IDEA - IRL

INTEGRATED DESIGN OF FLOATING WIND ARRAYS IRELAND

Reference Site Technical Report: Ground Conditions Summary

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Executive Summary

The development of Offshore Wind Farms is significantly influenced by ground conditions, which are crucial for determining appropriate design techniques. This technical note provides an overview of geotechnical parameters and stratigraphy expected at six selected sites which will be used as reference sites for the design of reference floating wind farms for the IDEA-IRL and IEA Wind Task 49 projects. This report will primarily serve as an appendix to the Summary Report for Work Package 1 (WP1) Deliverable (D1) (IDEA-IRL_WP1_D1), which collates the various site conditions defined as part of WP1 D1. These conditions will be provided to WP2 of the IDEA-IRL project, to inform reference floating offshore wind farm designs.

The presented parameters are indicative, and detailed, site-specific studies are necessary during a project's early stages to develop a comprehensive design. This analysis, based on scenario-based case studies and a simplified methodology, underscores the importance of understanding ground conditions and geotechnical parameters for each soil type to assess foundation behaviour under various loads. Data for each scenario was sourced from NOAA, EMODnet, INFOMAR, and GDG's regional experience.

The findings emphasize the necessity of early soil investigation programs and scenario-based analyses to tailor anchoring systems to the unique conditions of each site, ensuring the structural integrity and success of the wind farms.

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1 Introduction

The development of Floating Offshore Wind Farms is influenced by various factors, with ground conditions being among the most critical. Ground conditions determine the most appropriate anchoring techniques. This technical note aims to provide general information about the geotechnical parameters and to establish a baseline for the geotechnical parameters and stratigraphy that may be encountered at the selected reference sites for the IDEA-IRL project.

The site conditions identified in this report will be used by the IDEA-IRL Work Package (WP) 2 team as inputs to inform reference wind farm designs and preliminary anchor sizing.

Figure 1-1 illustrates the location of selected reference sites. The sites considered in this note are listed as follows:

- IDEA-IRL Reference Site 1: The Moneypoint Offshore one site in the Atlantic Ocean off the Clare/Kerry Coast
- IDEA-IRL Reference Site 2: A Celtic Sea site off the Irish south east coast, near the M5 buoy
- IDEA-IRL Reference Site 3: A Celtic Sea site off the Irish south west near the Kinsale Energies Alpha Platform
- IDEA-IRL Reference Site 4: The Ulsan Floating Offshore Wind Farm
- IEA Wind Task 49 'Intermediate' Reference Site: Utsira Nord, Norway
- IEA Wind Task 49 'Deep' Reference Site: Humboldt, California, USA

It should be noted that IDEA-IRL will be required to prepare anchor designs for reference sites 1 – 4, and the IEA Wind Task 49 'Intermediate' reference site. Reference wind farm design for the Humboldt site will be prepared by members of IEA Wind Task 49, with input from the IDEA-IRL team. Preliminary site information is still presented here, however.

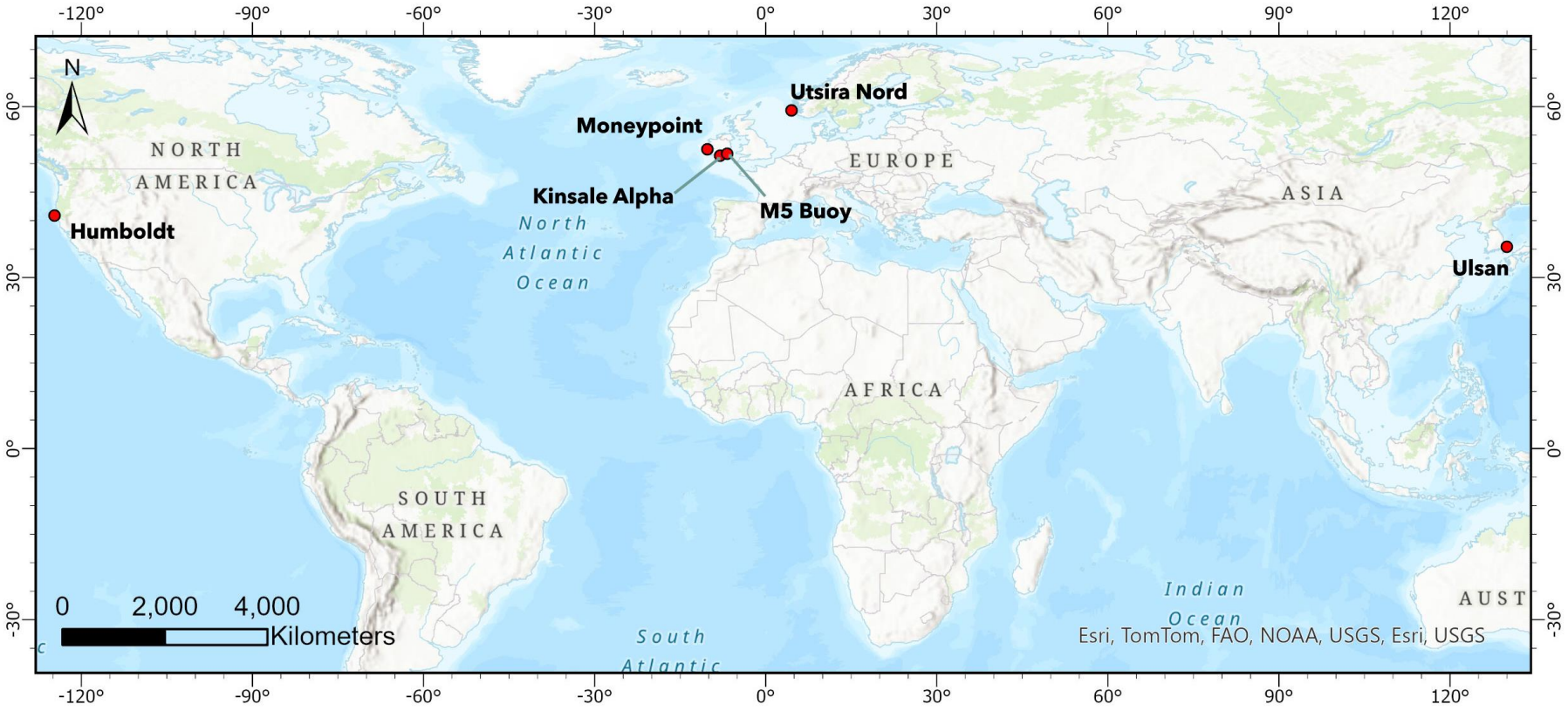
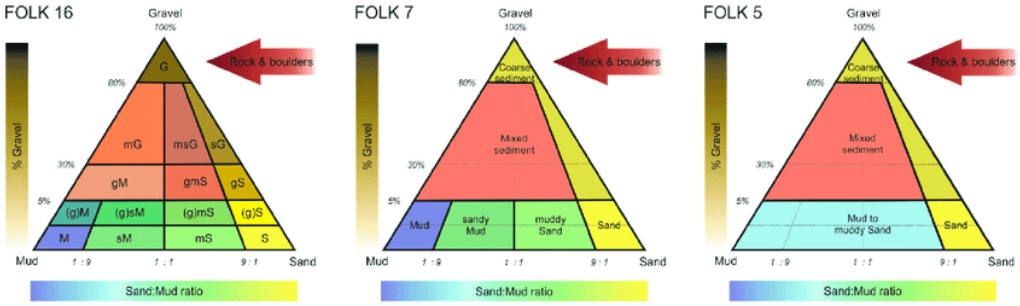


