Morecambe Offshore Windfarm: Generation Assets

Environmental Statement

Volume 5

Appendix 15.2 Seismic Data Review

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Morecambe Offshore Wind Farm

Seismic Data Review

MSDS Marine

2022/MSDS22219/2

Morecambe Offshore Wind Farm

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1.0 Introduction

1.0.1 MarineSpace Limited (MarineSpace) were contracted by MSDS Marine Limited (MSDS), on behalf of Royal Haskoning DHV, to undertake a review of a subset of the seismic data over the Morecambe Offshore Windfarm Site (Windfarm Site) located in the Irish Sea and identify potential facies of archaeological interest.

1.0.2 As part of the Phase 1 Geophysical Ground Investigation for the Windfarm Site, a geophysical survey was conducted by MMT in late 2021 where Sub-bottom Profiler (SBP) (2 types), Sidescan Sonar (SSS), Multibeam Bathymetry (MBES), and Magnetometer data were acquired over the Windfarm Site. The results of the survey and initial interpretations were provided in the survey report by MMT (2022b). This report investigates potential palaeolandscape features of interest with particular emphasis on potential channelised deposits in upper units (Units 1 and 2), as identified in the existing ground model (MMT, 2022b).

1.1 Project overview

1.1.1 The Morecambe Offshore Windfarm (the Project) is a proposed offshore windfarm , southwest of Morecambe Bay, in the east Irish Sea, approximately 30 km west of Blackpool (Figure 1), which was awarded in the Wind Leasing Round 4 by The Crown Estate in early 2021. The project is a joint venture between Cobra Instalaciones Servicios, S.A., and Flotation Energy plc. The Project is up to 125 km^2 with an anticipated capacity of 480 MW. The proposed infrastructure (the generation assets) includes wind turbine generators (WTGs), one or more offshore substation platforms, inter-array cables to connect WTGs to offshore substation(s), and potentially platform link cables between offshore substations. The Windfarm Site boundary is under revision and the focus of the assessment is undertaken on a Revised Windfarm Site, as shown in Figure 1. The Windfarm Site incorporates the areas shown in red and blue on Figure 1, while the revised Windfarm Site is shown in red.

1.1.2 Existing infrastructure within the Windfarm Site includes several communication cables and pipelines, as well as one decommissioned and one active gas platform. The South Morecambe Gas Fields are currently expected to cease production around 2027 (+/-2 years). In the meantime, the Morecambe Offshore Windfarm is anticipated to be the first windfarm to co-exist with oil and gas operations.

1.1.3 A geophysical survey was carried out within the Windfarm Site by MMT, as part of the Phase 1 Geophysical Ground Investigation, to characterise the site including investigation of the shallow sub-seafloor geology.

1.1.4 As part of the environmental assessment, an archaeological review of the data was performed by MSDS (MSDS, 2022) to identify potentially significant archaeological material on the seafloor and the potential for prehistoric remains within the sub-seafloor geology. This report forms a supplementary study to the archaeological assessment.

1.1.5 A geotechnical campaign is planned for Spring/Summer 2023 to provide further site characterisation as part of the environmental assessment and engineering design and feasibility study involved with the project development. The updated scope of the geotechnical survey will only include the Revised Windfarm Site area, which excludes the northwest portion of the Windfarm Site (Figure 1).

1.2 Aims and objectives

1.2.1 The principal aim of this data review is to provide further information to inform on the archaeological potential of the palaeolandscapes within the Windfarm Site.

1.2.2 This involved both a literature review and a targeted review of the SBP data to investigate any facies that may help constrain the depositional environment; in particular, assessing whether any seismic features may be indicative of a terrestrial environment of potential archaeological interest.

1.2.3 The initial ground model interpreted 5 stratigraphic units (Table 1; MMT, 2022b). Two units were flagged as of potential archaeological interest (Seismic Units 1 and 2) and were initially interpreted to be post-glacial; deposited during the Holocene transition. Any facies of potential archaeological interest will feed into recommendations for sampling during the upcoming geotechnical site investigation to further test the archaeological potential or constraints of any of these deposits, and to confirm which potential mitigation strategies could be emplaced.

1.2.4 Throughout the review, the timing of glacial retreat and the onset of the associated marine transgression is key to understanding the potential for Seismic Unit 1 and Unit 2 deposits to contain Upper Palaeolithic to Mesolithic material. If the site was submerged during the Late Glacial and the early part of the Holocene, then there is no potential for in-situ Upper Palaeolithic and Mesolithic material. However, if the site was fully or partly terrestrial during this time then Mesolithic communities could have been present. The primary landscape features that may indicate a terrestrial environment are palaeochannels and associated floodplain environments that may contain alluvial deposits. Additionally, high amplitude and reverse polarity seismic reflections can be an indicator of the presence of peat or other organic deposits, which are typically of terrestrial origin and may contain archaeologically significant material.

1.2.5 The marine lowstands during which the site may have been aerially exposed correspond to the Loch Lomond stadial (12.9 – 11.7 ka) and early Holocene (~11.7 ka; Shennan *et al.,* 2018). There is currently no evidence of human activity in the UK during the Loch Lomond stadial, though early Holocene evidence is recorded. If this site was exposed it would have been dominated by glacial landforms and meltwater river systems (Fitch *et al.,* 2011) with a cold climate that was not likely to have been hospitable for human settlement. However, the conditions may not have been prohibitive for human activity and the area could have been used for resource exploitation (MSDS, 2022). Therefore, there is some potential for Palaeolithic remains in Seismic Unit 2, which was inferred to have been deposited during this time (MMT, 2022b). There is also the potential for redeposited remains in Unit 2, which tend to survive in sheltered locations such as cave sites. The Holocene transgression is likely to have eroded and reworked Unit 2, further affecting the potential for archaeological or paleoenvironmental remains.

1.2.6 The timing of the marine transgression is key to understanding the potential for Mesolithic remains in Seismic Unit 1. If all or part of the site was exposed when the climate ameliorated during the early Holocene, then Mesolithic communities could have thrived in the Liverpool Bay area (Fitch *et al.,* 2011). The West Coast Palaeolandscape Survey (WCPS) suggested that the site was a low-lying plain on the landward edge of an intertidal zone, with two river channels modelled that could have been conducive to human exploitation (Fitch et al., 2011). Gas blanking in comparable units elsewhere in the Irish Sea may be indicative of organic remains (Schroot and Schuttenhelm, 2003). However, no gas blanking was identified within the seismic survey (MMT, 2022b) limiting the potential for Mesolithic archaeological remains. Seismic Unit 1 may also contain earlier archaeological or palaeoenvironmental material reworked during the Holocene transgression.

Unit	Base	Lithology	Correlated formation	Interpretation (MMT, 2022b)	Age	Depth of base of unit (mbsb)
1	H17	Marine silty sand	Western Irish Sea (A) – mud facies	Glaciomarine to shallow marine	Devensian to early Holocene	<1 – 10
2	H40	Sand	Western Irish Sea (A) – prograded facies	Deltaic to glaciomarine	Devensian	1 – 23
3	H45	Silty sand	Western Irish Sea (A/B) – mud facies	Glaciomarine to shallow marine	Devensian	1 – 29
4	H50	Till	Cardigan Bay formation – upper and lower till member	Glacial	Devensian – Wolstonian	3 – 43
5	N/A	Mudstone and halite	Triassic bedrock	Glacial	Triassic	N/A

Table 1: Summary of seismic units from MMT (2022b). Depth to the base of the unit is calculated using a sediment velocity of 1600 m/s

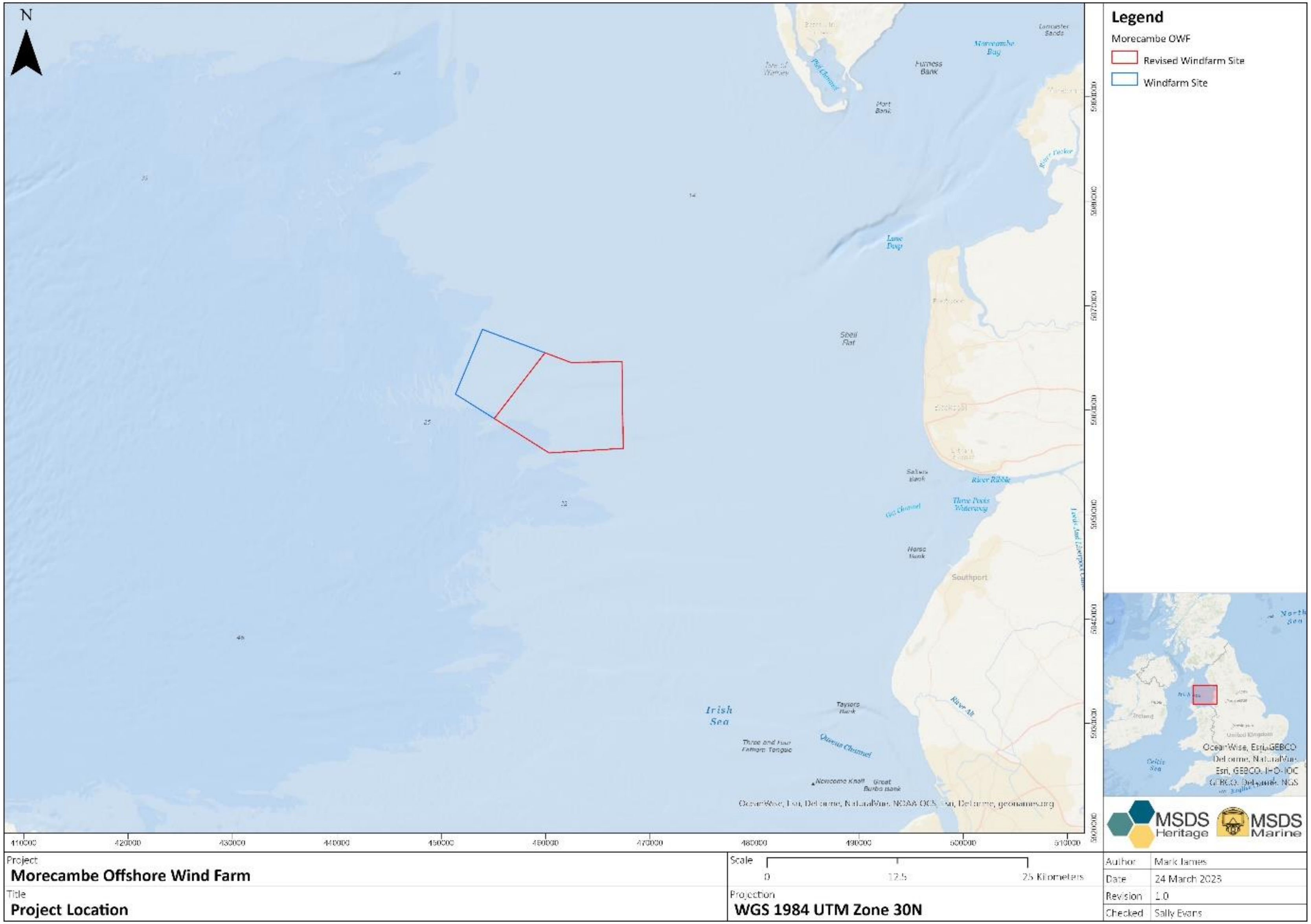

Figure 1: Location of Morecambe Offshore Wind Farm (modified from MSDS, 2022)

2.0 Methodology

2.1 Data acquisition

2.1.1 A geophysical survey (MBES, SSS, SBP, and magnetometer) was undertaken by MMT over the Windfarm Site between October to December 2021, onboard the offshore survey vessel M/V *Franklin* (Figure 2). Two SBPs were used: a parametric Innomar SBP (8 kHz) and a single channel GeoSpark 200 sparker-type SBP (18,000 hz and 22,500 hz)[1]. The sparker was towed behind the vessel, whereas the parametric SBP was mounted to the hull of the vessel. Further details on the survey can be found in the Operations Report (MMT, 2022b).

2.1.2 All data were acquired and processed with the geodetic datum of WGS 1984 and provided with the projection of UTM 30N. The data were provided with the vertical reference of lowest astronomical time (LAT).

2.2 Data deliverables to MarineSpace

2.2.1 MarineSpace were provided with the geophysical survey data, as well as interpreted deliverables and supporting reports. Table 2 provides a summary of the survey data provided for the review.

2.2.2 No velocity model was provided with the SBP data, however, a velocity of 1,600 m/s was assumed in the sediment and 1,500 m/s within the water column.

2.2.3 It should be noted that the grids and horizons received were in both two-way travel time (TWTT) and depth below seabed (DBSB) using a velocity of 1,600 m/s for the sediments. However, a picked seabed horizon was not received for use as part of the interpretation. Therefore, a two-step process was required to enable review of the MMT interpretation and further interrogation of the sub-units. Firstly, the MBES was converted from depth (LAT) to TWTT, using a velocity of 1500 m/s, creating a proxy for the picked seabed horizon. Secondly, the grids were converted within Kingdom from time below seabed to TWTT using the MBES data at a 5 m grid size.

2.2.4 The received interpreted grids, horizons and contours correspond only to the sparker SBP lines and not the parametric Innomar SBP.

[1] The frequency of the sparker was changed mid survey to reduce the system crashing (MMT, 2021b).

