Characterising shallow subsurface variability in the UK North Sea: a regional analysis using geotechnical records

Marine Geoscience programme

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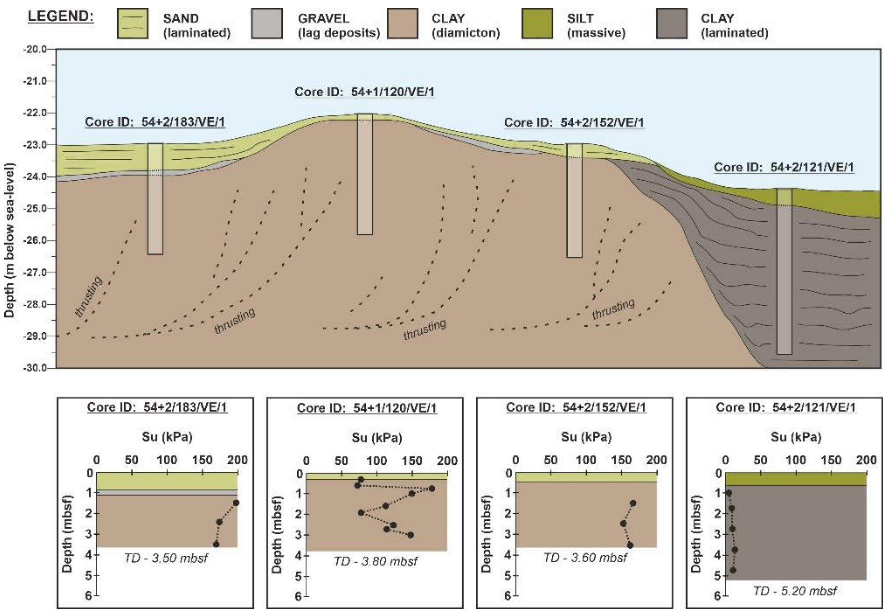

BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCE PROGRAMME

Characterising shallow subsurface variability in the UK North Sea: a regional analysis using geotechnical records

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Conceptual cross-section along a cable route in the UK North Sea

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Foreword

This report is the published product of a collaborative study by the British Geological Survey, Durham University and University of Dundee, funded by the Engineering and Physical Sciences Research Council (EPSRC) under grant EP/W000954/1, EP/W000970/1 and EP/W000997/1. The overarching aim of the project is to address the critical question regarding burial for the offshore cable industry: how deep is deep enough?

A previous report (OR/24/031; *Johnson et al., 2024*) provided a baseline statistical assessment of shallow subsurface conditions across the North Sea. That study evaluated the prevalence of layered soils within typical cable burial depths (<6 m below seabed) and identified the most common layering combinations (e.g., sand-over-clay). These findings highlighted the limitations of current Cable Burial Risk Assessment (CBRA) methodologies, which largely assume homogeneous soil profiles.

This report builds on that foundation by structuring and standardising geotechnical records from multiple sources within a consistent, layer-based framework. This enables more reliable and spatially resolved analysis of shallow subsurface variability across the UK North Sea, extending beyond the primarily statistical assessment presented in the earlier report. The analyses presented here strengthen the evidence base for improved CBRA approaches and provide a structured basis to support the physical and numerical modelling work packages within the EPSRC project.

Acknowledgements

This report was produced as part of the UKRI EPSRC grant EP/W000954/1 *"Offshore Cable Burial: How deep is deep enough?"*. We gratefully acknowledge the continued support and collaboration of our academic partners, Durham University (EP/W000970/1) and University of Dundee (EP/W000997/1), whose expertise and input have been invaluable throughout this project.

Special thanks go to Professor David White (University of Southampton) for his guidance and leadership as Chair of the Industry Steering Group, ensuring the study remained focused and aligned with industry needs. We also extend our appreciation to the industry partners - Ørsted A/S, Cathie Group, Arup, Lloyds Register, Global Marine Group, The Crown Estate, and First Marine Solutions who form the project steering group for their engagement and practical insights. Their contributions have been instrumental in shaping the direction and relevance of this research.

Riccardo Arosio is thanked for his valuable internal review and constructive feedback, as is Gareth Carter for his role in supporting the original project development and his guidance as initial project lead and member of the steering group. Kirstin Johnson, Raushan Arnhardt, Kingsley Ezenwaka, Torin Hughes and Ben Murphy are thanked for their contributions to the database.

We acknowledge The Crown Estate and Crown Estate Scotland for provision of data via the Marine Data Exchange.

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Summary

Subsea power and telecommunications cables are critical offshore infrastructure, commonly protected through burial within the upper few metres of seabed. Determining appropriate burial depths, and managing anchor-related damage risk, therefore depends on an accurate understanding of shallow subsurface conditions. Current Cable Burial Risk Assessment (CBRA) workflows typically simplify the seabed into vertically homogeneous soil units (e.g. sand or clay), despite evidence that shallow stratigraphy is frequently layered and geotechnically variable.

This report presents an expanded regional assessment of shallow subsurface conditions across the UK North Sea. Building on earlier work (*Johnson et al., 2024*), geological and geotechnical records from the British Geological Survey (BGS) and the Crown Estate Marine Data Exchange (MDE) have been restructured and standardised within a consistent layer-based framework, increasing the dataset to over 12,000 records. The resulting database enables direct comparison of lithological and geotechnical data information across previously heterogeneous data sources, provides improved spatial coverage, particularly in nearshore and actively developed regions, and supports the mapping of layered soils, coarse deposits, organic-rich sediments and shallow bedrock within the upper 2 metres below seabed (mbsb) presented in this report.

The results demonstrate that layered soils are a dominant characteristic of the shallow subsurface across the UK North Sea. Approximately three-quarters of sites penetrating at least 2 mbsb contain two or more lithological units within this interval, indicating that vertically variable ground conditions are more common than homogeneous profiles. Most sites contain one to three distinct layers, with sand-over-clay representing the most frequently encountered configuration. Clear regional contrasts are evident: the southern North Sea is generally characterised by extensive sand-dominated sediments, whereas the northern North Sea shows a more balanced distribution of sand- and clay-dominated profiles, often with marked internal variability. Coarse deposits occur widely but are most commonly present as thin gravel veneers, whilst thicker gravel layers and shallow bedrock are more localised, particularly in nearshore areas, where they may represent potential burial-limiting conditions. Peat and organic-rich soils are comparatively rare but occur predominantly in the southern North Sea, commonly beneath thin sand veneers where they are not readily identifiable from seabed sediment mapping alone.

These features can influence trenching performance, achievable Depth of Lowering (DoL), and anchor penetration behaviour, highlighting the limitations of representing the seabed as a single homogeneous soil profile within CBRA workflows which can lead to over- or under-conservative burial estimates. The structured dataset used in this report provides a consistent framework for incorporating more complex ground conditions into regional-scale assessments and supports both the physical and numerical work packages of the EPSRC project. In addition, the resulting analyses provide an evidence base for early-stage route planning and risk screening, in line with the Crown Estate's Cable Route Identification and Leasing Guidelines, while providing a foundation for future work aimed at improving the representation of shallow subsurface variability within offshore engineering assessments.

1 Introduction

Subsea cables are critical global infrastructure, with more than 95% of international digital data transferred through over 400 subsea fibre-optic cables spanning approximately 1.8 million km of the seafloor (*Clare et al., 2023; Burnett and Carter, 2017; Carter et al., 2009*). Power cables supporting offshore renewable energy developments are equally important for achieving Net Zero targets (*DESNZ, 2024*). However, these assets remain vulnerable to external damage, particularly from fishing activity and ship anchor strikes, which account for approximately 85% of reported cable faults (*Clare et al., 2023; Carter et al., 2009*). Industry guidance typically mitigates these risks through cable burial to depths of less than 5 metres below seabed (mbsb), generally assuming that soil cover will prevent anchors from reaching the cable (*The Carbon Trust, 2015*). Determining appropriate burial depths therefore depends on an accurate understanding of shallow ground conditions. Current Cable Burial Risk Assessment (CBRA) practice commonly represents the seabed as a single homogeneous soil unit (e.g. sand or clay), despite evidence that layering, variations in density, and changes in shear strength can strongly influence anchor penetration behaviour.

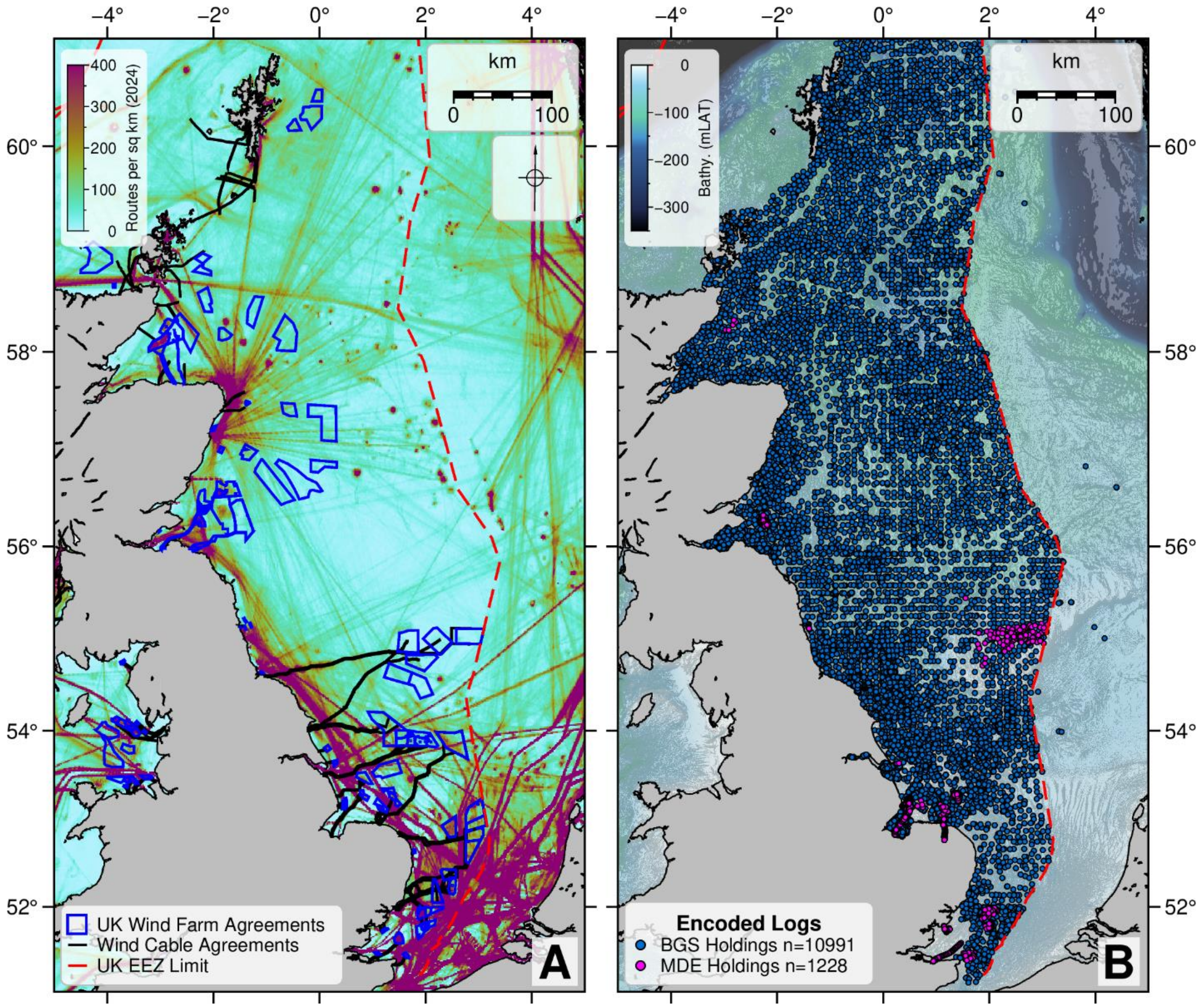


Figure 1 (A) AIS-derived shipping density across the UK North Sea (EMODnet Human Activities, 2026), shown with existing UK offshore windfarm and cable agreements (Crown Estate Scotland, 2026a, 2026b; The Crown Estate, 2026a, 2026b) and the UK Exclusive Economic Zone (EEZ) limit. **(B)** Integrated dataset of shallow geotechnical logs used in this study, combining digitised BGS holdings (British Geological Survey, 2024) with a subset of the Marine Data Exchange (© The Crown Estate, 2025; © Crown Estate Scotland 2022) holdings. These data provide the spatial foundation for all subsequent analyses. Contains Crown Estate and Crown Estate Scotland data (Marine Data Exchange). Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

Understanding this variability requires geological and geotechnical datasets capable of characterising subsurface conditions at regional scales. Improved regional understanding of shallow subsurface variability has therefore become a priority for offshore infrastructure development. This is reflected in the Crown Estate's Cable Route Identification and Leasing Guidelines (*The Crown Estate, 2024*), which emphasise the need for early identification of geological constraints, and in national-scale data requirements outlined by *Finlayson et al. (2025)*, such as soil variability, shallow bedrock, and problematic ground conditions. Together, these requirements highlight the importance of consistent, spatially extensive geological datasets to support early-stage decision-making. **Figure 1A** shows AIS-derived shipping density across the UK North Sea, overlain with existing offshore wind farm (OWF) and cable agreements, illustrating the intensity of marine activity in areas targeted for future subsea infrastructure development.

To address these challenges, the British Geological Survey (BGS) compiled and analysed a large, spatially distributed set of shallow geological and geotechnical records from across the UK North Sea (**Figure 1B**). The dataset comprised both legacy survey data and more recent site-specific investigations from both the BGS Offshore Geoindex and the Crown Estate Marine Data Exchange. The following sections describe the structure of the integrated dataset, the methods used to standardise and encode lithological and geotechnical information, and the resulting analyses of shallow subsurface variability across the UK North Sea.

This report builds on the findings presented in "*Layered Soils in the Shallow Subsurface (<6.0 m), North Sea; A Data Report*" (*Johnson et al., 2024; BGS Open Report OR/24/031*), which demonstrated the widespread occurrence of layered soils and identified common lithological combinations using the extensive archive of BGS core data. The study was primarily statistical in nature and limited by the heterogeneity of the input data. To address these limitations, the dataset was integrated with additional datasets from the BGS, as well as more recent site investigation data from the Crown Estate Marine Data Exchange, and systematically standardised lithological and geotechnical information within a unified database framework. This enables more consistent comparison across previously heterogeneous data sources and supports spatially resolved analysis of shallow subsurface variability across the UK North Sea. The report moves beyond a purely statistical description of layering by using a structured dataset to support the analysis and generate maps presented here for regional characterisation and application within CBRA workflows.