Figure 1-1 Location of the selected reference sites discussed in this note

2 Limitations and assumptions

It is important to note that the requirements and parameters presented in this report are indicative only and that detailed and site-specific studies are required during the early stages of a project to develop a comprehensive design. The analysis presented in this study is based on scenario-based case studies using a simplified methodology. Understanding the ground conditions and associated geotechnical parameters for each soil type is essential for assessing the foundation's behaviour under various loads. Therefore, a soil investigation program should be undertaken in the early stages of floating offshore wind projects. Additional considerations are noted below:

- Data provided for each scenario in this technical note has been extracted from several sources, including literatures, the public domain data from NOAA, EMODnet, INFOMAR, and GDG experience on nearby sites. Due to the nature of these publicly accessible sources, the availability of parameters varies across locations.
- For certain selected sites, direct data at the desired location is unavailable. Consequently, the data is generally derived from broader regional geology, geophysics, and geotechnical information. For these sites, several assumptions will be made during the design stage.
- To best observe the changes in seabed morphology, hillshade rasters were derived from the multibeam echosounder (MBES) data and applied as a semi-transparent layer for the visualization. This allows the identification of more subtle changes in seabed morphology.
- The seabed substrate classification presented in this technical note are mainly based on Folk 7 in the EMODnet Folk sediment triangles and the hierarchy of Folk classification (Figure 2-1).



FOLK, 16 classes	FOLK, 7 classes	FOLK, 5 classes
Rock & Boulders	Rock & Boulders	Rock & Boulders
Gravel - G sandy Gravel - sG) gravelly Sand - gS	Coarse sediment	Coarse sediment *(Gravel >= 80% or (Gravel >= 5% and Sand >=90%)*
muddy Gravel - mG muddy sandy Gravel - msG gravelly Mud - gM gravelly muddy Sand - gmS	Mixed sediment	Mixed sediment *(Mud 95-10%; Sand < 90%; Gravel >= 5%)*
(gravelly) Mud - (g)M Mud - M	Mud *(Mud >= 90%; Sand < 10%; Gravel < 5%)*	Mud to muddy Sand *(Mud 100-10%; Sand < 90%; Gravel < 5%)*
(gravelly) sandy Mud – (g)sM sandy Mud - sM	sandy Mud *(Mud 50-90%; Sand 10-50%; Gravel < 5%)*	
(gravelly) muddy Sand – (g)mS muddy Sand - mS	muddy Sand *(Mud 10-50%; Sand 50-90%; Gravel <5%)*	
(gravelly) Sand – (g)S Sand	Sand *(Mud < 10%; Sand >= 90%; Gravel < 5%)*	Sand

Figure 2-1 The Folk sediment triangle and the hierarchy of Folk classification (EMODnet Geology project).

3 Ground Condition Scenarios

A summary of the identified conditions at each site considered is presented below. These conditions will be used to inform preliminary anchor design for the relevant sites. Where sufficient information cannot be found publicly to inform design, an assumed most representative soil profile shall be taken forward. This will be outlined in future reporting.

3.1 Reference Site 1: Moneypoint One, Atlantic, West Ireland

3.1.1 Water Depths

Water depths at the Wind Energy Area (WEA) vary from - 89 m LAT in the central north of the site to - 107 m LAT (Figure 3-1). Water depths at the site are generally deepest in the central north of the WEA.