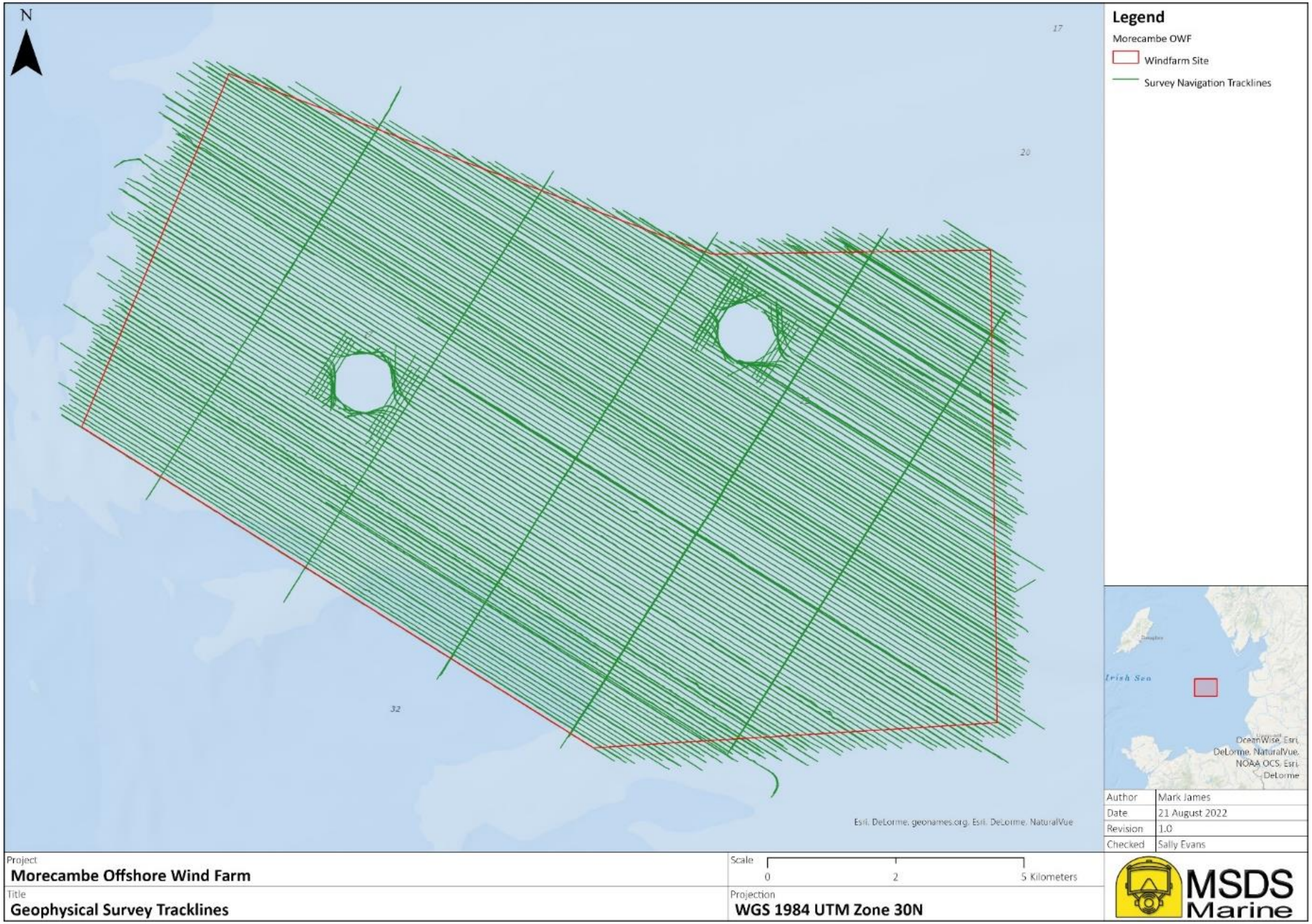

Figure 2: Geophysical survey tracklines (from MSDS, 2022)

Sensor	Data type	Format	Further details
Sub-bottom profiler	Raw lines (Innomar and Sparker)	.sgy	TWTT
	Processed lines (Innomar and Sparker)	.sgy	Reduced to LAT TWTT
	Grids (Sparker only)	.dat	TWTT and DBSB (Converted using a velocity of 1600 m/s for the sediments) Interpreted Units only
	Horizons (Sparker only)	.dat	TWTT and DBSB (Converted using a velocity of 1600 m/s for the sediments) Interpreted Units only
	Contours (Sparker only)	.dxf	
Multibeam bathymetry	Grid (at 5 m)	.xyz	(re-exported by MSDS)
	Grid (at 1 m)	.xyz	(re-exported by MSDS)
	Grids (at 0.2 m)	.txt	
Vessel	Vessel trackplot	.shp	
Reports	Archaeological assessment (MSDS)	.pdf	MSDS (2022.).
	Survey report (MMT)	.pdf	MMT (2022b)
	Operations report (MMT)	.pdf	MMT (2022a)

Table 2: Summary of 2021 survey data

2.3 Interpretation Methodology

2.3.1 A project was set up within IHS Kingdom (version 2022) for the Windfarm Site within which the SBP SEG-Y data were imported for interpretation.

2.3.2 As per the agreed methodology, a subset of the data were reviewed, approximately 1 in every 5 lines (~ 400 m spacing). Initially only the sparker SEG-Ys were reviewed against the MMT interpretations, however, the review of the data expanded as it was apparent that the resolution of the upper units afforded by the Innomar data were to prove key in providing a higher confidence in interpreted facies.

2.4 Data Quality and Limitations

2.4.1 The overall quality of the data within the seismic lines was good, with good vertical and horizontal resolution and minimal artefacts from weather, currents, interferences etc. seen. The data were deemed suitable for the identification of potential facies of interest within Seismic Units 1 and 2. There were however limitations on the interpretation undertaken as described below.

2.4.2 The objective of this data review was not to create a full detailed ground model interpretation of all of the sub-units within Seismic Units 1 and Unit 2 (e.g., MMT, 2022b). Instead, this geophysical assessment focused on facies that may be significant for determining the palaeolandscape and archaeological potential of the study area.

2.4.3 Only seismic reflection data were available for this review. Therefore, any interpretation was based solely on the seismic characteristics. Without any boreholes their corresponding geological units cannot be determined and the palaeolandscape interpretation is limited.

2.4.4 Both the Innomar and sparker SBP lines were used for interpretation, whilst the MMT interpretation only used the sparker data (MMT, 2022a). This meant that while most of the facies of interest were only clearly identifiable in the Innomar data, the location of these within the units identified in the MMT interpretation were not always clear.

2.4.5 The horizon grids were used to provide an overview of the interpretation within the individual SEG-Y lines, which had a variable fit to the true horizon due to factors such as interpolation during grid creation and the original seabed horizon not being available (e.g., Figure 3). The precision of the grid horizon was somewhat dependent on the distance between the sparker and the Innomar lines and the complexity of the stratigraphy, i.e., there was a greater misfit in areas with heterogeneous stratigraphy (e.g., Figure 4). This was apparent with notable inconsistencies within the interpreted boundary of H17 (base of U1) in some areas. There was greater confidence in the interpretation of H40 (base of Unit 2), which is a strong continuous reflector in the sparker profiles.

2.4.6 The SEG-Y data were provided in TWTT with no corresponding velocity data. Therefore, the interpretation was carried out in time. Where required, approximations of depth were calculated using a velocity of 1,500 m/s to allow for comparisons to be made between sea-level data and the interpreted horizons. This assumed velocity is commonly used for depth approximations in SBP data due to the shallow nature of the geology of interest. However, it may under or overestimate the true depth depending on the geological conditions, which is likely to vary throughout the Windfarm Site . In these water depths a 100 m/s uncertainty for the sub-seabed TWTTs would result in an uncertainty of +0.5 m at 10 ms TWTT and +1 m at 20 ms TWTT. Where required, approximations of depth of features below seabed were calculated using a sediment velocity of 1,600 m/s.

2.4.7 The SEGY files were not tidally corrected and so needed to be bulk-shifted to a time-converted MBES bathymetry grid. An assumption of the velocity in the water column of 1500 m/s was used to convert the MBES grid into TWTT. Any individual adjustment was only undertaken on key lines (e.g., Figure 3). The grids were converted from time below seabed to TWTT using the MBES grid with a 5 m grid size. The fit of the grids with their corresponding seismic horizon depended on the fit of the MBES with the seafloor; the fit was poorer where there were short wavelength bedforms in the seismic data that had been smoothed in the MBES data.

2.4.8 2D seismic reflection data have inherent limitations in spatial coverage and resolution. The line spacing was 75-85 m, which means that features of interest between these profiles may not have been imaged. Additionally, where the deposits are complex it is difficult to trace sub-unit horizons between lines (e.g., Figure 4). Features such as channels are inherently challenging to identify in 2D seismic data; their identification depends on their location and orientation relative to the seismic profiles, the size and geometry of the channels, and the signal to noise ratio of the seismic profiles. Small depressions (up to 120 m wide and 3 m deep) were only investigated if they could be interpreted on more than one line.

2.5 Data Sources

2.5.1 A number of secondary sources were utilised alongside the site specific survey data, these included third party survey data (such as core from BGS, 2014 [ID: 71/40]), regional data (WCPS; (Fitch *et al.,* 2011), relevant journals, publications, and unpublished reports and papers. References have been provided in Section 7.2.

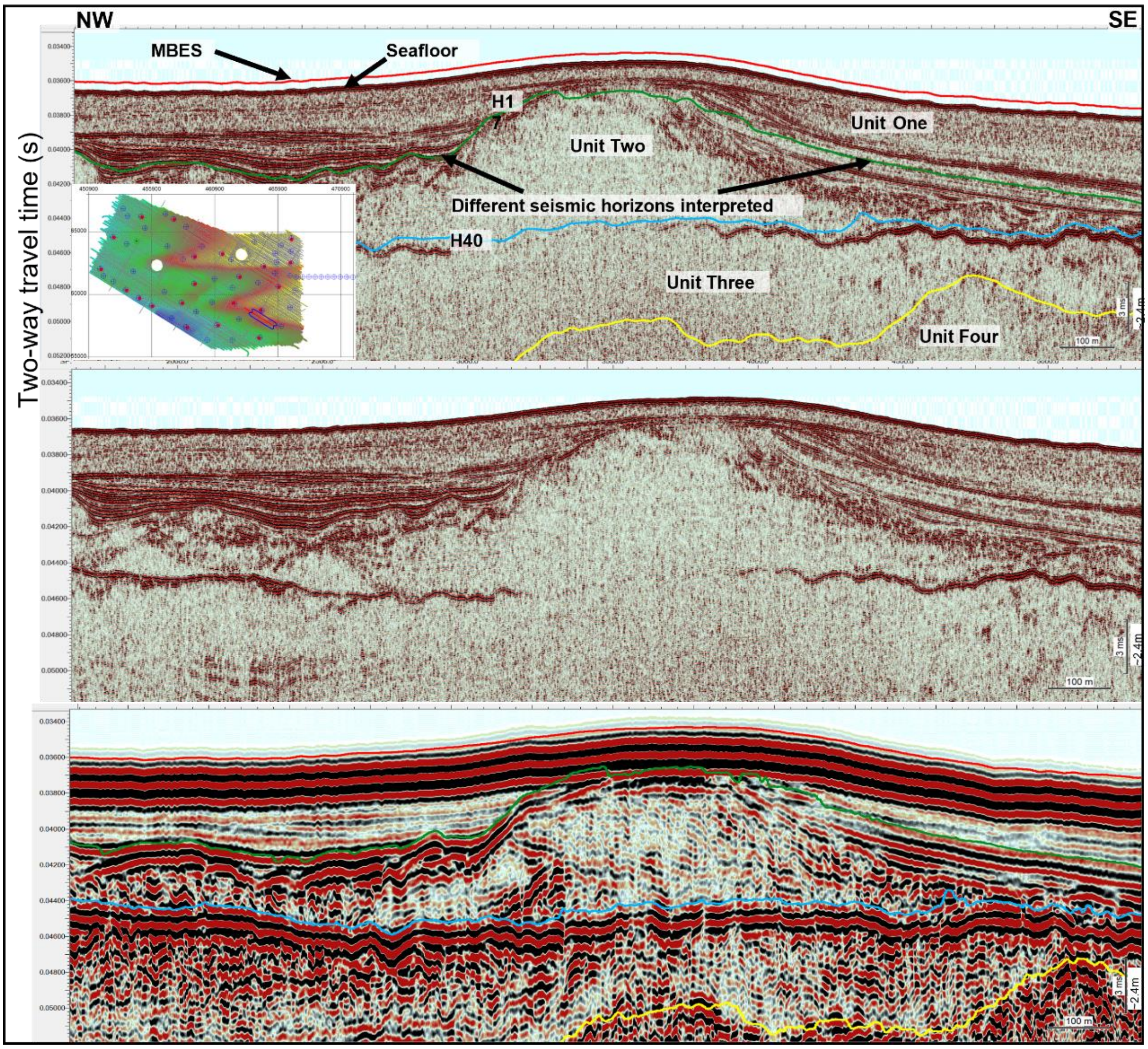

Figure 3: Innomar sub-bottom profiler line OWF_4140_R_20211217_074459 (top two panels) and sparker line 4140_R-CH-1.part-01 (bottom panel). The coloured lines are horizon grids received from MMT (interpreted based on the sparker lines) except for the red line which is the MBES data approximated in two-way travel time without the section being bulk shifted. The inset shows the MBES surface with the location of the line is highlighted by a blue box. Vertical Exaggeration x ~33

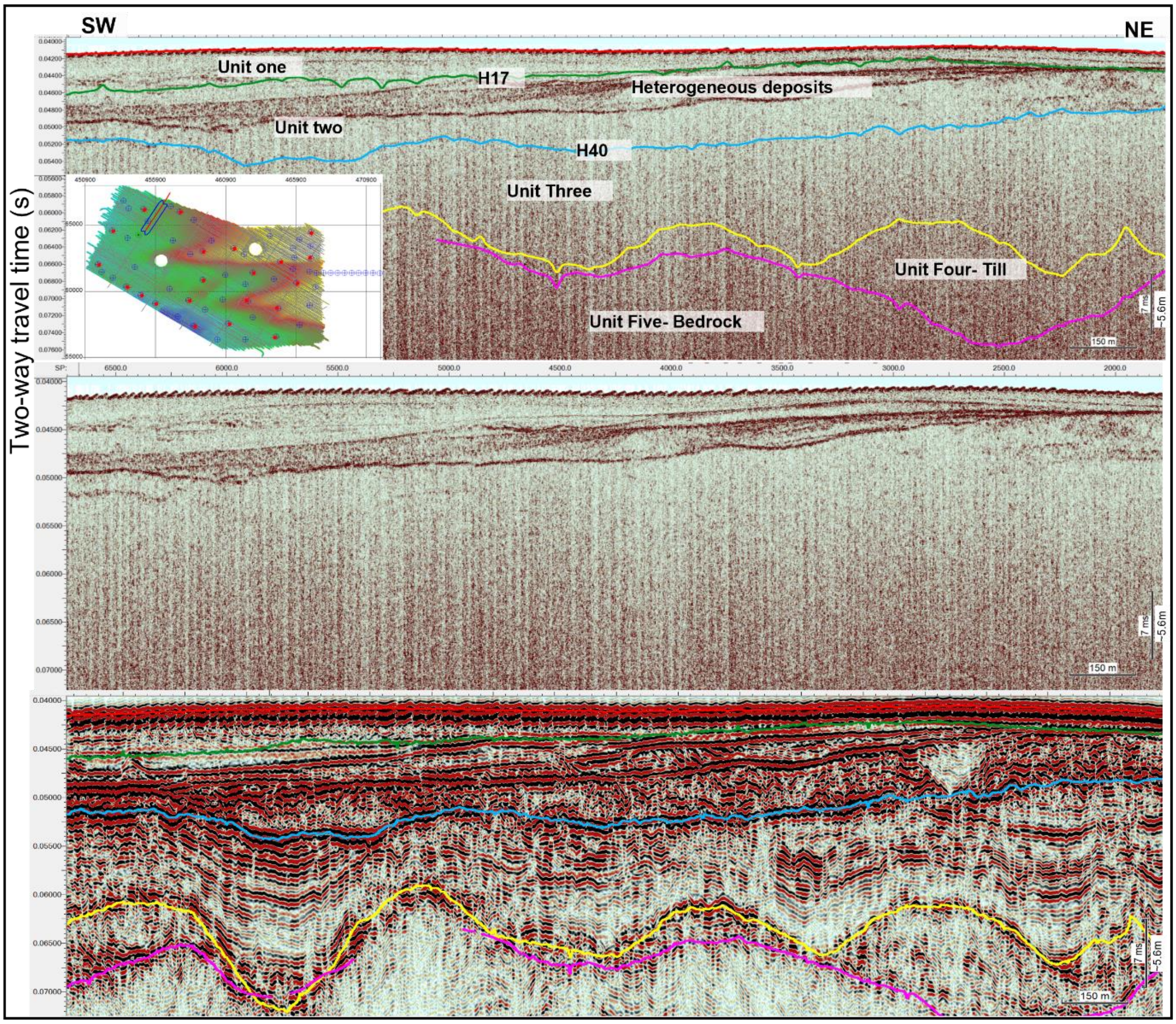

Figure 4: Innomar sub-bottom profiler line OWF_X_4000_20211217_140902 (top two panels) and sparker line X_4000-CH-1 (bottom panel). The coloured lines are horizon grids received from MMT (interpreted based on the sparker lines) except for the red horizon which is the MBES data approximated in two-way travel time. The inset shows the MBES surface with the location of the line is highlighted by a blue box. Vertical Exaggeration x~27