This work was undertaken as part of the Engineering & Physical Sciences Research Council (EPSRC) funded project "*Offshore Cable Burial: How deep is deep enough?*" (EP/W000954/1, EP/W000970/1, EP/W000997/1). The project is a collaboration between the British Geological Survey (BGS), Durham University and the University of Dundee, supported by industry partners Ørsted, Cathie Group, Arup, Global Marine Group, Lloyds Register, First Marine Solutions and the Crown Estate.

2 Methodology

2.1 DATASET

The dataset used in this study comprises 12,219 shallow geological and geotechnical records from across the UK North Sea (**Figure 1B**), sourced from the BGS Offshore GeoIndex and the Crown Estate Marine Data Exchange repositories (**Figure 2**). It incorporates the shallow core archive used in a prior Open Report by *Johnson et al., 2024*, and is expanded through the inclusion of the additional BGS and Marine Data Exchange records, increasing both the spatial coverage and volume of available data. The integrated dataset forms the basis for all subsequent analyses presented in this report.

The source data spans a wide range of acquisition methods, investigation objectives, logging conventions and data formats. Much of the BGS archive is derived from scanned handwritten logs, some dating back to the 1950s, whereas the Marine Data Exchange contains data from numerous offshore site investigations undertaken by different contractors (**Figure 2**). Consequently, the data exhibits considerable variability in file formats (e.g., PDF, Excel, AGS, shapefiles), metadata structure and terminology (*Bow et al., 2023*). To enable consistent analysis, all records were digitised and reorganised into a standardised unit-based format that captures lithological unit boundaries, thicknesses and associated geotechnical attributes. The methods used to structure and encode these data are outlined in **Section 2.2**.

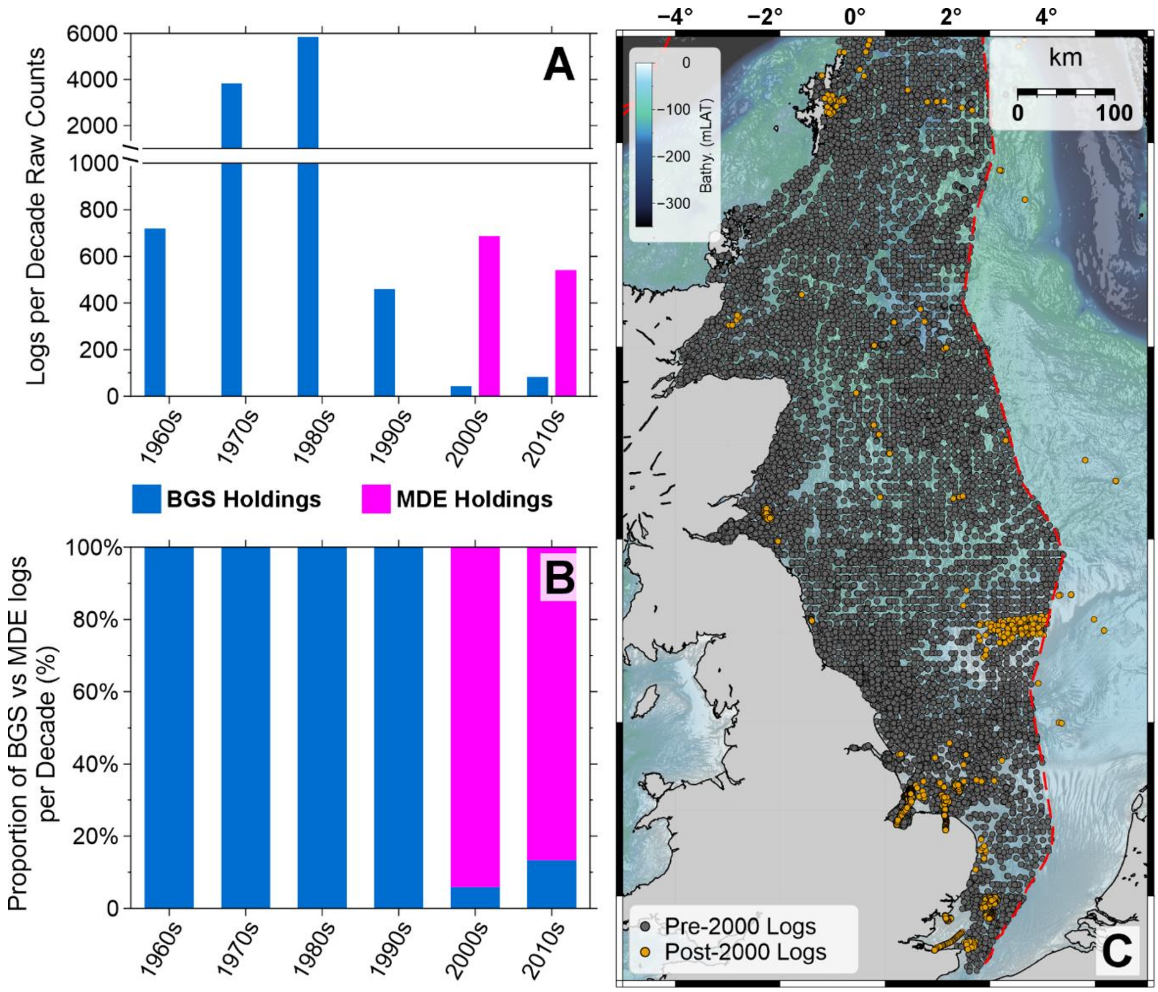


Figure 2 **(A)** Number of geotechnical investigation logs per decade, separated into BGS legacy holdings and Marine Data Exchange (MDE) data holdings (© The Crown Estate, 2025; © Crown Estate Scotland 2022). **(B)** Proportion of BGS and MDE log holdings by decade. **(C)** Spatial distribution of pre-2000 and post-2000 site investigation locations. Legacy (pre-2000) sites are broadly distributed across the UK North Sea, whereas post-2000 sites form concentrated clusters in areas of recent offshore wind development. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

The dataset includes a range of investigation types, comprising 10,607 shallow cores (e.g., gravity cores and vibrocores), which typically sample the upper 0-6 mbsb, together with 1,024 Boreholes and Cone Penetration Tests (CPTs) that commonly extend to greater depths (**Figure 3**). A smaller number of additional investigation types (n=526), including box cores, trial pits and piston cores are represented. Collectively, these data provide a combination of regionally distributed observations and more concentrated site investigations associated with offshore developments.

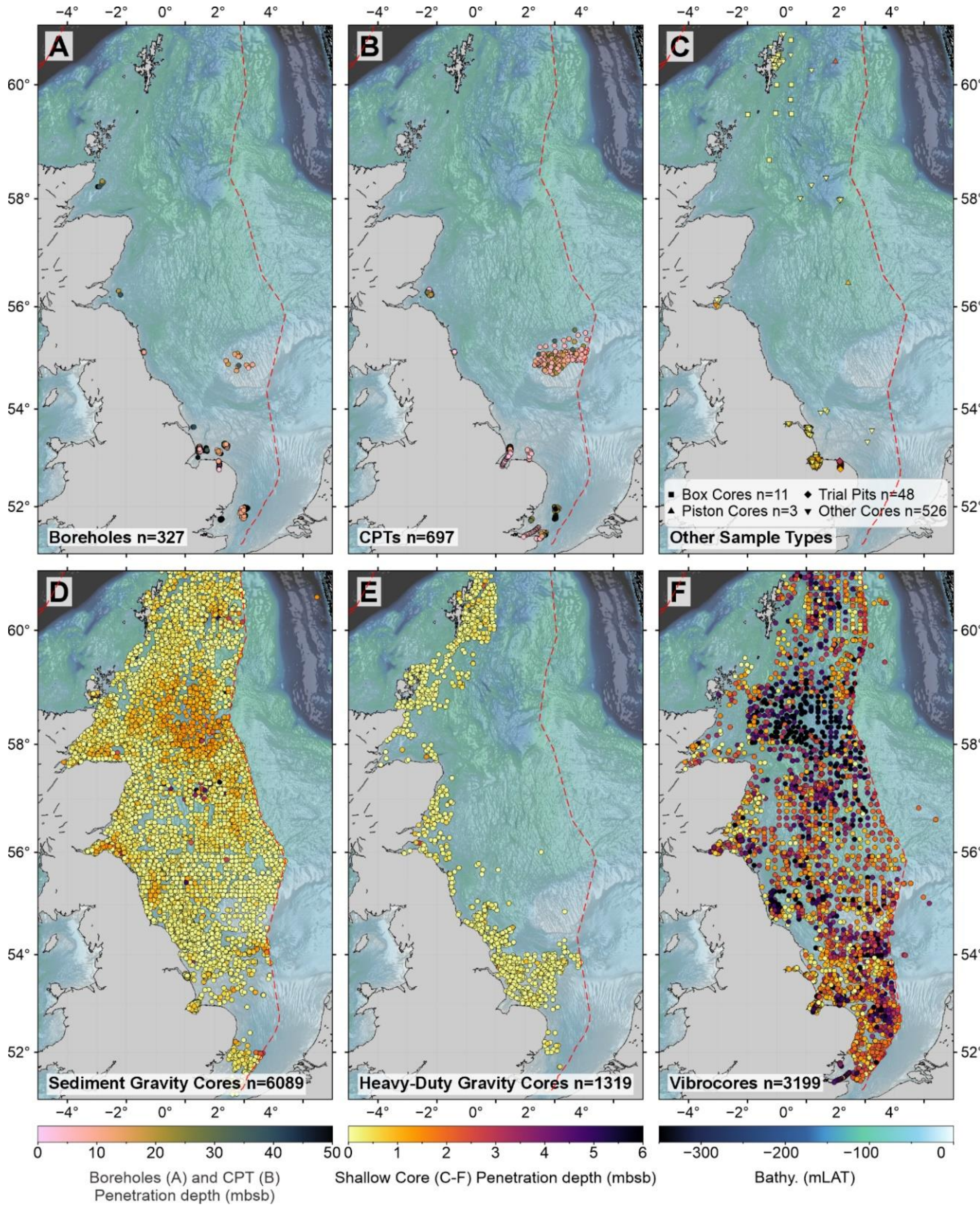


Figure 3 Spatial distribution of the main geotechnical investigation types in the integrated dataset across the UK North Sea. **(A)** Boreholes, **(B)** Cone Penetration Tests (CPTs), **(C)** box cores, trial pits and other minor sample types, **(D)** sediment gravity cores, **(E)** heavy-duty ("rock") gravity cores, and **(F)** vibrocores (© British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022). Panels illustrate the differing survey footprints and depth capabilities of each method. Note different ranges for penetration depths between Boreholes and CPTs vs all other sample types ("shallow cores"). Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

Penetration depths vary considerably between investigation types. Boreholes and CPTs typically extend beyond 20-30 mbsb, whereas shallow coring methods generally recover only the upper 1-6 mbsb. When aggregated spatially (**Figure 4**), median penetration depths remain relatively shallow across much of the UK North Sea. As a result, the dataset is inherently weighted toward near-surface conditions, and subsequent analyses are constrained by the depth range and continuity of available data. Depth intervals were therefore selected to maximise spatial coverage, whilst retaining a sufficiently large number of sites for robust analysis.

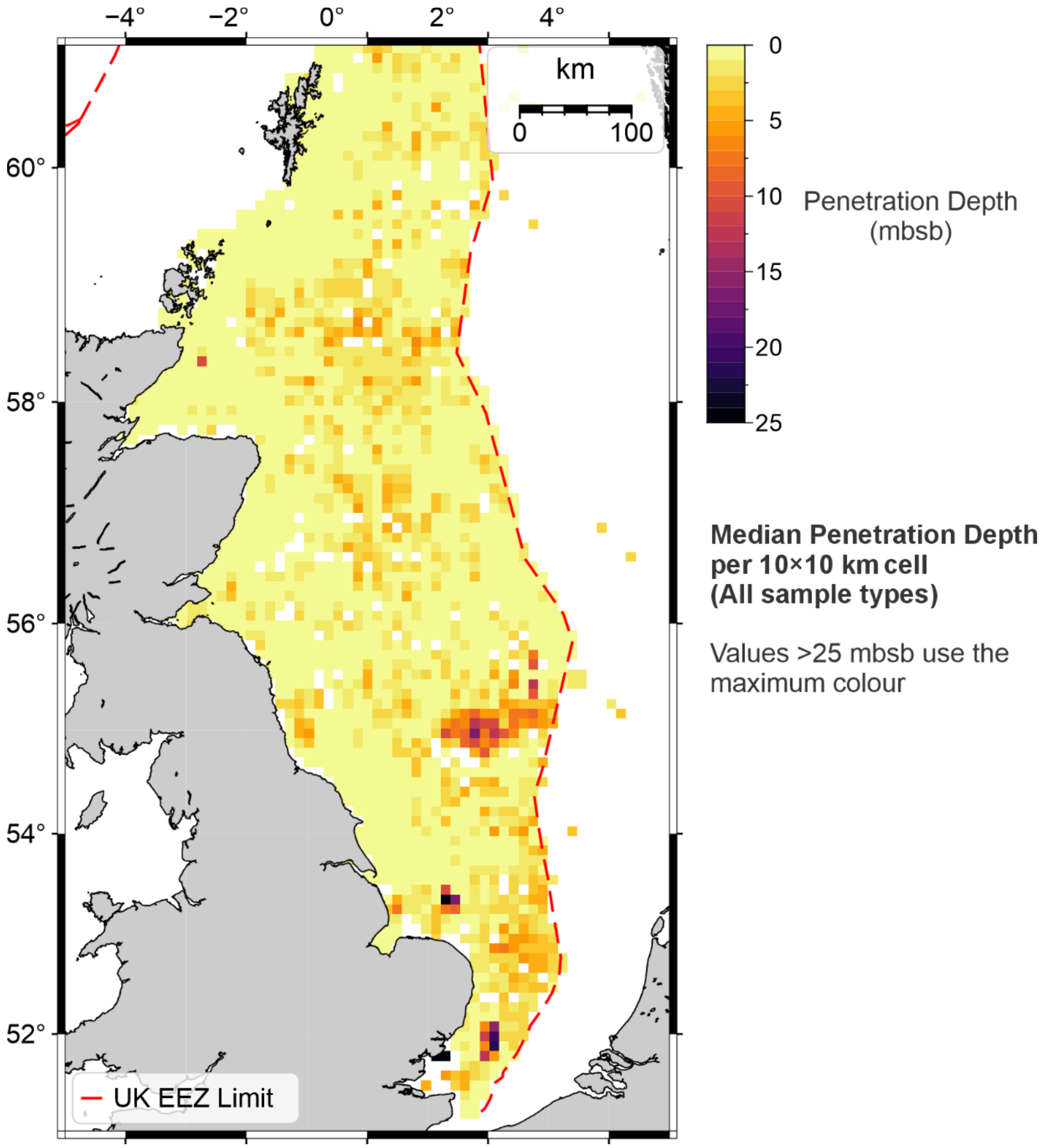


Figure 4 Median penetration depth of all shallow geotechnical investigations in the dataset (© British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022), calculated within 10×10 km grid cells. Deeper values indicate areas with greater stratigraphic sampling (typically CPTs and boreholes), while shallower values reflect regions dominated by shallow cores only (shallow samples). Penetration depths above 25 m are shown using the maximum colour for clarity. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

2.2 DATABASE STRUCTURE

Geological and geotechnical information from all sources was organised within a unit-based database structure, in which each record is defined by discrete lithological units with associated depth intervals, thickness, and descriptive attributes. This framework enables observations from individual records to be represented in a consistent format, despite differences in original data format, acquisition method and logging style. Throughout this report, the term "log" refers to an individual geotechnical or geological investigation (e.g., core, borehole, or CPT), within which discrete lithological units (layers) are defined.