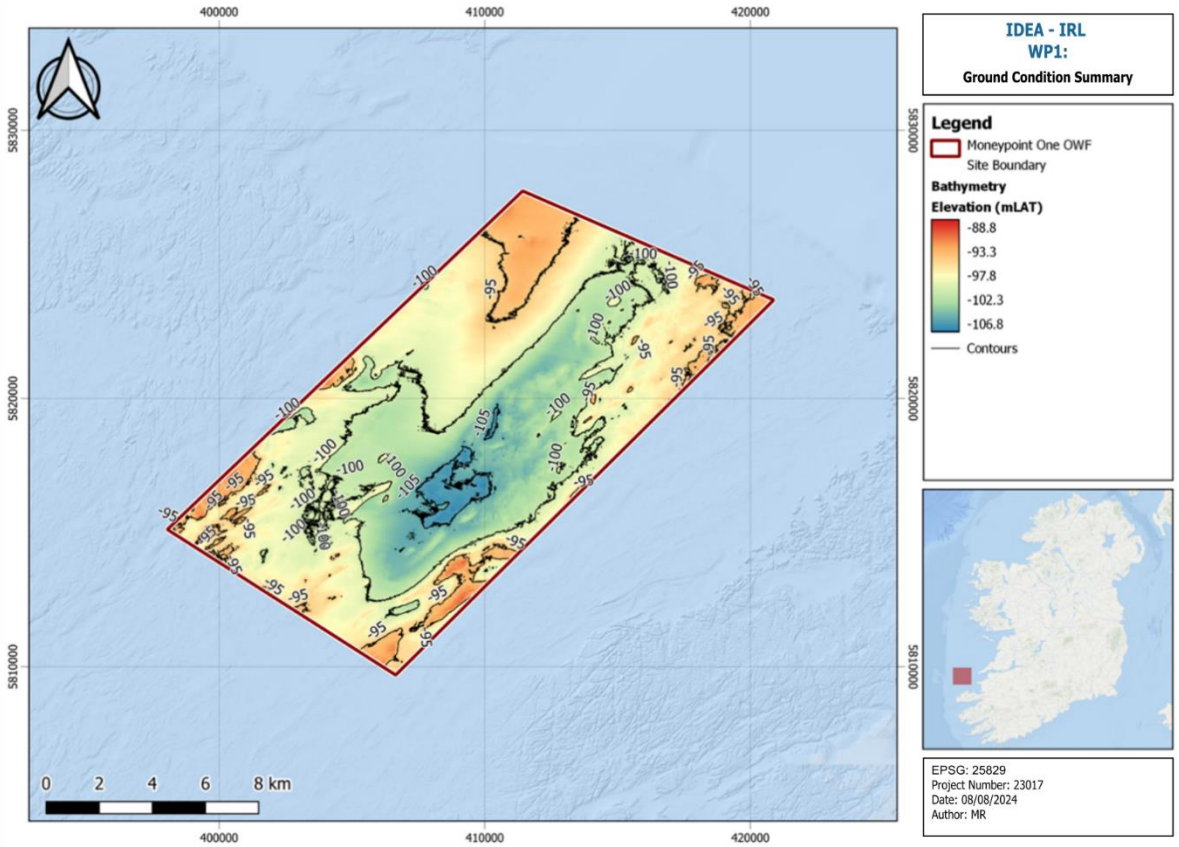


Figure 3-1 Bathymetry (mLAT) with 5m contours in the vicinity of the WEA.

3.1.2 Seabed Composition

The seabed substrate classification map (Figure 3-2) shows that the majority of the seabed within the WEA boundaries is composed of mud to muddy sand, with a significant amount of coarse sediment covering the site also. There are some indications of rock or other hard substrate to the south and southeast of the site.

3.1.3 Ground Conditions Summary

A summary of the interpreted units is provided in Table 3-1. It is impractical to create a soil zonation map due to the uncertainty in seismic facies interpretation and the presence of Units 3 and 4.