3.0 Background Overview and Context

3.0.1 The Windfarm Site has been impacted by 3 major glaciations over the last 500,000 years including the Anglian (480-430 ka), the Wolstonian (350-132 ka), and the Devensian (122-10 ka). During the last glacial period (approximately 29 – 12 ka) the British and Irish Ice Sheet (BIIS) covered much of Britain and Ireland (Clark *et al.,* 2022). In the Irish Sea sector of the BIIS there were two termini separated by an ice divide: the marine terminating Irish Sea Ice Stream (ISIS) in the west, and the lake/land-terminating Irish Sea Glacier (ISG) in the east which merge north of the current North Wales Coast in Liverpool Bay (Figure 5: Scourse *et al.,* 2021). The ISIS reached its maximum extent in the southern Celtic Sea 25.6 ka BP, whereas the ISG reached its maximum extent slightly earlier around 26.5 ka (Scourse *et al*., 2021). The ISIS retreated rapidly through the Celtic Sea, reaching the Llŷn Peninsula where it exhibited readvance sequences between 24 – 20 ka before retreating northwards across Liverpool Bay to the Isle of Man (~20 ka: Clark *et al.,* 2022). The retreat slowed as it reached the Isle of Man where the ice sheet stabilised and oscillated generating glaciotectonised thrust stratigraphy around the Isle of Man before the ice sheet continued to retreat northwards to Scotland (Scourse *et al.,* 2021). The ISG retreat was around five times slower, passing through Shropshire and Cheshire between around 25.3 – 22.5 ka before pulling back offshore at approximately 21 ka (Chiverell *et al.,* 2021). Liverpool Bay and the Windfarm Site became ice free by ~20.3 ka.

3.0.2 Numerous studies have generated and/or modelled the past sea-level curves in the Irish Sea since the Last Glacial Maximum (LGM). In terms of sea-level index points data for Morecambe Bay goes back to 10.5 ka (Shennan, *et al.,* 2018) with the majority of available data being between ~ 10 – 2 ka. Modelled curves (Peltier *et al.,* 2002; Shennan *et al.,* 2006; Brookes *et al.,* 2008; and Bradley *et al.,* 2011 – summarised in Lloyd *et al.,* 2013) extend back to 20 ka BP. Modelled sea level curves from around Liverpool Bay (Figure 6) predict a sea-level high at 20 ka CalBP but varying from ~+2 mOD (Peltier *et al.,* 2002) to ~-23 mOD (Shennan *et al.,* 2006), with the most recent models suggesting a predicted highest sea level of -15 mOD (Brookes *et al.,* 2008 and Bradley *et al.,* 2011). From this Lateglacial high, the models predicted sea level dropping to at least ~ -20 mOD and potentially deeper than -25 mOD at ~15 ka CalBP. Reported sea-level index points from the Menai Straits suggests that sea level dropped to -28 mOD at 12.3 ka CalBP (Roberts *et al.,* 2011). From this variable lowstand altitude, all the models predict very rapid sea level rise reaching a mid-Holocene highstand of +1.5 – 2 mOD at ~ 4-7 ka CalBP and then slowly dropping to the current levels. During the Holocene these models are strongly supported by sea-level index points recorded around the Bay (Roberts *et al.,* 2006, 2011; Lloyd *et al.,* 2013).

3.0.3 Past studies in the region interpret the geology of the near surface deposits in the Irish Sea as prodeltaic and glaciomarine to shallow marine. However, the WCPS, used 2D and 3D deep seismic reflection data from the petroleum industry and the British Geological Survey (BGS) to characterise the palaeolandscape and archaeological potential of Liverpool Bay and interpreted potential proglacial channels within a large floodplain across the Windfarm Site (Fitch *et al.,* 2011). This interpretation was based on data of a much lower resolution than the data acquired for the Morecambe Windfarm Site (MMT, 2022a, 2022b) and the surveys were designed for investigating much deeper sediments than archaeologists are interested in. Therefore, although of use in a broad context there is low confidence associated with their interpretation on a fine scale. The identified channels are not necessarily terrestrial and could be deposited in a marine or lacustrine environment.

3.0.4 A recent study immediately west of the Windfarm Site (between the Isle of Man and Anglesey, in water depths of 28-92 m) used geophysical, sedimentological, and geotechnical data to reconstruct the glacial environment associated with the LGM (Van Landeghem and Chiverrell, 2020). They identified overprinted subglacial bedforms that indicated differing flow directions and highlighted the erosive capability of the ice stream. Mega-scale glacial lineations were identified parallel to the main axis of the ice stream. The lineations were inferred to have formed via sub-glacial erosion into the bedrock and deposition of till. Ribbed moraines, drumlins, and flutes overprint the glacial lineations and formed subglacially transverse to the direction of ice flow. Push and end moraines were also identified which formed near or at the ice margin. These glacial features vary from being fully or partially exposed at the seafloor in some areas, to being buried by a couple of metres of normally consolidated sediments (Van Landeghem and Chiverrell, 2020).

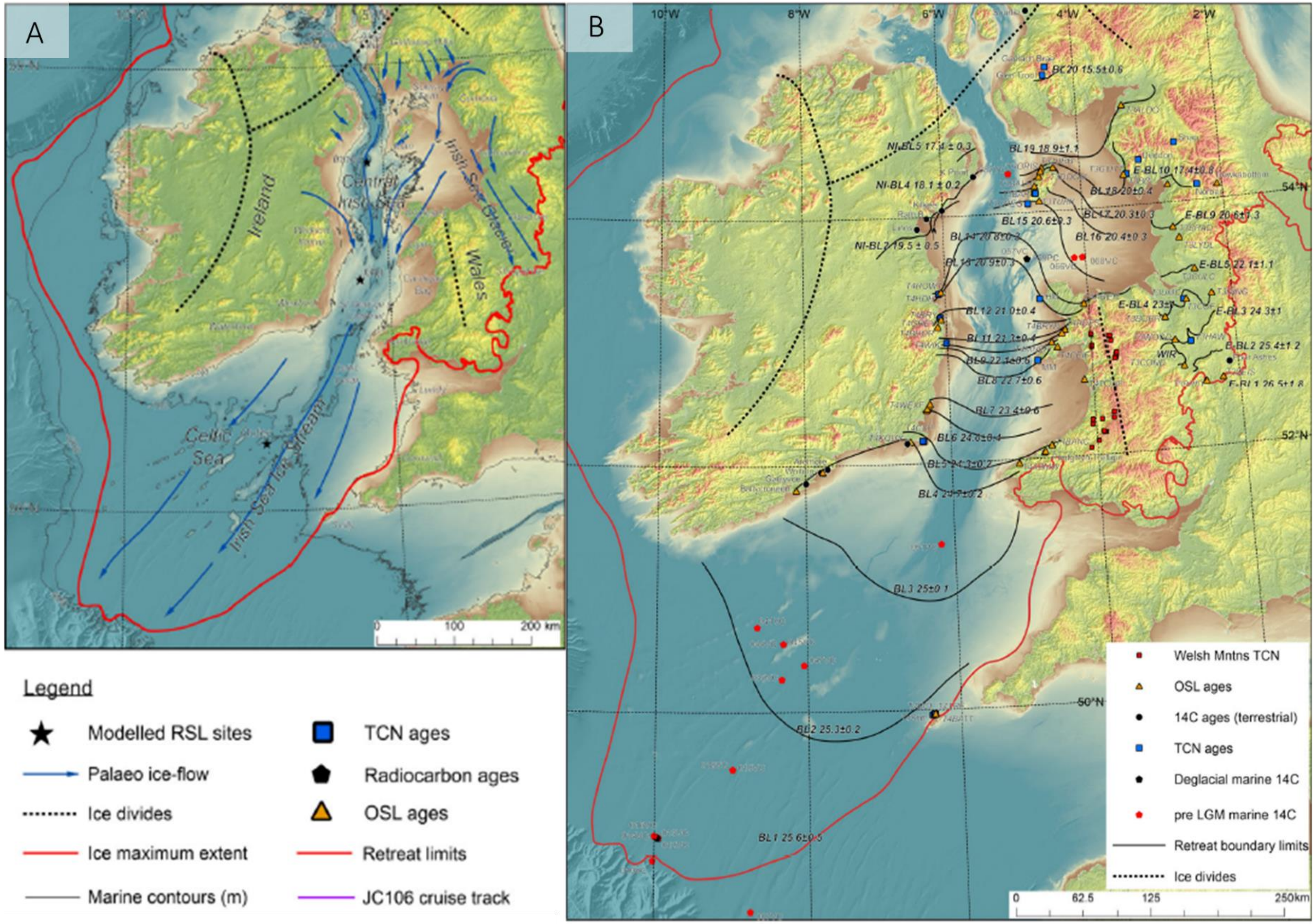

Figure 5: A) The Irish Sea Ice Stream (ISIS) with maximum ice extent, ice flow lines, and ice divide plotted over topographic and bathymetric data from Scourse et al., (2021) B) Chronology for the major ice sheet retreat limits in the Irish Sea from Scourse et al., (2021)

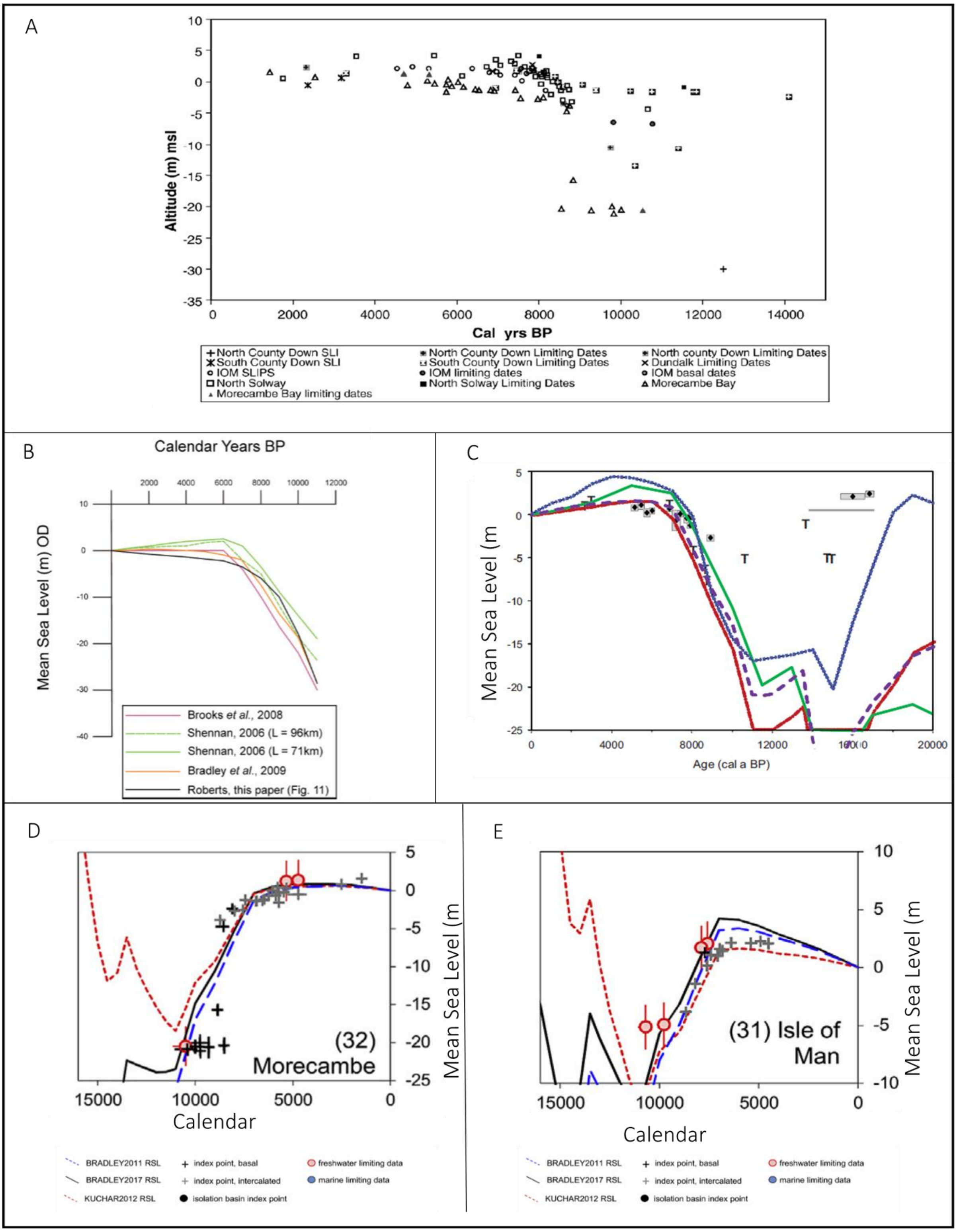

Figure 6: Sea level curves corrected locally for chart datum at: A) Ireland, Isle of Man, Scotland, and Morecambe Bay from Roberts et al. (2006); B) North Wales from Roberts et al. (2011); C) Cumbria from Lloyd et al. (2013); D) Morecambe Bay from Shennan et al. (2018); Isle of Man from Shennan et al. (2018).

