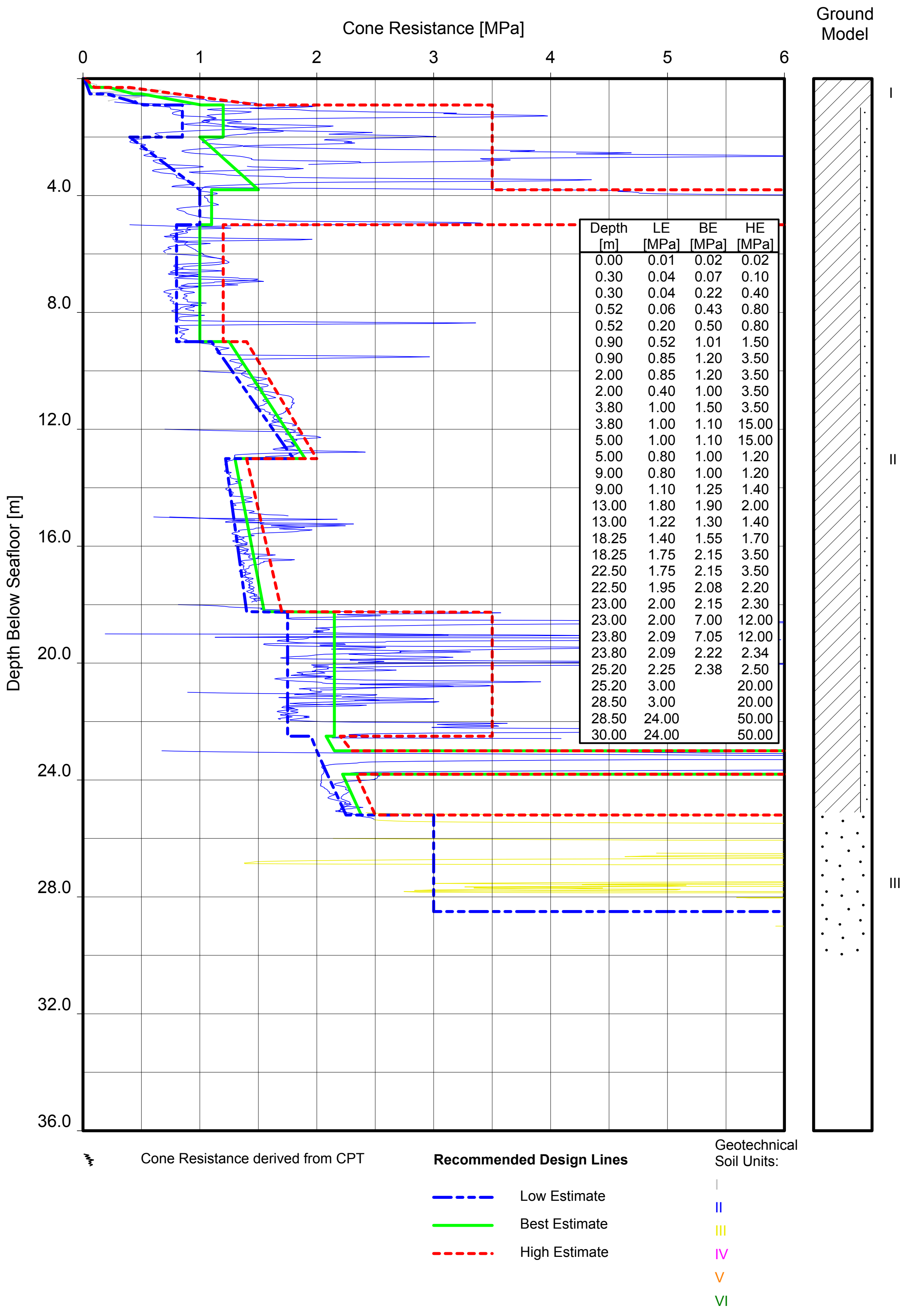
LIQUIDITY INDEX VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [MPa]	BE [MPa]	HE [MPa]
0.00	0.01	0.02	0.02
0.30	0.04	0.07	0.10
0.30	0.04	0.22	0.40
0.52	0.06	0.43	0.80
0.52	0.20	0.50	0.80
0.90	0.52	1.01	1.50
0.90	0.85	1.20	3.50
2.00	0.85	1.20	3.50
2.00	0.40	1.00	3.50
3.80	1.00	1.50	3.50
3.80	1.00	1.10	15.00
5.00	1.00	1.10	15.00
5.00	0.80	1.00	1.20
9.00	0.80	1.00	1.20
9.00	1.10	1.25	1.40
13.00	1.80	1.90	2.00
13.00	1.22	1.30	1.40
18.25	1.40	1.55	1.70
18.25	1.75	2.15	3.50
22.50	1.75	2.15	3.50
22.50	1.95	2.08	2.20
23.00	2.00	2.15	2.30
23.00	2.00	7.00	12.00
23.80	2.09	7.05	12.00
23.80	2.09	2.22	2.34
25.20	2.25	2.38	2.50
25.20	3.00		20.00
28.50	3.00		20.00
28.50	24.00		50.00
30.00	24.00		50.00