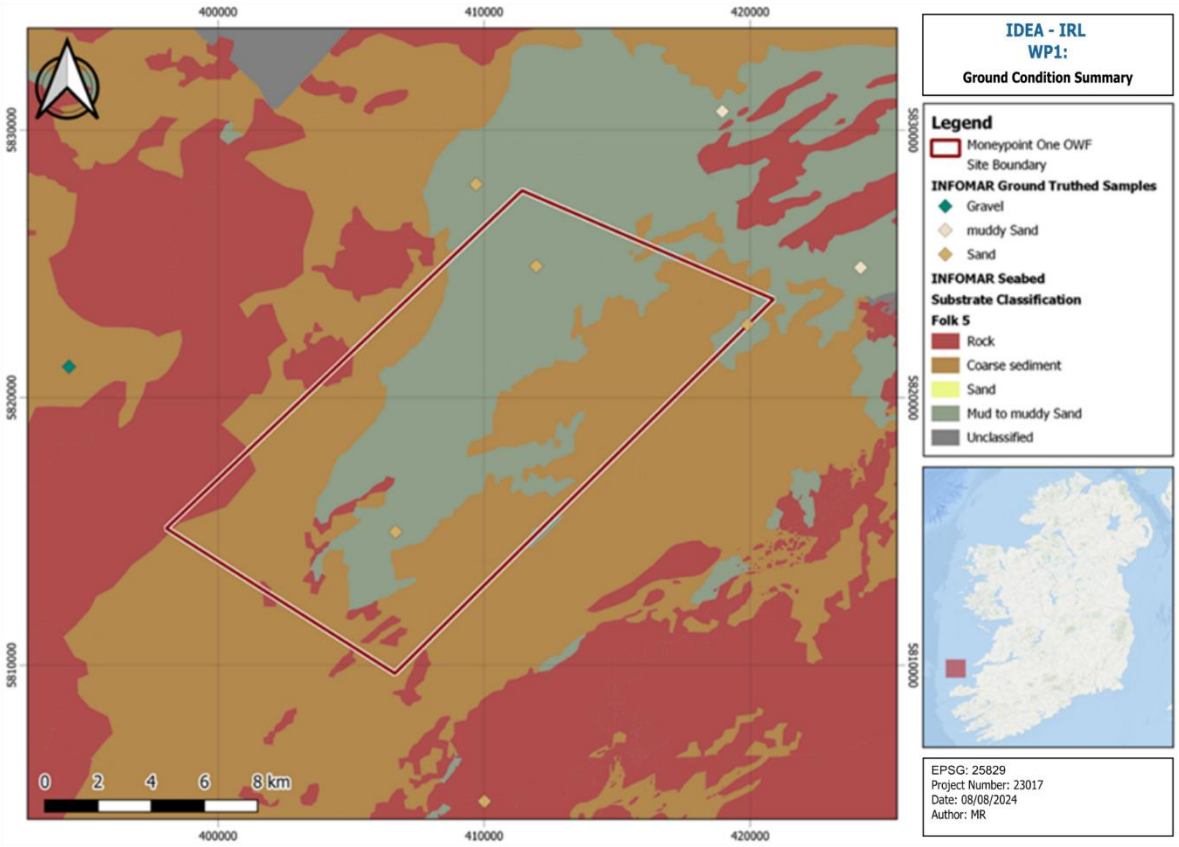


Figure 3-2 Grab samples compared to sediment classification at the WEA.

Table 3-1 Summary of each interpreted unit.

Unit	Interpreted description	Seismic characteristics	Depth to base/top of Unit (mBSF)	Thickness (m)	Shear Stress (kPa)	Density (g/cm^3)
Unit 1	Marine sediments composed of sand	The unit is acoustically transparent, with occasional internal reflections	0 – 8.2 (Base)	0 – 8.2	2-10	2.1
Unit 2	Reworked sand and possible gravel	Acoustically transparent, occasionally displaying sub-parallel internal reflections	0 – 8.1 (Base)	0 – 8.1	10-25	2.2
Unit 3	Comprise sands, silts and clays	Acoustically transparent with a similar background amplitude to Unit 2	-	0 – 17.8	15-35	2.25
Unit 4	Potential till	Internally acoustically transparent	0 – 13.1 (Top)	0 – 14.2	15-50	2.35
Unit 5	Bedrock	Chaotic or acoustically transparent internally	0 – 21.9 (Top)	-	60-250	2.30

3.2 Reference Site 2: Celtic Sea site off the Irish Southeast coast, near the M5 buoy

3.2.1 Water Depths

Seabed elevation at the WEA considered to vary from -69 m LAT to -99 m LAT, although the exact site area to be considered is not yet defined. Water depths at the site generally increase away from the coast to the south. The deepest areas are at the southwest of the site within an interpreted exposed tunnel valley formed by subglacial hydrologic processes in the Late-Pleistocene.

3.2.2 Seabed Composition

The seabed substrate classification documents that the seabed of the WEA could be characterised into three sections. In the north, the seabed is primarily coarse substrate with patches of well-sorted sand which decrease in occurrence towards the centre of the site. The centre of the site is characterised mostly by rock outcrop with some sandy areas. The southern part of the site is chiefly coarse substrate with patches of sand and mud to muddy sand becoming predominantly sand with patches of coarse substrate towards the southernmost boundary.

3.2.3 Ground Conditions Summary

A summary of the interpreted lithological units and geotechnical parameters is provided Table 3-2. A full ground investigation is required to identify geotechnical parameters with confidence and confirm the local bedrock presence.

Table 3-2: Summary of possible geotechnical parameters

Unit	Interpreted Description	ϕ' (degrees)	s_u (kPa)	UCS (MPa)
Unit 1	Soft, muddy SAND/GRAVEL to SAND/GRAVEL (Holocene)	-	-	-
Unit 2	Sandy GRAVEL and gravelly SAND	25 – 42	130-2800	-
Unit 3	Fine SILT and CLAY	21 – 22	20 + 20z	-
Unit 4	TILL deposits	20 – 32	0 – 80	-
Unit 5	BEDROCK	-	-	0.2 – 74

3.3 Reference Site 3: Celtic Sea site off the Irish Southwest coast near the Kinsale Energies Alpha Platform

3.3.1 Water Depths

Water depths at the WEA vary from approximately - 42.7 m LAT in the central north of the site to -74.6 m LAT. Water depths are generally shallowest in the central north of the WEA, at the area closest to the shoreline, gently deepening towards the south.

3.3.2 Seabed Composition

According to the modified seafloor sediment maps, most of the seabed within the WEA is composed of muddy sand. The seabed across the north of the proposed site, as well as a few smaller areas in the west and southwest, is dominated by exposed rocks and boulders. Other smaller areas of sandy mud, coarse and mixed sediment have also been identified.

3.3.3 Ground Conditions Summary

A summary of the interpreted units and representative geotechnical parameters is provided in Table 3-3.

Table 3-3 Summary of each interpreted unit.