4.0 Palaeolandscape Features

4.0.1 Units 1 and 2 were previously identified by MMT (MMT, 2022b) as being of archaeological interest, as they may represent lowstand, Lateglacial to early Holocene features, of potential fluvial origin. Consequently, this work focused on determining the seismic characteristics of these 2 Seismic Units and establishing if they could be of terrestrial origin. On this basis 5 seismic facies of interest have been identified and described.

4.0.2 The water depth in the Windfarm Site ranges from ~-18 – ~-40 mLAT (~-22.9 - -~44.9 mOD). The base of Unit 1 (H17) ranges from ~-18 - ~-42 mLAT (~-22.9 - ~-46.9 mOD: <1 to ~10 m below the seafloor). The base of Unit 2 (H40) ranges from ~-28 – ~-50 mLAT (~-32.9 - ~-54.9 mOD: ~1 to ~23 m below the seafloor). The units of interest are predominantly above the seafloor multiple.

4.1 Seismic Unit 2 – Seismic Facies Descriptions

4.1.1 The upper bounding reflector of Seismic Unit 2 (H17) describes two large east-west trending asymmetric ridges with a gentle north slope and steeper southern slope and extend across most of the site and are dominantly composed of, acoustically transparent, Seismic Facies A (Figure 7, Figure 8, Figure 9, Figure 10[2]). It was not possible to measure the full dimensions or geometry of these ridges because they extend beyond the eastern limits of the survey area. From the data available, the ridges are greater than 10 m high and 4 km wide, they extend 13 km, along axis, within the data extents. These ridges trend approximately perpendicular to the ice retreat direction inferred by previous studies (e.g., Figure 5), hence a morphology that supports their interpretation as being recessional moraines. Although Seismic Facies A has low archaeological potential, a desk-based review of any borehole data over these ridges would help develop a stratigraphic framework in relation to the archaeological context. Additionally, ground conditions within the ridge are likely to be highly variable which will have engineering implications (discussed in Section 7.0).

4.1.2 Seismic Facies B could be traced laterally, in the sparker data for more than 7 km along the northern margin of the northern, Seismic Unit 2 – Facies A, moraine ridge (Figure 11). At its widest point the distribution of Seismic Facies B is up to 1 km wide, perpendicular to the axis of elongation, and narrows westward where it is eroded into by an overlying seismic facies (Figure 12). Seismic Facies B is typically characterised by high amplitude concave, stacked parallel reflectors that do have erosive contacts with occasional reflectors present in the wider Seismic Facies A, which makes up the bulk of the moraine ridge. High amplitude reflections can be an indicator for the presence of peat or other organic deposits. However, the location at depth (~ -30 mLAT ≈ -34.9 mOD) within the ridge, suggests it is unlikely to have formed under exposed lowstand conditions (assuming a reasonable confidence in the sea-level models). Further, the lack of lateral extent beyond this moraine ridge suggests this facies is not of a lowstand fluvial origin and probably represents some form of complex glaciotectonism. These facies can be regarded as being of low archaeological potential.

[2] Note the different representation of these seismic facies attributes between the higher frequency Innomar and the lower frequency sparker data can be seen by comparing Figure 7B and Figure 9.

4.1.3 Seismic Facies C is a laterally extensive complex facies of discontinuous, short (100s m wide), high amplitude reflectors, with an irregular surface relief (Facies C; Figure 13), interspersed with areas of no acoustic reflectors. The lower boundary to Seismic Facies C is H40 (base of Seismic Unit 2) whilst the upper boundary broadly correlates with H17 (base Seismic Unit 1). H17 was picked from the sparker data and so is not an exact correlative of the top of this Seismic Facies. Consequently, to determine the lateral extent the upper boundary was re-picked and used for generating the distribution map (Figure 11). These deposits are typically located above relative lows in the base of Seismic Unit 2 (H40), except in the south of our survey area (Figure 11).

4.1.4 Across the Windfarm Site there are 4 areas of Seismic Facies C accumulation, the largest of which is in the southwest of the site (Figure 11**;** Figure 13). Here the deposit thickens to the north and west. Smaller accumulations occur in the north, and southeast of the Windfarm Site, where the thickness varies, but generally increases to the northeast to a maximum of about 5 m.

4.1.5 Again, Seismic Facies C occurs at depths deeper than ~ -33.5 mLAT (~ -38.4 mOD) so well below the recorded or modelled sea level curves. The initial interpretation is that these may represent proglacial, submarine, high energy, coarse grained deposits, of no obvious archaeological significance.

4.1.6 Finally, Seismic Facies F, was identified in the southern central part of the Windfarm Site, filling isolated discrete depressions at the top of Unit 2 (Figure 11**;** Figure 14). Again, H17, derived from the sparker data, does not consistently identify the base of this Seismic Facies nor does it correspond directly with the surfaces seen more clearly in the Innomar data. However, re-picking of this surface describes a series of asymmetric ridge and trough features that appear parasitic on the backs of Seismic Facies A material. Crest to crest distances are up to 550 m wide with ~6 m thick fills of Seismic Facies F. The high amplitude, concave-upward, reflectors of Seismic Facies A, some of which display reverse polarity, wholly or partially fill the troughs of these features. High amplitude reverse polarity reflections can be an indicator for the presence of peat or other organic deposits. However, they occur at a similar depth range as Seismic Facies B and C (-32 to -35 mLAT, -36.9 to -39.9 mOD at the top of the deposits) and so, given the modelled sea level curves (and assuming a reasonable level of confidence in those curves), are more likely of submarine origin and consequently have low archaeological potential.

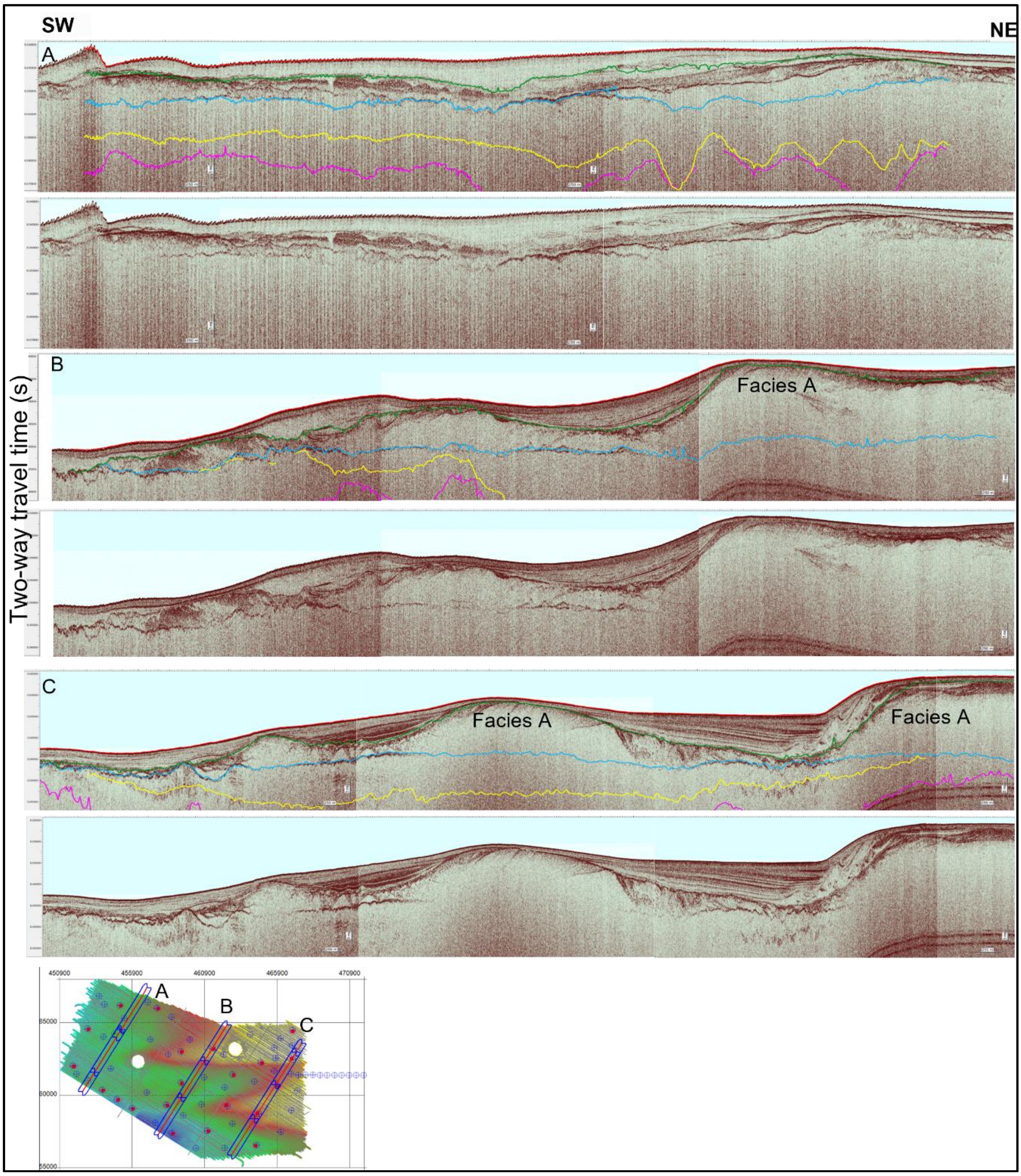

Figure 7: Innomar sub bottom profiler lines A) SBP_OWF_X_4000; B) SBP_OWF_X_10000; C) SBP_OWF_X_15000. The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2, yellow = base of Unit 3, pink = base of Unit 4). The red line which is the MBES data approximated in two-way travel time. The inset shows the MBES surface with the location of the line is highlighted by a blue box. Vertical Exaggeration x ~63

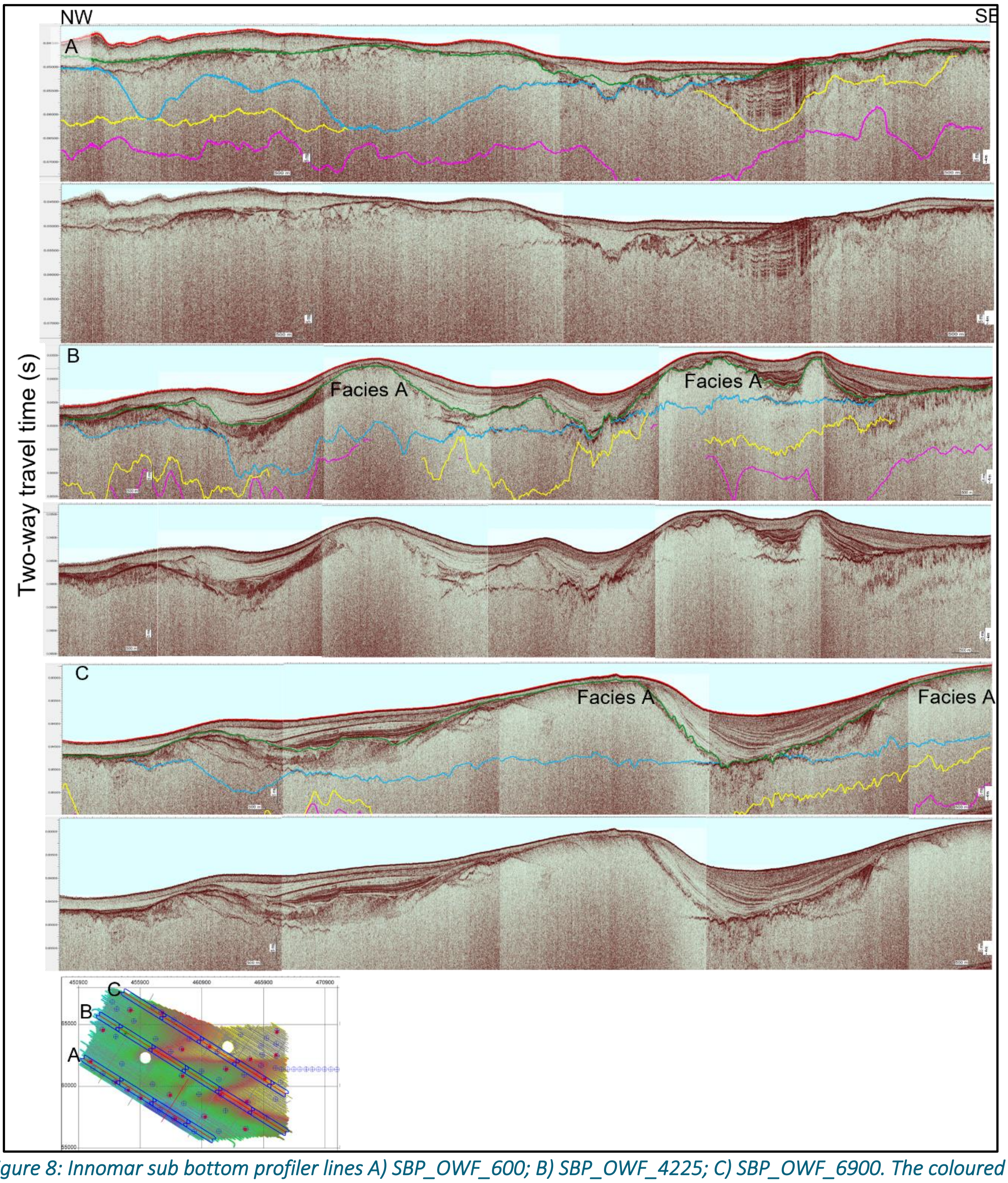

Figure 8: Innomar sub bottom profiler lines A) SBP_OWF_600; B) SBP_OWF_4225; C) SBP_OWF_6900. The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2, yellow = base of Unit 3, pink = base of Unit 4). The red line which is the MBES data approximated in two-way travel time. The inset shows the MBES surface with the location of the line is highlighted by a blue box. Vertical exaggeration x~63