GeODin/Cone Resistance vs Depth - Units_Soil_Stick.GLO/2018-05-23 09:35:33

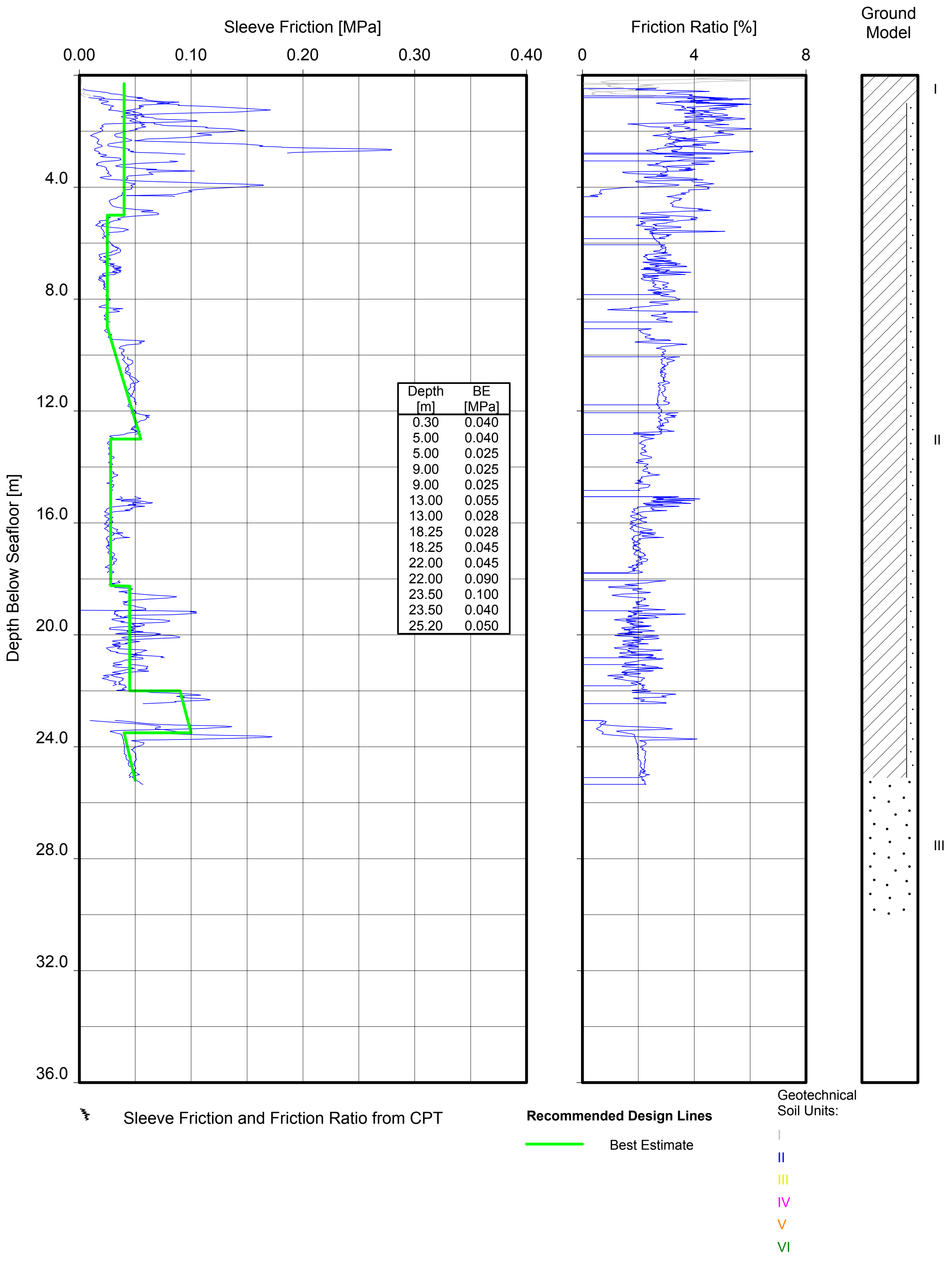
CONE RESISTANCE VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [MPa]	BE [MPa]	HE [MPa]
0.00	0.01	0.02	0.02
0.30	0.04	0.07	0.10
0.30	0.04	0.22	0.40
0.52	0.06	0.43	0.80
0.52	0.20	0.50	0.80
0.90	0.52	1.01	1.50
0.90	0.85	1.20	3.50
2.00	0.85	1.20	3.50
2.00	0.40	1.00	3.50
3.80	1.00	1.50	3.50
3.80	1.00	1.10	15.00
5.00	1.00	1.10	15.00
5.00	0.80	1.00	1.20
9.00	0.80	1.00	1.20
9.00	1.10	1.25	1.40
13.00	1.80	1.90	2.00
13.00	1.22	1.30	1.40
18.25	1.40	1.55	1.70
18.25	1.75	2.15	3.50
22.50	1.75	2.15	3.50
22.50	1.95	2.08	2.20
23.00	2.00	2.15	2.30
23.00	2.00	7.00	12.00
23.80	2.09	7.05	12.00
23.80	2.09	2.22	2.34
25.20	2.25	2.38	2.50
25.20	3.00		20.00
28.50	3.00		20.00
28.50	24.00		50.00
30.00	24.00		50.00

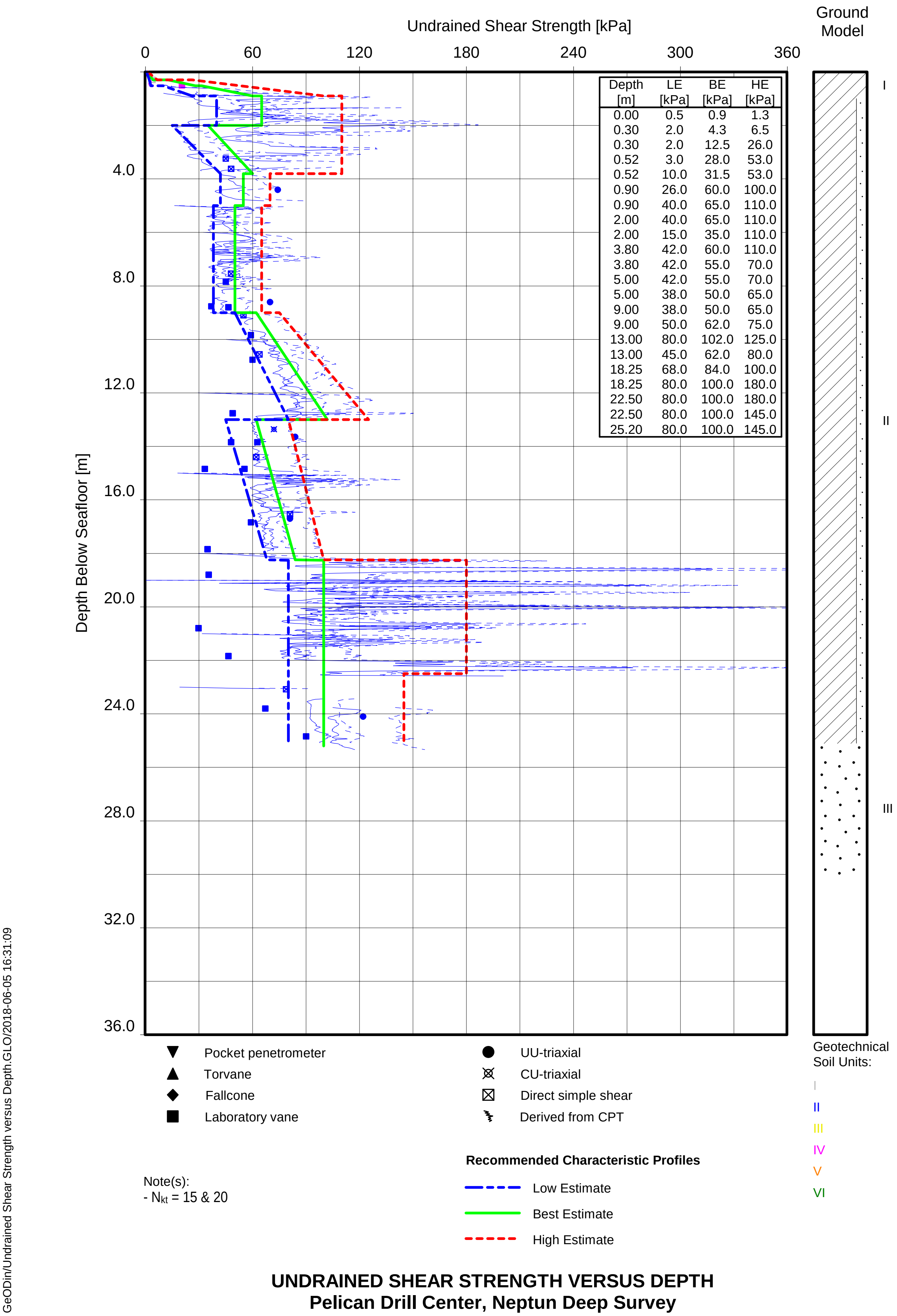
GeODin/Cone Resistance vs Depth - Units_Soil_Stick.GLO/2018-05-23 09:34:33