Figure 5 illustrates the diversity of source data within the dataset, ranging from handwritten geological logs and scanned records to structure borehole logs and CPT-derived interpretations.

Figure 6 summarises the workflow used to convert these heterogeneous logs into a standardised database structure. The process involved manually digitising source data, defining lithological unit boundaries, extracting descriptive information and assigning standardised attributes to each unit. This approach allows observations from multiple data sources to be integrated within a single analytical framework while preserving the original recorded descriptions.

The database structure builds upon that used by *Johnson et al., (2024)* but has been revised to provide a consistent representation of lithological and geotechnical information across all records. Refinements include the introduction of additional fields to capture bedrock weathering state and rock strength, together with clearer separation of descriptors for soil consistency and strength (cohesive soils), and density (granular soils). These refinements improve internal consistency and facilitate comparison between investigations while preserving the original descriptive information.

Lithological descriptions and geotechnical attributes were recorded using established classification schemes. Engineering soil descriptions follow British Standard *BS5930 (1999, 2015, 2020)*, while lithological coding is based on the BGS Rock Classification Scheme (*BGS, 2020*) and the Unlithified Deposits Coding Scheme (UDCS and UDCS-X) (*Cooper et al., 2006*). Where appropriate, Folk-based grain-size classifications (*Folk, 1954; Long, 2006*) were used to support sedimentological descriptions.

Primary and secondary lithologies were assigned from the original log descriptions and recorded without reinterpretation. Where attributes such as strength, density, or consistency were absent or ambiguously described, the relevant fields were left blank rather than inferred. Examples of the database structure and associated dictionary tables are provided in **Appendix 1**. The resulting database structure allows lithological and geotechnical information to be aggregated over defined depth intervals (e.g. 0–2 mbsb) and used to derive summary metrics such as dominant lithology based on cumulative unit thickness.

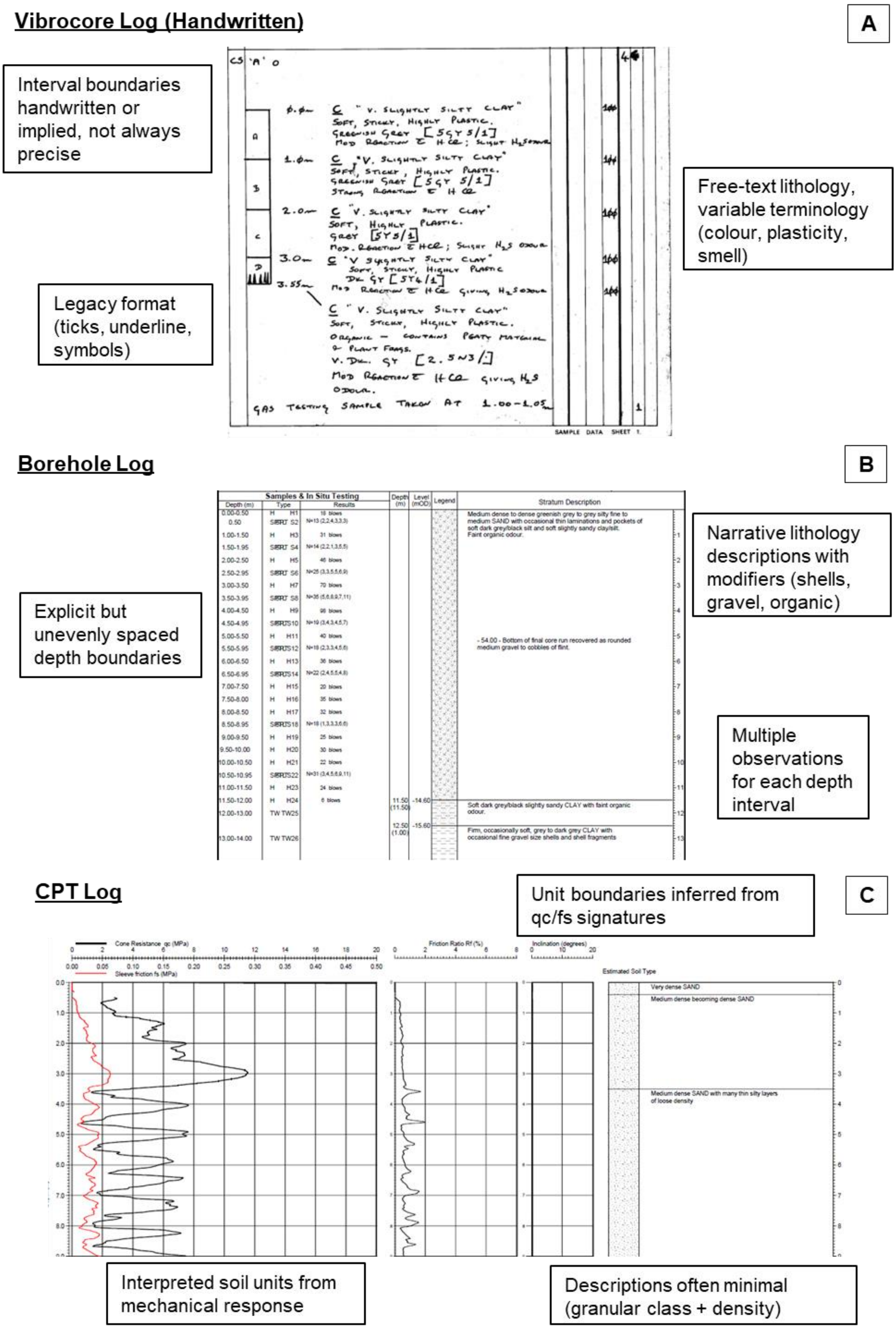
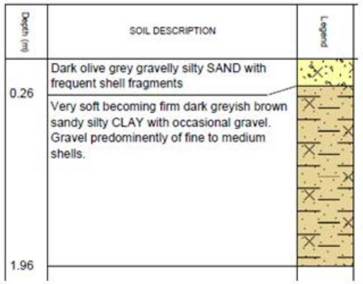


Figure 5 Examples of geological logs from BGS Offshore GeoIndex **(A)** and Marine Data Exchange (**B + C)** used as inputs to the offshore database (© British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022). **(A)** Vibrocore log showing handwritten lithology log with legacy notation and approximate depth intervals. **(B)** Borehole log with structured BS5930 stratum descriptions, multiple observations per unit, and explicit depth boundaries. **(C)** CPT log showing cone resistance and sleeve friction traces alongside interpreted soil units with minimal descriptive text. BGS © UKRI 2026.



Original log. Example from Gardline Geosciences (2010), Neart Na Gaoithe OWF Geotechnical Report downloaded from the MDE.

Unit Description

0 – 0.26m Dark olive grey gravelly silty SAND with frequent shell fragments
0.26-1.96m Very soft becoming firm dark greyish brown sandy silty CLAY with occasional gravel. Gravel predominantly of fine to medium shells.
1.96m End of vibrocore

Depth intervals and fill-text lithology extracted from logs. Inputs standardised to metres; multi-line descriptions merged.

Layer 1:
"gravelly silty SAND with shell fragments" = SAND + gravel + silt + shells

Layer 2:
"very soft to firm sandy silty CLAY with gravel/shells" = CLAY + sand + silt + gravel + shells + very soft to firm

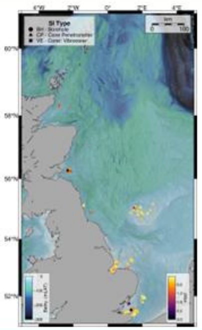
Apply BGS RCS lithology codes; identify modifiers; assign grain size; assign density/consistency

Top	Base	Primary Lithology	Modifiers	Consistency/Density	RCS
0.00	0.26	SAND	Silt + gravel + shells		SZVH
0.26	1.96	CLAY	Sand + silt + gravel + shells	Very soft to firm	CSZVH

Encoding into BGS Offshore Geotechnical Template. Note this is a subset of data for the purposes of this figure.

- Descriptions vary between operators/decades
- Density/consistency often missing
- Grain size sometimes ambiguous
- CPT units vary between contractors
- LEX & morphogenetic codes rarely assignable
- Organic/peat descriptors inconsistent
- Rockhead sometimes unclear

QC and limitations



Encoded outputs using standardised, analysable lithological units. Example map showing number of samples with a "loose surficial layer".

Figure 6 Example workflow illustrating the conversion of a raw geological log (© The Crown Estate, 2025; © Crown Estate Scotland 2022) into standardised lithological units. Depth intervals and full-text descriptions are extracted, normalised and merged; lithology, modifiers, density and grain size are assigned using BGS RCS codes; outputs undergo quality checks before being encoded into a template and used in to generate maps presented in this report. BGS © UKRI 2026.

2.3 LIMITATIONS

The dataset provides a robust basis for regional assessment of the shallow subsurface conditions across the UK North Sea. However, it is not intended to replace site-specific ground investigations and should be used as a regional-scale evidence base rather than a deterministic ground model.

The records span several decades, with site investigations ranging from the 1960s to 2016 (**Figure 2**). Penetration depths vary considerably between records (**Figure 4**), reflecting both the geological conditions and differences in investigation methods. Many sampling techniques were designed to recover only shallow intervals (i.e., ~1-6 mbsb), resulting in a dataset that is inherently biased towards near-surface conditions. In addition, the thickness and distribution of surficial sediments, particularly sands, may have changed over time as a result of sediment mobility, compared to the present-day seabed conditions at some locations.

The availability and quality of geotechnical information is also very variable. Many records lack quantitative measurements and instead rely on qualitative field descriptions or hand-test estimates, particularly with legacy datasets collected prior to the adoption of standardised reporting frameworks such as MEDIN (*Lewall et al., 2016*). Descriptions vary between operators, contractors, and decades, reflecting differences in investigation objectives, logging practices and reporting standards.

Additional uncertainty arises from differences in how lithological and geotechnical information were originally interpreted and recorded. Some legacy BGS logs contain relatively coarse or incomplete descriptions, while CPT-derived stratigraphic interpretations may reflect changes in mechanical behaviour rather than lithological variation. Variability in the use of descriptors for organic material, peat, weathered rock and rockhead, together with limited contextual information in some records, can also restrict the consistent application of stratigraphic or morphogenetic interpretation.

The dataset combines widely distributed regional observations with more concentrated site investigations, resulting in uneven spatial sampling density and variability in metadata completeness. No reinterpretation of lithological or CPT-derived stratigraphy has been undertaken, and all records retain the original interpretations provided in the source logs. These limitations are inherent to the dataset and should be considered when interpreting spatial patterns or derived metrics.

3 Results

The following sections describe the distribution and characteristics of the shallow subsurface lithological units across the UK North Sea, based on the compiled and structured database. All analyses focus primarily on the upper 2 mbsb, as this interval provides the most spatially extensive and consistently sampled coverage across the dataset, while remaining directly relevant to offshore cable burial and soil-structure interaction processes including anchor penetration and trenching.

3.1 SHALLOW SUBSURFACE CHARACTERISTICS

3.1.1 Number of layers

The distribution of layer counts within the upper 2 mbsb indicates that layered stratigraphy is the dominant shallow subsurface condition across the UK North Sea (**Figure 7**). Of 2,903 logs extending to ≥2 mbsb penetration depth, 77% contain two or more lithological layers, whereas only 23% comprise a single homogenous unit. Most profiles contain between one and three distinct layers (n=2626), with two-layer profiles being the most common (n=1379) (**Figure 7A**). Higher layer counts (≥4 layers) occur less frequently (n=277), representing only a small proportion of the dataset.