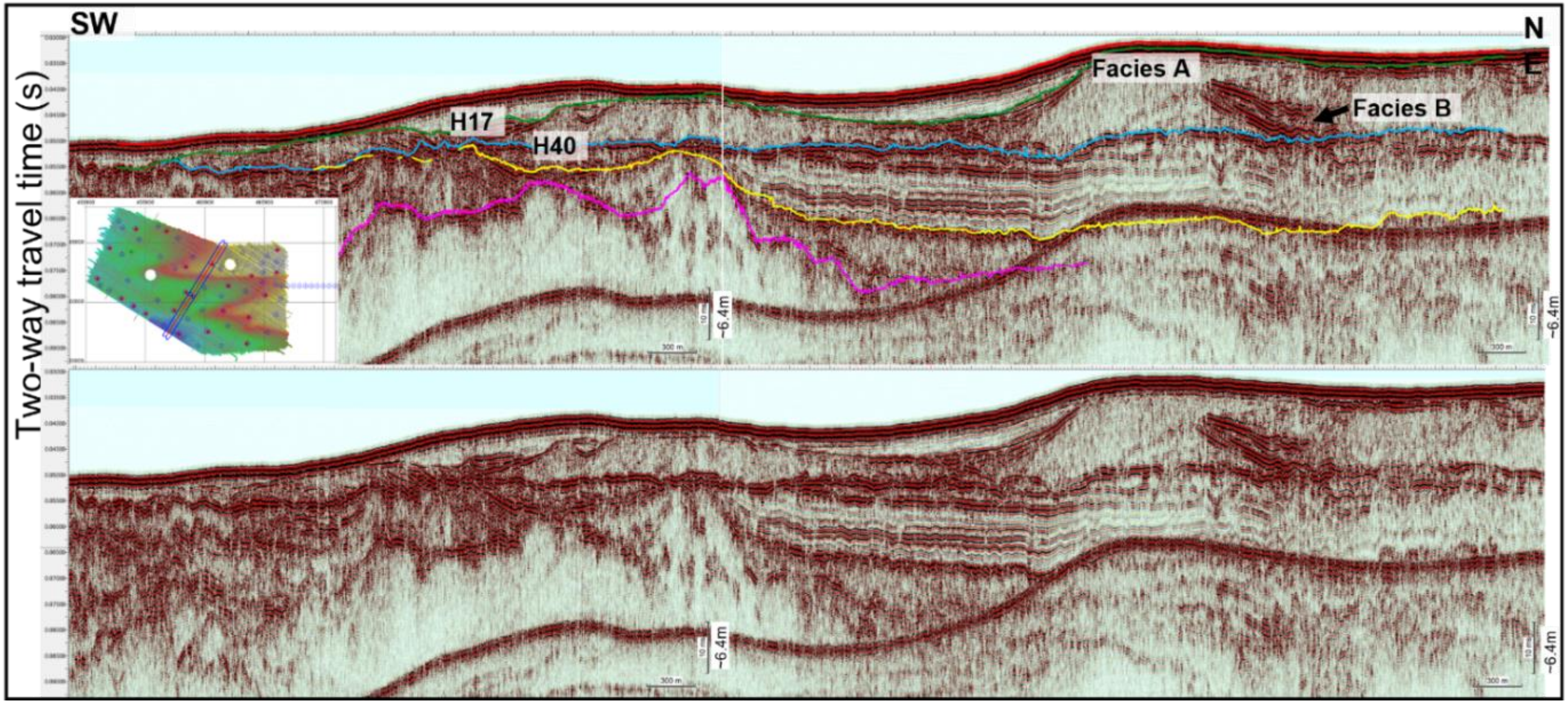

Figure 9: Sparker-type sub bottom profiler line X_10000-CH-1_Proc. The coloured lines are horizon grids received from. The red line which is the MBES data approximated in two-way travel time. The inset shows the MBES surface with the location of the line is highlighted by a blue box. Vertical exaggeration x ~47

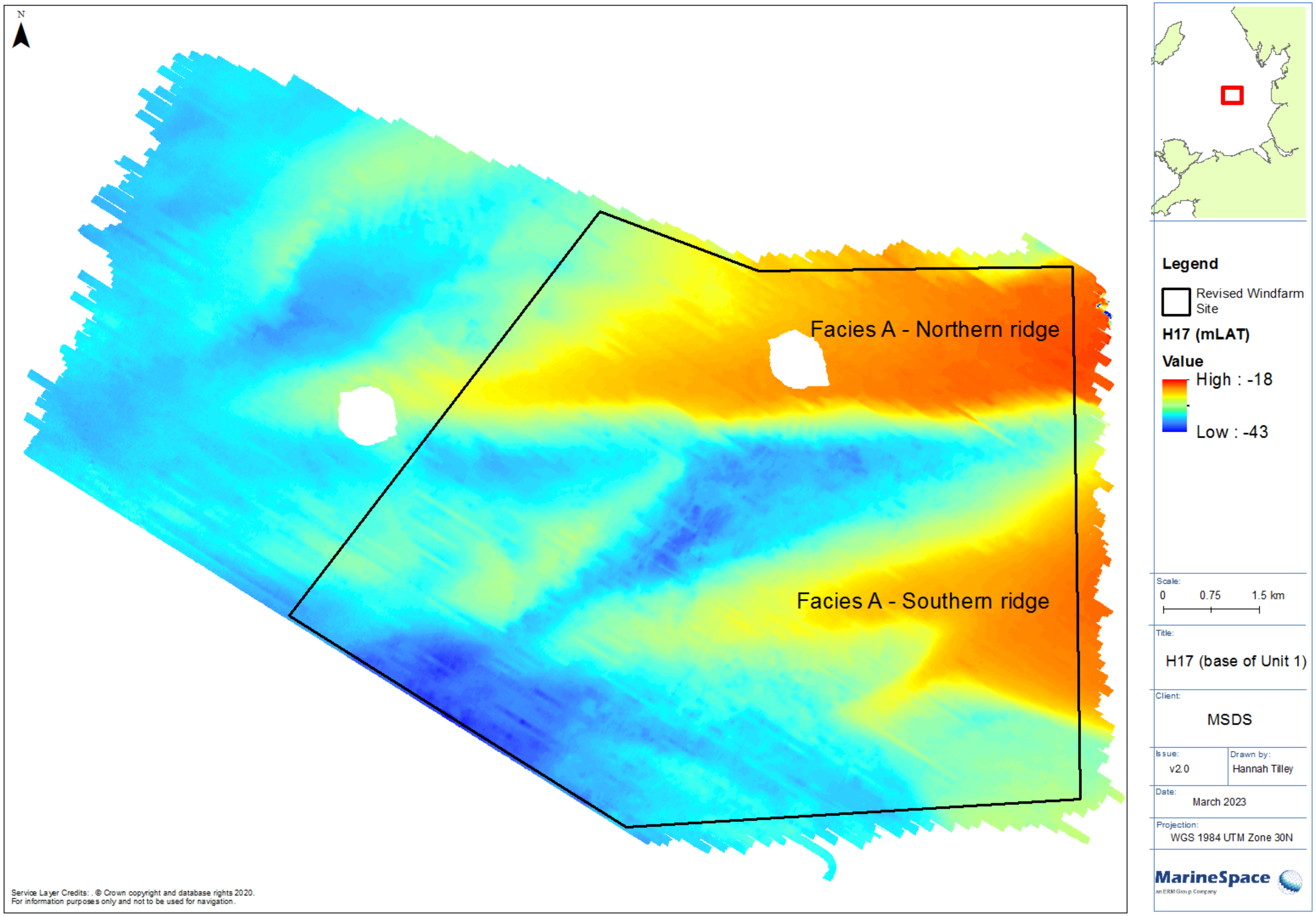

Figure 10: Horizon 17 - Top of Seismic Unit 2

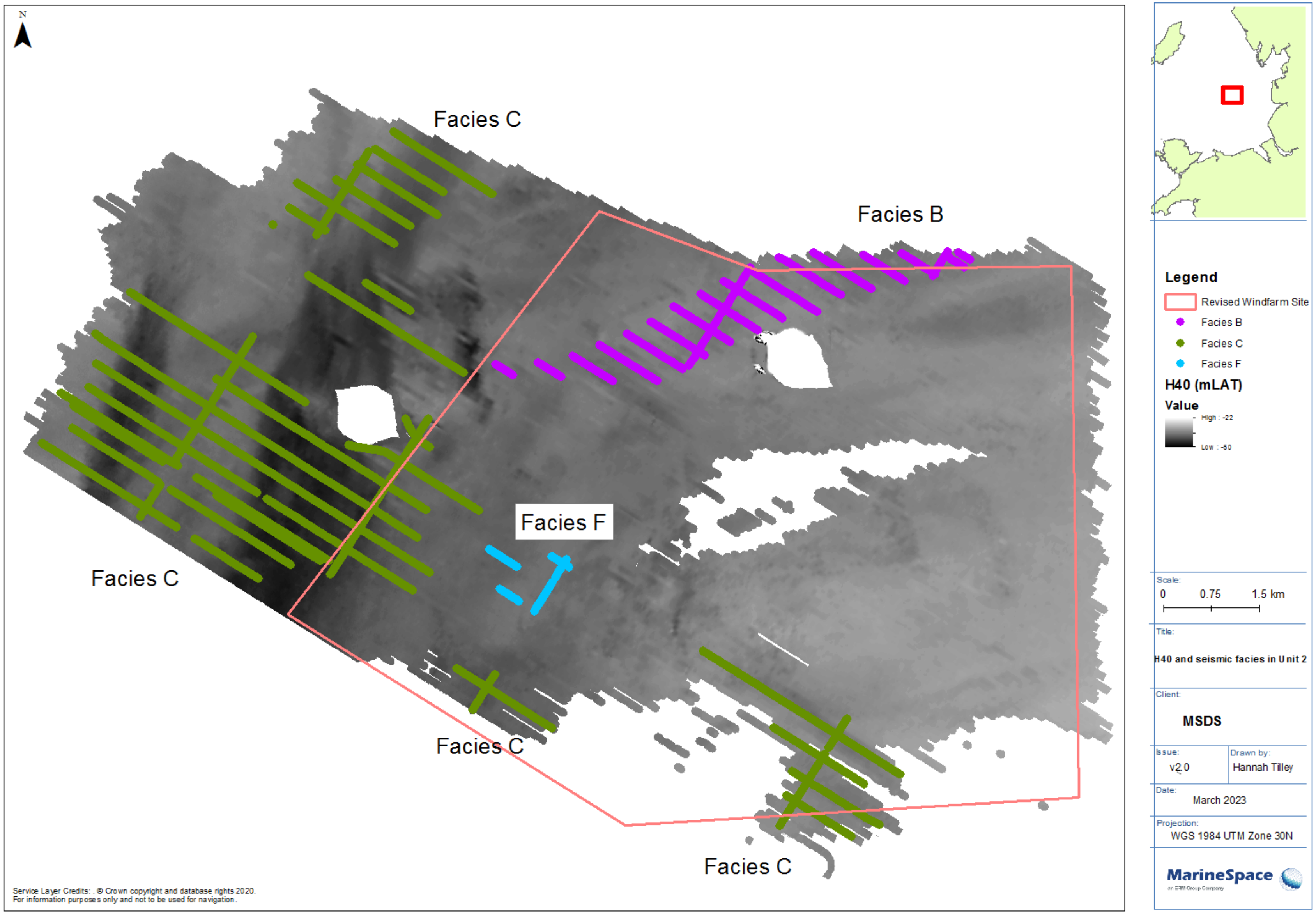

Figure 11: Distribution of facies of interest mapped on top of H40 (base of Unit 2). The base of the depressions (Facies B, F) are mapped, the top of Feature C is mapped.

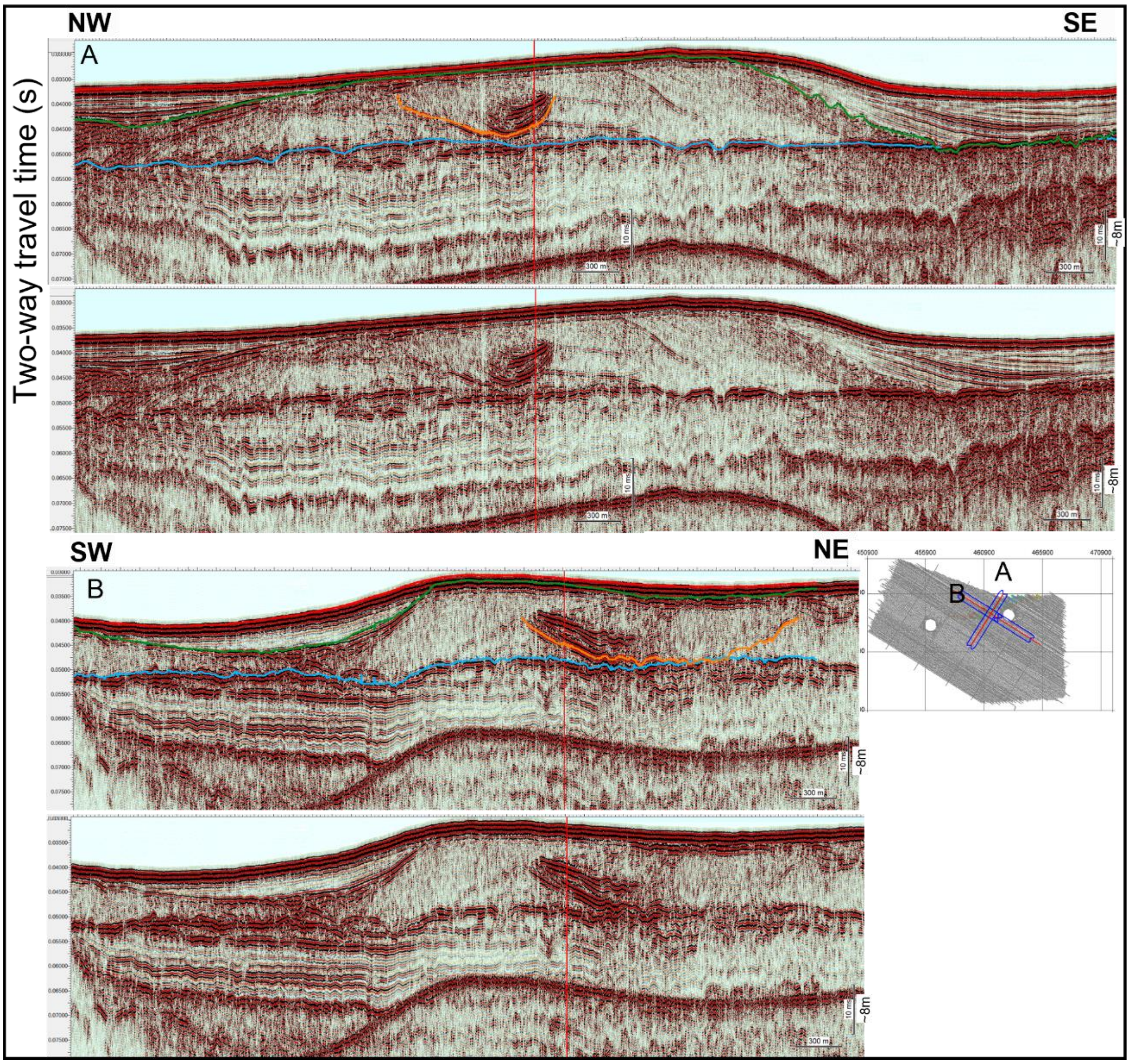

Figure 12: Sparker-type sub-bottom profiler lines A) SP_OWF_X_10000; B) SP_OWF_6900.033 The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2, yellow = base of Unit 3, magenta = base of Unit 4). The maroon is the interpreted base of Facies B. This horizon is mapped on the inset with the location of the line is highlighted by a blue box. The peach line is the upper boundary of facies B. The red line which is the MBES data approximated in two-way travel time. Vertical exaggeration x ~25

