CALEDONIA
Offshore Wind Farm

Code: UKCAL-CWF-CON-EIA-RPT-00007-7D02

Volume 7D Caledonia South Appendices

Appendix 3-2 Sediment Quality Baseline

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Volume 7D Appendix 3-2 Sediment Quality Baseline

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Acronyms and Abbreviations

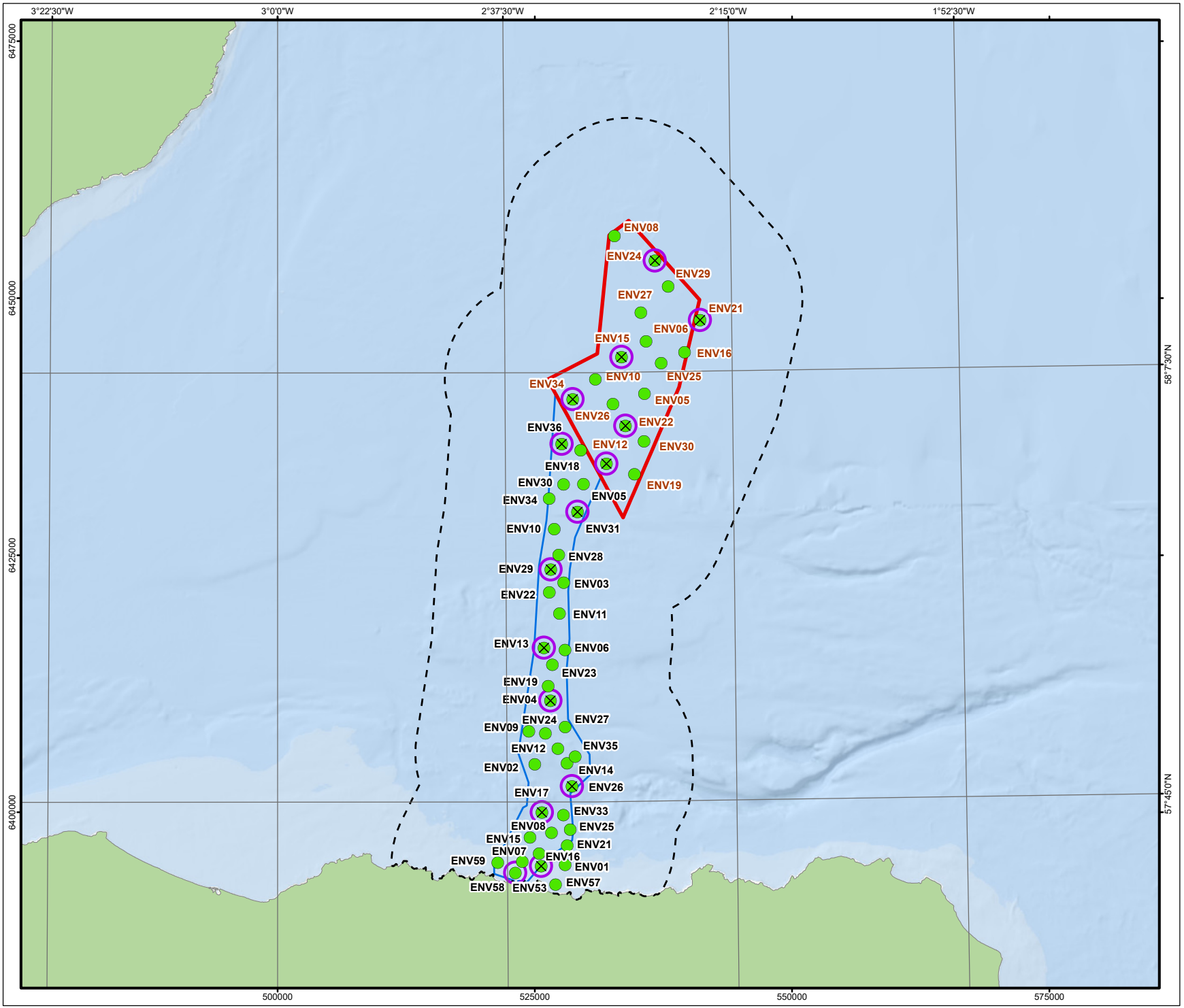
BGS	British Geological Survey
EIA	Environmental Impact Assessment
MW&SQ	Marine Water and Sediment Quality
OECC	Offshore Export Cable Corridor
OWF	Offshore Wind Farm
PSA	Particle Size Analysis
TOC	Total Organic Carbon

1 Introduction

1.1.1.1 This appendix covers an in-depth analysis of the sediment quality baseline environment of Caledonia South in terms of sediment quality parameters in the Marine Water and Sediment Quality (MW&SQ) Study Area, such as:

- Sediment Characterisation (including Particle Size Analysis (PSA)); and
- Total Organic Carbon (TOC) content.