Unit	Interpreted Description	Depth to base/top of Unit (mBSF)	Thickness (m)	Effective Unit Weight, γ'	Undrained Shear Strength, su	Small Strain Shear Modulus, G0	Sand Relative Density, Dr
Unit 1	Soft muddy SAND/GRAVEL to SAND/GRAVEL (Holocene)	0 - 3.7 (Base)	0 – 3.7	19	-	20	50
Unit 2	Sandy GRAVEL and gravelly SAND	0.5 – 6.3 (Base)	0-5.8	-	-	-	-
Unit 3	Fine SILT and CLAY	-	0-19.5	19	50	25	-
Unit 4	TILL deposits	2.2 – 12.0 (Top)	0 – 9.8	19	500	250	-
Unit 5	BEDROCK	0 – 25.5 (Top)	Not possible to determine	-	-	-	-

3.4 Reference Site 4: Noto Hantō, Japanese Sea, proxy for Ulsan conditions

3.4.1 Water depths

Due to a lack of publicly available data, this site was chosen as representative of the geological conditions at the Ulsan Floating Offshore wind farm site. Water depths at the WEA vary from approximately -28 m LAT to -990 m LAT (Figure 3-3). Water depths at the site are generally shallowest in the western part of the WEA, at the area closest to the shoreline, and deepest in the north-east.

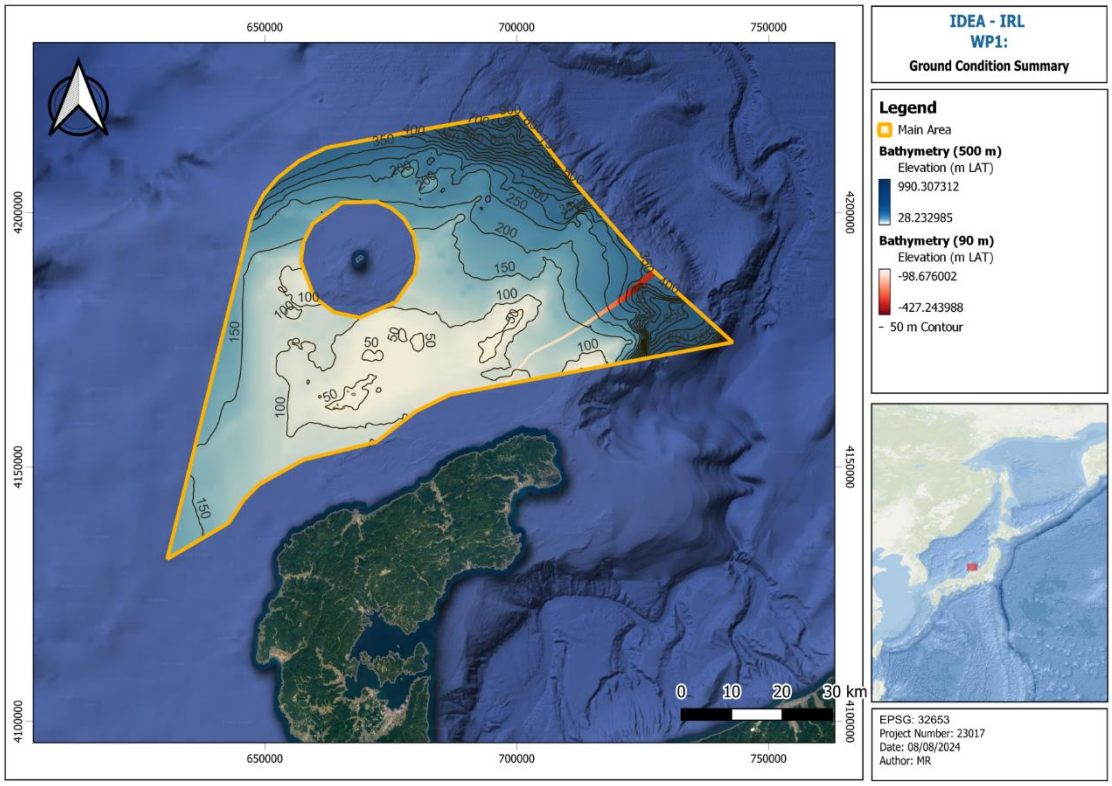


Figure 3-3: Bathymetry (mLAT) with 50 m contours at the WEA.

3.4.2 Seabed Composition

Seabed sediments encountered the study area range from coarse sand to fine silt (Figure 3-4). There is also rock exposed at the seabed close to the shore. Generally, the south to southeast of the WEA is dominated by medium to very coarse sand, whereas the southwest corner is dominated by fine and coarse silt and very fine sand.

3.4.3 Ground Conditions Summary

A review of seismic data and knowledge of marine deposits have also been used to provide a preliminary interpretation of expected lithologies (Table 3-4). Cores from multiple surveys have been used to inform an interpretation of lithologies in the WEA. Grab samples consist of silts and sand layers and are most likely representative of Unit A in the WEA. Geotechnical data is absence in the northern part of the WEA, so there is limited confidence in the expected lithologies outlined in Table 3-4. Since there were no geotechnical soil properties available within the WEA, the relevant parameters, have been extracted from a borehole drilled approximately 350 km south-west of the WEA. Is it uncertain how representative the geology/geotechnical conditions are at the investigated

location compared to the Area of Interest (AoI). Therefore, there is limited confidence in the indicative shear strength values and as such they should be treated with caution Table 3-4.