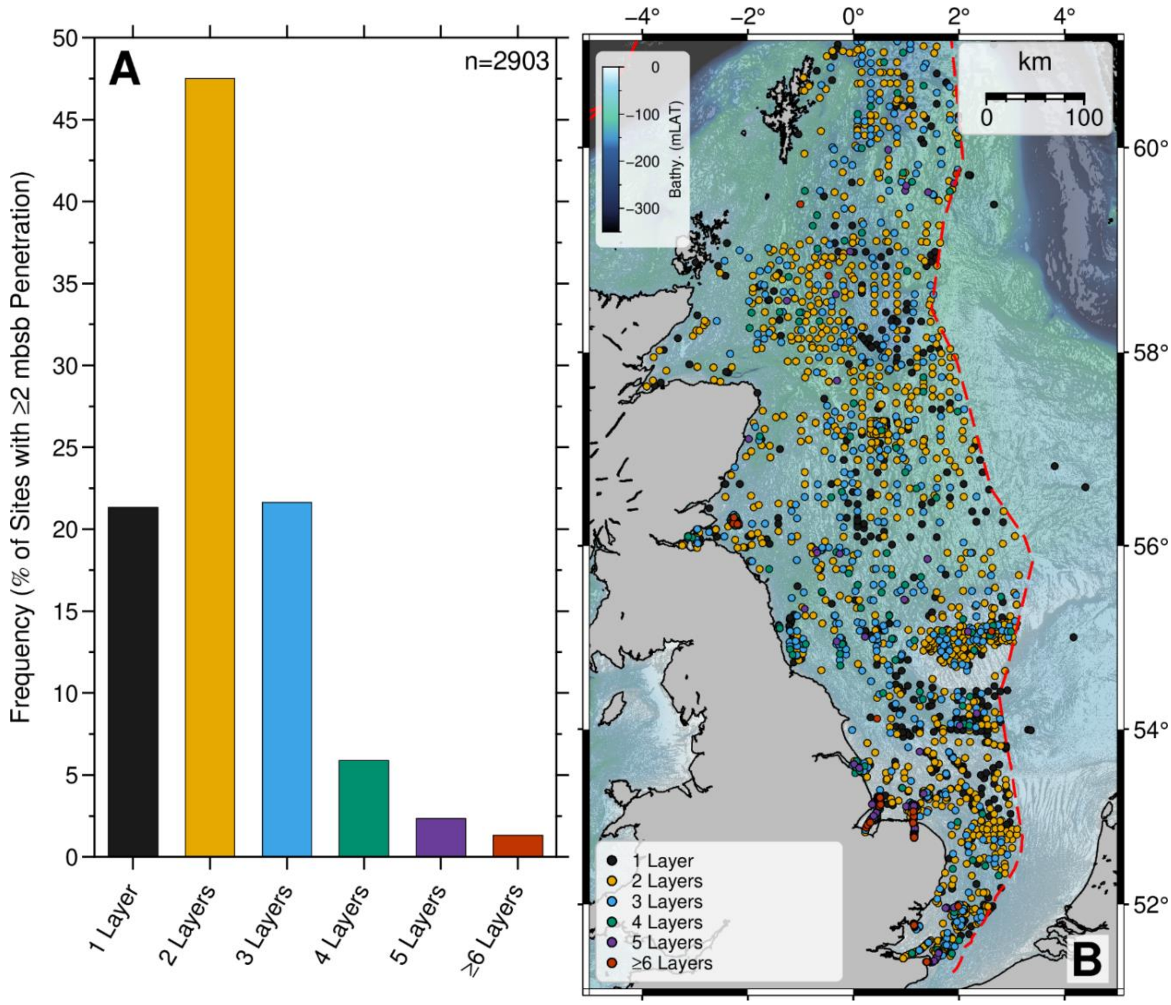


Figure 7 **(A)** Frequency of geotechnical layers within the upper 2 mbsb, based on all sites with ≥2 mbsb penetration depth (n=2903 sites). Most investigations contain one to three distinct layers. **(B)** Spatial distribution of layer counts: higher layer counts highlight areas with more variable shallow stratigraphy, whereas single-layer sites are associated with more uniform surficial sediments. Only sites with ≥2 mbsb penetration depth are shown. Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

Despite their lower frequency, profiles with ≥4 layers exhibit a distinct spatial distribution (**Figure 7B**). Areas characterised by higher layer counts are concentrated within coastal regions and offshore development zones, indicating greater shallow stratigraphic complexity. In contrast, broad areas of the UK North Sea are dominated by one- or two-layer profiles, reflecting comparatively simple shallow sediment sequences within the upper 2 mbsb. Overall, the mapped distribution demonstrates regional variation in shallow subsurface heterogeneity. While relatively simple profiles dominate much of the study area, more complex layered sequences occur locally, highlighting the potential for significant small-scale variability in shallow ground conditions.

3.1.2 Dominant Lithology

Across the UK North Sea, the shallow subsurface (0–2 mbsb) exhibits a broadly even distribution of sand- and clay-dominated conditions (**Figure 8**). Dominant lithology is defined here as the primary lithology (defined by UDCS/RCS code begins with "S" (sand) or "C" (clay)) accounting for more than 50% of the total unit thickness within the 0-2 mbsb interval for an individual log.

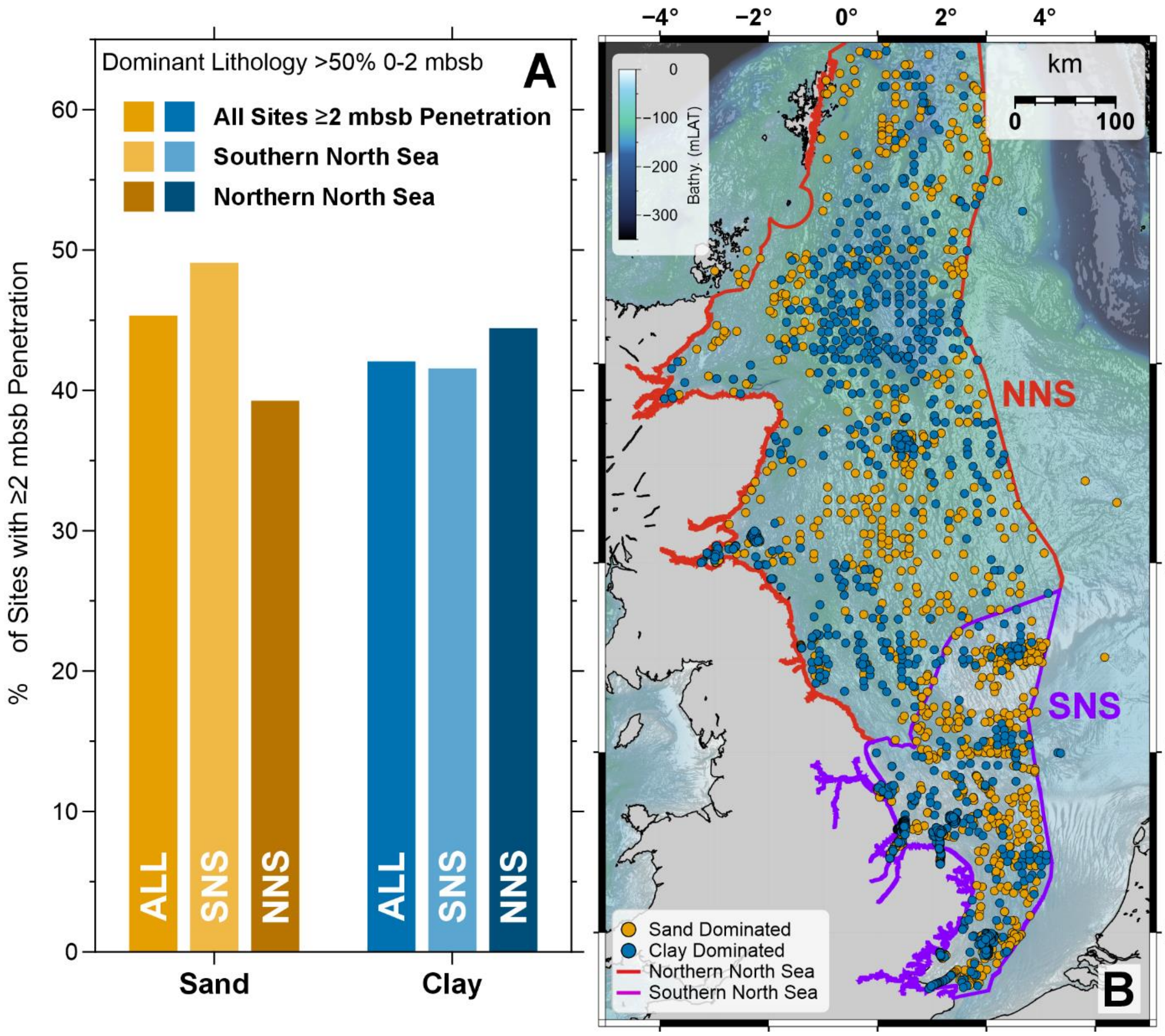


Figure 8 Distribution of sand- and clay-dominated lithologies within the upper 0-2 mbsb across the UK North Sea. **(A)** Proportion of logs with full 0–2 mbsb coverage classified as sand- or clay-dominated for all sites, and separately for the Southern North Sea (SNS) and Northern North Sea (NNS). Dominance is defined as a lithology ("S" (sand) or "C" (clay)) comprising >50% of the 0–2 mbsb interval. **(B)** Spatial distribution of dominant lithology (sand = amber; clay = navy) separated by regional outlines (SNS = red; NNS = cyan). Note: other lithologies can occur within the 0-2 mbsb interval and may overlap with areas of bedrock. Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

Of all logs containing a complete record from 0 to 2 mbsb penetration, just over half are classified as sand-dominated (n=1316; 52%), whereas slightly fewer exceed the >50% threshold for clay (n=1222; 48%). Regional differences are evident however, with the southern North Sea (SNS) showing a higher proportion of sand-dominated sites relative to the northern North Sea (NNS). In contrast, clay-dominated sites slightly outnumber sand-dominated sites in the NNS, resulting in a more balanced distribution between the two lithologies.

These regional contrasts are reflected in the spatial distribution of dominant lithologies (**Figure 8B**). Sand-dominated sites occur extensively throughout the SNS and central North Sea (CNS), particularly across areas characterised by widespread superficial sand deposits. Clay-dominated sites are more common in the NNS and along deeper parts of the central trough. Despite these regional variations, neither lithology clearly dominates at the scale of the UK North Sea as a whole, indicating substantial spatial variability in shallow subsurface conditions.

This broadly balanced distribution of sand- and clay-dominated sites is consistent with previous regional observations (*Johnson et al., 2024*). The mapped distribution, and associated database, also highlights that many 0-2 mbsb intervals contain subordinate lithologies in addition to the dominant unit. For example, some locations coincide with sites where bedrock is encounter close to seabed (see **Figure 11** & **Figure 12**), emphasising the complexity that may be present in the shallow subsurface.

3.1.3 Coarse Deposits

The thickness and distribution of gravel-, cobble- and boulder-dominated units within the upper 2 mbsb show a clear predominance of very thin coarse veneers (**Figure 9**). All logs in which coarse material is recorded within the 0-2 mbsb interval are included in this analysis, irrespective of total penetration depth, ensuring that shallow records intersecting coarse units within this interval are retained. Coarse deposits are recorded at 1,355 sites (~11% of the total datasets). Across these logs, very thin coarse deposits (<0.2 m total thickness) are most common (n=1009; ~75%). Moderate-thickness coarse deposits (0.2–1 m thick, n=315; ~23%) occur less frequently, while thick coarse units (>1 m) are comparatively rare, (n=31 ~2%).

Coarse deposits are widely distributed across the UK North Sea, with higher concentrations observed in nearshore regions, particularly along the east coast of England, and around Orkney and Shetland (**Figure 9B**). Thin coarse veneers dominate across most mapped locations, whereas moderate to thick coarse deposits occur more locally. The predominance of thin coarse deposits is consistent with the patterns reported in *Johnson et al., (2024*), indicating that coarse material within the upper 2 mbsb is most commonly present as a thin surface or near-surface veneer rather than as laterally extensive thick units.

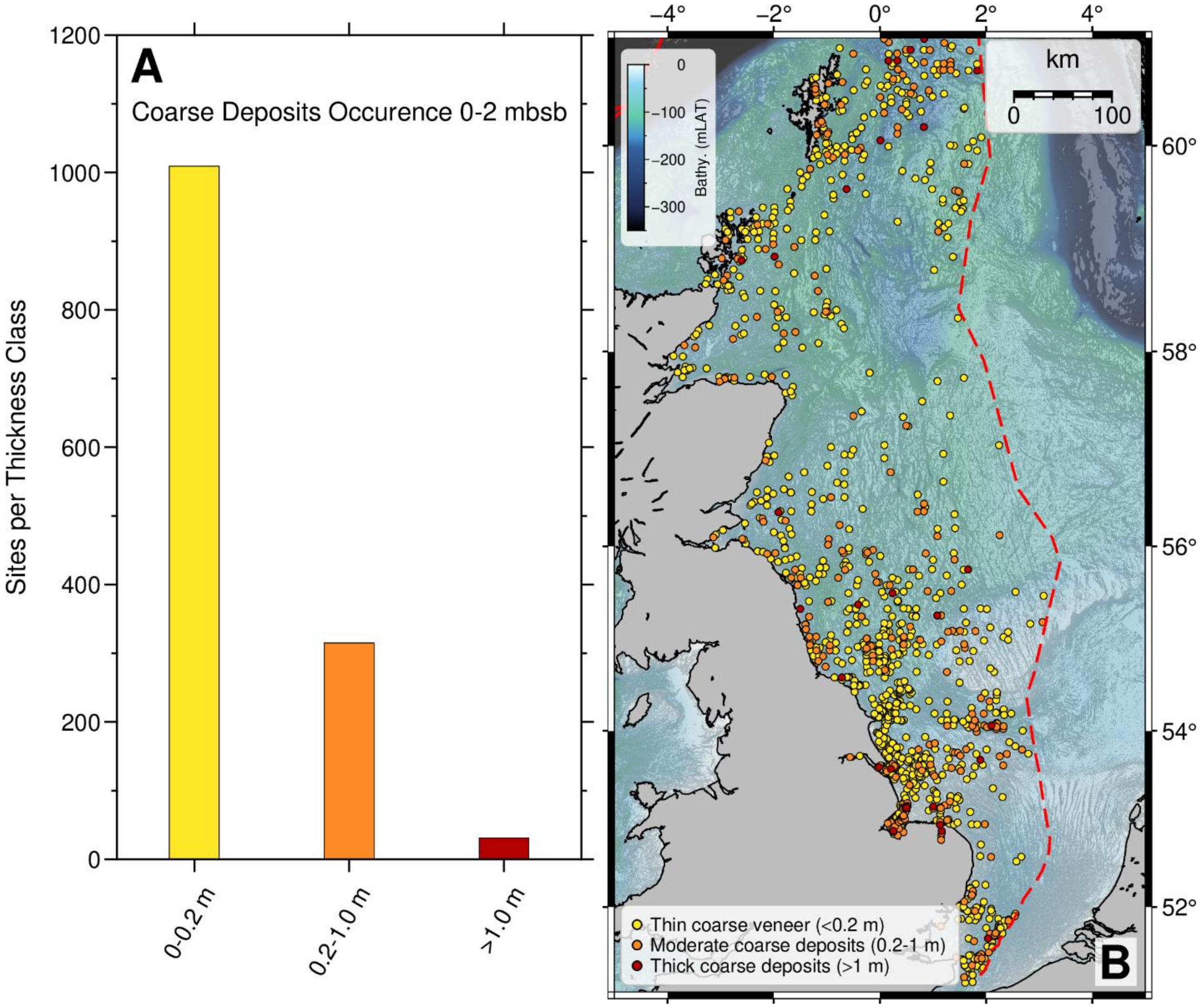


Figure 9 Distribution and thickness of gravel-, cobble- and boulder-dominated deposits within the upper 2 mbsb across the UK North Sea. **(A)** Number of sites grouped by total thickness of coarse-unit thickness within the 0-2 mbsb interval. Note: all sites are included where coarse material is intercepted within the 0-2 mbsb interval, regardless of total penetration depth. **(B)** Spatial distribution of coarse deposits classified as thin (<0.2 m), moderate (0.2–1 m), or thick (>1 m). Only units where coarse material is the primary lithology in the encoded UDCS classification are included. Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

3.1.4 Peat and organic-rich deposits

Peat and organic-rich deposits are relatively uncommon within the dataset, being recorded in only 89 logs (**Figure 10**). Within the upper 0-2 mbsb interval, these peaty deposits occur as thin veneers (<0.2 m thick; n=35), moderate-thickness layers (0.2-1 m; n=34) and less frequent thicker units (>1 m; n=20) (**Figure 10A**).