CONE RESISTANCE VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



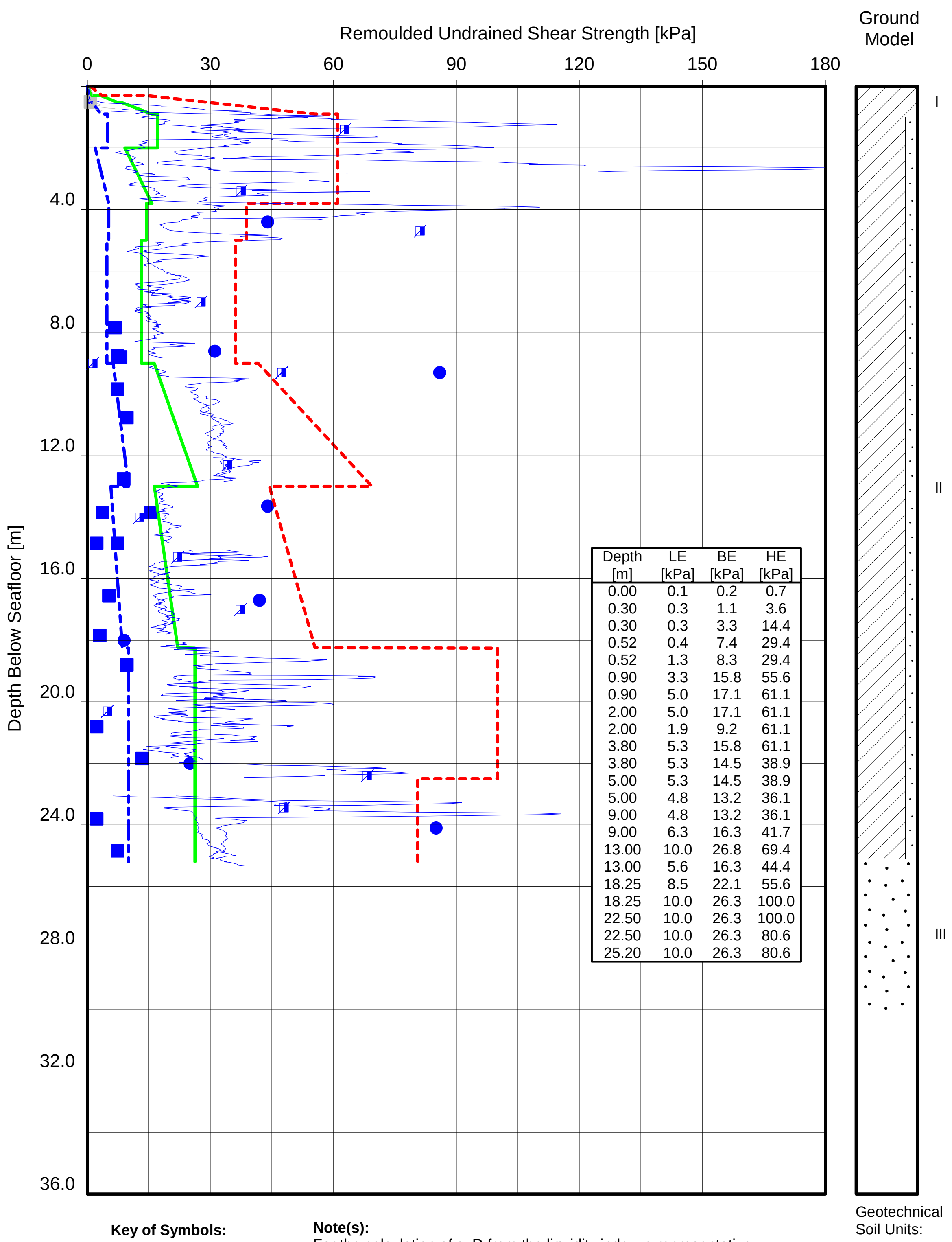
GeODin/Sleeve Friction.GLO/2018-05-23 11:51:59

SLEEVE FRICTION AND FRICTION RATIO VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [kPa]	BE [kPa]	HE [kPa]
0.00	0.5	0.9	1.3
0.30	2.0	4.3	6.5
0.30	2.0	12.5	26.0
0.52	3.0	28.0	53.0
0.52	10.0	31.5	53.0
0.90	26.0	60.0	100.0
0.90	40.0	65.0	110.0
2.00	40.0	65.0	110.0
2.00	15.0	35.0	110.0
3.80	42.0	60.0	110.0
3.80	42.0	55.0	70.0
5.00	42.0	55.0	70.0
5.00	38.0	50.0	65.0
9.00	38.0	50.0	65.0
9.00	50.0	62.0	75.0
13.00	80.0	102.0	125.0
13.00	45.0	62.0	80.0
18.25	68.0	84.0	100.0
18.25	80.0	100.0	180.0
22.50	80.0	100.0	180.0
22.50	80.0	100.0	145.0
25.20	80.0	100.0	145.0

UNDRAINED SHEAR STRENGTH VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	LE [kPa]	BE [kPa]	HE [kPa]
0.00	0.1	0.2	0.7
0.30	0.3	1.1	3.6
0.30	0.3	3.3	14.4
0.52	0.4	7.4	29.4
0.52	1.3	8.3	29.4
0.90	3.3	15.8	55.6
0.90	5.0	17.1	61.1
2.00	5.0	17.1	61.1
2.00	1.9	9.2	61.1
3.80	5.3	15.8	61.1
3.80	5.3	14.5	38.9
5.00	5.3	14.5	38.9
5.00	4.8	13.2	36.1
9.00	4.8	13.2	36.1
9.00	6.3	16.3	41.7
13.00	10.0	26.8	69.4
13.00	5.6	16.3	44.4
18.25	8.5	22.1	55.6
18.25	10.0	26.3	100.0
22.50	10.0	26.3	100.0
22.50	10.0	26.3	80.6
25.20	10.0	26.3	80.6

Key of Symbols:

- ◆ Fallcone
- ■ Laboratory Vane
- ● UU-triaxial
- Liquidity Index

In situ data:

- 2/3 Sleeve friction (fs) - Cone penetration test (CPT) data

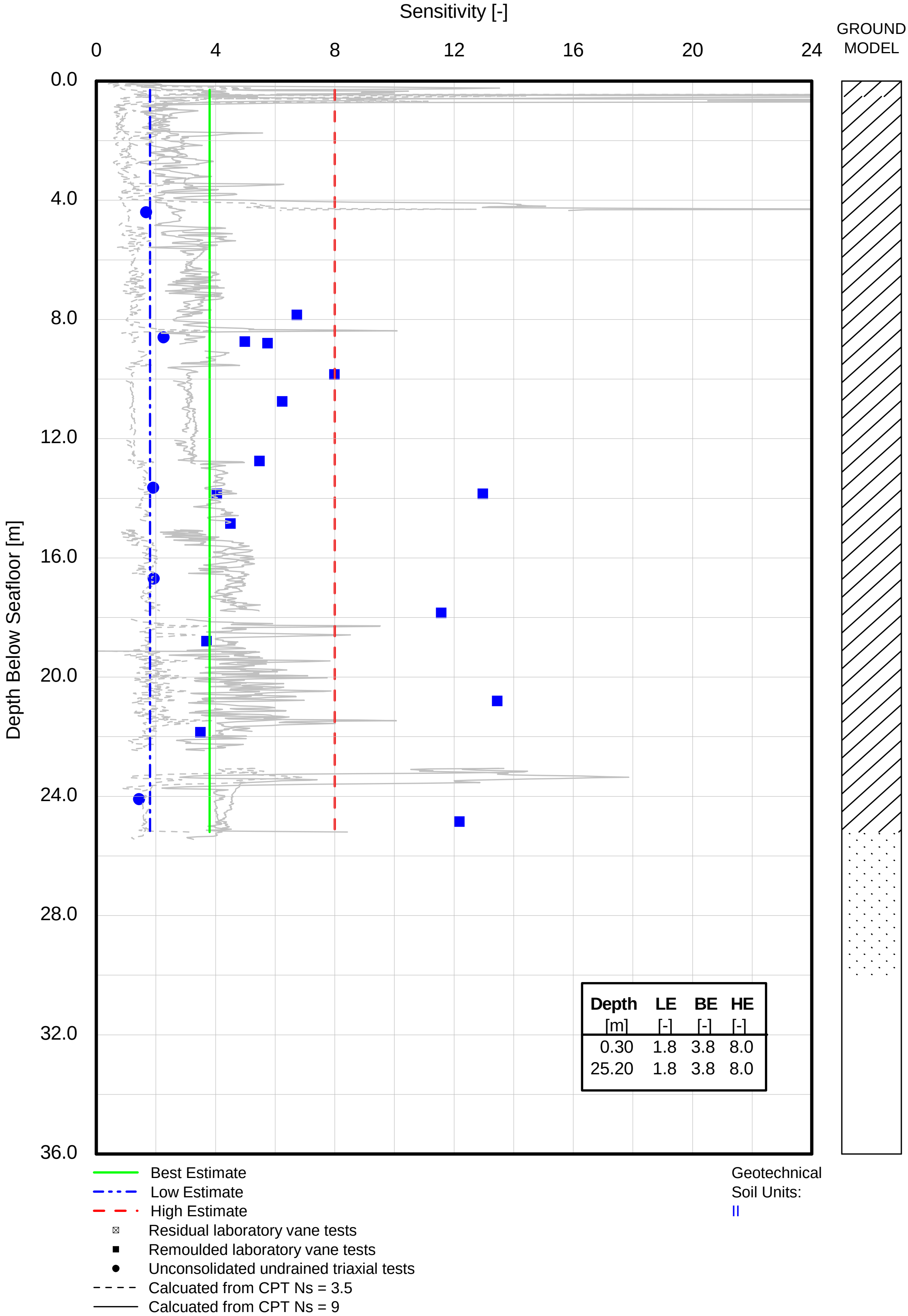
Note(s):
For the calculation of suR from the liquidity index, a representative value from the water content design profile was used.