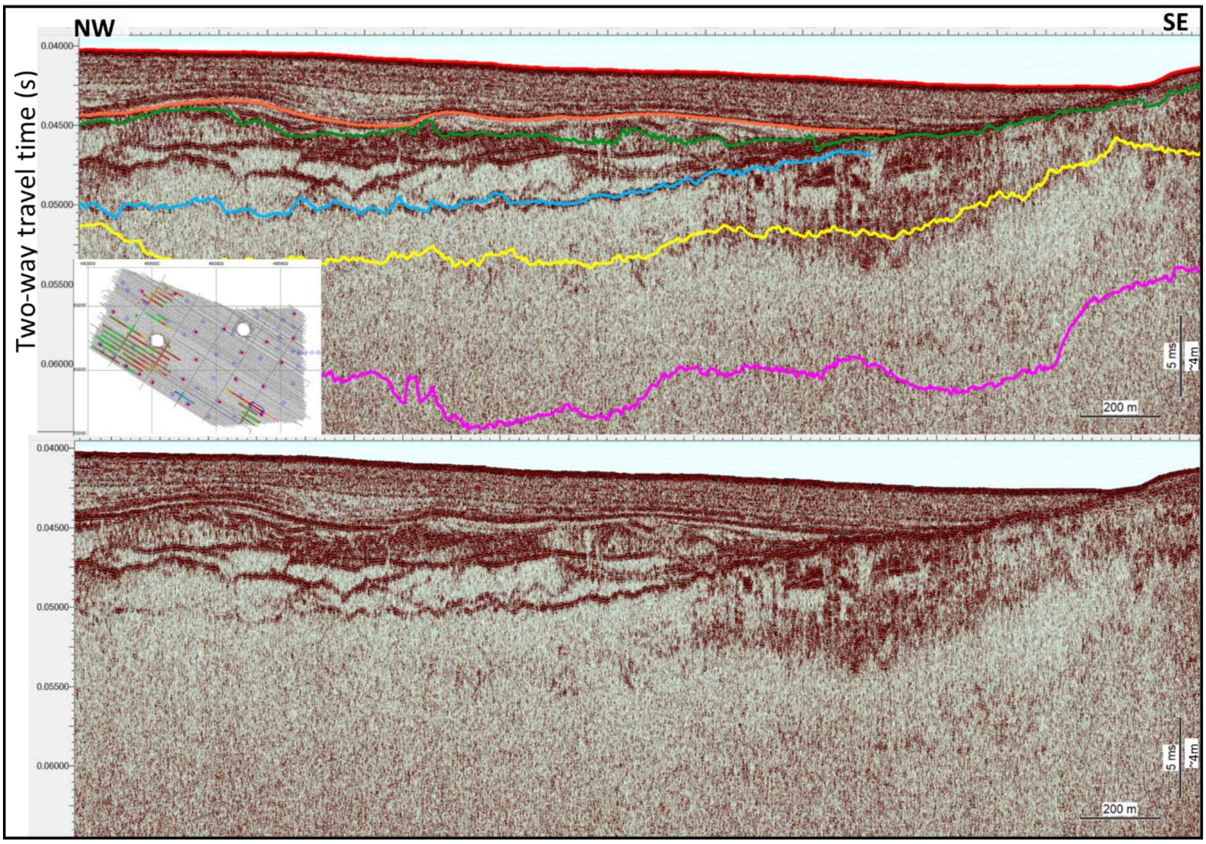

Figure 13: Innomar sub-bottom profile line SBP_OWF_2950_B. The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit two, yellow = base of Unit 3, pink = base of Unit 4). The orange line is the top of the heterogeneous facies (Facies C), which is mapped in the inset. The red line which is the MBES data approximated in two-way travel time. The location of the lines are highlighted by a blue boxes in the inset. Vertical Exaggeration x ~50

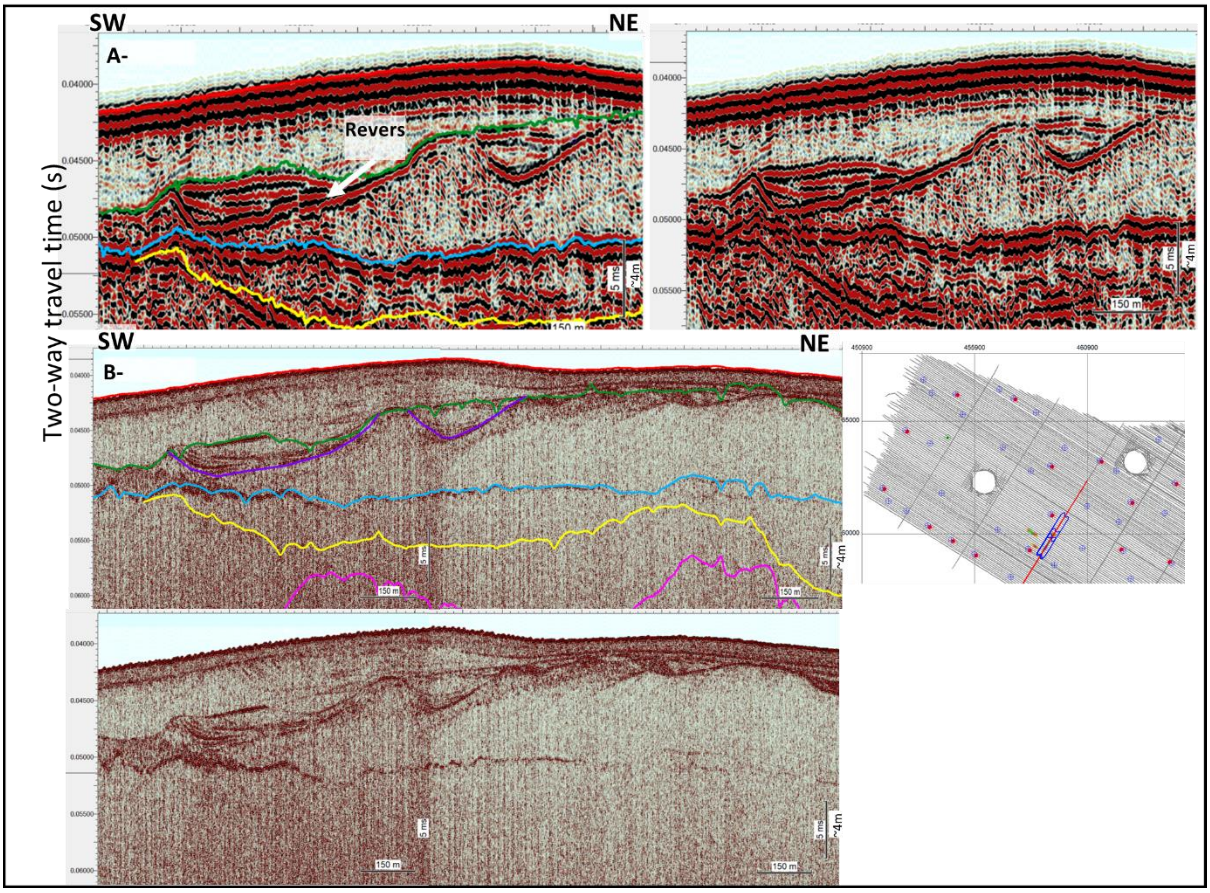

Figure 14: Sparker-type sub-bottom profile line SP_OWF_X_10000 B) Innomar sub-bottom profile line SBP_OWF_10000. The purple line is the base of the isolated depressions (Facies F), which are mapped in the inset. The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2, yellow = base of Unit 3, pink = base of Unit 4). The red line which is the MBES data approximated in two-way travel time. The location of the lines are highlighted by a blue boxes in the inset. Vertical Exaggeration x~38

4.2 Seismic Unit 1 – Seismic Facies Descriptions

4.2.1 Seismic Facies D was identified on the southern slope of the northern moraine ridge, in the east of the Windfarm Site (Figure 15; Figure 16). The lower boundary of Seismic Facies D aligns with the base of Unit 1 (H17) and the upper boundary is an unconformity against which the internal reflectors of Facies D terminate. The reflector amplitude and geometry of the packages vary greatly within this facies. The upper deposits are concave-upward, whereas some of the lower deposits have a convex-upward, mounded geometry. The deposit is thickest in the east and thins westward where it is becomes a thin slope cover with reflections sub-parallel to the underlying ridge slope. Due to the complex nature of this facies it would be challenging to trace any of the stacked deposits laterally without 3D data. In this dataset, no clear packages could be traced laterally for any significant distance. These deposits are indicative of a high-energy pro-glacial environment; however, it was not possible to determine if this was a terrestrial, marine, or lacustrine environment from the seismic data alone. The top of this facies is between -23.3 and -34.9 mLAT (-28.2 to -39.8 mOD). Given these depths relative to the predicted sea level (see Sections 3.0 and 5.0) it is probable that these were deposited in a marine environment. Further investigation through geoarchaeological assessment of geotechnical data would confirm this interpretation.

4.2.2 In the north of the Windfarm Site, there are a series of depressions within Unit 1 that incise into the surrounding deposits (Facies E; Figure 15**;** Figure 17). These depressions are subtle features that are approximately up to 120 m across and 3 m high. The base of this facies is between -31.6 and -37 mLAT (-36.5 to -41.9 mOD), and the seafloor in this area is -28.8 to -32 mLAT (-32.9 to -36.9 mOD). Within the depressions, there is typically a strongly reflective upper package that is discontinuous relative to the surrounding reflectors. Below this is a package that is acoustically weak or blank. The depressions are clustered in one area but do not show continuity between seismic profiles; for example, in some profiles there are three distinct depressions, whereas adjacent profiles have just one (approximately 75 m apart). Additionally, there are substantial variations in the size and seismic characteristics of the depressions between adjacent profiles. These are unlikely to be lowstand palaeochannels because they are not laterally continuous and the stratigraphy above and below the depressions looks consistent (likely glaciomarine), with no indication of an eroded surface. There is a subtle upward change in the seismic characteristics from higher amplitude to lower amplitude horizons at approximately the same depth as the top of the channels; this is likely indicative of a change in the marine processes. High amplitude reflections within depressions can be an indicator for the presence of peat or other organic deposits within palaeochannels. The archaeological potential of this unit is low, because it is unlikely that these depressions correlate to lowstand palaeochannels due to their limited continuity and their depth relative to the predicted sea level (see Sections 3.0 and 5.0). However, further investigation into the composition of these depressions, through geoarchaeological assessment of geotechnical data, would further assist in understanding the composition of the facies and in ruling out the potential for organic deposits (discussed in Section 7.0).

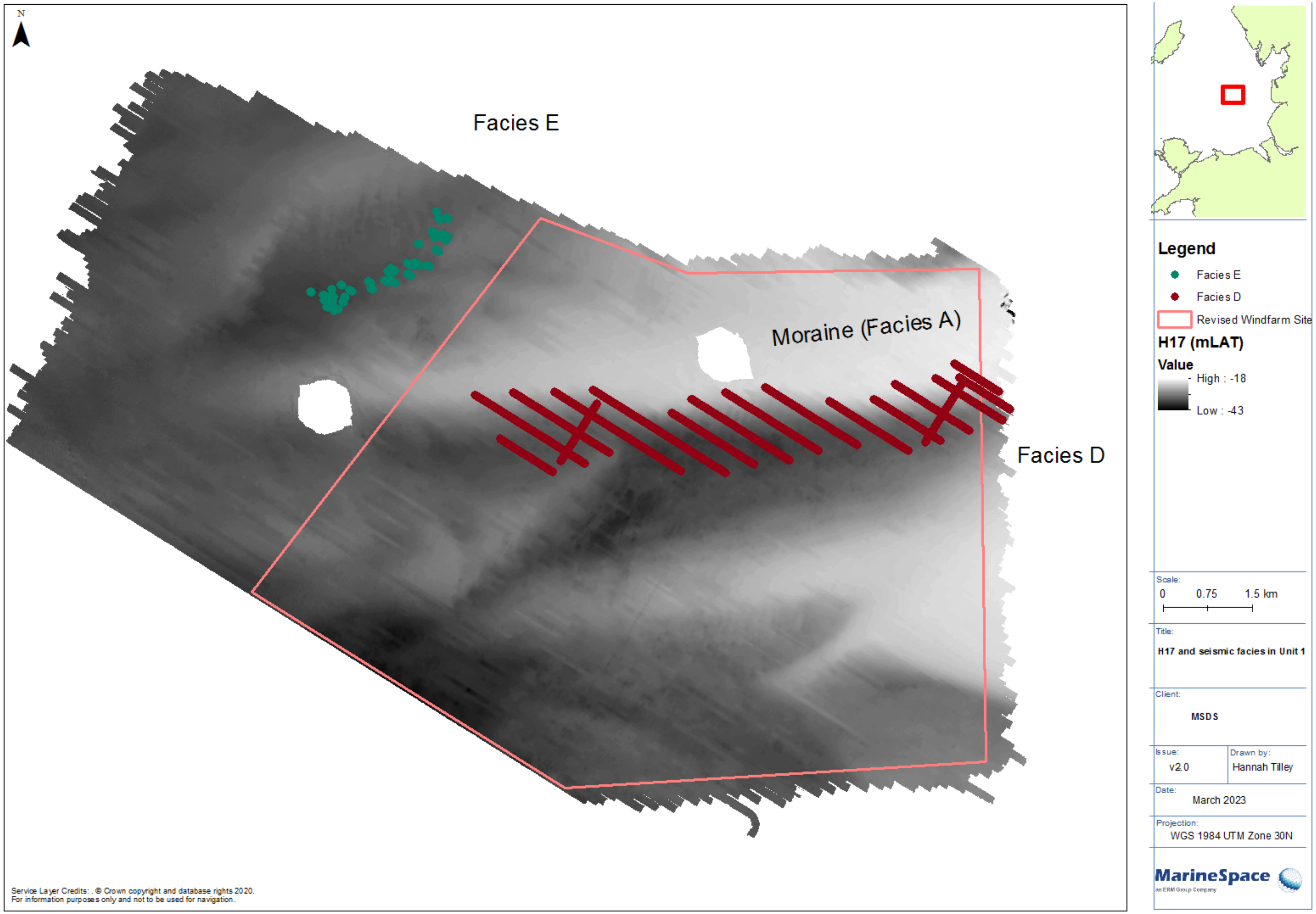

Figure 15: Facies within Unit 1 mapped on top of H17 (Base of Unit 1).