1.1.1.2 The location of sample stations across the Caledonia South Site and the Caledonia South Offshore Export Cable Corridor (OECC) are shown in Figure 1-1. The results of this site-specific survey are compared with publicly available regional data, including previous Offshore Wind Farm (OWF) Environmental Impact Assessments (EIAs), to provide a robust characterisation of the entire MW&SQ Study Area.



Caledonia South Site

Caledonia South Offshore Export Cable Corridor

10km Zone of Influence

PSA Sample

Chemistry Sample

Water Sample

0 5 10 15 20 km

REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP
01	16/09/2024	Approved	EV	BB	DH

CALEDONIA Offshore Wind Farm

GoBe APEM Group

CONTRACTOR DRAWING NO: UKCAL1_GO_WNF_MWS_MAP_00439	CONTRACTOR REV: 01
GEODETIC PARAMETERS: WGS 84 / UTM zone 30N (EPSG: 32630)	

DRAWING TITLE

Figure 1-1: Site-Specific Survey Locations in the Caledonia South Site and Caledonia South OECC

STATUS: Approved	SCALE: 1:500,000	
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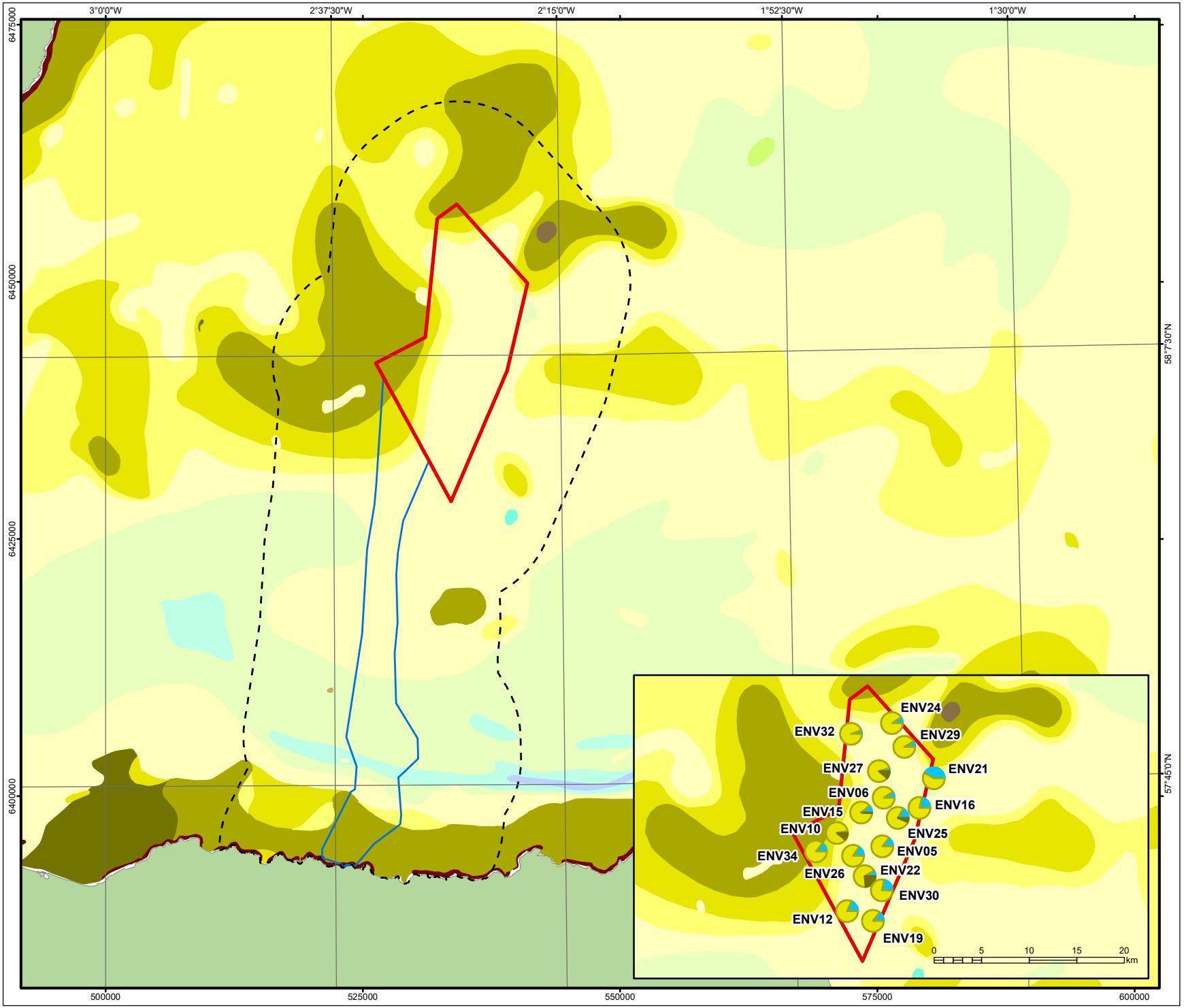
2 Sediment Characterisation