Recommended Characteristic Profiles

- Low Estimate
- Best Estimate
- High Estimate

GeODin/Su(R) rev1 vs Depth - All Units.GLO/2018-06-05 16:35:59

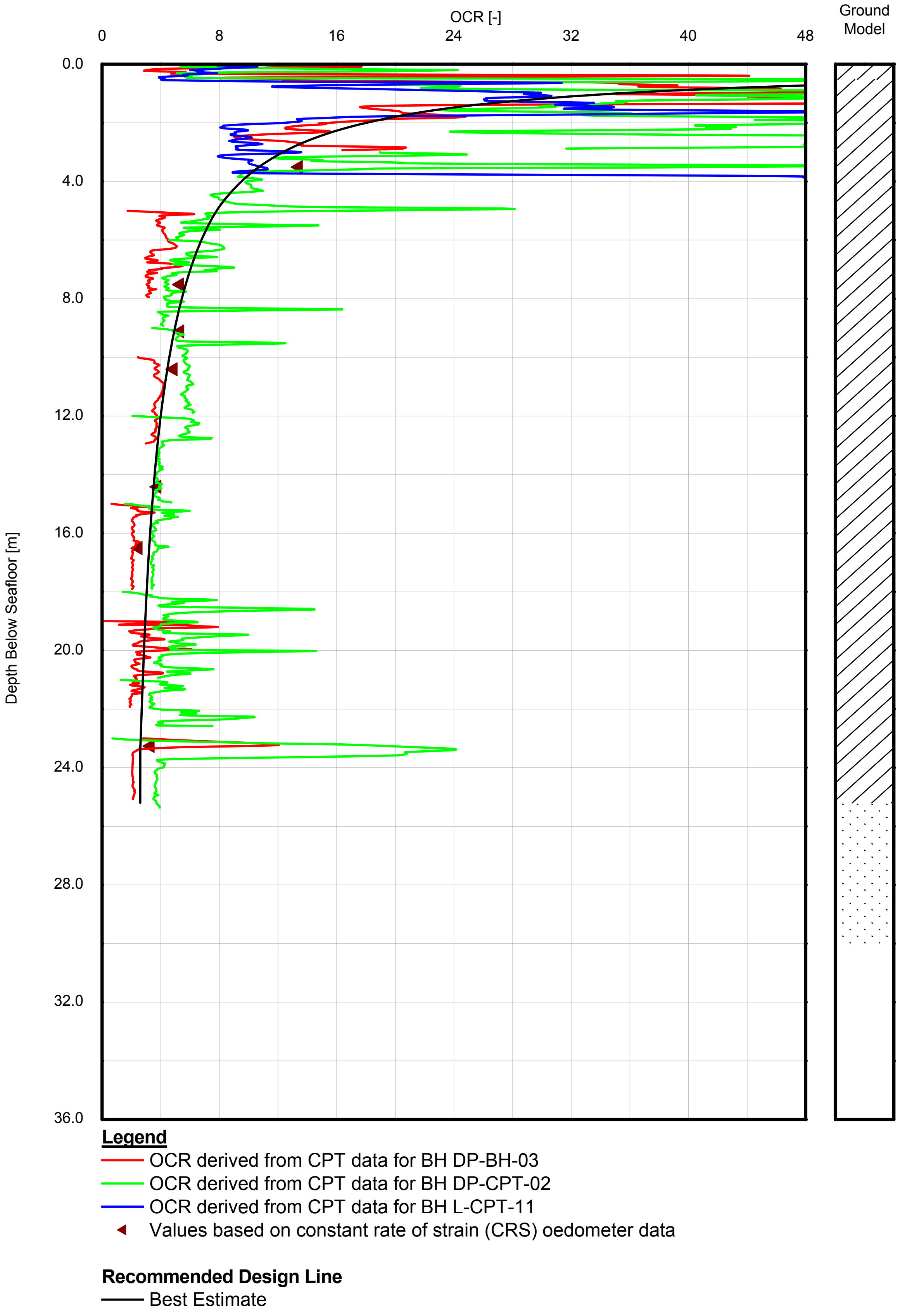
REMOULDED UNDRAINED SHEAR STRENGTH VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



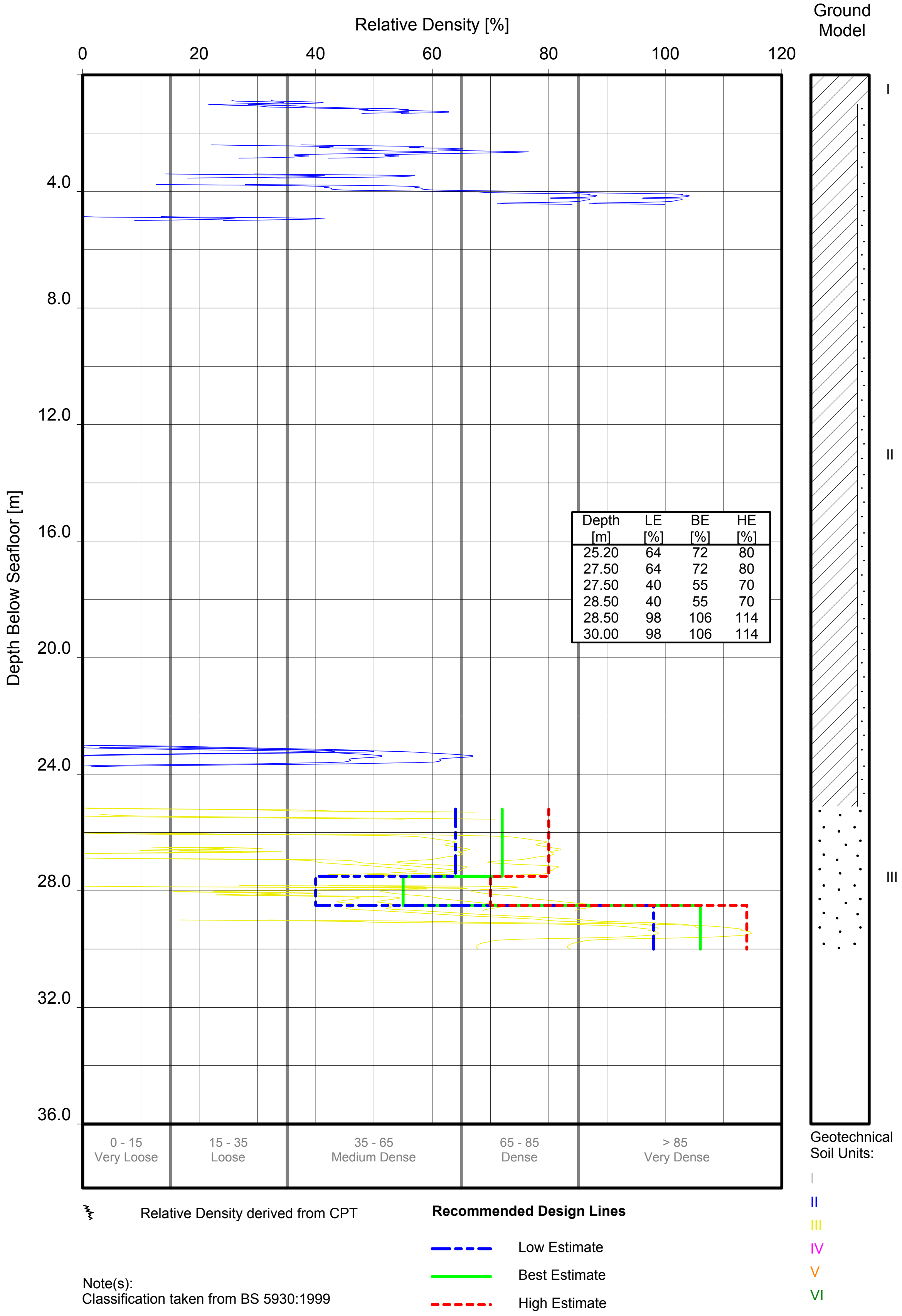
Depth [m]	LE [-]	BE [-]	HE [-]
0.30	1.8	3.8	8.0
25.20	1.8	3.8	8.0