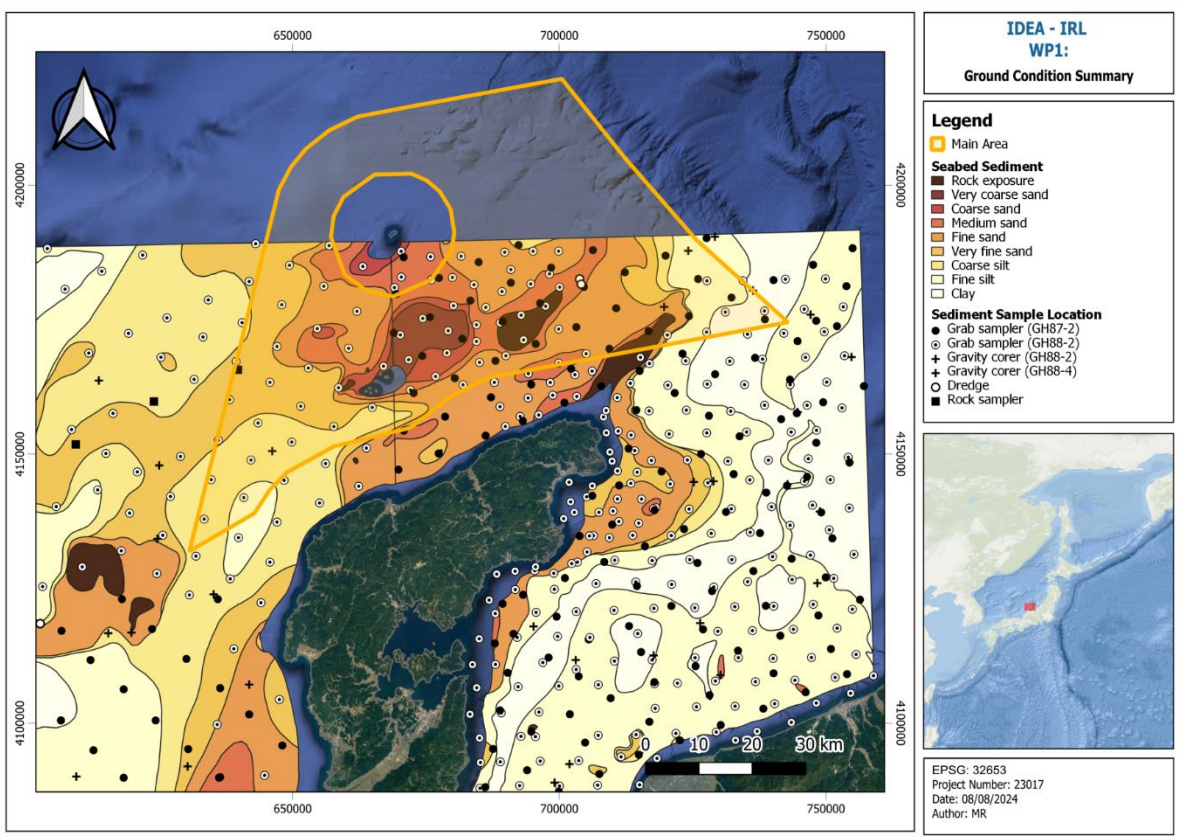


Figure 3-4: Seabed sediments in the vicinity of the WEA.

Table 3-4 Expected Lithologies and Distribution in the WEA

Unit	Interpreted Description	Indicative Depths (mBSF)	Shear Strengths (KPa)	Average Shear Strengths (KPa)
Unit 1	Terrigenous sediments. It is possible that this unit comprises mainly silts, very fine sands, clays and fine sands with granules.	Min: Very thin, approximately 1.5 metres Max: ~100 mBSF	17-93	45
Unit 2	Shallow marine sediments. Mainly sands with some clay, and gravels.	Min: Thin approximately <5 metres Max: ~ 200 mBSF	-	-
Unit 3	Glacial-interglacial cyclicity. Composed of layers of sands, silts, and clays.	Min: Thin approximately <5 metres Max: ~400 mBSF	-	-

Unit	Interpreted Description	Indicative Depths (mBSF)	Shear Strengths (KPa)	Average Shear Strengths (KPa)
Unit 4	It is possible that this unit comprises mainly consolidated clays, sands with layers of volcanic clastics and bedrock granites.	Min: Thin approximately <10 metres in the north of the site Max: Unknown	-	-
Unit 5	Early Miocene and older igneous rocks.	Min: Bottom of unit is difficult to refine. Max: Unknown	-	-

3.5 IEA Wind Task 49 'Intermediate' Reference Site: Utsira Nord, Norway

3.5.1 Water Depths

Water depths at the WEA vary from approximately – 98.7 m LAT to - 116.9 m LAT. The site has a gentle slope with no preferential directions, where slope is generally less than 1°.

3.5.2 Seabed Composition

According to the modified seafloor sediment maps, most of the seabed within the WEA is Weichselian and early Holocene silt/clay (Stoker, Long and Fyfe 1985, EMODnet 2021). Based on the available geological information and site investigations (Stoker, Long and Fyfe 1985, Long 1987, Stoker, et al. 2011, GEOxyz 2021), three formations were identified. All three Formations were interpreted to be bounded by 2 reflectors, with the uppermost unit being subdivided by two reflectors. The formations identified in the seismic record are:

- Witch Ground Formation;
    - Witch Member – interpreted as marine very soft to firm sandy silty CLAY.
    - Fladen Member interpreted as glaciomarine very soft sandy silty CLAY.
- Swatchway Formation interpreted as marine muddy SAND.
- Coal Pit Formation, interpreted as, glaciomarine Sandy silty CLAY.

3.5.3 Ground Conditions Summary

A summary of the expected lithologies in the WEA is provided in Table 3-5. The geological sequence at the WEA is interpreted to consist of veneer Holocene deposits over the Fladen Member of the Witch Ground Formation, underlain by the Swatchway Formation and followed by the Coal Pit Formation. The base of the Fladen Member is observed as gently undulating across the width of the WEA, reaching its mean maximum depth of 4.4 mBSF towards the centre of the site and decreases in depth at both the southwest and north east corners to a mean minimum depth of 1.2 mBSF. CPT data at the site shows an expected top of low strength clay where the Base of the Fladen Member is seen, marking the top of the Swatchway Formation.