2.1 Overview

2.1.1.1 Sediment characteristics (grain type and size) influence multiple of important biotic and abiotic aspects in the marine environment and are therefore considered an important impact pathway. For example, diversity and composition of macro and meio benthic communities, organic carbon storage and contaminant storage/distribution are strongly conditioned by sediment grain size. Sediments with a finer particle size, such as clays and muds, can act as adsorption surfaces for contaminants that may be released into the water column if the sediment is disturbed. This is due to their larger surface area to volume ratios and higher organic carbon content. Sediments consisting of coarser sand and gravel are accepted to carry a much lower contamination risk. Information regarding particle sizes is an important step in assessing the contamination risk to the marine environment. Figure 2-1 illustrates the anticipated sediment characterisation across the MW&SQ Study Area.



Caledonia South Site

Caledonia South Offshore Export Cable Corridor

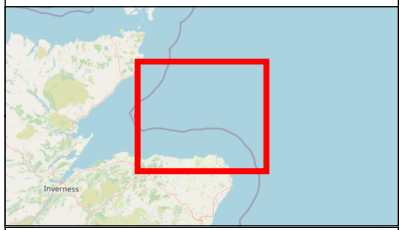
10km Zone of Influence

Seabed Sediments (Folk, 1954)

- 1.1.1 Mud
- 1.2.1 sandy Mud
- 1.2.2 (gravelly) sandy Mud
- 1.3.1 muddy Sand
- 1.3.2 (gravelly) muddy Sand
- 2.1.1 Sand
- 2.1.2 (gravelly) Sand
- 3.1.1 gravelly Sand
- 3.2.1 sandy Gravel
- 3.3.1 Gravel
- 4.3.1 gravelly muddy Sand
- 4.4.1 muddy sandy Gravel
- 5. Rock and Boulders

PSA Results (%)

- Fines
- Sand
- Gravel



0 5 10 15 20 km

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CONTRACTOR REV: 01

GEODETIC PARAMETERS: WGS 84 / UTM zone 30N (EPSG: 32630)

DRAWING TITLE

Figure 2-1: Existing Surficial Sediment Characterisation Combined with Site-Specific Sampling

STATUS: Approved

SCALE: 1:500,000

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SHEET NO: 01 of 01

REV: N/A

2.2 Caledonia South Site

2.2.1.1 Regional-scale sediment maps sourced from EMODnet (2020[1]), derived from BGS datasets (Figure 2-1), indicate that within the Caledonia South Site, the surficial seabed sediments predominantly consist of Holocene sediments, including sand, gravelly sand, sandy gravel, and slightly gravelly sand, as per the Folk classification (Folk, 1954[2]). These sediments are reported to contain only a small proportion of fines, less than 10%. It is important to acknowledge that the BGS sediment maps are constructed from a relatively sparse sampling density in this area. Nevertheless, these data can serve to provide broad-scale characterization, particularly when combined with site-specific sampling campaigns.