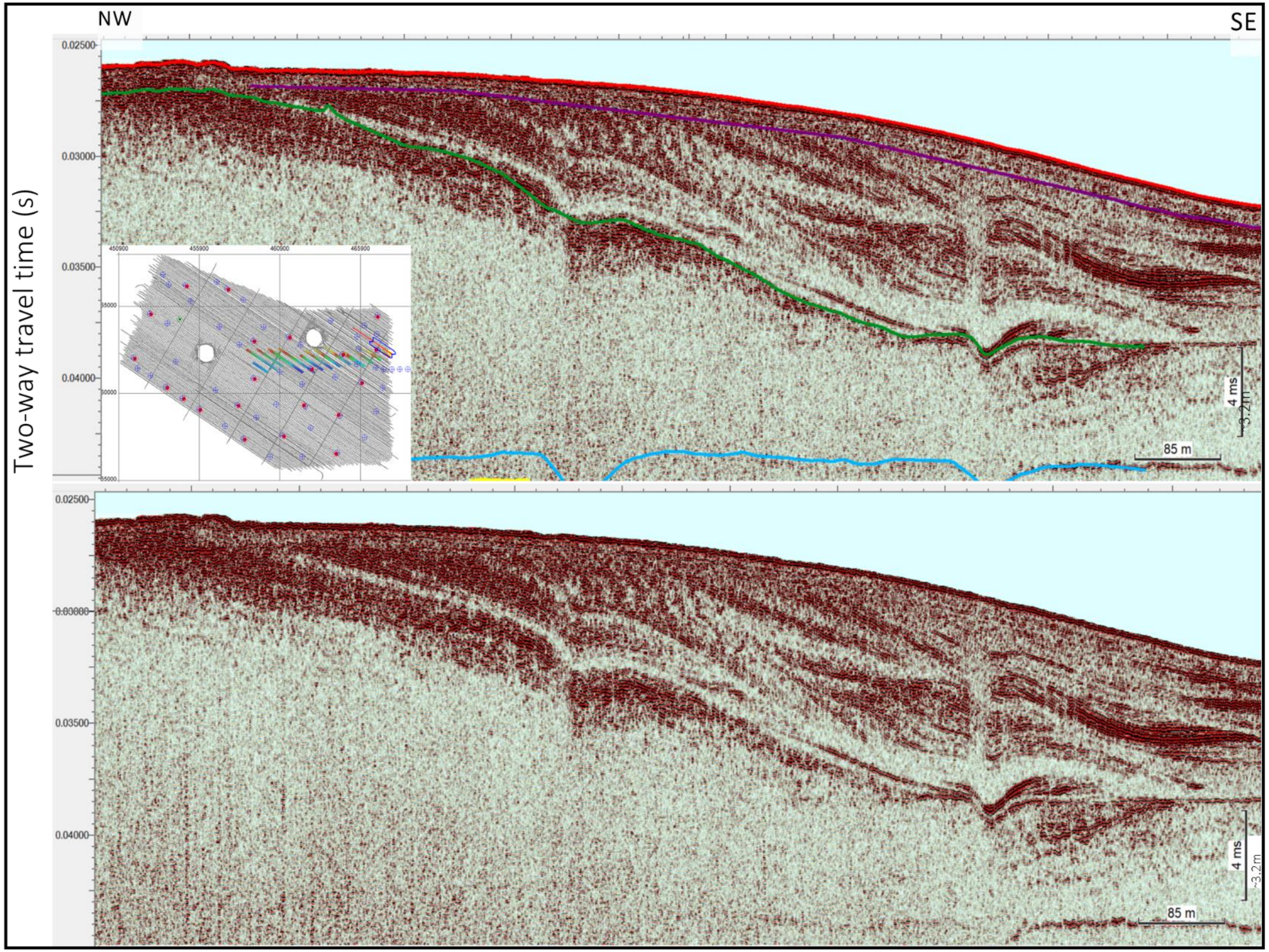

Figure 16: Innomar sub-bottom profiler line SBP_OWF_9375_2021119_182903_Proc displaying the top of the prograded sequence in purple (Facies D). The other coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2. The red line which is the MBES data approximated in two-way travel time. The location of the line is highlighted by a blue box in the inset where the distribution of the prograded sequence mapped. Vertical Exaggeration x ~27

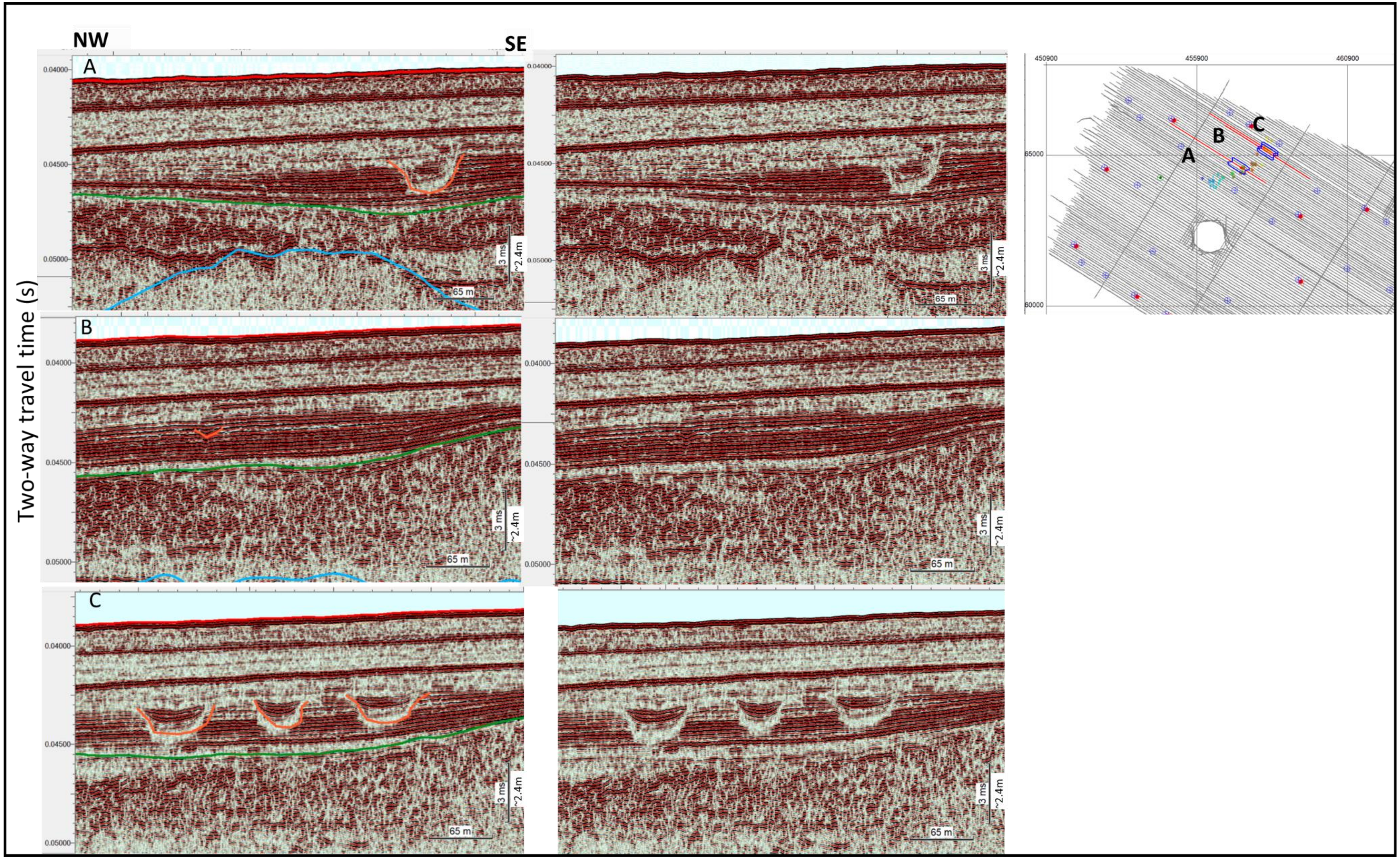

Figure 17: Innomar sub-bottom profile lines A) SBP_OWF_ 5775; B); SBP_OWF_6675; C) SBP_OWF_6750. The orange line is the base of the depressions (Facies E), which are mapped in the inset. The coloured lines are horizon grids received from MMT (green = base of Unit 1, blue = base of Unit 2). The red line which is the MBES data approximated in two-way travel time. The location of the lines are highlighted by a blue boxes in the inset. Vertical Exaggeration x ~27

5.0 Confidence in the Data and Interpretation

5.0.1 The data were generally of good quality, with both sparker and Innomar, enabling identification of facies of interest. These were limited to no weather artefacts noted within the data, and facies and horizons were clearly visible across main lines and cross lines. This enabled high confidence in the picking of the (sub-)horizons. The ground model was generally good at a broad scale, but it does appear to be only based on sparker data. Confidence in the ground model could be increased by integrating an interpretation of the Innomar data and taking a geological process-based approach.

5.0.2 As with any 2D seismic survey, the line spacing (approximately 75-85 m) enabled a good coverage across the survey area but there are limits in tracing facies laterally, i.e., a feature smaller than 150 m would only appear in one line, and therefore this can influence the confidence in facies identification. Many of the facies appeared to be larger than the line spacing, enabling a greater confidence in those facies (e.g. Facies B and C; Figure 11), however one group of facies, (Feature E; Figure 11**,** Figure 16) appeared as isolated features but were potentially smaller than the line spacing therefore appearing isolated; the confidence in this facie was lower.

5.0.3 It is important to note that the current interpretations are based on sub-bottom profile data. Currently there is no ground truthing across the survey area, and even where third party samples are available there is limited information available (BGS, 2014); with no borehole/core data and further analysis, the confirmation of the units, age and geology of facies remains unknown. Therefore, ground truthing is necessary to improve the confidence in the palaeolandscape interpretation and understand depositional history in relation to archaeological potential (discussed in Section 7.0).

5.0.4 Multiple glacial and proglacial facies were identified. Previous studies indicate that this area was glaciated until ~20.3 ka BP (Scourse *et al.,* 2021), which means that any possible archaeological artefacts prior to this would have been subject to substantial erosion and not be *in situ*. There is a reasonable confidence in the ice retreat models due to the range of multiple difference models referenced, the more recent of which are constrained by nearby geological features (e.g., Van Landeghem and Chiverrell, 2020), which all predict a similar timeframe of deglaciation. However, the exact timing remains a prediction, and as although multiple readvances have been recorded on the Isle of Man the marine limits of the readvances remain poorly constrained.

5.0.5 A possible moraine in Unit 2 was identified. This unit was interpreted in the previous ground model to be deltaic to glaciomarine. A moraine would typically be composed of till, but in the previous ground model Unit 2 was interpreted as sand, whereas Unit 4, which is older than Unit 2, was interpreted to be till (MMT, 2022b). The possible moraine is perpendicular to ice sheet retreat and comparable to moraines identified in nearby surveys (Van Landeghem and Chiverrell, 2020), but without assessment of geotechnical data, other interpretations such as large sand banks cannot be ruled out. Since the area was presumed to be ice-free by around 20.3 ka, if this feature is a recessional moraine, then Unit 2 is older than previously assumed (MMT, 2022b; MSDS, 2022) and the archaeological potential of Unit 2 is significantly reduced; in that case only Unit 1 would have any potential for archaeological remains.

5.0.6 A clear trend was seen across the sea level models with different techniques, whereby there was a rapid sea-level rise across the site during the early Holocene. Therefore, reasonable confidence in this trend can be assumed. The exact timing of the start of this rise, and the minimum sea level value, varies between studies (Figure 6). Sea level index points since the beginning of the Holocene (~12 ka BP) in Morecambe Bay indicate a minimum sea level of ~-21 mOD. If these depths are converted from OD to Chart Datum (CD: which is approximately equivalent to LAT) using a correction of 4.9 m at Liverpool (National Tidal and Sea Level Facility, 2023) the depths of the lowest sea level index points correspond to ~-16.1 mCD (or LAT). The seabed in the Windfarm Site is at -18 to -40 m LAT, and the base of the Unit 1 (H17), which was interpreted to be deposited during this time, is at -18 to -42 m LAT. Therefore, at the time of deposition it is most likely that the sea-level was not low enough to expose the area sub-aerially. Understanding there are spatially varying isostatic components to the sea level curves, and most of the sea level index points are done near the coast, we would still not expect several metres or more (likely much less than 5 m) difference over the Windfarm Site, given that a variation of less than 5 m is recorded between sea level sample sites with much greater separation: North Wales, Lancashire, and Mersey (Shennan *et al.,* 2018). Additionally, modelled sea level curves in Morecambe Bay (Figure 6) indicate that the sea level could have been deeper than -25 mOD (-20.9 mCD), so although sub-aerial exposure is unlikely, it could not be ruled out. Across the Windfarm Site, there are some areas where a review of Unit 1 (H17) may be beneficial as this assessment has identified discrepancies in the base of Unit 1 between the two datasets interpreted. However, any variation in the unit depth is likely to result in a change of less than 1 m and therefore it would not significantly alter the likelihood of sub-aerial exposure according to relative sea-level data, and hence the archaeological potential of the unit.

5.0.7 It is important to note that depth comparisons between sea level curves and the seismic data within this study were dependent on the assumed sediment velocity of 1,500 m/s. In reality, the velocity is likely to vary in space and time and so the true depth of the horizons may be marginally shallower or deeper (+/- 1 m).

5.0.8 There is a much lower confidence in the sea level curve prior to 12 ka BP, during which period it is assumed Unit 2 (H40) was deposited, following deglaciation around 20.3 ka. The base of Unit 2 is at -28 to -50 mLAT. Sea level models in Morecambe Bay predict a sea level high around 20 ka (models vary between approximately +2 mOD to -23 mOD) followed by a drop in sea level to at least ~-20mOD, potentially deeper that ~-25 mOD at ~15ka BP (Figure 6). Therefore, the deepest likely modelled sea level would be ~-20.5 mCD. This is higher than the base or Unit 2, which means that sub-aerial exposure is unlikely given the current sea-level models.

5.0.9 Based on the ice sheet retreat and sea-level models it is likely that the very rapidly rising sea levels approximately kept pace with the retreat of the ice sheet thus the depositional environment transitioned from glacial to marine almost immediately. Additionally, the thickness of Units 1 and Unit 2 would not be typical of a terrestrial environment. Marine transgressions tend to be erosive events, and there is no evidence of this in the seismic stratigraphy.

5.0.10 Within the limitations of the data assessed no facies were identified in Unit 1 and Unit 2 that are indicative of lowstand terrestrial fluvial channels inducive to archaeological activity.