Origin v7.03./ ### / 05/06/2018 17:00:45

SENSITIVITY VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Overconsolidation Ratio (OCR) versus Depth
DP-BH-03, DP-CPT-02 and L-CPT-11
Pelican Drill Center, Neptun Deep Survey

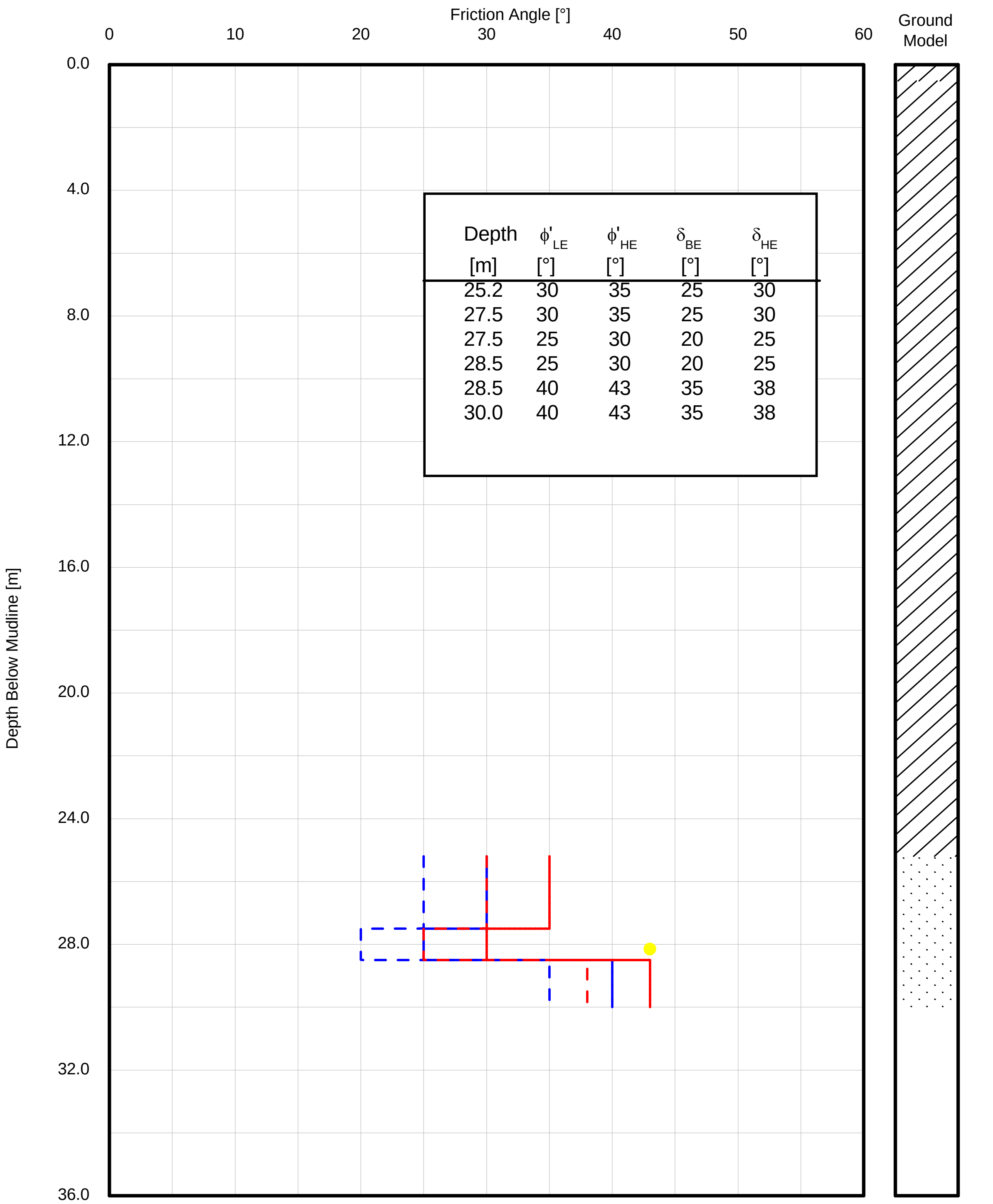


Depth [m]	LE [%]	BE [%]	HE [%]
25.20	64	72	80
27.50	64	72	80
27.50	40	55	70
28.50	40	55	70
28.50	98	106	114
30.00	98	106	114

Note(s):
Classification taken from BS 5930:1999

GeODin/Relative Density versus Depth 0-120 % - Units_v1.02.GLO/2018-05-23 11:47:52

RELATIVE DENSITY VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



Depth [m]	ϕ'_{LE} [°]	ϕ'_{HE} [°]	δ_{BE} [°]	δ_{HE} [°]
25.2	30	35	25	30
27.5	30	35	25	30
27.5	25	30	20	25
28.5	25	30	20	25
28.5	40	43	35	38
30.0	40	43	35	38