2.2.1.2 A site-specific survey (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)) sampled 17 stations across the Caledonia South Site using wet and dry sieving to determine the PSA of sediment grab samples, results of which are shown in Table 2-1 and Figure 2-1. The mean particle size ranged from 45µm at Station ENV21 to 1057µm at Station ENV22, with an average mean grain diameter of 253µm (±261SD). The dominant fraction, accounting for between 58.1% and 93.8% of the sediment was sand (with a particle size range of >63µm and <2mm). These data generally support the BGS sediment maps (i.e., reporting of less than 10% fines), where there was a slight exceedance of average portion of fines present in the survey samples of 13.9%. Surveys conducted across Moray East Offshore Wind Farm found levels of fine (silt/clay) particles were generally low across the survey array (<3%) but increased (around 4% and 5%) with increased water depth to the south (Moray Offshore Renewables Limited, 2012[3]). This is further validated by comparison with surveys undertaken by Moray West Offshore Wind Farm that found seabed sediments across the Moray West site generally consist of Holocene gravelly sand and sand with only a minor proportion of fines (<5 to 10% silt and clay sized) (Moray Offshore Windfarm (West) Limited, 2018[4]).

2.2.1.3 When survey results were classified under the modified Folk 16 classification (Folk, 1954[2]), stations ranged from muddy sand to gravelly sand. These classifications were validated by the analysis of the relative proportions of fines, sand and gravel. Similar results as seen reported from Moray East survey samples are observed in the Caledonia South Site where samples indicate a particle size distribution ranging from very poorly sorted to moderately sorted (Folk and Ward, 1957[5]). "Very poorly sorted" indicates that the sediment contains a wide range of particle sizes, with no dominant size fraction. This suggests a lack of uniformity in the particle sizes present. "Moderately sorted" suggests that there is some degree of uniformity in the particle sizes, but there is still noticeable variability present.

Table 2-1: Summary of Particle Size Analysis across the Caledonia South Site.

Station	Mean Diameter (µm)	Fines (%)	Sand (%)	Gravel (%)	Sorting	Modified Folk Classification	Total Organic Carbon (%) *
ENV05	160	14.1	85.7	0.1	Poor	Muddy sand	N/A
ENV06	208	9.3	90.4	0.3	Poor	Sand	N/A
ENV10	763	2.8	86.2	11.0	Poor	Gravelly sand	N/A
ENV12	106	18.2	81.8	0.0	Poor	Muddy sand	0.44
ENV15	157	11.0	87.9	1.1	Poor	Slightly gravelly muddy sand	0.44
ENV16	125	21.1	78.3	0.5	Poor	Muddy sand	N/A
ENV19	182	14.4	85.6	0.0	Poor	Muddy sand	N/A
ENV21	45	41.9	58.1	0.0	Very poor	Muddy sand	1.10
ENV22	1057	8.5	68.0	23.5	Very poor	Gravelly muddy sand	0.43
ENV24	197	8.9	90.7	0.4	Poor	Sand	0.32
ENV25	229	16.4	77.4	6.2	Very poor	Gravelly muddy sand	N/A
ENV26	120	15.6	84.4	0.0	Poor	Muddy sand	N/A
ENV27	325	4.5	84.3	11.2	Poor	Gravelly sand	N/A
ENV29	190	8.4	91.0	0.6	Poor	Sand	N/A

Station	Mean Diameter (µm)	Fines (%)	Sand (%)	Gravel (%)	Sorting	Modified Folk Classification	Total Organic Carbon (%) *
ENV30	85	21.6	78.4	0.0	Poor	Muddy sand	N/A
ENV32	230	5.5	93.8	0.7	Moderate	Sand	N/A
ENV34	124	14.4	85.5	0.1	Poor	Muddy sand	0.45
Summary Statistics							
Minimum	45	2.8	58.1	0.0	Very poor to Moderate	Muddy sand to Gravelly sand	0.32
Maximum	1057	41.9	93.8	23.5	Very poor to Moderate	Muddy sand to Gravelly sand	1.10
Mean	253	13.9	82.8	3.3	Very poor to Moderate	Muddy sand to Gravelly sand	0.53
Standard Deviation	261	9.1	9.1	6.4	Very poor to Moderate	Muddy sand to Gravelly sand	0.28
* TOC was analysed via chemistry samples acquired at nine sample stations. Therefore, N/A indicates where TOC was not analysed.							