The spatial distribution of peat and organic-rich deposits is strongly concentrated within the southern North Sea (**Figure 10B**). Notable clusters occur along the East Anglian coastline, within the Outer Thames Estuary, and extend offshore to the Dogger Bank region. Outside these areas, occurrences are relatively sparse, indicating that organic-rich deposits form a minor but locally significant component of the shallow subsurface stratigraphy across the UK North Sea.

Lithological classifications indicate a range of organic-rich facies, including peat, peat mixed with mineral components, peaty-clay, peaty-sand, peaty-silt, and peaty-gravel (**Figure 10C**). Peat-dominant deposits are the most common sub-type (n=37), followed by peaty clay (n=23), peaty-sand (n=14), other peat mix (n=9) and peaty silt (n=6). This diversity reflects varying degrees of organic accumulation and mineral sediment incorporation within the shallow subsurface.

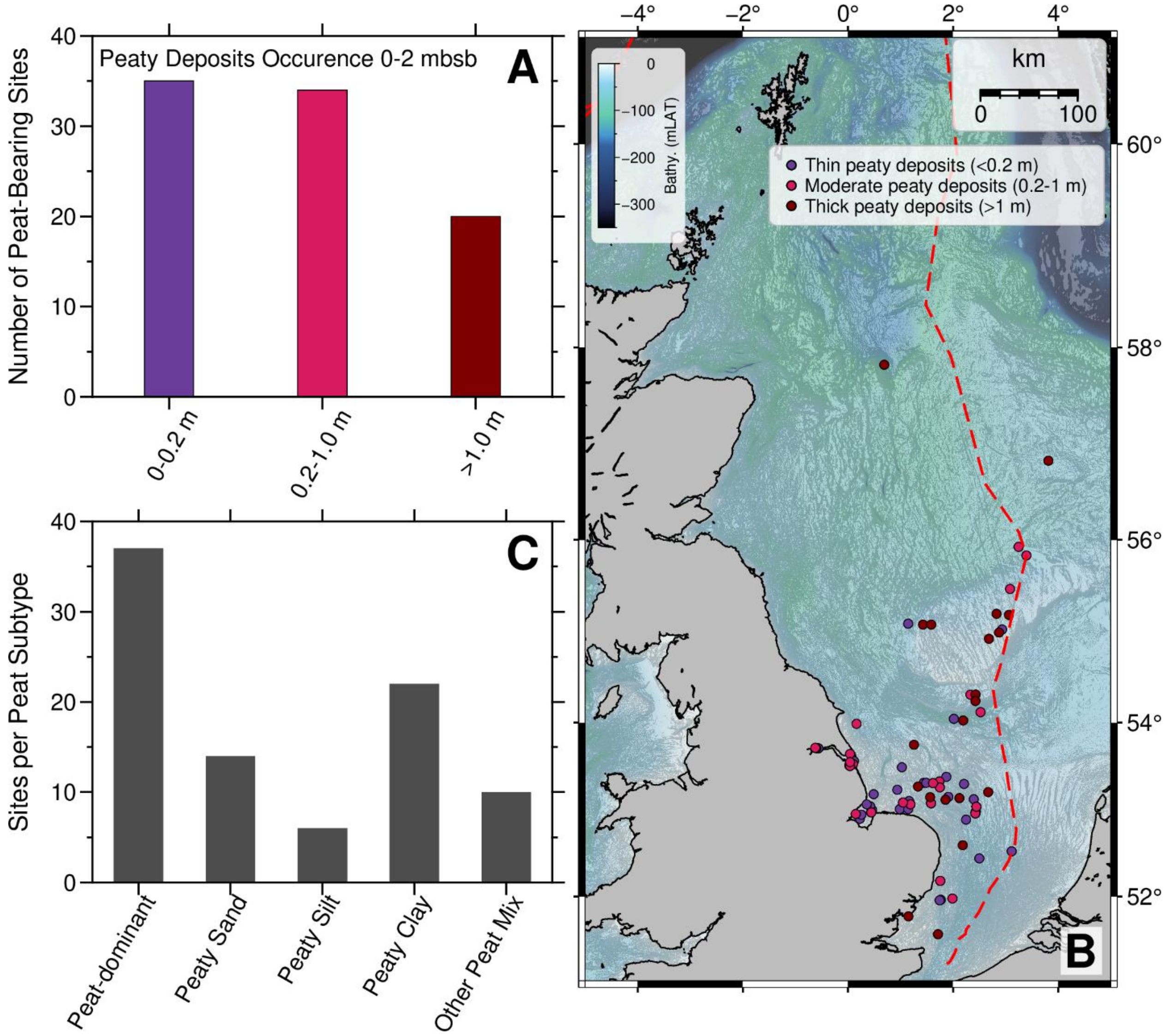


Figure 10 Distribution and thickness of peat and organic-rich deposits within the upper 2 mbsb across the UK North Sea. **(A)** Number of peat-bearing sites grouped by the total thickness of peat-containing units (i.e., where peat occurs anywhere within the UDCS code) within the 0–2 mbsb interval. **(B)** Spatial distribution of peat-bearing sites, classified as thin (<0.2m), moderate (0.2-1m) or thick (>1m). **(C)** Distribution of dominant peat subtypes at each peat-bearing site, classified from the encoded UDCS lithology (e.g. peat-dominant, peaty sand, silt or clay, and other peat mixtures). Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

3.1.5 Bedrock

Eight bedrock lithology groups are represented within the dataset, based on the BGS Rock Classification Scheme (RCS) (*BGS, 2020*) (**Figure 11**). Mudstone is the most frequently recorded bedrock type and occurs predominantly within the central and northern North Sea. Chalk is the second most common lithology, occurring primarily within the southern North Sea and along the margin of the Dogger shelf. Sandstones are also widely represented throughout the North Sea. Carbonate rocks (excluding chalk) occur less frequently and are largely restricted to nearshore settings. Igneous and metamorphic bedrock are recorded mainly around northern Scotland and Shetland, while diamictite is identified at a small number of sites. A final “other rock” category captures sites where bedrock lithology is insufficiently specified. The mapped distribution demonstrates that shallow bedrock is a widespread component of the near-surface stratigraphy across parts of the UK North Sea, although both its occurrence and lithological character vary considerably between regions.

The encoded lithological dataset identifies locations (n=733; 6% of total dataset) where bedrock is explicitly recorded within the 0-2 mbsb interval (**Figure 11**). All logs intercepting bedrock within this interval are included in this analysis, irrespective of total penetration depth so that shallow records intercepting bedrock within the near-surface are retained. Recorded bedrock occurrences within the upper 0-2 mbsb are concentrated along the western margin of the North Sea basin, extending from Shetland through the Moray Firth and into coastal areas off northeast England and the southern North Sea (**Figure 11B**).

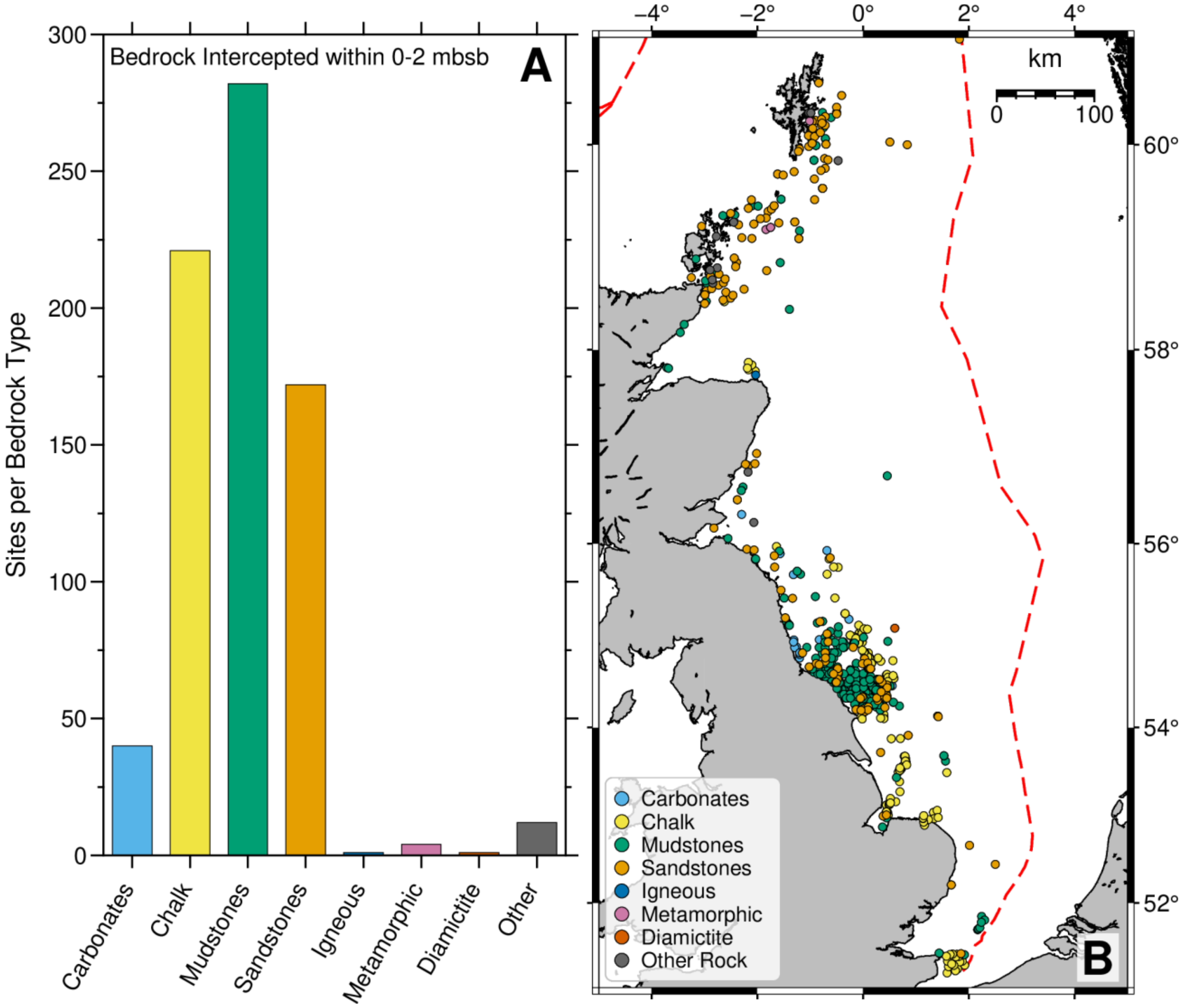
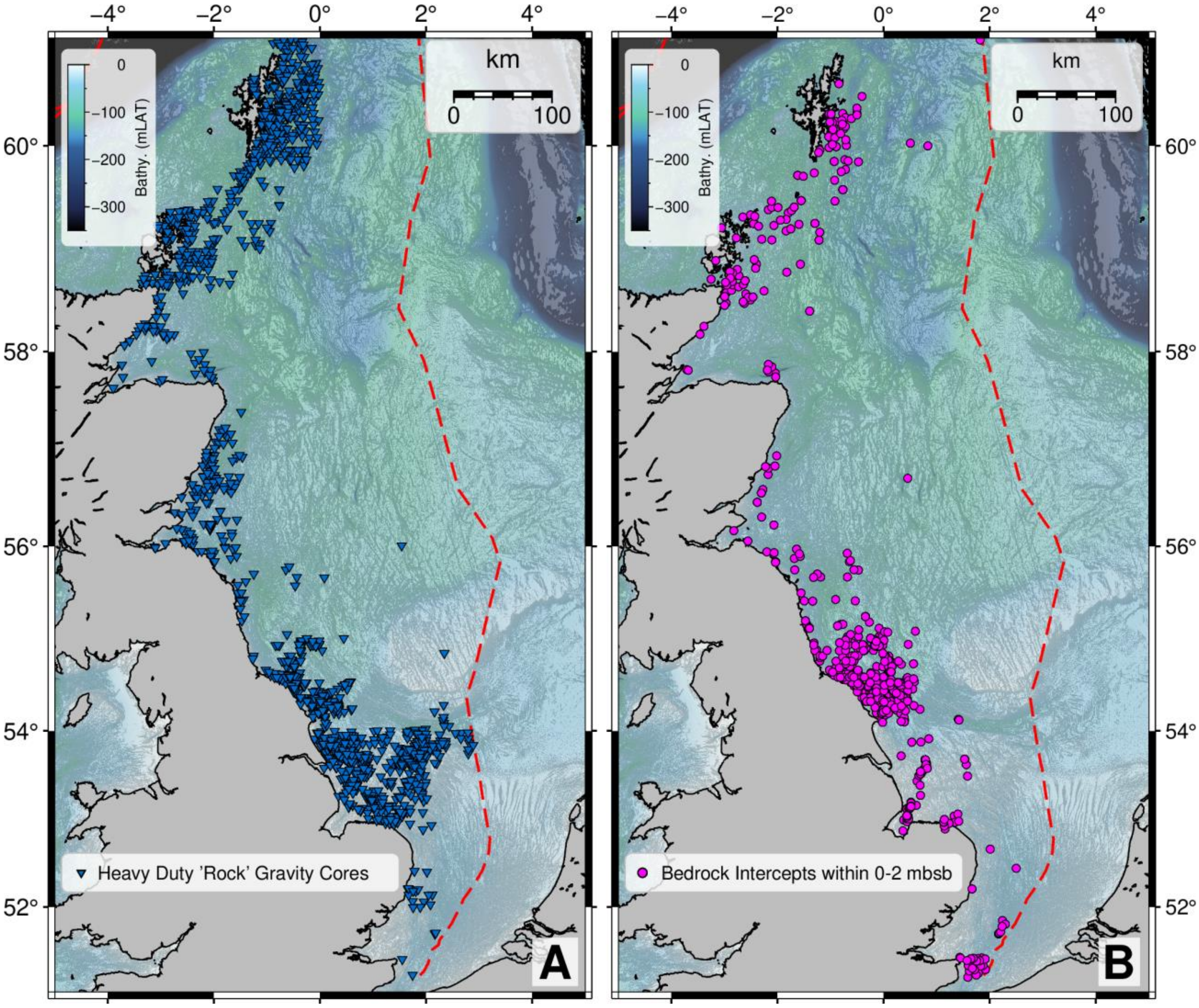


Figure 11 Distribution of bedrock types intercepted within the upper 0–2 mbsb across the UK North Sea. **(A)** Number of sites where each bedrock class is recorded, based on the shallowest bedrock unit encountered in each profile. **(B)** Spatial distribution of the shallowest bedrock intercept at each site, coloured by bedrock type (e.g., sandstone, mudstone, chalk, carbonate, igneous, metamorphic, diamictite, other rock). Bedrock classes follow the BGS Rock Classification Scheme (BGS, 2020). Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

Heavy-duty "rock" gravity corers have been deployed extensively across the North Sea, particularly in nearshore areas along the east coast of England, Scotland and the Orkney-Shetland Platform (**Figure 12A**). These investigations were typically targeted towards locations where very stiff substrate or bedrock is anticipated near the seabed. However, the distribution of these investigations reflects survey strategy rather than confirmed bedrock occurrence, and many cores did not encounter bedrock within the upper 0-2 mbsb.