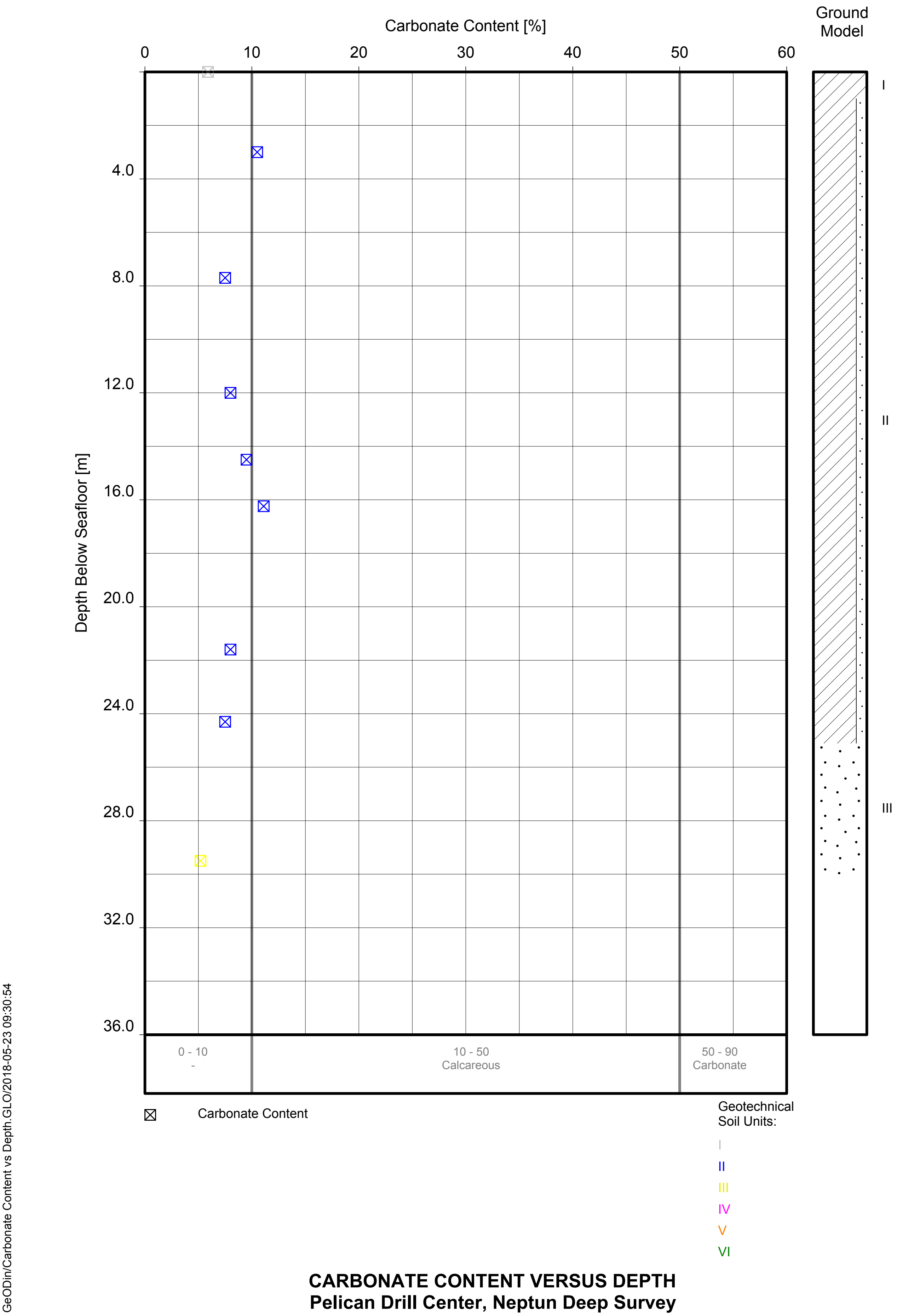
Key of Symbols:
- CID Triaxial
- Internal friction angle inferred from relative density design profiles
- Interface friction angle inferred from internal friction angle ($\delta = \phi' - 5°$)

Geotechnical Soil Units:
III

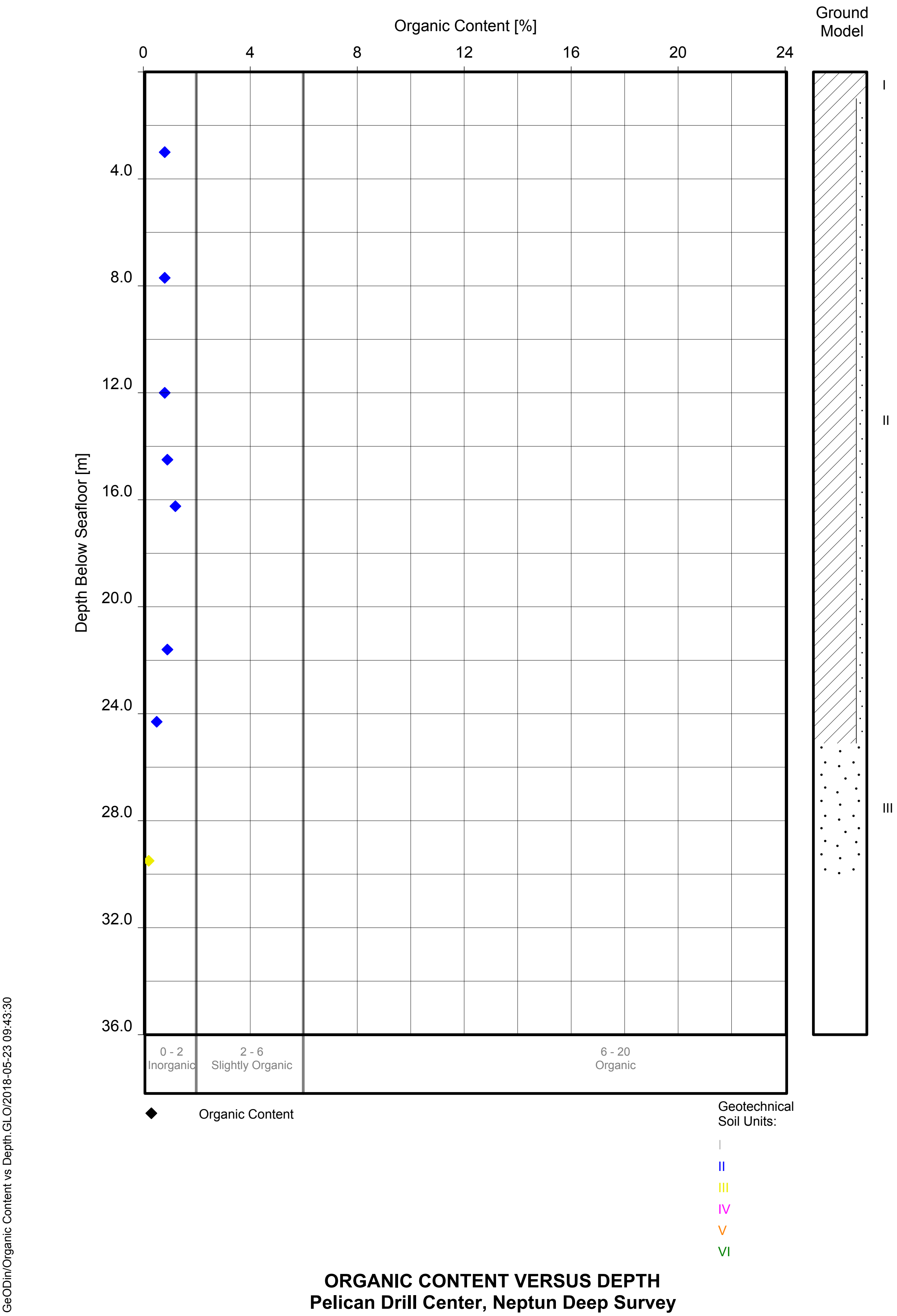
Internal Friction Angle Profiles
- Low Estimate
- High Estimate