2.3 Caledonia South OECC

2.3.1.1 Regional-scale sediment maps from EMODnet (2020[1]), sourced from BGS datasets, indicate that within the Caledonia South OECC the surficial seabed sediments are characterised by Holocene sediments of sand and gravels close to the Caledonia South Site, with mud content increasing towards the shore (Figure 2-1). Sediments generally appear to become progressively finer as water depth increases, with isolated patches of coarser sediment associated with bathymetric highs. Between approximately 8 and 20km offshore, the surficial sediments are classified as muddy sand, with a band of sandy mud approximately 10km offshore (Figure 2-1).

2.3.1.2 Across the Caledonia South OECC, 38 stations were sampled using wet and dry sieving to determine the PSA of sediment grab samples as part of a site-specific survey (Volume 7B, Appendix 4-2: Environmental Baseline Report (Offshore Export Cable Corridor)). Results, detailed in Table 2-2 and Figure 2-1, revealed a wide range in mean particle size, ranging from 41µm (Station ENV27) to 1813µm (Station ENV11). Stations closest to the shore, situated in water depths less than 35m (ENV07, ENV53, ENV57, ENV58, and ENV59), were predominantly sandy (>95%) and exhibited moderate to moderately well sorted characteristics based on Folk and Ward (1957[5]) statistics. These stations recorded minimal fines (<5%) and gravel. In contrast, stations in water depths exceeding 70m (ENV02 to ENV06, ENV08 to ENV10, ENV12, ENV17, ENV19, ENV23 to ENV31, ENV33 to ENV36) displayed poorly to very poorly sorted sediment, classified as muddy sand under modified Folk classification (1954[2]). These stations were primarily composed of fine sand to very fine sand, with fines content ranging from 11% at Station ENV08 to 45% at Station ENV27, and gravel content below 1%. Overall, there was a clear positive correlation between fines and water depth, where finer sediment was observed in areas of deeper water.

Table 2-2: Summary of Particle Size Analysis across the Caledonia South OECC.

Station	Mean Diameter (µm)	Fines (%)	Sand (%)	Gravel (%)	Sorting	Modified Folk Classification	Total Organic Carbon (%) *
ENV01	1591	1.8	59.6	38.6	Very poor	Sandy gravel	N/A
ENV02	90	27.3	72.6	<0.1	Very poor	Muddy sand	N/A
ENV03	115	19.1	80.9	0.0	Poor	Muddy sand	N/A
ENV04	61	31.3	68.7	0.0	Poor	Muddy sand	0.37
ENV05	83	22.1	77.9	<0.1	Poor	Muddy sand	N/A
ENV06	141	14.1	85.9	<0.1	Poor	Muddy sand	N/A
ENV07	520	1.7	97.4	0.8	Moderate	Sand	N/A
ENV08	167	11.1	88.9	<0.1	Poor	Muddy sand	N/A
ENV09	79	30.5	69.5	0.0	Very poor	Muddy sand	N/A
ENV10	51	34.9	65.1	0.0	Poor	Muddy sand	N/A
ENV11	1813	6.2	56.2	37.5	Very poor	Sandy gravel	N/A
ENV12	69	30.6	69.4	0.0	Very poor	Muddy sand	N/A
ENV13	220	9.5	90.3	0.2	Poor	Sand	0.19
ENV14	215	16	81.4	2.6	Poor	Slightly gravelly muddy sand	N/A
ENV15	490	6.1	79.8	14.1	Poor	Gravelly sand	N/A