<u>Figure 12</u> Comparison of heavy-duty "rock" gravity core locations and shallow bedrock intercepts across the UK North Sea. **(A)** Locations of heavy-duty gravity cores within the database. **(B)** Locations where bedrock is recorded within the upper 0–2 mbsb, showing only the shallowest bedrock intercept at each site. The red dashed line marks the boundary of the UK Exclusive Economic Zone (EEZ). Bathymetry (EMODnet multibeam) is shown for context to highlight the relationship between surficial morphology and areas of shallow rock. Contains © British Geological Survey, 2024; © The Crown Estate, 2025; © Crown Estate Scotland 2022 data. Coastline after Wessel & Smith (1996). BGS © UKRI 2026.

4 Discussion

The results presented in this report provide a regional characterisation of shallow subsurface variability across the UK North Sea, based on a large, consistently structured geological and geotechnical dataset. Building on previous assessments (*Macdonald et al., 2023*; *Johnson et al., 2024; Macdonald et al., 2025)*, the analyses demonstrate that the upper 2 mbsb is commonly heterogeneous, with layered stratigraphy representing the dominant condition.

The discussion focuses on regional-scale patterns within the upper 2 mbsb, constrained by the nature of the available data and the depth interval most relevant to cable burial, anchor penetration and other shallow soil-structure interaction processes. As the dataset comprises discrete geological and geotechnical observations rather than continuous spatial coverage, mapped distributions should be interpreted as indicators of regional trends rather than definitive representations of subsurface conditions at all locations.

Despite these limitations, the results reveal substantial vertical and lateral variability in lithology and material properties over relatively short distances, reflecting the combined influence of geological history, depositional processes and local environmental conditions. Understanding this variability is important for early-stage offshore planning and design, where assumptions regarding shallow ground conditions can influence route selection, site investigation strategy, and subsequent engineering assessments.

4.1 SHALLOW SUBSURFACE VARIABILITY IN THE UK NORTH SEA

A key finding of this study is that layered stratigraphy is the dominant condition within the upper 2 mbsb of the UK North Sea. Of all logs extending to at least 2 mbsb, 77% contain two or more lithological layers, demonstrating that vertically heterogeneous ground conditions are more common than homogeneous profiles. While many logs record relatively simple one- or two-layer profiles, a significant proportion contain multiple lithological units within the top 2 mbsb.

These layers commonly comprise contrasting lithologies and geotechnical properties, meaning that different ground conditions may occur within the depth range relevant to cable burial, trenching and anchor penetration. A location characterised at seabed as “sand” may, for example, comprise a thin sand layer overlying gravel, clay, peat or shallow bedrock within the upper 1-2 mbsb. Such configurations can result in geotechnical behaviour that differs from that expected for a homogenous sediment profile. This finding supports the conclusion of *Johnson et al. (2024)*, while extending them through the integration of additional geological and geotechnical datasets.

The distribution of layer counts highlights clear regional patterns. Simple one- and two- layer profiles, dominate much of the southern North Sea and parts of the Moray Firth, where mobile marine conditions favour relatively uniform, sand-dominated sediment sequences (*Cameron et al., 1992*). In contrast, higher layer counts are concentrated within coastal and nearshore environments, such as the Humber estuary and the Forth and Tay regions, where fluvial, estuarine, glacial and marine processes combine to produce more heterogeneous stratigraphy.

These patterns reflect broader geological and environmental controls. Mobile sandbank systems are typically characterised by well-sorted sediments and comparatively simple vertical profiles (*Cameron et al., 1992*), whereas areas influenced by glacial and post-glacial processes commonly preserve mixed sediment sequences, coarse deposits, organic-rich deposits and shallow bedrock (*e.g., Johnson et al., 1993; Gatliff et al., 1994)*. Variations in Quaternary sediment thickness also exert an important influence, with thin sediment cover increasing the likelihood of shallow bedrock within the depth range considered (*Andrews et al., 1990*).

Some variability in layer counts also reflects differences in investigation methods, sampling resolution and logging practices. Modern investigations are generally capable of resolving thinner units than legacy datasets, meaning that observed complexity may be influenced partly by data resolution rather than geology alone. Consequently, layer counts should be interpreted as an indicator of observed complexity rather than a directly comparable measure across all locations. Sampling bias in highly mobile sandy environments tend to produce simple, sand-dominated log profiles, reducing apparent heterogeneity, whereas transitional environments preserve a wider range of lithologies.

Overall, the results demonstrate that shallow stratigraphy within common cable burial depths is commonly more complex than implied by single-layer classifications alone. Vertical variability is therefore a fundamental characteristic of the UK North Sea shallow subsurface and should be considered explicitly in regional geological interpretations for offshore engineering applications.

4.1.1 Dominant Lithology: Sand and Clay

The distribution of dominant lithologies within the upper 0-2 mbsb shows a broadly even balance between sand- and clay-dominated profiles across the UK North Sea (**Figure 8**). The southern North Sea shows a higher proportion of sand-dominated sites, consistent with the extensive sandbank systems and mobile sediment regimes of the region (*Cameron et al., 1992*). In contrast, the northern North Sea contains more clay-dominated profiles, particularly within deeper basin settings such as the Witch Ground Basin where very soft to soft glaciomarine clays are widespread (*Gatliff et al., 1994*).

However, dominant lithology does not imply a homogenous sediment profile with uniform material properties and therefore does not fully capture the complexity of near-surface stratigraphy. Classification is based on cumulative “sand” or “clay” thickness within the 0-2 mbsb interval, and many profiles contain additional lithologies (such as gravel, clay or organic-rich layers within a sand-dominated profiles, or sand/silt horizons within a clay-dominated profile) with variations in consistency, strength and density. Dominant lithology should therefore be interpreted as a general descriptor of prevailing conditions within a profile rather than a complete representation of shallow subsurface structure.

4.1.2 Coarse Deposits

The occurrence of coarse deposits is widespread within the upper 0-2 mbsb (**Figure 9**) across the UK North Sea, representing an important component for cable burial that may not be evident from seabed observations alone. Typically, these occur as thin veneers (<0.2 m thick), indicating that coarse material is commonly present but less frequently forming thick, laterally extensive or vertically uniform deposits.

Coarse deposits are particularly common in nearshore and dynamic shelf-margin environments, including eastern England and around Orkney and Shetland, where high-energy conditions promote the removal of finer sediments by tidal currents and wave action, leaving residual coarse lags (*Papenmeier et al., 2020; Carter et al., 2025*). Thicker coarse deposits (>0.2 m) are more restricted and are typically associated with preserved Quaternary glacial and glaciofluvial deposits that have been partially preserved beneath more recent marine sediments (*e.g., Ottesen, 2020; Bide et al., 2023; Coughlan et al., 2024; Vervoort et al., 2025*). Their occurrence is often highly heterogeneous and localised, reflecting the influence of depositional history and subsequent reworking by contemporary hydrodynamic processes.

Although often thin, coarse layers can represent significant changes in mechanical behaviour within otherwise sand- or clay-dominated profiles and contribute substantially to shallow subsurface variability (*Johnson et al., 2024*).

4.1.3 Peat and Organic-Rich Deposits

Peat and organic-rich deposits are comparatively uncommon within the dataset (i.e., n=89 sites; ~3%) represent an important component of shallow North Sea stratigraphy where present. They are most frequently recorded in the southern North Sea, particularly in the Outer Thames Estuary, East Anglia and Dogger Bank, with only isolated occurrences further north (**Figure 10**).

Peat occurs in multiple forms, including peaty sands, silts, and clays, as well as mixed organic horizons (**Figure 10C**).These lithologies reflect their origin within transitional wetland, channel-fill or marginal environments that were subsequently inundated during early Holocene transgression, consistent with broader reconstructions of late-glacial and early- to mid-Holocene landscape drowning across the southern North Sea (e.g., *Hijma et al., 2025; Waller & Kirby, 2020*).

Within the upper 0-2 mbsb interval, peat typically occurs in a range of thicknesses including thin and discontinuous subsurface layers, often obscured beneath a superficial sand veneer, and as thicker organic-rich units exceeding 1m thickness. Their occurrence highlights the present of relict terrestrial surfaces beneath the modern seabed following marine inundation and reworking and provides a further example of subsurface variability that may not be apparent from seabed classifications alone.

4.1.4 Shallow Bedrock

Shallow bedrock represents a distinct end member of near-surface variability, occurring where sediment cover is thin or absent. Bedrock intercepts within the upper 0-2 mbsb are concentrated in coastal and shelf-margin settings, including eastern England, Scotland, and the Orkney-Shetland Platform (**Figure 11**). These occurrences broadly correspond to regions of reduced Quaternary sediment thickness and structural or geomorphological highs identified in regional geological studies (e.g., *Downie et al., 2016; BGS, 2023; BGS, 2024*).

Bedrock is often overlain by only a thin sediment veneer, meaning its presence may not be evident from seabed conditions alone. This is particularly relevant in areas such as the Moray Firth and parts of the northern North Sea, where limited sediment cover overlies lithified substrates (*Andrews et al., 1990; Dove et al., 2025*). In addition, isolated coarse clasts such as boulders or dropstones may occur within otherwise soft or fine-grained sediments, particularly in glaciomarine settings, further contributing to localised variability within the shallow subsurface.

The distribution and character of recorded bedrock types is influenced partly by sampling bias as shallow coring techniques are more effective at recovering weakly lithified or fractured rock than very strong or crystalline materials. In addition, the targeted deployment of “rock” coring systems reflects prior expectations of shallow bedrock, introducing an additional influence of survey design on the spatial distribution of observations. Despite this, the occurrence of shallow bedrock reinforces the high variability of near-surface conditions in the North Sea.

4.2 IMPLICATIONS FOR CABLE BURIAL RISK ASSESSMENT AND ANCHOR PENETRATION

The results highlight fundamental differences between how shallow subsurface conditions are currently represented in CBRA workflows and the complexity observed in reality across the UK North Sea. Standard approaches typically assign a single dominant soil type over relatively large, km-scale areas using simplified strength or density classifications. In contrast, the dataset analysed here, demonstrates that the shallow subsurface is commonly layered and heterogeneous, with contrasting lithologies and material properties occurring over short intervals, within the depth range relevant to cable burial and anchor penetration (typically 0-2 mbsb).

Several key factors contribute to this mismatch:

- Layered soils are widespread within the upper 0-2 mbsb, meaning that anchor flukes and cable trenching tools may encounter multiple mechanically distinct materials during penetration rather than a single homogenous unit.
- Sand and clay behaviour varies continuously over decimetre-scale intervals meaning that a single strength or density category rarely captures the full range of conditions present.
- Thin gravel lags, organic-rich layers, including peat, and shallow bedrock may be present beneath apparently uniform seabed sediments that may not be able to be identified from surface sediment mapping. These features can exert a strong control on near-surface mechanical behaviour and invalidate penetration-based DoL predictions where encountered within the target burial depth.

This variability has direct implications for both cable burial and anchor penetration behaviour, as penetration is highly sensitive to lithological contrasts and variations in strength and density. Modelling and experimental studies have demonstrated that transitions between loose and dense sands, or variations in clay consistency or strength, which may not be evident at seabed, can produce non-linear responses, with penetration behaviour varying significantly over short vertical distances (e.g., *Sharif et al., 2023; Bird et al., 2024; Bird et al., 2025; Bird et al., 2026*). Similarly, thin gravel or cobble layers, although only a few centimetres thick, can disrupt ploughing and trenching operations, resulting in plough deviation, tool refusal or reduced burial performance (*Dyer, 2011; Carter et al., 2025*). Organic-rich deposits, particularly peat layers, although typically thin, may significantly alter deformation and penetration behaviour because of their high compressibility (*Brown et al., 2015*) resulting in changes in resistance or embedment behaviour during installation that would not be anticipated from surface observations alone. Shallow bedrock invalidates penetration-based Depth of Lowering (DoL) predictions where encountered within or immediately beneath the target burial depth, requiring alternative cable protection methods (such as the use of rock dump or concrete mattresses), or routing strategies.

Collectively, these findings demonstrate that simplified sand- or clay-based classifications do not adequately represent the behaviour of the shallow subsurface within the burial zone. At a minimum, layering and associated strength and density contrasts, should be considered explicitly within early-stage routing and CBRA workflows where simplified assumptions may influence downstream design decisions.

While detailed geotechnical investigation, including CPTs, cores, and high-resolution shallow geophysical data, remains essential for site-specific characterisation, such investigations are typically undertaken only after preferred route corridors have been identified. The regional legacy dataset used in this analysis provides a practical screening tool that can be used alongside seabed sediment mapping to identify areas where shallow subsurface conditions are likely to be more complex than surface observations would suggest, improving the basis on which initial route selection is made.

Although the dataset does not provide continuous spatial coverage, it offers a regional framework for identifying where layered soils, coarse deposits, peat or shallow bedrock are more likely to occur. Used in this way alongside existing datasets, the analyses can support route selection, guide the targeting of higher-resolution investigations, and provide additional geological context during early-stage cable burial and anchoring assessments.

4.3 FUTURE WORK

The work presented here provides a foundation for improving the representation of shallow subsurface conditions within CBRA, and related offshore engineering applications. Ongoing research within the EPSRC project will continue to support numerical and physical modelling studies at Durham University and the University of Dundee through the provision of refined stratigraphic classifications, quantitative parameter sets, and CPT-derived indicators. This will help ensure that subsequent modelling more accurately reflects the complexity of shallow layered soils, burial-limiting conditions and sediment heterogeneity across the UK North Sea.