Interface Friction Angle Profiles
- Low Estimate
- High Estimate

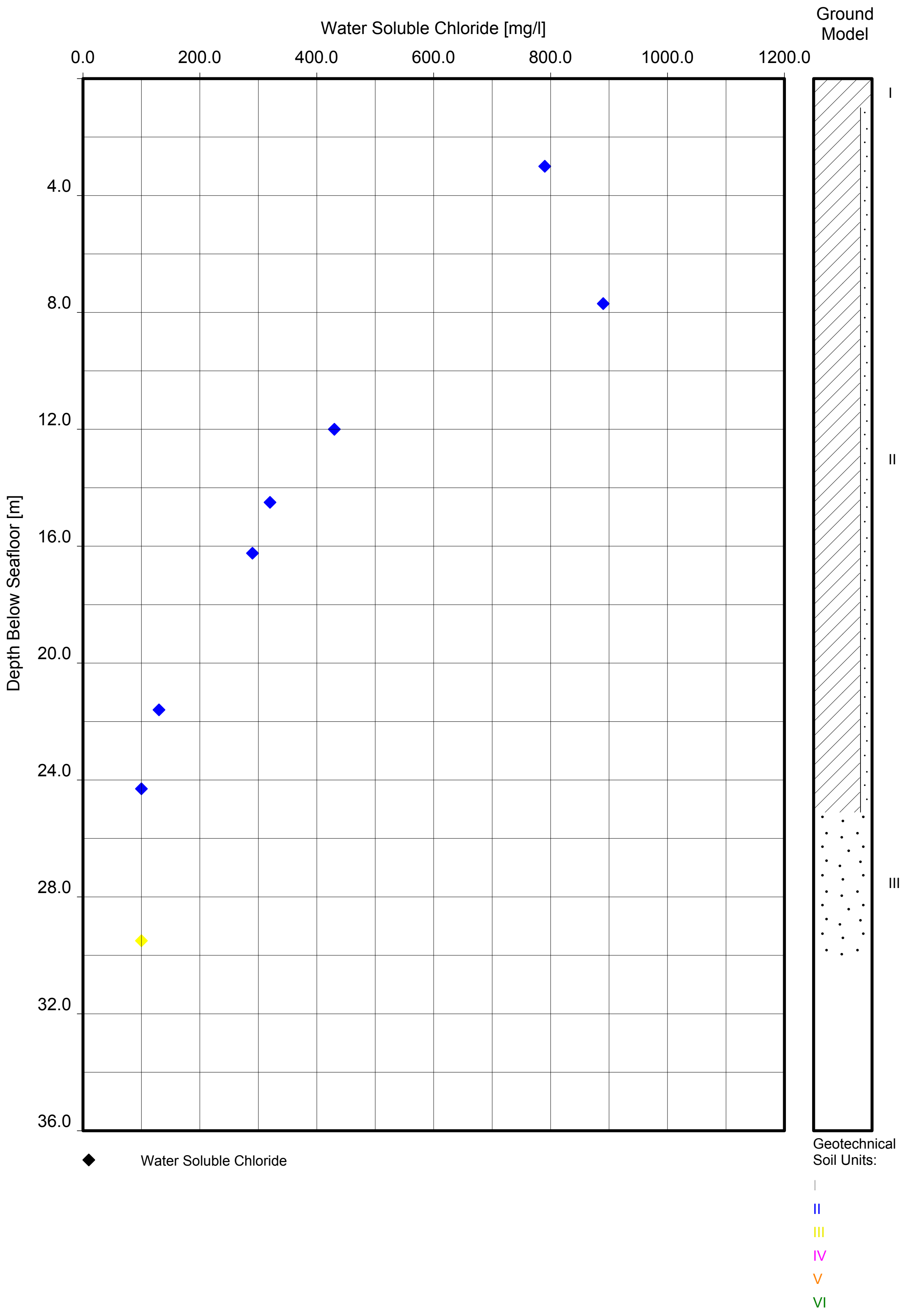
FRICTION ANGLES
DP-BH-01, DP-BH-03 and DP-CPT-02
Pelican Drill Center, Neptun Deep Survey