Table 3-5 A summary of each interpreted unit.

Seismic Unit	Interpreted Description	Depth to base of Unit along centre line (mBSF)	
		Minimum	Maximum
Forth Formation	very soft to firm sandy MUD	2.8	22.8
Witch Member	Very soft to firm sandy silty CLAY	0.8	3.8
Fladen Member	Very soft sandy silty CLAY	1.0	17.3
Swatchway Formation	Muddy SAND	5.2	44.0
Alternative Base of Swatchway Formation/Coal Pit Internal	-	27.1	44.0
Coal Pit Formation	Sandy silty CLAY	N/A	N/A

3.6 IEA Wind Task 49 'Deep' Reference Site: Humboldt, NW California, USA

3.6.1 Water depths

Water depths at the WEA vary from approximately -550 m LAT (Lowest Astronomical Tide) to -1226 m LAT. Water depths at the site are generally shallowest in the eastern part of the WEA, at the area closest to the shoreline (Figure 3-5).

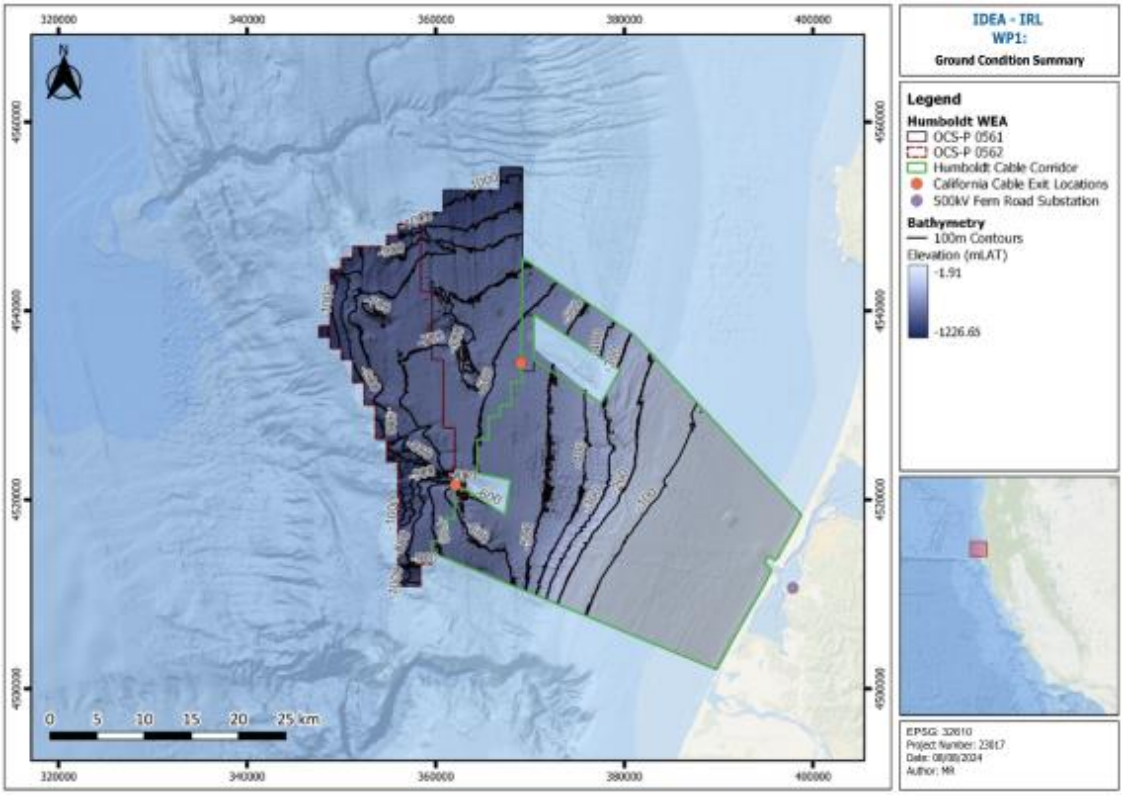


Figure 3-5 Bathymetry (m LAT) with 100 m contours at the WEA

3.6.2 Seabed Composition

For the majority of the site, the seabed is composed of mud (Clay to clayey silt) (Figure 3-6). Areas of exposed bedrock, running in a north-south trend, are present across the centre-west of the WEA.

3.6.3 Ground Conditions Summary

Preliminary interpretation of lithologies at the site is mainly based on regional geology and is presented in Table 3-6). No geotechnical or other data is available at this time to inform lithologies and geotechnical soil properties within the WEA, therefor this information has been extracted from neighbouring boreholes within the Cascadia Basin to the north (Table 3-6). Quaternary shear strengths appear to consistently increase with depth. Pliocene shear strengths do not appear to show any consistent depth trend.

Since the borehole locations lie a significant distance from the WEA, it is uncertain how representative the geology / geotechnical conditions are at borehole locations compared to the area of interest. Therefore, there is limited confidence in the indicative shear strength values and as such they should be treated with caution.