6.0 Gap Analysis of Data and Current Knowledge

6.0.1 The interpretations in this report are based on SBP data and assume a reasonable level of confidence in past sea-level and ice retreat models. Grounding truthing would confirm interpretations of palaeolandscape potential and validate assessment of archaeological potential. From a review of recent literature, reports for the study area and the site-specific data, the current gaps in knowledge include:

- Geological ground truthing of the seismic interpretation;
- Timing and rate of ice retreat at Windfarm Site after the LGM;
- Spatial limit of ice readvances;
- Timing and rate of marine inundation at Windfarm Site during the Holocene;
- Pre-Holocene sea-level change at Windfarm Site.

7.0 Recommendations for Geotechnical Sampling

7.0.1 The aim of the archaeological assessment of geotechnical data as set out within COWRIE's Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector (Gribble and Leather 2010) is to:

- *'Investigate the deposition sequence of sediments within the area represented by the cores to identify, as far as possible, the environments within which this deposition took place;*
- *Evaluate the potential for past human exploitation and occupation of these past environments;*
- *Produce an overview of the geological stratigraphy to provide an indication of the prehistoric archaeological potential for the area; and*
- *Comment on the archaeological importance of the identified deposits, within the context of the wider palaeoenvironmental history of the region and the UK'.*

7.1 2023 Geotechnical Sample Locations

7.0.2 A geotechnical campaign for engineering purposes is planned for Spring/Summer 2023. The results of the review of the seismic data for any facies of archaeological potential were reviewed alongside the proposed core locations to identify if and where ground truthing would assist in confirming and/increasing the confidence in the interpretations, and confirmation of archaeological significance, as summarised in Table 3.

7.0.3 Overall, geotechnical sampling of the facies of interest would assist in establishing the stratigraphy, constraining the depositional environment, particularly in relation to ice sheet retreat and sea-level change, and would result in greater confidence of the palaeolandscape interpretation, in particular the likelihood of sub-aerial exposure during a time period suitable for human activity. In turn, this would provide greater confidence in the assessment of archaeological potential of the units. Any dating of these units, where appropriate and practical, would further improve the confidence in the archaeological potential of the units and better constrain the Quaternary history, including potential for the presence of Upper Palaeolithic to Mesolithic material.

7.0.4 The proposed borehole positions for the 2023 campaign[3] cover the Windfarm Site. These locations sample the interpreted moraine (Facies A) and stacked sequences (Facies C and D), so no further recommendations for these are provided. Facies E is outside of the Revised Windfarm Site area, and therefore no further recommendations for this facies is provided. The two remaining facies, Facies B and Facies F, are not sampled and so the following recommendations are listed in Table 4 and presented in Figure 18.

[3] The borehole locations reviewed for this report were dated 31 October 2022, provided in Wood Plc (2022) Phase 2: Reconnaissance Geotechnical Investigation Scope of Work - Morecambe OWF Reference: 808685-01-SR-SOW-0001 (Wood); FLO-MOR-SCO-0002. The locations have subsequently been revised based on the Revised Windfarm Site boundary and recommendations from this report.

Facies	Description	Archaeological potential	Confidence	Geoarchaeological assessment of geotechnical data	Sampled	Archaeological aim
A	Potential moraine	Low/None	High	Sampling is of interest to Quaternary science as any confirmation of the potential moraine, or possible dating, would help constrain the timing of ice sheet retreat. This would result in greater confidence in identifying any period between ice sheet retreat and sea level rise in which sub-aerial exposure could be possible, further constraining the archaeological potential of the Windfarm Site. Minimum depth below seabed: -20 mLAT ≈ -34.9 mOD	Sampled by proposed locations BH109, BH112 (proposed and relocated location), BH118, BH119.	No requirement, but will assist to confirm interpretation and archaeological potential.
B	Elongated depression	Low	Med	Facies likely to be below low stand levels, however the high return may indicates potential for organic deposits, from which dating may occur. Geoarchaeological assessment of geotechnical sampling would provide an insight into the composition of the high amplitude facies, possibly ruling out the potential for organic deposits. Any possible dating would help constrain the palaeolandscape environment, confirming the low stand limits, and the archaeological potential of the facies. Minimum depth of interest (high amplitude return): -30 mLAT ≈ -34.9 mOD	Recommended adjustment of BH112; see Table 4.	Confirm presence of organics and confirm assessment of archaeological potential.

Facies	Description	Archaeological potential	Confidence	Geoarchaeological assessment of geotechnical data	Sampled	Archaeological aim
C	Laterally extensive complex	Low/None	Low	This complex seismic facies is indicative of proglacial, high energy coarse-grained deposits. This facies is interpreted to be submarine, but terrestrial or deltaic origin cannot be ruled out based on seismic data alone. Geoarchaeological assessment of geotechnical sampling would provide an insight into the origin of this facies, possibly ruling out terrestrial or deltaic origin. Sampling would also provide insight into the period between ice sheet retreat and sea level rise in which sub-aerial exposure could be possible, further constraining the archaeological potential of the Windfarm Site. Minimum depth of interest (top of facies): -33.5 mLAT ≈ -38.4 mOD	Sampled by proposed locations BH108 and BH114 (outside Revised Windfarm Site BH201, BH203, BH204, and BH206). No further recommendations	No requirement, but will assist in confirm interpretation and archaeological potential.
D	Prograded complex	Low/None	Low	This facies is indicative of proglacial, high energy coarse-grained deposits. This facies is interpreted to be submarine, but terrestrial or deltaic origin cannot be ruled out based on seismic data alone. Geoarchaeological assessment of geotechnical sampling would provide an insight into the origin of this facies, possibly ruling out terrestrial or deltaic origin. Sampling would also provide insight into the period between ice sheet retreat and sea level rise in which sub-aerial exposure could be possible, further constraining the archaeological potential of the Windfarm Site area. Depth of interest (top of facies): -23.3 to -34.9 mLAT ≈ -28.2 to -39.8 mOD)	Sampled by proposed locations BH113, BH116, and BH118. No further recommendations	No requirement, but will assist in confirm interpretation and archaeological potential.

Facies	Description	Archaeological potential	Confidence	Geoarchaeological assessment of geotechnical data	Sampled	Archaeological aim
E	Small depressions	Low	Low	Facies likely to be deeper than minimum predicted sea level, however, the high return within these depressions indicates potential for organic deposits, from which dating may occur. Geoarchaeological assessment of geotechnical sampling would provide an insight into the composition of the high amplitude facies, possibly ruling out the potential for organic deposits. Any possible dating would help constrain the palaeolandscape environment, confirming the low stand limits, and the archaeological potential of the facies. Depth of interest (base of depressions): -31.6 and -37 mLAT ≈ -36.5 to -41.9 mOD),	Outside of Revised Windfarm Site. Recommended sampling in the future if the Revised Windfarm Site is expanded to include this area for future campaigns.	Confirm presence of organics and confirm assessment of archaeological potential.
F	Isolated depressions	Low	Low	Facies likely to be deeper than minimum predicted sea level, however, the high amplitude reverse polarity returns indicates potential for organic deposits, from which dating may occur. Geoarchaeological assessment of geotechnical sampling would provide an insight into the composition of the high amplitude facies, possibly ruling out the potential for organic deposits. Any possible dating would help constrain the palaeolandscape environment, confirming the low stand limits, and the archaeological potential of the facies Depth of interest (base of depressions): -32 to -35 mLAT ≈ -36.9 to -39.9 mOD	Recommended adjustment of BH107; see Table 4.	Confirm presence of organics and confirm assessment of archaeological potential.

Table 3: Summary of archaeological potential of facies of interest for geoarchaeological assessment of geotechnical sampling

Core ID	Current position (X/Y; m)	Recommended movement (m)	Recommended position (X/Y; m)	Depth of interest	Feature
BH112	X: 461540.999 Y:5963197.026	200 m northwest along main line	X:461373.91 Y:5963302.85	6-12 m	Elongated depression with high amplitude – Facies B
BH107	X: 458352.851 Y:5959274.945	670 m northwest onto crossline	X: 459023.30 Y: 5959361.51	4-8 m	Isolated depressions with high amplitude and reverse polarity – Facies F

Table 4: Summary of recommendations locations for the geotechnical campaign

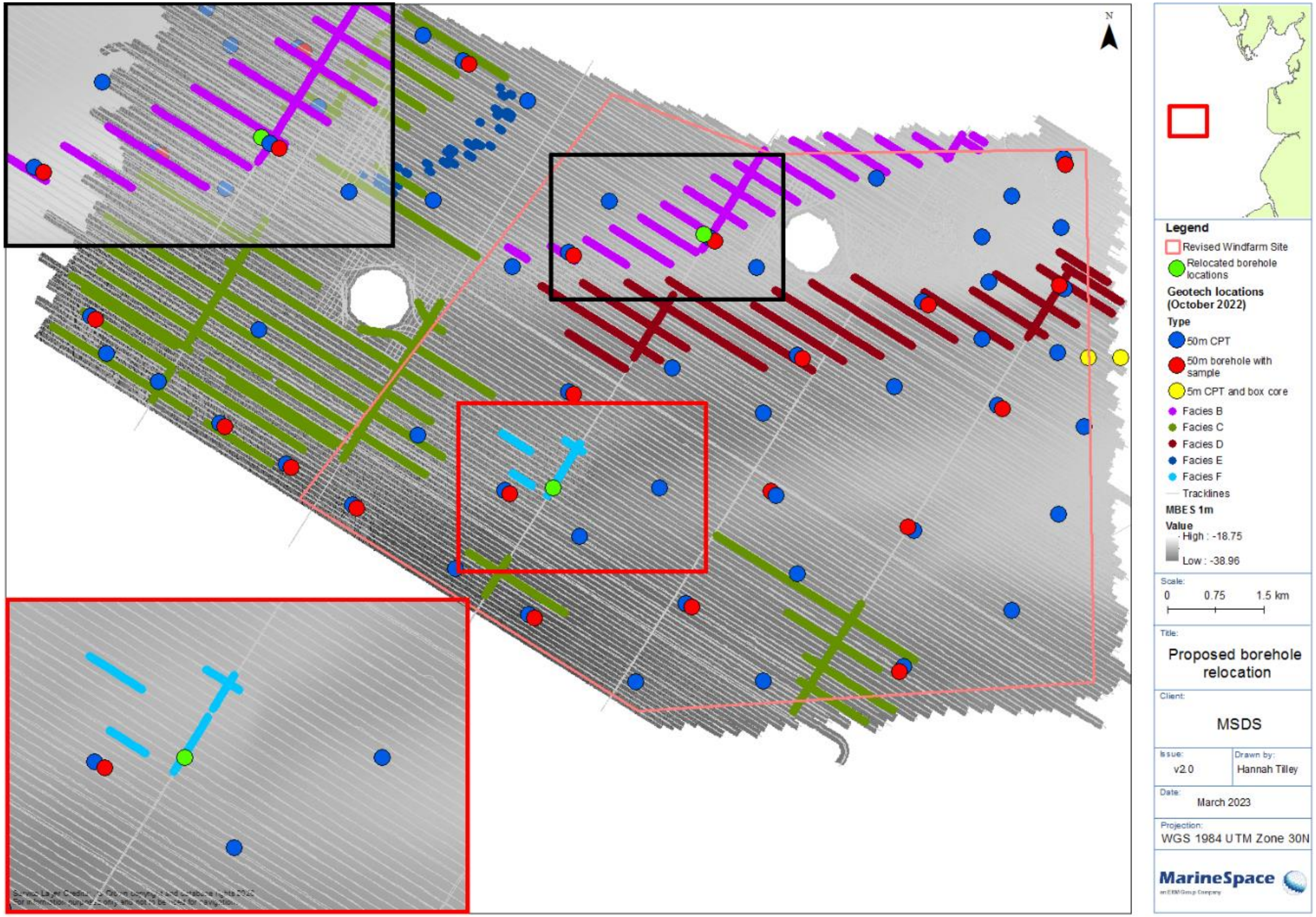

Figure 18: Proposed geotechnical sample locations

7.2 Recommended Methodology

7.2.1 It is recommended that the cores be acquired along the SBP lines of the interpreted unit/facies to enable accurate correlation between geotechnical properties and geophysical units.

7.2.2 It is recommended that the cores be acquired and stored, where possible, using methods suitable for geoarchaeological dating and testing[4]. Method statements should be produced and included under the project Written Scheme of Investigation, and the project archaeologist kept informed of developments and changes. Where core locations are adjusted, they should be provided for review to the project archaeologist.

7.2.3 Once acquired, the core logs and samples should be made available for geoarchaeological review to update the interpretations. As part of the COWRIE guidance (Gribble and Leather, 2010) there is a programme of staged recording, assessment and analysis; the 5 stage process is listed below:

7.2.4 **Stage 1.** Geoarchaeological review of core logs: consists of a desk-based assessment of geotechnical core logs by a trained geoarchaeologist to determine which cores contain sediments of archaeological interest. Recommendations are made to the client as to which cores the geoarchaeologist would like to look at in Stage 2. For Stage 1 to be undertaken the core logs must be recorded in a manner which will allow identification of sediments of archaeological interest. The OSL potential of the sediments is also assessed.

7.2.5 **Stage 2**. Geoarchaeological recording: a detailed inspection and recording of the cores identified in Stage 1 to further assess archaeological potential. This requires physical access by the geoarchaeologist, who will make a record of the sediments encountered, their archaeological potential, and recommendations for any Stage 3 assessment, if required.

7.2.6 **Stage 3**. Geoarchaeological assessment: samples are taken from the cores recommended (and recorded) in Stage 2 for specialist assessment to determine the age and palaeoenvironmental potential of the sediments. This stage comprises the sampling and laboratory analysis of a selected core, or cores, to a level sufficient to enable an assessment of the value of the palaeoenvironmental material (pollen, diatoms, ostracods and foraminifera) surviving within the core(s). The assessment seeks to establish the preservation, diversity, and quantity of palaeoenvironmental material, in order to further refine the interpretation of the sedimentary environment, and past human activity, identified in the Stage 2 recording. Recommendations are made as to whether a Stage 4 analysis programme, including dating, should take place on any of the core material.

7.2.7 **Stage 4**. Geoarchaeological analysis: consists of more detailed investigation of the core material typically using the same techniques as Stage 3, but with extended counting and / or higher

[4] It should be noted that some of the methods of analysis require special consideration and have requirements in terms of core processing and storage. In particular, OSL dating, which determines the age elapsed since sedimentary minerals were last exposed to sunlight. The time-dependent signal is extremely sensitive to light. Treatment of cores should follow the method set out below to ensure that they retain their potential for OSL dating.

sampling intervals within key stratigraphic units. The work will be undertaken to a high standard which should permit the publication / dissemination of the results.

7.2.8 **Stage 5**. Publication

8.0 References

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