CARBONATE CONTENT VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey

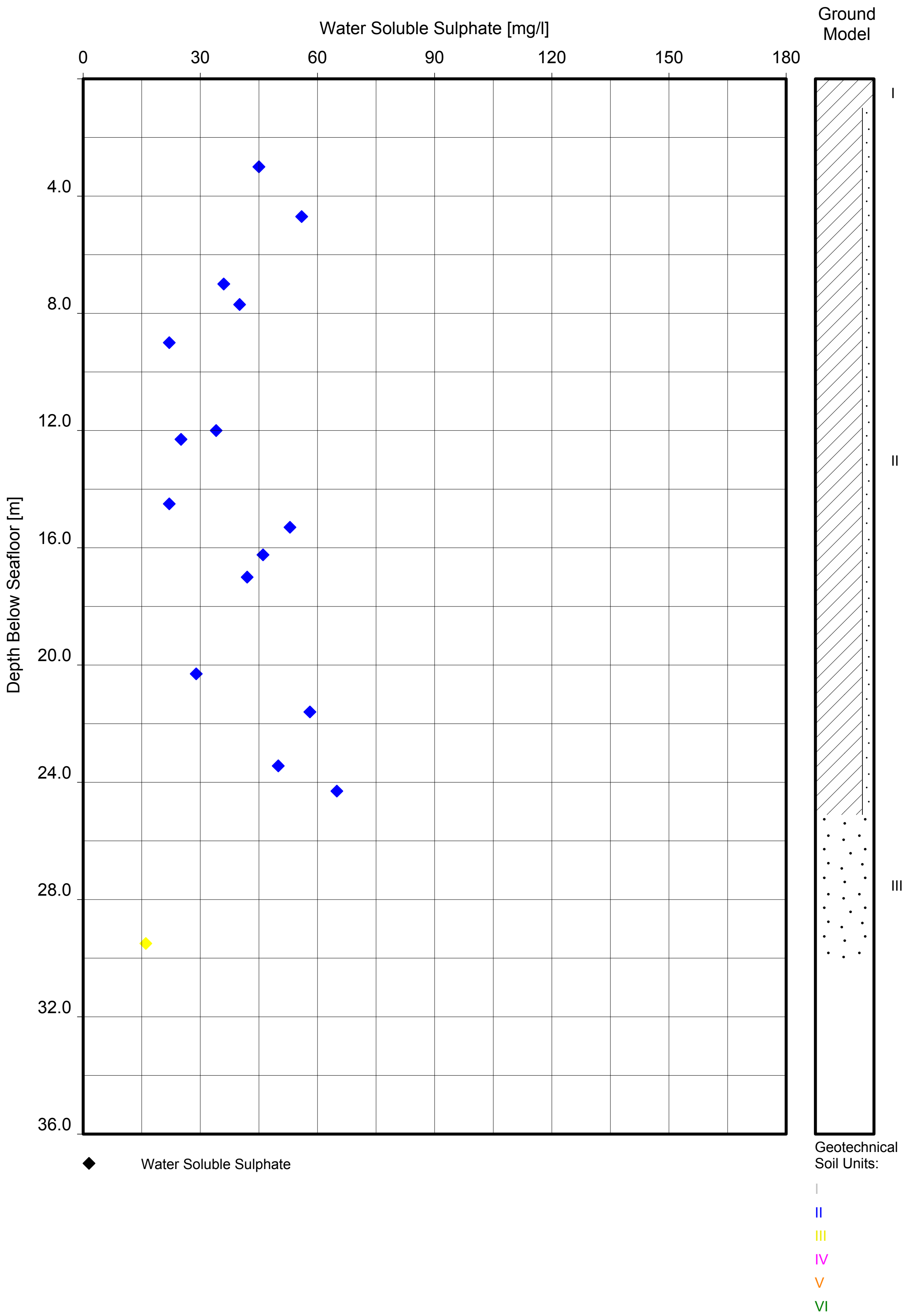


ORGANIC CONTENT VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



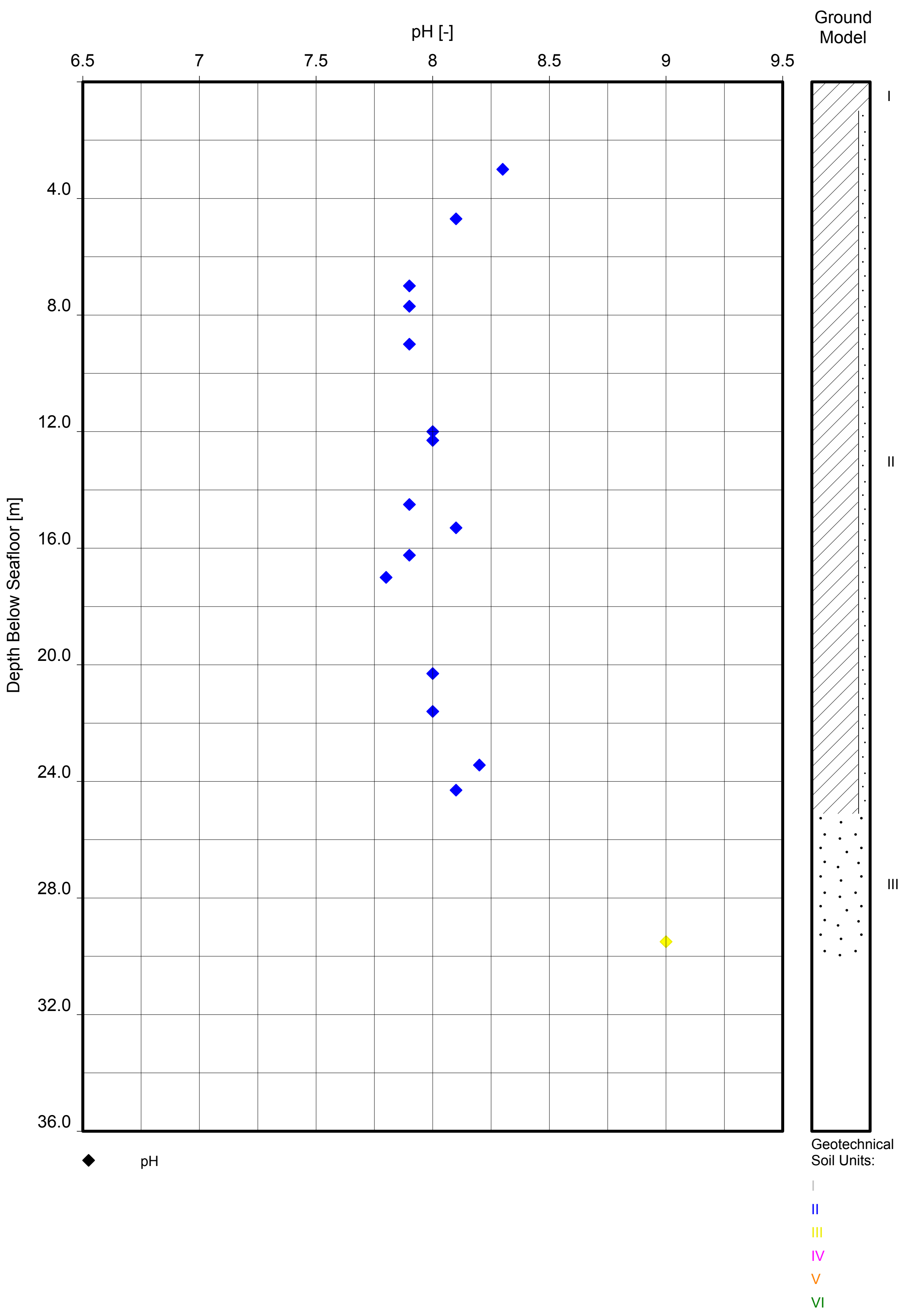
GeODin/Water Soluble Chloride vs Depth.GLO/2018-05-23 12:46:42

WATER SOLUBLE CHLORIDE VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



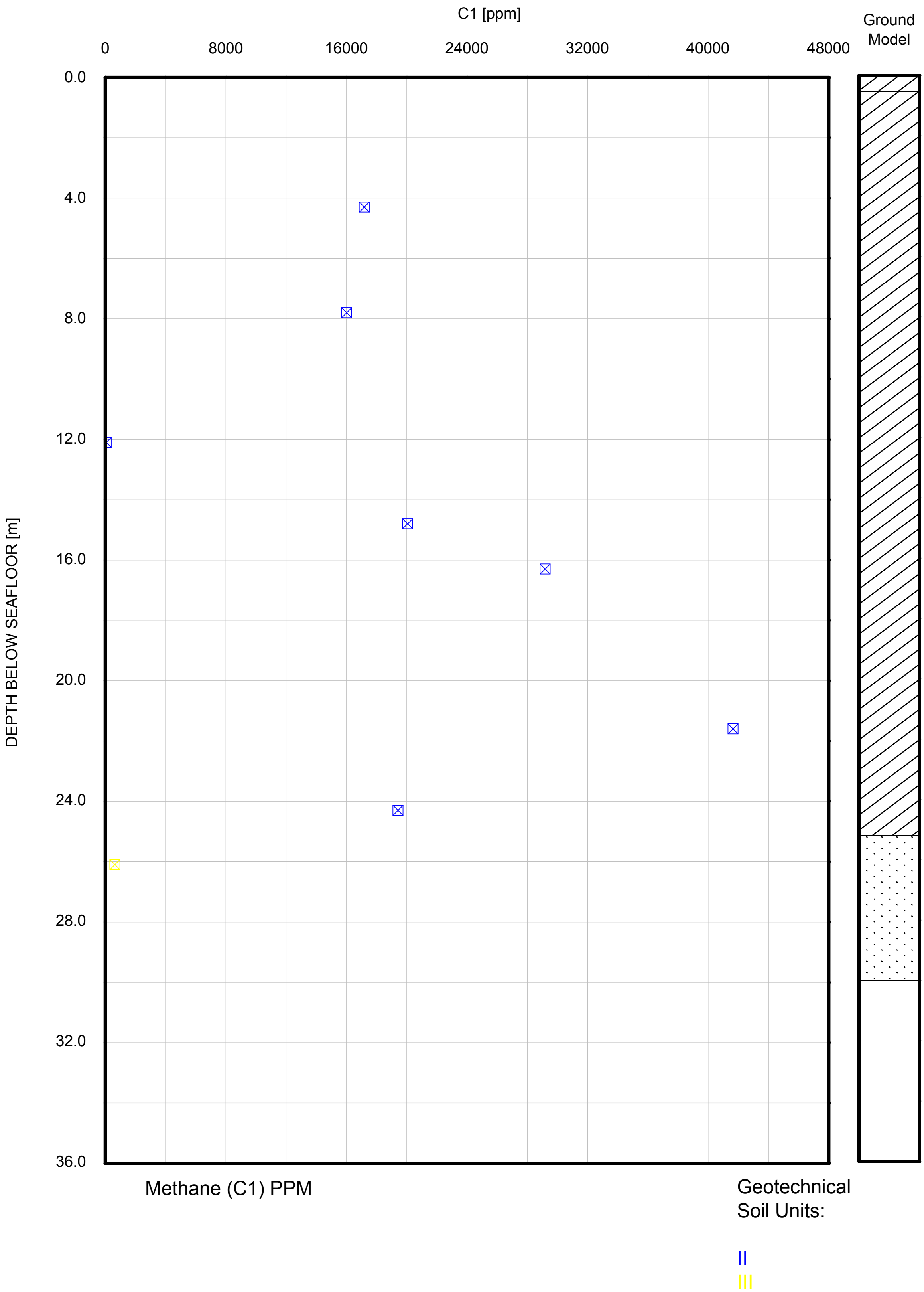
GeODin/Water Soluble Sulphate.GLO/2018-05-23 12:03:17

WATER SOLUBLE SULPHATE VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



GeODin/pH vs Depth - Units.GLO/2018-05-23 11:45:57

pH VERSUS DEPTH
Pelican Drill Center, Neptun Deep Survey



HEADSPACE GAS VERSUS DEPTH
C1 PARTS PER MILLION
Pelican Drill Center, Neptun Deep Survey

APPENDICES

A. GUIDELINES ON USE OF REPORT

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This report (the “Report”) was prepared as part of the services (the “Services”) provided by Fugro GB Marine Limited (“Fugro”) for its client (the “Client”) under terms of the relevant contract between the two parties (the “Contract”). The Services were performed by Fugro based on requirements of the Client set out in the Contract or otherwise made known by the Client to Fugro at the time.

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