Station	Mean Diameter (µm)	Fines (%)	Sand (%)	Gravel (%)	Sorting	Modified Folk Classification	Total Organic Carbon (%) *
ENV16	363	4.9	92.4	2.7	Poor	Slightly gravelly sand	N/A
ENV17	130	18.9	80.8	0.3	Poor	Muddy sand	0.30
ENV18	166	24.6	64.7	10.7	Very poor	Gravelly muddy sand	N/A
ENV19	118	19.1	80.6	0.3	Poor	Muddy sand	N/A
ENV21	497	8.7	72.1	19.1	Very poor	Gravelly muddy sand	N/A
ENV22	252	12.3	87.2	0.5	Poor	Muddy sand	N/A
ENV23	152	16.2	83.8	0.0	Poor	Muddy sand	N/A
ENV24	53	37.1	62.9	0.0	Very poor	Muddy sand	N/A
ENV25	143	12.2	87.8	<0.1	Poor	Muddy sand	N/A
ENV26	47	40.7	59.3	0.0	Very poor	Muddy sand	0.77
ENV27	41	45.2	54.8	0.0	Very poor	Muddy sand	N/A
ENV28	66	29.7	70.3	0.0	Poor	Muddy sand	N/A
ENV29	48	37.2	62.8	0.0	Poor	Muddy sand	0.61
ENV30	91	20.4	79.6	<0.1	Poor	Muddy sand	N/A
ENV31	99	23.2	76.8	0.0	Poor	Muddy sand	0.35
ENV33	111	18.7	81.3	0.0	Poor	Muddy sand	N/A

Station	Mean Diameter (µm)	Fines (%)	Sand (%)	Gravel (%)	Sorting	Modified Folk Classification	Total Organic Carbon (%) *
ENV34	73	25.3	74.6	0.1	Poor	Muddy sand	N/A
ENV35	102	24.4	75.6	<0.1	Very poor	Muddy sand	N/A
ENV36	107	16	84	<0.1	Poor	Muddy sand	0.62
ENV53	270	2.5	95.1	2.4	Moderately well	Slightly gravelly sand	0.17
ENV57	194	1.7	98.3	<0.1	Moderately well	Sand	N/A
ENV58	228	1.7	98	0.3	Moderately well	Sand	0.16
ENV59	350	1.1	98.8	0.1	Moderately well	Sand	N/A
Summary Statistics							
Minimum	41	1.1	54.8	0.0	Very poor to moderately well	Muddy sand to sandy gravel	0.16
Maximum	1813	45.2	98.8	38.6	Very poor to moderately well	Muddy sand to sandy gravel	0.77
Mean	248	18.5	78	3.4	Very poor to moderately well	Muddy sand to sandy gravel	0.40
Standard Deviation	371	12.2	12.3	9.2	Very poor to moderately well	Muddy sand to sandy gravel	0.43

* TOC was analysed via chemistry samples acquired at nine sample stations. Therefore, N/A indicates where TOC was not analysed

3 Total Organic Carbon

3.1 Overview

3.1.1.1 TOC is expressed as a percentage of the total weight and represents the carbon constituent of organic matter. The primary components of organic matter in marine sediment are detrital matter, naphthenic material (e.g., carboxylic acids) and humic substances with a small proportion of biological biomass. In general, for continental shelf sediment there is a close relationship between organic carbon content and the surface area of the mineral matrix (Mayer, 1994[6]). Increased TOC is expected with the presence of fine sediment, as it adsorbs to the increased surface area provided by the fine grain particles.

3.2 Caledonia South Site

3.2.1.1 A site-specific survey found that across the Caledonia South Site, TOC concentrations ranged from 0.23% at Station ENV07 to 1.10% at ENV21, where the mean TOC value was 0.49%. Station ENV21 was identified as a high outlier, also reporting the highest fines content. In the Caledonia South Site, these TOC values were expected considering the general predominant sand component of the sediment (see Table 2-1). This was supported by results where TOC concentration was positively correlated with the volume of fines across the Caledonia South Site.

3.3 Caledonia South OECC

3.3.1.1 A site-specific survey found that across the Caledonia South OECC, TOC concentrations ranged from 0.16% at Station ENV58 to 0.77% at Station ENV26, where the mean TOC value was 0.39% and there was a positive correlation with water depth. Similar to the Caledonia South Site, these TOC values were expected in the Caledonia South OECC considering the general predominant sand and muddy sand components of the sediment (see Table 2-2). This was supported by results where TOC concentration was positively correlated with the volume of fines across the Caledonia South OECC.

4 References

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[3] Moray Offshore Renewables Limited (2012) 'Moray East OWF Environmental Statement (Volume 2, Chapter 4: Biological Environment Baseline)'. Available at: https://marine.gov.scot/sites/default/files/chapter_4_-_biological_environment_baseline.pdf (Accessed 30/05/2024)

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[6] Mayer, L.M. (1994) 'Surface area control on organic carbon accumulation in continental shelf sediments'. Geochimica et Cosmochimica Acta 58: 1271-84

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