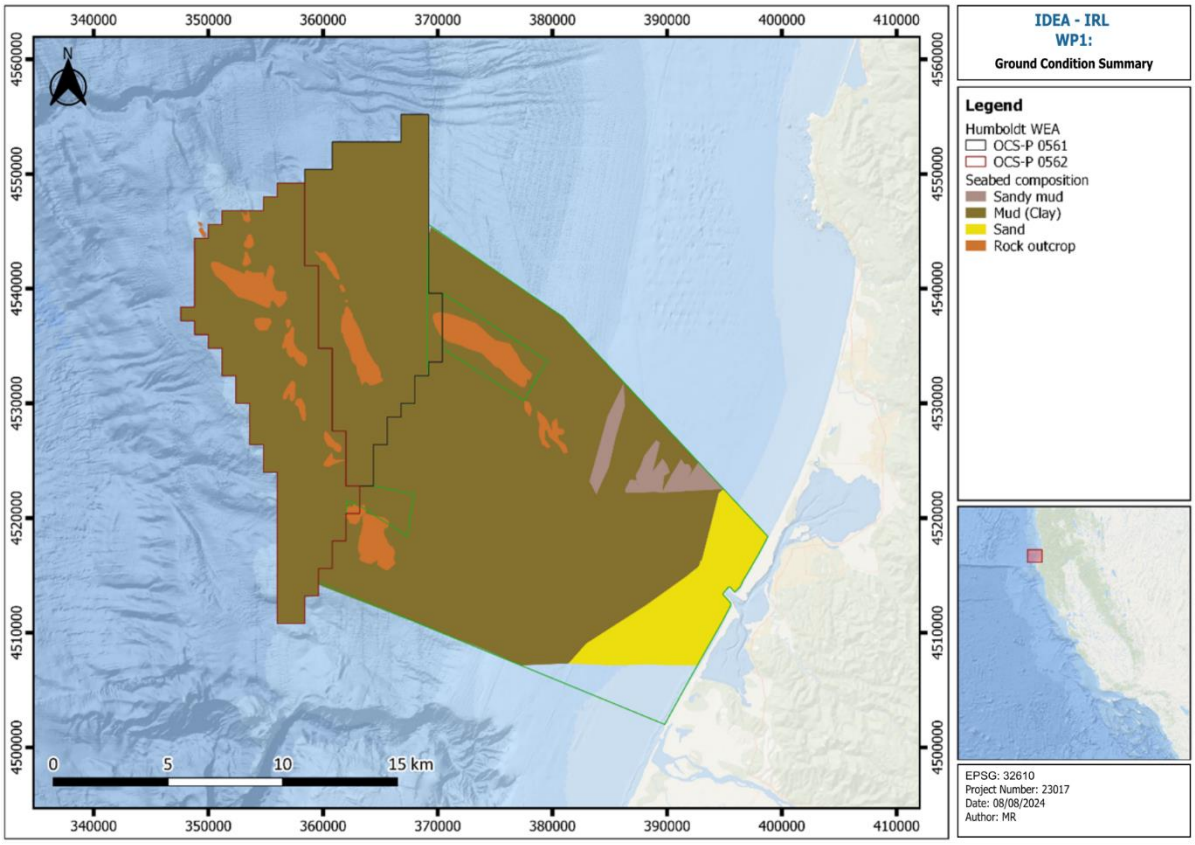


Figure 3-6 Seabed composition interpreted from backscatter data as well as include interpretations from Cooperman et al., (2022).

Table 3-6 Expected Lithologies and Distribution at the WEA.

Unit	Interpreted Description	Indicative Unit Depths (m BSF)	Shear Strengths (KPa)	Average Shear Strengths (KPa)
Unit 1	Clay to clayey silt with occasional thin fine to medium sands	Min: Thin to absent at Outcropping Pliocene anticlines Max: ~177 m BSF	5-79	35
Unit 2	Clayey silt to silty clay	Min: Outcropping or shallow sub-cropping at anticlines Max: ~688 m BSF	61-220	130
Unit 3	Unknown, possibly crystalline basement	Outcrops at seabed, but rapidly deepens either side below interpretable depth	-	-

4 Conclusion

The successful development of Floating Offshore Wind Farms in the selected sites hinges on a thorough understanding of the ground conditions, which play a pivotal role in determining appropriate anchoring techniques. This technical note has provided a general overview of the expected geotechnical parameters and established a baseline for the stratigraphy likely to be encountered at the selected sites. However, it is crucial to emphasize that the presented parameters and requirements are indicative and to be used for research purposes. A detailed, site-specific geotechnical study is necessary in the early stages of a project to develop a comprehensive design.

The six scenarios analysed, each characterized by varying water depths and ground conditions, underscore the importance of site-specific data. These scenarios highlight how different geotechnical conditions can influence foundation behaviour under diverse loads. The scenario-based case studies used a simplified methodology, drawing on data from multiple sources, including NOAA, EMODnet, INFOMAR, and GDG's regional experience.

Key observations from the scenarios include:

- Variable Water Depths: The range of water depths across the scenarios may necessitate tailored anchoring solutions. Shallower sites may allow for simpler design systems, while deeper waters require more complex, robust designs.
- Ground Condition Diversity: The differences in ground conditions, from soft sediments to harder substrates, indicate that a one-size-fits-all approach is not feasible. Each site demands a customized approach to anchoring and foundation design by WP2.
- Geotechnical Parameter Relevance: Understanding the specific geotechnical parameters of each soil type at the selected sites is essential. This knowledge ensures that the foundation design can accommodate various loads and environmental conditions.
- Importance of Early Soil Investigation: A comprehensive soil investigation program should be conducted early in the project lifecycle. This will provide the detailed data necessary to refine the design and ensure the structural integrity of the wind farms.

The site conditions discussed in this report will be used by the IDEA-IRL team to inform WP2 reference wind farm designs.

5 References

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