A key outcome of this work has been the demonstration of the value of integrating large volumes of legacy geological and geotechnical data within a consistent analytical framework. Future development will focus on expanding and refining the underlying database, extending the applicability of this methodology to a wider range of offshore engineering problems, and other areas of the UKCS. However, UKCS geotechnical data holdings remain highly variable in format, structure, metadata completeness and accessibility, limiting automated processing, large-scale integration, and the development of reproducible regional workflows. Wider adoption and sharing of standardised digital formats, such as AGS, together with improved long-term stewardship of geotechnical information, would substantially improve interoperability, and maximise the value of existing datasets. Recent proposals for a UK Geotechnical Data Bill highlight the potential benefits of treating geotechnical information as strategic infrastructure data, while established models such as the BGS-Network Rail partnership demonstrate how centralised curation and long-term accessibility can support research, improve asset management and reduce duplication on site investigation effort. Similar approaches within the offshore sector would strengthen the evidence base available for future infrastructure development.

Extending the vertical and quantitative scope of the dataset is also a key priority. The present compilation is focused on the upper ~6 mbsb and therefore constrains its use in broader geological and geotechnical applications, including efforts to develop more comprehensive regional data catalogues (e.g. *Dakin et al., 2026*). Integration of deeper stratigraphic information and higher-resolution site investigation datasets would improve regional geological context and support ground-model development. In parallel, incorporation of statistically robust, quantitative datasets (e.g. *Zheng et al., 2026*) would strengthen parameterisation and reduce reliance on qualitative sediment descriptions, supporting more rigorous representation of behaviour in heterogeneous or layered ground conditions.

Ongoing work is focused on the refinement and validation of CPT-derived indicators for identifying shallow subsurface variability. Particular emphasis is placed on the detection of layered soils, strength contrasts, burial-limiting conditions, and diagnostic signatures associated with transitions involving soft sediments, coarse deposits, organic-rich materials and shallow lithified units. These developments will provide a more systematic and transferable basis for characterising variability within the burial zone and improving prediction of near-surface ground behaviour.

Beyond database development, there is significant potential to move towards predictive regional-scale assessments of shallow subsurface variability. Combining geological mapping, bathymetry datasets, shallow geophysical interpretations and machine-learning approaches with the database may enable spatial prediction between existing investigation locations. Expanding the geographic coverage through collaboration with neighbouring North Sea organisations would further support the development of a harmonised regional geotechnical resource, facilitate basin-scale analyses and improve consistency in regional ground model development. Together, these developments would help move from descriptive regional characterisation towards predictive, spatially integrated assessments of shallow subsurface conditions, supporting both early-stage route screening, risk assessment and more effective targeting of site-specific investigation.

5 Conclusions

This study provides a regional assessment of shallow subsurface variability across the UK North Sea based on a consistently structured database of 12,219 geological and geotechnical records. By integrating legacy BGS data with information from the Crown Estate Marine Data Exchange, heterogenous geological and geotechnical datasets have been standardised within a unified, layer-based framework, enabling direct comparison of lithological and geotechnical information across a wide range of investigation types from different sources and time periods.

The results demonstrate that shallow subsurface conditions within the depth range most relevant to cable burial, anchor penetration and trenching operations (typically 0-2 mbsb) are commonly layered and heterogenous. Approximately three-quarters of logs penetrating 2 mbsb contain two or more lithological units, indicating that vertically variable ground conditions represent the dominant condition across much of the UK North Sea.

Although sand- and clay-dominated profiles occur in broadly similar proportions, the upper few metres of the seabed also commonly contain thin coarse layers, organic-rich deposits and shallow lithified materials. Many of these features are not reliably identifiable from seabed observations alone yet may exert a strong influence on penetration behaviour, burial performance and installation risk.

These findings highlight an important limitation of CBRA approaches that rely on single homogenous soil units. Vertical variability, layering and contrasts in material properties occur frequently within the depth range relevant to CBRA and should be considered during early-stage route selection and risk assessment.

The database and analytical framework used in this study provide an additional source of evidence for identifying areas of increased geological complexity and supporting regional-scale screening. While not a substitute for site-specific ground investigation, the approach complements existing seabed mapping and geotechnical investigations by providing broader geological context and improving understanding of shallow subsurface variability. More broadly, the study highlights the value of accessible, standardised geotechnical datasets for supporting regional-scale offshore infrastructure planning and assessment.

In this context, the study supports the objectives of The Crown Estate's Cable Route Identification and Leasing Guidelines (The Crown Estate, 2024) by contributing to the early identification of geological constraints and providing a foundation for more realistic, layered and spatially informed representations of the shallow seabed within offshore infrastructure planning and cable burial assessment workflows.

Glossary

BGS – British Geological Survey

CBRA – Cable Burial Risk Assessment

CPT – Cone Penetration Test

DEA – Drag Embedment Anchor

DoL – Depth of Lowering

Dr – Relative Density (granular soils)

DU – Durham University

EPSRC – Engineering and Physical Sciences Research Council

GC – Gravity Core

GS – Grab Samples

mbsf – metres below seafloor

OWF – Offshore Wind Farm

RCS – Rock Classification Scheme

Su – Shear Strength (cohesive soils)

UDCS – Unlithified Deposits Coding Scheme

UoD – University of Dundee

UK – United Kingdom

UKCS – United Kingdom Continental Shelf

UKRI – United Kingdom Research & Innovation

VC – Vibrocore

WP1 – Work Package 1

References

The British Geological Survey holds most of the references listed and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at https://ukrinerc.on.worldcat.org/discovery.

Andrews, I.J., Long, D., Richards, P.C., Thomson, A.R., Brown, S., Chesher, J.A. and McCormac, M. (1990) *The geology of the Moray Firth*. London: HMSO, 96 pp. (United Kingdom Offshore Regional Report, 3).

Bellwald, B, Kurjanski, B, Carter, G D O, Wood, G, Arlott, L, Plaza-Faverola, A, Stewart, H A, Hjelstuen, B O, Løseth, H, Andresen, K J, Wenau, S, Birchall, R, McGhee, C, Gibbons, S J, Harbitz, C B, Carlton, B D, Newton, A M W, Huuse, M, Issler, D, Løvholt, F, Forsberg, C F, Coughlan, M, Caruso, S, Long, M, Tappin, D, Dimmock, P, Klinkvort, R T, and Vanneste, M. (*In review*). *Marine geohazards and geo-engineering constraints on the glaciated European margins*. DOI: https://doi.org/10.31223/X57734

Bide, T., Balson, P., Mankelow, J. & Selby, I., (2016). *A new sand and gravel map for the UK Continental Shelf to support sustainable planning*. Resources Policy, 48, pp. 1–12. ISSN: 0301-4207. https://doi.org/10.1016/j.resourpol.2016.02.004.

Bird, R.E., Pretti, G., Coombs, W.M., Augarde, C.E, Sharif, Y., Brown, M.J., Carter, G., Macdonald, C. & Johnson, K. (2024*), Dynamic three-dimensional rigid body interaction with highly deformable solids, a material point approach*, In W. Coombs (Ed.), Proceedings of the 2024 UK Association for Computational Mechanics Conference (153-156).

Bird, R.E., Pretti, G., Coombs, W.M., Augarde, C.E., Sharif, Y., Brown, M.J., Carter, G., Macdonald, C. & Johnson, K. (2025), *A dynamic implicit 3D material point-to-rigid body contact approach for large deformation analysis*, International Journal for Numerical Methods in Engineering, 126(14), Article e70080.

Bird, R.E., Coombs, W.M., Brown, M.J., Augarde, C.E., Sharif, Y., Pretti, G., Macdonald, C. Stevens, D., & Carter, G. (2026). *Three-dimensional modelling of drag anchor penetration using the material point method*. Ocean Engineering, Volume 358, Part 2, 125456, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2026.125456.

Bow, J., Dobbs, M., Lewis, E., Macdonald, C., Mowat, M. and Rautenberg, S. (2023) *A review of public geotechnical data held on the Marine Data Exchange.* British Geological Survey Report, 59 pp.

British Geological Survey (2022) *GeoIndex Offshore*. National Geoscience Data Centre. Available at: https://www.bgs.ac.uk/map-viewers/geoindex-offshore/ (Accessed: May 2022)

British Geological Survey (2020). *The BGS Rock Classification Scheme* [online]. Keyworth, Nottingham: British Geological Survey. Available at: https://www.bgs.ac.uk/technologies/bgs-rock-classification-scheme/.

British Geological Survey. (2023) *User guide for BGS Seabed Geology 10k: Offshore Yorkshire*. Edinburgh, UK, British Geological Survey, 53pp. (OR/22/063) (Unpublished)

British Geological Survey. (2024) *User Guide for BGS Seabed Geology: Offshore East Anglia*. Edinburgh, UK, British Geological Survey, 45pp. (OR/24/003)

British Geological Survey (1984) *Marr Bank. Sheet 56 N – 02 W. Solid Geology. 1:250,000 UTM Series of the United Kingdom and Continental Shelf.* Southampton: Ordnance Survey for the British Geological Survey.

British Standards Institution (2020). *BS 5930:2015+A1:2020 Code of practice for ground investigations*. London: BSI. Accessed February 2023.

Brown, M.J., Bransby, M.F., Knappett, J.A., Tovey, S., Lauder, K. & Pyrah, J. (2015). *The effect of buried fibres on offshore pipeline plough performance*. Ocean Engineering Journal. Vol. 108. pp. 760-768. DOI: 10.1016/j.oceaneng.2015.08.022, ISSN: 0029-8018.

Burnett, D.R. and Carter, L. (2017) *International Subsea Cables and Biodiversity of Areas Beyond National Jurisdiction: The Cloud Beneath the Sea.* Brill Research Perspectives in the Law of the Sea, vol. 1. Leiden: Brill/Nijhoff. ISBN 9789004351592.

Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffery, D.H., Lott, G.K., Bulat, J. & Harrison, D.J. (1992) *The geology of the southern North Sea.* British Geological Survey. British Geological Survey. London: HMSO. ISBN 0 11 884492 X.

Carter, L., Burnett, D., Drew, S., Marle, G., Hagadorn, L., Bartlett-McNeil, D. and Irvine, N. (2009) *Submarine Cables and the Oceans — Connecting the World.* Cambridge: United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC Biodiversity Series, No. 31).

Carter, G.D.O., Birchall, R., Flint, A., Rose, M., Bellwald, B., Cotterill, C., Arlott, L. & Wood, G., (2025). *Formation and implications of glacially-derived gravel lag deposits; mapping a geo-constraint to shallow offshore infrastructure*. Proceedings of the 5th International Symposium on Frontiers in Offshore Geotechnics (ISFOG 2025), Nantes, France, 9–13 June 2025. International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). ISBN: 978-2-85782-758-0

Clare, M.A., Yeo, I.A., Bricheno, L., Aksenov, Y., Brown, J., Haigh, I.D., Wahl, T., Hunt, J., Sams, C., Chaytor, J., Bett, B.J. and Carter, L. (2022) 'Climate change hotspots and implications for the global subsea telecommunications network', *Earth-Science Reviews*, article 104296.

Cooper, A.H.; Kessler, H.; Ford, J. (2006). *A revised scheme for coding unlithified deposits (also applicable to engineering soils).* British Geological Survey, 45pp. (IR/05/123) (Unpublished)

Coughlan, M., Fleischer, M., Wheeler, A. J., Hepp, D. A., Hebbeln, D. & Mörz, T. (2018) *A revised stratigraphical framework for the Quaternary deposits of the German North Sea sector: a geological-geotechnical approach*. Boreas, Vol. 47, pp. 80–105. 10.1111/bor.12253. ISSN 0300-9483.

Crown Estate Scotland. (2026a). Offshore Wind (Crown Estate Scotland). https://crown-estate-scotland-spatial-hub-coregis.hub.arcgis.com/datasets/coregis::offshore-wind-crown-estate-scotland/explore

Crown Estate Scotland. (2026b). Subsea Cables (Crown Estate Scotland). https://crown-estate-scotland-spatial-hub-coregis.hub.arcgis.com/datasets/coregis::cables-crown-estate-scotland/explore

Dakin, N, Dove, D, Lee, J, Finlayson, A, Stewart, M, and MacDonald, C. (2026). *The shallow subsurface geology of the southern North Sea (UK): an updated assessment using data from offshore wind farms*. British Geological Survey Open Report, OR/26/005. 80pp.

Department for Energy Security and Net Zero (DESNZ). (2024) *Clean Power 2030 Action Plan: A new era of clean electricity – main report.* London: UK Government. Available at: https://www.gov.uk/government/publications/clean-power-2030-action-plan (Accessed: 05/03/2026).

Dove, D., Bradwell, T. & Barlow, N.L.M. (2025) Submerged bedrock shore platforms, Orkney Islands, UK: A new record of significant, though chronologically uncertain sea-level change and coastal erosion. Marine Geology, 487, 107577. https://doi.org/10.1016/j.margeo.2025.107577

Downie, A.L., Dove, D., Westhead, R.K., Diesing, M., Green, S.L. & Cooper, R., (2016), *Semi-automated mapping of rock in the North Sea*, JNCC Report No. 592, JNCC, Peterborough, ISSN 0963-8091.

Dyer, J.M. (2011). *Geohazard identification: the gap between the possible and reality in geophysical surveys for the engineering industry*. Marine Geophysical Research, 32(1): 37-47. https://doi.org/10.1007/s11001-011-9137-x

EMODnet Human Activities. (2026). EMODnet Human Activities: Offshore Wind Farms (OWF). https://ows.emodnet-humanactivities.eu/geonetwork/srv/eng/catalog.search#/metadata/74eef9c6-13fe-4630-b935-f26871c8b661

Finlayson, Andrew; Mowat, Mary; Dove, Dayton; Gafeira, Joana. (2025) *National Seabed Geology Scoping Project: stakeholder needs and existing data review.* British Geological Survey, 40pp. (OR/24/055) (Unpublished)

Folk, R.L. (1954). *The distinction between grain size and mineral composition in sedimentary rock nomenclature*. Journal of Geology 62 (4), pp. 344-359.

Gatliff, R.W., Richards, P.C., Smith, K., Graham, C.C., McCormac, M., Smith, N.J.P., Long, D., Cameron, T.D.J., Evans, D., Stevenson, A.G., Bulat, J. & Ritchie, J.D. (1994). *The Geology of the Central North Sea*. British Geological Survey, United Kingdom Offshore Regional Report No. 5. London: HMSO. ISBN 0118845047.

Hijma, M.P., Bradley, S.L., Cohen, K.M. *et al. Global sea-level rise in the early Holocene revealed from North Sea peats*. *Nature* **639**, 652–657 (2025). https://doi.org/10.1038/s41586-025-08769-7

Johnson, H, Richards, P C, Long, D, and Graham, C C. (1993). *United Kingdom offshore regional report: the geology of the northern North Sea*. (London: HMSO for the British Geological Survey.)

Johnson, K.R. Carter, G.D.O. Macdonald, C. (2024), *Layered soils in the shallow subsurface (<6.0 m), North Sea; a data report*, Nottingham, UK, British Geological Survey, 40pp. (OR/24/031).

Lewall, A., Higgs, D., Terente, V. and Ellery, G. (2016) *MEDIN data guideline for the recording of offshore geotechnical site investigation data.* Version 2.4. Marine Environmental Data and Information Network (MEDIN). Available at: https://repository.oceanbestpractices.org/bitstream/handle/11329/1703/MEDIN_geotechnical_investigation_2_4.pdf.

Long, D. (2006). BGS detailed explanation of seabed sediment modified Folk classification.

Macdonald, C., Carter, G., Johnson, K., Augarde, C.E., Coombs, W.M., Bird, R.E., Brown, M.J. & Sharif, Y. (2023), *Depth of Lowering and layered soils; a case study from across the North Sea*, in 9th Int. SUT OSIG Conference "Innovative Geotechnologies for Energy Transition". London, UK.

Macdonald, C., Stevens, D., Arnhardt, R., Carter, G., Johnson, K., Coombs, W.M., Bird, R.E., Augarde, C.E., Brown, M.J. & Sharif, Y. (2025), Regional analysis of layered soils in the shallow subsurface across the North Sea for offshore cable burial, in 5th International Symposium on Frontiers in Offshore Geotechnics, Nantes, France, 9-13 June 2025. International Society for Soil Mechanics and Geotechnical Engineering.

Mortimore, R, and James, L. (2015). The search for onshore analogues for the offshore Upper Cretaceous Chalk of the North Sea. Proceedings of the Geologists' Association, Vol. 126(2), 188-210. DOI: https://doi.org/10.1016/j.pgeola.2015.01.008

Ottesen, D., Stewart, M., Brönner, M. and Batchelor, C.L., (2020). Tunnel valleys of the central and northern North Sea (56 N to 62 N): Distribution and characteristics. Marine Geology, 425, p.106199.

Papenmeier, S., Galvez, D., Günther, C-P., Pesch, R., Propp, C., Hass, H.C., Schuchardt, B. & Zeiler, M. (2020) '*Winnowed gravel lag deposits between sandbanks in the German North Sea*', in Harris, P.T. & Baker, E. (eds.) Seafloor Geomorphology as Benthic Habitat (2nd ed.). Elsevier, pp. 451–460. ISBN: 9780128149607. Available at: https://doi.org/10.1016/B978-0-12-814960-7.00025-7.

Ritter, S., von der Tann, L., Dahl, M., Paniagua, P. & Long, M. (2024). *Settlement behaviour of peat underneath a sand and sawdust embankment: centrifuge modelling.* In: Proceedings of the 5th European Conference on Physical Modelling in Geotechnics (ECPMG 2024), Delft, Netherlands, 2–4 October 2024.

Sharif, Y., Brown, M.J., Coombs, W.M., Augarde, C.E., Bird, R.E., Carter, G., Macdonald, C. & Johnson, K. (2023), Characterization of anchor penetration behaviour for Cable burial risk assessment, in 9th Int. SUT OSIG Conference "Innovative Geotechnologies for Energy Transition". London, UK.

Sharif, Y., Brown, M.J., Davidson, C., Bird, R.E., Coombs, W.M., Augarde, C.E., Carter, G., Macdonald, C. & Johnson, K. (2024), Comparison of the behaviour of a drag embedment anchor using 1-g and centrifuge scale model testing, in Proceedings of the 5th European Conference on Physical Modelling in Geotechnics, Delft, Netherlands.

Spink, T.W. (2002). *The CIRIA Chalk description and classification scheme*. Quarterly Journal of Engineering Geology and Hydrogeology, 35(4), 363–369. https://doi.org/10.1144/1470-9236/00045

The Carbon Trust (2015) *Cable Burial Risk Assessment Methodology: Guidance for the Preparation of Cable Burial Depth of Lowering Specification.* CTC835. London: The Carbon Trust.

The Crown Estate (2024) *Cable Route Identification and Leasing Guidelines: Transmission Assets for Offshore Renewable Installations.* Version 1.1, August 2024. London: The Crown Estate. Available at: https://www.thecrownestate.co.uk/ (Accessed: 05/03/2026).

The Crown Estate (2025) *Marine Data Exchange*. Available at: https://www.marinedataexchange.co.uk/ (Accessed: April 2025).

The Crown Estate. (2026a). *Wind Cable Agreements (England, Wales, and Northern Ireland)*. https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::wind-cable-agreements-england-wales-ni-the-crown-estate/explore

The Crown Estate. (2026b). *Wind Site Agreements (England, Wales, and Northern Ireland).* https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::wind-site-agreements-england-wales-ni-the-crown-estate/explore

Vervoort, M., Plets, R., Kyriakoudi, D., Missiaen, T. and De Batist, M. (2026) *Geomorphology of the Axial Channel (Southern Bight, North Sea)*, Journal of Maps, 22(1). doi:10.1080/17445647.2026.2620910.

Waller, M. and Kirby, J. (2021), *Coastal peat-beds and peatlands of the southern North Sea: their past, present and future*. Biol Rev, 96: 408-432. https://doi.org/10.1111/brv.12662

Wessel, P., and W. H. F. Smith (1996), A global, self-consistent, hierarchical, high-resolution shoreline database, *J. Geophys. Res.*, 101(B4), 8741–8743, doi:10.1029/96JB00104.

Zheng, T, Buckley, R, and Febrianto, E. 2026. *A comprehensive approach for Bayesian soil classification using Cone Penetration Test data*. Computers and Geotechnics, Vol. 190, 107671. DOI: https://doi.org/10.1016/j.compgeo.2025.107671

Appendix 1

BGS OFFSHORE DATABASE STRUCTURE

This appendix provides an overview of the database structure, outlining the key headings used to organise the core interpretation and associated metadata to support efficient data storage and analysis. The accompanying data dictionary tables define the purpose, format, and valid ranges of each field within the database, ensuring clarity and consistency in how the dataset is interpreted and used.

Sample Metadata

Report
Sample Name
Equipment
Coordinates
EPSG Code
Start/End Date
Drilled Depth
Water Depth & Datum
Confidentiality
Notes

Sample Name
Interpreter
Unit top/base depth (m)
Primary Lithology
Modifier
RCS
Grain Size
Soil consistency
Soil strength
Soil density
Rock strength
Weathering
Notes

Dictionary Tables

TERMS FOR DESCRIPTIONS OF CONSISTENCY (BS5930; 2020)

Term	Code	Meaning	Example descriptors
Very soft	SFTV	<20kPa; exudes between fingers; offers almost no resistance	"very soft", "very soft to soft", "fluid", "ooze"
Soft	SFT	20-40kPa; easily moulded with fingers; deforms readily	"soft", "soft to stiff", "sticky", "plastic"
Firm	FRM	40-75kPa; strong finger pressure required to mould; noticeable resistance	"firm", "firm to stiff", "slightly stiff"
Stiff	STI	75-150kPa; can be indented slightly by thumb; crumbles when rolled into ~3 mm thread.	"stiff", "stiff to very stiff"
Very stiff	STIV	150-300kPa; only indented by a sharp object; very high resistance.	"very stiff", "very stiff to hard", "indurated"
Hard	HD	>300kPa; Difficult to indent; can be scratched by thumbnail; near-rocklike behaviour.	"hard", rare in shallow marine cores

TERMS FOR CLASSIFICATION OF STRENGTH (BS5930; 2020)

Term	Code	Meaning	Example descriptors
Extremely low strength	ELST	<10kPa; Material easily moulded by hand; offers almost no resistance to penetration.	“extremely low strength”, “extremely low strength to low strength”
Very low strength	VLST	10-20kPa; very soft; penetrated easily with fingers; can be remoulded with little effort.	“very low strength”, “very low strength to low strength”
Low strength	LST	20-40kPa; soft; thumb pushes in easily; material deforms readily under hand pressure.	“low strength”, “low strength to high strength”
Medium strength	MST	40-75kPa; firm; thumb makes an impression with moderate effort; distinct resistance to remoulding.	“medium strength”, “medium strength to high strength”
High strength	HST	75-150kPa; stiff; thumb barely indents; requires considerable hand pressure to deform.	“high strength”, “high strength to extremely high strength”
Very high strength	VHST	150-300kPa; very stiff; can only be indented slightly with thumb nail; difficult to remould.	“very high strength”, “very high strength to extremely high strength”
Extremely high strength	EHST	>300kPa; approaching weak rock; cannot be indented by thumbnail; requires tools to break.	“extremely high strength”, “extremely high strength to ultra-high strength”

TERMS FOR CLASSIFICATION OF RELATIVE DENSITY (BS5930; 2020)

Term	Code	Meaning	Example descriptors
Very loose	LSV	Minimal packing, very low relative density; SPT N-value 0–4	“very loose”, “very loose to loose”, “running sand”
Loose	LS	Low relative density; SPT N-value 4–10	“loose sand”, “loose to dense”
Medium dense	DENM	Typical marine sand; moderate relative density, SPT N-value 10–30	“medium dense fine sand”
Dense	DEN	High relative density; SPT N-value 30–50	“dense sand / gravel”, “very fine dense sand”, “dense to very dense”
Very dense	DENV	Near refusal, very high relative density; SPT N-value > 50	“very dense sand”, “medium dense to very dense”

TERMS FOR DESCRIPTIONS OF GRAINSIZE (BS5930; 2020)

Term	Meaning	Example descriptors
Fine	fine sand or finer fraction	“fine sand”, “very fine to fine gravelly sand”, “fine to medium”
Medium	medium sand	“medium sand”, “medium to coarse sand”
Coarse	coarse sand	“coarse to very coarse sand”
Gravel	presence of gravel fraction	“very coarse sand to fine gravel”, “very fine gravel”

Cobbles / boulders	coarse fraction > 64 mm	“coarse gravel to cobble”, “cobble to boulder”, “boulder”

TERMS FOR DESCRIPTIONS OF ROCK STRENGTH (BS5930; 2020)

Term	Code	Meaning	Example descriptors
Extremely weak	WKE	~0.6–1 MPa; can be indented by thumbnail; gravel-sized pieces crush between fingers.	“crumbly”, “extremely weak rock”
Very weak	WKV	1–5 MPa; can be peeled or indented with a pocketknife; crumbles under firm hammer taps	“very soft rock”, “very weak”, “crumbly”
Weak	WK	5–25 MPa; thin pieces break with heavy hand pressure; shallow indentations made by hammer point	“weak rock”, “breaks easily”, “friable”
Medium strong	STRM	25–50 MPa; cannot be scraped/peeled with knife; fractures with one hammer blow.	“moderately strong rock”
Strong	STR	50–100 MPa; requires more than one hammer blow to break when supported.	“strong rock”, “resistant”
Very strong	STRV	100–250 MPa; rock chips only under heavy hammer blows.	“very strong rock”, “highly resistant”
Extremely strong	STRE	>250 MPa; rock rings on hammer blows; may only chip even with geological hammer.	“massive”, “very hard”, “extremely strong”

TERMS FOR CLASSIFICATION OF WEATHERING (BS5390:2020 & CIRIA C574; SPINK, 2002)

Term	Meaning	Example descriptors
Uniform Rocks		
I: Fresh	Unchanged from original state.	“moderately weathered”, “smooth fractures partly filled with clay” “very weak completely weathered” “Grade V to VI weathered”, “behaving as gravelly sand”
II: Slightly weathered	Slight discolouration. Slight weakening.	
III: Moderately weathered	Considerably weakened, penetrative discolouration. Large pieces cannot be broken by hand.	
IV: Highly weathered	Large pieces can be broken by hand. Does not readily disaggregate (slake) when dry sample immersed in water.	
V: Completely weathered	Considerably weakening. Slakes. Original texture apparent.	
VI: Residual soil	Soil derived from in situ weathering but retaining none of the original texture or fabric.	
Material & Mass		
A: Unweathered	Original strength, colour, fracture spacing.	“residual soil”, “partly weathered”
B: Partially weathered	Slightly reduced strength, slightly closer fracture spacing, weathering penetrating in from fractures, brown oxidation.	
C: Distinctly weathered	Further weakened, much closer fracture spacing, gray reduction.	

D: Destructured	Greatly weakened, mottled, ordered lithorelicts in matrix becoming weakened and disordered, bedding disturbed.	
E: Residual or reworked	Matrix with occasional altered, random or 'apparent' lithorelicts, bedding destroyed. Classed as reworked when foreign inclusions are present as a result of transportation.	
Heterogeneous		
1: Zone 1	Behaves as rock, apply rock mechanics principles to mass assessment and design.	“weak rock”, “fractured along bedding planes filled with clay”, “massive”
2: Zone 2	Weak materials along discontinuities. Shear strength, stiffness and permeability affected.	
3: Zone 3	Rock framework still locked and controls strength and stiffness. Matrix controls permeability.	
4: Zone 4	Rock framework contributes to strength, matrix or weathering products control stiffness and permeability.	
5: Zone 5	Weak grades will control behaviour. Corestones may be significant for investigation and construction.	
6: Zone 6	May behave as soil although relict fabric may still be significant.	
Ciria		
A1	Close, > 600 mm	“Low density very weak to weak very closely fractured” “Low density very weak to weak semi structured extremely closely fractured” “weak to moderately strong high density unstrained”, “fractures” “structureless”, “weak chalk in a matrix of chalk putty and crushed chalk with rare flint”, “low density ciria Dc” “structureless”, “Grade Dm”
A2	Close, 200 - 600 mm	
A3	Close, 60 - 200 mm	
A4	Close, 20 - 60 mm	
A5	Close, < 20 mm	
B1	Discontinuity < 3 mm, > 600 mm	
B2	Discontinuity < 3 mm, 200 - 600 mm	
B3	Discontinuity < 3 mm, 60 - 200 mm	
B4	Discontinuity < 3 mm, 20 - 60 mm	
B5	Discontinuity < 3 mm, < 20 mm	
C1	Discontinuity > 3 mm, > 600 mm	
C2	Discontinuity > 3 mm, 200 - 600 mm	
C3	Discontinuity > 3 mm, 60 - 200 mm	
C4	Discontinuity > 3 mm, 20 - 60 mm	
C5	Discontinuity > 3 mm, < 20 mm	
Dc	Structureless (clast dominated)	
Dm	Structureless (matrix dominated)	